3rd Edition

BASIC DENTAL MATERIALS

MANAPPALLIL

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JOHN J. MANAPPALLIL

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JOHN J MANAPPALLIL MDS

®

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Dedicated to
My Parents

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Preface

A successful dentist has to combine technical skills along with clinical knowledge. Dental materials is *the backbone* of dentistry. Knowledge of dental materials is one of the keys to a successful dental practice. To the beginner, the task may appear formidable because of the wide array of materials available. This is quite normal and fortunately disappears with familiarity. Dental materials does not end with the first year of the graduate training program. It is required throughout the course and subsequently for a successful practice. The popularity of the second edition was encouraging. The feedback helped in improving the current edition. Comments and suggestions may be e-mailed to me at *jonsbin@yahoo.com*—your feedback is valuable.

Revising the edition was a huge challenge. Dental materials is a vibrant subject as new products are constantly appearing in the market. The book has been entirely reorganized reflecting these changes. More color illustrations have been added to improve clarity. A few of the materials have been eliminated from the book or just briefly mentioned as they are no longer marketed. Knowledge of the history of dental materials is useful to understand how these materials evolved and why newer materials were developed. Over the past decade, the field of ceramics has seen vast improvements. The chapter on ceramics had to be entirely revamped to reflect the significant advances in technology. Actual values of the various materials have been presented wherever possible. Knowledge of values improve depth of understanding and is useful for making comparisons. However, one must remember that these values are not necessarily absolute, variations can occur between brands and methods of testing. Climatic differences affect properties like working and setting times.

Dentists in India are fortunate to have a wide choice of materials. In the past, however, the availability of materials in India was greatly limited, affecting the quality of both education and treatment. The economic liberalization of the late 1980s saw the opening of the market to a range of high quality international products. Some are entirely new products while others are modifications and improvements of existing materials. Dental practitioners should have a good understanding of basic dental materials science to enable them to critically assess the plethora of new materials that are constantly being introduced and aggressively marketed. It is also advisable for practitioners to request long-term *in vitro* and *in vivo* independently acquired evidence of the performance of a material before deciding to use it. Many of these materials have market lives shorter than the time required to adequately assess them.

Thanks to journals, conferences and the Internet, there is exchange of information between individuals, transcending geographical barriers. Concepts are constantly changing as knowledge keeps improving. An open mind is essential for learning—especially one open to new ideas as well as *criticism* and *suggestions*. It is encouraging to see a lot of new Indian authored books in the market. Indian researchers have also been contributing considerably to international journals. Indian manufactured materials are also gaining international attention. This is a quantum jump considering that previously we had been importing knowledge as well as materials. *Our* research, journals and professionals are gradually being recognized and respected the world over. We cannot rest as constant improvements are still needed in our training programs in order to provide the best care to the patients as well as compete internationally. It is my fervent hope that every new generation of highly trained and motivated dentists will emerge upholding the *dignity* of the profession and the country.

John J Manappallil

Acknowledgments

Every book has its share of contributors and influences and this book is certainly no exception. I would like to start with two of my colleagues George and Ashwin. Both of them contributed significantly to the review of the chapters on Wrought Alloys (George) and Dental Implant Materials (Ashwin). I express my sincere appreciation to these two wonderful clinicians.

A special thanks to Yohan Chacko and Lippee for their clarification on dentin bonding agents as well as with photography of materials. Vijai Dental, Chennai needs a special mention—not only for all the catalogues and the materials provided for photography, but also for their spirit of entrepreneurship and innovation.

I thank all those who helped with the proofreading—notably Angela, Siby, Rajesh, Pandit, Satheesh, Ginu, Bhavna, Suhas, Zacharia, Bella, Liji, Serene, Shobha, Hassan, Aflah and my wife, Divya. My deepest appreciation goes to my family, especially my wife Divya and to my two children. Without their tremendous sacrifice and support, this project would not have been possible.

The foreword in the previous edition was written by Dr V Surender Shetty Dean of the College of Dental Surgery, Mangalore and I thank him for the honor. Although it is not carried forward in this edition—it is my honor and privilege to have him continue the patronage. No amount of knowledge would be complete without the experience and I am indeed very fortunate to be associated with some of the foremost institutions in the country. I am indeed grateful to Dr Sadashiva Shetty, Principal of Bapuji Dental College and Hospital (BDCH), Davengere, Dr Surendra Shetty, Dean of College of Dental Surgery, Mangalore and Dr Shobha Tandon, Dean of College of Dental Surgery, Manipal, for the excellent facilities and hospitality offered. I am also indebted to my former teachers and guides Dr K Subbarao and Dr VK Subbarao for their excellent guidance during the period.

I express my sincere appreciation to all those who contributed to the previous editions. My gratitude goes to my former colleagues at BDCH, Davengere, who have contributed to this book. In spite of the siginificant modifications many of the chapters contain portions created by them. They include—Shubha Rao, R Sangur, Vinay Kumar, Akshay Bhargav and Atley George. My sincere thanks to *SI Bhalajhi* for his invaluable help with the digital photography and advice on various computer programs and applications. I would like to thank all my colleagues who helped with the proofreading.

I also take this occasion to once again renew bonds of friendship and affection with all my *current and former colleagues* and *classmate*s, my *teachers, my students* and with all my *well wishers*. It is my honor and privilege to be associated with all of you.

Finally, a special thanks to the *publishers* and the *team* out there at Jaypee Brothers Medical Publishers (P) Ltd., New Delhi, for the wonderful job in creating a truly remarkable book.

Contents

1

DENTISTRY AND DENTAL MATERIALS

Dental materials play an integral role in dentistry. Besides use in the oral cavity many materials are also used in the laboratory to aid in the fabrication of appliances or prostheses. Dentistry over the years has evolved into a highly complex field and materials play a crucial role in every aspect of treatment.

Most dental treatment may be divided into three phases:

- Prevention
- Restoration
- Rehabilitation

PREVENTION

The preventive phase is probably the most important. This includes *educating* the patient on how to maintain his oral hygiene through regular *brushing*, *flossing* and *periodic checkup* at the dental office. Regular brushing with a suitable brush and paste has been shown to be very effective at controlling caries as well as gum (periodontal) problems. The role of *fluorides* and fluoride therapy in the control of dental caries has been known to us for a long time. Fluoridation of drinking water and fluoride therapy at the dental office has played a significant role in reducing dental caries especially in children. Caries often begins in deep fissures in teeth. Fissure sealants is another preventive measure especially in children to prevent caries.

RESTORATION

The next stage is the actual development of dental caries and periodontal disease. Caries involves the actual demineralization and destruction of tooth structure. The next focus is to arrest the caries process. This involves removing the carious tooth structure and restoring the cavity with a suitable filling material. The famous *silver filling* has been in use for more than a century and is currently the most widely used filling material. The silver amalgam restoration would certainly look unpleasant if used for the front (anterior) teeth. Therefore anterior teeth are restored with an esthetic (tooth colored) material. Other ways to restore teeth involve the use of gold inlays and ceramic inlays.

As caries progresses, it gets closer to the pulp, which can lead to pain (pulpitis) and infection of the pulp. If the pulp is only mildly affected, pulp therapy is started using materials which have a therapeutic effect on the pulp. These materials can be soothing and promote healing by forming a new layer of dentin (secondary dentin).

If the pulp is infected, it is removed (pulpectomy) and *root canal treatment* popularly known as RCT is initiated. After removing the pulp, the canal is made sterile and sealed using root canal filling materials. The root canal treated tooth is weak and is prone to fracture if not protected with a crown or onlay.

Before the discovery of tooth colored crown materials, metallic crowns were given (the famous gold tooth). Modern dentists are able to provide crowns that are *natural looking* and pleasing. Many of these structures are processed outside the mouth, in the laboratory. The dental technician uses an accurate *model* of the teeth to fabricate these restorations. Models are made from a *negative record* of the mouth called *an impression*. This is sent to the laboratory where the technician pours a mix of plaster or stone into the impression. When the mix hardens we obtain a model.

If the coronal tooth structure is entirely gone or destructed, even a crown would not stay. In this case the dentist has to place a *post and core*. The part placed into the root canal is known as post and the rest of it is known as the core. The crown is then constructed and cemented on to the core.

REHABILITATION

Unfortunately the reality is that often patients come too late for any kind of conservative treatment. Hopeless teeth have to be *extracted*. After extraction the patient often desires that it be replaced with an *artificial tooth*. There are many ways of replacing the tooth. Today implants have become very popular. A *titanium screw* can be implanted into the jaw surgically followed by an artificial crown. The implant is quite an expensive proposition and involves surgery.

The next choice is the *fixed partial denture* (bridge). Usually the teeth by the side of the missing tooth is reduced in size (prepared) in order to receive the bridge. The bridge is then cemented on to these teeth.

If too many teeth are missing, we might have to consider the *removable partial denture* which replaces the missing teeth but is not fixed in the mouth. It can be removed by the patient for cleaning and hygiene. The ideal removable partial denture is usually made of a combination of metal and plastic (cast partial denture). Interim or temporary partial dentures are made entirely of plastic also and are often referred to as *treatment partial dentures.*

The final stage is when all the teeth have to be replaced. One is of course familiar with the *complete denture* which is often seen in elderly individuals. These artificial teeth replace the entire dentition and are usually of the removable type (*fixed complete dentures* are also available which are supported and retained by implants). The complete denture is usually made of a type of plastic called acrylic. The teeth used in the denture can be made of acrylic or porcelain.

Besides all the materials mentioned above, different specialties in dentistry have their special materials. Some of these are not covered in this book. For example, endodontists use various medicaments to clean and debride the root canal. A variety of root canal sealing pastes and medicaments are also available. The periodontist uses different types of graft material to restore lost periodontal bone and tissue. Unfortunately not all the materials used in dentistry are within the scope of this book.

THE DENTAL LABORATORY

Many materials are used in the dental laboratory to aid in the fabrication of stents, prostheses, appliances and other structures used in and around the mouth. These include cutting, abrading and polishing materials. Investment materials are used in the creation of moulds in the casting of metal structures. Waxes are used in various stages of construction of different structures. Gypsum products are used to make casts, models, molds and to secure articulators.

CLASSIFICATION OF DENTAL MATERIALS

Dental materials may be classified into: (1) Preventive materials (2) Restorative materials and (3) Auxiliary materials.

Preventive materials include pit and fissure sealants and other materials used to prevent the onset of dental diseases.

Restorative materials include materials used to repair or replace tooth structure. This includes materials like amalgam, composites, ceramics, cast metal structures and denture materials.

Auxiliary materials are substances that aid in the fabrication process but do not actually become part of the restoration, appliance or prosthesis. This includes materials like gypsum products, impression materials, casting investments, waxes, etching gels, custom tray materials, etc.

INTERNATIONAL STANDARDS

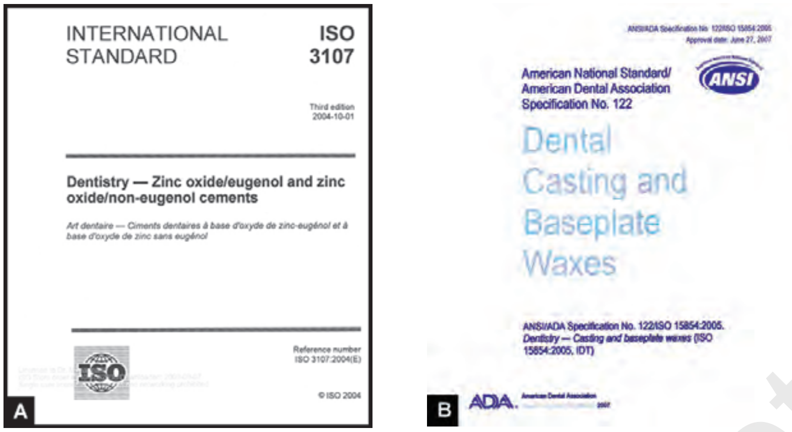
The Federation Dentaire Internationale (FDI) and the International Organizations for Standardization (ISO) are two organizations working for the development of specifications and terminology on an international level. The FDI is restricted to dental products whereas the ISO covers all products. The ISO is a nongovernmental body composed of the national organizations of more than 80 countries including India (Bureau of Indian Standards). The ISO standards ***(Fig. 1.1 A)*** *(see also appendix)* are formulated by a 'technical committee' (TC). Dental products are covered by TC 106. Various subgroups known as 'subcommittees' (SC) cater to specific areas. The subcommittees are further divided into 'working groups' (WG) to cover individual products or items. For example, TC 106/SC 1: WG 7 covers dental amalgam and mercury.

Considering the worldwide supply and demand for dental products the benefits from the ISO are invaluable. Suppliers and consumers can be assured of impartial reliable data to assess the quality of products and equipment regardless of its country of origin and use.

US STANDARDS FOR DENTAL MATERIALS

Standards are specifications by which the quality of a product can be gauged. Standards identify the requirements of physical and chemical properties of a material which ensures satisfactory performance for the function for which it is intended.

The earliest standards in the US were developed by The National Bureau of Standards in 1919 on the request of the US Army for the purchase and use of dental amalgam. The task was assigned to a team led by Wilmer Souder. Souder's report and testing methods were well received by the dental profession and test data were requested for other dental materials. By 1928 the responsibility for continued research into standards were assumed by the ADA.



INTERNATIONAL STANDARD

ISO 3107

Third edition
2004-10-01

Dentistry — Zinc oxide/eugenol and zinc oxide/non-eugenol cements

Art dentaire — Ciments dentaires à base d'oxyde de zinc-eugénol et à base d'oxyde de zinc sans eugénol

Reference number
ISO 3107:2004(E)

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ANSI/ADA Specification No. 122/ISO 15854:2005
Approval date: June 27, 2007

American National Standard/
American Dental Association
Specification No. 122

Dental
Casting and
Baseplate
Waxes

ANSI/ADA Specification No. 122/ISO 15854:2005.
Dentistry — Casting and baseplate waxes (ISO 15854:2005, IDT)

American Dental Association
2007

Figures 1.1A and B: Examples of standards: (A) International standards organization's specification for zinc oxide eugenol cement(ISO); (B) ANSI/ ADA Specification No. 122 for dental waxes.

ADA CERTIFICATION

Currently the ADA under direction of the ANSI (American National Standards Institute) sponsors two committees. The ADA Standards Committee for Dental Products develops specifications for all dental products, instruments and equipment (excluding drugs and X-ray films). The ADA's Council on Scientific Affairs is responsible for the evaluation of drugs, teeth cleaning agents, teeth whitening agents, therapeutic agents used in dentistry and dental X-ray films. After formulation of the specifications by the ADA, it is submitted to the ANSI. On approval it becomes a national standard ***(Fig. 1.1 B)***.

Manufacturers can submit their product for the ADA seal of approval. This falls into 3 categories—Accepted, Provisionally accepted, and Unaccepted. ADA certification is an important symbol of a dental products safety and effectiveness. ADA acceptance is effective for a period of 5 years.

SUMMARY

Materials used for dentistry are highly specialized. Each one is designed with a specific set of properties depending on what it is used for. For example, materials used as tooth restorations should be able to withstand occlusal forces as well as bond to tooth structure. Impression materials should be highly accurate and stable in order to duplicate the original structure. Modern science, research and technology has provided dentistry with an ever expanding selection of unique combinations of materials and techniques to serve dental treatment needs.

2

BASIC NATURE AND PROPERTIES OF DENTAL MATERIALS

All materials are made up of atoms. All dental restorations, whether they be ceramic, plastic or metal are built from atoms. If the reaction of a material and its properties are to be predicted, a basic knowledge of matter is essential.

FORMS OF MATTER

CHANGE OF STATE

Matter exists in three forms—solid, liquid and gas. The difference in form is mainly due to difference in energy. Matter is made up of atoms and for these atoms to be held together there must be a force, e.g., when 1 gm of water is to be changed into gaseous state at 100°C, 540 calories of heat are needed (known as heat of vaporization). Thus the gaseous state has more energy than the liquid state. Although the molecules in a gas have a certain amount of mutual attraction, they can diffuse readily and need to be confined in order to keep the gas intact.

Although atoms may also diffuse in the liquid state, their mutual attractions are greater and energy is required for this separation. As is well known, if the energy of the liquid is decreased by reducing the temperature sufficiently, a second transformation in state occurs and energy is released in the form of heat (latent heat of fusion). This decrease in energy state changes the liquid to a solid or *freezes* it.

The reverse is true when solid is changed to liquid, i.e. heat is required. The temperature at which it occurs is called *fusion temperature.*

Solid ⇔ Liquid ⇔ Gas

INTERATOMIC BONDS

Atoms are held together by some force. These interatomic bonding forces that hold atoms together are cohesive forces. Interatomic bonds may be classified as:

1. Primary bonds or
2. Secondary bonds

PRIMARY BONDS

These are chemical in nature:

Ionic
Covalent
Metallic

Ionic bonds These are simple chemical bonds, resulting from mutual attraction of positive and negative charges. The classic example is sodium chloride $Na^+ Cl^-$.

Covalent bonds In many chemical compounds, two valence electrons are shared. The hydrogen molecule H_2 is an example of covalent bonding. Another example is methane. The carbon atom has 4 valence electrons that can be stabilized by joining with hydrogen.

$$4\dot{\mathrm{H}} + \underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{C}}} \qquad \mathrm{H} : \underset{\underset{\mathrm{H}}{\cdot\cdot}}{\overset{\overset{\mathrm{H}}{\cdot\cdot}}{\mathrm{C}}} : \mathrm{H}$$

Metallic bonds One of the chief characteristics of a metal is its ability to conduct heat and electricity. Such conduction is due to the mobility of the so called free electrons present in the metals. The outer shield valence electrons can be removed easily from the metallic atom leaving the balance of the electrons tied to the nucleus, thus forming a positive ion.

The free valence electrons are able to move about in the metal space lattice to form what is sometimes described as an electrons 'cloud' or 'gas'. The electrostatic attraction between this electron 'cloud' and the positive ions in the lattice bonds the metal atoms together as a solid.

SECONDARY BONDS

This weaker bond may be said to be more physical than chemical. It is also known as van der Waals forces.

Van Der Waals Forces This is due to the formation of dipole. In a symmetric atom (e.g., inert gas) a fluctuating dipole is formed, i.e., within an atom there is accumulation of electrons in one half leading to a negative polarity and on the other half a positive polarity. This attracts other similar dipoles. A permanent dipole is formed within asymmetric molecules, e.g., water molecule.

THERMAL EXPANSION

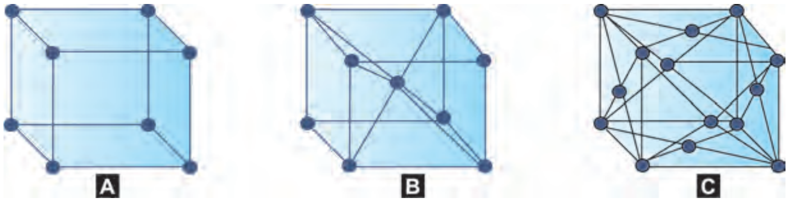
Thermal energy is due to the kinetic energy (internal energy) of the atoms or molecules at a given temperature. At temperatures above absolute zero, atoms are in a constant state of vibration. The average amplitude of vibration depends upon the temperature; the higher the temperature the greater will be the kinetic energy and amplitude of the atomic (or molecular) vibration increases. As the amplitude and internal energy of the atoms increase, the interatomic spacing increases as well. The gross effect is an expansion known as thermal expansion.

If the temperature continues to increase, the interatomic spacing will increase and eventually a change of state will occur (e.g., solid to liquid).

CRYSTAL STRUCTURE

Space lattice or crystal can be defined as any arrangement of atoms in space such that every atom is situated similar to every atom. Space lattice may be the result of primary or secondary bonds.

There are 14 possible lattice type forms, but many of the metals used in dentistry belongs to the cubic system. The simplest cubic space lattice is shown in ***Fig. 2.1 A to C.*** The solid circles represent the position of the atoms. Their positions are



Figures 2.1 A to C: Crystal structure: (A) Simple cubic; (B) Body centered cubic; (C) Face centered cubic.

located at the points of intersection of three sets of parallel planes, each set being perpendicular to other planes. These planes are often referred to as *crystal planes*.

NONCRYSTALLINE STRUCTURE

In a crystalline structure the arrangement of atoms in the lattice is orderly and follows a particular pattern. In noncrystalline structures or amorphous structures, e.g., waxes, the arrangement of atoms in the lattice is disorderly and distributed at random.

There is however a tendency for the arrangement of atoms or molecules to be regular, for example, glass is considered to be a noncrystalline solid, yet its atoms bind to form a short range order rather than long range order lattice. In other words, the ordered arrangement of glass is localized with large number of disordered units between the ordered units. Since such an arrangement is also typical of liquids, such solids are sometimes called *supercooled liquids*.

STRESS AND STRAIN

The distance between two atoms is known as interatomic distance. This interatomic distance depends upon the electrostatic fields of the electrons. If the atoms come too close to each other, they are repelled from each other by their electrons charges. On the other hand, forces of attraction keep them from separating. Thus the atoms are kept together at a position where these forces of repulsion and attraction become equal in magnitude (but opposite in direction). This is the normal equilibrium position of the atoms.

The normal position of the atoms can be changed by application of mechanical force. For example the interatomic distance can be increased by a force pulling them apart. If the displacing force is measured across a given area it is known as a *stress* and the change in dimension is called a *strain*. In simple words, stress is the force applied and strain is the resulting change in shape.

Theoretically, a stress and a strain exist whenever the interatomic distance is changed from the equilibrium position. If the stress pulling the atoms apart exceeds the resultant force of attraction, the atoms may separate completely, and the bonds holding them together are broken.

Strain can also occur under compression. However in this case, the strain produced is limited because when the atoms come closer than their normal interatomic distance, a sudden increase in energy is seen.

DIFFUSION

The diffusion of molecules in gases and liquids is well known. However, molecules or atoms diffuse in the solid state as well. Diffusion rates depend mainly on the temperature. The higher the temperature, the greater will be the rate of diffusion.

The diffusion rate will, however, vary with the atom size, interatomic or intermolecular bonding lattice imperfections. Thus every material has its own diffusion rate. The diffusion rate in noncrystalline materials may occur at a rapid rate and often may be seen.

SURFACE TENSION

Energy at the surface of a solid is greater than in its interior. For example, inside a lattice, all the atoms are equally attracted to each other. The interatomic distances are equal, and energy is minimal. However, at the surface of the lattice the energy is greater because there are no atoms on the outside. Hence there is only a force from the inside of the lattice pulling the outermost atoms inwards. This creates a tension on the outer surface and energy is needed to pull the outermost atoms away. The increase in energy per unit area of surface is referred to as the surface energy or surface tension.

The surface atoms of a solid tend to form bonds to any atom that come close to the surface in order to reduce the surface energy of the solid. This attraction across the interface for unlike molecules is called adhesion. In summary, the greater the surface energy, the greater will be the capacity for adhesion.

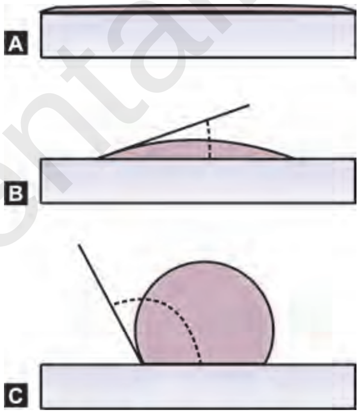
WETTING

It is very difficult to force two solid surfaces to adhere. However smooth their surfaces may appear, they are likely to be very rough at the atomic or molecular level. When they are placed together, only the 'hills' or high spots are in contact. Since these areas form only a small percentage of the total surface, no adhesion takes place. For proper adhesion, the distance between the surface molecules should not be greater than 0.0007 micrometer or micron (µm).

One method of overcoming this difficulty is to use a fluid that will flow into these irregularities and thus provide contact over a great part of the surface of the solid. For example, when two glass plates are placed one on top of the other, they do not usually adhere. However, if a film of water is placed in between them, it becomes difficult to separate the two plates.

To produce adhesion in this manner, the liquid must flow easily over the entire surface and adhere to the solid. This characteristic is referred to as *wetting*.

CONTACT ANGLE



Figures 2.2 A to C: Contact angles.

The contact angle is the angle formed by the adhesive (e.g., water) and the adherend (e.g., glass) at their interface. The extent to which an adhesive will wet the surface of an adherend may be determined by measuring the *contact angle* between the adhesive and the adherend. If the forces of adhesion are stronger than the cohesive forces holding the molecules of the adhesive together, the liquid adhesive will spread completely over the surface of the solid and no angle will be formed (e.g., water on a soapy surface, ***Fig. 2.2 A***). If the liquid remains as a drop without spreading, the contact angle will be high (e.g., water on an oily surface, ***Fig. 2.2 C***).

PHYSICAL PROPERTIES OF DENTAL MATERIALS

To select and use a dental material one must understand its properties.

STRESS

When a force acts on body, tending to produce deformation, a resistance is developed within the body to this external force. The internal resistance of the body to the external force is called stress. Stress is equal and opposite in direction to the force (external) applied. This external force is also known as load. Since both applied force and internal resistance (stress) are distributed over a given area of the body, the stress in a structure is designated as a force per unit area.

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

The internal resistance to force (stress) is impractical to measure. The convenient way is to measure the external force applied to the cross-sectional area.

Area over which the force acts is an important factor especially in dental restorations in which areas over which the forces applied often are extremely small. Stress at a constant force is inversely proportional to the area—the smaller the area the larger the stress and *vice versa*.

TYPES OF STRESSES

- Tensile stress
- Compressive stress
- Shear stress

Tensile Stress

Results in a body when it is subjected to two sets of forces that are directed away from each other in the same straight line. The load tends to stretch or elongate a body.

Compressive Stress

Results when the body is subjected to two sets of forces in the same straight line but directed towards each other. The load tends to or shortens a body.

Shear Stress

Shear stress is a result of two forces directed parallel to each other. A stress that tends to resist a twisting motion, or a sliding of one portion of a body over another is a shear or shearing stress.

STRAIN

If the stress (internal resistance) produced is not sufficient to withstand the external force (load) the body undergoes a change in shape (deformation). Each type of stress is capable of producing a corresponding deformation in the body. The deformation resulting from a tension, or pulling force, produces an elongation of a body, whereas a compression, or pushing force, causes compression or shortening of the body.

$$\text{Strain} = \frac{\text{Deformation or change in length}}{\text{Original length}} = \frac{E}{L}$$

Strain is expressed as change in length per unit length of the body when a stress is applied. It is a dimensionless quantity and may be elastic or plastic or a combination of the two.

COMPLEX STRESSES

It is difficult to induce just a single type of stress in a body. Whenever force is applied over a body, complex or multiple stresses are produced. These may be a combination of tensile, shear or compressive stresses. These multiple stresses are called complex stresses. For example, when a wire is stretched the predominant stress is tensile, but shearing and compressive stresses will also be present because the wire is getting thinner (compressed in cross-section) as it elongates ***(Fig. 2.6)***.

POISSON'S RATIO

If we take a cylinder and subject it to a tensile stress or compressive stress, there is simultaneous axial and lateral strain. Within the *elastic range* the ratio of the lateral to the axial strain is called Poisson's ratio.

PROPORTIONAL LIMIT

A tensile load is applied to a wire in small increments until it breaks. If each stress is plotted on a vertical coordinate and the corresponding strain (change in length) is plotted on the horizontal coordinate a curve is obtained. This is known as *stress-strain curve* ***(Fig. 2.3)***. It is useful to study some of the mechanical properties. The stress-strain curve is a straight line up to point 'P' after which it curves.

The point 'P' is the proportional limit, i.e., up to point 'P' the stress is proportional to strain (Hooke's Law). Beyond 'P' the strain is no longer elastic and so stress is no longer proportional to strain. Thus proportional stress can be *defined as* the greatest stress that may be produced in a material such that the stress is directly proportional to strain.

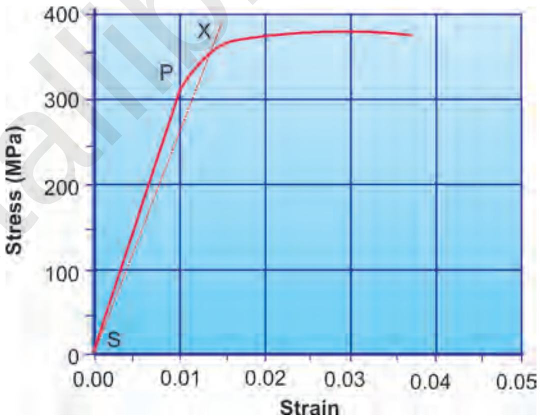


Figure 2.3: Stress-strain curve: P-proportional limit, X-yield strength, S-offset.

ELASTIC LIMIT

Below the proportional limit (point 'P') a material is elastic in nature, that is, if the load is removed the material will return to its original shape. Thus elastic limit may be *defined as* the maximum stress that a material will withstand without permanent deformation (change in shape). For all practical purposes, the elastic limit and the proportional limit represent the same stress. However the fundamental concept is different, one describes the elastic behavior of the material whereas the other deals with proportionality of strain to stress in the structure.

YIELD STRENGTH

Very few materials follow Hooke's law perfectly and some permanent change may be seen in the tested material. A small amount of permanent strain is tolerable. The limit of tolerable permanent strain is the yield strength. Thus yield strength is *defined as* the stress at which a material exhibits a specified limiting deviation from proportionality of stress to strain.

Determination of Yield Strength

How much of permanent deformation can be tolerated? This varies from material to material and is determined by selecting an offset. An *offset* is an arbitrary value put for a material. It represents the percent of total permanent deformation that is acceptable for the material. In dentistry 0.1% (1% offset) and 0.2% (2% offset) are most commonly used. The yield strength is determined by selecting the desired offset and drawing a line parallel to the linear region of the stress-strain curve ***(Fig. 2.3)***. The point on the stress-strain curve where the offset meets is the yield strength (point X).

MODULUS OF ELASTICITY

It is also referred to as 'elastic modulus' or 'Young's modulus'. It represents the relative stiffness or rigidity of the material within the elastic range.

Young's modulus is the ratio of stress to strain. Since stress is proportional to strain (up to the proportional limit), the stress to strain ratio would be constant.

Modulus of elasticity
or
Young's modulus

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{E/L} = \frac{FL}{EA}$$

It therefore follows that the less the strain for a given stress, the greater will be the stiffness, e.g., if a wire is difficult to bend, considerable stress must be placed before a notable strain or deformation results. Such a material would possess a comparatively high modulus of elasticity.

Application

The metal frame of a metal-ceramic bridge should have a high stiffness. If the metal flexes, the porcelain veneer on it might crack or separate.

FLEXIBILITY

Generally in dental practice, the material used as a restoration should withstand high stresses and show minimum deformation. However, there are instances where a large strain is needed with a moderate or slight stress. For example, in an orthodontic appliance, a spring is often bent a large distance with a small stress. In such a case the material is said to be flexible. The 'maximal flexibility' is *defined as* the strain that occurs when the material is stressed to its proportional limit. The relation between the maximum flexibility, the proportional limit and the modulus of elasticity may be expressed as:

$$\text{Maximum flexibility (EM)} = \frac{\text{Proportional limit (P)}}{\text{Modulus of elasticity (E)}}$$

Application

It is useful to know the flexibility of elastic impression materials to determine how easily they may be withdrawn over undercuts in the mouth.

RESILIENCE

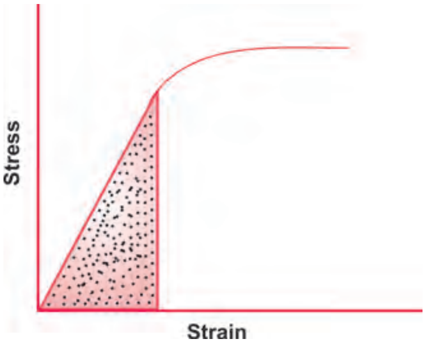


Figure 2.4: Area of resilience in a stress-strain curve.

Popularly, the term resilience is associated with 'springiness'. Resilience can be *defined as* the amount of energy absorbed by a structure when it is stressed not to exceed its proportional limit. For example, when an acrobat falls on a trapeze net the energy of his fall is absorbed by the resilience of the net, and when this energy is released, the acrobat is again thrown into the air.

The resilience of a material is measured in terms of its *modulus of resilience,* which is the amount of energy stored in a body, when a unit volume of a material is stressed to its proportional limit. It is expressed mathematically as:

$$\text{R (Modulus of Resilience)} = \frac{P^2 \text{ (proportional limit)}}{2E \text{ (modulus of elasticity)}}$$

Resilience is also measured by the area under the straight line portion of the stress-strain curve ***(Fig. 2.4).***

IMPACT

It is the reaction of a stationary object to a collision with a moving object. Depending upon the resilience of the object, energy is stored in the body without causing deformation or with deformation.

The ability of a body to resist impact without permanent deformation is represented by the formula—*KVR*

Where, K = Constant of proportionality
V = Volume
R = Modulus of resilience

But we know $R = P^2/2E$

$$\text{Therefore impact resistance} = \frac{KVP^2}{2E}$$

From the above formula we can conclude:

Impact resistance will be *decreased* with an increase in the modulus of elasticity, which means that stiffer materials will have less impact resistance. Resilient materials will have better impact resistance (however, a high stiffness is also necessary to provide rigidity to a material under static loads, e.g., a cement base should be able to support an amalgam restoration). Increase in volume leads to an increase in impact resistance.

IMPACT STRENGTH

It is the energy required to fracture a material under an impact force. A *Charpy* type impact tester is used. It has a heavy pendulum which swings down to fracture the specimen. Another instrument called Izod impact tester can also be used.

Application

Dentures should have a high impact strength to prevent it from breaking if accidentally dropped by the patient.

PERMANENT DEFORMATION

Once the elastic limit of a material is crossed by a specific amount of stress, the further increase in strain is called permanent deformation, i.e., the resulting change in dimension is permanent.

Application

An elastic impression material deforms as it is removed from the mouth. However due to its elastic nature it recovers its shape and little permanent deformation occurs. Some materials are more elastic than others. Thus permanent deformation is higher in hydrocolloids than in elastomers.

STRENGTH

It is the maximal stress required to fracture a structure.

The three basic types of strength are:

- Tensile strength
- Compressive strength
- Shear strength

TENSILE STRENGTH

Tensile strength is determined by subjecting a rod, wire or dumbbell shaped specimen to a tensile loading (a unilateral tension test). Tensile strength is *defined as* the maximal stress the structure will withstand before rupture.

Tensile Strength of Brittle Materials

Brittle materials are difficult to test using the unilateral tension test. Instead, an indirect tensile test called ‘*Diametral compression test*’ (or Brazilian test) is used ***(Fig. 2.5)***. In this method, a compressive load is placed on the diameter of a short cylindrical specimen. The tensile stress is directly proportional to the load applied as shown in the formula.

$$\text{Tensile Stress} = \frac{2P}{p \times D \times T} = \frac{\text{(load)}}{\text{(diameter} \times \text{thickness)}}$$

COMPRESSIVE STRENGTH

Compressive strength or ‘crushing strength’ is determined by subjecting a cylindrical specimen to a compressive load. The strength value is obtained from the cross sectional area and force applied. Though the load is compressive in nature, the failure is due to complex stresses.

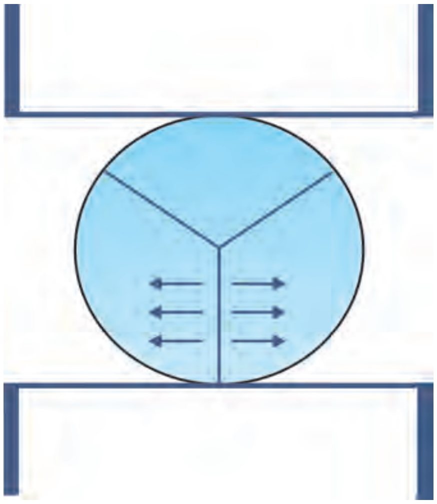


Figure 2.5: Diametral tensile test.

SHEAR STRENGTH

Shear strength is the maximum stress that a material can withstand before failure in a shear mode of loading. It is tested using the punch or pushout method. The formula is as follows:

$$\text{Shear Strength} = \frac{F}{\pi DH}$$

where, F is the force,
D is punch diameter
H is the thickness of the specimen.

Application

Used to study the interface between two materials, e.g., porcelain fused to metal.

TRANSVERSE OR FLEXURAL STRENGTH

Transverse strength or modulus of rupture, or bend strength, or fracture strength is obtained when a load is applied in the middle of a beam supported at each end. This test is also called a 3 *point bending test* (3PB) ***(Fig. 2.6)***.

Application

Used to test denture base resins and long span bridges.

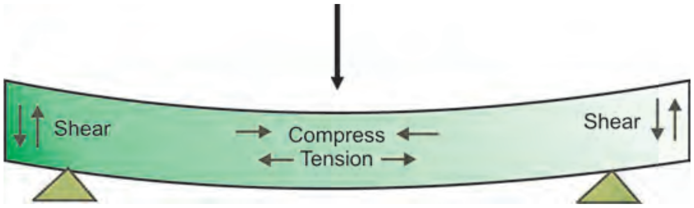


Figure 2.6: Complex stresses produced by a three point loading of a beam.

FATIGUE

A structure subjected to repeated or cyclic stresses below its proportional limit can produce abrupt failure of the structure. This type of failure is called fatigue. Fatigue behavior is determined by subjecting a material to a *cyclic stress* of a known value and determining the number of cycles that are required to produce failure. The stresses used in fatigue testing are usually very low. However the repeated application causes failure.

Application

Restorations in the mouth are often subjected to cyclic forces of mastication. In order to last, these restorations should be able to resist fatigue.

STATIC FATIGUE

It is a phenomenon exhibited by some ceramic materials. These materials support a high static load for a long period of time and then fail *abruptly*. This type of failure occurs only when the materials are stored in a wet environment and this property is related to the effect of water on the highly stressed surface of the material.

TOUGHNESS

It is *defined as* the energy required to fracture a material. It is a property of the material which describes how difficult the material would be to break. Toughness is also measured as the total area under the stress-strain curve ***(Fig. 2.7)***.

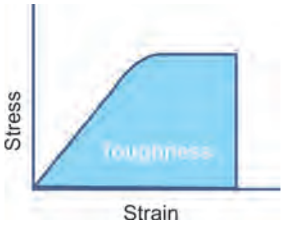


Figure 2.7: Area of toughness in the stress-strain curve.

BRITTLENESS

A brittle material *fractures at or near its proportional limit*. Brittleness is the opposite of toughness, e.g., glass is brittle at room temperature. It will not bend appreciably without breaking. It should not be wrongly understood that a brittle material lacks strength. From the above example of glass we see that its shear strength is low, but its tensile strength is very high. If glass is drawn into a fiber, its tensile strength may be as high as 2800 MPa.

Application

Many dental materials are brittle, e.g., porcelain, cements, dental stone, etc.

DUCTILITY

It is the ability of a material to withstand permanent deformation under a tensile load without rupture. A metal that can be drawn readily into a wire is said to be ductile. Ductility is dependent on tensile strength. Ductility decreases as the temperature is raised.

Ductility may be measured by three methods:

- By measuring the percentage elongation after fracture.
- By measuring reduction in cross-sectional area of fractured ends in comparison to the original area of the wire or rod and the method is called *reduction in area method*.
- By using the cold bend test.

MALLEABILITY

It is the ability of the material to *withstand rupture under compression*, as in hammering or rolling into a sheet. It is *not* dependent on strength as is ductility. Malleability increases with rise in temperature.

Toughness of a material is dependent upon the ductility (or malleability) of the material than upon the flexibility or elastic modulus.

Application of Malleability and Ductility

Gold is the most ductile and malleable metal. This property enables manufacturers to beat it into thin foils. Silver is second. Among other metals platinum ranks third in ductility and copper ranks third in malleability.

HARDNESS

Hardness is difficult to define specifically. There are numerous factors which influence the hardness of a material such as strength, proportional limit, ductility, malleability, etc. In mineralogy the hardness is described as the ability of a material to resist scratching. In metallurgy and in most other fields, the resistance to indentation is taken as the measure of hardness. There are many surface hardness tests ***(Fig. 2.8)***.

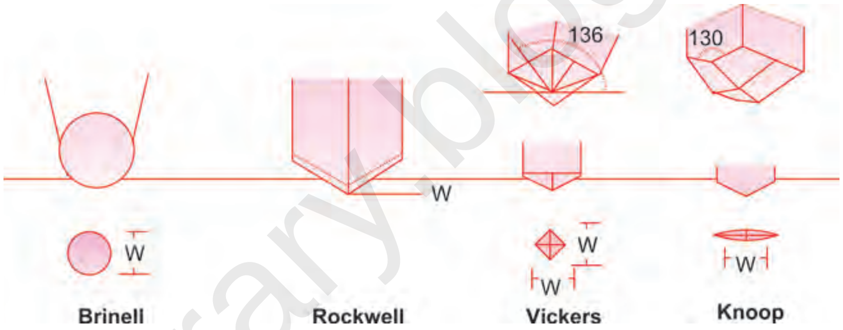


Figure 2.8: Various hardness tests.

BRINELL

The Brinell hardness scale was developed by a Swedish engineer named Johan August Brinell in 1900. The Brinell test utilizes a 10 mm diameter steel ball as an indenter, applying a uniform 3000 kgf (29 kN) force. A smaller amount of force is used on softer materials and a tungsten carbide ball is used for harder materials. The diameter of the indentation left in the test material is measured with a low powered microscope.The load is divided by the area of the surface of the indentation and the quotient is referred to as Brinell Hardness Number (BHN).

Application

Used for measuring hardness of metals and metallic materials.

ROCKWELL HARDNESS NUMBER (RHN)

Like the BH test, a steel ball or a conical diamond point is used. However, instead of measuring the diameter of the impression, the *depth* is measured directly by a dial gauge on the instrument.

Application

The Rockwell test has a wider application for materials, since Brinell test is unsuitable for brittle materials as well as plastic materials.

VICKERS HARDNESS TEST (VHN)

This is also similar to the Brinell test, however instead of a steel ball, a *diamond* in the shape of a square pyramid is used. Although the impression is square instead of round. The load is divided by the area of indentation. The length of the diagonals of the indentation (sides of the diamond) are measured and averaged.

Application

Vickers test is used in the ADA for dental casting golds. This test is suitable for brittle materials and so is used for measuring hardness of tooth structure.

KNOOP HARDNESS TEST (KHN)

A diamond indenting tool is used. Knoop hardness values is independent of the ductility of the material and values for both exceedingly hard and soft materials can be obtained from this test.

The Knoop and Vickers tests are classified as *microhardness tests*. The Brinell and Rockwell tests are classified as *macrohardness tests*.

THE SHORE AND THE BARCOL

These are less sophisticated tests. They are compact portable units. A metal indenter that is spring loaded is used. The hardness number is based on depth of penetration and is read directly from a gauge.

Applications

Used for measuring the hardness of rubber and plastics.

ABRASION RESISTANCE

Like hardness, abrasion is influenced by a number of factors. Hardness has often been used to indicate the ability of a material to resist abrasion.

Applications

It is useful for comparing materials in the same class, e.g., one brand of cement is compared to another and their abrasion resistance is quoted in comparison to one another. However it may not be useful for comparing materials of different classes like metals and plastics.

The only reliable test for abrasion is a test procedure which simulates the conditions which the material will eventually be subjected to, e.g., *toothbrush abrasion tests*.

RELAXATION

Every element in nature makes an attempt to remain in a stable form. If an element is changed from its equilibrium or stable form by either physical or chemical means it tries to come back to its original form.

When substances are deformed, internal stresses get trapped because of the displacement of the atoms. The condition is unstable and the atoms try to return to their original positions. This results in a change in shape or contour in the solid as atoms or molecules rearrange themselves. This change in shape due to release of stresses is known as *relaxation*. The material is said to warp or distort.

Examples Waxes and other thermoplastic materials like compound undergo relaxation after they are manipulated.

RHEOLOGY

Rheology is the study of flow of matter. In dentistry, study of rheology is necessary because many dental materials are liquids at some stage of their use, e.g., molten alloy and freshly mixed impression materials and cements. Other materials appear to be solids but flow over a period of time.

IMPORTANT TERMS AND PROPERTIES IN RHEOLOGY

Viscosity

Viscosity is the resistance offered by a liquid when placed in motion, e.g., honey is more viscous than water. It is measured in poise or centipoise (1 cp = 100 p).

Creep

Time dependent plastic deformation or change of shape that occurs when a metal is subjected to a constant load near its melting point is known as creep. This may be static or dynamic in nature.

Static creep is a time dependent deformation produced in a completely set solid subjected to a constant stress.

Dynamic creep produced when the applied stress is fluctuating, such as in fatigue type test.

Importance

Dental amalgam, has components with melting points that are slightly above room temperature and the creep produced can be very destructive to the restoration, e.g., glass tube fractures under a sudden blow but bends gradually if leaned against a wall.

Flow

It is somewhat similar to creep. In dentistry, the term flow is used instead of creep to describe rheology of amorphous substances, e.g., waxes. Although creep or flow may be measured under any type of stress, compression is usually employed for testing of dental materials.

SHEAR STRESS AND SHEAR STRAIN RATE

A liquid is placed between two plates and the upper plate is moved to the right. The stress required to move the plate is called shear stress (= F/A or force applied/ area of plate). The change produced is called shear strain rate (= V/d or velocity of plate/distance covered).

NEWTONIAN

Shear stress and shear strain rate can be plotted. An ideal fluid shows a shear strain rate that is proportional to shear stress. This behavior is called Newtonian ***(Fig. 2.9)***.

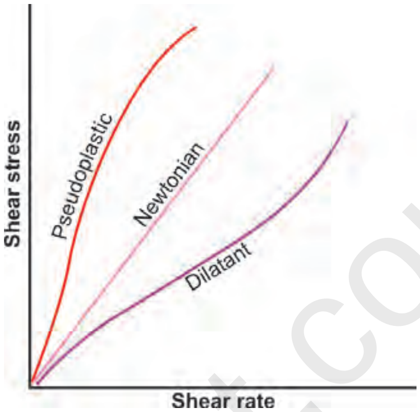


Figure 2.9: Shear diagrams of pseudoplastic, newtonian and dilatant liquids.

PSEUDOPLASTIC

If a material viscosity decreases with increase in shear rate it is said to exhibit pseudoplastic behavior, e.g., elastomeric impression materials when loaded into a tray shows a higher viscosity, whereas the same material when extruded under pressure through a syringe tip shows more fluidity ***(Fig. 2.9)***.

DILATANT

These are liquids that show higher viscosity as shear rate increases, e.g., fluid denture base resins ***(Fig. 2.9)***.

THIXOTROPIC

These materials exhibit a different viscosity after it is deformed, e.g. latex paints for ceilings show lower viscosity after it is stirred vigorously. Zinc oxide eugenol cements show reduced viscosity after vigorous mixing. Dental prophy paste is another example.

COLOR

Light is a form of electromagnetic radiant energy that can be detected by the human eye. The eye is sensitive to wave lengths from approximately 400 nm (violet) to 700 nm (dark red). The combined intensities of the wavelengths present in a beam of light determine the property called *color*.

In order for an object to be visible, either it must emit light or it must reflect or transmit light falling upon it from an external source. Objects of dental interest generally transmit light. The incident light is usually polychromatic (mixed light of various wavelengths). The reaction of an object to the incident light is to selectively absorb and/or scatter certain wavelengths. The spectral distribution of the transmitted or reflected light will resemble that of the incident light although certain wavelengths will be reduced in magnitude.

Cone shaped cells in the retina are responsible for color vision. The eye is most sensitive to light in the green-yellow region and least sensitive at either extremes (i.e., red or blue).

Dimensions of Color

The three dimensions of color are—hue, value and chroma.

HUE

Refers to the basic color of an object, e.g., whether it is red, green or blue.

VALUE

Colors can be separated into 'light' and 'dark' shades. Value represents the amount of lightness or darkness in the color. This lightness which can be measured independently of the hue is called value.

CHROMA

A particular color may be dull or more 'vivid', this difference in color intensity or strength is called chroma. Chroma represents the degree of saturation of a particular hue (color). In other words, the higher the chroma the more intense is the color. Chroma cannot exist by itself and is always associated with hue and value. The three dimensions of color is represented in ***Figures 2.10 and 2.11.***

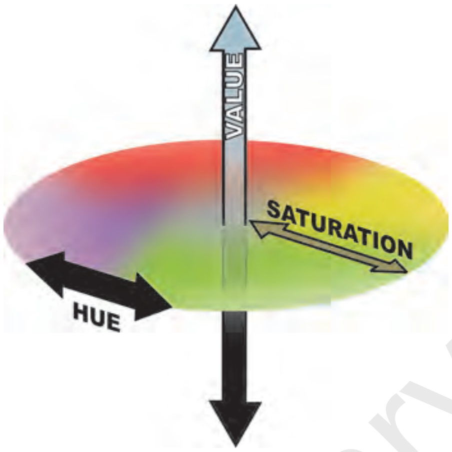


Figure 2.10: Illustration representing the 3 dimensions of color.

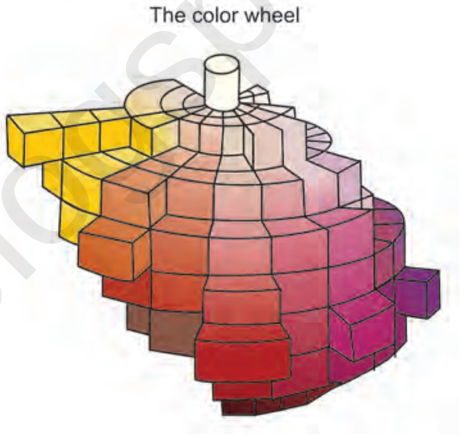


Figure 2.11: Munsells color solid is also used to demonstrate the three dimensions of color.

Measurement of Color

One of the most commonly used method to define and measure color quantitatively is the *Munsell System.* It is a coordinate system which can be viewed as a cylinder. The lines are arranged sequentially around the perimeter of the cylinder, while the *chroma increases along a radius* from the axis. The *value coordinate varies along the length* of the cylinder from black at the bottom to *neutral* grey at the center to white at the top.

METAMERISM

The appearance of an object depends on the type of the light by which the object is viewed. Daylight, incandescent lamps and fluorescent lamps are all common sources of light in the dental operatory. Objects that appear to be color matched under one type of light may appear very different under another light source. This phenomenon is called *metamerism.*

TRANSLUCENCE, TRANSPARENCE AND OPACITY

A transparent object allows all the light to pass through an object, whereas a translucent object allows only partial passage of light. For example plain glass

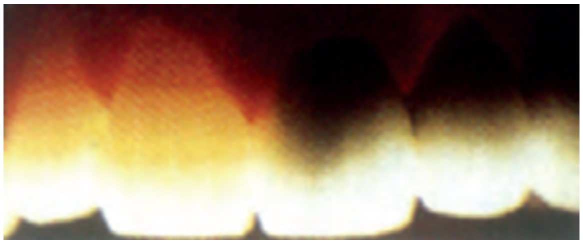


Figure 2.12: Esthetics can be compromised because of poor translucency exhibited by the metal-ceramic restoration on the right when compared to the natural teeth (left).

Figure 2.13: Natural teeth exhibiting fluorescence.

is transparent, whereas frosted glass is translucent. An object which does not allow any passage of light is said to be opaque.

Relevance

In some individuals the enamel may be translucent or in rare circumstances transparent. This may be particularly evident in the incisal edges of upper or lower incisors. Metal-ceramic restorations are opaque unlike naural teeth which are translucent ***(Fig. 2.12)***. One of the reasons for improved esthetics with all-ceramic restorations is the improved translucency.

FLUORESCENCE

Natural tooth structure also absorbs light of wavelengths which are too short to be visible to the human eye. These wavelengths between 300 to 400 nm are referred as *near ultraviolet*. Natural sunlight, photoflash lamps, certain types of vapor lamps and the ultraviolet lights used in decorative lighting are all sources containing substantial amounts of near U-V radiation and invisible U-V light.

This energy that the tooth absorbs is converted into light with larger wavelengths, in which case the tooth actually becomes a light source. The phenomenon is called fluorescence ***(Fig. 2.13)***. The emitted light is primarily in 400-450 nm range, having blue white color. Improved flourescence adds esthetic value to artificial restorations.

Figure 2.14: The Vitapan 3 D Master is used as a guide for selecting tooth color.

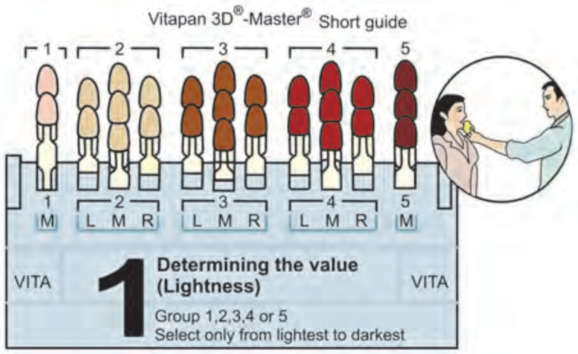
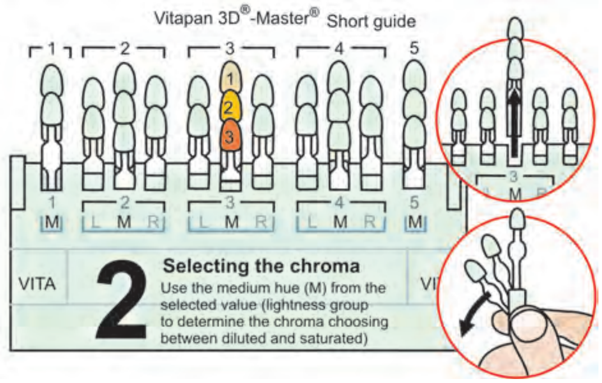
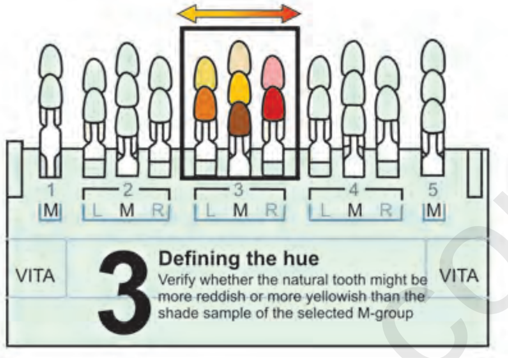


Figure 2.15: Selecting the color using the Vitapan system. The color is determined in 3 steps. The figure shows step 1. The guide is held along the patient's face at arms length.



Selecting the chroma
Use the medium hue (M) from the selected value (lightness group to determine the chroma choosing between diluted and saturated)

Figure 2.16: Step 2 determines the chroma (basic saturation).



Defining the hue
Verify whether the natural tooth might be more reddish or more yellowish than the shade sample of the selected M-group

Figure 2.17: Step 3 determines the hue (basic color).

Relevance

Some patients want their restorations to match natural tooth under fluorescent light conditions, e.g., in stage shows and discotheques. Some porcelain restorations are able to match the natural teeth under fluorecent lighting.

CLINICAL CONSIDERATIONS

Esthetics play a very important role in modern dental treatment. The ideal restorative material should match the color of the tooth it restores. In maxillofacial prosthetics the color of the gums, external skin and the eyes have to be duplicated.

Clinically in the operatory or dental lab, color selection is usually done by the use of *shade guides* ***(Figs 2.14 to 2.17)***. These are used in much the same way as paint chips are used to select the color for house paint.

3

BIOLOGICAL CONSIDERATIONS OF DENTAL MATERIALS

The science of dental materials must include a knowledge and appreciation of the biological considerations that are associated with selection and use of materials designed for the oral cavity. Strength and resistance to corrosion are unimportant if the material irritates or injures the pulp or soft tissue. The biological characteristics of dental materials cannot be isolated from their physical properties. In the early days of dentistry, the patient's mouth was often the testing ground of dental materials. Modern dentistry however involves extensive testing before the material is certified for human use.

BIOLOGICAL REQUIREMENTS OF DENTAL MATERIALS

A dental materials should:

1. Be nontoxic to the body
2. Be non-irritant to the oral or other tissues
3. Not produce allergic reactions
4. Not be mutagenic or carcinogenic

CLASSIFICATION OF MATERIALS FROM A BIOLOGICAL PERSPECTIVE

A. Those which contact the soft tissues within the mouth
B. Those which could affect the health of the dental pulp
C. Those which could affect the periapical areas of the tooth such as root-canal medicaments, filling materials, etc.
D. Those which affect the hard tissues of the teeth
E. Those used in the dental laboratory for fabricating dental appliances, which when handled may be accidentally ingested or inhaled

EXAMPLES OF HAZARDS FROM CHEMICALS IN DENTAL MATERIALS

- Some dental cements are acidic and may cause pulp irritation.
- Polymer based filling materials may contain irritating chemicals such as unreacted monomers, which can irritate the pulp.
- Phosphoric acid is used as an etchant for enamel.
- Mercury is used in dental amalgam, mercury vapor is toxic.

Figure 3.1: Nickel allergy from a necklace.

- Dust from alginate impression materials may be inhaled, some products contain lead compounds.
- Monomer in denture base materials is a potential irritant.
- Some people are allergic to alloys containing nickel ***(Fig. 3.1)***. Dental applications of nickel alloys include orthodontic wires, fixed and removable partial dentures, etc.
- During grinding of beryllium containing casting alloys, inhalation of beryllium dust can cause berylliosis.
- Some dental porcelain powders contain uranium.
- Metallic compounds (e.g., of lead, tin etc.) are used in elastomeric materials.
- Eugenol in materials like restorations and impressions can cause irritation and burning in some patients.
- Laboratory materials have their hazards, such as cyanide solution for electroplating, vapors from low fusing metal dies, silicious particles in investment materials, fluxes containing fluorides asbestos, etc.
- Some periodontal dressing materials have contained asbestos fibers.

A *biomaterial* can be defined as any substance other than a drug that can be used for any period of time as part of a system that treats, augments, or replaces any tissue, organ or function of the body.

PHYSICAL FACTORS AFFECTING PULP HEALTH

MICROLEAKAGE

One of the greatest deficiencies of all materials used for restoring teeth is that, they do not adhere to tooth structure and sal the cavity preparation (except those systems based upon polyacrylic acid and certain dentin-bonding agents). Thus a microscopic space always exists between the restoration and the prepared cavity. The use of radioisotope tracers, dyes, scanning electron microscope and other techniques have clearly shown that fluids, microorganisms and oral debris can penetrate freely along the interface between the restoration and the tooth and progress down the walls of the cavity preparation. This phenomenon is referred to as microleakage.

Microleakage can result in

1. *Secondary caries* The seepage of acids and microorganisms could initiate caries around the margins of the restoration.

2. *Stain or discoloration* can also develop.
3. *Sensitivity* Sometimes because of microleakage the tooth remains sensitive even after placement of the filling. If the leakage is severe, bacterial growth occurs between the restoration and the cavity and even into the dentinal tubules. Toxic products liberated by such microorganisms produce irritation to the pulp.

THERMAL CHANGE

Tooth structure and dental restorations are continually exposed to hot and cold beverages and foods. Instantaneous temperature fluctuation during the course of an average meal may be as great as 85°C. The temperature fluctuations can crack the restorative materials or produce undesirable dimensional changes in them because of thermal expansion and contraction.

Many restorative materials are composed of metals. Metals conduct heat and cold rapidly. Patients may often complain of sensitivity in a tooth with a metallic restoration when they are eating hot or cold foods. The problem is more in a very large restoration, where the layer of dentin remaining at the floor of the cavity may be so thin that it is not adequate to insulate the pulp against the temperature shock.

Protection from thermal changes The Dentist must place a layer of insulating cement (called base) under the restoration.

GALVANISM

Another cause for sensitivity is the *small currents* created whenever two *different* metals are present in the oral cavity (refer ***Fig. 4.1***). The presence of metallic restorations in the mouth may cause a phenomenon called galvanic action or galvanism. This results from a difference in potential between dissimilar fillings in opposing or adjacent teeth. These fillings in conjunction with saliva as electrolyte make up an electric cell. When two opposing fillings contact each other, the cell is short circuited and the patient experiences pain. A similar effect may occur when a restoration is touched by the edge of a metal fork.

Studies have shown that relatively large currents can flow. The current rapidly drops if the fillings are maintained in contact, probably as a result of polarization of the cell. The magnitude of the voltage is not of primary importance, but the sensitivity of the patient to the current has a greater influence on whether he will feel pain. Some patients may feel pain at 10 μ amp and other at 110 μ amp (average: 20 to 50 μ amp). That is why some patients are bothered by galvanic action and others are not despite similar conditions in the mouth.

The galvanic current magnitude depends on the composition and surface area of the metals. Stainless steel develops a higher current density than either gold or cobalt chromium alloys when in contact with an amalgam restoration. As the size of the cathode (e.g., a gold alloy) increases relative to that of the anode (e.g., amalgam), the current density may increase. The larger cathode can enhance the corrosion of the smaller anode. Current densities associated with non γ_2-containing amalgams appear to be less than those associated with γ_2-containing amalgam.

CLASSIFICATION OF ADVERSE REACTIONS FROM DENTAL MATERIALS

A number of biological responses are possible from materials. However, they may be broadly grouped into:

1. Toxic
2. Inflammatory
3. Allergic
4. Mutagenic

Fortunately, most materials are screened very early on for toxicity and mutagenicity, therefore most of the possible responses if any to dental materials usually fall in the inflammatory or allergic category.

Adverse effects may also be classified as:

1. Local
2. Systemic

A local effect is a result of the direct contact of the material to the regions immediately adjacent to the material. Example of a local reaction is the allergic response of the oral mucosa to the denture seen in some individuals.

A systemic reaction is caused by the absorption of the material into the body through local absorption, ingestion or inhalation.

TOXICITY EVALUATION

Toxicity test are classified as:

Level I Tests (Screening Tests)

The material is first checked for acute systemic toxicity and for its cytotoxic, irritational, allergic and carcinogenic potentials.

- *Acute systemic toxicity test* is conducted by administering the material orally to laboratory animals. If more than 50% of the animals survive, the material is safe.
- *Cytotoxic screening* may be done *in vivo* or *in vitro*. *In vitro* tests are conducted on cultured cells like mouse L-929 fibroblasts and human Hela cells. There are many *in vitro* tests. *Example,* Agar overlay technique; Agar is spread over a layer of culture cells in a culture plate. The test material is then placed on it and incubated. A toxic material will show a clear zone of dead cells.
- *Irritational properties* are checked by placing the material beneath the skin in rats or intramuscularly in rabbits. The animals are killed at different time intervals. The tissue response is then examined and compared.
- *Allergic potential* The material is first placed inside the skin of guinea pigs. Later the material is placed on the skin surface. Erythema and swelling at the site show allergic reaction.
- *Carcinogenic potential* (i) *In vivo* tests A material is placed beneath the skin (subcutaneously) of mice. They are then killed after 1 and 2 years and examined for tumors, (ii) *In vitro* tests Include *Ames test.* Here the material is tested with the help of mutant histidine dependent bacteria.

Level II (Usage Tests)

The material is tested in experimental animals similar to how it is used in humans, e.g., pulp reaction is studied by placing the material into class V cavities in teeth of primates (apes or monkeys). The teeth are then extracted periodically and compared with negative controls (ZOE cement) and positive controls (silicate cement).

Level III (Human Trials)

Once the material has passed screening and usage tests in animals, it is ready for trials in humans. The reactions and performance under clinical conditions are studied.

THERAPEUTIC EFFECTS OF DENTAL MATERIALS

Certain dental materials are utilized for their beneficial biological effects. For example zinc oxide eugenol cement has a pain relieving effect on irritated pulp. Calcium hydroxide pulp capping agent promotes the formation of secondary dentin and helps repair dentinal tissue.

OSSEOINTEGRATION

The osseointegration potential of titanium has been well documented in the literature. It is this property which allowed the successful use of materials like titanium as an implant material. The surface of titanium forms a very thin layer of oxide which promotes osseointegration. Materials that allow osseointegration have a very low degradation rate. Osseointegration with intervening connective tissue is called fibrous osseointegration and is generally considered a failure. When the bone closely approximates the implant without intervening connective tissue it is called osseointegration. If the bone actually fuses with the implant it is called *biointegration (refer chapter on Implants).*

INFECTION CONTROL

There is increased interest in expanding infection control measures to the dental laboratory. Concern over possible cross contamination to dental office personnel by microorganisms, including hepatitis-B virus and human immunodeficiency virus (HIV), through dental impressions has promoted the study of the effect of disinfecting techniques on dental materials.

INFECTION ROUTES

There are many ways by which microorganisms can spread:

1. Contaminated instruments and needles
2. Direct splashing of saliva and blood into the mouth or on to wounds
3. Breathing of contaminated aerosol from the air-rotor handpiece
4. Through contaminated dental materials.

Except for contamination occurring through dental materials, the other routes are beyond the scope of this book.

DISINFECTION OF DENTAL MATERIALS

Impressions

Impressions are the main source of spread of infection among the dental materials. However, disinfecting impression materials is more complex. The disinfectant must not affect its properties and accuracy. If the impression has not been disinfected, we must disinfect the cast.

Materials may be disinfected by:

1. Immersion in a disinfectant
2. Spraying with a disinfectant
3. Incorporating the disinfectant into the material as part of its composition.

Immersion in a disinfectant is the most common method of disinfection in the dental office as well as laboratory. However, certain materials like alginates may be affected if immersed beyond the recommended period. Alginates imbibe water and swell thereby affecting its accuracy.

Contaminated Restorations and Prostheses

Crowns, dentures and other prostheses that have been tried in the mouth are also a possible source of contamination. After the try-in many of these are sent for polishing without disinfection. These contaminate the polishing lathe and the pumice powder used for polishing which in turn cross contaminate other restorations and prostheses. Studies have shown complete dentures are massively contaminated with microorganisms and can serve as the primary source in the cycle of cross infection within dental laboratories. The polishing of dentures without previous disinfection leads to a high level of transfer of microorganisms to the professional, the polishing cone and the new dentures.

Infection control measures such as the use of barriers during polishing, the disinfection of dentures before being sent to the laboratory and upon return to the dental clinic, the disposal or sterilization of the cone after each use, as well as the addition of disinfectants to pumice and unit doses of pumice should be adopted with the objective of reducing the risk of cross-infection.

4

TARNISH AND CORROSION

Except for a few, pure metals do not occur naturally. They occur in the form of minerals such as oxides and sulfides and these have to be refined to produce the pure metal. Most pure metals attempt to reconvert to the combined state. The process by which this takes place is called corrosion.

One of the primary requisites of any metal that is to be used in the mouth is that it must not produce corrosion products that will be harmful to the body. The mouth is moist and continually subjected to fluctuations in temperature. The foods and liquids ingested have wide range of pH. All these factors make the mouth an extremely favorable environment for corrosion.

DEFINITIONS

TARNISH

Tarnish is a surface discoloration on a metal or even a slight loss or alteration of the surface finish or lustre.

Tarnish generally occurs in the oral cavity due to:

1. Formation of hard and soft deposits on the surface of the restoration, e.g., calculus, mucin and plaque.
2. Pigment producing bacteria, produce stains.
3. Formation of thin films of oxides, sulfides or chlorides.

PASSIVATION

In certain cases the oxide film can also be protective in nature. For example, chromium alloys (used in dental castings) are protected from corrosion by the formation of an oxide layer on its surface which protects the metal against any further corrosion. This is known as passivation. Another example is titanium.

CORROSION

It is not a surface discoloration but actual deterioration of a metal by reaction with the environment. Tarnish is often the forerunner of corrosion. In due course it may lead to rapid mechanical failure of the structure.

Water, oxygen, chloride ions, sulfides like hydrogen sulfide or ammonium sulfide contribute to corrosion attack in the oral cavity. Various acids such as phosphoric, acetic and lactic are also present. Among the specific ions responsible for corrosion, oxygen and chloride have been implicated in amalgam corrosion both at the tooth interface and within the body of amalgam. Sulfide has been implicated in the corrosion of silver containing casting alloys.

CLASSIFICATION OF CORROSION

CHEMICAL OR DRY CORROSION

The metal reacts to form oxides and sulfides in the absence of electrolytes.

Example — Formation of Ag_2S in dental alloys containing silver.
— Oxidation of alloy particles in dental amalgam.

ELECTROLYTIC OR ELECTROCHEMICAL OR WET CORROSION

This requires the presence of water or other fluid electrolytes. There is formation of free electrons and the electrolyte provides the pathway for the transport of electrons. An electrolytic cell is as follows:

$$M^0 \rightarrow M^+ + e^-$$

The anode is the surface where positive ions are formed. This metal surface corrodes since there is loss of electrons. This reaction is sometimes referred to as *oxidation reaction*.

$$M^+ + e^- \rightarrow M^0$$

$$2H^+ + 2e^- \rightarrow H_2$$

$$2H_2O + O_2 + 4e^- \rightarrow 4(OH)^-$$

At the cathode a reaction must occur that will consume the free electrons produced at the anode. The reactions 2, 3 and 4 occur at the cathode and are referred to as *reduction reactions*. Hence, the anode looses electrons and the cathode consumes. The surface of the anode corrodes due to loss of electrons.

ELECTROMOTIVE FORCE SERIES (EMF)

The EMF series is a classification of elements in the order of their dissolution tendencies. That is, if two metals are immersed in an electrolyte and are connected by an electrical conductor, an electric couple is formed. The metal that gives up its electrons and ionizes is called the anode. In the EMF series hydrogen has been used as the standard electrode to which other metals have been compared. Hydrogen has been given the value zero in the EMF series ***(Table 4.1)***.

The metal with lowest electrode potential corrodes. Also the more active metal corrodes (anode) and the more noble metal becomes the cathode.

TYPES OF ELECTROLYTIC CORROSION

GALVANIC CORROSION

Saliva with its salts provides a weak electrolyte. Galvanic corrosion occurs when dissimilar metals lie in direct physical contact with each other ***(Fig. 4.1)***.

Table 4.1

Electromotive force values

Metal	*Ion*	*Electrode potential*
Gold	Au	+ 1.50
Platinum	Pt	+ 0.86
Silver	Ag	+ 0.88
Copper	Cu	+ 0.47
Hydrogen	H^+	0.00
Cobalt	Co	–0.28
Iron	Fe	–0.44
Zinc	Zn	–0.76

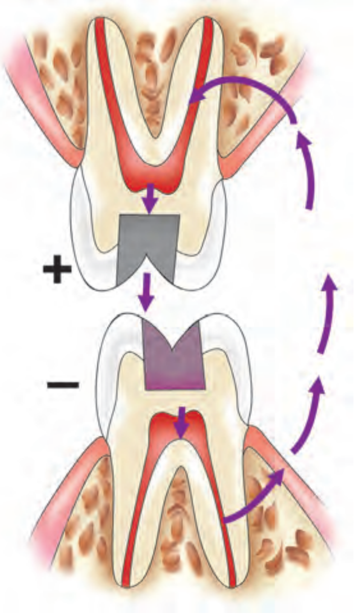


Figure 4.1: Potential galvanic current pathway when dissimilar metals contact. The tissue fluid and saliva behaves like an electrolyte.

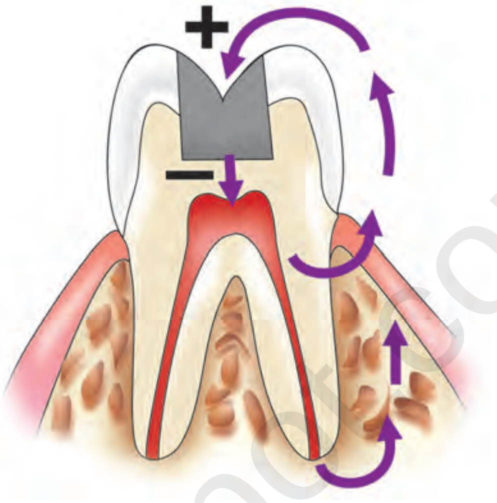


Figure 4.2: A current pathway may exist even in a single metallic restoration. In this case the tissue fluid behaves like a cathode (because of the higher concentration of Cl^- ions in tissue fluid when compared to saliva) whereas saliva behaves like anode. This current is usually less intense.

If a gold restoration comes in contact with an amalgam restoration, the amalgam forms the anode and starts corroding. The electric couple (500 millivolts) created when the two restorations touch causes sharp pain called *'galvanic shock'*. It usually occurs immediately after insertion and can be minimized by painting a varnish on the surface of the amalgam restoration. However, the best precaution is to *avoid dissimilar metals* in contact. Another variation of galvanic corrosion can occur even in a lone standing restoration **(*Fig. 4.2*)**.

HETEROGENOUS COMPOSITIONS

This kind of corrosion occurs *within* the structure of the restoration itself. Heterogenous (mixed) compositions can cause galvanic corrosion:

- When an alloy containing eutectic is immersed in an electrolyte the metallic grains with the lower electrode potential are attacked and corrosion results.
- In a cored structure differences in the composition within the alloy grains are found. Thus a part of a grain can be anode and part cathode. Homogenization improves the corrosion resistance of the alloy.
- In metals or alloys the grain boundaries may act as anodes and the interior of the grain as the cathode.
- Solder joints may also corrode due to the inhomogeneous composition.
- Impurities in any alloy enhance corrosion.

Note: Seldom is any one type of corrosion found alone, generally two or more act simultaneously and thus aggravate the problem

STRESS CORROSION

A metal which has been stressed by cold working, becomes more reactive at the site of maximum stress. If stressed and unstressed metals are in contact in an electrolyte, the stressed metal will become the anode of a galvanic cell and will corrode. For example, if an orthodontic wire has been cold worked, stress corrosion may occur and cause the wire to break.

CONCENTRATION CELL CORROSION OR CREVICE CORROSION

- *Electrolyte concentration cell* In a metallic restoration which is partly covered by food debris, the composition of the electrolyte under the debris will differ from that of saliva and this can contribute to the corrosion of the restoration.
- *Oxygen concentration cell* Differences in oxygen tension in between parts of the same restoration causes corrosion of the restoration. Greater corrosion occurs in the part of the restoration having a lower concentration of oxygen.

PROTECTION AGAINST CORROSION

PASSIVATION

Certain metals readily form strong adherent oxide film on their surface which protects them from corrosion. Such metals are said to be passive. *Chromium, titanium,* and *aluminium* are examples of such metals.

Adding more than 12% Cr to iron or cobalt produces a chromic oxide layer on the surface of stainless steel or cobalt chromium alloys which is highly corrosion resistant. Since this film is passive to oxidative chemical attack, their formation is called passivation.

INCREASING NOBLE METAL CONTENT

Alloys with a noble metal content below 65% may tarnish. So it has been suggested that at least 50% of the atoms in a dental alloy should be gold, platinum or palladium to ensure against corrosion. Noble metals resist corrosion because their EMF is positive with regard to any of the common reduction reactions found in the oral environment.

POLISHING

Polishing metallic restorations like amalgam and cast metal to a high luster minimizes corrosion. The patient should also maintain good oral hygiene.

OTHER METHODS

Dissimilar metal restorations should be avoided. Avoid using a high mercury containing amalgam as it is more susceptible to corrosion. Mercury tarnishes gold, thus, care must be taken to protect gold ornaments worn by the operator, assistant or patient.

5

INTRODUCTION TO RESTORATIONS, LUTING AND PULP THERAPY

This chapter serves as an introduction to restorative dentistry, including cements, liners and varnish. An emphasis is also placed on the effect of these materials on the pulp.

RESTORATIONS

Tooth material is often lost as a result of caries and trauma. A restoration is a material which substitutes the missing tooth structure and restores the form and function of the tooth ***(Fig. 5.1)***.

TYPES OF RESTORATIONS

Restorations may be classified in a number of different ways:

1. Temporary, intermediate and permanent
2. Direct and indirect
3. Esthetic and nonesthetic

TEMPORARY RESTORATIONS

Temporary restorations are often required before the placement of a permanent restoration. Materials used for temporary restorations are expected to last for only a short period of time, a few days or a few weeks at most. They serve as an interim restoration while the pulp heals; and/or till the permanent restoration

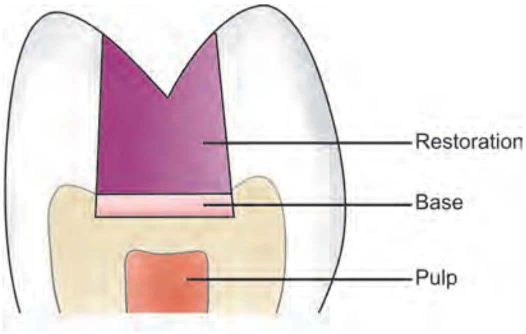


Figure 5.1: Restoration of a tooth.

can be fabricated and inserted. At one time gutta-percha (temporary stopping), a thermoplastic gum that is used to fill root canals was popular for this purpose. However, it did not adapt well to the cavity walls, microleakage ensued and sensitivity was a common occurrence.

Because of its excellent initial sealing ability and kind pulpal response, *zinc oxide eugenol (ZOE)* is the cement of choice for temporary restorations. This material is particularly useful when a sedative treatment is required until the pulp has healed well enough for the permanent restoration to be placed. The Type-I ZOE is very popular for sedative treatment, temporary coverage and temporary cementation. Type III ZOE is used for temporary restorations.

INTERMEDIATE RESTORATIONS

Intermediate or holding type of restoration is particularly used in pedodontics. For example, in rampant caries, it is desirable to remove all the caries quickly in order to change the oral health and arrest the caries process. Once the initial ‘clean up’ has been done, the dentist can proceed with placement of the permanent restorations. The interval between removal of the caries and completion of final restorative work may take several months. During this time teeth are protected with a desirable intermediate restoration.

Conventional zinc-eugenol cements used as temporary restorations are deficient in toughness. They have inadequate strength and abrasion resistance to serve for a longer period. As a result polymer reinforced cement (IRM) is used. Earlier Type II- zinc phosphate and Type II or Type III- zinc silicophosphate cements were used. However these materials were irritating to the pulp and required more precise cavity preparation and placement time. They are now replaced by improved ZOE formulations. The combination of surface treatment and polymer reinforcement results in good strength, improved abrasion resistance and toughness. They can last for a period of *one year or more*.

REQUIREMENTS OF A TEMPORARY FILLING MATERIAL

1. It should have adequate strength to last a few weeks, but weak enough to be dislodged easily.
2. It should be easy to insert and remove.
3. It should have adequate seal.
4. It should have antibacterial properties.
5. It should have a therapeutic effect (pain relief, healing, etc.) on the pulp.
6. It should have cariostatic properties.

PERMANENT

The term permanent is *not an absolute term*. However, it obviously serves to denote any material that is expected to last much longer than the temporary and intermediate restorations. Therefore, it is expected to have improved properties than the temporary and intermediate restorations. Examples of permanent restorative materials are direct filling gold, amalgam ***(Fig. 5.1)***, composite resins, glass ionomer cement, as well as porcelain, composite and cast metal inlays and onlays.

The length of time each material lasts varies on the technical skills of the operator, the material itself and other patient related factors. A well made amalgam restoration would probably last a life time or more. On the other hand the composite restoration might have to be replaced much earlier as a result of wear, fracture or discoloration.

DIRECT AND INDIRECT RESTORATIONS

Direct restorations These are materials used to build and restore the tooth structure directly in the mouth. They are usually placed in increments. They are usually soft and plastic when initially placed and harden later with time. Examples are amalgam, direct filling gold, composite (can be used both directly and indirectly) and glass ionomer.

Indirect restorations These are usually fabricated outside the mouth on models of the tooth and then cemented into place in the mouth. Examples of indirect restorations are porcelain, composite and cast metal inlays and onlays.

ESTHETIC AND NONESTHETIC

The terms esthetic and nonesthetic are again relative.

Esthetic An esthetic material is obviously something which is pleasing to an individual. At one time gold fillings and crowns were considered esthetic. Today, however, an esthetic material implies any material that is capable of reproducing the color and appearance of a *natural tooth*. Examples are composite, glass ionomer and porcelain.

Nonesthetic Currently, it denotes any material that is not tooth colored. This includes amalgam, direct filling gold and cast metal inlays and onlays.

LUTING

Synonyms Bonding, cementing

Luting or cementation ***(Fig. 5.2)*** is the process by which crowns, restorations and other devices are fixed or attached to tooth structure using an intermediate material called cement. Cements have multiple uses. For example, glass ionomer can be used as a base, luting agent and as a restorative material. Besides attaching the restoration a luting agent must also seal the space between the restoration and the tooth structure to prevent caries and chemical and bacterial irritation of the tooth and pulp.

TYPES

1. Temporary cementation
2. Permanent cementation

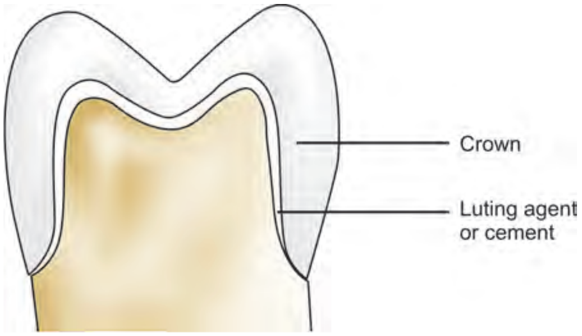


Figure 5.2: The luting agent attaches as well as seals the space between the restoration and tooth structure.

TEMPORARY CEMENTATION

Temporary cementation of crowns and fixed partial dentures (FPD) are often required. Temporary crowns and FPDs are required to stay in place only until the permanent structure is ready. Therefore it must be weak enough to be easily removed when the permanent structure is ready for cementation. In addition, this cement should have some soothing effect on the pulp of the freshly prepared vital tooth which would have been traumatized during the preparation. Permanent structures (e.g., crowns or FPDs) are also sometimes cemented temporarily. This allows the patient to take it for a home trial or to observe the pulpal response. Once the patient and dentist are satisfied with the results, the restoration is removed and cemented permanently. An example of such a temporary bonding cement is a zinc oxide eugenol based cement (Temp Bond).

PERMANENT CEMENTATION

A permanent cementing material on the other hand should be strong and insoluble in oral fluids. It would also be advantageous if it had some chemical bonding to the tooth structure. In addition, it should be fluid enough to flow well to ensure the complete seating of the restoration.

Examples of permanent cementing materials are zinc phosphate cement, glass ionomer cement, resin cement, polycarboxylate cement, etc.

GENERAL REQUIREMENTS OF LUTING MATERIALS

1. They should be nontoxic and non-irritant to pulp and tissues.
2. They should be insoluble in saliva and liquids taken into the mouth.
3. Mechanical properties: These must meet the requirements for their particular applications, e.g., a cement base should develop sufficient strength rapidly to enable a filling material to be packed on it.
4. Protection of the pulp from insults.
   - Thermal insulation, a cement used under a large metallic restoration should protect the pulp from temperature changes.
   - Chemical protection, should be able to prevent penetration into the pulp of harmful chemicals from the restorative material.
   - Electrical insulation under a metallic restoration to reduce galvanic shock.
5. Optical properties: For cementation of a translucent restorations (e.g., porcelain) the cement should simulate the color of tooth substance.
6. Cement should ideally be adhesive to both tooth structure and restorative material (gold alloys, porcelain, etc.), but not to dental instruments.
7. They should be bacteriostatic in a cavity with residual caries.
8. They should have an obtundent (soothing) effect on the pulp.
9. Rheological properties. A luting cement should have sufficiently low viscosity to give a low film thickness.

PULP CAPPING

Pulp capping is the process of placing a specialized agent in contact with or in close proximity to the pulp with the intention of encouraging formation of new dentin (secondary dentin) and promote the healing of the pulp. Prior to the discovery of pulp capping agents, a pulp exposure often led to irreversible pulpitis or pulpal infection and ultimately pulp necrosis. Thanks to these pulp capping agents, it became possible to treat pulpal tissue which otherwise would have had to undergo root canal therapy. Example of a pulp capping agent is *calcium hydroxide* cement.

CRITERIA FOR PULP CAPPING

Are all exposed pulps suitable for pulp capping therapy? The answer is obviously no. The dentist has to apply certain criteria and select his cases carefully.

1. The pulp should be healthy and uninfected.
2. The area of exposure should be no more than 0.5 mm.
3. Following exposure the dentist should make all attempts to immediately isolate the tooth and prevent contamination.

TYPES OF PULP CAPPING

1. Direct pulp capping
2. Indirect pulp capping

DIRECT PULP CAPPING

Direct pulp capping is the placement of the agent directly on the exposed pulp ***(Figs 5.3 A and B)***. Such a situation is often encountered during:

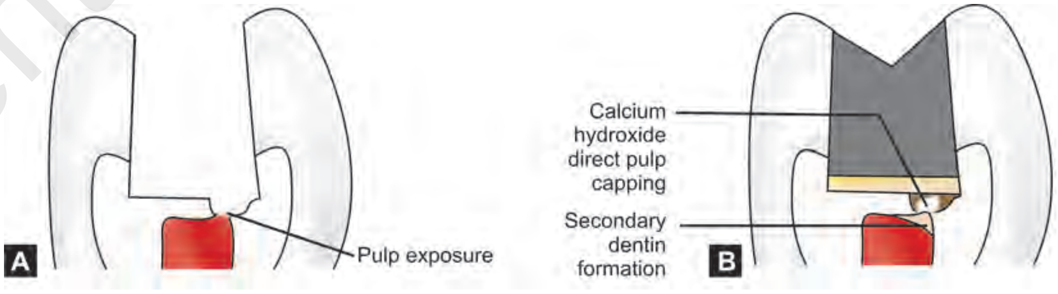
1. The excavation of deep carious lesions when the dentist accidentally exposes the pulp.
2. Traumatic fractures of the tooth.
3. Iatrogenic (doctor induced) exposure during cavity preparation.
4. Iatrogenic exposure during crown preparation.

INDIRECT PULP CAPPING

Secondary dentin formation can be induced even when the pulp is not exposed but is near exposure. When the calcium hydroxide is placed in the region of the near exposure, it can still induce new dentin formation. This is known as *indirect pulp capping***.**

Indications

1. Deep carious lesions close to the pulp.



Figures 5.3 A and B: (A) Pulp exposure. (B) Direct pulp capping and subsequent secondary dentin formation several weeks later.

2. During excessive crown preparation the pulp is often visible through the remaining dentin as a pinkish or reddish spot or area.
3. Similar near exposures may be seen in cases of traumatic tooth fracture.

BASES

A base is a layer of cement placed beneath a permanent restoration to encourage recovery of the injured pulp and to protect it against numerous types of insults to which it may be subjected. The type of *insults* depends upon the particular restorative material. It may be thermal or chemical or galvanic. The base serves as replacement or substitute for the protective dentin, that has been destroyed by caries or cavity preparation.

TYPES

They belong to two categories.

High Strength Bases

These are used to provide *thermal protection* for the pulp, as well as *mechanical support* for the restoration.

Examples of high strength bases: zinc phosphate, zinc polycarboxylate, glass ionomer and reinforced ZOE cements.

Some important properties of cements used as high strength bases are strength, modulus of elasticity and thermal conductivity.

Low Strength Bases

Low strength bases have minimum strength and low rigidity. Their main function is to act as a *barrier* to irritating chemicals and to provide *therapeutic benefit* to the pulp. Examples are: calcium hydroxide and zinc oxide eugenol.

PROPERTIES

Thermal Properties

The base must provide thermal protection to the pulp. This property is important especially when the tooth is restored with *metallic restorations*.

The thermal conductivity of most cement bases is similar to tooth structure and is in the range of recognized insulators such as cork and asbestos.

For effective thermal protection the base should have minimal thickness of 0.75 mm. A thin wash of cement would not offer protection against thermal insults through metallic restorations.

Protection Against Chemical Insults

The cement base also serves as a barrier against penetration of irritating constituents (e.g., acids, monomer, etc.) from restorative materials. Calcium hydroxide and zinc oxide-eugenol are most effective for this especially in deep (close to the pulp) cavities. Polycarboxylate and glass ionomer bases are also used as chemical barriers in more moderate cavities.

Therapeutic Effect

Some bases are used for their therapeutic benefit to the pulp. For example, calcium hydroxide acts as a pulp capping agent and promotes the formation of secondary dentin. Zinc oxide-eugenol has an obtundent effect on the pulp.

Strength

The cement base must have sufficient strength to:

- Withstand the forces of condensation. Fracture or displacement of the base permits the amalgam to penetrate the base and contact the dentin. Likewise, in deep cavities the amalgam may be forced into the pulp through microscopic exposures in the dentin.
- Withstand fracture or distortion under masticatory stresses transmitted to it through the permanent restoration.

Also the cement base should develop sufficient strength rapidly in order to allow early condensation of amalgam. The minimum strength requirement of a base is between 0.5 and 1.2 MPa.

CLINICAL CONSIDERATIONS

The base is selected according to:

- Design of the cavity
- Type of permanent restorative material used
- Proximity of the pulp to the cavity walls.

With amalgam, calcium hydroxide or zinc oxide-eugenol cement is usually sufficient.

In case of direct filling gold where the condensation pressure is higher, a stronger cement is indicated as base.

With resin restorations, calcium hydroxide is the material of choice, as zinc oxide-eugenol cements interface with its polymerization. Glass ionomer cement can also be used as base.

LINERS AND VARNISH

Liners and varnishes are agents in a volatile solvent which when applied to a surface evaporates leaving behind a thin film. This film acts as a barrier which has different functions depending on the circumstance and the location where it is applied. These materials are discussed in more detail in the subsequent chapter.

6

CAVITY LINERS AND VARNISH

CAVITY LINERS

A cavity liner is used like a cavity varnish to provide a barrier against the passage of irritants from cements or other restorative materials and to reduce the sensitivity of freshly cut dentin. They are usually suspensions of calcium hydroxide in a volatile solvent. Upon the evaporation of the volatile solvent, the liner forms a *thin film* on the prepared tooth surface.

SUPPLIED AS

Solutions in bottles
Powder and liquid
Paste in tubes

COMPOSITION

Suspension of calcium hydroxide in an organic liquid ***(Fig. 6.1)*** such as methyl ethyl ketone or ethyl alcohol. Acrylic polymer beads or barium sulphate calcium monofluorophosphate.

PROPERTIES

Like varnishes, cavity liners neither possess mechanical strength nor provide any significant thermal insulation. The calcium hydroxide liners are soluble and *should not* be applied at the margins of restorations. Fluoride compounds are added to some cavity liners in an attempt to reduce the possibility of secondary caries around permanent restorations or to reduce sensitivity.

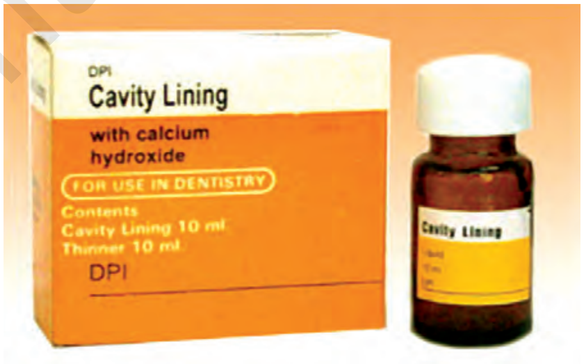


Figure 6.1: Calcium hydroxide suspension used for cavity lining.

MANIPULATION

Cavity liners are fluid in consistency and can be easily flowed or painted over dentinal surfaces. The solvents evaporate to leave a thin film residue that protects the pulp. The paste form is applied in the cavity and then light cured.

OTHER LINERS

Some other materials have been claimed as liners. These include Type III glass ionomer and ZOE.

CAVITY VARNISH

Cavity varnish is a solution of one or more resins which when applied onto the cavity walls, evaporates leaving a thin resin film, that serves as a barrier between the restoration and the dentinal tubules.

APPLICATION

1. It reduces microleakage around the margins of newly placed amalgam restorations, thereby reducing, postoperative sensitivity.
2. It reduces passage of irritants into the dentinal tubules from the overlying restoration or base, e.g., silicate.
3. In amalgam restorations, they also prevent penetration of corrosion products into the dentinal tubules, thus, minimizing tooth discoloration.
4. Varnish may be used as a surface coating over certain restorations to protect them from dehydration or contact with oral fluids, e.g., silicate and glass ionomer restorations.
5. Varnish may be applied on the surface of metallic restoration as a temporary protection in cases of galvanic shock.
6. When electrosurgery is to be done adjacent to metallic restorations, varnish applied over the metallic restorations serves as a temporary electrical insulator.
7. Fluoride containing varnishes release fluoride.

SUPPLIED AS

Liquid in dark colored bottles ***(Fig. 6.2).***

Commercial Names Harvard lac, Chem Varnish, Secura, Fuji Varnish (GC)

COMPOSITION

Natural gum such as copal, rosin or synthetic resin dissolved in an organic solvent like alcohol, acetone, or ether. Medicinal agents such as chlorbutanol, thymol and eugenol may be added. Some varnishes also contain fluorides.

PROPERTIES

Varnishes neither possess mechanical strength nor provide thermal insulation because of the thin film thickness. The film thickness ranges from 2 to 400 µm. The solubility of dental varnishes is low; they are virtually insoluble in water.

MANIPULATION

The varnish may be applied by using a brush, wire loop or a small pledget of cotton. Several thin layers are applied. Each layer is allowed to dry before

Figure 6.2: Some of the various commercially available varnishes.

applying the next one. When the first layer dries, small pinholes develop. These voids are filled in by the succeeding varnish applications. The main objective is to attain a uniform and continuous coating.

PRECAUTIONS

1. Varnish solutions should be tightly capped immediately after use to prevent loss of solvent by evaporation.
2. It should be applied in a thin consistency. Viscous varnish does not wet the cavity walls properly. It should be thinned with an appropriate solvent.
3. Excess varnish should not be left on the margins of the restorations as it prevents proper finishing of the margins of the restorations.

CLINICAL CONSIDERATIONS

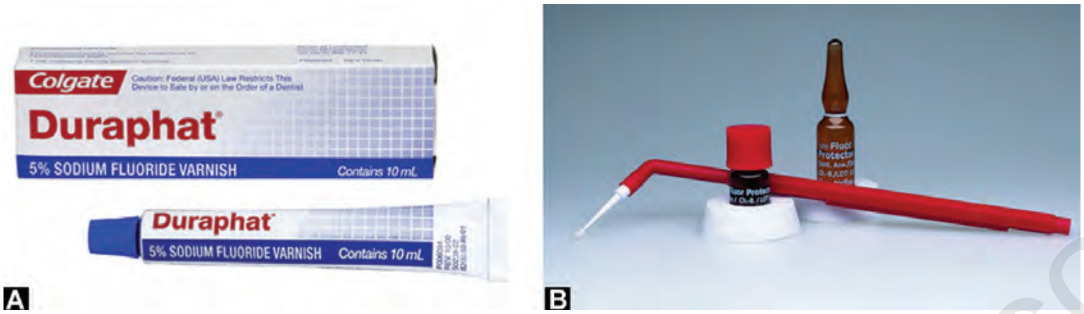
When placing a silicate restoration, the varnish should be confined to the dentin. Varnish applied on the enamel inhibits the uptake of fluoride by the enamel.

CONTRAINDICATIONS

1. Composite resins: The solvent in the varnish may react with the resin.
2. Glass ionomer: Varnish eliminates the potential for adhesion, if applied between GIC and the cavity.
3. When therapeutic action is expected from the overlying cement, e.g., zinc oxide-eugenol and calcium hydroxide.

FLUORIDE VARNISHES

Fluoride varnishes are used to prevent or arrest tooth decay in smooth surfaces in young children, especially when applied before age three as their teeth erupt. The taste does not appear to be offensive so is considered acceptable to young children. The technique is well accepted by parents. It hardens on contact with saliva and stays in contact with the teeth for several hours or days, but is not meant to adhere permanently. Families should be told that their child can eat and drink afterward but they should not brush the teeth until the next day, or at least 12 hours later, as it may remove some of the varnish. Most protocols suggest two applications per year, although some recommend up to four, with the first ones occurring fairly close together or in the first 1-2 weeks.



Figures 6.3 A and B: Two commercially available fluoride varnishes. (A) Duraphat; (B) Fluor Protector.

Trade names

Commonly used varnishes are Duraphat ***(Figs 6.3 A and B)*** (Colgate-Oral Pharmaceuticals, Inc), Duraflor (Pharmascience, Inc), Fluor Protector (Ivoclar-Vivadent) and Cavity Shield (OMNII - Oral Pharmaceuticals).

COMPOSITION

Composition varies depending on the particular brand. It contains concentrated fluoride dissolved in an organic solvent. One varnish (Colgate Duraphat) contains 22,600 ppm (5%) Sodium fluoride. Another product Fluor Protector (Ivoclar-Vivadent) contains 0.1% fluoride (fluorsilane) in ethyl acetate (65%), isoamyl-propionate (21%) and polyisocyanate (12%).

MANIPULATION

Fluoride varnishes are painted on to the teeth using a special tiny brush. The teeth are cleaned with a toothbrush first and then dried with a gauze square; professional tooth cleaning with prophylactic paste is not indicated. Some varnishes are colored for visualization during placement ***(Fig. 6.4).***

Figure 6.4: Application of Duraphat varnish.

CONTRAINDICATIONS

Varnishes should not be used in cavitated carious lesions because the caries may spread to other portions of the tooth, but can be used to remineralize white spot lesions.

7

DENTAL CEMENTS

Dental cements are materials of multiple uses including restorations, luting and therapeutic. They are generally materials of comparatively low strength, but have extensive use in dentistry. The first dental cement is said to have been introduced in 1785 by Sorel who created the 'zinc-oxide-chloric-cement'. Nearly a hundred years later Rostain and then Flak developed and introduced the zinc phosphate cement. Around the same period silicates were also developed.

Cements have come a long way since then. Many of them have been improved considerably, while some like the silicate cements have been discontinued. Some like the glass ionomers and the polycarboxylate have adhesive properties and form a chemical bond to dentin and enamel. Regardless of some inferior properties, they possess so many desirable features that they are widely used in dentistry.

CLASSIFICATION

Cements have a wide variety of uses, properties and reaction mechanisms. This makes them generally difficult to classify.

ISO standards covering cements

ISO 9917-1:2003 Water-based cements-Part 1: Powder/liquid acid-based cements
ISO 9917-2:1998 Water-based cements-Part 2: Light-activated cements
ISO 3107:2004 Zinc oxide/eugenol and zinc oxide/non-eugenol cements
ISO 4049:2000 Polymer-based filling, restorative and luting materials

According to setting reaction

The materials may be classified as follows:

- Acid-base reaction cements
- Polymerizing cements
- Dual cure cements
- Tricure cements

Acid-base reaction cements They are formulated as powder and liquid. The liquid acts as the acid and the powder as the base. On mixing the two an acid-base reaction takes placing resulting in a viscous paste, which hardens to a solid mass.

Polymerizing cements These cements set by polymerizing reaction which may be light activated or chemically activated, e.g., resin cements.

Dual and Tricure cements Dual cure cements set by acid base and any one of the polymerization (light activated or chemically activated) mechanisms. Tricure cements utilize all three mechanisms for hardening.

Classification of cements based on application

Type I: Luting agents.

- Type I Fine grain for cementation, luting
- Type II Medium grain for bases, orthodontic purpose.

Type II: Restorative applications.

Type III: Liner or base applications.

GENERAL STRUCTURE

On mixing the powder and liquid, only a part of the powder reacts with the liquid and the final set material is composed of:

A core: of unreacted powder, surrounded by

A matrix: formed by the reaction product of the powder and the liquid.

USES OF CEMENTS

Cements have a wide variety of usage in dentistry.

Function	*Cement used*
Final cementation	Zinc phosphate, Zinc silicophosphate, EBA cement, Zinc polycarboxylate, Glass ionomer, Resin cement
Temporary cementation	Zinc oxide-eugenol, Non-eugenol zinc oxide
Bases	Zinc phosphate, Reinforced zinc oxide-eugenol, Zinc polycarboxylate, Glass ionomer, Zinc oxide-eugenol, Calcium hydroxide
Long term restorations	Glass ionomer, Compomer, metal modified GIC
Temporary and intermediate restorations	Zinc oxide-eugenol, Reinforced zinc oxide eugenol, Zinc polycarboxylate, Glass ionomer
Pulp therapy	Calcium hydroxide
Obtundant (pain relief)	Zinc oxide eugenol
Liners	Calcium hydroxide in a suspension
Root canal sealer	Zinc oxide-eugenol, Zinc polycarboxylate

GENERAL PROPERTIES OF CEMENTS

Though cements are formulated to serve a variety of functions, the two most common applications of dental cements are luting and restorations. The ideal requirements of materials serving each of these functions has been listed in the introductory chapter on the subject.

ISO Classification

Water-based cements

e.g., Zinc phosphate, glass ionomer, etc.

Oil based cements

e.g., ZOE and Non-eugenol cements

Resin or polymer based cements

e.g., resin cements, compomer, etc.

STRENGTH

Most cements are comparatively weak when compared to restorative materials like amalgam and composites. The strength required depends on the application. For example a cement used as a base under amalgam should have sufficient strength to withstand condensation forces. Many dental cements as well as restorative materials continue to gain strength with time. For this reason patients are often advised to wait at least 2 hours before any food is placed in the mouth. In addition the side in which the restoration has been placed is avoided for a further 24 hour period.

MODULUS OF ELASTICITY (MOE)

This is a measure of the stiffness of the cement. Cements under ceramic crowns should have sufficient stiffness to withstand masticatory loads. A low MOE can result in flexing of the restoration resulting in fracture.

SOLUBILITY AND DISINTEGRATION

This is an important property as it can determine the long term survivability of restorations ***(Figs 7.1 and 7.2)***. Solubility and disintegration of the cement at the margins can eventually lead to problems like inflammation, caries, sensitivity, etc. Most cements exhibit varying degrees of solubility. *ADA specification No. 96* uses vitro testing with 0.1 M lactic acid. However a more reliable test would be an *in vivo* test as conditions in the mouth are far more complex. Solubility and disintegration can be reduced by proper manipulation, minimizing the exposure of the cement to the oral environment and protecting of the cement during setting and the initial 24 hour period.

Cements manufactured for various applications would have been modified slightly to suit the particular application. For example glass ionomer manufactured for luting may be slightly different from glass ionomer used for restorations. Luting cements are usually more fine grained and have a different powder-liquid ratio. Restorative GIC has better translucency and esthetics when compared to the luting GIC which may be more opaque.

FILM THICKNESS

Film thickness is an important property especially for luting cements. A thinner film is more advantageous for luting.

- It improves the seating of the restoration.
- It helps in greater flow and wetting of the tooth and restoration surface, thus improving bonding.
- It minimizes the air spaces and structural defects present in the bulk of the cement.

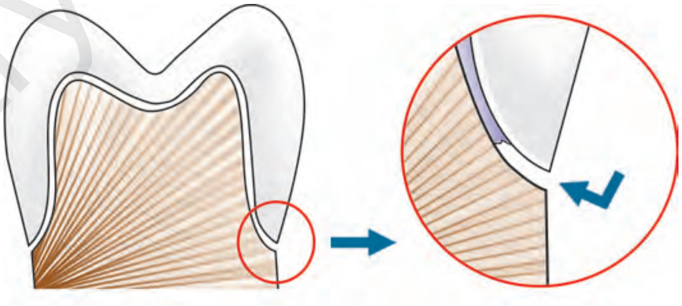
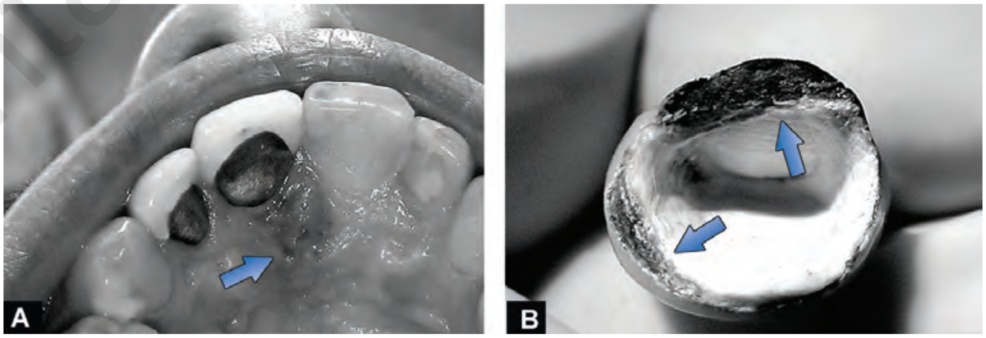


Figure 7.1: One cannot rely entirely on the cement for sealing an open margin. Most cements slowly dissolve and disintegrate in the oral cavity leading to microleakage and subsequent failure. A good marginal fit of the crown is therefore essential.



Figures 7.2A and B: Cement dissolution; (A) Area of inflammation in relation to the leaking margin (arrow). On removing the crown, area of cement dissolution is clearly visible (arrows) (B).

Film thickness is measured in µm. Specifications are laid out by ADA/ISO

ADA Sp. No. 96. (ISO 9917-1:2003) Specifies the minimum film thickness

For Type I – Film thickness not more than 25 µm

For Type II – Film thickness not more than 40 µm

BIOLOGICAL PROPERTIES

Most cements are placed within the dentin and in many instances in close proximity to the pulp. Thus it is important that the cement should not be irritant or toxic to the pulp.

PH of the cement

Most cements are acidic. The exceptions are zinc oxide eugenol, calcium hydroxide and resin cements. The acidity of cements is higher at the time of placement but gradually decrease with time.

Pulpal response

The pulp response may be classified as *mild, moderate* or *severe*. Originally silicate cement was used as a reference to compare the pulpal response to various cements. Because of its high acidity, silicates were classed as severe irritant. High acidity can irritate and sometimes lead to irreversible pulpal damage. In some patients it can cause severe pain and sensitivity. Monomer present in resin based cements is also a potential irritant.

Pulp protection

In case of deep cavities and where the cement is classed as an irritant measures to protect the pulp are indicated.

- Avoid thin mixes.
- Pulp protection should be carried out in deep cavities through the use of an intervening liner or base.

SILICATE CEMENTS

Silicate cements ***(Fig. 7.3)*** are said to have been introduced in 1878 by Fletscher as an anterior esthetic filling material. They were translucent and resembled porcelain in appearance. Though the initial esthetic was satisfactory, over a period of time silicates degraded and stained. Leakage around the margins result in dark margins. Silicates are attacked by oral fluids and in time degrade.

Figure 7.3: Silicate cement (CODS Mangalore, 1997).

The average life of a silicate restoration is four years. Some may last as long as 25 years, others may require replacement in a year or even less.

The incidence of secondary caries is markedly less around silicate restorations. This is surprising when considering that severe leakage takes place at its margins. Also the incidence of contact caries is less when compared to amalgam restorations (contact caries is the term applied to caries occurring on the proximal surface of the tooth adjacent to the restoration). The anticariogenic property is due to presence of 15% fluoride. Fluoride release is *slow* and occurs throughout the *life* of the restoration. Silicate cements were classed as a *severe irritant* to the pulp because of its low pH (acidic). For many years silicate served as a standard for comparing the pulpal response to other material. In deep cavities the pulp had to be protected with varnish or calcium hydroxide.

With the development of better alternate materials like composite resin and glass ionomer cements, silicates gradually fell out of favor. By the 1980s and 1990s they were gradually phased out of the market. However silicate cements are of historical interest. It also forms the basis for the glass ionomer system.

ZINC PHOSPHATE CEMENT

Zinc phosphate is the oldest of the luting cements and thus serves as a standard with which newer cements can be compared. The terms 'Crown and Bridge' and 'Zinc Oxyphosphate' have also been used for this cement.

APPLICATIONS

1. Luting of restorations (inlays, crowns, fixed dental prostheses, etc.)
2. High strength bases.
3. Temporary restorations.
4. Luting of orthodontic bands and brackets.

CLASSIFICATION

ADA Sp. No. 96 designates them as:

Type I: Fine grained for luting.
Film thickness should be 25 µm or less.
Type II: Medium grain for luting and filling.
Film thickness should not be more than 40 µm.

AVAILABLE AS

- Powder and liquid system.
- Capsules of preproportioned powder and liquid.

Supplied in shades of yellow, grey, golden brown, pink and white.

Representative commercial products: Confit, Harvard, Zinc cement (DPI), Modern Tenacin, Poscal (VOCO), De Trey Zinc (Dentsply), Hy Bond, etc. Some representative products are shown in ***Fig. 7.4.***

Figure 7.4: Three representative zinc phosphate cements.

COMPOSITION

Powder		
Zinc oxide	90.2%	Principal constituent
Magnesium oxide	8.2%	Aids in sintering
Other oxides (like bismuth trioxide, calcium oxide, barium oxide, etc.)	0.2%	Improves smoothness of mix
Silica	1.4%	Filler, aids in sintering

Liquid		
Phosphoric acid	38.2%	Reacts with zinc oxide
Water	36.0%	Controls rate of reaction
Aluminum phosphate or sometimes zinc phosphate	16.2%	Buffers, to reduce rate of reaction
Aluminum	2.5%	
Zinc	7.1%	

MANUFACTURE

The ingredients are mixed and heated at temperatures between 1000°C and 1400°C (sintering). After sintering, the cake formed is cooled quickly. This causes the material to crack which helps in grinding of the material to a fine powder. This process is known as *fritting*.

The liquid is produced by adding aluminum and sometimes zinc or their compounds into orthophosphoric acid solution.

SETTING REACTION

When the powder is mixed with liquid, phosphoric acid attacks the surface of the particles and releases zinc ions.

The *aluminum* in the liquid is essential for cement formation. The aluminum complexes with the phosphoric acid and the zinc ions to form a *zinc aluminophosphate gel*. The reaction is *exothermic*.

Structure of Set Cement

The set cement has a cored structure consisting primarily of unreacted zinc oxide particles embedded in a matrix of zinc aluminophosphate.

Setting Time

According to *ADA Sp. No. 96* (which supersedes the previous Sp. No. 8 for zinc phosphate cements) the setting time can vary between 2.5 and 8 minutes).

The setting time of cements in general vary widely. The setting time varies between different manufacturers. Climatic conditions too have a significant effect. Warm humid climatic conditions accelerate the setting. The portion of the material placed in the mouth sets faster than that on the table. This is because of the warm and moist conditions in the mouth.

Control of Setting Time

Manufacturing process

- Sintering temperature: The higher the temperature, the more slowly the cement sets.
- Particle size: Finer particles react more quickly as a greater surface area is exposed to the liquid.
- Water content of liquid: Presence of excess water accelerates, whereas insufficient water retards the reaction.
- Buffering agents: When added slow down the reaction.

Factors under control of operator

- Temperature: Higher temperatures accelerate the reaction. Cooling the mixing slab is one of the most effective ways of slowing the reaction and prolonging the working time.
- P/L ratio: More the liquid, slower the reaction.
- Rate of addition of powder to liquid: The reaction is slower if the powder is incorporated slowly.
- Mixing time: The longer the mixing time (within practical limits), the slower is the rate of reaction.

PROPERTIES

COMPRESSIVE STRENGTH

The fully set zinc phosphate cement has a relatively high compressive strength ranging from 104 to 119 MPa. The set cement gains approximately 70% of its maximum strength in the first 30 minutes. The strength continues to rise with time and maximum strength is attained at the end of 24 hours.

The strength of zinc phosphate cement is sufficient when used as a base or luting agent. However when it is exposed to the oral environment, e.g., temporary restorations, its brittleness and low strength causes it to fracture and disintegrate. Also, the prolonged contact with the oral fluids or water gradually reduces its strength. This may be due to the slow dissolution of the cement.

When used as a base for an amalgam or a DFG restoration, the operator must allow the cement to gain sufficient strength before proceeding with the condensation.

Factors affecting strength

- P/L ratio: More the powder, greater the strength.
- Water content of the liquid: Both loss or gain, reduces the strength.

TENSILE STRENGTH

The set cement is weaker in tension (5.5 MPa), thus making it brittle.

MODULUS OF ELASTICITY (STIFFNESS)

It is comparatively high (13.7 GPa). This makes it stiff and resistant to elastic deformation. This is beneficial when it is used to cement restorations that are subjected to high masticatory stresses.

SOLUBILITY AND DISINTEGRATION

This property is important for cements used for permanent cementation. When tested according to ADA specification, it shows low solubility (0.06% wt.).

However in the mouth they show greater disintegration over a period of time. This shows that other factors are involved (like wear, abrasion, chemical attacks by products from decaying food, etc.). The solubility is greater in dilute organic acids like lactic, acetic and especially citric acids, all of which are present in the human diet. Thus it is important to minimize the exposure of the cement in the mouth by having minimum gaps at the margins of restorations.

Factors affecting solubility

- P/L ratio: Thicker mixes show less solubility.
- Water content of liquid: Any change in the water content is accompanied by increased solubility.
- Effect of moisture contamination: Premature contact of the incompletely set cement with water results in the dissolution and leaching of the surface. Varnish application over the exposed cement margin is beneficial.

FILM THICKNESS

The smaller the particle size, less is the film thickness. The thickness is lesser than the size of the particles because, during mixing the particles are crushed and dissolved. The thickness can also be reduced by applying pressure on the casting during seating.

THERMAL PROPERTIES

Zinc phosphate cements are good thermal insulators and may be effective in reducing galvanic effects.

ADHESION PROPERTY

The primary retentive mechanism of zinc phosphate is *micromechanical*. The cemented restoration is held by mechanical interlocking of the set cement with surface roughness on the tooth and restoration.

BIOLOGICAL PROPERTIES

pH of the cement

The acidity is high at the time of insertion due to phosphoric acid. At the time of cementation, the pH is 2 (approx.). As time passes the acidity reduces. By the end of 24 hours the pH is 5.5, which is still in the acidic range (neutral value is 7).

Pulpal response

The pulp response may be classified as *moderate*.

Pulp protection

A thickness of dentin as great as 1.5 mm can be penetrated by the acid of the cement. If dentin is not protected against infiltration of this acid, pulpal injury may occur, especially during the first few hours.

- Avoid thin mixes.
- Pulp protection should be carried out in deep cavities through the use of an intervening liner or base:

- Zinc oxide-eugenol
- Calcium hydroxide
- Cavity varnish

➢ Some patients are extremely sensitive to the acid. Cementation of a restoration such as a crown or FPD on to vital teeth can cause severe sensitivity or pain. An anesthesia should be used in these instances.

OPTICAL PROPERTIES

The set cement is opaque.

MANIPULATION

Spatula used Stainless steel.

Mixing time 1 min. 15 seconds.

Powder to liquid ratio 1.4 gm/0.5 ml

A cool glass slab is used in order to delay the setting and allow more powder to be incorporated before the matrix formation occurs. The liquid should be dispensed just before mixing.

Procedure

The powder is added in *small increments*. Mixing is done with stainless spatula using brisk circular motion. Each increment is mixed for 15 to 20 seconds. A large area is covered during mixing in order to dissipate the exothermic heat ***(Fig. 7.5)***. Maximum amount of powder should be incorporated in the liquid to ensure minimum solubility and maximum strength. *Note:* An appropriate consistency is attained by addition of more powder to the liquid and not by allowing a thin mix to thicken.

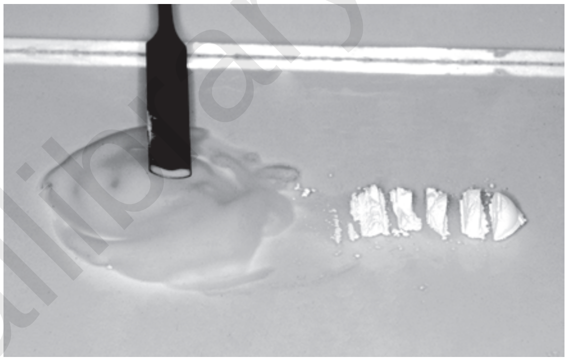


Figure 7.5: Manipulation of zinc phosphate cement.

Insertion

The crown should be seated immediately and held under pressure till set. Field of operation should be dry. Varnish is applied at the margins, where the cement is exposed.

ADVANTAGES AND DISADVANTAGES OF ZINC PHOSPHATE

Advantages

1. Long track record with proven reliability.
2. Good compressive strength.

Disadvantages

1. No chemical adhesion. Not indicated if the retention is poor.
2. No anticariogenic property.
3. Pulp irritation.
4. Poor esthetics; cannot be used with translucent (all ceramic) restorations like crowns and veneers.

COPPER CEMENTS

Copper cements are basically modified zinc phosphate cements. Silver salts or copper oxide are sometimes added to the powders of the zinc phosphate cements to increase their '*antibacterial*' properties. Copper cements gradually fell out of favor because of their poor biological properties. It was highly acidic and the copper was considered toxic to the cell. This may have been due to the extremely high copper content (97%) in certain cements (Ames). There has been a renewed interest in copper cements recently. New formulations have come out with lower copper content (2%). It is claimed that these new generation copper cements are safe and is especially recommended for indirect pulp capping and where there is active caries.

APPLICATIONS

1. Temporary fillings in children.
2. Intermediate restorations.
3. For retention of silver cap splints in oral surgery.
4. Indirect pulp capping.
5. As base beneath composite restorations.

CLASSIFICATION

Classified according to the percentage of the copper oxide that is used as a replacement for the zinc oxide.

Commercial Examples Ames copper (discontinued), Doc's Best Red and White copper kit ***(Fig. 7.6)***.

COMPOSITION

Copper oxide	(if cuprous oxide is used—cement is red, if cupric oxide is used, the cement is black)
Zinc oxide	

Liquid used is clear phosphoric acid.

Figure 7.6: White and red copper cement.

PROPERTIES

Biological properties: They have poor biological properties. Because its pH is 5.3, it is irritant to the pulp.

They are bactericidal or bacteriostatic.

MANIPULATION

The chemistry of the copper cements is very similar to that of the zinc phosphate cements and they are manipulated in the same manner.

ZINC POLYCARBOXYLATE CEMENT

Canadian biochemist Smith developed the first Polycarboxylate cement in 1968 by substituting the phosphoric acid of zinc phosphate cement with polyacrylic acid. Polycarboxylate became the first cement system developed with potential for adhesion to tooth structure.

APPLICATIONS

1. Primarily for luting permanent restorations.
2. As bases and liners.
3. Used in orthodontics for cementation of bands.
4. Also used as root canal fillings in endodontics.

AVAILABLE AS

- Powder and liquid in bottles ***(Fig. 7.7 A)***
- Water settable cements ***(Fig. 7.7 B)***
- As precapsulated powder/liquid system.

Commercial Examples

Poly F (Dentsply), Durelon and Durelon Maxicap (encapsulated) (3M ESPE), Carboco (Voco), Imibond P (Imicryl), Hy Bond polycarboxylate (Shofu).

Water Settable Cements

In these cement the polyacid is freeze dried and added to the cement powder. Water is used as the liquid. When the powder is mixed with water, the polyacrylic

Figures 7.7 A and B: (A) Representative zinc polycarboxylate cement products; (B) A water settable cement.

acid goes into the solution and the reaction proceeds as described for the conventional cements.

COMPOSITION

Powder		
Zinc oxide	—	Basic ingredient
Magnesium oxide	—	Principal modifier and also aids in sintering
Oxides of bismuth and aluminum	—	Small amounts
Stannous fluoride	—	Increases strength, modifies setting time and imparts anti-cariogenic properties

Liquid

Aqueous solution of polyacrylic acid or
Copolymer of acrylic acid with other unsaturated carboxylic acids, i.e. iticonic, maleic, or tricarballylic acid.

MANUFACTURE

The powder mixture is sintered at high temperature in order to reduce the reactivity and then ground into fine particles.

SETTING REACTION

When the powder and liquid are mixed, the surface of powder particles are attacked by the acid, releasing zinc, magnesium and tin ions. These ions bind to the polymer chain via the carboxyl groups. They also react with carboxyl groups of adjacent polyacid chains to form cross-linked salts.

Structure of Set Cement

The hardened cement consists of an amorphous gel matrix of zincpolyacrylate in which unreacted powder particles are dispersed.

PROPERTIES

MECHANICAL PROPERTIES

Compressive strength: 55 MPa. Polycarboxylate cement is inferior to zinc phosphate cement in this respect.

Tensile strength: 6.2 MPa. Its tensile strength is slightly higher than that of zinc phosphate cement.

The strength of the cement depends on

- Increase in P/L ratio increases strength.
- Molecular weight of polyacrylic acid also affects strength. A mix from a lower viscosity liquid is weaker.

SOLUBILITY AND DISINTEGRATION

It tends to absorb water and is slightly more soluble (0.6% wt) than zinc phosphate. Thus the marginal dissolution is more when used for cementing. It is more soluble in organic acids like lactic acid. Low P/L ratio results in a significantly higher solubility and disintegration in the oral cavity.

BIOCOMPATIBILITY

Pulpal response—classified as mild. Despite the initial acidic nature of polycarboxylate cement, The pH of the liquid is 1.0-1.7 and that of freshly mixed cement is 3.0-4.0. After 24 hours, pH of the cement is 5.0-6.0.

They are less irritant than zinc phosphate cement because:

- The liquid is rapidly neutralized by the powder. The pH of polycarboxylate cement rises more rapidly than that of zinc phosphate.
- Penetration of polyacrylic acid into the dentinal tubules is less because of its higher molecular weight and larger size. The histological reactions are similar to zinc oxide-eugenol cements but more reparative dentine is observed with polycarboxylate.

ADHESION

An outstanding characteristic of zinc polycarboxylate cement is that the cement *bonds chemically* with the tooth structure. The *carboxyl group* in the polymer molecules chelates with calcium in the tooth structure.

Bond strength to enamel 3.4-13.1 MPa and to dentine 2.07 MPa.

Factors affecting bond

1. A clean dry tooth surface improves bonding.
2. If the inside surface of the metal crown is not clean, the cement cannot bond with the metal. So to improve the mechanical bond, the surface should be carefully abraded with a small stone or with airborne abrasives.
3. The presence of saliva reduces bond strength.
4. Unlike zinc phosphate cements, the adhesion is better to a smooth surface than to a rough surface.
5. Does not adhere to gold or porcelain.
6. Adhesion to stainless steel is excellent. Thus it is used in orthodontics.

OPTICAL PROPERTIES

They are very opaque due to large quantities of unreacted zinc oxide.

ANTICARIOGENIC PROPERTIES

Some manufacturers have attempted to incorporate fluoride within the cement. However the fluoride release is limited when compared to glass ionomer cement.

THERMAL PROPERTIES

They are good thermal insulators.

MANIPULATION

CONDITIONING

The tooth structure should be meticulously clean for proper bonding. To clean the surface, 10% polyacrylic acid solution followed by rinsing with water, or 1 to 3% hydrogen peroxide may be used. Then dry and isolate the tooth.

PROPORTIONING

1.5 parts of powder to 1 part of liquid by wt.

PROCEDURE

The powder and liquid are taken on a cooled glass slab. The liquid is dispensed just prior to the mixing, otherwise its viscosity increases. The powder is incorporated into the liquid in bulk (90%) with a stiff cement spatula and remaining powder is added to adjust consistency. The mix appears quite thick, but this cement will flow readily into a thin film when seated under pressure.

MIXING TIME AND SETTING TIMES

Mixing time ranges from 30 to 40 seconds. Setting time can be from 7 to 9 minutes (The setting time can be increased by cooling the glass slab. It also depends on method of manufacture of powder and liquid).

Things to note

- The cement should be used while the surface is still *glossy*. Loss of luster indicates that the setting reaction has progressed to an extent that proper wetting of the tooth surface by the mix is no longer possible. If the surface is not creamy and shiny and is matted and tends to form cobwebs, the mix should be discarded.
- After insertion the excess is not removed immediately as it passes through a *rubbery stage,* it tends to get lifted from the cavity. Remove excess cement only when it has hardened and breaks off.
- The powder may be cooled, but the liquid should not be cooled since the viscosity of the liquid increases.

Polycarboxylate cement adheres to instruments, so

- Use alcohol as release agent for mixing spatula.
- Instruments should be cleaned before the cement sets.
- Excess cement from the spatula can be chipped off. Any remaining material is removed by boiling in sodium hydroxide solution.

ADVANTAGES AND DISADVANTAGES

ADVANTAGES

1. Comparatively less irritating to the pulp.
2. Chemical bond to tooth structure.

DISADVANTAGES

Limited fluoride release when compared to GIC.

ZINC OXIDE-EUGENOL CEMENT

These cements have been used extensively in dentistry since the 1890s. Depending on their use they vary widely in their properties. In general, they are cements of low strength. They are the least irritating of all dental cements and are known to have an obtundant (sedative) effect on exposed dentin.

To improve the strength many modified zinc oxide-eugenol cements have been introduced, e.g., EBA—alumina modified and polymer—reinforced zinc oxide-eugenol cements non-eugenol zinc oxide cements are also available. They are suitable for patients sensitive to eugenol.

CLASSIFICATION: (ISO 3107:2004/COR.1:2006)

Type I ZOE — Temporary cementation
  Class I—setting cement
  Class II—non-setting cement

Type II ZOE — Permanent cementation
Type III ZOE — Bases and temporary restorations
Type IV ZOE — Cavity liners

Type I cements are meant for short term luting (1 to 6 weeks - ***Fig. 7.8 A***). They are used to cement provisional restorations for the period it takes to make the definitive restoration. Permanent restorations are also sometimes cemented for a short period for the patient to try it. They have low strength which allows easy removal of the restoration without damage to the restoration or the tooth.

Type II cements Although they are meant for long term cementation of permanent restorations, they are somewhat inferior to other cements. Modified ZOE cements are usually used for this purpose because of their increased strength (see also EBA cements and resin modified cements).

Type III cements are used for the interim period (few weeks to few months) when a tooth is under going treatment or until it is ready for a permanent restoration. They can also be used as bases under permanent restorations.

Type IV cements are low strength materials for use as liners.

AVAILABLE AS

- Powder and liquid ***(Fig. 7.8 B)***
- Two paste system ***(Fig. 7.8 C)***

Figures 7.8 A and B: (A) Type I zinc oxide eugenol for temporary cementation; (B) Type III zinc oxide eugenol cement for temporary restorations.

Figure 7.8 C: Type IV zinc oxide eugenol - cavity liner.

Representative commercial names

	Unmodified	*EBA modified*	*Polymer modified*	*Non-eugenol*
Type I	TempBond		TempBond clear	Nogenol, Zone Freegenol TempBond NE
Type II		SuperEBA		
Type III	DPI zinc oxide		IRM, Kalzinol	
Type IV	Cavitec (Kerr)			

COMPOSITION

*Powder **	*%*	*Function*
Zinc oxide	— 69.0	– Principal ingredient
White rosin	— 29.3	– To reduce brittleness of set cement
Zinc stearate	— 1.0	– Accelerator, plasticizer
Zinc acetate	— 0.7	– Accelerator, improves strength
Magnesium oxide		– Is added in some powders, acts with eugenol in a similar manner as zinc oxide.

Liquid	*%*	*Function*
Eugenol	— 85.0	– Reacts with zinc oxide
Olive oil	— 15.0	– Plasticizer

*Some powders may contain arsenic. ISO 3107 specifies maximum permissible arsenic content of 2 mg/kg.

SETTING REACTION

The setting reaction and microstructure are the same as that of the zinc oxide eugenol impression pastes.

In the first reaction hydrolysis of zinc oxide takes place. Water is *essential* for the reaction (dehydrated zinc oxide will not react with dehydrated eugenol).

$$ZnO + H_2O \rightarrow Zn(OH)_2$$

The reaction proceeds as a typical acid-base reaction.

$$\underset{\substack{\text{Base}\\ \text{(Zinc hydroxide)}}}{Zn(OH)_2} \quad + \quad \underset{\substack{\text{Acid}\\ \text{(Eugenol)}}}{2HE} \quad \rightarrow \quad \underset{\substack{\text{Salt}\\ \text{(Zinc eugenolate)}}}{ZnE_2} \quad + \quad 2H_2O$$

The chelate formed is an amorphous gel that tends to crystallize imparting strength to the set mass.

Structure of Set Cement

Thus, the set cement consists of particles of zinc oxide embedded in a matrix of zinc eugenolate.

GENERAL PROPERTIES OF ZINC OXIDE EUGENOL CEMENTS

MECHANICAL PROPERTIES

Compressive strength: They are relatively weak cements. The strength depends on what it is used for, e.g., cements intended for temporary purposes like temporary restorations and cementation (Type I and Type III) will have a lower strength. Cements intended for permanent cementation (and intermediate restorations will be stronger. The compressive strength therefore ranges from a low of 5 to 55 MPa. Lowest are the cavity liners (minimum 5 MPa).

Type I	6 to 28 MPa	(ISO - maximum of 35 MPa)
Type II	45 to 55 MPa	(ISO - minimum of 35 MPa)

Particle size affects the strength. In general the smaller the particle size, the stronger the cement. The strength can also be increased by reinforcing with alumina-EBA or polymers (see EBA and polymer modified ZOE cements).

Tensile strength: Ranges from 0.32 to 5.3 MPa.

Modulus of elasticity (0.22 to 5.4 GPa) This is an important property for those cements intended for use as bases.

THERMAL PROPERTIES

Thermal conductivity: 3.98 [Cal. Sec-1 cm-2 (°C/cm)-1] × 10^{-4}. Their thermal insulating properties are excellent and are approximately the same as for human dentin. The thermal conductivity of zinc oxide-eugenol is in the range of insulators like cork and asbestos.

Coefficient of thermal expansion: 35 × 10^{-6}/°C.

SOLUBILITY AND DISINTEGRATION

The solubility of the set cement is highest among the cements (0.4 to 1.5 % wt). They disintegrate in oral fluids. This break down is due to hydrolysis of the zinc eugenolate matrix to form zinc hydroxide and eugenol. Solubility is reduced by increasing the P/L ratio.

FILM THICKNESS

This property is important for those cements (Type I and II) used for luting of restorations. The film thickness of zinc oxide-eugenol cements (ISO max of 25 µm) is generally higher than other cements.

ADHESION

They do not adhere well to enamel or dentin. This is one reason why they are not often used for final cementation of crowns and other fixed dental prosthesis. The other reasons are low strength and high solubility.

BIOLOGICAL PROPERTIES

- pH and effect on pulp: (pH is 6.6 to 8.0). They are the least irritating of all cements. Pulpal response—classified as mild.
- Bacteriostatic and obtundant properties: They inhibit the growth of bacteria and have an anodyne or soothing effect (obtundant) on the pulp in deep cavities, reducing pain.

OPTICAL PROPERTIES

The set cement is opaque.

MANIPULATION

Powder/Liquid System

Powder/liquid ratio: 4:1 to 6:1 by wt.

The bottles are shaken gently. Measured quantity of powder and liquid is dispensed onto a cool glass slab. The bulk of the powder is incorporated into the liquid and spatulated thoroughly in a circular motion with a stiff bladed stainless steel spatula. Zinc oxide eugenol exhibits *pseudothickening*. Although it appears to thicken early during spatulation. Further vigorous spatulation or stropping loosens the mix. Smaller increments are then added until the mix is complete.

For temporary restorations a thick *putty-like* consistency is recommended.

Oil of orange is used to clean eugenol cement from instruments.

Two Paste System

Equal lengths of each paste are dispersed and mixed until a uniform color is observed.

Setting Time

4-10 minutes.

ZOE cements set quicker in the mouth due to moisture and heat.

Factors Affecting Setting Time

The complete reaction between zinc oxide and eugenol takes about 12 hours. This is too slow for clinical convenience.

1. *Manufacture* The most active zinc oxide powders are those formed from zinc salts like zinc hydroxide and zinc carbonate by heating at 3000° C.
2. *Particle size* Smaller zinc oxide particles set faster.
3. *Accelerators* Alcohol, glacial acetic acid and water.
4. *Heat* Cooling the glass slab, slows the reaction.
5. *Retarders* The set can be retarded with glycol and glycerine
6. *Powder to liquid ratio* Higher the ratio, faster the set.

MODIFIED ZINC OXIDE-EUGENOL CEMENTS

These were introduced to improve some of the shortcomings of the regular unmodified zinc oxide eugenol. The modified ZOE cements are:

- EBA-Alumina modified cements
- Polymer reinforced.

EBA-ALUMINA MODIFIED CEMENTS

These are modified ZOE cements ***(Fig. 7.9)***. It is available as a white powder and a pinkish liquid. Its greater strength allows its use as an intermediate filling material and as a base. A part of the liquid is substituted by orthoethoxy benzoic acid. Alumina is added to the powder. These cements are increasing in popularity as a retrograde filling material because of the high cost of MTA.

USES

1. Long term cementation.
2. Temporary and intermediate restorations.
3. Root end filling material.

COMPOSITION


Figure 7.9: EBA cement.

Powder

Zinc oxide - 60-75%
Fused Quartz or Alumina - 20-35%.
Hydrogenated Rosin - 6%

Liquid

EBA — 62.5% (orthoethoxy benzoic acid)
Eugenol — 37.5%.

PROPERTIES

Their properties are better than that of unmodified ZOE. They are more easier to handle and have improved carvability.

Compressive strength is higher 55 to 60 MPa (8000 psi)

Tensile strength 4.1 MPa (600 psi)

Modulus of elasticity 2.5 GPa (0.36 psi × 106)

Film thickness—25 µm

Solubility and disintegration in water—0.05% wt. Despite their low solubility, these cements disintegrated and wore more quickly clinically when compared to the polymer modified zinc oxide cements.

Effect on pulp—These cements are relatively mild to the pulp.

Adhesion—These materials adhere well to tooth structure.

MANIPULATION

A glass slab is recommended for EBA-alumina modified cements. After dispensing, the powder is incorporated into the liquid in bulk, kneaded for 30 seconds and then stropped for an additional 60 seconds with broad strokes of the spatula to obtain a creamy consistency. They have long working times.

Setting Time

9.5 minutes.

POLYMER REINFORCED ZINC OXIDE-EUGENOL CEMENT

The modifications take the form of resins added to the powder or the liquid. The aim is to improve the strength and reduce the solubility of the cement. Resin modified cements are among the strongest of the zinc oxide-eugenol based cements. Their high strength and low wear make them ideal intermediate restorative materials that can last as long as 1 year.

USES

1. Luting agent
2. As base
3. As temporary filling material

Commercial Names IRM (Dentsply) and Kalzinol (DPI) ***(Fig. 7.10)***.

Figure 7.10: IRM and Kalzinol are two popular resins modified zinc oxide cements for intermediate restorations (Type II).

COMPOSITION

Powder

Zinc oxide—70%
Finely divided natural or synthetic resins

Liquid

Eugenol
Acetic acid—accelerator
Thymol—antimicrobial

The zinc oxide powder is surface treated. The combination of surface treatment and polymer reinforcement results in good strength, improved abrasion resistance and toughness.

SETTING REACTION

The setting reaction is similar to zinc oxide-eugenol cements. Acidic resins if present, may react with zinc oxide, strengthening the matrix.

PROPERTIES

These cements have improved mechanical properties.

Compressive strength : 48 MPa (7000 psi)
Tensile strength : 4.1 MPa (600 psi)
Modulus of elasticity : 2.5 GPa
Film thickness : 32 µm
Solubility and disintegration: 0.03% wt

Pulp response: Classified as moderate which is similar to unmodified ZOE.

Improved abrasion resistance and toughness.

MANIPULATION

The proper powder/liquid is dispensed on a dry glass slab. The powder is mixed into the liquid in small portions with vigorous spatulation.

After mixing, the plastic zinc oxide eugenol is swiped into the tooth cavity and condensed using a moist cotton pellet.

Working time These cements have a long working time.

Setting time 6 to 10 minutes. Heat and moisture in the mouth cause it to set faster than on the mixing pad.

Factors Affecting Setting Time

1. Low powder-liquid ratio increases setting time
2. Moisture: accelerates setting time.
3. Cooling the glass slab slows the setting.

SPECIAL ZINC OXIDE-EUGENOL PRODUCTS

ENDODONTIC SEALERS

ZOE is very popular as an endodontic sealer. Two traditional formulations [Rickert's formula and Grossman's formula ***(Table 7.1)***] are very popular. Along with gutta percha these materials are used in endodontic therapy to seal the canals. Some materials are used as therapeutic sealers and are formulated with ingredients such as iodoform, paraformaldehyde or trioxymethylene which have therapeutic value. Others contain antibiotics such as tetracyclines and steroids as antiinflammatory agents. Some formulations can also be used for pulp capping. Endodontic sealers also contain radiopaque materials such as barium sulphate, bismuth salts or silver powder.

Table 7.1	*Powder*		*Liquid*
Grossman's formula	Zinc oxide	42%	Eugenol
	Staybelite resin	27%	
	Bismuth subcarbonate	15%	
	Barium sulfate	15%	
	Sodium borate anhydrate	1%	

ZINC OXIDE/ ZINC SULPHATE CEMENTS

These are single component temporary filling materials.

SUPPLIED AS

As putty in small tubes, syringes or plastic containers ***(Fig. 7.11)***.

Representative products: Cavit (ESPE), Caviton (GC), Coltosol (Coltene).

USE

Short term restorations after caries excavation, root canal therapy, etc.

COMPOSITION

Zinc oxide
Zinc sulphate-1-hydrate
Calcium sulphate-hemihydrate
Dibutyl phthalate (plasticizer)
Diatomaceous earth

Figure 7.11: Various zinc oxide/ sulphate temporary restorations.

SETTING REACTION

The material sets by reacting with water which it absorbs from the mouth or from the cavity. The setting occurs slowly. It expands on setting.

PROPERTIES

It may be white or pink colored. It has good initial sealing. Since it expands on setting (up to 18%), the marginal seal is further improved. The seal gradually decreases with time. Unfortunately, the strength is low and its life is short. The material should be used for not more than 1 to 2 weeks. It slowly disintegrates with time and is therefore not indicated for any longer term temporary restorations. The material is radiopaque. Short term pain may be experienced because of dehydration of the cavity.

MANIPULATION

The material is dispensed and inserted into the cavity using a cement carrier. The container should be closed immediately. It is condensed into the cavity using a plastic filling instrument (condenser). Since it sets by hydration, the cavity should not be fully dried before placing the material.

Setting Time

The surface hardens in about 20 to 30 minutes. Complete hardening takes place in 2 to 3 hours.

GLASS IONOMER CEMENTS

Glass ionomer cements are adhesive tooth colored anticariogenic restorative materials which were originally used for restorations of eroded areas. Current glass ionomers have been modified to allow a wider application. These cements evolved from a general dissatisfaction with silicate cements. The first usable glass ionomer system was formulated in 1972 by Wilson and Kent and was known as ASPA. Subsequently great improvements were made and today these materials are very popular and widely used.

It was named glass ionomer because, the powder is a type of glass and the setting reaction and adhesive bonding to tooth structure is due to ionic bond. Unlike other restorative materials, this cement requires minimal cavity preparation as it bonds adhesively to tooth structure. Compared to composite resin they are less technique sensitive. Glass-ionomer cement is often known as a *biomimetic* material, because of its similar mechanical properties to dentine. For this reason it is one of the most popular cements in dentistry.

Synonyms

- Poly (alkenoate) cement
- GIC (glass ionomer cement)
- ASPA (alumino silicate polyacrylic acid)

APPLICATION

1. Anterior esthetic restorative material for class III cavities.
2. Restorative material for eroded areas and class V restorations ***(Fig. 7.16).***
3. As a luting agent for restorations and orthodontic brackets.
4. As liners and bases.
5. For core build up.
6. To a limited extent as pit and fissure sealants.
7. Intermediate restorative material.

Glass ionomer cements are not recommended for class II and class VI restorations, since they lack fracture toughness and are susceptible to wear.

CLASSIFICATION

Type I — For luting
Type II — For restorations
Type III — Liners and bases

Difference between various types

The various types of GIC cements are chemically identical. They vary primarily in the powder/liquid ratio and particle size. The Type I GIC's used for luting have a lower powder/liquid ratio and a smaller particle size when compared to the Type II restorative variety. These features enable the luting GIC to have a thinner film and better flow.

Representative commercial products

Aquacem, Fuji I — Type I
Chem Fil, Fuji II — Type II
Ketac bond — Type III
Vitra bond — Light cure GIC

AVAILABLE AS

- Powder/liquid in bottles ***(Figs 7.12 and 7.13)***
- Pre-proportioned powder/liquid in capsules
- Light cure system
- Powder/distilled water (water settable type)

Figure 7.12: Representative glass ionomer luting cements (Type I).

COMPOSITION

Powder

The powder is an acid soluble calcium fluoroaluminosilicate glass. It is similar to that of silicate, but has a higher alumina-silica ratio. This increases its reactivity with liquid.

Component		*%*
Silica $(SiO)_2$	—	41.9
Alumina (Al_2O_3)	—	28.6
Aluminum fluoride (AlF_3)	—	1.6
Calcium fluoride (CaF_2)	—	15.7
Sodium fluoride (NaF)	—	9.3
Aluminum phosphate $(AlPO_4)$	—	3.8

The fluoride component acts as a 'ceramic flux'. Lanthanum, strontium, barium or zinc oxide additions provide radiopacity.

Liquid

Originally the liquid was a 50% aqueous solution of polyacrylic acid. It was very viscous and had a tendency to gel. Modern glass ionomer liquids are in the form of copolymers.

Component	*Function*
Polyacrylic acid in the form of copolymer with iticonic acid, maleic acid and tricarballylic acid	*Copolymerizing* with iticonic, maleic acid, etc. tends to increase reactivity of the liquid, decrease viscosity and reduce tendency for gelation.
Tartaric acid	Improves the handling characteristics, increases working time and shortens setting time.
Water	*Water* is the most important constituent of the cement liquid, it is the medium of reaction and it hydrates the reaction products. The amount of water in the liquid is critical. Too much water results in a weak cement. Too little water impairs the reaction and subsequent hydration.

Figure 7.13: Water settable glass ionomer luting cement.

Water Settable Cements

The polyacrylic acid copolymer is *freeze dried* and then added to the glass ionomer powder. The liquid is water or water with tartaric acid. An example of a water settable cement is shown in ***Fig. 7.13.***

When the powder is mixed with water, the polyacrylic acid powder goes into solution to form liquid acid. Then the chemical reaction takes place as in the conventional powder and liquid systems. These cements are known as water settable cements and they set *faster* than those with polyacrylic acid.

MANUFACTURE

The components are sintered at 1100°C to 1500°C. The glass is then ground to particle sizes ranging from 15 to 50 um.

SETTING REACTION

Leaching When the powder and liquid are mixed together, the acid attacks the glass particles. Thus calcium, aluminum, sodium and fluoride ions leach out into the aqueous medium.

Calcium cross-links The initial set occurs when the calcium ions cross-links (binds) the polyacrylic acid chains. This forms a solid mass.

Aluminum cross-links In the next phase, the aluminum also begins to cross-link with polyacrylic acid chains.

Sodium and fluorine ions These ions do not take part in the cross-linking. Some of the sodium ions may replace the hydrogen ions in the carboxylic groups. The rest combine with fluorine to form sodium fluoride which is uniformly distributed within the cement.

Hydration Water plays a very important role in the cement. Initially it serves as the medium. Later it slowly hydrates the matrix, adding to the strength of the cement (maturation process).

Silica gel sheath The unreacted glass (powder) particle is sheathed (covered) by a silica gel. It is formed by the leaching of the ions (Ca^{2+}, Al^{3+}, Na^{+}, F^{-}) from the outer portion of the glass particle.

Structure of Set Cement

The set cement ***(Fig. 7.14)*** consists of agglomeration of unreacted powder particles surrounded by a silica gel sheath and embedded in an matrix of hydrated calcium and aluminum crosslinked polyacrylic gel.

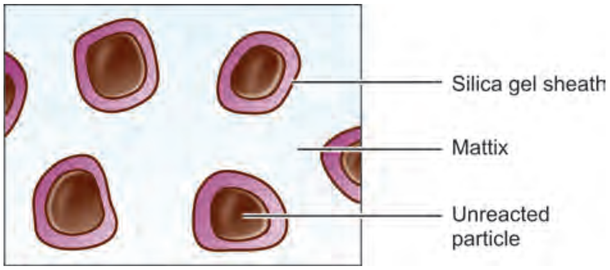


Figure 7.14: Representation of structure of set glass ionomer.

Sensitivity to air and moisture

Exposure of the cement to water before the hardening reaction is complete, leads to loss of cations and anions which form the matrix as they can be dissolved. Thus it is very important to protect the cement surface (by applying varnish, etc.) after it is placed in the mouth.

PROPERTIES

PHYSICAL PROPERTIES

Compressive strength Because of differences in the powder-liquid ratio GIC used for different applications show variations in their physical properties. Restorative GIC (Type II) has a compressive strength of 150 MPa. The luting GIC (Type I) has a lower compressive strength of about 85 MPa.

Tensile strength	Type I - 6.2 MPa
	Type II - 6.6 MPa.

Hardness (49 KHN) Less harder than silicates. The hardness is also far lower when compared to composites.

Fracture toughness A measure of energy required to produce fracture. Type II GIC's are far inferior to composites in this respect.

Elastic modulus (7.3 GPa) It is a measure of their stiffness. The MOE is half that of zinc phosphate cement.

Wear resistance They are more susceptible to tooth brush abrasion and occlusal wear when compared to composites.

SOLUBILITY AND DISINTEGRATION

The initial solubility is high due to leaching of intermediate products. The complete setting reaction takes place in 24 hours; therefore the cement should be protected from saliva in the mouth during this period. Glass ionomer cements are more resistant to attack by organic acids.

Solubility in water for Type I - 1.25 % wt.
Solubility in water for Type II - 0.4 % wt.

ADHESION

It adheres well to enamel and dentine. Shear bond strength ranges from 3-5 MPa.

Mechanism of adhesion Glass ionomer bonds chemically to tooth structure. The exact mechanism has not been fully understood. The bonding is due to the reaction between the carboxyl groups of the polyacids and the calcium in the enamel and dentine. The bond to enamel is always higher than that to dentine, probably due to the greater inorganic content of enamel and its greater homogeneity.

ESTHETICS

Esthetically they are inferior to silicates and composites. They lack translucency and have a rough surface texture. They may stain with time. The restorative GICs are available in different shades. The esthetics are sufficient for restoring cervical lesions and minor defects in nonesthetic zones. The luting cement (Type I) is more opaque than the restorative cement (Type II).

BIOCOMPATIBILITY

Pulpal response to GIC is classified as *mild*.

Type II glass ionomers are relatively biocompatible. The pulpal reaction is greater than that from zinc oxide-eugenol cements but less than that produced by zinc phosphate cement. Polyacids are relatively weak acids.

The water settable cements show higher acidity. Type I GIC (luting) is more acidic than Type II (restorative) because of the lower powder/liquid ratio. Occasionally sensitive patients show a painful response to GIC luting cement.

Pulp protection In deep cavities, the smear layer should not be removed as it acts as a barrier to acid penetration. Deep areas are protected by a thin layer of calcium hydroxide cement.

ANTICARIOGENIC PROPERTIES

Type II glass ionomer releases fluoride in amounts comparable to silicate cements initially and continue to do so over an extended period of time.

In addition, due to its adhesive effect they have the potential for reducing infiltration of oral fluids at the cement-tooth interface, thereby preventing secondary caries.

MANIPULATION

- Conditioning of tooth surface.
- Proper manipulation.
- Protection of cement during setting.
- Finishing.

PREPARATION OF TOOTH SURFACE

The tooth should be clean for effective adhesion of cement. The smear layer present after cavity preparation tends to block off the tooth surface and so should be removed to achieve adhesive bonding.

This is achieved by:

— Rubbing with a cotton pellet and pumice slurry

— Etching with 10% polyacrylic acid or 37% phosphoric acid.

(The objective is to remove the smear layer but still leave the collagenous plug in place. The plug acts as a barrier to the penetration of acid from the cement).

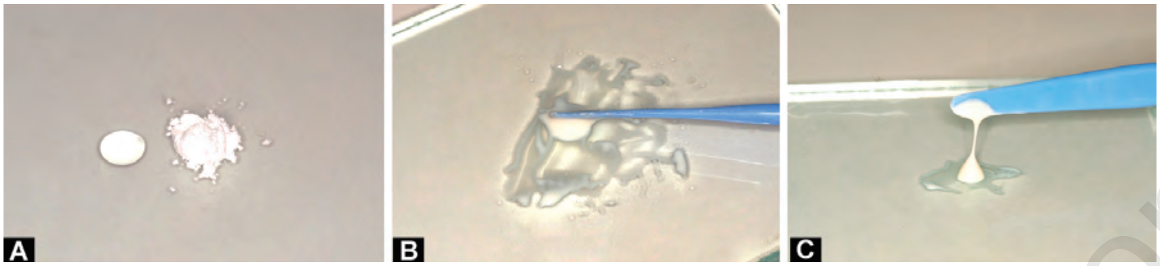
Conditioning This is achieved with 10% polyacrylic acid or 37% phosphoric acid for about 10 to 20 seconds. Next rinse with water for 20 seconds. Very deep areas of the preparation should be protected by a dab of calcium hydroxide.

After conditioning and rinsing, the surface is dried but not desiccated. It should be kept free of saliva or blood as these will interfere with bonding. If contaminated the whole procedure is repeated.

PROPORTIONING AND MIXING

Powder/liquid ratio: Manufacturers recommendation should be followed. Low P/L ratio reduces mechanical properties and increase the chances of cement degradation. Powder/liquid ratio varies according to the Type of GIC and manufacturer. Moisture contamination alters the acid-water balance. Most manufacturers provide a plastic scoop which is useful for measuring.

Spatula used Stiff plastic or metal spatula.

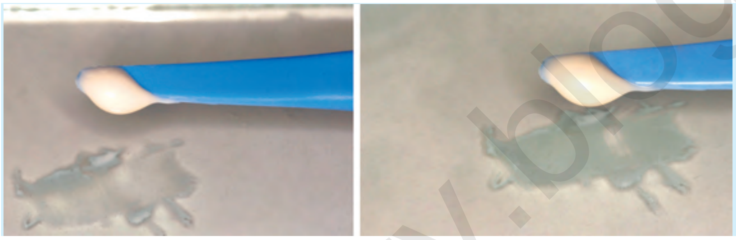


Figures 7.15 A to C: (A) Dispensed powder and liquid; (B) Mixing of glass ionomer; (C) Mixed glass ionomer showing right consistency for luting.

Manual mixing The powder bottle is tumbled gently. The powder and liquid is dispensed just prior to mixing. A nonabsorbent paper pad or a cool and dry glass slab may be used.

The powder is divided into two or more increments ***(Figs 7.15 A to C)***. The first increment is incorporated rapidly into the mix with a stiff bladed spatula. The material should not be spread over a large area. Subsequent increments are incorporated and mixed using a swiping and folding technique.

Mixing time 45 seconds.



A good mix should have a *glossy surface (left)*. This indicates the presence of residual polyacid (which has not been used up in the setting reaction) and ensures proper bonding to the tooth. A mix with dull surface (right) is discarded as it indicates prolonged mixing and reduces the adhesion.

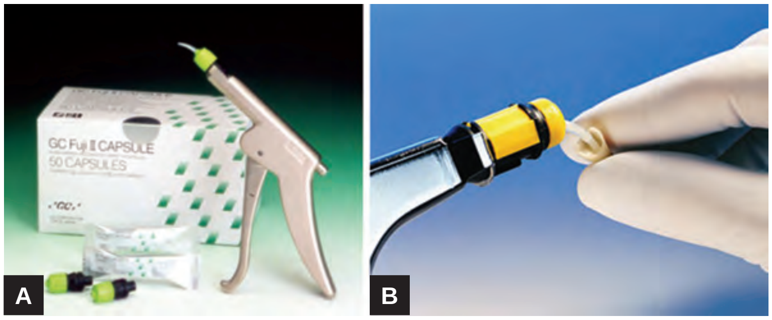
Insertion The mix is packed into the cavity without delay using a plastic filling instrument. If the mix loses its gloss or forms a skin it should be discarded.

Mechanical Mixing

GIC supplied in capsule form containing preproportioned powder and liquid is mixed in an amalgam triturator. The capsule has a nozzle and so the mix can be injected directly into the cavity or crown (***Figs 7.16 A and B)***.

Advantages

1. Better properties due to controlled P/L ratio.
2. Less mixing time required.
3. Convenient delivery system.



Figures 7.16 A and B: (A) Glass ionomer in capsule form. Mixing is done in a triturator (similar to an amalgam triturator); (B) The cement is expressed through the nozzle with the help of a special gun.

Disadvantages

1. Cement quantity limited by the manufacturer.
2. Shade selection is limited, colors cannot be blended.

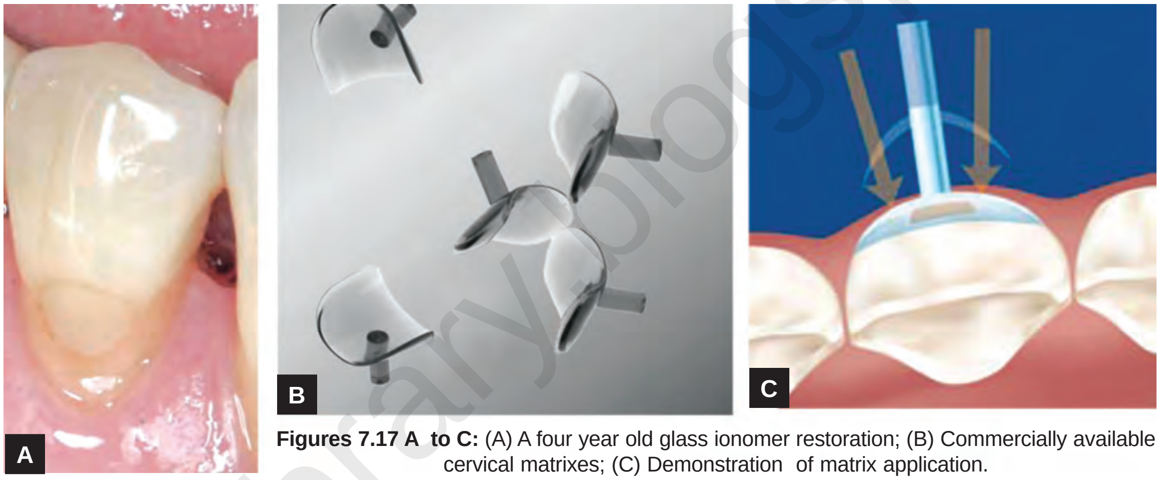
Setting Time

Type I — 7 minutes
Type II— 4 to 5 minutes

PROTECTION AND SHAPING OF CEMENT DURING SETTING

GIC is extremely sensitive to air and water during setting. It should be protected from moisture contamination as well as drying during setting and for a few days after setting. Thus immediately after placement into the cavity, a *preshaped matrix* ***(Figs 7.17 A to C)*** may be applied to:

1. Protect the cement from the environment while setting.
2. Provide maximum contour so that minimal finishing is required.
3. Ensure adequate adaptation on to the walls of the cavity.



Figures 7.17 A to C: (A) A four year old glass ionomer restoration; (B) Commercially available cervical matrixes; (C) Demonstration of matrix application.

PROTECTION OF CEMENT AFTER SETTING

The matrix is removed after complete set. Immediately after removal, the cement surface is again protected with:

1. A special varnish supplied by manufacturer, or
2. An unfilled light cured resin bonding agent, or
3. Cocoa butter or petroleum jelly.

This protects the cement from drying while the dentist proceeds with the finishing. Failure to protect the cement surface from contact with air results in a chalky or crazed surface.

The causes for chalky or crazed surface:

— Inadequate protection of freshly set cement (from air)
— Low powder/liquid ratio
— Improper manipulation

FINISHING

Excess material is trimmed from the margins. Hand instruments are preferred to rotary tools to avoid ditching. Further finishing if required is done after 24 hours.

Before dismissing the patient, the restoration is again coated with the protective agent to protect the trimmed areas. Failure to protect the cement from saliva for the first 24 hours can weaken the cement.

Precautions

- If the liquid contains polyacids, it should not be placed in a refrigerator as it becomes very viscous.
- The restorations must be protected from drying at all times, even when other dental procedures are to be carried out later.
- The glass slab should not be below dew point, as moisture may condense on the slab and change the acid-water balance.

PACKABLE GLASS IONOMER FOR POSTERIOR RESTORATIONS

A packable GIC (Fuji IX - ***Fig. 7.18***) with a dough like consistency is available as a cheaper alternative to compomers and composites for posterior restorations.

Figure 7.18: Fuji IX - packable GIC.

This variety is indicated for

1. Pediatric and geriatric restorations.
2. Intermediate restorative material.
3. Permanent restorative material in non-stress zones.
4. As a core material.

Advantages

1. Higher wear resistance than conventional GICs.
2. Packable, pressable or condensable.
3. Fluoride release.
4. Simple to place (single step).

ATRAUMATIC RESTORATIVE DENTISTRY (ART)

In areas with no access to electricity or equipment, patients may be treated using the ART concept which involves hand excavation of caries. Since hand excavation is often incomplete, one has to rely on a materials that bonds adhesively to enamel and release fluoride in order to protect teeth under adverse conditions. The material of choice in this case is packable GIC ***(Fig. 7.18)***.

FISSURE SEALING (SPECIAL APPLICATIONS)

The traditional glass ionomer cement is somewhat viscous, which prevents penetration to the depth of the fissure. Thus the fissure orifice in general must exceed 100 um in width. Fissures or pits that are smaller are better treated with acid etching and light cured resin sealants. The use of glass ionomers in sealant therapy will increase as formulations are developed that are less viscous (e.g., light cured) and have good wear resistance.

MODIFIED GLASS IONOMERS

Over the years glass ionomer has been modified by manufacturers in order to compensate for some of their deficiencies. This has resulted in new products. The modified glass ionomers are:

1. Metal modified GIC
2. Resin modified GIC

METAL MODIFIED GIC

The metal modified GICs were introduced to improve the strength, fracture toughness and resistance to wear and yet maintain the potential for adhesion and anticariogenic property.

TYPES

Two methods are employed:

1. *Silver alloy admixed* Spherical amalgam alloy powder is mixed with type II GIC powder (Miracle Mix - ***Fig. 7.19***).
2. *Cermet* Silver particles are *bonded* to glass particles. This is done by sintering a mixture of the two powders at a high temperature (Ketac-Silver) ***(Fig. 7.20)***.

Figure 7.19: Miracle Mix. The bottle in the center contains the silver alloy.

Figure 7.20: Ketac-Silver.

USES

1. Restoration of small class I cavities as an alternative to amalgam or composite resins. They are particularly useful in young patients who are prone to caries.
2. For core-build up of grossly destructed teeth.

PROPERTIES

MECHANICAL PROPERTIES

- The *strength* of either type of metal modified cement (150 MPa) is not greatly improved over that of conventional cement.
- *Diametral tensile* strength of the cement is similar to conventional GIC.
- The *fracture toughness* of metal modified GIC is similar to that of conventional GIC.
- In the mouth both metal modified and conventional GIC appear to have similar wear rates.

From the above properties it is clear that there is no appreciable advantage of using metal modified GIC over conventional GIC.

ANTICARIOGENIC PROPERTY

Both metal modified ionomers have anticariogenic capability due to leaching of fluoride. However less fluoride is released from Cermet cement than Type II GIC, since the glass particle is *metal coated*. On the other hand the admixed cement releases more fluoride than Type II GIC. Here the metal filler particles are *not bonded* to the cement matrix and thus there are *pathways* for fluid exchange. This increases leaching of fluoride.

ESTHETICS

These materials are gray in color because of metallic phases within them; therefore they are unsuitable for use in anterior teeth.

RESIN-MODIFIED GLASS IONOMER

These are relatively new materials having various names like compomer, resin-ionomers, RMGI (resin modified glass ionomer), light cured GIC, dual cure GIC, tricure GIC, reinforced GIC, hybrid ionomers, etc. These materials were developed to over come some of the drawbacks of conventional GIC like

- Moisture sensitivity
- Low initial strength
- Fixed working times.

CLASSIFICATION

Depending on which is the predominant component. These materials may be classified as (McClean *et al).*

A. *Resin-modified glass ionomer cement* (RMGI), e.g., Fuji II LC ***(Figs 7.21 A to C)***, Vitremer, Photac Fil, etc.

B. *Compomers or Polyacid-modified composites (PMC),* e.g., Dyract Variglass VLC (this category will be discussed subsequently under the heading compomers).

USES

1. Restoration of class I, III or V cavities.
2. Bases and liners.

Figures 7.21 A to C: Resin modified glass ionomer cements; (A) 3M Vitrebond is a light cured base/liner, (B) GC's Fuji II LC is a radiopaque light cured restorative cement, (C) 3M RelyX is a luting cement.

3. As adhesives for orthodontic brackets.
4. Cementation of crowns and FPDs.
5. Repair of damaged amalgam cores or cusps.
6. Retrograde root filling.

Note Uses vary according to brand.

SUPPLIED AS

They are supplied as

- Chemical cure (acid-base setting reaction of the glass ionomer portion).
- Dual cure (combines acid-base setting reaction of the GIC portion and light curing of the resin portion).
- Tricure (combines acid base setting reaction, chemical and light cured polymerization of the resin portion).

All of them are usually supplied as *powder* and *liquid*. The light cured type is supplied in *dark shaded* bottles (for light protection).

COMPOSITION

Since these are combination materials, they contain components of both resin and glass ionomer. However their proportions vary.

Powder	*Liquid*
Ion leachable glasses (silica, alumina)	Polyacrylic acid
Photoinitiators or chemical initiators or both	Water
Polymerizable resin	Methacrylate monomer
	Hydroxyethyl methacrylate monomers

SETTING REACTION

Setting includes both polymerization and acid-base reaction. The initial setting occurs by polymerization of the methacrylate groups giving it a high early strength. Polymerization may be light cured or chemical cured depending on the type of cement. Subsequently the acid-base reaction sets it thereby completing the setting reaction and giving the cement its final strength.

MANIPULATION

RMGI is mixed and applied after conditioning the tooth with polyacrylic acid (10 to 25%). The powder and liquid is mixed according to the manufacturer's instruction. Light cured RMGI is cured by exposure to blue light (which is used for curing composite).

PROPERTIES

STRENGTH

The compressive strength is slightly lower (105 MPa) when compared to conventional GIC. The diametral tensile strength is however greater (20 MPa). They have a greater fracture toughness because of the greater resilience of the resin component.

HARDNESS

The hardness (40 KHN) is comparable to that of conventional GIC.

ADHESION

The bonding mechanism to tooth structure is similar to that of conventional GIC. Micromechanical retention also plays a role in the bonding process. These materials bond better to composite resins than conventional GIC. This may be because of the presence of residual unreacted monomers within the RMGI.

MICROLEAKAGE

These materials have a greater amount of microleakage when compared to GIC. This may be partly due to the polymerization shrinkage and partly due to the reduced wetting of the tooth by the cement.

ANTICARIOGENICITY

These materials have a significant anticariogenic effect because of the fluoride release. Some tests indicate fluoride release may be equivalent to that of conventional GIC.

PULPAL RESPONSE

The pulpal response to the cement is mild (similar to conventional GIC).

ESTHETICS

They are more translucent and therefore more esthetic than conventional GIC. This is due to the closeness of the refractive indices of the powder and the monomer in the liquid.

CALCIUM HYDROXIDE CEMENT

Calcium hydroxide is a relatively weak cement commonly employed as direct or indirect pulp capping agents. Due to their alkaline nature they also serve as a protective barrier against irritants from certain restorations.

A light cured calcium hydroxide base material and a calcium hydroxide root canal sealing paste is also available.

APPLICATIONS

1. For direct and indirect pulp capping.
2. As low strength bases beneath restorations for pulp protection.
3. Apexification procedure in young permanent teeth where root formation is incomplete.

AVAILABLE AS

- Two paste system containing base and catalyst pastes in soft tubes (***Fig. 7.22***)
- Light cured system
- Single paste in syringe form (Pulpdent, ***Fig. 7.23***)
- Powder form (mixed with distilled water).

Figure 7.22: Dycal is a well known brand of calcium hydroxide pulp capping agent.

Figure 7.23: Calcium hydroxide root canal pastes. The syringe form (top) allows the material to be conveniently applied into the narrow root canal.

Some representative commercial products

- Regular set—Dycal (Dentsply), Calcidor (Dorident), Recal (PSP), Hydrox (Bosworth)
- Light cured—Septocal LC (Septodont) and Calcimol LC (VOCO)

COMPOSITION

Base Paste		
l-methyl trimethylene disalicylate	— 40%	— reacts with $Ca(OH)_2$ and ZnO
Calcium sulphate		
Titanium dioxide		— inert fillers, pigments
Calcium tungstate or Barium sulphate		— provides radiopacity

Catalyst Paste		
Calcium hydroxide	50%	— principal reactive ingredient
Zinc oxide	10%	
Zinc stearate	0.5%	— accelerator
Ethylene toluene		
Sulfonamide	39.5%	— oily compound, acts as carrier

SETTING REACTION

Calcium hydroxide reacts with the l-methyl trimethylene disalicylate ester to form a chelate viz. amorphous *calcium disalicylate*. Zinc oxide also takes part in the reaction.

$$\text{Ca (OH)}_2 + \text{l-methyl trimethylene disalicylate} \longrightarrow \text{calcium disalicylate}$$

PROPERTIES

Calcium hydroxide cements have poor mechanical properties. However, they are better than zinc oxide-eugenol.

MECHANICAL PROPERTIES

Compressive strength (10-27 MPa after 24 hours). It has a low compressive strength. The strength continues to increase with time.

Tensile strength (1.0 MPa) is low.

Modulus of elasticity (0.37 GPa/m^2). The low elastic modulus limits their use to areas not critical to the support of the restoration.

THERMAL PROPERTIES

If used in sufficiently thick layers they provide some thermal insulation. However a thickness greater than 0.5 mm is not recommended. Thermal protection should be provided with a separate base.

SOLUBILITY AND DISINTEGRATION

The solubility in water is high (0.4 to 7.8%). Some solubility of the calcium hydroxide cement is necessary to achieve its therapeutic properties. Solubility is higher when exposed to phosphoric acid and ether. So care should be taken during *acid etching* and during application of *varnish* in the presence of this cement.

BIOLOGICAL PROPERTIES

Effect on pulp: The cement is alkaline in nature. The high pH is due to the presence of free $Ca(OH)_2$ in the set cement. The pH ranges from 9.2 to 11.7.

Formation of secondary dentin: The high alkalinity and its consequent antibacterial and protein lysing effect helps in the formation of reparative dentin.

ADHESION

The material is sensitive to moisture and does not adhere in the presence of blood, water or saliva. The adhesive bond is weak.

MANIPULATION

Equal lengths of the two pastes are dispensed on a paper and mixed to a uniform color. The material is carried and applied using a calcium hydroxide carrier or applicator (a ball ended instrument). It is applied to deep areas of the cavity or directly over mildly exposed pulp (contraindicated if there is active bleeding).

SETTING TIME

Ranges from 2.5 to 5.5 minutes.

Factors affecting setting time The reaction is greatly accelerated by moisture and accelerators. It therefore sets faster in the mouth.

LIGHT ACTIVATED CALCIUM HYDROXIDE CEMENT

FIGURE 7.24: Light cured calcium hydroxide.

Light activated calcium hydroxide cements are available. It consists of calcium hydroxide and barium sulphate dispersed in a urethane dimethacrylate resin. It also contains HEMA and polymerization activators. Some contain fluoride.

Light activated cements have a long working time and is less brittle than the conventional two paste system. They are radiopaque. They are supplied in syringe form ***(Fig 7.24)*** and is expressed directly on to the tooth through a replaceable nozzle. Examples are Septocal LC (Septodont) and Calcimol LC (VOCO).

CALCIUM HYDROXIDE ROOT CANAL SEALING PASTES

Root canal sealers containing calcium hydroxide are available ***(Fig 7.23)***. These are similar to the ones used for pulp capping but contain increased amount of *retarders* in order to extend the working time while they are being manipulated in the warm environment of the root canal. They are also radiopaque.

Commercial names: Sealapex (Kerr), Pulpdent, etc.

Their advantages are:

1. Effective antibacterial properties without irritation.
2. They stimulate hard tissue repair in the apical foramen.

RESIN CEMENTS

Resin cements based on methyl methacrylate have been available since 1952 for cementation of inlays, crowns and other appliances. Development of resin cements came naturally with the development of composites resins. They are essentially low viscosity flowable composites. These cements are known for their high esthetics and high bond strengths. They were widely used for the cementation of orthodontic brackets and resin bonded restorations ***(Figs 7.25 and 7.26)***. The development of esthetic all-ceramic restorations led to a renewed interest in an esthetic bonding system which complemented the esthetics of the restoration. The color of the underlying cement can influence the esthetics in translucent restorations. The resin cement also improves the esthetics at the margins of the restoration. According to some studies resin cements reduce fractures of all-ceramic restorations. Thus, they are popular for the cementation of all-porcelain restorations.

APPLICATIONS

1. For bonding of orthodontic brackets to acid-etched enamel ***(Fig. 7.26)***.
2. Cementation of porcelain laminates and inlays.
3. Cementation of all-porcelain crowns and FPDs.
4. Cementation of etched cast restorations ***(Fig. 7.27).***

Figure 7.25: Examples of resin luting cements.

Figure 7.26: Bonding of orthodontic brackets.

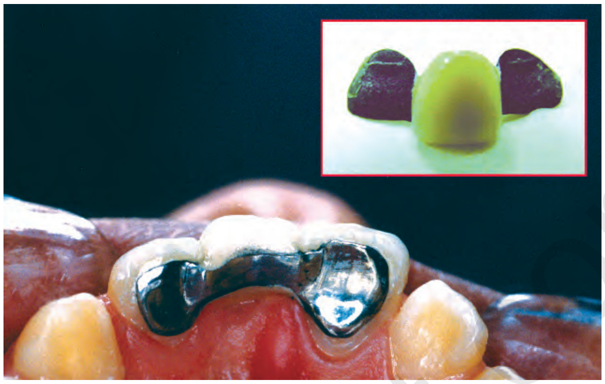


Figure 7.27: An etched resin-bonded cast restoration (Maryland bridge).

CLASSIFICATION

Based on curing system

- Chemical cure
- Light cure
- Dual cure

Chemically activated resins can be used for all types of restorations.

Light activated resins cannot be used in all situations because of problems of light penetration. Thus their use is limited to thin ceramic restorations which allows some passage of light, composite restorations like inlays, ceramic or plastic orthodontic brackets, etc.

Dual cure resins are used when the material being bonded allows some degree of light penetration, e.g., ceramic crown, brackets, inlays, etc. The resin around the margins are cured using light to initiate setting. The portions where light cannot penetrate cure subsequently by chemical reaction.

SUPPLIED AS

They are supplied in syringes

1. Chemical cured
    - Two paste system containing base and accelerator
    - Single paste system with activator in the bonding liquid
2. Light cured - Single paste system

Most systems also include a bonding agent and etchant.

Representative Commercial Names Panavia F, Infinity, ResiLute (Pulpdent), Transbond XT (3M), Maxcem Elite (Kerr), etc.

COMPOSITION

The resin cements have a composition similar to that of modern composites (refer chapter on composites). The filler content has to be lowered and diluent monomers are added to adjust the viscosity. Some contain fluoride (e.g., Panavia F).

To promote adhesion to enamel and dentin, organo phosphates (MDP), HEMA and 4 META are used as bonding agent (see chapter on composites for details).

POLYMERIZATION

- Chemically by peroxide-amine system
- Or by light activation
- Or by both chemical and light activation (dual cure).

Polymerization mechanisms are similar to that of composites (refer chapter on composites).

PROPERTIES

Compressive strength	:	180 MPa (26000 Psi)
Tensile strength	:	30 MPa (4000 Psi)
Film thickness	:	10-25 µm
Biological properties	:	Irritating to the pulp. Pulp protection with calcium hydroxide or GIC liner is necessary for areas close to the pulp.
Solubility	:	Insoluble in oral fluids.
Polymerization shrinkage	:	Is high
Adhesion properties	:	They do not adhere to tooth structure, which may lead to microleakage if used without etching and bonding.
Bond strength to enamel	:	7.4 MPa (1070 Psi). Bond strength to enamel is usually strong. Failure most often occurs at the metal-resin interphase.

MANIPULATION AND TECHNICAL CONSIDERATIONS

Like composites, resin cements are technique sensitive. Improper procedure can lead to poor bond strength and failure. The following processes are involved.

1. Etching the restoration
2. Etching the tooth surface
3. Bonding and curing
4. Removal of excess cement

ETCHING THE RESTORATION

Etching metal The metal surface can be etched or roughened by blasting with 30 to 50 µm alumina to improve retention. Etching is usually more effective. The process is carried out in a electrolytic bath containing an acid like sulfuric acid—also known as *electrochemical etching*. The non-bonding surface is protected with wax. Silica coating can also be used to improve bonding.

Etching porcelain Ceramic is a highly inert material and is immune to attack by most acids. However it can be etched by using hydrofluoric acid (see chapter on ceramics). The esthetic surfaces are protected with a coating of wax.

Orthodontic brackets In the case of orthodontic brackets, a fine mesh on the bonding side of the bracket helps to improve its retention. The cement flows into the mesh and locks to provide good mechanical retention. Coating with organosilane also improves bond strength.

ETCHING THE TOOTH SURFACE

The tooth surface is etched with phosphoric acid (similar to procedure described in restorative resins). This is followed by an application of bonding agent.

BONDING AND CURING

Chemically Activated Systems

2 paste systems The two components are combined by mixing on a paper pad. Mixing time is 20-30 seconds.

Single paste system with activator in bonding agent In some systems, the activator is present in the bonding agent. The bonding agent is painted on to the etched tooth surface as well as on to the restoration. Setting occurs when the cement on the restoration contacts the bonding agent on the tooth.

Dual Cure System

- The two components are mixed and light cured.
- Time of exposure should never be less than 40 seconds.
- Light curing gives high initial strength.
- Light curing polymerizes the exposed cement at the margins of the restoration which is affected by air inhibition.

REMOVAL OF EXCESS CEMENT

Excess cement removal is critical. Removal of excess cement can sometimes be very difficult because of the high strength of the material. Therefore removal of the excess cement should be attempted soon after seating before the material has fully hardened. Some manufacturers recommend a partial light cure to facilitate removal followed by completion of curing.

COMPOMER (POLYACID-MODIFIED COMPOSITE RESINS)

Shortly after the introduction of RM GICs, 'compomers' were introduced to the market. They were marketed as a new class of dental materials that would provide the combined benefits of composites (the 'comp' in their name) and glass ionomers ('omer'). These materials had the fluoride release features of GIC with the durability of composite. Based on their structure and properties, these materials belong to the class of dental composites. Often they have been erroneously referred to as 'hybrid glass ionomers', 'light-cured GICs' or 'resin-modified glass ionomers'. The proposed nomenclature for these materials is polyacid-modified composite resins, a nomenclature that is widely used in the literature.

APPLICATIONS

1. Restorative materials in pedodontics.
2. Restorative material in nonstress bearing areas.
3. Class V lesions.
4. Bases.
5. Luting (permacem).

Their applicability as orthodontic adhesives, amalgam bonding systems and veterinary restorative materials has also been reported.

SUPPLIED AS

These materials are sensitive to moisture. They are usually supplied as:

— Light cured single paste in moisture proof packets (Dyract, Compoglass) ***(Fig. 7.28)***

Figure 7.28: Single component compomer restorative (Dyract, Dentsply).

Figure 7.29: Two paste automixing compomer luting cement (PermaCem by DMG).

Figure 7.30: Powder/liquid type luting cement (Principle by Dentsply).

— Powder/ liquid (Principle)

— 2 paste automix system (PermaCem) ***(Fig. 7.29)***

Commercial products Restorative	-	Dyract (Dentsply), Compoglass (Ivoclar).
Luting	-	Permacem, Principle (Dentsply), ***(Fig. 7.30)*** etc.

COMPOSITION

These materials have two main constituents: dimethacrylate monomer(s) with two carboxylic groups present in their structure and filler that is similar to the ion-leachable glass present in GICs. The ratio of carboxylic groups to backbone carbon atoms is approximately 1:8. There is no water in the composition of these materials and the ion-leachable glass is partially silanized to ensure some bonding with the matrix.

Single component system	-	Silicate glass, sodium fluoride, and poly-acid modified monomer, photoinitiator.
Double component system	*Powder* -	Glass fillers, accelerators, initiator, TiO^2
	Liquid -	Acrylic monomers, photoinitiator, water, carboxylic acid dimethacrylate.

SETTING REACTION

The initial set is via a free radical polymerization reaction activated by light. Subsequently water from saliva is absorbed by the cement and an acid-base reaction sets in between the carboxylic groups and areas of filler not contaminated by the silane coupling agents. It is this reaction which releases fluoride.

MANIPULATION

For the single component system the tooth is etched and bonding agent applied. The material is injected into the cavity and cured by light.

For the powder/liquid system the powder and liquid is dispensed and mixed according to the manufacturer's instruction for 30 seconds.

For the automixing system, the material comes out mixed when it is forced through special mixing tips.

PROPERTIES

Considering the low volume fraction filler and the incomplete silanization of the filler, it could be postulated that they are inferior to composites. Both *in vitro* and *in vivo* investigations have confirmed this expectation. Lower flexural strength, modulus of elasticity, compressive strength, flexural strength fracture toughness and hardness, along with significantly higher wear rates compared to clinically proven hybrid composites, have been reported for these materials. Their clinical performance received mixed reviews during *in vivo* clinical trials.

Fluoride Release

Though these materials release fluoride they have significantly lower levels of fluoride release than GICs. Although low, the level of fluoride release has been reported to last at least 300 days.

Adhesion

Unlike glass ionomer they do not have the ability to bond to hard tooth tissues. Like composites acid etching and use of bond agents are necessary.

Biocompatibility

With the exception of concerns about the release of HEMA from these materials, no other biocompatibility issues have been associated with their usage.

ADVANTAGES AND DISADVANTAGES

The prime advantage of these materials are their fluoride release anticariogenic potential. The disadvantage is their lack of adhesion. Thus bonding agents are required which increase in the number of steps and time required for placement.

Constant reformulations of these types of materials may eventually make them comparable or even superior to existing composites, but as long as they do not set via an acid-base reaction and do not bond to hard-tooth tissues, they cannot and should not be classified with GICs.

8

DENTAL AMALGAM

An amalgam is defined as a special type of alloy in which mercury is one of the components. Mercury is able to react with certain alloys to form a *plastic mass*, which is conveniently packed into a prepared cavity in a tooth. This plastic mass hardens and is stronger than any dental cement or anterior filling material. Dental amalgam is *the most widely used* filling material for posterior teeth.

The alloys before combining with mercury are known as dental amalgam alloys. Strictly speaking, however, this is a misnomer as they are not dental amalgam alloys but alloys from which dental amalgam is prepared.

In dentistry, amalgam has been successfully used for more than a century as a restoration material for tooth decay. Over the years its quality has greatly improved, thanks to a lower amount of mercury and the addition of new components which can reduce its corrosion in the oral cavity.

HISTORY OF DENTAL AMALGAM

There are indications that dental amalgam was used in the first part of the T'ang Dynasty in China (618-907 AD). Prior to amalgam, dentists restored teeth using filling material such as stone chips, resin, cork, turpentine, gum, lead and gold leaf, among other metals. The renowned physician Ambroise Paré (1510–1590) used lead or cork to fill teeth.

In 1603, a German named Tobias Dorn Kreilius described a process for creating an amalgam filling by dissolving copper sulfide with strong acids, adding mercury, bringing to a boil and then pouring onto the teeth. In France D'Arcet's Mineral Cement was popular, but it had to be boiled into a liquid before being poured on patient's teeth. Louis Regnart added mercury to the mixture, lowering the temperature required significantly, and for this became known as the 'Father of Amalgam'. Amalgam was placed by Taveau of Paris as early as 1826, although he had developed it in 1816. Early amalgam had drawbacks, some mixtures caused expansion resulting in fractured teeth.

Amalgam was introduced in to the USA by the Crawcour brothers (from France) in 1833. Early amalgam was made by mixing mercury with the filings of silver coins. The early amalgams expanded on setting. In 1895, GV Black developed a formula (67% silver, 27% tin, 5% copper, 1% zinc) for modern amalgam alloy. Black's formula overcame the expansion problems of the existing amalgam formulations.

APPLICATIONS

1. As a permanent filling material for
   - — Class I and class II cavities, and
   - — Class V cavities where esthetics is not important.

2. In combination with retentive pins to restore a crown
3. For making dies
4. In retrograde root canal fillings
5. As a core material.

CLASSIFICATION OF AMALGAM ALLOYS

BASED ON COPPER CONTENT

Low copper alloys : Contain less than 6% copper (conventional alloys)
High copper alloys : Contain between 13-30% copper.

The high copper alloys are further classified as:

- Admixed or dispersion or blended alloys.
- Single composition or unicomposition alloys.

BASED ON ZINC CONTENT

Zinc-containing alloys : Contain more than 0.01% zinc
Zinc-free alloys : Contain less than 0.01% zinc

BASED ON SHAPE OF THE ALLOY PARTICLE

Lathe cut alloys (irregular shape)
Spherical alloys
Spheroidal alloys

BASED ON NUMBER OF ALLOYED METALS

Binary alloys, e.g., silver-tin
Ternary alloys, e.g., silver-tin-copper
Quaternary alloys, e.g., silver-tin-copper-indium.

BASED ON SIZE OF ALLOY

Microcut
Macrocut

MANUFACTURE OF ALLOY POWDER

The various components of the amalgam alloy are combined together by melting to form ingots. The ingots have to be heat treated in an oven for a set period of time. This process is called *annealing*. Annealing improves the homogeneity and grain structure of the alloy.

LATHE-CUT ALLOY POWDER

An annealed ingot of silver-tin alloy is placed in a lathe and fed into a cutting tool. The resulting chips obtained are often needlelike and some manufacturers reduce the chip size by ball-milling.

AGING, ACID TREATMENT AND ANNEALING OF PARTICLES

A freshly cut alloy reacts *too rapidly* with mercury. If the alloy filings are stored at room temperature for a *few months* the reactivity gradually decreases. Such alloys are said to have been aged. The filings can be aged faster by boiling in water for 30 minutes. Aging also improves the shelf life of the product.

Some manufacturers treat the filings with *acid* to improve reactivity.

The stresses induced during the cutting and grinding process must be relieved by an *annealing* process (100°C for several hours). Failure to anneal results in a slow release of stress over time (during storage) which can adversely affect the properties of the amalgam.

SPHERICAL ALLOY POWDER

The spherical alloy is prepared by an *atomization* process. The liquid alloy is sprayed under high pressure of an inert gas through a fine crack into a large chamber. If the droplets solidify before hitting a surface, the spherical shape is preserved. Like the lathe-cut powders, spherical powders are aged. A comparison of two types of powders is detailed in ***Table 8.1***.

SUPPLIED AS

Bulk powder and mercury in separate containers (***Figs 8.1 and 8.2***).

Alloy and mercury in disposable capsules (***Figs 8.3, 8.7 and 8.8***)

Preweighed alloy as tablet form in tubes (***Fig. 8.4)*** and mercury in sachets.

Figure 8.1: DPI alloy powder (*Courtesy:* Vijay Dental, Chennai).

Figure 8.2: Various brands of commercially available mercury (*Courtesy:* Vijay Dental, Chennai).

Figure 8.3: Alloy/mercury capsule form.

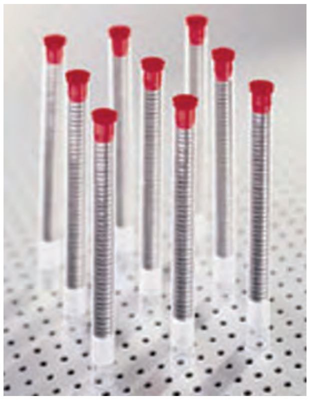


Figure 8.4: Alloy tablet form.

COMPOSITION

	Low copper	*High copper*		
		Admixed		*Unicomposition*
	Lathe-cut or spherical	*Lathe-cut 2/3*	*Spherical 1/3*	*Spherical*
Silver	63-70%	40-70%	40-65%	40-60%
Tin	26-29%	26-30%	0-30%	22-30%
Copper	2-5%	2-30%	20-40%	13-30%
Zinc	0-2%	0-2%	0	0-40%

FUNCTION OF CONSTITUENTS

Silver

- Major element in the reaction.
- Whitens the alloy.
- Decreases the creep.
- Increases the strength.
- Increases the expansion on setting.
- Increases tarnish resistance in the resulting amalgam.

Tin

- Tin *controls the reaction* between silver and mercury. Without tin the reaction would be too fast and the setting expansion would be unacceptable.
- Reduces strength and hardness.
- Reduces the resistance to tarnish and corrosion, hence the tin content should be controlled.

Copper

- Increases hardness and strength.
- Increases setting expansion.

Zinc

- In small amounts, it does not influence the setting reaction or properties of amalgam. Zinc acts as a *scavenger* or *deoxidizer* during manufacture, thus prevents the oxidation of important elements like silver, copper or tin. Oxidation of these elements would seriously affect the properties of the alloy and amalgam. Alloys without zinc are more brittle, and amalgam formed by them are less plastic.
- Zinc causes *delayed expansion* if the amalgam mix is contaminated with moisture during manipulation.

Mercury

In some brands a small amount of mercury (up to 3%) is added to the alloy. They are known as *pre-amalgamated alloys*. Pre-amalgamation produces a more rapid reaction.

Platinum

Hardens the alloy and increases resistance to corrosion.

Palladium

Hardens and whitens the alloy.

Indium

Indium when added to the mercury reduces mercury vapor and improves wetting. Indium can also added to the powder. Though it reduces early strength it increases the final strength. It reduces creep.

COMPARISON OF LATHE CUT AND SPHERICAL ALLOYS

Table 8.1

Comparison of lathe cut and spherical alloys

Spherical alloys	*Lathe-cut alloys*
1. Particles are spherical.	1. Particles are irregular.
2. Manufactured by atomization of molten alloy.	2. Manufactured by milling anannealed ingot of alloy.
3. More plastic (a contoured matrix is essential to establish proximal contour).	3. Less plastic and resists condensation pressure.
4. Requires less mercury hence has improved properties.	4. More mercury required hence has inferior properties.

LOW COPPER ALLOYS

Historically amalgam alloys were low copper alloys. The composition recommended by GV Black in the late 18th century remained virtually unchanged until the late 1960s when high copper amalgams were introduced.

COMPOSITION

Constituents		*Percent*
Silver	—	63-70%
Tin	—	26-29%
Copper	—	2-5%
Zinc	—	0-2%

AVAILABLE AS

- Lathe-cut alloys, which are further available as *coarse* or *fine grain* (fine grain type is preferred, because of the ease of carving).
- Spherical alloys.
- Blend of lathe-cut and spherical particles.

SETTING REACTION

When alloy powder and mercury are triturated, the silver and tin in the outer portion of the particles *dissolve* into the mercury. Simultaneously the mercury diffuses into the alloy particles and starts reacting with the silver and tin within forming crystals of silver-mercury (Ag_2Hg_3) and tin-mercury compounds (Sn_8Hg).

Table 8.2

Amalgam reaction phases and symbols

Phases	*Symbol*	*Chemically*
Gamma	γ	Ag_3Sn
Beta	β	$AgSn$
Gamma 1	γ_1	Ag_2Hg_3
Gamma 2	γ_2	Sn_8Hg
Eta	η	Cu_6Sn_5
Epsilon	ε	Cu_3S

Silver-tin compound (unreacted alloy powder) is known as the *gamma (γ) phase*. The silver-mercury compound is known as *gamma 1 (γ_1) phase* and the tin-mercury as the *gamma 2 (γ_2) phase* ***(Table 8.2).***

A simplified reaction is outlined below:

$$\underset{(\beta+\gamma)}{Ag_3Sn} + Hg \longrightarrow \underset{(\gamma_1)}{Ag_2Hg_3} + \underset{(\gamma_2)}{Sn_8Hg} + \text{(unreacted) }\underset{(\beta+\gamma)}{Ag_3Sn}$$

The alloy particles do not react completely with mercury. About 27% of the original Ag_3Sn remains as *unreacted particles*, which as previously mentioned is known as the gamma (γ) phase.

The properties of the hardened amalgam depends on the proportion of the reaction phases. If more unconsumed Ag_3Sn (γ phase) is present, the stronger the amalgam. The γ_2 phase is the weakest component and is least stable to corrosion.

MICROSTRUCTURE

Set amalgam consists of unreacted particles (γ) surrounded by a matrix of the reaction products (γ_1 and γ_2) ***(Fig. 8.5)***.

Note The properties of the hardened amalgam depends upon the proportion of each of the reaction phases. If more unconsumed Ag_3Sn (γ phase) is present, the stronger the amalgam. The γ_2 phase is the weakest component and is least stable to corrosion process. Also present are Cu_3Sn phase (ε or epsilon) formed from the small amounts of copper present in the composition.

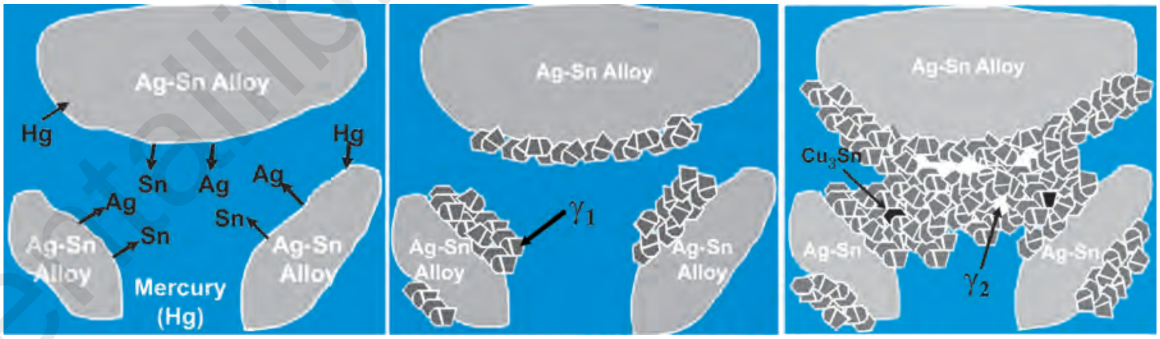


Figure 8.5: Schematic representation of setting reaction and microstructure of low copper amalgam.

HIGH COPPER ALLOYS

High copper alloys contain between 13 to 30% wt. copper. The majority of amalgam restorations placed currently are high copper. They are preferred because of their improved mechanical properties, resistance to corrosion and better marginal integrity.

TYPES

1. Admixed alloy.
2. Single-composition alloy.

ADMIXED ALLOY POWDER

The admixed alloy ***(Fig. 8.6)*** was introduced in 1963 and were originally made by mixing 1 part silver-copper eutectic alloy (high copper spherical particles) with 2 parts silver-tin alloy (low-copper lathe-cut particles).

(An eutectic alloy is one in which the components exhibit complete liquid solubility but limited solid solubility. The silver-copper phase exhibits a eutectic structure at the composition of silver 71.9% and copper 28.1%).


Figure 8.6: Admixed alloy (Dentsply).

Amalgam made from admixed powders is *stronger* than amalgam made from lathe-cut low-copper powder, because of three reasons:

- A change in the nature of the filler particles. The silver-copper particles are present in greater amounts, in addition to the silver-tin particles.
- A greater residual filler content thereby changing the filler to matrix ratio.
- A reduction in the weaker γ_2 phase.

Synonyms Dispersed phase alloy.

TYPES

Admixed alloys are of two types

1. Regular or traditional admixed alloy—contains irregular and spherical alloy particles having different compositions (low copper and high copper).
2. Unicompositional admixed alloys—contains irregular and spherical particles of uniform composition.

COMPOSITION

Admixed alloy powders usually contain between 30 to 55 weight percent spherical high-copper alloy powder. The total copper content ranges from 9 to 20 weight percent. A sample composition is presented below.

Constituents		*Percent*
Silver	—	69%
Tin	—	17%
Copper	—	13%
Zinc	—	1%

SETTING REACTION

When the components are mixed the mercury begins to dissolve the outer portion of the particles. Silver from the silver-copper eutectic alloy particles, and both silver and tin from the silver-tin alloy particles enter the mercury. The tin dissolved in the mercury reacts with the copper of the silver-copper particles and forms the Cu_6Sn_5 (η or Eta). The η crystals form around the unreacted silver-copper particle. At the same time γ_1 phase is also formed. As in the low copper alloys γ_1 surrounds everything forming the matrix. γ_2 is also formed at the same time but is later replaced by η. Thus in admixed alloy the undesirable γ_2 phase is greatly reduced.

The reaction may be simplified as follows:

$$\underset{(\beta+\gamma)}{Ag_3Sn} + \underset{\text{(eutectic)}}{\text{Ag-Cu}} + Hg \longrightarrow \underset{(\gamma_1)}{Ag_2Hg_3} + \underset{(\eta)}{Cu_6Sn_5} + \underset{(\beta+\gamma)}{Ag_3Sn\text{ unreacted}} + \underset{\text{(eutectic)}}{\text{Ag-Cu unreacted}}$$

Note In this reaction, γ_2 has been eliminated and is replaced by η phase. To accomplish this, it is necessary to have a net copper content of at least 12 percent in the alloy powder.

MICROSTRUCTURE OF SET HIGH COPPER ADMIXED AMALGAM

The Cu_6Sn_5 is present as a 'halo' surrounding the Ag-Cu particles.

The final set material consists of

Core particles of

— Unreacted Ag_3Sn, (γ phase) and

— Unreacted Ag-Cu surrounded by a halo of Cu_6Sn_5 (η).

Embedded in a matrix made up of

— γ_1 (Ag_2Hg_3).

Schematic representation of the setting reaction and microstructure is shown in ***Fig. 8.7.***

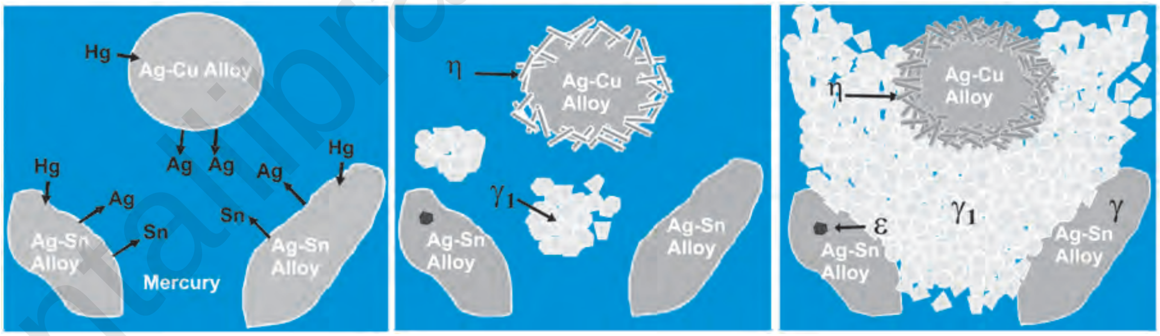


Figure 8.7: Schematic representation of setting reaction and microstructure of admixed amalgam.

SINGLE COMPOSITION ALLOYS

These are high copper amalgam alloys. Unlike admixed alloy powders, each particle of the alloy powder has the same composition. Therefore they are called single composition or 'unicompositional alloys' ***(Fig. 8.8)***. The spherical alloy particles are 5 to 40 µm in size.

Synonyms Single composition, unicompositional, non-gamma 2.

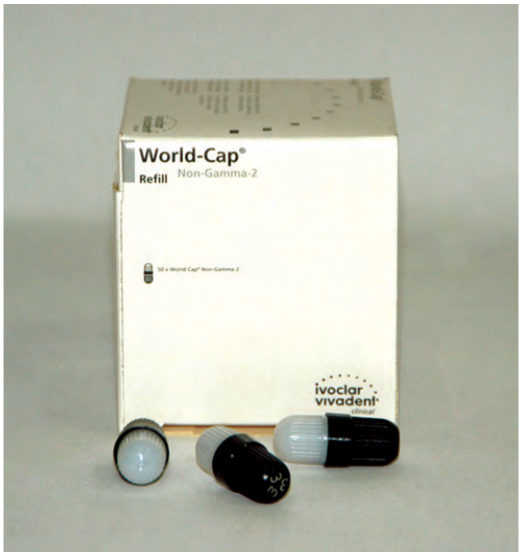


Figure 8.8: Single composition high copper alloy (Ivoclar).

COMPOSITION

Constituents		*Percent*
Silver	—	40-60%
Tin	—	22-30%
Copper	—	13-30%
Zinc	—	0-4%
Indium or palladium	—	Small amounts

SETTING REACTION

Though each particle has the same composition, the silver, tin and copper present exist in various phases within the particle. Thus each particle contains Ag_3Sn (γ), AgSn (β) and Cu_3Sn (ε). When triturated, silver and tin from the particle dissolve in mercury forming the γ_1 (Ag_2-Hg_3) crystal matrix that binds together the partially dissolved alloy particles. At this stage very little copper dissolves. Later, a layer of η (Cu_6Sn_5) crystals are formed at the surface of alloy particles. Some η (Cu_6Sn_5) crystals also form in the matrix.

The overall simplified reaction is:

$$\underset{(\gamma+\beta+\varepsilon)}{\text{Ag-Sn-Cu}} + \text{Hg} \longrightarrow \underset{(\eta)}{Cu_6Sn_5} + \underset{(\gamma_1)}{Ag_2Hg_3} + \underset{\text{(unreacted)}}{\text{Ag-Sn-Cu}}$$

Note The undesirable γ_2 does not usually form in most single composition alloys. The η (Cu_6Sn_5) crystals are much larger and rod-shaped than those in the admixed amalgam.

MICROSTRUCTURE OF SET SINGLE-COMPOSITION AMALGAM

Final set material ***(Fig. 8.9)*** consists of:

Particles of

— Unreacted Ag_3Sn (γ phase) and surrounded by a mesh of rod shaped η (Cu_6Sn_5).

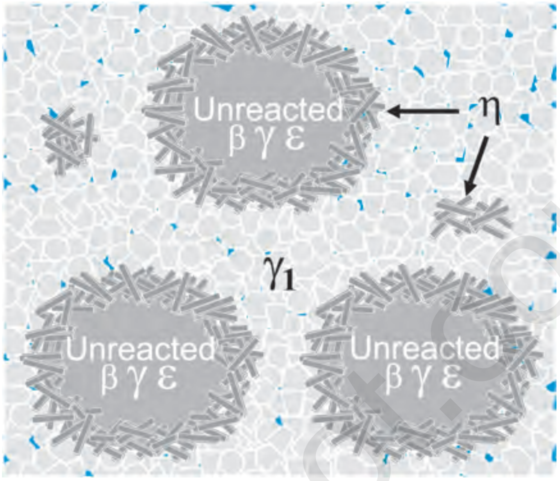


Figure 8.9: Schematic representation of setting reaction and microstructure of single composition amalgam.

Embedded in a matrix made up of
— γ_1 (Ag_2Hg_3).

ADVANTAGES/ DISADVANTAGES OF SPHERICAL HIGH-COPPER AMALGAM

ADVANTAGES

1. Faster set.
2. Lower residual mercury.
3. Lower creep during condensation.
4. Faster finishing.
5. Higher early strength.
6. Low condensation pressure.

DISADVANTAGES

1. Less working time.
2. Condensation pressure not sufficient to displace matrix during condensation (while restoring proximal cavities). Contouring of matrix band required.

PROPERTIES OF SET AMALGAM

MICROLEAKAGE

Penetration of fluids and debris around the margins may cause secondary caries. Dental amalgam has an exceptionally fine record of clinical performance because of its tendency to minimize marginal leakage (see tarnish and corrosion).

Self sealing The small amount of leakage under amalgam restorations is unique. If the restoration is properly inserted, leakage decreases as the restoration *ages* in the mouth. This may be due to the formation of *corrosion products* in the tooth-restoration interface. Over a period of time they *seal the interface* and reduce leakage. Thus amalgam is a *self sealing* restoration. Both low and high copper amalgams are capable of sealing against microleakage but the accumulation of corrosion products is slower with the high-copper alloys. Initial leakage can be reduced through the application of varnish on the cavity walls. Use of dentin bonding agents (bonded amalgam technique) also show promise.

DIMENSIONAL CHANGE

The earliest amalgams exhibited expansion while setting. This was because of the greater mercury/alloy ratio used. Amalgams may expand or contract, depending on its manipulation. Ideally, dimensional change should be small. Excessive contraction can lead to microleakage, sensitivity and secondary caries. Excessive expansion can produce pressure on the pulp and *postoperative sensitivity*. *Protrusion* of the restoration can also occur.

ADA Sp. no. 1 requires that amalgam should not expand more than 20 µm/cm or contract less than 15 µm at 37°C, between 5 minutes and 24 hours from the start of trituration. Mechanically triturated modern amalgams, both low and high copper, prepared from low mercury/alloy ratios show a slight contraction.

Theory of Dimensional Change

Contraction

When the alloy and mercury are mixed contraction results initially as the particles dissolve and the γ_1 grows. The final volume of γ_1 is less than the initial volumes of silver and mercury that go into making the γ_1. Therefore, contraction will continue as long as growth of γ_1 continue.

Expansion

The γ_1 crystals as they grow, impinge against one another, and produce an outward pressure tending to oppose contraction. If there is sufficient mercury present to provide a plastic matrix, an expansion will occur when γ_1 crystals impinge on each other.

After a rigid γ_1 matrix has formed, growth of γ_1 crystals cannot force the matrix to expand. Instead γ_1 crystals will grow into interstices containing mercury, consuming mercury, and producing continued reaction. Therefore, reducing mercury in the mix will favor contraction.

Thus factors favoring contraction are:

- Low mercury/alloy ratio
- Higher condensation pressure (squeezes out mercury)
- Smaller particles (consumes more mercury because of increased surface area)
- More trituration (accelerates setting).

Modern amalgams show a net contraction, whereas older amalgams always showed expansion. Two reasons for this difference are:

- Older amalgams contained larger alloy particles and were mixed at higher mercury/alloy ratios.
- Hand trituration was used before. Modern amalgams are mixed with high speed amalgamators (equivalent to increase in trituration time).

EFFECT OF MOISTURE CONTAMINATION (DELAYED EXPANSION)

If a zinc-containing-low-copper or high-copper amalgam is contaminated by moisture during trituration or condensation, a large expansion can take place. It usually starts after 3-5 days and may continue for months, reaching values

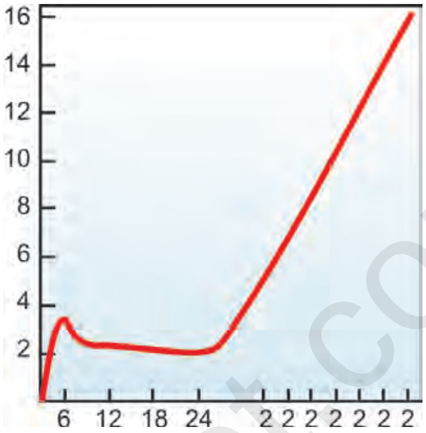


Figure 8.10: Delayed expansion of amalgam.

greater than 400 µm (4%). This is known as *delayed expansion* or *secondary expansion* ***(Fig. 8.10)***. The expansion is caused by the releases of hydrogen gas from the reaction of zinc with water.

$$H_2O + Zn \longrightarrow ZnO + H_2 \text{ (gas)}$$

This hydrogen gas does not combine with the amalgam, but collects within the restoration, creating extreme internal pressure and expansion of the mass. This causes protrusion of the restoration out of the cavity, increased creep, increased microleakage, pitted surfaces and corrosion. Dental pain, recurrence of caries, and fracture of the restoration are seen as a result of these poorly inserted restorations.

Note

Moisture contamination *after* the cavity has been filled does not cause delayed expansion. *Nonzinc alloys* do not show this type of expansion when contaminated with water. However, moisture contamination of the mix of any alloy results in inferior physical properties.

Indications for Zinc Free Alloys

Amalgam without zinc tends to be less plastic and less workable. These alloys are used only for cases where it is difficult to control moisture, e.g., patients having excessive salivation, retrograde root canal filling, subgingival lesions, etc.

STRENGTH

Well designed amalgam restorations have sufficient compressive strength to withstand normal intraoral masticatory forces.

Compressive strength	*1 Hour*	*7 Days*
Low copper (lathe cut)	45 MPa	302 MPa
Low copper (spherical)	141 MPa	366 MPa
Admixed	137 MPa	431 MPa
Single composition	262 MPa	510 MPa

Figure 8.11: A fractured amalgam restoration. Amalgam is technique sensitive. If improperly placed it can result in many problems including fracture, leakage, sensitivity, periodontal problems, etc.

TENSILE STRENGTH

Amalgam cannot withstand high tensile or bending stresses and can fracture easily in improperly designed restorations ***(Fig. 8.11)***. Therefore, the *cavity should be designed* so that the restoration will receive *minimal tension* or shear forces in service.

Low Copper	*Admixed*	*Single composition*
60 MPa	48 MPa	64 MPa

Factors Affecting Strength

Effect of Rate of Hardening

Amalgams do not gain strength as rapidly as might be desired. After 20 minutes, compressive strength may be only 6% of the one week strength. ADA specifications stipulates a minimum of 80 MPa at one hour. Since the initial strength of amalgam is low, patients should be cautioned not to bite too hard for a least 8 hours after placement, the time at which at least 70% of its strength is gained. The one hour compressive strength of high-copper single-composition amalgams is exceptionally high (262 MPa), so the chances of accidental fracture is less.

Even after six months, some amalgams may still be increasing in strength, suggesting that the reactions between the matrix phases and the alloy particles may continue indefinitely.

Clinical significance The rate of hardening should be considered during the placement of amalgam. In class II restorations where a supporting matrix has been placed, removal of the matrix should be done at the appropriate time. *Early removal* can result in fracture. Excessive pressure on the restoration by the patient *prematurely* to test the occlusion can also result in fracture.

Effect of Trituration

Either undertrituration or overtrituration will decrease the strength for both low-copper, and high-copper amalgams.

Effect of Mercury Content

Sufficient mercury should be mixed with the alloy to wet each particle of the alloy. Insufficient mercury produces a *dry, granular mix* ***(Fig. 8.18)*** which can result in a rough and pitted restoration which is prone to *corrosion*.

Excess mercury in the mix can produce a marked reduction in strength because of the higher γ_2 content (which is the weakest phase—see setting reaction).

Effect of Condensation

Higher condensation pressure results in higher compressive strength (only for lathe-cut alloys).

Reason A good condensation technique will minimize porosity and remove excess mercury from lathe-cut amalgams. If heavy pressures are used in spherical amalgams, the condenser will punch through. However, spherical amalgams condensed with lighter pressures produce adequate strength.

Effect of Porosity

Voids and porosities reduce strength.

Porosity is caused by:

- Decreased plasticity of the mix (caused by too low Hg/ alloy ratio, under trituration and over trituration).
- Inadequate condensation pressure.
- Irregularly shaped particles of alloy powder.
- Insertion of too large increments.

Increased condensation pressure improves adaptation and decreases voids. Fortunately, voids are not a problem with spherical alloys.

Effect of Cavity Design

- The cavity should be designed to reduce tensile stresses.
- Amalgam has strength in bulk, therefore, the cavity should have adequate depth and width.

CREEP

It is defined as a time dependent plastic deformation. Creep of dental amalgam is a slow progressive permanent deformation of set amalgam which occurs under constant stress (static creep) or intermittent stress (dynamic creep).

Creep Test
Creep is tested by subjecting a 7 day old cylindrical specimen to a load of 36 MPa (at 37°C) for a specified time usually between 1 and 4 hours.

Significance of Creep

Creep is related to *marginal breakdown* of low-copper amalgams. The higher the creep, the greater is the degree of marginal deterioration (***Fig. 8.12***).

According to ADA Sp. No. 1 creep should be below 3%.

Figure 8.12: Amalgam with high creep rate displaying marginal breakdown.

Creep Values

In general lathe-cut low-copper alloys show the highest creep values, often exceeding ADA limits. The lowest creep values are shown by the high copper amalgams.

Low-copper lathe cut amalgam	— 6%
Low-copper spherical	— 1.5%
High-copper admixed amalgam	— 0.5%
High-copper unicompositional amalgam	— 0.05 to 0.09%

Factors Affecting Creep

Microstructure The γ_1 (Ag-Hg) phase has a big effect on low-copper amalgam creep rates. Increased creep rate is shown by larger γ_1 volume fractions. Decreased creep rate is shown by larger γ_1 grain sizes. The γ_2 phase is associated with higher creep rates.

Single composition high-copper amalgams have very low creep rates, due to absence of γ_2 phase and due to the presence of η (Cu_6Sn_5) rods, which acts as barrier to deformation of the γ_1 phase. Increased zinc content reduces creep.

Effect of manipulative variables For increased strength and low creep values.

- Mercury/alloy ratio should be minimum.
- Condensation pressure should be maximum for lathe-cut or admixed alloys.
- Careful attention should be paid to timing of trituration and condensation. Either under or over-trituration or delayed condensation tend to increase the creep rate.

RETENTION OF AMALGAM

Amalgam does not adhere to tooth structure. Retention of the amalgam filling is obtained through mechanical locking. This is achieved by proper cavity design (see cavity design in technical considerations). Additional retention if needed can be obtained by placing pins within the cavity. Amalgam can also be bonded using special bonding agents.

TARNISH AND CORROSION

Amalgam restorations often tarnish and corrode in the mouth. Black silver sulfide can form on the surface of an amalgam restoration in some patients. Both high and low-copper amalgams show corrosion. However corrosion in high-copper amalgams is limited because η phase is less susceptible.

Factors Related to Excess Tarnish and Corrosion

- High residual mercury.
- Surface texture—small scratches and exposed voids.
- Contact of dissimilar metals, e.g., gold, and amalgam.
- Patients on a high sulfur diet.
- Moisture contamination during condensation.
- Type of alloy—low copper amalgam is more susceptible to corrosion (due to greater γ_2 content) than high copper. Also η (Cu_6Sn_5) phase of high copper is less susceptible to corrosion.
- A high copper amalgam is cathodic in respect to a low-copper amalgam. Therefore, mixed high copper and low copper restorations should be avoided.

Corrosion of Amalgam can be Reduced by

- Smoothing and polishing the restoration.
- Correct Hg/alloy ratio and proper manipulation.
- Avoid dissimilar metals including mixing of high and low copper amalgams.

TECHNICAL CONSIDERATIONS

MANIPULATION OF AMALGAM

The clinical success of amalgam restorations is highly dependent on the correct cavity design and selection and manipulation of the alloy. If a restoration is defective, it is usually the fault of the operator and not the material.

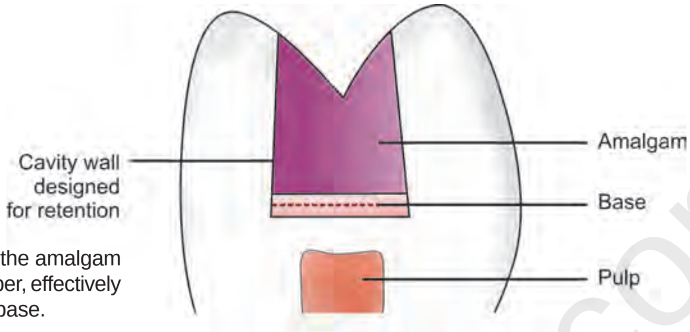


Figure 8.13: The cavity walls are designed to lock the amalgam restoration. This is achieved by creating walls that taper, effectively making the mouth of the cavity narrower than the base.

CAVITY DESIGN

Providing retention Since amalgam does not adhere to tooth structure, proper design of the cavity is very important. The amalgam cavity is designed to provide maximum mechanical locking of the amalgam ***(Fig. 8.13)***. This is achieved by creating a cavity with walls that diverge towards the floor of the cavity (or converge towards the mouth of the cavity). This results in a cavity mouth that is narrower, effectively locking the amalgam within the cavity. Additional retention if needed can be obtained by placing pins within the cavity.

Four wall support For effective condensation, the cavity should have *four walls* and *a floor*. If one or more of the walls of the cavity is absent, a stainless steel matrix ***(Figs 8.19 and 8.20)*** can compensate for the missing walls. Failure to have a four wall support can result in inadequate condensation which can weaken the amalgam. Additional retention can be obtained with amalgam pins or screws.

Preventing tensile fracture Since amalgam has poor tensile strength, the cavity should have sufficient depth and width in order to provide *sufficient bulk* to the amalgam, especially those in high stress areas.

Cavosurface angle The junction of the cavity with the external surface should be as close to a right angles as possible. Beveling is *not indicated* for amalgam as it can cause fracture of the amalgam at the margins.

SELECTION OF MATERIALS

Alloy

The alloy is selected based on clinical need:

- For restorations subjected to occlusal forces, an amalgam with high resistance to marginal fracture is desirable.
- If strength is needed quickly the best choice is spherical or high copper alloys, but they require a fast operator.
- A non-zinc alloy is selected in cases where it is difficult to control moisture.
- Indium containing alloys: Indium performs the same functions as zinc and in addition, it decreases the γ_2 phase.

Mercury

There is only one requisite for dental mercury and that is its purity. Common contaminating elements such as arsenic, can lead to pulpal damage. A lack of purity may also adversely affect physical properties. High purity mercury is labelled as 'triple distilled'.

Freezing point : –38.87°C
Boiling point : 356.9°C

ADA Sp. No. 6 for dental mercury requires that the mercury should possess no surface contamination and less than 0.02% nonvolatile residue.

DISPENSERS

Because proportioning is important, manufacturers have developed some simple dispensers for alloy and mercury ***(Fig. 8.14)***. Dispensing by volume is unreliable because it is affected by particle size and the degree of packing (trapped air and voids) in the dispenser.

TABLETS

This is the most accurate method of dispensing. Manufacturers compress alloy powder into tablets of controlled weight which is used with measured amounts of mercury.

PREPROPORTIONED CAPSULES

Preproportioned capsules containing alloy powder and mercury in compartments separated by a membrane are available ***(Fig. 8.15)***. They usually contain 400, 600, 800 or in rare cases 1200 mg of alloy powder with corresponding proportion of mercury. Before use, the membrane is ruptured by compressing the capsule, and the capsule is then placed in a mechanical amalgamator.

Advantages

1. Consistent proportioning.
2. Low mercury/alloy ratio.
3. Physical handling not required thus reducing health hazard.

Disadvantages

Mercury and alloy may leak. The dentist is forced to use one alloy/mercury ratio for all situations when using disposable capsules. Also, the disposable capsules are expensive.

MERCURY: ALLOY RATIO (PROPORTIONING)

Prior to mechanical triturators, when amalgam was triturated manually excess mercury had to be used in order to achieve smooth and plastic amalgam mixes.

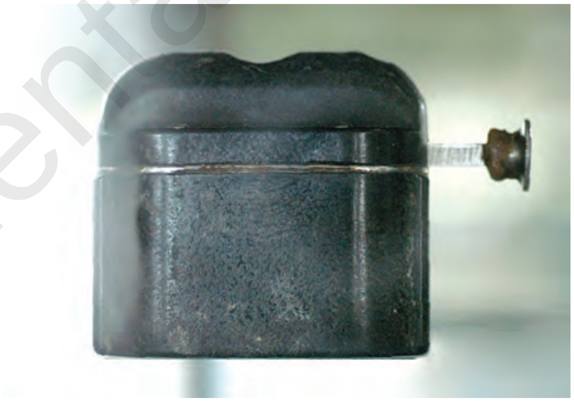


Figure 8.14: Mercury/alloy dispenser.

Figure 8.15: Preproportioned capsules.

This excess mercury was removed from the amalgam by:

- Using a *squeeze cloth to* squeeze out the excess mercury.
- *Increasing dryness technique:* During condensation of each increment, a mercury rich soft layer comes to the surface. This is removed by condensing excess amalgam and carving off the excess.

Eames Technique

The better method of reducing mercury content is to reduce the original mercury/alloy ratio. This is known as the minimal mercury or Eames technique (mercury/alloy 1:1). However, it is still necessary to squeeze mercury out of the mix using the increasing dryness technique. Hence, with this technique, 50% or less mercury will be in the final restoration, with obvious advantages.

Mercury alloy ratios ranges from 43 to 54%. In preproportioned capsule the mercury/alloy ratio is determined by the manufacturer and is usually less than 50%.

Low mercury/alloy ratios are not easy to triturate manually. In order to benefit from a low mercury/alloy ratio a high speed mechanical triturator (amalgamator) is absolutely essential.

TRITURATION

The objective of trituration is to wet all the surfaces of the alloy particles with mercury. For proper wetting, the alloy surface should be clean. Rubbing of the particles mechanically removes the oxide film coating on alloy particles.

Trituration is achieved either by:

- Manually by hand
- Mechanical mixing

Manual Mixing

A glass mortar and pestle is used ***(Fig. 8.16)***. The mortar has its inner surface roughened to increase the friction between amalgam and glass surface. A rough surface can be maintained by occasional grinding with carborundum paste. A pestle is a glass rod with a round end.

Figure 8.16: Glass mortar and pestle.

The three factors to obtain a well mixed amalgam mass are:

— The number of rotations,

— The speed of rotation and

— The magnitude of pressure placed on the pestle. Typically a 25 to 45 second period is sufficient.

Mechanical Trituration

Mechanical amalgamators are more commonly used to triturate amalgam alloy and mercury ***(Fig. 8.17)***.

- The disposable capsule serves as a mortar. Some capsules have a cylindrical metal or plastic piece in the capsule which serves as the pestle. The capsule is inserted between the arms on top of the machines. When switched on, the

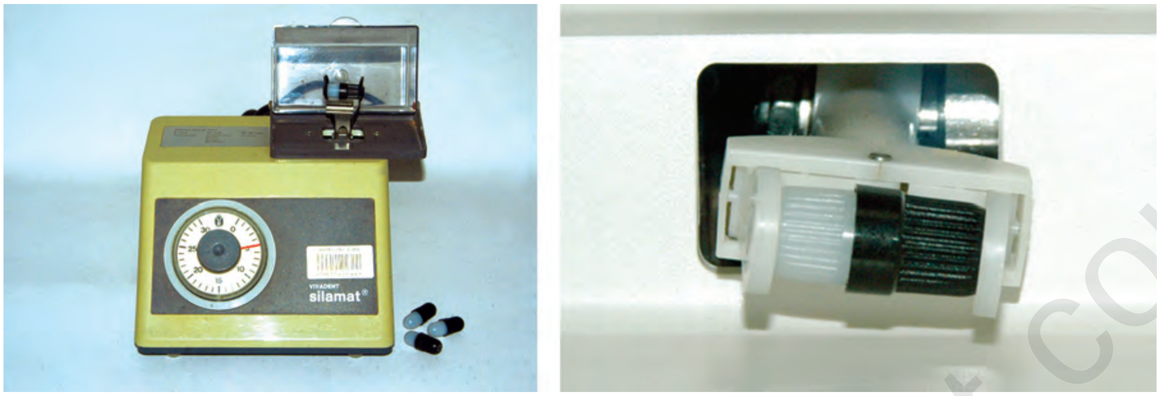


Figure 8.17: Mechanical amalgamator for preproportioned capsules (left). Close-up of the mechanical arm that grips and vibrates the capsules (right).

arms holding the capsule oscillate at high speed thus triturating the amalgam. Most amalgamators have hoods that cover the arms holding the capsule in order to confine mercury spray and prevent accidents.

- Reusable capsules are available with friction fit or screw-type lids. This type uses alloy in tablet form and capsulated mercury. At one time not more than two pellets alloy should be mixed in a capsule.

With either type, the lid should fit the capsule tightly, otherwise, the mercury can spray out from the capsule, and the inhalation of fine mist of mercury droplets is a health hazard.

Amalgamators have automatic timer and speed control device. The speed ranges from 3200 to 4400 cycles per minute. High copper alloys require higher mixing speeds.

Mixing time The mixing time can vary depending on the speed, oscillating pattern, and capsule designs. Spherical alloys usually require less amalgamation time than do lathe-cut alloys. A large mix requires slightly longer mixing time than a smaller one. Manufacturer's recommendations should be followed when determining mixing speed and time.

Advantages of mechanical trituration:

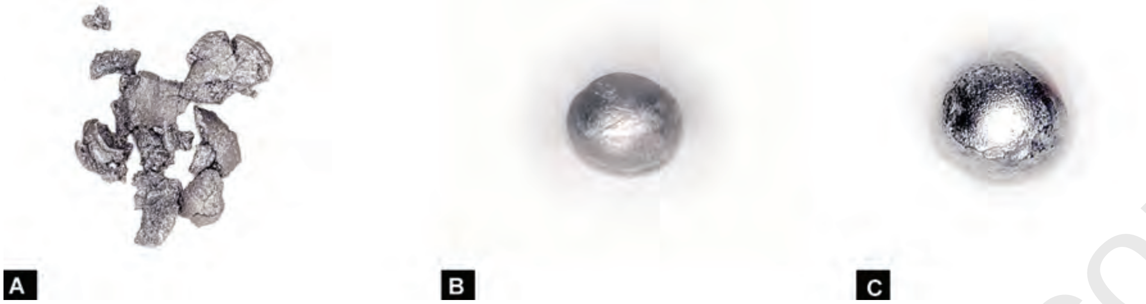
1. Shorter mixing time.
2. More standardized procedure.
3. Requires less mercury when compared to hand mixing technique.

Under-Triturated Mix

- It is rough and grainy and may crumble ***(Fig. 8.18 A).***
- It gives a rough surface after carving and tarnish and corrosion can occur.
- Strength is less.
- Mix hardens too rapidly and excess mercury will remain.

Normal Mix

- It has a shiny surface and a smooth and soft consistency ***(Fig. 8.18 B).***
- It may be warm (not hot) when removed from the capsule.
- It has the best compressive and tensile strength.



Figures 8.18 A to C: Three types of mixes: (A) An under-triturated mix; (B) A normal mix; (C) An over-triturated mix.

- The carved surface retains its lustre after polishing, hence increased resistance to tarnish and corrosion.

Over-Triturated Mix

- The mix is soupy, difficult to remove from capsule and too plastic to manipulate ***(Fig. 8.18 C)***.
- Working time is decreased.
- Results in higher contraction of the amalgam.
- Strength increases for lathe-cut alloys, whereas it is reduced in high copper alloys.
- Creep is increased.

MULLING

Mulling is actually a continuation of trituration. It is done to improve the homogeneity of the mass and get a single consistent mix. It can be accomplished in two ways:

- The mix is enveloped in a dry piece of rubber dam and vigorously rubbed between the first finger and thumb, or the thumb of one hand and palm of another hand for 2-5 seconds.
- After trituration the pestle is removed and the mix is triturated in the pestle-free capsule for 2-3 seconds.

Mulling is not necessary for mechanical triturated amalgams.

CONDENSATION

The amalgam is placed in the cavity after trituration, and packed (condensed) using suitable instruments.

Aims

1. To adapt it to the cavity wall.
2. Remove excess mercury.
3. Reduce voids.

Proper condensation increases the strength and decreases the creep of the amalgam. Condensation *must always* be done within the *four walls and floor*. If one or more walls of the cavity are missing, a steel *matrix* ***(Figs 8.19 and 8.20)*** may be used to compensate for it. Failure to use a matrix can result in a poorly condensed and

Figure 8.19: Tofflemire matrix retainer and bands.

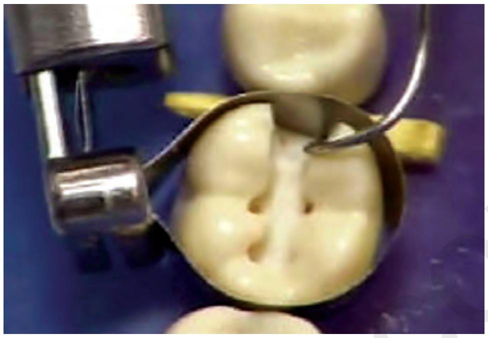


Figure 8.20: Tofflemire matrix in position. Small wooden pegs are used to seal off the embrasure area.

weak restoration. Amalgam can also escape into the interdental space (amalgam overhang) resulting in bleeding and pain ***(Fig. 8.21)***.

Condensers

Condensers are instruments with serrated tips of different shapes and sizes. The shapes are oval, crescent, trapezoidal, triangular, circular or square. The condenser type is selected as per the area and shape of the cavity. Smaller the condenser, greater is the pressure exerted on the amalgam. Condensation can be done manually or mechanically. For spherical amalgams, a large condenser tip should be selected to reduce punching through and improve condensation.

Manual Condensation

The mixed material is packed in *increments*. Each increment is carried to the prepared cavity by means of a small forceps or an *amalgam carrier*.

Once inserted, it should be condensed immediately with sufficient pressure (approximately 3 to 4 pounds). Condensation is started at the center, and the condenser point is stepped sequentially towards the cavity walls.

As the mix is condensed some *mercury rich material* rises to the surface. Some of this can be removed, to reduce the final mercury content and improve the mechanical properties. The remainder will assist bonding with the next increment.

Modern amalgams are fast setting and so working time is short. Therefore, condensation should be as rapid as possible. A fresh mix of amalgam should be ready if condensation takes more than 3 or 4 minutes. Long delay between

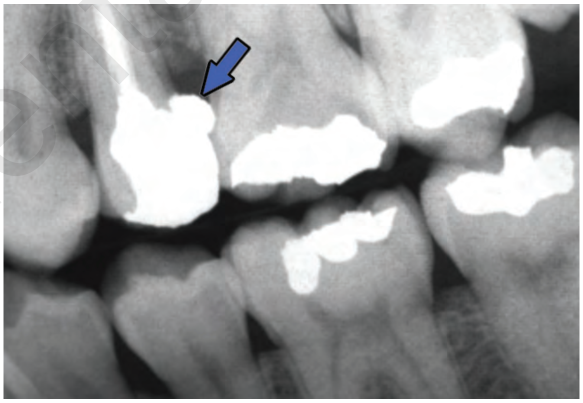


Figure 8.21: Amalgam overhang resulting from failure to use matrix.

mixing and condensation, results in weaker amalgam and increased mercury content and creep.

Spherical alloys have little 'body' and thus offer only mild resistance to the condensation. When condensing these alloys, a *larger* condenser is recommended.

Mechanical Condensation

Mechanical condensers provide vibration or impact type of force to pack the amalgam mix. Less effort is needed than for hand condensation.

SHAPING AND FINISHING

CARVING

The amalgam is *overfilled* into the cavity and the *mercury rich* surface layer is trimmed away. The filling is carved to reproduce the tooth anatomy. The carving should not be started until the amalgam is hard enough to offer resistance to the carving instrument. A *scraping* or *ringing* sound should be heard when it is carved. If the carving is started too soon, the amalgam may be so plastic that it may *pull away* from the margins. Sharp carvers are used with strokes proceeding from tooth surface to amalgam surface.

BURNISHING

After the carving, the restoration is smoothened, by burnishing the surface and margins of the restoration. Fast setting alloys gain sufficient strength by this time to resist rubbing pressure. Burnishing slow setting alloys can damage the margins of the restoration.

Burnishing is done with a ball burnisher using light stroke proceeding from the amalgam surface to the tooth surface. Final smoothing can be done by rubbing the surface with a moist cotton pellet.

POLISHING

Polishing minimizes corrosion and prevents adherence of plaque. The polishing should be delayed for at least *24 hours* after condensation, or preferably longer. Wet polishing is advised, so a wet abrasive powder in a paste form is used. Dry polishing powders can raise the temperature above 60°C. If the temperature rises above 60°C, mercury is released which may cause corrosion and fracture at the margins. High copper unicompositional alloys with high early strength may be polished at the same sitting after the materials has hardened sufficiently.

Figure 8.22: A completed amalgam restoration.

However, polishing should be carried out delicately using soft abrasives and gentle pressure. A completed amalgam restoration is shown in ***Fig. 8.22.***

AMALGAM BONDING

Amalgam restorations do not reinforce the teeth. Teeth with MOD cavities are susceptible to cuspal fractures. Bonding of the amalgam with a suitable adhesive (4-META) has been shown to considerable improve fracture resistance of the tooth (twice as much as unbonded restorations). Amalgam bonding also reduces marginal leakage. However, amalgam to amalgam bond is not so effective and therefore repair with bonding agents is not recommended.

MERCURY TOXICITY

Mercury is toxic. Free mercury should not be sprayed or exposed to the atmosphere. This hazard can arise during trituration, condensation and finishing of the restoration, and also during the removal of old restorations at high speed. Mercury *vapors* can be inhaled. Skin contact with mercury should be avoided as it can be absorbed.

Any excess mercury should not be allowed to get into the *sink*, as it reacts with some of the alloys used in plumbing. It also reacts with *gold ornaments.*

Mercury has a cumulative toxic effect. Dentists and dental assistants, are at high risk. Though it can be absorbed by the skin or by ingestion, the primary risk is from *inhalation.*

Precautions

The clinic should be *well ventilated*. All excess mercury and amalgam waste should be stored in *well-sealed containers*. Proper disposal systems should be followed, to *avoid environmental pollution*. Amalgam scrap and materials contaminated with mercury or amalgam should not be subjected to heat sterilization. Spilled mercury is cleaned as soon as possible as it is extremely difficult to clean it from carpets. Vacuum cleaners *are not* used because they disperse the mercury further through the exhaust. Mercury suppressant powders are helpful but these are temporary measures. Skin contacted with mercury should be washed with *soap and water.* The alloy mercury capsules, should have a tightly fitting cap to avoid leakage. While removing old fillings, a water spray, mouth mask and suction should be used.

The use of ultrasonic amalgam condenser is not recommended as a spray of small mercury droplets is observed surrounding condenser point during condensation. Annually, a *program for handling toxic materials* is monitored for actual exposure levels.

ADVANTAGES AND DISADVANTAGES OF AMALGAM RESTORATIONS

Advantages

1. Reasonably easy to insert.
2. Not overly technique sensitive.
3. Maintains anatomic form well.
4. Has adequate resistance to fracture.
5. After a period of time prevents marginal leakage.
6. Have reasonably long service life.

7. Cheaper than other alternative posterior restorative material like cast gold alloys.

Disadvantages

1. The color does not match tooth structure.
2. They are more brittle and can fracture if incorrectly placed.
3. They are subject to corrosion and galvanic action.
4. They eventually show marginal breakdown.
5. They do not bond to tooth structure.
6. Risk of mercury toxicity.

THE AMALGAM CONTROVERSY

Amalgam has been the subject of much public concern because of the presence of mercury. Studies have often been taken out of context resulting in considerable alarm among the general public. Some of these controversies have been created by dentists themselves. It is of the uppermost importance that people be correctly informed on the position taken by the international scientific community and the leading health care agencies with respect to the potential risk of amalgam. The following reports have justified the continued use of amalgam.

In the US, the Assistant Secretary for Health established in 1991, a research committee with the aim of carefully reviewing nearly 500 scientific publications on amalgam. The study, which appeared in 1995, failed to show any harmfulness for the amalgam fillings.

Following the advice of the General Surgeon and the Center for Disease Control and Prevention of the Food and Drug Administration, the US Public Health Service recently published an article in a magazine with a very high circulation. The purpose was to clarify the issue and reassure the American people, who had been alarmed by the many news reports on the amalgam risk.

In Switzerland, Chairmen from the four Dental Departments at Universities of Berne, Basel, Geneva and Zurich replied to the alleged charges of amalgam-induced damages which appeared on newspapers and nonscientific journals with a review article. Amalgam was judged as a safe and effective material for posterior tooth filling, with the only exception of allergic patients.

At two meetings of the Federation Dentaire Internationale held in 1994 in Vancouver and Budapest, amalgam was acquitted on the charge of toxicity and was judged as a valid, cheap and still irreplaceable material.

In 1995, a joint statement from the World Health Organization (through two of its agencies, the Oral Health Program and the Office for Global and Integrated Environmental Health, and from the FDA, amalgam fillings were considered to be safe and inexpensive, although their color was different from that of natural teeth. For *environmental reasons,* the document also reported, there could be in the future some limitation to the use of amalgam. Unfortunately, such restrictions were misinterpreted by the mass media, causing unjustified fears in the public opinion and a rising demand for substitution of the restorations.

Ever since the first environmentalist protests against the use of amalgam, a research center was created in Germany by the University Departments of Münster and Erlangen. After reviewing several scientific papers and following hundreds of patients, including 200 pregnant women, the center concluded that: (i) no harmful effects from amalgam had been found in both the general population and the newborns; (ii) high plasma levels of Hg had been found as a consequence of elevated fish consumption.

After careful studies, the Swedish Medical Research Council concluded that all restoration materials currently in use, including amalgam and composite resins, are safe and effective. Nevertheless the Swedish government, through the Department of Environment, recently issued a series of rules to limit the use of amalgam for filling purposes. The main argument was based on an *ecological ground*, as it was estimated that between 40 and 60 tons of amalgam are carried in the mouth of Swedish people. It was feared that, as a consequence of crematory habits, Hg would be massively released in the environment. In Sweden alone, nearly 300 kgs of Hg are estimated to be dispersed in the atmosphere, and between 200 and 400 kgs in the water mains, every year.

There is no question about the fact that the international dental community has been strongly reducing the use of amalgam for filling carious teeth; the main reason, however, has been an *esthetic demand* from patients rather than a toxicological need. Not unexpectedly, most colleagues from all over the world have kept using amalgam in their own or their offspring’s mouth, whenever needed.

As reported in the literature, a certain number of patophobic or easily influenced patients still prefer to have restorations with materials other than amalgam, even after receiving all possible information. Their demands should be satisfied as long as this decision may have a placebo effect; however, these patients should be discouraged from having their still perfect amalgam restorations substituted by other materials.

As a useful reminder to the student, the best filling is *the one that has never been applied*; the most effective therapy is *prevention*.

9

DIRECT FILLING GOLD

Prior to the discovery of amalgam, pure gold was very popular as a filling material. Its use was documented in Europe in the 15th century. Robert Woofendale is credited to have introduced it to the USA in 1766 on his arrival from England. However, its use became widespread in the USA only towards the beginning of the 19th century (***Fig. 9.1***).

Figure 9.1: An example of gold foil marketed in the early 1900**s**.

It is the most noble of metals and rarely tarnishes in the oral cavity. Gold in its pure form is very soft (25 BHN). Its malleability and lack of a surface oxide layer permit increments to be welded together. This unique characteristic of gold *to be welded at room temperature (cold-welded),* allows gold to be used as a direct filling material.

Although the dental profession sometimes refers to all direct filling golds (DFGs) as 'Gold Foils' the present products may be divided into three categories. All are of 99.99% or higher purity, except two (Platinized foil and Electraloy RV).

Currently, direct filling gold is not as widely used as it once was. However, it will continue to be described because it is still used and is an excellent restorative material when placed properly.

APPLICATIONS

1. Pits and small class I restorations ***(Fig. 9.2 A).***
2. For repair of casting margins.
3. For class II, class V and class VI restorations ***(Fig. 9.2 B).***
4. Repair of cement vent holes and perforations in gold crowns ***(Fig. 9.3)***.

Figure 9.2A: Class I gold restoration. Gold restorations are esthetic, corrosion resistant and long lasting if placed properly. (*Courtesy:* Sechena).

Figure 9.2B: Class V gold restoration on a premolar. (*Courtesy:* Sechena).

Figure 9.3: Pictures demonstrate how a perforation in a cast gold crown can be repaired with DFG. (*Courtesy:* Sechena).

CONTRAINDICATIONS

1. Teeth with very large pulp chambers.
2. Severely periodontally weakened teeth.
3. Handicapped patients who are unable to sit for the long dental appointments required for the procedures.
4. Root canal filled teeth because these teeth are brittle.

TYPES

Many categories of direct filling gold are available and is based on its physical form and manufacturing process.

Foil (fibrous gold)

- Sheet
  - Cohesive
  - Noncohesive
- Ropes
- Cylinders
- Laminates
- Platinized

Electrolytic precipitate (crystalline gold)

- Mat
- Mat foil
- Gold-calcium alloy

Granulated gold (encapsulated powder)

COMPOSITION AND PURITY

Most modern gold restorations are made of gold of high purity (99.99 % or higher) excepting for the platinized and alloyed gold.

GOLD FOIL

Gold foil is the oldest of all products described. It was manufactured for dental applications as early as 1812 by Marcus Bull (USA). It is manufactured by beating gold into sheets.

Figure 9.4: Cut gold foil strip.
(*Courtesy:* CODS, Manipal).

Figure 9.5: Gold foil cylinders (Morgan Hastings).

MANUFACTURE

Gold is malleable. A cast ingot of 15 mm thickness is beaten to a submicroscopic thickness of 15 or 25 µm. The product is called gold foil ***(Fig. 9.4)***. The crystals of the original cast metal are deformed and elongated so that they have a fibrous structure, hence it is also known as fibrous gold.

SUPPLIED AS

- Flat square sheets (of varying thickness) in booklet form, 12 sheets (each 10 cm × 10 cm) per booklet.
  - No. 4 wt. 4 grains (0.259 gram) 0.51 µm thick.
  - No. 3 wt. 3 grains (0.194 gram) 0.38 µm thick.

  The number denotes the weight of the gold. Other sheets also available are Nos. 20, 40, 60 and 90. No. 3 foil is used to manufacture electrolytic and powder gold.
- These sheets may be cut and then rolled and compressed into pellets or cylinders in the dental office.
- Foils are available commercially as preformed cylinders ***(Fig. 9.5)*** and ropes.
- A number of sheets of foil may be placed one top of each other to form laminated gold foil. One type of laminated foil is the *platinized foil*, which is a sheet of pure platinum foil sandwiched between two sheets of pure gold foil.

Preformed Foils

Rolling into a pellet or cylinder form is convenient for carrying and compacting into cavities. Many dentists cut and roll their own gold. Preformed gold foil in the form of ropes and cylinders is also available commercially. Both are made from No. 4 foil that has been *'carbonized' or 'corrugated'*. This form of gold foil is of historical interest because it was an outcome of the *great Chicago fire* in 1871. By placing the gold foil in between sheets of paper and igniting it in a closed container corrugated foil can be obtained. On igniting, the paper gets charred, but the gold foil is left unharmed except that it becomes 'corrugated'. This is because of the shriveling of the paper while oxidizing in the airtight safe. After the carbon is removed it is found that the gold exhibits *superior welding property*.

Platinized Foil

This is a laminated foil in which pure platinum foil is sandwiched between two sheets of No. 4 gold foil. The sheets are beaten and joined together. Platinum is added to gold foil to increase the hardness of the restoration. This product is available only in No. 4 sheet form.

Cohesive and Noncohesive Gold

In practice only the sheet foil is furnished in both conditions, though all forms of direct filling gold could be supplied in cohesive and noncohesive form.

Cohesive

For cold-welding, gold should have a clean surface free from impurities. Gold attracts gases, e.g., oxygen to its surface and any absorbed gas film *prevents cohesion* of individual increments of gold during their compaction. The manufacturer, therefore, supplies the gold essentially free of surface contaminants. This type of gold is known as cohesive gold foil.

Noncohesive

The manufacturer subjects the foil to a volatile agent such as *ammonia*, which is absorbed on the surface of the gold. This acts as a *protective film* to minimize adsorption of less volatile gases and prevents premature cohesion of pellets in their container. Ammonia-treated foil is called noncohesive foil. Noncohesive gold can also have adsorbed agents like iron salt or an acidic gas (sulfur or phosphorous containing groups) on its surface. The volatile film is readily *removed by heating (see annealing)*, thereby restoring the cohesive character of the foil. Noncohesive gold is rarely used nowadays, but may be used to build-up the bulk of a direct gold restoration.

ELECTROLYTIC PRECIPITATE

Crystalline gold powder is formed by electrolytic precipitation. The powder has a dendritic crystalline structure. The powder is formed into shapes or strips by sintering (heat fusion) at high temperatures but below their melting point. The particles coalesce or join together at this temperature.

AVAILABLE AS

Mat, mat foil and alloyed.

MAT GOLD

Mat gold is electrolytically precipitated gold sandwiched between sheets of foil and then formed into strips. The strips can be cut by the dentist into the desired size. Mat gold is used to build-up the bulk of the restoration, as it can be more easily compacted and adapted to the cavity. However, mat gold has lots of voids and results in a pitted external surface. Therefore, foil gold is used to cover the mat gold and form the surface of the restoration.

MAT FOIL

It is a sandwich of electrolytic precipitated gold powder between sheets of No. 3 gold foil. The sandwich is sintered and cut into strips of differing widths. The dentist can then cut these to the desired lengths. Sandwiching mat between foil sheets was done to try to eliminate the need to veneer the restoration with a layer of foil. This type is no longer marketed.

ALLOYED ELECTROLYTIC PRECIPITATES

A form of electrolytic gold is an alloy of gold and *calcium* (0.1% by wt.) called ‘Electraloy RV’. For greater ease of handling, the alloy is sandwiched between two layers of gold foil. Calcium produces stronger restorations by *dispersion strengthening*, which locks in cold work strengthening. Thus alloying with calcium changes the crystalline structure and makes it harder and stronger.

POWDERED GOLD

Synonym Granular gold

Since the 19th century, chemically precipitated gold powders have been available in agglomerated form with a liquid such as alcohol or dilute carbolic acid, which held the agglomerate together. The agglomerates usually disintegrated when compaction was attempted, so the gold powder was mixed with a wax binder and *enclosed in a No. 3 gold foil.* This form was first marketed commercially in the 1960s as 'Goldent' (Morgan Hastings Co). In the 1980s another brand 'EZ Gold' (Ivoclar North America) was introduced.

MANUFACTURE

A fine powder is formed by *chemical precipitation* or by *atomizing* the metal. The particle sizes vary (average 15 µm). The pellets are mixed with soft wax (0.01% organic wax, which is burnt off prior to use) and then wrapped with gold foil (No. 3), rather than sintering the mass, like for mat gold.

AVAILABLE AS

The powdered gold pellets have a cylindrical or irregular shape and a diameter of 1 to 2 mm. The ratio of gold foil to powder varies from 1 to 3 for the smallest pellets to approximately 1 to 9 for the largest.

The foil acts as an effective container and matrix for the powdered metal, while it is condensed. Some operators believe that the use of powdered gold pellets increases cohesion during compaction and reduces the time required for placing the restoration. This is because each pellet contains 10 times more metal by volume than comparable sized pellet of gold foil.

MANIPULATION OF DIRECT FILLING GOLD

There are three processes involved:

- Desorbing
- Compaction
- Finishing

DESORBING OR DEGASSING

Synonym Degassing, annealing

The direct filling golds are received by the dentist in a cohesive condition, except for the noncohesive golds. However during storage and packaging, they absorb gases from the atmosphere. Adsorbed gases *prevent gold from fusing*. Hence, it is necessary for the dentist to *heat* the foil or pellet immediately before it is carried into the prepared cavity. This heating process which *removes surface gases* (oxygen, nitrogen, ammonia, moisture or sulfur dioxide) and ensures a clean surface is called *desorbing* or *degassing* (rather than annealing). Storage in air tight containers is advised and the operator should wear chamois finger tips to protect the gold from contamination. A totally *dry cavity* is essential throughout the compaction process in order to allow complete cohesion.

Direct filling golds may be heated by one of two methods:

- In bulk on a tray by gas-flame or electricity.
- Piece by piece, in a well-adjusted alcohol flame.

In practice, all but the powder gold may be desorbed, on a tray heated electrically. Powder gold must be heated in a flame to ensure the complete burning away of the wax.

Precaution during bulk heating: Excessive amounts should be avoided, since the difficulties arising from prolonged heating can arise from repeated heating as well. Care should be taken to handle pieces with stainless steel wire points or similar instruments that will not contaminate the gold.

Electric Annealing

The electric 'annealer' is maintained at a temperature between 340°C and 370°C. The time required varies from 5 to 20 minutes depending on the temperature and the quantity of gold on the tray.

Problems associated with electric annealing are:

1. Pellets may stick together, if the tray is moved.
2. Air currents may affect the uniformity of heating.
3. Difficult to anneal appropriate amounts of gold.
4. Over sintering.
5. Greater exposure to contamination.
6. Size selection among the pieces of desorbed gold is limited.

To prevent their sliding and sticking together, the tray of a recent electric annealer (Neibert electric gold foil annealer) provides individual compartments for each piece of foil (***Fig. 9.6***).

Moisture from the fingers can conaminate the gold. When the operator prepares his own pellets, ropes, etc., and the foil is handled with the fingers, it is advisable always to wear chamois finger-tips.

Flame Desorption

Each piece is picked individually by a clean sharp pointed nonoxidizing instrument (nickel chrome, stainless steel, iridoplatinum, etc.), heated directly over the open flame, and placed in the prepared cavity (***Fig. 9.7***). The fuel for the flame may be

Figure 9.6: Electric annealer with compartments.

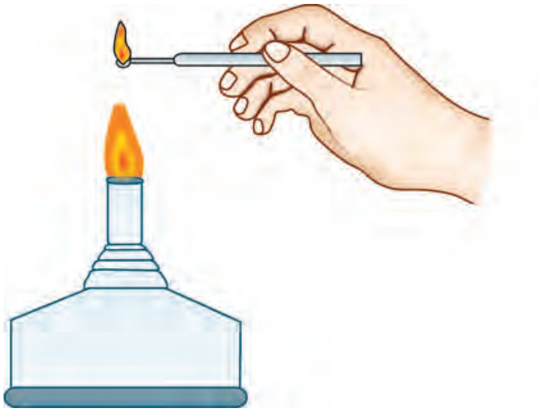


Figure 9.7: Flame desorption.

alcohol or gas. Alcohol is preferred as there is less danger of contamination. The alcohol should be pure methanol or ethanol without colorants or other additives.

Advantages of flame desorption are:

1. Ability to select a piece of gold of the desired size.
2. Desorption of only those pieces used.
3. Less exposure to contamination between degassing and use.
4. Less danger of oversintering.

Under-heating does not remove impurities well and results in incomplete cohesion. Carbon deposited by the flame can cause pitting and flaking of the surface.

Overheating leads to oversintering and possibly contamination from the tray, instruments or flame. This results in incomplete cohesion, embrittlement of the portion being heated and poor compaction characteristics. Overheating can result from *too long a time* even at a proper temperature or from *too high a temperature*.

COMPACTION

The gold may be compacted by:

- Hand mallet
- Pneumatic vibratory condensers
- Electrically driven condensers

Hand Mallet

Earlier gold was compacted entirely with a mallet. Starting points are cut in the prepared cavity. The first pieces of foil are wedged into these areas and compacted. The condenser is placed against the foil and struck sharply, with a small mallet. Subsequently additional foil is wedged in the same manner, till the cavity is filled (***Fig. 9.8***). Each increment of gold must be carefully *'stepped'* by placing the condenser point in successive adjacent positions. This permits each piece to be compacted over its entire surface so that voids are not bridged.

Condensers

The original foil condensers had a single pyramid-shaped face, but current instruments have a series of small pyramidal serrations on the face. These serrations act as swaggers, exerting lateral forces on their inclines in addition to providing direct compressive forces. They also cut through the outer layers to allow air trapped below the surface to escape.

Size of the condenser point: This is an important factor in determining the effectiveness of compaction. Small condenser points compact without using forces that might damage oral structures. The diameter of circular points should be 0.5 mm and 1 mm.

Mechanical Condensers

Electromagnetic or spring-loaded (not used now a days) have provided a mechanical means of applying force. The mechanical devices consist of points activated by comparatively light blows that are repeated with frequencies that range from 360–3600/minute. Vibrations can be produced either pneumatically (air driven) or electrically.

Advantages: Faster and more comfortable for the patient.

The cavity is designed for retention and resistance.

Gold is wedged in to the corners of the box and condensed.

No. 4 gold foil is used on the surface of the restoration to reduce porosity.

Shaping the proximal side with an abrasive strip.

Finishing and polishing is done with a variety of burs, stones, abrasive points and disks (sof-lex).

The completed restoration.

Figure 9.8: Some of the steps in the placement of a direct filling gold restoration. (*Courtesy:* John Sechena).

FINISHING

As with amalgam the cavity is slightly overfilled. The surface is probed with a explorer to test for proper compaction and to make sure all voids are eliminated. If the probe penetrates easily, condensation is continued with more force. The excess is removed with a gold file or burs. The surface is burnished with a ball burnisher to strain harden the surface. Final polish (optional) is achieved with sof-lex disks (***Fig. 9.8***) or other commercially available gold polishing kits.

PROPERTIES OF COMPACTED GOLD

STRENGTH

The greatest strength is in the most dense area and the weakest part is the porous area, where layers or crystals are not closely compacted ***(Table 9.1)***. In direct filling gold, the failure occurs from tensile stress, due to *incomplete cohesion*. Thus transverse strength is a measure of cohesion.

HARDNESS

The hardness indicates the overall quality of compacted gold. A reduction in hardness probably indicates the presence of porosity.

DENSITY

True density of pure gold is 19.3 gm/cm^3. However in DFGs this is not achieved, because it is not possible to eliminate voids completely during compaction. Thus density of DFGs is usually less than ideal.

The transverse strength, hardness and (apparent) density are somewhat greater when gold foil is used alone or in combination with mat gold, as compared with other forms. The difference in physical properties among the various forms of gold including the gold-calcium alloy and the method of compaction are not clinically significant. The physical properties are probably more greatly *influenced by the competence of the operator* in manipulating and placing the gold.

EFFECT OF VOIDS

The amount of voids is estimated by the apparent density of compacted gold. Voids on the restoration surface (pits) increase the susceptibility to corrosion and deposition of plaque. Voids at the restoration-tooth interface may cause gross leakage and secondary caries development (in properly compacted gold, microleakage is minimum).

TARNISH AND CORROSION

Resistance to tarnish and corrosion is good, if compacted well.

BIOCOMPATIBILITY

The pulpal response is minimal if compacted well. The technique, however, does involve a certain amount of trauma to the tooth and its supporting tissues.

Table 9.1

Physical properties of compacted gold

Type	*Transverse*	*Hardness*	*Density*
Mat gold	161-169 MPa	52-60 KHN	14.3-14.7 gm/cm^3
Powdered gold	155-190 MPa	55-64 KHN	14.4-14.9 gm/cm^3
Gold foil	265-296 MPa	69 KHN	15.8-15.9 gm/cm^3
Mat/gold foil	196-227 MPa	70-75 KHN	15.0-15.1 gm/cm^3

In smaller teeth, this is an important consideration. The mechanical condenser causes less trauma than the manual technique.

DISADVANTAGES

1. Poor esthetics (it is not tooth colored).
2. High CTE (coefficient of thermal conductivity).
3. Manipulation is difficult.

ADVANTAGES

1. Tarnish and corrosion resistant.
2. Good mechanical properties.
3. Good biocompatibility.

The technical skill of the dentist is very important for the success of the direct gold restoration. A gold restoration of poor quality can be one of the most inferior of all restorations.

10

COMPOSITE RESINS AND BONDING AGENTS

A BRIEF HISTORY OF TOOTH COLORED RESTORATIVE MATERIALS

Silicates

The earliest tooth colored restorative materials were the *silicate cements*. These were used extensively in the early 20th century. Though they had a fluoride release mechanism but eroded quickly and had a problem of marginal discoloration.

Acrylic resin restorations

Silicates were subsequently replaced by the *tooth colored acrylic resins. These* were basically polymethyl methacrylate (PMMA) resins similar to those used in dentures. They were widely welcomed at the time because of their superior esthetics, ease of manipulation, low cost and insolubility in oral fluids.

The material was supplied as a powder and liquid (in brown bottles). With time however, many restorations began to fail, due to microleakage, staining and caries. This happened primarily because these materials shrink on setting causing them to pull away from the cavity walls. Their high thermal expansion and contraction caused further stresses at the margins. In addition, they had poor wear resistance. The monomer within was also implicated in pulpal irritation especially in deep restorations. Manufacturers tried to offset these problems by adding quartz filler particles. This greatly reduced the shrinkage by reducing the proportion of resin in the mix. It also reduced the thermal expansion. However, the quartz did not bond to the resin which resulted in staining and poor wear resistance.

Bowen’s resin

The real breakthrough came with the discovery by Ray L Bowen in 1962 of a new type of resin called bisphenol A glycidyl methacrylate (popularly called bis-GMA or Bowen’s resin). In addition to this he also developed a process by which the resin was bonded to the filler particles within the composite (silane coupling). The acrylic resin restorative materials soon became obsolete and were replaced by the composite resins. Today composite resins are widely used for both posterior and anterior restorations.

COMPOSITE RESINS

Essentially, it is a resin which has been strengthened by adding silica particles called fillers. The pioneering research of Bowen together with the development of the acid etching technique and bonding agents, revolutionized restorative dentistry. It largely replaced the earlier silicate and restorative acrylics.

The composite is a system composed of a mixture of two or more macromolecules which are essentially insoluble in each other and differ in form. The composite material’s properties are superior to those of its individual components, e.g., fiberglass has a resin matrix which is reinforced by glass fibers. The resulting composite is harder and stiffer than the resin matrix material, but less brittle than glass. Examples of natural composite materials are tooth enamel and dentin. Matrix is made of collagen, with hydroxyapatite crystals acting as fillers. Though the early composites were developed for restorative purposes their uses subsequently expanded to include provisional, restorations, luting, etc.

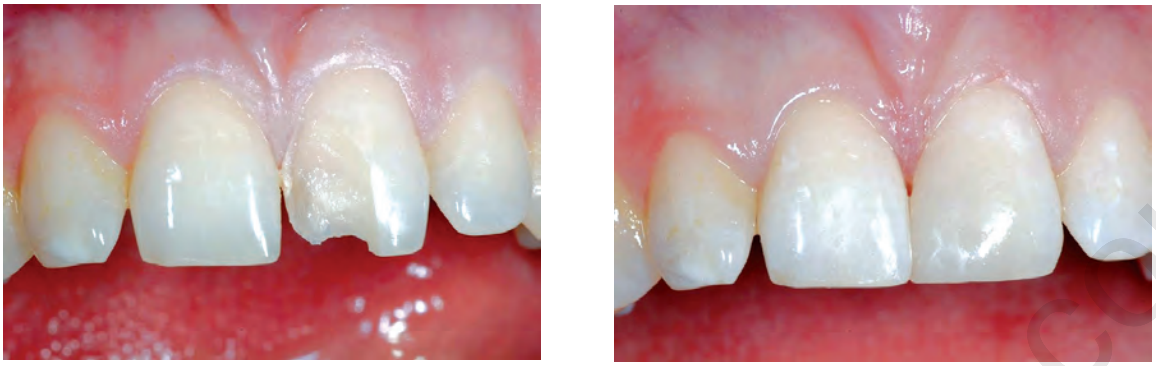


Figure 10.1: The Illustrations show a fractured central incisor (above left) restored quite realistically with composite resin.

USES

1. Restoration of anterior (***Fig. 10.1***) and posterior teeth (directly or indirectly).
2. To veneer metal crowns and fixed partial dentures (prosthodontic resins).
3. To build-up cores (post core).
4. Bonding of orthodontic brackets, etched cast restorations, ceramic crowns, posts, inlays, onlays and laminates.
5. Pit and fissure sealant.
6. Esthetic laminates.
7. Repair of chipped porcelain restorations.

(Different composites are available for the above purposes. Each of them have their properties adjusted to suit the specific application for which it was intended. They are usually not interchangeable).

TYPES

Composites are classified by initiation techniques (curing mechanism), filler size and viscosity.

Based on Curing Mechanism

- Chemically activated
- Light activated
- Dual cure

ISO 4049/ ANSI/ADA Sp. No. 27

Type 1: Polymer based materials suitable for restorations involving occlusal surfaces

Type 2: Other polymer based materials

- Class 1 — Self cured materials
- Class 2 — Light cured materials
  - Group 1 — Energy applied intraorally
  - Group 2 — Energy applied extraorally
- Class 3 — Dual cured materials

Based on Filler Particle Size (Willems 1993)

Willems developed an extensive classification based on a number of parameters such as Young's modulus, the percentage (by volume) of inorganic filler, the size of the main particles, surface roughness and compressive stress. Though the classification is not presented, terminology from Willems classification is still used today to describe some commercially available composites. With the inclusion of nano sized particles the particle sizes can be described as

➢ Fine	Particle size > 3 µm
➢ Ultrafine	Particle size < 3 µm
➢ Microfine	Average particle size = 0.04 µm
➢ Nano	Nano range (5-100 nm or 0.005-0.01 µm)

Based on Filler Particle Size

Fillers play an important role in the composite performance. However, a universal system of classifying fillers has not been agreed upon. Differences exist on the nomenclature and the size range of the filler particles.

- Macrofillers (10-100 µm)
- Midifillers (1-10 µm)
- Minifillers (0.1-1 µm)
- Microfillers (0.01-0.1 µm)
  - a. homogenous — contains only microfillers
  - b. heterogenous — microfillers combined with prepolymerized fillers
    - — splintered prepolymerized particles
    - — spherical prepolymerized particles
  - c. agglomerated — microfiller sintered to form larger filler complexes
- Nanofillers (0.005-0.01 µm)
- Hybrid (range of sizes which usually includes micro or nano fillers with macro, midi or mini fillers

Based on Viscosity

- Flowable
- Packable

Viscosity determines the flow characteristics during placement. A flowable composite flows like liquid or a loose gel. A packable composite is firm and offers some resistance to condensation.

Based on Applications and Commercial Availability

- Restorative composites—direct intraoral restorations
  - —Hybrids ***(Fig. 10.2)***
  - —Microfilled ***(Fig. 10.3)***
  - —Flowable ***(Fig. 10.4)***
  - —Packable
  - —Nanocomposites ***(Fig. 10.6)***
- Core build-up composites ***(Fig. 10.27)***
- Prosthodontic composites (for fabrication of veneers, crowns and FPDs)
- Provisional composites (for temporary crowns, restorations, FPDs, etc.)
- Luting composites

RESTORATIVE COMPOSITE RESINS

The first tooth colored restorative system were developed in the late 1950s and early 1960s by Bowen (also known as Bowen's resin). The early composite resins

Figure 10.2: Representative microhybrid composite.

Figure 10.3: A microfilled composite.

were generally macrofilled resins and were referred to as conventional composites. These were chemically activated. This was followed by U-V light activated and later visible light activated systems. The early composites had poor wear resistance and stained easily. This was attributed to the large sized (macrofillers) filler particles used. The introduction of the microfilled composites improved wear resistance and better esthetics. However, they had poor mechanical properties. The hybrid composites attempted to combine the esthetics and wear resistance of the microfilled with the mechanical properties of the macrofilled composites. The latest entry into the field—the *nanocomposites* ***(Fig. 10.6)*** holds the promise of high polishability with further improvement in mechanical properties.

SUPPLIED AS

Composites used for restoring teeth are usually supplied as a kit ***(Fig. 10.2)*** containing the following:

- Composite resin—either chemical or light cured
- Etching liquid (37% phosphoric acid)
- Bonding agent
- Shade guide

Chemically Activated Composite Resins are Available as

Two paste (base and catalyst) system Supplied in small jars or syringes ***(Fig. 10.5)***.

Figure 10.4: Flowable composites are often identified by the suffix ‘flow’.

Figure 10.5: Chemically cured composite.

Powder-liquid systems Powder (inorganic phase plus the initiator) is supplied in jars. Liquid (BIG-GMA diluted with monomers) in bottles.

Light Activated Resins are Available as

Single paste form in dark or light proof syringes ***(Fig. 10.4)***.

Trade names: Various commercial products available are presented in ***Table 10.2.***

INDICATIONS FOR VARIOUS COMPOSITE RESINS

The indications for different products are presented in ***Table 10.1***.

Table 10.1

Various restorative composites currently marketed and their uses

Type	*Indications*
Hybrid or universal (microhybrids)	Anterior and posterior restorations in high stress areas requiring improved polishing (e.g., Classes I, II, III, IV)
Packable Hybrids	Class II cavities where greater packability is needed for improved contact with adjacent teeth.
Flowable Hybrids	– Class V lesions subjected to flexing stresses. – Mini cavities – Repair of composite – In layered composite restorations as first layer (for better adaptation)
Microfilled (homogenous and hetrogenous)	– Low stress areas – Areas requiring high polish (to reduce plaque accumulation, e.g., subgingival areas, Class V lesions, etc.)
Hybrid or universal (Nanohybrids) including	Anterior and posterior restorations in high stress areas requiring greater polishability, e.g., Classes I-IV and Class V cervical lesions.

Table 10.2

Representative commercial products

Chemically Activated—Isopast, Alfa comp (voco), Brilliant (coltene), Medicept	
Light Activated	
Hybrid (Universal)	Filtek Z250 (3M), Herculite (Kerr), TPH spectrum, Venus and Charisma (Heraeus), Tetric Ceram (Ivoclar), Point-4 (Kerr) etc.
Microfilled	Helio Progress, Durafil VS (Heraeus), A110 (3M-ESPE), Sculpt-it (Jeneric/Pentron), Amelogen Microfill (Ultra-dent), Renamel Microfill (Cosmedent).
Flowable	C- Fill Flow, Synergy D6 Flow (Coltene), Tetric flow, Venus Flow (Heraeus), Flow Plus (Medicept), etc.
Packable	Surefil (Dentsply), Heliomolar HB (Ivoclar), Solitaire 2 (Heraeus), Tetric Ceram HB, etc.
Nanocomposite	Grandio (Voco), Filtek Supreme (3 M), Venus Diamond (Heraeus), Composite-nanohybrid (Medicept)

COMPOSITION AND STRUCTURE

The Essentials Components of a Composite Resin *(Fig. 10.7)*

Resin matrix/ binder — BisGMA or urethane dimethacrylate
Filler — Quartz, colloidal silica or heavy metal glasses
Coupling agent — Organo silanes

Figure 10.6: Universal nano-hybrid composite.

In Addition They Contain

A curing system	— Chemical or light curing chemicals
Inhibitors (0.01%)	— Prevents premature polymerization, e.g., butylated hydroxytoluene (BHT)
UV absorbers	— to improve color stability
Opacifiers (0.001 to 0.007%)	— e.g., titanium dioxide and aluminum oxide
Color pigments	— to match tooth color

RESIN MATRIX

Dental composites use a blend of monomers that are aromatic or aliphatic dimethacrylates. Of these, Bis-GMA (Bisphenol-A-glycidyl methacrylate), urethane dimethacrylate (UDMA) and Bis-EMA (Bisphenol-A-polyethylene glycol diether dimethacrylate) are most commonly used. Triethylene glycol dimethacrylate (TEGDMA) is added to control the viscosity.

Bis-GMA was developed by RL Bowen (Bowens resin) in the early 1960s. Its properties were superior to those of acrylic resins. However, it had a few limitations like:

- A high viscosity which required the use of diluent monomers.
- Difficulty in synthesizing a pure composition.
- Strong air inhibition to polymerization.
- High water sorption because of diluents used.
- Polymerization shrinkage and thermal dimensional changes still existed.
- Like other resins it does not adhere to tooth structure.

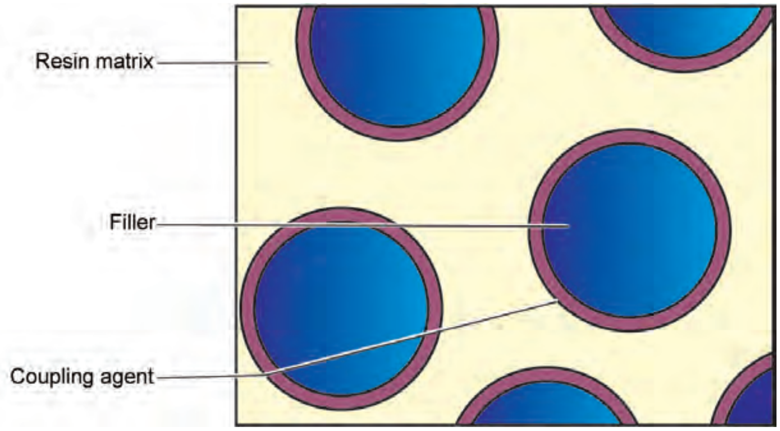


Figure 10.7: Essentials of a composite.

To make it clinically acceptable, diluent monomers are added to the resin matrix to reduce the viscosity of the resin. It also allows more fillers to be incorporated.

Diluents allow extensive cross-linking between chains, thereby increasing the resistance of the matrix to solvents. The commonly used diluent monomer is TEGDMA (triethylene glycol dimethacrylate). Thus composite resins have to be blended with different monomers to optimize their properties.

Drawbacks of TEGDMA include

- High shrinkage.
- Contributes to reduced shelf-life by migration in to the plastic walls.
- Being hydrophilic it makes the composite susceptible to moisture leading to thickening or softening of the paste in certain climatic conditions.

(Because of these drawbacks some manufacturers have replaced the majority of the TEGDMA with a blend of UDMA and Bis-EMA).

The refractive index is an important property for anterior restorative materials. To have acceptable esthetics composite resins must match the translucency of enamel. Bis-GMA and TEGDMA have a refractive index of 1.55 and 1.46 respectively which average to around 1.5 when combined together.

FILLER PARTICLES

Fillers play a crucial role in the composite resin. Most of the important properties of the resin is determined by its filler content. Composite fillers are classified by material, shape and size. Many different classifications of fillers have been proposed. They are broadly classified into 3 groups - macrofillers, microfillers and nanofillers. A mixture of different particle sizes is referred to as a hybrid. For details of filler size and nomenclature see 'classification of composite resins.'

Advantages of Fillers

Addition of filler particles in to the resin significantly improves its properties:

1. As less resin is present, the curing shrinkage is reduced thereby reducing marginal leakage.
2. Fillers play a crucial role in the wearing of composite resins. The smaller the size and higher the concentration of fillers the better the wear resistance.
3. Fillers play a crucial role in the surface smoothness and subsequent esthetics of the composite.
4. Reduces water sorption.
5. Improves mechanical properties like strength, stiffness, hardness, etc.
6. Reduces thermal expansion and contraction.
7. Improves clinical handling (increased viscosity makes them easier to handle clinically).
8. Radiopaque fillers help improve diagnostics (caries detection through roentgenograms, etc.).

Important attributes of fillers, that determine the properties and clinical application of composites are:

— Amount of filler added (filler loading)
— Size of particles and its distribution
— Shape of fillers

— Index of refraction

— Radiopacity

— Hardness

Filler size The size of the fillers affect the surface smoothness and the wear resistance. The smaller the fillers the greater the surface smoothness. Microfilled composites have the best surface smoothness and lowest wear. This is because the particles are removed at the same rate as the resin matrix if they are smaller. Larger particles result in a rougher surface. The introduction of the nano particles hold *great promise* of improved smoothness, good wear resistance as well as improved mechanical properties.

Filler loading Filler loading refers to the amount of fillers that can be practically incorporated into the resin. The amount of filler that can be added depends on the type of filler and the purpose for which it is intended. Most hybrid composites have a filler loading ranging from 60 to 70% volume. The introduction of the newer nanofillers allow a greater filler loading of up to 79.5% vol. Microfillers thicken the resin quickly. Thus microfilled resins usually do not have the same filler loading as resins with larger particle sizes such as the hybrids.

Particle size distribution Most modern hybrid composites have particles range in size from 0.01 to 10 µm. Microfillers are usually in the range of 0.01 - 0.07 (average 0.04 µm). In order to increase the filler amount in the resin, it is necessary to add the fillers in a range of particle sizes. If a single particle size is used, a space will exist between the particles. Smaller particles can then fill-up these spaces, thus increasing the filler content ***(Fig. 10.8)***.

Shape of fillers Based on shape 3 types of fillers are used—irregular, spherical and fibrous. The shape affects the filler loading and the handling characteristics of the composite.

Refractive index For esthetics, the filler should have a translucency similar to tooth structure. To achieve this, the refractive index of the filler should closely match that of the resin. Most glass and quartz fillers have a refractive index of 1.5, which match that of Bis-GMA and TEGDMA.

Measurement of Filler Content—Volume versus Weight Percentage

Filler content is designated in percent volume (vol.%) or percent weight (wt.%). Weight percent is usually higher in value than percent volume. The volume

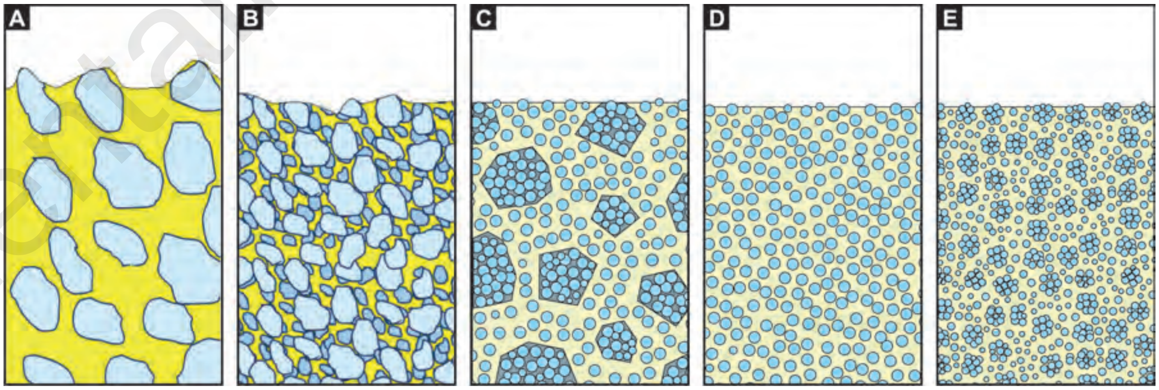


Figure 10.8: Effect on particle size on surface smoothness: A - Traditional composite; B - Hybrid composite; C - Microfilled heterogenous type (showing prepolymerized fillers); D - Microfilled homogenous type; E - Nanocomposite showing nanoparticles and nanoclusters.

percentage may be a *more reliable indicator* of filler content than the weight percentage. This is because of differences in density between different fillers. For example, composites can have a similar volume percentage of fillers yet different weight percentages. This is because the composite containing a larger fraction of heavy metal glass fillers will have a higher weight percentage.

Fillers Types

Composite resins use many types of fillers:

- Ground quartz
- Glasses or ceramic containing heavy metals
- Boron silicates
- Lithium aluminum silicates
- Ytterbium trifluoride
- Colloidal silica

Quartz fillers They are obtained by grinding or milling quartz. They are mainly used in conventional composites. They are chemically inert and very hard. This makes the restoration more difficult to polish and can cause abrasion of the opposing teeth and restorations.

Glasses/ceramics containing heavy metals These fillers provide radiopacity to the resin restoration. Increased radiopacity make composites detectable on radiographs which aid diagnostics. Examples are barium, zirconium and strontium glasses. The most commonly used is barium glass. It is not as inert as quartz. Some barium may leach out with time.

Fluoride releasing fillers Some current composites have fluoride releasing capability. This includes fillers like *Ytterbium trifluoride* and *Ba-Al-fluorosilicate glass*. In one commercial product (Tetric ceram) the YbF_3 content is as high as 17 wt.%. The Ba-Al-fluorosilicate glass content was 5 wt.%.

Colloidal silica Referred to as 'microfillers'. They are obtained by a pyrolytic or a precipitation process. Colloidal silica particles (***Fig. 10.9***) have a large surface area (50 to 400 m^2/g), thus, even small amounts of microfillers thicken the resin. They are added in small amounts in hybrid composites (5 wt %) to adjust the paste viscosity. The hybrid varieties have a microfiller loading of 10 to 15% weight. In *microfilled composites* it is the main filler used (20 to 59% volume). Since they cannot be added in large amounts the overall filler loading of microfilled composites is lower than conventional or hybrid varieties.

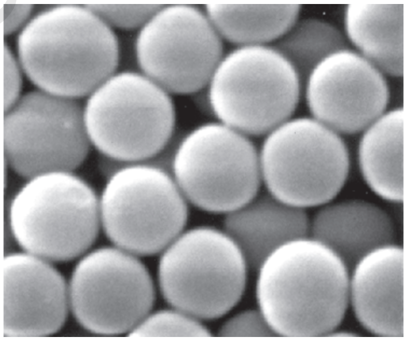


Figure 10.9: Electron microscopic picture of colloidal silica 0.06 µm.

Methods to increase microfiller loading

Manufacturers are constantly on the look out for methods to increase the filler content of the microfilled composites.

1. One method is to sinter (fuse) the colloidal silica particles, thereby reducing surface area. These are known as agglomerated silica.
2. Addition of *prepolymerized fillers:* This is the more common method. Also known as '*organic fillers*'. They are prepared by adding 60 to 70 wt.% of silane coated colloidal silica to the monomer, which is held at a slightly higher temperature to reduce its viscosity. It is then heat cured and ground.

The composite is obtained by adding these prepolymerized fillers along with more silane coated microfillers into unpolymerized resin matrix (***Fig. 10.13***).

Silica nanoparticles These are currently the smallest filler particles used in dental composites. Adoption of nanoparticle technology have ushered in the next generation of composite resins. Incorporation of silica nanoparticles into the composite resins have improved many of the properties of composite resins, particularly wear resistance and polishability. Nanoparticles in composites can be used in 2 forms.

- Nanoparticle - a single nanoparticle (size ranges from 5-25 nm)
- Nanoclusters - a group of nanoparticles (forms larger sized particles)

Manufacture of Fillers

Filler particles can be generated: (1) by crushing, grinding, and sieving large blocks of ceramic, (2) by condensation of SiO_2 from the vapor phase as small droplets of microfiller, or (3) by precipitation of filler particles from solution (sol-gel). The smallest fillers can only be manufactured in a practical way from the vapor phase or by sol-gel processes.

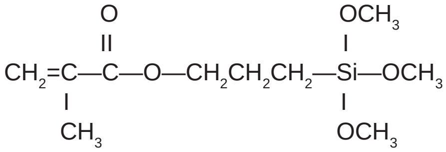
COUPLING AGENTS

Coupling agents bond the filler particles to the resin matrix. The earliest composites did not use coupling agents. This resulted in microscopic defects between the filler and surrounding resin. Microleakage of fluids into these defects led to surface staining and failure. Typically the manufacturer treats the surface of the filler with the coupling agent.

Function of Coupling Agents

1. They improve the properties of the resin through the transfer of stresses from the more plastic resin matrix to transfer stresses to the stiffer filler particles.
2. They prevent water from penetrating the filler-resin interface.
3. They bond the fillers to the resin matrix thereby reducing the wear.

The most commonly used coupling agents are *organosilanes* (i.e., 3-methacryloxypropyl-trimethoxysilane).



$$CH_2{=}\underset{\displaystyle CH_3}{\underset{|}{C}}{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}O{-}CH_2CH_2CH_2{-}\overset{\displaystyle OCH_3}{\overset{|}{\underset{\displaystyle OCH_3}{\underset{|}{Si}}}}{-}OCH_3$$

The agent is a molecule with a methacrylate groups on one end and methoxy groups (OCH_3) on the other end. In the presense of adsorbed water the methoxy groups hydrolyze to form silanol groups (-Si-OH) which then form ionic bonds with the silanol groups of the filler forming a siloxane bond (-Si-O-Si-). The other end has a methacrylate group which forms a covalent bond with the resin when it is polymerized. This completes the coupling process. *Zirconates* and *titanates* can also be used as coupling agents.

POLYMERIZATION (SETTING) MECHANISMS

They polymerize by the addition mechanism that is initiated by *free radicals* as described in resins. The free radicals can be generated by chemical activation or external energy (heat, light or microwave).

Based on the mode of activation of polymerization, there are three main types:

A. Chemically activated resins
B. Light-activated resins
C. Combination of the above (dual cure)

CHEMICALLY ACTIVATED COMPOSITE RESINS

This is a two-paste system

- Base paste contains—benzoyl peroxide initiator
- Catalyst paste—tertiary amine activator (i.e., N, N-dimethyl-p-toluidine).

Setting

When the two pastes are spatulated, the amine reacts with the benzoyl peroxide to form the *free radicals* which starts the polymerization.

LIGHT ACTIVATED COMPOSITE RESINS

Under normal light they do not interact. However, when exposed to light of the correct wavelength the photoinitiator (camphoroquinone) is activated and reacts with the amine to form *free radicals* which then start the polymerization.

UV light activated systems The earliest systems used ultraviolet (UV) light for curing. Light activation put control of the working time firmly in the hand of the dentist.

Limitations of UV light curing were:

- Limited penetration of the light into the resin. Thus, it was difficult to polymerize thick sections.
- Lack of penetration through tooth structure.

Visible-light activated resins These have totally replaced U-V light systems. They are also more widely used than the chemically activated resins.

These are single paste systems containing:

Photoinitiator : Camphorquinone 0.2 wt.%
Amine accelerator : Dimethylaminoethyl-methacrylate (DMAEMA 0.15 wt.%)

Camphorquinone has light absorption range between 400 and 500 nm. This is in the *blue region* of the visible light spectrum. In some cases inhibitors are added to enhance its stability to room light or dental operatory light.

DUAL CURE RESINS

A combination of chemical and light curing is used to overcome some of the drawbacks of light curing. Dual cure resins are supplied as two pastes. When mixed together a slow setting reaction is initiated. These resins are used for cementing crowns or bulk restorations where there is limited or no light penetration. After the initial light cure, the remainder of the resin cures over a period of time by the chemical process.

CURING LAMPS

A number of curing lights are manufactured. Most use visible light in the blue spectrum (between 400 and 500 nm). In some units the light source is remote and is transmitted to the site of restoration through a light guide which is a long, flexible fiber-optic cord. There are also hand held light curing devices which transmit the light through short light guides ***(Fig. 10.10)***.

Types of Lamps

Currently many forms of curing lights are available. These include

QTH (Quartz tungsten halogen) These were the earliest visible light lamps. The light source is a *tungsten halogen quartz bulb* ***(Fig. 10.11)***. The white light generated passes through a filter that removes all wavelengths except those in the blue range. Heat is also generated thus requiring a cooling fan. The intensity of light gradually reduces with time and so calibration is required at intervals.

LED (Light emitting diodes) LED ***(Fig. 10.12)*** is increasingly popular as a light source in all spheres including dentistry ever since the discovery of the blue diode in the 1990s. It is similar in power to QTH lamps (700 mW/cm^2). Research has shown that the curing depth and degree of conversion is significantly better with LEDs than with QTH. It emits light only in the blue part of the spectrum. Thus, it does not require filters. Its advantages also include low power consumption (can even be operated by batteries), no heat generation (eliminating cooling fan), and low noise (due to the absence of cooling fan).

PAC (Plasma arc curing) These lamps generate an intense white light by ionizing xenon gas to produce a plasma. Filters are required to remove heat and the unwanted wavelengths. Their high power allows faster cures as well as greater depth of cures.

Argon laser These produce light of the greatest intensity. They emit light of a single wavelength of ~490 nm and therefore do not require filters. However, these lamps are more expensive.

The high intensity lights like the PAC and the laser provide a faster cure (as short as 5 seconds for a 2 mm section). Besides being expensive the accelerated curing can introduce substantial stresses. Further studies are needed.

Figure 10.10: A dental curing light in the visible blue range (QTH).

Figure 10.11: A wired curing light device (QTH).

Figure 10.12: A wireless LED lamp.

EYE PROTECTION

Staring into the curing lights for prolonged periods can cause retinal damage. It is best to look away while the curing is in progress. Various kinds of eye protection are available and should be used when working with composites.

DEGREE OF POLYMERIZATION AND DEPTH OF CURE

The total amount of resin polymerized depends on several factors:

- *Transmission of light through the material* This is controlled by absorption and scattering of light by the filler particles, as well as any tooth structure interposed between the light source and the resin. For this reason, microfilled composites with smaller and more numerous particles will not cure to as great a depth as conventional composites.
- *Shade of resin* *Darker shades* require longer exposure time.
- *Amount of photoinitiator and inhibitor present* For polymerization to take place at any depth, a particular amount of photons must be available. This is directly related to the intensity of light and time of exposure.
- *Curing time* Manufacturers recommend curing times for each material and shade. This depends on the output of the particular curing device. Thus, 80 to 240 seconds is required with a low intensity light whereas to achieve the same result, a high intensity light requires only a 20 to 60 second exposure.
- *Intensity of light* Light intensity is measured in milliwatts/cm^2. The time required for curing a 2 mm depth of resin by a QTH lamp is 40 seconds. The same thickness can be cured in 20 seconds if the light intensity is increased to 800mW/cm^2.
- *Type of light* High intensity lights like PAC and LASER cure faster and to a greater depth than the QTH and LED generated lights.
- *Thickness of resin* Thickness greater than 2-3 mm are difficult to cure because of the lack of light penetration.
- *Distance from light* Optimum distance is 1 mm with the light positioned 90 degrees from the surface of the resin.

TRADITIONAL COMPOSITE

Traditional composites are also referred to as 'conventional' or 'macrofilled composite' (because of the large size of the filler particles). Traditional composites are rarely used currently and have been largely replaced by other hybrids. However their discussion will continue largely for comparison to the newer composites.

Composition

Ground quartz was most commonly used as filler. There is a wide distribution of particle sizes. Although average size is 8 to 12 µm, particles as large as 50 µm may also be present.

Filler loading: 70-80 wt.% or 60-70 vol.%.

Properties

The conventional composites have significantly improved properties when compared to the unfilled restorative resins which preceded them. The improvement is the result of the improved resin, the filler loading and the strong bond between the filler and the resin matrix.

Compressive Strength It is four to five times greater than that of unfilled resins (250 to 300 MPa).

Tensile Strength It is double that of unfilled acrylic resins (50 to 65 MPa).

Elastic Modulus It is four to six times greater than the unfilled resins (8 to 15 GPa).

Hardness It is considerably greater (55 KHN) than that of unfilled resins.

Water Sorption It is less than that of unfilled resins (0.5 to 0.7 mg/cm^2).

Co-efficient of Thermal Expansion The high filler-to resin ratio reduced the CTE (25 to 35 × 10^{-6}/°C) significantly.

Esthetics Polishing of the conventional composite results in a rough surface. This is due to the selective wear of the softer resin matrix leaving the hard filler particles elevated. This resulted in a tendency to stain over a period of time.

Radiopacity Radiopacity is measured by a photodensitometer. Radiopacity allows proper assessment of the restoration as well as future diagnosis of caries. The heavy metal fillers contribute to the radiopacity of composites. Aluminum is used as a standard reference for radiopacity. A 2 mm thickness of dentin and enamel is equivalent to 2.5 and 4 mm of aluminum respectively. Traditional composites have a radiopacity of 2-3 mm of aluminum equivalent.

Adhesion Composites do not adhere to tooth structure and require special bonding techniques to provide adhesion to the tooth structure.

Disadvantages

Although the conventional composites were superior to unfilled resins, they had certain disadvantages:

- High surface roughness
- Polishing was difficult
- Poor resistance to occlusal wear
- Tendency to discolor—the rough surface tends to stain.

Because of these disadvantages as well as the introduction of improved composites this type was gradually phased out. It is probably no longer marketed.

MICROFILLED COMPOSITE

The microfilled composites ***(Fig. 10.3)*** were introduced soon after the traditional composites. They were developed to overcome the problems of surface roughness of traditional composites. The resin achieved the smoothness of unfilled acrylic direct filling resins and yet had the advantage of having fillers. Unfortunately, they could not achieve high levels of filler loading and therefore had somewhat inferior mechanical properties when compared to the traditional composites. For this reason these composites are primarily used for esthetic restorations in stress free areas and in areas close to the gingiva where a smooth finish is required for reduced plaque accumulation.

Synonyms: Also referred to as microfine composites.

COMPOSITION

The smoother surface is due to the incorporation of microfillers. *Colloidal silica* is used as the microfiller and is the only type of filler present in this type. The problem with colloidal silica was that it had a large surface area that could not be adequately wetted by the matrix resin. Thus, addition of even small amounts of microfillers resulted in *thickening* of the resin matrix. Thus, it was not possible to achieve the same filler loading as conventional composites.

Manufacturers tried to overcome this problem by:

1. Using prepolymerized or organic fillers (see section on fillers). These composites were refererred to as 'heterogenous'.
2. Using silica in cluster or agglomerate form. These were referred to as 'homogenous' microfilled composites.

Filler size The colloidal silica is 200-300 times smaller than the quartz fillers of conventional composite. Size ranges from 0.04 to 0.4 µm.

Filler content With the inclusion of prepolymerized (organic) fillers, the filler content is 70 wt.% or 60 vol.%. However, the actual inorganic filler content is only 50 wt.%.

CLINICAL CONSIDERATIONS

With the exception of compressive strength their mechanical properties are inferior to the other types of composites. This is because of their higher resin content (50 vol.%). Their biggest advantage is their esthetics. The microfilled composite is the resin of choice for esthetic restoration of anterior teeth, especially in non-stress bearing situations. For most applications, the decreased physical properties do not create problems. However, in stress bearing situations like Class IV and Class II restorations they have a greater potential for fracture. Sometimes chipping occurs at the margins.

HYBRID COMPOSITE RESINS

The hybrid type forms the majority of the composites used in dentistry currently ***(Fig. 10.2)***. These were developed to obtain better surface smoothness than that of the conventional large particle composites, yet maintain the properties of the latter. Hybrid composites have a surface smoothness and esthetics competitive with microfilled composites for anterior restorations. The hybrids are generally considered as multipurpose composites suitable for both anterior and posterior use.

Filler Volume

The total filler content is 75-80 wt.% or 60-65 vol.%. The overall filler loading is not as high as small particle composites because of the higher microfiller content.

Filler Type

Two kinds of filler particles are employed:

1. *Heavy metal glasses:* Average particle size is 0.4 to 1 µm. 75% of the ground particles are smaller than 1.0 µm.
2. *Colloidal silica*: Size - 0.04 µm. It is present in higher concentrations (*10 to 20 wt.%*) and therefore, contributes significantly to its properties.

The hybrids are generally considered as multipurpose composites suitable for both anterior and posterior use. They are widely used for anterior restorations, including class IV because of its smooth surface and good strength.

The hybrids are also widely employed for stress bearing restorations.

NANO AND NANOHYBRID COMPOSITE RESINS

Continued interest in the reduction of the size of fillers has led to the adaptation of nanotechnology to the field of composite resins. A new type of composite resin based on nanosized filler particles has been recently introduced. Nanocomposites ***(Fig. 10.6)*** are similar to the microfilled, comprising of uniformly sized nanofillers. Nanohybrids like the conventional hybrids, come in a range of filler sizes including nanofillers.Unfortunately conflicting reports exist on the efficacy of these relatively new materials. Initial reports indicate that these materials have the mechanical properties of the hybrid composites with the esthetics and polishability of the microfilled composites. Thus they can be used for both anterior and posterior restorations. Nanohybrids are generally stronger than the nanocomposites. However, nanocomposites have improved polishability. Continued development along these lines might eventually lead to the phasing out of conventional hybrid and microfilled composites. However, further research is required to establish the efficacy of the nano and the nanohybrid composites.

Filler Volume and Type

The predominent fillers are zirconium/silica or nanosilica particles measuring approximately 5 to 25 nm and nanoaggregates of approximately 75 nm. The aggregates are treated with silane so that they bind to the resin. The aggregates and nanoparticles filler distribution gives a high load, up to 79.5%.

PROPERTIES OF COMPOSITE RESINS

Composite resins were developed after amalgam and therefore it is a useful material with which to compare restorative composite resins. The mechanical properties of these materials have steadily improved over the years. Hovever, when compared to amalgam these materials are highly technique sensitive and therefore optimal properties can be achieved only if proper techniques of manipulation and insertion are followed. The common factor affecting most physical and mechanical properties of the composite is the filler content.

FLEXURAL STRENGTH

Hybrid	80 - 160	MPa	Nanohybrids	180	MPa
Microfilled	60 - 120	MPa	Amalgam	90-130	MPa

COMPRESSIVE STRENGTH

Hybrid	240 - 290	MPa	Nanohybrids	460	MPa
Microfilled	240 - 300	MPa	Amalgam	510	MPa

TENSILE STRENGTH

Hybrid	30 - 55	MPa	Nanohybrids	81	MPa
Microfilled	25 - 40	MPa	Amalgam	64	MPa

MODULUS OF ELASTICITY

Hybrid	8.8 - 13	GPa	Amalgam	62	GPa
Microfilled	4 - 6.9	GPa	Enamel	83	GPa
Nano	18	GPa	Dentin	19	GPa

HARDNESS

Hardness determines the degree of deformation of a material and it is generally accepted as an important property and a valuable parameter for comparison with tooth structure. To assure an optimized clinical performance of restorations, it is of paramount importance to employ materials with hardness at least similar to that of the dentinal substrate, not only superficially, but also in depth, since an accentuated decrease in hardness would adversely affect their mechanical properties and marginal integrity.

Enamel	343 KHN
Dentin	70 KHN

Composites generally show lower hardness than enamel. The hardness varies between different products and depends on the amount and type of filler used.

Hybrid	60 - 117	KHN
Microfilled	22 - 80	KHN
Amalgam	110	KHN

Factors Affecting Hardness

Time period Composites show an increase in surface hardness with time due to continued polymerization. The best results are seen 7 days afer polymerization. For those unable to wait for a subsequent appointment a 15 minute delay is recommended before start of polishing procedures.

Polishing Polishing has been shown to increase the surface hardness of composites. Polishing removes the surface organic layer and exposes the harder fillers below. However, polishing is best delayed at least 24 hours after polymerization.

POLYMERIZATION SHRINKAGE

Polymerization in composite resins is accompanied by a shrinkage which varies between different composites depending on the resin to filler ratio. Thus, the polymerization ranges from 0.6 - 1.4% (in composites with higher filler content) to 2-3% (in composites with lower filler content like microfilled composites). This creates tensile stresses as high as 130 kg/cm^2 which severely strains the bond and can lead to marginal leakage. Sometimes it may also cause the enamel at the restoration margin to crack or fracture.

The total polymerization shrinkage between light activated and chemically activated resins do not differ. However, the pattern of shrinkage is different (see differences). The polymerization shrinkage is highest in case of the microfilled composites because of the higher resin content.

The polymerization shrinkage can be reduced by:

- Polymerizing the composite resin in layers or ramps.
- **Soft start** In this technique polymerization is initiated slowly. The device automatically begins with a low intensity light, gradually increasing and ending with high intensity light. This gives time for stress relaxation.
- **Delayed curing** The restoration is partially cured with a low intensity light. The operator continues working on the restoration and then follows it with a final high intensity exposure.
- Fabricating and curing the restoration extraorally on a cast (indirect technique) and then cementing on to the tooth, thereby completing the polymerization before cementing

AIR OR OXYGEN INHIBITION

Polymerization is inhibited by air or oxygen. To avoid this the surface of the restoration should be protected by a transparent matrix strip or celluloid crown former. If the composite is unprotected during polymerization the surface of the composite remains tacky. This is known as the *air inhibited layer*.

THERMAL PROPERTIES

Thermal Expansion Coefficient (CTE)

Thermal expansion and contraction is cyclic in nature in the mouth and this can place additional strain on the tooth-resin bond. Over time this can lead to material fatigue, bond failure and percolation of fluids into the gap. Ideally the CTE of a restorative material should be close to that of tooth structure.

Dentin	$8.3 \times 10^{-6}/°C$
Enamel	$11.4 \times 10^{-6}/°C$

The CTE of composite resins is again related to the proportion of resin. Thus composites with higher resin content like microfilled will show a greater CTE.

Hybrid	25 - 38	$\times 10^{-6}$/°C
Microfilled	55 - 68	$\times 10^{-6}$/°C

Thermal Conductivity

The thermal conductivity influences the rate at which heat or cold is transmitted through the restoration. Ideally restorative materials should have low thermal conductivity to reduce transfer of excessive thermal stimuli to the pulp.

Hybrid	25 - 30	$\times 10^{-4}$ cal/sec/cm^2 (°C/cm)
Microfilled	12 - 15	$\times 10^{-4}$ cal/sec/cm^2 (°C/cm)

WATER SORPTION

Water sorption is related to the resin content. The water sorption of hybrid composites are comparitively lower than that of the microfilled resins. ISO 4049 requirements limit the water sorption to a maximum of 40 µg/mm^2.

Hybrid	5 - 17	µg/mm^2
Microfilled	26 - 30	µg/mm^2

DIMENSIONAL STABILITY

A slow expansion (hygroscopic expansion) is associated with water sorption. The expansion which starts 15 minutes after polymerization reaches equilibrium in about 7 days. Microfilled resins show more expansion than hybrid varieties.

RETENTION

Composite resins do not adhere chemically to tooth structure. Micromechanical retention together with bonding agents have to be used to enhance adhesion to tooth structure.

ESTHETICS

Composites are highly esthetic direct restorative materials. Composites are supplied in a variety of shades. Special composite stains and other effects are also available to create lifelike restorations.

Ideally, with wear the silica filler should be removed along with the resin in which it is embedded. This is possible by using smaller filler sizes. In nanofilled and microfilled composites, the higher resin content and presence of microfillers is responsible for the increased surface smoothness. The inorganic filler particles are smaller than the abrasive particles used for finishing the restoration. Composites with larger fillers have a reduced surface smoothness which results in staining over a period of time. Age related effects also include stress cracks, a partial debonding of the filler-resin bond. This results in a loss of opacity/ and or loss of shade match over time.

BIOCOMPATIBILITY OF COMPOSITE RESINS

The resin components are cytotoxic *in vitro*. Composites release some resin components for weeks after insertion. The level of release depends on the type of composite and efficiency of the cure.

Thus composites resins have biocompatibility issues from three aspects:

- Inherent chemical toxicity of the material on the pulp
- Pulpal involvement due to microleakage
- Allergic potential on contact with the oral mucosa

- Allergic potential for personnel handling the material
- Concerns over estrogenicity of Bisphenol A and its dimethacrylate

Inspite of the controversies properly polymerized composites appear to be relatively biocompatible as long as there is sufficient thickness of dentin. In cases where the pulp is exposed some form of pulp capping overlayed with a glass ionomer liner is recommended. Issues concerning estrogenicity have not been proven to be of sufficient concern under intraoral conditions.

Pulp Protection

Glass ionomer liners are applied as pulp protection in deep cavities. *Zinc oxide-eugenol* is *contraindicated* as it interferes with polymerization. Bacterial contamination should be avoided by using rubber dam isolation.

WEAR RATES AND LIFE EXPECTANCY OF COMPOSITES

Composites are ideal as an anterior restorative material where wear rates are low. For posterior teeth amalgam has long been the standard direct filling material. Due to the increasing demand for esthetics, concern about mercury toxicity and aggressive marketing, there is an increasing interest in the use of composites for class I and II restorations. The older generation composites showed high attrition rates. Newer formulations have shown improvements in wear resistance.

All types of composites have been used for posterior restorations. Current guidelines require posterior composites to show less than 50 µm wear over 18 months. For posterior use, the cavity preparation should be conservative, and the manipulation technique meticulous.

Problems in the Use of Composites for Posterior Restorations

- In Class V restorations, when the gingival margin is located in cementum or dentin, the material shrinks away from the margin leading to a gap.
- The placement technique is more time consuming and demanding.
- Composites wear faster than amalgam. However, the newer materials like hybrids and nanocomposites have less wear (20 µm per year), which approaches that of amalgam (10 µm). In terms of years the average life expectancy of the composite resin is around 8 years which is near to that of amalgam (10 years).

The major indications of composites for posterior use are:

— When esthetics is the prime consideration.
— When a patient is allergic to mercury.

ADHESION

Composites do not adhere to tooth structure or any dental related surface. Acid etch technique and bonding agents have to be used to ensure adhesion.

Adhesion to instruments Composite adhere to the sculpting and packing instruments which interfere with adaptation to the cavity walls, increase porosity and reduce operator comfort. Some clinicians use alcohol or the bonding agent as a release agent. Howver both these techniques should be avoided as these materials are solvents that can weaken the resin.

RADIOPACITY

Radiopacity is a useful feature for any restorative material. Posterior restorations must demonstrate adequate radiopacity to permit detection of secondary caries,

Figures 10.13 A to C: (A) Rubber dam isolation is critical. (B) Preformed celluloid crown formers or matrix strips are used to shape and protect the restoration from air inhibition. (C) The completed restoration.

excess or inadequate quantities of material, air bubbles and other imperfections. ISO norm states that the minimum radiopacity of a restorative material should be equal or greater than that of the 2 mm-thick aluminum step wedge. Composites containing heavy metal glass fillers are radiopaque (2- 3 mm Al).

Enamel	4	mm/Al	Hybrid	2 - 5	mm/Al
Dentin	2.5	mm/Al	Microfilled	2 - 3	mm/Al
Amalgam	10	mm/Al			

MANIPULATION OF COMPOSITE RESINS

Steps in the manipulation of composite resin are illustrated in ***Fig. 10.14***

Placement of rubber dam Composite resins are highly technique sensitive and contamination from saliva, gingival fluid or blood is best avoided with rubber dam isolation (***Figs 10.13 A to C***).

Cavity preparation The cavity is prepared and margins bevelled.

Cleaning The tooth is cleaned with a mild abrasive.

Etching The enamel at the cavity margins is acid etched. The acid is rinsed off and the area is dried thoroughly.

Bonding agent An enamel or dentin bond agent is applied and polymerized. (Discussed in detail subsequently). The cavity is now ready for the composite.

TECHNIQUES OF INSERTION

Resins are manipulated with plastic or plastic coated instruments. Metal instruments should be avoided as it may abrade and discolor the composite. Composites are tacky and stick to metal instruments. Some operators use alcohol or bonding liquid as a release agent to reduce tackiness. However, this should be avoided as it can interfere with the properties of the resin. This is especially true of the bonding agent as it can dissolve the resin matrix and cause dilution.

It is inserted in to the cavity using a plastic instrument or a special syringe. Some manufacturers supply it in the form of a capsule which can be injected directly into the cavity with a special extruding gun.

CHEMICALLY ACTIVATED COMPOSITES

The correct proportions of base and catalyst pastes are dispensed onto a mixing pad and combined by rapid spatulation for 30 seconds. It is inserted while still plastic for better adaptation to cavity walls. Air inclusions can be avoided by swiping the material into one side of the cavity and filling the cavity from bottom outward.

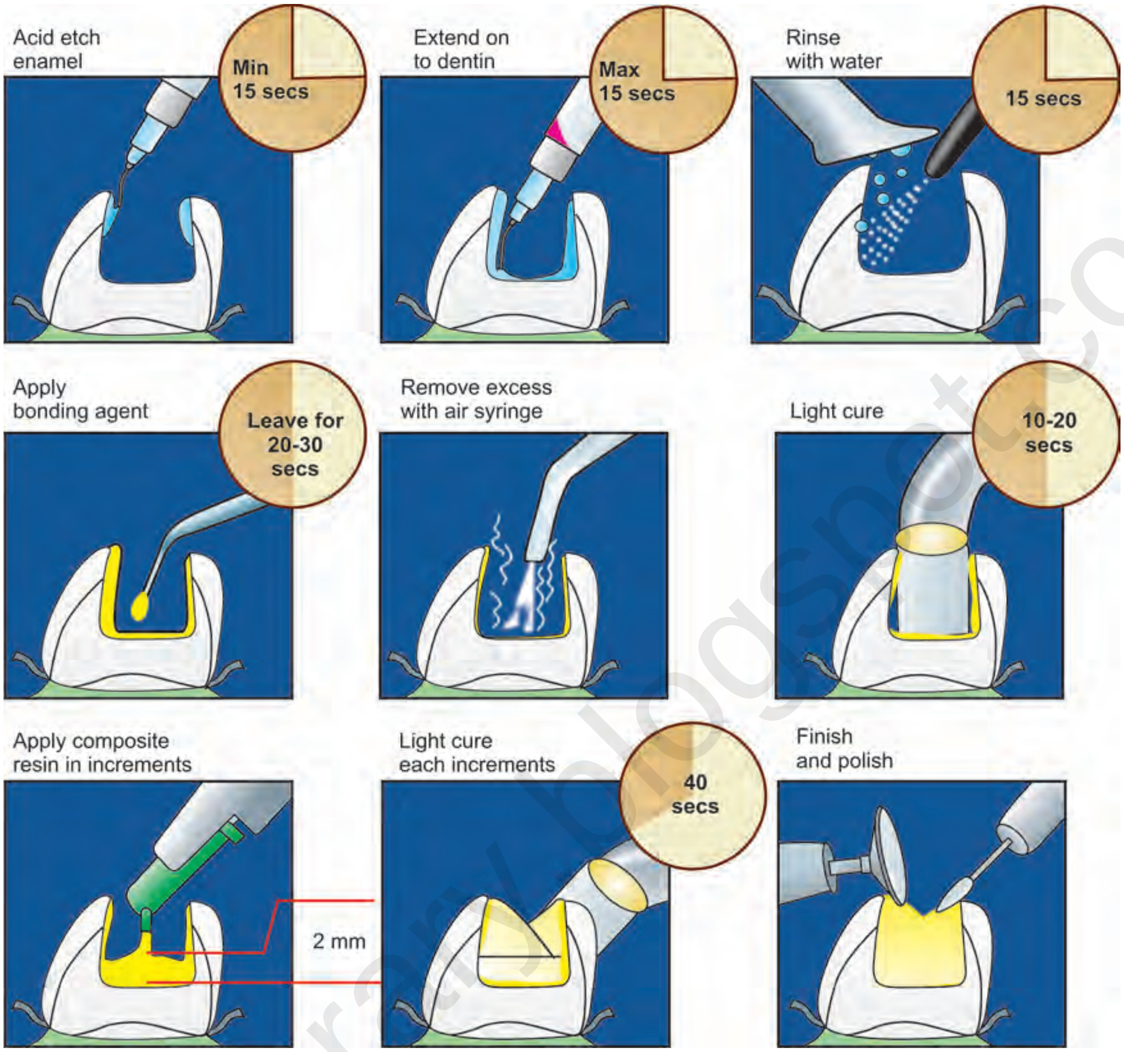


Figure 10.14: Technique for placing a light-cured composite restoration.

The cavity is slightly overfilled. A *matrix strip* is used to apply pressure and to avoid inhibition by air.

LIGHT ACTIVATED COMPOSITES

The light activated composites are single component pastes and require no mixing. The working time is under the control of the operator.

Effect of ambient light Light cured composites are vulnerable to prolonged exposure to ambient room light or the operatory light if they are left exposed and unprotected on the mixing pad. The composite begins slow polymerization as soon as it is exposed to ambient light and within 60 to 90 seconds it may lose its ability to flow. Therefore, some precautions to be observed when using light activated materials.

— The paste is dispensed just before use

— Avoid dispensing excessive quantities

— The depth of cure is limited, so in deep cavities the restorations must be built up in increments, each increment being cured before inserting the next

— Between cures any exess material is protected by covering with a light proof dark or orange tinted cover

The material hardens rapidly, on exposure to the curing light. To ensure maximal polymerization a high intensity light unit should be used. The light tip should be held as close as possible to the restoration. The exposure time should be no less than 40 to 60 seconds. The resin should be no greater than 2.0 to 2.5 mm thick. Darker shades require longer exposure times, as do resins that are cured through enamel. Microfilled resins also require a longer exposure.

Retinal damage The high intensity light can cause retinal damage if one looks at it directly. Avoiding looking at the light directly and use of protective eye glasses is recommended. Even greater care should be exercised when using laser as even a short exposure can cause damage.

Control of polymerization shrinkage As mentioned earlier composites exhibit polymerization shrinkage and build-up of stresses. This can be controlled by

— *Incremental curing* The restoration is built-up in increments each increment being cured before inserting the next.

— *Soft-start technique* The curing is started with low intensity and finished with high intensity. This extends the time for stress relaxation. Some commercially available lamps have this feature built in. Ramped curing is a variation of this technique.

— *Delayed curing* In delayed curing the restoration is partially cured at low intensity. The operator then completes the shaping and contouring and follows it with a second exposure for the final cure.

FINISHING AND POLISHING

Finishing is best done after 24 hours during which time the polymerization is complete. However, if a subsequent appointment is not desired finishing procedures can be started 15 minutes after curing. The initial contouring can be done with a knife or diamond stone. The final finishing is done with rubber impregnated abrasives or rubber cup with polishing pastes or aluminium oxide disks. The best finish is obtained when the composite is allowed to set against a *matrix or mylar strip*.

Special glazes and coatings are available. These are basically lightly filled resins. They are applied with a brush on the surface of the restoration and cured.

BONDING

One of the initial problems when resin restoratives were introduced was microleakage which resulted from the shrinkage of the resin while curing. The problem was overcome to a great extent by the introduction of the acid etch technique by Buonocore in 1955.

ACID ETCH TECHNIQUE

The acid etch technique was initially developed to improve retention to enamel. Initial bond agents did not appear to bond to the dentin.

At the time it was widely believed that:

- dentin could not be etched as well as enamel
- acid etching of dentin would cause injury to the pulp

One reason for the low bond strength to dentin was because of the hydrophobic nature of the early adhesive resins. In 1979 Fusyama demonstrated that dentin could be etched without causing any significant harm to the pulp. This together with the development of hydrophilic bonding agents significantly improved the bond strength to dentin.

The acid etch technique together with the application of current bonding agents is one of the most effective ways of improving the bond and marginal seal between resin and tooth structure.

ETCHANT/CONDITIONER

The etchants are acidic in nature. They may be grouped as

- mineral (e.g., phosphoric, nitric acid, etc.)
- organic (e.g., maleic, citric, ethylene-diamine-tetracetic (EDTA), etc.)
- polymeric (e.g., polyacrylic acid)

The most frequently used etchant is ***37% phosphoric acid.*** The acid in concentrations greater than 50% results in the formation of *monocalcium phosphate monohydrate* that reduces further dissolution. It may be supplied as clear or colored gel or liquid. Brushes are used to apply or the acid is supplied in a syringe for direct application on to the enamel (***Fig. 10.15***).

Another acid used is ***10% maleic acid***.

Figure 10.15: 37% phosphoric acid gel supplied in syringe form.

MODE OF ACTION ON ENAMEL

- It creates microporosities by discrete etching of the enamel, i.e., by selective dissolution of enamel rod centers (***Fig. 10.16***), or peripheries, or both.
- Etching increases the surface area.
- Etched enamel has a high surface energy, allowing the resin to wet the tooth surface better and penetrate into the microporosities. When polymerized, it forms resin 'tags' which forms a mechanical bond to the enamel (***Fig. 10.17***).

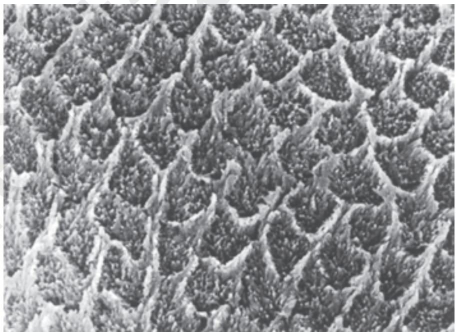


Figure 10.16: SEM of etched enamel showing dissolution of rod centers (*Courtesy:* Mario Fernando).

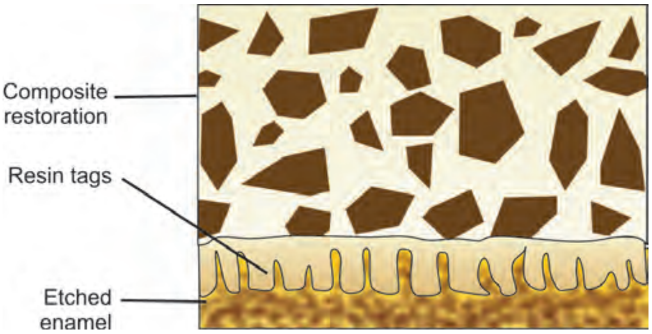


Figure 10.17: Diagrammatic representation showing mechanism of composite adhesion to etched enamel.

MODE OF ACTION ON DENTIN

- Removes smear layer and partially opens the dentinal tubules (***Fig. 10.19)***.
- Provides modest etching of the intertubular dentin.

PROCEDURE

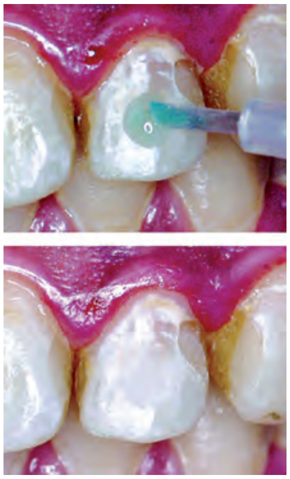


Figure 10.18: The frosted appearance is evident after a 15 second etch with 37% phosphoric acid.

The tooth is cleaned and polished with *pumice* before etching. The phosphoric acid is then applied onto the enamel and then on to the dentin (also known as *total-etch technique*). Originally the length of application was set at 60 seconds but now it has been shown that *15 seconds* is sufficient. The etching time also depends on the history of the tooth, e.g., a tooth with high fluoride content and primary teeth requires longer etching time (to produce a similar etch pattern and bond strength 10% maleic acid needed at least 60 seconds of etching time).

The acid along with dissolved minerals should be *rinsed off* with a stream of water for 15 seconds and the enamel dried using compressed air. After drying the enamel should have a *white, frosted* appearance ***(Fig. 10.18***).

This surface must be kept *clean and dry* until the resin is placed. Even momentary contact of saliva, or blood can prevent effective resin tag formation and severely reduce the bond strength.

Avoiding desiccation of dentin

Desiccation (excessive drying) of the dentin should be avoided. Desiccation can result in the collapse of the collagen mesh ***(Fig. 10.20***) or network which forms a dense film that is difficult to penetrate by the bond agent. After drying the tooth the dentin may be lightly remoistened with cotton and then blotted dry.

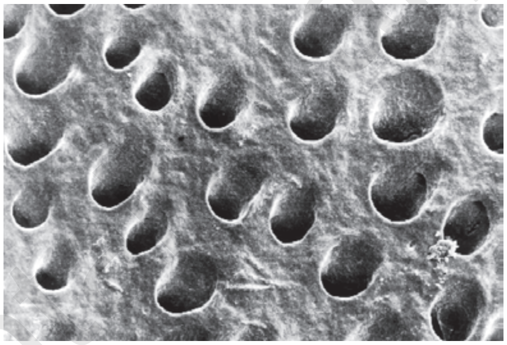


Figure 10.19: SEM of etched dentin showing the open dentinal tubules (*Courtesy:* Mario Fernando).

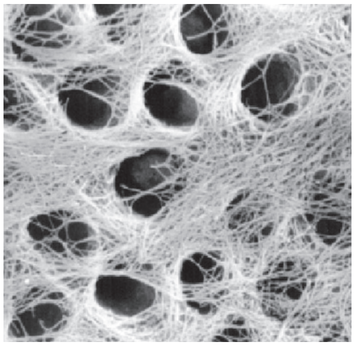


Figure 10.20: SEM of etched dentin showing collagen mesh (x 5000).

ENAMEL BOND AGENTS

These were the earliest bond agents. The more viscous composite did not bond well to the etched enamel. The enamel bond agent helped improve the bond by flowing into all the microporosities of the etched enamel and creating a mechanical retention.

COMPOSITION

They are unfilled resins similar to that of the resin matrix of composite resin, diluted by other monomers to lower the viscosity. These materials have been replaced by agents that bond to both enamel and dentin.

BOND STRENGTH

Bond strengths to etched enamel range from 16 MPa (230 Psi) to 22 MPa (3200 Psi). Drying the enamel with warm air or using an ethanol rinse can increase the bond strength.

ENAMEL/ DENTIN BOND SYSTEMS

The term dentin bond agent is no longer relevant as current bond agents bond to both enamel and dentin. The usage of the term is relevant only to discuss their evolution. Due to acid etching, microleakage or loss of retention is no longer a hazard at the resin-enamel interface. The problem lies at the resin-dentin/ cementum interface. Thus agents that could bond to dentin were needed. Developing agents that will adhere to dentin was more difficult because:

- It is heterogenous.
- The high water content interferes with bonding. Its tubular nature provides a variable area.
- Presence of a *smear layer* on the cut dentin surface (The smear layer is the layer of debris which adheres tightly to the dentin and fills the tubules after cavity cutting).

Ideally, the bond agent should be hydrophilic to displace the water and thereby wet the surface, permitting it to penetrate the porosities in dentin as well as react with the organic/inorganic components.

Restorative resins are hydrophobic, therefore, bonding agents should contain both hydrophilic and hydrophobic parts. The hydrophilic part bonds with either calcium in the hydroxyapatite crystals or with collagen. The hydrophobic part bonds with the restorative resin.

SUPPLIED AS

Dentin bond systems are supplied in one or more bottles containing conditioners (etchant)/ primers/ and adhesive depending on the generation (see box below and also evolution of dentin bond agents - the various generations).

EVOLUTION OF DENTIN BOND AGENTS - THE VARIOUS GENERATIONS

For ease of description the evolution of bonding agents for composite resins are described under various generations (see also ***Table 10.3***).

First generation (1950 to 1970) Mineral acids were used to etch enamel. *Dentin etching was not recommended* as it was believed it would harm the pulp. They

ESSENTIALS OF CURRENT BONDING SYSTEMS

Etchant	– The etchant is an acid which selectively dissolves the tooth structure to provide retention for the restoration. They are also known as conditioners. The most popular etchant is 37% phosphoric acid.
Primer	– Primers are hydrophilic monomers usually carried in a solvent. Because of their hydrophilic nature they are able to penetrate the moist tooth structure especially the dentin and its collagen mesh thus improving the bond. Thus they serve as a bridge connecting the tooth structure to the adhesive. The solvent used are acetone, ethanol or water. Some are used without solvents.
Adhesive	– Adhesive are generally hydrophobic monomers. Being hydrophobic they do not wet the tooth leading to air entrapment, air inhibition and thereby poor bonding. Thus they have to be used in combination with primers to form an effective bond to tooth structure. The adhesive bonds the resin to the primer which in turn penetrates and binds to the tooth structure thus completing the bonding sequence.

used glycerophosphoric acid dimethacrylate to provide a bifunctional molecule. The hydrophilic phosphate part reacted with calcium ions of the hydroxyapatite. The hydrophobic methacrylate groups bonded to the acrylic restorative resin. These were generally self cured. The main disadvantage was their low bond strength (2 to 6 MPa) because of their high polymerization shrinkage and the high CTE. Leakage was a concern at the dentin-resin interphase.

Second generation (1970s) Developed as adhesive agents for composite resins which had by then replaced acrylic restorations. One system used NPG-GMA. It was proposed that the NPG portion bonded to the calcium of the tooth by chelation. Other products included phenyl-P, 2-methacryloxy phenyl phosphoric acid. Bond strengths achieved were three times more than the earlier generations.

Disadvantage: Bond strengths were still low. The adhesion was short term and the bond eventually hydrolysed, e.g., Prisma, Universal Bond, Clearfil, Scotch Bond.

Third generation (1980s) The third generation bond agents made a serious attempt to deal with the smear layer which is formed when dentin is cut. It was believed that the smear layer prevented proper bonding to the underlying dentin. Yet its complete removal by aggressive etching was contraindicated because it was believed that it protected the pulp by preventing direct contact with the monomer. The third generation bond agents had bond strengths comparable to that of resin to etched enamel. Thus bond strengths improved to 12 to 15 MPa. However, their use is more complex and requires two to three application steps.

— Etching of enamel using 37% phosphoric acid.
— Conditioning of dentin using mild acids
— Application of seperate primer
— Application of polymerizable monomer
— Placement of the resin.

Examples are Tenure, Scotch bond 2, Prisma, Universal bond, Mirage bond, etc.

Fourth generation (early 1990s) The fourth generation systems were possible because of some important ideological breakthroughs - like the *total etch* technique and the development of the *hybrid zone*. Research showed that acid etching of dentin did not significantly harm the pulp as long as bacterial contamination and microleakage was avoided. Thus the *total-etch technique* was introduced.

The hybrid layer In 1982, Nakabayashi and Fusayama reported the formation of a hybrid layer. The hybrid layer is defined as “the structure formed in dental hard tissues (enamel, dentin, cementum) by demineralization of the surface and subsurface, followed by infiltration of monomers in to the *collagen mesh* (***Fig. 10.20***) and subsequent polymerization. However, dealing with the collagen mesh was not easy. It is delicate and can be destroyed by desiccation. *Kanca* (1991) introduced the idea of wet bonding again breaking with the traditional belief that thorough drying was necessary to improve bonding.

Examples are All Bond 2, Scotch bond multipurpose (***Fig. 10.21***), Optibond, etc.

The All Bond consists of 2 primers (NPG-GMA and Biphenyl dimethacrylate (BPDM) and an unfilled resin adhesive (40% BIS-GMA, 30% UDMA, 30% HEMA). This system bonds composite not only to dentin but to most dental related surfaces like enamel, casting alloys, amalgam, porcelain and composite. Bond strengths were high but as with the earlier system, multiple application steps were required.

Fifth generation (mid 1990s) Because of the clinical complexity and multiple steps of the fourth generation dentists began asking for more simple adhesives. The fifth generation combined the primer and adhesive in to one bottle (self

Figure 10.21: 4th generation bonding system consisting of the conditioner (etchant), primer and the adhesive.

Figure 10.22: A 5th generation self priming adhesive (3M single Bond 2).

Figure 10.23: A 6th generation Type I - self etching primer (Adhese - Ivoclar).

priming adhesive). Examples of the fifth generation self-priming adhesives are Single Bond (3M) ***(Fig. 10.22***), One Step (BISCO), Prime and Bond (Dentsply).

The advantages claimed are:

1. Reduced application steps.
2. Less technique sensitive as it can bond to moist dentin.
3. Less volatile liquid.
4. Pleasant odor.
5. Higher bond strength.

Sixth generation (mid to late 1990s) A separate etchant is not required. These are 2 bottle systems. Two varieties are seen - Type I and Type 2.

Type I 2 bottle 2 step system. Etchant and primer are combined in one bottle (called self etching primer). Other bottle contains adhesive. Examples are Clearfil SE bond (Curare), Adhese (Ivoclar ***-Fig. 10.23***), Optibond solo plus(Kerr), Nano bond (Pentron) etc.

Type II 2 bottle 1 step system. Liquid A contains the primer. Liquid B contains a phosphoric acid modified resin (self etching adhesive). Both liquids are mixed just before application. For example, Xeno III (Dentsply ***- Fig. 10.24***), Adper prompt L-pop (3 M), Tenure unibond (Dent Mat) etc.

Seventh generation (early 2000) Attempts to combine all three (etchant, primer and adhesive) into a single product. Thus, seventh generation adhesives may be characterized as - '*no mix self etching adhesives*'.

Examples include iBond (Heraeus kulzer - ***Fig. 10.25***), G bond (GC), Xeno IV (Dentsply) (glass ionomer based), Clearfil S3 (Curare). Unfortunately, insufficient research exists of the efficacy of the newer systems. Composition ***(Table 10.4)*** and procedure (***see box below***) for one such product is presented.

PROCEDURE FOR IBOND

1. Isolate the tooth from saliva contamination during the adhesive procedure.
2. Clean the preparation, removing all debris with water. Remove excess water.
3. Saturate the microbrush with iBond^{TM} liquid from either the bottle or single dose vial.
4. Apply 3 consecutive coats of iBond^{TM} to both the enamel and dentin followed by gentle rubbing for 30 seconds.
5. Use gentle air pressure or vacuum to remove the acetone and water solvent.
6. Cure for 20 seconds with a dental curing light of at least 500 mW/C^{2}.
7. Place composite.

Figure 10.24: 6th generation type II (Xeno-Dentsply).

Figure 10.25: 7th generation iBond (Heraeus kulzer).

Table 10.3

Various generations of bond agents

Generation	*Enamel etchant*	*Dentin conditioner/ primer*	*Adhesive*
1st generation	37% phosphoric acid	(not recommended)	GPDM
2nd generation	37% phosphoric acid	(not recommended)	Phenyl-P BisGMA/ TEGDMA MPPA
3rd generation	37% phosphoric acid	Citric acid (10%)/ CaCl (20%) Oxalic acid/ aluminium nitrate EDTA	NPG-GMA/BPDM BisGMA/TEGDMA HEMA/BPDM 4 META/MMA HEMA/GA
4th generation	37% phosphoric acid	(total etch technique)	NPG-GMA/BPDM BisGMA/TEGDMA HEMA/BPDM 4 META/MMA HEMA/GPDM
5th generation	37% phosphoric acid	(total etch technique)	PENTA, Methacrylated phosphonates
6th generation			Methacrylated phosphates in water (acidic primer-adhesive)
7th generation			Methacrylated phosphates in water (acidic primer-adhesive)

Abbreviations

BisGMA	–	Bisphenol-A-glycidyl methacrylate
BPDM	–	Biphenyl dimethacrylate
EDTA	–	Ethylenediaminetetraacetic acid
GPDM	–	Gylcerophosphoric acid dimethacrylate
GA	–	Glutaraldehyde
HEMA	–	2-Hydroxyethyl methacrylate
4-META	–	4-Methyloxyethyl trimellitic acid
MMA	–	Methyl mehtacrylate
MPPA	–	2-methacryloxphenyl phosphoric acid
TEGDMA	–	Triethylene glycol dimethacrylate
PENTA	–	Dipentaerythritol pentacrylate phosphoric acid ester
NPG-GMA	–	N-Phenyl glycine glycidylmethacrylate
NTG-GMA	–	N-Tolyl glycine glycidylmethacrylate

Table 10.4

Composition of a 7th generation bonding agent (iBond)

Component	*Function*
UDMA	Matrix component Etching and conditioning of enamel and dentin Wetting of the surface Promotion of infiltration Bonding to collagen via hydrogen bonding Bonding to Ca^{2+} ions of the apatite via chelation complexes
4-Meta (pH = 2.2)	Matrix component Film-forming properties Cross-linking
Acetone	Solvent for monomers Facilitates solvent evaporation
Water	Solvent for monomers Hydrolysis of 4-Meta to 4-Met (= acid) Provides water for etching process
Camphorquinone	Photoinitiators
Glutaraldehyde	Disinfectant/Desensitizer agent Cross-linking of collagen fibrils
Stabilizers	

INDICATIONS FOR USE OF BOND AGENTS

1. For bonding composite to tooth structure.
2. Bonding composite to porcelain and various metals like amalgam, base metal and noble metal alloys.
3. Desensitization of exposed dentin or root surfaces.
4. Bonding of porcelain veneers.

Contraindication Bonding should not be done immediately after bleaching a tooth. It is advisable to wait at least a week following the procedure.

BONDING MECHANISMS

Though chemical bonding schemes have been proposed, there is little evidence supporting it. The bonding is more probably micromechanical, due to the penetration of the polymerizable monomer into the finely textured primed dentin. A fine collagen mesh exists on the surface of the dentin which current bond agents are able to infiltrate because of their hydrophilic components. One more precaution is that the dentin should not be dried excessively as *desiccation* can cause the collapse of the fine collagen meshwork thereby reducing the bond strength.

BOND STRENGTH OF DENTIN BOND AGENTS

Current dentin bond agents generate bond strengths comparable to that of resin to etched enamel. Bond strength is difficult to measure because of the wide variations in the dentin itself, test methods, and other factors. Bond strength reduces with increased depth of dentin. Various studies have shown values ranging from 15 to 35 MPa.

An increasing number of studies are using the microtensile test methodology. The size of the specimen is smaller (1 mm^2 in cross section). Thus, a number of specimens can be prepared from the same tooth thereby increasing the uniformity of the study.

DYE PENETRATION TESTS

These are improtant tests related to the performance of the bonding system. A test for microleakage is indicative of the success or failure of a bond. These tests are done using tracers and staining to determine the depth of penetration.

SPECIALIZED APPLICATIONS AND MATERIALS

SANDWICH TECHNIQUE

Composite does not bond adequately to dentin, therefore during polymerization, a gap may result if the cavity margin is situated in dentin. The bond to dentin can be improved by placing a glass ionomer liner between the composite restoration and dentin. The glass ionomer bonds to the dentin through chemical adhesion whereas the resin bonds mechanically to porosities and crazing present on the surface of the glass ionomer liner. The glass ionomer can also be etched with the help of phosphoric acid to improve retention. In addition it also provides an anticariogenic effect due to its fluoride release. When used in this context it is often referred to as *'sandwich technique'*.

Indications

1. Lesions where one or more margins are in dentin, e.g., cervical lesions.
2. Class II composite restorations.

Procedure

Dentin is conditioned and a thin layer of GIC cement is placed. The cement must be exposed at the margins in order to achieve fluoride release. Phosphoric acid is used to etch the enamel portion. Some operators also *etch the GIC surface* with the same phosphoric acid for 15 to 20 seconds to increase surface roughness (light cured GIC is not etched). The surface is then washed for 25 to 30 seconds. After adequate drying, a bond agent is applied to the cement surface and to the etched enamel. The composite resin is then inserted in the usual manner.

FLOWABLE COMPOSITES

As suggested by the name these are hybrid composites modified to have an increased flow. The increased flow is achieved by a reduction in the filler content (30-55 vol % or 40-60 wt.%). When placed in the cavity the material flows readily and intimately adapts to the cavity wall. The reduced filler content affects some of the properties. Thus these materials

- Are more prone to wear
- Have half the stiffness (more flexible) of regular hybrids (4-8 GPa)
- Greater polymerization shrinkage (3-5 vol%)

These materials are intended for specialized usage

1. As a preventive material (fissure sealant and small class I cavity)
2. Cervical lesions and class V restorations
3. As a base or liner
4. Areas of reduced access

PACKABLE COMPOSITES

These are composites that have very high viscosity and low surface tackiness. They have a high filler loading (66-70% vol) with porous or irregularly shaped particles. They are not condensable like classic amalgam, rather they can be compressed and forced to flow using flat faced instruments. They are considered as posterior composites. They have a higher wear resistance. Claims also include a greater depth of cure and low polymerization shrinkage.

Indications

They are indicated for use in Classes I and II cavities. In class II cavities where improved contacts with adjacent teeth are desired.

REPAIR OF COMPOSITES

Composite resins may be repaired by adding new material over the old. This is useful in correcting defects or altering contours of an existing restoration. The procedure differs depending on whether the restoration is fresh or old.

- A freshly polymerized restoration still has an inhibited layer of resin on the surface. More than 50% of unreacted methacrylate groups are available to copolymerize with the newly added material.
- In older composites, the presence of fewer methacrylate groups and the greater cross-linking reduces the ability of fresh monomer to penetrate into the matrix.

Method

Remove contaminated material from the surface and roughen it. Place fresh composite after applying bonding agent.

PROSTHODONTIC VENEER COMPOSITES (LABORATORY COMPOSITES)

Resin may be used as a veneer (a tooth colored layer used to hide the underlying metal) for crowns and fixed partial dentures. They are also known as *composites for dental indirect restorations*. The early materials were heat cured poly (methyl methacrylate) improved by fillers and cross-linking agents. Current veneer materials are hybrid, micro or nanofiller reinforced resins such as bis-GMA, urethane dimethacrylate or 4,8-di(methacryloxy methylene) tricyclo-(5.2.1.02,6) - decane ***(Fig. 10.26 A to C)***. Some are fiber reinforced. The newer resins have superior physical properties and are polymerized by light or heat and pressure.

The resins are mechanically bonded to the metal using wire loops or retention beads ***(Fig. 10.26 B)***. Recent improvements, include micromechanical retention created by acid etching the base alloy and the use of chemical bonding systems such as 4-META, phosphorylated methacrylate, epoxy resin, or silicon dioxide that is flame sprayed to the metal surface followed by the application of a silane coupling agent (silicoating).

Commercial examples SR Adoro (Ivoclar), GC Gradia (GC), Targis Vectris, etc.

Available as A kit containing various materials which include - incisal, dentin and other specialized resins, masking resins ***(Fig. 10.26 B)***.

Figures 10.26 A to C: (A) Prosthodontic resin kit (SR Adoro (Ivoclar Vivadent). (B) Opaquer resin is applied to mask the metal. Multiple tiny nodules provide retention for the resin. (C) The completed restoration.

Indications

1. Inlays, onlays, veneers and anterior crowns (metal free).
2. As veneer over metal supported crowns and FPDs.
3. Long term temporaries (alone or in combination with Kavo C-temp blanks).

The advantages of resin when compared to porcelain

1. Ease of fabrication.
2. Easily repairable intraorally.
3. Less wear of opposing teeth or restorations.

Disadvantages

1. Microleakage of oral fluids and staining under the veneers due to thermal cycling and water sorption.
2. Surface staining and intrinsic discoloration.
3. Susceptibility to toothbrush wear.
4. Cannot be used in crowns serving as abutments for removable partial dentures. The clasp arm will abrade the resin.
5. Not as durable as other prosthodontic materials like ceramics and PFM.

RESIN INLAY SYSTEMS

These were introduced in an attempt to overcome some of the limitations of traditional posterior composite resin restoration. The resin inlay is completely polymerized outside the mouth by light, heat, pressure or combination and then luted to the tooth using a resin cement. They may be fabricated using the direct method or indirect method.

Direct Inlay System (Fabricated in the Mouth)

Hybrid or microfilled resins are used. A separating medium (agar solution or glycerine) is applied to the prepared tooth. The restoration is then formed, light-cured, and removed from the tooth. The rough inlay is subjected to additional polymerization by light (6 minutes) or heat (100°C for 7 minutes). After this the prepared tooth is etched and the inlay luted to place with a dual-cure resin cement and then polished.

Indirect Inlay System (Fabricated on a Die)

The inlay is fabricated with prosthodontic resin (described earlier) in the laboratory on a die made from an impression of the prepared tooth. Conventional light and heat or heat and pressure may also be used for polymerization.

Advantages of Inlays

1. Improved physical properties and wear resistance due to the higher degree of polymerization attained.
2. Induced stresses and potential for microleakage is reduced as polymerization shrinkage occurs outside the mouth.
3. Being resins they do not abrade opposing teeth and are repairable in the mouth.

PREFORMED COMPOSITE RESIN LAMINATES

Composite resins are used as preformed laminate veneers to mask tooth discoloration or malformation. These shells are adjusted by grinding and are bonded to teeth using acid-etch technique and resin cement.

Figure 10.27: Core composite resin.

CORE BUILD-UP COMPOSITE RESINS

Modified highly filled resins are used as core materials in combination with prefabricated posts during the restorations of broken down teeth. They are highly colored opaque materials. They are usually chemically cured or dual cured with a longer working time and shorter setting time. Some concerns exist regarding the strength of composite cores when compared to cast post and cores. Failures are often seen when these materials form the bulk of the support for crowns and FPDs. The lower stiffness (greater flexibility) can result in slightly more frequent debonding of crowns and other restoration. Therefore, when using composite cores *shared* support from remaining tooth structure is indicated. *MultiCore (Ivoclar Vivadent)* ***(Fig. 10.27)*** is an example of a core build-up composite. The product also contains fluoride.

RESIN CEMENTS

Lower viscosity filled resins (e.g., Panavia Ex, Infinity) are used for the cementation of laminates, crowns and orthodontic brackets. Etching and bonding is done before cementing (described in detail in chapter on cements).

PROVISIONAL COMPOSITES

A temporary restoration is necessary to protect the teeth after preparation and in the interim period while the definitive restoration is being constructed. Composite resins are available for making provisional inlays, onlays, crowns and FPDs. One such product is protemp (ESPE) ***(Fig. 10.28)***.

Figure 10.28: Composite for provisional crowns and FPDs.

Its advantages include

- Can be made directly in the mouth because of its low exothermic heat.
- It is easily ground and shaped using regular high speed diamond burs without melting and clogging the burs (unlike the conventional acrylic temporary crown and bridge resins).

It comes as base and catalyst. Currently, two shades are available. It is supplied in a syringe form and is dispensed by rotating the plunger until a clicking sound is heard, this represents one unit. The catalyst is a two component system and only a small amount is required. As the plunger is turned the two components are dispensed simultaneously. The base and catalyst are mixed quickly and used. Setting occurs in approximately two to three minutes.

The material is also available in the autodispensing form. It consists of a caulking gun which forces the materials through special auto-mixing tips. The material comes out mixed and ready to use when expressed through these tips. After curing in the mouth the hardening can be accelerated by placing in hot water.

COMPOSITE RESIN BLANKS FOR CAD-CAM SYSTEMS

Composite resin blanks are available for the fabrication of long term (upto 1 year) provisional restorations including crowns and fixed partial dentures. They are fabricated by a CAD CAM process (see chapter on ceramics for further details of the process). One such product is the *Everest C-Temp* (Kavo) ***(Fig. 10.29)***. The whole restoration may be fabricated as one piece or it may be fabricated as a framework which is subsequently veneered with conventional prosthodontic resins. These resins are characterized by high flexural strength.

Figure 10.29: Composite resin CAD CAM blanks.

PORCELAIN REPAIR COMPOSITE RESINS

Composite resins are occasionally used to repair fractured or chipped ceramic restorations. The kit consists of an silane based bonding agent, a metal masking agent (opaquer). Conventional composite is then used to carry out the final repair. The material and procedure is discussed in further detail (refer chapter on porcelain).

PIT AND FISSURE SEALANTS

Deep pits and fissures on posterior teeth are susceptible to decay as they provide shelter for organisms. They are often too narrow making it difficult to clean. Various materials have been used to seal these areas, especially in the child patient. The *objective* is for the resin to penetrate into the pits and fissures, thereby, sealing these areas against oral flora and debris ***(Figs 10.30 A and B)***.

Indications

Sealants are most effective in children with high risk of caries. Both deciduous molars and young permanent molars with deep pits and fissures are common candidates. Commonly surfaces that are free of caries should be selected. However, a recent study where the sealant was placed intentionally in pits and fissures having caries showed that the lesion did not progress.

Types

- Based on filler content 2 types are available—Filled and Unfilled.
- Based on curing mechanism—they may be light cured or chemical cured.
- Color—The sealants are available as transparent, tooth colored, opaque, tinted or white materials. The color contrast helps to determine the efficacy of the application. Recent products include photosensitive color reversible sealants. These sealants are nomally colorless but change to a pink or green when exposed to a curing light. The color change which lasts about 5 - 10 minutes is useful for diagnosis during periodic recalls.

Composition

The most commonly and successfully used sealant is Bis-GMA ***(Figs 10.30 B and C)***. It may be cured chemically (amine-peroxide system) or by light. The BisGMA resin is mixed with a diluent to obtain a low viscosity sealant that flows readily. In filled sealants small amounts of filler (upto 40%) are added to improve its stiffness and wear resistance. Other resins systems include polyurethanes and cyanoacrylates.

Properties

Important properties of sealants are flow, wear resistance, fluoride release and long term retention.

Sealants must have low viscosity so that they will flow readily into the depths of the pits and fissures ***(Fig. 10.30 A)*** and wet the tooth. Wettability is also important for proper adaptation and penetration. Acid etching improves the wettability.

Proper retention of the sealant is important for caries prevention. Acid etching with bonding agents is necessary for the retention of the sealant.

Figures 10.30 A to C: (A) Diagrammatic representation of a sealant in a fissure. (B) A pit and fissure sealant on a deciduous molar. (C) A typical pit and fissure sealant kit.

The sealant must have sufficient mechanical properties like strength, stiffness and wear resistance for effective function and durability. Sealants with fillers usually have better mechanical properties than unfilled resins.

Current products have been formulated for fluoride release during service. Initial fluoride release is high especially during the first 24 hours but gradually tapers to low levels which may not be effective for long term protection.

Air inhibition during polymerization is also a problem in sealants. The tacky air inhibited layer is removed using a pumice paste on a cotton pellet or rotary cup or brush. The operator must ensure that sufficient thickness of sealant is applied to compensate for this loss.

The unpolymerized surface layer was once a health concern because of the presence of BPA (bisphenol A) which is chemical similar to estrogen. However, this has since been discredited and is no longer a major concern.

Efficacy of sealant therapy

Early clinical studies showed a retention rate of 42% and a caries reduction rate of 35% over 5 years. Improvements in materials and technique over the years have dramatically improved the success rates. Current studies indicate a success rate of over 90% in caries reduction.

Periodic recall

Evidence has shown that sealant therapy cannot be taken for granted. The sealant should be re-examined every six months. If the sealant is missing it should be reapplied. Improper case selection and application of sealant may actually enhance caries.

COMPOSITE RESIN DENTURE TEETH

Over the years various types of materials have been used for denture teeth. Traditionally conventional acrylic (Biotone), cross-linked acrylics (SR-Postaris, Genios-P, etc.) and porcelain denture teeth are used.

Since their introduction composite resins too have been tried as denture teeth. Some examples are nano-filled (Veracia) and micro-filled composites (SR-Orthosit, Endura, Duradent, Surpass). In one study, the composites and cross-linked acrylic resins did not show significant difference in wear resistance properties. However, both were significantly better than conventional resin acrylic teeth.

ADVANTAGES AND DISADVANTAGES OF RESTORATIVE COMPOSITE RESINS

ADVANTAGES

1. Highly esthetic tooth colored restorations possible.
2. Multiple curing systems allow choice of working time
3. Relatively ease of placement.

DISADVANTAGES

1. Highly technique sensitive.
2. Sticks to instruments.
3. Not condensable like amalgam.
4. Possibility of microleakage and secondary caries if improperly placed.

5. Some materials exhibit slumping.
6. Does not bond to tooth structure; requires dentin bonding techniques.
7. Not as wear resistant as other more permanent restorative materials.
8. Shorter lifespan when compared to other more durable restorative materials like ceramics, DFGs, amalgam and cast metal restorations.
9. Potential for color instability and staining over time.

11

RIGID IMPRESSION MATERIALS

A dental impression is a negative record of the tissues of the mouth. It is used to reproduce the form of the teeth and surrounding tissues.

The negative reproduction of the tissues given by the impression material is filled up with dental stone or other model materials to get a positive cast. The positive reproduction of a single tooth is described as a 'die', and when several teeth or a whole arch is reproduced, it is called a 'cast' or 'model'.

ADVANTAGES OF USING A CAST OR MODEL

1. Models provide a three-dimensional view of the oral structures, thus aiding in diagnosis and treatment planning.
2. Many restorations or appliances are best constructed on casts. It may be inconvenient to both dentist and patient if these have to be made directly in the patient's mouth.
3. Models can be used to educate the patient.
4. They serve as treatment records.
5. By using casts, technical work can be passed on to technicians, saving valuable clinical time.

DESIRABLE PROPERTIES OF AN IMPRESSION MATERIAL

1. Should be nontoxic and nonirritant to dentist and patient.
2. Acceptable to the patient.
   a. Have a pleasant taste, odor, consistency and color.
   b. Should set quickly once placed in the mouth.
3. Should be accurate
   a. Accurate surface detail.
   b. Elastic properties with freedom from permanent deformation after strain.
   c. Dimensionally stable.
4. Have adequate shelf life for storage and distribution.
5. Be economical.
6. Handling properties.
   a. Sufficient working time.
   b. Set quickly in mouth (saves chairside time)
   c. Be easy to use with the minimum equipments
   d. Satisfactory consistency and texture.

7. Have adequate strength so that it will not break or tear while removing from the mouth.
8. Should be compatible with the die and cast materials.
9. Should be able to be electroplated.

CLASSIFICATION OF IMPRESSION MATERIALS

There are several ways of classifying impression materials

1. According to mode of setting and elasticity
2. According to tissue displacement during impression procedure
3. According to their uses in dentistry

ACCORDING TO MODE OF SETTING AND ELASTICITY

The terms thermoset, thermoplastic, rigid and elastic are used to describe these materials (see ***Table 11.1***).

Table 11.1

Classification of impression materials according to mode of setting and elasticity

Mode of setting	*Rigid*	*Elastic*
Set by chemical reaction (irreversible or thermoset)	Impression plaster Zinc oxide eugenol	Alginate hydrocolloid Nonaqueous elastomers, e.g., polysulfide, silicone, etc.
Set by temperature change (reversible/thermoplastic)	Compound Waxes	Agar hydrocolloid.

ACCORDING TO TISSUE DISPLACEMENT

Depending on whether tissues are displaced while making impressions a material may be

1. Mucostatic
2. Mucocompressive (Mucodisplacive)

Mucostatic materials produce minimal displacement of the tissue during impression, e.g., plaster, zinc oxide eugenol, low viscosity alginates, low viscosity elastomeric materials, etc.

Mucocompressive materials are more viscous and displace the tissues while recording them, e.g., compound, high viscosity alginates, high viscosity elastomers, etc.

ACCORDING TO THEIR USES IN DENTISTRY

Impression Materials used for Complete Denture Prosthesis

Impression plaster, impression compound and impression paste set to a hard rigid mass and hence cannot be removed from undercuts without the impression being fractured or distorted. Therefore these materials are best suited for *edentulous* mouth.

Impression Materials used for Dentulous Mouths

On the other hand alginates and rubber base impressions are sufficiently elastic to be withdrawn from undercut areas. Such elastic impression materials are suitable for impressions for fabrication of removable and fixed partial denture prostheses, where the impressions of the ridge and teeth are required.

THE RIGID IMPRESSION MATERIALS

As mentioned earlier the rigid impression materials are:

1. Impression plaster
2. Impression compound
3. Zinc oxide eugenol impression paste
4 Impression waxes

(Impression plaster is described in the chapter on Gypsum Products).

IMPRESSION COMPOUND

Impression compound is one of the oldest of the dental impression materials. It can be described as a rigid, reversible impression material which sets by physical change. On applying heat, it softens and on cooling it hardens. It is mainly used for making impressions of edentulous ridges. A more viscous variety of compound (tray compound) is used to form a tray in which a second more fluid material is placed to make a more detailed impression impression compound.

Synonyms Modeling compound or modeling plastic.

CLASSIFICATION

Type I - Impression compound
Type II - Tray compound

Type II: Tray compound is used to prepare a tray for making an impression. A second material is then carried in it in order to make an impression of oral tissues. Since reproduction of the fine details is not essential, it is generally stiffer and has less flow than regular impression compound.

SUPPLIED AS

Supplied as sheets, sticks, cakes and cones in a variety of colors (***Fig. 11.1***).

APPLICATIONS

1. For making a preliminary impression in an edentulous (mouth without teeth) mouth
2. For individual tooth impression } Type I
3. Peripheral tracing or border moulding }
4. To check undercuts in inlay preparation
5. To make a special tray Type II

Single Tooth Impression

In conservative dentistry, an impression is made of a single tooth in which a cavity is prepared. The compound is softened and carried in a copper band. The filled band is pressed over the tooth and the compound flows into the prepared cavity. It is referred to as a *tube impression.* Tube impressions were also used to make electroformed dies.

Complete Denture Impressions

In complete denture fabrication, it is common to make two sets of impressions — the *preliminary* and the *final impression.* The preliminary impression is made

Figure 11.1: Impression compound cakes and sticks.

in a stock tray. A study cast made from this is used to construct a custom tray or special tray. The custom tray is used to make the final impression. The technique of making a preliminary and final impression greatly improves the accuracy of the complete denture.

REQUIREMENTS OF IDEAL IMPRESSION COMPOUND

It should:

- Harden at or little above mouth temperature.
- Be plastic at a temperature not injurious or harmful to oral tissues.
- Not contain irritating or toxic ingredients.
- Harden uniformly when cooled without distortion.
- Have a consistency when softened which will allow it to reproduce fine details.
- Be cohesive but not adhesive.
- Not undergo permanent deformation or fracture while withdrawing the impression from the mouth.
- Be dimensionally stable after removal from the mouth and during storage.
- Exhibit a smooth glossy surface after flaming.
- Withstand trimming with sharp knife without flaking or chipping after hardening.
- Should not boil and lose volatile components on flaming.
- Should remain stable without losing soluble plasticizers when immersed in water for long periods.

COMPOSITION

In general impression compound is a mixture of waxes, thermoplastic resins, organic acids, fillers and coloring agents.

Ingredients	*Parts*
Resin	30
Copal resin	30
Carnauba wax	10
Stearic acid	5
Talc	25
Coloring agent (e.g., rouge)	

Plasticizers Compounds such as shellac, stearic acid and gutta-percha are added to improve plasticity and workability. These substances are referred to as *plasticizers*. Synthetic resins are being used in increasing amounts. Waxes and resin give the material its characteristic thermoplastic properties.

Fillers These are small particles of inert materials which strengthen or improve the physical properties of many materials. Fillers are chemically different from the principal ingredient. In such a case the filler particles are sometimes referred to as the core and the surrounding ingredients as the matrix. For example, the waxes and resins in impression compound impart high flow and low strength. Consequently, a filler such as talc is added to reduce the plasticity and increase strength of the matrix material. Other fillers used are diatomaceous earth, soap stone and French chalk.

PROPERTIES OF IMPRESSION COMPOUND

FUSION TEMPERATURE

When impression compound is heated in a hot water bath the material *starts to soften* at approximately 39°C. However at this stage, it is still not plastic or soft enough for making an impression. This temperature at which the material looses its hardness or brittleness on heating or forms a rigid mass upon cooling is referred to as *fusion temperature*. Impression compound exhibits a fusion temperature range rather than a fixed point.

On continued heating above 43.5°C, the material continues to soften and flow to a plastic mass that can be manipulated. Thus all impressions with compound should be made above this temperature. Below this temperature an accurate impression cannot be expected.

THERMAL PROPERTIES

Thermal Conductivity

Impression compound has very low thermal conductivity, i.e., they are poor conductors of heat.

Significance

- During softening of the material, the outside will soften first and the inside last. So to ensure uniform softening the material should be kept immersed for a sufficient period in a water bath. Kneading of the material ensures further uniform softening.
- The low thermal conductivity affects the cooling rate. The layer adjacent to the oral tissues cools faster than the inside. Removal of the impression at this stage can cause serious distortion. Thus it is important to wait for the compound to cool thoroughly before removing it from the mouth.

Coefficient of Thermal Expansion (CTE)

The CTE of compound is comparatively high due to the presence of resins and waxes. The linear contraction from mouth temperature to room temperature is 0.3%. *Errors from thermal distortion can be reduced:* (i) By obtaining an impression and then passing the impression over a flame until the surface is softened and then obtaining a second impression. During the second impression, the shrinkage is relatively lower, since only the surface layer has been softened, (ii) Another way of reducing the thermal contraction is by spraying cold water on the metal tray just before it is inserted in the mouth. Thus the material adjacent to the tray will be hardened, while the surface layer is still soft. In both techniques, the impression is likely to be stressed considerably and so the stone cast should be constructed at the earliest.

FLOW

Flow of the impression material could be advantageous as well as harmful. Good flow is desirable during impression making. The softened material should flow into all the details of the tissue contour. Once the compound hardens, it should have minimum flow, otherwise it will get distorted.

DIMENSIONAL STABILITY

Since the release of strains is unavoidable, the safest way to prevent distortion is to *pour the cast immediately* or at least within the hour. Another cause of warpage is removal of the impression too early from the mouth.

DETAIL REPRODUCTION

Surface detail reproduction is comparatively less because of its high viscosity and low flow. Because of the viscosity, pressure has to be used during impression, which compresses the tissues. Thus the tissues are recorded in a distorted state.

MANIPULATION

STICKS

Small amounts of compound (stick compound) can be softened over a flame (***Fig. 11.2***). When a direct flame is used, the compound should not be allowed to boil or ignite, otherwise, the plasticizers are volatilized.

CAKES

Larger amounts of compound are softened in warm water in a thermostatically controlled water bath (***Fig. 11.3***) usually in the range of 65 to 75°C. After the compound is removed from the water bath, it is usually kneaded with the fingers in order to obtain uniform plasticity throughout the mass.

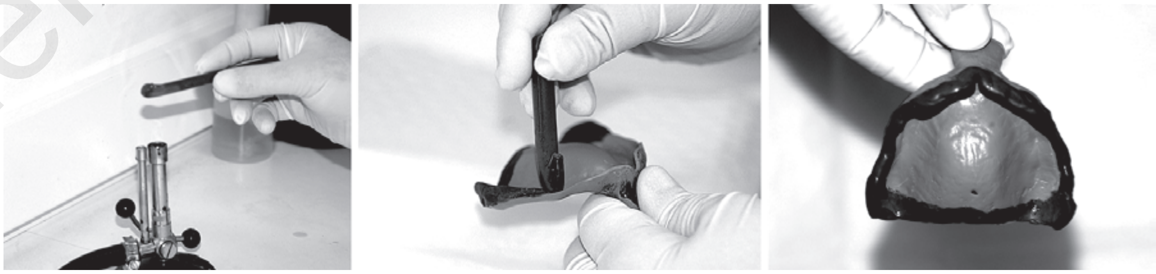


Figure 11.2: Manipulation of stick compound for border molding of a custom tray.

Figure 11.3: A thermostatically controlled water bath. This water bath maintains a steady softening temperature and is ideal for softening impression compound.

Figure 11.4: A slightly oversized stock metal tray.

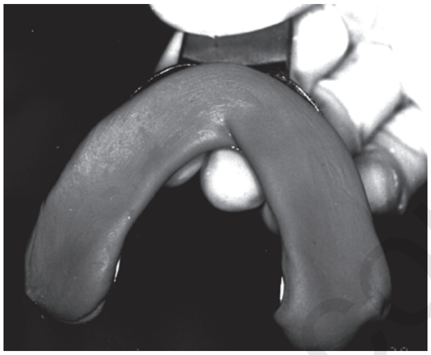


Figure 11.5: Placing the material in the tray is known as loading the tray.

Figure 11.6: Positioning the loaded tray over the ridges for the impression.

Loading the Tray

A slightly oversized tray is selected. The softened material is loaded onto the tray and quickly seated on to the tissues to be recorded (***Figs 11.4 to 11.6***). Any delay can cause the impression to harden prematurely. If the compound is too hot, it may be tempered by briefly immersing in slightly cooler water. The lips are manipulated to mold the borders of the impression while it is still soft.

Precautions

- Prolonged immersion in a water bath causes the compound to become brittle and grainy because some of the ingredients may be leached out.
- Overheating in water makes the compound sticky and difficult to handle.
- Avoid incorporating water while kneading.

REMOVAL OF IMPRESSION FROM THE MOUTH

The impression is removed from the mouth only after it has completely cooled and hardened.

DISINFECTION

The recommended disinfectant is 2% glutaraldehyde.

POURING THE CAST AND CAST SEPARATION

The cast should be poured without delay. The cast is separated from the impression by immersing it in warm water until it is soft enough. Excessively hot water is avoided as it can make the material sticky and difficult to remove from the cast.

ADVANTAGES

1. The material can be reused a number of times (for the same patient only) in case of errors.

2. Inaccurate portions can be remade without having to remake the entire impression.
3. Accuracy can be improved by flaming the surface.
4. The material has sufficient body to support itself especially in the peripheral portions. It does not collapse completely if unsupported by the tray.

DISADVANTAGES

1. Records less detail because of its high viscosity.
2. Compresses soft tissues during impression.
3. Distortion due to its poor dimensional stability.
4. Difficult to remove if there are severe undercuts.
5. There is always the possibility of overextension especially in the peripheries.

ZINC OXIDE EUGENOL IMPRESSION PASTE

Zinc oxide and eugenol based products are widely used in dentistry:

1. Cementing and insulating medium.
2. Temporary filling material.
3. Root canal filling material.
4. Surgical pack in periodontal surgical procedures.
5. Bite registration paste.
6. Temporary relining material for dentures.
7. Impressions for edentulous patients (***Fig. 11.7***).

In dentistry, zinc oxide eugenol is popular as an impression material for making impressions of edentulous arches for the construction of complete dentures. It is classified as a rigid, irreversible impression material. It cannot be used for recording impressions of dentate arches and in areas of severe undercuts.

Figure 11.7: Impressions of the upper (right) and lower (left) edentulous arches made with zinc oxide eugenol impression paste in custom trays.

CLASSIFICATION

ADA specification No. 16.

- Type I or Hard
- Type II or Soft

AVAILABLE AS

In paste form in two tubes ***(Fig. 11.8)***

- Base paste (white in color).
- Accelerator or reactor or catalyst paste (red in color).

COMPOSITION

Base Paste			*Accelerator paste*		
Zinc oxide	—	87%	Oil of cloves or eugenol	—	12%
Vegetable or mineral oil	—	13%	Gum or polymerized rosin	—	50%
			Filler (Silica type)	—	20%
			Lanolin	—	3%
			Resinous balsam	—	10%
			Calcium chloride and color	—	5%

Zinc oxide should be finely divided and should contain slight amount of water.

Fixed vegetable or *mineral oil* acts as plasticizer and also aids in masking the action of eugenol as an irritant.

Oil of cloves contains 70-85% eugenol. It is sometimes used in preference to eugenol because it reduces burning sensation.

Gum or polymerized rosin speeds the reaction and improves homogeneity.

Canada and Peru balsam improves flow and mixing properties.

Calcium chloride acts as an accelerator of setting reaction.

Other accelerators are: 1. Zinc acetate
2. Primary alcohols
3. Glacial acetic acid

SETTING REACTION

The setting reaction is a typical acid-base reaction to form a chelate. This reaction is also known as *chelation* and the product is called *zinc eugenolate.*

1. $ZnO + H_2O \longrightarrow Zn(OH)_2$

2. $$\begin{array}{lllllll} Zn(OH)_2 & + & 2HE & \longrightarrow & ZnE_2 & + & 2H_2O \\ \text{(Base)} & & \text{(Acid)} & & \text{(Salt)} & + & \text{(Water)} \\ & & \text{(Eugenol)} & & \text{(Zinc eugenolate)} & & \end{array}$$

Figure 11.8: DPI (India) and SS white (USA) are examples of two commercially available zinc oxide eugenol impression pastes (*Courtesy:* KDC, Kannur).

MICROSTRUCTURE

The chelate (zinc eugenolate) forms a matrix surrounding a core of zinc oxide particles. The chelate is thought to form as an amorphous gel that tends to crystallize giving strength to the set mass. Formation of crystalline zinc eugenolate is greatly enhanced by zinc acetate dehydrate (accelerator) which is more soluble than $Zn(OH)_2$ and can supply zinc ions more rapidly.

SETTING TIME

Working Time

There should be sufficient time for mixing, loading onto the tray and seating the impression into the mouth.

Setting Time

Once the material is in place, it should set fast.

Why should an impression material set quickly in the mouth? Any material which takes a long time to set in the mouth:

- Would obviously be uncomfortable to the patient.
- Movement is bound to occur, resulting in stresses and errors in the impression.
- Result in a wastage of time for the dentist. In a busy practice, this is unacceptable.

Initial setting time is the period from the beginning of the mixing until the material ceases to pull away or string out when its surface is touched with a metal rod of specified dimensions. The impressions should be seated in the mouth before the initial set.

The final set occurs when a needle of specified dimension fails to penetrate the surface of the specimen more than 0.2 mm under a load of 50 gm.

	Initial setting time	*Final setting time*
Type I	3-6 minutes	10 minutes
Type II	3-6 minutes	15 minutes

Factors Controlling Setting Time

1. *Particle size of zinc oxide powder:* If the particle size is small and if it is acid coated, the setting time is less.
2. By *varying the lengths* of the two pastes (not recommended).
3. Setting time can be decreased by adding *zinc acetate* or a drop of water or *acetic acid* (acetic acid is a more effective than water. It increases speed of formation of the zinc hydroxide).
4. Longer the *mixing time,* shorter is the setting time.
5. High atmospheric *temperature* and *humidity* accelerate setting.
6. Setting can be delayed by *cooling* the mixing slab, spatula or adding small amounts of *retarder* or *oils* or *waxes.*

PROPERTIES

CONSISTENCY AND FLOW

These are clinically important properties. A paste of thick consistency can compress the tissues. A thin free flowing material copies the tissues without distorting them.

According to ADA specification No. 16, the spread is:

Type I pastes — 30 to 50 mm
Type II pastes — 20 to 45 mm

Clinically, these materials have a very good flow. Poor quality impression pastes, thicken unduly and have a poor flow.

DETAIL REPRODUCTION

It registers surface details quite accurately due to the good flow.

RIGIDITY AND STRENGTH

The impression should resist distortion and fracture when removed from the mouth after setting. The compressive strength of hardened ZOE is approximately 7 MPa two hours after mixing.

DIMENSIONAL STABILITY

The dimensional stability is quite satisfactory. A negligible shrinkage (less than 0.1%) may occur during hardening.

BIOLOGICAL CONSIDERATIONS

Some patients experience a burning sensation in the mouth due to eugenol. It can also cause tissue irritation. Non-eugenol pastes can be substituted.

MANIPULATION

The mixing is done on an oil-impervious paper or glass slab. Two ropes of paste of *same length and width*, one from each tube are squeezed onto the mixing slab (***Fig. 11.9)***. A flexible stainless steel spatula is used. The two ropes are collected with the spatula and mixed until a uniform color is observed (***Figs 11.10 A and B***).

Mixing time 1 minute.

Mechanical mixing A rotary mixing device can also be used (***Fig. 11.11***). Special circular mixing pads are attached to the circular table of the device. After dispensing the material, the machine is switched on. As the table rotates, the operator first collects the material using the sides of the spatula. He then spreads the material by flattening the spatula. The process of collecting and flattening is repeated

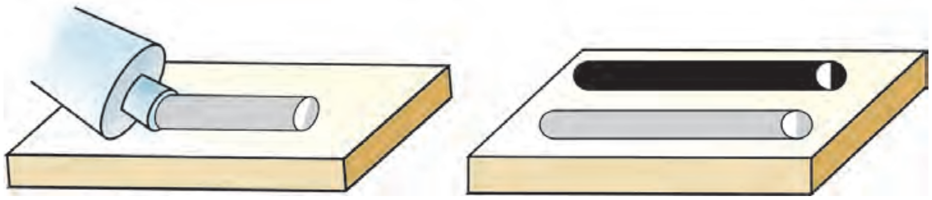


Figure 11.9: Proper dispensing is an important aspect of the manipulation of materials supplied in tubes. For zinc oxide eugenol both the ropes should be of equal length and width in order to ensure correct proportioning. One way of obtaining this is by ensuring the extruded paste has a uniform width and length.

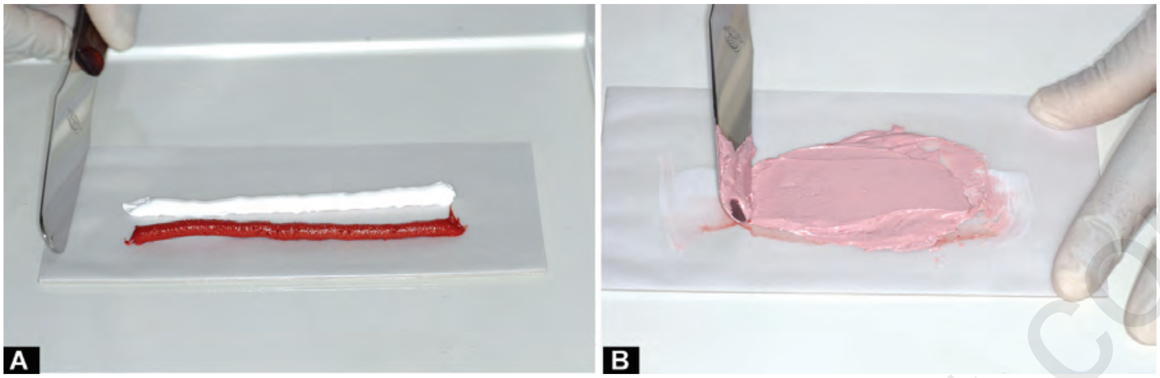


Figure 11.10: Manipulation of zinc oxide eugenol paste: (A) Equal lengths of base and reactor pastes are dispensed. (B) Mixing is done with a stainless steel spatula using circular motions until a streak free mix is obtained (Manufacturers usually provide such materials in contrasting colors to aid in visually ascertaining completion of mix).

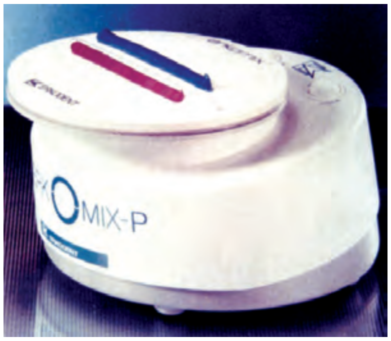


Figure 11.11: Mechanical mixer.

alternately until a uniform mix is obtained. Mechanical mixing gives a faster, uniform mix with less voids and bubbles.

IMPRESSION TRAY

Custom impression tray made of stable resin is recommended for zinc oxide eugenol. The material adheres to the tray so no special adhesive is required. A primary compound impression can also be used as a tray. The material is loaded into the tray by swiping on to the sides of the tray and then spread in a smooth uniform motion. Loading and spreading through a patting motion can trap air.

DISINFECTION

The impression is rinsed and placed in disinfectant solution. Rinsing removes saliva and other contaminants. The recommended disinfectant solution is 2% gluteraldehyde solution.

POURING THE IMPRESSION

As with most impression materials the pouring of the cast should not be delayed for too long. After setting, the impression is removed off the cast after softening it through immersion in hot water.

ADVANTAGES

1. It has sufficient body so as to make-up for any minor under extensions in the tray itself during impression making.
2. It has enough working time to complete border moulding.
3. It can be checked in the mouth repeatedly without deforming.
4. It registers accurate surface details.
5. It is dimensionally stable.
6. Does not require separating media since it does not stick to the cast material.
7. Minor defects can be corrected locally without discarding a good impression.

DISADVANTAGES

1. It requires a special tray for impression making.
2. It is sticky in nature and adheres to tissues.
3. Eugenol can cause burning sensation and tissue irritation.
4. It cannot be used for making impression of teeth and undercut areas as it is inelastic in nature.

OTHER ZINC OXIDE PASTES

SURGICAL PASTES (PERIODONTAL PACKS)

After certain periodontal surgeries (e.g., gingivectomy, i.e., surgical removal of diseased gingival tissues) where sutures cannot be placed, a zinc oxide based surgical paste (***Fig. 11.12***) may be placed over the wound to aid in the retention of the medicament, to protect the wound and to promote healing (also known as periodontal pack). Earlier pastes were eugenol based and have been around since 1923 (Ward's Wondrpak). Current surgical pastes avoid eugenol because of the potential of tissue irritation. These are called noneugenol pastes.

NONEUGENOL IMPRESSION AND SURGICAL PASTES

The chief disadvantage of zinc oxide eugenol paste is the burning sensation caused by eugenol. Some patients find the taste of eugenol disagreeable and in cases where the surgical pack is worn for several weeks chronic gastric disturbance may result. Hence noneugenol pastes were developed.

Noneugenol pastes consist of a base and reactor paste. The base paste contains ZnO, gum and lorothidol (fungicide). The reactor pastes contains coconut fatty acids, rosin (thickening), chlorothymol (bacteriostatic), etc. Antibiotics like tetracycline may be incorporated at the time of mixing.

Here, the zinc oxide is reacted with a carboxylic acid.

$$\mathrm{ZnO} + 2\mathrm{RCOOH} \longrightarrow (\mathrm{RCOO})_2\,\mathrm{Zn} + \mathrm{H_2O}$$

The reaction is not greatly affected by temperature or humidity.

Compared to impression pastes the surgical pastes are less brittle and weaker after hardening. The setting time is longer (around 15 minutes). They are

Figure 11.12: COE-PAK is a popular brand of periodontal dressing material.

Figure 11.13: Bite registration paste.

available as a 2 paste system. The paste is mixed and formed into a rope that is packed over the gingival wounds (using wet fingers) and into the interproximal spaces to provide retention. The final product after setting should be sufficiently strong so that it is not readily displaced during mastication. Light cured periodontal dressing materials and single component pastes (that set by heat and moisture in the mouth are also available). An automixing cartridge version of Coe-PAK is also available.

BITE REGISTRATION PASTES

These are materials used for recording the occlusal relationship between two occluding surfaces, e.g., teeth, occlusion rims, etc. ZOE pastes (***Fig. 11.13)*** used for this purpose have slightly different properties:

- Shorter setting time to prevent distortion.
- More plasticizers to prevent it from sticking to the teeth or occlusion rims.

Other bite registration materials include wax and silicones. ZOE registrations are more rigid than registrations made in wax or silicones. They are more stable, and offer less resistance to the closing of the jaw than wax.

12

ELASTIC IMPRESSION MATERIALS — AGAR AND ALGINATE

The rigid impression materials described till now are best suited for recording edentulous areas. Teeth or severe undercuts if present, would make the removal of such impressions difficult. The impression could distort or fracture on removal.

The ideal impression material for accurately reproducing tooth form and relationship would be an elastic substance which can be withdrawn from the undercut area and return to its original form without any distortion.

By definition, an elastic impression material is one that can transform from a semisolid, nonelastic state to a highly elastic solid state.

TYPES OF ELASTIC IMPRESSION MATERIALS

Two systems are used:

1. Hydrocolloids
2. Elastomeric materials

HYDROCOLLOIDS

SOLUTION AND SUSPENSION

In a *solution* (e.g., sugar in water) one substance, usually a solid is dispersed in another, usually a liquid and the two phases are microscopically indistinguishable. Thus, a solution exists as a single phase because there is no separation between the solute and the solvent.

A *suspension* on the other hand, consists of larger particles that can be seen under a microscope or even by the naked eye, dispersed in a medium. Similarly, liquid distributed in liquids are *emulsions*. Suspensions and emulsions are two phase systems.

COLLOIDS

They are often classed as the fourth state of matter known as colloidal state. A colloid is a two-phase system. The 'colloidal solution' or 'colloidal sol' is somewhere between the smaller molecules of a solution and the larger particles of a suspension.

The two phases of the colloidal sol are:

- Dispersed phase or dispersed particle (the suspended particle).
- Dispersion phase or medium (the substance in which it is suspended).

Types of Colloids

Colloidal sols may be:

- Liquid or solid in air (Aerosol)
- Gas, liquid or solid in liquid (Lyosol)
- Gas, liquid or solid in solid.

HYDROCOLLOIDS

They consist of gelatin particles suspended in water (Lyosol). Since water is the dispersion medium it is known as hydrocolloid. The particles are larger than those in solutions and size ranges from 1-200 nanometers (1 nm = 10^{-9} m). There is no clear demarcation between solutions, colloids and suspensions (emulsions).

GELS, SOLS, GELATION

Colloids with a liquid as the dispersion medium can exist in two different forms known as 'Sol' and 'Gel'. A *Sol* has the appearance and many characteristics of a viscous liquid. A *Gel* is a jelly like elastic semisolid and is produced from a sol by a process called *gelation* by the formation of fibrils or chains or micelles of the dispersed phase which become interlocked. Gelation is thus the conversion of a sol to gel. The dispersion medium is held in the interstices between the fibrils by capillary attraction or adhesion.

Gelation may be brought about in one of the two ways:

1. Lowering the temperature, e.g., Agar.
2. By a chemical reaction, e.g., Alginate.

Gel Strength

The gel strength depends on:

- Density of the fibrillar structure: Greater the concentration, greater will be the number of micelles and hence greater the brush heap density.
- Filler particles trapped in the fibrillar network. Their size, shape and density determine their effectiveness. Fillers also increases the viscosity of the sol.
- In reversible hydrocolloids, the lower the temperature, the greater is the strength, as gelation is more complete.

Types of Hydrocolloids

Based on the mode of gelation, they are classified as:

Reversible hydrocolloids They are called reversible because their physical state can be reversed. This makes them reusable.

Irreversible hydrocolloids Once these set, it is usually permanent, and so are known as irreversible.

REVERSIBLE HYDROCOLLOIDS—AGAR

In 1925, *Alphous* Poller of Vienna was granted a British patent for a totally different type of impression material. Poller's material was later described by skinner as colloidal sols of emulsoid type. It is said that Poller's objective was to develop a material that could be sterilized and applied without pressure to the exposed surface of the dura mater for perfectly recording its convulsion and the bony margins of the skull. Later Poller's *Negacol* was modified and introduced to the dental profession as *Dentacol* in 1928.

Figure 12.1: Gelidium seaweed. Agar has been used for centuries in Asia where it is called ‘kanten’ by the Japanese and ‘dongfen’ by the Chinese. It was brought to Malaysia by Chinese immigrants where it came to be known as agar.

Agar hydrocolloid was the first successful elastic impression material to be used in dentistry. It is an organic hydrophilic colloid (polysaccharide) extracted from a type of *seaweed (Gelidium, Gracilaria, etc.,* ***Fig. 12.1****)*. China and South America are major sources of farmed seaweed.

Agar is a sulfuric ester of a linear polymer of galactose. Although it is an excellent impression material and yields accurate impressions, presently it has been largely replaced by alginate hydrocolloid and rubber impression materials.

CLASSIFICATION (ISO 1564: 2001)

Type I – High consistency (for use as tray material)
Type II – Medium consistency (for use as tray or syringe material)
Type III – Low consistency (for syringe use only)

USES

1. Widely used at present for cast duplication (e.g., during the fabrication of cast metal removable partial dentures, etc.).
2. For full mouth impressions without deep undercuts.
3. It was used extensively for FPD impressions prior to elastomers.
4. As a tissue conditioner.

SUPPLIED AS

- ➢ Gel in collapsible tubes (for impressions).
- ➢ As cartridges or gel sticks (syringe material, ***Fig. 12.2***).
- ➢ In bulk containers (for duplication, ***Figs 12.3 A and B***).

Commercial names Syringe materials include—Herculloid, Cartriloids (Van R), etc. Duplicating materials include Wirogel (Bego), Dubliform (Dentaurum).

Figures 12.3 A and B: (A) Agar duplication gel sample, (B) in bulk packing.

Figure 12.2: Agar impression syringe and syringe material.

COMPOSITION

Ingredients	*Percentage by Weight*
Agar	13 - 17 %
Borates	0.2 - 0.5 %
Potassium sulphate	1 - 2 %
Wax, hard	0.5 - 1 %
Thixotropic materials	0.3 - 0.5 %
Alkylbenzoates	0.1 %
Coloring and flavoring agents	Traces
Water	Balance (around 84%)

FUNCTIONS OF THE INGREDIENTS

Agar Basic constituent 13-17% for tray material 6-8% for syringe material.

Borates Improves the strength of the gel, (it also retards the setting of plaster or stone cast when poured into the finished impression - a disadvantage).

Potassium sulphate It counters retarding effect of borates, thereby ensures proper setting of the cast or die.

Hard Wax It acts as a filler. Fillers affect the strength, viscosity and rigidity of the gel. Other fillers are zinc oxide, diatomaceous earth, silica, rubber, etc.

Thixotropic materials It acts as plasticizer. Examples are: Glycerine, and Thymol. Thymol acts as bactericide also.

Alkylbenzoates It acts as preservative.

Coloring and flavoring For patient comfort and acceptance.

Water It acts as the dispersion medium.

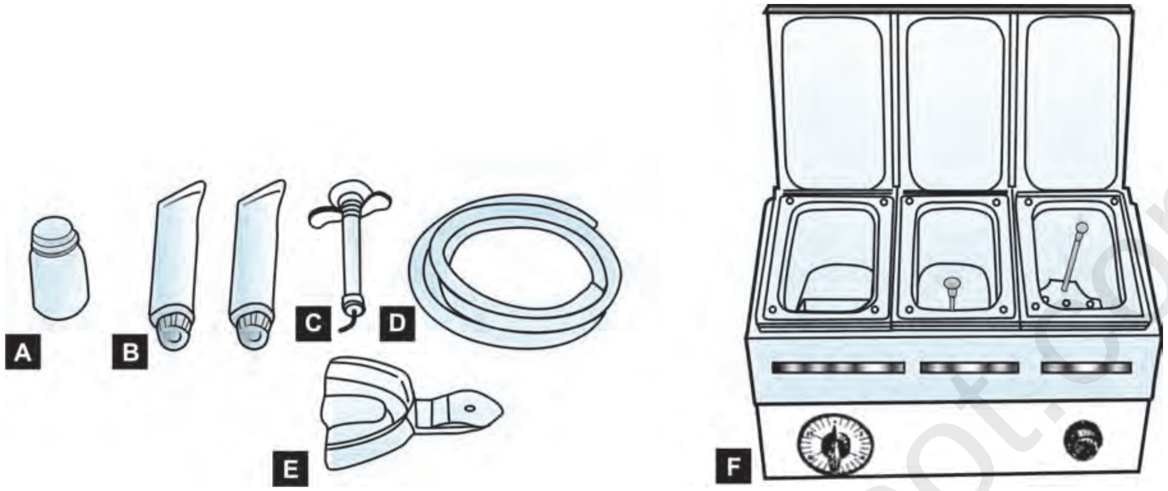
GELATION OR SETTING OF AGAR

Agar changes from the sol to the gel state (and vice versa) by a physical process. As the agar sol cools the dispersed phase groups to form fibrils called *micelles*. The fibrils branch and intermesh together to form a brush-heap structure. The fibrils form weak covalent bonds with each other which break easily at higher temperatures resulting in gel turning to sol. The process of converting gel to sol is known as liquefaction which occurs at a temperature between 70 and 100° C. On cooling agar reverses to the gel state and the process is called gelation. Gelation occurs at or near mouth temperature which is necessary to avoid injury to oral tissues.

MANIPULATION

The equipment and material required for an agar impression are:

- Hydrocolloid conditioner (***Fig. 12.4 F***)
- Water cooled rim lock trays (***Figs 12.4 E and 12.5***)
- Impression syringes (***Figs 12.3 and 12.4 C***)
- Connecting water hose (***Fig. 12.4 D***)
- Agar tray material in tubes (***Fig. 12.4 B***)
- Agar syringe material (***Figs 12.3 and 12.4 A***)



Figures 12.4 A to F: Typical equipment and material for an agar impression procedure.

The Hydrocolloid Conditioner

Boiling section or Liquefaction section	Ten minutes in boiling water (100°C). The sol should be homogeneous and free of lumps. Everytime the material is liquefied, three minutes should be added. After every use the agar brush heap structure gets more difficult to break.
Storage section	65-68°C temperature is ideal. It can be stored in the sol condition.
Tempering section	46°C for about two minutes with the material loaded in the tray. This reduces the temperature so that it is tolerated by the sensitive oral tissues. It also makes the material viscous.

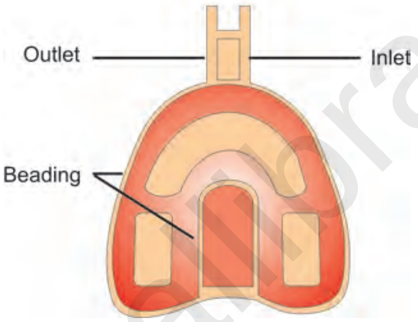


Figure 12.5: A water cooled tray.

IMPRESSION TRAYS

Rim lock trays with water circulating devices are used. The rim lock is a beading on the inside edge of the tray which helps to retain the material (as agar does not adhere to the tray). It also has an *inlet* and *outlet* for connecting the water tubes (***Fig. 12.5)***. The tray should allow a space of 3 mm occlusally and laterally and extend distally to cover all teeth.

MAKING THE IMPRESSION

The tray containing the tempered material is removed from the bath. The outer surface of the agar sol is scraped off, then the water hoses are connected and the tray is positioned in the mouth by the dentist. Water is circulated at 18 to 21° C through the tray until gelation occurs. *Rapid cooling* (e.g., ice cold water) is not recommended as it can induce distortion. To guide the tray into position, three *stops* of compound are prepared on non-involved teeth. A *post dam* is constructed with compound to prevent distal flow of the impression material. In a deep palate case, compound is placed on the palatal aspect of the tray in order to provide a uniform thickness of the hydrocolloid. The mandibular tray is prepared by placing compound on the distal aspect to limit the impression material. Black tray compound is used as it is not affected in the tempering bath.

WORKING AND SETTING TIME

The working time ranges between 7-15 minutes and the setting time is about 5 minutes. Both can be controlled by regulating the flow of water through the cooling tubes. Since the cooling tubes are on the periphery, the material sets from the periphery towards the teeth surfaces.

REMOVAL OF IMPRESSION

When the agar has gelled, the peripheral seal is broken, and the impression is removed from the mouth rapidly. The impression is rinsed thoroughly with water and the excess water is removed by shaking the impression.

STORAGE OF AGAR IMPRESSION

Storage of agar impression is to be avoided at all costs. The cast should be poured immediately. Storage in air results in dehydration, and storage in water results in swelling of the impression. Storage in 100% relative humidity results in shrinkage as a result of continued formation of the agar network agglomeration. If storage is unavoidable, it should be limited to one hour in 100% relative humidity.

SEPARATION FROM CAST

When the gypsum product has set, the agar impression must be removed promptly since the impression will dehydrate, become stiff and difficult to remove. Weaker portions of the model may fracture. In addition, prolonged contact will result in a rougher surface on the model.

PROPERTIES OF AGAR HYDROCOLLOIDS

The ISO 1564:1995 sets the standard for properties required of the available Agar-Hydrocolloid impression materials.

GELATION, LIQUEFACTION AND HYSTERESIS

Most materials melt as well as resolidify at the same temperature. However in agar this does not coincide. Gelation (solidification) occurs at 37°C approximately, whereas liquefaction (melting) occurs at a higher temperature, i.e., 60 to 70°C higher than the gelation temperature. This temperature lag between liquefaction and gelation is known as *hysteresis.*

SYNERESIS AND IMBIBITION (DIMENSIONAL STABILITY)

Since hydrocolloids use water as the dispersion medium, they are prone for dimensional change due to either loss or gain of water. If left in a dry atmosphere, water is lost by syneresis and evaporation, and if it is immersed in water, it absorbs water by a process known as *imbibition.*

The exuding of fluid from the gel is known as *syneresis.* Some of the more soluble constituents are also lost. During syneresis small droplets of exudate are formed on the surface of the hydrocolloid and the process occurs irrespective of the humidity of the surrounding atmosphere.

Agar exhibits the properties of syneresis and imbibition. *However, when immersed in water they do not imbibe more than original content which was lost by evaporation (unlike alginates).*

Importance Syneresis and imbibition can result in dimensional changes and therefore inaccurate casts. To avoid this hydrocolloid impressions should be poured immediately.

FLEXIBILITY

The flexibility of the gel is between 4-15%, when a stress of 14.2 psi is applied. A few set materials, however, have a flexibility of 20%. On an average a flexibility of 11% is desirable.

ELASTICITY AND ELASTIC RECOVERY

They are highly elastic and elastic recovery occurs to the extent of 98.8%.

GEL STRENGTH INCLUDING TEAR AND COMPRESSIVE STRENGTHS

The gel can withstand great stresses particularly shear stress, without flow, provided the stress is applied rapidly. Thus the impression should be removed as rapidly as possible in order to avoid distortion.

Agar has a tear strength of 0.8 to 0.9 kN/m and compressive strength of 0.5 to 0.9 gm/cm^2. According to ISO 1564:1999 specification for agar, compressive strength should not be less than 35.6 psi. The above values are for tray materials. The syringe materials have poorer mechanical properties.

Factors affecting strength

1. The composition—agar concentration, borate and filler content, etc.
2. The temperature—the lower the temperature the greater the strength.

FLOW

The material is sufficiently fluid to record the fine details if correctly manipulated.

REPRODUCTION OF DETAIL

A reproduction of a groove of 25 µm (micrometers) is achievable with agar.

ACCURACY AND DIMENSIONAL CHANGE

Some contraction takes place during gelation. If the material is retained well in the tray, the material contracts towards the tray resulting in larger dies. Agar impressions are highly accurate at the time of removal from the mouth, but shrink when stored in air or 100% relative humidity and expand when stored in water. The least dimensional change occurs when the impressions are stored in 100% humidity (for not more than one hour). However, *prompt pouring* of plaster or stone models is recommended.

LAMINATE TECHNIQUE (AGAR-ALGINATE COMBINATION TECHNIQUE)

After injecting the syringe agar on to the area to be recorded, an impression tray containing a mix of chilled alginate that will bond with the agar is positioned over it. The alginate gels by a chemical reaction, whereas the agar gels through contact with the cool alginate rather than the water circulating through the tray.

Advantages

1. The syringe agar gives better details than alginate.
2. Less air bubbles.
3. Water cooled trays are not required and therefore more convenient.
4. It sets faster than the regular agar technique.

Figures 12.6 A to C: (A) The agar hydrocolloid duplicating machine liquefies the agar using heat. Rotating blades in the machine further break up the agar, (B) Liquefied agar is poured into a duplicating flask, (C) which holds the cast.

WET FIELD TECHNIQUE

In this technique the areas to be recorded are actually flooded with warm water. Then the syringe material is introduced quickly, liberally, and in bulk to cover the occlusal and/or incisal areas only. While the syringe material is still liquid, the tray material is seated. The hydraulic pressure of the viscous tray materials forces the fluid syringe hydrocolloid down into the areas to be recorded. This motion displaces the syringe materials as well as blood and debris throughout the sulcus.

CAST DUPLICATION

With the introduction of alginate, agar slowly lost its appeal as an impression material. However, it is still popular as a duplicating material primarily because:

- When liquefied it flows readily (like a fluid) over the cast to be duplicated. This makes it an ideal mould material.
- Large quantities can be prepared relatively easily.
- It is economical because it can be reused.

The agar is broken into small chunks and loaded into the liquefying machine (***Figs 12.6 A to C***) where it is liquefied and stored. The liquid agar is poured into a mould former to create a mould. Later, investment is poured into this to create a *refractory cast* which is used in the fabrication of the cast partial denture framework.

IMPRESSION DISINFECTION

Since the impression has to be sent to the laboratory, the need to disinfect it is very important. Most manufacturers recommend a specific disinfectant. The agent may be iodophor, bleach or glutaraldehyde. Apparently little distortion occurs if the recommended immersion time is followed and if impression is poured promptly.

ADVANTAGES AND DISADVANTAGES OF AGAR HYDROCOLLOID

Advantages

1. Accurate dies can be prepared, if the material is properly handled.
2. Good elastic properties help reproduce most undercut areas.

3. It has good recovery from distortion.
4. Hydrophilic, moist mouth not a problem. It also gives a good model surface.
5. It is palatable and well tolerated by the patient.
6. It is economical when compared to synthetic elastic materials.
7. It can be reused when used as a duplicating material (reuse is not recommended when used as impression material).
8. Low cost because it can be reused.

Disadvantages

1. Does not flow well when compared to newly available materials.
2. It cannot be electroplated.
3. During insertion or gelation the patient may experience thermal discomfort.
4. Tears relatively easily. Greater gingival retraction is required for providing adequate thickness of the material.
5. Only one model can be poured.
6. Has to be poured immediately. Cannot be stored for too long.
7. Requires special and expensive equipment.
8. A soft surface of the gypsum cast results unless a plaster hardener is used.
9. Although it can be reused, it is impossible to sterilize this material. Also with repeated use there may be contamination of the materials and a deterioration in its properties.

IRREVERSIBLE HYDROCOLLOID—ALGINATE

The word alginate comes from 'alginic acid' (anhydro-β-d-mannuronic acid) which is a mucous extract yielded by species of brown seaweed (*Phaeophyceae*). Alginic acid is a naturally occurring hydrophilic colloidal polysaccharide.

Alginate was developed as a substitute for agar when it became scarce due to World War II (Japan was a prime source of agar). Currently alginate is more popular than agar for dental impressions, because it is simpler to use. Alginate is perhaps the most widely used impression material in the world.

TYPES

Type I — Fast setting.
Type II — Normal setting.

SUPPLIED AS

A powder that is packed:

- Commonly in bulk packing (tins, bins or sachets) ***(Fig. 12.7)***.
- In preweighed packets for individual impression (***Fig. 12.8)***.
- A plastic scoop is supplied for dispensing the bulk powder and a plastic cylinder is supplied for measuring the water.

Modified Alginates

- In the form of a *sol,* containing the water. A reactor of plaster of Paris is supplied separately.

Figure 12.7: Representative commercially available bulk packed alginate.

Figure 12.8: Preweighed sachet for individual impressions are also available. The one displayed in the illustration is a special low viscosity alginate for use with syringe (*Courtesy:* The dental center, Chennai).

- *As a two paste system* One contains the alginate sol, while the second contains the calcium reactor. These materials are said to contain silicone and have superior resistance to tearing when compared to unmodified alginates. They may be supplied in both tray and syringe viscosity.
- One product is supplied in low density for use with syringe (***Fig. 12.8)***
- *Dust free alginates* Concern over the inhalation of alginate dust have prompted manufacturers to introduce 'dust free alginates' (***Fig. 12.9***).
- *Chromatic alginates* Alginates which change color on setting (***Fig. 12.9***).

Commercial Names Zelgan (DPI), Jeltrate (Dentsply), Hydrogum (Zhermack), etc.

Figure 12.9: Other commercially available alginates including dust free (extreme left) and chromatic alginate (extreme right).

APPLICATIONS

1. It is used for impression making
   - —When there are undercuts.
   - —In mouths with excessive flow of saliva.
   - —For partial dentures with clasps.
2. For making preliminary impressions for complete dentures.
3. For impressions to make study models and working casts.
4. For duplicating models.

COMPOSITION

Ingredients	*% wt.*	*Function*
1. Sodium or potassium or triethanolamine alginate	15%	Dissolves in water and reacts with calcium ions
2. Calcium sulphate (reactor)	16%	Reacts with potassium alginate and forms insoluble calcium alginate
3. Zinc oxide	4%	Acts as a filler
4. Potassium titanium fluoride	3%	Gypsum hardener
5. Diatomaceous earth	60%	Acts as a filler
6. Sodium phosphate (retarder)	2%	Reacts preferentially with calcium sulphate
7. Coloring and flavoring agent	Traces	e.g., wintergreen, peppermint, anice, orange, etc.

SETTING REACTION

When alginate powder is mixed with water a sol is formed which later sets to a gel by a chemical reaction.

The final gel, i.e., insoluble *calcium alginate* is produced when soluble *sodium alginate* reacts with *calcium sulphate* (reactor). However, this reaction proceeds too fast. There is not enough working time. So the reaction is delayed by addition of a retarder (trisodium phosphate) by the manufacturer.

Calcium sulphate prefers to react with the retarder first. Only after the supply of the retarder is over does calcium sulphate react with sodium alginate. This delays the reaction and ensures adequate working time for the dentist.

In other words, two main reactions occur during setting:

$$2Na_3PO_4 + 3CaSO_4 \longrightarrow Ca_3(PO_4)_2 + 3Na_2SO_4$$

$$\underset{\text{(Powder)}}{\text{Sodium alginate}} + CaSO_4 + H_2O \longrightarrow \underset{\text{(Gel)}}{\text{Ca alginate}} + Na_2SO_4$$

Initially the sodium phosphate reacts with the calcium sulphate to provide adequate working time. Next after the sodium phosphate is used up, the remaining calcium sulphate reacts with sodium alginate to form insoluble calcium alginate which forms a gel with water.

Gel Structure

The final gel consists of a brush heap of calcium alginate fibril network enclosing unreacted sodium alginate sol, excess water, filler particles and reaction byproducts. It is a cross-linked structure (i.e., each fiber is tied to each other at certain points). Calcium is responsible for cross-linking.

PROPERTIES OF ALGINATE HYDROCOLLOID

TASTE AND ODOR

Alginate has a pleasant taste and smell. Over the years, manufacturers have added a variety of colors, odors and tastes to make it as pleasant as possible to the patient. Flavors include strawberry, orange, mint, vanilla, etc.

FLEXIBILITY

It is about 14% at a stress of 1000 gm/cm^2. However, some of the hard set materials have lower values (5 to 8%). Lower W/P ratio (thick mixes) results in lower flexibility (ADA Sp. No. 18/ISO 1563:1990 for alginate hydrocolloids).

ELASTICITY AND ELASTIC RECOVERY

Alginate hydrocolloids are highly elastic (but less when compared to agar) and about 98.2% elastic recovery occurs. Thus, permanent deformation is more for alginate (about 1.8%). Permanent deformation is less if the set impression is removed from the mouth quickly.

REPRODUCTION OF TISSUE DETAIL

Detail reproduction is also lower when compared to agar hydrocolloid. ADA Sp. requires the material to reproduce a line that is 0.075 mm in width. A number of products exceed this minimum value.

STRENGTH

Compressive strengths

— Ranges from 0.5 to 0.9 MPa

Tear strength

This is an important property for alginates. Values range from 0.4 to 0.7 kN/m

Factors affecting strength are

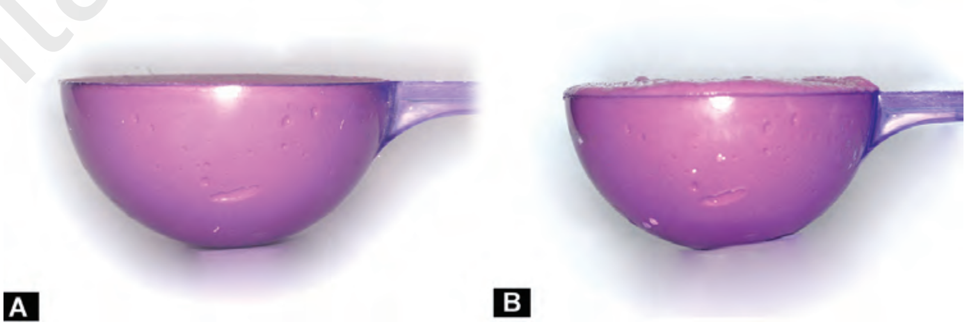
- *Water/powder ratio* Too much or too little water reduces gel strength.
- *Mixing time* Over and under mixing both reduce strength.
- *Time of removal of impression* Strength increases if the time of removal is delayed for few minutes after setting.

SYNERESIS AND IMBIBITION

Like agar-agar alginate also exhibits the properties of synerisis and imbibition. When placed in contact with water alginates absorb water and swell ***(Figs 12.10 A and B)***. Continued immersion in water results in the total disintegration of the alginate.

DIMENSIONAL STABILITY

Set alginates have *poor* dimensional stability due to evaporation, syneresis and imbibition. Therefore, the cast should be poured *immediately*. If storage is unavoidable, keeping in a humid atmosphere of 100% relative humidity (humidor) results in the least dimensional change.



Figures 12.10 A and B: Demonstration of imbibition: (A) Alginate shortly after setting, (B) The dimensional change is evident after a 48 hour storage in water.

BIOLOGICAL PROPERTIES

No known chemical or allergic reaction have been identified for alginate. Silica particles present in the dust which rises from the can after fluffing alginate powder, are a possible health hazard. Avoid breathing the dust. Some manufacturers supply *'dust free'* alginates. Dustless alginates contain glycol. It acts by coating the powder.

ADHESION

Alginate does not adhere well to the tray. Good adhesion is important for the accuracy of the impression. Retention to the tray is achieved by mechanical locking features in the tray or by applying an adhesive.

SHELF LIFE AND STORAGE

Alginate material deteriorates rapidly at elevated temperatures and humid environment.

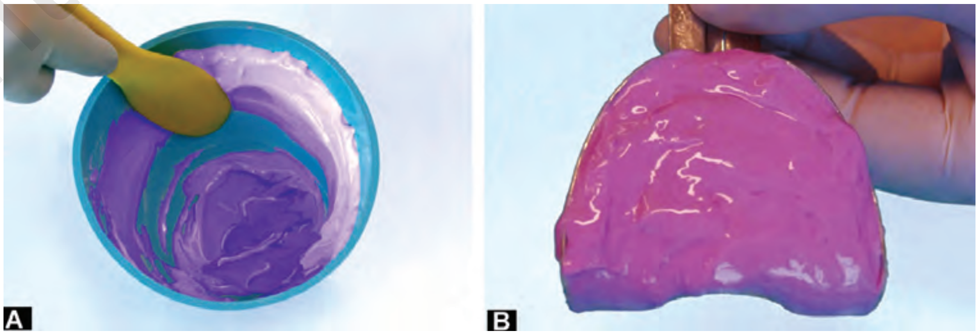
- The material should be stored in a cool, dry environment (not above 37°C).
- The lid of bulk package can, must be replaced after every use, so as to minimize moisture contamination.
- Stock only for one year.

MANIPULATION

- Fluff or aerate the powder by inverting the can several times. This ensures uniform distribution of the filler before mixing. The top of the can should be taken off carefully to prevent the very fine silica particles from being inhaled.
- Mixing equipment includes:
  - A clean flexible plastic bowl and
  - A clean wide bladed, reasonably stiff metal spatula.

Note: It is better to use separate bowls for plaster and alginate as plaster contamination can accelerate setting.

The proper W/P ratio as specified by the manufacturer should be used (usually one measure water with two level scoops of powder. The water measure and scoop are supplied by the manufacturer). The water is taken first. The powder is sprinkled in to the water in the rubber mixing bowl and the lid of the metal can is replaced immediately. The mixing is started with a stirring motion to wet the powder with water. Once the powder has been moistened, *rapid* spatulation by *swiping* or *stropping* against the side of the bowl is done. A vigorous figure - eight motion can also be used (***Figs 12.11 A and B)***.



Figures 12.11 A and B: (A) Alginate is mixed by stroping or swiping the material against the sides of the bowl, (B) The loaded tray.

Figure 12.12: Alginate mixing device.

This helps:

- Remove most of the air bubbles.
- Wipe dissolved algin from the surface of the yet undissolved algin thereby promoting complete dissolution.

Mechanical devices (***Fig. 12.12***) are available for spatulating alginate.

Their main advantages are:

1. Speed
2. Convenience
3. Elimination of the human variable.

A proper mix is smooth and creamy with minimum voids and does not drip off the spatula when it is raised from the bowl.

MIXING TIME

For fast set alginate - 45 seconds.
For normal set alginate - 60 seconds.

Over Mixing Results In

— Reduction in final strength as the gel fibrils are destroyed.
— Reduction in working time.

Under Mixing Results In

— Inadequate wetting, lack of homogeneity and reduced strength.
— The mix being grainy and poor recording of detail.

WORKING TIME

Fast set alginate — 1¼ minutes.
Normal set alginate: — 2 minutes.

GELATION TIME (SETTING TIME)

Type I (fast set) — 1.5-2.0 mins.
Type II (normal) — 3-4.5 mins.

Control of Gelation Time

Ideal gelation time is 3-4 minutes (at 20°C room temperature).

- Gelation time is best controlled by adding retarders (which is in manufacturer's hands).
- The dentist can best control the setting time by altering the *temperature* of the water for mixing alginate material.
  - Colder the water, the longer is the gelation time.
  - Warmer the water, the shorter is the gelation time.
  - Even the mixing bowl and spatula can be cooled.

Note Control of setting by changing W/P ratio is not recommended.

Figure 12.13: Tray with rim lock and perforations is recommended for alginate.

Figure 12.14: Tray adhesive improves the retention of the material to the tray.

Figure 12.15: Alginate is loaded using the sides of the tray to force the material in to the tray and through the perforations.

TRAY SELECTION

Since alginate has poor adhesion, tray selection is very important. Alginate can be retained by:

- Mechanical locking features in the tray
  - A rim lock (a beading round the edges of the tray)
  - Perforations (holes or slits) in the tray (***Fig. 12.13***)
- Applying adhesive (available as liquid or sprays) (***Fig. 12.14***)
- A combination of the above.

The tray should cover the entire impression area and provide a space of at least 3 mm on all sides.

LOADING THE TRAY

The mixed alginate is *pressed and swiped* (***Fig. 12.15***) into the perforated rim lock tray so that the material is forced out through the holes in the tray, thereby locking itself mechanically into the tray (***Fig. 12.16***).

The surface of the alginate in the tray may be smoothened out using a moist finger. However, this is not mandatory.

A small amount of material is taken on the index finger and applied on the occlusal surfaces of the teeth and on the rugae area. This help to reduce air voids and improve accuracy.

Figure 12.16: Alginate extruding through the holes helps in retention of the material to the tray.

Figure 12.17: The completed impression.

SEATING THE TRAY

Since the material sets from tissues towards periphery any movement during gelation may result in distortion. So once the tray is seated, it must be held in place firmly without any movement.

TIME OF REMOVAL AND TEST FOR SET

The alginate impression should be left in the mouth for at least 2-3 minutes after initial gelation. The strength and elasticity of the alginate gel continues to increase for several minutes after initial gelation.

Test for Set

The material loses its tackiness when set. It should rebound fully when prodded with a blunt instrument.

Color indicators Although chromatic alginates indicate a color change after setting, it is still best to test for set by prodding the material at the periphery with a blunt instrument.

REMOVAL OF THE IMPRESSION

An alginate impression when set, develops a very effective peripheral seal. This seal should be freed by running the finger round the periphery. In addition to holding the tray handles, additional displacing force may be applied with a finger on the buccal flange of the set material and tray. The impression must be removed as quickly as possible. The brush-heap structure of a gel responds more favorably to a sudden force. A gentle, long, continued pull will frequently cause the alginate to tear or separate away from the tray (***Fig. 12.18***). It also causes higher permanent deformation.

After removal from the mouth, the impression should be:

- Washed with cold water to remove saliva.
- Disinfected by immersion in a suitable disinfectant.
- Covered with a damp napkin to prevent drying.
- Cast should be poured as soon as possible, preferably within 15 minutes after making the impression.

IMPRESSION DISINFECTION

Disinfection of impression is a concern because of viral diseases such as hepatitis B, AIDS and herpes simplex. The viruses can contaminate the gypsum models and present a risk to dental laboratory and operating personnel.

Figure 12.18: Separation from tray is a serious error. The impression should be repeated.

Recommended disinfectants include phenol, iodophor, bleach or gluteraldehyde. Irreversible hydrocolloids may be disinfected by immersion in, or spraying. Current protocol recommended by the center for disease control is to spray the impression with disinfectant. The impression is then wrapped in disinfectant soaked paper towel. Immersion disinfection if used should not exceed 10 minutes to reduce dimensional change.

STORAGE OF ALGINATE IMPRESSION

Alginate impressions must be poured as soon as possible. If it becomes necessary to store the impression, the following methods may be used:

- Wrap the impression lightly with a moist paper towel and cover with a rubber bowl or
- Keep the impression in a sealed plastic bag.

Note Even under these conditions storage should not be done for more than one hour. Care should be taken not to use a *soaking wet* paper towel or gauze as it can cause imbibition of water.

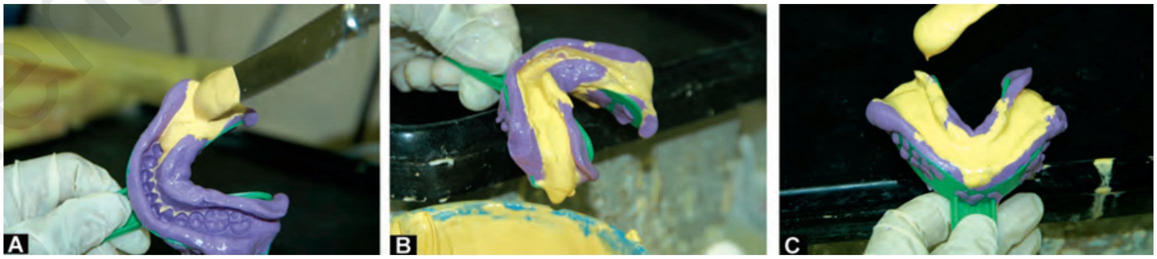
CONSTRUCTION OF CAST

Figure 12.19: Rinsing removes traces of saliva, bacteria and other contaminants.

The early alginates required immersion in a gypsum hardening solution, such as potassium sulphate, zinc sulfate, manganese sulfate, and potash alum (most effective is 2% potassium sulfate solution). However, the formulas of presently available alginates have been adjusted so that no hardening solution is required.

Alginate is a hydrophilic material and wets easily reducing the entrapment of air. After rinsing (***Fig. 12.19***) the excess water is shaken off. The impression is held against a vibrator to reduce the trapping off air. Freshly mixed stone is placed at one end of the impression. The impression is rotated to facilitate the flow of the stone around the arch. The stone displaces water and wets the surface of the impression as it flows. It is then allowed to flow out through the other side and discarded (***Figs 12.20 A to C***). This helps to:

- Reduce the trapping of air bubbles.
- Removes the water rich surface layer which can result in a weaker cast surface.



Figures 12.20 A to C: Pouring an alginate impression: (A) The first portion of stone is placed in one corner of the impression. (B) With the help of a vibrator, the stone is flowed along the surface of the impression and round to the other side and allowed to drip off. This improves the wetting of the impression and reduces air entrapment, (C) The rest of the stone is poured to complete the cast.

The impression is filled with the remaining stone and placed aside to set. The stone cast should not be separated for at least 30 minutes. For alginate, best results are obtained if the cast is removed in one hour. The cast should not be left in the impression for too long a period either because:

- It can result in a rough and chalky surface.
- Alginate, dries and stiffens. Removal can break the teeth and other thin portions of the cast.

ADVANTAGES AND DISADVANTAGES OF ALGINATE

ADVANTAGES

1. It is easy to mix and manipulate.
2. Minimum requirement of equipment.
3. Flexibility of the set impression.
4. Accuracy if properly handled.
5. Low cost.
6. Comfortable to the patient.
7. It is hygienic, as fresh material must be used for each impression.
8. It gives a good surface detail even in presence of saliva.

DISADVANTAGES

1. Cannot be electroplated so metal dies are not possible.
2. It cannot be corrected.
3. Distortion may occur without it being obvious if the material is not held steady while it is setting.
4. Poor dimensional stability—it cannot be stored for long time.
5. Poor tear strength.
6. Because of these drawbacks and the availability of better materials, it is not recommended where a higer degree of accuracy is required, e.g., cast RPD, crowns and FPDs, etc.

MISUSE OF ALGINATES

Because of their low cost alginates are often used to make final impressions during the fabrication of high precison restorations like RPDs, crowns and FPDs. Although they are reasonably accurate, they have a few properties which make them inferior to elastomeric materials. These include poor dimensional stability, poor tear strength, lower detail reproduction, etc. Often the impressions are processed in distant laboratories after a period of delay. Alginate impressions are inaccurate if pouring is delayed. For these reason alginates are not recommended where high levels of accuracy is required, especially where it has to be withdrawn over severe undecuts (as in dentate subjects) and where very thin areas which can tear easily are present (gingival margins).

13

ELASTOMERIC IMPRESSION MATERIALS

In addition to the hydrocolloids, there is another group of elastic impression materials. They are soft and rubber like and far more stronger and stable than the hydrocolloids. They are known as elastomers or synthetic rubbers. The ADA Sp. No. 19 refers to them as *nonaqueous elastomeric dental impression materials.*

Elastomeric materials contain large molecules with weak interaction between them. They are tied together at certain points to form a three-dimensional network. On stretching the chains uncoil, and on removal of the stress they snap back to their relaxed entangled state.

They are liquid polymers which can be converted to solid rubber at room temperature. By mixing with a suitable catalyst, they undergo polymerization and/or crosslinking (by condensation or addition) reaction to produce a firm elastic solid. These materials are the most accurate and dimensionally stable impression materials available in dentistry.

Synonyms Initially they were called *rubber-base or rubber* impression materials. Currently, they referred to as elastomeric impression materials.

The first elastomeric rubber-based impression materials to be introduced was the polysulfide which was introduced in 1950. This was followed by condensation silicone in 1955, polyether in 1965 and the addition silicones in 1975.

TYPES

ACCORDING TO CHEMISTRY

Chemically, there are four kinds of elastomers:

- Polysulfide
- Condensation polymerizing silicones
- Addition polymerizing silicones
- Polyether

ACCORDING TO VISCOSITY

Each type may be further divided into four viscosity classes (***Fig. 13.1***):

- Light body or syringe consistency
- Medium or regular body
- Heavy body or tray consistency
- Very heavy or putty consistency

Figure 13.1: Elastomers are available in different viscosities and forms.

ADA/ ISO 4823 CLASSIFICATION

Based on selected elastic properties and dimensional change of the set materials, they are divided into three types—Type I, Type II and Type III

ACCORDING TO WETTABILITY

Impression materials are also classified as
hydrophilic, if their contact angle is from 80 to 105°
hydrophobic, if their contact angle is from 40 to 70°

USES OF ELASTOMERIC IMPRESSION MATERIALS

1. In fixed partial dentures for impressions of prepared teeth.
2. Impressions of dentulous mouths for removable partial dentures.
3. Impressions of edentulous mouths for complete dentures.
4. Polyether is used for border molding of edentulous custom trays.
5. For bite registration.
6. Silicone duplicating material is used for making refractory casts during cast partial denture construction.

SUPPLIED AS

Regardless of type all elastomeric impression materials are supplied as *two component* (base and catalyst) systems.

- Collapsible tubes
- Light and regular body material are also supplied in cartridges to be used with automixing tips and dispensers
- Putty consistency is supplied in jars

The various forms of elastomers are shown in ***Figure 13.1***.

GENERAL PROPERTIES OF ELASTOMERIC MATERIALS

- Excellent reproduction of surface details. The low viscosity is capable of producing very fine details.
- They are generally *hydrophobic* (except polyether which is hydrophilic), so the oral tissues in the area of impression should be absolutely dry for better flow of the impression material. Because of their hydrophobic (water hating)

nature, care must be taken while pouring stone in the impression. The poor wetting and high contact angle can result in air entrapment. Commercial surfactants sprays are available which improve wetting.

- Elastic properties of elastomers is good with near complete elastic recovery. Repeated pouring of impression is possible (though not recommended when high accuracy is critical).
- Coefficient of thermal expansion of elastomers is high. Thermal contraction occurs when impression is transferred from mouth to room temperature.
- In general dimensional changes and inaccuracies occur due to:
  - Curing shrinkage.
  - Loss of byproducts of reaction, e.g., condensation silicones lose alcohol and shrink. Polysulfides (hydroperoxide type) lose volatile accelerators causing contraction.
  - Polyether being hydrophilic absorbs water and loses soluble plasticizers causing change in dimension (e.g., when immersed in disinfectant).
  - Thermal contraction when transferred from mouth to room temperature.
  - Removing impression before complete setting can cause serious distortion.
  - Incomplete recovery after deformation during removal.
  - *Amount of filler:* When filler content is increased, the polymer content is reduced and shrinkage is less. Thus less shrinkage is seen in putty, and higher shrinkage is observed in light bodied.
  - Uniform thickness of material gives more accurate impression as the shrinkage is uniform.
  - Good adhesion of impression to the tray (using adhesives) minimizes dimensional changes as the shrinkage is directed towards the tray. In the absence of adhesion between the tray and impression, the shrinkage is directed centrally and the model prepared will be smaller in size.
  - *Time of pouring:* Impression should be poured after elastic recovery but before dimensional changes set in.
- The tear strength of these materials are excellent, thus making it more resistant to tearing even when the impression is in thin sections.
- *Electroplating:* Elastomers can be copper and/or silver plated.
- *Tray adhesives:* Elastomeric materials do not adhere well to the impression tray. They may be retained by:
  - Mechanically by using perforated trays (e.g., putty).
  - *Tray adhesives:* These are tacky liquids that are applied with a brush. Each elastomer type has a specific adhesive which is not interchangeable.
- The shelf life is about two years. The silicones have a reduced shelf life. Storage under cool conditions increases shelf life.

POLYSULFIDES

This was the first elastomeric impression material to be introduced (1950). It is also known as *Mercaptan or Thiokol.*

SUPPLIED AS

They are supplied as a two-paste system in collapsible tubes. The base paste is white colored. The accelerator is brown or gray.

Available in Three Viscosities

- Light bodied
- Medium bodied
- Heavy bodied.

Commercial Names

Permlastic (Kerr) (***Fig. 13.2***)

Coe-flex : Lead dioxide system

Omni flex : Copper hydroxide system.

Figure 13.2: Polysulfide.

COMPOSITION

Base Paste

Liquid polysulfide polymer	— 80 to 85%
Inert fillers (Titanium dioxide, zinc sulfate, copper carbonate or silica)	— 16 to 18%

Reactor Paste

Lead dioxide	— 60 to 68%
Dibutyl phthalate	— 30 to 35%
Sulfur	— 3%
Other substances like magnesium stearate (retarder) and deodorants	— 2%

Tray adhesive The adhesive cement should be compatible with the polysulfide impression material. Butyl rubber or styrene/ acrylonitrile dissolved in a volatile solvent such as chloroform or a ketone is used with polysulfide.

CHEMISTRY AND SETTING REACTIONS

When the base and accelerator pastes are mixed, it undergoes a chemical reaction, whereby the liquid polymer sets to form a solid, but highly elastic and flexible rubber like material.

The lead dioxide reacts with the polysulfide polymer causing:

- Chain lengthening by oxidation of terminal—SH groups.
- Cross-linking by oxidation of the pendant—SH groups.

The reaction is exothermic with a 3 to 4°C rise in temperature. It is accelerated by heat and moisture.

$$HS-R-SH \xrightarrow{PbO_2 + S} HS-R-S-S-R-SH + H_2O$$

OR

$$\text{Mercaptan} + \text{Lead dioxide} \longrightarrow \text{Polysulfide} + \text{Water}$$

As an alternative to lead dioxide, an organic hydroperoxide can be used (e.g., t-butyl hydroperoxide). However, these compounds are volatile and so are dimensionally unstable. The other cross-linking system successfully used are certain complex inorganic hydroxides (e.g., copper).

PROPERTIES

1. Unpleasant odor and color. It stains linen and is messy to work with.
2. These materials are extremely viscous and sticky. Mixing is difficult. However, they exhibit *pseudoplasticity*, i.e., if sufficient speed and force is used for spatulation, the material will seem easier to handle. The mixing time is 45 seconds.
3. It has a long setting time of 12.5 minutes (at 37°C). In colder climates setting can take as long as 16 minutes. This adds to the patient's discomfort. Heat and moisture accelerate the setting time (sets faster in the mouth).
4. Excellent reproduction of surface detail.
5. *Dimensional stability:* The curing shrinkage is high (0.45%) and continues even after setting. It has the highest permanent deformation (3 to 5%) among the elastomers. Elastic recovery improves with time and so pouring of the model should be delayed by half an hour. Further delay is avoided to minimize *curing shrinkage.* Loss of the byproduct (water) also causes shrinkage.
6. It has high tear strength (4000 gm/cm).
7. It has good flexibility (7%) and low hardness. A 2 mm spacing in the tray is sufficient for making an impression.
8. It is hydrophobic so the mouth should be dried thoroughly before making an impression. Care should also be taken while pouring the stone to avoid air pockets.
9. It can be electroplated. More with silver than copper.
10. The shelf life is good (2 years).

SILICONE RUBBER IMPRESSION MATERIALS

These materials were developed to overcome some of the disadvantages of polysulfide materials, such as their objectionable odor, the staining of linen and clothing by the lead dioxide, the amount of effort required to mix the base with the accelerator, the rather long setting times, the moderately high shrinkage on setting, and the fairly high permanent deformation.

TYPES

Two types of silicone impression materials are available based on the type of polymerization reaction occurring during its setting.

- Condensation silicones
- Addition silicones

Both silicones are available in a variety of colors such as pastel pinks, purples, blues, greens, oranges, etc. Different viscosities may be identified by their color.

CONDENSATION SILICONE

This was the earlier of the two silicone impression materials. It is also referred to as *conventional silicones.*

SUPPLIED AS

Paste Supplied as two pastes in unequal sized collapsible tubes. The base paste comes in a *larger tube* while the catalyst paste is supplied in a much *smaller tube* (***Fig. 13.3 B***).

Putty The putty is supplied in a single large plastic jar (***Fig. 13.3 A***). The catalyst may be in paste form or sometimes it may be supplied as a *liquid*.

They come in a variety of colors. The base and accelerator are typically in contrasting colors (which aids mixing).

Available in Three Viscosities

- Light bodied
- Medium bodied
- Putty

Commercial names Sil 21, Coltex, dent-a-scon, etc.

COMPOSITION

Base

Polydimethyl siloxane (hydroxy—terminated)

Colloidal silica or microsized metal oxide filler
—35 to 75% (depending on viscosity)

Color pigments.

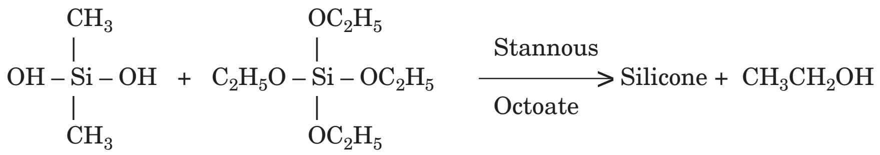
Accelerator

Orthoethyl silicate — crosslinking agent
Stannous octoate — catalyst

CHEMISTRY AND SETTING REACTION

It is a condensation reaction. Polymerization occurs as a result of crosslinkage between the orthoethyl silicate and the terminal hydroxy group of the dimethyl siloxane, to form a three-dimensional network. Stannous octoate acts as the catalyst. The reaction is exothermic (1°C rise).

Figures 13.3 A and B: (A) Condensation silicone putty (B) Regular body base and catalyst. Notice the smaller size of the catalyst paste. Note also quantity of activator dispensed is less.



$$\mathrm{OH}-\underset{\mathrm{CH_3}}{\overset{\mathrm{CH_3}}{\mathrm{Si}}}-\mathrm{OH} + \mathrm{C_2H_5O}-\underset{\mathrm{OC_2H_5}}{\overset{\mathrm{OC_2H_5}}{\mathrm{Si}}}-\mathrm{OC_2H_5} \xrightarrow[\text{Octoate}]{\text{Stannous}} \text{Silicone} + \mathrm{CH_3CH_2OH}$$

OR

$$\text{Dimethyl siloxane} + \text{Orthoethyl silicate} \xrightarrow[\text{Octoate}]{\text{Stannous}} \text{Silicone rubber} + \text{Ethyl alcohol}$$

The ethyl alcohol formed as a by-product evaporates gradually from the set rubber leading to shrinkage.

Tray adhesive The adhesive for silicones contain poly (dimethyl siloxane) or a similar reactive silicone, and ethyl silicate. Hydrated silica forms from the ethyl silicate to create a physical bond with the tray, and poly (dimethyl siloxane) bonds with the rubber.

PROPERTIES

TEAR STRENGTH

In fixed prosthodontics the impression material is often injected into the sulcus of the prepared tooth. When the impression is removed, the material in the sulcus being very thin, can tear away and remain in the sulcus. Therefore a high tear strength is advantageous.

1. Pleasant color and odor. Although nontoxic, direct skin contact should be avoided to prevent any allergic reactions.
2. Setting time is 6 to 9 minutes. Mixing time is 45 seconds.
3. Excellent reproduction of surface details.
4. Dimensional stability is comparatively less because of the high curing shrinkage (0.4 to 0.6%), and shrinkage due to evaporation of the *ethyl alcohol* byproduct. To avoid this the cast should be poured immediately. The permanent deformation is also high (1-3%).
5. Tear strength (see box) (3000) gm/cm is lower than the polysulfides.
6. It is stiffer and harder than polysulfide. The hardness increases with time. The spacing in the tray is increased to 3 mm to compensate for the stiffness.
7. It is hydrophobic. The field should be *well-dried* before making an impression. Care should also be taken while pouring the cast to avoid air entrapment.
8. Can be plated with silver/copper. Silver-plating is preferred.
9. Shelf life is slightly less than polysulfides due to the unstable nature of the orthoethyl silicates.

ADDITION SILICONES (POLYVINYL SILOXANE)

These materials were introduced subsequent to the introduction of the condensation silicones. These new materials had better properties when compared to the condensation silicones. It is also known as *polyvinyl siloxane*. Currently, the addition silicones are very popular and is perhaps the most widely used elastomeric impression material worldwide.

SUPPLIED AS

Tubes The base and catalyst pastes come in *equal* sized tubes (unlike condensation silicones). The different viscosities usually come in different colors like orange, blue, green, etc.

Cartridge form with automixing tips For use with a dispensing gun.

Putty jars Two equal sized plastic jars—containing the base and catalyst.

A larger electric driven autodispenser and mixing device is also available (Pentamix—ESPE). This machine stores larger quantities. At the press of the button, it dispenses and mixes the material.

Available in Four Viscosities (*Fig. 13.1*)

- Light bodied
- Medium bodied
- Heavy bodied
- Putty

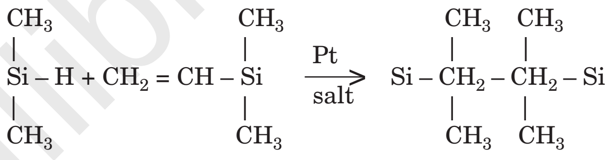
Representative Commercial names Reprosil (Dentsply) (see ***Fig. 13.1***), Provil, President (Coltene), etc.

COMPOSITION

Base	*Accelerator*
Poly (methyl hydrogen siloxane)	Divinyl polysiloxane
Other siloxane prepolymers	Other siloxane prepolymers
Fillers	Platinum salt—catalyst (chloroplatinic acid)
	Palladium or hydrogen absorber
	Retarders
	Fillers

CHEMISTRY AND SETTING REACTION

It is an addition reaction. In this case, the base polymer is terminated with vinyl groups and is crosslinked with silane (hydride groups). The reaction is activated by the platinum salt.



$$\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{Si}} - H + CH_2 = CH - \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{Si}} \xrightarrow[\text{salt}]{\text{Pt}} Si - \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{CH_2}} - \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{CH_2}} - Si$$

OR

$$\text{Vinyl siloxane} + \text{Silane siloxane} \xrightarrow[\text{Salt}]{\text{Pt}} \text{Silicone rubber}$$

There are no byproducts as long as, there is balance between the vinyl siloxane and the silane siloxane. If unbalanced, *hydrogen gas* is produced causing air bubbles in the stone models. To avoid this, palladium is added to absorb the hydrogen.

EFFECT OF SULFUR COMPOUNDS

Sulfur compounds retard the setting of silicones. One source of sulfur contamination is from latex gloves worn by the operator when mixing putty. Vinyl gloves should be used.

PROPERTIES

1. Pleasant odor and color.
2. This may also cause allergic reaction so direct skin contact should be avoided.
3. Excellent reproduction of surface details.
4. Setting time ranges from 5 to 9 minutes. Mixing time is 45 seconds.
5. It has the best dimensional stability among the elastomers. It has a low curing shrinkage (0.17%) and the lowest permanent deformation (0.05 to 0.3%). If hydrogen gas is liberated pouring of stone should be delayed by 1-2 hours. Otherwise air bubbles will result.
6. It has good tear strength (3000 gm/cm).
7. It is extremely hydrophobic, so similar care should be taken while making the impression and pouring the wet stone. Some manufacturers add a surfactant (detergent) to make it more hydrophilic.
8. It can be electroplated with silver or copper. However, hydrophilic silicones are more difficult to electroplate because of the surfactant added.
9. It has low flexibility and is harder than polysulfides. Extra spacing (3 mm) should be provided in the impression tray. Care should also be taken while removing the stone cast from the impression to avoid any breakage.
10. Shelf life ranges from 1 to 2 years.

POLYETHER RUBBER IMPRESSION MATERIAL

Polyether was introduced in Germany in the late 1960s. It has good mechanical properties and dimensional stability. Its disadvantage was that the working time was short and the material was very stiff. It is also expensive.

AVAILABLE AS

Available as base and accelerator in collapsible tubes. The accelerator tube is usually smaller (***Fig. 13.4***). Earlier, it was supplied in a single viscosity. A third tube containing a *thinner* was provided.

Now it is available in three viscosities:

- Light bodied
- Medium bodied
- Heavy bodied

Representative commercial names: Impregum F (premier), Ramitec, Polyjel (Dentsply).

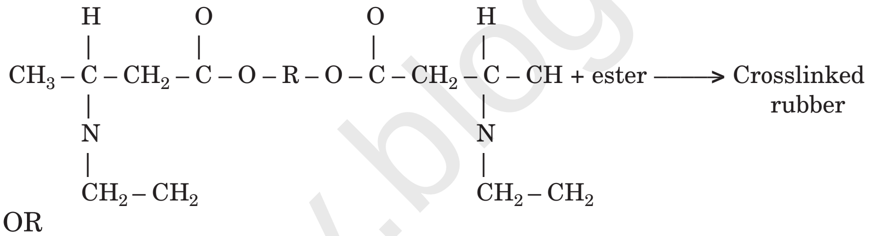
Figure 13.4: Polyether impression paste. Notice the smaller size of the reactor tube.

COMPOSITION

Base		
Polyether polymer		
Colloidal silica	—	filler
Glycolether or phthalate	—	plasticizer
Accelerator Paste		
Aromatic sulfonate ester	—	cross-linking agent
Colloidal silica	—	filler
Phthalate or glycolether	—	plasticizer

CHEMISTRY AND SETTING REACTION

It is cured by the reaction between aziridine rings which are at the end of branched polyether molecule. The main chain is a copolymer of ethylene oxide and tetrahydrofuran. Crosslinking is brought about by the aromatic sulfonate ester via the imine end groups. The reaction is exothermic (4 to 5°C).



$$CH_3-\underset{\underset{\underset{CH_2-CH_2}{|}}{\underset{|}{N}}}{\overset{\overset{H}{|}}{C}}-CH_2-\overset{\overset{O}{|}}{C}-O-R-O-\overset{\overset{O}{|}}{C}-CH_2-\underset{\underset{\underset{CH_2-CH_2}{|}}{\underset{|}{N}}}{\overset{\overset{H}{|}}{C}}-CH + \text{ester} \longrightarrow \text{Crosslinked rubber}$$

OR

Polyether + Sulfonic ester ⟶ Crosslinked rubber

PROPERTIES

1. Pleasant odor and taste.
2. The sulfonic ester can cause skin reactions. Thorough mixing is recommended before making an impression and direct skin contact should be avoided.
3. Setting time is around 6 to 8 minutes. Mixing should be done quickly that is 30 seconds. Heat decreases the setting time.
4. Dimensional stability is very good. Curing shrinkage is low (0.24%). The permanent deformation is also low (0.8 to 1.6%). However, polyethers absorb water and can change dimension. Therefore prolonged storage in water or in humid climates is not recommended.
5. It is extremely stiff (flexibility 3%). It is harder than polysulfides and increases with time. Removing it from undercuts can be difficult, so additional spacing (4 mm) is recommended. Care should also be taken while removing the cast from the impression to avoid any breakage.
6. Tear strength is good (3000 gm/cm).
7. It is hydrophilic, so moisture in the impression field is not so critical. It has the best compatibility with stone among the elastomers.
8. It can be electroplated with silver or copper.
9. The shelf life is excellent — more than 2 years.

- It has excellent detail reproduction (20 micron).
- Retraction cord containing epinephrine, 8-hydroxyquinoline sulfate or iron (III) sulfate may impair the setting of impressions.

Prolonged exposure may cause the surface of the impression to become sticky (depolymerizes) after several days.

MANIPULATION OF RUBBER IMPRESSION MATERIALS

PUTTY

With addition silicones, equal scoops of base and accelerator are taken. With condensation silicones, the required number of scoops of base and recommended amount of liquid or paste accelerator is taken. In either case mixing is done by kneading between the fingers. Mixing is done until a streak free mix is obtained.

PASTE

For Polysulfides and Addition Silicones

Equal lengths of base and accelerator is extruded onto the mixing pad side-by-side without touching. The accelerator paste is then incorporated into the base paste. Mixing is done using a tapered stiff bladed spatula. Just before loading the tray the material should be spread in a thin layer to release the trapped air bubbles. A streak free mix is obtained in 45 seconds.

Condensation Silicone

Unlike addition silicone, the quantity of catalyst paste needed is very little. The manufacturer usually marks the length required on the mixing pad. The two pastes therefore are of *unequal* length and diameter (***Fig. 13.3 B***).

For Polyether

The required amount of thinner (when supplied) may be added to the base and accelerator depending on the viscosity needed. Again, like condensation silicone, the quantity of accelerator needed is very little. The ratio is usually displayed on the mixing pad. The mixing should be done quickly. The mixing time is 30 seconds.

TECHNICAL CONSIDERATIONS

- ➢ Impressions can be made in custom or stock trays.
- ➢ Elastomers do not adhere well to the tray. An adhesive (***Fig. 13.5 A***) should be applied to the tray and allowed to dry before making impressions. The adhesive cements provided with the various elastomers are not interchangeable. A slightly roughened tray surface will increase the adhesion. For putty impressions, a perforated stock tray is used. The perforations help to retain the putty in the tray ***(Fig. 13.5 B)***.

Figures 13.5 A and B: (A) Tray adhesive; (B) Mechanical retention through perforations in tray.

- The spacing given is between 2 to 4 mm.
- The bulk of the impression should be made with a heavier consistency (to reduce shrinkage). Light bodied should only be used in a thin layer as a wash impression.

METHODS OF MAKING IMPRESSIONS

SINGLE MIX TECHNIQUE

Tray used Resin custom tray with 2-4 mm spacing.

Viscosity used Regular only.

Method The paste is mixed and part of it is loaded on to the tray and part into a syringe. The syringe material is then injected on to the prepared area of impression. The tray with material is seated over it. The material is allowed to set.

MULTIPLE MIX TECHNIQUE

Tray used Resin custom tray with 2-4 mm spacing.

Viscosity used (a) Heavy bodied and (b) light bodied.

Method The two viscosities are mixed simultaneously on separate pads. The heavy body is loaded into the tray while the light bodied is loaded into the syringe. The syringe material is injected over the preparation. The tray containing the heavy body if then seated over it. Both materials set together to produce a single impression.

RELINE TECHNIQUE (TWO-STAGE PUTTY-WASH TECHNIQUE)

Tray used Perforated stock tray.

Viscosity used (a) Putty and (b) Light body.

Method (***Figs 13.6 A to J***) First a preliminary impression is made with putty in the stock tray. Before seating the tray, a thin plastic sheet is placed over the putty (it acts as a spacer). After setting it is removed and kept aside. Mixed light bodied is loaded into a syringe and injected over the preparation. The remainder is loaded into the putty impression. The primary impression is then seated over the injected material and held till it sets.

Advantage No special tray required.

RELINE TECHNIQUE (ONE-STAGE PUTTY-WASH TECHNIQUE)

Tray used Perforated stock tray.

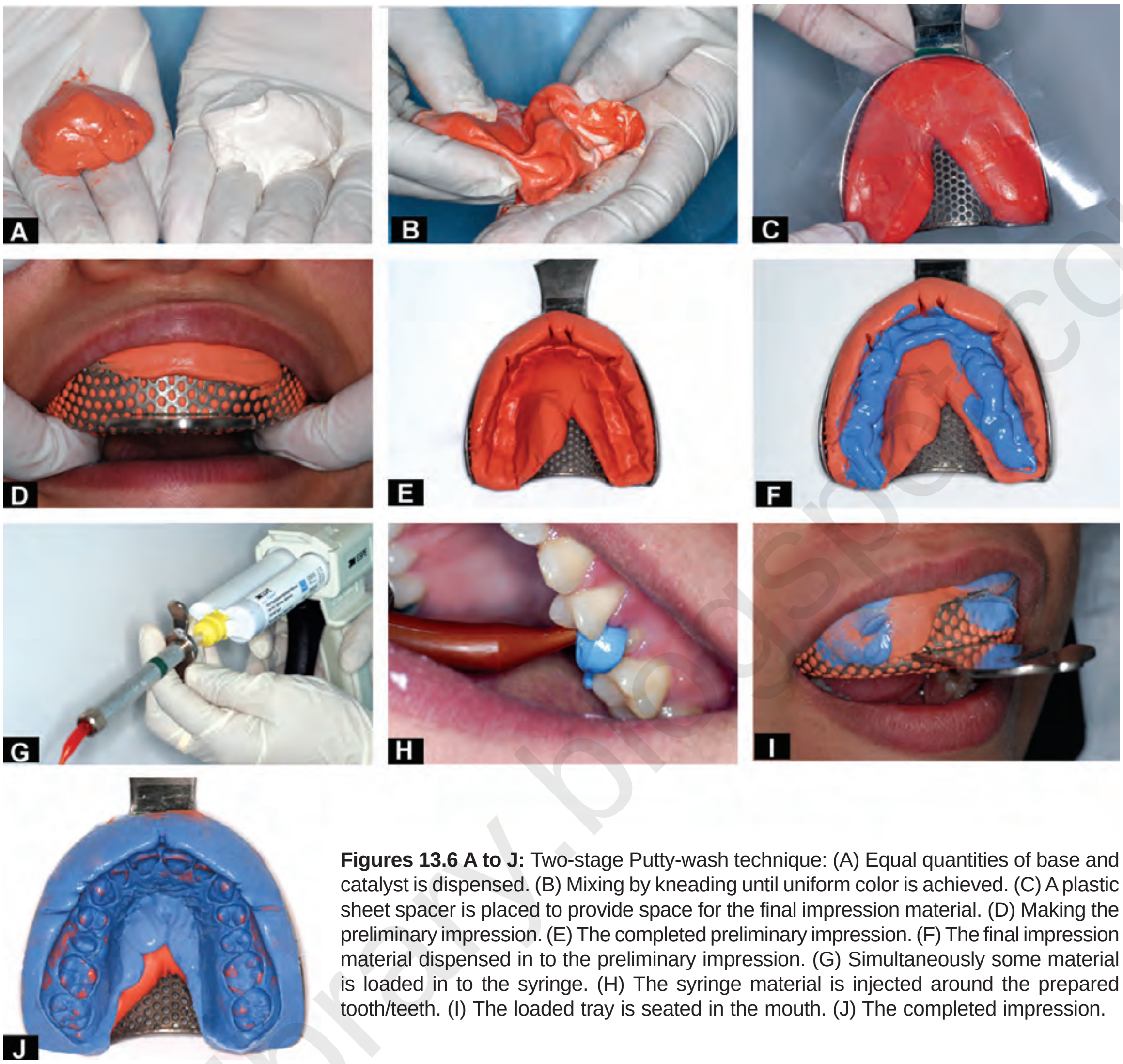
Viscosity used (a) Putty and (b) Light body.

Method Unlike the previous technique the putty and light body are dispensed and mixed simultaneously. The putty is loaded into a perforated stock tray whereas the light body is injected on to the prepared tooth. The tray is then taken to the mouth and pressed into position. The heavier putty forces the lighter material into the details. Both material set simultaneously to produce an accurate impression.

Advantage No special tray required. The technique is simple and quick.

AUTOMATIC DISPENSING AND MIXING DEVICES

It consists of a double barrel caulking gun with mixing tip. The tip contains spirals on the inside. Forcing of the base and accelerator through these spirals result in its mixing (***Fig. 13.7 A***).



Figures 13.6 A to J: Two-stage Putty-wash technique: (A) Equal quantities of base and catalyst is dispensed. (B) Mixing by kneading until uniform color is achieved. (C) A plastic sheet spacer is placed to provide space for the final impression material. (D) Making the preliminary impression. (E) The completed preliminary impression. (F) The final impression material dispensed in to the preliminary impression. (G) Simultaneously some material is loaded in to the syringe. (H) The syringe material is injected around the prepared tooth/teeth. (I) The loaded tray is seated in the mouth. (J) The completed impression.

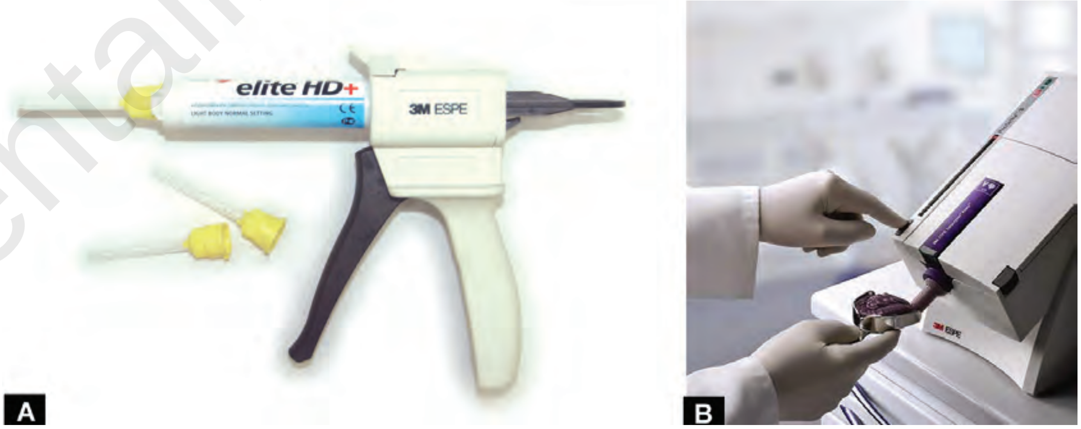


Figure 13.7: (A) Autodispensing and mixing device. (B) The ESPE Pentamix 2.

Another device is a dynamic mechanical mixer (ESPE Pentamix—***Fig. 13.7 B***). The base and catalyst are supplied in large plastic bags which are loaded in to the machine. On pressing a button, the material is mixed and extruded through the tip directly into the impression tray.

Advantages

1. More uniform mix.
2. Less air bubbles incorporated in mix.
3. Reduced working time.

REMOVAL OF THE IMPRESSION

The material is checked for set by prodding with blunt instrument. When set, it should be firm and return completely to its original contour.

The impression is dislodged from the mouth as quickly as possible for the following reasons:

- Elastic recovery is better.
- Tear resistance is higher.

However, rapid removal may be difficult as well as uncomfortable to the patient. Removal is facilitated by breaking the airseal. This can be done by teasing the borders of the tray parallel to the path of insertion until the air leaks into the tray. Compressed air through an air syringe may also be used. In addition to the holding the tray handle, a finger on the buccal portion of the tray may be used to apply additional pressure to dislodge the tray.

INFECTION CONTROL

Rubber impression materials are disinfected by immersing in disinfectant solutions. 10 minutes in 2% glutaraldehyde or 3 minutes in chlorine dioxide solutions have been found to be satisfactory. Because of its tendency to absorb water, a spray of chlorine dioxide is preferred in case of polyether. Other disinfectants used are phenol and iodophor.

SPECIALIZED MATERIALS

VISIBLE LIGHT-CURED POLYETHER URETHANE DIMETHACRYLATE

For historical purposes it is interesting to note that a light activated final impression material was marketed years ago. The product, Genesis (Dentsply) was a visible light-activated polyether urethane dimethacrylate impression material. The advantages with this material were that its working time is controlled by the operator, the high tear strength, and low dimensional change. Its disadvantages were difficulty in curing a full arch tray and postpolymerization tackiness. Its chemistry similar to that of light cured composites. This product is no longer marketed.

It was available in two viscosities:

- Light bodied (3.5 ml disposable syringe)
- Heavy bodied (41 ml tube)

Composition

- Polyether urethane dimethacrylate
- Photoinitiators

- Photoaccelerators
- Silicone dioxide filler (40 to 60%—to enhance light transmission)

Properties

These materials had long working times but short setting times. Blue light was used for curing. A transparent impression tray was used to make the impression.

Genesis was said to be capable of being polymerized to a depth of 16 mm in 20 seconds. Recommended curing times were 1.5 minutes for a quadrant tray and 2.5 minutes for a full arch tray. After polymerization, the surface of the material was tacky because of air inhibition.

It had the highest resistance to tearing among the elastomers (tear strength—6000 to 7500 gm/cm). The dimensional stability, flow, detail reproduction, permanent deformation, wettability, compatibility with cast and die materials, and electroforming were similar to addition silicone.

BITE REGISTRATION SILICONES

Registering the three-dimensional relationship between two articulating surfaces is known as bite registration ***(Fig. 13.8)***. Many materials are used for this purpose in dentistry. The earliest materials were wax and plaster. A specialized addition type of silicone is increasingly popular as a bite registration material. Unlike the regular impression silicone these materials show greater stiffness and greater hardness (32 to 45 Shore D), when set. A faster setting time is also important to reduce errors caused by movement and to reduce discomfort to the patient. Setting time ranges from as low as 20 seconds to a minute depending on the type. Other important properties required of these materials is that they should not slump or drip when initially placed. A scannable version has also been introduced for use in CAD CAM (Virtual CADbite Registration, Ivoclar). Most are supplied in cartridge form for use with a caulking gun. Some are supplied in collapsible tubes. One product (Colorbite D, Zhermack—***Fig. 13.9***) has thermochromic indicators to help the clinician ascertain setting in the mouth.

FIT CHECKING SILICONES

Another specialized addition type silicone is used for detecting errors in the internal surface of crowns and fixed partial dentures. They are available as a two-paste system ***(Fig. 13.10)***. Small but equal lengths of the two pastes are

Figure 13.8: Bite registration procedure using bite registration silicone.

Figure 13.9: Bite registration silicone.

Figure 13.10: Addition silicone for revealing high spots and pressure points (fit checking).

mixed and applied to the internal surface of the crown. The crown is seated on the tooth and the material allowed to set. Areas of premature contact are revealed as bare areas or areas where the internal surface of the crown is showing through. These areas are marked and reduced. The material can also be used to assess the fit of complete and partial dentures.

14

INTRODUCTION TO MODEL, CAST AND DIE MATERIALS

Casts and models are an important part of dental services. Plaster and stone are the usual materials used to prepare casts and models. However, it must be remembered that other materials can also be used for this purpose.

DENTAL IMPRESSIONS ARE POURED TO PREPARE

MODELS

Models are used primarily for observation, diagnosis, patient education, e.g., orthodontic study models.

CASTS

A working model or master cast. It is the positive replica on which restorations or appliances are fabricated, e.g., complete denture, removable partial denture, orthodontic appliances. Casts should be made with a high level of accuracy. They should be handled with great care, taking care not to scratch or damage its surface.

DIES

A positive replica of a prepared tooth or teeth in a suitable hard substance (***Fig. 14.1***) on which inlays, crowns and other restorations are made. Similar care should be taken in ensuring its accuracy as well as handling.

TYPES OF DIE MATERIALS

Gypsum

— Type IV dental stone
— Type V dental stone, high strength, high expansion
— Type V dental stone + lighosulfonates (this wetting agent reduces the water requirement of a stone and thus enables the production of a hard, stronger and more dense set gypsum).

Metal and metal coated dies

— Electroformed
— Sprayed metals
— Amalgam

Polymers

— Metal or inorganic filled resins
— Epoxy

Figure 14.1: Dies are used to fabricate dental restorations.

Cements Silicophosphate or polyacrylic acid bonded cement.

Refractory materials This includes investments and divestments. Investment casts are used to make patterns for RPD frames. Divestment dies are used in direct baking of porcelain crowns or preparation of wax patterns.

IDEAL REQUIREMENTS OF DIE MATERIALS

An ideal die material should:

1. Be dimensionally accurate.
2. Have good abrasion resistance, strength and toughness to allow burnishing of foil and resist breakage.
3. Have a smooth surface.
4. Be able to reproduce all fine details in the impression.
5. Be compatible with all impression materials.
6. Have a color contrast with wax, porcelain and alloys.
7. Be easy to manipulate and quick to fabricate.
8. Be noninjurious to health by touch or inhalation.
9. Be economical.

ALTERNATE DIE MATERIALS

Polymers	:	They shrink during polymerization and so tend to produce an undersized die.
Cements	:	All cements shrink slightly and exhibit brittleness and have a tendency to crack due to dehydration.
Metal-sprayed	:	The bismuth-tin alloy is rather soft; care is needed to prevent abrasion of the die.

IMPROVED DENTAL STONE OR DIE STONE

The most commonly used die materials are still alpha hemihydrate type IV and type V gypsum products. Type IV gypsum products have cuboidal-shaped particles and the reduced surface area produce the required properties of strength, hardness and minimal setting expansion.

The most recent gypsum product, having an even higher compressive strength than the type IV is dental stone, high strength, high expansion—type V stone. The setting expansion has been increased from 0.01 to 0.3%. This higher setting expansion is required in the stone used for the die to aid in compensation for the base metal alloy solidification shrinkage.

ADVANTAGES

1. Good strength.
2. Minimal shrinkage.
3. Easy manipulation.
4. Good working time.
5. Sets quickly.
6. Compatible with impression materials.
7. Has smooth, hard surface.
8. Can be easily trimmed.
9. Has good color contrast.
10. Is economical.

DISADVANTAGES

1. Brittle.
2. Not as abrasion resistant as the epoxy and electroformed dies. Edges and occlusal surface may be rubbed off.

ELECTROFORMED/ELECTROPLATED CASTS AND DIES

Electrodeposition of copper or silver on the impression gives a hard metallic surface to the cast. Electroformed dies are not used currently, however, they will be described for historical reasons.

ADVANTAGES

1. Dimensional accuracy.
2. Hard and abrasion resistant.
3. Imparts a smooth surface to the wax pattern in contact.
4. Not very expensive.
5. Better marginal definition.
6. Does not absorb oil or water.
7. Prevents cuspal wear due to repeated contact with opposing cast.

DISADVANTAGES

1. Difficult to trim.
2. Silver bath is a potential health hazard.
3. Not compatible with all impression materials.
4. Color contrast not as good as die stone.
5. Adaptation of wax not as good, pattern tends to lift from margins.

ELECTROFORMING

Electroforming (also known as electroplating or electrodeposition) is a process by which a thin coating of metal is deposited on the impression, after which a gypsum cast is poured. The cast thus obtained will have a metallic surface layer.

Metals used for electroforming are:

— Copper
— Silver

Plating can be done for:

— Individual tooth impression
— Full arch impression

Plating is done on:

— Compound impression (usually copper plated)
— Polysulfide impression (usually silver plated)
— Silicone impression

Other impression materials show dimensional changes when plated.

COMPONENTS OF AN ELECTROPLATING APPARATUS

1. *Cathode* The impression to be coated is made the cathode.
2. *Anode* is the metal to be deposited, i.e., copper or silver.
3. Anode holder, cathode holder.
4. *Electrolyte* is the solution through which the electric current is passed. Ions are deposited from anode to cathode, e.g., silver cyanide or copper sulphate.
5. *Ammeter* registers the current in milliamperes (8-500 mA). The current passed is 10 mA per tooth area, for 12 hours.
6. *Plating tank* is made of glass or hard rubber with a well-fitting cover to prevent evaporation.
7. *Temperature* 77 to 80°F (room temperature).

COMPOSITION OF THE ELECTROPLATING BATH

Copper forming		*Silver forming*	
Copper sulphate crystals	200 gm	Silver cyanide	36 gm
Sulfuric acid (concentrated)	30 ml	Potassium cyanide	60 gm
Phenol sulfonic acid	2 ml	Potassium carbonate	45 gm
Water (distilled)	1000 ml	Water (distilled)	1000 ml

PROCEDURE

➢ Wash and dry the impression.

➢ *Metallizing* Most impression materials do not conduct electricity. They are made conductive by applying a metallizing solution or powder with a brush.

The metallizing agents are:

— Bronzing powder suspended in almond oil.

- — Aqueous suspension of silver powder.
- — Powdered graphite.

- ➢ The surface of the impression tray is covered with wax 2 mm beyond the margin of the impression. This protects the tray and prevents its plating.
- ➢ With a dropper, the impression is filled with electrolyte, avoiding air-bubbles.
- ➢ The impression is attached to the cathode holder with an insulated wire.
- ➢ The electrode is attached to the cathode and the impression is immersed in the electrolyte bath. Distance between the cathode (impression) and anode (metal) should be at least 4 inches.
- ➢ Initially, current should not exceed 5 mA. Later the current is increased to 10 mA per tooth for 12-15 hours, to get a deposit of 0.5 mm (If a high current is used the surface will be granular, uneven and weak. With low currents the deposit is smooth and hard).
- ➢ The current is disconnected. The impression is washed. The die is completed by pouring resin or dental stone to form the cast and base.

EPOXY RESIN DIE MATERIALS

They are most effective with rubber impression materials ***(Fig. 14.2).***

ADVANTAGES

Tougher and more abrasion resistant than die stone.

DISADVANTAGES

1. Slight shrinkage (0.1%).
2. Viscous, does not flow readily.
3. Setting may take up to 24 hours.

AVAILABLE AS

Two components—resin paste and hardener.

Figure 14.2: Epoxy resin die.

REFRACTORY CAST FOR WAX PATTERNS

A refractory cast is a special cast made from a heat resistant (investment) material. Such casts are used in the fabrication of certain large metal structures, e.g., cast removable partial dentures. Small wax structures like inlays, crowns and small FPDs can be constructed on a regular die as it can be removed from the die without significant distortion and invested separately. However, larger wax structures like that for the cast RPD, would distort if removed from the cast. RPD patterns are best constructed on a refractory cast. The pattern is invested together with the refractory cast.

Why not Invest an Ordinary Gypsum Cast?

The regular (nonrefractory) gypsum cast cannot withstand the high temperatures involved in the casting of metal and would disintegrate under these conditions.

REFRACTORY CAST FOR CERAMICS

Refractory dies are also available for ceramic restorations (e.g., polyvest and VHT—Whipmix). The all-porcelain restoration is directly built up on these refractory dies and fired (further detail in chapter on investments.)

DIE STONE-INVESTMENT COMBINATION (DIVESTMENT)

This is a combination of die material and investing medium. A gypsum-bonded material called divestment is mixed with a colloidal silica liquid. A die is prepared from the mix and a wax pattern is constructed on it. Then the wax pattern together with die is invested in divestment.

The setting expansion of divestment is 0.9% and thermal expansion 0.6%, when heated to 677°C.

As it is a gypsum-bonded material it is not recommended for high fusing alloys, e.g., metal-ceramic alloys.

ADVANTAGE

It is a highly accurate technique for conventional gold alloys especially for extra-coronal preparations. In this technique, removal of the wax pattern from the die is not required. Thus possibility of distortion of wax pattern during removal from the die or during setting of the investment is minimized.

DIVESTMENT PHOSPHATE OR DVP

This is a phosphate-bonded investment that is similar to the divestment and is suitable for use with high fusing alloys.

DIFFERENCE BETWEEN DIVESTMENT CAST AND REFRACTORY INVESTMENT CAST

Though both are quite similar, there are some fundamental differences. The investment casts are not as strong and abrasion resistant as the divestment cast. In fact they are quite fragile and can disintegrate easily. Manufacturers have provided certain hardening solutions to compensate for this. Divestment is generally used for smaller castings, whereas investment refractory casts are used during the fabrication of larger structures such as partial dentures frames and complete denture bases.

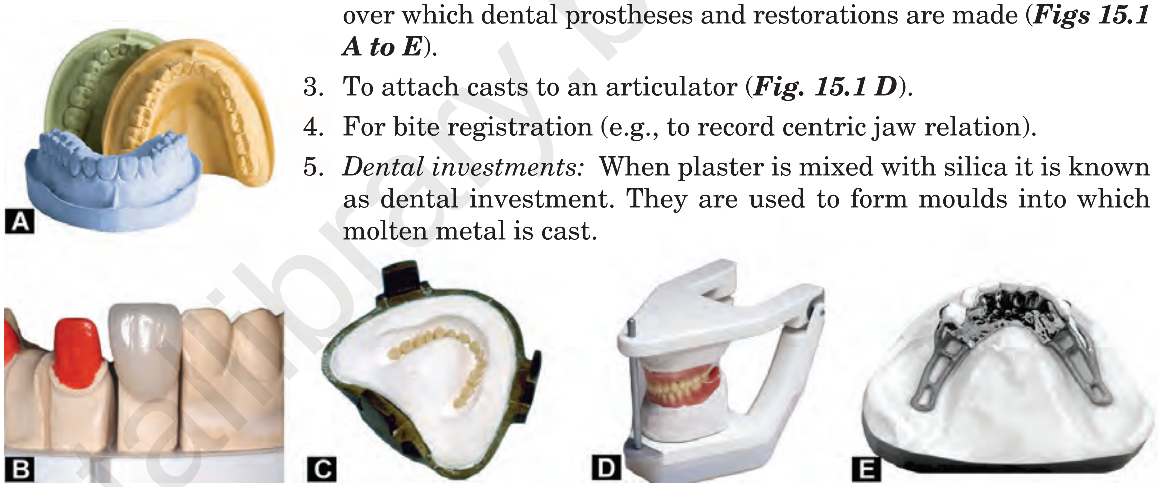
15

GYPSUM PRODUCTS

Products of gypsum are used extensively in dentistry. Gypsum was found in mines around the city of Paris, so it is also called *plaster of Paris*. This is a misnomer as gypsum is found in most countries. The mineral gypsum $CaSO_4 . 2H_2O$ is usually white to yellowish white in color and is found as a compact mass. Gypsum is also an industrial by-product. For centuries gypsum has been used for construction purposes and making statues. Alabaster, a form of gypsum which is white in color was used for building in ancient times. Besides dentistry gypsum is also used in orthopedics for splinting fractured bones.

APPLICATIONS

1. Impression plaster was used extensively in the past for impressions of the mouth and face.
2. Various types of plasters are used to make moulds, casts and dies over which dental prostheses and restorations are made (***Figs 15.1 A to E***).
3. To attach casts to an articulator (***Fig. 15.1 D***).
4. For bite registration (e.g., to record centric jaw relation).
5. *Dental investments:* When plaster is mixed with silica it is known as dental investment. They are used to form moulds into which molten metal is cast.



Figures 15.1 A to E: Gypsum products are widely used in dentistry. (A) An orthodontic model with a plaster base; (B) a cast with removable die made from die stone; (C) a plaster mold used in denture construction; (D) mounting plaster for mounting casts on an articulator; (E) dental restorations are constructed on stone working casts.

SUPPLIED AS

Powders of various colors in small preweighed sachets, in medium sized bags or containers or in large bags, sacks or bins (bulk) ***(Figs 15.2 A to C)***.

CLASSIFICATION

ADA/ANSI Specification No. 25/ ISO 6873:1998:

Type 1 — Dental plaster, impression
Type 2 — Dental plaster, model

Figures 15.2 A to C: Gypsum products are supplied in a variety of forms; as preweighed sachets, in medium sized containers or in large bags or sacks (bulk packing). (A) Mounting plaster; (B) High strength stone (die stone) in 1 to 3 kg container; (C) dental stone (can range from 5 to 25 kg bulk pack).

Type 3 — Dental stone, model
Type 4 — Dental stone, die, high strength, low expansion
Type 5 — Dental stone, die, high strength, high expansion

TYPE 1 OR DENTAL PLASTER, IMPRESSION

Impression plaster ***(Fig. 15.3 A)*** was one of the earliest impression materials in dentistry. Because of its rigidity (not elastic), it often had to be fractured to remove it from undercut areas in the mouth. The fractured pieces were then reassembled outside and a cast poured. Since the introduction of better materials, it is rarely used as an impression material. Currently, it is more useful as a bite registration material. Impression plaster may be flavored to make it more acceptable by the patient. It is colored to help the dentist and technician distinguish between the cast material and the impression. Impression plaster sometimes contain *potato starch* to make it soluble. After the cast has hardened, the impression and cast, are put in hot water. The starch swells and the impression disintegrates, making it easy to separate the cast. This type is often called *'soluble plaster'*.

USES

1. For making impressions in complete denture and maxillofacial prosthetics (not used currently for this purpose).
2. Bite registration material.

IDEAL PROPERTIES

1. The setting time should be under accurate control. The dentist must have sufficient time to mix, load the impression tray, carry the loaded tray to the patient's mouth and place it in position. However, once in position the plaster should harden promptly, so that there is minimum discomfort to the patient. The setting time desirable is 3 to 5 minutes.
2. For better accuracy the setting expansion should be low. Both setting time and expansion are controlled by modifiers (accelerators and retarders) added by the manufacturers.
3. The plaster should have enough strength to fracture cleanly without crumbling to facilitate removal from undercuts.

COMPOSITION

Dental plaster + K_2SO_4 + Borax + Coloring and flavoring agents.

Figures 15.3 A to E: The 5 types of gypsum products in dentistry. (A) Type 1—Impression plaster, (B) Type 2—Dental plaster, (C) Type 3—Dental stone, (D) Type 4—Die stone, High strength low expansion, (E) Type 5—Die stone, high strength, high expansion.

TYPE 2 OR DENTAL PLASTER, MODEL

Synonyms: Model plaster, laboratory plaster ***(Fig. 15.3 B)***.

USES

1. For making study casts and models.
2. To make molds for curing dentures.
3. For mounting casts on articulator.

REQUIREMENTS OF AN IDEAL CAST MATERIAL

1. It should set rapidly but give adequate time for manipulation.
2. It should set to a very hard and strong mass.
3. It should flow into all parts of the impression and reproduce all the minute details.
4. It should neither contract nor expand while setting.
5. After setting it should not warp or change shape.
6. It should not lose its strength when subjected to moulding and curing procedures.

COMPOSITION

Contains beta hemihydrate and modifiers.

TYPE 3 OR DENTAL STONE, MODEL

Synonym: Class I stone or Hydrocal (***Fig. 15.3 C***).

USES

For preparing master casts and to make molds.

COMPOSITION

- Alphahemihydrate
- 2 to 3% coloring matter
- K_2SO_4—Accelerator
- Borax—Retarder

Some commercial dental stones contain a small amount of beta hemihydrate to provide a mix of smoother consistency.

A stone with a setting time established by the addition of proper quantities of both accelerator and retarder is called *'balanced stone'*. Typical accelerators are potassium sulfate and potassium sodium tartrate (Rochelle Salts). Typical retarders are sodium citrate and sodium tetraborate decahydrate (Borax).

- The compressive strength varies from 3000 to 5000 psi.
- The setting expansion of dental stone is 0.06% to 0.12%.
- Hardness: 82 RHN.

TYPE 4 OR DENTAL STONE, DIE, HIGH STRENGTH, LOW EXPANSION

Synonyms: Class II stone, die stone, densite, improved stone.

USES

Die stone (***Fig. 15.3 D***) is the strongest and hardest variety of gypsum product. It is used when high strength and surface hardness is required, e.g., dies used for inlay, crown and bridge wax patterns.

A thick mix is prepared as per manufacturer's instruction and vibrated into a rubber base impression. The base for such a model is poured in dental stone or dental plaster. Die stone should be left for twenty four hours to gain maximum hardness and the cast should be separated one hour after pouring. The abrasion resistance of die stone is not high as other die materials like epoxy resin.

TYPE 5 OR DENTAL STONE, DIE, HIGH STRENGTH, HIGH EXPANSION

It is the most recent gypsum product (***Fig. 15.3 E***) having a higher compressive strength than Type 4 stone. Improved strength is attained by making it possible to lower the w/p ratio even further. Setting expansion has been increased from a maximum of 0.10 to 0.30%. This is to compensate for the shrinkage of base metal alloys, during solidification (see Casting Alloys). Hard Rock, Jade Rock and Resinrock XL5 (by Whipmix) and Denflo-HX are examples of Type 5 stone

USES

To prepare dies with increased expansion.

MANUFACTURE OF GYPSUM PRODUCTS

The process of heating gypsum for the manufacture of plaster is known as *calcination*. Mined gypsum is ground and heated. When heated, gypsum (calcium sulphate dihydrate) loses part of its water of crystallization and changes to calcium sulphate hemihydrate. On further heating, the remaining water of crystallization is lost. First, hexagonal anhydrite (soluble anhydrite) is formed. Later, orthorhombic anhydrite (insoluble anhydrite) is formed.

$$\underset{\text{(Calcium sulphate dihydrate)}}{CaSO_4.2H_2O} \xrightarrow{110\text{-}130°C} \underset{\text{(Calcium sulphate hemihydrate)}}{CaSO_4.½H_2O} \xrightarrow{130\text{-}200°C} \underset{\text{(Hexagonal anhydrite)}}{CaSO_4} \xrightarrow{200\text{-}1000°C} \underset{\text{(Orthorhombic anhydrite)}}{CaSO_4}$$

Alpha and Beta Hemihydrate

Depending on the method of calcination there are two forms of hemihydrates.

- (β) Beta hemihydrate (plaster)
- Alpha hemihydrate (stone)
- Alpha modified hemihydrate (die stone)

Note: Chemically both α and β types are the same. They differ mainly in crystal size and form. The β type is spongy and irregular. Whereas, α crystals are more dense and prismatic. Some authors suggest that the use of α and β prefixes should be discontinued.

Manufacture of Dental Plaster

Gypsum is ground and heated in an open kettle on kiln at a temperature of 110 to 130° C. The process is called *dry-calcination.* β type of crystals are formed.

Microscopically Fibrous aggregate of fine crystals with capillary pores. They are then ground to breakup the needlelike crystals. This improves packing.

$$CaSO_4.2H_2O \xrightarrow[110°\text{-}130°C]{\text{Heat}} \underset{\text{(β hemihydrate)}}{CaSO_4.{}^1/_2H_2O}$$

Manufacture of Dental Stone

Gypsum is calcined under steam pressure in an autoclave at 120 to 130°C at 17 lbs/sq. inch for 5 to 7 hours. Thus, the product obtained is much stronger and harder than β hemihydrate.

$$CaSO_4.2H_2O \xrightarrow[\text{17 lbs/sq. inch pressure}]{120°\text{-}130°C} \underset{\text{(α hemihydrate)}}{CaSO_4.½H_2O}$$

Microscopically Cleavage fragments and crystals in the form of rods and prisms.

Manufacture of High Strength (α modified) Stone

The gypsum is calcined by boiling it in 30% *calcium chloride solution. The* chlorides are then washed away or autoclaved in presence of *sodium succinate* 0.5%. These particles are the densest of all three types. After controlled grinding these powders have an even higher apparent density and yield a stronger set.

Microscopically cuboidal in shape.

SETTING REACTION

When plaster is mixed with water it takes up one and a half molecules of water, i.e., it regains its water of crystallization and becomes calcium sulphate dihydrate.

$$(CaSO_4)_2.H_2O + 3H_2O \longrightarrow 2\ CaSO_4.2H_2O + \text{unreacted } (CaSO_4)_2 . ½H_2O + \text{Heat}$$

Hemihydrate + Water ⟶ Dihydrate + Unreacted hemihydrate + Heat

The reaction is exothermic and is the same for all gypsum products. The amount of water required to produce a workable mix varies between the products. As evident from the above reaction not all of the hemihydrate converts to dihydrate. The amount of conversion is dependent on the type of stone. The highest conversion rate is seen in plaster (90%). In Type 4 and 5 stone the dihydrate content is about 50%.

THEORIES OF SETTING

Three theories have been proposed:

1. Colloidal theory
2. Hydration theory
3. Dissolution - precipitation theory

COLLOIDAL THEORY

The theory proposes that when mixed with water, plaster enters into a colloidal state through a sol-gel mechanism. In the sol state, hemihydrate combines with water (hydrates) to form dihydrate. As the water is consumed the mass turns to a '*solid gel*'.

HYDRATION THEORY

The hydration theory suggests that rehydrated plaster particles join together through hydrogen bonding to the sulfate groups to form the set material.

DISSOLUTION - PRECIPITATION THEORY (CRYSTALLINE THEORY)

This theory is *more widely* accepted. According to the theory, the plaster dissolves and reacts to form gypsum crystals which interlock to form the set solid. The setting reaction is explained on the basis of difference in solubility of hemihydrate and dihydrate. Hemihydrate is four times more soluble than dihydrate.

- When hemihydrate is mixed in water it forms a fluid workable suspension.
- Hemihydrate dissolves until it forms a saturated solution.
- Some dihydrate is formed due to the reaction. Solubility of dihydrate is much less than hemihydrate, the saturated hemihydrate is supersaturated with respect to the dihydrate. All supersaturated solutions are unstable. So the dihydrate crystals precipitate out.
- As the dihydrate precipitates out, the solution is no longer saturated with hemihydrate and so it continues to dissolve. The process continues until no further dihydrate precipitates out of the solution.

Initially there is little reaction and thus little or no rise in temperature. This time is referred to as *induction period*. As the reaction proceeds gypsum is formed in the form of needlelike clusters, called *spherulites* (***Fig. 15.4***). Continued growth and intermeshing of crystals of gypsum leads to thickening and hardening of the mass into a strong solid structure.

EXCESS WATER

The actual amount of water necessary to mix the calcium sulphate hemihydrate is greater than the amount required for the chemical reaction (18.61 gm of water per 100 gm of hemihydrate). This is called *excess water.*

The excess water itself does not react with the hemihydrate crystals. It is eventually lost by evaporation once the gypsum is set. The excess water serve only to aid in mixing the powder particles and is replaced by voids.

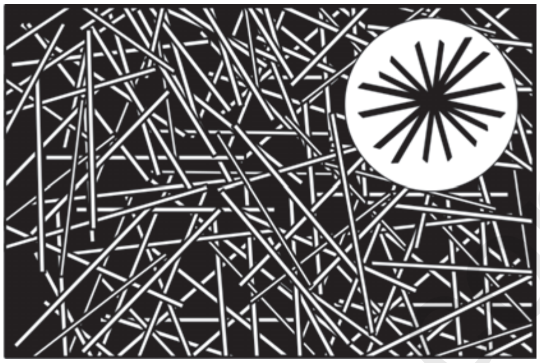


Figure 15.4: Structure of set gypsum showing needle-like clusters. A single crystal is called a spherulite (inset).

The Microstructure of Set Gypsum

The set material consists of an entangled aggregate of gypsum crystals (***Fig. 15.4***) having lengths of 5 to 10 µm. Two distinct types microscopic porosity can be seen in the mass.

- Microporosity caused by residual unreacted water. These voids are spherical and occur between clumps of gypsum crystals.
- Microporosity resulting from growth of gypsum crystals. These voids are associated with setting expansion and are smaller than the first type. They appear as angular spaces between individual crystals in the aggregate.

MANIPULATION

PROPORTIONING

To secure maximum strength a low water/powder ratio should be used. The water should be measured and the powder weighed.

Water/Powder Ratio

The W/P ratio is a very important factor in deciding the physical and chemical properties of the final product.

Example The higher the water-powder ratio, the longer is the setting time and weaker will be the gypsum product. Therefore, water/powder ratio should be kept as low as possible but at the same time sufficient to produce a *workable* mix.

Water Requirement of a Product is Affected by

1. *Shape and compactness of crystals* Thus, irregular, spongy plaster particles need more water than the denser stone.
2. Small amounts of surface active materials like gum arabic plus lime markedly reduce water requirement of all gypsum products.
3. *Particle size distribution* Grinding of the powder breaks up needle like crystals. This improves packing characteristics and reduces the water needed.

Recommended W/P Ratio

- Impression plaster : 0.50 to 0.75
- Dental plaster : 0.45 to 0.50
- Dental stone : 0.28 to 0.30
- Die stone, Type 4 : 0.22 to 0.24
- Die stone, Type 5 : 0.18 to 0.22

Figure 15.5: Stone/plaster dispenser.

INSTRUMENTS

Flexible rubber/plastic bowl, stiff bladed spatula.

PROCEDURE FOR HAND-MIXING

- Water is taken first to prevent adherence of dry powder to the sides of the bowl. Water and powder are dispensed according to the recommended W/P ratio. The powder is sifted into water in the rubber bowl. Plaster/stone dispensers are also available (***Fig. 15.5***).
- It is allowed to settle for 30 seconds to minimize air entrapment.
- The mix is stirred vigorously. Periodically wipe the inside of the bowl with a spatula to ensure wetting of the powder and breaking up of lumps. Continue till a smooth creamy mix is obtained. Spatulation should be completed in 45 to 60 seconds.
- *Vibrate* the mix (using a mechanical vibrator (***Fig. 15.6***) or by repeated tapping against a bench) and pour it into the impression, taking care not to entrap air (***Fig. 15.7***).

The mixing equipment must be meticulously clean. There should be no particles of set plaster from a previous mix sticking to the bowl or spatula. These if present will act as additional nuclei of crystallization and cause faster setting. No air must be trapped in the mixed mass. It causes loss of surface detail and weakens the cast.

MECHANICAL MIXING

Mechanical mixing under vacuum gives stronger and denser casts. However, the equipment is expensive.

Figure 15.6: Stone/plaster vibrator.

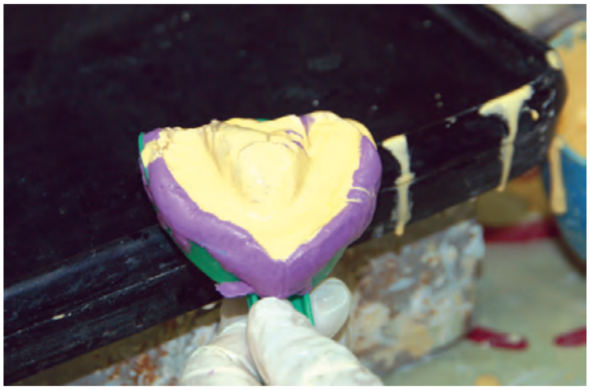


Figure 15.7: A vibrator improves the flow and reduces voids, thereby improving strength and accuracy.

SETTING TIME

The time elapsing from the beginning of mixing until the material hardens is called setting time.

Mixing time is the time from the addition the powder to the water until mixing is complete. A mixing time of 1 minute is usually sufficient.

Working time is the time available to work with the mix for the intended purpose, i.e., one that maintains an even consistency. At the end of the working period the material thickens and is no longer workable. The freshly mixed mass is semifluid in consistency and quite free flowing. A working time of 3 minutes is usually sufficient.

Initial setting time As the reaction proceeds, more hemihydrate crystals react to form dihydrate crystals. The viscosity of the mass is increased and it can no longer be poured. The material becomes rigid (but not hard). It can be carved but not moulded. This is known as *initial* setting time.

Final setting time The time at which the material can be separated from the impression without distortion or fracture.

Measurement of Setting Time

Usually by some type of penetration tests. Occasionally, other tests are used.

1. *Loss of gloss method* As reaction proceeds the gloss disappears from the surface of plaster mix (sometimes used to indicate initial set).
2. *Exothermic reaction* The temperature rise of the mass may also be used for measurement of setting time as the setting reaction is exothermic.
3. *Penetration tests* By using penetrometers.

Types of Penetrometers

- Vicat needle
- Gillmore needles

Vicat needle (***Fig. 15.8***) It weighs 300 gm and the needle diameter is 1 mm. The time elapsing from the start of mixing till the needle does not penetrate to the bottom of the plaster is the *setting time*. The setting time obtained with the Vicat needle is similar to the initial Gillmore.

Gillmore needles Two types—small and large (***Fig. 15.9***). The small Gillmore needle has a 1/4 lb weight and a diameter of 1/12" (2.12 mm) while the large Gillmore has a 1 lb wt and diameter of 1/24" (1.06 mm).

Figure 15.8: Vicat needle.

Figure 15.9: Gillmore apparatus. Besides dentistry it is also used in general industry to determine initial and final set times of Portland cement, masonry cement, hydrated lime, mortars, etc.

Initial Gillmore The time elapsing from the start of mixing until the time when the point of the 1/4 lb Gillmore needle no longer penetrates the surface is the *initial setting time*.

Final Gillmore Similarly the time elapsing from the start of mixing until the point of the 1 lb Gillmore needle leaves only a barely visible mark on the surface of the set plaster is known as the *final setting time*.

Factors Affecting Setting Time

1. Manufacturing process.
2. Mixing and spatulation (time and rate).
3. Water/Powder ratio.
4. Temperature.
5. Modifiers.

Manufacturing Process

1. If calcination is incomplete and excess gypsum (dihydrate) is left in the final product, the resulting plaster will set faster.
2. If soluble anhydrite is in excess, plaster will set faster.
3. If natural anhydrite is in excess, plaster will set slow.
4. Fineness: Finer the hemihydrate particle size, the faster the set, because
    - —Hemihydrate dissolves faster and
    - —The gypsum nuclei are more numerous and therefore, crystallization is faster.

Mixing and spatulation Within limits the longer and faster the plaster is mixed, the faster it will set because nuclei of crystallization are broken and well distributed within the mass.

Water/Powder ratio More the water used for mixing, the fewer the nuclei per unit volume. Thus setting time will be prolonged.

Temperature On increasing from a room temperature of 20°C to a body temperature of 37°C, the rate of the reaction increases slightly and the setting time is shortened. As the temperature is raised above 37°C the rate of reaction decreases and the setting time is lengthened. At 100°C the solubilities of hemihydrate and dihydrate are equal, in which case no reaction can occur and the gypsum will not set.

Modifiers (Accelerators and Retarders) Modifiers are chemicals added in order to alter some of the properties and make it more acceptable to the dentist. If the chemical added decreases the setting time it is called an *accelerator,* whereas if it increases the setting time it is called a *retarder*.

Accelerators and retarders not only modify setting time, they also affect other properties like setting expansion and strength.

Accelerators

- Finely powdered gypsum (up to 1%) is added by manufacturers to accelerate setting time. *Acts by* providing additional nuclei of crystallization. One source of gypsum is slurry water.
- In low concentrations, salts like sodium or potassium sulphate (2 to 3%) and sodium chloride (up to 2%) are accelerators. They *act by* making the hemihydrate more soluble.

Retarders

Retarders generally act by forming a layer on the hemihydrate to reduce its solubility. It also inhibits the growth of gypsum crystals.

- Borax (1- 2%) is the most effective retarder. During setting it forms a coating of calcium borate around the hemihydrate. Thus, the water cannot come in contact with the hemihydrate.
- In higher concentrations, sodium chloride (3.4% to 20%) and sodium sulphate act as retarders. In higher concentrations, the salt precipitates and poisons the nuclei of crystallization.
- Acetates, borates, citrates, tartrates and salts like ferric sulphate, chromic sulphate, aluminium sulphate, etc., are retarders, which *act by* nuclei poisoning by reducing the rate of solution of hemihydrate or by inhibiting growth of dihydrate crystals. Some additives react with hemihydrate, e.g., soluble tartrates and citrates precipitate calcium tartrate and citrate, respectively.
- Colloids such as gelatine, glue, agar, coagulated blood, etc. are effective retarders, presumably acting by nuclei poisoning. Contact with the gypsum during setting results in a soft, easily abraded surface.

To avoid The impression should be thoroughly rinsed in cold water to remove blood and saliva before pouring.

PROPERTIES

The important properties of gypsum products are

1. Setting expansion
2. Strength
3. Hardness and abrasion resistance
4. Reproduction of detail

SETTING EXPANSION

Setting expansion is of two types

1. Normal setting expansion
2. Hygroscopic setting expansion

NORMAL SETTING EXPANSION (0.05 TO 0.5%)

All gypsum products show a linear expansion during setting, due to the outward thrust of the growing crystals during setting. Crystals growing from the nuclei not only intermesh but also intercept each other during growth.

Importance of setting expansion In dentistry, setting expansion may be both desirable and undesirable depending on the use. It is undesirable in impression plaster, dental plaster and stone as it will result in an inaccurate cast or change in the occlusal relation if used for mounting. ADA/ANSI/ISO requirements for setting expansion for the various types is given in (***Table 15.1***).

Increased setting expansion is desired in case of investment materials as it helps to compensate the shrinkage of the metal during casting.

Control of setting expansion

1. Mechanical mixing reduces setting expansion when compared to hand mixed stone.
2. Increase in W/P ratio reduces the setting expansion.

Table 15.1

Properties of various gypsum products

	* % Setting Expansion	* Comp str. (1 hr) (MPa)	Hardness (Dry)(RHN)	* (μm) Detail Reproduction
Type 1	0.15 max	4 min 8 max		75 + 8
Type 2	0.30 max	9		75 + 8
Type 3	0.20 max	20	82	50 + 8
Type 4	0.10 max	35	92	50 + 8
Type 5	0.16 min 0.30 max		35	50 + 8

*Minimum requirement ADA sp. No. 25

3. Modifiers generally reduce the setting expansion.
4. *Potassium sulphate* 4% solution reduces setting expansion from 0.5 to 0.06 %.
5. *Sodium chloride* and borax also decrease setting expansion.

For accuracy in dental procedures, the setting expansion has to be minimized. The manufacturers achieve this by addition of K_2SO_4. This however, reduces the setting time. To counteract this, retarders like borax are also added (borax also reduces setting expansion).

HYGROSCOPIC SETTING EXPANSION

When a gypsum product is placed under water before the initial set stage, a greater expansion is seen. This is due to hygroscopic expansion. When expansion begins, externally available water is drawn into pores forming in the setting mass and this maintains a continuous aqueous phase in which crystal growth takes place freely. Under dry conditions this additional water is not available and as expansion occurs the aqueous phase in the mix is reduced to a film over the growing crystals. It is greater in magnitude than normal setting expansion.

Importance Used to expand some gypsum bonded investments.

STRENGTH

The strength increases rapidly as the material hardens after the initial setting.

Factors Affecting Strength

The free water content (excess water) The greater the amount of free water in the set stone, the less the strength.

Wet strength is the strength when excess free water (more than is necessary for reaction) is present in the set gypsum. The wet strength (1 hour compressive strength) for model plaster, dental stone, and die stone are 12.5, 31 and 45 MPa respectively.

Dry strength is the strength of gypsum when the excess free water is lost due to evaporation. It is two or more times greater than the wet strength.

Excess water may be removed from gypsum cast by low-temperature drying. But there is no strength increase until the last 2% of free water (***Fig. 15.10***) is removed. This strength increase on drying is reversible, thus soaking a dry cast in water reduces its strength to the original level. Many products have strength values in excess of the ADA requirements. One Type 4 product claims a wet strength (1 hr) of 67 MPa and a dry strength of 121.6 MPa.

Temperature Gypsum is stable only below about 40°C. Drying at higher temperatures must be carefully controlled. Loss of water of crystallization occurs rapidly at 100°C or higher and causes shrinkage and a reduction in strength.

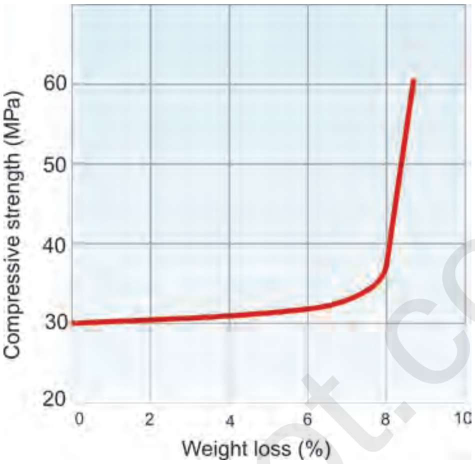


Figure 15.10: Effect of drying on the strength of dental stone.

Other factors affecting strength are:

- *W/P ratio* The more the water, the greater the porosity and less the strength.
- *Spatulation* Within limits, strength increases with increased spatulation.
- *Addition of accelerators and retarders* Lowers strength.

TENSILE STRENGTH

Gypsum is a brittle material, thus weaker in tension than in compression.

The one hour tensile strength of model plaster is approximately 2.3 MPa. When dry, the tensile strength doubles. The tensile strength of dental stone is twice than that of plaster.

Significance Teeth on a cast may fracture while separating from the impression. Since in practice fracture of gypsum typically occurs in tension, tensile strength is a better guide to fracture resistance.

Time at which cast can be used The cast cannot be used as soon as it reaches its final setting (as defined by the Vicat and Gillmore tests). This is because the cast has not reached its full strength. Technically the cast can be used when it has attained at least 80% of its one hour strength. Current products are ready for use in *30 minutes*.

HARDNESS AND ABRASION RESISTANCE

Dies and casts are often used to construct restorations and prostheses. A good surface hardness and abrasion resistance is therefore essential.

Hardness is related to the compressive strength. The higher the compressive strength of the hardening mass, the higher the surface hardness. After the final setting occurs, the surface hardness remains practically constant until most of the excess water is dried, after which it increases.

The surface hardness increases at a faster rate than the compressive strength since the surface of the hardened mass reaches a dry state earlier than the inner portion of the mass. Commercial hardening solutions are available to increase the surface hardness of stone. However, surface hardness and abrasion resistance are not always related, for example, epoxy resin is more abrasion resistant than die stone, even though die stone is the more harder of the two.

FLOW

The flow of freshly mixed gypsum depends on the amount of water used (W/P ratio). The greater the amount of water used, the greater would be the flow. However, a correctly proportioned mix has sufficient flow. Vibrating the mix greatly improves the flow. The flow reduces as it approaches its initial set.

REPRODUCTION OF DETAIL

Gypsum products reproduce detail accurately (***Table 15.1***).

Significance This property is important for:

- Impression plaster because it has to accurately duplicate oral tissues
- Cast material has to duplicate all the detail recorded by the impression. Factors which affect detail reproduction include compatibility with the impression material, trapped air bubbles in the mix and surface contaminants like saliva. Use of a mechanical vibrator and proper technique considerably improve detail reproduction.

SPECIALIZED GYPSUM PRODUCTS

Some gypsum products are manufactured for specific uses in dentistry. Each type is developed with specific physical properties suitable for the particular purpose.

Figure 15.11: Gypsum bonded investment (*Courtesy:* CODS, Manipal).

DENTAL CASTING INVESTMENTS

Uses

To prepare refractory molds for casting dental alloys.

Adding a refractory material like silica or quartz or crystobalite to dental plaster or stone permits it to withstand high temperatures. These are called dental casting investments (***Fig. 15.11)*** (detailed in Chapter on investments).

DIVESTMENT

Uses

To make refractory dies.

It is a combination of die stone and gypsum-bonded investment mixed with colloidal silica. A die is made and the wax pattern constructed on it. Then the entire assembly (die and pattern) is invested in the divestment (normally the wax pattern is removed from the die and invested separately).

The setting expansion of the material is 0.9% and thermal expansion is 0.6% when heated to 677°C. The *advantage* of divestment is that the wax pattern does not have to be removed from the die, thus distortion of the pattern can be avoided.

SYNTHETIC GYPSUM

It is possible to make alpha and beta hemihydrate from the by-products during the manufacture of phosphoric acid.

Figure 15.12: Orthodontic stone (kalabhai) and model.

Figure 15.13: Mounting plaster.

The synthetic product is usually more expensive than that made from natural gypsum, but when the product is properly made, its properties are equal to or exceed the latter. However, manufacture is difficult and a few have succeeded (e.g., Japan and Germany).

ORTHODONTIC STONE

For orthodontic study models many orthodontists prefer to used white stone or plaster (***Fig. 15.12***). These products have a longer working time for pouring of multiple models. To produce a glossy surface, finished models may be treated with '*model glow*' model soap.

RESIN MODIFIED STONES

A new resin fortified die stone (e.g., ResinRock, Whipmix corporation) is available. It is a blend of synthetic resin and alpha gypsum. These stones are less brittle, have improved surface smoothness and increased resistance to abrasion. When mixed it forms a creamy, thixotropic mix which flows more easily under vibration. Their compressive strength can be as high as 79 MPa.

MOUNTING PLASTER

Plaster used for attaching the cast to the articulator is known as mounting plaster (***Fig. 15.13***). Regular plaster (type II) is used for this purpose. However, plaster specialized for this purpose are available commercially. Important properties for these products include a low setting expansion (0.09) which is important for the accuracy of the mounting, low strength (12 MPa) which allows easy separation from the cast and fast setting time (3 minutes).

FAST SETTING STONE

These are exceptionally fast setting stones (2 minutes) with an early high compressive strength (1 hour - 41 MPa) which allows separation of the cast from the impression in 5 minutes. An example includes *Snap stone* (Whipmix).

CARE OF GYPSUM

CARE OF THE CAST

If the gypsum cast has to be soaked in water it must be placed in a water bath in which plaster debris is allowed to remain constantly on the bottom of the container to provide a saturated solution of calcium sulfate at all times. This is known as '*slurry water*'. If the cast is washed in ordinary water, surface layer may dissolve, hence slurry water is used to preserve surface details. Such a procedure also causes a negligible expansion. All gypsum casts must be handled carefully as any departure from the expected accuracy may result in a poorly fitting appliance.

STORAGE OF THE POWDER

- As plaster is hygroscopic it should be kept in *air tight containers*. When the relative humidity is more than 70%, plaster starts taking up moisture initiating a setting reaction. This produces small crystals of gypsum which act as nuclei of crystallization. Thus in the early stages, moisture contaminated plaster *sets faster*. In later stages, as the hygroscopic action continues, the entire hemihydrate mass is covered by more crystals of gypsum. The water penetrates the mass with difficulty, thereby delaying setting. Thus heavily moisture contaminated stone or plaster *sets slower*. The humidity factor is a major consideration in parts of India with high atmospheric humidity.
- It should be kept clean with no dirt or other foreign bodies.

INFECTION CONTROL

There has been an increased interest over possible cross contamination to dental office personnel through dental impressions. If an impression has not been disinfected it is wise to disinfect the stone cast.

Gypsum products may be disinfected by:

1. Immersing cast in a disinfection solution.
2. Addition of disinfectant into the stone.
3. Overnight gas sterilization while treating patients known to have an infection (impractical for routine use).

DIFFERENCES BETWEEN DENTAL PLASTER AND DENTAL STONE

Though chemically identical, their differences are detailed in ***(Table 15.2)***:

Table 15.2

Comparison of plaster and stone

	Plaster	*Stone*
Manufacture	Dry calcination	Wet calcination
Particle size/shape	Larger, irregular porous	Smaller, regular and dense
W/P ratio	Requires more water	Requires less water
Porosity	Porous	More dense
Properties	Lower strength and hardness	Greater strength and hardness
Application	Used when strength is not of primary importance (e.g., diagnostic casts)	Used when greater strength and hardness is required (e.g., dies, master casts)

16

WAXES IN DENTISTRY

During construction of a denture and many other appliances, wax is used as a modelling material. Different types of waxes are used to prepare patterns for alloy castings.

There are many varieties of waxes used, both in the clinic and laboratory. Each have particular properties depending on what it is used for. Their basic constituents are essentially similar, their exact proportion is different.

COMPONENTS OF DENTAL WAXES

Dental waxes contain natural waxes, synthetic waxes and additives (***Table 16.1***).

CHEMICAL NATURE OF WAXES

Natural waxes are complex combinations of organic compounds of reasonably high molecular weight. The two principal groups of organic compounds contained in waxes are:

- Hydrocarbons, e.g., saturated alkanes, and
- Esters, e.g., myricyl palmitate.

Some waxes in addition contain free alcohol and acids (Ester—formed from union of higher fatty acids with higher aliphatic alcohol with elimination of water).

$$\text{Alcohol} + \text{Fatty Acid} \longrightarrow \text{Ester} + \text{Water}$$

MINERAL WAXES

Paraffin and microcrystalline waxes A distillation products of petroleum. They are both hydrocarbons. Paraffin (melts 40-70°C) tends to be brittle. Microcrystalline (60 - 90°C) is more flexible and tougher.

Bees wax Its addition reduces brittleness.

PLANT WAXES

Carnauba and ouricury Carnauba occurs as fine powder on the leaves of certain tropical plants. Melting range: 84 - 91°C. Ouricury melts between 79-84°C. Both raise melting range and hardness of paraffin.

Candellila (68 to 75°C) Mainly hardens paraffin wax.

Japan wax and cocoa butter Are not true waxes but are chiefly fats. Japan wax is tough, malleable and sticky and melts at 51°C. Cocoa butter is brittle. Japan wax improves tackiness and emulsifying ability of paraffin.

Table 16.1

Component of waxes

	Natural waxes	*Synthetic waxes*	*Additives*
Minerals	Paraffin Microcrystalline Barnsdahl Ozokerite Ceresin Montan	Acrawax C Aerosol, OT Castorwax Flexowax C Epolene N-10 Albacer Aldo 33 Durawax 1032	Fats – Stearic acid – Glyceryl tristearate Oils Turpentine Color
Plants	Carnauba Ouricury Candelilla Japan wax Cocoa butter		Natural Resins Rosin – Copal – Dammar – Sandarac – Mastic – Shellac – Kauri
Insect	Beeswax		
Animal	Spermaceti		Synthetic Resins – Elvax – Polyethylene – Polystyrene

INSECT WAX

Beeswax (63 - 73°C) Brittle at room temperature, plastic at body temperature.

ANIMAL WAX

Spermaceti is obtained from the sperm whale. It is not widely used. Mainly used as a coating for dental floss.

SYNTHETIC WAXES

The natural waxes are not consistent in their composition, and thus their properties. To overcome this, synthetic waxes are used. These are carefully prepared under controlled conditions to give standardized reliable results. They are highly refined unlike natural waxes which are frequently contaminated. Their use is still limited.

Ozokerite It is an earth wax found in western US and central Europe. It improves the physical characteristics of paraffin.

Ceresin It is obtained from petroleum and lignite refining. They are harder and are used to raise melting range of paraffin.

Barnsdahl It raises melting range and hardness, reduces flow of paraffin.

WAX ADDITIVES

Montan It is hard, brittle and lustrous. It can be substituted for plant waxes.

Gums They are viscous, amorphous exudates from plants that harden when exposed to air. They are complex substances mainly made of carbohydrates. They either dissolve in water or form sticky, viscous liquids, e.g., gum Arabic and tragacanth.

Fats They are tasteless, odorless and colorless substances. They are similar to wax but have lower melting temperatures and are softer. Chemically they are composed of glycerides, e.g., beef tallow and butter. They can be used to increase melting range and hardness of waxes.

Oils They lower the melting point of paraffin. Hydrocarbon oils soften waxes. Silicone oils improve ease of polishing of waxes.

Resins are exudates of certain trees and plants (except shellac which is from insects). They are complex, amorphous mixtures of organic substances. They are insoluble in water. They improve toughness. They are also used to make varnishes (by dissolving in an organic solvent).

Synthetic resins are also used.

CLASSIFICATION OF DENTAL WAXES

ACCORDING TO ORIGIN (DESCRIBED EARLIER)

- Mineral
- Plant
- Insect
- Animal

ACCORDING TO USE

Pattern waxes	*Processing waxes*	*Impression waxes*
Inlay casting	Boxing	Corrective
RPD casting	Utility	Bite registration
Base plate	Sticky	

ADA/ISO CLASSIFICATION (ADA SP NO 122/ ISO 15854:2005) FOR DENTAL CASTING INLAY AND BASEPLATE WAX)

Classified according their flow characteristics that represent their hardness.

Type I (Inlay casting wax)

    Class 1: Soft
    Class 2: Hard

Type II (Baseplate wax)

    Class 1: Soft
    Class 2: Hard
    Class 3: Extra hard

GENERAL PROPERTIES

Waxes have a number of important properties in relation to their dental use. Different uses require different properties. Waxes for patterns probably require most careful balance. Some of the important properties are:

1. Melting range
2. Thermal expansion
3. Mechanical properties
4. Flow
5. Residual stresses
6. Ductility.

MELTING RANGE

Waxes have melting ranges rather than melting points. Mixing of waxes may change their melting range. Melting range varies depending on its use.

THERMAL EXPANSION

Waxes expand when subjected to a rise in temperature and contract as the temperature is decreased.

Coefficient of thermal expansion and its importance Dental waxes and their components have the largest CTE among the materials used in restorative dentistry. Temperature changes in wax patterns after removal from the mouth, can produce *inaccuracies* in the finished restoration.

MECHANICAL PROPERTIES

The elastic modulus, proportional limit and compressive strength of waxes are low compared to other dental materials. These properties are strongly dependent on the temperature. As temperature decreases, the properties improve.

FLOW

Flow is an important property, especially in inlay waxes. When melted the wax should flow readily into all the parts of the die. Flow is dependent on:

- Temperature of the wax
- Force applied
- The length of time the force is applied.

Flow increases as the melting point of the wax is approached.

RESIDUAL STRESS

Regardless of the method used to make a wax pattern, residual stresses will exist in the completed pattern. The stress may be compressive or tensile in nature.

Example A When a specimen is held under compression during cooling the atoms and molecules are forced closer together. After the specimen is cooled to room temperature and the load is removed, the motion of the molecules is restricted. This restriction results in residual stress (hidden stresses) in the specimen. When the specimen is heated, release of the residual stress is added to the normal thermal expansion, and the total expansion is greater than normal.

Example B When a specimen is cooled while under tension, the release of the residual tensile stress results in a dimensional change that is opposite to thermal expansion, i.e., it can result in overall contraction of the specimen.

DUCTILITY

Like flow, the ductility increases as the temperature of the wax is increased. In general, waxes with low melting points have greater ductility than those with high melting points.

PATTERN WAXES

Many dental restorations or prostheses are first made with pattern waxes. The wax is later replaced with the permanent material, e.g., cast gold alloys, cobalt-chromium-nickel alloys, or polymethyl methacrylate resin. All pattern waxes have two major qualities which cause serious problems in their use—thermal change in dimension and tendency to warp or distort on standing, e.g., inlay casting wax, RPD casting wax and baseplate wax.

TYPES

1. Casting waxes
    - ➢ Inlay
    - ➢ Removable partial denture (the metal frame)
2. Baseplate wax (used in the construction of complete and partial denture).

INLAY CASTING WAX

USES

The pattern for inlays, crowns and FPDs is first made in wax ***(Fig. 16.1)***, and then replaced by metal during casting.

Direct and indirect techniques If the pattern is made directly in the tooth (in the mouth), it is said to be prepared by direct technique. If it is prepared on a replica of the tooth (die), it is called indirect technique.

IDEAL REQUIREMENTS OF INLAY CASTING WAXES

1. When softened, the wax should be uniform, there should be no graininess or hard spots in the plastic material.
2. The color should contrast with the die. A definite color contrast helps in identifying and finishing of margins.
3. The wax should not flake or crumble when the wax is softened.
4. The wax should not chip, flake or tear during carving.
5. During burnout (500°C), it should vaporize completely without residue.
6. The wax pattern should be completely rigid and dimensionally stable at all times until it is eliminated.
7. It should be sufficiently plastic slightly above mouth temperature and become rigid when cooled to mouth temperature (for class I waxes).
8. The wax should have good flow when heated and set rigidly when cooled (at the recommended temperature for each type see ***Table 16.1***).

CLASSIFICATION

Inlay casting waxes are classified as:

Class 1: Soft
Class 2: Hard

Figure 16.1: Inlay casting waxes are usually available as sticks.

SUPPLIED AS

Blue, green or purple sticks (***Fig. 16.1***). Also available as small pellets and cones.

Commercial Names Harvard, Kerr, etc.

COMPOSITION

Paraffin wax, gum dammar, carnauba or candellila and coloring agents.

Paraffin wax (40 - 60%) Main ingredient. It is used to establish the melting point. Different varieties, with different melting points can be produced. Paraffin wax flakes when trimmed and does not give a smooth surface, so other waxes are added to modify.

Ceresin (10%) Partially replaces paraffin. Increases toughness. Easy to carve.

Gum dammar (1%) Dammar resin (a natural derivative from pine tree) improves the smoothness during molding and makes it more resistant to cracking and flaking. It also increases toughness of the wax and enhances the luster of the surface.

Carnauba wax (25%) This wax is quite hard and has a high melting point. It is combined with paraffin to decrease the flow at mouth temperature. It has an agreeable odor and gives glossiness to the wax surface.

Candellila wax This wax can be added to replace carnauba wax. It contributes the same qualities as carnauba wax, but its melting point is lower and is not as hard as carnauba wax.

Synthetic waxes In modern inlay waxes, carnauba wax is often replaced partly by certain synthetic waxes (Montan). Because of their high melting point, more paraffin can be incorporated and the general working qualities are improved.

PROPERTIES OF INLAY WAX

Type I inlay wax is meant for use in the mouth whereas, Type II wax is used in the laboratory (indirect technique). Obviously, both would have slightly different properties.

Flow

Requirements according to ADA sp. No. 122/ ISO 15854:2005 (***Table 16.2***)

At 45°C - Both Class I and Class II should have a flow between 70 to 90%.
At 37°C - Class I should not flow more than 1%.
At 30°C - Class II should not flow more than 1%.

From the above requirements it is clear that:

Class I inlay wax This type melts and flows, when heated to around 45°C. This temperature is tolerated by the patient. Good flow at this temperature ensures good reproduction of the inlay cavity. The wax cools down and hardens at 37°C (mouth temperature), allowing the operator to carve and shape it in the mouth.

Table 16.2

Flow requirements for inlay casting wax (Adapted from ADA SP No. 122)

	Flow in %				
	At 30°C	*At 37°C*	*At 40°C*	*At 45°C*	
Class 1	Max 1%	-	Min 50%	Min 70%	Max 90%
Class 2	-	Max 1%	Max 20%	Min 70%	Max 90%

Class II inlay wax This type on the other hand hardens at 30°C (room temperature). This wax is more suitable for the laboratory. The flow characteristics are not suitable for use in the mouth.

Thermal Properties

Thermal conductivity The thermal conductivity of these waxes is low. It takes time to heat the wax uniformly and to cool it to body or room temperature.

Coefficient of thermal expansion Inlay wax has a high CTE. It has a linear expansion of 0.7% with increase in temperature of 20°C. Its thermal changes are higher than any other dental material.

Importance This property is more significant in direct technique because contraction of the pattern can occur when it is taken from mouth to room temperature (especially in air conditioned rooms or in cold climates).

Factors affecting If the wax is allowed to cool under pressure, its thermal properties are changed. When reheated, the linear CTE is increased. The temperature of the die and the method used to apply pressure on the wax as it solidifies also influences the CTE.

Wax Distortion

Wax distortion is the most serious problem in inlay wax. It is due to *release of stresses* in the pattern caused due to:

- Contraction on cooling
- Occluded gas bubbles
- Change of shape of the wax during molding
- From manipulation - carving, pooling, removal, etc.

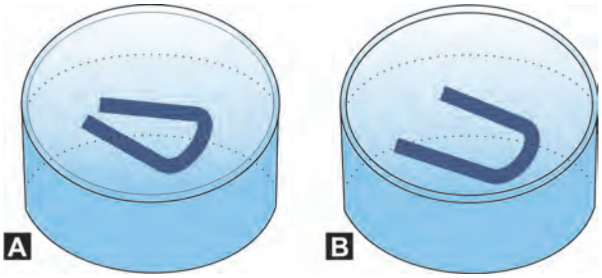
Thus the amount of residual stress is dependent on:

— The method of forming the pattern
— Its handling and
— Length of time and temperature of storage of the wax pattern.

Causes of distortion Distortion is due to any method of manipulation that creates inhomogeneity of wax involving the intermolecular distance ***(Fig. 16.2)***.

Factors causing distortion under control of the operator *cannot be* totally eliminated. Distortion of the wax can occur:

— If wax is not at uniform temperature when inserted in the cavity. Some parts of the wax pattern may thermally contract more than others when stresses are introduced.
— If wax is not held under uniform pressure during cooling.



Figures 16.2 A and B: Demonstration of wax distortion. (A) Bent stick of wax kept in water at room temperature, (B) Straightened appreciably after 24 hours.

— If fresh wax is melted and added in an area of deficiency, the added wax will introduce stresses during cooling.

- During carving, some molecules of wax will be disturbed and stresses will result.

To avoid

- Minimal carving and change in temperature.
- Minimal storage of pattern. Invest immediately.
- Store it in a refrigerator if necessary.
- Some relaxation and distortion of pattern occurs regardless of the method used. It cannot be totally eliminated. It can only be reduced to a point which is not of clinical importance.

RESIDUE ON IGNITION

Waxes vaporize during burnout. ADA Sp. limits the non-vaporizable residue to a maximum of 0.1%. Excess residue can result in an incomplete casting.

MANIPULATION OF INLAY WAX

Direct Technique

Hold the stick of wax over the visible flame and *rotate it* rapidly until it becomes plastic taking care not to volatilize the wax. The softened wax is shaped approximately to the form of the prepared cavity.

After the wax is inserted into the cavity, it is held under *finger pressure* while it solidifies. The wax should be allowed to *cool gradually* to mouth temperature. Cooling rapidly by application of cold water results in differential contraction and development of internal stresses.

Localized reheating of wax with warm carving instruments has a similar effect and more distortion may occur. A cold carving instrument should be used for direct wax pattern. Withdraw the wax pattern carefully in the long axis of the preparation. The pattern should be touched as little as possible with the *hands* to avoid temperature changes.

Indirect Technique

Inlay pattern is prepared over a *lubricated die*. If molten wax is used, very little residual stresses occur.

- *Dipping method* In case of full crowns, the die can be dipped repeatedly, into hot liquid wax. The wax is allowed to cool, carved, and removed from the die.
- *Softening in warm water* This technique is not recommended as
  - Soluble constituents may leach out and the properties of wax will change
  - Water gets into the wax causing splattering on the flame, interference with the softening of the wax surface and distortion of the pattern on thermal changes.
- *Addition* The wax is melted and added in layers using a spatula or a brush.

Polishing

Polishing is done by rubbing with a silk cloth.

Note

1. Invest all wax patterns as soon as possible to avoid distortion
2. Waxes oxidize on heating. Prolonged heating causes it to evaporate. There will also be darkening and precipitation of gummy deposits. To avoid this, use the lowest temperature needed for melting.

RPD CASTING WAX

The partial denture casting waxes are quite unlike the inlay casting waxes in appearance and handling properties. Currently, no ADA or ISO specification have been formulated for these waxes. However, a US federal specification (U-W-140) has been formulated to cover these waxes. These specifications are different from those of inlay waxes.

USES

To make patterns of the metallic framework of removable partial dentures.

SUPPLIED AS

It is available in different forms ***(Fig. 16.3 A)***

- Sheets 0.40 and 0.32 mm thickness
- Readymade shapes
  - Round (10 cm), half round and half pear shaped rods
  - Reticular, grid or mesh form
  - Clasp shapes
  - Other forms
- Bulk

PROPERTIES

These waxes are *tacky* and highly *ductile* as they must adapt easily and stick onto the refractory cast. They should copy accurately the surface against which they are pressed. The pattern for the RPD frame is made on a special cast known as the *refractory cast* ***(Fig. 16.3 B)***. Since the wax comes in ready-made shapes, it is quite easy to assemble. The wax forms are sticky and pliable and can be adapted

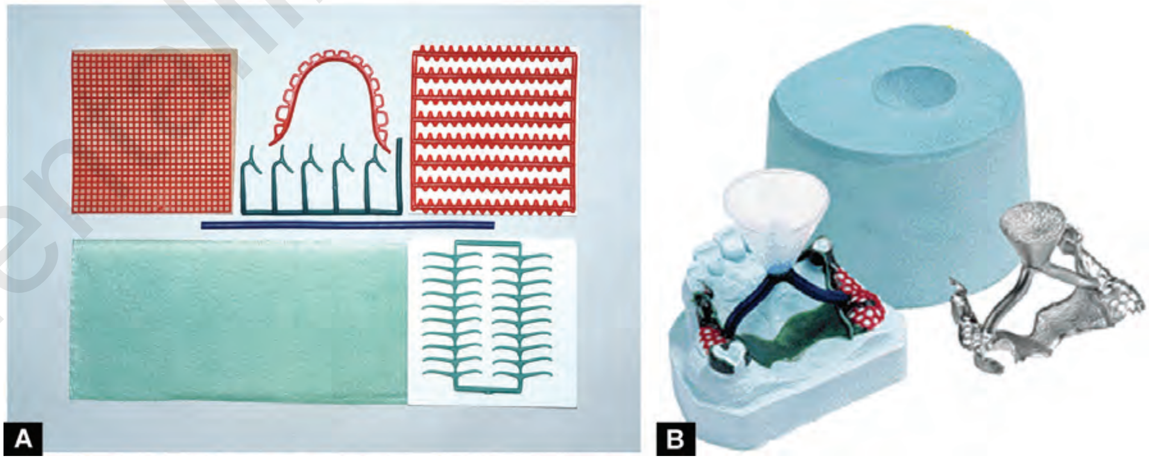


Figure 16.3: (A) Preformed casting waxes saves valuable laboratory time and gives more consistent results. (B) RPD pattern formed from preformed waxes are used in the construction of removable partial dentures.

Figure 16.4: Occlusion rims.

Figure 16.5: Baseplate wax.

easily on to the cast. After the pattern is completed it is invested and ignited. Like inlay wax they too must vaporize with *little residue* during burnout.

BASEPLATE WAX

Most students would be familiar with this wax. it is sometimes referred to as modeling wax. They are classified under pattern waxes because they are used in the construction of dentures and appliances made of acrylic and like materials.

USES

These waxes are used for the following:

1. To make occlusion rims ***(Fig. 16.4)***.
2. To form the contour of the denture after teeth are set.
3. To make patterns for orthodontic appliances and other prostheses which are to be constructed of plastics.

CLASSIFICATION (ADA SP. NO. 122/ ISO 15854:2005)

Type I soft — for building veneers
Type II hard — to use in mouths in normal climates
Type III extra-hard — for use in tropical climates

SUPPLIED AS

Sheets of pink or red color ***(Fig. 16.5)***.

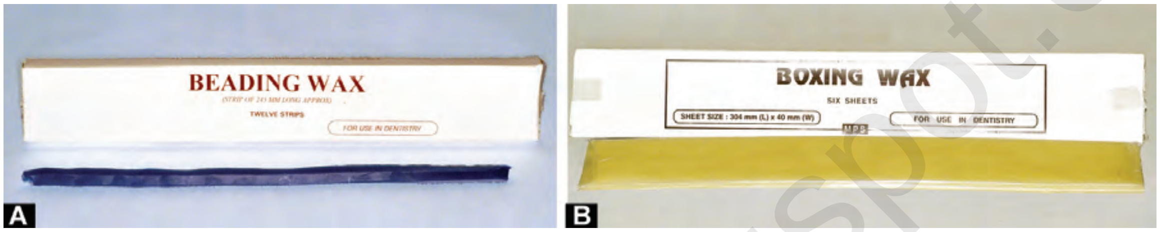
COMPOSITION

Component	*Percent*
Paraffin or ceresin	80.0%
Beeswax	12.0%
Carnauba	2.5%
Natural or synthetic resins	3.0%
Microcrystalline	2.5%.

PROCESSING WAXES

These are those waxes used mainly as accessory aids in the construction of a variety of restorations and appliances, either clinically or in the laboratory, e.g., boxing wax, beading wax, utility wax and sticky wax.

Figure 16.6: Boxed impression ready for pouring stone.



Figures 16.7 A and B: (A) Beading wax, (B) Boxing wax.

BOXING WAX AND BEADING WAX

USES

Used to build up vertical walls around the impression, in order to pour the stone and make a cast. The procedure is known as *boxing* ***(Fig. 16.6)***.

SUPPLIED AS

Boxing wax as sheets, beading wax as strips ***(Figs 16.7 A and B)***.

ADVANTAGES OF BEADING AND BOXING

1. Preserves the extensions and landmarks.
2. Controls the thickness of the borders.
3. Controls the form and thickness of the base of the cast.
4. Conserves the artificial stone.

PROPERTIES

They are pliable and can be adapted easily. A slight tackiness allows it to stick to the impression.

Note The terms carding wax and boxing wax have been used interchangeably. Carding wax was the original material on which porcelain teeth were fixed when received from the manufacturer. Boxing wax is a more acceptable term.

TECHNIQUE

Beading wax is adapted around the periphery. This wax should be approximately 4 mm wide and 3-4 mm below the borders of the impression. The height is adjusted until a boxing wax strip extends approximately 13 mm above the highest point on the impression. Stone is vibrated into the boxed impression.

Figure 16.8: Utility wax.

UTILITY WAX

COMPOSITION

Consists mainly of beeswax, petrolatum, and other soft waxes in varying proportions.

SUPPLIED AS

It is available in the form of sticks and sheets ***(Fig. 16.8)***.

USES

It is *used* to adjust contour of perforated tray for use with hydrocolloids (e.g., to raise flange height, to extend the tray posteriorly, to raise palatal portion of the tray in cases of deep palate, etc.). It is pliable and can be easily molded. It is adhesive and can stick to the tray.

STICKY WAX

COMPOSITION

It consists mainly of yellow beeswax, rosin, and natural resins such as gum dammar.

PROPERTIES

It is sticky when melted and adheres closely to the surfaces to which it is applied. At room temperature, it is firm, free from tackiness, and brittle ***(Fig. 16.9).***

Figure 16.9: Sticky wax.

USES

Used for joining (assembling) metal parts before soldering and for joining fragments of broken dentures before repair procedure. A variety of other uses, mainly joining, are possible with this wax.

IMPRESSION WAXES

These are used to record non-undercut edentulous portions of the mouth, and are generally used in combination with other impression materials such as polysulfide rubber, ZOE, or dental impression compound, e.g., corrective impression wax, bite registration wax.

CORRECTIVE IMPRESSION WAX

Waxes were used widely in the past for making dental impressions. Waxes are highly unstable and susceptible to distortion and are therefore, not particularly suited for impressions. However, they may be used in certain situations.

USES

It is used as a wax veneer over an original impression to contact and register the details of the soft tissues ***(Fig. 16.10)***.

1. To make functional impression of free end saddles (Class I and II removable partial dentures).
2. To record the posterior palatal seal in dentures.
3. Functional impression for obturators.

COMPOSITION AND PROPERTIES

They *consist of* paraffin, ceresin and beeswax. It may also contain metal particles. The flow at 37°C is 100%. These waxes are subject to distortion during removal from the mouth. They should be *poured immediately*.

BITE REGISTRATION WAX

USES

It is used to record the relationship between the upper and lower teeth. This is necessary in order to mount the casts correctly in the articulator.

SUPPLIED AS

U-shaped rods or wafers ***(Fig. 16.11).*** A thin metallic foil may be present on the undersurface or between the wax layers.

Figure 16.10: An example of impression wax.

Figure 16.11: Bite registration wax.

COMPOSITION

Beeswax or paraffin or ceresin. Some contain aluminum or copper particles.

PROCEDURE

The wax is softened in warm water. The soft wax is then placed between the teeth and the patient is asked to bite. After the wax hardens, it is then taken out and placed in chilled water. It is replaced back in the mouth and the patient asked to occlude for a final check. The casts of the patient is placed in the indentations formed by the teeth in the wax. It is then mounted with plaster on the articulator. Mounting should not be delayed as wax distortion can lead to inaccurate results. Bite registration can be done with other materials like zinc oxide eugenol and silicones.

17

DENTAL CASTING INVESTMENTS

An investment can be described as a ceramic material which is suitable for forming a mold into which molten metal or alloy is cast. The procedure for forming the mold is described as 'investing'. These materials can withstand high temperatures. For this reason they are also known as *refractory* materials.

REQUIREMENTS OF AN INVESTMENT MATERIAL

1. The investment mold must expand to compensate for the alloy shrinkage, which occurs during the cooling of the molten alloy.
2. The powder should have a fine particle size to give a smooth surface to the casting.
3. The manipulation should be easy. It should have a suitable setting time.
4. The material should have a smooth consistency when mixed.
5. The set material should be porous enough to permit air in the mold cavity to escape easily during casting.
6. At higher temperatures, the investment must not decompose to give off gases that may corrode the surface of the alloy.
7. It must have adequate strength at room temperature to permit handling, and enough strength at higher temperatures to withstand the impact force of the molten metal.
8. Casting temperatures should not be critical.
9. After casting, it should break away readily from the surface of the metal and should not react chemically with it.
10. The material should be economical.

TYPES OF INVESTMENT MATERIALS

There are three types of investment materials. They all contain silica as the refractory material. The type of binder used is different.

1. *Gypsum bonded investments* They are used for casting gold alloys. They can withstand temperature up to 700°C.
2. *Phosphate bonded investments* For metal ceramic and cobalt-chromium alloys. They can withstand higher temperatures.
3. *Ethyl silica bonded investments* They are an alternative to the phosphate bonded investments, for high temperature casting. They are principally used in the casting of base metal alloy partial dentures.

GENERAL COMPOSITION OF INVESTMENTS

All investment materials contain a refractory and a binder.

REFRACTORY

A material that will withstand high temperatures without decomposing or disintegrating, e.g., silica.

Allotropic forms Silica exists in at least four allotropic forms:

- Quartz
- Tridymite
- Cristobalite
- Fused quartz

They serve two functions

1. Acts as a material that can withstand high temperatures.
2. Regulates the thermal expansion.

BINDER

A material which will set and bind together the particles of refractory substance, e.g., gypsum, phosphate and silicate. The common binder used for *gold alloys* is dental stone (alpha-hemihydrate). The investments for casting *cobalt chromium alloys* use ethyl silicate, ammonium sulphate or sodium phosphate.

CHEMICAL MODIFIERS

Chemicals such as sodium chloride, boric acid, potassium sulfate, graphite, copper powder or magnesium oxide are added in small quantities to modify properties.

GYPSUM BONDED INVESTMENTS

CLASSIFICATION

According to ADA Sp. No. 2 (ISO 7490:2001)* for gypsum bonded investments, there are two types based on use.

Type— I	For casting inlays or crowns
Type— II	For casting partial and complete denture bases

USES

For casting of inlays, fixed partial dentures, removable partial denture frame works using gold alloys and other low fusing alloys.

SUPPLIED AS

Powder in bulk or preweighed packs (***Fig. 17.1***).

Representative commercial products Prestobalite, Novocast (Whipmix), etc.

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* The original name for the standard was 'gypsum bonded investments for gold alloy casting investments.' In the 2001 revision the limitation to 'gold alloys' was removed.

Figure 17.1: Representative gypsum bonded investments.

COMPOSITION

Component	*Proportion*
Silica	– 60 to 65%
Alpha-hemihydrate (dental stone)	– 30 to 35%
Chemical modifiers	– 5%

FUNCTION OF CONSTITUENTS

Alpha hemihydrate:

- — It binds and holds the silica particles together.
- — Permits pouring of the mix into the mold.
- — It imparts strength to the mold.
- — Contributes to mold expansion (by setting expansion).

Silica: Quartz or cristobalite

- — Acts as a refractory during heating.
- — Regulates thermal expansion.
- — Increases setting expansion of stone.
- — Silica in the investment eliminates contraction of gypsum and changes it to an expansion during heating.

Modifiers

- — Coloring matter
- — *Reducing agents* They reduce any oxides formed on the metal by providing a nonoxidizing atmosphere in the mold when the mold alloy enters, e.g., carbon or copper powder.
- — *Modifying chemicals* They regulate setting expansion and setting time and also prevent shrinkage of gypsum when heated above 300°C, e.g., boric acid and sodium chloride.

MANIPULATION

The measured quantity of powder and water is mixed manually using a flexible rubber bowl and spatula or in a vacuum investment mixing machine.

SETTING REACTION

The setting reaction is similar to dental stone. When the water is mixed, the hemihydrate reacts to form dihydrate which sets to form a solid mass which binds the silica particles together.

SETTING TIME

According to ADA Sp. No. 2 for inlay investments, setting time should not be less than 5 minutes and not more than 25 minutes. The modern inlay investments set initially in 9 to 18 minutes. This provides sufficient time for mixing and investing the pattern.

FACTORS CONTROLLING SETTING TIME

1. Manufacturing process
2. Mixing time and rate
3. Water-powder ratio
4. Temperature
5. Modifiers—accelerators and retarders

PROPERTIES OF GYPSUM INVESTMENTS

THERMAL BEHAVIOR OF GYPSUM

When gypsum is heated to a high temperature, it shrinks and fractures. At 700°C, it shows slight expansion and then great amount of contraction. The shrinkage is due to decomposition and release of sulfur dioxide. It contaminates the casting with the sulfides of silver and copper. So the gypsum bonded investments should not be heated above 700°C.

THERMAL BEHAVIOR OF SILICA

When heated, quartz or cristobalite changes its *crystalline form*. This occurs at a *transition temperature*, characteristic of the particular form of silica.

- quartz when heated, inverts from a 'low' form known as *alpha-quartz* to a 'high' form called as *beta-quartz* at a temperature of 375°C.
- cristobalite similarly when heated, inverts from 'low' or *alpha-cristobalite* to 'high' or *beta-cristobalite* at a temperature between 200°C and 270°C.

The beta forms are stable only above the transition temperature. It changes back to the low or alpha-form occurs upon cooling in each case. The density changes (decreases) as alpha-form changes to beta-form, with a resulting increase in volume and a rapid increase in linear expansion.

EXPANSION

Expansion aids in enlarging the mold to compensate for the casting shrinkage of the gold alloys.

Three types of expansions may be seen:

1. Normal setting expansion
2. Hygroscopic setting expansion
3. Thermal expansion

Normal Setting Expansion

A mixture of silica and dental stone results in a setting expansion which is greater than when the gypsum product is used alone. The silica particles probably interfere with the intermeshing of the crystals as they form. Thus, the thrust of the crystals is outward during growth.

ADA Sp. No. 2 for Type-I investment permits a maximum setting expansion in air of 0.5%. Modern investments show setting expansion of 0.4%. It is regulated by retarders and accelerators.

Hygroscopic Setting Expansion (HSE)

When gypsum products are allowed to set in contact with water, the amount of expansion exhibited is much greater than the normal setting expansion. The increased amount of expansion is because, water helps the outward growth of crystals. This expansion is known as hygroscopic setting expansion. The investment should be immersed in water before initial set is complete.

ADA Sp. No. 2 for Type-II investments requires a minimal 1.2% and maximum 2.2% expansion.

Factors Affecting Hygroscopic Setting Expansion

1. *Composition* The finer the particle size of the silica, the greater is the HSE. Alpha-hemihydrate produces a greater expansion than beta-hemihydrate. Higher the silica content, greater is the expansion.
2. *W-P ratio* The higher the W-P ratio of the original investment water mixture, the less is the HSE.
3. *Temperature* Higher the temperature of the immersion water, less is the surface tension and hence, greater is the expansion.
4. *Effect of time of immersion* Immersion before the initial set results in greater expansion.
5. *Spatulation* Shorter the mixing time, the less is the HSE.
6. *Effect of shelf-life of the investment* The older the investment, the less is the hygroscopic expansion.
7. *Confinement* of the investment by the walls of the container or the wax pattern reduces HSE. This effect is much more pronounced on the HSE than on the normal setting expansion.
8. *Effect of the amount of added water* More amount of water added during the setting period, more is the expansion.

Thermal Expansion

In case of gypsum investments, thermal expansion (TE) is *achieved by* placing the mold in a furnace at a temperature not greater than 700°C (the investment breaks down if it exceeds this temperature releasing gases which can contaminate the gold alloys). The thermal expansion behavior of one investment is shown in ***Fig. 17.2***.

The amount of thermal expansion required depends on which method is used for casting shrinkage compensation. If hygroscopic expansion technique is used, then TE of 0.5 to 0.6% is sufficient. But if the compensation is by TE together with normal setting expansion, then the TE should be 1 to 2%.

Type-l investments should have a TE not less than 1 nor greater than 1.6%.

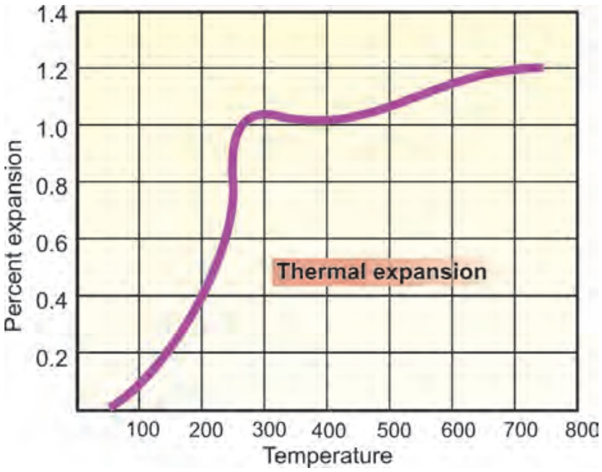


Figure 17.2: Thermal expansion of a gypsum bonded investment (Novocast, *Courtesy:* Whipmix Corporation).

Factors Affecting Thermal Expansion

1. TE is related to the amount and type of silica used.
2. *Effect of the W-P ratio:* more the water, less the TE.
3. *Effect of chemical modifiers* Small amounts of sodium chloride, potassium chloride and lithium chloride increases TE and eliminates the contraction caused by gypsum.

STRENGTH

According to ADA Sp. No. 2, the compressive strength for inlay investments should not be less than 2.5 MPa when tested 2 hours after setting.

Factors affecting strength

1. Use of alpha-hemihydrate increases compressive strength (than beta-hemihydrate).
2. Use of chemical modifiers increases the strength.
3. More water used during mixing, less is the strength.
4. Heating the investment to 700°C may increase or decrease strength as much as 65% depending on the composition. The greatest reduction in strength upon heating is found in investments containing sodium chloride.
5. After the investment has cooled to room temperature, its strength decreases considerably because of fine cracks that form during cooling.

POROSITY

The more the gypsum crystals present in the set investment, the less is its porosity. The less the hemihydrate content and greater the amount of gauging water, the more is its porosity. A mixture of coarse and fine particles exhibits less porosity than an investment composed of a uniform particle size (a certain amount of porosity is essential in the mold in order to allow escape of gases during casting).

FINENESS

A fine particle size is preferable to a coarse one. The finer the investment, the smaller will be the surface irregularities on the casting.

STORAGE

Investments should be stored in airtight and moistureproof containers. Purchase in small quantities.

HYGROSCOPIC THERMAL INLAY CASTING INVESTMENT

Investment that can be used as a hygroscopic or thermal type is available (e.g., Beauty cast - Whipmix). The investment contains a blend of quartz and cristobalite as the refractory. For the hygroscopic expansion technique, the investment is heated only up to 482°C. When the thermal casting technique is used the investment (is not immersed in water but) is heated to 649°C to achieve expansion.

INVESTMENTS FOR CASTING HIGH MELTING ALLOYS

The metal-ceramic alloys and the cobalt-chromium alloys have high melting temperatures. They are cast in molds at 850 to 1100°C. At these temperatures the gypsum bonded investments disintegrates. Hence, investments which can withstand higher temperatures are required. The binders used (phosphate and silicate) in these investments can withstand these high temperatures.

The investment used for this purpose are:

— Phosphate bonded investments

— Silica bonded investments

— Magnesia/alumina/zrconia based investments for titanium

PHOSPHATE BONDED INVESTMENT

Phosphate bonded investments are perhaps the most widely utilized investment in dentistry. This is because a substantial amount of cast dental structures today use high fusing noble or base metal alloys.

USES

For casting high fusing alloys, e.g., high fusing noble metal alloys, metal ceramic alloys and base metal alloys like nickel-chromium and cobalt-chromium.

CLASSIFICATION

ASI/ADA Sp.No. 42 (ISO 9694:1998)

Type I : For inlays, crowns and other fixed restorations.

Type II : For partial dentures and other cast removable restorations.

SUPPLIED AS

Powder in packets of varying weight with special liquid ***(Fig. 17.3)***.

COMPOSITION

Powder contains:

Ammonium diacid phosphate $NH_4H_2PO_4$

— It gives strength at room temperature.

— It is soluble in water and provides phosphate ions.

— It reacts with silica at high temperatures to increase strength at casting temperatures.

Figure 17.3: Representative phosphate bonded investments. They are mixed with a special liquids.

Silica in the form of quartz or cristobalite (80%) functions as refractory

Magnesium oxide: Reacts with phosphate ions.

Carbon: Some investments contain carbon while others are carbon free. Carbon helps to produce clean castings and helps in easier divestment from the mold. For noncompatible alloys carbon free investments are preferred.

Liquid The phosphate bonded investments are mixed with a special liquid supplied by the manufacturer. This liquid is a form of silica sol in water, which gives higher thermal expansion.

SETTING REACTION

At room temperature ammonium diacid phosphate reacts with magnesium oxide to give the investment green strength or room temperature strength.

$$NH_4H_2PO_4 + MgO + 5H_2O \longrightarrow NH_4MgPO_4.H_2O$$

The ammonium diacid phosphate is used in a greater amount than is necessary for this reaction, so that the additional amount can react with silica at an elevated temperature. At higher temperatures there is probably a superficial reaction between P_2O_5 and SiO_2 to form silicophosphate, which increases the strength of investment at higher temperature.

MANIPULATION

Powder/liquid ratio - 16 to 23 ml/ 100 gm.

(The liquid is usually diluted with water. The amount of liquid to water ratio varies with the particular brand of investment and type of alloy used. The amount of water used ranges from 0 to 50%. depending on the expansion required).

The powder is mixed with a measured amount of liquid using a bowl and spatula. Following hand mixing for 20 seconds mechanical mixing under vacuum is done for a further 90 seconds ***(Fig. 17.4)***. Working time is around 8-9 minutes. The mixed material is vibrated into the casting ring or agar mold (RPD framework). The material is allowed to bench set for a minimum 30-45 minutes depending the particular investment. Following this the glaze on top of the investment is scraped to allow air escape and reduce back pressure porosity during casting.

Figure 17.4: Vacuum investment mixer.

Factors affecting setting time

1. Temperature of the mix and environment. Warmer temperatures accelerate the setting. Cooling the liquid prolongs the working time.
2. Increasing the mixing time accelerates the set.
3. An increased L-P ratio delays setting and gives more working time.

PROPERTIES

EXPANSION

As mentioned earlier expansion of the mold is desirable to compensate for casting shrinkage. Phosphate investments get their expansion from 3 sources.

1. *Wax pattern expansion* The heat during setting allows a significant expansion of the wax pattern.
2. *Setting expansion* This is around 0.7 to 1%.
3. *Thermal expansion* Ranges from around 1 to 1.5%.

The amount of expansion is adjusted by the manufacturer for each product depending on the alloy it is intended for.

Factors affecting expansion

1. *Special liquid to water ratio* The liquid has a considerable influence on the setting and thermal expansion of the investment. The greater the concentration of special liquid to water the greater the thermal and setting expansions (***Fig. 17.5***).
2. *Powder to liquid ratio* A greater powder to liquid ratio increases expansion.

Strength

Regular investments are generally materials of low strength. *Wet strength* ranges from 4 - 10 MPa. Wet strength is important for handling the set material prior to casting. *Dry strength* is the strength of the investment under high temperatures. The investment should have sufficient strength to withstand the casting force of the molten alloy at high temperatures. Studies have shown that there is no correlation between wet and dry strength of phosphate bonded investments. One study indicates that investments exhibit plastic behavior at high temperatures which under casting pressure may be a source of inaccurate casting, a hitherto unrecognized source of error.

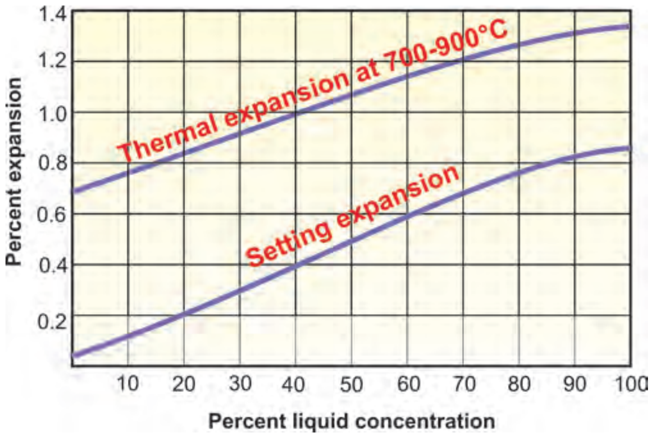


Figure 17.5: Influence of liquid to water concentration on the setting and thermal expansion of Ceramigold investment (*Courtesy:* Whip-mix Corporation).

Thermal Reactions

Phosphate bonded investments undergo thermochemical reactions when heated to high temperatures. The silica portion remains essentially unchanged. However the binder goes through various phases. On heating, the material initially dehydrates to $(NH_4MgPO_4.H_2O)_n$. Subsequently it degrades into polymeric $(Mg_2\ P_2O_7)_n$, crystalline $Mg_2\ P_2\ O_7$; then the latter reacts with excess MgO present to form the final product, $Mg_3(PO_4)_2$.

Flow

Investments appear to have low flow when mixed. However, they flow readily and envelope the pattern when poured into the mold under vibration. Therefore use of a vibrator is recommended. Surface tension reducing agents are available and should be used on the wax pattern to improve wetting.

Surface Smoothness

Early phosphate investments produced rough castings when compared to gypsum based investments. Current investments have improved and now approach surface smoothness comparable to that of gypsum bonded investments.

SPECIALIZED REFRACTORY MATERIALS

PHOSPHATE BONDED REFRACTORY CASTS FOR RPDS (TYPE II)

A refractory cast is a special cast made from a heat resistant (investment) material. Such casts are used in the fabrication of certain large metal structures like cast removable partial dentures. Small wax structures like inlays, crowns and small FPDs can be constructed on a regular die as it can be removed from the die without significant distortion and invested separately. However, larger wax structures like that for the cast RPD, would distort if removed from the cast. RPD patterns are best constructed on a refractory cast ***(Fig. 17.6 A)***. The pattern is invested together with the refractory cast.

INVESTMENTS FOR CERAMICS

Phosphate based investments are also available for ceramic restorations (e.g., Polyvest and VHT - Whipmix, ***Fig. 17.6 B)***. Two types are available. The first type is used for the cast glass technique. The second type is a refractory die type of material (ISO 11245) which is used to construct all-porcelain restorations.

Figures 17.6 A and B: (A) Refractory casts with pattern; (B) Representative phosphate bonded investment.

These are fine-grained phosphate investment with a working time of 4 - 5 minutes. Unlike regular refractory materials these can withstand repeated firings at furnace temperatures of up to 1200°C without disintergrating. They can be used with high-expanding porcelains because of their compatible CTEs.

INVESTMENTS FOR TITANIUM CASTINGS

Conventional silica (SiO_2) based dental casting investments are used for the casting of pure titanium using casting machines specifically developed for this metal. Highly reactive molten titanium reduces SiO_2 and titanium is in turn oxidised. For this reason possible alternatives to SiO_2 have been studied in the past decade and MgO (magnesia) and Al_2O_3 (alumina) are the most common in current commercial investments released for titanium casting. The surface of titanium castings presents a layered structure and its evaluation in relation to clinical performance requires further study especially in relation to the setting and thermal behavior of newly developed investments for successful compensation of metal shrinkage.

SILICA BONDED INVESTMENTS

The silica is the binder. It is derived from ethyl silicate or aqueous dispersion of colloidal silica or sodium silicate. These are less commonly used.

TYPES (TWO TYPES)

One such investment consists of silica refractory, which is bonded by the hydrolysis of ethyl silicate in the presence of hydrochloric acid. The product of the hydrolysis is the formation of a colloidal solution of silicic acid and ethyl alcohol.

$$\mathrm{Si(OC_2H_5)_4 + 4H_2 \xrightarrow{HCl} Si(OH)_4 + 4C_2H_5OH}$$

Ethyl silicate has the disadvantage of containing inflammable components which are required for manufacture.

Sodium silicate and *colloidal silica* are more commonly used as binders because of the above disadvantage. These investments are supplied along with *two bottles* of special liquid. One bottle contains dilute water-soluble *silicate solution* such as sodium silicate. The other bottle usually contains diluted acid solution such as *hydrochloric acid.*

MANIPULATION

The content of each bottle can be stored indefinitely. Before use equal volume of each bottle is mixed so that hydrolysis can take place and freshly prepared silicic acid is formed. The powder/liquid ratio is according to manufacturer's instruction.

BRAZING (SOLDERING) INVESTMENT

In the process of assembling the parts of a restoration by soldering, such as clasps on a removable partial denture, it is necessary to surround the parts with a suitable ceramic or investment.

TYPES

ANSI/ADA Sp. No. 93/ ISO 11244 for dental brazing investments defines two types of investment.

Type I – Gypsum-bonded (for low melting alloys, e.g., Hi Heat, Whipmix, etc.)

Type II – Phosphate-bonded (for high melting alloys).

COMPOSITION

The investment for soldering purpose is similar to casting investments containing quartz and a calcium sulfate hemihydrate/or phoshate binder.

PROPERTIES

Soldering investments ***(Fig. 17.7)*** are designed to have *lower setting (0.2%) and thermal expansions* (0.6 - 1%) than casting investments, a feature that is desirable so that the assembled parts do not shift position. Soldering investments do not have as fine a particle size as the casting investment, since the smoothness of the mass is less important. The compressive strength is generally low (beween 2 to 10 MPa). Water-powder ratio ranges from 0.24 to 0.28. Setting time ranges from 15 to 20 minutes.

Figure 17.7: Soldering investment.

PROCEDURE

The parts are temporarily held together with sticky wax until they are surrounded with the appropriate investment material, after which the wax is removed. The portion to be soldered is left exposed and free from investment to permit removal of the wax and effective heating before being joined with solder. After settng the material must be completely dry befor soldering. Recommended drying temperature varies between 400 to 450°C.

18

CASTING PROCEDURES

Many dental restorations are made by casting, e.g., inlays, crowns, removable partial denture frameworks, etc.

Casting can be *defined as* the act of forming an object in a mold (*GPT-8*). The object formed is also referred to as 'a casting'.

STEPS IN MAKING A CAST RESTORATION

Casting is a complex process involving a number of steps and costly equipment. A restoration having a perfect fit is possible only if we have a good understanding of the techniques and materials used in casting. Given below is the series of steps involved in the fabrication of a simple full metal crown.

- Tooth/teeth preparation
- Impression
- Die preparation
- Wax pattern fabrication
- Attachment of sprue former
- Ring liner placement
- Assembly of casting ring
- Investing
- Burn out or wax elimination
- Casting
- Sand blasting and recovery
- Finishing and polishing

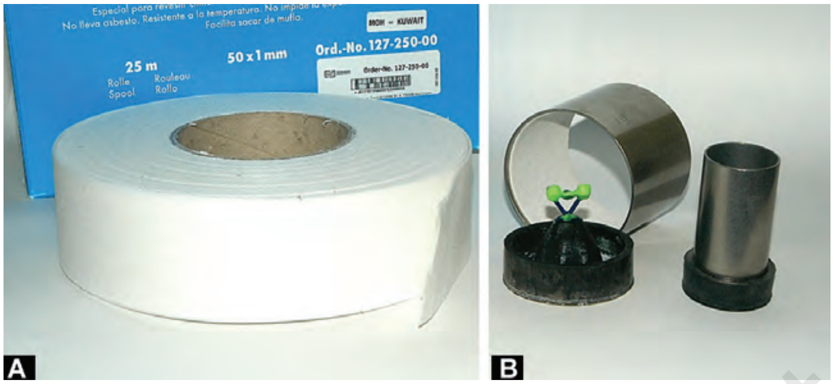
The procedures vary slightly depending on the type of restoration. Construction of larger structures like a removable partial denture frame involve additional steps like duplication.

TOOTH/TEETH PREPARATION

The teeth are prepared by the dentist to receive a cast restoration. An accurate impression of the tooth/teeth is made, usually with elastomers.

DIE PREPARATION

A die is prepared from die stone or a suitable die material ***(see Fig. 7.1)*** or the impression is electroformed. A die spacer is coated or painted over the die which provides space for the luting cement.



Figures 18.1 A and B: (A) Ring liner, (B) a rubber crucible former with attached wax pattern and casting rings.

WAX PATTERN

A pattern of the final restoration is made with type II inlay wax ***(Figs 18.1 A and B)*** or other casting waxes with all precautions to avoid distortion. Before making the pattern, a die lubricant is applied to help separate the wax pattern from the die.

SPRUE FORMER

A sprue former is made of wax, plastic or metal. The thickness is in proportion to the wax pattern. A reservoir is attached to the sprue or the attachment of the sprue to the wax pattern is flared. The length of the sprue is adjusted so that the wax pattern is approximately 1/4" from the other end of the ring ***(Fig. 18.2)***.

FUNCTIONS OF SPRUE FORMER/SPRUE

1. To form a mount for the wax pattern.
2. To create a channel for the elimination of wax during burnout.
3. Forms a channel for entry of molten alloy during casting.
4. Provides a reservoir of molten metal which compensates for alloy shrinkage during solidification.

CASTING RING LINING

A ring liner is placed inside of the casting ring. It should be short at one end. Earlier asbestos liners were used. Its use has been discontinued due to health hazard from breathing its dust.

TYPES OF NONASBESTOS RING LINERS USED ARE

1. Fibrous ceramic aluminous silicate
2. Cellulose (paper)
3. Ceramic-cellulose combination ***(Fig. 18.1)***.

FUNCTIONS OF THE RING LINER

1. Allows for mold expansion (cushion effect).
2. When the ring is transferred from the furnace to the casting machine it reduces heat loss as it is a thermal insulator.
3. Permits easy removal of the investment after casting.

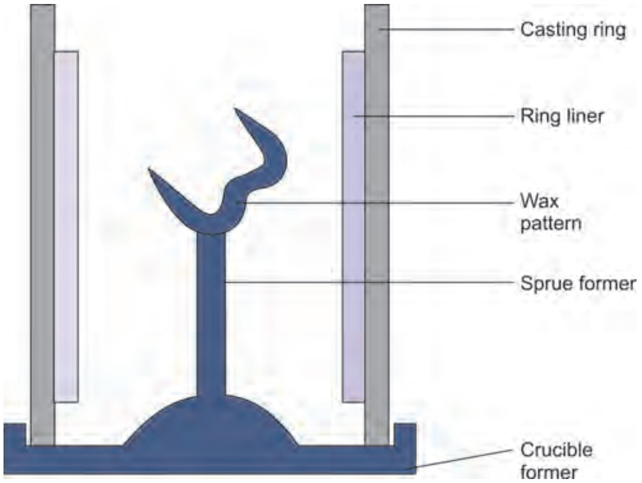


Figure 18.2: An assembled casting ring.

Figure 18.3: A vacuum investment mixer.

INVESTING

Apply wetting agent (to reduce air bubbles) on the wax pattern. Seat the casting ring into the crucible former taking care that it is located near the center of the ring ***(Fig. 18.2)***. Mix the investment (in a vacuum mixer, ***Fig. 18.3***) and vibrate. Some investment is applied on the wax pattern with a brush to reduce trapping air bubbles. The ring is reseated on the crucible former and placed on the vibrator and gradually filled with the remaining investment mix. It is allowed to set for 1 hour.

WAX ELIMINATION (BURNOUT) AND THERMAL EXPANSION

The *purpose* of burnout is:

(i) To eliminate the wax (pattern) from the mold.
(ii) To expand the mold (thermal expansion).

The crucible former is separated from the ring. If a metallic sprue former is used, it should be removed before burnout. Burnout is started when the mold is *wet*. If burnout has to be delayed the mold is stored in a humidor. The heating should be *gradual*. Rapid heating produces steam which causes the walls of the mold cavity to flake. In extreme cases an explosion may occur. Rapid heating can also cause cracks in the investment due to uneven expansion. It is very important to follow the investment manufacturer's technique regarding time and temperature for burnout and expansion.

Two stage burnout and expansion technique

The ring is placed in a *burnout furnace* ***(Fig. 18.4)*** and heated gradually to 400°C in 20 minutes. Maintain it for 30 minutes. Over the next 30 minutes, the temperature is raised to 700°C and maintained for a further 30 minutes. This technique may be used for wax but is particularly indicated if the patterns or sprues contains plastic.

Figure 18.4: Wax elimination and thermal expansion of mold.

Single stage burnout and expansion (Rapid technique)

This technique is followed only if patterns and sprues are wax

- Place molds directly into preheated oven at 700 – 850°C (if higher temperature is warranted, place mold in preheated oven at 370°C and then raise to final temperature).
- Hold for 30 – 40 minutes and cast.

The casting should be completed as soon as the ring is ready. If casting is delayed the ring cools and the investment contracts. The crown becomes smaller.

CASTING-PROCESS AND EQUIPMENT

It is the process by which molten alloy is forced into the heated investment mold.

CASTING MACHINES

Based on method of casting the machines are:

1. Centrifugal force type
2. Air pressure type

Centrifugal machines may be spring driven or motor driven ***(Fig. 18.5)***. The main advantage of the centrifugal machines is the simplicity of design and operation, with the opportunity to cast both large and small castings on the same machine.

In air pressure type of machine, either compressed air or gases like carbon dioxide or nitrogen, can be used to force the molten metal into the mold. This type of machine is satisfactory for making small castings. This machine does not have vibration and high noise levels owing to the pressure casting and water cooling method. Some systems use argon gas to protect the alloy from oxidation (especially useful for melting titanium, ***Fig. 18.8***).

Attached vacuum system Casting machines (both centrifugal and gas pressure type) with attached vacuum system are available. The vacuum creates a negative pressure within the mold, which helps to draw the alloy into the mold.

Casting machines can also be grouped based on heating system employed

1. Torch melted
2. Induction melted
3. Arc melted.

Numerous combinations of these principles are employed in different machines.

Figure 18.5: An induction casting machine. The molten metal is driven into the mold by centrifugal force. One arm of the machine has a counter weight (CW) which balances the weight of the arm carrying the crucible and mold as it rotates. The red hot crucible (C) and the casting ring is visible in the machine. The induction coil (IC - copper colored) is half visible and is used to melt the metal.

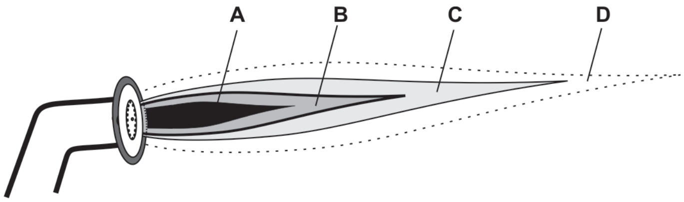


Figure 18.6: Parts of the flame: (A) Mixing zone, (B) Combustion zone, (C) Reducing zone, (D) Oxidizing zone.

Torch melting

The fuel used is a combination of:

- Natural or artificial gas and air, or
- oxygen and acetylene gas (high fusion alloys).

The flame has four zones (***Fig. 18.6***):

1. *Mixing zone* Air and gas are mixed here. No heat is present. It is dark in color.
2. *Combustion zone* This surrounds the inner zone. It is green in color. It is a zone of partial combustion and has an oxidizing nature.
3. *Reducing zone* It is a blue zone just beyond the green zone. It is the hottest part of the flame. This zone is used for the fusion of the casting alloy.
4. *Oxidizing zone* Outermost zone in which final combustion between the gas and surrounding air occurs. This zone is not used for fusion.

The air and gas mixture is adjusted to get a reducing flame, which is used to melt the alloy, because it does not contaminate the alloy and is the hottest part of the flame.

Induction melting

Heating through induction is a common method of melting dental alloys today ***(Figs 18.5 and 18.7).*** Induction heating is the process of heating an electrically conducting object (usually a metal) by electromagnetic induction, where eddy currents are generated within the metal and resistance leads to Joule heating of the metal. An induction heater consists of an electromagnet, through which a

Figure 18.7: White hot molten alloy in crucible surrounded by the induction coil.

Figure 18.8: Titanium casting machine by Dentaurum.

Figure 18.9: Casting crucible.

Figure 18.10: Casting flux.

high-frequency alternating current (AC) is passed. Induction melting is useful for melting high fusing alloys like metal-ceramic and base metal alloys.

Arc melting

Alloys may also be melted by a process known as arc melting. Arc melting is used to melt industrial alloys like steel. Direct current is passed between two electrodes - a tungsten electrode and the alloy. Arc melting produces very high temperatures and is used to melt high fusion metals like titanium. Arc melting may be done under vacuum or in an inert atmosphere like argon.

Crucibles

The crucible is a heat resistant container ***(Fig. 18.9)*** in which the alloy is melted prior to casting. Four types of casting crucibles are available. These are clay, carbon, quartz and ceramic. In dentistry, quartz or ceramic crucibles are commonly preferred as some alloys may be sensitive to carbon contamination. These include palladium-silver and nickel or cobalt based alloys.

Casting

The alloy is melted with the suitable heat source. *Flux powder* ***(Fig. 18.10)*** may be sprinkled over the molten metal to reduce the oxides and increase fluidity for casting. When the alloy is molten it has a *mirror-like* appearance and shifts like a ball of mercury. The hot casting ring is shifted from the burnout furnace to the casting machine. The ring is placed in the casting cradle so that the sprue hole adjoins the crucible. The crucible is slid and placed against the ring to avoid spilling of molten metal. The arm is released and allowed to rotate. This creates a centrifugal force which forces the liquid metal into the mold cavity. The arm is allowed rotate till it comes to rest. The ring is allowed to cool for 10 minutes till the glow of the metal disappears.

QUENCHING (FOR GOLD ALLOYS)

The ring is then immersed into water. This leaves the cast metal in an annealed (softened) condition and also helps to fragment the investment. Metal-ceramic alloys and base metal alloys are not quenched.

RECOVERY OF CASTING

The investment is removed and the casting recovered. A *pneumatic* (compressed air driven) *chisel* may be used to remove the investment. Final bits of investment is removed by sandblasting.

Figure 18.11: Casting trimmed with a carbide bur.

SANDBLASTING

Sandblasting is the process by which particles of an abrasive (usually aluminum oxide) is projected at high velocity using compressed air in a continuous stream. The casting is held in a sandblasting machine ***(Figs 18.12 A and B)*** to clean the remaining investment from its surface.

PICKLING

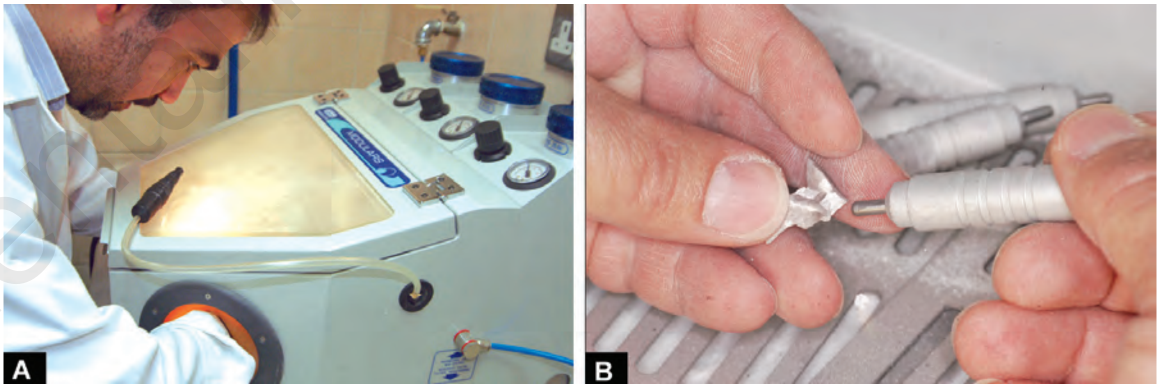
Surface oxides (e.g., black castings) from the casting are removed by pickling in 50% hydrochloric acid. HCl is heated but not boiled with the casting in it (done for gold alloys). Pickling is not a routine procedure and is performed only when indicated. Care should be exercised when handling strong acids.

TRIMMING

The sprue is sectioned off with a cutting disc. The casting is trimmed, shaped and smoothed with suitable burs or stones ***(Fig. 18.11)***.

POLISHING

Minimum polishing is required if all the procedures from the wax pattern to casting are followed meticulously (see abrasives chapter).



Figures 18.12 A and B: (A) Sandblasting in progress; (B) Closeup of sandblasting.

DEFECTS IN CASTING

Errors in the procedure often results in defective castings. The casting in such a case may not fit or may have poor esthetic and mechanical properties.

CLASSIFICATION OF CASTING DEFECTS

1. Distortion
2. Surface roughness
3. Porosity
4. Incomplete casting
5. Contaminated casting

DISTORTION

Distortion of the casting is usually due to distortion of wax pattern.

➢ Some distortion of wax occurs when the investment hardens or due to hygroscopic and setting expansion. It does not cause serious problems.

➢ Some distortion occurs during manipulation due to the release of stresses.

Wax distortion is minimized by

— Manipulation of wax at high temperature.

— Investing pattern within one hour after finishing.

— If storage is necessary, store in refrigerator.

SURFACE ROUGHNESS

Surface roughness can usually be traced to:

1. Air bubbles on the wax pattern cause nodules on the casting.

   Avoided by

   — Proper mixing of investment

   — Vibration of mix or by vacuum investing

   — Application of wetting agent
2. Too rapid heating cracks the investment resulting in fins.

   Avoided by Heat the ring gradually to 700°C (in at least 1 hr).
3. W-P ratio: A higher W-P ratio gives rougher casting. Larger particle size of investment has the same effect.

   Avoided by Using correct W/P ratio and investment of correct particle size.
4. Prolonged heating causes disintegration of the mold cavity.

   Avoided by Complete the casting as soon as the ring is heated and ready.
5. Overheating of gold alloy has the same effect. It disintegrates the investment.
6. Too high or too low casting pressure.

   Avoided by Using 15 lbs/sq inch of air pressure or three to four turns of centrifugal casting machine.
7. Composition of the investment. Proportion of the quartz and binder influences the surface texture of casting. Coarse silica produces coarse castings.
8. Foreign body inclusion shows sharp, well-defined deficiencies. Inclusion of flux shows as bright concavities.

POROSITY

Porosity may be internal or external. External porosity can cause *discoloration* of the casting. Severe porosity at the tooth restoration interphase can even cause *secondary caries*. Internal porosity *weakens* the restoration.

Types of Porosities

1. Those caused by solidification shrinkage:
    - —Localized shrinkage porosity
    - —Suck back porosity
    - —Microporosity

    Irregular in shape
2. Those caused by gas:
    - —Pin hole porosity
    - —Gas inclusions
    - —Subsurface porosity

    Usually spherical in shape
3. Those caused by air trapped in the mold (back pressure porosity).

Shrink-Spot or Localized Shrinkage Porosity

These are large irregular voids usually found near the sprue-casting junction ***(Fig. 18.13)***. It occurs when the cooling sequence is incorrect and the sprue *freezes before* the rest of the casting. During a correct cooling sequence, the sprue should freeze last. This allows more molten metal to flow into the mold to compensate for the shrinkage of the casting as it solidifies. If the sprue solidifies before the rest of the casting no more molten metal can be supplied from the sprue. The subsequent shrinkage produces voids or pits known as shrink-spot porosity.


Figure 18.13: Localized shrink spot porosity.

Avoid by

- ➢ Using sprue of correct thickness
- ➢ Attach sprue to thickest portion of wax pattern
- ➢ Flaring the sprue at the point of attachment or placing a reservoir close to the wax pattern.

Suck Back Porosity

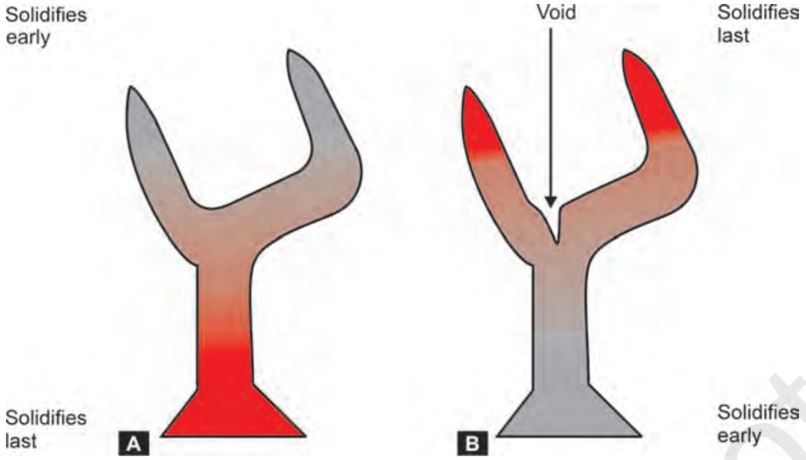
It is a variation of the shrink spot porosity. This is an external void usually seen in the inside of a crown opposite the sprue. A hot spot is created by the hot metal impinging on the mold wall near the sprue which causes this region to freeze last. Since the sprue has already solidified, no more molten material is available and the resulting shrinkage causes a type of shrinkage called suck back porosity ***(Figs 18.14 A and B)***. It is avoided by reducing the temperature difference between the mold and the molten alloy.

Microporosity

These are fine irregular voids within the casting. It is seen when the casting cools too rapidly. Rapid solidification occurs when the mold or casting temperature is too low.

Pin Hole Porosity

Many metals *dissolve gases* when molten. Upon solidification the dissolved gases are expelled causing tiny voids, e.g., platinum and palladium absorb hydrogen. Copper and silver dissolve oxygen.



Figures 18.14 A and B: (A) Correct sequence of hardening; (B) Suck back porosity caused by incorrect sequence of solidification.

Gas Inclusion Porosities

Gas inclusion porosities are also spherical voids but are larger than the pin hole type. They may also be due to dissolved gases, but are more likely due to gases carried in or trapped by the molten metal. A poorly adjusted blow torch can also occlude gases.

Back Pressure Porosity

This is caused by inadequate venting (air escape) of the mold. The sprue pattern length should be adjusted so that there is not more than 1/4" thickness of the investment between the bottom of the casting ring and the wax pattern. When the molten metal enters the mold, the air inside is pushed out through the porous investment at the bottom. If the bulk of the investment is too great, the escape of air becomes difficult causing increased pressure in the mold. The gold will then solidify before the mold is completely filled resulting in a *porous* casting with *rounded short margins.*

Avoided by

— Using adequate casting force.
— Use investment of adequate porosity.
— Place pattern not more than 6 to 8 mm away from the end of the ring.
— Providing vents in large castings.

Casting with Gas Blow Holes

If there is any *wax residue* remaining in the mold, it gives off a large volume of gas as the molten alloy enters the mold cavity. This gas can cause deficiencies in the casting and blow holes in the residue button. To help eliminate wax completely from the mold, the burnout should be done with the sprue hole facing downwards for the wax to run down.

INCOMPLETE CASTING

An incomplete casting ***(Fig. 18.15)*** may result when:

1. Insufficient alloy used.
2. Alloy not able to enter thin parts of mold.

3. Mold is not heated to casting temperature.
4. Premature solidification of alloy.
5. Sprues are blocked with foreign bodies.
6. Back pressure due to gases in mold cavity.
7. Low casting pressure.
8. Alloy not sufficiently molten or fluid.

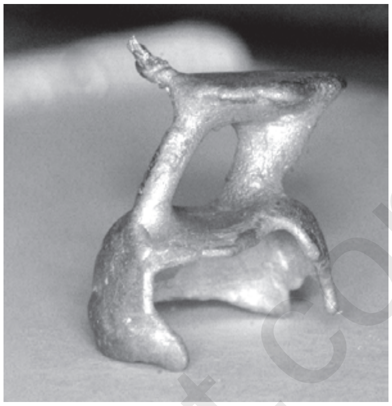


Figure 18.15: Incomplete casting.

Too Bright and Shiny Casting with Short and Rounded Margins

When the wax is not completely eliminated, it combines with oxygen or air in the mold cavity forming carbon monoxide which is a reducing agent. The gas prevents the oxidation of the surface of the casting gold with the result that the casting which comes out from the investment is bright and shiny. The formation of gas in the mold is so rapid that it also has a back pressure effect.

Small casting

If compensation for shrinkage of alloy is not done by adequate expansion of mold cavity, then a small casting will result. Another reason is the shrinkage of the impression material.

CONTAMINATION

A casting can be contaminated due to:

1. Oxidation, caused by:
   - — Overheating the alloy
   - — Use of oxidizing zone of flame
   - — Failure to use flux
2. Sulphur compounds, formed by the breakdown of the investment when the ring is overheated (see black casting below).

   Avoid by
   - — Not overheating alloy
   - — Use reducing zone of the flame
   - — Use flux.

Black Casting

Can be due to two reasons:

1. Overheating the investment above 700°C causes it to decompose liberating sulphur or sulphur compounds. They readily combine with the metals in gold alloy forming a sulfide film. This gives a dark casting which cannot be cleaned by pickling.
2. A black casting can be also due to incomplete elimination of the wax pattern, as a result of heating the mold at too low temperature. A carbonized wax remains which sticks to the surface of the casting. It can be removed by heating over a flame.

19

DENTAL CASTING ALLOYS

Casting is the most commonly used method for the fabrication of metal structures (inlays, crowns, partial denture frames, etc.) outside the mouth. A pattern of the structure is first made in wax. This is then surrounded by an investment material. After the investment hardens, the wax is removed (burnt out) leaving a space or mould. Molten alloy is forced into this mould. The resulting structure is an accurate duplication of the original wax pattern.

METAL RESTORATIONS IN DENTISTRY

There are many ways of fabricating a metallic restoration in dentistry.

1. Direct filling (e.g., gold, amalgam)
2. Casting (e.g., cast crowns, posts, inlays, etc.)
3. Machining
    - ➢ Prefabricated (e.g., prefabricated posts)
    - ➢ CAD-CAM* (e.g., metal inlays, crowns, etc.)
    - ➢ Copy milling and electrical discharge machining* (e.g., crowns, copings for PFM, etc.)
4. Swaging* (e.g., copings for PFM)

TERMINOLOGY

ALLOY

An alloy is defined as a metal containing *two or more* elements, *at least one* of which is *metal* and all of which are mutually soluble in the molten state.

NOBLE METALS

Noble metals have been used for inlays, crowns and FPDs because of their resistance to corrosion in the mouth. Gold, platinum, palladium, rhodium, ruthenium, iridium, osmium, and silver are the eight noble metals. However, in the oral cavity, silver can tarnish and therefore is not considered a noble metal.

PRECIOUS METALS

The term precious indicates the intrinsic value of the metal. The eight noble metals are also precious metals and are defined so by major metallurgical societies and federal government agencies, e.g., National Institute of Standards and Technology and National Material Advisory Board.

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* See also chapter on dental ceramics

All noble metals are precious but all precious metals are not noble. Of the eight noble metals, four are very important in dental casting alloys, i.e., gold, platinum, palladium and silver. All four have a face-centered cubic crystal structure and all are white colored except for gold.

Gold Pure gold is a soft and ductile metal with a yellow 'gold' hue. It has a density of 19.3 gm/cm^3 and a melting point of 1063°C. Gold has a good lustre and takes up a high polish. It has good chemical stability and does not tarnish and corrode under normal circumstances.

Silver Sometimes described as the 'whitest' of all metals. It has the lowest density (10.4 gm/cm^3) and melting point (961°C) among the precious casting alloys. Its CTE is 15.7×10^{-6}/°C which is comparatively high.

Palladium Density is 12.02 gm/cm^3. Palladium has a higher melting point (1552°C) and lower CTE (11.1×10^{-6}/°C) when compared to gold.

Platinum It has the highest density (21.65 gm/cm^3) highest melting point (1769°C) and the lowest CTE among the four precious metals.

SEMIPRECIOUS METALS

There is no accepted composition which differentiates 'precious' from 'semiprecious'. Therefore, the term semiprecious should be avoided.

BASE METALS

These are non-noble metals. They are important components of dental casting alloys because of their influence on physical properties, control of the amount and type of oxidation and their strengthening effect. Such metals are reactive with their environment and are referred to as 'base metals'. Some of the base metals can be used to protect an alloy from corrosion by a property known as passivation. Although they are frequently referred to as nonprecious, the preferred term is base metal.

Examples Chromium, cobalt, nickel, iron, copper, manganese, etc.

HISTORY AND CLASSIFICATION OF DENTAL CASTING ALLOYS

At the beginning of the twentieth century when dental casting techniques were evolving, the alloys were predominantly gold based. Taggart in 1907 was the first to describe the *lost wax technique* in dentistry. The existing jewelry alloys were quickly adopted for dental purposes. Initially, copper, silver and platinum were the main alloying elements. As the alloys evolved it was felt that a classification was needed. In 1932, the National Bureau of Standards classified the alloys according to their hardness (Type I, Type II, etc.).

At that time it was felt that gold alloy with less than 65% gold, tarnished too easily in the oral cavity. By 1948, metallurgists experimenting with various alloys were able to decrease the gold content while maintaining their resistance to tarnish. This breakthrough was due to *palladium.* It counteracted the tarnish potential of silver.

The main requirements of the original dental casting alloys were simple:

1. They should not tarnish in the mouth.
2. They should be strong (for use as bridges).

This soon changed with the introduction of special alloys (metal-ceramic alloys) that could bond to porcelain in the late 1950s. The composition and requirements of these alloys became more complex. For example, they had to contain elements that could enhance bond to porcelain, they had to have a higher melting temperature (because porcelain had high fusion temperatures), etc.

Another important development were the rapid increase in gold prices in the 1970s. As gold became more expensive, people began to look for less expensive metals for dental castings. Manufacturers began experimenting with base metal alloys like nickel-chromium and cobalt-chromium. These alloys were already in use since the 1930s for the construction of cast partial denture frameworks. Prior to this, the Type IV gold alloys were used extensively for this purpose. These base metals soon replaced the Type IV gold alloys for partial denture use because of their light weight, lower cost and tarnish resistance. When the gold prices shot-up, these base metal partial denture alloys were quickly adapted for use in fixed prosthodontics. Subsequently, newer formulations allowed their use as metal-ceramic alloys.

Today there is such a wide variety of alloys in the market that classifying them is not easy. A number of different classifications are mentioned below.

ACCORDING TO USE

A. Alloys for all metal and resin veneer restorations* (e.g., inlays, posts, resin and composite veneered crowns and FPDs)

B. Alloys for metal-ceramics restorations (e.g., PFM crowns and FPDs)

C. Alloys for removable dentures ** (e.g., RPD frames and complete denture bases)

CLASSIFICATION BASED ON YIELD STRENGTH AND PERCENT ELONGATION (ADA SP. 5)

Type I	Soft
Type II	Medium
Type III	Hard
Type IV	Extra hard

(This 1934 classification was *originally intended for gold alloys* and were based on hardness. Since 1989, it was relaxed to include any dental alloy as long as they met the new yield strength and percentage elongation criteria. Type I and II are known as 'inlay alloys' and Type III and IV are known as 'crown and bridge alloys'. Type IV is occasionally used for RPD frames).

ACCORDING TO NOBILITY (ADA 1984)

A. High noble metal alloys	Contains > 40 wt% Au and > 60 wt% noble metals
B. Noble metal alloys	Contains > 25 wt% of noble metals
C. Predominantly base metal alloys	Contains < 25 wt% of noble metals
D. Base metal	

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*Some authors classify this as—crown and bridge alloys. Unfortunately this can create confusion, for example—metal ceramic alloys are also crown and bridge alloys.

**Also known as RPD alloys, which again unfortunately is not fully accurate as they can be used for other structures. However, until a more suitable terminology is found, this classification will be continued.

(> means equal to or greater than; < means less than. This classification is popular among manufacturers).

ACCORDING TO MAJOR ELEMENTS

A. Gold alloys
B. Silver alloys
C. Palladium alloys
D. Nickel alloys
E. Cobalt alloys
F. Titanium alloys

ACCORDING TO THE THREE MAJOR ELEMENTS

A. Gold-palladium-silver
B. Palladium-silver-tin
C. Nickel-chromium-molybdenum
D. Cobalt-chromium-molybdenum
E. Iron-nickel-chromium
F. Titanium-aluminum-vanadium

ACCORDING TO THE NUMBER OF ALLOYS PRESENT

A. Binary—two elements
B. Ternary—three elements
C. Quaternary (and so forth)—four elements

CLASSIFICATION ACCORDING TO USE OF DENTAL CASTING ALLOYS

The huge choice of alloys in the market makes the process of identification a difficult task. They are similar in some aspects but yet each have their own distinct features. These alloys vary not only in the type of metal but also the percentage of each within the alloy. In spite of their wide variation in composition, they must meet the requirements of their intended use. For example, all metal-ceramic alloys regardless of whether they are noble or base must meet the requirements of porcelain bonding. For this reason the classification according to use is recommended and will be the basis of the subsequent discussion of alloys.

A. Alloys for all metal and resin veneer restorations
  ➢ High noble ➢ Noble ➢ Predominantly base metal ➢ Base metal

B Alloys for metal-ceramics restorations
  ➢ High noble ➢ Noble ➢ Predominantly base metal ➢ Base metal

C Alloys for casting large structures
  ➢ High noble ➢ Noble ➢ Predominantly base metal ➢ Base metal

GENERAL REQUIREMENTS OF CASTING ALLOYS

All cast metals in dentistry have some basic common requirements

1. They must not tarnish and corrode in the mouth.
2. They must be sufficiently strong for the intended purpose.
3. They must be biocompatible (nontoxic and nonallergic).
4. They must be easy to melt, cast, cut and grind (easy to fabricate).
5. They must flow well and duplicate fine details during casting.

6. They must have minimal shrinkage on cooling after casting.
7. They must be easy to solder.

Not all of them meet all the requirements. Some have shown a potential for allergic reactions (nickel containing alloys) and other side effects when used without proper precautions. Some are quite difficult to cast. Some are so hard (base metal alloys) that they are difficult to cut, grind and polish. All alloys shrink on cooling. Some (base metal alloys) show more shrinkage than others. The shrinkage cannot be eliminated but it can be compensated for (see investments). Besides these general requirements, alloys intended for a certain specific use must meet requirements for that. For example, metal-ceramic alloys must have additional requirements in order to be compatible with porcelain. The requirements for metal-ceramic alloys will be described later.

ALLOYS FOR ALL METAL RESTORATIONS

These alloys were among the earliest alloys available to dentistry. The early alloys were mostly gold alloys. Since they were intended for all-metallic and later for resin veneered restorations, they just had to meet the basic requirements (see general requirements). No special requirements are needed for veneering with resin.

Currently, the use of these alloys are slowly declining because of

- Increased esthetic awareness has reduced the trend for metal display.
- Increasing popularity of all-ceramic and metal-ceramic restorations.
- Reducing popularity of resin and composite as veneering material. Resin facings have a number of disadvantages.
  - They wear rapidly (poor wear resistance)
  - They may change color (color instability and stain absorption)
  - They are porous. They tend to absorb food material and bacteria. This makes it unhygienic and gives it a bad odor.

CLASSIFICATION (ANSI/ ADA SP. NO. 5)

(As mentioned before this 1934 classification was *originally intended for gold alloys* and were based on hardness. In 1989, it was relaxed to include any dental alloy as long as they met the new yield strength and percentage elongation criteria).

TYPE I SOFT

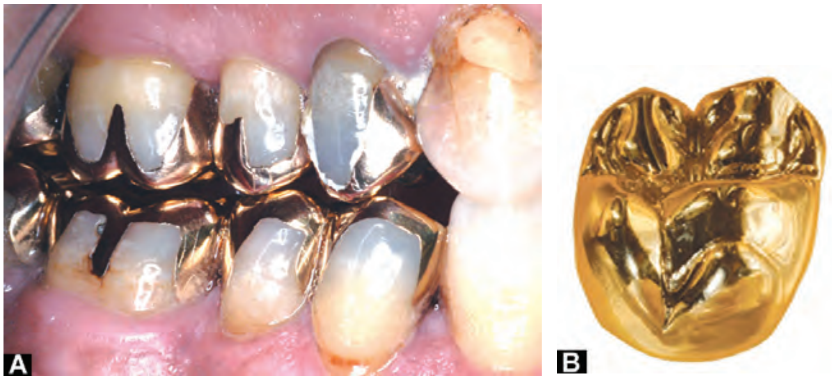
Small inlays, Class III and Class V cavities which are not subjected to great stress. They are easily burnished.

TYPE II MEDIUM

Inlays subject to moderate stress, thick 3/4 crowns, abutments, pontics, full crowns, and sometimes soft saddles.

TYPE III HARD

Inlays, crowns and bridges, situations where there may be great stresses involved. They usually can be age hardened.



Figures 19.1 A and B: (A) Gold onlays; (B) A gold crown.

Figure 19.2: Post-core.

TYPE IV EXTRA HARD

Inlays subjected to very high stresses, partial denture frameworks and long span bridges. They can be age hardened.

Type I and II are generally called 'inlay alloys' and Type III and IV are known as 'crown and bridge alloys'. Because of the increased use of composite and ceramic inlays, the Type I and II inlay alloys are rarely used currently. Most of the discussion will focus on the Type III and IV alloys.

USES

These alloys are *not intended* for porcelain bonding. They may be used as an *all-metal* restoration or with a *resin veneer*.

1. Inlays and onlays ***(Figs 19.1 A and B)***
2. Crowns and FPDs
3. Partial denture frames (only the Type IV)
4. Post-cores ***(Fig. 19.2)***

TYPES

These alloys will be discussed under the following categories:

High noble — Gold alloys
Noble — Silver palladium alloys
Base metal — Nickel-chrome alloys
Cobalt-chrome alloys
Titanium and its alloys
Aluminum-bronze alloys

GOLD ALLOYS (FOR ALL METAL RESTORATIONS)

Synonyms Traditional gold alloys, Au-Ag-Cu alloys.

Why do we alloy gold?

Pure gold is a soft and ductile metal and so is not used for casting dental restorations and appliances in its pure state. It is alloyed commonly with copper, silver, platinum, nickel and zinc. Alloying gold with these metals not only improves its physical and mechanical properties but also reduces its cost.

The display of metal particularly gold was once acceptable and probably was even a symbol of social status. The current trend is to avoid the display of metal. At the same time, increase in the platinum, palladium and silver content of modern alloys have resulted in whiter colored gold alloys. Thus, there are *'yellow gold alloys'* and *'white gold alloys'*. The rise in gold prices have also led to the availability of alloys with low gold content. These are the *'low golds'*.

The gold alloys discussed here are high noble alloys because of their high noble metal content (see classification according to nobility).

GOLD CONTENT

Traditionally, gold content of dental casting alloys was called:

- Karat
- Fineness

KARAT

It refers to the parts of pure gold present in 24 parts of alloy, e.g.,

— 24 karat gold is pure gold.

— 22 karat gold is 22 parts pure gold and 2 parts of other metal.

Note In current dental alloys, the term karat is rarely used.

FINENESS

Fineness of a gold alloy is the parts per thousand of pure gold. Pure gold is 1000 fine. Thus, if 3/4 of the gold alloy is pure gold, it is said to be 750 fine.

Note The term fineness also is rarely used to describe gold content in current alloys (however, it is often used to describe gold alloy solders).

PERCENTAGE COMPOSITION

The percentage composition of gold alloys is preferred over karat and fineness. Since 1977, ADA requires manufacturers to specify the percentage composition of gold, palladium and platinum on all their dental alloy packaging.

$$\frac{\text{Karat} \times 100}{24} = \%\ \text{Gold}$$

Similarly, fineness is 10 times the percentage gold composition, i.e., fineness × 10 = % gold.

COMPOSITION OF GOLD ALLOYS

Type	*% Au*	*% Cu*	*% Ag*	*% Pd*	*% Pt*	*% In, Sn, Fe, Zn, Ga*
I	83	6	10	0.5	-	Balance
II	77	7	14	1	-	Balance
III	75	9	11	3.5	-	Balance
IV	69	10	12.5	3.5	3	Balance

FUNCTIONS OF CONSTITUENTS

Gold

Provides tarnish and corrosion resistance and has a desirable appearance. Also provides ductility and malleability.

Copper

It is the principal hardener. It reduces the melting point and density of gold. If present in sufficient quantity, it gives the alloy a reddish color. It also helps to age harden gold alloys. In greater amounts, it reduces resistance to tarnish and corrosion of the gold alloy. Therefore, the maximum content should not exceed 16 percent.

Silver

It whitens the alloy, thus helping to counteract the reddish color of copper. It increases strength and hardness slightly. In large amount, however, it reduces tarnish resistance.

Platinum

It increases strength and corrosion resistance. It also increases melting point and has a whitening effect on the alloy. It helps to reduce the grain size.

Palladium

It is similar to platinum in its effect. It hardens and whitens the alloy. It also raises the fusion temperature and provides tarnish resistance. It is less expensive than platinum, thus reducing the cost of the alloy.

The Minor Additions Are

Zinc

It acts as a scavenger for oxygen. Without zinc, the silver in the alloy causes absorption of oxygen during melting. Later during solidification, the oxygen is rejected producing gas porosities in the casting.

Indium, Tin and Iron

They help to harden ceramic gold-palladium alloys, iron being the most effective.

Calcium

It is added to compensate for the decreased CTE that results when the alloy is made silver free (the elimination of silver is done to reduce the tendency for green stain at the metal-porcelain margin).

Iridium, Ruthenium, Rhenium

They help to decrease the grain size. They are added in small quantities (about 100 to 150 ppm).

Note All modern noble metal alloys are fine grained. Smaller the grain size of the metal, the more ductile and stronger it is. It also produces a more homogeneous casting and improves the tarnish resistance. A large grain size reduces the strength and increases the brittleness of the metal. Factors controlling the grain size are the rate of cooling, shape of the mold and composition of the alloy.

PROPERTIES OF GOLD ALLOYS

COLOR

Traditionally, the gold alloys were gold colored. The color of modern gold alloys can vary from gold to white. It depends on the amount of whitening elements (silver, platinum, palladium, etc.) present in the alloy.

MELTING RANGE

Ranges between 920 to 960°C. The melting range of an alloy is important. It indicates the type of investment required and the type of heating source needed to melt the alloy.

DENSITY

It gives an indication of the number of dental castings that can be made from a unit weight of the metal. In other words, more number of cast restorations per unit weight can be made from an alloy having a lower density, than one having a higher density. Gold alloys are lighter than pure gold (19.3 gm/cm^3).

Type III — 15.5 gm/cm^3

Type IV — 15.2 gm/cm^3

The castability of an alloy is also affected by density. Higher density alloys cast better than lower density alloys.

YIELD STRENGTH

The yield strength is

Type III — 207 MPa

Type IV — 275 MPa

HARDNESS

The hardness indicates the ease with which these alloys can be cut, ground or polished. Gold alloys are generally more user friendly than the base metal alloys which are extremely hard.

The hardness values

Type III — 121 MPa

Type IV — 149 MPa

ELONGATION

It indicates the ductility of the alloy. A reasonable amount is required especially if the alloy is to be deformed during clinical use, e.g., clasp adjustment for removable partial dentures, margin adjustment and burnishing of crowns and inlays. Type I alloys are easily furnished. Alloys with low elongation are very brittle. Age hardening decreases ductility.

Type III - 30 to 40%

Type IV - 30 to 35%.

MODULUS OF ELASTICITY

This indicates the stiffness/flexibility of the metal. Gold alloys are more flexible than base metal alloys (Type IV - 90 × 10^3 MPa).

TARNISH AND CORROSION RESISTANCE

Gold alloys are resistant to tarnish and corrosion under normal oral conditions. This is due to their high noble content. Noble metals are less reactive.

CASTING SHRINKAGE

All alloys shrink when they change from liquid to solid. The casting shrinkage in gold alloys is less (1.25 to 1.65%) when compared to base metal alloys.

The shrinkage occurs in three stages.

1. Thermal contraction of the liquid metal.
2. Contraction of the metal while changing from liquid to solid state.
3. Thermal contraction of solid metal as it cools to room temperature.

Shrinkage affects the fit of the restoration. Therefore, it must be controlled and compensated for in the casting technique.

BIOCOMPATIBILITY

Gold alloys are relatively biocompatible.

CASTING INVESTMENT

Gypsum-bonded investments may be used for low fusing gold alloys.

HEAT TREATMENT OF GOLD ALLOYS

Heat treatment of alloys is done in order to alter its mechanical properties. Gold alloys can be heat treated if it contains sufficient amount of *copper*. Only Type III and Type IV gold alloys can be heat treated.

There are two types of heat treatment:

1. Softening heat treatment (solution heat treatment).
2. Hardening heat treatment (age hardening).

SOFTENING HEAT TREATMENT

Softening heat treatment increases ductility, but reduces strength, proportional limit and hardness.

Indications

It is indicated for appliances that are to be ground, shaped or otherwise cold worked in or outside the mouth.

Method

The casting is placed in an electric furnace for 10 minutes at 700°C and then it is quenched in water. During this period, all intermediate phases are changed to a *disordered solid solution* and the rapid quenching prevents ordering from occurring during cooling. Each alloy has its optimum temperature. The manufacturer should specify the most favorable temperature and time.

HARDENING HEAT TREATMENT (OR AGING)

Hardening heat treatment increases strength, proportional limit and hardness but decreases ductility. It is the copper present in gold alloys which helps in the age hardening process.

Indications

For strengthening metallic dentures, saddles, FPDs and other similar structures before use in the mouth. It is not employed for smaller structures such as inlays.

Method

It is done by 'soaking' or aging the casting at a specific temperature for a definite time, usually 15 to 30 minutes. It is then water quenched or cooled slowly. The ageing temperature depends on the alloy composition but is generally between 200 and 450°C. During this period, the intermediate phases are changed to an *ordered solid solution* (the proper time and temperature for age hardening an alloy is specified by its manufacturer).

Ideally, before age hardening an alloy, it should first be subjected to a softening heat treatment in order to relieve all strain hardening (stresses which occurs during finishing). Starting the hardening treatment when the alloy is in a disordered solid solution allows better control of the ageing process.

LOW GOLD ALLOYS

Also known as 'economy golds'. They are crown and FPD alloys having gold content below 60% (generally in the 42 to 55% range). However, gold must be the major element.

The low gold alloys were developed because of the increase in gold prices. However, reducing gold content increased tarnish and corrosion. This problem was overcome by two discoveries.

- Palladium made the silver in gold alloy more tarnish resistant. 1% palladium was required for every 3% of silver.
- The silver-copper ratio had to be carefully balanced to yield a low silver rich phase in the microstructure.

ADVANTAGES

Because of this research numerous low gold alloys were introduced into the market. Thus, these alloys were not only less expensive but also had good tarnish and corrosion resistance. Their properties are comparable to Type III and IV gold alloys.

SILVER-PALLADIUM ALLOYS

These alloys were introduced as a cheaper alternative to gold alloys. It is predominantly silver in composition. Palladium (at least 25%) is added to provide nobility and resistance to tarnish. They may or may not contain copper and gold. They are white in color.

Ag-Pd (non-copper)	:	Ag - 70 to 72%	Properties are like
		Pd - 25%	Type III gold alloys.
Ag-Pd-Cu	:	Ag - 60%	Properties are like
		Pd - 25%	Type IV gold alloys.
		Cu - 15%	

The properties of the silver-palladium alloys are similar to the Type III and IV gold alloys. However, they have lower ductility and corrosion resistance. They also have a significantly lower density than gold alloy. This may affect its castability.

A major difference between Type III and IV Ag-Pd alloys is that the latter can be significantly age hardened because of its gold and copper content.

TECHNIC ALLOY

This is a *gold colored base metal alloy* which was frequently (mis) used in India to make all-metal crowns and FPDs since many years. They are also sometimes referred to as *Japanese gold* or *K-metal.* These alloys *do not contain any gold* or precious metal. The alloy is absolutely *contraindicated* for any intraoral dental use because of its low strength, low wear resistance and tendency to tarnish. It has a high initial gold-like luster and patients were deliberately misled by unscrupulous practitioners into believing it was gold. Thanks to the availability of better materials its use has declined considerably. Unfortunately, one does come across restorations made from this alloy even to this day. Some practitioners still offer this material as a lower cost alternative, in addition to the regular alloys.

NICKEL-CHROME AND COBALT-CHROMIUM ALLOYS

These are known as base metal alloys and are extensively used in many of the developing countries. In India, because of their relatively low cost many of the laboratories use these alloys along with resin facings.

These metals are very strong and hard. Because of this, they are generally difficult to work with (cutting, grinding, polishing, etc.). They are dealt within more detail in subsequent sections.

TITANIUM AND TITANIUM ALLOYS

Though these metals can be used for all-metal and metal-ceramic restorations, as well as partial dentures. They are described later under metal-ceramic restorations.

ALUMINUM BRONZE ALLOY

Figure 19.3: Aluminum bronze alloys (*Courtesy:* BDCH, Davengere).

Bronze is an alloy known to man since ancient times. Traditional bronze is copper alloyed with tin. The ADA approved bronze ***(Fig. 19.3)*** does not contain tin. The composition is as follows:

Copper	81 to 88%
Aluminum	8 to 10%
Nickel	2 to 4%
Iron	1 to 4%

Being relatively new, the information on these alloys is relatively scanty.

PROPERTIES*

Color—Yellow gold
Melting range—1012 to 1068°C
Density 7.8 gm/cm^3
Brinell harness number of 104
Yield strength—30,000 psi
Elongation—29%

METAL-CERAMIC ALLOYS

Metal-ceramic alloys are those alloys that are compatible with porcelain and capable of bonding to it. A layer of porcelain is fused to the alloy to give it a natural tooth-like appearance. Porcelain being a brittle material fractures easily, so these alloys are used to reinforce the porcelain.

Several types of alloys are used to cast substructures for porcelain-fused-to-metal crowns and FPDs. They may be noble metal alloys or base metal alloys (see classification). All have coefficient of thermal expansion (CTE) values which match that of porcelain.

Note CTE has a reciprocal relationship with melting point, i.e., the higher the melting point of a metal, lower is its CTE.

Synonyms

Porcelain-fused-to-metal (PFM), ceramometal alloys, porcelain-bonded-to-metal (PBM). The preferred term, however, is metal ceramic or PFM.

EVOLUTION OF METAL-CERAMIC ALLOYS

The metal-ceramic alloys evolved from resin-veneered crown and bridge alloys. Resin facing faced the problem of gradual wear and had to be replaced over time. Besides resin could not be used on the occlusal surface. To retain a resin veneered restoration undercuts had to be provided. The early metal-ceramic alloys were high gold alloys (88% gold). They were not strong enough for FPD use. In the early days before porcelain-metal bonding was clearly understood, porcelain had to be retained by mechanical means with the help of undercuts. Later it was discovered that adding 1% of base metals like iron, tin, indium, etc., induced chemical bonding by the formation of an oxide layer. This significantly improved the bond strength between porcelain and metal.

REQUIREMENTS OF ALLOYS FOR PORCELAIN BONDING

In addition to the general requirements of alloys mentioned earlier, metal-ceramic alloys have certain specific requirements in order to be compatible with porcelain veneering.

1. Its melting temperature should be higher than porcelain firing temperatures.
2. It should be able to resist creep or sag at these temperatures.
3. Its CTE should be compatible with that of porcelain.
4. They should be able to bond with porcelain.
5. It should have a high stiffness (modulus of elasticity). Any flexing of the metal framework may cause porcelain to fracture or delaminate.
6. It should not stain or discolor porcelain.

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* Properties (as provided by the manufacturer)

Figure 19.4: Metal-ceramic fixed partial denture.

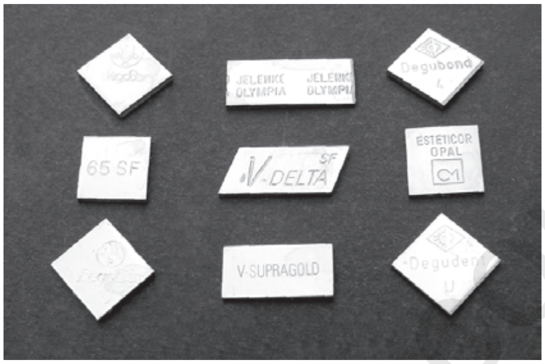


Figure 19.5: Gold based metal-ceramic alloys (1 gm). Most are white gold alloys. V supra gold (Bottom row middle) has a light gold color. SF denotes silver free.

USES OF METAL-CERAMIC ALLOYS

1. As the name implies these alloys are intended for porcelain veneered restorations (crowns and FPDs—***Fig. 19.4***).
2. They can also be used for all-metal restorations.

TYPES (CLASSIFICATION) OF METAL-CERAMIC ALLOYS

Alloys for metal ceramics restorations may be categorized as:

1. High noble (commonly referred to as gold alloys) ***(Fig. 19.5)***
   - Gold-palladium-platinum alloys
   - Gold-palladium-silver alloys
   - Gold-palladium alloys
2. Noble (commonly referred to as palladium alloys)
   - Palladium-silver alloys
   - Palladium-gallium-silver alloys
   - Palladium-gold alloys
   - Palladium-gold-silver alloys
   - Palladium-copper alloys
   - Palladium-cobalt alloys
3. Base metal
   - Nickel-chromium alloys
   - Nickel-chromium-beryllium alloys
   - Cobalt-chromium alloys
   - Pure titanium
   - Titanium-aluminum-vanadium

THE HIGH NOBLE (GOLD-BASED) METAL-CERAMIC ALLOYS

The high noble alloys contain more than 40 wt% gold and are therefore also referred to as gold alloys or gold-based alloys ***(Fig. 19.5)***.

COMMON FEATURES OF HIGH NOBLE (GOLD BASED) ALLOYS

Cost These are the most expensive crown and bridge alloys. However, in spite of the cost, these alloys are user friendly and are preferred in practices where the clientele can afford the cost.

Color The color can range from white to gold depending on the gold content. The whitening alloys are palladium and platinum. The gold color when present can enhance the vitality of the porcelain thus improving the esthetics.

Melting range Porcelain is fired at a temperature of 900 to 960°C. Thus obviously these alloys must have melting temperatures much higher than the temperatures at which porcelain is fired. Pure gold has a melting temperature of 1063°C. The melting temperature is raised by the addition of platinum (1769°C) and palladium (1552°C).

The melting temperatures of these alloys range from 1149 to 1304°C.

Density Ranges from 13.5 to 18.3 gm/cm^3 (depending on the gold content). Because of the high gold and noble metal content, these alloys have a high density. The density reduces as more palladium is added.

Castability The high density of these alloys make them easy to cast. If done well one can expect most of the fine features to be accurately duplicated.

Yield strength Ranges from 450 to 572 MPa.

Hardness and workability Ranges from 182 to 220 VHN. These alloys are relatively softer when compared to the base metal alloys and so are extremely easy to work with. They are easy to cut, grind and polish.

Percent elongation Ranges from 5 to 20%. This gives an indication of the ductility of the alloy. The higher the value the more ductile it is.

Porcelain bonding The presence of an oxide layer on the surface of metal ceramic alloys assists in chemical bonding of porcelain to the alloy. Pure noble metal alloys rarely form an oxide layer. To induce the formation of an oxide layer, 1% of base metals like *tin, indium, iron*, etc., are added to the alloy. This significantly improved the bond strength between the porcelain and the metal.

Sag resistance During porcelain firing, the metal frame has to withstand temperatures as high as 950°C. At these temperatures, there is a danger of the metal substructure sagging under its own weight, thereby deforming. The longer the span the greater the risk. The ability of a metal to resist sag is known as sag resistance. Compared to base metal alloys, gold alloys are less sag resistant.

Tarnish and corrosion Because of their high noble metal content, these alloys are extremely stable in the oral environment. Noble metals have low reactivity to oxygen and therefore do not tarnish easily.

Biocompatibility High noble alloys have had a good and safe track record. They are not known to cause any problems in the mouth.

Reusability These alloys are stable and so scrap from these alloys can be recast at least two or three times. However, the more volatile base metals like zinc, indium, tin, etc., may be lost. To compensate for this, *equal amounts* of new alloys should be mixed. The scrap should be cleaned by sandblasting and ultrasonic cleaning before use. Alloys from different manufacturers should not be mixed as it may change its composition and properties.

Scrap value The high noble alloys have good scrap value. Many suppliers and manufacturers accept used alloy scrap.

Soldering Gold-based alloys are quite easy to solder.

Table 19.1

Commercial names of some noble and high noble alloys

High noble alloys (Au > 40%)	Gold-palladium-platinum	Jelenko'O' (Jelenko) SMG-3 (Ney)
	Gold-platinum	Willbond Bio 88 PF (Willkinson)*
	Gold-platinum-palladium	Degudent H (Degussa)
	Gold-palladium-silver	Wilbond 75 (Willkinson)** Cameo (Jelenko) RxWCG (Jeneric/Pentron) Special white (Degussa)
	Gold-palladium	Olympia (Jelenko) Orion (Ney) Deva 4 (Degussa) Willbond 65SF(Willkinson)***
Noble alloys (Au < 40%)	Palladium-gold	Nobilium 30 NS
	Palladium-gold-gallium	Olympia II (Jelenko)
	Palladium-gold-silver	Rx SWCG (Jeneric) Regent (Sterngold) Shasta (Willkinson)
	Palladium-silver-gallium-gold	Wilpal 76 (Willkinson) Integrity (Jensen) Protocol (Williams)
	Palladium-silver	Jelstar (Jelenko) Pors On (Degussa) Will-Ceram W-1 (Williams)
	Palladium-copper-gallium-gold	Spirit (Jensen) Wilpal 76SF (Willkinson)
	Palladium-gallium-cobalt	PTM-88 (Jelenko)
	Palladium-cobalt-gallium	APF (Jeneric)
	Palladium-cobalt	Bond-on (Aderer)

* Rich yellow colored ** Yellow *** *SF* denotes silver free

TYPES

The following three will be briefly described.

1. Gold-palladium-platinum alloys
2. Gold-palladium-silver alloys
3. Gold-palladium alloys

Commercial names Some alloys along with their commercial names are presented in ***Table 19.1.***

GOLD-PALLADIUM-PLATINUM ALLOYS

COMPOSITION

Gold	80 to 88 wt%
Palladium	5 to 11 wt%
Platinum	6 to 8 wt%
Silver	0 to 4.9 wt% (rarely present)
Base metals	Balance (around 1%)

Sag resistance These alloys have a slightly lower sag resistance. Therefore, long span FPDs should be avoided with this alloy.

GOLD-PALLADIUM-SILVER ALLOYS

COMPOSITION

Gold	39 to 77 wt%
Palladium	10 to 40 wt%
Silver	9 to 22 wt%
Base metals	Balance (around 1%)

The silver has a tendency to discolor some porcelains.

GOLD-PALLADIUM ALLOYS

COMPOSITION

Gold	44 to 55 wt%
Palladium	35 to 45 wt%
Base metals	Balance (around 1%)

The absence of silver eliminates the discoloration problem.

THE NOBLE (PALLADIUM-BASED) METAL-CERAMIC ALLOYS

By definition, these alloys must contain at least 25% of noble metal alloy. Currently, the noble metal-ceramic alloys are mostly palladium-based. The high cost of gold prompted the development of the cheaper base metal alloys. Unfortunately many soon became disillusioned because of the difficulty to work with these alloys (poor castability and high hardness). The palladium based alloys were developed during this period. Their properties were between that of the high noble alloys and the base metal alloys. They also had good scrap value.

COMMON FEATURES OF PALLADIUM BASED (NOBLE) ALLOYS

Cost Their cost range between that of the gold alloys and the base metal alloys.

Color They are white in color.

Density They are less denser than the gold alloys (10.5 to 11.5 gm/cm^3).

Castability These alloys have a lower density than the gold alloys and so do not cast as well. However, they are better than the base metal alloys in this regard.

Workability Like the gold alloys these alloys are extremely easy to work with. They are easy to cut, grind and polish.

Melting range A typical melting range is 1155 to 1304°C. The melting range of these alloys like the gold ceramic alloys are high. This is desirable to ensure that these alloys do not melt or sag during porcelain firing.

Yield strength Ranges from 462 to 685 MPa. These compare favorably with the high noble ceramic alloys which in turn compare favorably to the Type IV alloys.

Hardness Ranges from 189 to 270 VHN. They tend to be slightly harder than the high noble metal-ceramic alloys.

Percent elongation Ranges from 10 to 34%. This gives an indication of the ductility of the alloy. The higher the value the more ductile it is.

Porcelain bonding Like the gold alloys, base metals like tin, indium, etc. are added to enhance porcelain bonding.

Tarnish and corrosion Because of their high noble metal content, these alloys are extremely stable in the oral environment.

Scrap value The palladium based alloys have good scrap value. Many suppliers and manufacturers accept used alloy scrap.

Biological considerations These alloys are very safe and biocompatible. Some concerns have been expressed over the copper content.

TYPES

The following are the palladium based alloys

Palladium-silver alloys
Palladium-copper alloys
Palladium-cobalt alloys
Palladium-gallium-silver alloys
Palladium-gold alloys
Palladium-gold-silver alloys

Brand names The representative alloys are presented in ***Table 19.1.***

PALLADIUM-SILVER ALLOYS

These alloys were introduced in the 1970s as an alternative to gold and base metal alloys. Their popularity has declined a little because of the *greening* problem.

COMPOSITION

Palladium	53 to 60 wt%
Silver	28 to 40 wt%
Base metals	Balance (1 to 8%)

Esthetics (greening) The high silver content causes the most severe *greening* (greenish-yellow discoloration) problem among all the metal-ceramic alloys. This must be kept in mind when using it for anterior teeth. Some manufacturers have provided special agents to minimize this effect (gold metal conditioners and coating agents). Another alternative is to use special *non-greening porcelain*.

PALLADIUM-COPPER ALLOYS

These are relatively new alloys. Information is available regarding their properties.

COMPOSITION

Palladium	74 to 80 wt%
Copper	5 to 10 wt%
Gallium	4 to 9 wt%
Gold	1 to 2 wt% (in some brands)
Base metals	around 1 wt%

Esthetics Copper does cause a slight discoloration of the porcelain, but is not a major problem. During the oxidation firing the metal acquires a dark brown almost black oxide layer. Care should be taken to mask this completely with opaquer. Also of concern is the dark line which develops at the margins.

Castability These alloys are technique sensitive. Slight errors can lead to faulty castings.

PALLADIUM-COBALT ALLOYS

COMPOSITION

Palladium	78 to 88 wt%
Cobalt	4 to 10 wt%
Gallium	up to 9 wt% (in some brands)
Base metals	around 1 wt%

Esthetics Cobalt can cause some insignificant discoloration. However, more care should be taken for masking the dark oxide layer with opaque.

Sag resistance They are the most sag resistant of all the noble alloys.

PALLADIUM-GALLIUM ALLOYS

There are two groups of these alloys, viz., the palladium-gallium-silver and the palladium-gallium-silver-gold.

COMPOSITION

Palladium	75	wt%
Gallium	6	wt%
Silver	5 to 8	wt%
Gold	6	wt% (when present)
Base metals	around 1 wt%	

Esthetics The oxide layer though dark is still somewhat lighter than the palladium copper and palladium cobalt alloys. The silver content does not cause any greening.

BASE METAL ALLOYS FOR METAL-CERAMIC RESTORATIONS

Alloys which contain little or no noble metals are known as base metal alloys. As mentioned earlier, these alloys were introduced as a cheaper alternative to the more expensive noble metal-ceramic alloys. In countries like the USA, Western Europe and the oil rich Middle-Eastern states, there is a preference for noble and high noble metal-ceramic alloys. In contrast, developing countries have shown a preference for base metal-ceramic alloys. This is because the economic concerns far outweigh the advantages of the more user-friendly high noble alloys.

The first base metal alloys were the cobalt-chromium alloys primarily used for removable partial denture alloys. The nickel-chrome alloys were introduced later. The latest in the series are titanium and its alloys.

Like the gold alloys, the base metal alloys can be used for many purposes. However, one must differentiate between the ones used for all-metal and the metal-ceramic restorations. Obviously, the metal-ceramic alloys would be formulated with specific properties since they are to be used with ceramics.

Base metal alloys used for metal-ceramics are:

- Nickel-chromium (nickel based) alloys
- Cobalt-chromium (cobalt based) alloys
- Pure titanium
- Titanium-aluminum-vanadium alloys

Table 19.2 **Commercial names of some base metal-ceramic alloys**

Class	*Alloy*	*Commercial name*
Nickel-based alloys	Ni-Cr-Mo	Wiron 99 (Bego) Wirocer (Bego)
	Ni-Cr-Mo-Be	Litecast B (Williams) Rexillium III (Pentron)
Cobalt-based alloys	Co-Cr-Mo	Wirobond C (Bego)
	Co-Cr	Remanium LFC

Commercial names The commercial names of some of the metal-ceramic alloys are presented in ***Table 19.2.***

NICKEL-CHROMIUM ALLOYS

Although cobalt chromium alloys are used for metal-ceramic crowns and FPDs, many laboratories prefer to use nickel-chromium alloys. For this reason, the discussion will focus mostly on these alloys. Cobalt-chromium will be discussed later under alloys for removable dentures. Representative commercial alloys are shown in ***Fig. 19.6***.

COMPOSITION

Basic Elements

Nickel	61 to 81 wt%
Chromium	11 to 27 wt%
Molybdenum	2 to 9 wt%

(Some alloys occasionally contain one or more minor elements).

The minor additions include

Beryllium	0.5 to 2.0 wt%
Aluminum	0.2 to 4.2 wt%
Iron	0.1 to 0.5 wt%
Silicon	0.2 to 2.8 wt%

Figure 19.6: Representative nickel chromium alloys for metal-ceramic restorations (*Courtesy:* CODS, Davengere).

Copper	0.1 to 1.6 wt%
Manganese	0.1 to 3.0 wt%
Cobalt	0.4 to 0.5 wt%
Tin	1.25 wt%

(Function of the ingredients are described under removable partial denture alloys).

GENERAL PROPERTIES OF NICKEL BASED ALLOYS

Cost They are the cheapest of the casting alloys.

Color They are white in color.

Melting range A typical melting range is 1155 to 1304°C. The melting range of these alloys like the gold ceramic alloys are high.

Density Ranges from 7.8 to 8.4 gm/cm^3. They have just half the density of the gold alloys making them much lighter. One can get more castings per gram compared to the gold alloys.

Castability They are extremely technique sensitive. One reason may be their lower density compared to the gold alloys.

Hardness and workability Ranges from 175 to 360 VHN. They tend to be much harder than the high noble metal ceramic alloys. Unlike the gold alloys these alloys are extremely difficult to work with in the laboratory. Their high hardness makes them very difficult to cut (sprue cutting), grind and polish. In the mouth, more chair time may be needed to adjust the occlusion. Cutting and removing a defective crown or FPD can be quite demanding. The high hardness results in rapid wear of carbide and diamond burs.

Yield strength Ranges from 310 to 828 MPa. These alloys are stronger than the gold and palladium based alloys.

Modulus of elasticity Ranges from 150 to 218 GPa. This property denotes the stiffness of the alloy. Base metal alloys are *twice as stiff* as the gold ceramic alloys. Practically, this means that we can make thinner, lighter castings or use it in longspan FPDs where other metals are likely to fail because of flexing. Gold alloys require a minimum thickness of at least 0.3 to 0.5 mm, whereas base metal alloys copings can be reduced to 0.3 mm (some even claim 0.1 mm).

Percent elongation Ranges from 10 to 28%. This gives an indication of the ductility of the alloy. Though they may appear to be ductile, these alloys, however, are not easily burnishable. This may be related to additional factors like the high hardness and yield strength.

Porcelain bonding These alloys form an adequate oxide layer which is essential for successful porcelain bonding. However, occasionally the porcelain may delaminate from the underlying metal. This has been blamed on a poorly adherent oxide layer which occurs under certain circumstances which have not been fully understood.

Sag resistance These materials are far more stable at porcelain firing temperatures than the gold based alloys. They have a higher sag resistance.

Esthetics A dark oxide layer may be seen at the porcelain metal junction.

Scrap value As may be expected these alloys have poor scrap value because of the low intrinsic value of the elements.

Tarnish and corrosion resistance These alloys are highly resistant to tarnish and corrosion. This is due to the property known as *passivation*.

Passivation is the property by which a resistant oxide layer forms on the surface of chrome containing alloys. This oxide layer protects the alloy from further oxidation and corrosion. These alloys can maintain their polish for years. Other self passivating alloys are *titanium* and *aluminum*.

Soldering Soldering is necessary to join bridge parts. Long span bridges are often cast in two parts to improve the fit and accuracy. The parts are assembled correctly in the mouth and an index made. The parts are then reassembled in the laboratory and joined together using solder. Base metal alloys are much more difficult to solder than gold alloys.

Casting shrinkage These alloys have a higher casting shrinkage than the gold alloys. Greater mould expansion is needed to compensate for this. Inadequate compensation for casting shrinkage can lead to a poorly fitting casting.

Etching Etching is necessary for resin-bonded restorations (e.g., Maryland bridges) to improve the retention of the cement to the restoration. Etching of base metal alloys is done in a electrolytic etching bath.

Biological considerations Nickel may produce allergic reactions in some individuals. It is also a potential carcinogen.

Beryllium which is present in many base metal alloys is a potentially toxic substance. Inhalation of beryllium containing dust or fumes is the main route of exposure. It causes a condition known as 'berylliosis'. It is characterized by flu-like symptoms and granulomas of the lungs.

Precautions Adequate precautions must be taken while working with base metal alloys. Fumes from melting and dust from grinding alloys should be avoided (wear mask). The work area should be well-ventilated. Good exhaust systems should be installed to remove the fumes during melting.

CASTING INVESTMENTS FOR METAL CERAMIC ALLOYS

Due to the high melting temperature of these alloys, only phosphate-bonded or silica-bonded investments are used. However, in case of gold-based metal-ceramic alloys, carbon containing phosphate bonded investments are preferred.

TITANIUM AND ITS ALLOYS FOR METAL-CERAMIC APPLICATIONS

Titanium in the form of the oxide rutile, is abundant in the earth's crust. The ore can be refined to metallic titanium using a method called the Kroll's process.

Titanium and its alloys have been available to the dental profession since the 1970s. Historically, titanium has been used extensively in aerospace, aeronautical and marine applications because of its high strength and rigidity, its low density and corresponding low weight, its ability to withstand high temperatures and its resistance to corrosion.

The use of titanium for medical and dental applications has increased dramatically in recent years. Over the past three decades, the development of new processing methods-like computer-aided machining and electric discharge machining, has expanded titanium's useful range of applications in biomedical devices.

Titanium has become available for use in metal-ceramics. It is also used for removable partial denture alloy frames and of course commercial implants. It has been adapted in dentistry because of its excellent biocompatibility, light weight, good strength and ability to passivate.

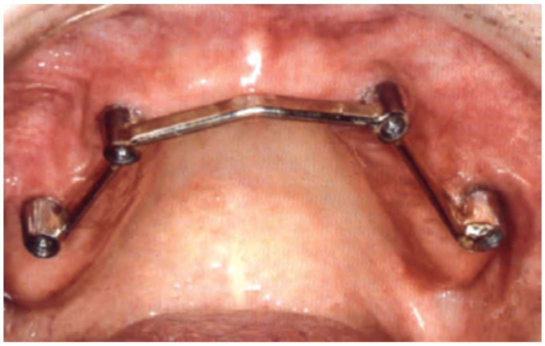


Figure 19.7: A maxillary bar connector made of titanium supported by 4 implants.

Figure 19.8: Grade 4 titanium (Rematitan by dentaurum).

USES

In Dentistry

1. Metal-ceramic restorations.
2. Dental implants.
3. Partial denture frames.
4. Complete denture bases.
5. Bar connectors ***(Fig. 19.7).***
6. Titanium mesh membranes (Tiomesh) are used in bone augmentation.

(In dentistry, it is especially useful as an alternative alloy to those who are allergic to nickel).

In Surgery

1. Artificial hip joints.
2. Bone splints.
3. Artificial heart pumps.
4. Artificial heart valves parts.
5. Pacemaker cases.

ASTM GRADES OF TITANIUM

ASTM International (the American Society for Testing and Materials) recognizes four grades of *commercially pure* titanium (CpTi) and three titanium alloys (Ti-6Al-4V, Ti-6Al-4V extra low interstitial [low components] and Ti-Al-Nb).

SUPPLIED AS

Ingots weighing 18 to 40 gm (height of 11.8 to 16.8 mm) in 1 kg boxes (***Fig. 19.8***).

Representative products	Rematitan M (Dentaurum)	- Grade 4
	Tritan (Dentaurum)	- Grade 1

PROPERTIES OF COMMERCIALLY PURE TITANIUM

Phases In its metallic form at ambient temperature, titanium has a hexagonal, close-packed crystal lattice (α phase), which transforms into a body-centered cubic form (β-phase) at 883°C. The phase is susceptible to oxidation.

Color It is a white color metal.

Density It is a light weight metal (density 4.5 gm/cm^3) when compared to nickel chrome (8 gm/cm^3) and gold alloys (15 gm/cm^3).

Modulus of elasticity Its modulus of elasticity is 110 Gpa which makes it only half as rigid as base metal alloys. However, this appears to be sufficient for most dental uses.

Melting point Its melting point is quite high (1668°C). Special equipment is needed for casting titanium.

Yield strength Varies from 460 to 600 MPa.

Tensile strength Varies from 560 to 680 MPa.

Coefficient of thermal expansion This is an important property when it is used as a metal ceramic alloy. When used as a metal ceramic alloy the CTE (8.4×10^{-6}/°C) is far too low to be compatible with porcelain (12.7 to 14.2×10^{-6}/°C). For this reason special *low fusing porcelains* have been developed to get around this problem.

Biocompatibility It is nontoxic and has excellent biocompatibility with both hard and soft tissues.

Tarnish and corrosion Titanium has the ability to *self-passivate*. The metal oxidizes almost instantaneously in air to form a tenacious and stable oxide layer approximately 10 nanometers thick. The oxide layer protects the metal from further oxidation. In addition, the oxide layer allows for bonding of fused porcelains, adhesive polymers or, in the case of endosseous implants, plasma-sprayed or surface-nucleated apatite coatings.

FABRICATION OF TITANIUM RESTORATIONS

Titanium structures can be made by

1. Casting or
2. Machining

Casting

Casting of titanium is a challenge because of its high melting temperature, low density and high reactivity to atmospheric air. Machines for casting titanium are generally more expensive than that for other dental casting alloys.

Dental castings are made via pressure-vacuum or centrifugal casting methods. The metal is melted using an electric plasma arc or inductive heating in a melting chamber filled with inert gas or held in a vacuum. The inert gas prevents surface reaction with the molten metal. Investments with high setting expansion are used to compensate for the high casting shrinkage of titanium.

Machining

Dental implants generally are machined from billet stock of pure metal or alloy. Dental crowns and FPD frameworks also can be machined from metal blanks ***(Fig. 19.9)*** via CAD-CAM. Abrasive machining of titanium, however, is slow and

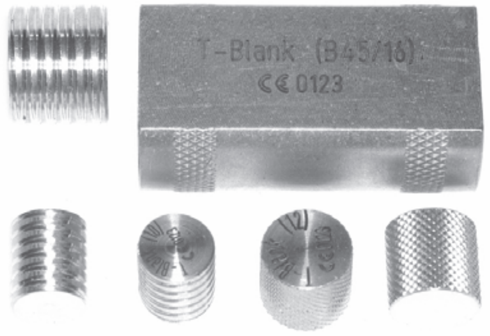


Figure 19.9: Titanium blanks for CAD-CAM.

inefficient, which greatly limits this approach. Another method for fabricating dental appliances is electric discharge machining, which uses a graphite die (often reproduced from the working die) to erode the metal to shape via spark erosion.

CERAMIC VENEERING

Special low fusing porcelains with fusing temperatures below 800°C are used with titanium. This is because titanium changes to the β-form (at 883°C) which is susceptible to oxidation.

ADVANTAGES AND DISADVANTAGES OF TITANIUM

Advantages

1. High strength.
2. Light weight.
3. Bioinert.
4. Low tarnish and corrosion because of ability to passivate.
5. Can be laser welded.
6. Limited thermal conductivity.

Disadvantages

1. Poor castability.
2. Highly technique sensitive.
3. Requires expensive machines for casting and machining.
4. Low fusing porcelains (below 800°C) required to prevent β phase transformation.

REMOVABLE DENTURE ALLOYS

Larger structures like complete denture bases and partial denture frames are also made from dental alloys. Being larger structures they require more quantities of alloy, which can make them quite heavy and expensive (if gold were to be used). Thus it became necessary to develop lighter and more economical alloys. Most of the large castings today are made from base metal alloys, occasionally Type IV gold alloys are used.

ADDITIONAL REQUIREMENTS FOR PARTIAL DENTURE ALLOYS

Besides all the earlier mentioned general requirements of casting alloys, RPD alloys have a few special requirements.

1. They should be light in weight. Being much larger structures, the lighter weight aids in retention in the mouth.
2. They should have high stiffness. This aids in making the casting more thinner. This is important especially in the palate region, where having a thin palatal portion makes it more comfortable to the patient. The high stiffness prevents the frame from bending under occlusal forces.
3. They should have good fatigue resistance. This property is important for clasps. Clasps have to flex when inserted or removed from the mouth. If they do not have good fatigue resistance they may break after repeated insertion and removal.

4. They should be economical. Large structures would require more metal and therefore the cost of the alloy should be low.
5. They should not react to commercial denture cleansers.

TYPES

The alloys for removable denture use are:

1. Cobalt-chromium alloys
2. Nickel-chromium alloys
3. Aluminum and its alloys
4. Type IV noble alloys
5. Titanium

COBALT-CHROMIUM ALLOYS

Cobalt-chromium alloys have been available since the 1920s. They possess high strength. Their excellent corrosion resistance especially at high temperatures, makes them useful for a number of applications.

These alloys are also known as *'stellite'* because of their shiny, star-like appearance. They are bright lustrous, hard, strong and possess nontarnishing qualities.

SUPPLIED AS

Small ingots (cuboidal, cylindrical shapes) in 1 kg boxes ***(Fig. 19.10)***.

Representative products Wironium plus (Bego), Sheralit imperial (Shera).

Figure 19.10: Cobalt-chromium alloy packet and individual pieces (*Courtesy:* BDCH, Davengere).

APPLICATIONS

1. Denture base
2. Cast removable partial denture framework ***(Fig. 19.11)***.
3. Crowns and fixed partial dentures
4. Bar connectors

COMPOSITION

Content	*Percent*
Cobalt	35 to 65%
Chromium	23 to 30%
Nickel	0 to 20%

Figure 19.11: Cast RPD frame can be made from cobalt-chromium.

Molybdenum	0 to 7%
Iron	0 to 5%
Carbon	up to 0.4%

Tungsten, manganese, silicon and platinum in traces

According to ADA Sp. No. 14 a minimum of 85% by weight of chromium, cobalt, and nickel is required.

FUNCTIONS OF ALLOYING ELEMENTS

Cobalt

Imparts hardness, strength and rigidity to the alloy. It has a high melting point.

Chromium

Its passivating effect ensures corrosion resistance. The chromium content is directly proportional to tarnish and corrosion resistance. It reduces the melting point. Along with other elements, it also acts in solid solution hardening. 30% chromium is the upper limit for attaining maximum mechanical properties.

Nickel

Cobalt and nickel are interchangeable. It decreases strength, hardness, MOE and fusion temperature. It increases ductility.

Molybdenum or Tungsten

They are effective hardeners. Molybdenum is preferred as it reduces ductility to a lesser extent than tungsten. Molybdenum refines grain structure.

Iron, Copper and Beryllium

They are hardeners. In addition, beryllium reduces fusion temperature and refines grain structure.

Manganese and Silicon

Primarily oxide scavengers to prevent oxidation of other elements during melting. They are also hardeners.

Boron

Deoxidizer and hardener, but reduces ductility.

Carbon

Carbon content is most critical. Small amounts may have a pronounced effect on strength, hardness and ductility. Carbon forms carbides with the metallic constituents which is an important factor in strengthening the alloy. However, excess carbon increases brittleness. Thus, control of carbon content in the alloy is important.

PROPERTIES

The cobalt-chromium alloys have replaced Type IV gold alloys especially for making RPDs because of their lower cost and good mechanical properties.

Density

The density is half that of gold alloys, they are lighter in weight (8 to 9 gm/cm^3).

Fusion Temperature

Thus casting temperature of this alloy is considerably higher than that of gold alloys (1250°C to 1480°C).

ADA Sp. No. 14 divides it into two types, based on fusion temperature, which is defined as the liquidus temperature.

Type-l (high fusing)—liquidus temperature greater than 1300°C.

Type-ll (low fusing)—liquidus temperature not greater than 1300°C.

Yield Strength

It is higher than that of gold alloys (710 MPa).

Elongation

Their ductility is lower than that of gold alloys. It depends on composition, rate of cooling and the fusion and mould temperature employed. The elongation value is 1 to 12%.

Caution These alloys work harden very easily, so care must be taken while adjusting the clasp arms of the partial denture. They may break if bent too many times.

Modulus of Elasticity

They are twice as stiff as gold alloys (225 × 10^3 MPa). Thus, casting can be made thinner, thereby, decreasing the weight of the RPD.

Hardness

These alloys are 50% harder than gold alloys (432 VHN). Thus, cutting, grinding and finishing are difficult. It wears off the cutting instrument. Special hard, high speed finishing tools are needed.

Tarnish and Corrosion Resistance (Passivation)

Formation of a layer of chromium oxide on the surface of these alloys prevents tarnish and corrosion in the oral cavity. This is called ‘passivating effect’.

Caution Hypochlorite and other chlorine containing compounds that are present in some denture cleaning solutions will cause corrosion in base metal alloys. Even the oxygenating denture cleansers will stain such alloys. Therefore, these solutions should not be used to clean chromium based alloys.

Casting Shrinkage

The casting shrinkage is much greater (2.3%) than that of gold alloys. The high shrinkage is due to their high fusion temperature.

Porosity

As in gold alloys, porosity is due to shrinkage of the alloy and release of dissolved gases. Porosity is affected by the composition of the alloys and its manipulation.

TECHNICAL CONSIDERATIONS FOR CASTING ALLOYS

Based on the melting temperatures of the alloys, we can divide the alloys into high fusing and low fusing alloys.

Low Fusing Alloys

The gold alloys used for all-metal restorations may be considered as low fusing. Obviously the technical requirements of these alloys would be different from the high fusing alloys.

Investment material Gypsum bonded investments are usually sufficient for the low fusing gold alloys.

Melting The regular gas-air torch is usually sufficient to melt these alloys.

High Fusing Alloys

The high fusing alloys include noble metal-ceramic alloys (gold and palladium alloys) as well as the base metal alloys (all-metal, metal-ceramic alloys and partial denture alloys).

Investment material for noble metal alloys The high melting temperatures prevent the use of gypsum-bonded investments. Phosphate bonded or silica bonded investments are used for these alloys.

Investment material for base metal alloys Phosphate-bonded or silica-bonded investments are also used for these alloys. However, there is one difference. These alloys are very sensitive to a change in their carbon content. Therefore, *carbon containing investments* should be avoided when casting base metal alloys.

Burnout A slow burnout is done at a temperature of 732 to 982°C. It is done two hours after investing.

Melting The high fusion temperature also prevents the use of gas-air torches for melting these alloys. Oxygen-acetylene torches are usually employed. Electrical sources of melting such as carbon arcs, argon arcs, high frequency induction, or silicon-carbide resistance furnaces may also be used.

Technique for Small Castings

The wax pattern is usually constructed on a die stone model. The wax pattern is removed and then invested (for more details see chapter on casting techniques).

Figures 19.12 A and B: Partial denture wax patterns are constructed directly on the refractory cast (A). The whole cast together with the pattern is invested to form a mold (B). The completed casting is also shown (C).

Technique for Large Castings

The procedure for large castings like RPD frames is slightly more complex. Unlike the crown or FPD pattern, the RPD pattern is difficult to remove from the model without distortion and damage. Therefore, a modification in the technique is required. A duplicate of the model is made using investment material (this is called refractory cast – ***Figs 19.12 A and B***). The wax pattern is constructed on the refractory cast. The pattern is not separated from the refractory cast, instead the refractory cast is invested along with the pattern.

ADVANTAGES AND DISADVANTAGES OF BASE METAL ALLOYS

ADVANTAGES OF BASE METAL ALLOYS

1. Lighter in weight.
2. Better mechanical properties (exceptions are present).
3. As corrosion resistant as gold alloys (due to passivating effect).
4. Less expensive than gold alloys.

DISADVANTAGES

1. More technique sensitive.
2. Complexity in production of dental appliance.
3. High fusing temperatures.
4. Extremely hard, so requires special tools for finishing.
5. The high hardness can cause excessive wear of restorations and natural teeth contacting the restorations.

COMPARISON OF A GOLD ALLOY AND A BASE METAL ALLOY

	Properties	*Cobalt-chromium*	*Gold Type - IV*
1.	Strength	Adequate	Adequate
2.	Density (gm/cm)	8 (lighter)	15 (heavier)
3.	Hardness	Harder than enamel	Softer than enamel
4.	Stiffness	Stiff	More flexible
5.	Melting temperature	1300°C	900°C
6.	Casting shrinkage	2.25%	1.25-1.65%
7.	Heat treatment	Complicated	Simple
8.	Tarnish resistance	Adequate	Adequate
9.	Cost	Reasonable	High for large castings
10.	Castability	Technique sensitive	Casts well
11.	Workability	Difficult to cut, grind and polish	Cutting and polishing easy
12.	Investment	Phosphate bonded (non-carbon)	Gypsum bonded
13.	Heat source for melting	Oxyacetylene torches	Gas-air torch
14.	Solderability	Difficult	Easier

20

ABRASION AND POLISHING

Before any restoration or appliance is placed permanently in the mouth it should be highly polished. In spite of all the care taken during processing, many restorations and prostheses usually require further trimming, smoothing and finally polishing.

A rough or unpolished surface may:

- Be uncomfortable to the patient
- Cause food and other debris cling to it and makes it unhygienic
- Lead to tarnish and corrosion.

ABRASION

It occurs when a hard, rough surface slides along a softer surface and cuts a series of grooves.

DEFINED AS

The wearing away of a substance or structure through a mechanical process, such as grinding, rubbing or scraping (*GPT-8*).

TYPES OF ABRASION

Abrasion may be:

- *A two body process,* e.g., action of a diamond bur on enamel.
- *A three body process,* e.g., pumice applied with a bristle brush.

SUPPLIED AS

In dentistry the abrasive is applied to the work by a variety of tools ***(Figs 20.1 A to C)***.

- *Paper/plastic coated* The abrasive particles may be glued on to a paper or plastic disc that can be attached to a handpiece. Sand paper falls in this group.
- *Coated strips* The abrasive (e.g., diamond) may be attached to stainless steel or plastic strips ***(Fig. 20.1 A)*** (used for proximal stripping of teeth). This category is similar to the above.
- *Electroplating bonding* In case of diamond rotary instruments the diamond chips are attached to steel wheels, discs and cylinders by electroplating with nickel based matrix.
- *Bonded stones* In grinding wheels and dental stones ***(Figs 20.1 B and C)***, the abrasive particles are mixed with a bonding agent that holds the particles

Figures 20.1 A to C: Abrasive and polishing materials come in a wide variety of shapes and forms. (A) Abrasive strip, (B) Electroplated diamond, (C) Bonded stones.

together. Before hardening, the matrix material with the abrasive is moulded to form tools of desired shapes.

- *Powder form* An abrasive may also be mixed with water or glycerine to form a paste or slurry. It is applied with felt cone, rubber cup or brush and used for smoothening irregularities, e.g., pumice powder ***(Fig. 20.2 A)***.
- *Cake form* They are also available in the form of cakes ***(Fig. 20.2 B)***.
- *Rubber impregnated* Abrasives can be incorporated into rubber or shellac discs or cups for 'soft grade' abrasion ***(Fig. 20.3)***.
- *Paste form* The abrasive is made into a paste and supplied in a tube, e.g., Ivoclar polishing paste, tooth paste, etc.

Abrasion is affected by the properties of the abrasive as well as the target material. The important properties include hardness, strength, ductility, thermal conductivity, etc.

MECHANISM OF ABRASIVE ACTION

In a cutting tool, e.g., carbide bur, the blades or cutting edges are regularly arranged and the removal of material corresponds to this regular arrangement. An abrasive tool on the other hand has many abrasive points that are not arranged in an ordered pattern. Thus innumerable random scratches are produced.

The action of an abrasive is essentially a *cutting action*. Each tiny particle presents a sharp edge that cuts through the surface similar to a chisel. A shaving is formed which crushes to a fine powder. This powder clogs the abrasive tool and frequent cleaning is required.

Figures 20.2 A and B: Forms of abrasives. (A) Pumice powder, (B) Polishing abrasive in cake form.

STRESS, STRAIN AND HEAT PRODUCTION DURING ABRASION

While abrading metals, the crystalline structure of the metal is disturbed to depth of 10 µm. The grains become disoriented and strain hardening may occur. Thus, the surface hardness increases.

In denture resins too, rigorous abrasion introduces stresses. The generation of heat during abrasion partially relieves such stresses but if it is too great, it may relieve processing stresses and a warpage may result. The resin surface may even melt.

Similarly high speed cutting of tooth structure generates excessive heat which can lead to pulpal damage. Therefore it is very important to control the heat by air/water spray and intermittent cutting (rather than continuous cutting).

RATE OF ABRASION

The rate of abrasion of a given material by a given abrasive is determined primarily by three factors.

1. Size of the abrasive particle.
2. The pressure of the abrasive agent.
3. Speed at which the abrasive particle moves across the surface being abraded.

SIZE OF THE PARTICLES

Larger particles cause deeper scratches in the material and wear away the surface at a faster rate. The use of course abrasive is indicated on a surface with many rough spots or large nodules. The scratches caused by the coarse abrasive must then be removed by finer ones.

PRESSURE

Heavy pressure applied by the abrasive will cause deeper scratches and more rapid removal of material. However, heavy pressure is not advisable as it can fracture or dislodge the abrasive from the grinding wheel, thus reducing the cutting efficiency. In addition, operator has less control of the abrasion process because removal of material is not uniform.

SPEED

The higher the speed, the greater the frequency per unit of time the particles contacts the surface. Thus increasing the speed increases the rate of abrasion. In a clinical situation it is easier to control speed than pressure to vary the rate of abrasion. Varying the speed has the additional advantage that low pressure can be used to maintain a high cutting efficiency.

Rotational Speed and Linear Speed

Rotational speed and linear speed should be differentiated. The speed with which the particles pass over the work is its linear speed or it is the velocity with which the particles pass over the work. Rotational speed is measured in revolutions per minute (RPM or r/min), whereas, linear speed is measured in meters per second

Linear speed is related to rotational speed according to the following formula:

$V = CR$ where

V = linear speed
C = circumference of the bur or disc
R = revolutions per minute

CLASSIFICATION

A. Finishing abrasives
B. Polishing abrasives
C. Cleansing abrasives

FINISHING ABRASIVES

Finishing abrasives are hard, coarse abrasives which are used initially to develop contour and remove gross irregularities, e.g., coarse stones.

POLISHING ABRASIVES

Polishing abrasives have finer particle size and are less hard than abrasives used for finishing. They are used for smoothening surfaces that have been roughened by finishing abrasives, e.g., polishing cakes, pumice, etc.

CLEANSING ABRASIVES

Cleansing abrasives are soft materials with small particle sizes and are intended to remove soft deposits that adhere to enamel or a restorative material.

TYPES OF ABRASIVES

EMERY

Emery consists of a natural oxide of aluminum called corundum. There are various impurities present in it such as iron oxide, which may also act as an abrasive. The greater the content of alumina, the finer the grade of emery.

ALUMINUM OXIDE

Pure alumina is manufactured from bauxite, an impure aluminum oxide. It can be produced in fine grain sizes and has partially replaced emery for abrasive purpose. Pure alumina is also used as a polishing agent. Alumina is used in sandblasting machines ***(Figs 20.7 and 20.8)***.

GARNET

It is composed of different minerals which possess similar physical properties and crystalline form. The mineral comprises of silicates of aluminium, cobalt, magnesium, iron and manganese. Garnet is coated on paper or cloth with glue. It is used on discs which are operated on handpieces.

PUMICE

It is a highly siliceous material of volcanic origin and is used either as an abrasive or polishing agent depending on particle size. Its use ranges from smoothening dentures to polishing teeth in the mouth.

KIESELGURH

Consists of siliceous remains of minute aquatic plants known as diatoms. The coarser form (diatomaceous earth) is used as a filler in many dental materials. It is excellent as a mild abrasive and polishing agent.

TRIPOLI

This mild abrasive and polishing agent is often confused with kieselgurh. True tripoli originates from certain porous rocks, first found in North Africa near Tripoli.

ROUGE

Rouge is a fine red powder composed of iron oxide. It is used in cake form. It may be impregnated on paper or cloth known as 'crocus cloth'. It is an excellent polishing agent for gold and noble metal alloys, but is likely to be dirty to handle.

TIN OXIDE

Putty powder used as polishing agent for teeth and metallic restorations in the mouth. It is mixed with water, alcohol or glycerin and used as paste.

CHALK

It is calcium carbonate prepared by precipitation method. There are various grades and physical forms available for different polishing techniques. It is sometimes used in dentifrices.

CHROMIC OXIDE

A relatively hard abrasive capable of polishing a variety of metals. It is used as a polishing agent for stainless steel.

SAND

Sand as well as other forms of quartz is used as sand paper or as powder in sandblasting equipment.

CARBIDES

Silicon carbide and boron carbide are manufactured by heating silicon and boron at a very high temperature to effect their union with carbon. The silicon carbide is sintered, or pressed with a binder into grinding wheels or discs. Most of the stone burs used for cutting tooth structure are made of silicon carbide.

DIAMOND

It is the hardest and most effective abrasive for tooth enamel. The chips are impregnated in a binder or plated on to a metal shank to form the diamond 'stones' and disks so popular with the dental profession.

ZIRCONIUM SILICATE

The mineral zircon is ground to various particle sizes and used as a polishing agent. It is used in dental prophylactic pastes and in abrasive impregnated polishing strips and discs.

ZINC OXIDE

Zinc oxide in alcohol can be used for polishing amalgam restorations.

DESIRABLE CHARACTERISTICS OF AN ABRASIVE

1. It should be irregular in shape so that it presents a sharp edge. Round smooth particles of sand are poor abrasives. Sand paper with cubical particles present flat faces to the work and so they are not effective. Irregular and jagged particles are more effective.
2. Abrasive should be harder than the work it abrades. If it cannot indent the surface to be abraded, it cannot cut it and the abrasive dulls or wears out.
3. The abrasive should possess a high impact strength. The abrasive particle should fracture rather than dull out, so that a sharp edge is always present.

Fracture of an abrasive is also helpful in shedding the debris accumulated from the work. A diamond does not fracture, it loses substances from the tip. They become clogged when used on ductile metals. They are most effective when used on brittle tooth enamel.

4. They should have attrition resistance, so that it does not wear.

GRADING OF ABRASIVE AND POLISHING AGENTS

Abrasives are graded according to the number of the last sieve it passed through Examples: Silicon Carbide is graded as 8, 10, 12, 14, 16, 20, 24, etc. Finer abrasives are designated as powder or flours and are graded in increasing fineness as F, FF, FFF, etc., and impregnated papers as 0,00,000 etc.

BINDER

The abrasives on a disc and wheel are held together by a binder.

Commonly used binders in dentistry are

- Ceramic bonding is used for silicon carbide or corundum in a mounted abrasive point.
- Electroplating with nickel is often used to bind the diamond chips on to the diamond rotary instruments ***(Fig. 20.3)***.
- For soft grade abrasion, rubber ***(Fig. 20.5)*** or shellac may be used. These wear rapidly, but they are useful in some dental operations in which delicate abrasion is required.

The type of binder is related to the life of the tool in use. In most abrasives the binder is impregnated throughout with an abrasive of a certain grade so that, as a particle is removed from the binder during use another takes its place as the binder wears. Further more the abrasive should be so distributed that the surface of the tool wears evenly, particularly if the disc or wheel is used for cutting along its periphery.

DIAMOND BURS

Either synthetic or natural diamond chips are employed for dental rotary instruments ***(Fig. 20.3)***. The cutting efficiency of diamond rotary instruments depends on whether the diamonds used are natural or synthetic, the grit size, the

Figure 20.3: Diamond burs of various grits. The color indicates grit size. Black - coarse, Blue - medium, Red - fine and White - Ultra fine.

Figure 20.4: Steel bur. Unlike diamond these burs remove material by cutting or shaving.

Figure 20.5: Rubber bonded abrasives.

distribution and the extent of plating that attaches the particles to the instrument shank. The larger the grit size the greater the abrasion. Some companies indicate the grit size by color coding. Adequate water spray is essential not only to minimize heat but also to reduce clogging.

POLISHING

It is the production of a smooth mirror like surface without much loss of any external form. If the particle size of an abrasive is reduced sufficiently, the scratches become extremely fine and may disappear entirely. The surface then acquires a smooth shiny layer known as a polish.

The polishing agents remove material from the surface molecule by molecule. In the process fine scratches and irregularities are filled in by powdered particulates being removed from the surface. The microcrystalline layer is referred to as polish layer or *Beilby layer*. A polishing agent is employed only after an abrasive obliterates or eliminates most of the fine scratches, leaving a smooth finish.

DIFFERENCE BETWEEN ABRASION AND POLISHING

The difference between an abrasive agent and a polishing agent is difficult to define. The terms are generally interchangeable.

- *Particle size* A given agent having a large particle size acts as an abrasive, producing scratches. The same abrasive with a smaller particle size is a polishing agent.
- *Material removed* Very little of the surface is removed during polishing—not more than 0.005 mm (0.002 inch).
- *Speed* The optimum speed for polishing is higher than that for abrading. Linear speed as high as 10000 ft/min may be used. It varies with the polishing agent. Average speed is approximately 7500 ft/min.

NONABRASIVE POLISHING

Polishing is usually achieved by an abrasive process. However a smooth shiny surface can also be achieved through nonabrasive means. These include:

1. Application of a glaze layer
   e.g., Glazing of composites
   Glazing of ceramics
2. Electrolytic polishing
3. Burnishing

COMPOSITE GLAZING

A layer of glaze or gloss (a clear transparent liquid made of unfilled resin) is applied over the restoration and cured. This results in a smooth glossy surface.

GLAZING CERAMICS

Ceramics are difficult to polish conventionally. The finished restoration is subjected to high temperatures. At this temperature the surface layer melts and flows to produce a smooth glass-like surface (refer ceramics chapter for more details).

ELECTROLYTIC POLISHING

Figure 20.6: Electrolytic polishing unit.

Electrolytic polishing ***(Fig. 20.6)*** is not true abrasion. Although material is removed, it is removed through an *electrochemical process* rather an abrasive process.

This is the reverse of electroplating. The alloy to be polished is made the anode of an electrolytic cell. As the current is passed, some of the anode is dissolved leaving a bright surface. This is an excellent method for polishing the fitting surface of a cobalt-chromium alloy denture. So little material is removed, that the fit of the denture is virtually unaltered.

BURNISHING

It is related to polishing in that the surface is drawn or moved. Instead of using many tiny particles, only one large point is used.

If a round steel point is rubbed over the margins of a gold inlay, the metal is moved so that any gap between the inlay and the tooth can be closed. A special blunt bur revolving at high speed can also be used.

Note The burnishing instrument should not adhere to or dissolve in the surface of the burnished metal, e.g., brass instruments impregnate copper into the surface of a gold inlay.

TECHNICAL CONSIDERATIONS (PROCEDURE)

METHODS OF ABRASION

Abrasion may be carried out

1. *Manually*, e.g., proximal stripping of enamel using abrasive strips.
2. *Rotary instruments,* e.g., burs, wheels, cups, discs, cones, etc.
3. *Blasting:* The object is blasted with a steady stream of abrasive, e.g., prophy-jet polishing of enamel, sandblasting ***(Figs 20.7 and 20.8)*** to remove investment of castings, shell blasting, etc.
   - ➢ Smoothen work with a coarse abrasive or bur ***(Fig. 20.9 A)*** which leaves large scratches. These scratches are removed with finer abrasives but the difference in fineness should not be too great ***(Figs 20.9 B and 20.10)***. The use of too fine an abrasive after a relatively coarse abrasive wastes time and may cause streaking.

Figure 20.7: Sandblasting.

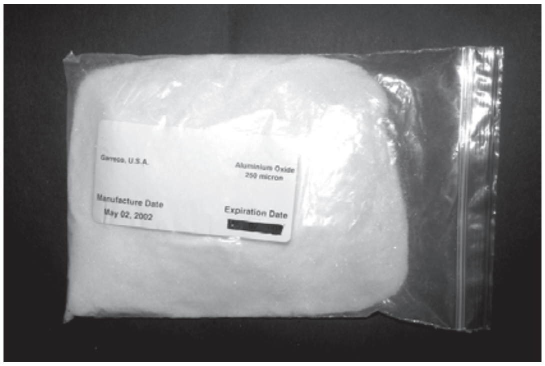
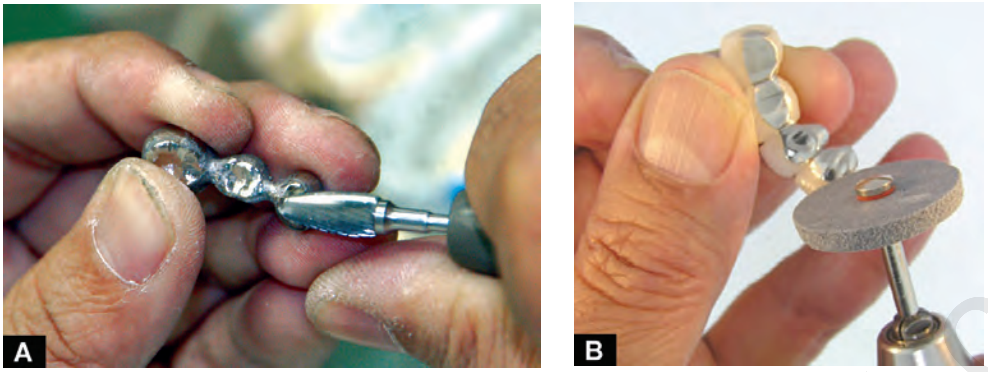


Figure 20.8: The term sandblasting is misleading. The process actualy uses 250 micron alumina (Al_2O_3).



Figures 20.9 A and B: Sequence of finishing is important - one should proceed from coarse to fine.

Figure 20.10: Canvas buff wheel with pumice is used for polishing complete dentures.

- After changing to a finer abrasive, the direction of abrasion should be changed each time if possible, so that new scratches appear at right angles to the coarser scratches, for uniform abrasion.
- When the scratches are no longer visible to the eye, the preliminary polishing can be accomplished with pumice flour applied with a canvas buff wheel (used for resin dentures—***Fig. 20.10***).
- The work is cleaned to remove all traces of abrasives and the particles of the material removed by the abrasive.
- A paste is formed of pumice and water to a sticky 'muddy' consistency. The buff wheel is turned at high speed. Apply the paste to the work and carry it to the buff. Hold the work firmly but without excessive pressure. Repeat this over the entire surface till the surface is bright and well polished.
- Clean the work with soap and water. Change to a flannel buff wheel. Rotate at high speed. A polishing cake with grease is held against the buff wheel to impregnate with the agent. The work is held against the wheel and turned, so that all of the surfaces are polished uniformly. A light pressure is used to avoid excess heat generation (especially in resins).

DENTIFRICES

Popularly known as toothpastes these are agents used with a toothbrush to cleanse and polish natural teeth. They should have maximum cleansing efficiency with minimum tooth abrasion. Highly abrasive dentifrices should not be used especially when dentin (abrades 25 times faster) or cementum (35 times faster) is exposed.

FUNCTION

1. Assists the toothbrush to mechanically remove stains, debris and soft deposits from the teeth.
2. To impart a polished surface to the tooth.

Table 20.1

Composition of toothpaste

Abrasives	Dibasic calcium phosphate Calcium pyrophosphate Insoluble sodium metaphosphate Hydrated silica (most efficient) Alumina Magnesium oxide, etc.	
Water		Vehicle
Humectants	Glycerin Sorbitol Propylene glycol	Prevents drying of paste
Detergents	Sodium lauryl sulfate	Decreases surface tension
Foaming agents		
Binders	Carboxy methyl cellulose	
Artificial sweeteners	Sorbitol, Saccharin	
Therapeutic	Sodium fluoride Stannous fluoride Strontium chloride	Anticariogenic agents
	Urea Pencillin	Bacteriostatic and Bactericidal
	Dibasic ammonium phosphate	Acid neutralizing
Coloring and flavoring	Mint	

Thus, they help to reduce caries, maintain healthy gingiva, improve esthetics and reduce mouth odors.

AVAILABLE AS

Pastes, powders, liquid and gels ***(Fig. 20.11).***

COMPOSITION

The basic component of a dentifrices is the abrasive. However pastes today contain numerous other components. Specialized dentifrices contain medicaments for various problems such as sensitivity and gum diseases. Composition of a typical dentifrices is presented in ***Table 20.1.***

Figure 20.11: Some popular dentifrices.

Figure 20.12: Prophylaxis in a dental office.

PROPHYLACTIC ABRASIVES

Oral prophylaxis is a widely used procedure in the dental office. Prophylactic polishing agents may be available commercially or can be made in the dental office. They are usually employed in paste form by mixing with a suitable vehicle.

FUNCTION

1. They remove extrinsic stains, pellicle, materia-alba and oral debris.
2. Impart a highly polished and esthetic appearance.

Different types of abrasives may be employed, e.g., zirconium silicate, silica, pumice, etc. In addition, some may contain fluoride in order to reduce caries.

They are applied onto the teeth with the help of rubber cups or bristle brushes ***(Fig. 20.12)*** which are attached to a rotary instrument.

PROPHYJET

The Prophyjet ***(Fig. 20.13 A)*** is a relatively new dental prophylaxis system of removing intraoral stains. An abrasive blasting process ***(Fig. 20.13 C)*** is used to mechanically remove extrinsic (tobacco) stains as well as light supragingival adherent plaque and calculus. The powder is loaded into the device, which then directs the abrasive through a small nozzle in a steady *stream* of air and water.

Composition Contains sodium carbonate, hydrophobic modified silica and a flavoring agent. It is supplied as powder in sachets or containers ***(Fig. 20.13 B)***.

Clinical considerations The prophyjet is directed at 45° angles to the tooth surface. For obvious reasons it is less effective in proximal areas. The chances of soft tissue injury exist especially if the tissue is inflamed and friable.

Figures 20.13 A to C: (A) Prophy jet unit (Cavitron); (B) Prophy jet powder; (C) High pressure abrasive jet blasting through the nozzle.

DENTURE CLEANSERS

Dentures collect deposits in the same manner as natural teeth during their use. These can be removed by two ways:

- Professional—repolishing in the laboratory or clinic.
- Soaking or brushing the dentures daily at home.

Figure 20.14: A home cleansing kit for dentures.

Figure 20.15: A commercially available chemical cleanser for soaking.

BRUSHING

The dentures may be brushed using a soft bristle brush ***(Fig. 20.14)*** and gentle abrasive or cream. Hard abrasives and stiff bristles should be avoided because they may produce scratches on the denture surface.

SOAKING

Chemical cleaners ***(Fig. 20.15)*** are an alternative to brushing especially among very old or handicapped persons.

- Alkaline perborates
- Alkaline peroxides
- Alkaline hypochlorites
- Dilute acids

The dentures are soaked in these chemical solutions for a prescribed period of time. Their main requirements are that they should be nontoxic, non-irritant and should not attack the materials used in denture construction.

21

DENTAL CERAMICS

Dental ceramics holds the promise of a restorative material, that can realistically duplicate teeth, to the extent that the layperson may find it difficult to differentiate (***Fig. 21.1***). One might argue that composite resins have a similar esthetic potential. However, there is a difference - dental ceramics are far more stronger, durable, wear resistant, and virtually indestructible in the oral environment. They are impervious to oral fluids and absolutely biocompatible. They do have some drawbacks which will be discussed subsequently. Because of their huge potential, it is still a fast growing area in terms of research and development. Thanks to the continuing research, these materials once restricted to restoring single crowns have now expanded to include long span fixed partial dentures.

USES AND APPLICATIONS

1. Inlays and onlays
2. Esthetic laminates (veneers) over natural teeth
3. Single (all ceramic) crowns
4. Short and long span (all ceramic) FPD
5. As veneer for cast metal crowns and bridges (metal ceramics)
6. Artificial denture teeth (for complete denture and partial denture use)
7. Ceramic post and cores
8. Ceramic orthodontic brackets.

EVOLUTION OF DENTAL CERAMICS

Ceramics are among the oldest materials known to man. An *esthetic and durable* material that could accurately reproduce missing teeth or teeth structure had always been a dream. Prior to the use of porcelain, crowns were made entirely of gold or other alloys. As demands for esthetics increased, tooth colored resin was used as a veneer over the metal in the esthetic areas. Around the early 1900s, porcelain crowns were introduced to dentistry by Charles Land (grandfather of aviator Charles Lindbergh). These crowns were known as *porcelain jacket crowns (PJC)*. These early crowns had a lot of problems. They were very difficult to fabricate, did not fit well (poor margins), and tended to fracture easily (half moon fracture). For this reason they fell out of favor.

It was not until the late 1950s and early 1960s that McLean developed ceramics that could bond to metal. This led to the era of the metal-ceramics ***(Fig. 21.1)***. Prior to this, metal FPDs were veneered (covered) with tooth colored acrylic in order to hide the metal. These veneers did not last very long and had to be replaced often. Besides they could not be used to cover the occlusal surface because of their poor wear resistance. The metal-ceramic crowns and fixed partial

Figure 21.1: Porcelain-fused-to-metal fixed partial denture.

dentures were instantly accepted because of their superior esthetics, wear resistance and strength. The ceramic could be used to veneer the occlusal surface as well. Since the margins were in metal, the marginal fit was highly accurate. The metal-ceramics are still popular and represent a major percentage of restorations being made today.

The research into the *all-ceramic crown*, however, continued. In spite of the success of the metal-ceramic restorations, they did not represent the final solution. The underlying metal did not allow the natural passage and reflection of light as in natural teeth ***(Fig. 21.45)***. Under certain lighting conditions these crowns appeared dense, dark and *opaque*. The esthetics would certainly have been better if it could reflect the color of the underlying dentin. Similarly the margin of the restoration appeared to be *dark*, even when hidden below the gums as it sometimes showed through the gums (the gums developed a bluish discoloration). Some manufacturers did attempt to solve this problem by introducing '*shoulder porcelains*'. A portion of the metal was removed from the labial margin (metal free margin) and replaced with shoulder porcelain. However, this still did not entirely solve the problem of translucency.

The first breakthrough at developing a stronger all-ceramic restoration came in 1965. McLean and Hughes introduced an alumina reinforced core material which improved the strength of the porcelain. However, they were still not strong enough for posterior use and of course the problem of marginal adaptation still remained. Thus further improvements were required in technique as well as material.

The 1990s saw the reemergence of the *all-ceramic crown* ***(Fig. 21.2)*** *as well as small fixed partial dentures*. The strength of the restorations had been improved

Figure 21.2: All porcelain (metal free) crowns.

through a variety of technological advances and introduction of newer porcelains. The marginal adaptation and fit had also improved considerably when compared to the first generation all-porcelain crowns. The new generation ceramics included *castable glass* ceramics, *shrink free* core ceramic, *injection molded* core ceramic, high strength *glass infiltrated* alumina core ceramics, *CAD-CAM* (computer aided design, computer aided machining) ceramics, etc. One of the drawbacks of the early ceramics (metal-free) were that they were not strong enough for all-ceramic FPDs. Some of the modern ceramics are strong enough for an *all-ceramic FPDs* (including *posterior* FPDs). Drawbacks still exist in modern porcelains. Some of the ceramic systems are highly complicated and tedious and require expensive machines to fabricate. There is still much scope for improvement in porcelain technology because of the high demand for esthetic tooth colored restorations.

Definition

Compounds of one or more metals with a nonmetallic element, usually oxygen. They are formed of chemical and biochemical stable substances that are strong, hard, brittle, and inert nonconductors of thermal and electrical energy (*GPT- 8*).

CLASSIFICATION OF DENTAL PORCELAINS

The wide variety of ceramic systems available in the market make classification of ceramics a challenging task. The manufacturer provides equipment and material compatible for the particular system. They are usually not interchangeable.

ACCORDING TO FIRING TEMPERATURE

High fusing	1300°C or above
Medium fusing	1101 to 1300°C
Low fusing	850 to 1100°C
Ultra low fusing	less than 850°C

ACCORDING TO TYPE

Feldspathic porcelains
Leucite reinforced glass ceramics
Tetrasilicic fluormica based glass ceramics
Lithia disilicate based ceramics
Alumina reinforced ceramics
Spinel reinforced ceramics
Zirconia reinforced ceramics

ACCORDING TO ITS FUNCTION WITHIN THE RESTORATION

Core ceramics – Supports and reinforces the restoration
Opaquer ceramics – Masks or hides the metal
Veneering ceramics
  – Body or dentin – Simulates the dentin portion of natural teeth
  – Incisal – Simulates the enamel portion of natural teeth
  – Gingival – Simulates the darker gingival portion of teeth

– Translucent	Simulates translucent incisal enamel seen sometimes in natural teeth
Stains	Used to color ceramics to improve esthetics
Glaze	Imparts a smooth glossy surface to the restoration

ACCORDING TO MICROSTRUCTURE

Glass ceramics
Crystalline ceramics
Crystal containing glasses

ACCORDING TO FABRICATION PROCESS

Condensable ceramics
Slip-cast glass-infiltrated ceramics
Heat pressed ceramics
Castable ceramics
Machinable ceramics
Various combinations of the above

BASIC CONSTITUENTS AND MANUFACTURE

The wide variety of ceramic products in the market, makes it virtually impossible to provide a single composition. Traditionally, porcelains were manufactured from a mineral called *feldspar*. These porcelains are referred to as *feldspathic porcelains*. As technology improved other ceramic systems were introduced, like core porcelains, glass ceramics, etc. The composition of these differ from the traditional feldspathic porcelains.

BASIC STRUCTURE

Most current ceramics consist of two phases

Glassy phase	acts as the matrix
Crystalline phase	dispersed within the matrix and improves strength and other properties of the porcelain, e.g., alumina, spinel, zirconia, etc.

The structure of porcelain is similar to that of glass. The basic structure therefore consists of a three dimensional *network of silica* (silica tetrahedra). Pure glass melts at too high a temperature for dental use. Adding certain chemicals lowers the melting temperature by disrupting the silica network. The glass obtains porcelain-like qualities when the silica network is broken by *alkalies* like sodium and potassium. This also lowers the fusion temperature. These chemicals are known as *glass modifiers* or *fluxes*. Other substances which act as glass modifiers are alumina (Al_2O_3) and boric oxide (B_2O_3). Boric oxide forms its own separate network between the silica network. Adding certain opacifiers reduces the transparency and completes the transformation to dental porcelain.

BASIC CONSTITUENTS

The basic constituents of feldspathic porcelains are:

Feldspar	Basic glass former
Kaolin	Binder
Quartz	Filler

Alumina – Glass former and flux
Alkalies – Glass modifiers (flux)
Color pigments – Modifies color
Opacifiers – Reduces transparency

Feldspar

It is a naturally occurring mineral and forms the basic constituent of feldspathic porcelains. Most of the components needed to make dental porcelain are found in feldspar. It thus contains potash (K_2O), soda (Na_2O), alumina (Al_2O_3) and silica (SiO_2). It is the basic glass former. When fused at high temperatures (during manufacture) it forms a feldspathic glass containing potash feldspar ($K_2O.Al_2O_3.6SiO_2$) or soda feldspar ($Na_2O.Al_2O_3.6SiO_2$). Pure feldspathic glass is quite colorless and transparent. As explained earlier, various glass modifiers and opacifiers are added to alter its sintering temperature, viscosity, thermal coefficient of expansion (CTE) and appearance.

Kaolin

It is a white clay-like material (hydrated aluminum silicate). It acts as a binder and gives opacity to the mass. Some manufacturers use sugar or starch instead of kaolin.

Quartz

Quartz is a form of silica. Ground quartz acts as a refractory skeleton, providing strength and hardness to porcelain during firing. It remains relatively unchanged during and after firing.

Alumina

Aluminum oxide (alumina) replaces some of the silica in the glass network. It gives strength and opacity to the porcelain. It alters the softening point and increases the viscosity of porcelain during firing.

Glass Modifiers

Alkalies such as sodium, potassium and calcium are called glass modifiers. Glass modifiers lower the fusion temperature and increase the flow of porcelain during firing. They also raise the CTE (important in metal-ceramics). However, too high a concentration of glass modifiers is not good for the ceramic because:

- It reduces the chemical durability of the ceramic
- It may cause the glass to devitrify (crystallize)

Another glass modifier is boric oxide (B_2O_3) which forms its own glass network (also called lattice) interspersed between the silica network (lattice).

Opacifiers

Since pure feldspathic porcelain is quite colorless, opacifiers are added to increase its opacity in order to simulate natural teeth. Oxides of zirconium, titanium and tin are commonly used opacifiers.

Color Modifiers

Natural teeth come in a variety of shades. In addition, it acquires external stains from the environment. Thus color modifiers are required to adjust the shades of the dental ceramic. Various metallic oxides provide a variety of color, e.g., titanium oxide (yellow-brown), nickel oxide (brown), copper oxide (green), manganese oxide (lavender), cobalt oxide (blue), etc. They are fused together with regular feldspar and then reground and blended to produce a variety of colors.

OTHER SPECIALIZED PORCELAINS

Glazes

It is a special type of colorless porcelain applied to the surface of the completed ceramic restoration to give it a smooth finish as well as increase the life of the restoration. Obviously they do not contain opacifiers. They must also have a lower fusion temperature and therefore must contain a lot of glass modifiers. This also makes them somewhat less chemically durable.

Stains

They are porcelain powders containing a high concentration of color modifiers (as described previously). They too have a lower fusion temperature made possible by an increased content of glass modifiers. Stains are used to provide individual color variation in the finished restoration ***(Fig. 21.2)***.

Opaquer Porcelains

It is a specialized type of porcelain which is used to conceal the metal core in PFM (metal-ceramic) restorations. It is the first layer applied before the addition of the regular porcelain. Obviously it contains a high concentration of *opacifiers*. Some amount of color modifiers are also added.

Reinforced Core Ceramics

The low strength of traditional feldspathic porcelain prompted research into methods of reinforcing ceramics. The first reinforced ceramic (alumina reinforced) was introduced by McLean and Hughes in 1965. Subsequently other materials and techniques were introduced. Among the strongest of the core ceramics currently available are the machined zirconia cores.

MANUFACTURE

Traditionally, porcelain powders are manufactured by a process called *fritting*. Various components are mixed together and fused. While it is still hot, it is quenched in water. This causes the mass to crack and fracture, making it easier to powder it. The frit is ground to a fine powder and supplied to the consumer in bottles. Most of the chemical reaction takes place during the manufacture (pyrochemical reaction). During subsequent firing in the dental laboratory, there is not much of chemical reaction). The porcelain powder simply fuses together to form the desired restoration.

PORCELAIN / CERAMIC SYSTEMS

Currently, various ceramic systems exist which can be quite confusing to the dental student. The entire restoration may be made of just one type of porcelain (e.g., an inlay machined from a single block of ceramic) or it may be *layered* with different types of porcelains. Many crowns and FPDs are fabricated as layered restorations. A layered restoration can be divided into 2 basic parts ***(Fig. 21.3)***.

- Core (or substructure)
- Veneer (outer layer)

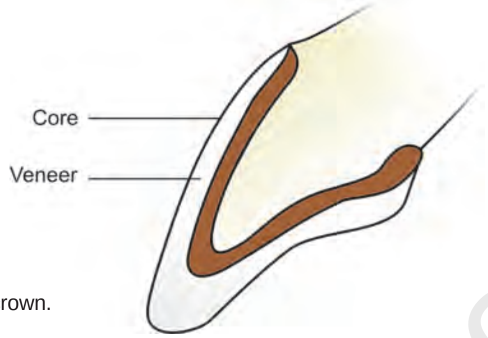


Figure 21.3: Simplified structure of a ceramic crown.

Core The core provides support and *strength* for the crown. Early crowns were constructed entirely of a single type of feldspathic porcelain (e.g., PJC). In 1965 McLean demonstrated improved strength in crowns layered over an aluminous core. Since then other core materials and techniques have been introduced. The core functions as a supporting frame. Freshly mixed porcelain is like wet sand. It needs to be supported while it is being condensed and built up. The core is therefore usually constructed *first*. The rest of the restoration is built up on to the core.

With metal-ceramic crowns the *metal coping* or *frame* takes the role of the ceramic core. They provide the support and reinforcement. Examples of *core materials currently available are* alumina, spinel, zirconia, etc.

Veneer The core is usually dense and opaque and generally unesthetic. The esthetics is improved by firing additional layers of ceramic known as veneer porcelains. The core is veneered with various layers of specialized porcelains called dentin, enamel, cervical and translucent. It can also be internally and externally (surface) stained to mimic natural teeth color and finally glazed.

CLASSIFICATION AND DESCRIPTION OF CERAMIC SYSTEMS

The ceramic restorations available today may be metal bonded or made completely of ceramic. Based on the substructure or core material used there are two basic groups. They are further divided based on the fabrication method.

A. Metal-ceramic (metal bonded or PFM) restorations

1. Cast metal-ceramic restorations
    - Cast noble metal alloys
    - Cast base metal alloys
    - Cast titanium (ultra low fusing porcelain)
2. Swaged metal ceramic restorations
    - Gold alloy foil coping (Renaissance, Captek)
    - Bonded platinum foil coping

B. All ceramic restorations

1. Platinum foil matrix condensed porcelain restorations
    - Conventional feldspathic porcelain restorations
    - Porcelain restorations with aluminous core
    - Ceramic jacket crown with leucite reinforced core (Optec HSP)

2. Castable glass ceramics (Dicor)
3. Pressable glass-ceramics
   - Leucite reinforced glass-ceramics (IPS Empress)
   - Lithia disilicate reinforced glass-ceramics (IPS Empress 2)
4. Glass infiltrated core porcelains
   - Glass infiltrated aluminous core (In-Ceram)
   - Glass infiltrated spinel core (In-Ceram Spinell)
   - Glass infiltrated zirconia core (In-Ceram Zirconia)
5. Ceramic restorations from CAD-CAM ceramic blanks
   - Feldspathic porcelain blanks (Vitablocs Mark II)
   - Lithia disilicate glass ceramic blanks (IPS e max CAD, Kavo)
   - Glass infiltrated blanks (Alumina, Spinell, Zirconia)
   - Partially sintered zirconia blanks (Vita In-Ceram YZ)
   - Sintered zirconia blanks (Everest ZH blanks)
6. Ceramic restorations from copy milled ceramic blanks
   - Alumina blocks (Celay In-Ceram)
   - $MgAl_2O_4$ blocks (In-Ceram spinell)

METAL-CERAMIC RESTORATIONS

Synonyms Porcelain-fused-to-metal (PFM), metal-bonded restorations, ceramo metal, etc.

The early porcelain jacket crowns (PJC) did not use reinforcing cores and were therefore weak. The metal-ceramic restorations ***(Fig. 21.5)*** were developed around the same time Mclean introduced the aluminous core porcelains (1965). The cast metal core (called coping) or framework ***(Fig. 21.4)*** significantly strengthened the porcelain restoration and this soon became the most widely used ceramic restoration. According to a 1994 survey, 90% of all ceramic restorations were porcelain-fused-to-metal. The metal-ceramic systems are covered by *ISO 9693*.

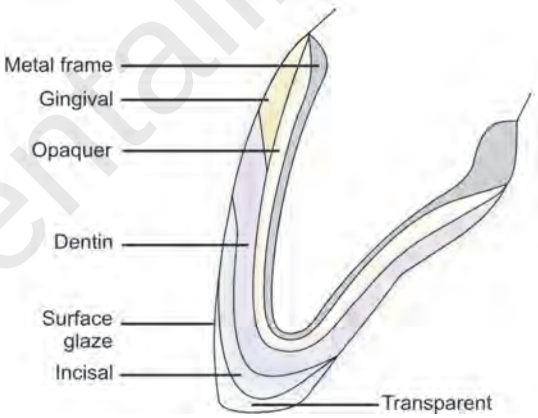


Figure 21.4: Parts of a metal ceramic crown. Transparent is used to duplicate the thin translucent enamel seen in some natural teeth.

Figure 21.5: Cross section through a metal ceramic crown fused to nickel chromium alloy.

The metal-ceramic system was possible because of some important developments.

- Development of a metal and porcelain that could bond to each other
- Raising of the CTE of the ceramic in order to make it more compatible to that of the metal.

This obviously meant that a lot of research had to go into both porcelain and metal composition before they could be used for metal-ceramics.

TYPES OF METAL-CERAMIC SYSTEMS

As previously mentioned the metal-ceramic systems can be divided into:

1. Cast metal ceramic restorations
    - Cast noble metal alloys (feldspathic porcelain)
    - Cast base metal alloys (feldspathic porcelain)
    - Cast titanium (ultra low fusing porcelain)
2. Swaged metal ceramic restorations
    - Gold alloy foil coping (Renaissance, Captek)
    - Bonded platinum foil coping.

CAST METAL-CERAMIC RESTORATIONS

The cast metal-ceramic restoration is hugely popular. Because of the strong metal frame it is possible to make long span fixed partial dentures. It can also be used in difficult situations where an all-ceramic restoration cannot be given because of high stresses and reduced preparation depth.

USES

1. Single anterior and posterior crowns.
2. Short and long span anterior and posterior FPDs.

COMPOSITION OF CERAMIC FOR METAL BONDING

Feldspathic porcelains are used for metal bonding. The basic composition is quite similar to that of feldspathic porcelain described earlier except for the higher alkali content (soda and potash). The higher alkali content was necessary in order to raise the CTE. Unfortunately this also increased the tendency of the ceramic to devitrify and appear cloudy. A typical composition is shown in ***Table 21.1***.

A special opaquer porcelain is needed to mask the underlying metal so that it does not show through the ceramic ***(Fig. 21.8)***. The opaquer has a high content of opacifiers. Similarly, the composition of glazes would be different. Glazes have a higher concentration of glass modifiers like soda, potash and boric oxide.

Table 21.1

A sample percentage composition of porcelain powder for metal ceramics

	Dentin porcelain	*Enamel porcelain*
Silica (SiO_2)	59.2	63.5
Alumina (Al_2O_3)	18.5	18.9
Soda (Na_2O)	4.8	5.0
Potash (K_2O)	11.8	2.3
Boric oxide (B_2O_3)	4.6	0.12
Zinc oxide (ZnO)	0.58	0.11
Zirconium oxide (ZrO_2)	0.39	0.13

Figure 21.6: Enamel and dentin powders with the modelling liquid (left box).

Figure 21.7: Opaquer powder is mixed and applied to hide the metal. It is mixed with the liquid to produce a sandy mix. A glass spatula is used for mixing as metal might abrade and contaminate the porcelain.

SUPPLIED AS

1. Enamel porcelain powders in various shades (in bottles) ***(Fig. 21.6)***
2. Dentin porcelain powders in various shades (in bottles)
3. Liquid for mixing enamel, dentin, gingival and transparent
4. Opaquer powders in various shades/ and liquid for mixing ***(Fig. 21.7)***
5. Gingival porcelain powder in various shades
6. Transparent porcelain powder
7. A variety of stain (color) powders
8. Glaze powder
9. Special liquid for mixing stains and glaze.

MANIPULATION AND TECHNICAL CONSIDERATIONS

CONSTRUCTION OF THE CAST METAL COPING OR FRAMEWORK

A wax pattern of the restoration is constructed and cast in metal. Metals used for the frame or coping include noble metal alloys, base metal alloys and recently titanium (see chapter on casting alloys and casting procedures).

METAL PREPARATION

A clean metal surface is essential for good bonding. Oil and other impurities from the fingers can contaminate. The surface is finished with ceramic bonded stones or sintered diamonds. Final texturing is done by sandblasting with an alumina air abrasive, which aids in the bonding. Finally, it is cleaned ultrasonically, washed and dried.

DEGASSING AND OXIDIZING

The casting (gold porcelain systems) is heated to a high temperature (980° C) to burn off the impurities and to form an oxide layer which help in the bonding. Degassing is done in the porcelain furnace.

OPAQUER

The opaquer is a dense yellowish white powder supplied along with a special liquid. The opaquer has *two important functions*. It is used to cover (mask) the metal frame and prevent it from being *visible*. It also aids in bonding the

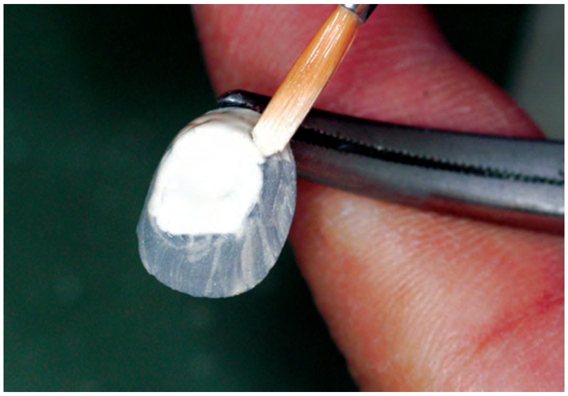


Figure 21.8: Application of opaquer.

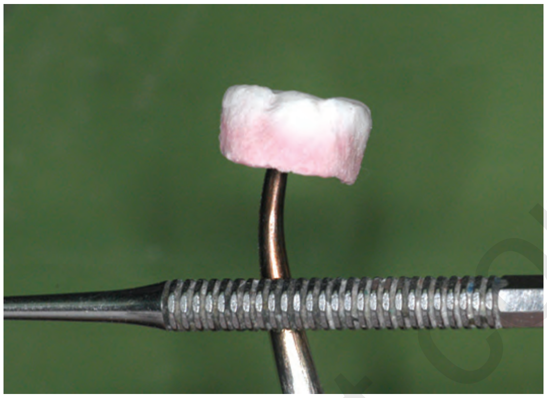


Figure 21.9: Condensing with mild vibration.

veneering porcelains to the underlying frame. The metal framework is held with a pair of *locking forceps*. Opaquer powder is dispensed on to a ceramic palette and mixed with the special liquid to a *paste like* consistency ***(Fig. 21.7)***. It is applied on to the metal frame with a *brush* and *condensed* ***(Fig. 21.8)***. The excess liquid is blotted with a tissue paper. The opaquer is built up to a thickness of 0.2 mm. The casting with the opaquer is placed in a porcelain furnace ***(Fig. 21.12)*** and fired at the appropriate temperature (see firing in box on page 322). Opaquer may be completed in two steps.

CONDENSATION

The process of packing the powder particles together and removing the excess water is known as condensation.

Purpose

Proper condensation packs the particles together. This helps minimize porosity, improve strength and reduce firing shrinkage. It also helps remove the excess water.

Condensation Techniques

Vibration Mild vibration by tapping or running a serrated instrument ***(Fig. 21.9)*** on the forceps holding the metal frame helps to pack the particles together and bring out the excess water which is then blotted by an absorbent paper ***(Fig. 21.11)***. An ultrasonic vibrator is also available for this purpose.

Spatulation A small spatula is used to apply and smoothen the wet porcelain. This helps to bring out the excess water.

Dry powder Dry powder is placed on the side opposite a wet increment. The water moves towards the dry powder pulling the wet particles together.

DENTIN AND ENAMEL

The dentin powder (pink powder) is mixed with distilled water or the supplied liquid. A glass spatula should be used (ceramic powder is abrasive and can abrade the metal and contaminate the porcelain). The bulk of the tooth is built up with dentin. A portion of the dentin in the incisal area is cut back and enamel porcelain (white powder) can be added ***(Fig. 21.10)*** building the restoration. After the build-up and condensation is over ***(Fig. 21.13)***, it is returned to the furnace for sintering.

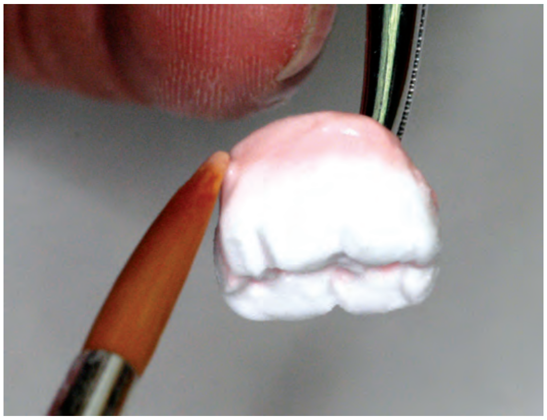


Figure 21.10: Building the restoration.

Figure 21.11: Blotting to remove excess water.

Figure 21.12: Ceramic furnace.

Figure 21.13: The built up crown.

ADDITIONS

It is not necessary to build up the restoration in one step. Large or difficult restorations may be built up and fired in 2 or more stages. After each firing the porcelain may be shaped by grinding and additional porcelain is placed in deficient areas. Each additional firing is done at a lower temperature.

FIRING

The process of sintering and fusing the particles of the condensed mass is known as firing. The powder particles flow and fuse together during firing. Making the restoration dense and strong. Firing is done in a porcelain furnace.

The Porcelain Furnace

Firing is carried out in a porcelain furnace. There are many companies which manufacture furnaces. Modern furnaces are computer controlled and have built in programs to control the firing cycle. The programs can also be changed by the operator.

Firing Cycle

The entire program of preheating, firing, subjecting to vacuum, subjecting to increased pressure, holding and cooling is known as a firing cycle. The firing cycles vary depending on the stage - opaquer firing, dentin firing, glaze firing, etc. The firing temperature is lowered gradually for each subsequent firing cycle. The opaquer has the highest temperature and the glaze has the lowest.

Preheating

The condensed mass should not be placed directly into the hot furnace. This can cause a rapid formation of *steam* which can break up the mass. Modern furnaces have a mechanism whereby the work is gradually raised into the furnace. This is known as preheating.

Vacuum Firing

During firing of the porcelain, a vacuum (negative pressure) is created in the furnace. This helps to reduce the *porosity* in the ceramic. The vacuum is later released raising the pressure in the furnace. The increased pressure helps to further reduce the size of any residual air bubbles not eliminated by the vacuum. The vacuum is not activated during the glaze firing.

Cooling

The cooling of the fired porcelain should be well controlled. Rapid cooling can cause the porcelain to *crack* or it can *induce stresses* inside which weaken the porcelain. Cooling is done slowly and uniformly and is usually computer controlled.

Caution The restoration should not be subject to too many firings. Excessive firings can give rise to a over translucent, lifeless restoration.

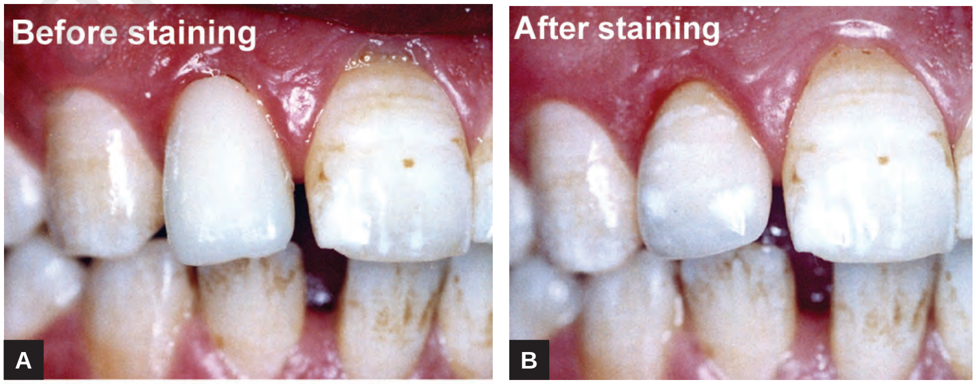
GINGIVAL AND TRANSPARENT PORCELAIN

The enamel of some natural teeth may appear transparent. This is usually seen near the incisal edges. If present it can be duplicated using *transparent* porcelain. The cervical portions of natural teeth may appear more darker (e.g., more yellow) than the rest of the tooth. When indicated *cervical* porcelains are used to duplicate this effect (They are also referred to as *gingival* or *neck* dentin).

SURFACE STAINING, CHARACTERIZATION AND EFFECTS

Natural teeth come in variety of hues and colors. Some of them are present at the time of eruption (intrinsic, e.g., white fluorosis stains), while others are acquired over a period of time from the environment (extrinsic, e.g., coffe, tobacco, etc.). Staining and characterization helps make the restoration look natural and helps it to blend in with the adjacent teeth ***(Figs 21.15A and B)***. The stain powders ***(Fig. 21.14)*** are mixed with a special liquid, applied and blended with a brush.With more and more emphasis on recreating the natural look, *effects* are created using special techniques. This includes defects, cracks or other anomalies within the enamel.

Figure 21.14: Porcelain stains and glazes.



Figures 21.15 A and B: Stained porcelain crown. Staining improves the vitality of the crown. The lateral incisor before staining appears white and artificial. The same tooth after applying yellow brown cervical stains and white fluorosis streaks and patches.

GLAZING

Before final glazing, the restoration is tried in the mouth by the dentist. The occlusion is checked and adjusted by grinding. Final alterations can be made to improve the shape of the restoration. After all changes have been completed the restoration is ready for glazing. The restoration is smoothened with a fine stone prior to glazing to remove gross scratch marks. Glazing provides a smooth glossy surface to the restoration.

Objectives of glazing

1. Glazing enhances esthetics.
2. Enhances hygiene.
3. Improves the strength. Glazed porcelain is much stronger than unglazed ceramic. The glaze inhibits crack propagation.
4. Reduces the wear of opposing teeth. The rough surface on unglazed porcelain can accelerate wear of the opposing natural teeth.

Types

Over glaze The glaze powder is mixed with the special liquid and applied on to the restoration. The firing temperature is lower than that of the body porcelain. The firing cycle does not usually include a vacuum. Chemical durability of over glaze is lower because of the high flux content.

Self glaze A separate glaze layer is not applied. Instead the restoration is subject to a controlled heating at its fusion temperature. This causes only the surface layer to melt and flow to form a vitreous layer resembling glaze.

GLAZING VERSUS CONVENTIONAL POLISHING

Porcelain can be polished using special abrasives. Porcelain is an extremely hard material and is quite difficult to polish. Glazing is considered by some to be superior to conventional polishing.

PORCELAIN-METAL BOND

Falls into two groups:

— Chemical bonding across the porcelain-metal interface.

— Mechanical interlocking between porcelain and metal.

CHEMICAL BONDING

Currently regarded as the primary bonding mechanism. An adherent *oxide layer* is essential for good bonding. In base metal alloys, *chromic oxide* is responsible for the bond. In noble metal alloys, *indium and tin oxide* and possibly *iridium oxide* does this role. Both inadequate oxide formation and excessive oxide build up can lead to a weak bond resulting in delamination of the overlying porcelain ***(Fig. 21.16)***.

MECHANICAL INTERLOCKING

In some systems mechanical interlocking provides the principal bond. Sandblasting is often used to prepare the metal surface. Presence of surface roughness on the metal oxide surface improves retention, especially if undercuts are present. Wettability is important for bonding.

Figure 21.16: A failed metal ceramic FPD. The ceramic veneer (canine) has delaminated leaving the metal exposed. In this case it was because of a poorly adherent metal oxide layer.

ADVANTAGES AND DISADVANTAGES OF METAL-CERAMIC RESTORATIONS

ADVANTAGES

1. Better fracture resistance because of the metal reinforcement.
2. Better marginal fit because of the metal frame.

DISADVANTAGES

1. Poor esthetics when compared to all-ceramic restorations because the underlying metal and opaquer reduces the overall translucency of the tooth.
2. The metal frame and the lack of translucency sometimes shows through the gingiva resulting in the characteristic dark margins.

OTHER METAL-CERAMIC SYSTEMS

SWAGED GOLD ALLOY FOIL-CERAMIC CROWNS

Swaging gold alloy foils (Renaissance and Captek) is a novel way of making a metal frame without having to cast it. The system was developed by Shoher and Whiteman. Captek is an acronym for ‘capillary casting technique’.

Composition, mode of supply and capillary casting

They are supplied as thin strips in two forms called Captek P and Captek G ***(Fig. 21.17)***. Captek P (Platinum/ Palladium/ Gold) has a porous structure and serves as the internal reinforcing skeleton. Captek G is 97.5% Gold and 2.5% Silver. On heating in a furnace, the Captek P acts like a metal sponge and draws in (capillary action) the hot liquid gold completely into it. Captek G provides the characteristic gold color of this system. The final coping can be described as a composite structure.

Technique *(Fig. 21.17)*

- A refractory die is made after duplicating the original die.
- An adhesive is painted on to the die.
- Strips of Captek P are cut and adapted to the die by swaging and burnishing. Care should be taken while adapting as the material tears and breaks easily.
- The Captek P layer is fused in a furnace.

Captek P and G

Adapting Captek P

Adapting Captek G

Completed coping

Completed crowns

Figure 21.17: Swaged gold foil alloy restorations.

- Next the Captek G layer is adapted and again heated in the furnace to induce melting and infusion.
- The composite coping is divested and trimmed.
- A thin layer of gold slurry (called Capbond - composition similar to Captek G) is coated on to the coping to replenish areas of the coping that have been trimmed away.
- Opaquer and the various layers of porcelain are then condensed and fired to form the final crown.

Advantages

1. The thinner foil alloy coping allows a greater thickness of ceramic, thereby, improving the esthetics.
2. The gold color of the alloy improves the esthetics of the restoration.

BONDED PLATINUM FOIL-CERAMIC CROWNS

A platinum foil coping is adapted on to the die. To improve the bonding of the ceramic to the platinum foil coping, an *electrodeposition technique* is used. A thin layer of tin is electrodeposited on to the foil and then oxidized in a furnace. The advantages of using bonded platinum foil is similar to that for swaged gold alloy foil.

The Electrodeposition Technique

This is a technique used to improve both esthetics and bonding. A layer of *pure gold* is electrodeposited on to the metal. This is followed by a quick minimal deposition of *tin* over the gold.

The advantages are

1. The gold color enhances the vitality of the porcelain, thereby, enhancing esthetics (the normal technique requires a heavy unesthetic opaque layer to cover the dark metal oxide surface).
2. The tin helps in chemical bonding (through formation of tin oxide).
3. Improves wetting at the gold-porcelain interface thereby reducing porosity.

The electrodeposition technique can be used on metals such as stainless steel, cobalt chromium, titanium and other non-gold and low gold alloys.

ALL-CERAMIC RESTORATIONS

The all-ceramic restorations are made *without* a metallic core or sub-structure. This makes them esthetically superior to the metal-ceramic restoration. Unfortunately, all-ceramic restorations had lower strength, thus, metal-ceramics continued to be the restoration of choice for the majority of restorations till the 1990s. Continued research have led to improved all-ceramic systems with greater strength and fracture resistance. Manufacturers today claim the new generation all-ceramic materials are capable of producing not only single crowns but anterior and even posterior all-ceramic FPDs as well. Long span FPDs have also been attempted.

The all-ceramic restorations are grouped according to their type and method of fabrication

1. Condensed sintered
    - Traditional feldspathic porcelain jacket crown
    - Porcelain jacket crown with aluminous core (Hi-Ceram)
    - Ceramic jacket crown with leucite reinforced core (Optec HSP)
2. Cast glass ceramics (Dicor)
3. Injection molded (leucite reinforced) glass ceramic (IPS Empress)
4. Slip cast-glass infiltrated ceramics
    - Glass infiltrated aluminous core restorations (In-Ceram)
    - Glass infiltrated spinell core restorations (In-Ceram Spinell)
    - Glass infiltrated zirconia core (In-Ceram Zirconia)
5. Milled ceramic restoration or cores
    - CAD-CAM restorations
    - Copy milled restorations

(Blocks or blanks of various ceramics are machined to form the restoration. Examples are alumina, zirconia, lithia disilicate, etc. The various types are detailed in a subsequent section - see classification of machinable ceramics).

PORCELAIN JACKET CROWN

These are crowns made entirely of porcelain. They are constructed on a platinum foil matrix which is subsequently removed.

TYPES

1. Porcelain jacket crown (traditional).
2. Porcelain jacket crown with aluminous core.
3. Porcelain jacket crown with leucite reinforced core (Optek HSP).

Note The above two are generally referred to as '*porcelain jacket crowns*' or *PJCs*. The subsequently introduced ceramics are referred to as '*ceramic jacket crowns*' or *CJCs'* and '*glass ceramic crowns*'.

TRADITIONAL PORCELAIN JACKET CROWN

The all-porcelain crown (PJC) has been around since a century (early 1900s). These early crowns are also referred to as *traditional* or *conventional* PJCs.

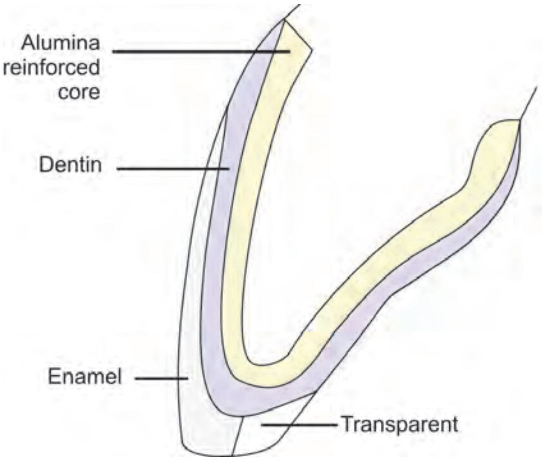


Figure 21.18: The porcelain jacket crown with aluminous core.

They were made from conventional high fusing feldspathic porcelains. As mentioned before these were very brittle and fractured easily (half moon fractures). The marginal adaptation was also quite poor. Because of these problems they gradually lost popularity and are no longer used presently.

PORCELAIN JACKET CROWN WITH ALUMINOUS CORE

The problems associated with traditional PJCs led to the development of the PJC with an *alumina reinforced core (McLean and Hughes, 1965)* ***(Fig. 21.18)***. The increased content of alumina crystals (40 to 50%) in the core strengthened the porcelain by interruption of crack propagation. In spite of the increased strength they were still brittle and therefore not indicated for posterior teeth and their use was restricted to anterior teeth. The composition of the alumina reinforced PJC is shown in ***Table 21.2***.

Table 21.2

A sample percentage composition of aluminous porcelain

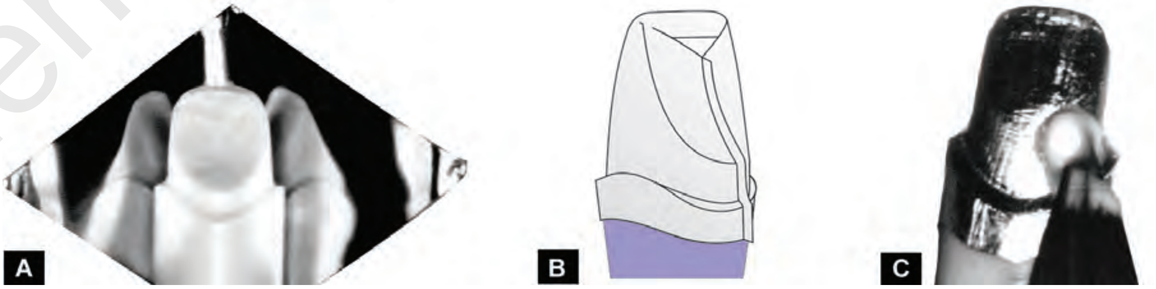
	Aluminous core	*Dentin*	*Enamel*
Silica (SiO_2)	35.0	66.5	64.7
Alumina (Al_2O_3)	53.8	13.5	13.9
Calcium oxide (CaO)	1.12	—	1.78
Soda (Na_2O)	2.8	4.2	4.8
Potash (K_2O)	4.2	7.1	7.5
Boric oxide (B_2O_3)	3.2	6.6	7.3
Zinc oxide (ZnO)			
Zirconium oxide (ZrO_2)			

Technical Considerations

The porcelain jacket crowns are made using the platinum foil matrix technique.

Platinum Foil Matrix

A platinum foil is adapted to the die ***(Figs 21.19 A and B)*** with a wooden point. The platinum foil functions as matrix. It supports the porcelain during condensation and firing.



Figures 21.19 A to C: (A) Platinum foil prior to adaptation; (B) Method for folding; (C) Application of the aluminous core.

Condensation and Firing

The core porcelain is carefully condensed on to the foil ***(Fig. 21.19 C)***. The foil with the condensed porcelain is carefully removed from the die. It is then placed in the furnace and fired. After cooling, the rest of the crown is built up with conventional feldspathic porcelain.

Removing the Foil

After completion of the restoration the platinum foil is gently teased out and discarded. This can be quite difficult.

LEUCITE REINFORCED PORCELAIN (OPTEC HSP)

Optec HSP is a feldspathic porcelain with a higher leucite crystal content (leucite reinforced). Its manipulation, condensation and firing is quite similar to the alumina reinforced porcelain jacket crowns (using platinum foil matrix).

Uses

Inlays, onlays, veneers and low stress crowns.

Advantages

1. They are more esthetic because, the core is less opaque (more translucent) when compared to the aluminous porcelain.
2. Higher strength.
3. No need of special laboratory equipment.

Disadvantages

1. Fit is not as good as metal ceramic crowns.
2. Potential marginal inaccuracy.
3. Not strong enough for posterior use.

CASTABLE GLASS CERAMIC

The castable glass ceramic is quite unlike the previously mentioned porcelains. Its properties are more closer to that of glass and its construction is quite different. This is the only porcelain restoration made by a centrifugal casting technique. The subsequent 'ceramming' process is also quite unique to this porcelain. Ceramming enhances the growth of mica crystals within the ceramic.

SUPPLIED AS

The first commercially available castable glass-ceramic for dental use was 'Dicor' developed by Corning glass works and marketed by Dentsply. They are supplied as glass ingots. A precrystallized form called Dicor MGC is also available as machinable blanks for CAD-CAM.

COMPOSITION

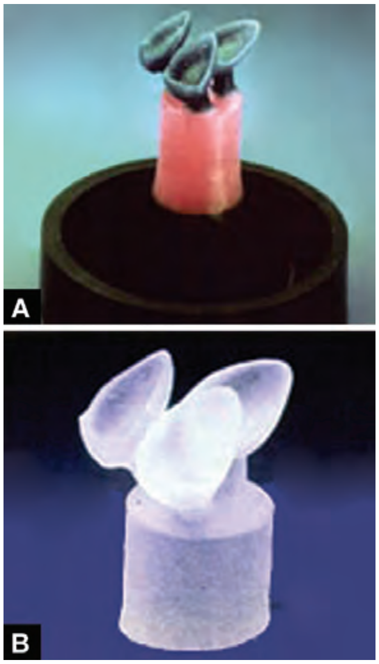
Dicor glass-ceramic contains 55 vol% of *tetrasilicic fluormica crystals*.

FEATURES

The Dicor glass-ceramic crown is very esthetic. This is because of its greater translucency (unlike some other porcelains which have more opaque core). It also picks up some of the color from the adjacent teeth (chameleon effect) as well as from the underlying cement. Thus the color of the bonding cement plays an important role.

USES

Inlays, onlays, veneers and low stress crowns.



Figures 21.20 A and B: Castable glass ceramics (Dicor). (A) Wax pattern; (B) Cast glass.

FABRICATION OF A DICOR CROWN

To understand the salient features of this material the step-by-step construction of a crown will be described:

1. The pattern is first constructed in wax ***(Fig. 21.20 A)*** and then invested in refractory material like a regular cast metal crown.
2. After burning out the wax, nuggets of Dicor glass are melted and cast into the mold in a centrifugal casting machine.
3. The glass casting ***(Fig. 21.20 B)*** is carefully recovered from the investment by sandblasting and the sprues are gently cut away.
4. The glass restoration is then covered with an embedment material to prepare it for the next stage called *ceramming*.
5. Ceramming is a heat treatment process by which the glass is strengthened. Ceramming results in the development of microscopic crystals of mica, which
    - ➢ improves the strength and toughness of the glass
    - ➢ improves the esthetics of the restoration (it reduces the transparency of the glass making it more opaque and less glass-like).
6. The cerammed glass can be built up with special veneering porcelain and fired to complete the restoration. Surface stains may be applied to improve the esthetics.

GLASS CERAMICS

Glass ceramics are materials that are formed initially as glass, and then transformed into ceramic usually by a controlled heat treatment. The heat induces partial devitrification (crystallization within the glass) which increases the strength as well as improves esthetics by making it less transparent and more tooth-like. The two glass-ceramics used in dentistry are the castable and the pressable glass-ceramics.

ADVANTAGES

1. Ease of fabrication
2. Good esthetics (greater translucency and chameleon effect)
3. Improved strength and fracture toughness
4. Good marginal fit
5. Very low processing shrinkage
6. Low abrasion of opposing teeth.

DISADVANTAGES

1. Inadequate strength for posterior use
2. Internal characterization not possible. Has to be stained externally to improve esthetics.


Figure 21.21: IPS Empress ingots.


Figure 21.22: IPS Zir Press.

PRESSABLE CERAMICS

This is another ceramic material which again is quite unlike the previous ceramics because of its unique way of fabrication (injection molding). It is a precerammed glass-ceramic having a high concentration of reinforcing crystals. The material supplied in the form of ingots is softened under high temperatures and forced into a mold created by a lost wax process.

Synonyms Injection molded or Heat-pressed glass-ceramics.

TYPES AND MODE OF SUPPLY

Pressable ceramics are supplied as *ingots* ***(Figs 21.21 and 21.22)*** of various compositions. These include:

1. Pressable glass ceramics
   - Leucite or $KAlSi_2O_6$ reinforced (IPS Empress, Finesse, Optimal, Cerpress, etc).
   - Lithium disilicate reinforced (IPS empress 2, OPC 3G)
2. Pressable veneering ceramics (e.g., IPS Zir Press ***Fig. 21.22***, Vita PM9) are available for use as a pressed layer over machined zirconia cores.

Compatible veneering ceramics in powder-liquid form may be provided along with the ingots or acquired separately.

USES

Inlays, onlays, veneers ***(Fig. 21.25 D)*** and low stress crowns. Small 3 unit FPDs may be constructed with IPS Empress 2.


Figure 21.23: The pressing furnace.

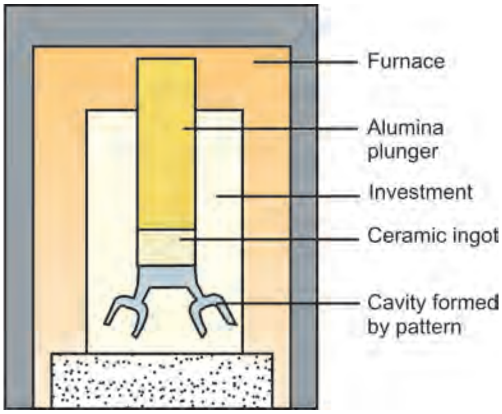


Figure 21.24: Schematic representation of the pressing process.

Table 21.3

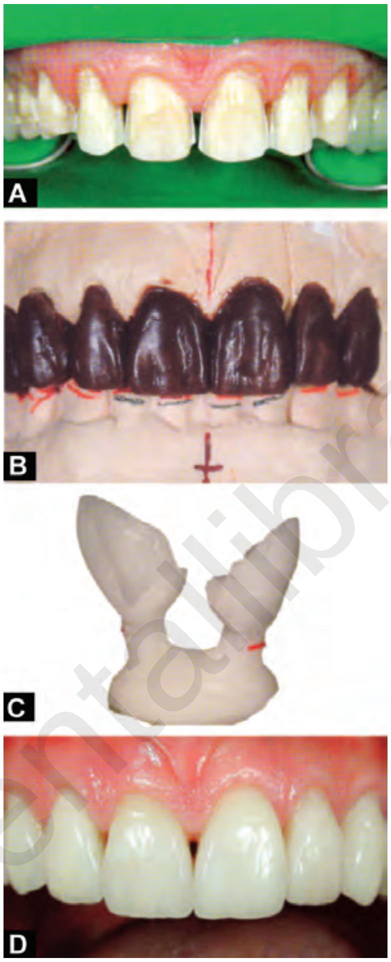
A sample percentage composition of IPS Empress and IPS Empress 2

IPS Empress		*IPS Empress 2*	
Silica (SiO_2)	63	Silica (SiO_2)	57-80
Alumina (Al_2O_3)	17.7	Alumina (Al_2O_3)	0-5
Soda (Na_2O)	4.6	Potash (K_2O)	0-13
Potash (K_2O)	11.2	Phosphorous pentoxide (P_2O_5)	0-11
Boric oxide (B_2O_3)	0.6	Lithium (Li_2O)	11-19
Calcium oxide (CaO_2)	1.6	Zinc oxide (ZnO)	0-8
Titanium dioxide (TiO_2)	0.2	Magnesium MgO	0-5
Barium oxide (BaO)	0.7	Lanthanum oxide (La_2O_3)	0.1-6
Cerium oxide (CeO_2)	0.4	Pigments	0-8
Pigments			

MICROSTRUCTURE

IPS Empress—contains 35 to 40% vol of leucite crystals ***(Table 21.3)***.

IPS Empress 2—consists of 65 to 70% by volume ***(Table 21.3)*** of interlocked elongated lithia disilicate crystals. The crystal size varies from 0.5 to 4 μm in length.



Figures 21.25 A to D: IPS empress; (A) Teeth prepared for veneers; (B) Wax patterns; (C) Pressed ceramic still attached to the sprue; (D) The completed restorations.

The crystals within the structure improve the fracture resistance by reducing crack propagation.

FABRICATION *(Figs 21.25 A to D)*

1. The wax ***(Fig. 21.25 B)*** patterns of the restorations are invested in refractory material and heated to 850°C in a furnace to burn off the wax and create the mold space.
2. It is then transferred to the pressing furnace ***(Fig. 21.23)***. A ceramic ingot and an alumina plunger is inserted in to the sprue ***(Fig. 21.24)***.

   Pressing temperature for IPS Empress - 1075 to 1180°C

   Pressing temperature for IPS Empress 2 - 920°C

   The pressing is done under air pressure of 1,500 psi.
3. The core or restoration ***(Fig. 21.25 C)*** is retrieved from the flask.
4. Compatible veneering porcelains are added to the core to build up the final restoration ***(Fig. 21.25 D)***.
5. It can also be directly fabricated as a crown in which case, the crown is stained and glazed directly.

ADVANTAGES

1. Better fit (because of the lower firing shrinkage).
2. Better esthetics due to the absense of metal or an opaque core.

DISADVANTAGES

1. Need for costly equipment.
2. Potential of fracture in posterior areas.

GLASS INFILTRATED CERAMICS

These are specialized core ceramics reinforced by an unique *glass infiltration process*. They are also sometimes referred to as *slip-cast ceramics*.

Figure 21.26: Alumina powder and other accessories used to make the core.

Figure 21.27: Glass powder.

Figure 21.28: Vita VM7 is a veneering ceramic designed for inceram.

Types

Currently there are three types depending on the core material used.

1. Glass infiltrated alumina core (In-Ceram Alumina)
2. Glass infiltrated spinell core (In-Ceram Spinell)
3. Glass infiltrated zirconia core (In-Ceram Zirconia)

Supplied as

Oxide powder (alumina, spinell or zirconia) with mixing liquids, glass powder and veneering ceramics ***(Figs 21.26 to 21.28).***

GLASS INFILTRATED ALUMINA CORE (IN-CERAM ALUMINA)

This ceramic system has a unique *glass infiltration process* and the first of its kind claimed for anterior FPD fabrication. The glass infiltration process compensates for firing shrinkage. The final core after completion of the glass infiltration is made up of about 70% alumina and 30% (sodium lanthanum) glass.

Indications

Anterior and posterior crowns, and short span anterior FPDs.

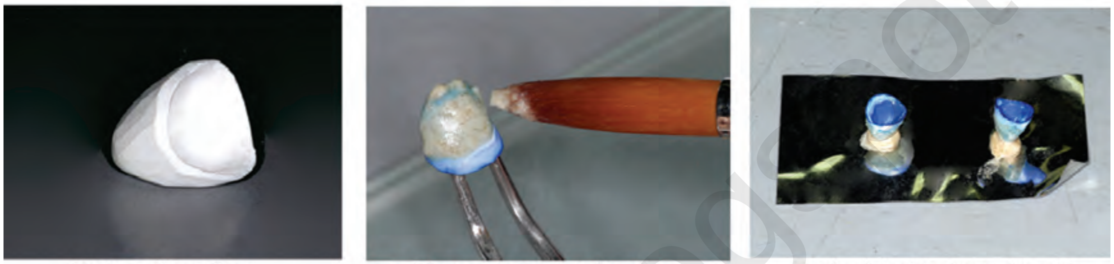
Composition

Alumina powder		*Infiltration glass powder*	
Al_2O_3	99.7	La_2O_3	49.6
MgO	0.03	SiO_2	19.1
		TiO_2	6.16
		CaO	3.14
		Others	2.0

Fabrication *(Fig. 21.29)*

1. Two dies are required. One in stone and the other in *refractory die* material.
2. Preparing the slip—Measured quantity (38 gm) of alumina powder is added slowly into a beaker containing 1 ampoule of mixing liquid and a drop of additive liquid. Mixing is done with the help of a special ultrasonic unit (Vitasonic). The water in the Vitasonic should be chilled using ice cubes. The prepared slip should be smooth and homogenous. The slip is applied on to the refractory die using the *slip cast* method (the water from the slurry is absorbed by the porous die leaving a dense layer of alumina on the surface). Once started the slip should not be allowed to dry out before the coping is completed. The process is continued until an alumina coping of sufficient thickness is obtained.

Slip casting Inceram furnace Sintering of the slip



Sintered coping Glass slurry application Embedded in investment

Glass infiltration furnace Glass infiltrated coping The completed restoration

Figure 21.29: Fabrication of an inceram restoration.

3. The fragile slip cast alumina coping is dried at 120°C for 2 hours.
4. The coping is sintered (Inceramat furnace) for 10 hours at 1120°C.
5. After sintering the copings are tested for cracks using a special dye.
6. The next step is *glass infiltration*. Glass powder is mixed with distilled water. One or two thick coats (1-2 mm) is applied on to the sintered alumina coping (outer surface only) and fired for 2-3 hours at 1110°C on a platinum foil. The glass melts and infiltrates into the porous alumina coping through capillary action.
6. The excess glass forms a glassy layer on the surface which is trimmed off using special diamond burs, followed by sandblasting. A glass control firing (1000°C) is carried out.
7. The coping is then built up using special veneering ceramics (Vita VM 7).

Advantages

1. Good fit and marginal adaptation
2. Good strength when compared to the earlier all ceramic crowns. Claimed to be strong enough for posterior single crowns and anterior FPD use.

Disadvantages

1. Comparatively less esthetic because of the opacity of the alumina core.
2. Quite tedious to fabricate.
3. Not all the FPDs were successful, a few of them did fracture occasionally.

Uses

1. In addition to inlays, onlays, veneers and low stress (anterior and posterior) crowns, this material can be used to construct low stress anterior FPDs. Because of its occasional tendency to fracture when used for FPD construction its use should be carefully selected
2. For people allergic to metal based restorations
3. Where esthetics is absolutely critical.

GLASS INFILTRATED SPINELL CORE (IN-CERAM SPINELL)

In-Ceram Spinell is an offshoot of In-Ceram Alumina. Because of the comparatively high opacity of the alumina core, a new material was introduced known as In-Ceram spinell. It uses spinel ($MgAl_2O_4$) instead of alumina. The fabrication process is quite similar to that for In-Ceram Alumina.

The In-Ceram Spinell is more translucent and therefore more esthetic compared to the In-Ceram Alumina core. Since the strength is lower, its use is limited to low stress situations.

Indications

Its high translucency makes it a material of choice for crowns and restorations in *esthetic* (anterior crowns) and stress free zones.

Contraindications

The high translucency contraindicates it in situations where the underlying tooth structure is severely discolored and needs to be masked. Its low strength also contraindicates it for posterior situations and FPDs.

GLASS INFILTRATED ZIRCONIA (IN-CERAM ZIRCONIA)

Zirconia (ZrO_2) is a naturally occurring mineral. Crystals of Zirconia are used as a substitute for diamond. In-Ceram Zirconia is the strongest of the three glass infiltrated core materials. The final glass infiltrated ICZ cores contains around 30 wt% zirconia and 70 wt% alumina.

Indications

Its high strength makes it a material of choice for posterior crowns and short span fixed partial dentures in high stress areas (posterior FPDs).

It is *not particularly suited for esthetic zones* because of its greater opacity.

However, in cases where there is severe discoloration, In-Ceram Zirconia helps mask the discolored tooth structure because of its greater opacity.

CAD-CAM CERAMICS

Constructing a dental ceramic restoration is technique sensitive, labor intensive and time consuming. Machined ceramics were introduced to overcome some of these problems. They are also known as milled or machined ceramics.

Machinable ceramic systems can be divided into two categories

1. CAD CAM systems
2. Copy milled systems

CAD CAM SYSTEMS

These are systems that can design and produce restorations out of *blocks* or *blanks of ceramics* with the aid of a computer. CAD CAM is acronym for *computer aided design-computer aided manufacturing*.

HISTORY OF CAD-CAM

The major development in the field of dental CAD-CAM took place in the 1980s. They were influenced by three important pioneers. The first was Duret who fabricated crowns through a series of processes starting with an optical impression of the prepared tooth. The milling was done by a numerically controlled milling machine (the precursor of modern CAM-CAM). The second pioneer was Mörmann, developer of the CEREC system at the University of Zurich. A compact chair-side machine milled the crown from measurements of the preparation taken by an intraoral camera. At the time, the system was innovative as it allowed 'same-day restorations'. With the announcement of this system, the term CAD-CAM spread rapidly to the dental profession. The third was Andersson, the developer of the Procera system in the 1980s. The Japanese also developed many systems in the 1980s but these were not commercially successful because of the resistance from health insurance companies. The early systems had to overcome many problems including limited computing power, poor marginal accuracy, etc. Current CAD-CAM systems have come a long way. With improvements in technology, material and software, restoration fabrication is considerably more accurate and operator friendly as well. CAD/CAM systems are now part of everyday dentistry.

Commercially Available CAD-CAM Systems

Many systems are currently available using a variety of techniques and materials (***Fig. 21.30***). Some examples of commercially available CAD-CAM systems are - Cerec (Sirona), Sirona InLab, Everest (Kavo), Cercon (Dentsply), Lava (3M ESPE), Zeno (Weiland), 5-tec (Zirkonzahn), etc.

COMBINING VARIOUS PORCELAINS AND PROCESSING TECHNIQUES

- In some systems the entire restoration can be made entirely from the same material. Example - An inlay or laminate may be constructed entirely with pressable ceramics or from a machined feldspathic block.
- In many systems at least 2 or more processing tecniques and materials have to be combined to produce the final restoration for a variety of reasons like esthetics, ease of fabrication, need for correction, etc.

  Most reinforced core ceramics are too opaque to be used to construct the entire restoration with it. These cores have to be built up with veneering ceramics, characterized with stains and then glazed to produce the final restoration. Example 1 - Glass infiltrated cores are too opaque and have to be layered with condensing type veneering porcelains to produce the final restoration. Example 2 - Machined alumina cores are frequently built up with condensable ceramics. Example 3 - In one system machined zirconia blocks are overlayed with a pressable veneering material (Zir Cad and Zir Pres).

An important point to remember is that various ceramics should be compatible with each other when used together. Non-compatible products may have difference in CTE which can cause failure of the restoration. The manufacturers usually specify the veneering materials compatible with their products.

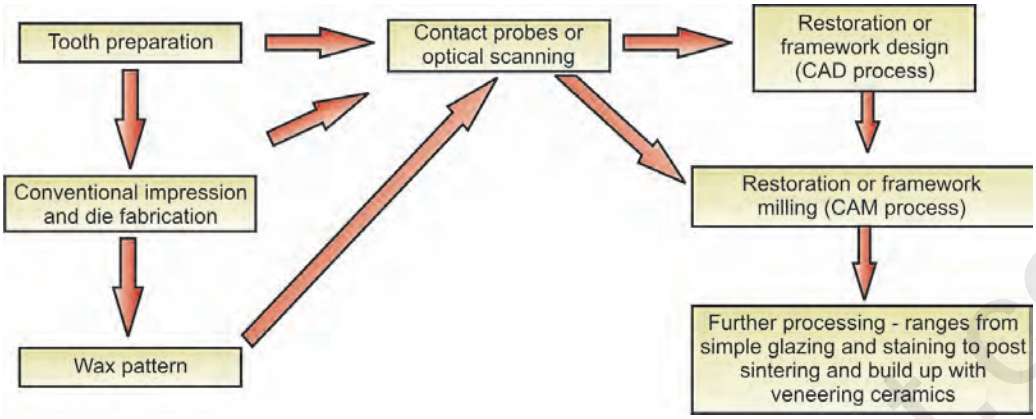


Figure 21.30: Showing CAD-CAM production.

ESSENTIALS OF A CAD-CAM SYSTEM

The CAD-CAM system consists of 5 essentials

- Scanner or digitizer – Virtual impression
- Computer – Virtual design (CAD)
- Milling station – Produces the restoration or framework
- Ceramic blanks – Raw material for the restoration
- Furnace – For post-sintering, ceramming etc.

Scanner or Digitizer

The dimensions of the prepared tooth (or die or wax pattern) are picked up and digitized in order to create a 3 dimensional image of the prepared tooth in the computer. This is achieved by scanning of the preparation or the die.

The 2 types of digitizers currently employed are

- Probes Physically contacts the die as it moves along its surface while transmitting the information to the computer.
- Scanners Unlike contact probes, scanners are optical devices. These include:
  - Intraoral hand-held wands ***(Fig. 21.32 A)***. These are chairside scanners. The intraoral scanner reflects light (visible light, laser or LED) and captures it with a camera to create an optical impression of the prepared tooth and adjacent structures. Multiple images have to be captured to stitch together a composite 3 D image in the computer. In some systems a special powder is dusted to reduce reflection and improve readability.
  - Laboratory scanners. These are larger devices that scan the cast or die using different technologies. Some use a camera to capture multiple images similar to the intraoral scanner (white light optical scanner). Others use 2 cameras to capture the object from multiple angles using white light (e.g., Kavo Everest - ***Fig. 21.31 and Fig. 21.32 B***) or laser planes projected in a grid pattern.

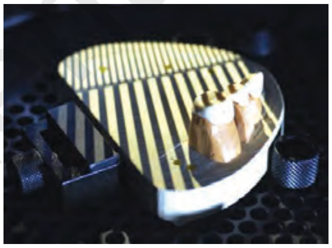


Figure 21.31: Light beam scanner (Kavo Everest).

Computer (CAD Process)

The restoration or the core is designed in the computer ***(Fig. 21.32C)***. Most manufacturers have their own software for the CAD process. The CAD process aids in designing either the restoration, coping or the FPD substructure. The computer can automatically detect the finish line. Some use a library of tooth shapes that is stored on the computer to suggest the shape of the proposed restoration. A recording of the bite registration (the imprint of the opposing or antagonist tooth in a wax-like or rubbery material) is also added to the data. The combined information together with the 3D optical impression of the prepared tooth establishes the approximate zone in which the new restoration can exist. The proposed restoration can then be morphed to fit into this zone in an anatomically and functionally correct position. The dentist can make corrections or modify the design if required and then send it to the milling unit for completion.

Milling Station

Milling stations have evolved considerably since they were first introduced into the market ***(Figs 21.32F to I)***. The earlier models ground only the internal surface. The external surface had to be manually ground. Current CAD-CAM machines can grind the external surface also. Signals from the computer control the milling tool which shapes the ceramic block according to the computer generated design.

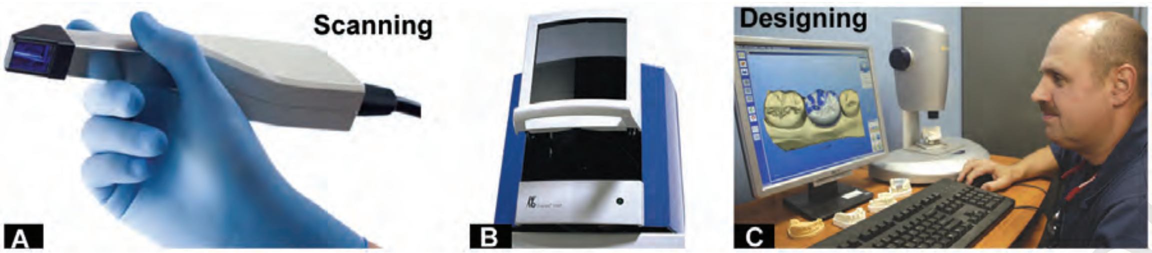
To begin the process the ceramic block is attached to the machine via a frame or built-in handle(s). The enlargement factor (see presintered zirconia) is also calculated where applicable. Milling is performed by a diamond or carbide milling tool. The Cerec station ***(Fig. 21.32 F)*** uses 2 diamond burs to grind the internal and external surface simultaneously ***(Fig. 21.32 D)***. Other machines use a single tool that moves along multiple axis (3 to 5 axis) and performs the milling action. The Everest (Kavo) Engine ***(Fig. 21.32 I)*** is an example of a 5 axis milling action. Some machines (Kavo Everest) can mill both ceramic and titanium.

Ceramic blanks

A variety of ceramic blanks in various sizes, shades and shapes are available for milling. Multiple units can be produced from the larger blocks. The smaller blanks may produce only a single coping or restoration. The blank is attached via a frame to the machine or by one or more handles on the blank itself.

Classification of machinable ceramic blanks

1. Feldspathic porcelain blanks [Vitablocs Mark II (Vita)]
2. Glass ceramic blanks
   - Tetrasilicic fluormica based glass ceramic [Dicor MGC (Dentsply)]
   - Leucite based [ProCad (Ivoclar), Everest G (Kavo)]
   - Lithia disilicate glass ceramic [IPS e max CAD (Kavo)]
3. Glass infiltrated blanks
   - Alumina (Vita In-Ceram Alumina)
   - Spinell (Vita In-Ceram Spinell)
   - Zirconia (Vita In-Ceram Zirconia)
4. Presintered blanks
   - Alumina (Vita In-Ceram AL)
   - Ytrria stabilized Zirconia (Vita In-Ceram YZ)
5. Sintered blanks
   - Ytrria stabilized Zirconia (Everest ZH blanks).



Tooth preparation may be scanned directly in the mouth with a hand held scanner

The preparation may also be scanned from a cast (Kavo scanner)

A computer aids in designing the final restoration or coping

The design is transferred to the milling station and A restoration is milled

A milled laminate

CEREC 3 (Sirona) inlab

Zeno 2100 (Weiland)

Lava (3 M Espe)

Everest (Kavo) milling station

Figures 21.32 A to I: CAD-CAM systems.

Brief description of various materials for CAD-CAM

The fabrication process is system and material specific. The prepared tooth or teeth is scanned directly from the mouth or from a model made from a regular impression. Next the restoration or substructure is designed on the computer. The blank is attached to the milling station and the bar code scanned. The time taken for milling depends on the size and complexity of the restoration as well as the material used. For example presintered zirconia is easier to mill than sintered zirconia. It also reduces wear of the milling tools.

After milling, the structure is separated from the blank using water cooled cutting and grinding disc or burs. Subsequent processing procedures are then initiated depending on the material and system used.

Figure 21.33: Feldspathic porcelain.

Figure 21.34: Glass ceramic blanks - leucite based (above) and lithia disilicate (bottom).

Figure 21.35: CAD-CAM blanks for glass infiltration method.

Figure 21.36: Presintered zirconia blank for multiple units.

Feldspathic blanks ***(Fig. 21.33)*** Feldspathic restorations can be milled to full contour. The restoration is glazed after milling. Optional processing includes veneering and staining. *Uses* - inlays, laminates and anterior crowns.

Leucite reinforced ***(Fig. 21.34*** These blanks can be milled to full contour. The restoration is glazed after milling. Optional processing includes veneering and staining. *Uses* - inlays, onlays, laminates and anterior crowns.

Lithium disilicate ***(Fig. 21.34)*** The ceramic is machined in an intermediate crystalline state in which the material shows its characteristic bluish shade ***(Fig. 21.39)***. In this stage the material is easier to shape and can be tried in the mouth. This is followed by a simple, quick crystallization process (30 minutes) in a conventional ceramic oven in which it reaches its final strength and the desired esthetic properties such as tooth color, translucence and brightness. Optional processing includes veneering and staining. *Uses* - inlays, onlays, and anterior and posterior crowns.

Glass infiltrated ceramics ***(Fig. 21.35)*** These are usually machined as cores or FPD substructures. Subsequent processing includes glass infiltration, veneering, and glazing.

Uses - In-Ceram Spinell is recommended for anterior single crowns copings. In-Ceram Alumina is indicated for anterior and posterior crowns and 3 unit anterior FPD substructures. In-Ceram Zirconia can be used for anterior and posterior crowns and 3 unit FPD substructures.

Presintered zirconia ***(Figs 21.36 and 21.38)*** These are usually machined as cores or FPD substructures. In the presintered condition they are usually softer and easier to mill. They are milled to a slightly (20%) larger size, to compensate for the subsequent sintering shrinkage. Following milling they have to be sintered (called post sintering). Sintering is done in a furnace. Sintering time and temperature varies between brands.

Sintering time – 6 to 7.5 hours
Sintering temperature – 1350 to 1530°C

Because of the high temperatures involved special furnaces are required for zirconia sintering. All grinding and adjustments should be completed prior to sintering. Adjustments following sintering especially in the connector areas weaken the structure. Any adjustments required after post sintering should be done with water cooled, vibration free, fine diamonds. The restoration may be immersed in special coloring liquid to improve the esthetics. The restoration is then built up with compatible veneering ceramics. *Uses* - core construction for crowns and long span anterior and posterior FPDs.

Sintered zirconia ***(Figs 21.37 and 21.40)*** - Since these materials are already fully sintered, *post sintering* is not required. This material is milled in 1:1 ratio as no shrinkage

Figure 21.37: Sintered zirconia blanks (KAVO).

Figure 21.38: Zirconia blanks showing bar code.

is expected. Because of its extreme hardness milling takes more time and causes more wear of the milling tool. Subsequent processing includes build up with compatible veneering ceramics. *Uses* - core construction for crowns and long span anterior and posterior FPDs. (Zirconia is described in greater detail in a subsequent section).

Sintering Furnaces

Furnaces are an important part of CAD-CAM dentistry. A variety of furnaces are available depending on the type of blank used. For example: In-Ceram alumina blanks have to be glass infiltrated in a furnace following machining. Leucite or lithia disilicate blanks have to be cerammed to induce partial crystallization. The furnace for the sintering of zirconia is highly specialized as it involves very high temperatures. Zirconia sintering can involve temperatures greater than 1500°C.

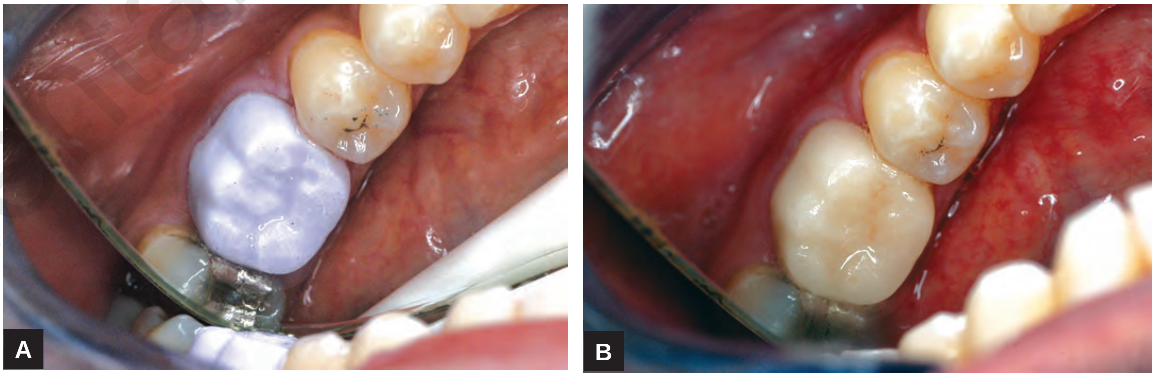
COPY MILLED (CAM) SYSTEMS

Some systems use a copy milling technique to produce ceramic cores or substructures for FPDs. In copy milling a *wax pattern* of the restoration is scanned and a replica is milled out of the ceramic blank.

Commercial systems available

Examples of commercially available copy-milling systems are:

1. Celay-***(Fig. 21.42)*** (*Mikrona* AG, Spreitenbach, Switzerland).
2. Cercon (Degudent, Dentsply). Cercon has both CAD-CAM and copy-milling systems.
3. Ceramill system.



Figures 21.39 A and B: Milled lithia disilicate crown in the presintered state can be tried in the mouth. This is possible because there is no shrinkage during the subsequent ceramming process. Note the color change after heat treatment. (*Courtesy:* Dr Hanan).

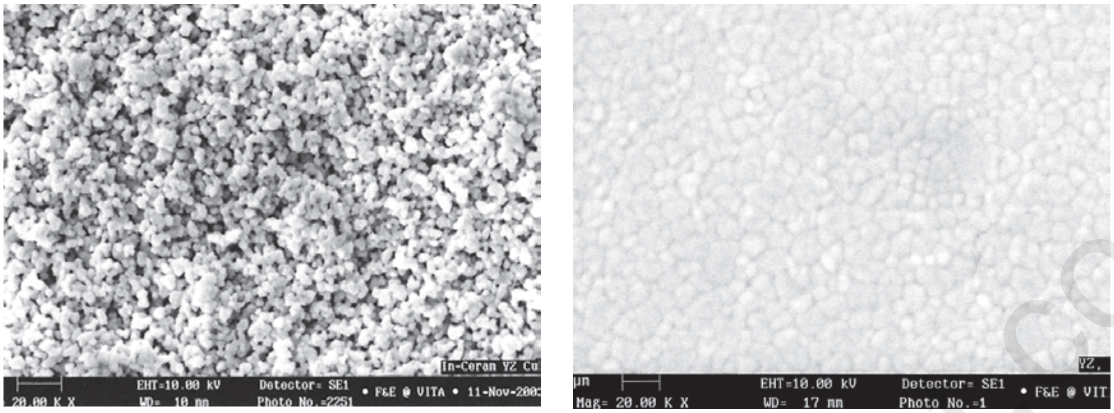


Figure 21.40: SEM shows microstructure of unsintered (presintered) (left) and sintered (right) In-Ceram Zirconia. Sintering fuses the particles to form dense ceramic.

Fabrication of a Copy-milled Restoration Substructure

The Cercon system will be described ***(Fig. 21.41)***.

- Stone die prepared from impression of preparation
- A pattern of the structure is created using wax
- The pattern is fixed on the left side of the milling machine (Cercon Brain)
- A presintered zirconia blank is attached to the right side (milling section) of the machine. The machine reads the bar code ***(Fig. 21.38)*** on the blank which contains enlargement information.
- On activation the pattern on the left side is scanned (non-contact optical scanning) while the milling tool on the right side mills out the enlarged replica (30% larger) of the pattern from the attached ceramic blank.
- The milled structure is removed from the machine and sectioned off from the frame. Any remaining attachment stubs are trimmed and final adjustments are made.
- The zirconia structure is then placed in a sintering furnace (Cercon Heat) and fired for 6 hours at 1350°C to complete the sintering process.
- The restoration is completed using compatible veneering porcelains.

Table 21.4

Comparison of CAD-CAM and copy-milling

CAD-CAM	*Copy-milling*
Scans preparation	Scans pattern
Restoration designed virtually	Restoration designed manually
Object milled from virtual pattern	Restoration mills replica of pattern

Ceramill System

Unlike the earlier system the Ceramill system ***(Fig. 21.43)*** is based on the pantograph type of copy milling, which, according to the company, “puts the material back in the hands of the technician”. To create a zirconia coping, the user applies a light-cured resin over a traditional die, attaches the resin pattern into a plastic plate and inserts it into the milling unit, side by side with a YtZP zirconia blank. The unit has two conjoined arms that hold the probe tip and the milling handpiece. The user manually traces the resin buildup with the probe

Cercon brain (milling unit) Zirconia blanks Wax pattern

Milling Separating

Sintering (cercon heat) A completed substructure A completed prosthesis

Figure 21.41: Fabrication of a zirconia restoration with the Cercon system.

tip while the other arm simultaneously mills a duplicate coping out of the zirconia block.

Networked CAD-CAM Production (Procera AllCeram)

The Procera system by Nobel Biocare is a unique system where restorations are produced using information sent via internet. In this system impression is sent to a local Nobel licenced laboratory. Here the impression is poured and the traditional die produced is scanned by a contact scanner (Nobel Forte). The coping is designed (CAD) and together with the dimensions of the scanned die, the information is passed via internet to a fully automated industrial scale remote production facility which may be in another country. Here an enlarged die is milled via CAM process. The core is produced by dry pressing on to the die and is followed by sintering. The sintered copings are individually checked for quality control and shipped to the laboratory of origin where the subsequent veneering

Figure 21.42: Celay copy milling system.

Figure 21.43: Ceramill.

is completed. Thus in this system the laboratory needs to invest only in the scanner and the CAD software.

YTTRIA STABILIZED ZIRCONIA

Zirconium oxide (ZrO_2) is a white crystalline oxide ceramic with unique properties. Its most naturally occurring form is the rare mineral, baddeleyite. A form of cubic zirconia is popularly used as a diamond simulant. It has the highest strength among the dental ceramics because of its high degree of crack resistance. This is possible because of a unique property of zirconia to undergo a process known as *transformation toughening* ***(Fig. 21.44)***. The stable form of zirconia is the monoclinic form. When zirconia is heated it changes to its tetragonal high-temperature phase which again reverts back to the monoclinic form on cooling. However, addition of yttrium oxide also known as yttria maintains the zirconia in its high temperature tetragonal form at room temperature. Thus this form of zirconia is known as 'yttria stabilized zirconia polycrystal'.

When a stress is applied to the zirconia as in the beginning of a crack formation, it reverts back to its monoclinic form locally with an accompanying increase in volume. The local increase in volume introduces compressive stresses around the crack and slows its growth. This is also known as 'tension expansion' - a phenomenon otherwise known only in the case of steel. For this reason zirconium oxide is also known as '*ceramic steel*'.

The introduction of zirconia as a core material revolutionized dental ceramics. Its unique transformation toughening process, made it possible to construct

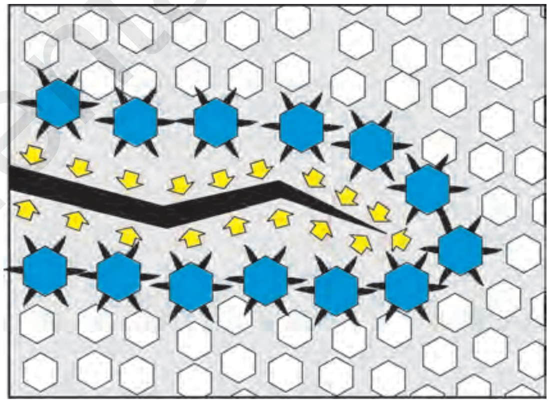


Figure 21.44: Representation of transformation toughening. The illustration shows the compressive forces around the crack caused by transformation and expansion of the zirconia crystals around the crack (adapted from Vita).

relatively long span fixed partial dentures in both anterior and posterior locations.

Composition	*wt%*
Zirconium dioxide (ZrO_2)	90-92
Yttrium oxide (Y_2O_2)	3-5
Hafnium oxide (HfO_2)	< 3
Aluminum oxide (Al_2O_3)	<0.25
Silicon dioxide (SiO_2)	< 1

ZIRCONIA PHYSICAL PROPERTIES

Density 5.89 g/cm^3

Melting point 2715 °C

Available as

Blanks of different sizes and shapes. Both sintered and presintered forms are available. Presintered form is a partially sintered form and is easier to mill. Following milling the dental laboratories complete the sintering to achieve full density. Blanks may be of a single color in which case manufacturers provide special coloring liquids for dipping or painting. Some manufacturers provide blanks in different shades (preshaded blanks).

Manufacture

Ingredients which are in powder form are compacted (isostatic or axial) to form blanks of different sizes and shapes.

ADVANTAGES AND DISADVANTAGES OF CAD-CAM

Advantages

1. Reduced chair time.
2. Stronger porcelain. Milled ceramic is stronger.
3. In some systems the scanning is done directly in the mouth so there is no need to make impression.
4. Reduced porosity, therefore greater strength.
5. One visit (only in systems that mill full contour restorations with minimal subsequent processing. CAD-CAM restorations which employ core ceramics, subsequent processing like sintering or glass infiltration, ceramming, layering, etc., require more time).
6. Lab equipment can be minimized as equipment involved with metal casting and processing are not required.
7. Ability to copy the original form of the tooth can produce restorations that are duplicates of the pre-prepared tooth.

Disadvantages

1. Costly equipment
2. Scanning the preparation is technique sensitive.

PROPERTIES (GENERAL) OF FUSED PORCELAIN

The properties of porcelain vary widely depending on type and composition.

Table 21.5

Properties of different ceramics used in dentistry

Ceramic type	*Flexure strength MPa*	*MOE GPa*	*CTE × 10^{-6}/°C*	*Hardness VHN*	*Fracture toughness MPa.m$^{1/2}$*
PFM (VMK 68)	70	69	6.4 - 7.8		0.7
Dicor	90-124				1.2
IPS Empress	120-170	65	15 - 17	370	1.3
IPS Empress 2	350	95	9.7 - 10.6	400	3.3
Inceram Alumina	500				4.4-4.8
Inceram Spinell	350				2.7
Inceram Zirconia	700				6.8
Stabilized Zirconia	900-1200	210	10.5		9

Strength

The early porcelains were weak and brittle and tended to break easily. Current porcelain systems have considerably improved in strength and toughness. However, care still has to be taken during manufacture and fabrication of these materials to ensure that flaws that can lead to fracture are not incorporated. The strength of porcelain is usually measured in terms of flexure strength (or modulus of rupture).

Flexure strength It is a combination of compressive, tensile, as well as shear strength. The strength of various types of porcelains are given in Table 21.5. Flexure strength of dental ceramic restorations vary from 70 MPa for feldspathic veneering porcelains to 1200 MPa for machined zirconia core restorations.

METHODS OF STRENGTHENING

Porcelains are by nature brittle. Minute scratches, cracks, defects, porosity, etc., on the surface of the porcelain act as stress concentration points. When excessive tensile force or a sharp impact force is applied on the ceramic, the crack propagates through the crack tip until it penetrates through the entire thickness of the ceramic. This is the reason why surface glazing or polishing is important to eliminate as many of the surface defects as possible. The methods to improve the fracture resistance of ceramic materials are described.

Residual Compressive Stresses through CTE Mismatch

The method is to have layers of ceramic with slight differences in the coefficient of thermal expansion (CTE). The inner layer should have a slightly higher CTE than the outer layer. Thus on cooling to room temperature after firing the inner layer shrinks faster than the outer layer thereby pulling the outer layer inwards and creating compressive stresses within the outer layer. The principle is applied in both metal-ceramic restorations and all ceramic restorations where restorations are built up through layering. The inner metal coping usually has a higher CTE than the veneering ceramic. The innermost layers of ceramic like the opaquer will have a higher CTE than the enamel and dentin layers. Similarly in multilayered all ceramic restorations the inner core will have a higher CTE than the outer veneering ceramic. (However, one must remember that CTE differences should be precisely calculated. Extreme differences in CTE can actually lead to failure of the ceramic).

Residual Compressive Stresses through Thermal Tempering

The method is used in the automobile industry to strengthen glass. Residual compressive stresses may be created by rapidly cooling the surface of the object while it is in the hot or molten state. The outer portions cools and forms a rigid skin while the inner portion is still hot. As the inner portion cools it shrinks and creates compressive stresses within the outer portion.

Residual Compressive Stresses through Ion Exchange

The ion exchange process involves 2 ions with difference in size. When a ceramic object is placed in a bath of molten potassium salt, some of the sodium ions present in the surface glass is replaced by the potassium ions. The potassium ion is about 35% larger than the sodium ion. When the larger ion squeezes into the place formerly occupied by the smaller sodium ion large compressive stresses are created. The resulting compression leads to greater toughening of the glass than is possible by thermal strengthening. Glass thus treated is used in particular in the aircraft industry and other sectors where safety is all-important. The ion-exchange process is also sometimes referred to as chemical tempering. One commercially available product GC Tuf-Coat (GC) is used for chemical toughening. This potassium rich slurry is applied on the restoration and heated at 450°C for 30 minutes in a furnace. However, the fracture resistance is confined to the surface of the glass to a thickness of just 100 µm.

Dispersion Strengthening

Many of the modern glass based ceramics use dispersion strengthening. The process involves the dispersion of a crystalline material within the ceramic which interrupts the formation of a crack. The crack cannot pass as easily through the crystal particle as easily as it does through the glass matrix. Dispersion strengthening is dependent on the type, size, CTE and total content of the crystal within the ceramic. Examples of crystals used for dispersion strengthening are leucite, lithia disilicate, tetrasilic fluormica, alumina, spinell, zirconia, etc.

Transformation Toughening

The transformation toughening phenomenon is primarily associated with yttria-stabilized zirconia core ceramics. The process involves stress-induced transformation of the material at the tip of the crack with accompanying volume expansion. This places tha area at the tip of the crack under compression and thereby halts the progress of the crack. For further explanation see section on yttria stabilized zirconia.

Minimizing Stresses through Optimal Design

Even the strongest ceramics can fail if the restoration is not designed properly. This includes sufficient thickness (at least 2 mm) for the ceramic, avoiding sharp internal line angles and point angles, avoiding marked changes in thickness, etc. Sharp angles or points on the internal surface of the restoration can act as stress raisers. Excessive thickness of porcelain in metal-ceramic restoration may lead to fracture because of insufficient support by the metal substructure. In the case of all-ceramic FPDs, the connector should have sufficient height and width. It should be concave and should avoid sharp angles.

Minimizing Surface Defects through proper Glazing or Polishing

Large scratches caused by grinding or minute porosities on the surface of the restoration can act as stress concentration points. This is why it is important to glaze or polish the ceramic restoration after all adjustments have been completed.

Strengthening by Bonding to a Stronger Substrate

The strength of porcelain can be improved considerably when it is bonded to a stronger substructure. For example: in metal-ceramic restorations the inner metal coping provides a stiff and stable support which reduces the tensile forces on the overlying ceramic. In all-ceramic restorations, the alloy frame is substituted by high strength reinforced core ceramics like zirconia and alumina. The inner coping also acts as a skin, reducing the formation and propagation of internal cracks. This function is evident is ceramics bonded to platinum or gold foil. The foils obviously do not provide the same kind of high strength support as seen in cast alloy copings but rather provides a protective inner skin that reduces internal defects.

Minimizing Fabrication Defects and Stresses

The ceramic can be made stronger by proper manipulation and fabrication. Proper condensation and vacuum firing reduces porosity in the restoration. Proper cooling reduces the development of internal stresses and strains. Manufacturers instructions should be followed. Proper oxidation firing favors bond formation in metal-ceramics.

Tensile strength Porcelains are inherently brittle materials. Tensile strength is low because of the unavoidable surface defects like porosities and microscopic cracks. When porcelain is placed under tension, stress concentrates around these imperfections and can result in brittle fractures.

Shear strength is low and is due to the lack of ductility caused by the complex structure of porcelain.

Factors affecting strength

1. *Composition*
2. *Surface integrity* Surface imperfections like micro-cracks and porosities reduce the strength. Thus grinding should be followed by glazing or polishing.

   E.g.: Ground – 75.8 MPa Glazed – 141.1 MPa
3. *Improper condensation* Poor condensation introduces voids and reduces density of the porcelain.
4. *Firing procedure* Inadequate firing and overfiring weakens the structure.

Modulus of Elasticity

Porcelain has high stiffness. The stiffness values range from 69 to 210 GPa for the various ceramic systems ceramics.

Surface Hardness

Porcelain is much harder (370 to 400 VHN) than natural teeth.

Abrasiveness of ceramics

Unglazed or unpolished can cause severe wear of natural teeth especially if dentin is exposed. This can happen in cases of occlusal interferences or when excessive masticatory forces are involved as in bruxing. Thus ceramic restorations are contraindicated in bruxers. Porcelain restorations must always be glazed or polished after grinding. Wear of enamel occurs by the gouging action caused by asperities (projecting crystals) on the ceramic surface. The abrasiveness of the ceramic depends on the type of asperities present. Alumina and zirconia are more abrasive than plain glass. Prolonged exposure to carbonated beverages increases the wear rate of enamel. Ultralow fusing ceramics are less abrasive to enamel than conventional ceramics (see box). Ceramics having smaller crystal size or finer particles show reduced enamel wear.

LOW FUSING AND ULTRALOW FUSING CERAMICS

Duceram LFC (Degussa) or Finesse (Dentsply)

This relatively new porcelain is also referred to as a “hydrothermal low fusing ceramic” (LFC). It is composed of an amorphous glass containing hydroxyl ions. It is claimed to have higher flexural strengths, greater fracture resistance and lower hardness than feldspathic porcelain (hence less abrasion). The inner core for the crowns is made from Duceram Metal Ceramic porcelain which is a leucite containing porcelain placed on a refractory dye and baked at 930°C. The Duceram LFC on the surface is subsequently baked at 660°C and can be surface characterized. There are no clinical studies substantiating these claims but in theory the material sounds promising. It has been suggested that the material is “self healing” as the potential cracks self-repair within the material. The wear rate is similar to that of the natural tooth. There are also some reports that the polishing of the surface with rubber wheels (e.g., Brassler polishing wheels) generates enough heat to “heal” the micro-cracks thus reducing the potential for crack propagation.

Finesse

This is a low fusing ceramic which can be used with many high-gold alloys as well. In addition to the standard shades, it is available in two new shades AO and BO to match bleached white teeth.

LFCs do not etch very well and therefore cannot be used alone for bonded restorations. For this application, a thin coping of conventional porcelain must first be fired.

Thermal Properties

Thermal conductivity Porcelain has low thermal conductivity which is important to prevent extreme cold or heat transmission to the sensitive dentin and pulpal tissues in cases of restorations in vital teeth.

Coefficient of thermal expansion The CTE is an important property for dental ceramics especially for layered restorations. The CTE of the various layers should be closely matched. Extreme differences can induce a lot of stresses in the ceramic leading to immediate or subsequent failure. The CTE values range depending on the type of ceramic. Some of the veneering ceramics for metal-ceramic have value ranging from 6.4 to 7.8 × 10^{-6}/°C which is close to that of natural teeth. The CTE values for metal-ceramic alloys have to be lowered to improve its compatibility with ceramics.

Specific Gravity

The true specific gravity of porcelain is 2.242. The specific gravity of fired porcelain is usually less (2.2 to 2.3), because of the presence of air voids.

Dimensional Stability

Fired porcelain is dimensionally stable.

Chemical Stability

It is insoluble and impermeable to oral fluids. Also it is resistant to most solvents. However, hydrofluoric acid causes etching of the porcelain surface. A source of this is APF (acidulated phosphate fluoride) and stannous fluoride which are used as topical fluorides. *Hydrofluoric acid* is used to etch the porcelain (see ***Fig. 20.11***). Etching improves the bonding of the resin cement. Ceramic etchants are also used for intraoral repair of fractured ceramic.

Porcelain-metal and Inter-ceramic Bonds

The interphase between the veneer porcelains and the supporting ceramic or metal core is an area of interest. The restoration can fail if the bond is weak. Many test methods have been used to determine bond strengths. One study (Petra et al, 2008) using a shear bond test have shown metal-ceramic systems to have a far higher bond strength than zirconia-based all-ceramic systems (12.5±3.2 for Vita In-Ceram YZ Cubes/Vita VM9, 11.5±3.4 for DC-Zirkon/IPS e.max Ceram, and 9.4±3.2 for Cercon Base/Cercon Ceram S compared to 27.6±12.1, 26.4±13.4 MPa).

Esthetic Properties

The esthetic qualities of porcelain vary according to the type of ceramic and its intended function. In general they have excellent esthetic properties especially the all-ceramic restorations. It is able to match adjacent tooth structure in translucence, color and intensity. Some of the current ceramics are also able to match the fluorescence ***(Fig. 21.46)*** of natural teeth under certain artificial lighting, e.g., in discotheques. The color stability is also excellent. It can retain its color and gloss for years.

Metal-ceramic restorations do not have the same level of translucence as some of the all-ceramic restorations ***(Fig. 21.45).*** These concerns include

- Darkening of the gums around the margins of the restoration
- Visibility of the margin as a dark line because of display of metal
- Certain esthetic concerns have been raised when the dense opaquer layer is visible through thin crowns (in metal-ceramic and In-Ceram crowns). However, this is more of an error in technique. The dentist must ensure an

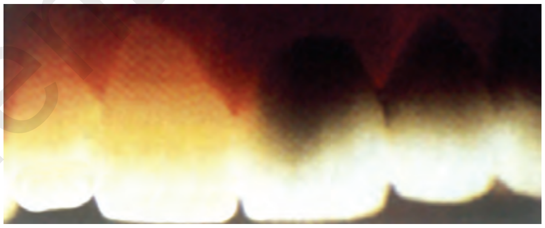


Figure 21.45: Classic illustration demonstrating difference in transluscence between all-ceramic crowns and metal-ceramic crowns.

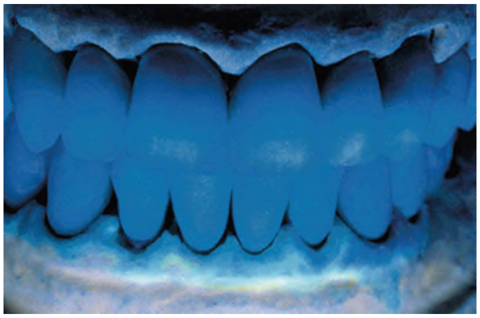


Figure 21.46: Fluorescence under certain artificial lighting.

adequate depth of preparation (at least 1.2 to 1.4 mm) to ensure sufficient thickness of dentin/enamel veneer to mask the opaquer. The technician on the other hand should ensure correct thickness of opaquer.

Some porcelains are highly translucent (Dicor) whereas others are highly opaque (zirconia). The translucent ones pick up the color of the underlying cement, tooth structure as well as neighboring teeth (chameleon effect). Different porcelains together with internal and external stains are available to mimic almost any effect seen in natural teeth.

Biocompatibility

Glazed porcelain is one of the most biocompatible materials in dentistry when placed in direct contact with tissues. However, ceramic dust which is produced when grinding or machining ceramics is harmful if inhaled. Proper evacuation of the dust and wearing of mouth mask is mandatory.

CEMENTING OF CERAMIC RESTORATIONS

The type of cement used depends on the type of restoration (metal ceramic or full ceramic) and its location (anterior or posterior).

CEMENTING ALL-CERAMIC CROWNS, INLAYS AND VENEERS

Because of the translucency of *some* all-ceramic restorations (e.g., glass ceramic crowns), the underlying cement may influence the esthetics (color) of the restoration. Therefore the shade of the cement used should be carefully selected. Conventional cements may be used especially for most other crowns and FPDs. However, veneers and inlays are best bonded with resin cements using the traditional acid etch technique. Resin bonding generates the high bond strengths needed for such restorations to succeed. Esthetics at the margins is better with resin cements. Bonding of the cement to the porcelain can be improved by:

- Sandblasting
- Chemical etching

Sandblasting The inner surface of the ceramic restoration creates minute irregularities helping the cement to retain better. However, chemical etching appears to be superior.

Etching of Porcelain

Ceramic restorations which are bonded using resin cements (usually *veneers* and *inlays*) have to be etched. Etching improves the bond of the resin to the ceramic. Etching is done using *hydrofluoric acid* ***(Fig. 21.47)***. The acid attacks and selectively dissolves the inner surface of the ceramic ***(Fig. 21.48)***. The acid is available in 2 concentrations 5 and 9.5%. An etching time of 2 minutes is usually sufficient. The tooth surface is also etched using phosphoric acid. Before placing the cement, a bond agent is applied to both surfaces (tooth and porcelain).

CEMENTING METAL-CERAMIC CROWNS AND FIXED PARTIAL DENTURES

These are cemented like conventional restorations. The cement does not affect the esthetics because it is not visible through the restoration. Any conventional cement may be used.

Figure 21.47: Two brands of ceramic etchants consists of hydrofluoric acid (5%).

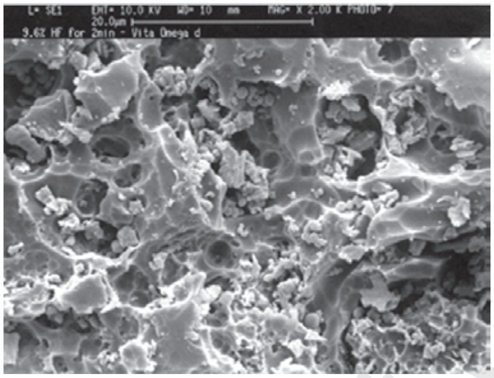


Figure 21.48: SEM of etched ceramic (Vita Omega) using 9.6% hydrofluoric acid.

REPAIR OF CERAMIC RESTORATIONS

Ceramic restorations are difficult to repair intraorally primarily because of poor bond strength of the repaired fragment. However, in certain situations intraoral repair may be undertaken as a temporary or intermediate procedure before a new restoration is fabricated. Intraoral repair is carried out using composite.

A typical intraoral repair kit ***(Fig. 21.49)*** consists of a porcelain etching gel (HFl acid), a bonding agent, and opaquer to mask the metal and a glaze. The gingival tissues are first protected with a protective gel (Kool Dam). Next the ceramic is etched with the gel. The bonding agent is applied and light cured followed by the opaquer (usually in case of metal-ceramic restorations). For the bulk of the repair a regular light cured composite is used of the appropriate shade. After trimming and shaping the final glaze coat is applied (super shine).

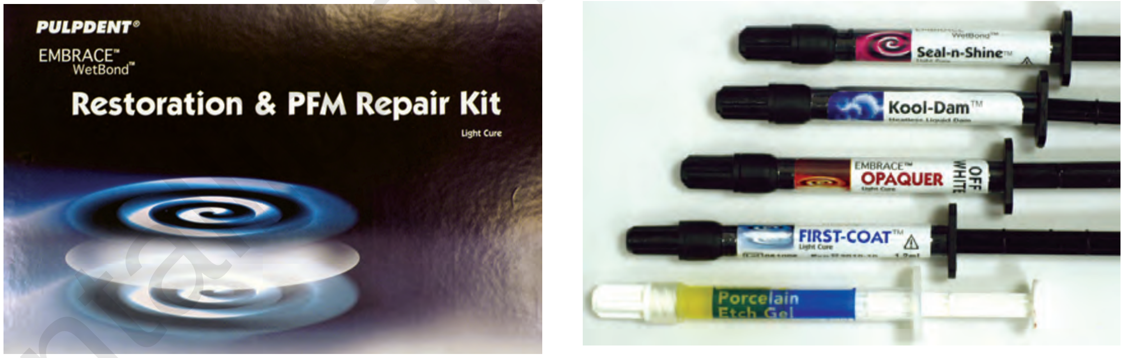


Figure 21.49: A representative porcelain repair kit.

PORCELAIN DENTURE TEETH

Porcelain denture teeth are more natural looking than acrylic teeth. They have excellent biocompatibility and are more resistant to wear. Porcelain denture teeth also have the advantage of being the only type of denture teeth that allow the denture to be rebased.

Porcelain teeth are made with high fusing porcelains. Two or more porcelains of different translucencies for each tooth are packed into metal molds and fired

Figure 21.50: Porcelain denture teeth. Porcelain teeth are similar in appearance to resin teeth. However, unlike resin teeth they are retained with projecting pins (anterior teeth). Posterior teeth have channels in them into which the resin flows and locks (*Courtesy:* Vijay Dental, Chennai).

on large trays in high temperature ovens. The retention of porcelain teeth on the denture base is by mechanical interlocking. Anterior teeth have projecting metal pins that get embedded in the denture base resin during processing. Posterior teeth on the other hand are designed with holes (diatoric spaces) in the underside into which the denture resin flows ***(Fig. 21.50)***.

The disadvantages of porcelain denture teeth are:

1. They are brittle and make a clicking sound during contact.
2. They require a greater interridge distance as they cannot be ground as thin as acrylic teeth in the ridge-lap areas without destroying the diatoric channels or pins that provide their only means of retention.
3. The higher density increases their weight.

CERAMIC POSTS

Figure 21.51: Zirconia post and core.

Metallic post and cores can sometimes reduce the esthetics of a ceramic restorations by a reduced passage of light through the restoration. With the increasing demand for esthetic restorations, ceramic posts may be used to replace metallic post and cores. One such product is the CosmoPost (Ivoclar Vivadent). The CosmoPost ***(Fig. 21.51)*** is a parallel conical ceramic post com posed of ZrO_2, HfO_2, Y_2O_3 and Al_2O_3. The Cosmospost in combination with the Cosmo Ingot which is a pressable ceramic is used to fabricate esthetic post and core foundations on which crowns may be fabricated. However, care must be exercised in selecting cases as these posts are susceptible to fracture.

22

WROUGHT ALLOYS

Wrought alloys are obtained from cast alloys. A wrought alloy is one that has been worked, drawn or shaped into a serviceable form, e.g., plates, band materials, bars, and wires. The process of forming wrought metal objects has been known since ancient times. For example, swords used in warfare were formed by subjecting a hot piece of metal to a beating process. Other things used in daily life like farming equipment and kitchen utensils are also made by a similar process.

MANUFACTURE OF WROUGHT ALLOYS

Wrought metals are usually derived from cast metals or alloys. Wrought alloys are obtained when the parent metal is subject to various deformative processes like drawing, extruding, machining, beating, rolling, forging, etc. Examples of some of these processes are

1. Round wires are obtained by drawing a cast alloy through a series of dies.
2. Rolling process is used to form sheets and rods.
3. Forging is a process by which an object is formed by compressing the parent metal between two dies. Stainless steels crowns are made by this process.

Manufacture of wrought alloys results in a tremendous amount of stresses (known as work hardening). These stresses are relieved by heat treatment during or after manufacture.

STRUCTURE OF WROUGHT ALLOYS

All alloys are initially formed by casting. When a cast metal is subject to any deformation it is considered a wrought metal. Wrought alloys have a fibrous structure which results from the cold working applied during the drawing operation to shape the wire. At the atomic level the deformative processes involved in the manufacture of wrought alloys results in various types of atomic deformations and disruptions. These include dislocations, twinning and fracture.

DISLOCATIONS

On application of a shear force dislocation of the atoms occur along a plane called as the slip plane. The simplest type of dislocation is known as edge dislocation. The dominant slip planes are characteristic for each type of crystal structure. For example, face-centered cubic (fcc) structures have the greatest number of slip planes. Therefore, metals with a fcc structure like gold, copper, nickel, palladium, silver, platinum, etc. are highly ductile and easy to draw. Body-centered cubic (bcc) metal have intermediate levels of ductility. Hexagonal close-packed structures (hcp) have the least amount of slip systems and therefore are relatively brittle, e.g., zinc. Dislocations occur only in materials having a crystalline structure. Dislocations cannot exist in materials with a noncrystalline structure like dental ceramics and polymeric materials.

TWINNING

Another type of permanent deformation is known as twinning. The deformation occurs along either side of a plane in such a way that it mirrors each other. Twinning is favored over dislocation in metals that have relatively few slip systems.

FRACTURE

Continuation of cold working in a heavily deformed metal eventually leads to fracture. The fracture initiates from microcracks that occurs at points where there is an accumulation of dislocations or at boundaries between different microstructural phases. Alloys can undergo brittle or ductile fracture depending on a variety of factors, such as composition, microstructure and strain rate. When a ductile alloy fractures under tension there is a reduction in the diameter of the metal (necking down) of the fracture site prior to fracture. Ductile fracture sites are characterized by a dimpled morphology. Microvoids or porosity may be seen at the fracture site.

Fracture due to cold working is a cause for concern in dentistry. Examples are fractures of endodontic instruments like root canal files and reamers within the canal. Retrieval of such instruments can often be difficult. That is why it is necessary to use these instruments in the correct sequence and manner and to change these instruments at regular intervals rather than use them till it breaks.

ANNEALING

The effects of cold working like strain hardening, susceptibility to corrosion and loss of ductility can be neutralized by a heating process called *annealing*.

STAGES OF ANNEALING

Annealing takes place in three stages

1. Recovery
2. Recrystallization
3. Grain growth

The time and temperature for annealing is dependent on the melting temperature of the alloy. A commonly observed rule is to use a temperature that is approximately half the melting point of the metal or alloy on the absolute scale (K).

Recovery

In the recovery stage, there is a slight decrease in tensile strength with no change in ductility. The most important beneficial changes occur during the recovery phase. As mentioned earlier cold worked metal contain a lot of residual stresses. The purpose of annealing heat treatment is to relieve these stresses. Maximum stress relief occurs during the recovery stage.

Recrystallization

On further heating, changes in the microstructure begin to take place. The deformed grains begin to recrystallize forming new stress free grains. The metal essentially regains its old soft and ductile condition. The metal loses its properties of resilience rendering it useless for its intended purpose. Thus recrystallization must be avoided.

Grain Growth

In this phase the recrystallized grains continue to grow with larger grains consuming smaller grains. Grain growth does not proceed indefinitely, but rather ceases until a coarse grain structure is formed. There is no significant difference in ductility and tensile strength from that observed in the previous stage.

Significance It is clear from the above that annealing should be done only until the recovery stage. Uncontrolled heating of dental related appliances can result in unintended changes within the structure.

USES OF WROUGHT ALLOYS

1. Orthodontic wires.
2. Prosthodontic clasps.
3. Root canal instruments like files and reamers.
4. Steel bands and brackets for orthodontic and pedodontic use.
5. Stainless steel crowns.
6. Dental instruments.

GENERAL PROPERTIES OF ORTHODONTIC WIRES

Orthodontic wires are formed into various configurations or incorporated into appliances. When activated these wires apply forces to the teeth and move them to the desired alignment. The force is determined by the appliance design and the material properties of the wire.

The following properties are important in orthodontic treatment.

- *Force generated* The force generated by the wire on the tooth is dependent on its composition and design. For a given design, the force generated is proportional to the wire's stiffness.
- *Elastic deflection and working range* Biologically, low constant forces are less damaging. This is best achieved by a large elastic deflection because it produces a more constant force and has a greater *'working range'*.

$$\text{Maximum elastic deflection} = \frac{\text{Proportional limit (PL)}}{\text{Modulus of elasticity (MOE)}}$$

- *Springiness* It is a measure of how far a wire can be deflected without causing permanent deformation.
- *Stiffness* Amount of force required to produce a specific deformation

$$\text{Stiffness} = 1/\text{springiness}.$$

- *Resilience* It is the energy storage capacity of the wires which is a combination of strength and springiness.
- *Formability* It represents the amount of permanent bending the wire will tolerate before it breaks.
- *Ductility* of the wire.
- *Ease of joining* Most wires can be soldered or welded together.
- *Corrosion resistance* and stability in the oral environment is important for the appliance durability as well as biocompatibility.

- *Biocompatibility* in the oral cavity. Most orthodontic wires are biocompatible. People generally allergic to nickel may get allergic reactions from nickel containing orthodontic wires.
- *Cost* is a factor in orthodontics. The titanium alloy wires are more expensive than the stainless steel or the cobalt chromium nickel wires.

TYPES

1. Wrought gold alloys
2. Wrought base metal alloys
    — Stainless steel
    — Cobalt-chromium-nickel
    — Nickel-titanium
    — Beta-titanium

WROUGHT GOLD ALLOYS

USES

Primarily to make clasps in partial dentures.

CLASSIFICATION

Type I—High precious metal alloys
Type II—Low precious metal alloys

COMPOSITION

The composition varies widely.

Gold — 25 to 70%
Platinum — 5 to 50%
Palladium — 5 to 44%
Silver — 5 to 41%
Copper — 7 to 18%
Nickel — 1 to 3%
Zinc — 1 to 2%

PROPERTIES

They generally resemble Type IV casting gold alloys. Because of the cold working, wires and other wrought forms have improved mechanical properties like hardness and tensile strength when compared to cast structures.

However, care should be taken during soldering. Prolonged heating at higher temperatures can cause it to recrystallize. Recrystallization changes the properties and makes the wire brittle.

WROUGHT BASE METAL ALLOYS

A number of wrought base metal alloys are used in dentistry, mainly as wires for orthodontic treatment. The alloys are:

— Stainless steel (iron-chromium-nickel)
— Cobalt-chromium-nickel
— Nickel-titanium
— Beta-titanium.

STAINLESS STEEL

Steel is an iron-based alloy which contains less than 1.2% carbon. When chromium (12 to 30%) is added to steel, the alloy is called as stainless steel. Elements other than iron, carbon and chromium may also be present, resulting in a wide variation in composition and properties of the stainless steels.

PASSIVATION

These stainless steels are resistant to tarnish and corrosion, because of the *passivating effect* of the chromium. A thin, transparent but tough and impervious oxide layer forms on the surface of the alloy when it is exposed to air, which protects it against tarnish and corrosion. It loses its protection if the oxide layer is ruptured by mechanical or chemical factors.

TYPES

There are three types of stainless steel based on the lattice arrangement of iron.

1. Ferritic
2. Martensitic
3. Austenitic

FERRITIC STAINLESS STEELS

Pure iron at room temperature has body-centered cubic (BCC) structure and is referred to as ferrite, which is stable up to 912°C.

PROPERTIES AND USE

The ferric alloys have good corrosion resistance, but less strength and hardness. So they find little application in dentistry.

MARTENSITIC STAINLESS STEELS

When austenite (face-centered cubic structure) is cooled very rapidly (quenched) it will undergo a spontaneous, diffusionless transformation to a body-centered tetragonal (BCT) structure called martensite. This is a highly distorted and strained lattice, which results in a very hard and strong but brittle alloy.

PROPERTIES AND USES

Corrosion resistance of the martensitic stainless steel is less than that of the other types. Because of their high strength and hardness, martensitic stainless steels are used for surgical and cutting instruments. Bur shanks are also made from this steel.

AUSTENITIC STAINLESS STEELS

At temperatures between 912°C and 1394°C, the stable form of iron is a face-centered cubic (FCC) structure called austenite. The austenitic stainless steel alloys are the most corrosion resistant of the stainless steels.

COMPOSITION

Chromium — 18%
Nickel — 08%
Carbon — 0.08-0.15%

Figure 22.1: A stainless steel wire roll (left) and some of the appliances made from the wires.

Figure 22.2: High tensile stainless steel wire.

USES

This alloy is also known as *18-8 stainless steel*. They are commonly used by orthodontists and pedodontists in the form of bands and wires (***Figs 22.1 and 22.2***). Type 316 L (contains carbon-0.03% maximum) is the type usually used for implants.

Available as They are available as annealed and partially annealed wires. They are usually supplied as rolls of varying thickness.

Annealed and partially annealed wires

When stainless steel wires are fully annealed they become soft and highly formable. When it is partially annealed the yield strength is increased and formability decreases. Stainless steel is available in different grades depending on their yield strength. Both the fully annealed and partially annealed wires are used as orthodontic wires.

ADVANTAGES

Austenitic steel is preferred to ferritic alloys because of some desirable properties:

1. Greater ductility and ability to undergo more cold work without breaking.
2. Substantial strengthening during cold working.
3. Greater ease of welding.
4. The ability to readily overcome sensitization.
5. Less critical grain growth.
6. Comparative ease in forming.

PROPERTIES

Sensitization

The 18-8 stainless steel may lose its resistance to corrosion if it is heated between 400 and 900°C (temperature used during soldering and welding).

The reason for a decrease in corrosion resistance is the precipitation of *chromium carbide* at the grain boundaries at these high temperatures. The small, rapidly diffusing carbon atoms migrate to the grain boundaries from all parts of the crystal to combine with the large, slowly diffusing chromium atoms at the periphery of the grain. When the chromium combines with the carbon in this manner, its *passivating qualities are lost* and the corrosion resistance of the steel is reduced.

Stabilization (Methods to minimize sensitization)

1. From a theoretical point, the carbon content of the steel can be reduced to such an extent that carbide precipitation cannot occur. However, this is not economically practical.
2. By stabilization, i.e., some element is introduced that precipitates as a carbide in preference to chromium. Titanium is commonly used. Titanium at six times the carbon content, inhibits the precipitation of chromium carbide at soldering temperatures. These are known as *stabilized stainless steels.*

Mechanical Properties

In orthodontic wires, strength and hardness may increase with a decrease in the diameter because of the amount of cold working in forming the wire.

- Tensile strength — 2100 MPa
- Yield strength — 1400 MPa
- Hardness — 600 KHN

BRAIDED AND TWISTED WIRES

Very small diameter stainless steel wires (about 0.15 mm) can be braided or twisted together to form either *round* or *rectangular* shaped (about 0.4 to 0.6 mm in cross section) wires ***(Fig. 22.3)***. These wires are available as straight lengths or as formed archwires in the form of 3 strands or in increasing number of strands.

These braided or twisted wires are able to sustain large elastic deflections in bending, and apply low forces for a given deflection when compared with solid stainless steel wire.

Figure 22.3: A braided wire.

SOLDERS FOR STAINLESS STEEL

Silver solders are used. The soldering temperatures for orthodontic silver solders are in the range of 620 to 665°C.

FLUXES

It is similar to that recommended for gold soldering with the exception of:

- The addition of the potassium fluoride. Fluoride helps to dissolve the passivating film supplied by the chromium.
- A higher boric acid to borax ratio lowers the fusion temperature.

WROUGHT COBALT-CHROMIUM-NICKEL ALLOYS

These wrought alloys were originally developed for use as watch springs (Elgiloy). Their properties are excellent also for orthodontic purposes.

COMPOSITION

Co — 40%
Cr — 20%
Ni — 15%
Mo — 7%
Mn — 2%
C — 0.15%
Be — 0.04%
Fe — 15.8%

HEAT TREATMENT

Softening heat treatment: 1100 to 1200°C followed by a rapid quench. Hardening heat treatment: 260 to 650°C, e.g., 482°C for 5 hours.

The wires are usually heat treated and supplied in several degrees of hardness (soft, ductile, semispring temper and spring temper).

PHYSICAL PROPERTIES

Tarnish and corrosion resistance is excellent. Hardness, yield, and tensile strength similar to those of 18-8 stainless steel.

NICKEL-TITANIUM ALLOYS

Nickel –titanium shape memory alloys were first discovered by Buehler in the early 1960s. He was working at the Naval Ordinance Laboratory (NOL) at the time, hence the name Nitinol. His discovery formed the basis of the first commercial shape memory alloy. These nickel-titanium alloy (also called nitinol) wires have large elastic deflections or working range and limited formability, because of their low stiffness and moderately high strength. They are used extensively as arch wires in fixed orthodontic treatment (***Fig. 22.4***). They are also used to manufacture endodontic instruments (***Fig. 22.5***).

AVAILABLE AS

Nickel titanium alloy wires are available as springs in addition to formed arch wires. Nickel titanium wires are commercially available in martensitic (M-Niti) and austenitic (A-Niti) depending on their use in different phases of orthodontic treatment.

COMPOSITION

The primary elements are nickel and titanium. Addition of copper to nickel and titanium alloy improves the thermal reactive properties of the wire, which help in consistent and efficient orthodontic tooth movement. Other additions made to alter the phase transformation temperature are elements such as iron and chromium which lower the temperature.

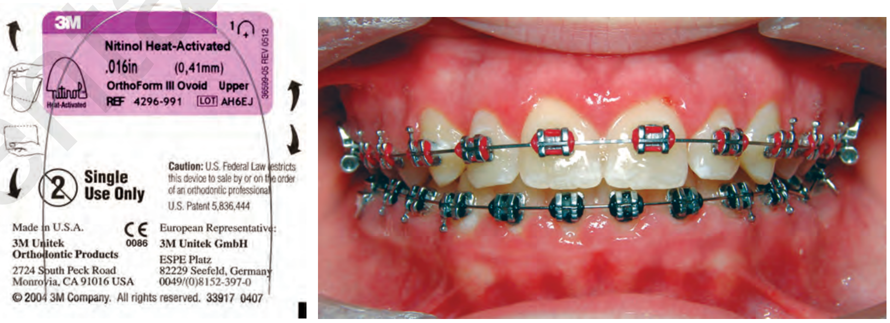


Figure 22.4: Nitinol arch wires (left) are used extensively in orthodontic treatment (above).

Figure 22.5: Nickel-titanium files.

PROPERTIES OF NITINOL ALLOYS

SHAPE MEMORY AND SUPERELASTICITY

This alloy exists in various crystallographic forms. At high temperature, a stable body-centered cubic lattice (austenitic phase) exists. On appropriate cooling or an application of stress, this transforms to a close-packed hexagonal martensitic lattice with associated volumetric change. This behavior of the alloy (austenite to martensite phase transition) results in two features of clinical significance called as ‘shape memory’ and ‘superelasticity’, or ‘pseudoelasticity’.

The ‘memory’ effect is achieved by first establishing a shape at temperatures near 482°C. The appliance, e.g., archwire is then cooled and formed into a second shape. Subsequent heating through a *lower transition temperature* (37°C - mouth temperature) causes the wire to return to its original shape. The phenomenon of superelasticity is produced by transition of austenite to martensite by stress due to the volume change which results from the change in crystal structure.

Stressing an alloy initially results in standard proportional stress-strain behavior. However at a stress where it induces the phase transformation, there is a increase in strain, referred to as superelasticity. At the completion of the phase, it reverts to standard proportional stress-strain behavior. Unloading results in the reverse transition and recovery. This characteristic is useful in some orthodontic situations because it results in *low forces* and a very *large working range* or springback.

These wires are useful because it is possible to achieve phase transformation at *room temperature* when force is applied. Wires with different transformation temperatures are now available, which enables the clinician to select the precise wires for different needs.

Density Their density is approximately 6.5 g/cm^3.

Melting range Melting temperature in the range 1240 to 1310°C.

TITANIUM ALLOYS

Like stainless steel and nitinol, pure titanium has different crystallographic forms at high and low temperatures. At temperatures below 885°C the hexagonal close packed (HCP) or alpha lattice is stable, whereas at higher temperatures the metal rearranges into a body-centered cubic (BCC) form called β-titanium.

α-titanium is not used in orthodontic applications. The β-form is more useful in orthodontics. However, to retain the β-form as it cools to room temperature elements like molybdenum are added. This stabilizes the β-form and prevents its transformation to the α-form. For orthodontic use the titanium alloys are supplied as precut arch wires (***Fig. 22.7)***usually in a rectangular cross-sectional form (***Fig. 22.6)***.

COMPOSITION

Ti — 79%
Mo — 11%
Zr — 6%
Sn — 4%

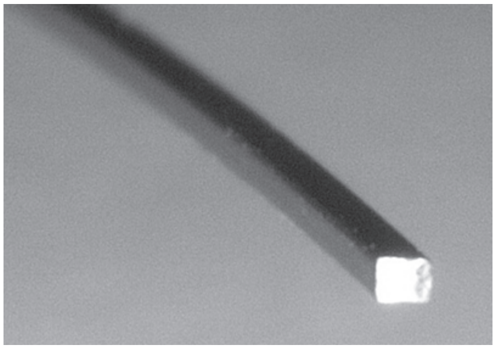


Figure 22.6: Wires come in different cross sectional shapes including round, square and rectangular.

Figure 22.7: Titanium (Beta III by 3M) arch wire.

MECHANICAL PROPERTIES

1. Modulus of elasticity — 70 GPa.
2. Yield strength —860 to 1200 MPa.
3. The high ratio of yield strength to modulus produce orthodontic appliances that can undergo large elastic activations when compared with stainless steel.
4. Beta-titanium can be highly cold-worked. It can be bent into various configurations and has formability comparable to that of austenitic steel.
5. Welding Clinically satisfactory joints can be made by electrical resistance welding of beta-titanium.
6. Corrosion resistance Both forms have excellent corrosion resistance and environmental stability.
7. Heat treatment can alter its properties and therefore heat treatment of these wires is not recommended.

23

BRAZING AND WELDING

It is often necessary to construct a dental appliance as separate parts and then join them together either by a soldering or welding process. Dental brazing is covered by ISO 9333.

TERMS AND DEFINITIONS

Metal joining operations are usually divided into four categories: welding, brazing, soldering and cast-joining.

WELDING

The term welding is used if two pieces of similar metal are joined together without the addition of another metal that is, the metal pieces are heated to a high enough temperature so they join together by melting and flowing.

BRAZING AND SOLDERING

The words soldering and brazing are used if two pieces of metal are joined by means of a third metal called as filler.

BRAZING

During soldering, metal parts are joined together by melting a filler metal between them at a temperature below the solidus temperature of the metal being joined and below 450°C.

In dentistry, the joining of metal parts are done at temperatures above 450°C, and therefore the operation should ideally be called *brazing*. This is also the term used by the ISO. However, most dentists still prefer to use the word soldering. The term 'brazing material' is often used interchangeably with the term 'solder'.

SUBSTRATE METAL

Substrate metal or parent metal refers to the metal parts to be joined. In dentistry alloys that can be soldered or welded include alloys of gold, silver, palladium, nickel, cobalt, titanium, etc.

IDEAL REQUIREMENTS OF A BRAZING MATERIAL (DENTAL SOLDER)

1. It should melt at temperatures below the solidus temperature of the parent metal.
2. When melted, it should be wet and flow freely over the parent metal.
3. Its color should match that of metal being joined.
4. It should be resistant to tarnish and corrosion.
5. It should resist pitting during heating and application.

TYPES OF SOLDERS OR BRAZING MATERIALS

They may be divided into two major groups:

1. Soft solders
2. Hard solders

SOFT SOLDERS

Soft solders have low melting range of about 260°C. They can be applied by simple means like hot soldering iron. They lack corrosion resistance and so are not suitable for dental use, e.g., lead-tin alloys (plumbers solders).

HARD SOLDERS

These have a higher melting temperature and greater strength and hardness. They are melted with the help of gas blowtorches or occasionally in an electric furnace. Hard solders are more commonly used in dentistry. They are also used for industrial purposes and in the jewelry trade, e.g., gold solders and silver solders.

PRESOLDERING AND POSTSOLDERING

The term presoldering (prebrazing) refers to soldering operation performed on metal-ceramic alloys prior to ceramic firing. Postsoldering (postbrazing) refers to soldering performed on the alloy after ceramic firing. Obviously properties required of the two solders would be different. Solders used in presoldering would be required to permit ceramic bonding as well as withstand the high porcelain firing temperatures.

APPLICATIONS OF SOLDERING

In dentistry they are used as follows:

1. For soldering various types of wires in orthodontics.
2. In pedodontics, to construct various types of space maintainers.

   In fixed prosthodontics:
   - For joining of various components of fixed partial prostheses (see box below).
   - For repair of perforations in crowns and bridges.
   - To develop contact points in crowns.
   - For cutting and rejoining an ill-fitting distorted bridge.
3. In removable partial prosthodontics for soldering of clasps.

COMPOSITION

GOLD SOLDERS

In the past solders were referred to by a karat number. The numbers did not describe the gold content of the solder but rather the carat of gold alloys for which the solder was to be used. In recent years the term fineness has been

IMPROVING THE FIT OF A FIXED PARTIAL DENTURE THROUGH SOLDERING

The fit of a FPD is often improved when it is cast as *two separate pieces*. Long span FPDs are especially prone to poor fit because of distortion. The two parts of the prosthesis are tried separately in the mouth. After the operator is satisfied with the individual fit of the castings, the two pieces are assembled in the mouth and their relationship is recorded and transferred with the help of a suitable index material (impression plaster or zinc oxide eugenol or elastomers). The pieces are reassembled in the laboratory and invested using soldering investment. The parts are then joined with solder. If done correctly this technique can give superior fitting fixed partial dentures.

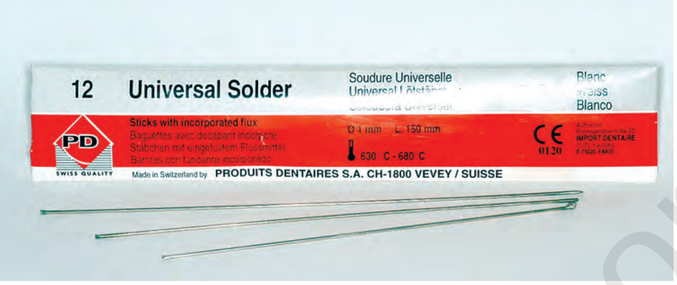


Figure 23.1: Silver solder.

substituted for karat. The composition of gold solders vary considerably depending on its fineness.

Gold – 45 to 81%
Silver – 8 to 30%
Copper – 7 to 20%
Tin – 2 to 4%
Zinc – 2 to 4%

SILVER SOLDERS

Silver solders ***(Fig. 23.1)*** are less commonly used in dentistry. They are used when a low fusing solder is required for soldering operations on stainless steel or other base metal alloys.

Silver – 10 to 80%
Copper – 15 to 50%
Zinc – 4 to 35%
Cadmium or phosphorous – may be present in small amounts

PROPERTIES OF DENTAL BRAZING MATERIALS

FUSION TEMPERATURE

The fusion temperature of the solder should be at least 50°C lower than the parent metal.

Gold solders – 690 to 870°C
Silver solders – 620 to 700°C

FLOW

A good flow and wetting (low wetting angle) of the parent metal by the solder is essential to produce a good bond.

Factors Affecting Flow

1. Melting range: Solders with short melting ranges have better flow.
2. Composition of parent metal: Gold and silver based alloys have better flow than nickel based alloys.
3. Oxides: Presence of an oxide layer on the parent metal reduces the flow.
4. Surface tension of solder.

COLOR

The color of gold solders varies from deep yellow to light yellow to white. In practice, most dental solders are able to produce an inconspicuous joint.

TARNISH AND CORROSION RESISTANCE

Tarnish resistance increases as the gold content increases. However, lower fineness gold alloys also perform well clinically without any serious tendency to discolor. Silver solders have reduced tarnish resistance when compared to gold alloy solders.

MECHANICAL PROPERTIES

Gold solders have adequate strength and hardness and are comparable to dental cast gold alloys having a similar gold content.

Silver solders also have adequate strength and are similar to the gold solders.

MICROSTRUCTURE OF SOLDERED JOINTS

Microscopic examination of an ideal well formed soldered joint shows that the solder alloy does not combine excessively with the parts being soldered. There is a well-defined boundary between the solder and the soldered parts. If the heating is prolonged a diffusion takes place and the new alloy formed has inferior properties.

FLUXES

The Latin word 'flux' means flow. For a solder to wet and flow properly, the parent metal must be free of oxides. This is accomplished with the help of a flux.

FUNCTION OF FLUX

1. To remove any oxide coating on the parent metal.
2. To protect the metal surface from oxidation during soldering.

TYPES

Fluxes may be divided into three activity types.

Protective

This type covers the metal surface and prevents access to oxygen so no oxide can form.

Reducing

This reduces any oxide present to free metal and oxygen.

Solvent

This type dissolves any oxide present and carries it away. Most fluxes are usually combination of two or more of the above.

COMMONLY USED DENTAL FLUXES

The commonly used fluxes are:

1. Boric and borate compounds
2. Fluoride fluxes

Figure 23.2: A fluoride flux for base metal alloys.

Boric and Borate Compounds

Boric acid and borax are used with noble metal alloys. They act as protective and reducing fluxes.

Fluorides

Fluoride fluxes ***(Fig. 23.2)*** like potassium fluorides are used on base metal alloys and are usually combined with borates. They help to dissolve the more stable chromium, nickel and cobalt oxides. Fluoride fluxes should be used carefully around porcelain as it can attack the porcelain.

Note Excess flux should be avoided as it can get entrapped within the filler metal and result in a weak joint.

FLUXES MAY BE SUPPLIED AS

- Liquid (applied by painting)
- Paste
- Powder
- Fused onto the solder
- Prefluxed solder in tube form.

ANTIFLUX

There are times when the operator desires that the solder should not flow out of a specific area. The flow can be controlled by use of an antiflux material. Solder will not flow into an area where antiflux has been applied. It is applied before the flux or solder is applied. Examples of antiflux are graphite (soft lead pencil), rouge (iron oxide) or whiting (calcium carbonate) in an alcohol and water suspension.

TECHNICAL CONSIDERATIONS

HEAT SOURCE

The heat source is a very important part of brazing. In dentistry, two heat sources may be used:

1. Flame 2. Oven

FLAME BRAZING OR SOLDERING

The most commonly used heat source is a gas-air or gas-oxygen torch. The flame must provide enough heat not only to melt the filler metal but also to compensate for heat loss to the surroundings. Thus, the flame should not only have a high temperature but also a high heat content. Low heat content of fuels lead to longer soldering time and more danger of oxidation. Heat content is measured in Btu per cubic foot of gas.

The Various Gases Used are

- *Hydrogen* It has the lowest heat content (275 Btu) and therefore heating would be slow ***(Fig 23.3)***. It is not indicated for soldering of large FPDs.
- *Natural gas* It has a temperature of 2680°C and heat content is four times that of hydrogen (1000 Btu). However, normally available gas is nonuniform in composition and frequently contains water vapor.

Figure 23.3: A micro flame soldering unit such as this uses hydrolysis to split water into hydrogen and oxygen which is then used as fuel for the flame.

- *Acetylene* It has the highest flame temperature (3140°C) and a higher heat content than H_2 or natural gas. However, it has certain problems. Temperature from one part of its flame to another may vary by more than 100°C. Therefore, positioning the torch is critical and proper part of the flame should be used. It is chemically unstable and decomposes readily to carbon and hydrogen. The carbon may get incorporated into the Ni and Pd alloys, and hydrogen may be absorbed by the Pd alloys.
- *Propane* It is the best choice. It has the highest heat content (2385 Btu) and a good flame temperature (2850°C).
- *Butane* It is more readily available in some parts of the world and is similar to propane. Both propane and butane are uniform in quality and water-free.

OVEN BRAZING (FURNACE BRAZING)

An electric furnace with heating coils may be used for brazing. The furnace also provides heated surroundings, so less heat is lost to other parts of the fixed partial denture and the atmosphere.

TECHNIQUE OF SOLDERING

Two techniques of dental soldering are employed to assemble dental appliances:

A. Free hand soldering
B. Investment soldering.

FREE HAND SOLDERING

In free hand soldering the parts are assembled and held in contact manually while the heat and solder are applied.

INVESTMENT SOLDERING

In investment soldering, the parts to be joined are mounted in a soldering type of investment. The hardened investment holds it in position while the heat and solder are applied.

STEPS IN SOLDERING PROCEDURE

1. Selection of solder
2. Cleaning and polishing of components

3. Assembly of the prosthesis in soldering investment
4. Application of flux
5. Preheating the bridge assembly
6. Placement of solder
7. Application of hot gas flame to joint and solder
8. Cooling of assembly followed by quenching in water.

TECHNICAL CONSIDERATIONS FOR SUCCESSFUL SOLDERING

- Cleanliness—Metal should be free of oxides
- Gap between parts
- Selection of solder—Proper color, fusion temperature, and flow
- Flux-type and amount
- Flame—Neutral or reducing in nature
- Temperature
- Time

Gap The liquid solder is drawn into the joint through capillary action. Therefore, an optimum gap is necessary for proper flow, strength of the joint and to avoid distortion of the assembly. Gap width ranging from 0.13 to 0.3 have been suggested.

If the gap is too narrow, strength is limited due to

— Porosity caused by incomplete flow

— Flux inclusion

If the gap is too great

— The joint strength will be the strength of the solder.

— There is a tendency for the parts to draw together as the solder solidifies.

Figure 23.4: A neutral or reducing flame is used.

Flame The flame has multiple zones ***(Figs 18.6 and 23.4)***. The portion of the flame that is used should be neutral or slightly reducing. An improperly adjusted or positioned flame can lead to oxidation and/or carbon inclusion. Once the flame has been applied to the joint area, it should be removed until brazing is complete. Due to its reducing nature, the flame gives protection from oxidation.

Temperature The temperature used should be the minimum required to complete the brazing operation. Prior to the placement of the solder, the parent metal is heated till it is hot enough to melt the filler metal as soon as it touches. A lower temperature will not allow the filler to wet the parent metal. A higher temperature increases the possibility of diffusion between parent and filler metal.

Time The flame is held until the filler metal has flowed completely into the connection and a moment longer to allow the flux or oxide to separate from the fluid solder. Insufficient time increases chances of incomplete filling of joint and possibility of flux inclusion in the joint. Excessive time increases possibility of diffusion. Both conditions cause a weaker joint.

PITTED SOLDER JOINTS

Pits or porosities in the solder joint often become evident during finishing. They are due to:

- *Volatilization* of the lower melting components due to heating at higher temperatures and for longer time.
- Improperly melted or excess *flux* that is *trapped* in the solder joint. To avoid such pitting, less flux is applied and the heating should be discontinued as soon as the flux and solder are well melted and flowed into position.

WELDING

The term welding is used if two pieces of similar metal are joined together *without* the addition of another metal. It is usually used to join flat structures such as bands and brackets.

INDICATIONS

1. In orthodontics to join flat structures like bands and brackets.
2. In pedodontics, to weld bands and other appliances.
3. In prosthodontics, to join wrought wire clasps and repair of broken metal partial dentures.

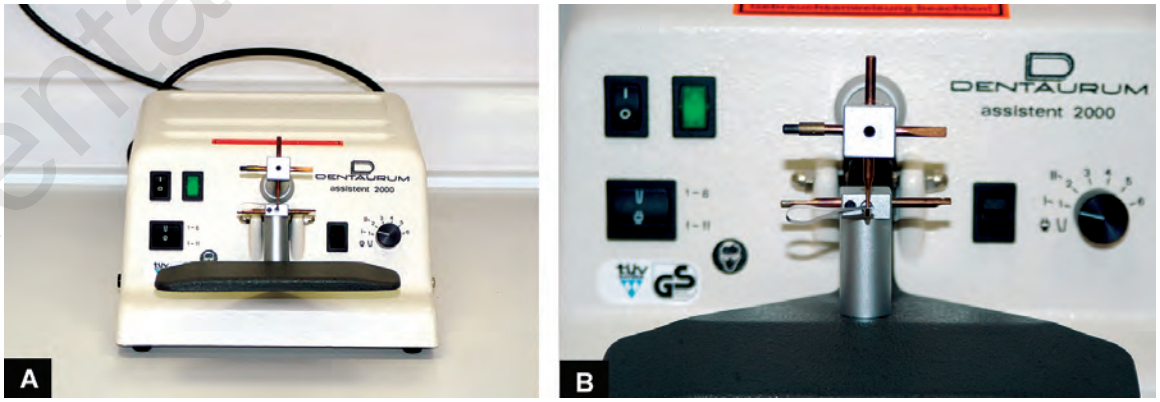
TECHNICAL CONSIDERATIONS

Welding is done by passing an *electric current* through the pieces to be joined. These pieces are also simultaneously *pressed* together. The resistance of the metal to flow of current causes *intense localized heating* and fusion of the metal. The combined heat and pressure *fuses* the metals into a single piece.

Welding is done in an *electric spot welding* apparatus ***(Figs 23.5 A and B)***. The wires or the band to be welded is placed between the two copper electrodes of the welder. A flexible spring attached to the electrode helps to apply pressure on the metals. A hand controlled switch is used to operate the welder. On pressing the switch a large current passes through the wires or band between the copper electrodes. The combined heat and pressure fuses the metal pieces at that point and joins them. This kind of welding may also be referred to as ‘spot welding’.

Prosthodontic appliances are welded in a larger machine. The parts to be joined are held together in a clamp. A hand or foot controlled switch controls the current.

Weld joints are susceptible to corrosion because of precipitation of chromium carbide and consequent loss of passivation.



Figures 23.5 A and B: (A) An electric orthodontic spot welder (B) close up of the spot welder.

LASER AND PLASMA WELDING

Laser is finding increasing applications in dentistry (see box on page 372) including welding. The laser used is a pulsed neodymium laser with a very high power density.

COMMERCIAL NAMES

- Dental laser DL 2002 (Dentaurum, Germany)
- Haas laser LKS (Haas Laser GmbH, Germany)
- Heraeus Haas laser 44P (Heraeus Kulzer GmbH, Germany)

The unit ***(Figs 23.6 A to C)*** consists of a small box that contains the laser tip, an argon gas source and a stereo microscope with lens crosshairs for correct alignment of the laser beam with the components. The maximum depth the laser can penetrate is 2.5 mm. The heat generated is small, so the parts can be hand held during welding and it can be done close to the ceramic or even resin facings without damaging it.

Figures 23.6 A to C: (A) A Laser welding unit. (B) A laser unit in operation. (C) Close-up of laser welding process.

INDICATIONS

Laser welding is used mainly to join titanium components. This is because the commercially pure titanium (cpTi) used in dentistry for fixed and removable partial denture frameworks is highly reactive in air. Ordinary soldering procedures result in a weak joint because of the formation of thick layer of titanium oxide (especially when heated above 850°C). Laser welding or plasma welding can be done at lower temperatures.

ADVANTAGES OF LASER WELDING

1. Lower heat generation.
2. Welding can be done close to resin or ceramic portions without fear of damage to these materials.
3. No oxide formation because of the inert argon atmosphere.
4. Joint made of the same pure titanium as the components, thus reducing the risk of galvanic corrosion.

CAST-JOINING

Cast-joining is an alternative method of joining metals parts that are difficult to solder such as base metal alloys. The two parts are joined by a third metal which is cast into the space between the two. The two parts are held together purely by mechanical retention which is achieved by proper flow of the new metal during casting. Therefore, if the cast metal is poorly adapted it can result in a weak joint.

The joint area is ground to make a space of at least 1 mm. Mechanical undercuts are prepared at the interphase ***(Fig. 23.7)***. The parts to be joined are assembled with the help of an index. Hard inlay casting wax is flowed into the space and a sprue is attached. The structure is then invested in a casting ring using suitable casting investment. The wax is burnt out and molten metal is cast into the space.

Figure 23.7: A mechanical interlocking design between two parts joined by cast-metal.

RADIOGRAPHIC ASSESSMENT OF JOINTS

Most prosthodontic structures are usually fabricated in commercial laboratories. The quality of the structure especially that of the joints can be assessed through a radiograph. The structure is placed on a film and exposed. It is turned 90 degrees and exposed a second time on a new film. The structure is assessed for defects like porosity and cracks especially in the joints. Porosity and other defects in the joints can weaken the restoration causing it to fail in the mouth during function. The best joints are those that are cast as one piece, followed by soldered and cast-joined.

LASER USE IN DENTISTRY

Lasers have been used in dentistry since 1994 to treat a number of dental problems. But, despite FDA approval, no laser system has received the American Dental Association's (ADA) Seal of Acceptance. That seal assures dentists that the product or device meets ADA standards of safety and efficacy, among other things. The ADA, however, states that it is cautiously optimistic about the role of laser technology in the field of dentistry. These lasers are different from the cold lasers used in phototherapy for the relief of headaches, pain, and inflammation.

Dental Applications of Laser

Tooth decay Lasers are used to remove decay within a tooth and prepare the surrounding enamel to receive the filling.

Curing Lasers are also used to "cure" or harden composite fillings.

Gum disease Lasers are used to reshape gums and eliminate pockets.

Pulpectomy Remove bacteria during root canal procedures.

Biopsy or lesion removal Lasers can be used to remove a small piece of tissue (called a biopsy) so that it can be examined for cancer. Laser are also used to remove lesions in the mouth

Pain relief Used to relieve the pain of canker sores.

Surgical procedures Like frenectomy.

Figures 23.8 A to D: (A) Waterlase; (B) Laser handpiece; (C) Laser handpiece for tooth whitening; (D) Diode hand held laser.

Teeth whitening Lasers are used to speed up the in-office teeth whitening procedures. A peroxide bleaching solution, applied to the tooth surface, is "activated" by laser energy ***(Fig. 23.8 C)***, which speeds up of the whitening process.

Welding For joining of metal parts.

How Do Lasers Work in Dentistry?

All lasers work by delivering energy in the form of light ***(Fig. 23.8 B)***. When used for surgical and dental procedures, the laser acts as a cutting instrument or a vaporizer of tissue that it comes in contact with. When used for "curing" a filling, the laser helps to strengthen the bond between the filling and the tooth. When used in teeth whitening procedures, the laser acts as a heat source and enhances the effect of tooth beaching agents.

ADVANTAGES

Compared to the traditional dental drill, lasers:

1. They may cause less pain in some instances, therefore, reducing the need for anesthesia.
2. They may reduce anxiety in patients uncomfortable with the use of the dental drill.
3. They minimize bleeding and swelling during soft tissue treatments.
4. They may preserve more healthy tooth during cavity removal.

DISADVANTAGES

1. Lasers can not be used on teeth with fillings already in place.
2. Lasers can not be used in many commonly performed dental procedures. For example, lasers can not be used to fill cavities located between teeth, around old fillings, and large cavities that need to be prepared for a crown. In addition, lasers cannot be used to remove defective crowns or silver fillings, or prepare teeth for fixed prostheses.
3. Traditional drills may still be needed to shape the filling, adjust the bite and polish the filling, even when a laser is used.
4. Lasers do not fully eliminate the need for anesthesia.
5. Laser treatment is more expensive since the cost of the laser is much higher than a dental drill. Lasers can cost between 6 to 7 times the cost of a standard drill.

Different Types of Dental Lasers Used

Many different types of lasers are used in dentistry ***(Fig. 23.8 D)***. The following lasers can be used in high powers, from a fraction of a watt to 25 watts or even more.

1. The Erbium: YAG laser possesses the potential of replacing the drill. This laser is also used to alter pigmentation in the gingival tissues, providing the patient with pink gums. This laser is commonly used to prepare the patient for a cavity filling.
2. The carbon dioxide laser can be used to perform gingivectomy and to remove small tumors. As a laser that does not require local anesthesia, it poses no discomfort for the patient and is practically a bloodless procedure.
3. The argon laser is used in minor surgery. Its gas laser releases blue-green light through a fiber-optic cable to a handpiece or microscope.
4. The Nd:YAG is used in tissue retraction, endodontics and oral surgery. This laser usually does not require anesthesia. For procedures regarding the gingival pockets, the fiber is inserted between the gingiva and the tooth to sterilize and stimulate the tissue, causing the gingiva to adhere to the neck.
5. The Diode laser ***(Fig. 23.8 D)*** introduced in the late 1990s has been effective for oral surgery and endodontic treatment. This laser also helps treat oral diseases and correct esthetic flaws. The diode is a compact laser.
6. Low level lasers are less well known, smaller and less expensive. Sometimes referred to as “soft lasers” the therapy performed by these lasers is called “low level laser therapy.” Low level lasers improve blood circulation and regenerate tissues.

WATERLASE (FROM BIOLASE)

The Waterlase ***(Fig. 23.8 A)*** combines a laser with an ultra-fine stream of water, which is capable of cutting into tooth, bone and soft tissues. As the stream of water flows into the laser beam, the water molecules become laser energized and create tiny explosions on impact with teeth or soft tissue.

24

DENTAL IMPLANT MATERIALS

Implanting a foreign material directly into the bone in order to replace missing teeth has been a goal sought since ancient times. Though many materials have been tried, currently, the vast majority of implant systems use titanium in some form.

DEFINITION

A dental implant is a material or device placed in and/or on oral tissues to support an oral prosthesis ***(GPT-8)***.

HISTORY AND DEVELOPMENT OF IMPLANTS

Man has been searching for ways to replace missing teeth for thousands of years. Ancient Egyptians used tooth shaped shells and ivory to replace teeth. The Etruscans living in what is now modern Italy, replaced missing teeth with artificial teeth carved from the bones of oxen.

Further evidence of tooth replacement was found in 1931 by an archeological team excavating in Honduras. A mandible of Mayan origin was discovered that had tooth shaped pieces of shells placed in the sockets of three missing lower incisor teeth.

Modern implant dentistry began in the early 19th century. A lot of experiments were conducted on what material would work best. Attempts were first made at implanting natural teeth from another person's mouth, but these implants failed due to infection or were rejected by the host tissue. Implants made of gold, porcelain, silver and even lead were being tried, with only a fair measure of success and little or no predictability.

As early as 1918, Greenfield devised the *Iridoplatinum root form basket implant*. Other early implants were those of Chercheve, Formiggini and others. An interesting design was the *Tripodal pin implant* of Scialom. Interestingly some of these early designs were ahead of their times. Their failure to gain widespread popularity could probably be attributed to the fact that prosthetic techniques, antibiotic use, infection control, instrumentation and impression materials had not yet advanced far enough.

One of the early pioneers in this field *Dr. A. E. Strock* in 1931, suggested using Vitallium, a metal alloy for dental implants. In 1947 *Manlio Formiggini* of Italy developed an implant made of *tantalum*. At the same time, *Raphael Chercheve* was using implants made of a *chrome-cobalt alloy*. By 1964 *commercially pure titanium* was accepted as the material of choice for dental implants. Ever since almost all dental implants are made of titanium. The body does not recognize titanium as a foreign material, resulting in less host rejection of the implant. Other areas of medicine recognize this fact and use titanium for other implants such as joint replacements and heart valves.

In the 1950s an important discovery was made which had great implications for tooth replacement therapy. During an experiment involving the study of blood circulation in animals, *Dr. Per-Ingvar Branemark* discovered that the hollow titanium rod used in the study was not retrievable when the experiment was complete. Further studies showed that the animals' bone had directly attached to the titanium surface. This phenomenon was called *osseointegration*, defined by the American Academy of Implant Dentistry as "the firm, direct and lasting biological attachment of a metallic implant to vital bone with no intervening connective tissue." This firm anchor is what makes dental implants a wonderful option for replacing teeth.

Experimentation with *implant designs*, not just those that were shaped like the tooth root, was also being done. In 1941 *Dr. Gustav Dahl* of Sweden provided a retentive mechanism for jaws that were completely edentulous. This was the introduction of the *subperiosteal implant*. Dr. Leonard Linkow of New York introduced the blade form implant in 1967. These blades came in a variety of sizes and forms and were the most widely used type of implant until the 1980s.

Implants are no longer restricted to the mouth. They have been successfully used all over the body for various roles. Whether implants are here to stay is no longer a question, but research into perfecting materials, procedures and training will continue in this exciting field of dentistry.

TYPES OF IMPLANTS

A. *Subperiosteal*—a framework that rests upon the bony ridge but does not penetrate it ***(Fig. 24.1)***.

B. *Transosteal*—penetrates completely through the mandible ***(Fig. 24.2)***.

C. *Endosseous*—partially submerged and *anchored within the bone* ***(Fig. 24.3)***.

MATERIALS USED

Metals — Stainless steel
— Cobalt-chromium-molybdenum based
— Titanium and its alloys
— Surface coated titanium

Ceramics — Hydroxyapatite
— Bioglass
— Aluminum oxide

Polymers and composites

Others — Gold, tantalum, carbon, etc.

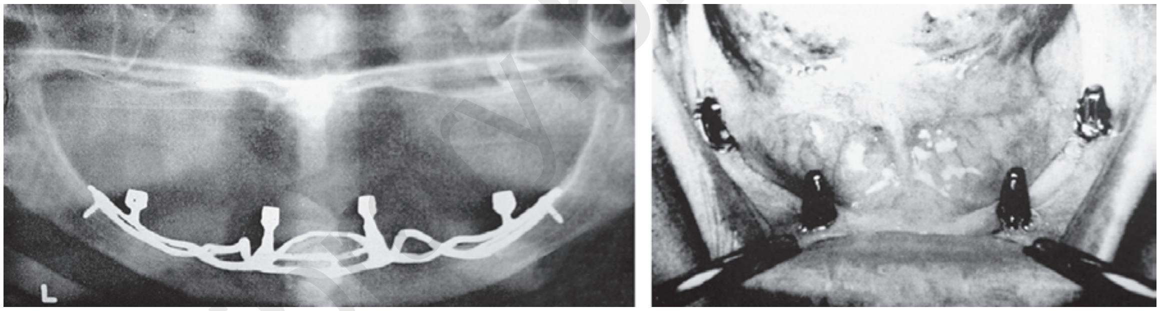


Figure 24.1: Subperiosteal implant radiograph (left); Intraoral view (right).

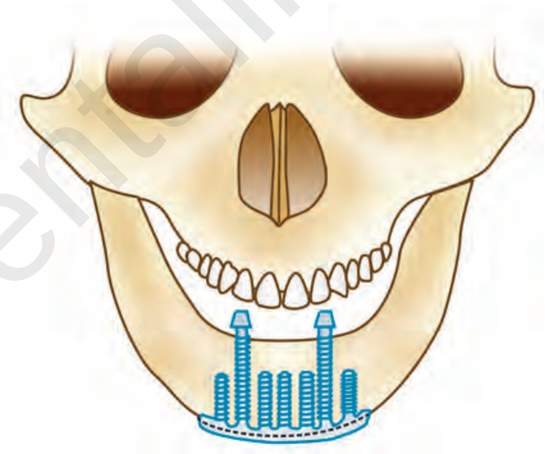


Figure 24.2: Transosteal implant.

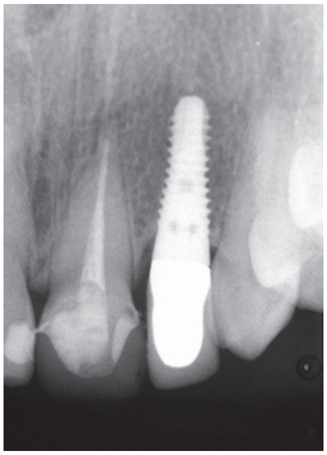


Figure 24.3: Radiograph showing an endosteal implant.

TITANIUM

Commercially pure titanium (cp Ti) is currently the most widely used material for implants ***(Fig. 24.4)***. It has become the material of choice because of its:

- Low density (4.5 gm/cm^2) but high strength.
- Minimal biocorrosion due of its passivating effect.
- Biocompatible.

Titanium also has good stiffness. Although its stiffness is only half that of steel, it is still 5 to 10 times higher than that of bone.

Titanium alloys Alloyed forms of titanium are also used. Its alloyed form contains 6 wt.% aluminum and 4 wt.% vanadium.

Surface Coated Titanium

The newer implant designs use titanium that is coated with a material that bonds and promotes bone growth (bioactive). The implant is coated with a thin layer of *tricalcium phosphate* or *hydroxyapatite* or has been *plasma sprayed*.

CERAMICS

These may be *bioactive* on *bioinert*. Their applications are still limited because of their low tensile strength and ductility. Currently they are primarily used as surface coats on titanium implants.

Bioactive, e.g.,

— Hydroxyapatite
— Bioglass (CaO, NaO, P_2O_5 and SiO_2)

Bioinert, e.g., aluminum oxide is used either in the polycrystalline form or as a single crystal (sapphire). It is well tolerated by bone but does not promote bone formation. They are available in screw or blade form and are used as abutments in partially edentulous mouths.

STAINLESS STEEL

18-8 or Austenitic steel had been tried as an implant material. It has high strength and ductility. Currently these materials are rarely used.

Precautions

Since it contains nickel, it should be avoided in nickel sensitive patients. It is most susceptible to pit and crevice corrosion so the passivating layer must be preserved. Direct contact of the implant with a dissimilar metal crown is avoided to prevent galvanism.

Figure 24.4: Four titanium screw implants in the maxillary edentulous jaw are used to support a screw retained fixed prosthesis.

POLYMERS AND COMPOSITES

Polymers have been fabricated in porous and solid forms for tissue attachment and replacement augmentation. However, in some implants they are mainly used within the implants as connectors for stress distribution (shock absorption).

OTHER MATERIALS

In the past, gold, palladium, tantalum, platinum and alloys of these metals have been used. More recently, zirconium and tungsten have been tried. Titanium has replaced most of these materials. Carbon compounds were used for root replacement in the 1970s. They are also marketed as coatings for metallic and ceramic devices.

IMPLANT PARTS

Since endosseous cylindrical root form implants are the most widely used design, subsequent discussions will focus on these. Implants can range from complex, having multiple components to more simple yet effective designs. Most endosseous implants can be divided into 2 basic parts ***(Fig. 24.5)***

- Fixture — embedded in bone
- Transmucosal abutment — supports the crown

Over the years various implant designs have been developed and used ***(Fig. 24.6)***. Currently, the most favored form is the cylindrical screw or the tapered screw. The implant is inserted through a surgical procedure. The abutment is usually

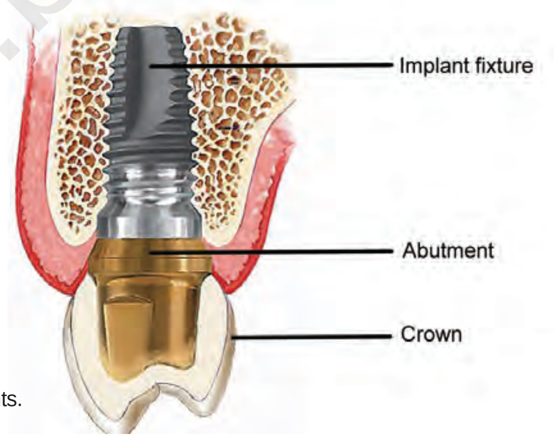


Figure 24.5: Components of endosseous implants.

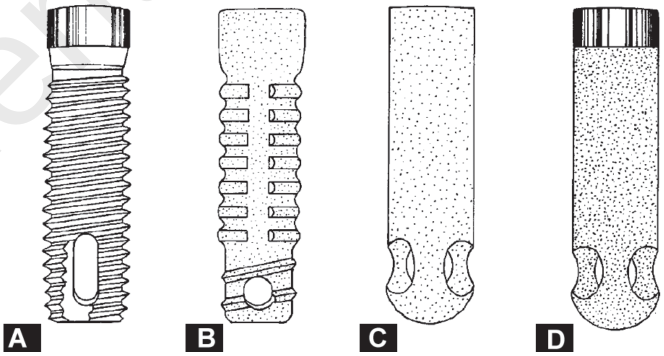


Figure 24.6: Edosseous root form implants: (A) Titanium srew; (B) Hydroxyapatite screw; (C) Hydroxyapatite; (D) Titanium plasma sprayed.

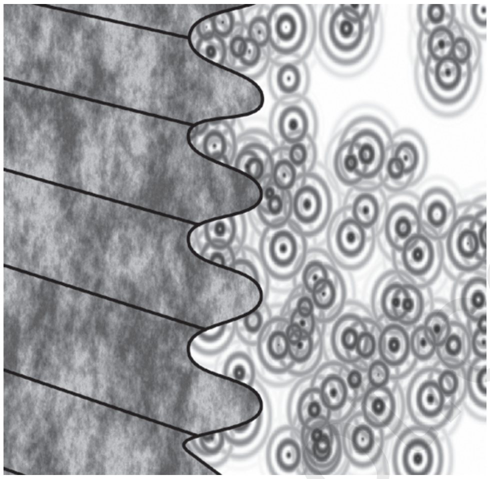


Figure 24.7: Representation of osseointegration.

screwed on to the implant at a later date. The crown is then constructed and either screwed on or cemented on to the abutment thus completing the restoration.

Implants are usually designed as a system and depending on the company various accessory components are also available. The components are usually specific for the particular system and are usually not interchageable. Some of them become part of the implant itself while others aid in the various stages of implant placement and tooth restoration. These include the drills, healing caps, impression copings, implant analogue, laboratory accessories, etc.

BIOINTEGRATION AND OSSEOINTEGRATION

For an implant to function it must integrate with the oral tissues. The term osseointegration was first described by Per Ingvar Branemark and refers to the fusion of the bone with the implant.

Defined as An apparent direct connection of an implant surface and host bone without intervening connective tissue *[GPT-8]* (***Fig. 24.7***).

Thus a direct structural and functional connection between the bone and implant allows the implant to transmit functional stresses directly to the bone.

To achieve osseointegration the bone must be viable, space between the implant and bone should be less than 10 nm and contain no fibrous tissue. Presence of fibrous tissue usually signifies failure.

Factors Favoring Osseointegration

1. Proper treatment planning
2. Atraumatic drilling of bone
3. Selection of proper implant material
4. Implant design
5. Favorable occlusal forces
6. Bone quality
7. Good oral hygiene
8. No contraindicating local or systemic factors

Other factors include the nature of the surface coating and surface configuration. Recently there has been interest in coating titanium with certain materials that actively promote a favorable bone response. These are referred to as 'bioactive'. Examples of bioactive materials are hydroxyapatite, tricalcium phosphate and bioactive glasses. Commercially available bioactive glasses include Bioglass, Ceravital, Biogran and glass ceramic A-W. These materials are generally too weak and brittle to stand alone. However, when used as a coating (50 to 75 μm) on the surface of titanium combine the strength of titanium with its bioactive qualities.

If successful the ceramic coating becomes completely fused with the surrounding bone. In this case the interphase is termed *'biointegration'* because there is no intervening space between the bone and the implant.

Implant material and design is continually evolving. With every passing year the failure rates are gradually reducing. Current implants enjoy a 95 to 98% clinical success rate. More advances in both design, material and technique may be expected in the future.

25

DENTURE RESINS AND POLYMERS

HISTORY OF DENTURES

Replacements for decaying or lost teeth have been made for thousands of years. Skillfully designed dentures were made as early as 700 BC using ivory and bone. Unfortunately, this level of technology was lost until about the 1800s. During Medieval times, dentures were seldom considered. Gaps between teeth were expected, even nobles had them. Queen Elizabeth I filled the holes in her mouth with cloth to improve her appearance in public. When dentures were installed, they were hand-carved and tied in place with silk threads. Retention of false teeth became more difficult as the number of teeth diminished in the mouth and those that wore full sets of dentures had to remove them before eating. Upper and lower plates fit poorly, and were held together by steel springs ***(Fig. 25.1)***. Many including George Washington suffered from tooth loss and unfit dentures.

The major reason that the level of technology didn't increase is because suitable materials for false teeth were hard to find. These problems began to be solved in the 1700s. In ancient times, the most common material for false teeth were animal bone or ivory, especially from elephants or hippopotamus. Human teeth were also used; pulled from the dead or sold by poor people from their own mouths ***(Fig. 25.2)***. These teeth soon rotted or decayed. Rich people got dentures made of silver, gold, mother of pearl, or agate. In 1774, Duchateau and Dubois de Chemant designed a full set of dentures that would not rot ***(Fig. 25.3)***. They were made of porcelain. Giuseppangelo Fonzi created a single porcelain tooth held in place by a steel pin in 1808. Claudius Ash made an improved porcelain tooth in 1837. Porcelain dentures moved to the United States in the 1800s. They were marketed on a large scale.

Figure 25.1: George Washington's dentures.

Figure 25.2: Ivory dentures inlaid with natural human teeth.

Figure 25.3: 18th century porcelain dentures retrieved from a grave in France.

Figure 25.4: Vulcanite dentures.

Figure 25.5: Vulcanite denture material were available in India under British rule (*Courtesy:* CODS, Manipal).

Fit and comfort eventually improved as well. In the 1700s plaster of Paris was introduced. It was used to make a mold of the patient's mouth. This helped the shape of the dentures to be more precise. Swaged gold was used as denture base for those who could afford it. There was a real breakthrough when vulcanized rubber was discovered by Charles Goodyear in 1840 ***(Fig. 25.4)***. This is a cheap, easy to work with material that could be shaped to fit the mouth and hold the denture. Vulcanite dentures were available in India under British rule primarily used by British and other European dentists of the period ***(Fig. 25.5)***. A little later celluloid was tried in place of rubber but it didn't prove to be the best material to use. The discovery of modern dental plastics and impression techniques have revolutionized denture treatment.

EARLIER DENTURE MATERIALS

Before 1937, the materials used for denture bases were vulcanite, nitrocellulose, phenol formaldehyde, vinyl plastics and porcelain.

VULCANITE

It contains rubber with 32% sulphur and metallic oxides for color.

Advantages

- Nontoxic and non-irritant
- Excellent mechanical properties
- The material is quite hard to polish.

Disadvantages

- It absorbs saliva and becomes unhygienic due to bacterial proliferation. Unpleasant odor, when processed.
- Poor esthetics due to opacity of rubber.
- Dimensional changes occur due to:
  - Thermal expansion during heating in the vulcanizer
  - Contraction of 2 to 4% by volume during addition of the sulphur to the rubber.

NITROCELLULOSE

- Dimensionally unstable
- Excessive warpage
- High water absorption
- Poor color stability (turns from pink to green with time)
- Contains unpleasant tasting plasticizers.
- Highly flammable

PHENOL FORMALDEHYDE

Becomes discolored and unesthetic and being thermosetting it is difficult to repair.

PORCELAIN

Porcelain was tolerated by denture bearing mucosa but was difficult to fabricate and easily broken.

CLASSIFICATION OF DENTURE BASE MATERIALS

I. Denture Base Materials

- Metallic
  - e.g., Acrylic resins
  - Vinyl resins
- Non-Metallic
  - e.g., Cobalt chromium
  - Gold alloys
  - Stainless steel

II. Denture Base Materials

- Temporary
  - e.g., Self cure acrylics
  - Shellac base plate
  - Base plate wax
  - Injection molded resins
  - Metallic bases
- Permanent
  - e.g., Heat cure denture resins
  - Light cured resins
  - Pour type resins

III. ANSI/ ADA Classification (Sp. No. 12/ ISO 1567)

- Type I – Heat polymerizable polymers
  - Class 1 – Powder and liquid
  - Class 2 – Plastic cake
- Type 2 – Autopolymerizable polymers
  - Class 1 – Powder and liquid
  - Class 2 – Powder and liquid pour-type resins
- Type 3 – Thermoplastic blank or powder
- Type 4 – Light activated materials
- Type 5 – Microwave-cured materials

SYNTHETIC RESINS

Modern living has been greatly influenced by synthetic plastics. Originally they were laboratory nuisances - waxy, sticky residues left after certain organic reactions. These resinous materials composed of giant molecules attracted the attention of chemists giving rise to the field of plastics. Synthetic plastics are nonmetallic compounds which are molded into various forms and then hardened for commercial use (e.g., clothing, electronic equipment, building materials and household appliances). These materials are composed of polymers or complex molecules of high molecular weight.

A variety of resins are used in dentistry. These include acrylics, polycarbonates, vinyl resins, polyurethanes, styrene, cyanoacrylates, epoxy resins, etc.

CLASSIFICATION OF RESINS

Due to their heterogenous structure and complex nature they are difficult to classify. *Based on the thermal behavior,* they are classified as

- Thermoplastic
- Thermosetting

THERMOPLASTIC

These are resins that *can be repeatedly* softened and molded under heat and pressure without any chemical change occurring. They are fusible and are usually soluble in organic solvents. Most resins used in dentistry belong to this group, e.g., polymethyl methacrylate, polyvinyl acrylics and polystyrene.

THERMOSETTING

This category refers to resins which can be molded only once. They set when heated. These cannot be softened by reheating like the thermoplastic resins. They are generally infusible and insoluble.

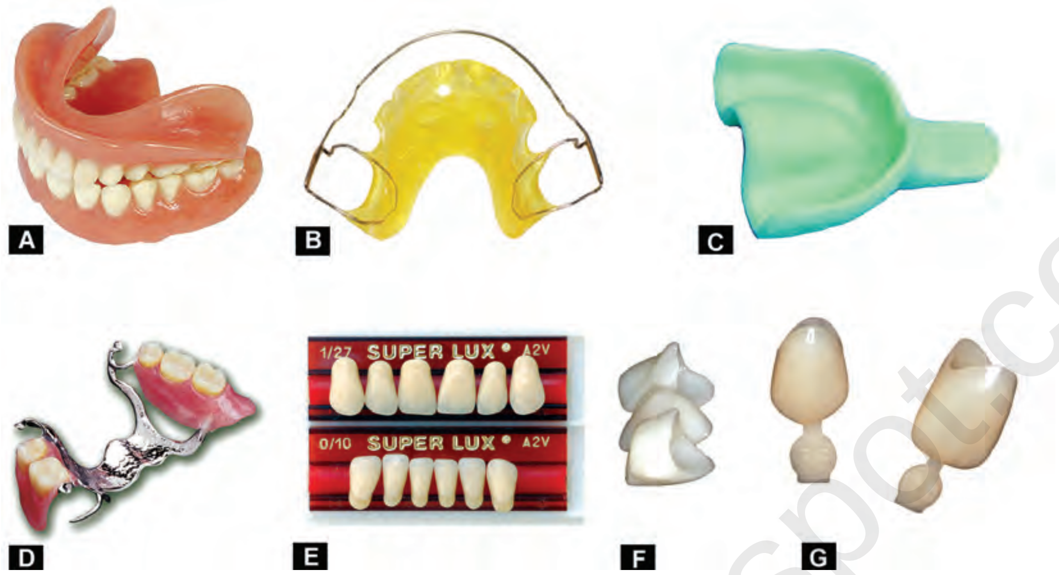
IDEAL REQUIREMENTS OF DENTAL RESINS

Dental resins, both restorative and denture base should:

1. Be tasteless, odorless, nontoxic and non-irritant to the oral tissues.
2. Be esthetically satisfactory, i.e., should be transparent or translucent and easily pigmented. The color should be permanent.
3. Be dimensionally stable. It should not expand, contract or warp during processing and subsequent use by the patient.
4. Have enough strength, resilience and abrasion resistance.
5. Be insoluble and impermeable to oral fluids.
6. Have a low specific gravity (light in weight).
7. Tolerate temperatures well above the temperature of any hot foods or liquids taken in the mouth without undue softening or distortion.
8. Be easy to fabricate and repair.
9. Have good thermal conductivity.
10. Be radiopaque (so that denture/ fragments can be detected by X-rays if accidentally aspirated or swallowed and also to examine the extensions of the resin restoration in a tooth).
11. When used as a filling material it should:
    — Bond chemically with the tooth.
    — Have coefficient of thermal expansion which match that of tooth structure.
12. Be economical.

USES OF RESINS IN DENTISTRY

1. Fabrication of dentures (denture base resins) ***(Fig. 25.6 A and D)***
2. Artificial teeth (cross-linked acrylic resins) ***(Fig. 25.6 E)***
3. Tooth restoration, e.g., fillings, inlays and laminates (composite resins)
4. Cementation of orthodontic brackets, crowns and FPDs (resin cements)
5. Orthodontic and pedodontic appliances ***(Fig. 25.6 B)***
6. Crown and FPD facings (tooth colored acrylic or composite resins)
7. Maxillofacial prostheses (e.g., obturators for cleft palates)
8. Inlay and post-core patterns (pattern resins)
9. Dies (epoxy resins)
10. Provisional restorations ***(Fig. 25.6 F)*** in fixed prosthodontics [tooth colored resins, provisional composites and polycarbonate crowns ***(Fig. 25.6 G)***]
11. Endodontic and core filling material
12. Athletic mouth protectors
13. Custom impression trays ***(Fig. 25.6 C)***



Figures 25.6 A to G: (A) Dentures (B) Orthodontic appliance (C) Acrylic custom tray (D) Removable partial denture (E) Resin artificial denture teeth (F) Temporary bridge (G) Polycarbonate crowns.

14. Splints and stents
15. Models

NATURE OF POLYMERS

POLYMER

A polymer is large and often complex macromolecule that is made from smaller molecules. A macromolecule is any chemical possessing a molecular weight greater than 5000. Some polymers have weights in excess of 50 million. The *mer* ending represents the simplest repeating chemical structural unit from which the polymer is composed, e.g., poly (methyl methacrylate) is a polymer having chemical structural units derived from methyl methacrylate.

MONOMER

The molecules from which the polymer is constructed are called monomers (one part). Polymer molecules may be prepared from a mixture of different types of monomers and they are called copolymers.

MOLECULAR WEIGHT

The molecular weight of the polymer molecule equals the molecular weight of the various *mers* multiplied by the number of mer units. They may range from thousands to millions of units depending on preparation conditions. The molecular weight of polymers plays an important role in determining its physical properties. The average molecular weight for various denture polymers range from 8000 to 39000. Cross-linked resin teeth may have weights in excess of 600,000.

DEGREE OF POLYMERIZATION

Defined as total number of mers in a polymer.

— The higher the molecular weight of the polymer made from a single monomer, the higher the degree of polymerization.

— The strength of the resin increases with increase in the degree of polymerization until a certain molecular weight is reached. Above this there is no change.

MOLECULAR WEIGHT DISTRIBUTION

A narrow molecular weight distribution gives the most useful polymers. However most polymers have a wide range of molecular weights and so vary widely in their properties, e.g., the higher the molecular weight, the higher the softening and melting points and the stiffer the plastic.

STRUCTURE OF POLYMERS (SPATIAL STRUCTURE)

The physical structure of the polymer molecule is also important in determining the properties of the polymer. There are three basic structures.

LINEAR

Here the 'mer' units are connected to each other in a linear sequence ***(Fig. 25.7)***. They can be further divided into:

Linear homopolymer: It has mer units of the same type.

...– M – M – M – M – M – M – M – ...

Random copolymer of linear type: It has two types of mer units, randomly distributed along the chain.

...– M – M – M – Y – M – Y – M – M – Y – Y – M – M –...

Block copolymer: It has two types of mers distributed in segments or blocks.

... – M – M – M –...– M – M – Y – Y –...– Y – Y – M – M – ...

Homopolymer

Random copolymer

Block copolymer

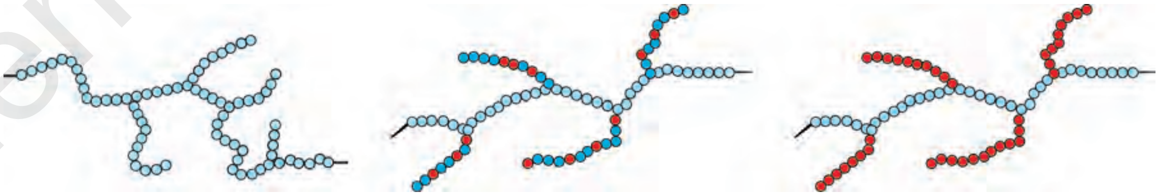
Figure 25.7: Structure of linear polymers.

BRANCHED

Linear molecules are rarely realized. In practice the mer units are arranged in a branched fashion or cross-linked ***(Fig. 25.8)***.

Branched homopolymer: The mer units are of the same type.

... – M – M – M – M – M – ... – M – M – M – M – M – ...
: :
M M
: :
M M



Branched homopolymer

Branched random

Branched graft

Figure 25.8: Structure of branched polymers.

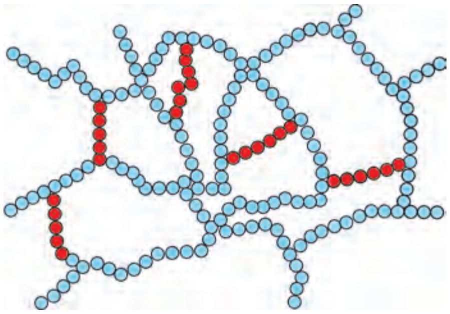


Figure 25.9: Cross-linked polymer.

Random copolymer of branched type: It has two types of mer distributed randomly.

```
... – M – M –  M – M – M – ... – M – M – M – M – M – ...
               :                                :
               M                                Y
               :                                :
               M                                M
               :                                :
               Y                                Y
               :                                :
```

Graft copolymer of branched type: It has one type of mer unit on the main chain and another mer for the branches.

```
... – M – M – M – M – M – ... – M – M – M – M – M – ...
              :                        :
                                       Y
              :                        :
              Y                        Y
              :                        :
```

CROSS LINKED POLYMER

It is made up of a homopolymer cross linked with a single cross-linking agent. It is a network structure ***(Fig. 25.9)***.

```
... – M – M – M –Y – M – M – M – M –Y – ...
                 :
                 Y
                 :
                 Y
                 :

             ... – M –Y – M – M – M – M –Y – ...
                      :                  :
                      Y                  Y
                      :                  :
                      Y                  Y
                      :                  :
             ... – M –Y – M – M – M – M – Y – ...
```

POLYMERIZATION—CHEMISTRY

The term polymerization refers to a series of chain reactions by which a macromolecule or polymer is formed from a group of smaller single molecules known as ‘monomer’. These structural units are connected to each other within the polymer molecules by bonds. Polymerization is a repetitive intermolecular reaction that is capable of proceeding indefinitely.

TYPES

Most polymerization reactions fall into two basic types.

Condensation Polymerization (Step growth)

Condensation resins are divided into two groups:

- Those in which polymerization is accompanied by repeated elimination of small molecules, i.e., the primary compounds react with the formation of by-products such as water, halogen acids, and ammonia. The process can repeat itself and form macromolecules.
- Those in which functional groups are repeated in the polymer chains. The mers are joined by functional groups (like amide, urethane, ester or sulfide linkages). Formation of a by-product is not necessary, e.g., polyurethane.

In the past several condensation resins have been used to make denture bases. At present, condensation resins are not widely used in dentistry.

Addition Polymerization

Most resins employed extensively in dental procedures are produced by addition polymerization. Here, there is no change in chemical composition and no by-products are formed. In this type of polymer, the structure of the monomer is repeated many times in the polymer.

Starting from an active center, one molecule at a time is added and a chain rapidly builds up, which can grow almost indefinitely as long as the supply of building blocks is available.

CHEMICAL STAGES OF POLYMERIZATION

Occurs in four stages:

Induction

Induction or initiation period is the time during which the molecules of the initiator becomes energized or activated and start to transfer the energy to the monomer. Any impurity present increases the length of this period. The higher the temperature, the shorter is the length of the induction period. The initiation energy for activation of each monomer molecular unit is 16000-29000 calories per mol in the liquid phase.

There are three induction systems for dental resins:

- *Heat activation* Most denture base resins are polymerized by this method, e.g., the free radicals liberated by heating benzoyl peroxide will initiate the polymerization of methyl methacrylate monomer.
- *Chemical activation* This system consists of at least two reactants, when mixed they undergo chemical reaction and liberate free radicals, e.g., the use of benzoyl peroxide and an aromatic amine (dimethyl-p-toluidine) in self-cured dental resins.
- *Light activation* In this system, photons of light energy activate the initiator to generate free radicals, e.g., camphoroquinone and an amine will react to form free radicals, when they are irradiated with visible light.

Propagation

Once the growth has started only 5000 to 8000 calories per mole are required, the process continues rapidly and is accompanied by evolution of heat.

Theoretically, the chain reactions should continue with evolution of heat until all the monomer has been changed to polymer. In reality however, the polymerization is never complete.

Termination

The chain reactions can be terminated either by direct coupling of two chain ends or by exchange of a hydrogen atom from one growing chain to another.

Chain Transfer

The chain termination can also result from chain transfer. Here the active state is transferred from an activated radical to an inactive molecule and a new nucleus of growth is created. An already terminated chain can be reactivated by chain transfer resulting in continued growth.

INHIBITION OF POLYMERIZATION

Such reactions are inhibited by:

- *Impurities* Impurities react with the activated initiator or any activated nucleus, or with an activated growing chain to prevent further growth, e.g., hydroquinone (0.006%). It is added to prevent polymerization of the monomer during storage.
- *Oxygen* Presence of oxygen (air) also inhibit polymerization.

COPOLYMERIZATION

The macromolecule may be formed by polymerization of a single type of structural unit. However, in order to improve the physical properties, it is often advantageous to use two or more *chemically different* monomers as starting materials. The polymers thus formed may contain units of these monomers. Such a polymer is called a copolymer and its process of formation is known as copolymerization.

TYPES OF COPOLYMERS

There are three different types ***(Fig. 25.10)***.

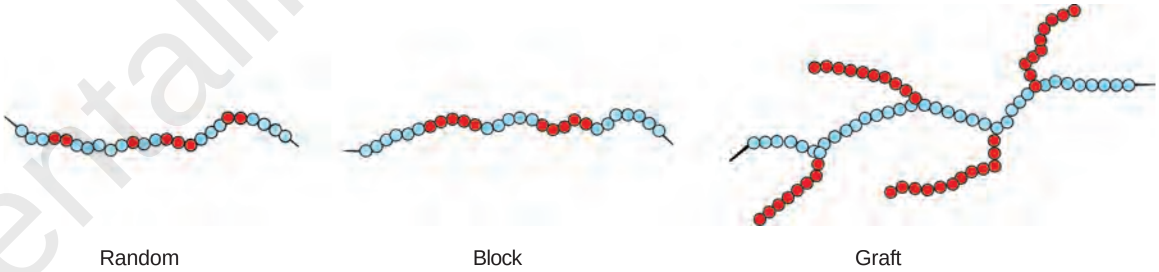


Figure 25.10: Types of copolymers.

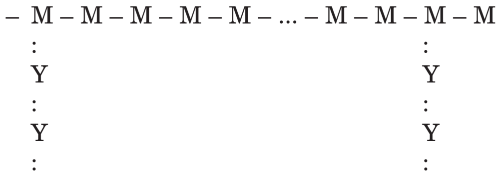
Random Type

In random type of copolymer the different *mers* are randomly distributed along the chain, such as:

– M – M – M – M – Y – M – Y – M – Y – Y – M – M –

Graft Type

In graft copolymers, sequence of one of the monomers are grafted onto the ‘backbone’ of the second monomer species.



$$\begin{array}{ccccc} - & \mathrm{M} & -\mathrm{M}-\mathrm{M}-\mathrm{M}-\mathrm{M}-\ldots-\mathrm{M}-\mathrm{M}- & \mathrm{M} & -\mathrm{M} \\ & \vdots & & \vdots & \\ & \mathrm{Y} & & \mathrm{Y} & \\ & \vdots & & \vdots & \\ & \mathrm{Y} & & \mathrm{Y} & \\ & \vdots & & \vdots & \end{array}$$

Block Type

In a block copolymer, identical monomer units occur in relatively long sequences along the main polymer chain.

$$\ldots-\mathrm{M}-\mathrm{M}-\mathrm{M}-\mathrm{M}-\ldots-\mathrm{M}-\mathrm{M}-\mathrm{Y}-\mathrm{Y}-\mathrm{Y}-\ldots-\mathrm{Y}-\mathrm{Y}-\mathrm{M}-\mathrm{M}-\ldots$$

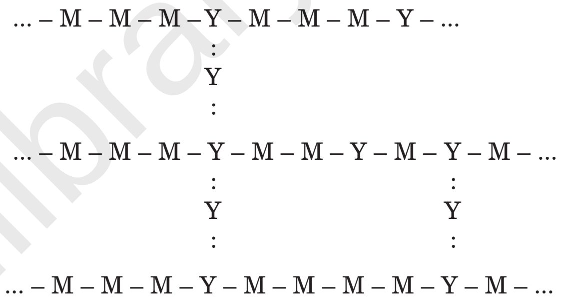
IMPORTANCE OF COPOLYMERIZATION

Copolymerization is used to improve the physical properties of resins. Many useful resins are manufactured by copolymerization.

- Small amounts of ethyl acrylate may be copolymerized with methyl methacrylate to alter the flexibility.
- Block and graft polymers show improved impact strength. In small amounts they modify the adhesive properties of resins as well as their surface characteristics.

CROSS-LINKING

The formation of chemical bonds or bridges between the polymer chains is referred to as cross-linking. It forms a three-dimensional network.



$$\begin{array}{lcccl} \ldots-\mathrm{M}-\mathrm{M}-\mathrm{M}- & \mathrm{Y} & -\mathrm{M}-\mathrm{M}-\mathrm{M}-\mathrm{Y}-\ldots & & \\ & \vdots & & & \\ & \mathrm{Y} & & & \\ & \vdots & & & \\ \ldots-\mathrm{M}-\mathrm{M}-\mathrm{M}- & \mathrm{Y} & -\mathrm{M}-\mathrm{M}-\mathrm{Y}-\mathrm{M}- & \mathrm{Y} & -\mathrm{M}-\ldots \\ & \vdots & & \vdots & \\ & \mathrm{Y} & & \mathrm{Y} & \\ & \vdots & & \vdots & \\ \ldots-\mathrm{M}-\mathrm{M}-\mathrm{M}- & \mathrm{Y} & -\mathrm{M}-\mathrm{M}-\mathrm{M}-\mathrm{M}- & \mathrm{Y} & -\mathrm{M}-\ldots \end{array}$$

APPLICATIONS

1. The more recent acrylic resins are of cross-linked variety. Cross-linking increases rigidity and decreases solubility and water sorption.
2. Acrylic teeth are highly cross-linked to improve its resistance to solvents, crazing and surface stresses.

PLASTICIZERS

These are substances added to resins:

1. To increase the solubility of the polymer in the monomer.
2. To decrease the brittleness of the polymer.

However, it also decreases strength, hardness, and softening point.

TYPES

They are of two types:

1. *External* It penetrates between the macromolecules and neutralizes the secondary bonds or intermolecular forces. It is an insoluble high boiling compound. It is not so widely used as it may evaporate or leach out during normal use of the resin.
2. *Internal* Here, the plasticizing agent is part of the polymer. It is done by copolymerization with a suitable comonomer.

ACRYLIC RESINS

The acrylic resins are derivatives of ethylene and contain a vinyl group in their structural formula. The acrylic resins used in dentistry are the esters of:

1. Acrylic acid, $CH_2 = CHCOOH$
2. Methacrylic acid, $CH_2 = C(CH_3)COOH$

The acrylic resins were so well received by the dental profession that by 1946, it largely replaced the earlier denture base materials like vulcanite.

POLY (METHYL METHACRYLATE) RESINS

These are widely used in dentistry to fabricate various appliances. One of the reasons for its wide popularity is the ease with which it can be processed. Although, it is a thermoplastic resin, in dentistry it is not usually molded by thermoplastic means. Rather, the liquid (monomer) methylmethacrylate is mixed with the polymer (powder). The monomer plasticizes the polymer to a dough-like consistency which is easily molded.

TYPES

Based on the method used for its activation:

- Heat activated resins
- Chemically activated resins
- Light activated resins

HEAT ACTIVATED DENTURE BASE ACRYLIC RESINS

Heat activated polymethyl methacrylate resins are the most widely used resins for the fabrication of complete dentures.

AVAILABLE AS

(1) Powder and liquid ***(Fig. 25.11)***. (2) Gels—sheets and cakes.

The powder may be transparent or tooth colored or pink colored (to simulate the gums, some even contain red fibers to duplicate blood vessels). The liquid (monomer) is supplied in tightly sealed amber colored bottles (to prevent premature polymerization by light or ultraviolet radiation on storage).

Commercial names: Stellon (DPI), Lucitone (Bayer), Trevelon (Dentsply).

Figure 25.11: Heat cured denture base acrylic.

COMPOSITION

Liquid

Methyl methacrylate	Plasticizes the polymer
Dibutyl phthalate	Plasticizer
Glycol dimethacrylate (1-2%)	Cross-linking agent (reduces crazing)
Hydroquinone (0.006%)	Inhibitor-prevents premature polymerization

Powder

Poly (methyl methacrylate)	Major component
Ethyl or butyl methacrylate (5%)	Copolymers - improves properties
Benzoyl peroxide	Initiator
Compounds of mercuric sulfide, cadmium sulfide, etc.	Dyes
Zinc or titanium oxide	Opacifiers
Dibutyl phthalate	Plasticizer
Inorganic fillers like glass fibers, zirconium silicate, alumina, etc.	Improves physical properties like stiffness etc.
Dyed synthetic nylon or acrylic fibers	To simulate small capillaries

POLYMERIZATION REACTION

Polymerization is achieved by application of heat and pressure. The simplified reaction is:

$$\underset{\text{(Polymer)}}{\text{Powder}} + \underset{\text{(Monomer)}}{\text{Liquid}} + \underset{\text{(External)}}{\text{Heat}} \longrightarrow \text{Polymer} + \underset{\text{(Reaction)}}{\text{Heat}}$$

TECHNICAL CONSIDERATIONS

Complete and partial dentures are usually fabricated by one of the following techniques.

1. Compression molding technique (usually heat activated resins)

2. Injection molding technique (heat activated resins)
3. Fluid resin technique (chemically activated resins)
4. Visible light curing technique (VLC resins)

COMPRESSION MOLDING TECHNIQUE

This is the commonly used technique in the fabrication of acrylic resin dentures.

Resin used Usually heat activated acrylic resin.

Steps

1. Preparation of the waxed denture pattern.
2. Preparation of the split mold.
3. Application of separating medium.
4. Mixing of powder and liquid.
5. Packing.
6. Curing.
7. Cooling.
8. Divesting, finishing and polishing.

Preparation of a Waxed Denture Pattern

Many structures in dentistry are constructed using a *wax pattern*. The structure to be created (in this case a denture) is first constructed in wax. The wax portions will be replaced later with acrylic.

Preparation of the Split Mold

The waxed denture is *invested* in a dental flask with dental stone or plaster (also called flasking) using a 3 pour technique ***(Fig. 25.12)***. After the stone or plaster sets, it is dewaxed by placing the flask in boiling water for not more than 5 minutes. After dewaxing the two halves of the flask are separated and the molten wax is flushed out with clean hot water. Removal of the wax leaves us with an empty space or mold into which soft acrylic is packed ***(Figs 25.14 A and B)***. Acrylic replaces the wax, assuming the shape of the final denture.

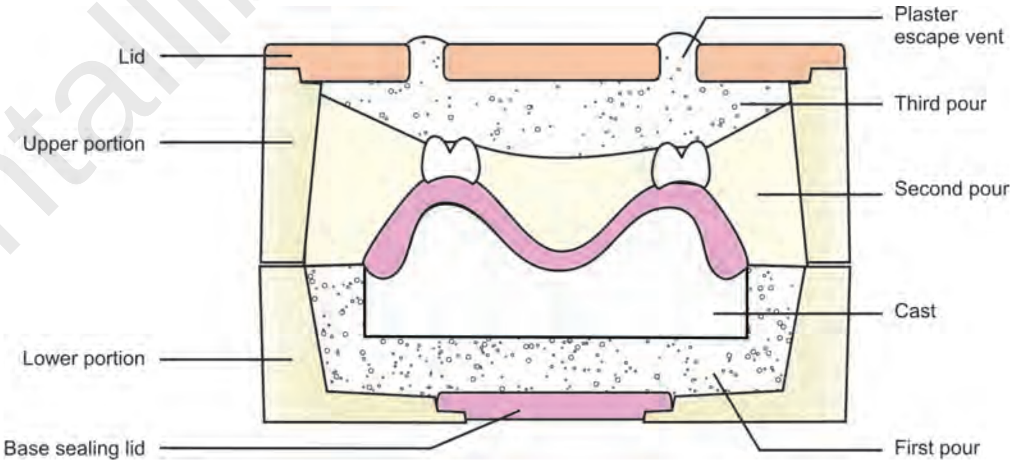


Figure 25.12: Schematic diagram of a fully assembled Hanau denture flask. The three pour technique of dental stone helps in easier retrieval of the denture, minimizing the risk of fracture.

Application of Separating Medium

The resin must not contact the gypsum surface while curing.

1. To prevent water from the mold entering into the acrylic resin. This may affect the rate of polymerization and color. It can also result in crazing.
2. To prevent monomer penetrating into the mold material, causing plaster to adhere to the acrylic resin and producing a rough surface.
3. Helps in easier retrieval of the denture from the mold.

Types of Separating Media

Various separating media used are:

- Tinfoil
- Cellulose lacquers
- Solution of alginate compounds
- Calcium oleate
- Soft soaps
- Sodium silicate
- Starches

Tin Foil

Tin foil was the material used earlier and was very effective. However, its manipulation is time consuming and difficult. It has been largely replaced by other separating media known as 'tin foil substitutes'.

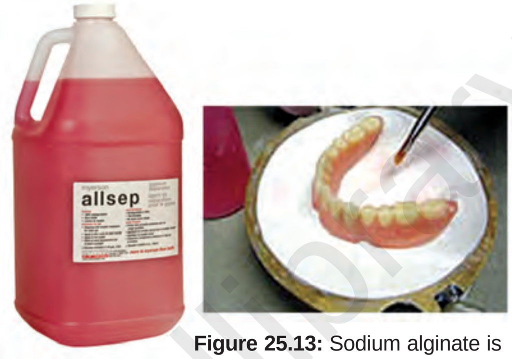


Figure 25.13: Sodium alginate is a popular separating media.

Sodium Alginate Solution (Fig. 25.13)

This is the most popular separating medium. It is water soluble. It reacts with the calcium of the plaster or stone to form a film of insoluble calcium alginate.

Composition

2% sodium alginate in water, glycerine, alcohol, sodium phosphate and preservatives.

Precautions to be Taken

1. Waxes or oils remaining on the mold surface will interfere with the action of the separating medium.
2. Mold should be warm, not hot. Continuity of the film will break if the mold is steaming hot.
3. Avoid coating the teeth as it will prevent bonding of teeth with denture base.

Application

Separating media is applied using a brush, coating only the plaster surfaces, and not the acrylic teeth. One or two coats may be applied.

Mixing of Powder and Liquid

Polymer—monomer proportion = 3:1 by volume or 2:1 by weight.

The measured liquid is poured into a clean, dry mixing jar. Powder is slowly added allowing each powder particle to become wetted by monomer. The mixture is then stirred and allowed to stand in a closed container.

If too much monomer is used (Lower polymer/monomer ratio)

- There will be greater curing or polymerization shrinkage.
- More time is needed to reach the packing consistency.
- Porosity can occur in the denture.

If too little monomer is used (Higher polymer/monomer ratio)

- Not all the polymer beads will be wetted by monomer and the cured acrylic will be granular.
- Dough will be difficult to manage and it may not fuse into a continuous unit of plastic during processing.

Physical Stages

After mixing the material goes through various physical stages. No polymerization reaction takes place during these stages. A plastic dough is formed by a partial solution of the polymer in the monomer.

Stage I

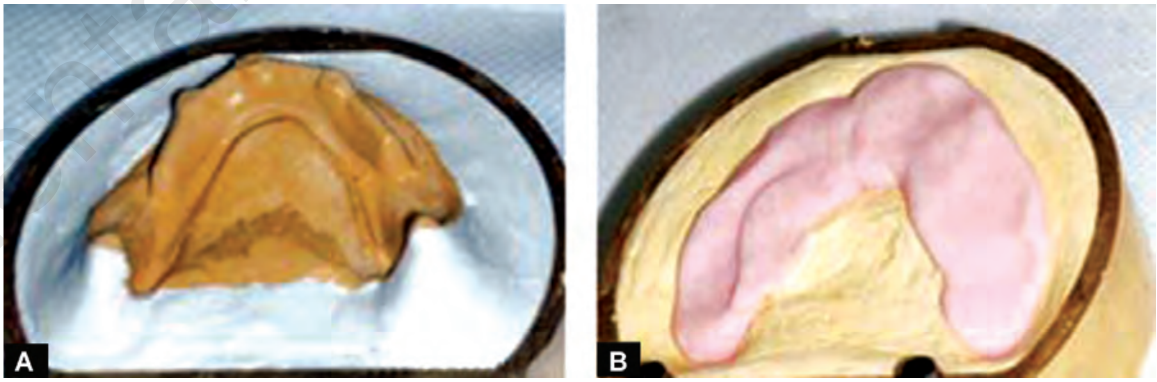
Wet sand stage The polymer gradually settles into the monomer forming a fluid, incoherent mass.

Stage II

Sticky stage The monomer attacks the polymer by penetrating into the polymer. The mass is sticky and stringy (cobweb like) when touched or pulled apart.

Stage III

Dough or gel stage As the monomer diffuses into the polymer, it becomes smooth and dough like. It does not adhere to the walls of the jar. It consists of undissolved polymer particles suspended in a plastic matrix of monomer and dissolved polymer. The mass is plastic and homogenous and can be *packed* into the mold at this stage ***(Fig. 25.14 B)***.



Figures 25.14 A and B: (A) Lower half of flask containing invested cast. (B) Upper half of flask containing packed acrylic dough. The two halves are closed and ready for trial closure in a hydraulic press.

Stage IV

Rubbery stage The monomer disappears by further penetration into the polymer and/or evaporation. The mass is rubberlike, non-plastic and cannot be molded.

Stage V

Stiff stage The mass is totally unworkable and is discarded.

Working Time

The working time is the time elapsing between stage II and the beginning of stage IV, i.e., the time the material remains in the dough stage (according to ADA Sp. No. 12, the dough should be moldable for at least 5 minutes).

The working time is affected by temperature. In warm weather when the working time is insufficient, the mixing jar is chilled to prolong the working time. Care is taken to avoid moisture.

Packing

The powder-liquid mixture should be packed into the flask at the dough consistency for several reasons:

- If it is packed at the sandy or stringy stages, too much monomer will be present between the polymer particles, and the material will be of too low a viscosity to pack well and will flow out of the flask too easily. Packing too early may also result in porosity in the final denture base.
- If packed at the rubbery to the stiff stage, the material will be too viscous to flow and metal to metal contact of the flask halves will not be obtained. Delayed packing may result in movement or fracture of the teeth, loss of detail and increase in the vertical height of the denture.

Trial Closure

The acrylic dough is packed into the flask in slight excess. The excess is removed during trial packing with a damp cellophane or polyethylene film used as a separator for the upper half of the flask. A *hydraulic or mechanical press* may be used to apply pressure ***(Fig. 25.15)***. The closing force is applied slowly during the trial packing to allow the excess dough, known as 'flash' ***(Fig. 25.16)*** to flow out between the halves of the flask. The flask is opened and the flash is trimmed away. Before final closure, the separating film is removed and discarded. The final closure of the flask or metal to metal contact of the flask halves is then completed in the press. The flasks are then transferred to a holding clamp ***(Fig. 25.16)*** which maintains the pressure throughout the curing process.

Figure 25.15: A hydraulic press (Kavo) is useful for trial and final closure of the flask. The pressure indicator dial indicates the pressure that is applied.

Figure 25.16: Assembled flasks after final closure in a holding clamp. (Excess acrylic called flash is evident in the picture).

Curing (Polymerization)

After final closure the flasks, are kept at room temperature for 30 to 60 minutes (sometimes called *'bench curing')*.

Purpose of Bench Curing

1. Permits an equalization of pressures throughout the mold.
2. It allows time for a more uniform dispersion of monomer throughout the mass of dough, since the last material added is usually drier than the first added to the flask.
3. It provides a longer exposure of resin teeth to the monomer in the dough, producing a better bond of the teeth with the base material.

Curing Cycle

The curing or polymerization cycle is the technical name for the heating process used to control the initial propagation of polymerization in the denture mold. The curing cycle selected depends on the thickness of the resin.

Following are the recommended curing cycles.

- Heat the flask in water at 60-70°C for 9 hours (long cycle).
- Heat the flask at 65°C for 90 minutes, then boil for 1 hour for adequate polymerization of the thinner portions (short cycle).

Electrically controlled curing baths are available which enable better control of the curing process ***(Fig. 25.17)***.

Figure 25.17: An automated curing bath (Kavo). The time and temperature of the curing cycle can be preset and regulated for optimum cure.

Cooling

The flask should be cooled slowly, i.e., bench cooled. Fast cooling can result in warpage of the denture due to differential thermal contraction of the resin and gypsum mold. Cooling *overnight* is ideal. However, bench cooling it for 30 minutes and then placing it in cold tap water for 15 minutes is satisfactory.

Deflasking

The cured acrylic denture is retrieved from the flask. This is called deflasking. The flask is opened and the mold is retrieved. The mold separates quickly, because the surrounding plaster was poured in layers (3 pour technique). Plaster cutting forceps may be used to break-up the plaster. Deflasking has to be done with great care to avoid flexing and breaking of the acrylic denture.

Finishing and Polishing

The denture is smoothened using progressive grades of sandpaper. Finely ground pumice in water is commonly used for final polishing (refer Abrasives).

INJECTION MOLDING TECHNIQUE

Resin used A special thermoplastic resin (Ivoclar) is available for this technique.

Figure 25.18: Injection molded denture resin technique. The picture shows the denture invested in a special flask. The lower denture utilizes a Y shaped sprue as shown by the operator.

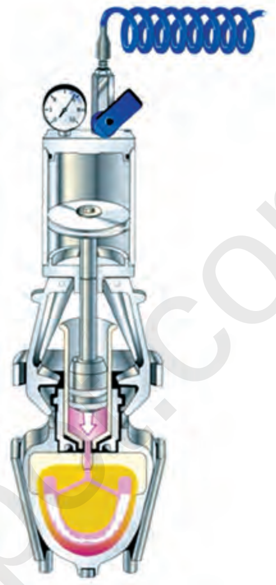


Figure 25.19: Schematic representation of the Injection molding process (Ivocap).

Equipment This technique uses special equipment including a special bath for curing ***(Figs 25.18 and 25.19)***. A sprue hole and a vent hole are formed in the gypsum mold. The soft resin is contained in the injector and is forced into the mold space as needed. It is kept under pressure until it has hardened. Continuous feeding of the material under pressure compensates for shrinkage.

There is no difference in accuracy or physical properties as compared to compression molding technique.

SOURCES OF HEAT

Apart from the heated water bath, there are other methods of supplying heat:

- Steam
- Dry air oven
- Dry heat (electrical)
- Infrared heating
- Induction or dielectric heating
- Microwave radiation.

MICROWAVE ENERGY POLYMERIZATION

Advantages

1. It is cleaner and faster than the conventional hot water.
2. The fit of the denture is comparable or superior.

Advantages

1. Dimensional accuracy (low shrinkage).
2. No increase in vertical dimension.
3. Homogeneous denture base.
4. Low free monomer content.
5. Good impact strength.

Disadvantages

1. High cost of equipment.
2. Difficult mold design problems.
3. Less craze resistance.
4. Special flask is required.

Table 25.1

Comparison of self cured and heat cured acrylic resin

Self cured	*Heat cured*
Heat is not necessary for polymerization	Heat is necessary for polymerization
Porosity is greater	Porosity of material is less
Has lower average mol. wt.	Higher molecular weights
Higher residual monomer content	Lower residual monomer content
Material is not strong (because of their lower molecular weights)	Material is strong
Rheological properties	
– Shows greater distortion	– Shows less distortion
– More initial deformation	– Less initial deformation
– Increased creep and slow recovery	– Less creep and quicker recovery
Poor color stability	Color stability is good
Easy to deflask	Difficult to deflask
	Increased rate of monomer diffusion at higher temperature

CHEMICALLY ACTIVATED DENTURE BASE ACRYLIC RESINS

The chemically activated acrylic resins polymerize at room temperature. They are also known as *'self-curing', 'cold-cure' or 'auto-polymerizing'* resins.

In cold cured acrylic resins, the chemical initiator benzoyl peroxide is activated by another chemical (dimethyl-para toluidine which is present in the monomer), instead of heat as in heat cure resins. Thus, unlike heat activated resins, polymerization is achieved at room temperature (see ***Table 25.1***).

AVAILABLE AS

Like the heat activated resins, chemically activated resins are supplied as powder and liquid ***(Fig. 25.20)***. The powder may be clear, pink, veined or tooth colored.

USES

1. For making temporary crowns and FPDs.
2. Construction of special trays (this type contains more fillers) ***(Fig. 25.6 C)***.
3. For denture repair, relining and rebasing.
4. For making removable orthodontic appliances ***(Fig. 25.21)***.
5. For adding a post-dam to an adjusted upper denture.

Figure 25.20: An example of self curing or autopolymerizing polymethylmethacrylate resin.

Figure 25.21: Orthodontic appliances can be constructed in different colors in order to make it more attractive to young patients. Special kits are available for this purpose (inset).

6. For making temporary and permanent denture bases.
7. For making inlay and post core patterns (specialized material is available).

COMPOSITION

Liquid

Methyl methacrylate monomer	Dissolves/plasticizes polymer
Dimethyl-p-toluidine	Activator
Dibutyl phthalate	Plasticizer
Glycol dimethacrylate 1 to 2%	Cross linking agent
Hydroquinone 0.006%	Inhibitor

Powder

Poly (methyl methacrylate) and other copolymers—5%	Dissolved by monomer to form dough
Benzoyl peroxide	Initiator
Compounds of mercuric sulfide, cadmium sulfide	Dyes
Zinc or titanium oxide	Opacifiers
Dibutyl phthalate	Plasticizer
Dyed organic fillers and inorganic particles like glass fibers or beads	Esthetics

POLYMERIZATION REACTION

The simplified reaction is outlined

$$\underset{\text{(Peroxide initiator)}}{\text{Polymer (Powder)}} + \underset{\text{(Amine accelerator)}}{\text{Monomer (Liquid)}} \longrightarrow \text{Polymer} + \underset{\text{(reaction)}}{\text{Heat}}$$

ADVANTAGES AND DISADVANTAGES

1. Better initial fit, which is because the curing is carried out at room temperature. Thus there is less thermal contraction.
2. Color stability is inferior to that of heat cure resin, due to subsequent oxidation of the tertiary amine.
3. Slightly inferior properties because the degree of polymerization of self curing acrylics is less than that of heat cured ones.
4. For repairing dentures, self curing resins are preferable to heat cured resins as heat curing causes warpage.

MANIPULATION OF AUTOPOLYMERIZING RESINS

1. Sprinkle on technique
2. Adapting technique
3. Fluid resin technique (special material is available for this)
4. Compression molding technique

Figure 25.22: A pressure pot for further curing of chemically activated resins. It has a pressure dial (some models have a temperature indicator). Pressure is increased in the chamber using compressed air.

Sprinkle on Technique

Separating media is applied first on the cast. Powder and liquid is applied alternatively from droppers. Powder is sprinkled on the cast and then wet with monomer. The appliance or prosthesis is constructed section by section until completion. To improve the strength, the appliance is further cured in hot water under pressure for around 20 minutes using a *pressure pot* ***(Fig. 25.22)***.

Adapting Technique

Powder and monomer liquid is proportioned and mixed in a glass or porcelain jar. When it reaches the dough stage, it is quickly removed and adapted on to the cast and manually molded quickly to the desired shape. An alternative technique uses a *template*. The resin is pre-shaped using a roller and template before adapting it to the cast. Curing is completed in a pressure pot.

Fluid Resin Technique (pour-type acrylic resins)

A special resin is available for this technique.

The chemical composition of the pour-type of denture resin is similar to the poly (methyl methacrylate) materials. The principal difference is that the pour-type of denture resins have high molecular weight powder particles that are much smaller and when they are mixed with monomer, the resulting mix is very *fluid*. Therefore they are referred as 'fluid resins'. They are used with significantly lower powder-liquid ratio, i.e., it ranges from 2:1 to 2.5:1. This makes it easier to mix and pour.

Method of Flasking and Curing

Agar hydrocolloid is used for the mold preparation in place of the usual gypsum. The fluid mix is quickly poured into the mold and allowed to polymerize under pressure at 0.14 MPa (20 psi).

Advantages of Fluid Resin Technique

1. Better tissue fit.
2. Fewer open bites.
3. Less fracture of porcelain teeth during deflasking.
4. Reduced material cost.
5. Simple laboratory procedure for flasking (no trial closure), deflasking and finishing of the dentures.

Disadvantages

1. Air inclusion (bubbles).
2. Shifting of teeth during processing.
3. Infraocclusion (closed bites).
4. Occlusal imbalance due to shifting of teeth.
5. Incomplete flow of denture base material over neck of anterior teeth.
6. Formation of films of denture material over cervical portions of plastic teeth that had not been previously covered with wax.


Figure 25.23: Light activated resin.

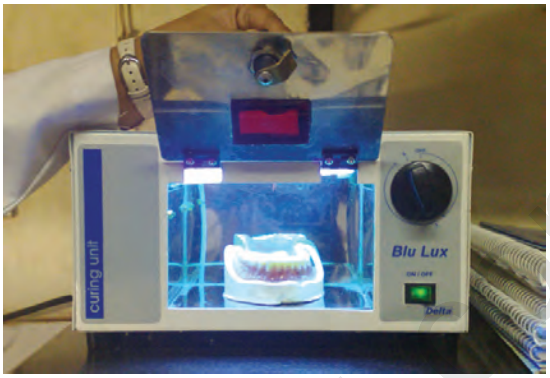


Figure 25.24: Light curing device (*Courtesy:* Yohan and Lippy, The Dental Center, Chennai).

7. Poor bonding to plastic teeth.
8. Technique sensitivity.

In general, these types of resins have some what lower mechanical properties than the conventional heat cured resins.

Clinically acceptable dentures can be obtained when using any of the techniques, provided proper precautions are exercised.

LIGHT ACTIVATED DENTURE BASE RESINS

It consists of a *urethane dimethacrylate* matrix with an acrylic copolymer, microfine silica fillers, and a camphoroquinone-amine photoinitiator system. One such product is known as *VLC triad.*

It is supplied in premixed sheets having a clay like consistency ***(Fig. 25.23)***. It is provided in opaque light tight packages to avoid premature polymerization.

The denture base material is adapted to the cast while it is in a plastic state. The denture base can be polymerized without teeth and used as baseplate. The teeth are added to the base with additional material and the anatomy is sculptured while the material is still soft. It is polymerized in a light chamber ***(Fig. 25.24)*** (curing unit) with blue light of 400-500 nm from high intensity quartz -halogen bulbs. The denture is rotated continuously in the chamber to provide uniform exposure to the light source.

MICROWAVE CURED DENTURE RESINS

Microwave cured resins are available (Nature-Cryl by GC). The material should comply with the requirements of ISO 1567 type 5 denture base. The denture is invested and cured in a unique plastic flask. Curing time is three minutes in a standard household microwave oven.

SPECIALIZED POLY (METHYL METHACRYLATE) MATERIALS

Several modified poly (methyl methacrylate) materials have been used as denture resins. These include hydrophilic polyacrylates, high impact strength resins rapid heat polymerized acrylic, light-activated denture base material (described earlier) and pour type acrylic resins (described earlier).

Figure 25.25: Impact resistant resin.

HIGH IMPACT STRENGTH MATERIALS

These materials are butadiene-styrene rubber-reinforced poly (methyl methacrylate) - ***(Fig. 25.25)***. The rubber particles are grafted to methylmethacrylate so that they will bond well to the heat polymerized acrylic matrix. These materials are supplied in a powder-liquid form and are processed in the same way as other heat-accelerated methyl methacrylate materials. These materials have twice the impact strength of conventional acrylic resins. They are indicated for patients who risk dropping their dentures repeatedly, e.g., senility, parkinsonism.

RAPID HEAT-POLYMERIZED RESINS

These are hybrid acrylics (e.g., QC 20) that are polymerized in boiling water immediately after being packed into a denture flask. After being placed into the boiling water, the water is brought back to a full boil for 20 minutes (reverse cure). After the usual bench cooling to room temperature, the denture is deflasked, trimmed and polished in the usual manner. The initiator is formulated to allow for rapid polymerization without the porosity that one might expect.

RESIN TEETH

The composition of resin teeth ***(Fig. 25.6 E)*** is essentially poly (methyl methacrylate) copolymerized with a cross-linking agent. A greater amount of the cross-linking agent is used in resin teeth in order to reduce the tendency of the teeth to craze upon contact with the monomer-polymer dough during construction. The gingival *ridge-lap area* may not be as highly cross-linked as the incisal in order to facilitate chemical bonding to the denture base. Various pigments are utilized to produce a natural esthetic appearance.

The bond between the resin teeth and denture base resin is chemical in nature unlike porcelain teeth which requires mechanical locking. A comparison of resin and porcelain teeth is presented in ***(Table 25.2)***. Failure may occur if the ridge lap area is *contaminated* with residual wax or separating media. The mold should be flushed well with a detergent solution in order to remove the wax completely.

Table 25.2

Comparison of resin and porcelain denture teeth

Resin	*Porcelain*
High fracture toughness	Brittle, may chip
Crazing if not cross-linked	Susceptible to crazing by thermal shock
Clinically significant wear	Insignificant wear
Easily ground and polished	Grinding difficult, danger of removing glaze
Silent on contact	Clicking sound on impact
Dimensional change with water sorption	Dimensionally stable
Cold flow under stress	No permanent deformation
Loss of vertical dimension	Stable
Self-adjusting	Difficult to fit in diminished inter arch space
Chemical bond to denture	Mechanical retention
Minimal abrasion of opposing dentition	Abrades opposing dentition

Figure 25.26: Autopolymerizing special tray acrylic resin.

Figure 25.27: Duralay is used for making direct patterns of inlays and posts. It is colored red to aid visual demarcation.

Use of a flame for smoothing of the wax during teeth setting should be done carefully since the teeth surfaces may melt or burn. The resultant stresses induced during cooling may contribute to crazing in service.

SPECIAL TRAY ACRYLIC RESINS

These are specialized chemically activated resins and are available as powder and liquid form ***(Fig. 25.26)***. Some are available as light activated materials. They contain a high amount of inorganic fillers (e.g., French chalk) which increases the plasticity and workability of the material. They come in colors like green and blue. They are used to fabricate custom trays for making final impressions using zinc oxide eugenol, elastomeric materials and alginate, etc.

The custom-made acrylic resin trays may not be dimensionally stable until 20 to 24 hours after fabrication. Therefore it is advisable to use the tray after this period.

PATTERN RESINS

Commercial Name—Duralay ***(Fig. 25.27).***

It is a special resin intended for making inlay, post and other patterns in the mouth. Like wax, these materials burn off completely before casting. But unlike wax, they are dimensionally very stable after setting and are not affected by small temperature variations. The inlay cavity is lubricated. The powder and liquid are mixed and inserted into the cavity. It is shaped quickly into the desired shape. Further shaping is done after it sets using a bur. The pattern is removed, invested and reproduced in metal.

PROPERTIES OF METHYLMETHACRYLATE AND DENTURE RESINS

Dentures are subjected to large stresses in the mouth. Acceptable denture resins must meet or exceed the standards specified in ADA/ANSI Sp. No. 12.

METHYL METHACRYLATE MONOMER

It is a clear, transparent, volatile liquid at room temperature. It has a characteristic sweetish odor. The physical properties of monomer are:

Melting point	– 48°C
Boiling point	100°C

Density	0.945 gm/ml at 20°C
Heat of polymerization	12.9 Kcal/mol
Volume shrinkage during polymerization	21%

POLY (METHYL METHACRYLATE)

Taste and Odor

Completely polymerized acrylic resin is tasteless and odorless. On the other hand poorly made dentures with a high amount of porosity can absorb food and bacteria, resulting in an unpleasant taste and odor.

Esthetics

It is a clear transparent resin which can be pigmented (colored) easily to duplicate oral tissue. It is compatible with dyed synthetic fibers. Thus esthetics is acceptable.

Density

The polymer has a density of 1.19 gm/cm^3.

Strength

These materials are typically low in strength. However they have adequate compressive and tensile strength for complete or partial denture applications.

Compressive strength	75 MPa
Tensile strength	48-62 MPa

Self cured resins generally have lower strength values.

The strength is affected by:

1. Composition of the resin
2. Technique of processing
3. Degree of polymerization
4. Water sorption
5. Subsequent environment of the denture

Impact Strength

It is a measure of energy absorbed by a material when it is broken by a sudden blow. Ideally denture resins should have high impact strength to prevent breakage when accidentally dropped. Unmodified acrylic resins are generally brittle. Plasticizers increase the impact strength. However, the significant improvement in impact strength is observed when the resin is modified with rubber. The Izod test values* are shown below.

Chemically activated resin	– 13 (J/m)
Conventional heat-cured acrylic resin	– 15 (J/m)
Rubber modified acrylic resin	– 31 (J/m)
Polyvinyl resins	– 30 (J/m)

Fatigue Strength

Fatigue strength refers to the ability of the denture to withstand large number of small cyclic loading such as during mastication over a period of time. Most current dental plastics have sufficient fatigue strength.

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* Values are useful for comparison only, as values vary with test methods, specimen dimensions and presence of surface defects.

Hardness and Wear Resistance

Acrylic resins are materials having low hardness. They can be easily scratched and abraded. Polyvinyl acrylics have the best wear resistance and pour type acrylics has the least.

Heat cured acrylic resin	: 18 KHN
Self cured acrylic resin	: 16 KHN
Rubber modified acrylic resin	: 14 KHN
Light cured resin	: 18 KHN

Modulus of Elasticity

They have sufficient stiffness for use in complete and partial dentures.

Self cured acrylic resins have slightly lower values.

Creep

Denture resins exhibit creep. When a load is applied an initial deflection is observed. If the load is sustained additional deformation is observed over time. The additional deformation is called creep. Chemically activated resins have higher creep rates.

Dimensional Stability

A well-processed acrylic resin denture has good dimensional stability. The processing shrinkage is balanced by the expansion due to water sorption.

Polymerization Shrinkage

Acrylic resins shrink during processing due to:

- Thermal shrinkage on cooling
- Polymerization shrinkage

During polymerization, the density of the monomer changes from 0.94 gm/cc to 1.19 gm/cc. This results in shrinkage in the volume of monomer-polymer dough.

However, in spite of the high shrinkage, the fit of the denture is not affected because the shrinkage is uniformly distributed over all surfaces of the denture. Thus, the actual linear shrinkage observed is low.

Volume shrinkage	8%
Linear shrinkage	0.53%

Self-cured type has a lower shrinkage (linear shrinkage— 0.26%).

Water Sorption

Acrylic resins absorb water (0.7 mg/cm^2) and expand. This partially compensates for its processing shrinkage. This process is reversible. Thus on drying they lose water and shrink. However, repeated wetting and drying should be avoided as it may cause warpage of the denture.

Solubility

Acrylic is virtually insoluble in water and oral fluids. They are soluble in ketones, esters and aromatic and chlorinated hydrocarbons, e.g., chloroform and acetone. Alcohol causes crazing in some resins.

Thermal Properties

Stability to heat Poly (methyl methacrylate) is chemically stable to heat up to a point. It softens at 125°C. However, above this temperature, i.e., between 125°C and 200°C it begins to depolymerize. At 450°C, 90% of the polymer will depolymerize to monomer.

Thermal conductivity They are poor conductors of heat and electricity. This is undesirable because patients wearing acrylic complete dentures often complain that they cannot feel the temperature of food or liquids they ingest, thus reducing the pleasure. Replacing the palatal portion with metal is one solution, because the metal is a better conductor of heat. Inclusion of sapphire whiskers improves conductivity.

Thermal conductivity for acrylic resin is 5.7 x 10^{-4} cal/sec/cm^2) (°C/cm).

Coefficient of thermal expansion These materials have a high coefficient of thermal expansion (CTE). The CTE for poly(methylmethacrylate) resin is 81 × 10^{-6}/°C. Addition of fillers reduces the CTE.

Heat distortion temperature This is the measure of the ability of a plastic to resist dimensional change when loaded under heat. It is measured by observing the temperature at which a specimen under a 1.8 MPa load deflects 0.25 mm.

Heat distortion temperature for PMMA – 71 to 91°C.
Heat distortion temperature for vinyl resin – 54 to 77°C.

Distortion is of concern during procedures like repair or polishing of dentures. Temperatures should be kept low to avoid distortion.

Color Stability

Heat-cured acrylic resins have good color stability. The color stability of self-cure resins is slightly lower (yellows very slightly).

Biocompatibility

Completely polymerized acrylic resins are biocompatible.

True allergic reactions to acrylic resins are rarely seen in the oral cavity. The residual monomer (approximately 0.4% in a well-processed denture) is the usual component singled out as an irritant. A true allergy to acrylic resin can be recognized by a patch test.

Direct contact of the monomer over a period of time may provoke dermatitis. The high concentration of monomer in the dough may produce a local irritation and a serious sensitization of the fingers. Inhalation of monomer vapor is avoided.

Precautions to be taken are:

1. Minimize residual monomer content by using proper processing techniques.
2. Avoid direct handling of acrylic dough with bare hands.
3. Work in well ventilated areas to avoid inhalation of the monomer vapor.

Residual Monomer

During the polymerization process the amount of residual monomer decreases rapidly initially and then later more slowly.

The highest residual monomer level is observed with chemically activated denture base resins at 1 - 4% shortly after processing. When they are processed for less than one hour in boiling water the residual monomer is 1 - 3%. If it is processed for 7 hours at 70°C and then boiled for 3 hours the residual monomer content may be less than 0.4%.

In heat cured acrylic before the start of curing the residual monomer is 26.2%. In 1 hour at 70°C it decreases to 6.6% and at 100°C it is 0.29%.

To reduce the residual monomer in heat cured dentures it should be processed for a longer time in boiling water. The temperature should be raised to boiling only after most of the polymerization is completed otherwise porosity may result.

Adhesion

The adhesion of acrylic to metal and porcelain is poor and mechanical retention is required. Adhesion to plastic denture teeth is good (chemical adhesion). Adhesion to metal or ceramic can be improved by treating with silane coupling agents.

Radiopacity

There have been instances of broken pieces of dentures being aspirated or swallowed. Radiopacity is a desirable property to enable easy location of the fragments. Most denture base materials are radiolucent. However a few radiopaque materials are being manufactured. Radiopacity is obtained by the inclusion of heavy metal salts like bismuth or uranyl at concentrations of 10 to 15%.

Shelf Life

Acrylic resins dispensed as powder/liquid have the best shelf life. The gel type has a lower shelf life and has to be stored in a refrigerator.

PROCESSING ERRORS

POROSITY

Porosity presents many problems

1. It makes the appearance of denture base unsightly.
2. Proper cleaning of the denture is not possible, so the denture hygiene and thus, the oral hygiene suffers.
3. It weakens the denture base and the pores are areas of stress concentration, thus the denture warps as the stresses relax.

Porosity may be:

A. Internal porosity
B. External porosity

Internal Porosity

Internal porosity appears as voids or bubbles within the mass of the polymerized acrylic. It is usually not present on the surface of the denture. It is confined to the thick portions of the denture base and it may not occur uniformly.

Cause Internal porosity is due to the vaporization of monomer when the temperature of the resin increases above the boiling point of monomer (100.8°C) or very low molecular weight polymers. Exothermic heat of the surface resin dissipates easily into the investing plaster. However, in the center of the thick portion the heat cannot be conducted away. Therefore, the temperature in the thick portions may rise above the boiling point of monomer causing porosity.

Figure 25.28: Surface and subsurface porosity from lack of insufficient pressure during curing.

Avoided by Dentures with excessive thickness should be cured using a long, low temperature curing cycle.

External Porosity

It can occur due to two reasons:

1. *Lack of homogeneity* If the dough is not homogenous at the time of polymerization, the portions containing more monomer will shrink more. This localized shrinkage results in voids. The resin appears white.

   Avoided by Using proper powder/liquid ratio and mixing it well. The mix is more homogenous in the dough stage, so packing should be done in the dough stage.

2. *Lack of adequate pressure* Lack of pressure during polymerization or inadequate amount of dough in the mold during final closure causes bubbles which are not spherical. The resin is lighter in color ***(Fig. 25.28)***.

   Avoided by Using the required amount of dough. Check for excess or flash during trail closure. Flash indicates adequate material.

CRAZING

Crazing is formation of surface cracks on the denture base resin ***(Fig. 25.29)***. The cracks may be microscopic or macroscopic in size. In some cases it has a hazy or foggy appearance rather than cracks.

Crazing weakens the resin and reduces the esthetic qualities. The cracks formed can cause fracture.

Causes Crazing is due to:

1. Mechanical stresses or
2. Attack by a solvent
3. Incorporation of water

In poly (methyl methacrylate) crazing occurs when tensile stresses are present. The cracks are at right angles to the direction of tensile stress. Crazing is a mechanical separation of the polymer chains or groups under tensile stress.

Figure 25.29: Representation of crazing in resins.

Crazing is visible around the porcelain teeth in the denture and is due to the contraction of the resin around the porcelain teeth during cooling after processing. Weak solvents like alcohol result in randomly placed cracks.

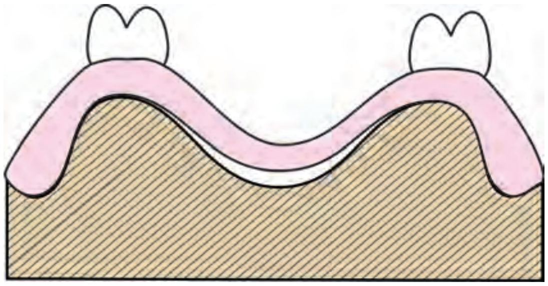

Figure 25.30: Denture warpage has resulted in a space between the palatal surface and the cast. Obviously this would affect the fit.

Water incorporation during processing will form stresses due to evaporation of water after processing, causing crazing.

Avoided by

1. Using cross linked acrylics
2. Tin foil separating medium
3. Metal molds

DENTURE WARPAGE

Denture warpage is the deformity or change of shape of the denture which can affect the fit of the denture ***(Fig. 25.30)***. Warpage can occur during processing as well as at other times.

It is caused by a release of stresses incorporated during processing. Some of the stresses are incorporated as a result of the curing shrinkage while other stresses may be a result of the uneven or rapid cooling. Packing of the resin during the rubbery stage can also induce stresses. Some stresses may be incorporated during improper deflasking. These stresses are released subsequently:

- During polishing, a rise in temperature can cause warpage
- Immersion of the denture in hot water can cause warpage
- Re-curing of the denture after addition of relining material, etc.

REPAIR OF ACRYLIC RESIN DENTURES

An acrylic denture fractured in service can be repaired. Repair resins may be:

- Heat cured, or
- Self cured

Heat Cured Resin

These resins are cured at 74°C for 8 hours or more. The use of a heat cured resin will tend to warp the denture during processing.

Self Cured Resin

Although the repair with a self-cured resin invariably has a lower transverse strength than that of the original heat-cured denture base resin, self-cured resins are usually preferred because warpage is insignificant as curing is done at room temperature.

INFECTION CONTROL FOR DENTURES

Care should be taken to prevent cross-contamination between patients and dental personnel. New appliances should be disinfected after construction.

Items such as rag wheels often can be steam-autoclaved. Appliances can be sprayed with disinfectants before they leave the operatory. Since the polymeric materials can absorb liquids, toxic agents such as phenol or glutaraldehyde are avoided. Ethylene oxide gas is a suitable method.

CARE OF ACRYLIC DENTURES

Denture treatment is time consuming and labor intensive, besides being expensive. Therefore proper care and maintenance of the denture is important.

Figure 25.31: A commercially available denture cleansing kit. It includes a brush and container for storage.

- Dentures should be stored in water when not in use, since dimensional changes can occur on drying.
- Acrylic dentures should not be cleaned in *hot water*, since processing stresses can be released and can result in distortion.
- Abrasive dentifrices (regular toothpastes) should not be used, since the plastic is soft and can be easily scratched and abraded. The *tissue surface* should be brushed carefully with a soft brush ***(Fig. 25.31)***, since any material removed alters the fit of the denture.
- Besides physical brushing various cleaning agents are commercially available (see denture cleansers).

DENTURE CLEANSERS

A wide variety of agents are used by patients for cleaning artificial dentures. They include dentifrices, proprietary denture cleansers, soap and water, salt and soda, household cleansers, bleaches and vinegar.

Dentures are cleaned by either:

1. Immersion in an agent or
2. By brushing with the cleanser.

The most common commercial denture cleansers are the immersion type ***(Fig. 25.32)***, which are available as a powder or tablet.

Figure 25.32: Immersion type denture cleaning tablets.

Their composition usually includes:

— Alkaline compounds
— Detergents
— Flavoring agents
— Sodium perborate

When the powder is dissolved in water, the perborate decomposes to form an alkaline peroxide solution, which in turn decomposes to liberate *oxygen*. The oxygen bubbles then acts mechanically to loosen the debris.

Vinegar is effective in dissolving calculus. The household cleansers are contraindicated, as they affect the fit of the denture and produce rough surface on prolonged use.

DENTURE RELINERS

Reliners may be classified as:

A. Hard or soft (resilient)
B. Heat cured or self cured
C. Short term or long term
D. Resin based or silicone based

HEAT CURED ACRYLIC RESIN (HARD LINER)

New resin is cured against the old denture by compression molding technique. A low curing temperature is necessary for the relining process to avoid distortion of the denture.

Disadvantages

There is a tendency for it to warp toward the relined side due to:

- Diffusion of the monomer from the reliner before curing, and
- Processing shrinkage of the liner. For this reason the rebasing is preferred to relining.

CHAIR SIDE RELINERS (HARD SHORT TERM LINER)

These materials are used for relining resin dentures directly in the mouth ***(Fig. 25.33)***. Some of them generate enough heat to injure oral tissues. According to ADA Sp. No. 17, peak temperature reached during curing should not be more than 75°C. Generally the specifications are far less demanding for these materials than for the regular denture base resins. On the whole their properties are inferior to laboratory processed acrylic resins. They have higher porosity and water sorption. They often contain low molecular weight polymers, plasticizers or solvents to increase their fluidity while seating the denture. They tend to discolor, become foul smelling and may even separate from the denture base. Thus, these materials have many disadvantages and are therefore considered as short term materials.

Light-activated resins are also available for relining.

Figure 25.33: Hard setting chairside denture liner.

Figure 25.34: Soft denture liner.

SOFT OR RESILIENT DENTURE LINERS

International standards organization describes categories of soft liners:

1. Short term soft liners (also known as tissue conditioners) (ISO 10139 Part 1)
2. Long term soft liners (ISO 10139 Part 2)

LONG TERM SOFT LINERS

The purpose of the 'permanent' soft liner ***(Fig. 25.34)*** is to protect the soft tissue by acting as a cushion. They are used when there is irritation of the mucosa, in areas of severe undercut and congenital or acquired defects of palate.

Requirements

1. Good bonding to the denture base.
2. Should be biocompatible.
3. Should be hygienic and not become foul smelling.
4. Should maintain its resilience for a long time.
5. Should have good dimensional stability.
6. Should inhibit bacterial growth.
7. Low water sorption.
8. Easy to process.

Classification (ISO 10139)

1. Based on depth of penetration:

Type A: stiff
Type B: medium
Type C: soft

2. Based on their method of processing they are further divided into:

Mouth cured or chairside soft liners – does not last beyond a few weeks
Processed soft liners – lasts up to a year

Several soft lining materials are available commercially

- Plasticized acrylic resin
- Plasticized vinyl resins

- Silicone rubbers
- Polyphosphazine

PLASTICIZED ACRYLIC RESIN

This is most commonly used. It may be self-cured or heat-cured. In self-cured type, poly (ethyl methacrylate), poly (methyl methacrylate) or an acrylate copolymer is mixed with an aromatic ester-ethanol liquid containing 30 to 60% plasticizer, such as dibutyl phthalate.

The heat-cured resin may be supplied in a sheet form or powder-liquid form. The powder is composed of selected acrylic resin polymers and copolymers, so that when they are mixed with the appropriate monomer and plasticizer liquid, the glass transition (softening) temperature of the cured resin will be below mouth temperature.

Disadvantages They lose plasticizers and harden with use.

VINYL RESINS

The plasticized poly (vinyl chloride) and poly (vinyl acetate) resins, like the plasticized acrylic resins, lose plasticizer and harden during use.

SILICONE RUBBERS

These materials retain their elastic properties but may loose adhesion to the denture base.

Room temperature curing chairside silicone

Heat-cured silicones They are generally a one-component system. They are supplied as a paste or gel containing an oxygen catalyst. It is heat polymerized against acrylic resin using compression molding technique.

For adhesion between silicones and the denture base, a rubber poly (methyl methacrylate) graft polymer solution cement may be used (one brand does not requires adhesive as it contains a copolymer of silicone and a second polymer that achieves adhesion to the acrylic resin).

Other polymers Polyurethene and polyphosphazine rubber.

Problems Associated with Soft Liners

1. Inadequate bonding to denture, especially silicone liners.
2. Some silicone liners and the hydrophilic acrylics undergo a high volume change (up to + 40%) with gain and loss of water.
3. The heat cured soft acrylics bond well to the hard denture base but loose their softness as plasticizer is leached from the liner.
4. It reduces the denture base strength, not only because of reduced base thickness but also by solvent action of the silicone adhesive and the monomer.
5. Trimming, cutting, adjusting and polishing of a soft liner is difficult. The silicone surface is abrasive and irritating to the oral mucosa when compared to that of hard acrylic resin.
6. The greatest disadvantage of the permanent soft liner, as well as the tissue conditioner (temporary soft liner) is that they often have a characteristic disagreeable taste and odor and they cannot be cleaned as effectively.
7. The debris that accumulate in pores in the silicone liner can promote fungal growth (*Candida albicans*).

None of the soft denture reliners can be considered entirely satisfactory. It is necessary to review the patients periodically and if necessary change the material.

TISSUE CONDITIONERS (SHORT TERM SOFT LINER)

Unlike the soft liners previously mentioned tissue conditioners are soft elastomers used to treat irritated mucosa. Their useful function is very short, generally a matter of a few days. They are replaced every 3-5 days. Their hardness ranges from 14-49. Shore a hardness units 24 hours after mixing. They lose alcohol over time resulting in a weight loss of 5-9%. These materials show both viscous and viscoelastic behavior which help in both adaptation to tissue and cushioning of masticatory forces.

Uses

1. Ill-fitting dentures can cause inflammation and distortion of the oral tissues. Relining an ill-fitting denture with tissue conditioner allows the tissues to return to 'normal' at which point a new denture can be made.
2. As an impression material (this material is used in a special impression technique known as *functional impression*).

Composition

These are highly plasticized acrylic resins, supplied as a powder and a liquid.

Powder	Poly (ethyl methacrylate) or one of its copolymers.
Liquid	Aromatic ester (butyl phthalate butyl glycolate) in ethanol or an alcohol of high molecular weight.

Manipulation

The denture base is relieved on the tissue surface. Powder and liquid are mixed together to form a gel and it is placed on the tissue surface of the denture and inserted in the mouth. The gel flows readily to fill the space between the denture base and the oral tissue.

The properties that make tissue conditioners effective are:

- Viscous properties, which allow excellent adaptation to the irritated denture-bearing mucosa over a period of several days and brings it back to health.
- Elastic behavior which cushions the tissues from the forces of mastication and bruxism.

DENTURE ADHESIVES

These are highly viscous aqueous solutions which are often used to improve the retention of complete dentures.

SUPPLIED AS

Powders or Paste ***(Figs 25.35 and 25.36)***

COMPOSITION

Keraya gum
Tragacanth
Sodium carboxy methyl cellulose
Polyethylene oxide
Flavoring agents
Some also contain antimicrobial agents and plasticizers.

Figure 25.35: Denture adhesive paste.

PROPERTIES

When applied to the denture base and inserted, the polymer portion absorbs water and swells. They improve the retention of the denture base through adhesion. It fills up the spaces between the denture and the tissue. The high viscosity also prevents displacement. They usually have a pleasant smell.

Figure 25.36: Denture adhesive powder.

Biological Consideration

Most of the components are permitted food additives and are generally safe. However, if ingested in excess, they can cause gastrointestinal disorders. Keraya gum can cause allergic reaction to some patients. It is also acidic (pH 4.7-5) and can cause caries if natural teeth are present. Therefore, its use is contraindicated in partially edentulous patients.

Disadvantages

It has an unpleasant feel, is difficult to clean and is diluted easily by saliva.

Indications

Considering its properties, its use should be limited to:

1. Temporary retention of poorly fitting dentures.
2. Patients having poor neuromuscular control.

REBASING OF DENTURES

Because of soft tissue changes that occur during wearing of the denture, it is often necessary to *change the tissue surface* of the denture. Such a re-adaptation of the denture is done by either rebasing or relining the denture.

DIFFERENCE BETWEEN REBASING AND RELINING

In rebasing, the *original teeth are retained* and new denture bearing area is constructed with heat-cure acrylic resin. In other words, the entire denture base is replaced with new material.

In relining, only a part of the tissue surface of the denture is removed and replaced with new material.

PROVISIONAL CROWN AND FPD MATERIALS

The fabrication of a crown or fixed partial denture (FPD) is a laboratory procedure, and several weeks may lapse between the preparation of the teeth and the cementation of the final restoration. A provisional restoration ***(Fig. 25.37)*** provides protection to the pulp from thermal and chemical irritation caused by food and liquids, maintains positional stability, aids mastication and maintains esthetics during this interim period.

Figure 25.37: A provisional fixed partial denture protects the abutment during the interim period.

REQUIRED PROPERTIES

1. A temporary restoration must be nonirritating to soft tissues and pulp.
2. They should have adequate strength to withstand forces of mastication.
3. They should be esthetic especially for the anterior teeth.
4. Low thermal conductivity.
5. Low dimensional change and low exothermic reaction.
6. Easy to manipulate.

MATERIALS

Provisional crown and FPD materials may be preformed or custom-made.

PREFORMED CROWNS

A preformed crown forms the external contour of the crown. These crowns can be luted directly to the prepared teeth after adjustment or they may be relined with a resin prior to cementation. The various preformed materials include:

- Polycarbonate
- Cellulose acetate
- Aluminum
- Tin-silver

Figure 25.38: A polycarbonate shell.

Polycarbonate

This is a polymer of high impact resistance ***(Fig 25.38).*** It has an esthetic natural appearance. It is available only in a single shade. They are supplied in incisor, canine and premolar shapes.

Cellulose Acetate Crown formers

Cellulose acetate is a thin transparent matrix available in all tooth shapes and a range of sizes. It is used in combination with a tooth colored resin. It primarily acts as a template within which the provisional material is filled and placed over the prepared tooth. After the acrylic resin sets, the cellulose acetate is peeled off and discarded and the crown is trimmed and cemented.

CUSTOM MADE CROWNS

Temporary or provisional crowns and FPDs ***(Fig. 25.37)*** can also be custom-made from various types of resin. The materials used are:

- Polymethyl methacrylate resins (Gel)
- Polyethyl (isobutyl) methacrylate resins (Trim, Snap)
- Epimine resins
- Microfilled composite resins (See provisional composites, restorative resins).

Polymethyl Methacrylate

These resins are generally self cured.

Commercial name: Gel

Advantages

1. Acceptable mechanical properties.
2. Color stability is better than that of poly (ethylmethacrylate) resins.

Disadvantages

1. High polymerization shrinkage.
2. High heat liberation during setting.
3. High irritation to gingival tissues.

Figure 25.39: Snap is a self curing polyethyl methacrylate resin used for making provisional restorations.

Polyethyl (Isobutyl) Methacrylate Resins

These are available as a two component powder-monomer system. The two components are mixed to form a dough and inserted into a template which is placed over the prepared tooth/teeth. When set the material assumes the shape of the crown or FPD. Heat accelerates the setting. The excess material is trimmed and the restoration smoothened and polished. The restoration is tried intraorally and cemented with a suitable temporary cement.

Commercial name: Trim, Snap ***(Fig. 25.39)***

Advantages

1. Less polymerization shrinkage and heat liberation.
2. Flow better during adaptation.
3. Less irritation to soft tissues.

Disadvantages

1. Less tensile strength.
2. Poor color stability.
3. Clogs bur if trimmed with high speed turbines.

Epimines

The epimines are supplied as a two-component system. A paste containing a high-molecular weight epimine monomer combined with a polyamide (nylon) filler and a liquid containing a benzene sulfonate catalyst.

Advantages

1. Less polymerization shrinkage.
2. Less exothermic heat.
3. Good flow properties.

Disadvantages

1. Tissue irritation (caused by catalyst).
2. Poor impact strength.
3. Poor resistance to abrasion.
4. Expensive.

MATERIALS IN MAXILLOFACIAL PROSTHESIS

Maxillofacial materials are used to correct facial defects or deformities resulting from cancer surgery, accidents or congenital deformities. Nose, ears, eyes or any other part of the head and neck may be reconstructed by these prostheses ***(Fig. 25.40)***. They are also used in the movie industry for special effects. Ancient Chinese and Egyptians used waxes and resins to reconstruct missing portions of the face and head. Modern maxillofacial prosthetics saw a resurgence after world war due to severe nature of the war related injuries. In spite of the advances in techniques and materials there is still a lot of scope for further development in this field.

IDEAL REQUIREMENTS

These materials must be biocompatible easy and inexpensive to fabricate, strong and durable. The prosthesis must be skin-like in appearance and texture. It must be color stable as it is subjected to sunlight (including ultraviolet light) heat, and cold. It must be easy to clean and manage by the patient. Facial prosthesis are often constructed wth thin margins to enable blending to the skin. This is then attached to the skin with adhesives. On removing at night the thin edges can tear. It must be resilient enough to prevent tearing. The water absorption of the prosthetic material is important since facial prostheses may absorb saliva or sweat from surrounding facial tissue. During washing the prosthesis can absorb water. Any absorbed water may affect the physical properties and also affect the perception of color matching to the surrounding facial tissue.

No material so far has all of these characteristics.

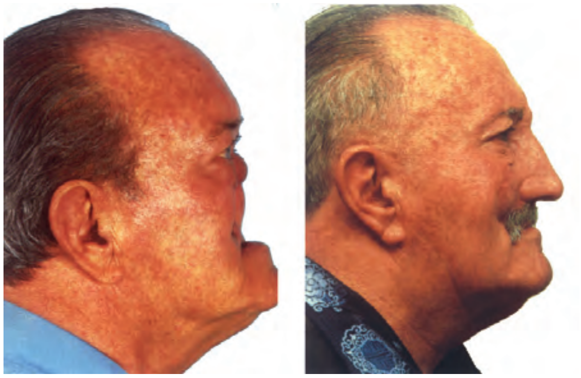

Figure 25.40: Pre and post-treatment photos of a maxillofacial prosthesis replacing the nose, part of the cheek and the upper lip which were removed following cancer of this region.

POLY (METHYL METHACRYLATE)

It was once commonly used for maxillofacial prosthesis. It is easy to manipulate, hygienic and durable. Its usefulness in extra-oral prosthesis is limited because acrylic is hard and heavy, does not move when the face moves and does not have the feel of skin.

LATEXES

Latexes are soft, inexpensive and easy to manipulate. They are realistic and form lifelike prostheses. However, the finished product is weak, degenerates rapidly with age and changes color. Latex is no longer a major facial prosthetic material.

PLASTICIZED POLYVINYLCHLORIDE

Polyvinylchloride is a rigid plastic and is made more flexible by adding a plasticizer. Other ingredients added to polyvinylchloride include cross-linking against (for strength) and ultraviolet stabilizers (for color stability). Color pigments can be incorporated to match individual skin tones.

It is supplied as finely divided polyvinyl chloride particles suspended in a solvent. When the fluid is heated above a critical temperature, the polyvinylchloride dissolves in the solvent. When the mix is cooled, an elastic solid is formed.

The prosthesis becomes hard with age because the plasticizers are lost from the surface of the prosthesis.

POLYURETHANE POLYMERS

It is the most recent addition. One of its components is acrylate, which needs careful handling to prevent a toxic reaction to the operator. Although the material is cured at room temperature, it requires accurate temperature control because a slight change in temperature can alter the chemical reaction. A metal mold is used to avoid moisture in the air affecting the processing.

It has lifelike feel and appearance and the color stability is better than that of polyvinyl chloride. But it is susceptible to deterioration with time.

SILICONE RUBBER

Currently silicone based maxillofacial materials are the most widely used. Based on curing mechanism two types of silicone rubber are available:

- RTV – These are similar to the condensation silicones and use a tin catalyst.
- HTV – These are similar to addition silicones and use a platinum catalyst.

Room Temperature-Vulcanized (RTV) Silicones

The prosthesis can be easily fabricated in the dental laboratory with little special equipment. However, such silicones are not as strong as the heat-vulcanized silicones and the intrinsic color is monochromatic.

One product (Cosmesil M521) consists of three parts (base, crosslinker and catalyst). Work time is approximately 1 hour. Curing takes 24 hours at room temperature. However, curing time varies with products and can range from 3 to 24 hours.

Heat Vulcanized Silicones

Heat vulcanizing silicone is a semisolid or putty-like material. They are supplied as a two component system—base (vinyl- and hydride-containing siloxanes) and catalyst (chloroplatinic acid catalyst) ***(Fig. 25.41)***. Fabrication involves milling, packing under pressure and curing. Pigments are milled into the

Figure 25.41: Heat vulcanized maxillofacial silicone with catalyst.

Figure 25.42: Extrinsic stains used for characterizing a prosthesis.

material which is then packed in discrete locations of the mold producing a lifelike and intrinsic color texture. This is the material of choice, particularly in terms of strength and color stability. The coloring procedure is faster. Both intrinsic and extrinsic stains can be used making it polychromatic.

One current silicone (Cosmesil M511) has a working time of approximately 1 hour and curing time approximately 1 hour at 100°C.

Commercial examples Cosmesil M511, Nusil, Factor II, etc.

Disadvantage Milling machine and press is required. A metal mold is normally used and the fabrication of the mold is a lengthy procedure.

Coloring Pigments and Effects

To simulate natural skin and body appearance various cosmetic grade pigments both intrinsic and extrinsic may be applied ***(Fig. 25.42)***. They include a range of colors as well as basic skin shades. Pigments and fibers are available as

- Dry powder
- Liquid stains
- Flocking micro fibers are added to silicones to provide increased appearance of depth and light scattering
- Short veining fibers
- Longer fibers for creating appearance of more complex veining structures

Skin Adhesives

Adhesives are often used to attach the prosthesis to the skin. Various forms of adhesives used are water based gels, creams, liquids or silicone based pastes. Water based adhesives are easily washed off with soap and warm water.

Appendix 1

ADA/ANSI SPECIFICATIONS

ADA Sp.	*ISO*	*Product*
No. 1	ISO 1559/24234:2004	Alloy for dental amalgam
No. 2	ISO 7490:2000	Dental gypsum-bonded casting investments
No. 6	ISO 1560/24234:2004	Dental mercury
No. 12	ISO 1567:1999/Amd 1:2003	Denture base polymers
No. 15	ISO 3336:1993	synthetic polymer teeth
No. 16		dental impression paste—zinc oxide-eugenol type
No. 17	ISO 10139-1:2005/Cor 1:2006	Denture base temporary relining resins
No. 18	ISO 1563:1990	Alginate impression materials
No. 19	ISO 4823:2000	Dental elastomeric impression material
No. 23		Dental excavating bur
No. 25	ISO 6873:1998	Dental gypsum products
No. 27	2005	Resin-based filling materials
No. 28		Root canal files and reamers, type K for hand use
No. 30	ISO 3107:2004/Cor 1:2006	Dental zinc oxide - eugenol and zince oxide - noneugenol cements
No. 32		Orthodontic wires
No. 33		Dental product standards development vocabulary
No. 34		Dental aspirating syringes
No. 37		Dental abrasive powders
No. 38	ISO 9693:1999/Amd 1:2005	Metal-ceramic dental restorative systems
No. 39	ISO 6874:2005	Pit and fissure sealants
No. 41		Biological evaluation of dental materials
No. 42	ISO 9694–1998	Dental phosphate-bonded casting investments
No. 43		Electrically powered dental amalgamators
No. 46		Dental chairs
No. 47		Dental units
No. 48		Visible light curing units
No. 53	ISO 10477:2004	Polymer-based crowns and bridge resins
No. 54		Double-pointed, parenteral, single use needles for dentistry
No. 57	ISO 6876:2001	Endodontic sealing material
No. 58		Root canal files, type H (Hedstrom)
No. 62		Dental abrasive pastes
No. 63		Root canal barbed broaches and rasps
No. 69	ISO 6872:1995/Amd 1:1997	Dental ceramic
No. 70		Dental X-ray protective aprons and accessory devices
No. 71	ISO 3630–3:1994,	Root canal filling condensers (pluggers and spreaders)

No. 73	ISO 7551:1991	Dental absorbent points
No. 74	ISO7493:1997	Dental operator's stool
No. 75	ISO 10139-1:2005/Cor 1:2006	Resilient lining materials for removable dentures - Part 1: Short-term materials
No. 76		Non-sterile natural rubber latex gloves for dentistry
No. 78	ISO 6877:2006	Endodontic obturating cones
No. 80	ISO 7491:2000	Dental Materials—determination of color stability
No. 82	ISO 13716:1999	Dental reversible/irreversible hydrocolloid impression material systems (syringeable materials).
No. 85		Part 1—disposable prophy angles
No. 87		Dental impression trays
No. 88	ISO 9333:1990	Dental brazing alloys
No. 89	ISO 9680	Dental operating lights
No. 91	ISO 11246:1996	Dental ethyl silicate bonded casting investment
No. 92	ISO 11245:1999	Dental phosphate-bonded refractory die materials
No. 93	ISO 11244:1998	Dental brazing investments
No. 94		Dental compressed air quality
No. 95		Root canal enlargers
No. 96	ISO 9917-1:2003	Dental water-based cements
No. 97	ISO 10271:2001/Cor 1:2005	Corrosion test methods
No. 99		Athletic mouth protectors and materials
No. 100		Orthodontic brackets and tubes
No. 101		Root canal instruments: general requirements
No. 102		Non-sterile nitrile gloves
No. 103		Non-sterile poly vinyl chloride gloves for dentistry
No. 109		Procedures for storing dental amalgam waste and requirements for amalgam waste storage/shipment containers: 2006
No. 110		Technical report—dental lasers *NEW!*
No. 113		Periodontal curettes—gracey type *NEW!*
No. 119		Manual toothbrushes *NEW!*
No. 122	ISO 15854:2005	Dental casting and baseplate waxes *NEW!*
No. 3950	ISO 3950–1984	Dentistry—designation system for teeth and areas of the oral cavity

Appendix 2

ISO STANDARD FOR DENTAL MATERIALS (2006)

11.060.10:	Dental materials
ISO 1562:2004	Dentistry casting gold alloys
ISO 1563:1990	Dental alginate impression material
ISO 1564:1995	Dental aqueous impression materials based on agar
ISO 1567:1999/Amd 1:2003	Denture base polymers
ISO 1942-2:1989/Amd 2:1992	Dental vocabulary — Part 2: Dental materials
ISO 3107:2004/Cor 1:2006	Zinc oxide/eugenol and zinc oxide/non-eugenol cements
ISO 4049:2000	Polymer-based filling, restorative and luting materials
ISO 4823:2000/Cor 1:2004/Amd 2007	Elastomeric impression materials
ISO 6871-1:1994/Cor 1:1998/Amd 1:2005	Dental base metal casting alloys — Part 1: Cobalt-based alloys
ISO 6871-2:1994/Amd 1:2005	Dental base metal casting alloys — Part 2: Nickel-based alloys
ISO 6872:2008	Dental ceramic
ISO 6873:1998	Dental gypsum products
ISO 6874:2005	Polymer-based pit and fissure sealants
ISO 6876:2001	Dental root canal sealing materials
ISO 6877:2006	Root-canal obturating points
ISO 7405:1997	Preclinical evaluation of biocompatibility of medical devices used in dentistry — Test methods for dental materials
ISO 7490:2000	Dental gypsum-bonded casting investments
ISO 7491:2000	Dental materials — Determination of color stability
ISO 7551:1996	Dental absorbent points
ISO 8891:1998	Dental casting alloys with noble metal content of at least 25% but less than 75%
ISO 9333:1990	Dentistry -Brazing materials
ISO 9693:1999/Amd 1:2005	Metal-ceramic dental restorative systems
ISO 9694:1998	Dental phosphate-bonded casting investments
ISO 9917-1:2003	Water-based cements — Part 1: Powder/liquid acid-base cements
ISO 9917-2:1998	Dental water-based cements — Part 2: Light-activated cements
ISO 10139-1:2005/Cor 1:2006	Soft lining materials for removable dentures — Part 1: Materials for short-term use
ISO 10139-2:1999	Soft lining materials for removable dentures — Part 2: Materials for long-term use
ISO 10271:2001/Cor 1:2005	Corrosion test methods
ISO 10477:2004	Polymer-based crown and bridge materials

Cor: Correction; Amd: Amendment; TR: Technical report. TS: Technical specification

ISO 11244:1998	Dental brazing investments
ISO 11245:1999	Phosphate-bonded refractory die materials
ISO 11246:1996	Dental ethyl silicate bonded casting investments
ISO/TS 11405:2003	Dental materials — Testing of adhesion to tooth structure
ISO 13716:1999	Reversible-irreversible hydrocolloid impression material systems
ISO 13897:2003/Cor 1:2003	Amalgam capsules
ISO 14233:2003	Polymer-based die materials
ISO 14356:2003	Duplicating material
ISO/TS 14569-1:1999	Guidance on testing of wear — Part 1: Wear by toothbrushing
ISO/TS 14569-2:2001	Dental materials — Guidance on testing of wear — Part 2: Wear by two - and/or three body contact
ISO 15854:2005	Casting and baseplate waxes
ISO 16744:2003	Base metal materials for fixed dental restorations
ISO/TS 17576:2004	Corrosion tests for amalgam
ISO 22112:2005	Artificial teeth for dental prostheses
ISO 24234:2004	Mercury and alloys for dental amalgam
11.060.15:	Dental implants including dentures
ISO 10451:2002	Dental implant systems — Contents of technical file
ISO/TR 11175:1993	Dental implants — Guidelines for developing dental implants
ISO 14801:2003	Fatigue test for endosseous dental implants
ISO 22803:2004	Membrane materials for guided tissue regeneration in oral and maxillofacial surgery — Contents of a technical file
ISO/TS 22911:2005	Preclinical evaluation of dental implant systems — Animal test methods

Appendix 3

To convert from	*To*	*Multiply by*
kilograms force	pounds	2.2046
kilograms force	Newtons	9.807
pounds	kilograms force	0.4536
pounds	Newtons	4.448
Newtons	kilograms force	0.1020
Newtons	pounds	0.2248
Force per unit urea		
psi	MPa (MN/m^2)	0.006895
psi	Kg/cm^2	0.0703
Kg/cm^2	MPa (MN/m^2)	0.09807
Kg/cm^2	psi	14.2233
MN/m^2	psi	145.0
MN/m^2	Kg/cm^2	10.1968

Appendix 4

ISO SPECIFICATION 3107: FOR ZOE CEMENT—SAMPLE

INTERNATIONAL STANDARD **ISO 3107:2004(E)**

Dentistry - Zinc oxide/eugenol and zinc oxide/noneugenol cements

1. Scope

This International Standard specifies the requirements and performance test methods for non-water-based zinc oxide/eugenol cements suitable for use in restorative dentistry for temporary cementation, for permanent cementation, for cavity liners and bases and as temporary restorations.

This lnternational Standard is also applicable to noneugenol cements contaning zinc oxide and aromatic oils suitable for temporary cementation.

2. Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2590, *General method for the determination of arsenic—Silver diethyldithiocarbamate photometric method*

ISO 3696:1987, *Water for analytical laboratory use—Specification and test methods*

ISO 8601, Data *elements* and *interchange* formats—*Information interchange—Representation of dates and times*

3. Classification

For the purposes of this document, the following classification for cements is used, based on their intended use:

a. Type I: for temporary cementation;
    1. Class 1: setting cement;
    2. Class 2: non-setting cement.
b. Type II: for permanent cementation;
c. Type III: for bases and temporary restorations;
d. Type IV: for cavity liners.

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Index