Basic
Dental Materials

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Second Edition

Editor

John J Manappallil

Foreword by

V Surendra Shetty

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To our Planet and all its Living Creatures
Its their home too...
Let’s not destroy our forests
Let’s not pollute our environment
Let’s consume less and recycle more and….
Let’s control our numbers
Lest we be a plague upon the Planet
Let’s start now….

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Foreword

It has been my fortuitous pleasure to write this foreword to the maiden venture of my colleague Dr. John J. Manappallil, Asst. Professor in Prosthodontics at College of Dental Surgery, Mangalore.

The advancement of dentistry and the quality of dental treatment are dependent upon a thorough knowledge of the basic sciences. Certainly no basic science could be more relevant to dentistry and dental specialty practice than materials used in dentistry. The Science of Dental Materials is becoming widely recognized as an important area of formal study for the dental graduates.

The dental science which is tremendously advancing, do absorb all the technical aspects of all other basic sciences such as Physics, Chemistry and other advancing sciences. The technical path of supremacy in science, education and training are important and that has to be delivered in our own country. So far we have depended on Western countries for education. Now we have Technocrat efficiency in India. Still we lack the literature and books written by our own people.

It is a welcome sign that now books are forthcoming in our own country on technical aspects. Dr. John J. Manappallil has written the first comprehensive book on *Basic Dental Materials.* This can serve as a keystone to the understanding of Dental Material Science in general and their application to clinical dentistry .

The sequential presentation of materials from the elementary principles to the more complicated systems in a simple and orderly manner will allow both the students and practitioners to gain a better understanding of their application in clinical practice. The young author deserves to be congratulated for bringing out the first book on Dental Materials in India. I wish him, the very best in this and all his other professional endeavors.

Dr. V. Surendra Shetty
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Preface

Dental Materials can appear quite *dry* and intimidating. Well, let us face the facts- ***'No Dental Materials - No Dentistry.'*** One of the reasons why this might be so is because of the inclusion of a lot of technical details. Unfortunately this is a part of our profession itself. A successful dentist has to combine good technical knowledge and skills along with medical 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 problems might appear insurmountable - so many materials to study, some being entirely different, while others seem to be so alike as to be confusing. Well this is quite normal and fortunately disappears with familiarity. Dental materials does not end with first year of B.D.S, so don't throw away your books, you will need it at some point during the rest of the course and for as long as you practice dentistry.

So what's new in this edition? Well, besides the usual updates, some of the chapters have been totally revamped. Two new chapters have been added. Also included are lots of new pictures and diagrams. Evolutions of certain materials have also been discussed. Revising the edition was quite a task. The good response to the previous book did encourage me and I would like to thank all those who wrote to me personally. I hope to receive more such letters. Please e-mail me at *cibala@arabia.com.* All comments - are welcome and I would be most happy to respond.

Today's dentist is fortunate to have such a wide choice of materials. It had not always been this good. In the past, the availability of materials in India was quite limited greatly affecting the quality of both education and treatment. However, thanks to the economic liberation of the 1980's and 1990's period, our market opened out to a whole range of high quality western products. In spite of the appearance of many new materials, the fact is that many basic materials have remained unchanged since decades. Most of the changes have involved modifying existing materials and improving their performances. A few of the materials have fallen by the wayside and are no longer used because of the introduction of better materials. Knowledge of the history of Dental Materials is useful because it helps us to understand how these materials evolved and why newer materials were developed. As in the last edition I have continued my emphasis on actual physical values of the various materials. The knowledge of these values helps us to achieve a depth of understanding as well make comparison between the various materials. However one must remember that these values are not necessarily absolute, variations can occur between brands and methods of testing as well as due to climatic differences. This includes properties like working time and setting time.

It is clear that Dental Materials is a *dynamic* subject. Thanks to journals, conferences and the Internet, there is a whole lot of exchange of information between individuals, transcending geographical barriers. Concepts are constantly changing and knowledge keeps improving. Unfortunately some among us are still in a *time warp*, clinging on to outdated ideas and concepts – both in our educational system as well as clinical practice. An open mind is also essential for learning - especially one open to new ideas as well as *criticism* and *suggestions*. Greatness begins with *humility*, and without humility one cannot learn.

Thus far we have been importing knowledge as well as material. I hope the time will come when research also becomes a norm in granting recognition to various institutions. In time I hope *our* research, *our* journals, *our* materials, as well as *our* professionals will be recognized and respected the world over. We need to advance our current undergraduate training with improved techniques as well as material and equipment. It is my fervent hope that a new generation of dentists will emerge upholding the *dignity* of the profession, rather than fall for questionable motives. It is my personal experience that *we* are as good as any in the West.

Let us begin our journey with Dental Materials.

John Joy Manappallil

Acknowledgements

Acknowledgement to the First Edition

Every book has its share of contributors and influences and this book is certainly no exception. I would like to express my gratitude to Dr. V.K. Subba Rao, former head of department of Dental Materials at Davengere. The many discussions and her emphasis on simplicity of presentation and attention to detail were invaluable.

My gratitude goes to my former colleagues at Davengere who have contributed to certain chapters in this book. They include: Shubha Rao, R. Sangur, Vinay Kumar, Akshay Bhargav, Atley George, and Satheesh S. Pillay. I am also grateful to R. Kotian and A. Shenoy for clarifications on certain aspects of the subject.

It is my honour and privilege to have the foreword written by Dr. V. Surendra Shetty, Dean of the College of Dental Surgery, Mangalore and I thank him for the honour.

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 grateful to Dr. Sadashiva Shetty, Principal of Bapuji Dental College and Hospital, Davengere, Dr. Surendra Shetty, Dean of College of Dental Surgery, Mangalore and Dr KS Bhat, Dean of College of Dental Surgery, Manipal for the excellent facilities and the opportunity to work with some of the most recent materials in dentistry .

My deepest appreciation goes to my wife Divya for her help with and support of this project. Thanks are also given to M. Yasin, N. Grover, and N. Gupta for their help with the index. I would also like to thank my colleagues and staff at the Department of Prosthodontics, Mangalore for their support and encouragement.

I thank Mr. Prem of Blue Chip computer school for preparation and correction of the manuscripts. His patience and skill are deeply appreciated. Finally I would like to thank the publishers and commend their excellent work and professionalism.

Acknowledgement to the Second Edition

My sincere thanks to *S. I. Bhalajhi* for his invaluable help with the digital photography and advice on various computer programs and applications. A special thanks to the *publishers* and the *team* out there at Jaypee in New Delhi for the wonderful job you have done.

I also take this occasion to once again renew bonds of friendship and affection with all the *contributors*, my *former colleagues* and *classmates*, my *teachers* and with all those whom I have had the good fortune to be associated with. How can I end this without mentioning my *current colleagues* and *friends* including our *technical staff* at the *Jahra Dental Center*, Ministry of Health, Kuwait, for their support and encouragement.

May God bless you all with health and happiness.

Contents

CHAPTER 1

Dentistry and Dental Materials

Dental treatment may be divided into 3 phases:

- Prevention,
- Restoration, and
- 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 problems. Caries involves the actual demineralization and destruction of tooth structure. Our next focus is to arrest the caries process. This involves removing the carious enamel 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 restoration would certainly look unpleasant if used for the front (anterior) teeth. Therefore, we would like to restore anterior teeth 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 special materials which have a beneficial effect on the pulp. These materials can be soothing and promote healing by forming a new layer of dentin (secondary dentin).

Once the pulp is infected, we have no choice but to remove the pulp (pulpectomy). This is the next step. This is known as *root canal treatment* popularly known as RCT. After removing the pulp, the canal is made sterile and sealed using root canal filling materials. The root canal treated tooth is fragile and can fracture if not protected with a crown or onlay.

Sometimes the tooth structure is so destructed and weakened that a simple restoration would not be sufficient. In such a case the tooth is covered with a *crown* or an *onlay*. Before the discovery of tooth colored crown materials, metallic crowns were given (the famous gold tooth). Today 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. How are these models made? The dentist makes 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). It can be made entirely of plastic also and is referred to as a *treatment partial denture.*

The final stage is of course 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 is 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 special 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. Unfortunately, not all the materials used in dentistry are within the scope of this book.

CHAPTER 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

Solid → Liquid → Gas

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.*

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 chemicals 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.

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.

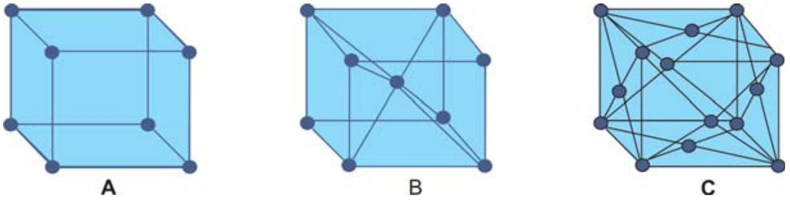


FIGURE 2.1: Crystal structure: A—Simple cubic, B—Body centered cubic, C—Face centered cubic

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

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). 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).

PHYSICAL PROPERTIES OF DENTAL MATERIALS

To select and use a dental material one must know and 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.

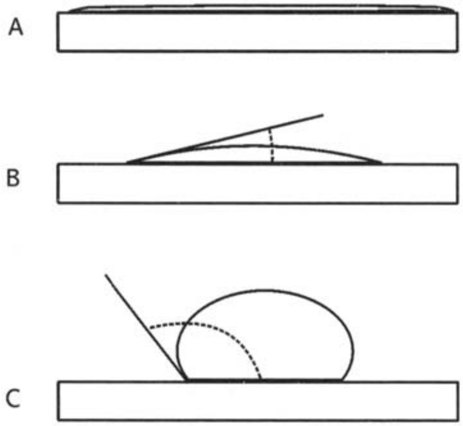


FIGURE 2.2: Wetting angle; A: Low wetting angle indicates good wettability. C: High contact angle indicates poor wettability

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

The internal resistance to force (stress) is impractical to measure, the more 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, is an elongation of a body, whereas a compression, or pushing force, causes compression or shortening of the body.

Strain is expressed as change in length per unit length of the body when a stress is applied.

$$\text{Strain} = \frac{\text{Deformation or change in length}}{\text{Original length}} = \frac{e}{l}$$

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 co-ordinate and the corresponding strain (change in length) is plotted on the horizontal co-ordinate 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 upto point ‘P’ after which it curves.

The point 'P' is the proportional limit, i.e. upto 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.

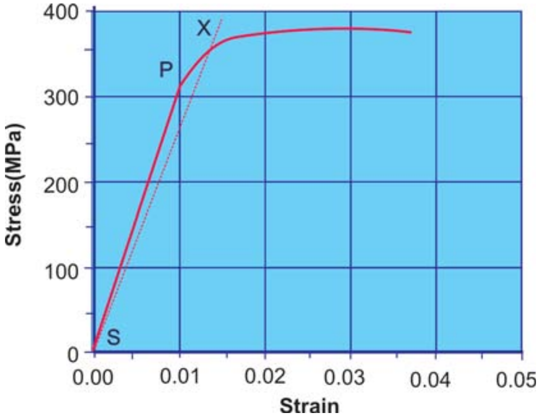


FIGURE 2.3: Stress-strain curve: P-proportional limit, X-yield strength, S-offset

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 behaviour 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 (upto the proportional limit), the stress to strain ratio would be constant.

$$\text{Modulus of elasticity or Young's modulus} \quad E = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{e/l} = \frac{FI}{eA}$$

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 seperate.

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

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

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

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

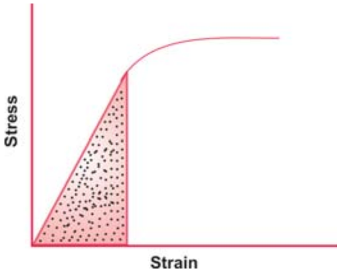


FIGURE 2.4: Area of resilience in a stress-strain curve

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 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, and
- Shear strength.

Tensile Strength

Tensile strength is determined by subjecting a rod, wire or dumbell 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.

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

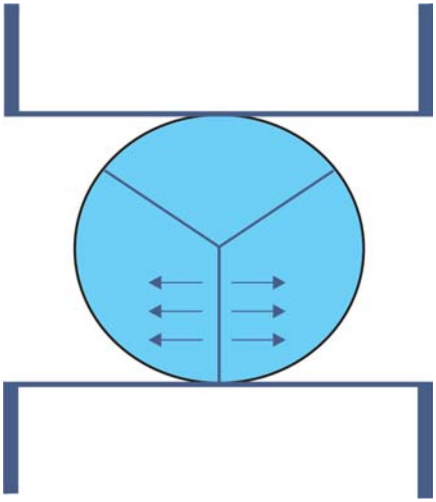


FIGURE 2.5: Diametral tensile test

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.

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:

$$\text{Shear Strength} = \frac{F}{\pi d h}$$

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 Flexure Strength

Transverse strength or modulus of rupture 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).

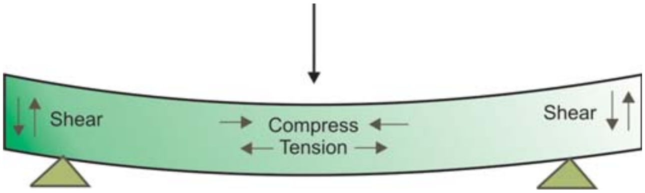


FIGURE 2.6: Complex stresses produced by three point loading of a beam

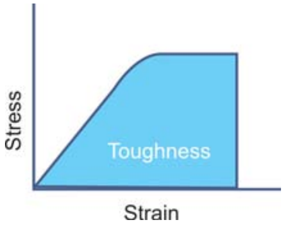


FIGURE 2.7: Area of toughness in stress-strain curve

Application

Used to test denture base resins and long span bridges.

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 behaviour 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).

BRITTLENESS

A brittle material is apt to *fracture at or near its proportional limit.* Brittleness is generally considered as 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 is lacking in 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 fibre, its tensile strength may be as high as 2800 MPA.

Application

Many dental materials are brittle, e.g. porcelain, cements, gypsum products, 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 is measured by three common 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).

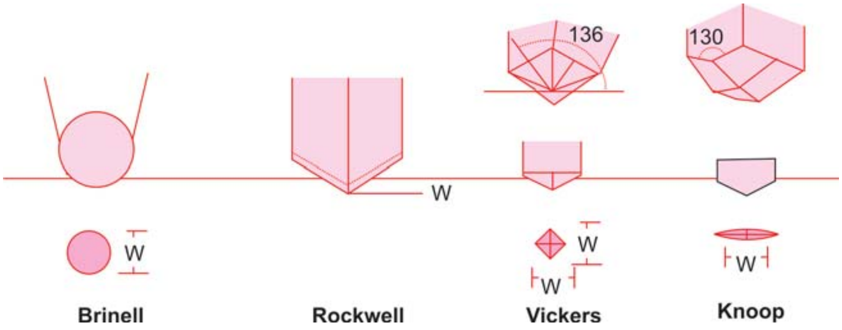


FIGURE 2.8: Various hardness tests

Brinell

A hardened steel ball is pressed into the polished surface of a material under a specified load. The load is divided by the area of the surface of the indentation and the quotient is referred to as Brinell Hardness Number (BHN).

BHN = Load/Area of indentation

Application

Used for measuring hardness of metals and metallic materials.

Rockwell Hardness Number (RHN)

Just like the BHN 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.

Applications

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 identing 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 has greater viscosity 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).

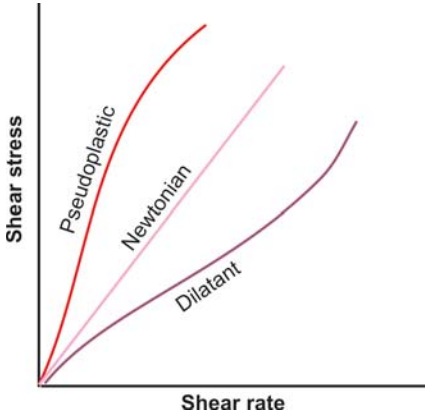


FIGURE 2.9: Shear diagrams of pseudoplastic, newtonian and dilatant liquids

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 electro-magnetic 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).

THREE DIMENSIONS OF COLOR

Quantitatively color has come to be described as a three dimensional quality specified by values for three variables: 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, e.g. the yellow of a lemon is lighter than the red of a sweet cherry. This lightness which can be measured independently of the color 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 and mature is the color. Chroma cannot exist by itself and is always associated with hue and value.

MEASUREMENT OF COLOR

One of the most commonly used method to define and measure color quantitatively is the *Munsell System.* It is a co-ordinate 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 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.*

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 invisible U-V light.

FIGURE 2.10: The Vita lumin shade guide. This famous shade guide has been in use for a long time to select the color of artificial porcelain teeth

FIGURE 2.11: The newer Vitapan 3D Master is just been introduced recently and is the advanced version of the Vita lumin

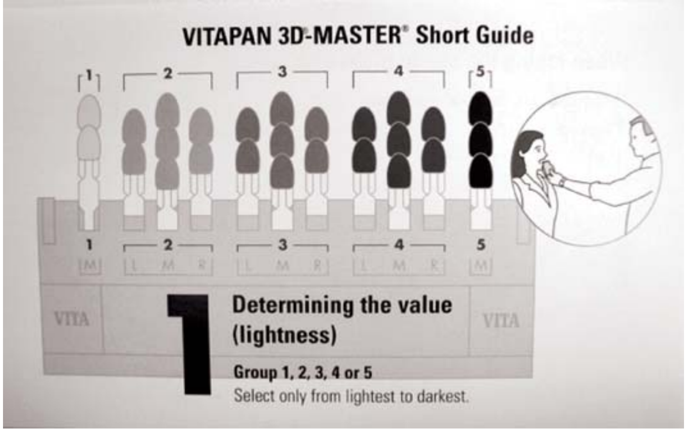


FIGURE 2.12: Selecting the color using the new Vitapan system. The color is determined in 3 steps. The figure above shows step 1 (lightness or darkness). The guide is held along the patients face at arms length. Step 2 determines the hue (basic color). Step 3 determines the chroma (saturation)

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. The emitted light is primarily in 400-450 nm range, having blue white color.

Flourescence makes a definite contribution to the brightness and vital appearance of a human tooth.

Importance

Some patients want their restorations to match natural tooth under U-V light conditions, e.g. in stage shows and discotheques. Some manufacturers of porcelain include fluorescence matching in their products.

CLINICAL CONSIDERATIONS

Esthetics plays 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 2.10 to 2.12). These are used in much the same way as paint chips are used to select the color for house paint.

CHAPTER 3

Biological Considerations of Dental Materials

The science of dental materials must include a knowledge and appreciation of certain 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 injures the pulp or soft tissue. The biological characteristics of dental materials cannot be isolated from their physical properties.

Biological Requirements of Dental Materials

A dental materials should:

1. Be non-toxic to the body,
2. Be non-irritant to the oral or other tissues,
3. Not produce allergic reactions, and
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 are used as root-canal filling materials,
D. Those which affect the hard tissues of the teeth, and
E. Those used in the dental laboratory which though not used in the mouth, are handled and 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.
- 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.
- 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 and tin) are used in elastomeric impression materials.
- Eugenol in impression pastes 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, and asbestos.
- Some periodontal dressing materials have contained asbestos fibres.

A *biomaterial* can be defined as any substance, other than a drug, that can be used for any period of time as a 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 seal 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, micro-organisms, 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 micro-organisms 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 micro-organisms 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 (Fig. 24.1, Chapter 24). 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 falls off 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 u amp and other at 110 u amp (average: 20 to 50 u 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 Y2-containing amalgams appear to be less than those associated with Y2-containing amalgam.

TOXIC EFFECTS OF MATERIALS

A few dental materials may contain a variety of potentially toxic or irritating ingredients, e.g. phosphoric acid in zinc phosphate cements.

Materials to be utilized in the oral cavity must also be non-irritating to soft tissue. For example, any material used to fabricate an artificial denture should not produce an allergic reaction on the underlying tissue.

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.

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 micro-organisms, 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 micro-organisms can spread, e.g.

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 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.

CHAPTER 4

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 pre- and post-treatment records.
5. By using casts, technical work can be passed on to technicians, saving valuable clinical time.

DESIRABLE PROPERTIES OF AN IMPRESSION MATERIAL

An impression material should:

1. Have a pleasant taste, odor and esthetic color.
2. Not contain any toxic or irritating ingredients.
3. Have adequate shelf life for storage and distribution.
4. Be economical.
5. Be easy to use with the minimum equipments.
6. Have adequate setting characteristics that meet clinical requirements.
7. Possess a satisfactory consistency and texture.
8. Have adequate strength so that it will not break or tear while removing from the mouth.
9. Possess elastic properties with freedom from permanent deformation after strain.
10. Exhibit dimensional stability.

11. Be compatible with the die and cast materials.
12. Faithfully reproduce the tissues of mouth.
13. Be able to be electroplated.

CLASSIFICATION OF IMPRESSION MATERIALS

There are several classifications:

According to Mode of Setting and Elasticiy

Mode of Setting	*Rigid*	*Elastic*
Set by chemical reaction (irreversible or thermoset).	Impression plaster Zinc oxide eugenol	Alginate hydrocolloid Non-aqueous elastomers, e.g. Polysulfide polymer Polyether, Silicone
Set by temperature change (reversible/thermoplastic).	Compound Waxes	Agar hydrocolloid.

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 in removable partial denture prosthesis and crown and bridge work, 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 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 mouth.

CLASSIFICATION

ADA specification No.3 two types:

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 mouth tissues. Since reproduction of the fine details is not essential, it is generally stiffer and has less flow than regular impression compound.

SUPPLIED AS

Sheets, sticks, cakes and cones (Fig. 4.1).

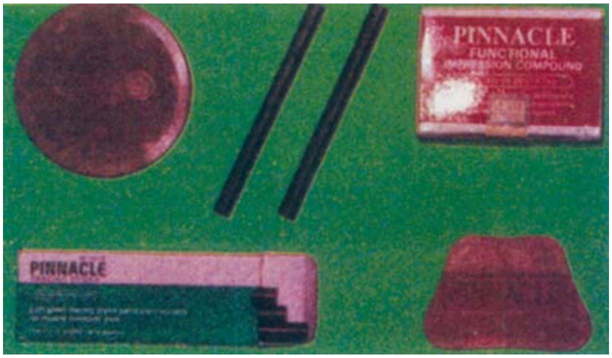


FIGURE 4.1: Impression compound cakes and sticks

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 operative 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 in a stock tray. A study cast is 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	75
Coloring agent	Appropriate amount

Plasticizers Bees wax is brittle, so 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, usually in combination with natural resins.

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 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 being non-crystalline in character cause high flow of the compound and low strength. Consequently a filler such as talc is added to reduce the plasticity of the matrix material by frictional action. Other fillers used are diatomaceous earth, soap stone and French chalk.

PROPERTIES OF IMPRESSION COMPOUND

Glass Transition Temperature and Fusion Temperature

When impression compound is heated in a hot water bath the material *looses* its hardness 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 *glass transition temperature.*

Fusion Temperature

On further heating at approximately 43.5°C, the material softens to a plastic mass that can be manipulated. This is called the fusion temperature. It is the temperature at which the crystalline fatty acids melt (or solidify).

Significance of fusion temperature Above this temperature, the fatty acids are liquid and lubricate the softened material to form a smooth plastic mass, while the impression is being obtained. Thus all impressions with compound should be made above this temperature. Below this temperature an accurate impression cannot be expected.

Significance of glass transition temperature Once the impression tray is seated, it should be held firmly in position until first fusion temperature and later the glass transition temperature is reached. Thus the impression is made above the fusion temperature whereas it is *removed* from the mouth only *after it cools down to its glass transition temperature*.

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 sufficiently long time in a water bath. Kneading of the material ensures further uniform softening.
- Due to poor thermal conductivity, the layer adjacent to the mouth tissues will remain soft. Removal of the impression at this stage will cause serious distortion. Thus it is important to cool the compound thoroughly before removing if from the mouth.

Coefficient of Linear Expansion (CTE)

The CTE of a compound is comparatively high because of the presence of resins and waxes. The linear contraction from mouth temperature to room temperature is 0.3%. *This error can be reduced:* (i) by obtaining an impression as usual 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 slight, since only the surface layer has been softened completely, and (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.

According to ADA specification No. 4

Type I : Flow not more than 3% at 37°C (Mouth temperature).
Flow not less than 80% and not more than 85% at 45°C.

Type II: Flow not more than 2% at 37°C.
Flow not less than 70% and not more than 85% at 45°C.

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 before it is thoroughly cooled in the mouth.

Reproduction of Detail

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 tissue are recorded in a distorted state.

MANIPULATION

Sticks

Small amounts of compound are softened over a flame. When a direct flame is used, the compound should not be allowed to boil or ignite, otherwise, the plasticizers are volatilized.

Cakes

When a large amount of compound is to be softened, it is difficult to heat the compound uniformly over a flame. The compound is softened in warm water in a thermostatically controlled water bath (Fig. 4.2) (usually in the range of 60 to 70°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 4.2: A thermostatically controlled water bath. This water bath maintains a steady softening temperature and is ideal for softening impression compound

Precautions

- Prolonged immersion in a water bath is not indicated; the compound may become brittle and grainy because some of the low molecular weight ingredients may be leached out.

- Over heating in water makes the compound sticky and difficult to handle.
- Avoid incorporating water while kneading.

Removal of Impression

The impression is removed from the mouth only after it has completely hardened.

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 material.
4. The material has sufficient body to support itself to an extent especially in the peripheral portions. It does not collapse completely if unsupported by the tray.

DISADVANTAGES

1. Difficult to record details because of its high viscosity.
2. Compresses soft tissues while making 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 peripheral portions.

ZINC OXIDE EUGENOL IMPRESSION PASTE

Zinc oxide and eugenol combination is widely used in dentistry:

- Cementing and insulating medium.
- Temporary filling.
- Root canal filling material.
- Surgical pack in periodontal surgical procedures.
- Bite registration paste.
- Temporary relining material for dentures.
- Impression material for edentulous patients (Fig. 4.3).

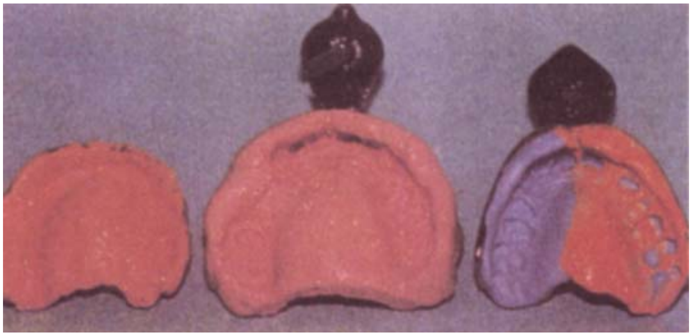


FIGURE 4.3: From left to right—a zinc oxide eugenol edentulous impression in a custom tray and dentulous alginate and elastomeric (putty reline) impressions in stock trays

CLASSIFICATION

ADA specification No. 16.

- Type I or Hard
- Type II or Soft

AVAILABLE AS

In paste form in two tubes (Fig. 4.4)

- Base paste (white in color).
- Accelerator or Reactor or Catalyst paste (red in color).

FIGURE 4.4: Representative zinc oxide eugenol pastes for impression making and periodontal dressing

COMPOSITION

Base Paste			*Accelerator Paste*		
Zinc oxide	—	87%	Oil of cloves or Eugenol	—	12%
Fixed vegetable or mineral oil	—	13%	Gum or Polymerised Rosin	—	50%
			Filler (Silica Type)	—	20%
			Lanolin	—	3%
			Resinous Balsam	—	10%
			Accelerator solution ($CaCl_2$) and coloring agents	—	5%

Zinc oxide should be finely divided and should contain slight amount of water.

Fixed vegetable or *mineral oil* acts as plaslicizer 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 polymerised rosin speeds the reaction.

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. $\underset{\text{Base}}{Zn(OH)_2} + \underset{\text{Acid (Eugenol)}}{2HE} \longrightarrow \underset{\text{The Salt (Zinc Eugenolate)}}{ZnE_2} + 2H_2O$

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.
- Result in a wastage of time for the dentist. In a busy practice, this could lead to a lot of stress.
- Movement is bound to occur, resulting in stresses and errors in the impression.

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

- *Particle size* of zinc oxide powder: If the particle size is small and if it is acid coated, the setting time is less.
- By *varying the lengths* of the two pastes (not recommended).
- 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).
- Longer the *mixing time,* shorter is the setting time.
- High atmospheric *temperature* and *humidity* accelerate setting.
- 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. Occasionally one does come across poor quality impression pastes, which 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 fracture and be unyielding when removed from the mouth. The compressive strength of hardened ZOE is 7 MPa 2 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. This may be overcome by using a non-eugenol paste.

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. 4.5). A flexible stainless steel spatula is used. The two ropes are combined with the first sweep of the spatula and mixed until a uniform color is observed (Figs 4.6A and B).

Mixing time 1 minute.

Mechanical mixing A rotary mixing device can also be used (Fig. 4.7). Special circular mixing pads are available. These 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 alternately until a uniform mix is obtained. Mechanical mixing gives a faster, uniform mix with less voids and bubbles.

ADVANTAGES

1. It has sufficient body so as to make up for any minor under extensions in the tray itself during impression making.

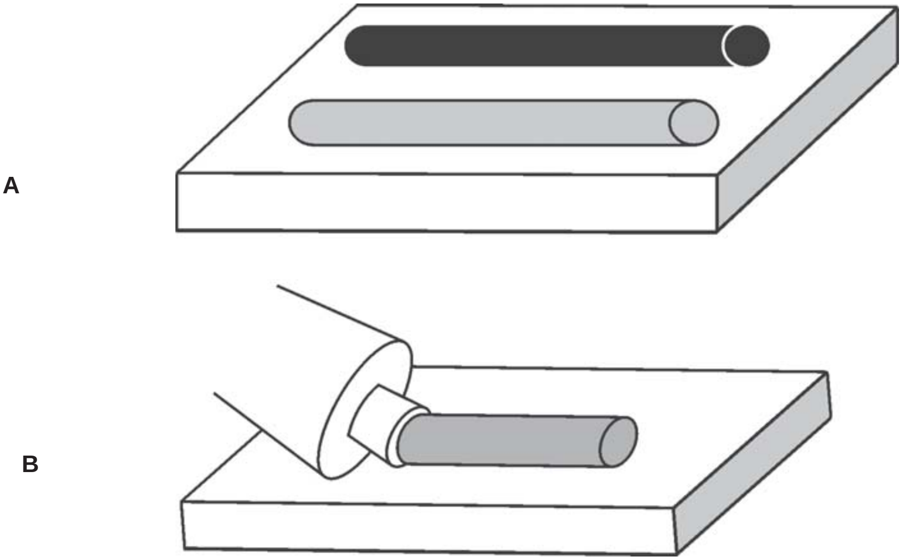


FIGURE 4.5: Paste dispensing: Paste dispensing is an important aspect of the manipulation of all impression materials dispensed in tubes that are of equal length. A—both the ropes should be of equal length and width in order to ensure the correct proportioning. One way of obtaining this is by ensuring the paste coming out of the tube is the same diameter as the mouth of the tube—B

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. It does not require any separating media since it does not stick to the cast material.
7. Minor defects can be corrected locally without discarding a good impression.

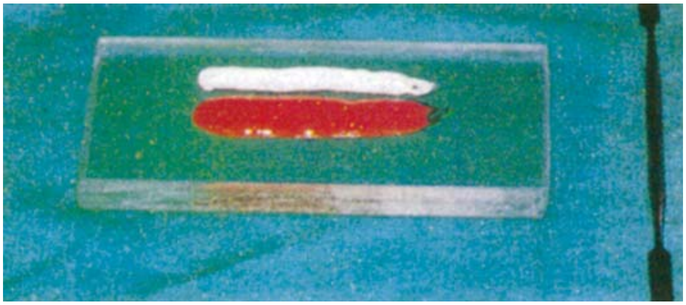


FIGURE 4.6A: Manipulation of zinc oxide eugenol paste: Equal lengths of base and reactor pastes are dispensed

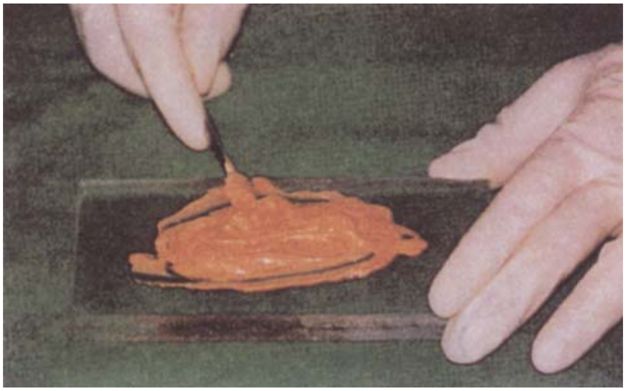


FIGURE 4.6B: Mixing is done with a stainless steel spatula using circular motions until a streak free mix is obtained (Manufacturers usually provide such materials in contrasting colors to aid in visually ascertaining completion of mix)

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 under-cut areas as it is inelastic in nature.

OTHER ZINC OXIDE PASTES

SURGICAL PASTES

After certain periodontal surgeries (e.g. gingivectomy, i.e. surgical removal of diseased gingival tissues) where suture cannot be placed, a zinc oxide eugenol surgical paste

FIGURE 4.7: A rotary automixing device for pastes and cements

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). These surgical pastes are less brittle and weaker after hardening. The setting time is longer. The paste is mixed and formed into a rope that is packed over the gingival wounds 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. These pastes may also contain more eugenol and the accelerator content is less.

NON-EUGENOL 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 non-eugenol pastes were developed. 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. Bactericides and other medicaments can be incorporated. This reaction can be substituted for the zinc oxide eugenol reaction to form any type of dental paste.

BITE REGISTRATION PASTES

These are materials used for recording the occlusal relationship between teeth or occlusion rims. ZOE pastes 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.

ZOE registrations are more rigid than registrations made in wax. They are more stable, and offer less resistance to the closing of the jaw.

CHAPTER 5

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 would 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 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 Dispersion 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

Basically they are lyosols. They consist of gelatin particles suspended in water. 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 semi-solid 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:

- Lowering the temperature, e.g. Agar
- 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 become trapped in the fibrillar network and their size, shape and density determine their effectiveness. Addition of 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.

Agar hydrocolloid was the first successful elastic impression material to be used in dentistry. It is an organic hydrophillic colloid (polysaccharide) extracted from certain types of *seaweed*. It is a sulphuric 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.

USES

1. Widely used at present for cast duplication (during fabrication of cast metal removable partial denture, etc.) (Fig. 5.1).
2. For full mouth impressions without deep undercuts.
3. Was used extensively for crown and bridge impressions before elastomers came to the market.
4. As tissue conditioner.

SUPPLIED AS

- Gel in collapsible tubes (for impressions).
- A number of cylinders in a glass jar (syringe material).
- In bulk containers (for duplication, Fig. 5.1).

The former is used with a water cooled impression tray (Fig. 5.3) and the latter with a syringe. The syringe material has a different color and is more fluid than the tray material.

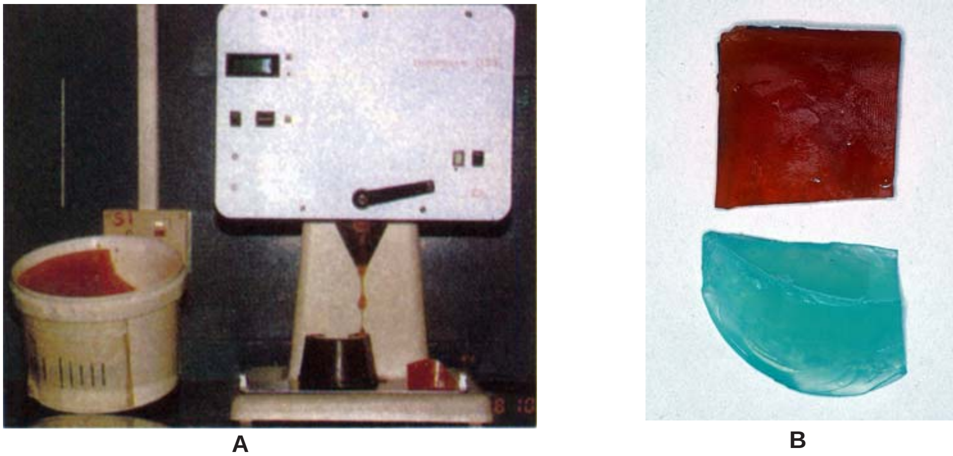


FIGURE 5.1: (A) Liquefied agar being poured into a duplicating mould. (B) Agar up close

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%)

Function of Each Ingredient

- *Agar* Basic constituent 13-17% for tray material 6-8% for syringe material.
- *Borates* It improves the strength of the gel, (it also retards the setting of plaster or stone cast when poured into the finished impression—this is a disadvantage).
- *Potassium sulphate* It counters retarding effect of borates, thereby ensures proper setting of the cast or die.
- *Wax, Hard* It acts as a filler. Fillers affect the strength, viscosity and rigidity of the gel. Other examples of fillers—zinc oxide, diatomaceous earth, silica, clay, 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 agents* For patient comfort.
- *Water* It acts as the dispersion medium.

MANIPULATION

Agar hydrocolloid requires special equipments:

- Hydrocolloid conditioner (Fig. 5.2)
- Water cooled rim lock trays (Fig. 5.3)

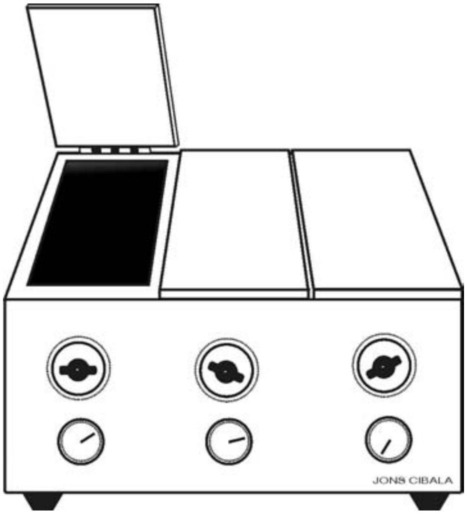


FIGURE 5.2: An agar hydrocolloid conditioner

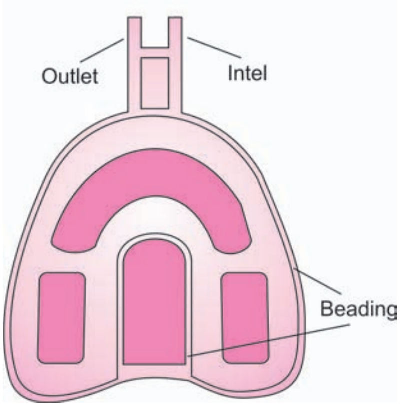


FIGURE 5.3: A water cooled rim lock tray for agar

The Hydrocolloid Conditioner Consists of

Boiling section or Liquefaction section	Ten minutes in boiling water (100° C). The sol should be homogeneous and free of lumps. Every time the material is reliquefied, three minutes should be added. This is because it is more difficult to break down the agar brush heap structure after a previous use.
Storage section	65-68°C temperature is ideal. It can be stored in the sol condition till needed.
Tempering section	46°C for about two minutes with the material loaded in the tray. This is done to reduce the temperature so that it can be tolerated by the sensitive oral tissues. It also makes the material viscous.

Impression Trays

Rim lock trays with water circulating devices. 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. 5.3).

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.

Removal of Impression

When the agar has gelled, the peripheral seal around the impression is broken, and the impression is removed rapidly from the mouth with a single stroke or snap. 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 and no satisfactory medium for storage is available. 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 ADA sp. No.11 sets the standard properties required of the available Agar-Hydrocolloid impression materials.

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 evaporation, and if it is immersed in water, it absorbs water by a process known as *imbibition.*

The gel may also loose water by exuding of fluid in a process 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.

Flow

The material is sufficient fluid to record the fine details if it is correctly manipulated.

Gelation, Liquefaction and Hysterisis

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 *hysterisis.*

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

Agar hydrocolloids are highly elastic in nature and elastic recovery occurs to the extent of 98.8%.

Reproduction of Detail

A reproduction of upto 25 um (micrometers) is achievable with agar hydrocolloids.

Accuracy and Dimensional Change

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.

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.

Tear and Compressive Strengths

Agar has a tear strength of 715 gm/cm^2 and compressive strength of 8000 gm/cm^2. According to ADA sp. No. 11 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.

LAMINATE TECHNIQUE: OR AGAR ALGINATE COMBINATION TECHNIQUE

Here, 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 syringe agar is positioned on it. The alginate gels by a chemical reaction, whereas the agar gels by means of contact with the cool alginate rather than the water circulating through the tray.

Advantage

1. The syringe agar gives better details than alginate.
2. Less air bubbles.
3. Water cooled trays are not required.
4. It sets faster than the regular agar technique.

WET FIELD TECHNIQUE

This is a relatively new technique which has become popular. 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

After the introduction of alginate, agar slowly lost its appeal as an impression material. However, it is still popular today 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 (Fig. 5.1) where it is liquefied and stored. The liquid agar is poured into a mould former in order 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. It has good elastic properties and reproduces most undercut areas correctly.
3. It has good recovery from distortion.
4. As it is not hydrophobic, it gives good model surface.
5. It is palatable and well tolerated by the patient.
6. It is cheap as 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).

Disadvantages

1. Does not flow well when compared to newly available materials.
2. It cannot be electroplated.
3. During insertion or gelation it may be painful to the patient.

4. Tears relatively easily. Greater gingival retraction is required for providing adequate thickness of the material.
5. Only one model can be poured.
6. Extensive and expensive equipment is required.
7. A soft surface of the gypsum cast results unless a plaster hardener is used.
8. 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 'Algin' which is a peculiar mucous extract yielded by certain brown seaweed (Algae). The term 'Algin' was coined by a chemist from Scotland at the end of the last century. Algin was used for many purposes.

In England 40 years later, another chemist, S. *William Wilding* received a basic patent for the use of algin as a dental impression material. 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.

TYPES

Type I- fast setting.
Type II- normal setting.

SUPPLIED AS

A powder that is packed

- In bulk containers (tins, bins or sachets) (Fig. 5.4).
- In preweighed packets for single impression.

A plastic scoop is supplied for dispensing the bulk powder, and a plastic cylinder, is supplied for measuring the water.

Modified Alginates

Other forms are also available:

- In the form of a *sol,* containing the water. A reactor of plaster of Paris is supplied separately.
- *As a two paste systems* 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.

FIGURE 5.4: Alginate is available in bulk packing or as small sachets for individual impressions. The plastic measures provided by the manufacturers usually give satisfactory water powder ratio

Commercial Names

Zelgan (DPI), Jeltrate (Dentsply).

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.*	*Functions*
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 and 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 (sodium 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:

- $2Na_3PO_4 + 3CaSO_4 \longrightarrow Ca_3(PO_4)_2 + 3Na_2SO_4$
- $\underset{\text{(Powder)}}{\text{Sodium Alginate}} + CaSO_4 + H_2O \longrightarrow \underset{\text{(Gel)}}{\text{Ca Alginate}} + Na_2SO_4$

First, 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 by products. It is a cross linked structure (i.e. each fibre is tied to each other at certain points). Calcium is responsible for cross linking.

PROPERTIES OF ALGINATE HYDROCOLLOID
(According to ADA specification No. 18 for Alginate hydrocolloids)

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.

Elasticity and Elastic Recovery

Alginate hydrocolloids are highly elastic (but less when compared to agar) and about 97.3% elastic recovery occurs. Thus permanent deformation is more for Alginate (about 1.2%). 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. The 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 5000-8000 gm/cm^2
- or 0343-.70 MPa

Tear strength

- varies from 350-700 gm/cm^2

Factors affecting gel strength

- *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.

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.

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.

Biological Properties

Silica particles present in the dust which rises from the can after fluffing alginate powder, are a possible health hazard. Avoid breathing the dust. Presently, some manufacturers supply *"dust free"* alginate. Dustless alginates contain glycol. It acts by coating the powder.

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.
- For mixing, we need:
  - 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 measured quantity of the powder is sprinkled in the measured amount of 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 (Fig. 5.5).

A B

FIGURE 5.5: (A) Alginate is mixed by stroping or swiping the material against the sides of the bowl. (B) The completed impression

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 are available for spatulating alginate. Their main advantages are:

— Speed
— Convenience
— 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): 1-2.0 mins.
Type II (normal): 2-4.5 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—longer is the gelation time.
  - Warmer the water—shorter is the gelation time.

Even the mixing bowl and spatula can be cooled.

Note Control of setting should not be done by changing W/P ratio and mixing time.

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
  - perforations (holes or slits) in the tray
- Applying a suitable adhesive (available as liquid or sprays)
- 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 into a perforated rim lock tray so that the material is forced out through the holes in the tray, thereby locking itself mechanically into the tray.

The surface of the alginate in the tray may be smoothened out by moistening the finger with water and running it over the surface of the alginate.

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.

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.

Test for Set

The material loses its tackyness when set. It should rebound fully when prodded with a blunt instrument.

Color indicators Some alginates are available which on mixing is one color and on setting change to a different color.

TIME OF REMOVAL

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.

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. The impression must be removed suddenly, with a jerk. 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. It also causes higher permanent deformation. An alginate impression is displayed in Figure 4.3.

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, preferrably within 15 minutes after making the impression.

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 in a wet paper towel and cover with a rubber bowl.
- Or Keep the impression in a 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 as it can cause imbibition of water.

CONSTRUCTION OF CAST

In the past, most alginate impressions 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.

The stone cast should not be separated for atleast 30 minutes. For alginate, best results are obtained if the cast is removed at 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.

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.

The irreversible hydrocolloids may be disinfected by 10 minutes immersion in, or spraying of, some antimicrobial agent (e.g. sodium hypochlorite, glutaraldehyde) without significant dimensional changes.

ADVANTAGES AND DISADVANTAGES OF ALGINATE

Advantages

Alginate is a popular material because:

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 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 some of the above drawbacks (and because of the availability of better materials), it is not recommended when a high level of accuracy is required, e.g. cast RPD, crown and bridge, etc.

TYPE OF FAILURES

Type	*Cause*
Distortion	• Delayed pouring of impression • Movement of tray during setting. • Removal from mouth too early • Improper removal from mouth
Grainy impression	• Inadequate mixing • Prolonged mixing • Less water in mix
Tearing	• Inadequate bulk • Moisture contamination • Removal from mouth too early • Prolonged mixing
Bubbles	• Early gelation, preventing flow • Air incorporated during mixing
Irregular voids	• Excess moisture or debris on tissues
Rough or chalky	• Inadequate cleaning of impressions
Stone cast	• Excess water left in impressions • Premature removal of cast • Leaving cast in impression too long • Improper manipulation of stone.

CHAPTER 6

Elastomeric Impression Materials

In addition to the hydrocolloids there is another group of elastic impression materials. They are soft and rubber like and are known as elastomers or synthetic rubbers. As per ADA Sp.No. 19 they are *non-aqueous 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 cross linking (by condensation or addition) reaction to produce a firm elastic solid.

Synonyms Initially they were called *rubber-base or rubber impression materials. Currently,* they referred to as elastomers or elastomeric impression materials.

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. 6.3)*:*

- light body or syringe consistency
- medium or regular body
- heavy body or tray consistency
- very heavy or putty consistency.

ADA Classification

This is based on selected elastic properties and dimensional change of the set materials.

Type I
Type II
Type III

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 moulding of special 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 paste* systems (base and catalyst) in collapsible tubes.

Putty consistency is supplied in jars.

GENERAL PROPERTIES OF ELASTOMERIC MATERIALS

- Excellent reproduction of surface details. The low viscosity is capable of producing very fine details.
- They are generally *hydrophobic* (polyether is hydrophillic), so the oral tissues in the area of impression should be absolutely dry for better flow of the impression material (hydrophobic means water hating). Because of their hydrophobic nature it is also difficult to pour die stone in the impression. Air bubbles can result. Commercial surfactants sprays are available which improve wetting.
- Elastic properties of elastomers is good (but elastic recovery is not complete). Repeated pouring of impression is possible.
- Coefficient of thermal expansion of elastomers is high. Thermal contraction in set material occurs when impression is transferred from mouth to room temperature.
- Dimensional changes and inaccuracies occur due to:
  - Curing shrinkage.
  - Loss of by-products of reaction: e.g. condensation silicones lose alcohol and shrink. Polysulfides (hydroperoxide type) lose volatile accelerators causing contraction.

  - Polyether being hydrophillic 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.
  - 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 (with the help of 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. It is also known as *Mercaptan or Thiokol.*

SUPPLIED AS

Paste in collapsible tubes as base and accelerator. Base is white colored. Accelerator is brown or grey.

Available in Three Viscosities

- Light bodied
- Medium bodied
- Heavy bodied.

Commercial Names

Permlastic (Kerr)
Coe-flex : Lead dioxide system
Omni flex : Copper hydroxide system.

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 acceleration 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—3 to 4°C rise in temperature. It is accelerated by heat and moisture.

$$HS - R - S \quad H \xrightarrow[\text{OR}]{PbO_2 + S} HS - R - S - S - R - SH \quad + \quad H_2O$$

Mercaptan + Lead dioxide → Polysulfide + 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 succesfully used are certain complex inorganic hydroxides (e.g. copper)].

PROPERTIES

- Unpleasant odor and color. It stains linen and is messy to work with.
- 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.
- 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 patients discomfort. Heat and moisture accelerate the setting time (sets faster in the mouth).
- Excellent reproduction of surface detail.
- 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. This 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 by-product (water) also causes shrinkage.
- It has high tear strength (4000 gm/cm).
- It has good flexibility (7%) and low hardness. A 2 mm spacing in the tray is sufficient for making an impression.
- 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.
- It can be electroplated. More with silver than copper.
- 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 uniforms 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 based on the type of polymerization reaction occurring during its setting.

- Condensation silicones
- Addition silicones.

Both type of silicones are available in a variety of colors such as pastel pinks, purples, blues, greens and oranges. Further more each viscosity may be identified by its color.

CONDENSATION SILICONE

This was the earlier of the two silicone impression materials. It is also known as *conventional silicones.*

Condensation Silicone is Available in Three Viscosities:

- — Light bodied
- — Medium bodied
- — Putty.

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. 6.1).

Putty The putty is supplied in a single large plastic jar. The same catalyst paste may be used or sometimes it may be supplied as a *liquid*.

They come in a variety of colors. The base and accelerator are as usual in contrasting colors (which aids mixing).

Commercial names Sil 21, Coltex.

COMPOSITION

Base

- Polydimethyl siloxane (hydroxy–terminated).
- Colloidal silica or microsized metal oxide filler–35 to 75% depending on viscosity.
- Color pigments.

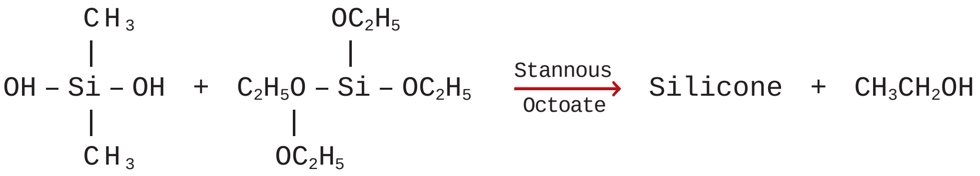
FIGURE 6.1: Medium bodied condensation silicone. The proportions of base and accelerator required is displayed on the mixing pad supplied by the manufacturer. As shown only a small amount of activator paste is required. The activator tube is therefore smaller than the base paste tube. **Inset** - Putty material (body) in a big jar

Accelerator

- Orthoethyl silicate—cross linking agent
- Stannous octoate—catalyst.

CHEMISTRY AND SETTING REACTION

It is a condensation reaction. Polymerization occurs as a result of cross linkage 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):



$$\mathrm{OH-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{Si}}-OH} + \mathrm{C_2H_5O-\overset{\overset{OC_2H_5}{|}}{\underset{\underset{OC_2H_5}{|}}{Si}}-OC_2H_5} \xrightarrow[\text{Octoate}]{\text{Stannous}} \text{Silicone} + \mathrm{CH_3CH_2OH}$$

OR

$$\begin{matrix}\text{Dimethyl}\\ \text{Siloxane}\end{matrix} + \begin{matrix}\text{Orthoethyl}\\ \text{Silicate}\end{matrix} \xrightarrow[\text{Octoate}]{\text{Stannous}} \begin{matrix}\text{Silicone}\\ \text{Rubber}\end{matrix} + \begin{matrix}\text{Ethyl}\\ \text{Alcohol}\end{matrix}$$

The ethyl alcohol formed as a by-product evaporates gradually from the set rubber leading to shrinkage.

Tray adhesive The adhesive for silicones (Fig. 6.2) 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.

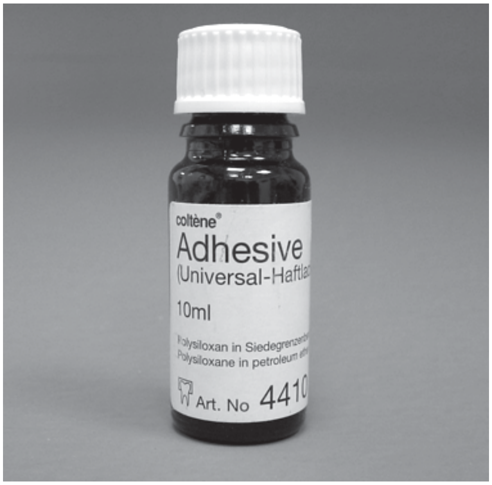


FIGURE 6.2: An adhesive for silicone type impression material. An adhesive is essential for rubber impression materials. Without an adhesive they might separate from the tray, thereby reducing the accuracy of the impression (An adhesive is not required in the putty reline technique when a perforated tray is used)

PROPERTIES

- Pleasant color and odor. Although non-toxic, direct skin contact should be avoided to prevent any allergic reactions.
- Setting time is 8 to 9 minutes. Mixing time is 45 seconds.
- Excellent reproduction of surface details.
- 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* by-product. To avoid this the cast should be poured immediately. The permanent deformation is also high (1-3%).
- Tear strength (3000) gm/cm is lower than the polysulfides.
- 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.
- It is hydrophobic. The impression field should be *dried* well before making an impression. Care should also be taken while pouring the cast to avoid air pockets.
- Can be plated with silver/copper. Silver-plating is preferred.
- Shelf life is slightly less than polysulfides due to the unstable nature of the orthoethyl silicates.

Importance of Tear Strength

In crown and bridge dentistry, 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. This is sometimes seen with condensation silicone

ADDITION SILICONES (POLY VINYL SILOXANE)

They were introduced later. It has better properties than condensation silicones. It is also known as *poly vinyl siloxane.*

Addition Silicone is Available in Four Viscosities (Fig. 6.3)

- Light bodied
- Medium bodied
- Heavy bodied
- Putty.

SUPPLIED AS

Paste 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.

Putty jars Two equal sized plastic jars - one containing the base and the other, the catalyst.

Commercial names Reprosil (Dentsply) (Fig. 6.3), Provil, President (Coltene).

FIGURE 6.3: Addition silicone is available in four different consistencies. Also displayed are the putty dispensing scoops, the adhesive and the syringe used for injecting the light bodied material

COMPOSITION

Base

- Poly (methyl hydrogen siloxane)
- Other siloxane prepolymers)
- Fillers.

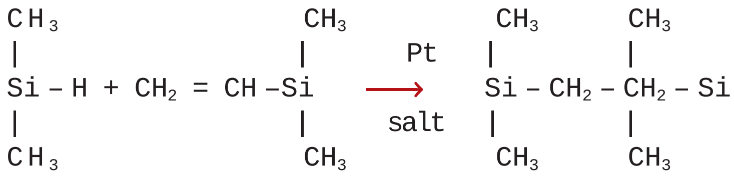
Accelerator

- Divinyl polysiloxane
- Other siloxane prepolymers
- Platinum salt—catalyst (chloroplatinic acid)
- Palladium or—hydrogen absorber
- Retarders
- Fillers.

Note The fillers added to silicone elastomers have a great influence on its strength. Optimum particle size is between 5-10 um. The particles are often surface treated to make it more compatible with, and reinforce the silicone rubber.

CHEMISTRY AND SETTING REACTION

It is an addition reaction. In this case the base polymer is terminated with vinyl groups and is cross linked with silane (hydride groups). The reaction is activated by the platinum salt.



$$\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{Si}}-H + CH_2=CH-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{Si}} \xrightarrow[\text{salt}]{\text{Pt}} \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{Si}}-CH_2-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{CH_2}}-Si$$

OR

$$\text{Vinyl Siloxane} + \text{Silane Siloxane} \xrightarrow[\text{Salt}]{\text{Pt}} \text{Silicone rubber}$$

There are no by-products as long as there is proper balance between the vinyl siloxane and the silane siloxane. If not balanced *hydrogen gas* is produced causing air bubbles in the stone models. To avoid this, palladium is added to absorb the hydrogen.

(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

- Pleasant odor and color.
- This may also cause allergic reaction so direct skin contact should be avoided.
- Excellent reproduction of surface details.
- Setting time is 5 to 9 minutes. Mixing time is 45 seconds.
- 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.
- It has good tear strength (3000 gm/cm).
- 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 hydrophillic.
- It can be electroplated with silver or copper. However, hydrophillic silicones are more difficult to electroplate because of the surfactant added.
- 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.
- Shelf life ranges from 1 to 2 years.

The Impression Field

One of the main drawbacks of the silicones are their hydrophobicity. To get a good impression, the field must be free of water, saliva and blood. This is known as *moisture control*. Moisture can result in voids or loss of detail in the impression.

POLYETHER RUBBER IMPRESSION MATERIAL

Polyether was introduced in Germany in the late 1960's. 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. 6.4). 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.

Commercial names: Impregum F (premier), Ramitec, Polyjel (Dentsply).

COMPOSITION

Base

- Polyether polymer
- Colloidal silica —filler
- Glycolether or phthalate —plasticizer.

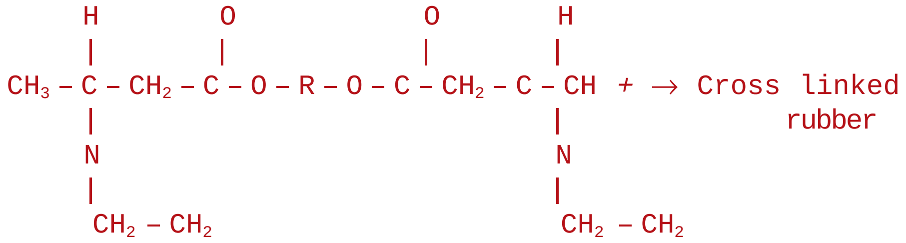
FIGURE 6.4: Polyether impression paste—Base and catalyst. Note the unequal size of the two tubes. Obviously the proportion of accelerator required is less when compared to the base

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. Cross linking is brought about by the aromatic sulfonate ester via the imine end groups. The reaction is exothermic (4 to 5°C).



$$CH_3-\underset{\substack{|\\N\\|\\CH_2-CH_2}}{\overset{\substack{H\\|}}{C}}-CH_2-\overset{\substack{O\\|}}{C}-O-R-O-\overset{\substack{O\\|}}{C}-CH_2-\underset{\substack{|\\N\\|\\CH_2-CH_2}}{\overset{\substack{H\\|}}{C}}-CH+\rightarrow \text{Cross linked rubber}$$

OR

Polyether + Sulfonic ester → Cross linked rubber.

PROPERTIES

- Pleasant odor and taste.
- The sulfonic ester may cause skin reaction. To avoid this, mix thoroughly before making an impression and direct skin contact should be avoided.
- Setting time is around 8.3 minutes. Mixing should be done quickly that is 30 seconds. Heat decreases the setting time.
- Dimensional stability is very good. Curing shrinkage is low (0.24%). The permanent deformation is also low (1 to 2%). However, polyethers absorb water and can change dimension. Should not be stored in water or in humid climates.
- It is extremely stiff (flexibility 3%). Its hardness is higher than polysulfides and increases with time. Removing it from undercuts is difficult, so extra spacing (4 mm) should be given. Care should also be taken while removing the cast from the impression to avoid any breakage.
- Tear strength is good (3000 gm/cm).
- It is hydrophillic, so moisture in the impression field is not so critical. It has the best compatibility with stone.
- It can be electroplated with silver or copper.
- The shelf life is excellent – more than 2 years.

MANIPULATION OF RUBBER IMPRESSION MATERIALS

Putty

In addition silicones, equal scoops of base and accelerator is taken. In condensation silicones, the required number of scoops of base and proportionate amount of liquid or paste accelerator is taken. In either case mixing is done by kneading between the fingers. 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 (Fig. 6.1). Obviously, the two pastes will be of *unequal* length and diameter.

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 are usually made in special trays. Perforated stock trays are used only for making impression in putty.
- The spacing given is between 2 to 4 mm.
- Elastomers do not adhere well to the tray. An adhesive should be applied onto the tray and allowed to dry before making impressions (Fig. 6.5A). The adhesive cements provided with the various elastomers are not interchangeable. A slightly roughened tray surface will increase the adhesion.
- 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 2-4mm spacing
— Viscosity used : Regular only.

Method The paste is mixed and part of it is loaded onto the tray and part into a syringe. The syringe material is then injected onto 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 but on separate pads. The heavy body is loaded onto the tray while the light bodied is loaded into the syringe. The syringe material is injected onto the area of impression. The tray containing the heavy body if then seated over it. Both materials set together to produce a single impression (Figs 6.5A to F).

Reline Technique (Two-stage Putty-wash Technique)

— Tray used : Perforated stock tray.
— Viscosity used : (a) Putty (b) Light body.

Method First a preliminary impression is made with putty in the stock tray. Before seating the tray, a then plastic sheet is placed over the putty (it acts as a spacer). After setting it is removed and kept aside. Light bodied is mixed and a portion of loaded into a syringe and injected into the impression area. The remainder is spread into the putty impression. The primary impression is then seated over the injected material and held till it sets (Fig. 4.3).

Advantage No special tray required.

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. 6.6).

Advantage Improved properties due to:

- More uniform mix
- Less air bubbles incorporated in mix
- Reduced working time.

FIGURE 6.5A: Multiple mix technique: Before making the impression an adhesive material is painted on the special tray

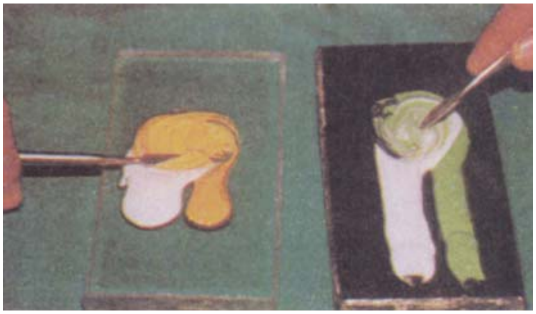


FIGURE 6.5B: Light bodied and heavy bodied material are mixed simultaneously

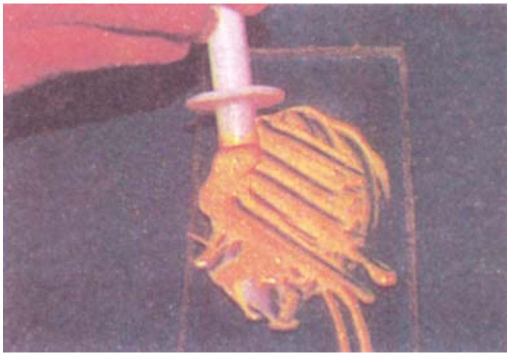


FIGURE 6.5C: The light bodied material is loaded into the syringe

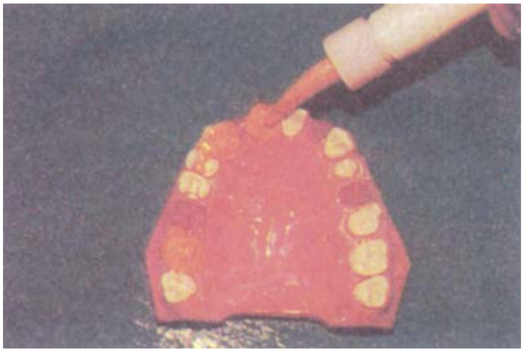


FIGURE 6.5D: The light bodied material is then injected into the prepared teeth, which helps to reduce air bubbles

FIGURE 6.5E: Meanwhile the heavy bodied material is loaded into a tray and seated over the syringed material

FIGURE 6.5F: Both materials set together to produce a single and highly accurate impression

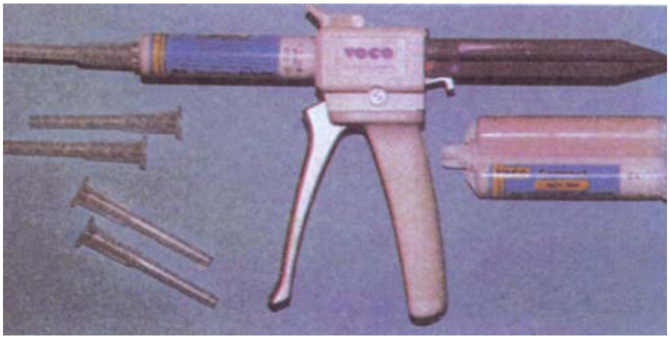


FIGURE 6.6: An auto mixing device for elastomers. The spirals in the mixing tip are clearly visible

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 air seal. 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.

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.

RECENT ADVANCES

Visible Light Cured Polyether Urethane Dimethacrylate

The advantage with this material is that its working time is controlled by the operator. Its chemistry similar to that of light cured composites.

Available in two viscosities:

– Light bodied
– Heavy bodied.

Composition

- Polyether urethane dimethacrylate
- Photoinitiators
- Photo-accelerators
- Silicone dioxide filler.

Properties

These materials have very long working times but short setting times. Blue light is used for curing. A transparent impression tray is used to make the impression. It has 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 is similar to addition silicone.

CHAPTER 7

Gypsum Products

Products of gypsum are used extensively in dentistry. Gypsum is a mineral mined in various parts of the world. Gypsum is also an industrial byproduct. Gypsum has been used for many centuries for construction purposes. Alabaster, a form of gypsum which is white in color was used in the building of King Solomon's Temple of Biblical times.

Gypsum was first 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.

APPLICATIONS

General

For preparing statues and in construction work.

In Orthopedics

For splinting and making plaster casts.

In Dentistry

1. Impression plaster was used extensively 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 (Fig. 7.1).
3. To attach casts to an articulator.
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.

SUPPLIED AS

Powders of various colors, in small preweighed satchets or in large bags, sacks or bins.

FIGURE 7.1: Gypsum products are widely used in dentistry; Background left to right—a stone working cast and plaster mould. For ground left to right—an orthodontic model, a die stone cast with removable die and a commercially available die stone material

CLASSIFICATION

ADA Specification No. 25:

- Type I — Impression plaster
- Type II — Dental plaster
- Type III — Dental stone or medium strength stone
- Type IV — Improved stone or high strength stone
- Type V — Dental stone, high strength, high expansion.

MANUFACTURE OF GYPSUM PRODUCTS

The process of heating gypsum for manufacturing plaster is known as *calcination.* 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.

$$\underset{\text{(Calcium sulphate dihydrate)}}{CaSO_4.2H_2O} \xrightarrow{110\text{-}130^\circ C} \underset{\text{(Calcium sulphate hemihydrate)}}{CaSO_4.\tfrac{1}{2}H_2O} \xrightarrow{130\text{-}200^\circ C} \underset{\text{(Hexagonal anhydrite)}}{CaSO_4} \xrightarrow{200\text{-}1000^\circ C} \underset{\text{(Orthorhombic anhydrite)}}{CaSO_4}$$

Alpha and Beta Hemihydrate

Depending on the method of calcination there are two forms of hemihydrates.

- Beta hemihydrate (plaster)
- Alpha hemihydrate (stone)

Note: Chemically both *alpha* and *beta* type are the same. They differ mainly in crystal size and form. The beta type is spongy and irregular. Whereas, alpha crystals are more dense and prismatic. Some authors suggest that use of the alpha and beta 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.* Beta type of crystals are formed.

Microscopically Fibrous aggregate of fine crystals with capillary pores. They are then ground to breakup the needle-like crystals. This improves packing.

$$CaSO_4.2H_2O \xrightarrow[110°\text{-}130°C]{\text{Heat}} CaSO_4.{}^1/_2H_2O$$

(Beta hemihydrate)

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 beta hemihydrate.

$$CaSO_4.2H_2O \xrightarrow[\text{17 lbs/sq. inch pressure}]{120°\text{-}130°} CaSO_4.½H_2O$$

(Alpha hemihydrate)

Microscopically Cleavage fragments and crystals in the form of rods and prisms.

Manufacture of Improved Stone

Here 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 an even 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.

$CaSO_4.½H_2O + 1½H_2O \longrightarrow CaSO_4.2H_2O$ + Heat (3900 cal)

Hemihydrate + Water ⟶ Dihydrate + Heat

The reaction is exothermic and is the same for all gypsum products.

THEORIES OF SETTING

Two theories:

- Crystalline Theory.
- Gel Theory.

Crystalline Theory

This theory is more widely accepted. It was first proposed by a French chemist Henry Louis Chatelier (1885).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 a suspension is formed which is fluid and workable.
- Hemihydrate dissolves until it forms a saturated solution. Some dihydrate is formed due to the reaction.
- Since 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. This brings the solution to saturation which is more stable.
- As the dihydrate precipitates out, the solution is no longer saturated with hemihydrate and so it continues to dissolve. The process continues until all hemihydrate converts to dihydrate.

Initially there is little reaction and thus little or no rise in temperature. This time is referred to as *induction period.* Later there is a thickening of the mass, which allows the mix to be poured. As the amount of gypsum formed increases,

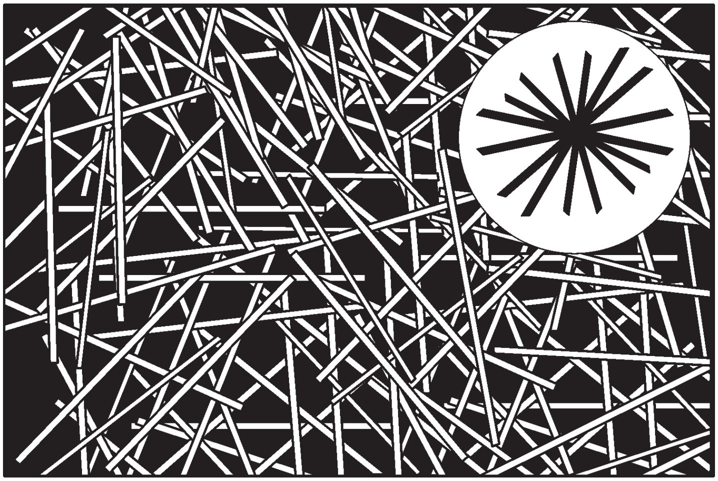


FIGURE 7.2: Schematic representation of structure of set gypsum which consists of dense, interlocking needle like crystals. The inset shows a single crystal known as spherulite

the mass thickens and then hardens into needle-like clusters, called *spherulites* (Fig. 7.2). Finally, the intermeshing of crystals of gypsum leads to a strong solid structure.

The Microstructure of Set Gypsum

The set material consists of an entangled aggregate of gypsum crystals, having lengths of 5 to 10 um. 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.

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

- *Shape and compactness of crystals* Thus, irregular, spongy plaster particles need more water than the denser stone.
- Small amounts of surface active materials like gum arabic plus lime markedly reduce water requirement of all gypsum products.
- *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.
- Improved stone : 0.22 to 0.24.
- Type V : 0.18 to 0.22.

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.

PROPERTIES

The important properties of gypsum products are :

- Setting time
- Setting expansion
- Strength
- Hardness and abrasion resistance
- Reproduction of detail.

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.

Working time is the time available a workable mix, i.e. one that maintains an even consistency that may be manipulated. Generally it is 3 minutes. The freshly mixed mass is semifluid in consistency and quite free flowing and can be poured into the mould in any shape.

Initial setting time (Craig) As the reaction proceeds, however, 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 (Craig) 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.

- *Loss of gloss method* As reaction proceeds, the gloss disappears from the surface of plaster mix (Sometimes used to indicate initial set).
- *Exothermic reaction* The temperature rise of the mass may also be used for measurement of setting time, as the setting reaction is exothermic.
- *Penetration tests* By using penetrometers.

Types of Penetrometers

— Vicat needle
— Gillmore needles

Vicat needle (Fig. 7.3)*:* 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 the similar to the initial Gillmore.

Gillmore needles: Two types—small and large (Fig. 7.4). The small Gillmore needle has 1/4 Ib weight and diameter of 1/12" while the large Gillmore has 1 Ib wt and diameter of 1/24".

Initial Gillmore The time elapsing from the start of mixing until the time when the point of the 1/4 Ib. 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 Ib. 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

- If calcination is incomplete and excess gypsum (dihydrate) is left in the final product, the resulting plaster will set faster.
- If soluble anhydrate is in excess, plaster will set faster.
- If natural anhydrate is in excess, plaster will set slow.
- Fineness: Finer the hemihydrate particle size, the faster the set, because
  — hemihydrate dissolves faster and

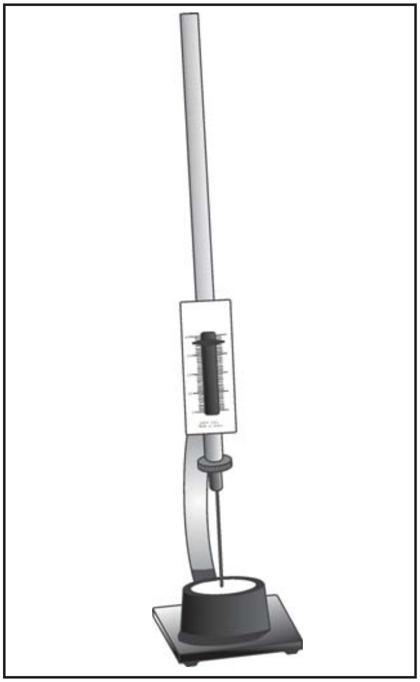


FIGURE 7.3: The Vicat needle is another penetration test to measure the setting time of gypsum

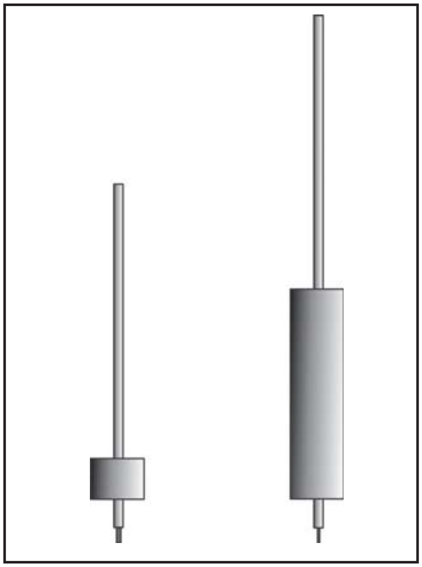


FIGURE 7.4: The Gillmore needles A—small Gillmore needle; B—large Gillmore needle

— the gypsum nuclei will be 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 the body temperature of 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, it decreases the setting time, it is called an *accelerator*, whereas if it increases the setting time, it is called a *retarder*.

(Note: Accelerators and retarders not only modify setting time, they also affect other properties like setting, expansion and strength).

Accelerators

- Finely powdered gypsum (terra alba 1%): *Acts by* providing additional nuclei of crystallizaton.
- In low concentrations, salts like sodium sulphate (upto 3.4%), potassium sulphate (2 to 3%) and sodium chloride (upto 2%), are accelerators. They *act by* making the hemihydrate more soluble.

Retarders

- In higher concentrations sodium chloride and sodium sulphate (above 3.4%), act as retarders. In higher concentrations the salt precipitates and poisons the nuclei of crystallization.
- Acetates, borates, citrates, tartrates, and inorganic salts like ferric sulphate, chromic sulphate, aluminium sulphate, 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.
- 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.

- Colloids such as gelatine, glue, agar, coagulated blood, etc. are effective retarders, presumably acting by nuclei poisioning. 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.

SETTING EXPANSION

Setting expansion is of two types

— Normal setting expansion
— 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 wanted or unwanted. 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.

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

- Increased spatulation increases setting expansion.
- Increase in W/P ratio reduces the setting expansion.
- Modifiers generally reduce the setting expansion.

  Potassium sulphate 4% solution reduces the setting expansion from 0.5% to 0.06%.

  Sodium chloride and *ground gypsum* increases setting expansion.

For accuracy in dental procedures, the setting expansion has to be minimised. 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 time.

Factors Affecting Strength

The free water content (excesss 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 (compressive), for Dental Plaster is 9 MPa and for improved dental stone is 35 MPa.

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 is removed (This strength increase on drying is reversible, thus soaking a dry cast in water reduces its strength to the original level).

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.

Other factors affecting strength are:

- *W/P ratio* The more the water, the greater will be the porosity and less the strength.
- *Spatulation* Within limits, the 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 atleast 80% of its one hour strength. Current products are ready for use in *30 minutes.*

Hardness and Abrasion Resistance

This 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.

Flow

The flow of freshly mixed gypsum would certainly depend 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.

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.

DESCRIPTION OF VARIOUS GYPSUM PRODUCTS

There are many different gypsum products for various uses in dentistry. Each type is developed with specific physical properties suitable for a particular purpose.

TYPE I OR IMPRESSION PLASTER

Impression plaster 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 was poured. Since then many newer materials have been introduced. It is not so widely used now as an impression material, however, it is still studied out of historical interest. Currently, it is more useful as a bite registration material.

Uses

1. For making impressions in complete denture and maxillofacial prosthetics (not used currently for this purpose).
2. Bite registration material.

Ideal Properties

- The setting time should be under accurate control. The dentist must have sufficient time to mix, load the impression tray, carry 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.
- 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.
- 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.

Impression plaster 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 from the impression. This type is often called *'soluble plaster.'*

TYPE II OR DENTAL PLASTER

Uses

For making study casts and models, to make moulds for curing dentures, for mounting casts on articulator.

Requirements

The requirements of an ideal cast material are as follows:

1. It should set rapidly but give adequate time for manipulation.
2. It should set to a very hard and strong mass.
3. After mixing, consistency should be such that it can 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 III OR DENTAL STONE

Synonym: Hydrocal

Uses

For preparing master casts and to make moulds.

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 tartarate ('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 .06% to .12%.
— Hardness: 82 RHN.

TYPE IV OR IMPROVED DENTAL STONE

Synonyms: Die stone or High-strength stone or Type IV stone.

Uses

Die stone 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.

TYPE V OR DENTAL STONE, HIGH STRENGTH, HIGH EXPANSION

Uses

To prepare dies.

It is the most recent gypsum product, having an even higher compressive strength than Type IV 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 for compensating for the shrinkage of base metal alloy, during solidification (see Casting Alloys chapter 19).

DENTAL CASTING INVESTMENTS

Uses

To prepare refractory moulds for casting dental alloys.

If it is necessary to heat the cast or mould to high temperatures, a refractory material like silica or quartz or crystobalite is added to dental plaster or stone. These are called dental casting investments (for more details refer Chapter 17).

DIVESTMENT

Uses

To make refractory dies (see also Chapter 17).

It is a combination of die stone + 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 byproducts during the manufacture of phosphoric acid.

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).

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 and with intelligence, 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 takes up moisture to start setting reaction. In earlier stages, this hydration produces crystals of gypsum which set as nuclei of crystallization. The plaster *sets faster*. In later stages the hygroscopic action continues, the entire hemihydrate mass is covered by more crystals of gypsum. The water penetrates with difficulty and setting is delayed. The humidity factor is a major consideration in India as there are many areas 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:

— Immersing cast in a disinfection solution.
— Addition of disinfectant into the stone.
— Overnight gas sterilization while treating patients known to have an infection (Impractical for routine use).

MANIPULATION

Proportioning

To secure maximum strength a low water/powder ratio should be used. The water should be measured and the powder weighed.

Instruments

Flexible rubber/plastic bowl, stiff bladed spatula.

Procedure for Hand-Mixing

- Take a measured quantity of water in the rubber bowl and sift a weighed quantity of powder into it (for hand-mixing, bowl should be parabolic in shape—Phillips).
- It is allowed to settle for 30 secs. to minimise 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 vibration or by repeated tapping against a bench) and pour it into the impression, taking care not to entrap air.

Note

— 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.

Differences between Dental Plaster and Dental Stone

These two materials are chemically identical, they differ in:

	Plaster	*Stone*
Manufacture	Dry calcination	Wet calcination
Particle size and shape	Larger, irregular and porous	Smaller, regular and dense
W/P ratio	0.5	0.3
Porosity	More porous	Less porous
Mechanical properties	Strength and hardness less	Strength and hardness more
Application	Used when mechanical properties are not of primary importance (e.g. diagnostic casts)	Used where strength and hardness is required (e.g. dies, master casts)

CHAPTER 8

Denture Resins and Polymers

HISTORY OF FALSE TEETH

Replacements for decaying or lost teeth have been produced 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 1800's. 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. Even 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 1700's. 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. 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. 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 1800's. They were marketed on a large scale.

Fit and comfort eventually improved as well. In the 1700's plaster of Paris was introduced. It was used to make a mould of the patient's mouth. This helped the shape of the dentures to be more precise. There was a real breakthrough when vulcanized rubber was discovered. This is a cheap, easy to work with material that could be shaped to fit the mouth and hold the denture. Another cheap base was also made; it used celluloid. 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 pigment.

Advantages

- Non-toxic 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 vulcaniser
  - 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
- Contains unpleasant tasting plasticizers.

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. Cobalt chromium
  Gold alloys
  Aluminium
  Stainless steel
- Non-Metallic
  e.g. Acrylic resins
  Vinyl resins

II. Denture Base Materials

- Temporary
  e.g. Self cure acrylics
  Shellac base plate
  Base plate wax
- Permanent
  e.g. Heat cure denture resins
  Light cured resins
  Pour type resins
  Injection moulded resins
  Metallic bases

The acrylic resins were so well received by the dental profession that by 1946, 98% of denture bases were constructed from methyl methacrylates or co-polymers.

SYNTHETIC RESINS

Modern living has been greatly influenced by synthetic plastics. Originally they were laboratory nuisances-waxy, sticky residues left after certain organic reactions. Only 40 to 50 years ago these resinous materials composed of giant molecules attracted the attention of chemists giving rise to the field of plastics.

Synthetic plastics are non-metallic compounds which are moulded 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.

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

Refers to resins that *can be repeatedly* softened and moulded under heat and pressure without any chemical change occurring. They are cooled after moulding, they are fusible and are usually soluble in organic solvents. Most of the resins used in dentistry belong to this group, e.g. polymethyl methacrylate, polyvinyl acrylics and polystyrene.

Thermoset

Refers to resins which can be moulded 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, non-toxic 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 radio-opaque (so that a denture or broken 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.

No resin has yet met all the above requirements.

USES OF RESINS

Some of the uses of resins are shown in Figure 8.1.

- Fabrication of dentures (denture base resins)
- Artificial teeth (cross-linked acrylic resins)
- Tooth restoration, e.g. fillings, inlays and laminates (composite resins)
- Cementation of orthodontic brackets, crowns and bridges (resin cements)
- Orthodontic and pedodontic appliances (Fig. 8.8)
- Crown and bridge facings (tooth colored acrylic or composite resins)

- Maxillofacial prosthesis (e.g. obturators for cleft palates)
- Inlay and post-core patterns (pattern resins)
- Dies (Fig. 15.1) (epoxy resins)
- Temporary crowns and bridges (tooth colored resins and composite resins)
- Endodontic and core filling material
- Athletic mouth protectors
- Impression trays (special trays, Fig. 8.13)
- Splints and stents
- Models

NATURE OF POLYMERS

Polymer

Denotes a molecule that is made up of many parts. 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. Usually any chemical possessing a molecular weight higher than 5000 is considered to be a polymer.

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 polymer molecule equals the molecular weight of the various *mers* multiplied by the number of mers. They may range from thousand to millions of molecular weight units depending on preparation conditions. The molecular weight of polymers plays an important role in determining its physical properties.

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

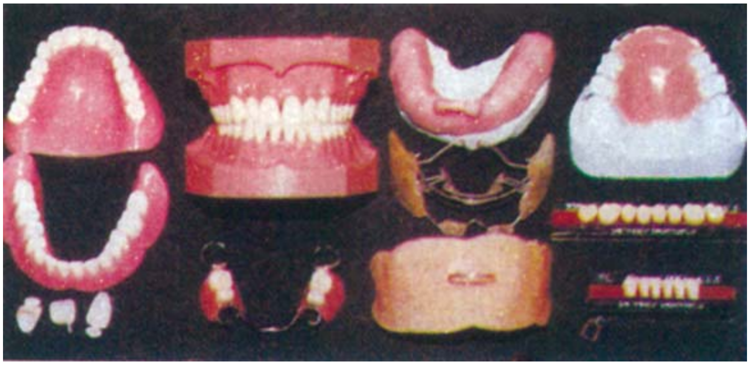


FIGURE 8.1: Complete dentures, partial dentures, custom trays, models, denture teeth and various orthodontic appliances are constructed from acrylic resin. Polycarbonate crowns (lower left corner) are also shown

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 (Fig. 8.2).

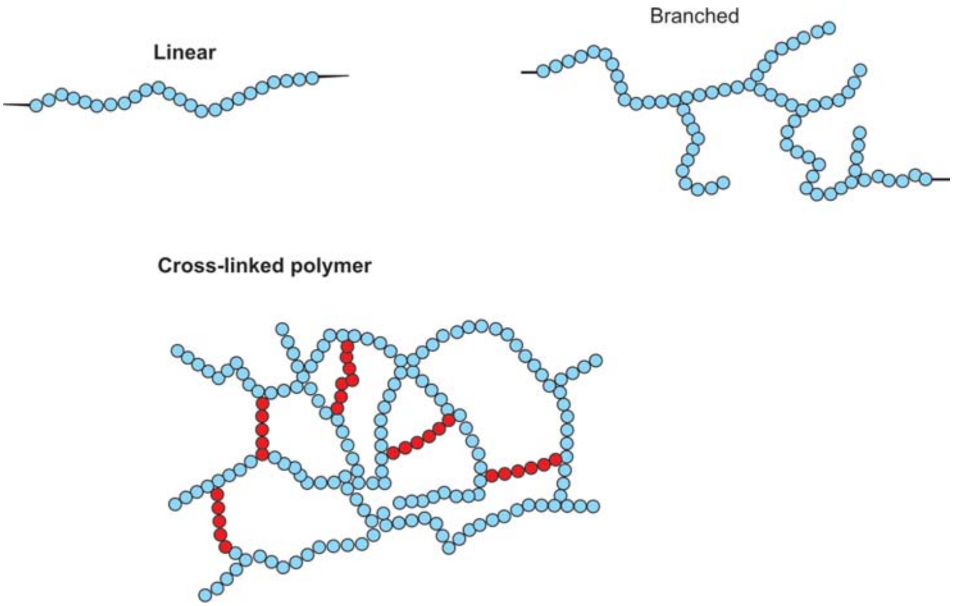


FIGURE 8.2: Structure of polymers

Linear

Here the ‘mer’ units are connected to each other in a linear sequence. 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 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 – ...
```

Branched

The mer units are arranged in a branched fashion.

Branched homopolymer: The mer units are of the same type.

```
... – M – M – M – M – M – ... – M – M – M – M – M – ...
          :                                    :
          M                                    M
          :                                    :
          M                                    M
          :                                    :
```

Random copolymer of branched type: It has two types of mer units distributed randomly

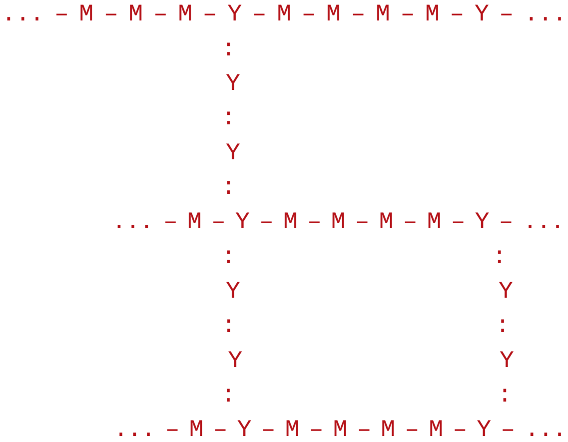
```
... – M – M – M – M – M – ... – M – M – M – M – M – ...
              :                                :
              M                                Y
              :                                :
              M                                M
              :                                :
              Y                                Y
              :                                :
```

Graft co-polymer 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                        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. 8.2).



POLYMERIZATION—CHEMISTRY

The term polymerization refers to a series of chain reactions by which a macromolecule or polymer is formed from a single molecule 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

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

All 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 centre, 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 4 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 with considerable velocity.

Theoretically, the chain reactions should continue with evolution of heat until all the monomer has been changed to polymer. Actually, the polymerization is never complete.

Termination

The chain reactions can be terminated either by direct coupling 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.

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. 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. 8.3).

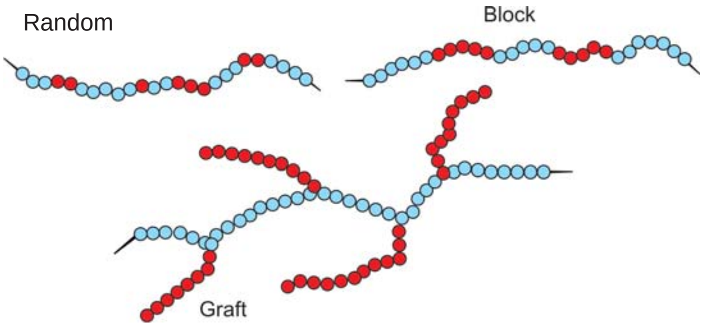


FIGURE 8.3: Types of copolymers

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.

```
– M – M – M – M – M – ... – M – M – M – M
  :                                 :
  Y                                 Y
  :                                 :
  Y                                 Y
  :                                 :
```

Block Type

In a block copolymer, identical monomer units occur in relatively long sequences along the main polymer chain.

```
... – M – M – M – M – ... – M – M – Y – Y – Y – ... – Y – Y – M – M – ...
```

Importance of Copolymerization

Copolymerization is used to better 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 linear polymers is referred to as cross-linking. It forms a three-dimensional network.

```
... – M – M – M – Y – M – M – M – Y – ...
                  :
                  Y
                  :
... – M – M – M – Y – M – M – Y – M – Y – M – ...
                  :                   :
                  Y                   Y
                  :                   :
                  Y                   Y
                  :                   :
... – M – M – M – Y – M – M – M – M – Y – M – ...
```

Applications

1. The more recent acrylic resins are of cross-linked variety. Cross-linking improves the strength, and decreases the 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:

- To increase the solubility of the polymer in the monomer.
- To decrease the brittleness of the polymer.
  However, it also decreases strength, hardness, and softening point.

Types

They are of two types:

- *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.
- *Internal* Here, the plasticizing agent is part of the polymer. It is done by co-polymerization with a suitable co-monomer.

TYPES OF RESINS

A variety of resins are used in dentistry:

- Acrylic resins (Fig. 8.4)
- Vinyl resins
- Polystyrene
- Epoxy resins (Fig. 15.1)
- Polycarbonates
- Polyurethanes
- Cyanoacrylates

FIGURE 8.4: Representative acrylic resin products. Ufi Gel P is a soft denture reliner

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, $CH_2 = C(CH_3)COOH$

95% of the dentures made today use one of the acrylic resins.

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 doughlike consistency which is easily moulded.

TYPES

Based on the method used for its activation:

- Heat activated resins
- Chemically activated resins
- Light activated resins.

HEAT ACTIVATED DENTURE BASE ACRYLIC RESINS

Available As

(1) Powder and liquid. (2) Gels—sheets and cakes.

The powder may be transparent or tooth colored or pink colored (to simulate the gums, some even contain red fibres 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) (Fig. 8.4).

Commercial names: Stellon (DPI), Lucitone (Bayer), Trevelon (Dentsply).

COMPOSITION

Liquid

- Methyl methacrylate : Plasticizes the polymer
- Dibutyl phthalate : Plasticizer
- Glycol dimethacrylate (1-2%) : Cross-linking agent
- Hydroquinone (0.006%) : Inhibitor-prevents setting

Powder

- Poly (methyl methacrylate) and other co-polymers (5%)
- Benzoyl peroxide : Initiator
- Compounds of mercuric sulphide, cadmium sulphide : Dyes
- Zinc or titanium oxide : Opacifiers
- Dibutyl phthalate : Plasticizer
- Dyed organic filler and inorganic particles like glass fibres or beads : For esthetics

POLYMERIZATION REACTION

Polymerization is achieved by application of heat and pressure. The simplified reaction is:

$$\begin{matrix}\text{Powder}\\\text{(Polymer)}\end{matrix} + \begin{matrix}\text{Liquid}\\\text{(Monomer)}\end{matrix} + \begin{matrix}\text{Heat}\\\text{(External)}\end{matrix} \dashrightarrow \text{Polymer} + \begin{matrix}\text{Heat}\\\text{(Reaction)}\end{matrix}$$

TECHNICAL CONSIDERATIONS

Complete and partial dentures are usually fabricated by one of the following techniques.

- Compression moulding technique
- Injection moulding technique
- Fluid resin technique
- Visible light curing technique

COMPRESSION MOULDING TECHNIQUE

This is the most 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 mould
3. Application of separating medium
4. Mixing of powder and liquid
5. Packing
6. Curing
7. Cooling
8. Deflasking, 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 Mould

The waxed denture is *invested* in a dental flask with dental stone or plaster (also called flasking) using a 3 pour technique (Fig. 8.5). 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 mould into which soft acrylic is packed. Acrylic replaces the wax, assuming the shape of the final denture.

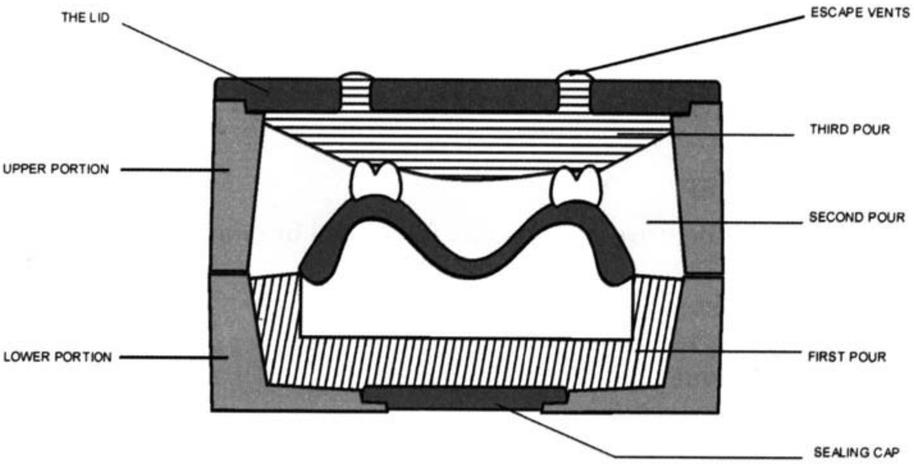


FIGURE 8.5: Schematic diagram of a fully assembled Hanau denture flask. The three pour technique of dental stone helps in easier retrieval of the denture, minimizing the risk of fracture

Application of Separating Medium

The resin must not contact the gypsum surface while curing.

1. To prevent water from the mould 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 mould material, causing plaster to adhere to the acrylic resin and producing a rough surface.
3. Application of separating media help in easier retrieval of the denture from the mould.

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'.

Sodium Alginate Solution

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

Two percent sodium alginate in water, glycerine, alcohol, sodium phosphate and preservatives.

Precautions to be Taken

- Waxes or oils remaining on the mould surface will interfere with the action of the separating medium.
- Mould should be warm, not hot. Continuity of the film will break if the mould is steaming hot.
- Coating of medium left on the teeth 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 mould at this stage.

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 moulded.

Stage V

Stiff stage

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 mouldable 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 will 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 by 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. 8.6). The closing force is applied slowly during the trial packing to allow the excess dough, known as 'flash' 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.

FIGURE 8.6: Left—A hydraulic press (Kavo) is useful for trial and final closure of the flask. The pressure indicator dial indicates the pressure that is applied. Right—An automated curing bath (Kavo). The time and temperature of the curing cycle can be preset and regulated for optimum cure

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 mould.
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. If resin teeth are used, if 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 propogation of polymerization in the denture mould. 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. 8.6).

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 mould. 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 mould is retrieved. The mould 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 sand-paper. Finely ground pumice in water is commonly used for final polishing.

INJECTION MOULDING TECHNIQUE

Resin used A special thermoplastic resin is available for this technique.

This technique requires special equipment and special material (thermoplastic). The mould space is filled by injecting the resin under pressure. A sprue hole and a vent hole are formed in the gypsum mould (Fig. 8.7). The soft resin is contained in the injector and is forced into the mould space as needed. It is kept under pressure until it has hardened.

No trial closures are required with this technique. There is no difference in accuracy or physical properties as compared to compression moulding technique.

Advantages

1. Dimensional accuracy
2. Low free monomer content
3. Good impact strength

Disadvantages

1. High cost of equipment
2. Difficult mould design problems
3. Less craze resistance
4. Special flask is required.

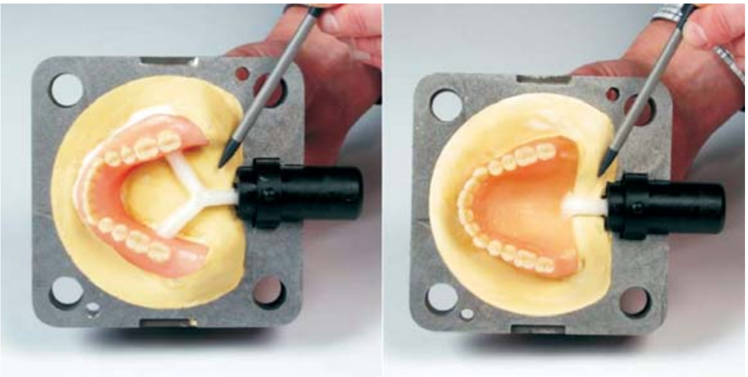


FIGURE 8.7: Injection moulded denture resin technique. The picture shows the denture invested in a special flask used. The lower denture utilizes a Y shaped sprue former as shown by the operator. For the upper denture a single sprue former is sufficient

OTHER SOURCES OF HEAT

Apart from water bath, there are other methods of supplying heat:

- Steam
- Dry air oven
- Dry heat (electrical)
- Infrared heating
- Induction or dielectric heating
- Microwave radiation.

Polymerization with Microwave Energy

Advantages

1. It is cleaner and faster than the conventional hot water.
2. The fit of the denture is comparable or superior.

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, polymerization is achieved at room temperature.

AVAILABLE AS

Like the heat activated resins, chemically activated resins are supplied as powder and liquid. The powder may be clear, pink, veined or tooth colored.

Uses

1. For making temporary crowns and bridges (specialized materials are available).
2. For the construction of special trays (this type contains more fillers) (Fig. 8.13).
3. For denture repair, and relining and rebasing.
4. For making removable orthodontic appliances (Fig. 8.8).
5. For adding a post-dam to an adjusted upper denture.
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

FIGURE 8.8: Orthodontic appliances can be constructed in attractive colors in order to make it more attractive especially to young patients. Special kits are available for this purpose (inset)

- 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 fibres or beads : Esthetics

POLYMERIZATION REACTION

The simplified reaction is outlined

Polymer (Powder) + Monomer (Liquid) → Polymer + Heat
(Peroxide initiator) (Amine accelerator) (reaction)

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 preferrable to heat cured resins as heat curing causes warpage.

MANIPULATION

- Sprinkle on technique
- Adapting technique
- Fluid resin technique (special material is available for this)
- Compression moulding technique
- Injection moulding technique.

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. 8.9).

FIGURE 8.9: A pressure pot for further curing of chemically activated resins. It has a pressure dial (some models even have a temperature indicator). Pressure is increased in the chamber using compressed air

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 moulded 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 as mentioned in the sprinkle on technique.

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 mould preparation in place of the usual gypsum. The fluid mix is quickly poured into the mould and allowed to polymerize under pressure at 0.14 MPa (20 psi).

Advantages

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
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.

COMPARISON OF HEAT AND SELF CURED RESINS

Self Cured	*Heat Cured*
• Heat is not necessary for polymerization	• Heat is necessary for polymerization
• Porosity is greater (it may be due to air dissolved in the monomer which is not soluble in the polymer at room temperature	• 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

LIGHT ACTIVATED DENTURE BASE RESINS

It consists of a *urethane dimethacrylate* matrix with an acrylic copolymer, microfine silica fillers, and a camphoroquinone-amine photo-initiator system. One such product is known as *VLC triad.*

It is supplied in premixed sheets having a clay like consistency. 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 (curing unit) with blue light of 400-500 nm from high intensity quartz -halogen bulbs (Fig. 8.10). The denture is rotated continuously in the chamber to provide uniform exposure to the light source.

FIGURE 8.10: A light curing chamber (VLC triad). The prosthesis is rotated continuously for optimum cure

PROPERTIES OF DENTURE RESINS

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 the oral tissue. It is also compatible with dyed synthetic fillers. 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	52 MPa

Self cured resins generally have lower strength values.

The strength is affected by:

- Composition of the resin
- Technique of processing
- Degree of polymerization
- Water sorption
- 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 base resins should have high impact strength to prevent breakage when it is accidentally dropped. Addition of plasticizers increase the impact strength.

Self cured resins have a lower impact strength.

Hardness

Acrylic resins are materials having low hardness. They can be easily scratched and abraded.

Heat cured acrylic resin : 18-20 KHN
Self cured acrylic resin : 16-18 KHN

Modulus of Elasticity

They have sufficient stiffness (2400 MPa) for use in complete and partial dentures. However, when compared with metal denture bases it is low.

Self cured acrylic resins have slightly lower values.

Dimensional Stability

A well processed acrylic resin denture has good dimensional stability. The processing shrinkage is balanced by the expansion due to water sorption.

Shrinkage

Acrylic resins shrink during processing due to:
- Thermal shrinkage on cooling
- Polymerization shrinkage.

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 (0.6 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 upto 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.

Coefficient of thermal expansion These materials have a high coefficient of thermal expansion ($81 \times 10^{-6°}$/C). Addition of fillers reduces the coefficient of expansion.

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:
- Minimise residual monomer content by using proper processing techniques.
- Avoid direct handling of acrylic dough with bare hands.
- Work in well ventilated areas to avoid inhalation of the monomer vapor.

Residual Monomer

During the polymerization process the amount of residual monomer decreases first rapidly 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).

Shelf Life

Varies considerably. 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

When porosity is present on the surface, it
1. 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

Is in the form of 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 centre 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.

Avoided by Dentures with excessive thickness should be cured using long, low temperature curing cycle.

External Porosity

It can occur due to two reasons:
1. *Lack of homogenity* If the dough is not homogenous at the time of polymerization the portions containing more monomer will shrink more than the adjacent area. 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 mould during final closure causes bubbles which are not spherical. The resin is lighter in color.
   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. 8.11). These cracks may be microscopic or macroscopic in size. In some cases it has a hazy or foggy appearance rather than cracks.

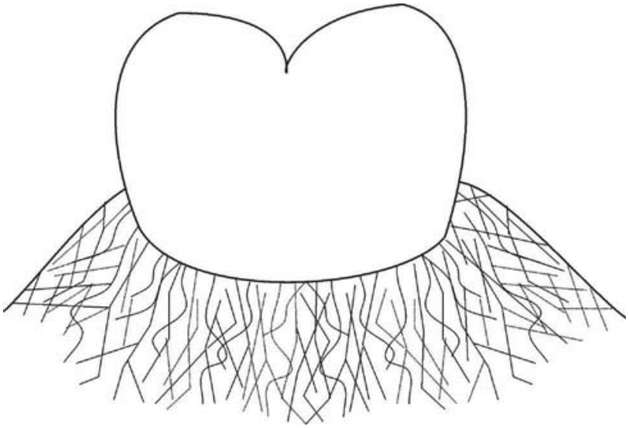


FIGURE 8.11: Crazing

Crazing has a weakening effect on the resin and reduces the esthetic qualities. The cracks formed can cause fracture.

Causes Crazing is due to:

- Mechanical stresses or
- Attack by a solvent
- 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.

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.

Due to the action of solvents the cracks are randomly placed, e.g. weak solvents, i.e. alcohol.

Water incorporation during processing will form stresses due to evaporation of water after processing, causing crazing.

Avoided by

- Using cross linked acrylics.
- Tin foil separating medium.
- Metal moulds.

Denture Warpage

Denture warpage is the deformity or change of shape of the denture which can affect the fit of the denture (Fig. 8.12). Warpage can occur during processing as well as at other times.

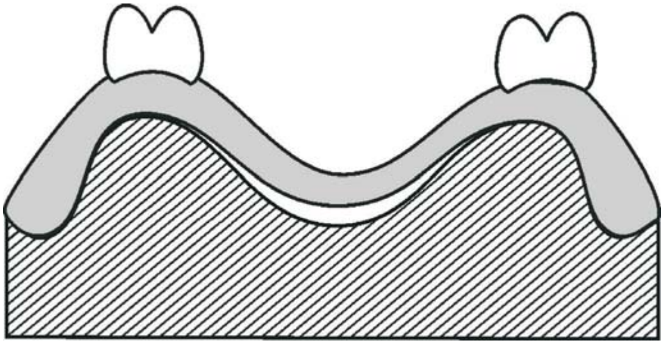


FIGURE 8.12: Denture warpage has resulted in a space between the palatal surface and the cast. Obviously this would affect the fit

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.

RECENT ADVANCES

Several modified poly (methyl methacrylate) materials have been used for denture resins, hydrophilic polyacrylates, high impact strength resins, rapid heat polymerized acrylic, light-activated denture base material (described earlier) and pour type acrylic resins (described earlier).

High Impact Strength Materials

These materials are butadiene-styrene rubber-reinforced poly (methyl-methacrylate). 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. Indicated for patients who drop their dentures repeatedly, e.g. senility, parkinsonism.

Rapid Heat—Polymerized Resins

These are hybrid acrylics 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.

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 phenolics or gluteraldehyde should not be used. Ethylene oxide gas is a suitable method.

CARE OF ACRYLIC DENTURES

- Dentures should be stored in water when not in use, since dimensional changes occur on drying.
- Abrasive dentifrices (regular toothpastes) should not be used, since the plastic is soft and can be easily scratched and worn away. The *tissue surface* should be brushed carefully with a soft brush, since any material removed alters the fit of the denture.
- Acrylic dentures should not be cleaned in *hot water*, since processing stresses can be released and can result in distortion.

DENTURE CLEANSERS

A wide variety of agents are used by patients for cleaning arificial dentures. They include dentrifrices, proprietary denture cleansers, soap and water, salt and soda, household cleansers, bleaches, and vinegar.

Dentures are cleaned by either:

- Immersion in an agent or
- By brushing with the cleanser.

The most common commercial denture cleansers are the immersion type, which are available as a powder or tablet.

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.

The household cleansers are contraindicated, as they affect the fit of the denture and produce rough surface on prolonged use.

RESIN TEETH

The composition of resin teeth is essentially poly (methyl methacrylate) copolymerized with a cross-linking agent.

Usually 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.

Chemical union between the resin teeth and denture base resins can be easily obtained. Bond failures may occur if the ridge lap area is *contaminated* with residual wax or separating media. The mould should be flushed thoroughly with a detergent solution in order to remove the wax completely.

Smoothing of the wax with flame during teeth setting should be done carefully since the tooth surfaces may melt or burn. The resultant surface stresses induced during cooling may contribute to crazing in service.

DENTURE ADHESIVES

These are highly viscous aqueous solutions which are often used to improve the retention of complete dentures.

Supplied As

- Powders
- Paste

Composition

- Keraya gum
- Tragacanth
- Sodium carboxy methyl cellulose

- Polyethylene oxide
- Flavoring agents
- Some also contain antimicrobial agents and plasticizers.

Properties

These are applied to the denture base and inserted. When wet, 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.

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. 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:

- Temporary retention of poorly fitting dentures
- Patients having poor neuro-molecular control.

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 natural teeth and gold surfaces

MISCELLANEOUS

REPAIR RESINS

If an acrylic denture is fractured in service, it 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.

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.

DENTURE RELINERS

Reliners may be classified as:

A. Hard or soft (resilient)
B. Heat cured or self cured
C. Temporary or permanent
D. Resin based or silicone based.

Heat Cured Acrylic Resin

New resin is cured against the old denture by compression moulding 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.

Self Cured Resins

Self cured resins may be used instead of heat cured.

Advantage

Less distortion due to room temperature curing.

Chair Side Reliners

These materials are used for relining resin dentures directly in the mouth. Some of them generate enough heat to injure oral tissues. They tend to discolor, become foul smelling, and may even separate from the denture base. They often contain low molecular weight polymers, plasticizers or solvents to increase their fluidity while seating the denture. Thus, these materials have many disadvantages.

Light-activated resins are also available for relining.

SOFT OR RESILIENT DENTURE LINERS

Soft liners can be said to be of two types:

1. Temporary soft liners (also known as tissue conditioners)
2. Permanent soft liners
   - Plasticized acrylic resin
   - Vinyl resins
   - Silicone rubbers

The purpose of the 'permanent' soft liner (Fig. 8.4) 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.

Types

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 60 to 80% 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 This is a temporary soft liner.

Heat-cured silicones Generally a one-component system. Supplied as a paste or gel containing an oxygen catalyst. It is heat polymerized against acrylic resin using compression moulding 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 (upto + 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. The soft liner decreases the denture base strength, not only because base thickness is reduced 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 helps in fungal growth (*Candida albicans*).

Thus, none of the soft denture reliners can be considered entirely satisfactory. This makes it necessary to constantly review these patients and if necessary change the material.

TISSUE CONDITIONERS

Unlike the soft liners previously mentioned tissue conditioners or temporary soft liners are materials whose useful function is very short, generally a matter of a few days.

Uses

1. Some poor health conditions or ill-fitting dentures, can cause oral tissues to become inflammed and distorted. Relining an ill-fitting denture with tissue conditioner allows the tissues to return to 'normal', at which 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.

SPECIAL TRAY ACRYLIC RESINS

These are specialized chemically activated resins. They are available as powder and liquid form. 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 (Fig. 8.13). They are used to fabricate special trays for making final impressions using zinc oxide eugenol, elastomeric materials and alginate, etc.

FIGURE 8.13: Autopolymerizing special tray acrylic resin. These are highly filled resins and are usually colored green or blue. They are used for constructing special impression trays

The custom-made acrylic resin trays may not be dimensionally stable until 20 to 24 hours after fabrication. Therefore, it is better to use the tray after this period.

PATTERN RESINS

Commercial Name—Duralay (Fig. 8.14)

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.

FIGURE 8.14: Duralay is a special resin used for making direct patterns of inlays and posts. It is colored red to aid visual demarcation

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. 8.15). They are also used in the movie industry for special effects.

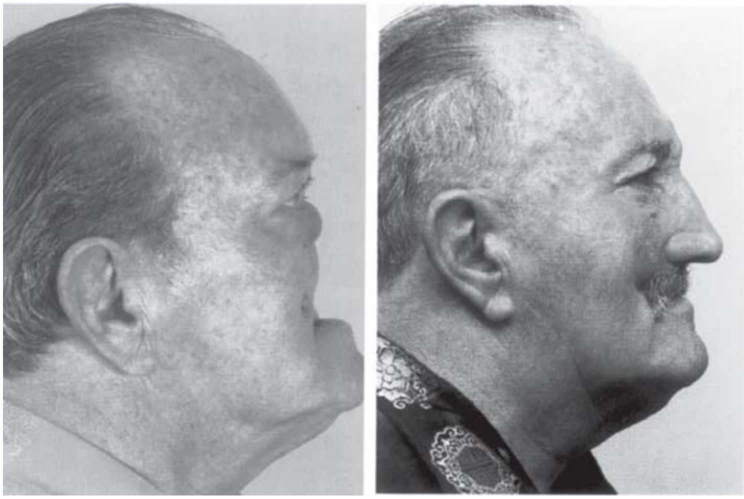


FIGURE 8.15: A maxillofacial prosthesis replacing the nose, part of the cheek and the upper lip which were removed following cancer of this region

Ideal Requirements

These materials must be easy and inexpensive to fabricate, and be biocompatible, strong, and sufficiently stable to endure. 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 resilient enough to prevent tearing. Must be easy to clean and manage by the patient.

No material so far has all of these characteristics.

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 and they form lifelike prosthesis. Since 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.

Silicone Rubber

Silicone rubber are of two types:

Room Temperature-Vulcanized (RTV) Silicones

These are similar to addition silicone impression materials in that they consist of vinyl- and hydride-containing siloxanes and are polymerized with a chloroplatinic acid catalyst.

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.

Heat Vulcanized Silicones

Heat vulcanizing silicone is a semi-solid or putty-like material that requires milling, packing under pressure, and 30 minutes curing at 180°C. Pigments are milled into the material which is then packed in discrete locations of the mould 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 and the color is entirely intrinsic and polychromatic.

Disadvantage Milling machine and press is required. A metal is normally used and the fabrication of the mould is a lengthy procedure.

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 mould 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.

TEMPORARY CROWN AND BRIDGE MATERIALS

The fabrication of a crown or fixed bridge is generally a laboratory procedure, and several weeks may lapse between the preparation of the teeth and the cementation of the permanent restoration. Therefore a temporary restoration must be made in order to provide protection to the pulp from thermal and chemical irritation caused by food and liquids, for positional stability, mastication and esthetics.

Required Properties

1. Biological—a temporary restoration must be non-irritating to soft tissues and pulp.
2. Mechanical—they should have adequate strength to withstand forces of mastication.
3. Esthetic—especially for the anterior teeth.
4. Low thermal conductivity.
5. Low dimensional change and low exothermic reaction.
6. Easy to manipulate.

Materials

Temporary crown and bridge materials may be preformed or custom-made.

PREFORMED CROWNS

A variety of preformed crowns are available commercially. A preformed crown forms the external contor of the crown. These crowns can be luted directly to prepare teeth after adjustment, or they may be relined with a plastic prior to cementation. The various materials from which preformed crowns are made include:

- Polycarbonate
- Cellulose acetate
- Aluminium
- Tin-silver.

Polycarbonate

This is a polymer of high impact resistance. It has the most natural appearance of all the preformed crowns. It is available only in a single shade. They are supplied in incisor, canine, and premolar shapes.

Cellulose Acetate Crowns

Cellulose acetate is a thin transparent material available in all tooth shapes and a range of sizes. The tooth colored chemically activated resin is mixed and filled in a preformed cellulose acetate shell. After the acrylic resin sets, the cellulose acetate is peeled off and discarded and the crown is trimmed and cemented.

CUSTOM MADE CROWNS

Temporary crowns and bridges 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 (Protemp, Fig. 9.14).

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.

Polyethyl (Isobutyl) Methacrylate Resins

Commercial name: Trim, Snap (Fig. 8.16)

FIGURE 8.16: Snap is a self cured resin used for making temporary crowns and bridges

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.

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.

CHAPTER 9

Restorative Resins

These are tooth colored materials used in the restoration of natural teeth. They are of two types:

- Unfilled, e.g. acrylic resins
- Filled, e.g. composite resins

RESTORATIVE ACRYLIC RESINS

When these materials were first introduced, they created quite a stir, because of their superior esthetics. Slowly many restorations began to fail, through microleakage and staining.

The type I unfilled direct resins have been largely replaced by the composite resins. However, a discussion on these older materials is necessary to understand the chemistry and properties of the newer resin systems. These materials are currently being used for temporary restorations.

COMPOSITION

They are supplied as powder and liquid.

The Powder Contains

- Polymethyl methacrylate—as beads or grindings
- Benzoyl peroxide (0.3 to 3%)—initiator
- Color pigments.

Liquid Contains

- Methyl methacrylate monomer
- Ethylene dimethacrylate (5%)—cross linking agent
- Hydroquinone (0.06%)—inhibitor.

The monomer is supplied in brown bottles, to protect them from ultraviolet light which can initiate polymerization.

CHEMISTRY

There are atleast 3 sytems of activation and initiation for these restorative materials.

Amine Peroxide System

Monomer contains 2% tertiary amine, e.g. dimethyl-p toluidine. Polymer contains benzoyl peroxide.

Disadvantage Yellowing of acrylic over a period of time on exposure to sunlight due to oxidation of amine. The reaction is inhibited by eugenol and oxygen (air).

Mercaptan-Peroxide System

Lauryl mercaptan is used in place of amine. The mercaptan can be in a tablet which is broken up in the monomer before adding proportionate amount of poly (methylmethacrylate) to the mix.

Sulphinate Curing System

Free radicals are supplied by salts of sulfinic acid (p-toluene sulfinic acid), which is dispersed in the powder along with benzoyl peroxide.

This system is more color stable and is less sensitive to oxygen and eugenol. However, they are very unstable in presence of moisture or water, which completely inhibits the polymerization.

MANIPULATION

Pressure Technique or Bulk Technique

Monomer and polymer mix at dough stage is placed in the cavity. Pressure is applied with a matrix strip to prevent it pulling away from the cavity margins while it contracts during polymerization.

Non-Pressure or Bead Technique

Mix is filled in the cavity in small increments with a brush and not in one bulk. This compensates for the polymerization shrinkage.

Flow Technique

A thin mix (fluid resin) is made and filled into the prepared cavity. A matrix is held against it without pressure. The matrix helps to contain the resin, and ensures proper contact and contour. Close adaptation is achieved due to the fluid nature of the resin.

Cavity Lining Agents

Adhesion can be improved by specially formulated lining agents which may be supplied by the manufacturer. It is applied prior to insertion of the resin. The hydrophilic lining is more attractive to the hydrophobic resin.

PROPERTIES

Mechanical Properties

Poor when compared to composites.

- Compressive strength is less—69 MPa
- It has low tensile strength—24 MPa
- It has low modulus of elasticity—2.4 GPa
- The proportional limit is also low
- It has low hardness and abrasion resistance. It is the softest of all restorative materials. Hardness—15 KHN.

Thermal Properties

- The coefficient of thermal expansion (92.8×10^{-6}/°C) of unfilled resins is very high. It is 8 times greater than that of enamel and dentin. Changes in mouth temperature causes expansion or contraction of the resin leading to percolation of oral fluids at the margins. This may result in discoloration and secondary caries.
- It has low thermal conductivity.

Polymerization Shrinkage

Shrinkage is high (5 to 8%). This causes a gap between the cavity margins and restoration which may lead to discoloration and secondary caries.

Solubility and Water Sorption

It is virtually insoluble in water and oral fluids, but tends to sorb water (1.7 mg/cm^2) and swell.

Adhesion

It does not adhere to enamel or dentin.

Esthetics

Excellent matching with tooth color. However, it tends to discolor and stain with use.

Biocompatibility

Monomer can penetrate dentinal tubules and cause irritation to the pulp. A calcium hydroxide or glass ionomer lining should be applied for pulp protection.

LIMITATIONS

- Recurrent caries and stains due to leakage of oral fluids at the margins of the restoration.
- Easily abraded.
- Irritant to pulp.

COMPOSITE RESINS

It is a tooth colored restorative system developed in the late 1950's and early 1960's by Bowen (also known as Bowen's resin). It is basically a resin which has been strengthened by adding silica particles.

The pioneering research of Bowen together with the development of the acid etch and bonding technique, revolutionized restorative dentistry. It largely replaced the earlier silicate and restorative acrylics.

A 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 materials 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.

USES

1. Restoration of anterior and posterior teeth (directly or as inlays).
2. To veneer metal crowns and bridges (prosthodontic resins).
3. To build up cores (post core).
4. Cementation of orthodontic brackets, Maryland bridges, and ceramic crowns, 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

Based on Curing Mechanism

- Chemically activated
- Light activated

Based on Size of Filler Particle

Conventional	8-12 um
Small particle	1-5 um
Microfilled	0.04-0.4 um
Hybrid	0.6-1-0 um

SUPPLIED AS

Composites used for restoring teeth are usually supplied in a kit (Fig. 9.1) containing the following:

- Syringes of composite resin pastes in various shades
- Etching liquid (37% phosphoric acid)
- Enamel dentin bonding agent
- Shade guide.

FIGURE 9.1: A typical light cured composite kit. The resin is supplied in dark syringes in a number of shades. A shade guide is also provided. An etching agent (blue) as well as primer (light green) and adhesive bonding agent (dark green) is also visible. Brushes are provided to apply these.

Chemically activated composite resins are available as:

Two paste system Base and catalyst paste supplied in small jars or syringes (Fig. 9.2).

Powder-liquid systems Powder (inorganic phase plus the initiator) is supplied in jars. Liquid (BIG-GMA diluted with monomers) in bottles.

FIGURE 9.2: Chemically activated hybrid composite. The above sample is supplied in small jars as base and catalyst. The bonding agent in this case is also chemically cured

Light activated composite resins are available as single paste system supplied in light-tight (dark) syringes (Fig. 9.1).

Commercial Names

Chemically Activated

- Isopast
- Alfa comp (voco)
- Brilliant (coltene)

Light Activated

- Z100 (3M)
- Herculite (Kerr)
- TPH spectrum
- Heliomolar (Vivadent)

COMPOSITION AND STRUCTURE

The essentials of a composite resin are (Fig. 9.3):

- Resin matrix/binder—BISGMA or urethane dimethacrylate
- Filler—Quartz, colloidal silica or heavy metal glasses
- Coupling agent—organo silanes.

They also contain

- Hydroquinone—inhibitor to prevent premature polymerization.
- UV absorbers—to improve color stability.
- Opacifiers—e.g. titanium dioxide and aluminum oxide.
- Color pigments—to match tooth color.

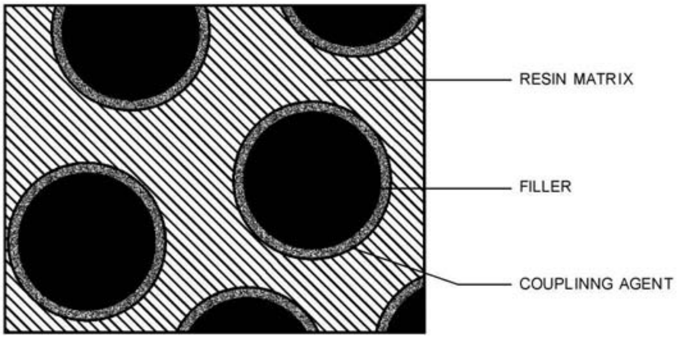


FIGURE 9.3: Essentials of a composite

RESIN MATRIX

Most composites use monomers that are aromatic or aliphatic diacrylates. Of these, BIS-GMA (Bisphenol-A-glycidyl Methacrylate) is most commonly used. Urethane dimethacrylate (UEDMA) is also used frequently.

BIS-GMA was developed by R.L. Bowen (Bowens resin) in the early 1960's. 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.

To make it clinically acceptable diluent monomers are added to the resin matrix to reduce the viscosity of the paste. It also allows more filler particles to be incorporated.

Diluents allow extensive cross-linking between chains, thereby increasing the resistance of the matrix to solvents. However, polymerization shrinkage is also increased. The commonly used diluent monomer is TEGDMA (triethylene glycol dimethacrylate).

FILLER PARTICLES

Addition of filler particles into the resin matrix significantly improves its properties:

- As less resin is present, the curing shrinkage is reduced.

- Reduces water sorption and coefficient of thermal expansion.
- Improves mechanical properties like strength, stiffness, hardness and abrasion resistance.

Important factors with regard to fillers, that determine the properties and clinical application of composites are:

— Amount of filler added
— Size of particles and its distribution
— Index of refraction
— Radiopacity
— Hardness.

Particle size distribution 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.

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.

Types of Fillers

Composite resins use 3 types of fillers

— Ground quartz
— Colloidal silica
— Glasses or ceramic containing heavy metals.

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.

Colloidal silica Referred to as “microfillers”. They are obtained by a pyrolytic or a precipitation process. They are added in small amounts (5 wt%) to modify the paste viscosity. Colloidal silica particles have large surface area (50 to 300 m^2/g), thus, even small amounts of microfillers thicken the resin. In microfilled composites it is the only inorganic filler used.

Glasses/ceramics containing heavy metals These fillers provide radiopacity to the resin restoration. Its refractive index is 1.5. 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.

COUPLING AGENTS

Coupling agents bond the filler particles to the resin matrix. This allows the more plastic resin matrix to transfer stresses to the stiffer filler particles.

Function of Coupling Agents

- They improve the physical and mechanical properties of the resin.
- They prevent water from penetrating the filler-resin interface.

The most commonly used coupling agents are *organosilanes* (i.e. 3-methoxy-propyl-trimethoxy silane). In its hydrolyzed state the silanol groups of the organo-silane bond with the silanol groups of the filler by formation of a siloxane bond (Si-O-S).The methacrylate group of the organosilane then forms covalent bond with the resin when it is polymerized. This completes the coupling process. *Zirconates* and *titanates* can also be used as coupling agents.

> 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.

POLYMERIZATION MECHANISMS

They polymerize by the addition mechanism that is initiated by *free radicals*. The free radicals can be generated by chemical activation or heat or light.

Based on the mode of activation of polymerization, there are two types of resins:

A. Chemically activated resins
B. Light-activated resins.

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

UV light activated systems The earliest systems used ultraviolet (UV) light. Their limitations 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 the U-V light system. They are also more widely used than the chemically activated resins.

These are single paste systems containing:
— Photoinitiator : Camphoroquinone 0.25 wt.%
— Amine accelerator : Diethyl-amino-ethyl-methacrylate (DEAEMA 0.15 wt.%)

Setting

Under normal light they do not interact. However, when exposed to light of the correct wavelength (Fig. 9.4) the photoinitiator is activated and reacts with the amine to form *free radicals.*

Camphoroquinone has an absorption range between 400 and 800 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.

Light Devices

A number of curing lights are manufactured. The light source is usually a *tungsten halogen bulb.* The white light generated passes through a filter that removes the infrared and visible spectrum for wavelengths greater than 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 fibreoptic cord. There are also hand held light curing devices that contain the light source and transmit the light through short light guides (Fig. 9.4).

Degree of Conversion: (Degree of Polymerization)

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 a great depth as conventional composites.
- *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.
- *Time of exposure* 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.

FIGURE 9.4: A visible light curing unit emits an intense blue light

Two to three times longer exposure is required to cure a resin through *tooth structure*. *Darker shades* require longer exposure time.

Polymerization Shrinkage

Polymerization in composite resins is accompanied by a shrinkage of 1 to 1.7%. 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
- Inserting and polymerizing the composite resin in layers.
- Preparing a composite inlay and then cementing into the tooth.

CONVENTIONAL COMPOSITE

Conventional composites are also referred to as 'traditional' or 'macrofilled composite' (because of the large size of the filler particles).

COMPOSITION

Ground quartz is most commonly used as filler. There is a wide distribution of particle size. Although average size is 8 to 12 um, particles as large as 50 to 100 um may also be present.

Filler loading: 70-80 wt.% or 50-60 vol.%.

Comparison of Light Activated and Chemically Activated Resins

Light activated	*Chemical activated*
Requires light of correct wavelength for its activation	Activated by peroxide-amine system
Cures only where sufficient intensity of light is received	Cures throughout its bulk
Working time under control of operator	Working time is limited
Shrinkage is towards light source	Shrinkage is towards center of bulk
Supplied as single component in light tight syringes	Supplied as two component system
Less chance of air entrapment during manipulation. More homogeneous mix	Air may get incorporated during mixing resulting in a reduction of properties

PROPERTIES

The conventional composites have improved properties when compared to unfilled restorative resins.

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 (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 reduces 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 (Fig. 9.5).

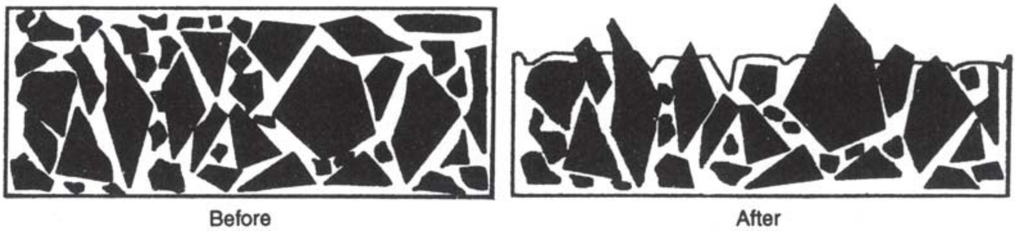


FIGURE 9.5: Effect of polishing on conventional composite

Radiopacity

Composites using quartz as a filler are radioluscent. The radiopacity is less than that of dentin.

CLINICAL CONSIDERATIONS

Although the conventional composites were superior to unfilled resins, they had certain disadvantages:

- Polishing was difficult
- Poor resistance to occlusal wear
- Tendency to discolor—the rough surface tends to stain.

MICROFILLED COMPOSITE

They were developed to overcome the problems of surface roughness of conventional composites. The resin achieved the smoothness of unfilled acrylic direct filling resins and yet had the advantage of having fillers.

COMPOSITION

The smoother surface is due to the incorporation of microfillers. *Colloidal silica* is used as the microfiller.

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.

The colloidal silica (size 0.02 to 0.04 um) is 200-300 times smaller than the quartz fillers of conventional composite.

Methods to Increase Filler Loading

1. One method is to sinter (fuse) the colloidal silica particles, thereby reducing surface area.
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. 9.6).

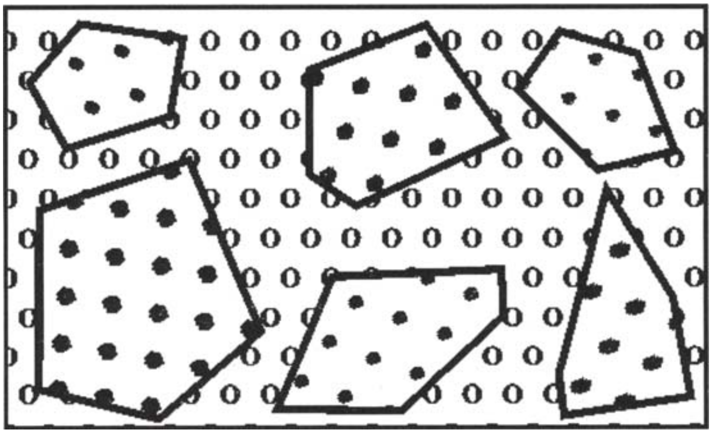


FIGURE 9.6: Prepolymerized filler particles in microfilled composites. These larger fillers are made of tiny densely packed microfillers (colloidal silica)

Filler Content

With the inclusion of prepolymerized fillers, the filler content is 80 wt.% or 70 vol.%. However, the actual inorganic filler content is only 50 wt.%.

PROPERTIES

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.

Compressive Strength

250 to 350 Mpa. Similar to conventional.

Tensile Strength

30 to 50 MPa. Lowest among composites.

Modulus of Elasticity

3 to 6 Gpa. Lowest among composites.

Hardness

25 to 30 KHN. Lowest hardness among the composites.

Thermal Expansion Coefficient

50 to 60 × 10^{-6}/°C. Highest among the composite resins.

Water Sorption

1.4 to 1.7 mg/cm^2. Highest among composites.

Esthetics

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. Thus, the silica filler is removed along with the resin in which it is embedded.

CLINICAL CONSIDERATIONS

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.

SMALL PARTICLE COMPOSITE

Small particle composites were introduced in an attempt to have good surface smoothness (like microfilled composites) and yet retain or improve the physical and mechanical properties of conventional composites.

COMPOSITION

The small particle composite use fillers that have been ground to smaller size. The fillers employed are :

- Glasses containing heavy metals. Ground quartz is also used.
- Colloidal silica is also added in small amounts – 5 wt.% to adjust the paste viscosity.

Average Filler Size

1-5 um, however the distribution is fairly broad (it helps to increase the filler loading).

Filler Content

65 to 77 vol.% or 80 to 90 wt.%.

PROPERTIES

Due to the higher filler content the best physical and mechanical properties are observed with this type.

Compressive Strength

Small particle composites have the highest compressive strength (350 to 400 MPa).

Tensile Strength

It is double that of microfilled and 50% greater than that of conventional (75 to 90 Mpa).

Modulus of Elasticity

It is the stiffest (15 to 20 Gpa).

Hardness

Hardness is similar to conventional composites (50-60 KHN). Wear resistance, however, is improved.

Thermal Expansion Coefficient

Though lower than that of the other composites, it is still twice that of tooth structure (19 to 26 × 10^{-6}/°C).

Water Sorption

Similar to conventional (0.5 to 0.6 mg/cm^2).

Esthetics

It has a better surface smoothness than conventional because of the small and highly packed fillers.

Polymerization Shrinkage

It is comparable to or less than that of conventional composite.

Radiopacity

Composites containing heavy metal glasses as fillers are radio-opaque. This is an important property for materials used in the restoration of posterior teeth.

CLINICAL CONSIDERATIONS

Due to their improved strength and abrasion resistance they can be used in areas of stress such as Class IV and Class II restorations.

Some of the products have reasonably smooth surfaces for anterior applications, but are still not as good as the microfilled and hybrid composites in this regard.

HYBRID COMPOSITE

The latest category of composites is the hybrid. These were developed so as to obtain better surface smoothness than that of the small particle, but yet maintain the properties of the latter. The hybrid composites have a surface smoothness and esthetics competitive with microfilled composites for anterior restorations.

COMPOSITION

Two kinds of filler particles are employed:

- Colloidal silica: Present in a higher concentration 10 to 20 wt.% and contributes significantly to the properties.
- Heavy metal glasses: Average particle size is 0.6 to 1 um. 75% of the ground particles are smaller than 1.0 um.

Filler Content

75-80 wt.% or 60-65 vol.%. The overall filler loading is not as high as some small particle composites.

PROPERTIES

Their properties range between conventional and small particle. They are generally superior to microfilled composites.

Compressive Strength

It is slightly less than that of small particle composite (300 to 350 Mpa).

Tensile Strength

Comparable to small particle (70 to 90 Mpa).

Elastic Modulus

It ranges between that of conventional and microfilled composite (7 to 12 Gpa).

Hardness

It is similar to small particle (50 to 60 KHN).

Coefficient of Thermal Expansion

Though CTE is high (30 to 40 × 10^{-6}/°C), it is still less than that of microfilled.

Water Sorption

It sorps less water than the microfilled resins (0.5 to 0.7 mg/cm^2). It is similar to conventional and small particle composite.

Esthetics

The surface smoothness and esthetics is competitive with microfilled composite for anterior restorations.

Radiopacity

The presence of heavy metal glasses makes the hybrid more radio-opaque than enamel.

CLINICAL CONSIDERATION

The hybrid composites are widely used for anterior restorations, including class IV because of its smooth surface and good strength.

The hybrids are also being widely employed for stress bearing restorations, even though its mechanical properties are somewhat inferior to small particle composites.

BIOCOMPATIBILITY OF COMPOSITE RESINS

Composites resins effect the pulp from two aspects:

- Inherent chemical toxicity of the material.
- Pulpal involvement due to microleakage.

Properly polymerized composites are relatively biocompatible. However, monomer from improperly cured or uncured composites can enter the dentinal tubules and cause inflammation of the pulp.

PULP PROTECTION

A layer of calcium hydroxide or glass inomer liner is applied to the pulpal wall of deep cavities. Zinc oxide-eugenol is *contraindicated* as it interferes with polymerization.

COMPOSITE RESINS FOR POSTERIOR RESTORATIONS

Amalgam has long been the standard direct filling material for posterior teeth. Due to the increasing demand for esthetics and concern about mercury toxicity, there is an increasing interest in the use of composites for class I and II restorations.

All types of composites have been used for posterior restorations. 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 the small particle and hybrids have less wear (20 um per year), which approaches that of amalgam (10 um). The major indications of composites for posterior use are:
  - When esthetics is the prime consideration.
  - When patient is allergic to mercury.

MANIPULATION OF COMPOSITE RESINS

Beveling The cavity margins are bevelled (Fig. 9.7).

Cleaning The tooth is first 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. The cavity is now ready for the composite.

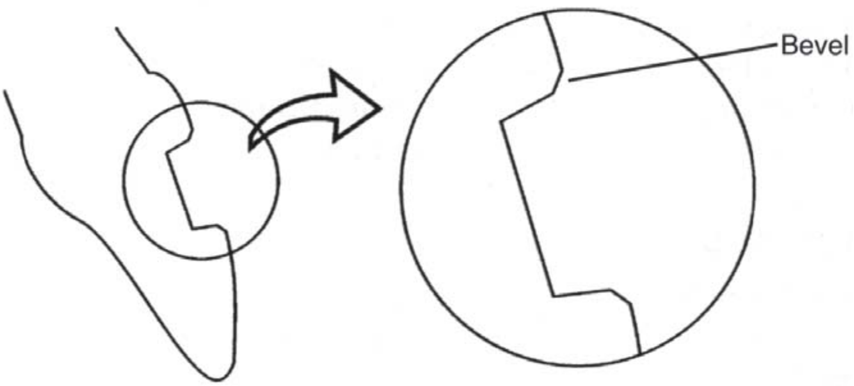


FIGURE 9.7: Cavity preparation for receiving a composite restoration. The enamel at the margins is bevelled to increase the area for acid etching. Beveling also exposes reactive enamel as well as helps to blend the restoration

TECHNIQUES OF INSERTION

Chemically Activated Composites

The correct proportions of base and catalyst pastes are dispensed onto a mixing pad and combined by rapid spatulation with a plastic instrument for 30 seconds. Metal instruments should be avoided as it may discolor the composite. Insert while it is still plastic for better adaptation to cavity walls. It can be inserted with a plastic instrument or syringe. Air inclusions can be avoided by wiping the material into one side of the cavity, filling the cavity from bottom outward. The cavity is slightly overfilled. A *matrix strip* is used to apply pressure and to avoid inhibition of 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.

The paste is dispensed just before use, as exposure to operatory lights may also initiate polymerization. The material hardens rapidly, once exposed to the curing light. The depth of cure is limited, so in deep cavities the restorations must be built up in increments, each increment being cured prior to insertion of the next one.

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 (Fig. 9.4). The exposure time should be no less than 40 to 60 seconds. The resin thickness should be no greater than 2.0 to 2.5 mm. Darker shades require longer exposure times, as do resins that are cured through enamel. Microfilled resins also require a longer exposure time.

Caution The high intensity light can cause retinal damage if one looks at it directly. Protective eye glasses should be used.

FINISHING AND POLISHING

Finishing procedures can be started 5 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 discs. The best finish is obtained when the composite is allowed to set against the matrix strip.

ACID ETCH TECHNIQUE

The acid etch technique is one of the most effective ways of improving the bond and marginal seal between resin and enamel.

Mode of Action

- It creates microporosities by discrete etching of the enamel, i.e. by selective dissolution of enamel rod centers, 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. 9.8).

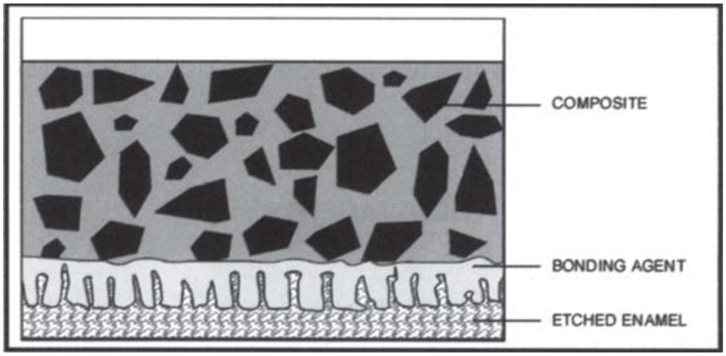


FIGURE 9.8: Section through a composite restoration. The bonding agent is fluid enough to penetrate the etched enamel and serves to attach the composite to the etched enamel

Acid Used

37% phosphoric acid is used for etching (concentrations greater than 50% results in the formation of *monocalcium phosphate monohydrate* that reduces further dissolution). It is supplied in the form of a colored gel. Brushes are used to apply or the acid is supplied in a syringe from which it can be dispensed onto the enamel (Fig. 9.9).

FIGURE 9.9: 37% Phosphoric acid etching agent in syringe form. The acid usually comes in a contrasting color in order to give better application control to the operator. The acid may be in liquid form or in gel form

Procedure

The tooth is cleaned and polished with *pumice* before etching. The acid is then applied onto the enamel. Originally the length of application was set at 60 seconds but now it has been shown that *15 seconds* provide as strong a bond. The etching time also depends on the history of the tooth, e.g. a tooth with high flouride content requires longer etching time.

The acid should be *rinsed off* thoroughly with a stream of water for 15 seconds and the enamel dried thoroughly. After drying the enamel should have a *white, frosted* appearance. This surface must be kept *clean and dry* until the resin is placed. Even momentory contact of saliva, or blood can prevent effective resin tag formation and severely reduce the bond strength.

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.

BOND AGENTS

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.

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 largely replaced by agents that bond to dentin also.

DENTIN BOND AGENTS

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. Acid etching of dentin is not done as it can injure the pulp. Thus, agents that could bond to dentin were developed. 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 hydrophillic to displace the water and thereby wet the surface, permitting it to penetrate the porosities in dentin or react with organic/inorganic components.

However, restorative resins are hydrophobic, therefore agents should contain both hydrophillic and hydrophobic parts. The hydrophillic part bonds with either calcium in the hydroxyapatite crystals or with collagen. The hydrophobic part bonds with the restorative resin.

Supplied As

Dentin bond agents are supplied as a kit containing primers/ conditioners and the bonding liquid.

Primers or Conditioners

Primers condition the dentin surface, and improve bonding. They are acidic in nature. Examples of primers are : Ethylene-diamine-tetracetic acid (EDTA), nitric acid, maleic acid, etc.

They have the following functions

1. Removes smear layer and provides subtle opening of dentinal tubules.
2. Provides modest etching of the inter-tubular dentin.

Dentin Bonding Agents are Classified As

First generation (developed before 1980's) They used glycerophosphoric acid dimethacrylate to provide a bifunctional molecule. The hydrophillic phosphate part reacted with calcium ions of the hydroxyapatite. The hydrophobic methacrylate groups bonded to the acrylic restorative resin. The main disadvantage was their low bond strength.

Another system used NPG-GMA. It was proposed that the NPG, portion bonded to the calcium by chelation.

Second generation (early 1980's) Developed as adhesive agents for composite resins which had replaced acrylic restorations. Bond strengths achieved were three times more than before. Some products had bond strengths 30 to 50% of that to etched enamel.

Chloro-substituted phosphate esters of various monomers were used. Bonding was by ionic bond to calcium by the chlorophosphate group. Disadvantage: adhesion was short term, the bond eventually hydrolysed, e.g. Prisma, Universal Bond, Clearfil, Scotch Bond (Fig. 9.10).

Third generation (late 1980's) These coupling agents had bond strengths comparable to that of resin to etched enamel. However, their use is more complex and requires two to three application steps. A primer is applied first followed by application of a polymerizable monomer, e.g. Tenure, Scotch bond 2, Prisma, Universal bond, Mirage bond.

Fourth generation All bond–2 system 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.

Fifth generation The most recent product is the single bond adhesive. Unlike the previous generations, this system is more simple to use as it needs only a single step application, e.g. 3M Single Bond, One Step (BISCO), Prime and Bond (Dentsply) (Fig. 9.11).

FIGURE 9.10: An etchant (37% phosphoric acid), primer and adhesive. Scotch bond is a third generation bonding agent

FIGURE 9.11: A fifth generation bonding agent—the 3M Single Bond

The advantages claimed are:

1. Single step application
2. Less technique sensitive as it can bond to moist dentin
3. Less volatile liquid
4. Pleasant odor
5. Higher bond strength.

Bond Agents

Several systems have been employed.

- *Ferric oxalate-NPG-GMA system* The acidic ferric oxalate combined cleansing and mordanting functions. This was followed by application of NPG-GMA. Ferric oxalate produced a black stain and so aluminium oxalate was substituted.
- *Hydroxyethyl methacrylate (HEMA) plus gluteraldehyde* EDTA is applied first as primer. The gluteraldehyde provides bonding to the collagen in dentin, whereas HEMA is a polymerizable monomer.
- *BIS-GMA plus HEMA* Maleic acid in a solution of HEMA is applied first as primer. This is followed by application of a polymerizable monomer composed of BIS-GMA and HEMA.
- *4-Methyloxyethyltrimellitic acid (4-META)* It is dissolved in methyl methacrylate and is a potential coupling agent to collagen.
- *Polyurethanes* They react with the -OH or -NH_2 groups in the organic or mineral components of dentin.
- *Polyacrylic acids* They bond to the hydroxyapatite in dentin.

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.

Mode of Bonding

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

The dentin bond agents generate bond strengths comparable to that of resin to etched enamel. A higher bond strength is obtained when dentin bond agents are applied to etched enamel.

HEMA plus gluteraldehyde — 11 to 17 MPa
NPG-GMA — 4 to 12.5 MPa
4-META — 3 to 7 MPa
Polyurethanes — 1 to 6 MPa
Polyacrylic acids — 2 to 4 MPa

Of the dentin bond agents the HEMA plus gluteraldehyde system generated the highest bond strength. The fifth generation bond agents are claimed to generate bond strengths as high as 31.2 MPa.

SPECIAL TECHNIQUES

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 flouride 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.

RESIN INLAY SYSTEMS

These were introduced in an attempt to over-come some of the limitations of traditional posterior composite resin restoration.

Hybrid or microfilled resins are used. 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)*

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 using a microfilled resin in a dental laboratory on a die made from an impression of the prepared tooth. The conventional light and heat or heat and pressure (140°C/85 Psi for 10 minutes) 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.

REPAIR OF COMPOSITES

Composite resins may be repaired by adding new material over the old. This is useful in correcting defects or altering contours on an existing restorations. 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.
- The presence of fewer methacrylate groups and the greater cross-linking reduces the ability of fresh monomer to penetrate into the matrix.

Method

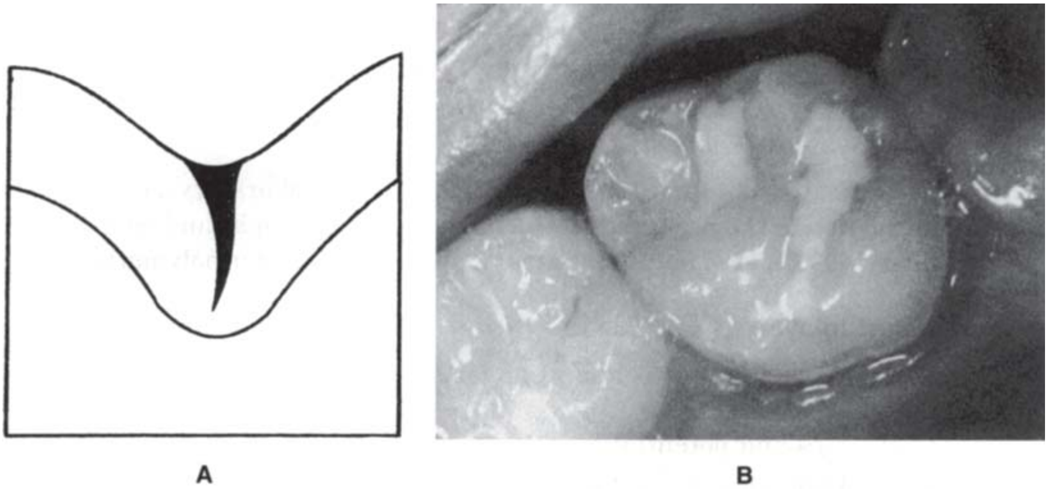
Remove contaminated material from the surface and roughen it. Place fresh composite after applying bonding agent.

SPECIAL APPLICATIONS AND MATERIALS

Pit and Fissure Sealants

Deep pits and fissures on posterior teeth are susceptible to decay as they provide shelter for organisms. They are difficult to clean.

Various materials have been to seal these areas, especially in the child patient. The most popular sealants are resin systems like cyanoacrylates, polyurethenes and the BIS-GMA reaction product (Another sealant technique uses type IV glass ionomer cement—refer cements). The *objective* is for the resin to penetrate into the pits and fissures, thereby sealing these areas against oral flora and debris (Figs 9.12A and B).



FIGURES 9.12A and B: (A) Sealing of occlusal fissure with sealant. (B) An applied fissure sealant on a deciduous tooth

FIGURE 9.13: Light cured—Pit and fissure sealant resin system (Vivadent-Helioseal F). The small bottle on the left is the acid etchant

The most commonly and successfully used sealant is BIS-GMA (Fig. 13.17). It may be cured chemically (amine-peroxide system) or by light (9.13).

Two types are available

- Filled
- Unfilled.

Unfilled resins are colorless or tinted transparent materials. Filled resins are opaque and available as tooth colored or white materials.

The sealant must have low viscosity so that they will flow readily into the depths of the pits and fissures and wet the tooth. The selected area is acid etched before applying the sealant. The physical properties of the sealants are closer to those of unfilled resins than composite resins.

Surfaces that are free of caries should be selected and the sealant should be examined every six months. If the sealant is missing it should be reapplied. Improper case selection and application of sealant may actually enhance caries.

Prosthodontic Veneers

Dental porcelain or resin may be used as veneers (a tooth colored layer used to hide the underlying metal) for crowns and bridges. Earlier heat cured poly (methyl methacrylate) was used improved by fillers and cross-linking agents. Now microfilled materials such as BIS-GMA, urethane dimethacrylate or 4,8 - di (methacryloxy methylene) tricyclo -(5.2.1.02,6) -decane are used. These new resins have superior physical properties and are polymerized by light (320 to 520 nm) or heat and pressure.

Originally, the resins were mechanically bonded to the metal using wire loops or retention beads. 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).

The advantages of resin when compared to porcelain are:

1. Ease of fabrication
2. Easily repairable intraorally
3. Less wear of opposing teeth or restorations.

The disadvantages include:

1. Microleakage of oral fluids and staining under the veneers due to thermal cycling and water sorption
2. Surface staining and intrinsic discoloration
3. Susceptability to toothbrush wear
4. Cannot be used as abutments for removable partial dentures. The clasp arm will abrade the resin.

Resin Laminates

Prosthodontic resins are also 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.

Core Build up Resins

Modified highly filled resins are used as core materials around pins and posts during the restorations of badly broken down teeth. They are highly colored opaque materials. They are usually chemically cured and have a longer working time and shorter setting time. They may be light cured also.

Orthodontic Resin

Lower viscosity filled resins (e.g. Panavia Ex, Infinity, Fig. 13.17) are used for the cementation of orthodontic brackets to the facial surfaces of anterior and posterior teeth. Acid etching should be done as usual before cementing the bracket (see also resin luting cements).

Temporary Crown and Bridge Composite

A composite resin is available for making temporary crowns and bridges (ESPE) (Fig. 9.14). Its main advantage is that it can be made directly in the mouth because of its low exothermic heat. It is easily ground and shaped with high speed diamond burs without melting and clogging the burs (unlike the conventional 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 turning 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 until the clicking is heard. The base and catalyst are mixed quickly and used. Setting occurs in approximately two to three minutes.

FIGURE 9.14: Protemp (ESPE) is a chemically cured composite resin used to make temporary crowns and bridges

CURRENT DEVELOPMENTS

The field of composites have advanced greatly since the days when only conventional composites were available. Current developments include hybrid composites with improved strength, zirconium filled composite (Z-100), ceramic filled composites for better esthetics, dual cure mechanisms (see resin cements), fifth generation bonding agents and the polyacid modified composites (Dyract).

CHAPTER 10

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

APPLICATIONS

1. As a permanent filling material in:
   - — 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 more than 6% 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

Lathe-Cut Alloy Powder

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

Aging

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. Aging can be done quickly by boiling the filings for 30 minutes in *water*. They can also be treated with *acid*. Aging also improves the shelf life of the product.

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.

SUPPLIED AS

- Bulk powder (Fig. 10.1)
- Alloy and mercury in disposable capsule (Fig. 10.2)
- Preweighed alloy as tablet/pellet and mercury in sachets.

FIGURE 10.1: Commercially available amalgam alloy and mercury products

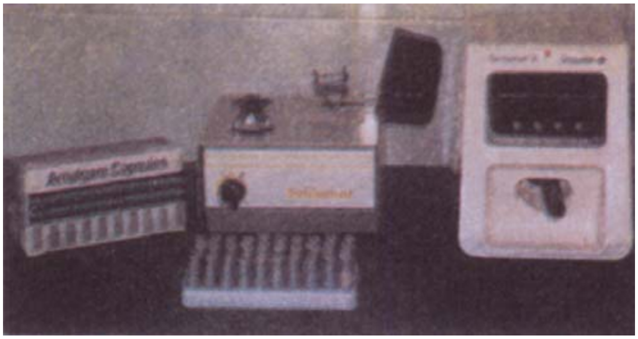


FIGURE 10.2: Two types of amalgamators along with preproportioned capsules of alloy and mercury

COMPOSITION

	Low copper	*High copper*		
		Admixed		*Unicomposition*
Particle shape	*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 EACH CONSTITUENT

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 (upto 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.

LOW COPPER ALLOYS

Composition

Silver —63-70%
Tin —26-29%
Copper —2-5%
Zinc —0-2%.

Available As

- Lathe-cut alloys, 2 types: 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. At the same time, mercury diffuses into the alloy particles and starts reacting with the silver and tin present in it, forming silver-mercury and tin-mercury compounds.

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

A simplied reaction is outlined below:

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

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

Microstructure (Fig. 10.3)

Set amalgam consists of unreacted particles (γ) surrounded by a matrix of the reaction products (γ1 and γ2).

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.

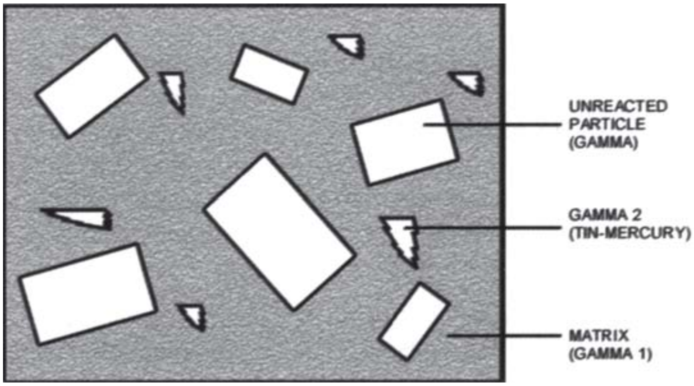


FIGURE 10.3: Schematic representation of the microstructure of low copper amalgam

HIGH COPPER ALLOYS

High copper alloys contain more than 6% wt. copper. They are preferred because of their improved mechanical properties, resistance to corrosion, and better marginal integrity (because the weakest γ2 phase is eliminated in high copper amalgam).

Types

- Admixed alloy powder.
- Single-composition alloy powder.

ADMIXED ALLOY POWDER

The admixed alloy was developed in 1963. They are 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%).

Amalgam made from admixed powders is *stronger* than amalgam made from lathe-cut low-copper powder, because of the silver copper particles which act as fillers in amalgam matrix, hence strengthening the amalgam.

Composition

The overall composition is

Silver — 69%
Tin — 17%
Copper — 13%
Zinc — 1%

Admixed alloy powders usually contain 30 to 55 weight percent spherical high-copper powder. The total copper content ranges from 9 to 20 weight percent.

Setting Reaction

Silver enters the mercury from the silver copper eutectic alloy particles, and both silver and tin enter the mercury from the silver-tin alloy particles. The mercury dissolved in the silver-tin particles will react like low copper alloys and will form the γ1 and γ2 phases, leaving some silver-tin particles unreacted.

In a relatively short time, the newly formed γ2 phase (Sn_8Hg) will react with silver-copper particles forming Cu_6Sn_5 (n or eta) phase. Some γ1 phase (Ag_2Hg_3) will also form around the silver-copper particles.

The reaction may be simplified as follows:

$$\underset{(\gamma)}{Ag_3Sn} + \underset{(\text{eutectic})}{Ag\text{-}Cu} + Hg \rightarrow \underset{(\gamma 1)}{Ag_2Hg_3} + \underset{(\gamma 2)}{Sn_8HG} + \underset{(\gamma)}{Ag_3Sn}\ \text{unreacted} + \underset{(\text{eutectic})}{Ag\text{-}Cu}\ \text{unreacted}$$

and later,

$$\underset{(\gamma 2)}{Sn_6Hg} + \underset{(\text{eutectic})}{Ag\text{-}Cu} \rightarrow \underset{(n)}{Cu_6Sn_5} + \underset{(\gamma 1)}{Ag_2Hg_3}$$

Note In this reaction, γ2 has been eliminated and is replaced by *n* 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 Amalgam (Fig. 10.4)

The Cu_6Sn_5 is present as a 'halo' surrounding the Ag-Cu particles. Final set material consists of:

Core

— Unreacted Ag_3Sn, (γ phase) and
— Unreacted Ag-Cu surrounded by a halo of Cu_6Sn_5 (n)

Matrix

— γ1 (Ag_2Hg_3).

SINGLE-COMPOSITION ALLOYS

Unlike admixed alloy powders, each particle of the alloy powder has the same composition. Therefore, they are called single-composition or 'uni-compositional alloys'.

The spherical alloy particles are 5 to 40 um in size.

Composition

Silver — 40-60%
Tin — 22-30%
Copper — 13-30%
Zinc — 0-4%
Indium or palladium—small amounts.

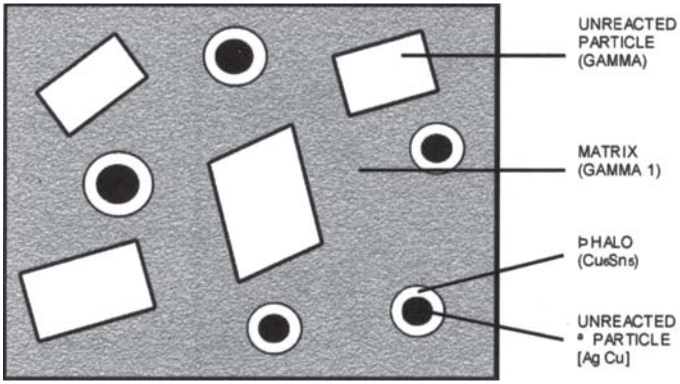


FIGURE 10.4: Schematic representation of the microstructure of high copper admixed amalgam. Note that the Gamma 2 phase has been eliminated

Setting Reaction

When triturated, silver and tin from Ag-Sn phases dissolve in mercury. Very little copper dissolves in mercury. The Ag_2-Hg_3 γ1 crystals grow forming a matrix that binds together the partially dissolved alloy particles. Later, *n* (Cu_6-Sn_5) crystals are formed at the surface of alloy particles.

The overall simplified reaction is:

$$\begin{array}{lllll} AgSnCu + Hg & \rightarrow Cu_6Sn_5 & + Ag_2Hg_3 & + & AgSnCu \\ (\gamma + E) & \quad (n) & \quad (\gamma 1) & & (\text{unreacted}) \end{array}$$

Note The difference between the elimination of the γ2 phase in an admixed and uni-compositional alloy is that, in the admixed type the γ2 forms around the silver-tin (lathe-cut) particles and is eliminated around the silver-copper (spherical) particles In unicompositional type, the particles at the beginning of the reaction function like silver-tin particles of the admixed type, and later the same particles function like the silver-copper particles of the admixed type, eliminating γ2 phase.

Microstructure of set amalgam (Fig. 10.5) Final set material consists of:

Core
- Unreacted Ag_3Sn (γ phase) and
- Unreacted Ag-Cu (E)

Matrix
- γ1 (Ag_2Hg_3)

Cu_6Sn_5 *(n)* is present in the γ1 matrix rather than as a halo surrounding Ag-Cu.

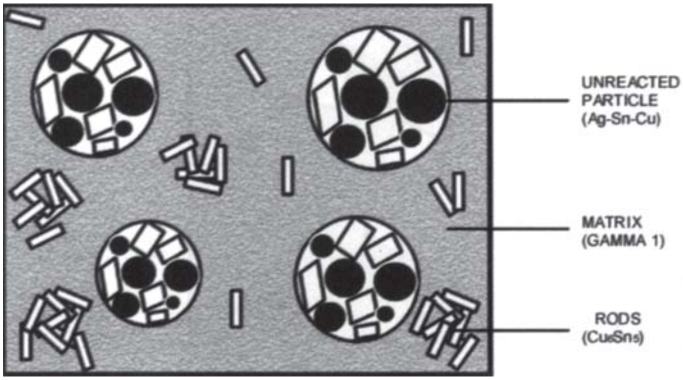


FIGURE 10.5: Schematic representation of the microstructure of high copper single composition amalgam. The *n* (Cu_6Sn_5) lie in clusters within the matrix rather than as a halo

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 decrease may be due to the *corrosion products* that forms in the tooth-restoration interface. These products over a period of time *seal the interface* and thereby prevent 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.

Dimensional Change

Amalgam may expand or contract, depending on its manipulation. Ideally, dimensional change should be small. Excessive contraction can lead to microleakage and secondary caries. Excessive expansion can produce pressure on the pulp and *postoperative sensitivity*. *Protrusion* of the restoration can also occur.

Measurement of Dimensional Change

ADA Sp.no. 1 requires that amalgam should not expand or contract more than 20 um/cm at 37°C, between 5 minutes and 24 hours from the beginning of trituration.

Theory of Dimensional Change-Contraction

When the alloy and mercury are mixed contraction results as the particles dissolve and the γ1 grows. The final volume of γ1 is less than the initial volumes of silver and mercury that go into making the γ1. Therefore, contraction will continue as long as growth of γ1 continue.

Expansion Theory

The γ1 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 γ1 crystals impinge.

After a rigid γ1 matrix has formed, growth of γ1 crystals cannot force the matrix to expand. Instead γ1 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 particle size (accelerates mercury consumption because of its larger surface area)
- Longer trituration times (accelerates setting).

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

— Older amalgmas 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 greater than 400 um (4%). This is known as *delayed expansion* or *secondary expansion:*

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

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 tend 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

Hardened amalgams have good compressive strength.

Compressive strength	*1 Hour*	*7 Days*
Low copper	145 MPa	343 MPa
Admixed	137 MPa	431 MPa
Single composition	262 MPa	510 MPa

Tensile Strength

Unfortunately, amalgam cannot withstand high tensile or bending stresses. Therefore, the *cavity design* should be such that the restoration will receive compression forces and *minimize tension* or shear forces in service. The tensile strength is 48 to 70 MPa.

Factors Affecting Strength

Effect of Trituration

Either under-trituration or over-trituration 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. Otherwise a *dry, granular mix* results which has rough and pitted surface that invites *corrosion*.

Excess mercury in the mix can produce a marked reduction in strength. The reason: High mercury amalgams have more 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 condensor 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 at the margins and decreases the number of voids. Fortunately, voids are not a problem with spherical alloys.

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.

The ADA 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.

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.

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).

The Significance of Creep to Amalgam Performance

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

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

Creep Values

Low-copper amalgam — 0.8 to 8.0%
High-copper amalgam— 0.4 to 0.1%

Factors Affecting Creep

Microstructure The $\gamma 1$ (Ag-Hg) phase has a big effect on low-copper amalgam creep rates. Increased creep rate is shown by larger $\gamma 1$ volume fractions. Decreased creep rate is shown by larger $\gamma 1$ grain sizes. The $\gamma 2$ phase is associated with higher creep rates.

Single-composition high-copper amalgams have very low creep rates, due to absence of $\gamma 2$ phase and due to the presence of *n* Cu_6Sn_5 rods, which acts as barrier to deformation of the $\gamma 1$ phase. An increase in zinc content gives less 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. Rather 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.

Tarnish and Corrosion

Amalgam restorations often tarnish, and corrode in the mouth.

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 γ2 content) than high copper. Also *n* (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. So, 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 most amalgam restorations is highly dependent on the correct selection, manipulation of the alloy and cavity design. If a restoration is defective, it is usually the fault of the operator and, not the material (Fig. 10.6).

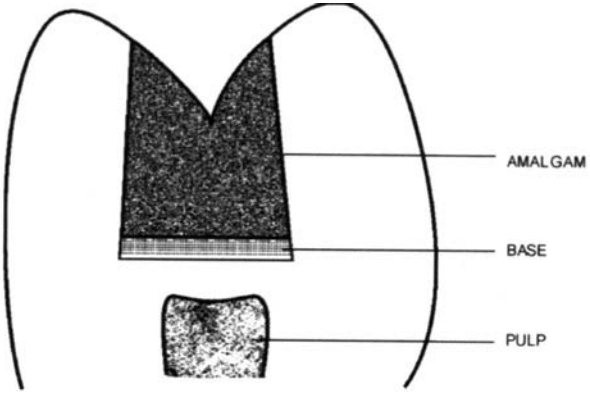


FIGURE 10.6: An amalgam restoration. The cavity design should be designed for mechanical retention (cavity walls diverge as it approaches the pulp creating an undercut design). The base is placed to protect the pulp from thermal shock

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. This is achieved by creating a cavity that converges towards the outer surface. 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 can compensate for the missing walls. Failure to have a four wall support can result in inadequate condensation which can weaken the amalgam.

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 clinically difficult to control moisture.
- Indium containing alloys: Indium performs the same functions as zinc and in addition, it decreases the $\gamma 2$ 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 : 356.90°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. 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 amount of mercury.

Pre-Proportioned Capsules

Pre-proportioned capsules containing alloy particles and mercury in compartments separated by a membrane. Before use, the membrane is ruptured by compressing the capsule, and the capsule is then placed in a mechanical amalgamator.

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)

In earlier days, when amalgam was triturated manually excess mercury had to be used in order to achieve smooth and plastic amalgam mixes.
This excess mercury was removed from the amalgam by:

- Squeezing the excess mercury out by using a *squeeze cloth.*
- *Increasing dryness technique:* During condensation of each increment, a mercury rich soft layer comes to the surface. This is removed during carving.

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.

- Hg/Alloy ratio for high copper—1:1
- Hg/Alloy ratio for low copper—40:60 percent.

Note: 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

Objective—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:
- Hand mixing
- Mechanical mixing

Hand Mixing

A glass mortar and pestle are used. 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.

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. 10.2).

- The disposable capsule serves as a mortar. A cylindrical metal or plastic piston is placed in the capsule which serves as the pestle (Fig. 10.7). The capsule is inserted between the arms on top of the machines. When put on, the arms holding the capsule oscillate at high speed, thus triturating the amalgam. Newer amalgamators have hoods that cover the arms holding the capsule in order to confine mercury spray and prevent accidents.

FIGURE 10.7: Capsule and pestle—2 varieties

- Reusable capsules are available with friction fit or screwtype lids. 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 will spray out from the capsule, and the inhalation of fine mist of mercury droplets is a health hazard.

The amalgamators have automatic timer and speed control device. The speed used is recommended by the manufacturer. High copper alloys require higher mixing speeds.

Mixing time There is no exact recommendations for mixing time, since amalgamators differ in 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.

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

- Is rough and grainy and may crumble
- 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
- May be warm (not hot) when removed from the capsule
- It has the best compressive and tensile strength
- 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.
- Working time is decreased.
- Results in higher contraction of the amalgam.
- Strength of lathe-cut alloys is increased, 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 homogenity 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.

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.

This increases the strength and decreases the creep of the amalgam. Condensation *must always* be accomplished within the *four walls and floor*. If one or more walls of the cavity are missing a stainless steel matrix may be used to compensate for it.

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.

Manual Condensation

The mixed material is packed in *increments*. Each increment is carried to, the prepared cavity by means of a small forcep 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 little by little 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 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 force. When condensing these alloys, a *large* condenser can often be used.

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. Heat generation should be avoided during burnishing. If the temperature rises *above 60°C,* mercury is released which may cause corrosion and fracture at margins. Final smoothing can be done by rubbing the surface with a moist cotting pellet.

Polishing

Polishing minimizes corrosion and prevents adherence of plaque. The polishing should be delayed for at least *24 hours* after condensation, or preferrably 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.

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 *vapours* 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 *programme for handling toxic materials*, is monitored for actual exposure levels.

COMPARISON

Lathe-cut alloys	*Spherical alloys*
• Particles are irregular	• Particles are spherical.
• Manufactured by milling an annealed ingot of alloy	• Manufactured by atomization of molten alloy
• Less plastic and resists condensation pressure	• More plastic, hence a contoured and wedged matrix is essential to establish proximal contour
• More mercury required hence has inferior properties	• Requires less mercury hence has better properties

Admixed high-copper amalgam	*Spherical high-copper amalgam*
Advantages 1. Longer working time 2. Less dimensional change 3. Displacement of matrix	*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. Slower set 2. High residual mercury 3. Higher creep 4. Less early strength 5. Harder to finish	*Disadvantages* 1. Less working time 2. Greater dimensional change 3. Failure to displace matrix during condensation (while restoring proximal cavities)

ADVANTAGES AND DISADVANTAGES OF DENTAL 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 non-scientific 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 a 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*.

CHAPTER 11

Direct Filling Gold

Pure gold can be used as a restorative material. It is the most noble of metals and rarely tarnishes in the oral cavity. Prior to the discovery of amalgam, gold was very popular as a filling material. Gold in its pure form is very soft (Brinell hardness-25). Its malleability and lack of surface oxide layer permit increments to be welded in the oral cavity. 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 (DFG's) 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).

APPLICATIONS

1. Pits and small class I restorations
2. For repair of casting margins
3. For Class II and Class V restorations
4. Repair of cement vent holes in gold crowns.

CLASSIFICATION

Foil

- Sheet
  - Cohesive
  - Non-cohesive
- Ropes
- Cylinders
- Laminated
- Platinized.

Electrolytic Precipitate (mat gold)

- Mat
- Mat foil
- Alloyed.

Powder

GOLD FOIL

It is the oldest of all products described.

Manufacture

Gold is malleable. A cast ingot of 15 mm thickness is beaten to a submicroscopic thickness of 15 or 25 um. The product is called gold foil. The crystals of the original cast metal are deformed and elongated so that they have a fibrous structure.

Supplied As

- Flat square sheets of varying thickness.
  - No. 4 wt. 4 grains (0.259 gram) 0.51 um thick.
  - No. 3 wt. 3 grains (0.194 gram) 0.38 um thick.
    (No. 3 foil is used to manufacture electrolytic and powder gold).
- These sheets may be cut into eighths, sixteenths, sixty-fourths, etc. and then compressd into pellets or cylinders.
- A number of sheets of foil may be placed one top of each other to form laminated gold foil. One of the types of laminated foil is *platinized foil*, which is a sheet of pure platinum foil sandwiched between two sheets of pure gold foil.
- The foils can also be made into preformed cylinders and ropes.

Preformed Foils

Nowadays ropes and cylinders are available in preformed shapes. 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 air-tight safe. After the carbon is removed it is found that the gold exhibits *superior welding property.*

Platinized Foil

This might be considered a laminated foil in which pure platinum foil is sandwiched between two sheets of pure gold foil. The layers of platinum and gold are bonded together by a "cladding" process during the rolling operation. Thus, the "sandwich" is already welded together before the beating begins. 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 Non-Cohesive Gold

In practice, only the sheet foil is furnished in both conditions, though all forms of direct filling gold could be supplied in cohesive, semi-cohesive and non-cohesive.

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.

Non-Cohesive

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 prevent adsorption of non-volatile gases and premature cohesion of pellets in their container. Ammonia-treated foil is called non-cohesive foil. Non-cohesive 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*, thereby restoring the cohesive character of the foil. Non-cohesive gold is rarely used nowadays, but may be used to buildup the bulk of a direct gold restoration.

ELECTROLYTIC PRECIPITATE

Crystalline gold powder is formed by electrolytic precipitation. The powder is formed into shapes or strips by sintering (heat fusion).

Available As

Mat, mat foil and alloyed.

Mat Gold

Mat gold is crystalline, electrolytically precipitated gold, formed into strips. These strips are cut by the dentist into the desired size. Mat gold is preferred because it is easy to buildup the internal bulk of the restoration, as it can be more easily compacted and adapted to the cavity. However, mat gold results in a pitted external surface. Therefore, the mat gold is usually covered with a veneer of foil gold.

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

The newest form of electrolytic gold is an alloy of gold and *calcium* (0.1 to 0.5% 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.

POWDER GOLD

Since the middle of the 19th century, chemically precipitated gold powders have been available in agglomerated form with a liquid such as a alcohol or dilute carbolic acid, which held the agglomerate together. The agglomerates usually disintegrated when compaction was attempted, so the gold powder was *enclosed in a No. 3 gold foil*.

Manufacture

A fine powder is formed by *chemical precipitation* or by *atomizing* the metal. The particle sizes vary (maximum –74 um, average 15 um). The pellets are mixed with soft wax, (which is burnt off later), 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 are comparable sized pellet of gold foil.

MANIPULATION OF DIRECT FILLING GOLD

There are two processes involved:

- Degassing
- Compaction

DESORBING OR DEGASSING

The direct filling golds are received by the dentist in cohesive condition, except for the non-cohesive 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:*

- Pellets may stick together, if the tray is moved
- Air currents may affect the uniformity of heating
- Difficult to anneal appropriate amounts of gold
- Over sintering
- Greater exposure to contamination
- Size selection among the pieces of desorbed gold is limited.

Flame Desorption

Each piece is picked individually, heated directly in the open flame, and placed in the prepared cavity. The fuel for the flame may be 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:

– Ability to select a piece of gold of the desired size
– Desorption of only those pieces used
– Less exposure to contamination between time of degassing and use
– Less danger of oversintering.

Under-heating does not adequately remove impurities and results in incomplete cohesion. Carbon deposited by the flame can cause pitting and flaking of the surface.

Over-heating 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. 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, excerting 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 nowadays) 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.

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. In direct filling gold, the failure occurs from tensile stress, due to *incomplete cohesion*. Thus, transverse strength is a measure of cohesion.

Hardness

Indicates the overall quality of compacted gold. Hardness probably indicates the presence of porosity.

Density

True density of pure gold is 19.3 gm/cm^3. However, in DFG's this is not achieved, because it is not possible to eliminate voids completely during compaction. Thus, density of DFG's is usually less than ideal.

Table Showing Physical Properties of Compacted Gold

Type	*Transverse*	*Hardness*	*Density*
Mat gold	161-169 Mpa	52-60 KHW	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

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. In smaller teeth this is an important consideration. The mechanical condenser causes less trauma than the manual technique.

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.

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.

CHAPTER 12

Restorations, Luting and Pulp Therapy—An Introduction

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. 12.1).

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

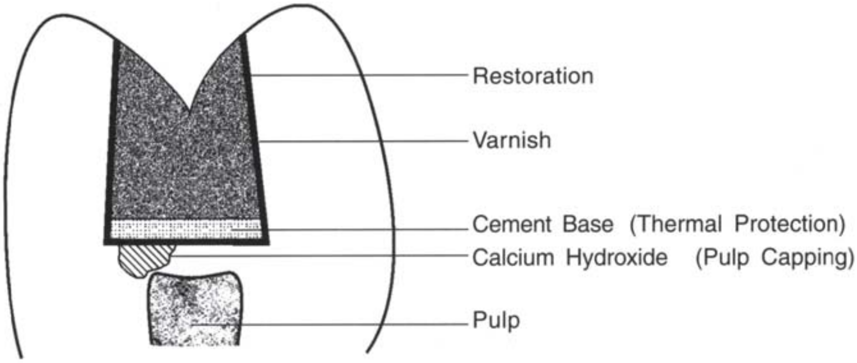


FIGURE 12.1: Restoration of a tooth with a deep carious lesion

Temporary Restorations

Temporary restorations are often required before the placement of a permanent restorations. 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 may serve as a treatment while the pulp heals; and/or till the permanent restoration 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.

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 ‘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 will 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. They can last for a period of *one year or more*. 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. Thus, 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. It can serve for one year.

Requirements of a Temporary Filling Material

1. Should have adequate strength to last a few weeks, but weak enough to be dislodged easily.
2. Should be easy to insert and remove.
3. Should have adequate seal.
4. Should have antibacterial properties.

5. Should have a beneficial effect (pain relief, healing, etc.) on the pulp.
6. 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. 12.1), composite resins, glass ionomer cement, silicate cement (probably no longer used), as well as porcelain, composite and cast metal inlays and onlays.

The length of time each material lasts varies. 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 inlays and onlays.

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

Cementation is the process by which crowns, restorations and other devices are fixed or attached to tooth structure using an intermediate material called cement. The same cement can be used for more than one purpose, which unfortunately, can be quite confusing to the student.

Types

1. Temporary cementation
2. Permanent cementation

Temporary Cementation

Temporary cementation of crowns and bridges are often required. Temporary bridges 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 bridges) are also sometimes cemented temporarily. This may be to allow the patient to take it for a home trial. Once the patient feels the permanent structure is satisfactory, it is removed and cemented permanently. An example of such a temporary bonding cement is a zinc oxide eugenol based cement called 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 crown or bridge.

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

PULP CAPPING

Pulp capping is a 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, and exposure of the pulp would quite likely lead to irreversible pulpitis or pulpal infection and ultimately death of the pulp. Thanks to these pulp capping agents, it became possible to save such exposed pulpal tissue or nearly exposed, which otherwise would have had to undergo root canal therapy. Example of a pulp capping agent is *calcium hydroxide* cement.

Criteria for Pulp Capping

The question now is 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 (Fig. 12.2). 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 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 through the remaining thin dentinal wall. This is known as *indirect pulp capping* (Fig. 12.1).

Indications

1. Deep carious lesions close to the pulp
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.

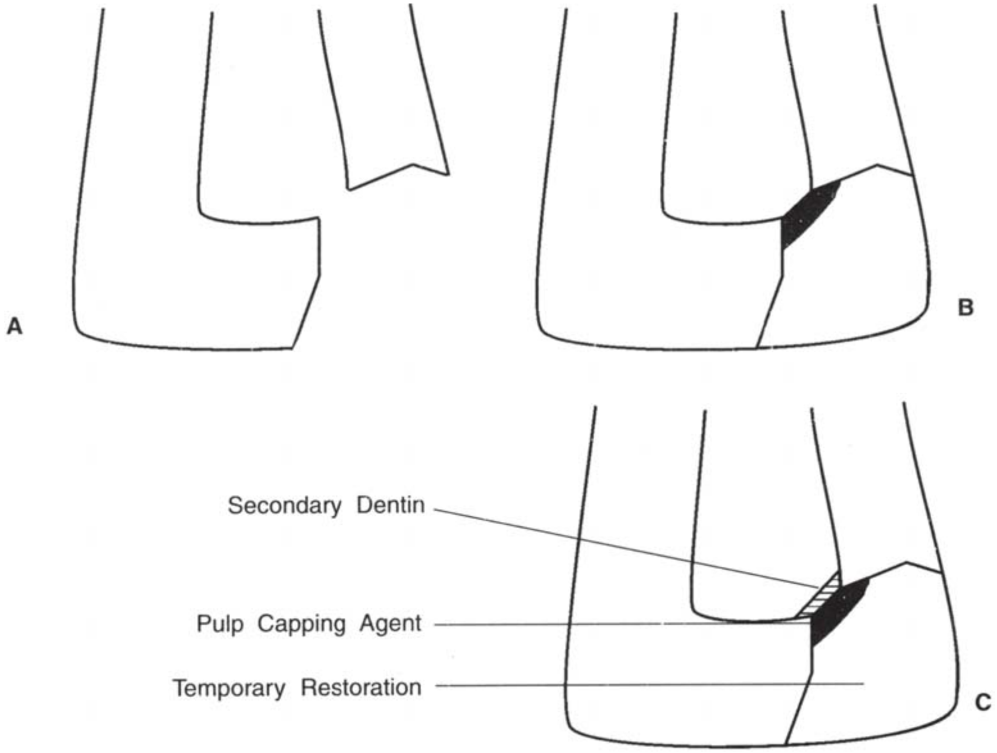


FIGURE 12.2: Direct pulp capping: A—Fractured tooth; B—Pulp capping was done immediately and the tooth temporarily restored; C—Secondary dentin is deposited and is visible three months later on the radiograph

BASES

CEMENT BASE

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 asbestors.

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 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 (Fig. 12.1). This film acts as a barrier which has different functions depending on the circumstance and the location where it is applied (see chapter 14).

CHAPTER 13

Dental Cements

Dental cements are materials of comparatively low strength, but they are used extensively in dentistry. With the exception of two, they are not truly adhesive to enamel or dentine. Except the resin cements, they dissolve and erode in oral fluids. Such defects make them impermanent.

Regardless of some inferior properties, they possess so many desirable characteristics that they are used in 40 to 60 percent of all restorations.

CLASSIFICATION

According to Craig

Functions	*Cements*
Final cementation of completed restorations	Zinc phosphate, Zinc silicophosphate, Reinforced zinc oxide-eugenol, Zinc polycarboxylate, Glass ionomer
Temporary cementation of completed restorations or cementation of temporary restorations	Zinc oxide-eugenol, Non-eugenol zinc oxide
High-strength bases	Zinc phosphate, Reinforced zinc oxide-eugenol, Zinc polycarboxylate, Glass ionomer
Temporary fillings	Zinc oxide-eugenol, Reinforced zinc oxide-eugenol, Zinc polycarboxylate
Low-strength bases	Zinc oxide-eugenol, Calcium hydroxide
Liners	Calcium hydroxide in a suspension
Varnishes	Resin in a solvent

Special Applications

Functions	*Cements*
Root canal sealer	Zinc oxide-eugenol, Zinc polycarboxylate.
Gingival tissue pack	Zinc oxide-eugenol
Surgical dressing	Zinc oxide-eugenol, Zinc oxide preparation
Cementation of orthodontic bands	Zinc phosphate, Zinc polycarboxylate
Orthodontic bonding	Acrylic resin, Composite resin

Phillips Classification

Cement	*Principal uses*	*Secondary uses*
Zinc phosphate	Luting agent for restorations and orthodontic bands	Intermediate restorations Thermal insulating bases Root canal restorations.
Zinc phosphate with silver or copper salts	Intermediate restorations	
Copper phosphate (red or black)	Temporary and intermediate restorations	
Zinc oxide restorations eugenol	Temporary and intermediate restorations Luting agent, thermal insulating base. Pulp capping agent	Root canal restorations Periodontic bandage
Polycarboxylate	Luting agent. Thermal insulating base	Luting agent for orthodontic bands. Intermediate restorations
Silicate	Anterior fillings	
Silicophosphate	Luting agent for restorations	Intermediate restorations Luting agent for orthodontic appliances
Glass ionomer	Coating for eroded areas. Luting agent for restorations	Pit and fissure sealant Anterior restorations Thermal insulating bases
Resin	Luting agent	Temporary restorations.
Calcium hydroxide	Pulp capping agent Thermal base	

According to Coombe

The materials may be classified as follows:

- Acid-base reaction cements.
- Polymerizing materials:
  - Cyanoacrylates
  - Dimethacrylate polymers
  - Polymer-ceramic composites.
- Other materials:
  - Calcium hydroxide
  - Gutta-percha
  - Varnishes.

Acid base reaction cements Most dental cements belong to this category. They are formulated as powder/liquid; 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.

ADA Specification has Further Classified Cements As

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

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 of the powder and liquid.

REQUIREMENTS

1. Should be non-toxic, and non-irritant to pulp and tissues.
2. 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 minimise galvanic effects.
5. Optical properties, for cementation of a translucent restoration, e.g. porcelain crown) the optical properties of the cement should simulate those of tooth substance.

6. Cement should ideally be adhesive to enamel and dentine, and to gold alloys, porcelain and acrylics, but not to dental instruments.
7. Should be bacteriostatic in a cavity with residual caries.
8. 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.

SILICATE CEMENTS

Silicate cements were introduced in 1903 as anterior esthetic filling materials. They are translucent and resemble porcelain in appearance. Silicates are attacked by oral fluids and in time degrade. 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.

Silicates are *rarely used* nowadays. This is due to development of better materials like composite resin and glass ionomer cements. However, silicate cements are being discussed because the glass ionomer system is based to a certain extent, on them.

MODE OF SUPPLY

As powder and liquid in bottles (Fig. 13.1).

FIGURE 13.1: Silicate cements

Commercial Names

Biotrey, Silicap, Achatit.

APPLICATIONS

1. Esthetic restoration of anterior teeth
2. Intermediate restoration in caries active mouths.

COMPOSITION

Powder

- Silica (SiO_2) – 40%
- Alumina (AI_2O_3) – 30%
- Sodium flouride (NaF)
- Cryolite (Na_3AIF_6) – 19%
- Calcium flouride (CaF_2)
- Calcium phosphate $[Ca\ (H_2PO_4)_2H_2O]$ or Lime (CaO)

Liquid

- Phosphoric acid – 52%
- Aluminum phosphate – 2%
- Zinc phosphate – 6%

or

Magnesium phosphate

Water – 40%

MANUFACTURE

The powder ingredients are fused (sintering) at approximately 1400°C to form an acid soluble glass. The flouride salts melt at a lower temperature and dissolve the other ingredients. They are known as 'Ceramic Fluxes'. Aluminium phosphate may also be used as a flux. It also furnishes additional aluminium to the glass.

After sintering the material is cooled quickly. This causes the glass to crack which helps in grinding of the material to a fine powder. This process is known as *fritting.*

SETTING REACTION

When the powder and liquid are mixed together, the chemical reaction is that of an acid and a base. Water is essential for the reaction.

The hydrogen ions of phosphoric acid attack the surface of the glass particle displacing aluminium ions and other Na and Ca ions along with flouride ions. A gel (hydrated aluminosilicate) is formed on the surface of the powder as the ions are liberated.

The displaced ions collect in a semiliquid phase, together with phosphate and other ions contained in the liquid. As the pH of the liquid phase rises, the metal ions precipitate as phosphates and flourides.

Structure of the Set Cement

It has a cored structure consisting of:

- A core of unreacted glass particles.
- Hydrated alumino silicate gel which covers the surface of the glass particle.
- An amorphous matrix of hydrated aluminium phosphate gel, which contains some crystals of $AI_2\ (OH_3)PO_4$.

Setting Time

3 to 6 minutes.

Factors Affecting Setting Time

- Manufacturer—controls composition and particle size of the material. The finer the particles, the faster the setting.
- In addition, the following factors give slower setting:
  - Longer mixing time
  - Lower temperature
  - Loss of water from the liquid (by evaporation)
  - Lower powder/liquid ratio.

PROPERTIES

As per ADA specification No. 9

Mechanical Properties

Compressive strength: (180 MPa) Silicate is the strongest of all the dental cements. The strength is affected by the powder/ liquid ratio and the water content of the liquid.

Tensile strength: (3.5 MPa) It is weak in tension.

Hardness: (70 KHN) It is similar to dentin.

Thermal Properties

The CTE is lower than any other restorative material. It is close to that of enamel and dentine.

Biological Properties

Classed as a *severe irritant* to the pulp. At the time of insertion it has a pH of 2.0 and even after one month, it remains below 7. Silicate serves as a standard for comparing the pulpal response to other material.

Pulp Protection

In deep cavities the pulp is protected with a layer of ZOE (followed by zinc phosphate cement lining as the unreacted eugenol discolors the silicate cement), calcium hydroxide or by coating the walls with varnish.

Solubility and Disintegration

Silicate restorations dissolve and disintegrate in oral fluids. The mechanism is as follows:

- Some of the constituents of the matrix dissolve
- Particles of unreacted silicate powder are washed away.

The rate of solubility of silicate cement is 0.7% in the first 24 to 48 hours, but after that it decreases. They are attacked by organic acids, like acetic, lactic and especially by citric acid.

The solubility of silicate cement is affected by:

- The lower the powder/ liquid ratio, higher the solubility
- Water content of the liquid
- Greater solubility at lower pH values.

Anticariogenic Properties

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% flouride. Flouride release is *slow* and occurs throughout the *life* of the restoration.

- It makes the adjacent tooth structure more resistant to acid decalcification.
- It acts as an antibacterial agent. It acts as an enzyme inhibitor and thus prevents the metabolism of carbohydrates.

Esthetics

The initial esthetics is *excellent*. The refractive index is similar to that of enamel and dentine. However, over a period of time, silicates may become *stained*, especially when the surface gets roughened due to abrasion and erosion. The surface of silicate is difficult to polish satisfactorily.

If the restoration is allowed to dry, the surface becomes *powdery* and *opaque*. Thus, it is *contraindicated in mouth breathers*. Sometimes a gap may appear between the restoration and cavity margin due to dissolution. This may stain and appear like a *black line*.

Adhesion

The bond to tooth structure is mechanical in nature.

Dimensional Change

A slight contraction occurs while setting.

MANIPULATION

The liquid is dispensed just prior to mixing (otherwise the water can evaporate and change the acid-water balance).

Powder/Liquid Ratio

1.6 gm/4 ml.

Spatula used Agate, plastic or cobalt-chromium spatula. Steel spatulas are contraindicated, as they may get abraded by the silicate powder leading to discoloration of the mix.

Mixing Time

One minute.

Procedure

The powder is dispensed on a thick, cool, dry slab and divided into two or three large increments. The increments are then rapidly folded into the liquid over a small area (folding preserves the gel structure). The mixed material should have a consistency like putty and have a shiny appearance.

- Too thick a mix produces a crumbly mass
- Too much of liquid increases setting time and solubility, reduces pH and strength and makes it more prone to staining.

Insertion

A *dry field* is required during insertion. Exposure of the cement to oral fluids prior to formation of the final reaction products results in higher solubility and a poor surface.

The mixed material should be inserted into the cavity in one portion (if small increments are used complete bonding between the portions will not occur and the set material will be weaker). A *cellulose acetate strip* is held against the setting material in the cavity. After the material sets the strip is removed and the excess cement is removed from *the margins.* The restoration is then painted with a water insoluble *varnish* to protect it from contact with oral fluids for the first 24 hours.

Finishing and Polishing

The final finishing should be delayed for several days. Early finish could disturb or fracture the margin.

Care of Restoration

Silicate cements are subject to dehydration throughout their life time. Therefore, during future operative procedures, they should be *protected* from exposure to *air* by a coat of varnish or silicone grease.

Mechanical Mixing

Mechanical mixing is done in a capsule containing preproportioned powder and liquid in separate sections. Prior to mixing the seal is broken by applying pressure to the capsule.

Advantages

1. Less chance of contamination
2. Correct powder/liquid ratio
3. Rapid mixing in 10-15 seconds.

ZINC PHOSPHATE CEMENT

Zinc phosphate is the oldest of the luting cements, and thus it 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 (cementation)
2. High strength bases
3. Temporary restorations
4. Luting of orthodontic bands and brackets.

CLASSIFICATION

ADA Sp. No. 3 designates them as:

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

Available As

- Powder and liquid system (Figs 13.1 and 13.2).
- Capsules of preproportioned powder and liquid.
  Available in shades of yellow, grey, golden brown, pink and white.

Commercial Names

- Confit
- Harvard
- Zinc cement improved
- Modern Tenacin.

FIGURE 13.2: Zinc phosphate is among the oldest of cements in dentistry. It has been quite successful when used properly and has been known to last for years. Its high acidity does not cause serious problems except when it is extremely close to the pulp

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
- Aluminium phosphate or sometimes zinc phosphate – 16.2% –Buffers, to reduce rate of reaction
- Aluminium – 2.5%
- Zinc – 7.1%.

MANUFACTURE

The ingredients are mixed and heated at temperatures between 1000°C and 1400°C (sintering). The cake formed is then ground into a fine powder (fritting).

The liquid is produced by adding aluminium 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, dissolving zinc oxide forming acid zinc phosphate.

The *aluminium* in the liquid is essential for cement formation. The aluminium complexes with the phoshoric acid to form a *zinc aluminophosphate gel* (without aluminium, a non-cohesive, crystalline structure matrix of hopeite, i.e. $Zn_3(PO_4)_2.4H_2O$, would be formed). 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 cohesive matrix of zinc alumino phosphate.

Setting Time

5 to 9 minutes.

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
- 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

Zinc phosphate cement is stronger (103.5 MPa) than zinc oxide-eugenol cement but not as strong as silicophosphate.

The set cement gains 75% of its maximum strength in the first hour. Maximum strength is attained in the first day.

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.

Factors affecting strength are:

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

Tensile Strength

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

Modulus of Elasticity

It is comparatively high (13.5 Gpa). This makes it stiff and resistant to elastic deformation.This is necessary when it is employed as a luting agent for 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, attacks by-products from decaying food). The solubility is greater in dilute organic acids like lactic, acetic and especially citric acids (Figs 13.3 and 13.4).

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

According to ADA specification No. 8.

- For Type I - Film thickness not more than 25 um
- For Type II - Film thickness not more than 40 um

A thinner film is more advantageous for luting:

- It has a better cementing action

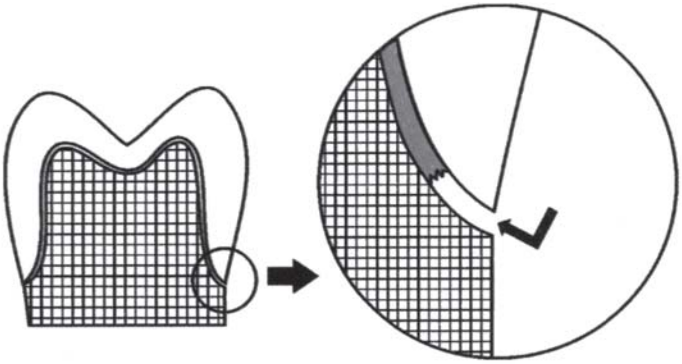


FIGURE 13.3: One cannot rely entirely on the cement for sealing an open margin. Most cements slowly dissolve and disintegrate in the oral cavity leading to microleakage and subsequent failure. A good marginal fit of the crown is therefore essential

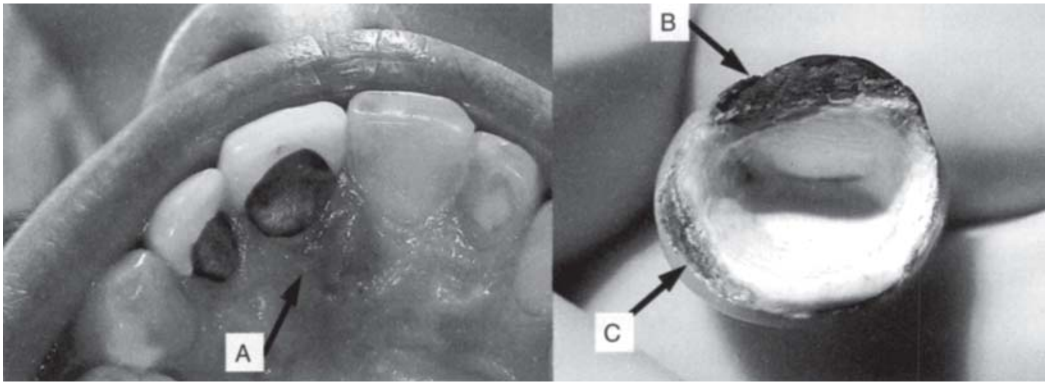


FIGURE 13.4: Cement dissolution resulted in leakage in this crown. A—Area of inflammation is seen in relation to the leaking margin as shown by the arrow. On removing the crown the area of cement dissolution is clearly visible—B and C

- It helps in more complete seating of the casting
- It minimizes the air spaces and structural defects present in the bulk of the cement.

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 retention of a cemented restoration is by mechanical interlocking of the set cement with surface roughness of the cavity and restoration.

Biological Properties

Pulp response-moderate. The acidity is high at the time of insertion due to phosphoric acid. Three minutes after mixing, the pH is 3.5. It approaches neutrality in 24 to 48 hours. Very thin mixes should be avoided as they are more acidic.

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

Pulp protection In deep cavities pulpal reaction can be minimized with a lining of:

- Zinc oxide-eugenol
- Calcium hydroxide
- Cavity varnish.

Optical Properties

The set cement is opaque.

MANIPULATION

Spatula used Stainless steel.

Mixing time 1 min. 15 seconds.

Powder-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. 13.5). 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.

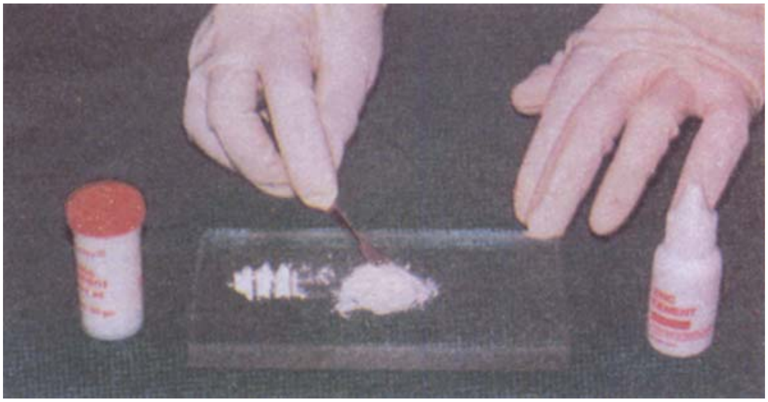


FIGURE 13.5: Zinc phosphate cement is mixed on a cool glass slab covering a large area in order to dissipate the exothermic heat

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.

ZINC OXIDE-EUGENOL CEMENT

These cements have been used extensively in dentistry since the 1890's. Depending on their use they vary widely in their properties. In general, they are cements of low strength. Also 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.

Recently non-eugenol zinc oxide cements have become available. They are suitable for patients sensitive to eugenol. Experimental vanillate and syringe cements without eugenol are presently under investigation.

CLASSIFICATION: (ADA SP. NO. 30:) 4 TYPES

Type I ZOE – For temporary cementation (Fig. 13.6)
Type II ZOE – Permanent cementation
Type III ZOE – Temporary filling and thermal insulation
Type IV ZOE – Cavity liners

AVAILABLE AS

- Powder and liquid (Fig. 13.7)
- Two paste system (Fig. 13.6)

FIGURE 13.6: Temp Bond is a zinc oxide and eugenol paste used for temporary cementation of crowns and bridges

A

B

FIGURE 13.7: (Left to right) unmodified zinc oxide eugenol; Kalginol and IRM are reinforced zinc oxide eugenol cements

Commercial Names

Unmodified

Tempac – Type III
Cavitic – Type IV
Tempbond – Type I (Fig. 13.6)

EBA alumina modified

Opotow
Alumina EBA – Type II

Polymer modified

Fynal – Type II
IRM – Type III (Fig. 13.7)

Non-eugenol

Nogenol – Type I
Freegenol – Type I

COMPOSITION

Powder

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

Eugenol — 85.0	Reacts with zinc oxide
Olive oil — 15.0	Plasticizer.

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 to its hydroxide 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.

$$\begin{array}{llll} Zn(OH)_2 \; + & 2HE & \longrightarrow & ZnE_2 + 2H_2O \\ \text{Base} & \text{Acid} & & \text{Salt} \\ \text{(Zinc hydroxide)} & \text{(Eugenol)} & & \text{(Zinc eugenolate)} \end{array}$$

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.

Setting Time

4-10 minutes.

Factors Affecting Setting Time

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

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

PROPERTIES

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 cavity lining (Type IV), will have a lower strength. Cements intended for permanent cementation (Type II) and intermediate restorations will be stronger. The compressive strength therefore ranges from a low of 3 to 4 MPa upto 50-55 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.

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

Solubility and Disintegration

The solubility of the set cement is highest among the cements (0.4% 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 used for luting of restorations. The film thickness of zinc oxide-eugenol cements (25 um) is 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 bridges. 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. Smaller increments are then added until the mix is complete.

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 quickly in the mouth due to moisture and heat.

MODIFIED ZINC OXIDE-EUGENOL CEMENTS

These were introduced to improve the mechanical properties of zinc oxide-eugenol cement. The modified ZOE cements are:

- EBA-Alumina modified cements
- Polymer reinforced.

EBA-ALUMINA MODIFIED CEMENTS

Composition

Powder

Zinc oxide—70%
Alumina—30%.

Liquid

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

Properties

Its properties are better than that of unmodified ZOE.

- Compressive strength is higher 55 MPa (8000 psi)
- Tensile strength 4.1 MPa (600 psi)
- Modulus of elasticity 2.5 GPa (0.36 psi × 106)
- Film thickness—25 um
- Solubility and disintegration in water—0.05% wt.

Manipulation

Glass slab are recommended for EBA-alumina modified cements. After dispensing, the powder is incorporated into the liquid in bulk and 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

Uses

1. Luting agent
2. As base
3. As temporary filling material and
4. As cavity liner.

Commercial Names

- IRM (Fig. 13.7)
- Kalzinol

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.

Setting Time

6 to 10 minutes.

Factors Affecting Setting Time

- Low powder-liquid ratio increases setting time
- Moisture: accelerates setting time.

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 um
- Solubility and disintegration : 0.03% wt.
- Pulp response : Similar to unmodified ZOE—moderate
- 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.

Working time These cements have a long working time.

SPECIAL ZINC OXIDE-EUGENOL PRODUCTS

Some zinc oxide-eugenol materials contain antibiotics such as tetracyclines, and steroids as anti-inflammatory agents. Their principal use is in pulp capping and root canal therapy. One product also contains barium sulphate, which is radiopaque.

ZINC OXIDE/ ZINC SULPHATE TEMPORARY RESTORATIONS

These are single component temporary filling materials.

Supplied As

It is a single component putty like paste in small tubes, syringes or plastic containers (Fig. 13.8).

FIGURE 13.8: Single component zinc oxide based restorative materials. They set slowly in the mouth through contact with moisture

Commercial Names

Cavit (ESPE), Caviton (GC), Coltosol (Coltene)

Use

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

Composition

Zinc oxide
Zinc sulphate-1-hydrate
Calcium sulphate-hemihydrate

Dibutyl phthalate (plasticizer)
Diatomaceous earth

Setting Reaction

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

Setting Time

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

Properties

It may be white or pink colored. It has good initial sealing. Since it expands on setting, 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.

GLASS IONOMER CEMENTS

Glass ionomer cements are adhesive tooth colored anticariogenic restorative materials which were originally used for restorations of eroded areas. Now, it has been modified to allow its use in other areas. These cements have the combined properties of silicate cements and poly carboxylate cements.

Unlike other restorative materials, this cement requires minimal cavity preparation as it bonds adhesively to tooth structure. It was named glass ionomer because, the powder is glass and the setting reaction and adhesive bonding to tooth structure is due to ionic bond.

Synonyms

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

APPLICATION

1. Anterior esthetic restorative material for class III cavities (Fig. 13.9)
2. For eroded areas and class V restorations
3. As a luting agent (Fig. 13.9)
4. As liners and bases
5. For core build up.
6. To a limited extent as pit and fissure sealants.

Not recommended for class II and class V restorations, since they lack fracture toughness and are susceptible to wear.

FIGURE 13.9: Commercially available glass ionomer cements are usually supplied for a specific use (from left to right) are shown two luting cements, a restorative cement and a root canal cement

CLASSIFICATION

Type I — For luting

Type II — For restorations

Type III — Liners and bases.

(Some authors include Type IV—fissure sealants, Type V—orthodontic cements and Type VI—core build up as part of the classification).

Commercial Names

- Aquacem, Fugi I — Type I
- Chem Fil — Type II
- Ketac bond — Type III
- Vitra bond — Light cure GIC (Fig. 13.9)

AVAILABLE AS

- Powder/liquid in bottles
- Pre-proportioned powder/liquid in capsules
- Light cure system
- Powder/distilled water (water settable type).

COMPOSITION

Powder

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

Silica $(SiO)_2$	–	41.9
Alumina (Al_2O_3)	–	28.6
Aluminium flouride (AlF_3)	–	1.6
Calcium flouride (CaF_2)	–	15.7
Sodium flouride (NaF)	–	9.3
Aluminium phosphate $(AlPO_4)$	–	3.8

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

Liquid

Earlier the liquid was a 50% aqueous solution of polyacrylic acid. It was very viscous and had a tendency to gel.

In most current cements, the liquid contains:

- Polyacrylic acid—in the form of copolymer with iticonic acid, maleic acid and tricarballylic acid
- Tartaric acid
- Water.

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 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.

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.

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 for powder and liquid. 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 20 to 50 um.

SETTING REACTION

Leaching When the powder and liquid are mixed together, the acid attacks the glass particles. Thus calcium, aluminium, sodium and flouride 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 (next 24 hours), 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.

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 consists of agglomerates of unreacted powder particles surrounded by silica gel and embedded in an amorphous matrix of hydrated calcium and aluminium polysalts.

Post Hardening Precipitation

Even after the cement has apparently set, precipitation of the polysalts continues to occur. Formation of calcium polysalts is probably responsible for the initial set. However, with time the slower forming aluminium polysalts becomes the dominant phase in the matrix.

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) after it is placed in the mouth.

Loosely Bound and Tightly Bound Water

The water content of the cement is an important part of its structure. This water is sometimes referred to as being loosely bound or tightly bound. The loosely bound water is that which is easily removed by dessication and it decreases with time.The loosely bound water gradually binds (hydrates) with the matrix, becoming tightly bound. Thus, tightly bound water increases with time. Tightly bound water is not easily removed by drying.

Thus, the *fresh* cement once hardened is prone to cracking or crazing due to drying of loosely bound water. So, the cement must be *protected* from changes in its structure. This tendency decreases with time as it is slowly converted into tightly bound water.

Setting Time

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

PROPERTIES

Mechanical Properties

Compressive strength: (150 MPa). It is less than silicate.

Tensile strength: (6.6 MPa). Higher than silicate.

Hardness: (49 KHN). Less harder than silicates. The wear resistance is also less when compared to composites.

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

Solubility and Disintegration

Like silicates, the initial solubility is high (0.4%) 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.

Adhesion

It adheres well to enamel and dentine.

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 homogenity.

Esthetics

Esthetically they are inferior to silicates and composites. They lack translucency and have a rough surface texture. They may accumulate stain with time.

Biocompatibility

Pulpal response—mild. Type II glass ionomers are relatively biocompatible. The pulpal reaction is greater than that of 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 is more acidic than Type II, because of the slower set and lower powder/liquid ratio.

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 dab of calcium hydroxide cement.

Anticariogenic Properties

Type II glass ionomer releases flouride 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:

- Pumice wash
- Polyacrylic acid.

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

Apply 10% polyacrylic acid for 10 to 15 seconds. Next, rinse with water for 30 seconds. Very deep areas of the preparation should be protected by a dab of calcium hydroxide.

Eroded areas The dentin and cementum are first cleaned with a pumice slurry followed by swabbing with polyacrylic acid for 5 seconds or more.

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

Proportioning and Mixing

Powder/liquid ratio: Generally 3:1 by wt (manufacturers recommendation should be followed). Low P/L ratio reduces mechanical properties and increase the chances of cement degradation. Moisture contamination alters the acid-water balance. Most manufacturers provide a plastic scoop, which is useful for measures.

Spatula used Agate or plastic.

Manual mixing The powder bottle is tumbled gently. The powder and liquid is dispensed just prior to mixing. A cool and dry glass slab is preferred as it allows all the powder to be incorporated into the mix and yet maintain its plasticity.

The powder is divided into two equal increments. The first increment is incorporated into the liquid rapidly with the stiff bladed spatula to produce a homogenous milky consistency. The remainder of the powder is then added. The mixing is done in a *folding method* in order to preserve the gel structure (Fig. 13.10).

Mixing time 45 seconds.

Insertion The mix is immediately packed into the cavity with a plastic instrument.

Mechanical Mixing

GIC supplied in capsule form containing preproportioned powder and liquid is mixed in an amalgamator which is operated at a very high speed. The capsule has a nozzle, and so the mix can be injected directly into the cavity (Fig. 13.11).

FIGURE 13.10: Glass ionomer is mixed by gentle patting and folding: Vigorous mixing disrupts the gel structure

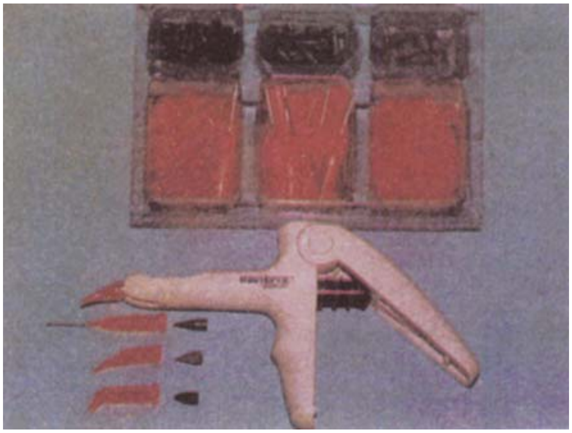


FIGURE 13.11: A cement dispensing system

Advantages

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

Disadvantages

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

Protection of Cement during Setting

GIC is extremely sensitive to air and water during setting. Thus, immediately after placement into the cavity, a *preshaped matrix* is applied to:

1. Protect the cement from the environment during intitial set.
2. Provide maximum contour so that minimal finishing is required
   The matrix is removed after five minutes. Immediately after removal, the cement surface is again protected with:
3. A special varnish supplied by manufacturer, or
4. An unfilled light cured resin bonding agent, or
5. Cocoa butter.

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.

Protection of Cement after Setting

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

- A good mix should have a glossy surface. 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 is discarded as it indicates prolonged mixing and reduces the adhesion.
- 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.

METAL MODIFIED GIC

The metal modified GIC's (Fig. 13.12) were introduced to improve the strength, fracture toughness and resistance to wear and yet maintain the potential for adhesion and anticariogenic property.

FIGURE 13.12: Modified glass ionomer cements: Metal modified glass ionomer cements — Miracle Mix and Ketac Silver (left) and resin modified glass—ionomer materials (right)

TYPES

Two methods are employed

A. *Silver alloy admixed:* Spherical amalgam alloy powder is mixed with type II GIC powder (Miracle Mix) (Fig. 13.13).

B. *Cermet:* Silver particles are *bonded* to glass particles. This is done by sintering of a mixture of the two powders at a high temperature (Ketac Silver) (Fig. 13.12).

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.
- The *fracture toughness* of GIC, whether modified or not is extremely low as compared to composite resin and amalgam.
- It is far *more resistant to wear* than type II GIC.

FIGURE 13.13: Miracle mix is the trade name for a metal-modified glass ionomer cement. Silver alloy powder is supplied separately (center). The silver powder is emptied into the GIC powder bottle. Once mixed it is ready for use as a metal-modified GIC cement

Anticariogenic Property

Both metal modified ionomers have anticariogenic capability due to leaching of flouride. However, less flouride 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 flouride 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 flouride.

Ethetics

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

GLASS IONOMER-RESIN COMBINATION MATERIALS

These are relatively new materials having various names like compomer, resin-ionomers, RMGI, light cured GIC, dual cure GIC and tricure GIC (Fig. 13.12).

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 (Fig. 13.14), Vitremer, Photac Fil .
B. *Poly acid–modified composites (PMC),* e.g. Dyract (Fig. 13.12), Variglass VLC.

FIGURE 13.14: Resin modified Glass ionomer (RMGI) cements - on the **left** is a chemically cured cement (3M's RelyX) and on the **right** is a light cured cement (GC's Fuji II LC). A light cured glass ionomer allows the setting to be under the control of the operator

USES

1. Restoration of class I, III or V cavities
2. Bases and liners
3. As adhesives for orthodontic brackets
4. Cementation of crowns and bridges
5. Repair of damaged amalgam cores or cusps
6. Retrograde root filling.

Note Uses vary according to brand.

SUPPLIED AS

They are supplied as
- Chemically cured
- Light cured
- Dual cured (combined chemical and light cured).

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.

The powder contains
- Ion leachable glasses (silica, alumina)
- Photoinitiators or chemical initiators or both
- Polymerizable resin.

The liquid contains:

- Polyacrylic acid
- Water
- Methacrylate monomer
- Hydroxyethyl methacrylate monomers.

MANIPULATION

RMGI is mixed and applied after conditioning the tooth with polyacrylic acid (10 to 25%). PMC is placed after phosphoric acid etching, bond agent application and light cured.

PROPERTIES

Strength

The compressive strength is slightly lower (105 MPa) when compared to conventional GIC. The diametral tensile strength is however, greater (20 MPa) because of the plastic nature 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 to conventional GIC.

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 flouride release.

Pulpal Response

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

Esthetics

They are less transluscent because of the significant differences in the refractive index between the resin matrix and powder particles.

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.

CURRENT DEVELOPMENTS

The good adhesion to tooth structure and the anticariogenic properties have ensured the continued development of these materials. Recent materials include a whole range of resin modified GlCs including the dual cure and tricure setting mechanisms and the light cured glass ionomer liners and bases.

ZINC POLYCARBOXYLATE CEMENT

Polycarboxylates cement was 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.
- Water settable cements.
- As precapsulated powder/liquid system.

Commercial Names

Poly F (Dentsply), Durelon, Carboco (voco) (Figs 13.1 and 13.15).

COMPOSITION

Powder

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

FIGURE 13.15: Two brands of polycarboxylate cement

Liquid

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

Water Settable Cements

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

MANUFACTURE

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

RECENT PRODUCTS

- Encapsulated material which contains 43% alumina in powder

- One product contains polymer with a structure slightly different from that of polyacrylic acid.

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.

Setting Time

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).

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 zincphosphate 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—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

- Under ideal conditions polycarboxylate has better adhesion to a clean dry surface of enamel than other cements.
- 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.
- The presence of saliva reduces bond strength.
- Unlike zinc phosphate cements, the adhesion is better to a smooth surface than to a rough surface.
- Does not adhere to gold or porcelain.
- Adhesion to stainless steel is excellent. Thus, it is used in orthodontics for cementation of fixed appliances.

Optical Properties

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

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

30 to 40 seconds.

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.
- 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 cement sets.
- From spatula it can be chipped off. Any remaining material is removed by boiling in sodium hydroxide solution.

ZINC SILICOPHOSPHATE CEMENT

The zinc silicophosphate cement resulted from the combination of zinc phosphate cement and silicate powders. It is sometimes referred to as zinc silicate, silicate zinc cement or simply silicophosphate cement.

APPLICATIONS

1. Luting agent for restorations.
2. Intermediate restorations.
3. Luting agent for orthodontic appliances.
4. As a die material.

CLASSIFICATION

ADA specification No. 21: Three types.

Type I — Cementing medium
Type II — Temporary posterior filling material
Type III — Used as a dual purpose cement—as both a cementing medium and a temporary posterior filling material.

Commercial name Fluorothin.

COMPOSITION

Powder

- Silicate glass
- Zinc oxide powder
- Magnesium oxide

Liquid

- Phosphoric acid
- Water
- Zinc and aluminium salts

SETTING REACTION

The setting reaction is the same as for silicate cements except that there is formation of zinc phosphate.

Setting Time

3-15 minutes.

PROPERTIES

- Compressive strength—165 MPa (23,000 psi)
- Film thickness — 25 um
- Solubility and disintegration — 0.9% by wt.
- Anticariogenic due to flouride
- It shows semitranslucency for cementation.

MANIPULATION

The powder and liquid are dispersed on a cool glass slab. The powder is incorporated into liquid in 2 or 3 large increments. Mixing time is 1 minute. Mix it in a circular motion to obtain the required consistency.

COPPER CEMENT

Silver salts or copper oxide are sometimes added to the powders of the zinc phosphate cements to increase their antibacterial properties.

APPLICATIONS

1. Temporary fillings in children
2. Intermediate restorations
3. For retention of silver cap splints in oral surgery.

CLASSIFICATION

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

Commercial name Ames copper.

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.

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 should be manipulated in the same manner.

RESIN CEMENTS

Synthetic resin cements based on methyl methacrylate have been available since 1952 for cementation of inlays, crowns, and other appliances. Since 1986, resin cements have remained popular because of their use in the cementation of porcelain veneers and orthodontic brackets.

APPLICATIONS

1. Cementation of crowns and bridges (etched cast restorations) (Fig. 13.16).

2. Cementation of porcelain veneers and inlays.
3. For bonding of orthodontic brackets to acid-etched enamel.

These cements have high bond strengths because of their ability to bond to etched enamel. Therefore they are popular for cementing porcelain veneers, etched cast bridges (Maryland bridges) and orthodontic brackets where a *high bond strength* is critical for its success.

Because of their good esthetics, these cements are popular for bonding porcelain veneers. Most other cements are opaque and could affect the esthetics of the ceramic restoration.

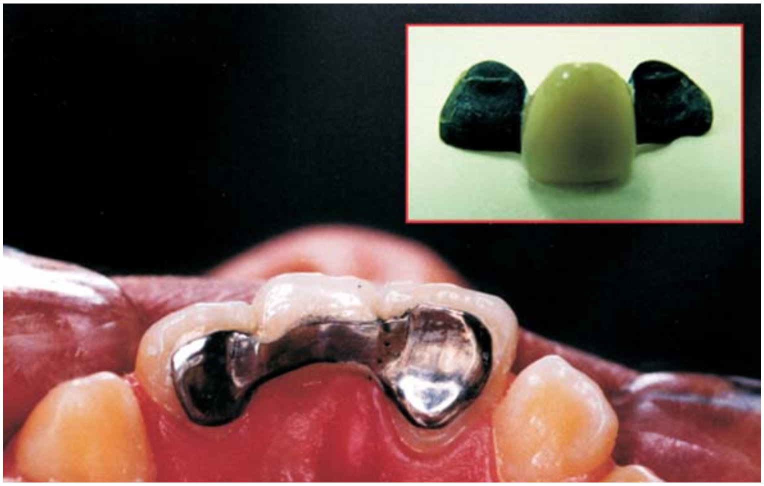


FIGURE 13.16: A Maryland bridge is a resin bonded restoration. Both metal and tooth surface have to be etched for better bonding

CLASSIFICATION

Filled and unfilled resins.

Commercial Names

- Panavia Ex (Fig. 13.17)
- Infinity
- Porcelite dual cure (Kerr)

SUPPLIED AS

Chemically cured

- Powder/liquid system
- Two paste system

- Single paste with accelerator in bonding agent
- Or dual cured–two paste system

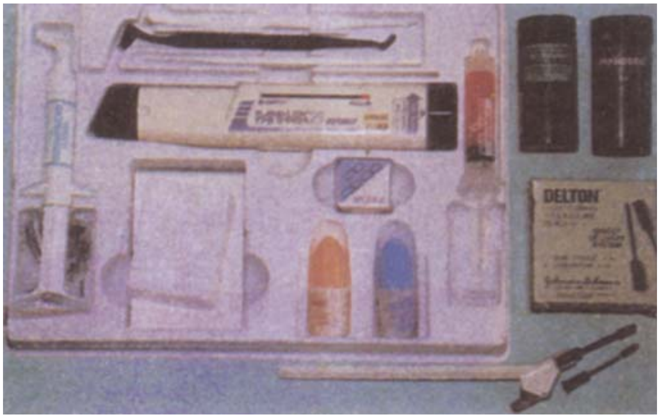


FIGURE 13.17: Resins are also used for luting (Panavia) and as pit and fissure sealants (Delton and Helioseal)

COMPOSITION

Powder

Resin matrix (diacrylate monomer)
Inorganic fillers
Coupling agent (organo silane)
Chemical or photo initiators and activators

Liquid

Methyl methacrylate
Tertiary amine.

POLYMERIZATION

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

PROPERTIES

- Compressive strength : 180 MPa (26000 Psi)
- Tensile strength : 30 MPa (4000 Psi)
- Film thickness : 10-25 um

- Biological properties : Irritating to the pulp Pulp protection with calcium hydroxide is necessary
- Solubility : Insoluble in oral fluids
- Polymerization shrinkage : Is high
- Adhesion properties : They do not adhere to tooth structure, which may lead to microleakage.
- Bond strength to enamel : 7.4 MPa (1070 Psi)

Enamel bonding can be attained by acid etch technique. Dentin bonding can be attained by dentin bonding agents organo phosphates, HEMA and 4 META.

MANIPULATION AND TECHNICAL CONSIDERATIONS

1. Etching the restoration
2. Etching the tooth surface
3. Cementing the restoration

Etching the Restoration

Etching metal Just as the tooth surface is etched, the metal surface can also be etched. The etching of both tooth surface and the restoration ensures the best possible bonding. The metal surface is usually etched in a electrolytic bath containing some acid like sulfuric acid—also known as electrochemical etching. The surfaces which do not require etching is protected by covering it with wax.

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 (Fig. 20.11). 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.

Etching the Tooth Surface

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

Cementing the Restoration

Powder/liquid system or 2 paste systems The two components are combined by mixing on a paper pad. Mixing time is 20-30 seconds. Removal of the excess cement is difficult, if it is delayed until the cement has polymerized.

Single paste system In one system, the accelerator is present in the bonding agent. 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
- Dual cure is used when the material being bonded allows some degree of light penetration, e.g. ceramic crown, brackets, inlays, etc.
- Light curing gives high initial strength
- Light curing polymerizes the cement at the margins of the restoration which is affected by air inhibition.

CALCIUM HYDROXIDE CEMENT

Calcium hydroxide is a relatively weak cement commonly employed as direct or indirect pulp capping agents (Fig. 13.18). Due to their alkaline nature they also serve as a protective barrier against irritants from certain restorations.

Recently, a light cured calcium hydroxide base material and a calcium hydroxide root canal sealing paste have been introduced.

FIGURE 13.18: Dycal is a well known brand of calcium hydroxide pulp capping agent. Another variety (Pulpdent) is used as a root canal paste. The syringe form allows the material to be conveniently applied into the narrow root canal

APPLICATIONS

1. For direct and indirect pulp capping.
2. As low strength bases beneath silicate and composite 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 collapsible tubes
- Light cured system
- Single paste in syringe form (pulpdent, Fig. 13.18)
- Powder form (mixed with distilled water).

Commercial Names

- Self cured—Dycal, Life, Care, Calcidor (Figs 13.7 and 13.18)
- Light cured—PrismaVLC dycal.

COMPOSITION

Base Paste

- Glycol salicylate 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 salicylate ester to form a chelate viz. amorphous *calcium disalicylate*. Zinc oxide also takes part in the reaction.

Setting Time

2.5 to 5.5 minutes.

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

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.

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). The material is applied to deep areas of the cavity or directly over mildly exposed pulp (contraindicated if there is active bleeding).

LIGHT ACTIVATED CALCIUM HYDROXIDE CEMENT

Light activated calcium hydroxide cements have recently become available. It consists of calcium hydroxide and barium sulphate dispersed in a urethane dimethacrylate. resin. It also contains HEMA and polymerization activators.

The light activated cement has a long working time and is less brittle than the conventional two paste system.

CALCIUM HYDROXIDE ROOT CANAL SEALING PASTES

Recently, a root canal sealer containing calcium hydroxide has been developed (Fig. 13.18). 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.

Their advantages are:

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

CHAPTER 14

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.

Note: A variety of formulations are now referred to as liners, e.g. GIC liner, zinc oxide-eugenol liner, and calcium hydroxide in paste form.

SUPPLIED AS

- Solutions in bottles (Detrey)
- Powder and liquid
- Single light cured paste in tubes (Time line-dentsply, Fig. 14.1).

FIGURE 14.1: Examples of commercially available varnishes and liners

COMPOSITION

Suspension of calcium hydroxide in an organic liquid 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 provides any significant thermal insulation. The calcium hydroxide liners are soluble and *should not* be applied at the margins of restorations.

Flouride compounds have been added to some cavity liners in an attempt to reduce the possibility of secondary caries around permanent restorations or to reduce sensitivity.

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

- Type III glass ionomer
- Type lV 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. In cases where 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.

Commercial Names

- Harvard lac (Fig. 14.1)
- Detrey varnish
- Bifluorid 2 (VOCO)
- Duraphat
- Fluorprotector

Fluoride containing

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 between 2 to 400 um.

The solubility of dental varnishes is low; they are virtually insoluble in distilled 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 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 or silicophosphate restoration, the varnish should be confined to the dentin. Varnish applied on the enamel inhibits the uptake of fluoride by the enamel.

Contraindications:

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

CHAPTER 15

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

Used primarily for observation, diagnosis, patient education etc., 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 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 + ligho-sulphonates (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.

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 PROPERTIES OF DIE MATERIALS

1. It should be dimensionally accurate.
2. It should have high abrasion resistance, should possess good strength and have a smooth surface.
3. Toughness—to allow burnishing of foil and resist breakage.
4. Ability to reproduce all fine details in the impression.
5. Compatibility with all impression materials.
6. Color contrast with wax, porcelain and alloys.
7. Easy to manipulate and quick to fabricate.
8. Non-injurious to health by touch or inhalation.
9. Economical—low cost.

DISADVANTAGES OF SOME 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 dies	: The bismuth-tin alloy is rather soft; care is needed to prevent abrasion of the die.

IMPROVED DENTAL STONE OR DIE STONE

The most accurate and 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 0.30%. 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.

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 cupsal wear due to repeated contact with opposing cast.

Disadvantages

1. Difficult to trim
2. Silver bath-health hazard

3. Not compatible with all impression materials
4. Colour contrast not as good as die stone
5. Adaptation of wax not as good as to the die stone, pattern tends to lift from margins.

Electroforming

Also known as electroplating or electrodeposition. Electroforming is a process by which a thin coating of metal is deposited on the impression, after which a gypsum cast is poured into the impression. The case thus obtained will have a metal surface.

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)
- Polysulphide (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 sulphonic 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 excess powder is blown off.

  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 the electrolyte, avoiding air-bubbles.
- Attach the impression to the cathode holder. An insulated wire is used for the purpose.
- 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 atleast 4".
- 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 support the surface of the cast and to form the base.

EPOXY RESIN DIE MATERIALS

They are most effective with rubber impression materials.

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 upto 24 hours.

Available As

Two components—resin paste and hardener (Fig. 15.1).

REFRACTORY CAST (INVESTMENT CAST)

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 bridges are constructed on a normal die, 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. 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 normal (non-refractory) gypsum cast cannot withstand the high temperatures involved in the casting of metal and would disintegrate under these conditions.

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 generally used for larger structures.

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.

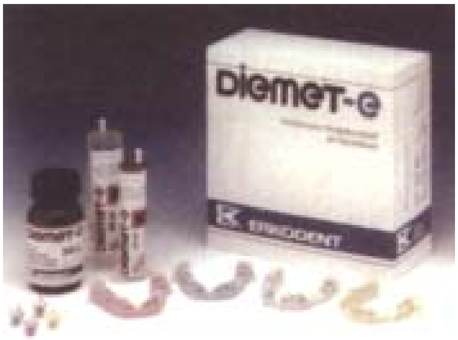


FIGURE 15.1: Epoxy resin and dies

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 minimised.

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.

CHAPTER 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:

Natural waxes		*Synthetic waxes*	*Additives*
Minerals:	Paraffin	Acrawax C	Fats
	Microcrystalline	Aerosol, OT	• Stearic acid
	Barnsdahl	Castorwax	• Glyceryl-tristearate
	Ozokerite	Flexowax C	
	Ceresin	Epolene N-10	
	Montan	Albacer	Oils
		Aldo 33	Turpentine
		Durawax 1032	Color
Plants:	Carnauba		Natural Resins
	Ouricury		Rosin
	Candelilla		• Copal
	Japan wax		• Dammar
	Cocoa butter		• Sandarac
			• Mastic
			• Shellac
			• Kauri
Insect:	Beeswax		
Animal:	Spermaceti		Synthetic Resins
		.	• Elvax
			• Polyethylene
			• Polystyrene

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).

Alcohol + Fatty Acid → Ester + 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 It's 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.

Insect Wax

Beeswax (63-73°C) Brittle at room temperature, but 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. Improves 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 Lowers the melting point of paraffin, hydrocarbon oils softens 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	

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:

- Melting range
- Thermal expansion
- Mechanical properties
- Flow
- Residual stresses
- 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 exist in the completed pattern. The residual 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

An artificial dental restoration is first made with pattern wax. 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

As mentioned before they are

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 bridges 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 die, it is called indirect technique.

Ideal Requirements of Inlay Casting Waxes

- When softened, the wax should be uniform, there should be no graininess or hard spots in the plastic material.
- The color should contrast with the die. A definite color contrast helps in identifying and finishing of margins.
- There should be no flakiness or roughening of the surface when the wax is moulded after softening.
- The wax should not pull or chip during carving.
- During burnout (500°C), it should vaporize completely without residue.
- The wax pattern should be completely rigid and dimensionally stable at all times until it is eliminated.
- It should be sufficiently plastic slightly above mouth temperature and become rigid when cooled to mouth temperature.
- The flow should be more than 70% at 45°C and less than 1% at 37°C.

Classification (ADA Sp. No.4)

Type I : A medium wax employed in direct technique
Type II : A soft wax used for indirect technique for inlays and crowns.

Supplied As

Blue, green or purple sticks (Fig. 16.1—bottom left corner). Also available as small pellets and cones.

Commercial Names Harvard, Kerr, etc.

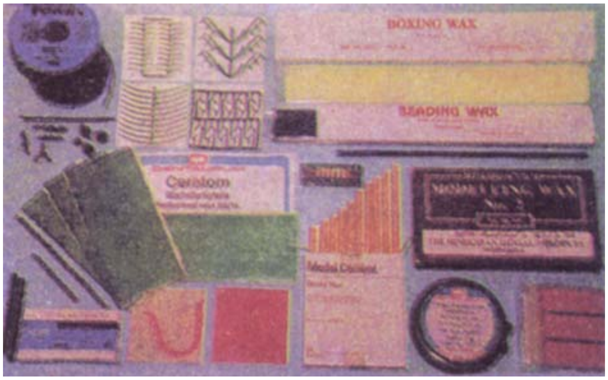


FIGURE 16.1: A wide variety of wax products are used in dentistry. Preformed casting waxes saves valuable laboratory time and gives more consistent results

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%) Or Dammar resin which is a natural derivative from pine tree improves the smoothness in moulding 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 it 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 Can be added to replace carnauba wax. It contributes the same qualities as carnauba wax, but its melting 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. 4.
At 45°C - Both Type I and Type II should have a flow between 70 to 90%.
At 37°C - Type I should not flow more than 1%.
At 30°C - Type II should not flow more than 1%.

From the above requirements it is clear that:
Type I inlay wax Melts and flows well, when heated at 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 finally hardens at 37°C (mouth temperature), allowing the operator to carve and shape it in the mouth.

Type II inlay wax On the other hand hardens at 30°C (room temperature). This wax is more suitable for the laboratory. In the mouth (at mouth temperature) it would be too soft.

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 high a CTE. It has a linear expansion of 0.7% with increase in temperature of 20°C. It's thermal changes are higher than any other dental materials.

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 to 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 moulding
- From manipulation, carving, pooling, and removal.

  Thus the amount of residual stress is dependent on:
  - The method of forming the pattern.
  - Its handling and
  - Time and temperature of storage of the wax pattern.

Causes of distortion Distortion is due to any method of manipulation that creates inhomogenity of wax involving the intermolecular distance (Fig. 16.2).

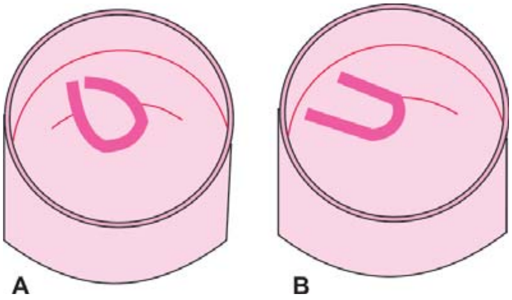


FIGURE 16.2: Demonstration of wax distortion. (A) A bent stick of wax kept in water at room temperature. (B) Straightened appreciably after 24 hours

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.
- If the 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.
Use warm instruments for carving.
Store it in a fridge 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.

Non-volatile Residue

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.
- *Adding in layers:* 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.

Uses

To make patterns of the metallic framework of removable partial dentures (Figs 16.3A and B).

FIGURE 16.3A: An assembled RPD pattern (lower left) made from ready made casting waxes on a refractory cast. The sprue formers have been attached. The pattern is invested in a suitable refractory material to create a mold (behind). The completed casting is shown on the right side

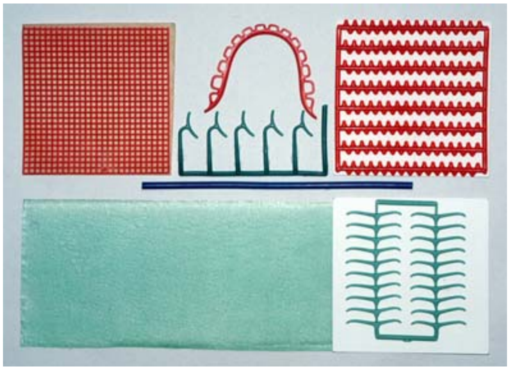


FIGURE 16.3B: Prefabricated RPD casting wax patterns

Supplied As

It is available in the form of (Fig. 16.1)

- Sheets 0.40 and 0.32 mm thickness
- Readymade shapes
  - Round (10 cm), half round and half pear shaped rods
  - Reticular, grid or meshform
  - Clasp shapes
  - Other forms.
- Bulk

Properties

These waxes are *tacky* and higly *ductile* as they must adapt easily and stick onto the refractory cast. Like inlay wax they too must vaporize with *little residue* during burnout.

The pattern for the RPD frame is made on a special cast known as the *refractory cast* (Fig. 16.3). 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 easily on to the cast. After the pattern is completed it is invested and cast.

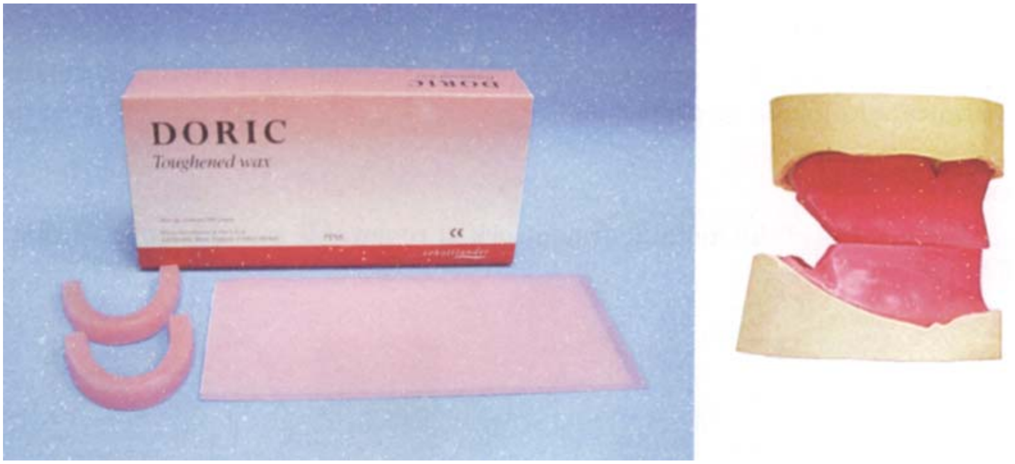


FIGURE 16.4: Baseplate wax is a pattern wax which is used in the fabrication of complete dentures. It is usually supplied as sheets. Prefabricated occlusion rims forms (foreground left) are also available. **Inset** - Occlusion rims made from baseplate wax

BASEPLATE WAX (Fig. 16.4)

Most students would be familiar with this wax. In some places it is referred to as modeling wax. They are classified under pattern waxes because they are used in the construction of dentures and other appliances made of acrylic and like materials.

Uses

These waxes are used for the following:

1. To make occlusion rims.
2. To form the desired 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. 24)

Type I soft — for building veneers
Type II medium — to use in mouths in normal climates
Type III hard — for use in tropical climates.

Supplied As

Sheets of pink or red color (Figs 16.1 and 16.4).

Composition

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.

BOXING WAX AND BEADING WAX

Uses

Uses 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. 16.5).

Supplied As

Boxing wax as sheets, beading wax as strips (Fig. 16.1).

Advantages of Beading and Boxing

1. Preserves the extensions and landmarks

FIGURE 16.5: Boxing wax and beading wax surrounding a silicone impression. The impression is ready to be cast with dental stone. The boxing wax will confine the dental stone

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 tackyness 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.

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. It is *used* to adjust contour of perforated tray for use with hydrocolloids (e.g. to raise flange height, to extend the tray posteriorly, and to raise palatal portion of the tray in cases of deep palate). It is pliable and can be easily moulded. 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 upon which it is applied. At room temperature, it is firm, free from tackiness, and brittle (Fig. 16.1).

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

Uses

It is used as a wax veneer over an original impression to contact and register the details of the soft tissues.

1. To make functional impression of free end saddles (Class I and II removable partial dentures)
2. To record 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 subjected 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 on wafers (Fig. 16.6). One side of the wax is usually covered with foil.

Composed Of

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. It is then taken out and placed in chilled water. The casts of the patient is placed in the indentations formed by the teeth. It is then mounted with plaster on the articulator.

FIGURE 16.6: Various bite registration waxes are used to record the relationship between the occluding surfaces of the upper and lower jaw

CHAPTER 17

Dental Casting Investment Materials

An investment can be described as a ceramic material which is suitable for forming a mould into which molten metal or alloy is cast. The procedure for forming the mould 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 mould 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 mould 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 upto 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.

COMPOSITION OF INVESTMENTS (IN GENERAL)

All investment materials must 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:
- Acts as a material that can withstand high temperatures.
- 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.

Other Chemicals

Other chemicals such as sodium chloride, boric acid, potassium sulfate, grafite, copper powder or magnesium oxide often are added in small quantities to modify the physical properties.

GYPSUM BONDED INVESTMENTS

CLASSIFICATION

According to ADA Sp. No. 2 for gold alloy casting investments, there are three types based on use and type of expansion used.

Type – I	Inlay, thermal
Type – II	Inlay, hygroscopic
Type – III	Partial denture, thermal.

USES

For casting of inlays, bridges, removable partial denture frame works using gold alloys and other low fusing alloys.

SUPPLIED AS

Powder in bulk or preweighed packs.

COMPOSITION

Silica	– 60 to 65%
Alpha-hemihydrate (dental stone)	– 30 to 35%
Chemical modifiers	– 5%

Function of Each Constituent

Alpha hemihydrate:

- It binds and holds the silica particles together.
- Permits pouring of the mix into the mould.
- It imparts strength to the mould.
- Contributes to mould 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 non-oxidizing atmosphere in the mould when the mould 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

Mix measured quantity of powder and water using a flexible rubber bowl and spatula or in a vacuum investment mixing machine.

SETTING REACTION

Same as 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

- Manufacturing process
- Mixing time and rate
- Water/powder ratio
- Temperature
- Modifiers—accelerators and retarders.

PROPERTIES OF GYPSUM INVESTMENTS

Thermal Behavior of Gypsum

When gypsum is heated to 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 mould to compensate for the casting shrinkage of the gold alloys.

Expansions are of 3 types:

- Normal setting expansion
- Hygroscopic setting expansion
- 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 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 mould in a furnace at a temperature not greater than 700°C. (The investment breakdown, if it exceeds this temperature bases are released, which contaminate the gold alloys).

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 1.0% to 2.0%.

Type-l investments should have a thermal expansion of not less than 1.0% nor greater than 1.6%.

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.

Strength is Affected By

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 gypsum crystals present in the set investment, the less is its porosity. 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 mould in order to allow escape of gases during casting).

Fineness

A fine particle size is preferrable to a coarse one. The finer the investment, the smaller will be the surface irregularities on the casting.

Storage

Investments should be stored in air-tight and moisture-proof containers. Purchase in small quantities.

HYGROSCOPIC THERMAL INLAY CASTING INVESTMENT

A new inlay casting investment that can be used as a hygroscopic or thermal type is now available. The investment contains a blend of quartz and cristobalite as the refractory. For the hygroscopic expansion technique, the investment is heated only upto 482°C. When used in the thermal casting technique, 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 moulds at 850 to 1100°C.

At high 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.

PHOSPHATE BONDED INVESTMENT

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.

Supplied as

Powder in packets with special liquid (Fig. 17.1).

FIGURE 17.1: Various phosphate bonded investment materials

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 temperature to increase strength at casting temperatures.
- Silica: Refractory
- Magnesium oxide: Reacts with phosphate ions.

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.

$$NH_4H_2PO_4 + MgO \rightarrow NH_4MgPO_4 + H_2O$$

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 temperature 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

The powder is mixed with a measured amount of liquid using a bowl and spatula. Hand mixing or mechanical mixing under vacuum can be done. The mixed material is vibrated into the casting ring or agar mould (RPD framework).

SILICA BONDED INVESTMENTS

The silica is the binder. It is derived from ethyl silicate or aqueous dispersion of colloidal silica or sodium silicate.

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.

$$Si(OC_2H_5)_4 + 4H_2) \xrightarrow{HCl} Si(OH)_4 + 4C_2H_5OH$$

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 a solution of *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 used according to manufacturers instruction.

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. 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 (Fig. 22.1).

Composition

The investment for soldering purpose is similar to casting investments containing quartz and a calcium sulfate hemihydrate binder.

Properties

Soldering investments are designed to have *lower setting and thermal expansions* 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. Relatively little information is available in the dental literature on the properties of soldering investments.

CHAPTER 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 mould (GPT-6). The object formed is also referred to as 'a casting.'

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 technique and materials used in casting.

STEPS IN MAKING A CAST RESTORATION

- 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
- Recovery
- Pickling
- Polishing.

TOOTH/TEETH PREPARATION

The teeth are prepared by the dentist to receive a cast restoration.

Impression An accurate impression of the tooth/teeth is made, usually with elastomers (Fig. 6.5F).

DIE PREPARATION

A die is prepared from die stone (Fig. 7.1) or the impression is electro-formed. A die spacer is coated or painted over the die which provides space for the luting cement.

WAX PATTERN

A pattern of the final restoration is made with type II inlay wax (Fig. 18.1) 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.

FIGURE 18.1: A roll of ring liner, a rubber crucible former with attached wax pattern and casting rings

SPRUE FORMER

A sprue former is made of wax, plastic or metal. 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. Adjust length of the sprue to 3/8" to 1/2", 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 a 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:

- Fibrous ceramic aluminous silicate
- Cellulose (paper)
- Ceramic-cellulose combination (Fig. 18.1).

Functions of the Ring Liner

1. Allows for mould expansion (acts as a cushion)
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.

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).

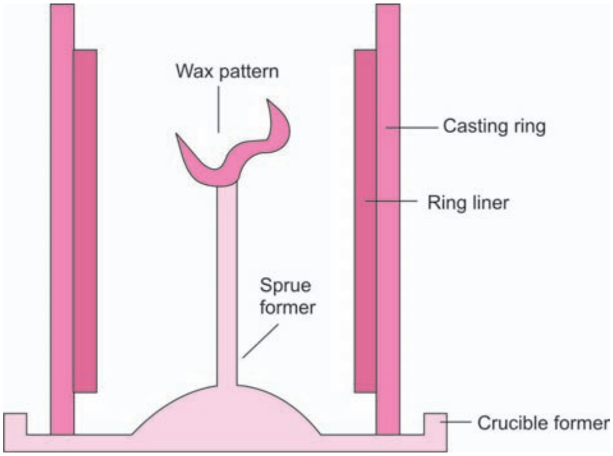


FIGURE 18.2: An assembled casting ring ready for investing

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. Allow it to set for 1 hour.

WAX ELIMINATION (BURNOUT) AND THERMAL EXPANSION

The *purpose* of burnout is: (i) to eliminate the wax (pattern) from the mould, and (ii) to expand the mould (thermal expansion).

Separate the crucible former from the ring. If a metallic sprue former is used, it should be removed before burnout.

FIGURE 18.3: An investment mixer (Bego - Germany). The investment is mixed under partial vacuum in order to minimize voids in the mix

Burnout is started when the mould is *wet.* Store in a humidor if burnout is to be delayed. The heating should be *gradual.* Rapid heating produces steam which causes the walls of the mould cavity to flake. In extreme cases an explosion may occur. Rapid heating also causes cracks in the investment due to uneven expansion.

The ring is placed in a *burnout furnace* and heated gradually to 400°C in 20 minutes. Maintain it for 30 minutes. In the next 30 minutes, raise the temperature to 700°C and again maintain it for 30 minutes (Fig. 18.4).

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

It is a process by which molten alloy is forced into the heated investment mould.

Casting Machines

Divided into two general types

- Centrifugal force type, and
- Air pressure type.

FIGURE 18.4: The burnout furnace. The wax pattern is vaporized in this furnace leaving behind an empty mould space. The furnace also increases the size of the mould (thermal expansion) which helps to compensate for casting shrinkage

Numerous modifications and variations of these principles are employed in different instruments.

Centrifugal machines may be spring driven or motor driven (Fig. 18.6). 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 mould. This type of machine is satisfactory for making small castings.

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 mould, which helps to draw the alloy into the mould.

Fusion of Noble Metal Alloy

Alloys can be melted by:
- Blow torch or
- By electrical resistance or induction.

Blow Torch

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. 18.5):

A. *Mixing zone* Air and gas are mixed here. No heat is present. It is dark in color.

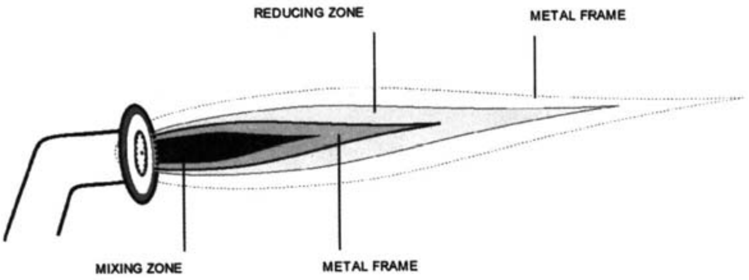


FIGURE 18.5: Parts of a flame

B. *Combustion zone* This surrounds the inner zone. It is green in color. It is a zone of partial combustion and has an oxidizing nature.

C. *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 fusion of casting alloy.

D. *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.

The hot casting ring is shifted from the burnout furnace to the casting machine (Fig. 18.6). The ring is placed in the casting cradle so that the sprue hole adjoins the crucible. Slide the crucible against the ring to avoid spilling of molten metal. The alloy may be melted by a torch or by induction heating (Figs 18.6 and 18.7).

FIGURE 18.6: An induction casting machine. The molten metal is driven into the mould by centrifugal force. One arm of the machine has a counter weight which balances the weight of the arm carrying the crucible and mould as it rotates. The red hot crucible and the casting ring is visible in the machine. The induction coil (copper colored) is half visible and is used to melt the metal

FIGURE 18.7: The above picture shows the alloy melting in the crucible. The crucible containing the alloy is surrounded by an induction coil which supplies the intense heat needed to melt the alloy pieces

Sprinkle *flux powder* over the molten metal to reduce the oxides and increase fluidity for casting. When the alloy is molten it has a *mirror like* appearance (Fig. 18.7), like a ball of mercury. Release the arm and allow it rotate till it comes to rest. This creates centrifugal force which forces the liquid metal into the mould cavity. 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 casting metal in an annealed (softened) condition and also helps to fragment the investment. Base metal alloys are not quenched.

RECOVERY OF CASTING

The investment is removed and the casting recovered. A pneumatic (air driven) chisel may be used to remove the investment.

SAND BLASTING

The casting is held in a sandblasting machine to clean the remaining investment from its surface.

PICKLING

The surface oxides from the casting are removed (when necessary) 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.

POLISHING

Minimum polishing is required if all the procedures from the wax pattern to casting are followed meticulously (for details see abrasives chapter).

DEFECTS IN CASTING

If proper procedure is not followed, the casting may have some defects. The casting in such a case may not fit or may have poor esthetic and mechanical properties.

CLASSIFICATION OF CASTING DEFECTS (COOMBE)

1. Distortion
2. Surface roughness
3. Porosity
4. Incomplete casting.

   In addition, a casting can be contaminated due to:

   Oxidation, caused by:
   - Overheating the alloy
   - Use of oxidizing zone of flame
   - Failure to use flux.
5. Sulphur compounds, formed by the breakdown of the investment when the ring is overheated.

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 of wax occurs during manipulation, because of the release of stresses.

Minimize distortion 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 wax pattern cause nodules on the casting.

   Avoid 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.
   Avoid by
   - Heat the ring gradually to 700°C (in at least 1 hr).
3. W/P ratio: higher W/P ratio gives rougher casting. Larger particle size of investment has the same effect.
   Avoid by
   - Using correct W/P ratio and select investment of correct particle size.
4. Prolonged heating causes disintegration of mould cavity.
   Avoid 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.
   Avoid by
   - Using 15 Ibs/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 will give coarse casting.
8. Foreign body inclusion shows sharp, well-defined deficiencies. Inclusion of flux shows bright concavities.

POROSITY

Porosity may be internal or external. External porosity can cause *discoloration* of the casting. Severe porosity at the tooth restoration junction can even cause *secondary caries*. Internal porosity *weakens* the restoration.

Porosities are Classified as (Phillips)

1. Those caused by solidification shrinkage:
   - Localised shrinkage porosity }
   - Suck back porosity } irregular in shape
   - Microporosity }
2. Those caused by gas:
   - Pin hole porosity } usually
   - Gas inclusions } spherical
   - Subsurface porosity } in shape
3. Those caused by air trapped in the mould (back pressure porosity).

Shrink-Spot or Localized Shrinkage Porosity

These are large irregular voids usually found near the sprue-casting junction. 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 mould 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.

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 mould wall near the sprue.

The hot spot causes this region to freeze last. Since the sprue has already solidified, no more molten material is available and the resulting shrinkage causes a peculiar type of shrinkage called suck back porosity (Fig. 18.8). It is avoided by reducing the temperature difference between the mould and the molten alloy.

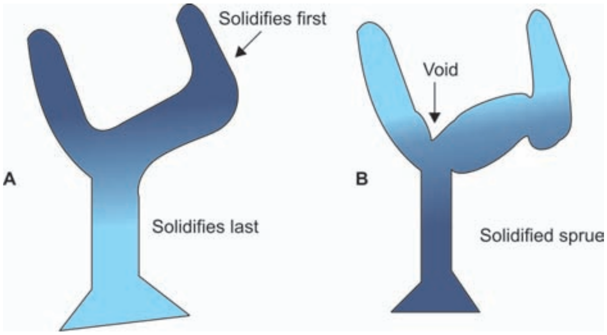


FIGURE 18.8: A—Correct sequence of hardening; B—Suck back porosity caused by incorrect sequence of solidification

Microporosity

These are fine irregular voids within the casting. It is seen when the casting freezes too rapidly. Rapid solidification occurs when the mould 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.

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 mould. 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 mould, 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 mould. The gold will then solidify before the mould is completely filled resulting in a *porous* casting with *rounded short margins.*

Avoid 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 mould, it gives off a large volume of gas, as the molten alloy enters the mould cavity. This gas can cause deficiencies in the casting and blow holes in the residue button. To help eliminate wax completely from the mould, the burnout should be done with the sprue hole facing downwards for the wax to run down.

INCOMPLETE CASTING

An incomplete casting may result when

1. Insufficient alloy used.
2. Alloy not able to enter thin parts of mould.
3. When mould 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 mould cavity.
7. Low casting pressure
8. Alloy not sufficiently molten or fluid.

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 mould 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 mould 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 mould cavity, then a small casting will result. Another reason is, the shrinkage of the impression material.

CONTAMINATION

1. Due to oxidation when molten alloy is over heated
2. Use of oxidizing zone of the flame
3. Failure to use flux
4. Due to formation of sulphur compounds (see black casting).

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 mould 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.

Table Summarising Casting Defects (Coombe)

Dimensional Errors in Casting

Problem	*Cause*	*Precaution*
Casting too large	Excessive expansion	Use correct temperature Use correct investment
Casting too small	Too little mould expansion	Heat the mould sufficiently
Distorted casting	Distorted wax pattern	Correct handling of wax

Rough Surface and Fins on Casting

Rough surface	Investment breakdown	• Avoid overheating of mould and alloy.
	Air bubbles on wax (nodules on casting)	• Correct use of wetting agent • Vacuum investing
	Weak surface of investment	• Avoid too high W/P ratio • Avoid dilution of investment from application of too much wetting agent
Fins on casting	Cracking of investment	• Avoid rapid heating of investment

Porosity

Irregular voids	Shrinkage on cooling of alloy	• Use correct sprue thickness • Attach sprue at thick part of wax pattern • Use reservoir
Irregular voids	Inclusion of foreign particles	• Heat mould upside down so that particles fall out
Spherical voids	Occluded gases in molten alloy	• Avoid overheating and prolonged heating of alloy
Rounded margins; regular large voids	Back pressure effect; air unable to escape from mould	• Use adequate casting force • Use porous investment • Avoid wax residue in mould • Place pattern 6 to 8 mm away from end of ring • Use vents
Porosity	Turbulent flow of molten alloy into the mould	• Correct placement of sprue

CHAPTER 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 orginal 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. By casting (e.g. cast crowns, posts, inlays, etc.)
3. By 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)

* See chapter on dental ceramics

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

These have been used for inlays, crowns, and bridges 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 as 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.

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 non-precious, 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 was 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:

- They should not tarnish in the mouth
- 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 1950's. The composition and requirements of these alloys became more complex. For example, they had to contain elements that could 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 1970's. 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 1930's 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 crown bridge. 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 quite so simple. 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 & bridges)
B. Alloys for metal ceramics restorations (e.g. PFM copings, PFM crowns & bridges)
C. Alloys for removable dentures ** (e.g. RPD frames & complete denture bases)

(*Some authors classify this as - Crown and bridge alloys. Unfortunately this can create slight 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).

According to Yield Strength and Percentage Elongation (ADA Sp. 5 Classification)

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

(≥ means equal to or greater than; < means less than. This classification is popular among manufacturers).

According to Major Element

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

DESCRIPTION (CLASSIFICATION) OF DENTAL CASTING ALLOYS

The huge choice of alloys in the market makes the process of identifying of these alloys quite a difficult task. The individual properties of many of these metals may be 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 all meet certain criteria - they must meet the requirements of their intended use. For example, all metal ceramic alloys regardless of whether they are made of noble metals or base metals 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
    - Base metal

B Alloys for metal ceramics restorations
    - High noble
    - Noble
    - Base metal

C Alloys for casting large structures
    - High noble
    - Noble
    - 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 (non-toxic and non-allergic).
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 the:

- 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. Resing facings have a number of disadvantages.
  - They wear rapidly (soon wear resistance)
  - They may change color (color instability and stain absorption)
  - They are porons. They tend to absorb food material and bacteria. This makes it unhygeinic and gives it a bad odor.

Classification

(As mentioned before 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 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.

Type IV Extra Hard

Inlays subjected to very high stesses, 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 these days. Most of the discussion will focus on the type III and IV alloys.

Uses

From the above it is clear that these alloys can be used for the following depending on which class they belong to. In addition, 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 (Fig. 19.1)
2. Crowns and bridges
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

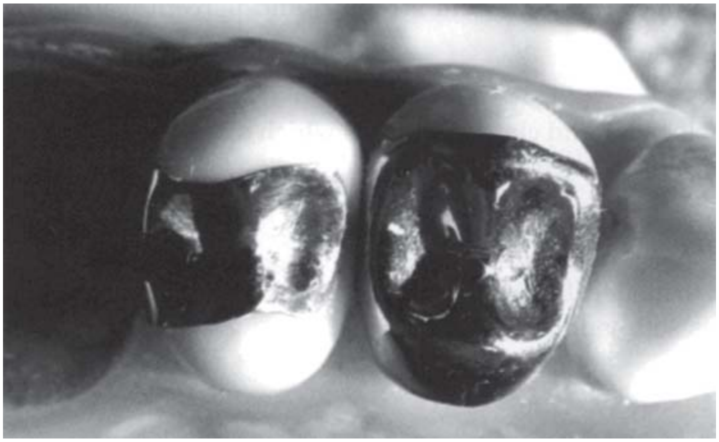


FIGURE 19.1: An inlay (left) and an onlay (right)

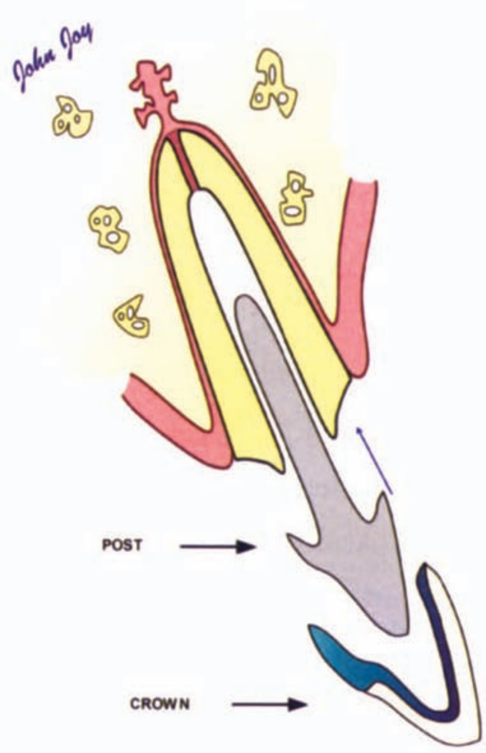


FIGURE 19.2: This cast metal post will be cemented into the root canal. This is followed by the construction and cementation of a crown. Without the post, it might not be possible to restore this badly broken down tooth

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. Dental casting golds are 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.

Earlier, people liked to display the yellow color of gold probably as a symbol of social status. Currently, the trend is to avoid 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'.*

These were the earliest alloys in dental use. 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 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

Function of Each Element

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

Similar to platinum in its effect. It hardens and whitens the alloy. It also raises 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 the 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 mould, 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 gms/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 for	Type III - 207 MPa
	Type IV - 275 MPa

Hardness

The hardness for	Type III - 121 MPa
	Type IV - 149 MPa

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.

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. This is due to their high noble metal 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 reaches 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 are used for gold alloys because of their lower fusion temperature.

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:
- Softening heat treatment (solution heat treatment)
- 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 Ageing)

Hardening heat treatment increases strength, proportional limit, and hardness, but decrease ductility. It is the copper present in gold alloys which helps in the age hardening process.

Indications

For strengthening metallic dentures, saddles, bridges, 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 ageing 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°C 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 bridge 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 (atleast 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% Pd - 25%	Properties are like Type III gold alloys.
Ag-Pd-Cu	:Ag - 60% Pd - 25% Cu - 15%	Properties are like Type IV gold alloys.

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.

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

Bronze is an alloy known to man since ancient times. Traditional bronze is copper alloyed with tin. The ADA approved bronze 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.

Technic Alloy

This is a *gold colored base metal alloy* (Fig. 19.5) which was frequently (mis) used in India to make all-metal crowns and bridges 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 poor strength, poor 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 (including some reputed clinics) still offer this material as a lower cost alternative, in addition to the regular alloys.

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 sub-structures for porcelain fused to metal crowns and bridges. 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 use in bridges. In those 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 the porcelain and the metal.

REQUIREMENTS OF ALLOYS FOR PORCELAIN BONDING

In addition to the general requirements of alloys mentioned earlier, metal ceramic alloys have some special requirements in order to be compatible with porcelain veneering.

1. It's melting temperature should be higher than the porcelain firing temperature.
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.
6. It should not stain or discolor porcelain.

USES OF METAL-CERAMIC ALLOYS

1. As the name implies these alloys are intended for porcelain veneered restorations (crowns and bridges).
2. They can also be used as an all metal restoration.

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. 19.3)
   - Gold-palladium-platinum alloys
   - Gold-palladium-silver alloys
   - Gold-palladium alloys

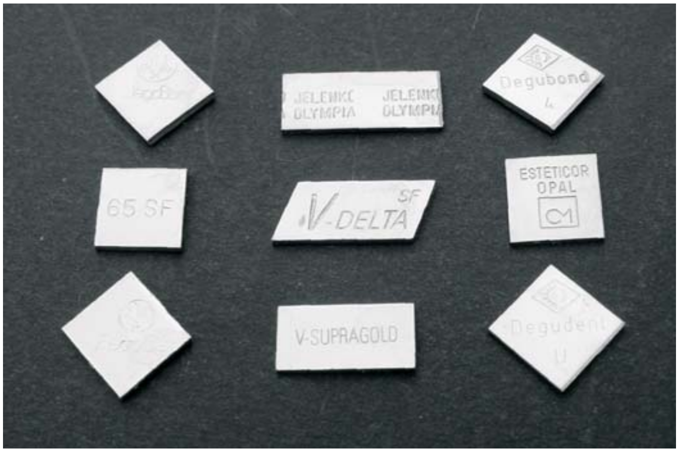


FIGURE 19.3: Different brands of gold alloys (all 1 gm pieces) used for metal ceramics. Most of the above are white gold alloys. V supra gold (Bottom center) has a light gold color. *SF* denotes silver free

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

As mentioned earlier, the high noble alloys contain more than 40 wt.% gold and are therefore also referred to as gold alloys or gold based alloys (Fig. 19.3).

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 metal ceramic gold 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 of as high as 950°C. At these high temperatures there is a danger of the metal substructure sagging under its own weight, thereby deforming. The longer the span the greater is the danger of sagging. 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.

TYPES

The following three will be briefly described.

1. Gold-palladium-platinum alloys
2. Gold-palladium-silver alloys
3. Gold-palladium alloys

Commercial names The 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 bridges 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.

Table 19.1: Commercial names of some noble and high noble alloys

Class	*Alloy*	*Commercial name*
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) Rx WCG (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

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. The density ranges from 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-ceramic 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 don’t melt 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 assist 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 copper.

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

Commercial names The alloys along with their commercial names are presented in Table 19.2.

Palladium-silver Alloys

These alloys were introduced in the 1970's 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. Little 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 more technique sensitive. Slight errors can lead to faulty castings.

Palladium-Cobalt Alloys

Composition

Palladium	78 to 88 wt%
Cobalt	4 to 10 wt%
Gallium	upto 9 wt% (in some brands)
Base metals	around 1 wt%

Esthetics Cobalt can cause some insignificant discoloration. However, more care should be given 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—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 very expensive noble metal ceramic alloys. In countries like the USA, western Europe and some middle eastern states, there is a preference for noble and high noble 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.

Just 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 special properties since they are to be used with ceramics.

The following base metal alloys are used for metal-ceramics.

- Nickel-chromium (nickel based) alloys
- Cobalt-chromium (cobalt based) alloys
- Pure titanium
- Titanium-aluminum-vanadium alloys

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 bridges, 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.

Composition

Basic Elements

Nickel	61 to 81 wt.%
Chrome	11 to 27 wt.%
Molybdenum	2 to 9 wt.%

(Some alloys occasionally contain one or more minor elements)

The minor additions include

Nickel	61 to 81 wt.%
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.%
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.%

(The functions of each ingredient is described in the section on removable partial denture alloys)

Table 19.2: Commercial names of some base metal-ceramic

Class	*Alloy*	*Commercial name*
Nickel based alloys	Ni-Cr-Mo	Neptune (Jeneric/Pentron) Forte (Unitek /3M)
	Ni-Cr-Mo-Be	Litecast B (Williams) Rexillium III (Jeneric/Pentron)
Cobalt based alloys	Co-Cr	Ultra 100 (Unitek /3M)
	Co-Cr-Ru	Genesis II (Jelenko)
	Co-Cr-W-Ru	Novarex (Jeneric/Pentron)

General Features and 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. 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 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 210 MPa ($\times 10^3$). 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 long span bridges 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 flulike symptoms and granulomas of the lungs.

Caution 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.

TITANIUM AND ITS ALLOYS

Recently titanium and its alloys have 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.

Uses

In Dentistry

1. Metal ceramic restorations
2. Dental implants (Figs 25.2 and 25.3)
3. Partial denture frames
4. Complete denture bases
5. Bar connectors (Fig. 19.4)

(In dentistry it is especially useful as an alternative alloy to those who are allergic to nickel).

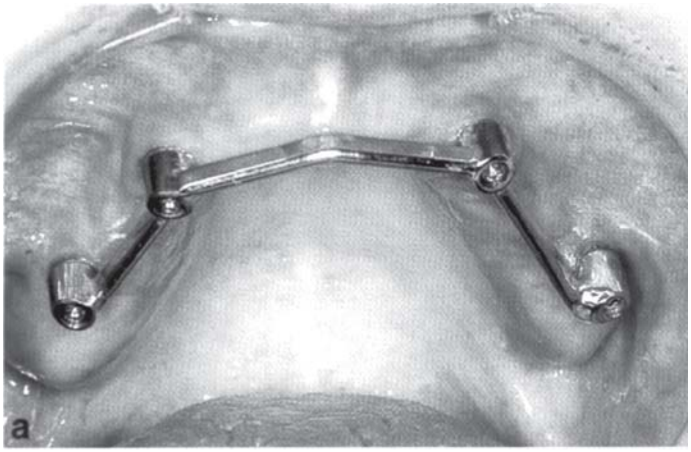


FIGURE 19.4: A maxillary bar connector made of titanium. The titanium bar is resting on four implants. Finally a complete denture will be constructed over this

In Surgery

1. Artificial hip joints
2. Bone splints
3. Artificial heart pumps
4. Artificial heart valves parts
5. Pacemaker cases

Properties of Commercially Pure Titanium

Color It is a white color metal

Density It is a light weight metal (density 4.1 gm/cm²) when compared to nickel chrome (8 gms/cm²) and gold alloys (15 gm/cm²).

Modulus of elasticity Its MOE 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.

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*. It forms a thin protective oxide layer which protects the metal from further oxidation.

Casting Investments

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.

REMOVABLE DENTURE ALLOYS

Larger structures like complete denture bases and partial denture frames are also made from dental alloys. Obviously these would need large amounts 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

- Cobalt chromium
- Nickel chromium
- Aluminum and its alloys
- Type IV noble alloys.

COBALT CHROMIUM ALLOYS

Cobalt-chromium alloys have been available since the 1920's. 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 have bright lustrous, hard, strong, and non-tarnishing qualities.

Supplied As

Small pellets (cuboidal, cylindrical shapes) in 1 kg boxes (Fig. 19.5).

FIGURE 19.5: Commercially available base metal casting alloys. In India base metal alloys are widely used. Also displayed is technic alloy (gold colored alloy on the left side)

FIGURE 19.6: A removable partial denture. This framework was cast from cobalt-chromium alloy

APPLICATIONS

1. Denture base
2. Cast removable partial denture framework (Fig. 19.6)
3. Crowns and bridges
4. Bar connectors.

COMPOSITION

• Cobalt	- 35 to 65%
• Chromium	- 23 to 30%
• Nickel	- 0 to 20%
• Molybdenum	- 0 to 7%
• Iron	- 0 to 5%
• Carbon	- upto 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 considered 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, 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, so 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-I (high fusing)-liquidus temperature greater than 1300°C.

Type-II (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 is 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).

Technique for Large Castings

The procedure for large castings like RPD frames is slightly more complex. Unlike the crown or bridge 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). The wax pattern is constructed on the refractory cast (Fig. 16.3). The pattern is not separated from the refractory cast, instead the refractory cast is invested along with the pattern.

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 equipment for finishing.
5. The high hardness can cause excessive wear of restorations and natural teeth contacting the restorations.

COMPARISON OF GOLD ALLOYS AND BASE METAL ALLOYS

	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	Oxy-acetylene torches	Gas-air torch
14.	Solderability	Difficult	Easier

CHAPTER 20

Dental Ceramics

Imagine a restorative material, that can accurately duplicate tooth structure, such that an average person may find it difficult to distinguish between the two (Fig. 20.1). Dental ceramics holds such a promise. One might argue that composite resins have a similar esthetic potential. However, there is a big difference—dental ceramics are certainly far more durable. They are far more stronger, 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.

USES AND APPLICATIONS

1. Inlays and onlays
2. Esthetic laminates (veneers) over natural teeth
3. Single (all ceramic) crowns
4. Short span (all ceramic) bridges
5. As veneer for cast metal crowns and bridges (metal ceramics)
6. Artificial denture teeth (for complete denture and partial denture use)
7. Ceramic orthodontic brackets

EVOLUTION OF DENTAL CERAMICS

Man has always been on the look out for material that could accurately reproduce missing teeth or teeth structure. Prior to the use of porcelain as a crown material dentists used crowns made of gold or other metal. One can obviously imagine their esthetics. Around the early 1900's porcelain crowns were introduced into dentistry. These crowns were known as *Porcelain jacket crowns (PJC)*. These early porcelain 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 gradually lost their popularity.

It was not until the late 1950’s and early 1960’s that research by McLean led to the discovery of ceramics that could bond to metal. This led to the era of the metal ceramics. Prior to this, metal bridges were veneered (covered) with tooth colored acrylic in order to hide the metal. These acrylics 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 bridges 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 today and represent almost 90 percent of all ceramic restorations made today.

The research into the *all ceramic crown*, however was not given up. 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 like the natural teeth. Under certain lighting conditions these crowns appeared dense 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, 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 solve the problem of translucency.

The first attempt at developing a stronger all ceramic restoration was 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 last decade or so, saw the reemergence of the *all ceramic crown*. This time the porcelain strength has been markedly improved through a variety of technological advances. The marginal adaptation had also improved considerably when compared to the first generation all porcelain crowns. The latest ceramics include *castable glass* ceramics, *shrink free* core ceramic, *injection moulded* core ceramic, high strength *glass infiltrated* alumina core ceramic, *CAD-CAM* (computer aided design, computer aided machining) ceramics, etc. One of the original drawbacks of the all porcelain crown materials were that they were not strong enough for all ceramic bridges. Today’s manufacturers claim that the modern porcelains are strong enough for to make an *all ceramic bridge* (the claims include anterior and *even posterior* bridges). 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.

CLASSIFICATION OF DENTAL PORCELAINS

According to Firing Temperature

High fusing	1300°	for denture teeth
Medium fusing	1101 to 1300°	” ”
Low fusing	850 to 1100°	for crown and bridge use
Ultra low fusing	less than 850°	used with titanium

According to Type

- Feldspathic or conventional porcelain
- Aluminous porcelain
- Leucite reinforced porcelain
- Glass infiltrated alumina
- Glass infiltrated spinell
- Glass ceramic.

According to Use

- Porcelain for artifical denture teeth
- Jacket crown, veneer and inlay porcelain
- Metal ceramics
- Anterior bridge porcelain.

According to Processing Method

- Sintered porcelain
- Cast porcelain
- Machined porcelain.

BASIC CONSTITUENTS AND MANUFACTURE

Because of the wide variety of porcelain products available in the market, it is virtually impossible to provide a single composition for them all. Traditionally, porcelains were manufactured from a mineral called *feldspar*. These porcelains are referred to as *feldspathic porcelains*. As porcelain technology improved other specialized porcelains were introduced, like reinforced core porcelains, opaquer porcelains, glass ceramics, glazes, etc. Obviously their composition would certainly differ from the traditional feldspathic porcelains. Our discussion will center around feldspathic porcelain.

Basic Structure

Basically porcelain is a type of glass. Therefore its basic structure 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 therefore known as *glass modifiers* or *fluxes*. Other substances which act like glass modifiers are alumina (Al_2O_3) and boric oxide (B_2O_3). Boric oxide forms its own separate network in 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 increase 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). It 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 (yellowish 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 Porcelain Powders

Glazes

It is a special type of colorless porcelain applied to the surface of the completed ceramic restoration to give it a glossy lifelike finish (Fig. 20.4F). Obviously they do not contain opacifiers. They must 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 (Figs 20.4G and 20.2).

Opaquer Porcelains

It is a specialized type of porcelain which is used to conceal the metal core in PFM (metal ceramic) restorations (Fig. 20.4A). 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 Porcelains

These are specialized porcelains containing a high concentration of a reinforcing material. The reinforced porcelains are stronger than regular feldspathic porcelains. They are used to create a strong inner core which imparts strength to the ceramic. A variety of reinforcing materials are currently being used. They include:

- Alumina (alumina reinforced porcelain)
- $MgAl_2O_4$ (spinell)
- Leucite (leucite reinforced porcelain).

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.

PARTS OF A CERAMIC RESTORATION

Currently, there are so many ceramic systems which can be quite confusing to the dental student. For simplicity of explanation we can divide the ceramic restoration into 2 parts (Fig. 20.1)

- Core (or substructure)
- Veneer

Core The core should be strong as it provides support and *strength* for the crown. Manufacturers have concentrated on strengthening the core through various means. The stronger the core, the stronger the crown. The core also functions as the *matrix*. The matrix is a supporting frame. Freshly mixed porcelain is like wet sand. It needs to be supported while it is being condensed and built up. The freshly built unfired

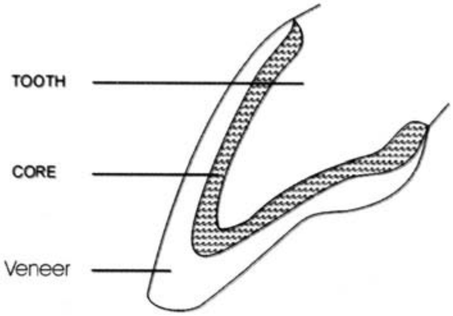


FIGURE 20.1: Parts of the ceramic crown

porcelain is very weak and fragile. Without the support of a matrix it would certainly breakup and collapse. The core is therefore usually constructed *first*. The rest of the restoration is built up on this core.

The cores or substructures are of two basic types depending on whether it is an all porcelain crown or a metal ceramic crown.

- Metal core
- Porcelain or ceramic core

Veneer The core is usually anesthetic. The esthetics is improved by additional layers of ceramic known as veneer porcelains. The core is veneered with various types of ceramic powders like dentin, enamel, cervical and transparent. It can also be surface stained 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 we have 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 constructed porcelains
    – Conventional porcelain jacket crown
    – Porcelain jacket crown with aluminous core
    – Ceramic jacket crown with leucite reinforced core (Optec HSP)

2. Castable glass ceramics (Dicor)
3. Injection moulded (leucite reinforced) glass ceramics (IPS Empress)
4. Glass infiltrated core porcelains
   - Glass infiltrated aluminous core (Inceram)
   - Glass infiltrated spinell core (Inceram spinell)
5. Ceramic restoration with CAD-CAM ceramic core
   - Glass ceramic blocks
   - Feldspathic porcelain blocks
6. Ceramic restoration with copy milled ceramic core (Celay)
   - Alumina blocks (Celay inceram)
   - $MgAl_2O_4$ (Inceram spinell)

METAL CERAMIC RESTORATIONS

Synonyms Porcelain fused to metal or PFM, metal bonded restorations.

The first porcelain jacket crowns (PJC) of a century ago did not have a strengthening core and were therefore very weak. Later in 1965, Mclean developed the aluminous core porcelains. The alumina reinforced core made the ceramic crown stronger by interrupting crack propagation. At around the same time, the metal-ceramic system was developed. The cast metal core (called coping) strengthened the porcelain restoration immensely and soon it became the most widely used ceramic restoration. According to a 1994 survey, 90 percent of all ceramic restorations are porcelain fused to metal.

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 mentioned in the classification, 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

This is one of the most commonest ways of constructing a ceramic restoration. Because of the strong metal frame it is possible to make long span bridges. 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 (Figs 20.2A and B).
2. Short and long span anterior and posterior bridges (Fig. 20.2C).

Composition of Ceramic for Metal Bonding

Feldspathic porcelains are used for metal bonding. The basic composition is quite similar 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 20.1.

Table 20.1: A sample percentage composition of porcelain powder for metal ceramics

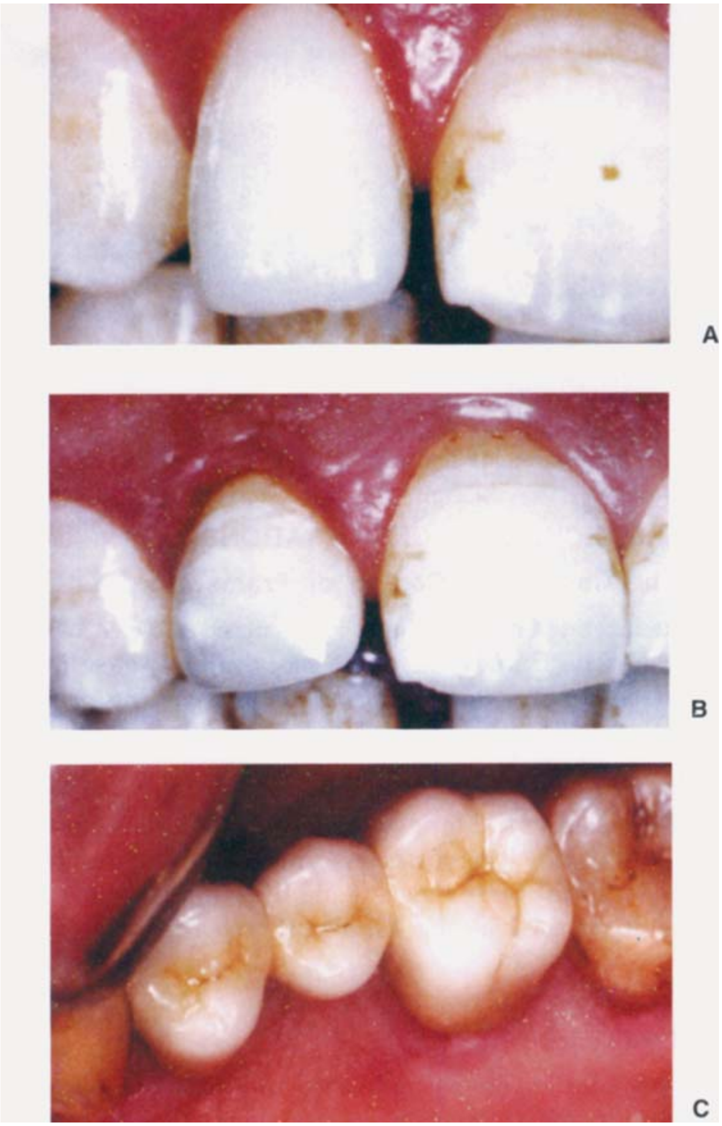
	Dentin porcelain	*Enamel porcelain*
Silica (SiO_2)	59.2	63.5
Alumina (Al_2O_3)	18.5	18.9
Soda (Na_2O)	4.8	5.0
Potash (K_2O)	11.8	2.3
Boric oxide (B_2O_3)	4.6	0.12
Zinc oxide (ZnO)	0.58	0.11
Zirconium oxide (ZrO_2)	0.39	0.13

A special opaquer powder is needed to mask the underlying metal so that it does not show through the ceramic (Figs 20.4A and B). The opaquer powder 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.

Supplied as

One typical kit (Fig. 20.3) consists of

1. Enamel porcelain powders in various shades (in bottles)
2. Dentin porcelain powders in various shades (in bottles)
3. Liquid for mixing enamel, dentin, gingival and transparent
4. Opaquer powders in various shades/ together with a liquid for mixing



FIGURES 20.2A to C: Metal-ceramic crown and bridge. Addition of stain improves the vitality of the crown. A - Lateral incisor before staining appears white and artificial; B - The same tooth after applying yellow brown cervical stains and white flourosis streaks and patches; C - Posterior bridge with occlusal fissure stains

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.

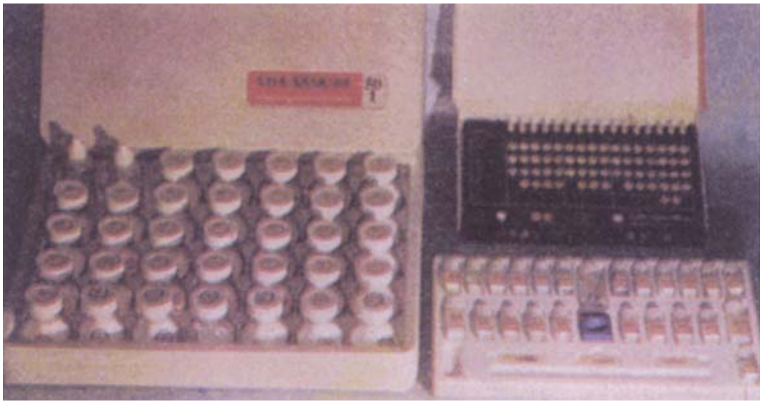


FIGURE 20.3: Various enamel, dentin, and opaquer powders with the modelling liquids (left box). Porcelain stains and glazes (right lower) and shade guide

MANIPULATION AND TECHNICAL CONSIDERATIONS

Construction of the Cast Metal Coping or Framework

A wax pattern of the intended restoration is constructed and cast in metal. A variety of metals are used for the frame, like 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 form 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. It is used to cover the metal frame and prevent it from being *visible*. 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. 20.4A). It is carried and applied on to the metal frame with a *brush* and

FIGURE 20.4A: Opaquer powder is a dense cream colored powder used to hide the metal. It is mixed with the modeling liquid to produce a sandy mix. A glass spatula is used for mixing as metal might abrade and contaminate the porcelain

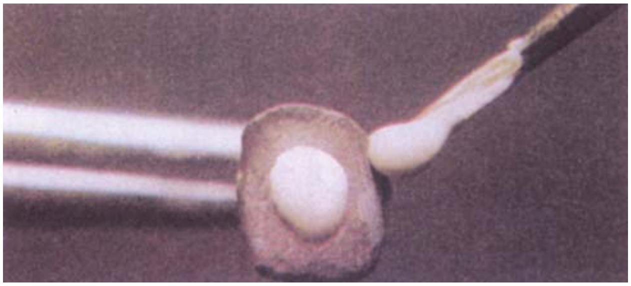


FIGURE 20.4B: The mixed material is applied with a brush. First an opaquer layer is applied to mask the underlying metal coping

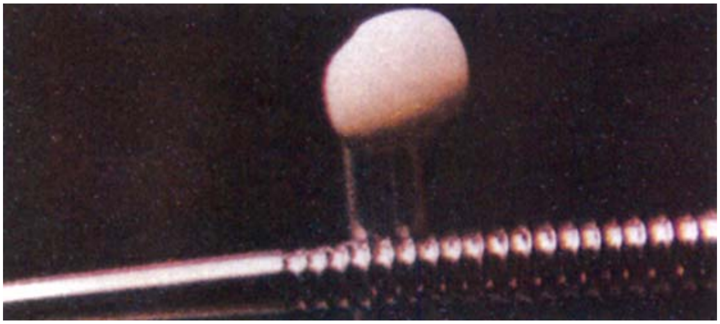


FIGURE 20.4C: Porcelain is condensed using mild vibrations. In this case a serrated instrument is used. The excess water which comes to the surface is gently blotted with tissue paper. The condensed material is placed in the furnace for firing

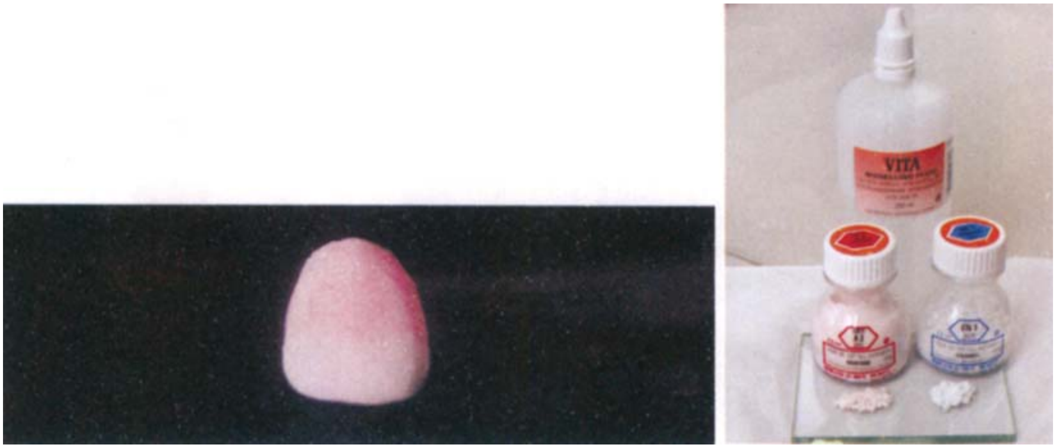


FIGURE 20.4D: Next dentin (pink) and enamel (white) porcelain of the desired shade is applied, condensed and fired. Unfired porcelain is usually color coded in order to differentiate between the different layers. The color changes after firing

FIGURE 20.4E: After each application the porcelain is fired in a computer controlled porcelain furnace at high temperatures

FIGURE 20.4F: The final step is the application of a glaze layer or self glazing. The above picture shows the completed restoration. Stains may be added or applied at any stage

FIGURE 20.4G: A variety of ceramic stains are used to improve the vitality of the artificial restorations

condensed (Figs 20.4B and C) (see condensation in box). The excess liquid is blotted with a tissue. The opaquer is built up to a thickness of 0.2 mm. The casting with the opaquer is placed in a porcelain furnace (Fig. 20.4E) and fired at the appropriate temperature (see firing in box). 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 the porosity and reduce the firing shrinkage. It also helps to remove the excess water.

Condensation Techniques

Vibration Mild vibration by tapping or running a serrated instrument on the forceps holding the metal frame by helps to pack the particles together and bring out the excess water. An ultrasonic vibrator is also available for this purpose.

Spatulation A small spatula is used to apply and smoothen the wet porcelain. This action 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 liquid supplied. 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. 20.4D). After the build-up and condensation is over, it is returned to the furnace for sintering.

Additions

It is not necessary to build up the restoration in one step. Large or difficult restoration may be built up and fired in 2 or 3 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.

Caution One must not subject the restoration to too many firings. Too many 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. cervical stains). Staining and characterization helps make the restoration look natural and helps it to blend in with the adjacent teeth (Fig. 20.2). The stain powders (Fig. 20.4G) 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.

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 the shape of the restoration by the dentist. The restoration is now ready for the final step which is the glazing. The restoration is smoothed with a stone prior to glazing.

Glazing is the process by which the restoration is given a smooth glossy surface. The competed restoration is seen in Figures 20.4F and 20.5.

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 (Fig. 20.4E). 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.

Objectives of glazing

1. Glazing enhances esthetics
2. Enhances hygiene
3. Improves the strength. Glazed porcelain is much stronger that unglazed ceramic. The glaze inhibits crack propagation.

4. Reduces the wear of opposing teeth. Unglazed porcelain can accelerate wear of the opposing natural teeth.

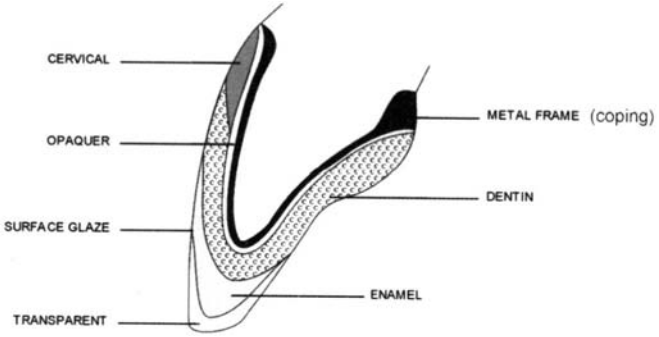


FIGURE 20.5: Parts of a metal ceramic crown. Transparent is used to duplicate the thin translucent enamel seen in some natural teeth. Cervical dentin is used to duplicate the darker cervical portions seen in some natural teeth

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 glazes 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 conventional abrasives. Porcelain is an extremely hard material and is quite difficult to polish. However, glazing is still 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 metals *chromic oxide* is responsible for the bond. In noble metal alloys *tin oxide* and possibly iridium oxide does this role.

Ocassionally one does come across a metal-ceramic restoration which has failed because of poor metal-ceramic bonding (Fig. 20.6).

Mechanical Interlocking

In some systems mechanical interlocking provides the principal bond. Presence of surface roughness on the metal oxide surface gives retention, especially if undercuts are present, wettability is important for bonding.

Advantages of Cast Metal Ceramic Restorations

1. Better fracture resistance because of the metal reinforcement.
2. Better marginal fit because of the metal frame.

Disadvantages

1. Comparatively less esthetic (when compared to the all porcelain crown) because of the reduced translucency as a result of the underlying metal and the opaquer used to cover it.
2. Margins may appear dark because of the metal. This sometimes shows through the gingiva causing it to appear dark and unesthetic.

FIGURE 20.6: A failed metal ceramic bridge. The ceramic veneer (canine) has delaminated leaving the metal exposed. In this case it was because of a poorly adherent metal oxide layer

OTHER METAL CERAMIC SYSTEMS

Swaged Gold Alloy Foil-Ceramic Crowns

Gold alloy foils (Renaissance and Captek) are a novel way of using metal without having to cast it. They come in a fluted form and is adapted to the die by swaging and burnishing. The foil coping is carefully removed and then flame sintered (fused). An *interfacial alloy* powder is applied and fired (it helps to bond the ceramic to the metal). Porcelain is then condensed and fired to form a crown.

Advantages

1. The thinner foil alloy coping allows a greater thickness of ceramic thereby improving the esthetics.
2. The underlying alloy is gold colored which gives more warmth and life to the restoration.

Bonded Platinum Foil-Ceramic Crowns

A platinum foil coping is constructed on the die. To improve the bonding of the ceramic to the platinum foil coping, an *electrodeposition technique* is used. 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 onto the metal. This is quickly 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. Improved 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.

THE ALL CERAMIC RESTORATIONS

The all ceramic restoration is a restoration without a metallic core or sub-structure. This makes them esthetically superior to the metal ceramic restoration (Fig. 20.6). Unfortunately they are not as strong. For a long time metal ceramics continued to be the restoration of choice. In the meantime, research continued on strengthening the ceramic core as manufacturers concluded that the *all ceramic restoration* would be esthetically superior to the metal ceramic restorations. Current developments have yielded stronger core porcelains. Ceramics have come a long way from the days when all porcelain was attempted only for single anterior crowns. Manufacturers today claim the new generation ceramics are capable of producing not only single crowns but anterior and even posterior all ceramic bridges as well.

The all ceramic restorations may be described under the following:

1. Porcelain jacket crowns
    - Porcelain jacket crown (traditional)
    - Porcelain jacket crown with aluminous core
2. Ceramic jacket crown with leucite reinforced core (Optec HSP)
3. Cast glass ceramic jacket crown (Dicor)
4. Injection moulded (leucite reinforced) glass ceramic jacket crown (IPS Empress)
5. Ceramic restoration with glass infiltrated aluminous core (Inceram)
6. Ceramic restoration with glass infiltrated spinell core (Inceram spinell)
7. Ceramic restoration with CAD-CAM ceramic core
    - Glass ceramic blocks
    - Feldspathic porcelain blocks
8. Ceramic restoration with copy milled ceramic core (Celay)
    - Alumina blocks (Celay inceram)
    - $MgAl_2O_4$ (Inceram spinell)

PORCELAIN JACKET CROWN

The all porcelain crown (PJC) has been around since a century. However, as mentioned before these were very brittle and fractured easily (half moon fractures). The marginal adaptation was also quite poor. Because of these problems its popularity gradually waned. This prompted *McLean and Hughes* to develop the PJC with an *alumina reinforced core in 1965*. This crown was developed in an attempt to improve the strength of the earlier porcelain jacket crowns. The increased content of alumina crystals (40 to 50 percent) in the core strengthened the porcelain by interruption of crack propagation. The composition of the aluminous core porcelain crown is shown in Table 20.2.

Table 20.2: A sample percentage composition of powder meant for an all porcelain (alumina reinforced) crown

	Aluminous core	*Dentin porcelain*	*Enamel porcelain*
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)			

Types

1. Porcelain jacket crown (traditional).
2. Porcelain jacket crown with aluminous core.

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*'.

Technical Considerations

The porcelain jacket crowns are made using the platinum foil matrix technique.

Platinum Foil Matrix

The porcelain jacket crowns are constructed with high fusing feldspathic porcelains. A platinum foil is first adapted to the die. The platinum foil functions as matrix. It supports the porcelain during condensation and firing. After completion of the restoration the platinum foil matrix is discarded.

Condensation and Firing

The platinum foil matrix is carefully removed from the die and the core porcelain is carefully condensed on to it. It is then placed in the furnace and fired. After cooling, the rest of the body is built up using dentin, enamel and other porcelains. The completed restoration is shown in Figure 20.7.

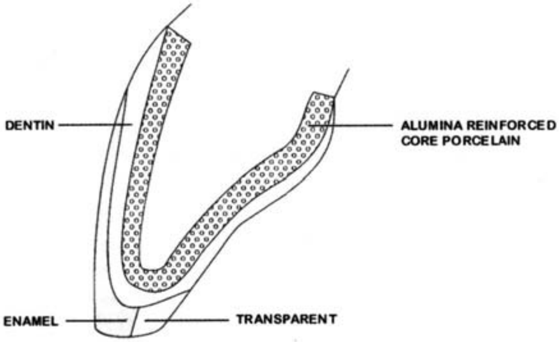


FIGURE 20.7: The porcelain jacket crown with aluminous core

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).

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.

Uses

Inlays, onlays, veneers and low stress crowns.

CASTABLE GLASS CERAMIC (DICOR)

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 crown made by a centrifugal casting technique. The ‘ceramming’ process is also quite unique to this porcelain.

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 crown pattern is first constructed in wax and then invested in investment material like a regular cast metal crown.
2. After burning out the wax, nuggets of Dicor glass is melted and cast into the mould in a centrifugal casting machine.
3. The glass casting is carefully recovered from the investment by sandblasting and the sprues are gently cut away.
4. The glass restoration is then covered with a protective ‘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 improve the strength of the glass. It also reduces the transparency of the glass making it more opaque and less glass like.

6. The cerammed glass is now built up with dentin and enamel (special veneering porcelain), condensed and fired to complete the restoration.

Features

The Dicor glass-ceramic crown is very esthetic. This is because of the absence of an opaque core (unlike the previous porcelains). 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.

INJECTION MOULDED GLASS-CERAMIC (IPS EMPRESS) (Fig. 20.8)

This is another ceramic material which again is quite unlike the previous ceramics because of its unique way of fabrication (injection moulding). It is a precerammed glass-ceramic having a high concentration of leucite crystals. The manufacturer blends it with *resins* to form cylindrical blocks. The resins being thermoplastic, allows the material to be injection moulded.

FIGURE 20.8: Injection moulded ceramic (IPS empress) is available in the form of small resin/ceramic nuggets

Fabrication

1. Using a wax pattern a mould is prepared in dental stone.
2. The resin-ceramic block is heated to 180°C and injected under air pressure of 1,500 psi into the mould.
3. The core (or crown) is retrieved from the flask and fired for several hours to a maximum temperature of 1300°C. During the firing, the resin is burnt off leaving behind a rigid leucite reinforced ceramic core.
4. The core is built up and fired using veneering porcelains in the conventional way.

5. It can also be directly fabricated as a crown in which case, the crown is stained and glazed directly.

Advantages

1. The crown is supposed to be having a better fit (because of the lower firing shrinkage).
2. The esthetics is better because of the lack of metal or an opaque core.

Disadvantages

1. Need for costly equipment
2. Potential of fracture in posterior areas.

Uses

Inlays, onlays, veneers and low stress crowns.

GLASS INFILTRATED ALUMINA CORE (INCERAM)

This ceramic system has a unique *glass infiltration process* and the first of its kind claimed for anterior bridge fabrication. The glass infiltration process compensated for firing shrinkage.

Fabrication

1. Two dies are required. One in stone and the other in *refractory die* material.
2. A slurry of alumina is prepared and deposited on the refractory die using the *slip cast* method (the water from the slurry is absorbed by the porous die leaving a layer of alumina on the surface). The process is continued until a alumina coping of sufficient thickness is obtained.
3. The fragile slip cast alumina coping is dried at 120°C for 2 hours.
4. The alumina coping is sintered for 10 hours at 1100°C.
5. The next step is *glass infiltration.* A slurry of glass material is applied on to the sintered alumina coping and fired for 3 to 5 hours at 1120°C. The glass fuses and infiltrates into the porous alumina coping.
6. The excess glass forms a glassy layer on the surface which is trimmed off using special diamond burs.
7. The coping is now ready for the rest of the build up using dentin and enamel veneering material (Fig. 20.9).

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 bridge use.

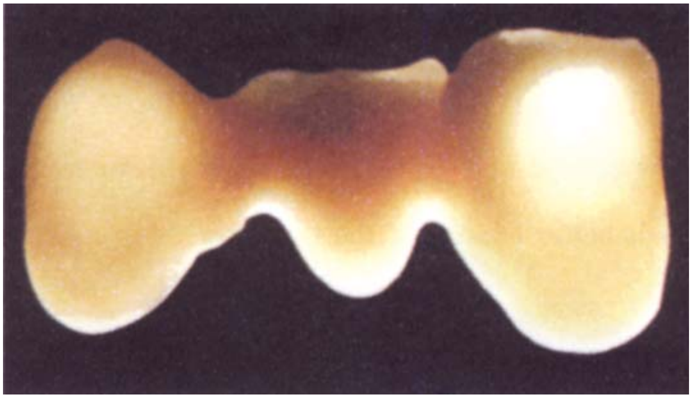


FIGURE 20.9: Inceram substructure for a bridge; An all-ceramic restoration is esthetically superior to metal ceramic restoration

Disadvantages

1. Comparatively less esthetic because of the opacity of the alumina core.
2. Quite tedious to fabricate.
3. Not all the bridges were successful, a few of them did fracture occasionally.

Uses

In addition to the usual inlays, onlays, veneers and low stress crowns, this material can be used to construct low stress anterior bridges. Because of its occasional tendency to fracture when used for bridge construction its use should be carefully selected

1. For people allergic to metal based bridges
2. Where esthetics is absolutely critical

Glass Infiltrated Spinell Core (Inceram Spinell)

Inceram spinell is an offshoot of In-ceram. Because of the comparatively high opacity of the alumina core, a new material was introduced known as Inceram spinell. It used $MgAl_2O_4$ instead of alumina. The fabrication is similar to the conventional Inceram.

The Inceram spinell was more translucent and therefore more esthetic compared to the alumina core. Since the strength is lower, its use is limited to low stress situations.

CAD-CAM CERAMICS

Many companies (e.g. Cerec, Germany) have come out with ceramics that can be ground into shape with the aid of a computer. These are known as *computer aided design-computer aided machined ceramics* or *CAD-CAM ceramics.*

Supplied as

Blocks of dense ceramic material, e.g. Feldspathic porcelain blocks (Vitablocs MK II) or glass-ceramic blocks (Dicor MGC).

Fabrication

1. The prepared crown or inlay cavity is scanned and fed into the computer.
2. Signals from the computer operate the milling machine which grinds the *internal surface* of the inlay or crown in accordance with the scanned image. The earlier models ground only the internal surface. The external surface had to be manually ground. Current CAD-CAM machine models can grind the external surface also (Fig. 20.10).

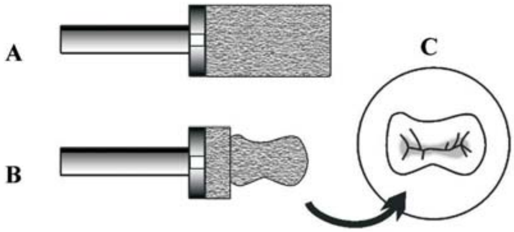


FIGURE 20.10: A—Ceramic block before milling; B—Ceramic block after completion of milling; C—Completed inlay after grinding of external morphology and glazing

Advantages

1. Reduced chair time
2. No need to make impression
3. Reduced porosity, therefore greater strength
4. Single appointment (especially for inlays).

Disadvantages

1. Costly equipment
2. Scanning the preparation is technique sensitive.

COPY MILLED CERAMICS

A new system (Celay by Mikron Technologies, Switzerland) uses a copy milling technique to produce ceramic cores or substructures for bridges. A similar copy milling process is used to produce duplicate keys. The original key is placed in the machine. A tool passes over the key tracing its outline. In the meantime, a milling machine simultaneously grinds a blank key to match the traced outline. The primary difference between this and the earlier system (CAD-CAM) is the manner in which the tooth dimensions are picked up. One scans the object whereas the other traces the object.

Blocks Used

Currently blocks of Inceram and Inceram spinell are available for copy milling.

Uses

This technology is used to make substructures for crowns and bridges.

Fabrication

1. A pattern of the coping or substructure is created using a special blue. The pattern may be created directly in the mouth or on a die made from an impression.
2. The pattern is placed in the machine. A tracing tool passes over the pattern and guides a milling tool which grinds a copy of the pattern from a block of ceramic (Inceram or In-ceram spinell).
3. The completed coping or bridge substructure is then glass infiltrated (as described earlier).
4. The glass infiltrated substructure is built up with veneering porcelain and fired to complete the restoration.

PROPERTIES (GENERAL) OF FUSED PORCELAIN

Again, because there are so many ceramic systems available there will be slight differences in the properties between them.

Strength

Porcelain has good strength. However, it is brittle and tends to fracture. 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. Glazed porcelain is stronger than ground porcelain.

Ground – 75.8 MPa
Glazed – 141.1 MPa.

Compressive strength (331 MPa) Porcelain has good strength.

Tensile strength (34 MPa) 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 (110 MPa) is low and is due to the lack of ductility caused by the complex structure of porcelain.

Factors affecting strength
- — *Composition*
- — *Surface integrity* Surface imperfections like microscopic cracks and porosities reduce the strength.
- — *Firing procedure* Inadequate firing and overfiring weakens the structure.

Modulus of Elasticity

Porcelain has high stiffness (69 GPa).

Surface Hardness

Porcelain is much harder (460 KHN) than natural teeth. It can wear natural teeth. Thus, it should be very carefully placed opposite natural teeth.

Wear Resistance

They are more resistant to wear than natural teeth.

Thermal Properties

Thermal conductivity Porcelain has low thermal conductivity.

Coefficient of thermal expansion (6.4 to 7.8 × 10^{-6}/°C). It is close to that of natural teeth.

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 (Fig. 20.11). Etching improves the bonding of the resin cement.

FIGURE 20.11: Ceramic etchant consists of hydrofluoric acid. A neutralizing powder is also supplied to neutralize this highly dangerous acid after use.

Esthetic Properties

The esthetic qualities of porcelain are excellent. It is able to match adjacent tooth structure in translucence, color and intensity (In addition, attempts have also been made to match the fluorescent property of natural teeth when placed under ultraviolet light, e.g. in discotheques). The color stability is also excellent. It can retain its color and gloss for years.

Certain esthetic concerns have been raised when the dense opaquer layer is visible through thin crowns (in metal ceramic and Inceram crowns). However, this is more of an error in technique. The dentist must ensure an adequate depth of preparation (atleast 1.2 to 1.4 mm) to ensure sufficient thickness of dentin/enamel veneer to mask the opaquer. The technician on the other should ensure correct thickness of opaquer.

Biocompatibility

Excellent compatibility with oral tissues.

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 bridges. 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 certainly 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

Certain ceramic restorations, especially *veneers* and *inlays*, have to be etched prior to bonding using resin cement. Etching improves the bond of the resin to the ceramic. Etching is done using *hydrofluoric acid* (Fig. 20.11) which attacks and selectively dissolves the inner surface of the ceramic. The tooth surface is also etched using phosphoric acid. Before placing the cement, a bond agent is applied to both surfaces (tooth and porcelain).

Caution Extreme care must be taken when handling hydrofluoric acid. Severe acidic burns may result if it accidentally contacts the skin.

Cementing Metal-Ceramic Crowns and Bridges

These are cemented like conventional restorations. The cement does not affect the esthetics because it is not visible through the restoration. Any convenient cement may be used.

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 moulds and fired 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.

The disadvantages of porcelain denture teeth are:

- They are brittle and make a clicking sound during contact.
- 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 that provide their only means of retention.
- The higher density increases their weight.

CHAPTER 21

Wrought Alloys

Wrought alloys are obtained from cast alloys. A wrought alloy is one that has been worked or shaped into a serviceable form, e.g. plate and band materials, bars, and various prosthodontic and orthodontic wires.

Structure of Wrought Alloys

Wrought alloys have a fibrous structure which results from the cold working applied during the drawing operation to shape the wire.

GENERAL PROPERTIES OF ORTHODONTIC WIRES

Orthodontic wires are formed into various configurations or appliances in order to apply forces to teeth and move them into a more desirable 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* The force applied to a tooth is proportional to the wire's stiffness. Biologically, low constant forces are less damaging. This is best achieved by large elastic deflections because they produce a more constant force and have a greater *'working range'.* Range is defined as the distance that the wire will bend elastically before permanent deformation occurs.
- *Springiness* Is a measure of how far a wire can be deflected without causing permanent deformation.
- *Stiffness* Is a measure of the amount of force required to produce a specific deformation

  Stiffness = 1/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.
- *Biocompatibility* in the oral cavity.

TYPES

- Wrought gold alloys
- 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. Wires and other wrought forms normally show better mechanical properties when compared to cast structures. This is due to the cold working. Thus, they have better hardness and tensile strength.

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 upon the lattice arrangements of iron.

- Ferritic
- Martensitic
- 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, 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 temperature 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%

Uses

This alloy is also called as *18-8 stainless steel.* These are used most commonly by the orthodontist and pedodontist in the form of bands and wires (Fig. 21.1). Type 316 L (contains carbon-0.03% maximum) is the type usually used for implants.

FIGURE 21.1: Various wrought structures. Flexiloy wires have a triangular cross section. Dentaflex co-axial is a braided wire. Wrought prosthodontic clasps are also displayed

Advantages

Austenitic steel is preferable to the ferritic alloys because of the following 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.

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)

- From a theoretical point, reduce the carbon content of the steel to such an extent that carbide precipitation cannot occur. However, this is not economically practical.
- 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 called 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. 21.1).

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.

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. Flouride helps to dissolve the passivating film supplied by the chromium.
- Boric acid is used in a greater ratio to the borax, which 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 (Fig. 21.1).

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

These nickel-titanium alloy (nitinol) (Fig. 21.1) wires have large elastic deflections or working range and limited formability, because of their low stiffness and moderately high strength.

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) 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, or pseudoelasticity. At the completion of the phase, behavior 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.

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) or beta crystal.

Alpha-titanium is not used in orthodontic applications, since they do not have improved springback characteristics. The beta form of titanium can be stabilized down to room temperature by the addition of elements like molybdenum. Beta-titanium alloy in wrought wire form is used for orthodontic applications.

COMPOSITION

Ti - 11%
Mo - 6%
Zr - 4%
Sn

MECHANICAL PROPERTIES

- Modulus of elasticity – 71.7 × 10^3 MPa.
- Yield strength –860 to 1170 MPa.
- The high ratio of yield strength to modulus produce orthodontic appliances that can undergo large elastic activations when compared with stainless steel.
- Beta-titanium can be highly cold–worked. It can be bent into various configurations and has formability comparable to that of austenitic stainless steel.
- Welding: clinically satisfactory joints can be made by electrical resistance welding of beta-titanium.
- Corrosion resistance: both forms have excellent corrosion resistance and environmental stability.

CHAPTER 22

Soldering, 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.

TERMS AND DEFINITIONS

Metal joining operations are usually divided into four categories: welding, brazing, soldering, and cast-joining (discussed at the end).

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 (filler) metal.

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 (Fig. 22.1).

Note: In dentistry, the joining of metal parts are done at temperatures above 450°C, and therefore the operation should ideally be called brazing. However, most dentists still prefer to use the word soldering. Also some authors use the term 'brazing filler metal' for solder.

IDEAL REQUIREMENTS OF A DENTAL SOLDER

1. It should melt at low temperatures
2. When melted, it should be wet and flow freely over the parent metal

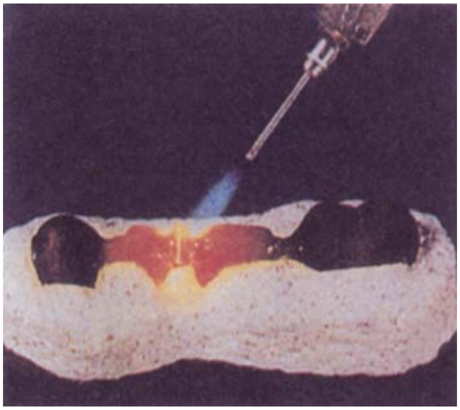


FIGURE 22.1: Flame soldering of a two part metal bridge after embedding in soldering investment

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

They may be divided into two major groups:

- Soft solders
- 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 have greater strength and hardness. They are melted with the help of gas blow-torches or occasionally in an electric furnace. Hard solders are more commonly used in dentistry. They are also used for industrial purposes and in the jewellery trade, e.g. gold solders and silver solders.

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 (Fig. 22.1)
- For repair of perforations in crowns and bridges
- To develop contact points in crowns.
- For cutting and rejoining an illfitting distorted bridge.

3. In removable partial prosthodontics for soldering of clasps.

Improving the fit of a bridge through soldering

The fit of a bridge is often improved when it is cast as *two separate pieces*. Long span bridges are especially prone to poor fit because of distortion. The two parts of the bridge are tied 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 (Fig. 22.1). If done correctly this technique can give superior fitting bridges.

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 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. 22.2) 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 solders are composed of:

Silver	– 10 to 80%
Copper	– 15 to 50%
Zinc	– 4 to 35%

Cadmium or phosphorous may be present in small amounts

FIGURE 22.2: Representative commercial solders and fluxes

PROPERTIES OF DENTAL SOLDERS

Fusion Temperature

The fusion temperature of the solder should be atleast 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 of the parent metal by the solder is essential to produce a good bond.

The following factors affect flow:
- Melting range: Solders with short melting ranges have better flow.
- Composition of parent metal: Gold and silver based alloys have better flow than nickel based alloys.
- Oxides: Presence of an oxide layer on the parent metal reduces the flow.
- 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 (Fig. 22.2).

FUNCTION OF FLUX

1. To remove any oxide coating on the parent metal
2. To protect the metal suface 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 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

Boric and Borate Compounds

E.g. boric acid and borax. They are used with noble metal alloys. They act as protective and reducing fluxes.

Fluorides

E.g. potassium fluorides. These are used on base metal alloys and are usually combined with borates. They help to dissolve the more stable chromium, nickel and cobalt oxides.

FLUXES MAY BE SUPPLIED AS

- Liquid (applied by painting)
- Paste
- Powder
- Fused onto the solder
- Prefluxed solder in tube form.

TECHNICAL CONSIDERATIONS

HEAT SOURCE

The heat source is a very important part of brazing. In dentistry, two heat sources may be used:

1. Flame brazing (Fig. 22.1)
2. Oven brazing.

Flame Brazing

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. This flame is not indicated for soldering of large bridges (Fig. 22.1).
- *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 non-uniform in composition and frequently contains water vapor.

- *Acetylene:* It has the highest flame temperatue (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 bridge 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 (Fig. 22.1). 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 bridge 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.

Requirements 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. Thus, an optimum gap is necessary for proper flow and strength of the joint and to avoid distortion of the assembly. Gap width ranging from 0.13 to 0.3 have been suggested as optimum.

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.

Flame

The portion of the flame that is used should be neutral or slightly reducing. An improperly adjusted and positioned flame can lead to oxidation and/or possibility of 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. Higher temperature increases the possibility of diffusion between parent and filler metal.

Time

The flame should be kept in place 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. Shorter time increases chances of incomplete filling of joint and possibility of flux inclusion in the joint. Longer times increases possibility of diffusion. Both conditions cause a weaker joint.

ANTIFLUX

There are times when the operator desires that the solder should not flow into a specific area. The flow can be prevented by use of an antiflux material. It is applied to the surface before the flux or solder is applied. Solder will not flow into an area where antiflux has been applied. Examples of antiflux are graphite (soft lead pencil), rouge (iron oxide) or whiting (calcium carbonate) in an alcohol and water suspension.

PITTED SOLDER JOINTS

Pits or porosites in the solder joint often become evident during finishing and polishing. 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 (Fig. 22.3). 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'.

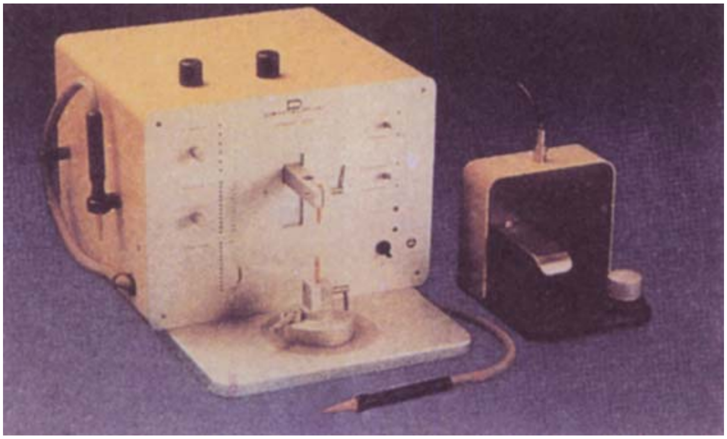


FIGURE 22.3: An electric orthodontic spot welder

Prosthodontic appliances are welded in a larger machine. The parts to be joined are held together using a special 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.

LASER AND PLASMA WELDING

Laser welding units are now available. The laser used is usually a pulsed high-power 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 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.

Indications

Laser welding is used mainly to join titaniums components. This is because the commercially pure titanium (cpTi) used in dentistry for bridges and 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. No oxide formation because of the inert argon atmosphere
3. 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.

FIGURE 22.4: A mechanical interlocking design between two parts to be joined by cast-metal

The joint area is ground to make a space of at least 1 mm. Mechanical undercuts are prepared at the inter-phase (Fig. 22.4). 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 bridge is then invested in a casting ring using suitable casting investment. The wax is burnt out and molten metal is cast into the space.

CHAPTER 23

Abrasion and Polishing Agents

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, an acrylic denture base may have minor surface roughness. This has to be removed before polishing.

A rough surface is:

- Uncomfortable to the patient
- Food and other debris cling to it and makes it unhygienic
- Tarnish and corrosion may occur.

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 (Glossary).

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 (Fig. 23.1).

- *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 belongs to this category.
- *Stainless steel coated strips:* The abrasive (e.g. diamond) may be attached to stainless steel or plastic strips (used for proximal stripping of teeth). This category is similar to the above.

FIGURE 23.1: Abrasive and polishing materials come in a wide variety of shapes and forms

- *Electroplating bonding:* In case of diamond rotary instruments the diamond chips are attached to steel wheels, discs and cylinders by electro-plating with nickel based matrix.
- *Bonded stones:* In grinding wheels and dental stones, the abrasive particles are mixed with a bonding agent that holds the particles 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 and 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.
- *Cake form:* They are also available in the form of cakes.
- *Rubber impregnated:* Abrasives can be incorporated into rubber or shellac discs or cups for “soft grade” abrasion.
- *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 properties of the abrasive as well as the material being abraded. The important properties are hardness, strength, ductility and thermal conductivity.

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.

STRESS, STRAIN AND HEAT PRODUCTION DURING ABRASION

While abrading metals, the crystalline structure of the metal is disturbed to depth of 10 um. 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. Also 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.

Linear speed is related to rotational speed according to the following formula:

V = gama dn where V = linear speed
d = diameter of the abrasive
n = revolutions per minute

CLASSIFICATION

A. Finishing abrasives
B. Polishing abrasives
C. Cleansing abrasives.

Finishing Abrasives

Finishing abrasives are hard, coarse abrasives which are used initialy 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 aluminium 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. Pure alumina is also used as a polishing agent.

Aluminium Oxide

Pure alumina is manufactured from bauxite, an impure aluminium oxide. It can be produced in fine grain sizes and has partially replaced emery for abrasive purpose.

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. 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

Occurs in nature as zircon. This mineral is ground to various particle sizes and used as polishing agent. 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

- 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 face to the work and so they are not effective. Irregular and jagged particles are more effective.
- 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.
- 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 susbtances from the tip. They become clogged

when used on ductile metals. They are most effective when used on brittle tooth enamel.
- 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 passes through and does not pass through a smaller sieve. 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.
- Ceramic bonding is used for silicon carbide or corundum in a mounted abrasive point.
- Electroplating with nickel base matrix is often used to bind diamond chip in diamond rotary instruments.
- For soft grade discs, rubber 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. The cutting efficiency of diamond rotary instruments depends on whether the diamonds used are natural or synthetic, the grit size, the distribution and the extent of plating that attaches the particles to the instrument shank. Adequate water spray is essential not only to minimize heat but also to reduce clogging.

Note Bur design has not been discussed in this chapter as currently, many authors are of the view that the topic is not within the scope of dental materials.

POLISHING

It is 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.

NON-ABRASIVE POLISHING

Polishing is usually achieved by an abrasive process. However, a smooth shiny surface can also be achieved through non-abrasive means. These include:

1. Composite glazing
2. Ceramic glazing
3. Electrolytic polishing.

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 highly 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

Electrolytic polishing is not truly an abrasive process. Although material is removed, it is removed through an *electrochemical process* rather an abrasive process.

Figure 23.2: An electrolytic polishing unit. The casting is suspended inside the bath (anode). Polishing is achieved when minute quantities of oxide and surface metal is removed electro-chemically

This is the reverse of electroplating. The alloy to be polished is made the anode of an electrolytic cell (Fig. 23.2). 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 caried 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, sand blasting to remove investment of castings, shell blasting, etc.

- Smoothen work with a coarse abrasive or bur which leaves large scratches. These scratches are removed with smaller (finer) abrasives but the difference in fineness should not be too great. The use of too fine an abrasive after a relatively coarse abrasive wastes time and may cause streaking.
- 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).
- 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 and remove, 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 too much heat generating (especially in resins).

DENTRIFICES

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 dentrifices 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.

Thus, they help to reduce caries, maintain healthy gingiva, improve esthetics and reduce mouth odors.

Available As

Pastes, powders, liquid and gels.

Composition

• Abrasives	Dibasic calcium phosphate Calcium carbonate (not used now - too abrasive) Calcium pyrophosphate Insoluble sodium metaphosphate Hydrated silica (most efficient) Alumina Magnesium oxide, etc.	
• Water		
• Humectants	Glycerin Sorbitol Propylene glycol	To keep paste from drying out
• Detergents	Sodium lauryl sulfate	Decreases surface tension of dentrifrice
• Foaming agents		
• Binders	Carboxy methyl cellulose	
• Artificial Sweeteners	Sorbitol Saccharin	
• Therapeutic agents	Sodium fluoride Stannous fluoride Strontium chloride	Anticariogenic
	Urea Pencillin	Bacteriostatic and Bactericidal
	Dibasic ammonium-phosphate	Acid neutralising
• Coloring and flavoring	Mint	

PROPHYLACTIC PASTE

Oral prophylaxis is a widely used procedure in the dental office. Prophylactic paste 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. 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, magnesium 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 which are attached to a rotary instrument.

Prophyjet

The Prophyjet is a relatively new dental prophylaxis system of removing intraoral stains. An abrasive blasting process is used to mechanically remove extrinsic (tobacco) stains as well as light supragingival adherent plaque and calculus. The powder is loaded into the cleaning device, which then directs the abrasive through a small nozzle in a steady *stream* of air and water.

Composition Consists of Sodium carbonate, hydrophobic modified silica and some flavoring agent. The abrasive is available as powder in a small sachet.

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.

DENTURE CLEANSERS

Dentures collect deposits in the same manner as natural teeth during their use. These can be removed by 2 ways:

- Professional—repolishing in the laboratory or clinic.
- Soaking or brushing the dentures daily at home.

Brushing

The dentures may be brushed using a soft bristle brush and gentle abrasive or cream. Hard abrasive and stiff bristles should be avoided because they may produce scratches on the denture surface.

Soaking

Chemical cleaners 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 non-toxic, non-irritant and should not attack the materials used in denture construction.

CHAPTER 24

Tarnish and Corrosion

Except for a few, pure metals do not occur naturally. They occur in the form of minerals such as oxides and sulphides 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 favorably 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:

- Formation of hard and soft deposits on the surface of the restoration, e.g. calculus, mucin and plaque.
- Pigment producing bacteria, produce stains.
- 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. This 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 in corrosion, oxygen and chloride have been said to be responsible for amalgam corrosion both at the tooth interface and within the body of amalgam. Sulfide has been implicated for corroding silver containing casting alloys.

CLASSIFICATION OF CORROSION

Chemical or Dry Corrosion

In which the metal reacts to form oxides, 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 loses electrons and the cathode consumes. The surface of 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 EMF series.

Some of the EMF Values are

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

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. 24.1).

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. An other variation of galvanic corrosion can occur even in a lone standing restoration (Fig. 24.2).

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, part of a grain can be anode and part cathode. Homogenization improves the corrosion resistance of the alloy.
- In metals or alloy, the grain boundaries may act as anodes and the interior of the grain as the cathode.

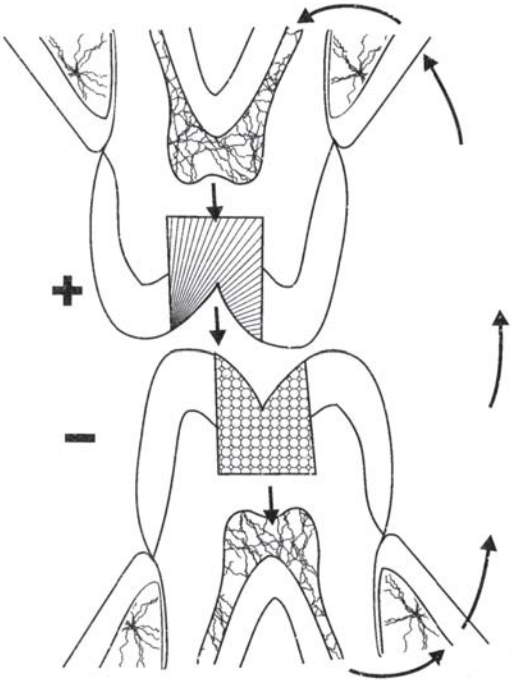


Figure 24.1: Representation of a potential galvanic current pathway when dissimilar metals contact. The tissue fluid and saliva behaves like an electrolyte. The shock produced can be quite uncomfortable initially

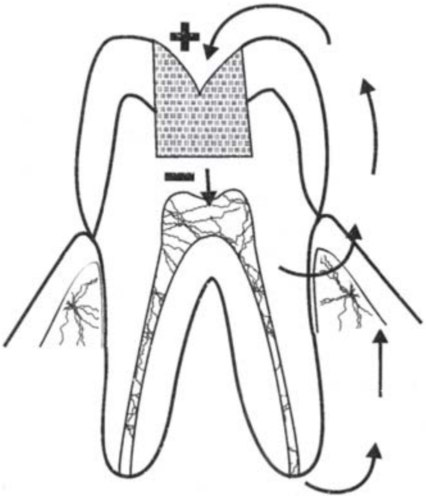


Figure 24.2: A current pathway may exist even in a single metallic restoration. In this case the tissue fluid behaves like a cathode (because of the higher concentration of Cl^- ions in tissue fluid when compared to saliva) whereas saliva behaves like the anode. This current is usually less intense

- Solder joints may also corrode due to the inhomogenous composition.
- Impurities in any alloy enhance corrosion.

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.

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 deoris, 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 occur in the part of the restoration having lower concentration of oxygen.

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

PROTECTION AGAINST CORROSION

Passivation

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

If more than 12% Cr is added to iron or cobalt, we get stainless steel or cobalt chromium alloys, which are lightly corrosion resistant and therefore suitable for dental use. 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 atleast 50% atoms in a dental alloy should be gold, platinum and 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 hygeine.

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, care must be taken to protect gold ornaments worn by the operator, assistant or patient.

CHAPTER 25

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. However, it is only recently that factors needed for its success have been understood.

DEFINITION

A dental implant is a material or device placed in and/or on oral tissues to support an oral prosthesis (GPT-6).

TYPES OF IMPLANTS

A. *Subperiosteal* a framework that rests upon the bony ridge but does not penetrate it (Fig. 25.1).
B. *Transosteal* penetrates completely through the mandible.
C. *Endosseous* partially submerged and anchored within the bone (Figs 25.2 and 25.3).

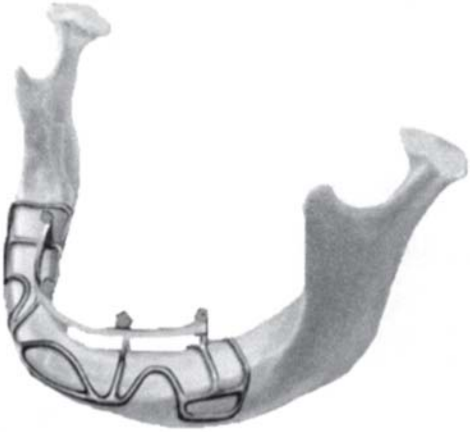


FIGURE 25.1: A subperiosteal implant

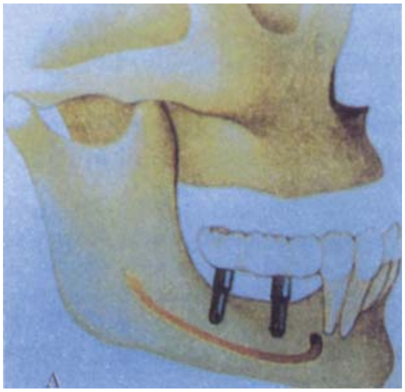


FIGURE 25.2: An endosseus titanium dental implant in the shape of a screw is used to support teeth

MATERIALS USED

Metals

- Stainless steel
- Cobalt-chromium-molybdenum based
- Titanium and its alloys
- Surface coated titanium.

Ceramics—hydroxy apatite

- Bioglass
- Aluminium oxide

Polymers and composites

Others gold, tantalum, carbon, etc.

Currently, the vast majority of implant systems use titanium in some form.

STAINLESS STEEL

18-8 or Austenitic steel is used. It has high strength and ductility.

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.

TITANIUM

Commercially pure titanium (cp Ti) has become one of the materials 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.

Its alloyed form contains 6 wt.% aluminium 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*.

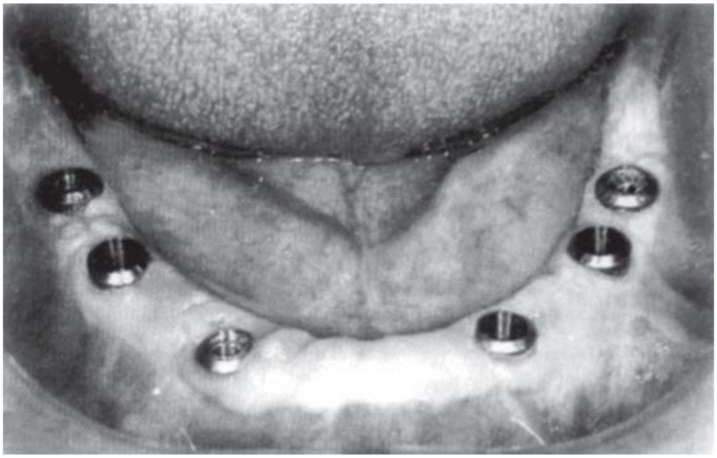


FIGURE 25.3: Six titanium screw implants in the mandibular edentulous jaw. These will be used to support a fixed screw retained complete denture later

CERAMICS

These may be *bioactive* on *bioinert*. Their applications are still limited because of their low tensile strength and ductility.

Bioactive, e.g.

- Hydroxyapatite
- Bioglass (CaO, NaO, P_2O_5 and SiO_2)

Bioinert, e.g. aluminium oxide—used either in the polycrystalline form or as a single crystal (sapphire). It is well tolerated by bone but does not promote bone formation. Available in screw or blade form and are used as abutments in partially edentulous mouths.

POLYMERS AND COMPOSITES

Polymers have been fabricated in porous and solid forms for tissue attachment and replacement augmentation. However, they are mainly used within some 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. Some of these older materials are still in use today.

Carbon compounds were used for root replacement in the 1970's. They are also marketed as coatings for metallic and ceramic devices.

Appendix

Appendix of Conversion Factors

To Convert From	*To*	*Multiply By*
Force		
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

List of American National Standards Institute/American Dental Association Specifications on Dental Materials, Instruments, and Equipment

Number	*Title*	*Date of specification or latest revision, addendum or reaffirmation*
1	Alloy for dental amalgam	1985
2	Gypsum-bonded casting investment for dental gold alloy	1987
3	Dental impression compound	1987
4	Dental inlay casting wax	1989
5	Dental casting gold alloy	1988
6	Dental mercury	1987
7	Dental wrought gold wire alloy	1989
8	Dental zinc phosphate cement	1987
9	Dental silicate cement	1986
10	Denture rubber (obsolete)	—
11	Dental agar impression material	1987
12	Denture base polymers	1987
13	Denture cold-curing repair resin	1987
14	Dental base metal casting alloy	1989
15	Synthetic resin teeth	1985
16	Dental impression paste—zinc oxide-eugenol type	1989
17	Denture base temporary relining resin	1990
18	Dental alginate impression material	1989
19	Elastomeric dental impression materials	1982
20	Dental duplicating material	1989
21	Zinc silico-phosphate cement	1987
22	Intraoral dental radiographic film	1972
23	Dental excavating burs	1984
24	Dental baseplate wax	1991
25	Dental gypsum products	1989
26	Dental X-ray equipment	1991
27	Direct filling resins	1989
28	Endodontic files and reamers	1988
29	Hand instruments	1987
30	Zinc oxide-eugenol restorative materials	1990
31	Exposure time designation for timers of dental X-ray machines	—
32	Orthodontic wires	1989
33	Dental terminology	1990
34	Dental aspirating syringes	1987
35*	High speed air-driven handpieces	—
36*	Diamond rotary instruments	—
37	Dental abrasive powders	1986
38	Porcelain-alloy systems	1991
39*	Pit and fissure sealants	—
40*	Dental implants	—

Contd...

Number	*Title*	*Date of specification or latest revision, addendum or reaffirmation*
40A	Unalloyed titanium for dental implants	—
40B	Cast cobalt-chromium-molybdenum alloys for dental implants	—
41	Recommended standard practices for biological evaluation of dental materials	1989
42*	Phosphate-bonded investments	—
43	Mechanical amalgamators	1986
44	Dental electrosurgical equipment	1986
45*	Porcelain teeth	—
46	Dental chairs	1985
47	Dental units	1989
48	Ultraviolet activator and disclosing lights	1989
49*	Analgesic equipment	—
50	Casting machines (deleted)	—
51	Gas furnaces (deleted)	—
52	Uranium content in dental porcelain and porcelain teeth	—
53*	Crown and bridge resins	—
54	Dental needles	1986
55	Dispensers of mercury and alloy for dental amalgam	1985
56	Dental floss (deleted)	—
57	Endodontic filling materials	1989
58	Root canal files, type H (Hedström)	1988
59*	Portable steam autoclave sterilizers	—
60	Jet injectors (deleted)	—
61	Zinc polycarboxylate cement	1986
62*	Dental abrasive pastes	—
63	Rasps and barbed broaches	1989
64	Dental explorers	1986
65	Low-speed handpieces	1989
66	Glass ionomer cements	1989
67*	Ligament injection syringes	—
68*	Aspirating syringes not operating on the harpoon mechanism	—
69	Dental ceramic	1991
70*	Dental X-ray protective aprons and accessory devices	—
71*	Root canal—filling condensers and spreaders	—
72	Endodontic spreaders	—
73*	Dental absorbent points	—
74*	Dental stools	—
75*	Resilient denture liners	—
76	Non-sterile latex gloves for dentistry	1991
77*	Stiffness of tufted area of toothbrushes	—

Contd...

Number	*Title*	*Date of specification or latest revision, addendum or reaffirmation*
78*	Dental obturating points	—
79*	Dental vacuum pumps	—
80	Color stability test procedure	1989
81*	Magnets and keepers used for intraoral and extraoral retainers for prosthetic restorations	—
82*	Combined reversible/irreversible hydrocolloid impression materials	—
83*	Indicator pastes	—
84*	Panoramic X-ray equipment	—
85*	Prophy angles	—
86*	Interligamentary and perio-syringes	—
87*	Impression trays	—
88*	Dental brazing alloys	—
89*	Dental operating lights	—
90*	Rubber dams	—

*Specifications still under development

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