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# Advancement in Denture Base Materials

A Project Submitted to

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in Partial Fulfillment for the Bachelor of Dental Surgery

By

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بسم الله الرحمن الرحيم

وَقُل رَّبِّ زِدْنِي عِلْمًا

صدق الله العظيم

# Certification of The Supervisor

I certify that this project entitled **" Advancement in Denture Base Materials"** was prepared by the fifth-year student **Mohammed Mahdi Salih** under my supervision at the College of Dentistry/University of Baghdad in partial fulfilment of the graduation requirements for the bachelor's degree in Dentistry.

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# DEDICATION

I dedicate this project to my mother,

you are my pillar, my strength, and my constant source of encouragement. Your unwavering love and support have made all the difference in my life, and I could not have done this without you. This research is a tribute to your boundless love and the sacrifices you have made for our family.

To the memory of my father
I will always be grateful for everything you did for me.
Even though you are no longer with us, your memory lives on in my heart and in everything I do. Your words of wisdom continue to guide me, and I am forever grateful for the time we spent together.

To my dear friends, who have been a constant source of love, support, and encouragement throughout my academic journey. Your unwavering belief in my abilities and your constant motivation has been invaluable in helping me achieve my goals.

This research is dedicated to each and every one of you, with heartfelt gratitude for being a part of my life.

Thank you for always being there, for the laughter and the tears, and for making every moment memorable. Your friendship means the world to me
Ahmed Husham, Max RH, Ridha Tariq

-Mohammed Mahdi

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# List of Abbreviations

| abbreviation | Meaning |
|---|---|
| **° C** | Celsius degree |
| **3-D** | Three dimensional |
| **ACP** | American college of prosthodontists |
| **ADA** | American dental associations |
| **Ag** | Silver |
| **Al** | Aluminum |
| **BP** | Benzyl peroxide |
| **BPA** | Bisphenol A |
| **C. *albicans*** | Candida *albicans* |
| **CAD-CAM** | Computer aided design-computer aided manufacturing |
| **cm** | centimeter |
| **CNC** | Computer numerical control |
| **Co** | cobalt |
| **Cr** | chromium |
| **CRDP** | Complete removable dental prosthesis |
| **DIN** | "Deutsches Institut fur Normung" (German Institute for Standardization) |
| **DMLS** | Direct Metal Laser Sintering |
| **gm** | gram |
| **Gr** | graphene |
| **HAP** | Hydroxyapatite |
| **ISO** | organization of standardization |
| **IU** | Indentation unit |
| **kcal/mol** | Kilocalorie per mole |
| **kg** | kilogram |
| **LED** | Light-emitting diode |
| **Mg** | Magnesium |
| **mL** | Milliliter |
| **mm** | Millimeter |
| **mm2** | square millimeter |
| **MMA** | Methyl-methacrylate |
| **MPa** | Mega pascal |
| **Ni** | nickel |
| **Nm** | Nanometer |
| **O** | Oxygen |
| **P/L** | Powder/Liquid |

| | |
|---|---|
| **PAEK** | Polyaryletherketone |
| **PC** | Polycarbonate |
| **PE** | Polyethylene |
| **PEEK** | Polyetheretherketone |
| **PMMA** | Poly methyl-methacrylate |
| **PP** | polyjet printing |
| **Pt** | Platinum |
| **PVC** | Polyvinyl chloride |
| **RP** | Rapid prototype |
| **S. *aureus*** | Staphylococcus aureus |
| **SLA** | Stereolithography Apparatus |
| **SLM** | Selective Laser Melting |
| **SLS** | Selective Laser Sintering |
| **STL** | Standard Transformation/ tessellation Language |
| **Tg** | Glass transition temerature |
| **Ti** | Titanium |
| **UV** | Ultraviolet |
| **Vitamin B12** | Cyanocobalamin |
| **Vitamin E** | RRR-alpha-tocopherol |
| **VLC** | visible light cure |
| **wt.%** | Weight percentage |
| **Zr** | Zirconium |
| **µ** | Micro |

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# Introduction

Lost teeth restoration is one of significant problems that dentists face, the need of an ideal material in order to provide effective dental services for the patients. These materials should be biologically compatible, easily available, inexpensive, and easy to manipulate with controlled technical procedures to develop an efficient prosthesis with satisfactory appearances **(Mohammed and Alla, 2011; Diwan, 2004)**.

The model denture base material should possess several key physical attributes. Some of these properties include biocompatibility, good esthetics,

A successful denture should be dimensionally stable to facilitate chewing efficiency, be comfortable for patients, and prevent oral tissues irritation **(Jagger *et al.,* 1999)**.

Many materials are being used to fabricate dentures and every type of materials that is used in denture base processing influences denture base dimension during fabrication and on other factors related to clinical use such as stability, support, retention, flexibility, impact resistance, and surface roughness etc. During the denture processing the properties of the finished denture are affected by the type of the material that is being used in denture manufacturing and other factors like polymerization shrinkage or stresses that resulted by cooling of flask, amount of the residual monomer and type of the processing technique **(Gharechani *et al*., 2014)**.

Acrylic resin innovation was a major breakthrough in 1936 that continues to have an influence on modern dentistry. In clinical practice, acrylic resin is the material of choice for the fabrication of removable dentures for the rehabilitation of edentulous patients **(Paranhos *et al*., 2013)**. However, acrylic resin is not considered an ideal material because of its mediocre mechanical and physical properties. With use, the denture base is subjected to many different influences, such as biting forces, thermal deviations, exposure to saliva, food, and water, and mechanical shocks, which may result in denture failure or fracture **(Alla *et al.,* 2015)**.

Adding fillers to the acrylic resin has emerged as a powerful platform to overcome undesirable acrylic properties. Those fillers can be in metal, ceramic, and polymeric forms **(Sheng *et al*., 2018)** The tremendous developments in nanotechnology have paved the way for a new era in oral healthcare known as nanodentistry, offering advanced therapeutic opportunities across various dental disciplines to enhance overall oral health **(Ali *et al*., 2017).**

The employment of computer aided designing and computer aided manufacture (CAD-CAM) technology in the fabrication of removable prostheses may eliminate many disadvantages of the conventional **(Steinmassl *et al*., 2017)**.

# Aim of the Review

The aim of this review is to survey various denture base materials from past to present, highlighting developments and advancements in the field of dental material science. Additionally, this review will also mention any additive materials that may be utilized to enhance denture base features and properties.

# Chapter One

# Review of Literature

## 1.1 The Historical Development of Denture Base Materials

Many different materials have been used for denture bases.

Historically materials such as wood, bone, ivory porcelain, gold, vulcanite dentures the fit of these vulcanite bases allowed self-retaining dentures, making earlier spring type dentures obsolete the main disadvantage of these denture bases was their dark red colour, which was difficult to pigment, and absorption of saliva making it unhygienic **(Supplee 2002)**.

CF Harrington 1850 introduced the first thermoplastic denture material, the tortoise shell base Also 1850, Edwin Truman used Gutta percha as a foundation for the dentures, but it was brittle.

Dr. Bean (1867) invented the casting machine and did the first casting of a denture base in aluminum. The first synthetic plastical molding product was awarded to John Wesley Hyatt (1869), cellulose nitrate that was later used as a denture base material because of its translucency and pink color However, this material did not gain much popularity because of distortion and discoloration **(Tandon *et al.*, 2010)**.

E. Haynes 1907 obtained Ni-Cr and Co-Cr, but they gained popularity after 1937 because of their low density, low material cost, higher resistance to tarnish and corrosion and high elasticity. Allergy to Nickel and difficulty in adjustment posed a practical problem **(Tandon *et al.*, 2010)**.

Vinyl Resin mixtures of polymerized vinyl chloride and vinyl acetate were under experimentation during 1930 due to their pleasing colour but had difficult processing method **(Tandon *et al.*, 2010)**.

Rohm and Hass (1936) introduced polymethyl methacrylate in sheet form and Nemours (1937) in powder form. Dr. Walter Wright (1937) introduced Polymethyl methacrylate as a denture base material which became the major polymer to be used in the next ten years. **(Khindria *et al*.,2009)**.

Polymethyl methacrylate (PMMA) resins are widely used in the fabrication of removable dentures. PMMA's popularity as a denture base material is due to its ease of processing and reparability, low cost, lightweight nature, biocompatibility, low water solubility and sorption, and excellent aesthetic appearance **(Alaa *et al*., 2015; Alaa *et al.*, 2013)**.

## 1.2 Ideal Characteristics Denture Base Material

Ideally, the denture base material should be able to withstand the masticatory forces, easy to manipulate and processed, and biocompatible with the oral tissues and other characteristics such as **(Alaa *et al*., 2015; Alaa *et al.*, 2013)**.:

A- Biological: Non-toxic, non-irritant and noncarcinogenic

B- Chemical:

1- Insoluble in the oral fluids or any other fluids being taken by the patient.
2- Not absorb oral fluids or any other fluids being taken by the patient as it causes dimensional changes.
3- Adhere very well with artificial teeth and liners.

C- Mechanical:

1- High modulus of elasticity.
2- High resiliency.
3- High elastic limit and proportional limit.
4- Adequate mechanical strength.
5- Dimensionally stable.
6- Adequate abrasion resistance.

7- Low Specific gravity.

D- Thermal:

1- Good thermal conductor.
2- Co-efficient of thermal expansion (cote) match with that of the artificial teeth.
3- Softening temperature more than the boiling temperature of the water.

E- Esthetic:

1- Exhibit sufficient translucency.
2- Capable of tinted or pigmented.

F- Other:

1- Maintain the desirable properties for extended period after manufacture.
2- Inexpensive.
3- Easy to manipulate.
4- Radio-opaque so that they can be detected if some part of the denture is accidentally swallowed.
5- Easy to repair.
6- Easy to clean.
7- Longer shelf life.

## 1.3 Types of Denture Base Materials

### 1.3.1 Celluloid

Celluloid is defined as natural cellulose polymer that was invented in circa 1870, celluloid could be formed by plasticizing cellulose nitrate with camphor after the implementation of pigment. A celluloid denture base is fabricated by pressing the blank celluloid into a dry, heated mold **(Rueggeberg, 2002)**

Celluloid was contemplated as promising substitute to the extensively utilized vulcanite **(Rueggeberg, 2002)**. The use of celluloid was diminished because its limitation such as: color instability and discoloration rapidly, water and stains absorption **(Tandon *et al.*, 2010)**., difficult to be repaired if fractured, and residual camphor taste from the denture base **(Ferracane, 2001)**.

**1.3.2 Phenol-Formaldehyde (Bakelite)**

In 1909 the phenol formaldehyde resin was invented by the Belgian Chemist Dr. Leo Baekeland, and another name of phenol formaldehyde resin was ‘Bakelite’. It was available for commercial use in dentistry in 1924 **(Alla *et al.*, 2015)**. Bakelite formed by condensing one or more types of phenols with formaldehyde through condensation polymerization.

Bakelite denture bases had outstanding aesthetics early after processing **(Murray and Darvell 1993)**. Despite that, phenol taste, stains rapidly, high brittleness and easy fracture, difficult to repair and have short shelf life is the obstacle of this material **(Khindria *et al.*, 2009)**.

**1.3.3 Polyvinyl chloride (PVC)**

Polyvinyl chloride, a co-polymer of vinyl acetate (20%) and vinyl chloride (80%), was introduced as a denture base material in the 1930s. The production technique for PVC dentures is similar to that of celluloid dentures **(Tandon *et al.*, 2010)**. The introduction of residual stresses during fabrication will result in slow denture base deterioration which can ultimately result in fracture during use **(Greener *et al.*, 1972)**. PVC is still utilized as a denture lining material and for fabrication of athletic mouth guards. Dibutyl or Dioctyl phthalate was used to plasticize PVC and pre-plasticized sheet, which can be utilized to produce athletic mouth guards **(Alla *et al.*, 2015)**.

In general processing includes heating the pre-plasticized sheet then molded to the required contour under vacuum to seal PVC sheet over the patient’s cast **(Patrick *et al*., 2006)**. the properties of PVC are far from ideality and have many limitations which include PVC became hard over time as a result of the out through service **(Munksgaard, 2004)**. Also, poor denture hygiene regarding its difficulty to polish, and this will cause irritation to the oral mucosal tissues **(Dar-Odeh *et al*., 2012)**.

### 1.3.4 Metallic Denture Base Material

#### 1.3.4.1 Precious Alloy

a type of metal alloy that contains a significant amount of precious metals. Precious metals typically include gold, iridium, platinum, rhodium, palladium, ruthenium, and osmium or a combination of these metals. These alloys are valued for their inherent rarity. Noble metals have high resistance to corrosion, but their use in the form of alloy considerably increases their resistance to imposed stresses and, consequently, the physical properties and resistance to corrosion are improved.

**(Valittu and Kokkonen, 1995)**

#### 1.3.4.2 Non-Precious Alloys

Are metal alloys that do not contain significant amounts of precious metals such as gold, silver, platinum, or palladium. Instead, they are composed of base metals and other alloying elements that offer specific properties for different applications. The compositions of the alloys are extremely important to prevent corrosive effects and stains, due to chemical attacks promoted by the presence of metals in the oral cavity in direct contact with intraoral fluids, causing failures in oral rehabilitation **(Wataha, 2001)**

Basic metal alloys are nickel-chromium (Ni-Cr), cobalt-chromium (Co-Cr) which have low cost, high modulus of elasticity, high strength, low flexibility, high melting temperature and low density **(Okuno *et al*., 1989.; Vallittu and Kokkonen, 1995)**. Titanium is also included in this class, being classified in its pure form as a basic metal and in the form of alloy as non-base metal **(Takeuchi *et al*., 2020)**.

However, basic alloys also have disadvantages, such as high hardness, which makes it difficult to finish prosthetic parts and restorative materials, porcelain pigmentation and low corrosion resistance in relation to noble alloys **(Tkachenko *et al*., 2014)**

Pure Titanium has the advantage of lightweight, strength and biocompatibility but requires an inert casting environment and casting defects can be a problem **(Tandon *et al*., 2010)**.

Another alloy that has shown prominence are those composed of niobium (Nb) Although these alloys contain a maximum of 0.1 %niobium, this small percentage gives a high mechanical resistance to steel **(Johansson and Albrektsson 1991; Ribeiro *et al*.,2009)**.

### 1.3.4.3 Main Chemical Elements of Metal Alloys and Their Applicability in Dentistry

Metal alloys commonly used in dentistry are usually composed of a mixture of different metals, with each contributing unique properties to the final material. The main chemical elements found in metal alloys used in dentistry include **(Matos *et al*.,2021)**:

- Aluminum: It increases tensile strength and ductility, especially when associated with nickel.
- Beryllium: It reduces the melting temperature of the alloy (100 degrees Celsius), the ductility and the resistance to corrosion.
- Carbon: The surface hardness of the alloy increases when it is above 0.2%.

- Cobalt: It increases the resistance (hardness) and elasticity.
- Copper: It increases the resistance by up to 20%, increases the hardness and reduces the melting zone of the alloy, allowing greater homogeneity of the alloy.
- Chrome: It increases the resistance to loss of shine and corrosion and should not exceed 29 %.
- Gold: It provides resistance to oxidation and increases the ductility and malleability of the alloy.
- Silver: It improves the alloy's ductility, neutralizes the reddish color conferred by copper and facilitates burnishing.
- Platinum and Palladium: It provides greater resistance to oxidation and corrosion, increasing the strength and hardness of the alloy.
- Tin: It increases malleability.
- Molybdenum: When it has 3 to 6 %, it increases resistance to corrosion and increases ductibility.
- Manganese: Increases the flow of the alloy.
- Nickel: It increases the malleability of the alloy.
- Titanium: It acts as a prosthetic rehabilitation material, replacing a lost dental element **(Hanawa, 2019; Koizumi *et al.*, 2019)**.
- Zinc: It acts as an antioxidant agent.
- Zirconia: It acts as an aesthetic rehabilitation material, being used in fixed dentures on teeth and on implants.

**(Matos et al.,2021)**

## 1.4 Thermoplastic Resin Material

These materials are classified according to DIN EN ISO–1567 comprise. They are classified according to their composition. Many thermoplastic resins are used in dentistry, such as acetyl resins, PC resins (belonging to the group of polyester resins), polyamides(nylons) and acrylic resins **(Negrutiu *et al.*, 2005)**.

The utilization of thermoplastic resins in dentistry have greatly increased in the recent decade. The technique used is based on plasticizing the material and only thermal processing is used without any chemical reaction **(Ardelean *et al*., 2012)**.

Successful changes in the chemical composition and the ability to injection mold present thermoplastic materials make them suitable for fabricating removable partial dentures that can eliminate metallic parts entirely or partially. This has led to the development of so-called "metal-free removable partial dentures **(Bortun *et al*., 2006)**.

Thermoplastics polymers are characterized by highly fracture strength, flexibility, impact resistance, but these thermoplastic polymers are devoid of the natural translucency in Polymethyl methacrylate, polycarbonate, on the other hand, are translucent, have adequate flexibility, fracture strength and high impact strength, but they are very susceptible to wear and tear. However, thermoplastic PMMA have excellent properties, it is difficult to be processed as a result of the high viscosity and processing temperature **(Vivek and Soni, 2015)**.

**1.4.1 Thermoplastic Polycarbonate (PC)**

In 1953, PC was introduced to the market by Bayer in Germany and General Electric in the US independently. Under trade name (LEXAN), After that, many companies in America, Japan and in Europe started the production of PC **(Bozzano *et al*., 2012)**.

The molecule of PC is consisted of a bisphenol A (BPA) and a group. The Bisphenol A have two aromatic rings; these aromatic rings give PC stiff backbone. PC contains, in its backbone, large aromatic content of phenyl groups (benzene ring), also has moderately large pendent oxygen and hydrogen groups. These groups allow the tangle with the nearby polymer chains, and the formation of hydrogen bond. All these factors will lead to improve the resistance to intermolecular movements **(Brydson, 1999)**.

The Bisphenol A group also prevent the crystallization of PC, and together with minimal molecular rotation about the bonds give PC high glass transition temperature (Tg = 145ºC) **(Bozzano *et al.*, 2012)**.

### 1.4.1.1 Properties of Polycarbonate

PC is amorphous polymer with evidence of some areas of crystallinity **(Horio and Nabeschima, 2000)**, light in weight safe and biologically inert material, simply colored and characterized, transparent, recycled easily **(Bozzano *et al.*, 2012)**. It has good coherence and adherence strength with excellent affinity to the mucous membrane.

Also, PC has excellent mechanical properties and maintain its properties through a wide range of working temperature change that range between -20°C and 140°C, very strong with outstanding impact strength and fracture resistant, little water sorption, high abrasion resistance, acceptable flexibility and ductile, high electrical and thermal resistance, and high plastic deformation without break or crack **(Nicholson, 2012; Bozzano *et al.*, 2012; Mark, 2007)**.

PC is monomer free, so no irritation or hypersensitivity to the oral tissue. The absence of monomer gives PC stably physical properties during processing **(Nicholson, 2012)**.

However, PC has some limitations in their properties, such as poor resistance to chemical, and scrapes, and exposure to UV rays cause color changes because PC is overly sensitive to UV rays **(Bozzano *et al.*, 2012)**.

Another disadvantage is the possibility of BPA release in oral cavity, as in Mariko's study in 2004 "Degradation and formation of BPA in PC used in dentistry", he reported that there was some possibility of BPA release in oral cavity as a result of PC hydrolysis by saliva over a period time been used in oral cavity which have damaging effect on human body. Also, reported that this release was controlled by the presence of additive, and suggested to treat the filler with coupling agent will decrease the hydrolysis PC which will reduce the amount of BPA release in oral cavity **(Watanabe, 2004)**.

### 1.4.2 Thermoplastic Acetyl

Acetyl as a homopolymer has a good short term mechanical property, but as a copolymer, Acetyl has better long-term stability, it is very strong, resist wear and fracturing and it is quite flexible, these characteristics make it an ideal material for performed clasps for partial denture, single pressed unilateral partial dentures, partial denture frame works, provisional bridges, occlusal splint, and even implant abutments. **(Kutsch *et al.*, 2003)**.

Acetyl resins are resistant to wear and are well suited for maintaining vertical dimension during provisional restoration therapy (temporary crown and/or bridge); however, stronger Acetyl does not have the natural translucency and vitality of thermoplastic acrylic and polycarbonate. Therefore, these materials might offer better results for short-term temporary restoration **(Negrutiu, 2005)**.

### 1.4.3 Thermoplastic Nylon

Nylon is a resin derived from dibasic acid monomers, from an engineering standpoint, nylon is a versatile material with a depth of characteristic making it suitable for abroad range of applications, it exhibits high physical strength, heat resistance and chemical resistance, it can be easily modified to increase stiffness and wear resistance **(Kutsch *et al.*, 2003).**

Nylons were one of the early polymers developed Today, nylons are an important thermoplastic also known as polyamides, are synthesized by condensation polymerization methods, often an aliphatic diamine and a diacid, Nylon is a crystalline polymer with high modulus, strength, and impact properties; low coefficient of friction; and resistance to abrasion **(Acohido, 1999)**.

The type of nylon is determined by the number of carbon atoms in the monomers used in the polymerization. The number of carbon atoms between the amide linkages also controls the properties of the polymer. When only one monomer is used (lactam or amino acid), the nylon is identified with only one number (nylon 6, nylon 12). When two monomers are used in the preparation, the nylon will be identified using two numbers (nylon 6/6, nylon 6/12) **(Ford, 1993)**.

The strength and stiffness will be increased as the number of carbon atoms between amide linkages is decreased, because there are more polar groups per unit length along the polymer backbone **(The Vinyl Institute, 2002)**.

Additives such as glass or carbon fibers can be incorporated to improve the strength and stiffness of the nylon. Mineral fillers are also used. A variety of stabilizers can be added to nylon to improve the heat and hydrolysis resistance. Light stabilizers are often added as well. Some common heat stabilizers include copper salts, phosphoric acid esters, and phenyl- β-naphthylamine. In bearing applications, self-lubricating grades are available, which may incorporate graphite fillers. Although nylons are generally impact resistant, rubber is sometimes incorporated to improve the failure properties**. (WTEC, 2000)**.

Nylon exhibit high physical strength, heat resistance and chemical resistance, it can be easily modified to increase stiffness and wear resistance **(Kutsch *et al.*, 2003)**.

### 1.4.4 Thermoplastic Acrylic

Thermoplastic acrylic refers to a type of acrylic material that possesses thermoplastic properties, the thermoplastic nature of the material allows it to become pliable and moldable when heated, enabling easy manipulation and adaptation to the patient's oral anatomy **(Ardelean *et al.*,2015)**.

while heat-cure polymethyl methacrylate is known for its high-water absorption, porosity, dimension instability, and residual monomer **(Negrutiu *et al.*, 2005)**. In comparison, thermoplastic acrylic has moderate impact resistance, which is greater than that of heat-cure PMMA **(Kutsch *et al.*, 2003)**. It also has adequate tensile and flexural strength and comes in both tooth and gingival colors, with translucency that gives outstanding aesthetics. However, the slow wear of thermoplastic acrylic during occlusal forces means that it may not be able to maintain vertical dimension over prolonged periods of time. Nevertheless, this material is easy to adjust, handle, and polish, and it can be relined or repaired chair-side **(Vivek and Soni, 2015)**.

Flexile thermoplastic acrylic is a special blend of polymers and has the highest impact rating of any acrylic, it has a surface hardness of 55-56 (kg/mm2), make it popular for bruxism appliances as well as dentures **(Kutsch *et al.*, 2003)**.

**1.4.5 Polyetheretherketone (PEEK)**

In 1978 PEEK was developed by a group of English scientists and it was first used in industry in 1980s Later PEEK was commercialized for industrial applications. By the late 1990s, PEEK became an important high-performance thermoplastic candidate for replacing metal implant components, in vertebral surgery **(Kurtz, 2019)**.

Polyaryletherketone (PAEK) is a family of high-performance thermoplastic polymers, consisting of an aromatic backbone molecular chain, interconnected by ketone and ether functional groups **(Kurtz, 2019)**. Thus, PEEK belongs to a larger family of PAEK polymers, sometimes referred to as polyetherketones, or more simply as "polyketones."

PEEK has an excellent mechanical property; hence it has been proposed for other prosthodontic applications such as fixed prostheses **(Schmidlin PR *et al.*, 2010)**.

The mechanical properties of PEEK do not change during the sterilization process and its elastic modulus is similar to those of human bone, enamel, and dentin, suggesting it to be a suitable restorative material. PEEK features stable chemical properties, and is biocompatible, wear-resistant, stable at elevated temperatures, insoluble in water. This material also presents low reactivity with other materials, is nonallergic, and has lower plaque affinity than other materials such as metals and resins **(Skirbutis *et al.*, 2017)**.

### 1.4.5.1 PEEK Processing and Manufacturing

PEEK implant components are manufactured using injection molding, extrusion, and compression molding techniques **(Kurtz, 2012)**. As an alternate to these techniques Rapid Prototyping and CAD CAM milling produces quick, highly precise prostheses without compromising quality of material **(Marcus, 2012)**.

#### A- Compression Molding

The fundamental procedure involves applying intense pressure to a closed mold cavity and heating polymers until the matrix hardens. The matrix liquefies and flows when put under pressure, taking the shape of the mold cavity, and then hardens to form the desired part or product. The cycle is finished when the part is sufficiently chilled and sturdy **(Robert., 2017)**.

**B- PEEK CAD-CAM milling**

PEEK (polyetheretherketone) can be milled using a variety of CAD/CAM (computer-aided design/computer-aided manufacturing) systems. Typically, the process involves using specialized software to create a 3D digital model of the desired prosthesis, which is then used to guide a milling machine to carve the PEEK material into the final shape. The milling process can produce highly precise and accurate results, making it a popular choice for manufacturing dental prosthetics, including implant abutments, bridges, and denture frameworks **(Marcus, 2012)**.

**1.4.6 Advantages of Thermoplastic Material**

Thermoplastic resins and copolymers have many advantages over conventional powder or liquid resin system **(Kutsch *et al*., 2003; Dittola, 2004)**:

1. Thermoplastic resins tend to have predictable long-term performance.

2. Stable and resist thermal polymer unzipping which means polymer degradation or bonds stability between polymer molecules.

3. Exhibit high creep resistance and high fatigue endurance as well as excellent wear characteristics and solvent resistance.

4. Typically have very little or almost no free monomer in the material.

5. Has almost no porosity, which reduces biologic material build up, odors and stains.

6. Typically the thermoplastic resins are almost flexible and stronger than their traditional counterparts.

7. Can also be reinforced with glass fillers or fibers to further enhance their physical properties.

8. Display excellent esthetics provide long-term comfortable use for the patient these provide excellent alternative cosmetic restorations for esthetic conscious patients.

9. Enables the patient natural tissue tone to appear through the material without visible metal, thus enhancing esthetics and a more natural looking smile.

### 1.4.7 Indications of Thermoplastic Material

Thermoplastic dentures can be used anywhere and everywhere cast framework is indicated but particularly used when:

1. Patient has high esthetic concern.

2. Fixed restoration is out of financial reach of patient.

3. Patient is reluctant to go for invasive procedure (implant).

4. Patient is unlikely to return for routine maintenance visit.

5. Patient is engaged in high-risk situations such as American Football, security, psychiatric patient, etc.

Definite indications in complete denture cases:

1. Patient is allergic to polymethyl methacrylate.

2. There are bilateral inoperable undercuts which cannot be managed by conventional acrylic dentures without resorting to surgery.

3. When there is a history of frequent breakage. **(Dittola, 2004)**

## 1.5 PolyMethyl Methacrylate (PMMA)

PMMA is a polymer of methyl methacrylate (MMA), its chemical formula $(C_5H_8O_2)n$, generally, it is a pure and colorless polymer; and either suspension or emulsion polymerization were used to fabricate PMMA **(Harper and Petrie, 2003)**. In dentistry suspension polymerization is utilized to form PMMA. PMMA is produced by addition polymerization reaction (free radical polymerization reaction) of multiple methyl methacrylate monomers. Initiator is presented in order to start the reaction.

The polymerization is activated either by chemical or heat activation to form free radical by Benzoyl peroxide break down. The free radical will react with the vinyl group of methyl methacrylate leading to open the double bond and new single carbon-carbon bond will form **(Alla *et al.*,2015)**.

"The asymmetrical free radical is produced from the double bond of methyl methacrylate. This results in the formation of a carbon atom that has an asymmetrical environment after the reaction, leading to the formation of atactic polymer **(Darvell, 2002)**.

PMMA, it formed by free radical polymerization reaction of the monomer with catalyst which reacted in one molecular space to form two-dimension network and increase in size by addition reaction this make it brittle at room temperature **(Stenzler, 2009)**.

PMMA denture base materials can de classified according to the mechanism of polymerization activation into heat activated, chemically activated and light activated PMMA denture base resins **(J'Obrien, 2002)**. PMMA based acrylic resins are used in the field of fabrication of various dental prostheses and denture liners, temporary crowns, and orthodontic appliances **(Johnson and jones, 1994)**.

PMMA is used widely as denture-base material because it has outstanding esthetic properties, sufficient strength, low water sorption and solubility **(Craig, 1977)** General properties of PMMA include the following: A Knop hardness number between 18 to 20 **(Phillips, 1996)**, with tensile strength 59MPa and its specific gravity is 1.19. The modulus of elasticity is about 2.4MPa. The polymer glass transition temperature is 125°C and depolymerize at 200°C and 90% of the polymer will depolymerize to the monomer at 450°C **(Yau, 1999)**.

In addition to what have been mentioned above, PMMA dentures are not toxic, repaired easily, with the ability to accurately reproduce, and indefinitely retain the pattern details and dimensions **(J'Obrien, 2002)**.

The main shortages of PMMA that it has low tensile strength, especially under impact and fatigue conditions, together with its high sensitivity to notch, poor resistance to abrasion **(Hargreaves, 1971)** and high coefficient of thermal expansion **(Leong and Harcourt, 1974)**. Furthermore, processing shrinkage and water sorption highly affect the dimensional accuracy of a poly (methyl methacrylate) denture and the range of reported linear shrinkage is between 0.20% and 0.26% **(Yau, 1999)**, and typical water sorption of dental acrylic resins is about 0.5% wt. **(Wong *et al*., 1999)**.

According to Mode of Activation PMMA is divided to **(Tandon *et al*., 2010)**:

1- Heat-Activated PMMA

2- Chemical Activated PMMA

3- Light-Cured PMMA

### 1.5.1 Chemical composition of acrylic resin

The powder-liquid typemay contain the materials listed in Table (1-1)

| **Table (1-1): The principal ingredients of acrylic denture base. (Powers and Sakaguchi, 2012)** | |
|---|---|
| **Powder** | **Liquid** |
| **Acrylic polymer (or copolymer) beads** | Monomer |
| **Initiator** | Inhibitor |
| **Pigments** | Accelerator |
| **Dyes** | Plasticizer |
| **Opacifier** | Cross-linking agent |
| **Plasticizer** | |
| **Dyed organic fibers** | |
| **Inorganic particles** | |

**Powder (polymer):**

Thermoplastic acrylic is made of pre-polymerized particles of poly (methyl methacrylate) which are spheres or granules of different. When combined with a liquid monomer and an initiator like benzoyl peroxide, polymerization is initiated, and the mixture hardens. The initiator is typically added in amounts ranging from 0.5% to 1.5% **(Powers and Sakaguchi, 2012)**.

Plasticizers are also incorporated in the powder beads to assist dough formation; Dibutyl phthalate was used for many years as external plasticizer. Internal plasticizers are used instead, containing various methacrylate or acrylic monomers; they locally soften the beads and allow the monomer to diffuse more rapidly into the beads during the dough stage **(O'Brien, 2002)**.

Pure polymers, such as poly (methyl methacrylate) are clear and adaptable to a wide range of pigmentation. Colorants are added to obtain the various tissue like shades, and zinc or titanium oxides are used as opacifiers. Dyed synthetic fibers made from nylon or acrylic are usually added to simulate the small capillaries of the oral mucosa **(Powers and Sakaguchi, 2012)**.

**Liquid (Monomer)**

It is predominantly un- polymerized methyl methacrylate (MMA) monomer.

It provides the building block for polymerization and characterized by clear, colorless transparent and flammable highly volatile liquid at room temperature, has low viscosity, boils at 100.3- 100.8°C, its density is about 0.945 gm/cm , heat of polymerization 12.9 kcal/mol and has a distinct odor **(Craig *et al.*, 2004; Powers and Sakaguchi, 2006; choudhary, 2009)**.

Stored in chestnut brown bottle because it polymerizes when being activated by heat or exposed to visible or ultraviolet light **(Anusavice, 2007)**. Inhibitors are added to give the liquid adequate shelf life; the inhibitor most commonly used to prevent premature polymerization is hydroquinone which may be present in concentration of 0.003% to 0.1% **(Craig and powers, 2002)**.

Plasticizers such as dibutylphthalate may be incorporated into the monomer to produce a softer and more resilient polymer. Plasticizer molecules do not enter. the polymerization reaction but does interfere with the interaction between polymer molecules. The main disadvantage of using plasticizer is that they may gradually leach out of the plastic by oral fluids, resulting in hardening of the denture base **(Craig and powers, 2002; Powers and Sakaguchi, 2006)**.

### 1.5.2 Chemically Activated Acrylic Resins

Chemical activated acrylic resin is often referred to as cold-curing, self-curing, or auto-polymerizing acrylic resin, it does not require the application of thermal energy and therefore may be completed at room temperature. The accelerator reacts with the peroxide initiator at room temperature and sufficient free radicals are produced to initiate the polymerization **(Power *et al.,* 2006)**. As a result, chemically activated resin often is referred to as cold curing **(Anusavice, 2006)**.

The principle difference between chemical activated and heat-activated denture is that more residual monomer is present in the chemically activated denture this is because the degree of polymerization achieved using chemically-activated resins is not high as that achieved using heat activated system, the residual monomer creates two major difficulties ; first :the residual monomer serves as tissue irritant; second, it acts as plasticizer; which results in decreased transverse strength of denture resin **(Craig, 2002;Anusavice, 2006)**.

### 1.5.3 Light Activated Acrylic Resins

Since 1984, visible light cure (VLC) denture base resin was available, and their use increased for relining and repair of the dentures. They are available in premixed ropes or sheets, powder-liquid system and gel. It requires a curing unit that emits shorter wavelength blue light in high intensity **(Murata *et al.,* 2007)**. Visible light cure resin shows higher hardness than heat cure and self-cure acrylic resin and there was a high significant difference between impact values of heat cure and visible light cure due to brittle nature of (VLC) resin. However, heat cure, self-cure and visible light cure resin have similar mechanical properties in term of rigidity and transverse strength **(Dar-Odeh *et al.,* 1997)**.

These resins display less porosity than self-cure acrylic resin, facilitate fabrication and adjustment, and 25% lighter and less polymerization shrinkage **(Tandon *et al.*, 2010)**.

### 1.5.4 Rapid heat- polymerized resin (Mixed cure system)

These are hybrid acrylic, with both chemical and heat activated initiators, to allow rapid polymerization without the porosity that might be expected **(Craig and Powers, 2002)**. These are polymerized in boiling water for 20 minutes. immediately after being packed into a denture flask, the adverse tissue response. occur due to relatively higher residual monomer which considered one the disadvantages of this material **(Bartoloni and Walker, 2000)**.

### 1.5.6 Heat Activated Acrylic Resins PMMA

These materials are used largely for the fabrication of removable complete or partial dentures. In heat-cured materials, heat energy used to start polymerization reaction and formation of free radical **(Bhola *et al*., 2010)**. Free radical will continue to react with the available monomer. **(Alla *et al*., 2015)**.

Heat activated PMMA are supplied in in powder/liquid form, the powder contains finely splitted, pre-polymerized beads of PMMA and the liquid contains MMA. Chestnut brown colored bottle is used to supply liquid to prevent any accidental polymerization caused by exposure to UV rays throughout storage and transportation and to prevent evaporation the bottle should remain closed **(Alla, 2013).**

### 1.5.7 Methods of Heat Applications

#### 1.5.7.1 Water Bath Curing

Water bath curing is the most common method for curing of acrylic denture base. The polymerization occurs by application of heat, which are maintained until the polymerization is completed. By heat application the benzoyl peroxide (initiator) will decompose, the decomposition occurs at relatively low temperature (about 70°C) and lead to production of free radicals. The free radicals will activate the monomer by attaching to them causing the double bond between two carbon atoms to open and in this way will initiate the polymerization **(Craig, 1997)**.

The polymerization occurs by heat application of external heat to the flask that contain denture base which is placed in water bath at specific time and specific temperature (curing cycle) and the strength of denture base will depend on the time and temperature of the curing cycle. The polymerization reaction is exothermic reaction and when heating large mass acrylic, the temperature in the center of the mass will rise above that of the investing plaster and the flask. The boiling point of pure monomer is 100.38°C, quick heating of large mass of dough will cause the internal temperature to elevate above this temperature, the monomer boils and produce spherical voids in the hottest part. This will result. in gaseous porosity of cured denture base **(McCabe and walls, 2008)**.

There are two methods for curing of acrylic resin according to polymerization cycles **(Criag and Power, 2002)**:

I- Short cycle: polymerization of acrylic done at 74C◦ for 1.5 to 2 hours after that the temperature increase to 100C◦ for half to one hour.

II- Long cycle: the polymerization done at 70C◦ for 8 hours or all night that remain constant.

### 1.5.7.2 Microwave Curing

**Nishii** in **1968** introduced microwave activation method. There are several problems faced with this method like reflection of microwave by metallic flasks. In **1984, Kimura *et al*.** solved the problem by production of fiber reinforced plastic flasks, but they were high in cost and easily braked which limit their use. With setting power at 450 Watt, 4.5 minutes are necessary for complete polymerization of 2 flasks, 8.5 minutes for 4 flasks, and 13 minutes for 6 flasks **(Botega *et al*., 2004)**.

The mechanical properties of denture base resin processed by microwave energy were compared to those processed by water bath, it was found that no significant difference between the values of strength of both methods **(Truong and Thomasez, 1988)**.

Conventional acrylic resin cured by microwave showed increase in porosity when compared with conventional acrylic cured by water bath, but this significant increase in the porosity is clinically acceptable so it can be used for curing dentures **(Singh S. *et al*., 2013)**.

### 1.5.7.3 Autoclave Curing

Autoclave can be defined as a pressure cooker that has a lid tight to air which traps the steam from boiling water, and it was first used by Muley 1976. The steam will increase the pressure inside the autoclave which increase the boiling point of water. In spite of the advantages of this technique like ease, simplicity and cost-effectiveness, the major disadvantage is long processing time required **(Banerjee *et al.,* 2010)**.

In **2012, Abdulwahhab and Alnakkash** conducted a study and concluded that there was no significant difference in transverse, hardness and impact strength between acrylic cured by autoclave and that cured by conventional water bath method, but there was significant decrease in porosity for autoclave cured acrylic resin, that is because the pressure will accelerate the polymerization and higher pressure prevent boiling of monomer.

### 1.5.5 Pour Type Acrylic Resins

The Austenal company (1955) introduced this technique. The principal difference is in the size of the polymer powder or beads. Small particle size results in a fluid mix. The mix is quickly poured into the mold and allowed to polymerize under pressure at 0.14MPa. Centrifugal casting may also be used to inject the slurry into the mold. These offered improved adaptation, dimensional stability, reduced cost and simple procedure but had low strength, higher solubility and high residual monomer levels **(Tandon *et al.*, 2010)**.

### 1.5.8 Advancements to improve PMMA performance

Over the recent years, a few endeavors have been conducted to overcome the issue of shortcoming and fragility as the drawbacks of mechanical properties affecting the utilization of PMMA as a denture base material. On the other hand, available knowledge in polymer reinforcement and progress in material science have assisted in the invention and creation of new methods or procedures that have resulted in the improvement of PMMA **(Kim *et al.*, 2004)**. The previous and ongoing investigations and studies on the enhancement of PMMA behavior towards flexural and sudden impact fall under three headings: the search for or development of an alternative material, chemical modification, and insertion of materials like fibers, metal nets and ultra-high modulus polyethylene. Trials on the reinforcement of the acrylic denture base can be outlined in two categories: chemical alteration and addition of fillers or fibers to the heat-polymerized conventional acrylic resin **(Amira, 2017)**.

#### 1.5.8.1 Chemical modification to PMMA

To date, a number of studies have evaluated the impact of chemical modifications on the performance and mechanical characteristics of PMMA.

Different theories exist in the literature regarding the chemical modifications of PMMA such as addition of a copolymer or a cross-linking agent of a poly-functional monomer, for example polyethylene glycol di-methacrylate **(Abuzar *et al.*, 2010)**. Another method is addition of rubber to the acrylic denture base, the aim of which is to produce a resin that absorbs greater amounts of energy at a higher strain rate before fracture than the standard resins. The problem is that the impact strength is often improved at the expense of the Young's modulus producing a denture base with increased impact strength but is too flexible. Addition of elastic to PMMA as a strategy for fortification is, to date, the best and generally acknowledged as a different option to the ordinary PMMA denture base material. In any case, the excessive cost - often up to 20 times that of traditional resin- limits its routine utilization. Nevertheless, it has multiple restrictions, particularly diminished firmness, increased creep and water sorption, which therefore may help to ease microbial plaque **(Jagger *et al.*, 1999)**.

Polyethylene fibers exhibit better impact strength followed by glass fibers and stainless-steel mesh. By using pre-impregnated glass and polyethylene fibers in woven form (prepregs) the impact strength of the denture bases can be increased effectively **(Murthy *et al.*, 2015)**.

#### 1.5.8.2 Fillers as PMMA reinforcer

Recently, composites (polymer + filler) have replaced materials/minerals in many applications and systems. The main reason behind this is its favorable characters and performance that polymers can offer over routine materials, such as simplicity of preparing, efficiency and cost-effectiveness. A polymer composite is an engineered material made up of more than one component. These components have distinct and different properties. In a polymer composite, one of the components is called the matrix, while the other is the filler material. Fillers are artificial or inorganic materials utilized to enhance the desired properties of the polymers **(Zhang *et al.*, 2003)**.

### 1.5.8.2.1 High-impact strength resin

For patient at higher risk of dropping dentures, dentures can be fabricated from butadiene-styrene rubber reinforced polymers. These polymers have significantly higher impact strength and may reduce the risk of fracture. In these denture base materials, butadiene- styrene rubber is incorporated with methyl methacrylate, the rubber is grafted with a methyl methacrylate which is dispersed in a poly (methyl methacrylate) matrix **(Craig *et al.*, 2004)**. The rubber could incorporate up to 30% by weight without deleterious effects on handling characteristics. The monomer that used to get high – impact beads is differs from conventional monomers in that it either contains extraordinarily little or no cross-linking agent **(O'Brien, 2002)**. The addition of rubber to PMMA as a method of reinforcement is most successful and widely accepted as an alternative to the conventional PMMA denture base resin, however, the high cost restricts its use **(Jagger et al., 1999)**.

### 1.5.8.3 Glass flakes

The addition of glass flakes to the heat polymerized PMMA material results in the improvement of some mechanical properties of the PMMA denture base and a study reported that the addition of glass flakes essentially enhanced fracture toughness and hardness of the material **(Franklin et al., 2005)**.

### 1.5.8.4 Hydroxyapatite whiskers

Hydroxyapatite (HAP, Ca10 (PO4)6 (OH) 2), is a natural organic material that has been universally used as a substitute material for damaged teeth or bone over the past three decades. Its compatibility with the surrounding tissues has been experimentally proven. Furthermore, it is an important bioceramic with tremendous potential for biomedical applications. PMMA-HAP filler has been evaluated with acrylic resin and shown enhance the mechanical properties of the acrylic denture base **(Pan *et al*., 2013)**.

### 1.5.8.5 Metal Inserts

To overcome the limitation in physical and mechanical properties of polymers, polymers have been reinforced by adding materials such as metal strengthener **(Vallittu and Lassila, 1992; Karacaer *et al*., 2003)**.

Metal wires had been used but were difficult to manipulate. The thickness of the reinforcing wire required to achieve adequate strength hindered the esthetic quality of the denture and was difficult in clinical application **(Polyzois *et al.*, 1996)**. Studies showed the effect of metal fillers on some physical properties of acrylic resin. The effect on the thermal conductivity, tensile strength, compressive strength, and radio opacity of PMMA when adding varying amounts of powdered silver, cooper, and aluminum. The compressive strength of PMMA increased with addition of these fillers and the tensile strength decreased. Explanations given for this reduction, because stress concentrations occur around embedded materials leading to weaken the polymer. This is often due to poor adhesion between the acrylic resin matrix and the filler metals inserts **(Jagger et al., 1999)**.

However, approaches of this particular kind come with various well-known limitations. A serious drawback of this approach is stress concentrations around embedded materials. In addition, the net effect of embedded metals results in the weakness of the polymer; this is often due to poor adhesion between the resin matrix and the metal inserted. Another limitation is that metal-reinforced dentures may be unaesthetic **(Balch *et al*., 2013)**.

Metal bases and frameworks have been consolidated into denture bases to enhance crack resistance. This method certified the support of the prosthesis. Nevertheless, a degree of troubles arises in the placement or alteration of the metal nets and frameworks position during processing **(Amira, 2017)**.

### 1.5.8.6 Nano technology

Nanotechnology (sometimes shortened to "nanotech") is the manipulation of matter on an atomic and molecular scale.

A more generalized description of nanotechnology was subsequently established by the National Nanotechnology Initiative, which defines nanotechnology as the manipulation of matter with at least one dimension sized from 1 to 100 nanometers **(Drexler, 1986; Drexeler, 1992)**.

Nanoparticles when incorporated into polymer matrices, increase reinforcement, leading to stronger plastics. These nanoparticles are hard and impart their properties to the polymer **(Bauer *et al.*, 2008)**.

Semi-solid and soft nanoparticles have been manufactured such as liposome nanoparticles. Several types of liposome nanoparticles are currently used clinically as delivery systems for anticancer drugs, antibiotics and antifungal drugs and vaccines **(Malam *et al.*, 2009)**.

#### 1.5.8.6.1 Various Nanostructures used in Dentistry

- **Nanorods**: Enamel-prism-like hydroxyapatite (HAP) nanorods have been synthesized which exhibited self-assembly properties.
- **Nanosphere**: Nanospheres can be used in a similar fashion like the nanorods in formulating in restorative technology.

- **Nanotubes**: modified single-walled carbon nanotubes have been shown to improve the flexural strength of resin-based composites

**(Saunders, 2009)**

### 1.5.8.7 Recent Advances in Modifying PMMA

**Zirconium Silicate Nanopowder:** The 1.5% wt. reinforcement of zirconium silicate nanoparticles results in a highly significant increase in impact strength, transverse flexural strength, and surface hardness. Although there is a non-significant increase in surface roughness, there is also a highly significant decrease in the total amount of water uptake and solubility of the reinforced heat-cured acrylic **(Esmael, 2015)**

**Silanized Zirconium Oxide (ZrO2) Nanoparticles**: Adding silanized zirconium oxide nanoparticles to high-impact heat-cured denture base resin significantly increases impact strength and transverse strength and results in a highly significant increase in surface hardness and significantly decreases water sorption and solubility **(Al-Hiloh, 2015)**.

**Al2O3 Nanoparticle and Plasma Treated Polypropylene Fibers:** By incorporating silanized alumina nanofillers 0.5% wt. and plasma-treated polypropylene fibers 2.5% wt into conventional heat-cured denture base resin, a new concept of three-phase composite is created, resulting in a highly significant increase in impact strength, surface hardness, and thermal conductivity in both tested groups. Although there was a non-significant increase in transverse strength, there was a significant increase in surface roughness **(Muklif, 2015)**.

**ZrO2-Al2O3 Nanoparticle:** The addition of (ZrO2-Al2O3) nanoparticles to heat cure acrylic resin denture base material improved the impact strength, transverse strength, and surface hardness of this material at the same time increased the surface roughness **(Basima *et al*., 2015)**.

**ZrO2-TiO2 Nanoparticles:** The addition of 2% wt. of ZrO2:TiO2 by means of 1:1 ratio considerably improved the impact and transverse strength and had a positive effect on the thermal conductivity **(Khalaf 2015)**.

- **Incorporation of Magnesium Oxide (MgO) Nano -Fillers:** The immersion of heat cured acrylic resin in 7% wt. MgO NPs solution was found to be effective in reducing the growth of *S. aureus* on acrylic surface **(Shakir *et al*., 2018)**.
- **Incorporation of Citrus Bergamia Essential Oil:** Bergamot essential oil was successfully incorporated into heat cure PMMA denture base material to function as a potent antifungal medication of natural herbal source and resulted in material with drug delivery system against C. *albicans*. Also increases denture base transverse strength values, decreased surface roughness **(Mawlood, 2019)**.
- **Incorporation of Silanated Pearl Powder:** The adding silanated pearl powder to heat cured acrylic denture base material improve the radiopacity (clinically facilitates easy detection of accidentally swallowed denture fragments and consequently saving the patient's life) and surface roughness, decrease the mean values of impact strength and transverse strength but still within the acceptable requirements of denture base materials **(Dekan, 2019)**.
- **Incorporation of graphene-silver nanoparticles:** 1% and 2% Gr-Ag showed significantly enhanced mechanical behavior of the Gr-Ag enriched PMMA resin, with 1% content being sufficient for higher applied loads and improved strength compared to unmodified PMMA. 2% Gr-Ag content exhibited lower water absorption ratios, potentially reducing water-

mediated degradation risks in clinical use of PMMA denture material **(Bacali *et al.*, 2019)**.

- **Incorporation of Vitamin E:** The addition of vitamin E acetate to PMMA has shown broad anti-inflammatory activity against C. *albicans* **(Barros *et al.*, 2020)**.
- **Incorporation of Bioactive Glass:** The incorporation of 10% wt. Fritex and 10% wt. Kavitan bioactive glass into heat-cured acrylic resin can potentially enhance the material properties of PMMA. The modified resin demonstrates bioactive fluoride ion release, which can persist for more than four weeks. Specifically, the resin with 10% wt. Fritex glass has the ability to absorb fluoride ions from toothpaste and efficiently release them. Furthermore, the addition of fluoride-releasing fillers has a negligible impact on the sorption and solubility increase of the modified PMMA resin **(Raszewski, 2021)**.
- **Incorporation of Vitamin B12:** Cyanocobalamin, which is a form of vitamin B12, has widespread clinical use due to its availability and stability. Template polymerization was used to optimize mass polymerization, resulting in highly crosslinked polymers with thermally, mechanically, and chemically resistant characteristics. This not only improves their mechanical strength but can also contribute to maintaining the superior health of the oral mucosa. Additionally, it can be a way of transporting vitamin B12 for the whole body **(Budală *et al.*, 2021)**.
- **Incorporation of Tellurium Oxide Micro Particles:** The addition of 3% and 5 % by wt. of tellurium oxide micro-particles to heat cure PMMA denture base increase Impact strength, transverse strength, and an improvement in the antifungal activity of PMMA materials against C. *Albicans* **(Hazim and Fatihallah, 2022)**.

- **Incorporation of Silanized Microcrystalline Cellulose:** Significant improvement of the mechanical and physical properties of the heat cured acrylic, including impact strength, surface hardness, water sorption, and water solubility **(Zaidan, 2022)**.
- **incorporation of Salvadora persica:** The raw S. *Persica* from the Salvadoraceae family was dried at room temperature and blended to produce particles of less than 40 µm. The resulting powder contains hydrated calcium sulfate and calcium phosphate compounds, as well as organic compounds that impart antimicrobial and antioxidant properties, The composite did not contain residual monomers that cause oral mucosa inflammation or irritation **(Chaaben *et al*., 2022)**.

## 1.6 Computer Aided Design-Computer Aided Manufacturing (CAD-CAM)

### 1.6.1 CAD-CAM Denture Base Materials

The fabrication of complete dentures by CAD-CAM methods has become popular in both clinical and laboratory practices in recent years **(Kalberer et al., 2019)**. This increased popularity may be attributed to the improvements in the CAD-CAM techniques and the growing awareness of dental practitioners and laboratory technicians, along with an increasing flexibility to combine parts of the digital workflow with conventional clinical and laboratory protocols **(Srinivasan *et al*., 2018)**.

The complexity of manipulation; the time-consuming procedures of waxing, investing, and wax elimination; and the deformation of heat polymerized PMMA diminish the accuracy of complete dentures **(Abduo, 2014; Lim, 2016)**. Therefore, CAD-CAM may offer similar or better results than conventional methods, including better fit of the intaglio surfaces, improved mechanical properties, **(Srinivasan, 2018)** and higher patient satisfaction **(Kattadiyil, 2015)**.

CAD-CAM systems consist of three parts: 1) a data acquisition unit that collects data from the area of the preparation, adjacent and opposing structures, 2) software for designing virtual restorations on a computer, and 3) a computerized milling device that creates the restoration from a block of restorative material or additive manufacturing. Data can be collected directly using intraoral scanners or indirectly using traditional impressions to create a virtual model **(Galhano *et al.*, 2012)**.

### 1.6.2 Stages in Fabrication of Prosthesis With CAD-CAM Technology

The stages in fabrication of prosthesis with CAD-CAM technology are as the followings **(Patil *et al.*, 2018)**:

1. Computer surface digitization
2. Computer-aided designing
3. Computer aided manufacturing
4. Computer-aided esthetics
5. Computer-aided finishing

#### 1.6.2.1 Computer surface digitization

Scanning of prepared tooth is done either digital (with Light emitting diode LED based or Laser based) or mechanical scanners **(Patil *et al.*, 2018)**.

#### 1.6.2.1 Computer-aided designing (CAD)

It is a computer unit with a software package for visualization of the scanned data, planning and designing dental restorations on a computer screen.

Software's collect data in the "Standard Tessellation Language" format. It is possible to design a variety of dental restorations such as veneers, inlays, onlays, individual crowns, bridge copings, partial denture frameworks and complete dentures. When the design of the restoration is complete, the CAD software transforms the virtual model into a specific set of commands, which in turn drive the CAM unit to fabricate the designed restoration **(Beuer *et al*., 2008; Bilkhair, 2013)**.

### 1.6.3 Computer-Aided Manufacturing (CAM)

The CAM technologies can be divided according to the technique used **(Parasher, 2014)**:

#### 1.6.3.1 Subtractive (Milling) Technique:

Subtractive manufacturing was used to improve and speed up the CAD CAM denture fabrication process, PMMA pucks used for the milling of denture are polymerized by injection under high temperature and pressure, a process that promotes the formation of longer polymer chains leading to a higher degree of monomer conversion and lower values of residual monomer as well as minimal porosity **(Murakami, 2013; Kattadiyil, 2015)**.

It has been reported that these processing conditions decrease the intermolecular distances and reduce the free volume **(Ali *et al*., 2008)**. Surface hardness indicates the density of the material and its resistance to wear and-or scratching which reflects on the dental prosthesis during its function and cleaning **(Murakami, 2013)**.

In this stage the milling is done with computerized electrically driven diamond disks or burs which cut the restoration from ingots or blocks. The CAM technique in recent years can milled any material in any sizes even a complete denture **(Parasher, 2014)**.

**1.6.3.1.1 Milling Materials**

The materials that are used in CNS milling dentures base and frameworks are: **(Alghazzawi, 2016)**

- **Presintered zirconia:** Cutting tool are diamond or carbide bur, with dry milling because wet milling will cause softening.
- **Fully sintered zirconia1:** Cutting tool is diamond bur, with wet milling because dry milling will cause cracks and fracture.
- **Chromium cobalt:** Cutting tool is carbide bur, dry or wet milling which depends on milling type (hard or soft).
- **Polymethylmethacrylate (PMMA):** Cutting tool is carbide bur, it can be both but preferred dry because wet milling will cause undesired residue.
- **Lithium disilicate based glass-ceramic:** Cutting tool is diamond bur, with wet milling because dry milling will cause cracks and fracture.

**1.6.3.2 Additive technique (3-D Printing)**

This category of innovative technologies originating from the area of rapid prototyping (RP), The term 3-D printing is generally used to describe a manufacturing approach that builds objects one layer at a time, adding multiple layers to form an object. This process is more correctly described as additive manufacturing and is also referred to as rapid prototyping which have been adapted to the needs of dental technology **(Prajapati, 2014)**.

Since photopolymerization has traditionally been heavily utilized in dentistry, it is not surprising that UV or visible light-based approaches to 3DP are among the first to be implemented as dentistry takes advantage of this quickly developing technology. Thus, a common 3D printed material used in dentistry currently is resin. Known to cause some degree of shrinkage due to mechanical and light activated polymerization properties **(Anadioti *et al*., 2018)**.

Additive manufacturing consumes less material and produces the fine details, undercuts, and voids that are difficult to reproduce with subtractive manufacturing **(Lindemann, 2017)**.

### 1.6.3.2.1 Additive Manufacturing Process

**Stereolithography (SLA):** Following the CAD design, a solid object is created by printing thin layers of a material curable by ultraviolet light. The ultraviolet light laser is focused on the surface of a tank containing acrylic resin, as the light beam scans and polymerizes each layer when it attracts the object to the liquid surface, repeating this process layer by layer until the model is complete **(Van Noort, 2012)**.

Type of material: Photopolymerized resin

Advantages: 1-High accuracy 2- Smooth surface finish 3-Good mechanical strength 4-Fine build details 5-Low tolerance

Disadvantages: 1-Expensive 2-High material cost 3-Only photopolymerized material 4-Post curing required

**Material jetting:** In the jet of material or polyjet printing (PP), a liquid resin is injected selectively from hundreds of nozzles and polymerized with ultraviolet light, allowing the use of varied materials that allow assorted colors or hardness (rigidity) in the same printing **(Katkar *et al*., 2018)**.

Type of material: Slurry

Advantages: 1-Fast fabrication 2-Low material cost 3-Multicolored material is possible Wide material options

Disadvantages: 1- Large tolerance 2- Low mechanical strength 3- Rough surface finish 4- Layers may collapse during 5- Build process

**Binder jetting:** Plaster material, such as a dust bed, is often used. A print head provides color and a layer-by-layer binder. The powder supports the piece. The completed part generally needs some kind of post-processing because the part is quite fragile **(Katkar *et al.*, 2018)**.

Type of material: Powder

Advantages: 1- Fast fabrication 2- Low material cost 3- Multicolored material is possible

Disadvantages: 1- Large tolerance 2- Low mechanical strength 3- Rough surface finish

**Laser sintering:** In Selective laser sintering, Selective laser melting, Direct metal laser melting- SLS/SLM/DMLS the layers are built sequentially by melting powder particles using a CO2 laser beam that traces a path in a powder bed based on the desired CAD design. In each layer, the laser raises the temperature to the melting point, which melts the powder particles. The process is repeated until the object is completed. SLM, is based on the melting of the powder instead of sintering it **(Vandenbroucke and Kruth, 2007)**.

Type of material: -SLS: Resin, metals, and ceramics -SLM/DMLS: Metals

Advantages: Printed object with 100% density is possible

Disadvantages:1- Expensive 2- Thermal distortion

### 1.6.4 Advantages of CAD-CAM Complete Dentures

The digital software used to design the CAD-CAM dentures allows for quicker cast analysis and faster denture teeth set-up. In addition, the laboratory technician can provide the clinician with a more accurate fitting, high quality complete denture. Finally, the dental technician does not have to mix PMMA resin as with the conventional "pack and press" technique and therefore is not exposed to monomer (Srinivasan et al., 2019). **(Kalberer *et al.*, 2019)**.

### 1.6.5 Disadvantages of CAD-CAM complete dentures

The impact of CAD-CAM on the environment should not be neglected, the milling procedures produce resin particles, which contribute to the plastic pollution of the environment. Similarly, silicone impression materials are not biodegradable **(Al-qarni *et al.*, 2020)**.

### 1.6.6 The Difference in trueness between CAD/CAM Milled and 3D printed dentures

A recent in vitro study compared the difference in trueness between CAD/CAM milled and 3D printed dentures **(Kalberer *et al.*, 2019)** concluded that:
"The CAD/CAM milled CRDPs, under the present manufacturing standards, are superior to the rapidly prototyped CRDPs in terms of trueness of the intaglio surfaces. "

### 1.6.7 CAD-CAM Denture base Compared to Conventional

One of the disadvantages of conventionally fabricated complete dentures is the net volumetric shrinkage of PMMA resulting in poor denture base adaptation because of dimensional changes.

Several studies have compared denture base adaptation between milled, printed and conventionally fabricated complete dentures. Compared the denture base adaptation of pack and press, pour, injection and CAD-CAM techniques for fabricating complete dentures to determine which process produces the most accurate and reproducible adaptation. When they superimposed each corresponding pre- and post-processing STL files, they found that no single technique produced perfect denture base adaptation. However, it was determined that the CAD-CAM fabrication process was the most accurate and reproducible denture fabrication technique when compared to the other processing techniques **(Goodacre *et al*., 2018; Baba *et al*., 2021)**.

# Conclusion

Throughout history, a variety of materials such as chromium-cobalt, PMMA, PEEK, Acetyl, and polyamide have been employed as denture base materials. Although these materials possess suitable properties for dental applications, they often have limitations in terms of their mechanical and physical properties, necessitating modification through the addition of various additives, including metal inserts, glass flakes, glass fibers, polyethylene fibers, micro fillers, and nano fillers/particles. However, further studies and research are necessary to fully investigate these additives and their effects.

Recently, CAD-CAM technologies have emerged as a widely used tool in dentistry, with different techniques such as milling and 3D printing facilitating the development of new materials that exhibit improved properties compared to traditional denture base materials. Nevertheless, it is crucial to conduct further investigations to evaluate these techniques and materials and compare them to the commonly used PMMA denture base material.

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