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Research Article

History and Development of Polymeric Denture Base Reinforcement

Ibrahim M Hamouda[1]* and Alaa Makki[2]

[1]Professor of Dental Biomaterials, Faculty of Dentistry, Umm-Al-Qura University, Saudi Arabia

[2] Professor of Dental Implantology, Faculty of Dentistry, Umm Al-Qura University, Saudi Arabia

***Corresponding Author:** Ibrahim M Hamouda, Professor of Dental Biomaterials, Faculty of Dentistry, Umm-Al-Qura University, Saudi Arabia.

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Abstract

Continuous developments in the biomaterials science over the last decades contributed to the marked production of new materials and techniques in dentistry. There are four major groups in dental biomaterials such as ceramics, metals, composites and polymers. Polymeric based materials are widely used for dentures construction. Poly methyl methacrylate (PMMA) was the most widely used non-metallic denture base material. PMMA has good esthetic property but it is still not fulfil the requirements of the ideal mechanical properties as a denture base material to resist the impact force. The researches were focused on the production of alternative denture base materials or to modify the present materials chemically and mechanically. So, this review article was aimed to go through the literatures reviewing the history and collecting the different reinforcing materials for polymeric denture base materials. This review article was built on the information from literatures available in PubMed, Google scholar, Research Gate and Scopus.

Keywords: Polymeric Denture; Poly Methyl Methacrylate; Polyamides

Introduction

Poly methyl methacrylate (PMMA) was the commonly used material in the field of prosthodontics. Nonmetallic dentures constructed from PMMA were widely used because of their easily manipulation, good esthetic quality and acceptable mechanical properties. PMMA materials show weak physical and mechanical properties. Dental researches in biomaterials have a steady progress from the past decades up to the beginning of the 21st century to change the properties of PMMA or produce a new material to meet the requirements of an acceptable denture base materials [1]. Treatment of edentulous patients with complete dentures dates back to 700 BC [2].

Numerous materials such as wood, ivory, bone, gold, ceramics and wax were developed from the sixteenth and through the eighteen century, and vulcanized rubbers were used for construction of complete dentures [2]. In the early 1900's, biomaterials such as vinyl acetate, poly vinyl chloride, modified phenol formaldehyde resin (bakelite) and cellulose plastics were used as a denture base material. Polycarbonates and polyamides were used as substitutes for PMMA [3].

In this review article we will collect the reinforcing methods and materials from the literatures that affect the properties of polymeric denture base materials.

Materials and Methods

The article was built from the revision of the PubMed database and Google scholar literatures. The selected researches were readied and their information was analyzed for writing this review.

History and development of polymeric denture materials

Charles Goodyear in 1839 was introduced the Vulcanite polymeric material as a denture base material. Vulcanite is a cost-effective material, stable in dimensions, comfortable, used for several years up to 1940s when replaced by the acrylic resins. Vulcanite has low density, light in weight, and fabricated easily. Vulcanite is a thermoset material produced by the addition reaction of natural rubber and the Sulphur. The formation of vulcanite was done in a steam pressure vessel. Cross linking was carried between the rubber polymer chains by sulphur bonding to form a rigid, opaque and stable solid [4]. Vulcanite has some disadvantages such as absence of chemical bonding with porcelain teeth, absorb saliva and fluids, dimensionally unstable and poor aesthetics [2].

Celluloid is a natural cellulose polymer introduced as a denture base material in circa, in 1870s. It is a polymeric material made by dissolving nitrocellulose under pressure. Celluloid was produced by plasticizing cellulose nitrate with camphor. It could be pigmented into pink color to match the oral tissues. It has several disadvantages such as discoloration by foods, drinks and tobacco, had unacceptable taste due to the presence of camphor and difficult in repair [2,5].

In 1909s, Dr. Leo Baekeland discovered phenol formaldehyde resin. It is called 'Bakelite' which introduced for use in dentistry in 1924s. Bakelite had excellent aesthetic quality but has some disadvantages such as difficulty in manipulation, difficulty in repair, brittleness, discolored easily and dimensionally unstable [2,6].

Poly vinyl chloride was used as a denture base material in 1930s. It is a co-polymer of vinyl chloride and vinyl acetate. It was processed by pressing technique of a heated blank of the material into a mold. It has low mechanical properties, difficulty during polishing, dimensional changes and discoloration. The dimensional instability was caused by release of processing stresses. It shows poor denture hygiene which leads to irritation to the oral tissues [2].

Thermoplastic polyamide (nylon) was introduced in 1950s as alternative to PMMA denture base materials. It is formed by the condensation reaction between a dibasic acid and a diamine. The first form of polyamides has some disadvantages such as roughness, unacceptable color, difficulty in polishing, in repairing and relining of denture, lack of chemical bonding between the denture base and the acrylic teeth, and high-water sorption [7]. They had several advantages such as higher elasticity, higher fracture toughness, higher strength, chemical resistance, and acceptable biological and esthetic properties [8]. The polyamide resins could be processed by injection-molding. In this system, the resin is supplied in a cartridge which overcome the mixing errors and provide good shape stability, gives high mechanical resistance to aging and reduces contraction [7,8]. Nylon is a crystalline polymer which leads to high strength, high heat resistance, higher ductility, and lack of solubility in solvents [9].

Poly methyl methacrylate (PMMA) was introduced in 1937 as denture base material. Since 1940s, it becomes the most widely used material for construction of complete and removable partial dentures [1]. The ideal requirements of PMMA denture base materials are excellent esthetics, good mechanical properties particularly impact strength, flexural strength, modulus of elasticity, hardness, biocompatibility and excellent bonding with artificial teeth, ability to repair. and dimensional stability [1]. There were several types of polymers such as PMMMA, acetal homo-polymer, and Polyamide resin [10]. PMMA has many advantages such as good aesthetic quality, repair easily, simple fabrication technique, acceptable strength, and low water sorption and solubility [2].

Poly-methyl methacrylate still have numerous disadvantages such as low mechanical properties, high dimensional changes, porosity, bad thermal conductivity, discoloration with time, radiolucent materials, irritation from residual monomer and questionable biocompatibility [11]. To overcome the disadvantages of the conventional poly methyl methacrylate denture materials, continuous development in the field of polymerizable dental resins resulted in the production of alternative thermoplastic resin material such as epoxy resins, polyamides (nylon) in 1950s, polystyrene in 1948s, acetal resins in 1971s, polycarbonate resins. The most important characteristics of thermoplastic resins are, they were monomer free, non-allergic, biocompatible, nontoxic, enhanced esthetic, and could be injected into a mold using special devices [5].

Polyamide is a thermoplastic, crystalline polymer. Polyamide has some disadvantages such as surface roughness, discoloration, water sorption, warpage, bacterial contamination, and difficulty during polishing [5]. Acetal is a thermoplastic homo-polymer of poly(oxymethylene). Acetal was developed with the polyurethane and polycarbonate. Acetal resins are produced from polymerization of formaldehyde. These resins characterized by high hardness, high toughness, rigid, good biocompatibility, low coefficient of friction, and high fatigue resistance [4,5].

Progressive development of dental biomaterials in the polymer field resulted in the appearance of a new thermoplastic material in the market known as Vertex ThermoSens. Vertex ThermoSens denture base material has higher flexural strength [12]. Vertex ThermoSens is a thermoplastic, monomer-free, rigid material, so, it is suitable for patient unable to wear PMMA dentures. So, it is suitable for patients allergic to residual monomers. It is innovative denture base material, and virtually unbreakable. Its composition based on the microcrystalline polyamide material and pigments. Vertex ThermoSens is based on the injection molding technique using automatic or manual injection device [12]. Vertex ThermoSens denture base material provides better fitness and unbreakable dentures [11,13]. These thermoplastic materials are flexible for removable partial dentures because it becomes better and stronger dentures. The flexibility of the thermoplastic materials prevent transfer of stresses from the dentures to the adjacent teeth and tissues. So, it prevents trauma from the partial denture. The color of the thermoplastic denture bases matches the adjacent oral tissues and prevent the use of metal clasps as in the conventional partial dentures [12]. There was a study that showed no significant difference between Vertex ThermoSens and other conventional denture base material regarding dimensional stability and warpage [13].

New thermoplastic resins which could be used in dentistry have been developed which depend on injection molding technique. The thermos-press injection molding system enables the use of careful processing of the materials to obtain high quality and metal free prosthesis such as Vertex ThermoSens. These new materials are alternatives to PMMA denture base materials. They have good dimensional stability and greater strength than that of the conventional PMMA [14]. Also they are biocompatible, resistant to fracture, free from residual monomer, and highly accurate. These improved properties were related to the injection molding technique; in which the polymerization shrinkage could be compensated by continuous injection of resin at certain pressure through a carefully controlled procedure [13,14]. Brecrystal is another type of thermoplastic resins that was used as a denture base material which will enthuse the dentist and his patients. This material is manufactured without monomers or catalysts that may cause adverse health drawbacks. This processing technique produce highly dense denture bases, which could be polished quickly and easily to a high luster. The density of the material prevents water absorption and prevents discoloration [14].

The most common failure form of the polymeric denture base materials is the fracture under different forces specially impact, tensile and compressive forces. In order to overcome these drawbacks, high number of researches have been done to improve the mechanical and physical properties of these polymeric materials. Modifications of the polymeric materials as dentures involve the mechanical reinforcement using other materials such as nanofillers, fibers, nanotubes and hybrid materials. These reinforcing materials enhanced the mechanical properties as the flexural strength, cyclic fatigue, impact strength, and wear resistance [15].

In the recent years, complete dentures could be produced using the computer-aided technology has guided the investigational, educational, and clinical abilities for the future In CAD/CAM fabrication techniques. CAD/CAM system becomes available for construction of complete dentures and becomes as an alternative to the conventionally manufactured acrylic resin dentures. These dentures could be milled from fully polymerized acrylic resin blocks [16]. These denture bases not subjected to distortion or shrinkage during processing [17]. Digital Dentures have good denture base fitness and better clinical retention than the conventional dentures, as well as reduced traumatic ulcers which caused by ill fitted dentures. This digital design and automatic processing overcome the manual related errors. CAD/CAM PMMA materials showed higher impact strength, flexural strength, and flexural modulus than that of the conventional heat-cured denture base resins [18].

PEEK

Polyether ketone (PEEK) is a semi-crystalline polymer (crystallinity = 30-35%). These materials were used as dental and bone implants due to its acceptable glass transition temperature (143°C) and good elastic modulus for the ease of molding to 3D printed materials.

Researchers suggested two approaches to strengthen PMMA material. The first approach was to increase the fatigue and impact strengths by addition of butadiene-styrene rubber in the bead polymer [16]. The second approach was the reinforcement of PMMA denture base materials with high modulus fibers such as carbon fibers, glass fibers, ultra-high modulus polyethylene fibers, titanium fillers, silver nanoparticles and zirconium oxide nanoparticles [16,19].

In the past, there were numerous reinforcing materials such as macro fibers, rubbers, and fillers have been used to increase the mechanical properties of the polymeric denture base materials. Continuous development in Nano dentistry resulted in introduction of a new strategies for reinforcing of the dental biomaterials. The interest in the nanostructured biomaterials characterized by high surface area to volume ratio. This nanotechnology improves the interfacial interaction and the specific new chemical, physical, and biological properties. There were numerous studies were done to reinforce the polymeric denture base resins using nanoparticles such as silver, alumina, ceramic, zirconia ($ZrO2$), and Titania ($TiO2$). Also, nanotubes and nanofiber were studied [19,20].

Addition of fillers to reinforce PMMA are the most acceptable and cost-effective technique. The fillers added to the resin were ceramic and metal forms to enhance the mechanical, chemical, and thermal properties of PMMA. Improvement of the polymer properties depends on the filler concentration, orientation, morphology, degree of dispersion, and the degree of adhesion to the polymer matrix. These materials have an excellent flexural properties and impact resistance [21]. Silane coupling agent can change the surface of the inorganic materials to become compatible with the acrylic monomer. The success of reinforcing technique depends on the type of particles used and treatment method followed. Surface treated particles could enhance the mechanical properties of PMMA and high-impact resins as a denture base material [19,21].

Strategies of polymeric materials reinforcements

Rubber materials reinforcement

Impact strength and fracture toughness are the most important properties for polymeric denture base materials. These polymeric denture base materials are susceptible to fracture on accidents and under high masticatory forces. Several studies have been conducted to evaluate the toughness and how to increase this important property by using rubbery materials to reinforce the conventional acrylic polymers [22]. This reinforcement method depends on the addition of rubbery particle to the polymeric resin matrix. The elastic modulus of the rubbery additives is lower than that of the polymer resin matrix. Also, the rubbery additives has higher Poisson's ratio than that of the polymeric resin matrix. The reinforced resin polymer has lower elastic modulus and increased Poisson's ratio than that of the unreinforced resin polymer. The main advantages of this reinforcing method are the increase in the toughness and the ultimate elongation [22].

The continuous progress in rubber reinforcement leaded to the introduction of high impact acrylic resin denture base materials. This mechanism depends on the addition of butadiene-styrene poly-methyl methacrylate particles which grafted to the methyl methacrylate monomer. The formed high impact resins have higher fatigue properties and impact strength. These reinforced resins are indicated for patients who drop their dentures accidentally and repeatedly e.g., in case of parkinsonism. These materials are supplied as powder and liquid forms and processed in a similar procedure to heat-cure resins [16]. The mechanism of reinforcement depends on the prevention of crack propagation through the resin matrix by the rubber particles [20].

Another research reported that. butadiene-styrene rubber increased the life of the polymeric resin dentures. The high impact polymer resins have good flow properties and high toughness but have low tensile properties. It was found higher flexural strength for the high impact resins when compared to conventional resins. On the other hand, the unidirectional glass fibers showed comparable flexural strength as that of the high impact strength resin [23]. Also, the problem of dimensional changes could be solved. The disadvantage of rubbery reinforced resin was its high flexibility that caused by low Young's modulus [21]. The high-impact acrylic resins(rubber reinforced resins) are a acceptable denture base materials for patients with repeated fracture of the acrylic resin dentures. The most commercially successful method for reinforcement to date is the rubber strengthening technique [20].

Metallic materials reinforcement

Metal wires were used to improve some of the physical and mechanical properties of acrylic resin materials, such as tensile strength and flexural strength. Perforated metal plates caused a higher flexural strength and flexural modulus. Heat cured acrylic resin were reinforced with stainless steel mesh indicated high impact strength. The elastic modulus. fracture load, and toughness of a complete denture were improved by using of a metal mesh. In general, the location of the metal reinforcement will affect the fracture resistance of the maxillary acrylic resin complete dentures [24]. The addition of 1% Colemanite to poly-methyl methacrylate increased the mechanical properties of PMMA. Boron reinforced acrylic resins may be the material of choice for increasing the strength of acrylic resins [25]. All metal wires were used as strengtheners increased the fracture resistance of the acrylic resin specially the semicircular metal wire [24]. Strain distribution resulting from reinforcing a maxillary denture using a thin Ni-Cr plate was determined by determining the strain distribution under occlusal loads. The use of a metal reinforcing plate resulted in a more uniform stress distribution in the palate of the maxillary denture. The stress intensity of the mid-palatal area decreased from -431 to -44 during buccal loading and from -239 to -19 during palatal loading [26]. One of the disadvantages of the metal reinforcement is, they could not bond chemically to the resin materials. Numerous works have been done to improve the bond between the metal fillers and the resin matrix such as sandblasting, silanization, and metal adhesive resins. Addition of metals as a reinforcing agents to the polymer resins have a limited values due to the unacceptable esthetics, stress concentration inside the structure, and the decreased benefits of metal wires on flexural fatigue resistance [22].

Alumina (Al2O3) nanoparticles reinforcement

A nanomaterial has a dimension of a nanometer scale (1 to 100 nm). Using of alumina Al2O3 nanoparticles to reinforce PMMA powder resulted in high biocompatibility. Silane-treated aluminum nanoparticles enhanced the mechanical properties such as the flexural strength, compressive strength, toughness, and wear resistance. Alumina nanoparticles added to PMMA showed good effect on water sorption. polymerization shrinkage, and thermal conductivity. The limitation of Al2O3 reinforcement was the discoloration of the resin materials [27]. Aluminum oxide nanofillers are important compounds that could be added to the resin denture bases to improve the flexural strength. The flexural properties of the heat-cured denture base resin improved after using of 8% and 13% aluminum oxide particles. Higher flexural strength of denture base is important to the longevity of prosthesis [28]. Addition of 2.5 to 5% aluminum oxide powder were increased the degree of conversion of heat-cured acrylic resin. Aluminum oxide powder was significantly decreased both released monomer and the amount of deflection during fracture of heat-cured resin material. Aluminum oxide reinforced resin has higher flexural strength than that of the unreinforced resin. There was a high positive correlation between the degree of conversion and flexural strength of the reinforced resin materials. On the other hand, there was a negative correlation between the degree of conversion and monomer released of the reinforced specimens [28]. Al_2O_3 particulate reinforced the resin materials, where 4% Al_2O_3 showed higher hardness, yield strength, elastic modulus, and ultimate tensile strength. The advantages of Al_2O_3 reinforcement were improved the compressive, flexural, impact, and tensile strengths and surface hardness and thermal properties of PMMA and decreased warpage [29]. A study concluded that addition of alumina to conventional heat cure acrylic resin, self-cure acrylic resin, and high impact heat cure acrylic resin increased the flexural strength. Enhancing the flexural strength of the acrylic resin base material resulted in higher clinical success [28].

Zirconia (ZrO2) nanoparticles reinforcement

Nanoparticles are used to increase the mechanical properties of the resins based on the principle of reduction of the filler size will improve these properties. The advantages of Zirconia reinforcement were increased flexural, compressive, and impact strengths, increased fatigue strength, hardness, fracture toughness, and increased thermal conductivity. It also may shows antifungal activity but may shows a low flexural strength values [29]. Addition of ZrO2 to PMMA increased the thermal conductivity. Using silane coupling agent (3.5%) may increased the PMMA-ZrO2 interface bonding and flexural strength. The ZrO2 nanotubes showed greater reinforcing effects when compared to ZrO2 nanoparticles but may increase the amount of water sorption [30].

Titanium dioxide (TiO2) nanoparticles reinforcement

Titanium dioxide nanoparticles increased the surface hydrophobicity and decreased the surface biomolecules that causes discoloration. The main advantages of Titanium dioxide nanoparticles were its excellent mechanical properties, pleasing color, higher stability, high biocompatibility, low cost, and acceptable antimicrobial activity. It has higher oxidizing activity under UV radiation and can decompose the organic matters and bacteria [31]. Adding TiO2 nanoparticles improved the fracture toughness, thermal conductivity, and hardness and increased the impact strength [20,31].

The addition of silanized TiO2 nanoparticles has similar actions by increasing the surface hardness, impact, and transverse strengths. Also, they decreased water sorption and solubility [32].

The flour-apatite or apatite-coated TiO2 showed antifungal activity which inhibits the growth of Candida albicane. Due to poor wettability of TiO2 nanoparticles, titanium coupling agent is required for reinforcement of PMMA resins. The modification of PMMA resins by the addition of barium titanate as a radio pacifier decreased the fracture toughness. TiO2 nanoparticles are highly dispersed in the prepared dental resin materials, which has excellent effect on bactericidal growth of gram-positive and gram-negative bacteria and also changed the cytocompatibility of dental pulp cells [33].

Silver nanoparticles reinforcement

Silver nanoparticles has been used in different fields in medicine for many years. Because of their small size, silver nanoparticles possess physical, chemical, and biological properties different from the conventional large-sized materials. The main advantages of silver nanoparticles reinforcement for denture resins are, they have broad-spectrum antibacterial action, antifungal activity at lower concentrations and have high strength. While its main disadvantage is the discoloration of the resin materials. Because of their metallic nature, adding silver nanoparticles to PMMA resins improved the compressive strength, thermal diffusivity and thermal conductivity [34]. Because of their antimicrobial activities, silver nanoparticles prevent bacterial adherence to denture bases. Dentures containing silver nanoparticles have shown antifungal activity [33]. The incorporation of silver and graphene nanoparticles to PMMA resins increased the mechanical properties (compressive, flexural, and tensile strengths) and decreased water sorption [35]. Water sorption and solubility of the resin dentures increased by addition of nanosilver and nanogold particles to acrylic resin denture base materials depending on their concentrations [36].

Other nanoparticles reinforcement

Nanomaterials were classified according to its dimensions (1) where the three dimensions are less than 100 nm, (2) when two dimensions are less than 100 nm named as nanotubes, nanowires, and nanofibers and, (3) when one dimension is less than 100 nm named as coatings, thin films, and layers [36]. Copper nanoparticles improved the anti-fungal and antibacterial action of the resin materials. These nanoparticles improved the flexural and tensile strengths when used in small quantities. The main disadvantage of copper reinforcement is the discoloration of the resin materials. Gold nanoparticles increased flexural and thermal properties resulting in more patient comfort. Platinum nanoparticles improved the mechanical properties and provides antimicrobial action to the PMMA resins. Also, it increases the deflection during bending of the denture base resin. Nano diamonds provide increased fracture toughness, high hardness and thermal conductivity, and improved impact strength of PMMA [11].

Silica reinforcement

The mechanical and thermal properties of PMMA were increased by addition of silica. Also, it increases the surface hardness, transverse strength, and impact strength. When the concentration of silica was increased, agglomeration of the silica particles were occurred and crack propagation was increased, which results in decreasing the hardness and fracture toughness [11]. Addition of a silica-containing nylon fibers mesh to the acrylic resin dentures resulted in increased flexural strength. The addition of untreated and surface treated silica not recommended as a method of denture strengthening method [37].

Fiber's reinforcement

Glass fibers

Glass fibers were studied as a reinforcing agent for denture base PMMA since 1960s [38]. Glass fibers were added to the PMMA denture base materials in various forms (A) Chopped fibers (B) Continuous fiber (C) E-glass fibers, (D) Roving fibers, (E) Woven fibers, and (F) Glass nanofibers. Glass fiber reinforcement could increases the Vickers hardness, impact strength, flexural strength, and toughness of acrylic resin dentures. On the other hand, it decreases the fatigue strength, and denture deformation [20,39]. Glass fibers has good aesthetics and excellent polishing characteristics. Also, they resist extreme moisture and temperature [39]. Glass fibers has several drawbacks such as incomplete wetting by resin matrix which affects the strength of the resin hue to the formation of voids and air inclusions. Void formation in fiber-polymer matrix due to polymerization shrinkage and poor impregnation of fibers. Another disadvantage of nanofibers is the incomplete dispersion into the resin matrix resulting in creation of fiber bundles. These fiber bundles act as defects inside the denture base [40]. E Glass fibers are translucent thus, provide good esthetics. Because of glass fiber bonding to the resin matrix, it improves strength [41].

Benefits of fibers reinforcement could obtained from increasing the length of the fibers rather than the cross-sectional diameter. Ihe improvement in the mechanical properties depend on the morphology of the fibers (diameter and length), orientation of the fibers in the resin matrix, concentration, pre-impregnation, and silane treatment or the fibers used as continuous or discontinuous [41]. Unidirectional orientation of fibers lead to anisotropy and increased strength in one direction. Woven or multidirectional orientation lead to isotropic dispersion of the fibers and increased strength in all directions [42]. Silane treated glass fibers showed improved flexural strength, where the strength could be affected by the proportion, position of the fibers and fiber-matrix interface. The pre-impregnation of fibers with monomers showed improved wettability and adhesion inside the resin matrix [41]. Silanated fibers has increased bonding strength when compared with the untreated fibers. Presence of fluoride with glass fillers prevents microbial adhesion to PMMA denture bases but may causes surface roughness. The impact strength of acrylic denture base could be increased by addition of unidirectional or woven glass fibers [43].

Polyethylene fiber

Polyethylene fibers improved the physical properties of acrylic resin. When they incorporated into PMMA resin dentures, they produced denture bases with improved elastic modulus in the axial direction. They exhibited several favorable properties when used as a strengthening agent for resin dentures such as low density, high ductility, natural color, and superior biocompatibility. They can be used as monofilament fibers or woven form. The adhesion of fibers to PMMA resin matrix could be enhanced when treated with electrical plasma. Plasma treatment causes etching of the fibers surfaces resulting in resin impregnation and bond mechanically to the resin matrix [44]. Polyethylene fibers increased the impact strength and modulus of elasticity and provide good esthetics. Linear drawing of polyethylene fibers caused high tensile strength, notch insensitivity and prevent cracks propagation through the fibers [45]. It has some drawbacks such as no increase in flexural strength; placement of fibers in the resin materials and its finishing are difficult [11]. Length, concentration, and orientation of the fibers has great effect on the mechanical properties of ultra-high molecular weight polyethylene reinforced PMMA acrylic resins. Fiber concentration less than 3% which treated with electrical plasma showed a significant increase in the strength [1].

Carbon/Graphite fiber

Several studies have investigated the reinforcement of acrylic resins with carbon fibers to improve the impact strength, flexural, and prevent fatigue failure. The orientations of carbon fibers include woven mat form, random, longitudinal, strand form, layered fibers, and perpendicular to the applied force. Resin materials which contain layered fibers of specific orientation showed improved resistance to the applied stresses and increased fatigue strength [34]. Impact and flexural strengths were increased and prevent fatigue failure. It has some disadvantages such as unaesthetic quality, difficult polishing and weakens the denture [15]. Carbon fibers used mainly for increasing the fatigue strength and impact strength of the PMMA resins. However, carbon fibers are difficult in handling when it was dry, so, it should be wetted with monomer to form the town of wet fiber [22]. Carbon fibers should be coated with a silane coupling agent to give strong adhesive bond between carbon fibers and PMMA resin matrix. Although carbon fibers have significant increased mechanical properties to PMMA resins, its cytotoxicity make it is not suitable for using as denture base application. Using of carbon reinforced denture base, it may cause skin irritation [46].

Placement of carbon fibers perpendicular to the direction of the applied stresses provided increased bending resistance and resistance to flexural fatigue. Carbon fiber reinforced acrylic resins showed high impact strength which could be increased by increasing the fiber length and fiber concentration in the resin denture base materials [46]. Carbon fibers are not used today because of their difficult handling properties, difficultly in polishing, unacceptable esthetics due to its black color, and possibility of toxicity [22].

Aramid fiber

The aramid fiber commercially named Kevlar fiber, and structurally, it is an organic material such as poly-paraphenylene terephthalamide which has the chemical formula(-CO-C6H4-CO-NH-C6H4-NH-) n [34]. Kevlar fibers are more popular because they provide excellent mechanical properties than E-glass and nylon fibers. Poly-aramid fibers have high wettability when compared to carbon fibers because they do not require coupling agent treatment. Incidence of a crack at the site of fiber reinforcement in the denture bases was less with Kevlar fibers. Kevlar fibers produced denture bases with increased modulus of elasticity and high tensile strength. Acrylic resin restorations reinforced with fiber content up to 2% and with unidirectional orientation exhibited higher fatigue resistance and impact strength [47]. It has unaesthetic quality, and polishing is difficult [11]. Hardness of denture base resins reinforced with aramid fibers were decreased by increasing fiber concentration. Also, aramid fibers reinforced dentures was biocompatible because they have no toxicity. These fibers are not used extensively because of its yellow color. Exposed fibers at the surface of the resin dentures lead to surface roughness resulting in difficulty in polishing. The adhesion between these fibers and resin matrix was poor as reported by several literatures [45,46].

Polypropylene fiber

The impact strength of PMMA resins was increased by reinforcement with poly- propylene fiber either untreated or surface treated. When the fibers were treated with plasma resulted in the highest impact strength. Silanization of the fibers increased the impact, transverse, and tensile, strengths, while wear resistance was significantly decreased [29].

Polyamide fiber

Polyamide fiber includes both Nylon and Aramid fibers. Aramid fiber- reinforced denture base resin was biocompatible, increased flexural strength and elastic modulus. Nylon fiber increased the fracture resistance and resistance to continuous application of stresses [29]. Aramid fibers decreased the hardness and it has yellow color which affect the resin color [11]. Polyamide fibers showed best wettability to the resin matrix, so using of coupling agent is not necessary but mechanical properties were improved [1]. On the other hand, these fibers have poor aesthetic quality due to its yellowish color. Also, fibers exposure on the surface of the restoration causes irritation to patient's tissues, difficulty in finishing and polishing [22].

Polyamide fibers are based chemically on the aliphatic chains. These fibers have several advantages such as high shock resistance and ability of repeated stressing. Water absorption by these fibers will affects the mechanical properties. Nylon-reinforced resin denture bases displayed higher fracture resistance than PMMA resin [48]. Adding nylon fibers to the resin materials improved the flexural strength [8], improved structural elasticity, and fracture resistance. Polyamide denture bases has good fracture resistance but with lower elastic modulus than that of PMMA resin materials. The aramid fibers have high resistance to impact forces and excellent wettability when compared to carbon fibers. Polyamide fibers require modification to produce better properties than that of PMMA resin materials [48].

Hydroxyapatite fibers

Addition of hydroxyapatite nanofibers to a resin polymer at low concentration can enhance their mechanical properties. They have some drawbacks such as incomplete dispersion inside the resin matrix that results in the formation of bundles which may become as defects in the resin matrix [40]. Incorporation of HA fillers into PMMA resin produced higher mechanical properties including flexural strength and elastic modulus. The mechanical properties of denture base materials reinforced with hydroxyapatite nanofibers could be minimal because of the poor compatibility between the PMMA resin matrix and these fibers [29].

Polyacrylonitrile and PMMA nanofibers

PMMA nanofibers could be surrounded by a dental resin matrix. After curing, the linear PMMA chains were interpenetrated and entangled with the cross-linked resin matrix. Also, a strong interfacial bonding between the nanofibers and the resin matrix was produced. It has been reported that sever reduction in fiber diameter size to the nanometer scale causes increasing in the elastic modulus, strength, and toughness. Fibers are the preferred reinforcing materials when compared with the particles because they provide a larger area for load transfer and improve the toughening mechanisms such as fiber pullout and fiber bridging [49].

The disadvantage for the use of nano fibers as a reinforcing material is the improper wetting by resin matrix, which results in reduction of strength due to air inclusion and voids. Another disadvantage of nano fibers is incomplete dispersion into the resin matrix which results in the formation of bundles. These bundles may act as defects which negatively affect the mechanical properties of the resin matrix and the resulting resin materials [40].

Natural fibers

Natural fibers were used to reinforce the resin materials such as vegetable fiber (ramie fiber) and oil palm empty fruit bunch (OPEFB). OPEFB fibers improved the flexural modulus and flexural strength of acrylic resin. Short ramie fiber improved the flexural modulus of the resins when compared with conventional materials. On the other hand, its flexural strength is decreased due to weak interfacial bonding. The disadvantage of these fibers was it supplied in a long form, which requires greater work such as cutting and preparation [50].

Hybrid reinforcement

The combination between different metal oxides fibers, and ceramics, different fibers, and fibers with metal oxides, or ceramic materials. Hybrid fiber strengthening were improved the toughness and flexural strength of the acrylic resin materials. Incorporation of metal oxides and ceramics provide similar results to PMMA. It has antibacterial activity without tissues cytotoxicity. A combination of fibers and other fillers also improved the impact strength, hardness, thermal conductivity, and surface roughness, as well as fatigue and compressive strengths [51].

Conclusions

The resin dentures are exposed in the oral cavity to a variety of affecting factors such as forces of mastication, interaction with the oral fluids and different beverages. PMMA resin material were used for a longer time in denture construction. Although these resins exhibiting many favorable properties, they could not be considered as an ideal material due the low strength. Several attempts have been done to improve the properties of acrylic materials used for denture construction. A higher compressive, tensile, impact, and flexural strengths, were improved by structural changes in PMMA, incorporation of different additives such as platelets, wires, micro or nano fibers and other fillers, or hybrid materials. The new era of nanosciences gives a new perspective in the improvement of PMMA resins used in the field of dentistry. Based on this review it can be concluded that: Glass fibers increased the mechanical properties of the resin polymers. Natural fibers and vegetable fibers could be used, but further studies are required. Silane coupling agents play an important role in enhancing the bonding between fillers and the resin matrix resulting in improved properties. Hybrid fillers, hybrid fibers, or hybrid fibers and fillers may significantly improve resin properties.

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