Review on poly-methyl methacrylate as denture base materials

Sheng, T. J.[1], Shafee, M. F.[1], Ariffin, Z.[2] and Jaafar, M.[1*]

[1]School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Pulau Pinang Malaysia
[2]School of Dental Science, Health Campus, Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan Malaysia

Abstract

The present paper reviews the current status of Poly-methyl methacrylate (PMMA) as the denture base materials. PMMA was the most commonly used denture base material in clinical fabrication. Few types of fillers have been introduced to improve the properties of the PMMA composites, for example polymer (polyethylene and vegetable fibres), metal (silver, stainless steel, aluminium and copper) and ceramic base materials (zirconia, glass fibres, carbon fibres, alumina, hydroxyapatite and tricalcium phosphate). Mechanical properties, thermal properties and water absorption are generally been measured to characterize the denture base materials. Comparisons on previous research work on PMMA composites for denture application are thoroughly examined.

Keywords: Denture base, poly-methyl methacrylate (PMMA), polymer composites.

ARTICLE INFO
Received 16th January 2018
Received in revised form 23rd May 2018
Accepted 25th October 2018
**Corresponding author: Prof. Dr. Mariatti Jaafar*
Tel: +604 599 5262 e-mail: mariatti@usm.my
 ISSN: 1823-7010 eISSN 2600-7444

Introduction

Denture base is defined as a part of denture that rests on the foundation tissue in which teeth are attached. While denture base material is any substance of which a denture base maybe made. According to Vishal et al. [1], denture base resins are classified into 3 categories. First, they can be classified into non-metallic (acrylic resin and vinyl resin) and metallic (cobalt chromium, gold alloys and stainless steel). Second, they can be classified into temporary form (self-cure, shellac base plate, base plate wax and injection molded resins) and permanent form (heat cure denture resins, light cured resins and pour type resins). Third, they are based on American National Standard/American Dental Association (ANSI/ADA) classification (Sp.No 12/ISO 1567) which are heat polymerizable polymers, auto-polymerizable polymers, thermoplastic blank or powder, light activated materials and microwave-cured materials [1].

There are some requirements for idea denture base resin. Firstly, it must be physiologic compatibility which means nontoxic, noncarcinogenic and nonallergenic. Secondly it must achieve acceptability to patients' senses, for example color stable, odorless, tasteless and light in weight. Third, the denture base resin must be cost effective, which include raw material, equipment for processing, cost of fabrication and good shelf life. Fourth, it must achieve certain properties such as adequate mechanical properties and satisfactory thermal properties, so that it would not influence oral function or mechanical destruction. Fifth, hygienic factor also one of the main requirements which consist of sterilizable, nonporous to microorganisms, low fluid absorption and easy to be cleaned. Finally, the durability of denture base resin needs to be high enough in oral environment. These include dimensionally stable, good bonding between base and teeth, resistant to weak acids and alkaline and resistant to abrasion and wear [2].

Since first polymerized by Walter Bauer in 1936, acrylic resin denture base gradually took the place of traditional metal base and became the most commonly used denture base material in clinical fabrication [3]. Until today, there are some scientists still finding the most suitable denture base materials. Poly-methyl methacrylate (PMMA) is still the most predominantly used denture base material in present because of low cost, light weight, insoluble in mouth fluid, excellent aesthetic properties and ability to be repaired easily [4].

Nonetheless, PMMA resin has some negative problems such as polymerization shrinkage, weak flexural, lower impact strength, and low fatigue resistance [5]. Hence there are few methods proposed by Mallikarjuna et al. [6] to improve the properties of PMMA resin such as:

- Using polycarbonates and polyamides as substitutes for PMMA.
- Chemical modification of PMMA by the addition of copolymers, cross-linking agents and rubber substances in the form of butadiene styrene.
- The incorporation of fibres, metal or ceramic inserts into the denture bases act as filler.

According to Rajul and Romesh [3], adding fillers to reinforce PMMA are considered the most cost effective and reasonable method. Those fillers are included in resin, metal and ceramic form to increase the mechanical, thermal and chemical properties of PMMA. However, improvement of polymer composite property depends on the filler concentration, filler morphology, degree of dispersion, orientation and degree of adhesion with the polymer matrix. Some of the materials from these developments have an excellent balance of impact resistance and flexural properties. However, most are not acceptable to the dental technician because of their processing characteristics. The most popular material at present for the fabrication of dentures, which has high impact strength, is a rubber modified acrylic polymer whose handling characteristics are more or less identical to conventional PMMA [3].

Denture base material

Since early centuries, different materials have been used to make denture base, which include polymer, metal and ceramic. In the current stage, acrylic resin is found to be the most suitable material used for dental base. However, every material has its own advantage and weaknesses. Hence, to overcome the weaknesses there were several ways to restore the defect and improve the properties [7-8].

Polymer

Polymer is a large molecule or macromolecule composed with repeated unit. They may be formed by condensation polymerization or addition polymerization. Acrylic resins are polymer esters of methacrylic acids. Among these, PMMA is one of the common polymers used as a denture base material. It is a thermoplastic which can be heated and manipulated repeatedly. PMMA is the combination of methyl methacrylate with chemical formula $(C_5H_8O_2)_n$.

PMMA is a linear thermoplastic polymer which lack of methyl group on its backbone carbon chain. To be used as a denture base material, acrylic polymer powder was mixed with methyl methacrylate monomer which is a thin liquid, and usually an organic peroxide hardener of some sort [7]. PMMA has several advantages such as excellent aesthetic characteristic, adequate strength, easy repair, low water absorption and solubility and simple fabrication process. However, PMMA also faced some drawback such as polymerization shrinkage, low impact strength, low fatigue resistance and weak flexural [8].

Polyamide resin was proposed as a denture base material in year 1950 [9]. Polyamide is a thermoplastic polymer which under part of nylon. The formation of polyamide is based of condensation reactions between diamine $N_2H_4(CH_2)_6$ and dibasic acid $C_2O_4H_2(CH_2)_4$. Polyamide is a crystalline polymer which the crystalline effect accounts for the lack of solubility in solvent. Besides it has high heat resistance, high strength couple with ductility, high elasticity than common polymerizing resin and non-toxic. The polymerization shrinkage of polyamide can also be controlled by using heat-molding method [5]. However, it has some drawback such as water absorption, surface roughness, warpage, colour deterioration, bacterial contamination and difficult in polishing [10].

Acetal was first proposed as an unbreakable thermoplastic resin removable partial denture material in year 1971. Thermoplastic acetal as a homo-polymer has good short term mechanical properties, however as a copolymer, acetal has better long term stability [11]. The homo-polymer of acetal is poly(oxymethylene) which is a chain of alternating methyl group linked together by an oxygen molecule, while for co-polymer for acetal which have been developed with are polycarbonate and polyurethane. Acetal resins are formed by the polymerisation of formaldehyde. These resins are hard, rigid, tough, low coefficient of friction, high fatigue resistance and good biocompatibility materials. However, under fluid environment, it may deleteriously affect the stress resistance and implication for the use of these resins [12].

Polystyrene (PS) is one of the polymer which can be used for denture base application [13]. In year 1948, polystyrene was developed by Charles Dimmer, and were introduced as a denture base material. Polystyrene had great transverse and high residual stress. However, it had not been uniformly used as denture base material due to lack of flexibility and strength. Although those properties can be obtained by injection molding method, but this method required very high pressures which unable to withstand by denture molding [14]. Polystyrene is also a versatile plastic used to make a wide variety of consumer products. In addition, it also made into foam material, which called expanded polystyrene (EPS) or extruded polystyrene (XPS), which is valued for its insulating and cushioning properties [15].

Polymer composite

Polymer composite is a combination of two or more chemically different materials with a distinct interface between them. Although the constituent materials maintain their separation identities in the polymer composite, however the combination shows the properties and characteristics that are different from those of the constituents. For polymer composite the continuous phase is polymer bases matrix, while the discontinuous phase which is the reinforcement part can be either in polymer, metal or ceramic bases. The reason of polymer composite exists due to pure polymer show some disadvantage in term of service life, mechanical properties and thermal properties. In order to improve the shortage of pure polymer, different bases of fillers are added to the polymer to improve the specific properties and reduce the costs needed for a product. In addition, to enhance the properties of composites, reinforcement surface may be treated chemically or coated with a very thin layer of chemicals. These methods are to improve the wetting and interfacial bonding between matrixes and reinforcements. Other than that, the surface treatment also may serve to protect the reinforcement surface from degradation by environmental attack [16].

Types of matrix

Starting from 19th century, there are several polymers had been used as denture base material. Among those polymers, PMMA were the most commonly used denture base material since its being introduced by Walter Bauer in year 1936 [17]. After year 1940, PMMA is the commonly used material to fabricate denture base by heat-curing technique. PMMA has the advantage of cost effective, simple fabrication process, lightweight, satisfactory aesthetics, and easy to do finishing and polishing, although it has some disadvantages such as insufficient surface hardness, low strength and brittle [18].

Types of fillers

Different fillers will have different influence toward the properties of the PMMA composites. Those fillers can be in polymer, metal and ceramic base materials. Generally, polymer base fillers, consist of polyethylene fibre and vegetable fibre. Silver, stainless steel, aluminium and copper are example of metal base fillers. Ceramic materials such as glass fibre, carbon fibre, silica, zirconia, alumina and barium titanium oxide are generally used to reinforce PMMA resin.

a) Polyethylene

Polyethylene (PE) is a naturally used crystalline polymer which is drawn at temperature below its melting point. This method is used to produce PE with enhanced modulus in the axial direction. PE exhibits many favourable properties to be used as a reinforcement agent in PMMA due to its high ductility, neutral colour, low density and superior biocompatibility. PE can be drawn as monofilament fibres and woven fibres. Other than that, in order to improve the adhesion between PMMA and PE, electrical plasma treatment can be used to treat the surface of PE. This treatment is to etch the surface of fibre into which the resin gets impregnated, so that it can bond mechanically to the resin phase [4]. The fibres concentration, orientation and length are also greatly influenced the mechanical properties of PE fibre reinforced PMMA resins. Based on Gutteridge [19], PE fibres treated with electrical plasma treatment show significant improvement in the strength. Concentration of PE as low as 1 wt% can significantly improve the impact strength of PMMA composite. Uzun et al. [20] reported that woven PE fibres reinforcement can significantly increase the impact strength and elastic modulus. Mallikarjuna et al. [6] stated that PE fibres in weave form exhibited better strength compared with metal base reinforcement since PE fibres are ductile and have high modulus of elasticity.

b) Vegetable fibre

Vegetable fibre is one of the promising biomaterials due to its biocompatibility properties. Ramie fibre occupies higher Young’s modulus and ultimate tensile strength than denture base resin, therefore it has the potential as reinforcing agents for denture base. Ramie is one of the oldest textile fibres which known as “china grass”, these are referred as bast fibres and come from the phloem tissue of plant [21]. Moreover, its whiteness might also fulfil the requirement of denture base aesthetical appearance. Based on previous work by Jie Xu et al. [21], fibre length and fibre volume were studied to identify their effect on the flexural properties of PMMA resin. Results showed that these two factors influenced the flexural modulus and strength of the PMMA composites.

c) Metal fillers

The function of metal filler in acrylic denture base materials is to improve the mechanical strength of composites. Those metals include silver, stainless steel, aluminium and copper filler. The purpose of adding metal fillers was to improve the compressive strength, thermal conductivity, decrease the curing shrinkage and water sorption of PMMA composite [22]. However due to the drawback of lacking interfacial bonding between metallic fillers and the PMMA resin, the addition of metallic fillers is considered not successful [19].

From the early research by Sehajpal and Sood [22], metallic filler of silver, aluminium and copper at 25 % concentration are able to increase the thermal conductivity of PMMA by 4.53, 4.43, 4.04 times compared to unreinforced PMMA resins. Besides, the compressive strength of PMMA composites was increased with the addition of metal fillers, however tensile strength decreased [22]. Based on the research by Mallikarjuna et al. [6], stainless steel showed the lowest impact strength compared to glass fibre and polyethylene fibres due to lack of interfacial bonding between stainless steel and PMMA resins. Other than that, based on Beyari [23], silver filler used as reinforcement of PMMA resin showed the lowest amount of water sorption which is around 0.39 mg/cm^3 compared to unreinforced resin which is around 0.42 mg/cm^3 [23].

d) Zirconia

ZrO_2 has variety of advantage properties which consists of excellent toughness, mechanical strength, resistance to physical corrosion, abrasion resistance and biocompatibility [24]. Zirconia had been applied as clinical materials, especially for denture and artificial bone production and reparation [25]. Based on the research by Wei Yu et al. [26], which used ZrO_2 nanotubes and nanoparticles as the reinforcing agent for PMMA resins, 2 wt% of untreated ZrO_2 nanotubes showed the highest reinforcement effect in bending stress and bending displacement compared to those of treated ZrO_2 nanotubes, treated ZrO_2 nanoparticles and untreated ZrO_2 nanoparticles. This is because ZrO_2 nanotubes had unique long tubular structures. Hence when mixed with PMMA, the polymer chains wound around the added nanotubes and formed a three-dimensional network structure without any bonding effect. These let the polymer chain could slip along the nanotubes axis under an external force [26]. In addition, PMMA incorporate with 2 wt% of ZrO_2 able to increase their impact strength up to 6.55 KJ/m^2 [27]. While the additional of ZrO_2 filler up to 20 wt%, will decrease the impact strength and hardness of PMMA composite compare to PMMA control group [28].

e) Glass fibres

Glass fibres were tested as reinforcement for denture base PMMA since 1960s [29]. They had been used in different forms to enhance dental polymers which include woven, loose, short-rod and continuous fibres. The reasons glass fibres were suitable to be used as reinforcing agent for denture base materials because they had excellent aesthetic appearance, superior mechanical properties and biological compatibility. Although glass fibres are not very resistant to impact forces, but it can be improved by using unidirectional or woven glass fibres [30]. However, due to the deleterious effect on the doughing properties, the incorporation of glass fibres was limited to 20 wt% [31]. In addition, to improve the mechanical properties of glass fibre in reinforced PMMA, strong adhesion bond between glass fibres and PMMA matrix is very important. Hence glass fibres were normally treated with silane coupling agent before loading into the PMMA resins.

There were several research had been carried in past few years regarding glass fibres as reinforcement in composites. For example, Unalan et al. [32] reported that the transverse strength is higher with woven fibre reinforcement than the unidirectional glass fibre reinforcement. Besides, Yondem et al. [33] observed low flexural strength with glass fibres compared to carbon and aramid fibres reinforced along the long axis of the specimens. Beyari [23] reported adding 0.16 gm weight of glass fibres, a significant dimensional accuracy of PMMA composites was obtained.

f) Carbon fibres

Carbon fibres were first made commercially by Edison in late 19th century by carbonizing thin bamboo shoots and carbon fibres. Carbon fibres were mainly used to improve fatigue behaviour and impact strength of the PMMA composite. However, carbon fibre is difficult to handle when it was dry, hence it must be wetted with monomer to form the town of wet fibre [31]. Besides, carbon fibres must be coated with a silane coupling agent to provide strong adhesion bond between carbon fibres and PMMA resins. Although carbon fibres provided significant improvement in mechanical properties of PMMA, its cytotoxicity properties make it not suitable used in denture application. It was a possibility of skin irritation on handling carbon reinforced denture base specimens [4].

g) Alumina (Al_2O_3)

Alumina is one of the most cost effective and widely used materials in the family of engineering ceramic. This is due to its excellent properties which are shape capability, high strength, high stiffness and high availability. Moreover, alumina was suitable to be used as reinforcing agent. Alumina is much stiffer and brittle than PMMA resins, therefore it is improves the properties of dental composite [34]. Nevertheless, numerous researches had been carried by using alumina as reinforcing agent. For examples, Zhang et al. [35] had studied the effect of particles size and filler contents on the thermal conductivity and mechanical properties of alumina with high density polyethylene (HDPE) composites. In their study, smaller particles size show better performance. Moreover, composite filled with 0.5 μm Al_2O_3 at 25 vol% shows the best properties. Besides, Alhareb and Ahmad [36] had studied the effect of Al_2O_3/ZrO_2 reinforcement on the mechanical properties of PMMA denture base. It was found that the Al_2O_3/ZrO_2 of 80: 20 ratios shows the highest values of fracture toughness and flexural properties. At this ratio, the distribution of Al_2O_3/ZrO_2 in the PMMA matrix is fairly homogeneous and the interface between the reinforcement particles and matrix is good. Alhareb et al. [37] continued study on the mechanical properties of Al_2O_3/ZrO_2 with PMMA resins, but in this research, they applied nitrile butadiene rubber (NBR) as impact modifier. The addition of NBR particles into composite could be useful in absorbed a portion of fraction or impact strength and transfer the composite from brittle to ductile characteristic.

h) Hydroxyapatite

Hydroxyapatite (HA) is an amorphous calcium phosphate which has calcium: phosphorus (C: P) ratio of 10: 6 with chemical formula $Ca_{10}(PO_4)_6(OH)_2$. HA was introduced in year 1975 as filling material for intrabody defects. Besides, HA is considered as bioactive filler because of its similarity toward the biological HA in impure calcium phosphate form which found in human bone and teeth. It is attractive biomedical material owing with its excellent biocompatibility, osteo-conductivity, osteophilic and non-toxicity chemical components [38].

Synthetic HA has almost similar composition to the mineral component which exists in bone and teeth of human. This is the reason why most of the clinics tend to use HA as biomaterial for medical and dental application [39]. There were a lot of researches been carried out on HA as reinforcing agent for bone cement and denture base agent. In year 2010, Tham et al. [40], carried out a research on the effect of treated PMMA/HA composite toward the mechanical, thermal and morphological properties. In this experiment, different percentages of surface treatment agent were used and its maximum performance toward mechanical and thermal properties was observed. Zebarjad et al. [41] reported on the mechanical properties of PMMA with HA nanocomposite to observe the compressive strength, yield strength and modulus of composite with different composition. Hamizah et al. [42], reported on the mechanical and thermal properties of PMMA bone cement reinforced with various weight precentage of HA and glass ceramic fillers. Hongquan et al. [43] published two articles on the failure behaviour and mechanical properties of HA whisker-reinforced bis-GMA-based resin composites. They used various filler loading to identify optimum filler for maximum properties. Calabrese et al. [44] compared between HA whiskers based resin composites with commercial dental composites in mechanical properties and bio-compatibility characterization. Positive results were obtained with addition of HA whiskers.

i) Tricalcium phosphate

Research on tricalcium phosphate (TCP) filler had been carried out since early 1970s. TCP exists in many different polymorphs which consists of α, β, γ, and super-α [45]. However, only α and β phases are used as biomaterials [46]. Extensive research has been carried out since early 1970s, but it is still lack of clarity concerning this material.

TCP mostly behave as osteo-conductive materials which permits bone growth on their surface or into pores, channels and pipes. Other than that, it is also a biocompatible material which useful in inducing hard tissue formation and support the bone growth. Although there are a lot of advantages for TCP, but it still has some drawbacks which consist of difficulty in sintering, low mechanical strength and low resistance to crack-growth propagation [47].

Recent research on TCP by Munoz-Corcuera et al. [48], reported on the post extraction application of β-TCP on alveolar socket [48]. Shu-Hsien et al. [49] studied on the fabrication and characteristic of polycaprolactone and β-TCP composites for tissue engineering application. In the same year, Sachiko et al. [50], reported on the effect of β-TCP particles on primary cultured murine dendritic and macrophages. Rupita and Ritwik [51] also investigated on the synthesis and characterization of sintered β-TCP which made a comparative study on the effect of preparation route.

Properties of PMMA composites

The drawback properties of PMMA resins create opportunity for more researchers to be carried out in order to improve the properties of PMMA resin. First is by substitute other polymer in PMMA resin. However, this method is not so suitable to be used due to high cost. Second, modification of PMMA, however this method does not show significant improvement in the strength of PMMA. Third, incorporation of filler with PMMA resin, this method is reported to show significant improvement of composite properties.

In reinforcing method, there are various factors which may cause PMMA reinforced composites to perform in different ways. For example, types of fillers, size of fillers, amount of fillers, shape of fillers, fabrication processes, mixing, curing temperature, curing period and sequence of fabrication process. Many researchers had been carried to identify different parameters that govern PMMA composites properties.

Mechanical properties

There are several reasons caused fracture happened on denture base. For example, improper fitting, anatomical notches and lack of adequate design. The reasons of fracture occur is due to the load applying excess the maximum limit of flexure fatigue limit of the denture base. Hence flexural strength is one of the most important mechanical properties required for denture base resin materials. The flexural strength of a material is defined as its ability to resist deformation. In addition, it had been reported that acrylic resin with incomplete polymerization which will have lower mechanical properties compare to those with complete polymerization [52]. Previous work by Calabrese et al. [44] on PMMA/HA composite reported that the maximum flexural properties is reported at 20 wt% of HA, after which the flexural properties decreased.

Besides, the interfacial interaction between filler and matrix becomes the driving force in strengthening and toughening effects on the composites [53]. In order to further improve the mechanical properties of PMMA/HA composites, surface treatment of HA filler was carried to enhance the surface interaction between filler and resin. Tham et al. [40], reported surface of HA fillers was treated by silane coupling agent which show significant improvement in flexural properties compared with untreated HA fillers. This is due to better HA dispersion and better interaction between PMMA resins and HA fillers.

Fracture toughness is an indication of the amount of stress required to propagate a pre-existing flaw. It is also a very important property to every material include denture bases. Puri et al. [54] stated that the fundamental requirement of a good performance of denture based resin is its adequate impact strength and fracture toughness. However, one of the major shortcomings of PMMA resins is low fracture toughness. This shortage can be improved by adding fillers in PMMA resins. Based on the previous research by Wei Yu et al. [26], the fracture toughness of PMMA resin was increased after adding ZrO_2 as filler and maximized at 2 wt% of ZrO_2 filler content. With 2 wt% of ZrO_2, the fracture toughness of PMMA composite improved from 0.549 to 1.057 KJ/m^2. In addition, the whisker structure of HA fillers show better improvement toward the fracture toughness compared to spherical nano-particle. Moreover, the fracture toughness value of whisker HA with PMMA composites increased as the volume fracture of filler increased [43].

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. It is also important in denture base because the hardness of the surface which helps to facilitate in finishing or polishing. Besides it will also provide good resistance to scratching during cleaning of prosthodontics [55]. Different type of filler added will direct influence the hardness of PMMA composites. For example, based on the research done by Alhareb et al. [18], they reinforced PMMA resin with mixture of Al_2O_3 with YSZ fillers. When increased the amount of Al_2O_3, the Vickers hardness value of PMMA composite dropped but when the amount of YSZ increased, the Vickers hardness value of PMMA composite increased.

Fracture is one of the frequent problem that faced by removable denture base. Fracture occurs may be due to accident dropping, repeated masticatory forces and areas of stress concentration around frenal notches [56]. Impact strength is the capability of the material to withstand a suddenly applied load and is expressed in term of energy. Hence impact strength of polymers used for production of denture bases is very important. It was reported that incorporation of PMMA resin and filler, results in impact strength improvement. For example, Merin et al. [57] reported that the impact strength of PMMA reinforced by polypropylene fibres increased with increasing weight percentage of polypropylene. Besides based on their research, 10 wt% with 12 mm long polypropylene fibres reinforced PMMA resins showed the highest impact strength which was 4.81 KJ/m^2 compared to other tested groups.

Thermal properties

Thermal stability of dental base is relatively important, because temperature of food will direct affect the oral temperature. Thermal stability of denture base measures the ability of the materials to function properly under various temperature conditions. Thermal stability of the composite is defined from the thermogravimetric analysis (TGA). In addition, the weight of the composite decreased with increasing temperature. The results showed that the mass loss of composite is lower than pure PMMA resin which indicates that PMMA composites are more stable than pure PMMA. Dynamic mechanical analysis is used to study viscoelastic behaviour of polymers. A sinusoidal stress is applied and the strain in the material is measured. Complex modulus is measured by varying temperature and frequency of stress. Normally reduction of storage modulus is attributed to the increase of polymer chain mobility when the temperature arises [58]. This phenomenon reflects that polymer chains are more mobile at high temperature which responsible for the reduction of low interaction between filler and matrix of the composites material hence resistance to deformation is reduced. According to Richeton et al. [59], the breakage of secondary bonds will cause transition in the polymer. This is due to the termination of the attractive interaction between specific atoms involved in the molecular motion corresponding to specific relaxation. Commonly, incorporation of filler into resins is able to change the mechanical and thermal properties of composites. This is due to some factors which consists of variation in the mobility of macromolecules in boundary layers, the orienting influence of filler surface and different types of filler-matrix interaction.

Water absorption

Water absorption is used to identify the amount of water being absorbed under specified condition. There are some factors which will affect the amount of water being absorbed, for example type of plastic, the additives used and the period expose. Acrylic resin has several desirable features, but water absorption is one of its drawbacks which cause the dimension change for denture base. In addition, high water absorption of a material will decrease the mechanical properties of the material. Munoz and Manrique [60] reported that, the flexural strength of water immersed samples decreased compared to the dry samples. This is due to the increase in the percentage of water absorption which will lead to the formation of higher number microcrack. Moreover, research by Beyari [23] reported that, adding silver filler at certain amount able to decrease the water absorption of PMMA resin significantly.

Microstructure analysis

Electron microscopy, such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are powerful imaging tools used to study the morphological and microstructure analysis of the denture base sample. For example in dental base application, SEM or TEM are usually used to investigate the cause of fracture happened on denture base materials. In SEM technique, a focused electron beam is scanned over the sample in parallel lines. For SEM sample preparation, the samples for imaging were mounted on the specimen stub with double-side tape. TEM image on the other hand obtain as a result of electron and sample interaction as the electron beam passing through. The samples for imaging were cut thin in order for the electron beams able to pass through the sample. For filler samples, they are usually dispersed in ethanol and the solution were placed onto mesh copper grid. Next, the grid was dried and ready to be imaging in the TEM. Tham et al. [40] used SEM to observe the micrographs of the fractured surfaces of PMMA and HA composites in their control state and after being subjected to water absorption. It can be seen that there is noticeable gap between PMMA and HA for the untreated composite. However, for the treated HA composites, there is a better interfacial interaction between PMMA and HA. This fracture morphology can support the excellent recovery and retention properties of PMMA composites after being subjected to water absorption. Previous work by Hamizah et al. [42] reported that based on the SEM observation it was found that filler agglomeration in PMMA matrix caused reduction in flexural strength and modulus of the PMMA composites.

Previous research works on PMMA composites for denture application

Research works on PMMA reinforced with different fillers have been investigated by many researchers since 1990 [6-43]. In their research, mechanical properties for the PMMA composites were measured and analyzed. Table 1 shows the mechanical properties of past research work on PMMA composites.

From the results reported on PMMA resin reinforced by different fillers, Hamizah et al. [42] obtained maximum flexural strength (85.8 MPa) by reinforced PMMA resin with 4 wt% of glass ceramic by vacuum mixer. However, PMMA resin reinforced by 4 wt% of glass ceramic showed lower fracture toughness compared to PMMA resin reinforced with HA. Research by Alhareb et al. [18] reported that PMMA resin reinforced by 5 wt% (40 % Al_2O_3/60 % YSZ) filler/7.5 % NBR achieved the highest fracture toughness which is about 2.61 MPa.$m^{1/2}$. While for impact strength, PMMA reinforced by 1 wt% (50 % Al_2O_3/50 % YSZ) filler/10 % NBR showed the highest value which is about 10.86 KJ/m^2 [37].

Table 1: Summary of PMMA denture base composites studied in previous works.

References	Type of fillers	Optimum filler loading	Flexural Strength (MPa)	Fracture Toughness ($MPa.m^{1/2}$)	Impact Strength (KJ/m^2)
Tham et al., [40]	HA treated with 6 % of γ-MPS	5 wt%	61.4	1.95	-
	HA treated with 8 % of γ-MPS		52.4	1.987	-
Hongquan and Brian, [43]	HA whisker-reinforced	19 vol%	104	1.61	-
Hamizah et al., [42]	HA	4 wt%	82.23	1.782	-
	glass ceramic		85.78	1.667	-
Jie Xu et al., [21]	Ramie fiber (fiber length of 1.5 mm)	10 vol%	78.7	-	-
	Ramie fiber (fiber length of 3.0 mm)	4 vol%	82	-	-
Mallikarjuna et al., [6]	Polyethylene fibre	3 wt%	-	-	0.252
	Glass Fibre		-	-	0.206
	Stainless-steel		-	-	0.185
Alhareb et al., [37]	Al_2O_3/YSZ+ nitrile rubber	5 wt% (50/50) filler + 10 wt% NBR	-	2.58	10.25
		1 wt% (50/50) filler + 10 wt% NBR	-	1.97	10.86
Alhareb et al., [18]	Al_2O_3/YSZ+ nitrile rubber	5 wt% (50/50) filler +7.5 % rubber	-	2.58	10.25
		5 wt% (40/60) filler +7.5 % rubber	-	2.61	9.17

Conclusions

Current status of the denture based materials has been reviewed. Polymer, metal and ceramic are the materials used to fabricate denture base since early centuries. Among these, PMMA is one of the most commonly used materials as denture base. It is a thermoplastic which can be heated and manipulated repeatedly. PMMA is still the most predominantly used denture base material in present because of low cost, light weight, insoluble in mouth fluid, excellent aesthetic properties and ability to be repaired easily. However, several disadvantages such as insufficient surface hardness, low strength, brittle, polymerization shrinkage, weak flexural, lower impact strength and low fatigue resistance create negative impact on PMMA resins. Recent development through PMMA reinforced by few types of fillers as been reported by previous works produced a significant improvement of PMMA composites properties.

Acknowledgement

The authors gratefully acknowledge the financial support for this study, provided by School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia (USM).

Author contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of conflict of interest

The authors have no disclosures to declare.

References

[1] Vishal, G., Shruti, G. & Shivangi, G. (2014). Denture Base Materials. Retrieved from https://www.slideshare.net/gohilvishal912/denture-base-materials-34531421.

[2] McCabe, J. F. & Angus, W. G. W. (2008). *Applied Dental Material*. 9th Edition (Blackwell Publishing Ltd).

[3] Rajul, V. & Romesh, S. (2015). Denture Base Materials: Some Relevant Properties and their Determination. *International Journal of Dentistry and Oral Health*, 1(4), 1-3.

[4] Rama, K. A., Suresh, S., Venkata, R. A., Kishore, G. & Nagaraj, U. (2013). Influence of Fibre Reinforcement on the Properties of Denture Base Resins. *Journal of Biomaterials and Nanobiotechnology*, 4, 91-97.

[5] Mahroo, V. & Rashin, G. (2015). Polyamide as a Denture Base Material: Literature Review. *J Dent Shiraz UnivMed Sci*, 16(1), 1-9.

[6] Mallikarjuna, H. B. M., Sharaz, S., Harleen, S., Sumit, K., Satheesh, B. H. & Roopa, K. T. (2015). Effect of Reinforcement Using Stainless Steel Mesh, Glass Fibers, and Polyethylene on the Impact Strength of Heat Cure Denture Base Resin. *Journal of International Oral Health*, 7(6), 71-75.

[7] Andrew, W. (2017). Different Between Polyester, Acrylic and Epoxy Resin. Retrieved from http://juxtamorph.com/difference-between-polyester-acrylic-and-epoxy-resins/.

[8] Athar, Z., Juszczyk, A. S., Radford, D. R. & Clark, R. K. (2009). Effect of Curing Cycles on The Mechanical Properties of Heat Cured Acrylic Resins. *Eur J Prosthodont Restor Dent*, 17, 58-60.

[9] Watt, D. M. (1955). Clinical Assessment of Nylon as Apartial Denture Base Material. *Br Dent J*, 98, 238-244.

[10] Yunus, N., Rashid, A. A., Azmi, L. L. & Abu-Hassan, M. I, (2005). Some Flexural Properties of a Nylon Denture Base Polymer. *J Oral Rehabil*, 32(1), 65-71.

[11] Shivani, K. & Shekhar, B. (2013). Polyamide in Dentistry. *International Journal of Science Study*, 1(1), 20-25.

[12] Fitton, J. S., Davies, E. H., Howlett, J. A. & Pearson, G. J. (1995). The Physical Properties of a Polyacetal Dental Resin. *Clinical Material*, 17, 125-129.

[13] Camilo, M., Eliana, S., Shereen, S. A. & Juan, M. U. (2007). Comparative Study of the Transverse Strength of Three Denture Base Materials. *Journal of Dentistry*, 35(12), 930-933.

[14] Dresch, I. J. (1944). Base Blank for Dentures. *United States Patent Office*, 439, 378.

[15] Khindria, S. K., Mittal, S. & Sukhija, U. (2017). Evolution of denture base materials. *The Journal of Indian Prosthodontic Society*, 9(2), 64-69.

[16] Mallick, P. K. (1997). *Composites Engineering Handbook*. (Marcel Dekker), pp.1-3.

[17] Catherine, Y. B. (2010). *A comparison of polymeric denture base materials.* MSc(R) thesis, University of Glasgow.

[18] Alhareb, A. O., Akil, H. M. & Ahmad, Z. A. (2017). Impact Strength, Fracture Toughness and Hardness Improvement of PMMA Denture Base through Addition of Nitrile Rubber/Ceramic Fillers. *The Saudi Journal for Dental Research*, 8, 26-34.

[19] Gutteridge, D. L. (1992). Reinforcement of poly (methylmethacrylate) with Ultra High Modulus Polyethylene Fibre. *Journal of Dentistry*, 20(1), 50-54.

[20] Uzun, G., Hersek, N. & Tinçer, T. (1999). Effect of Five Woven Fibre Reinforcements on the Impact and Transverse Strength of a Denture Base Resin. *Journal of Prosthetic Dentistry*, 81(5), 616-620.

[21] Jie, X., Yan, L., Tao, Y. & Lei, C. (2013). Reinforcement of Denture Base Resin with Short Vegetable Fibre. *Dental Material*, 29, 1273-1279.

[22] Sehajpal, S. B. & Sood, V. K. (1989). Effect of Fillers on Some Physical Properties of Acrylic Resin. *The Journal of Prosthetic Dentistry*, 61(6), 746-751.

[23] Beyari, M. M. (2015). Effect of Glass Fibres or Metallic Filler on the Linear Dimensional Changes and Water Sorption of Acrylic Resin Denture Base Material. *Int J Dentistry Oral Sci*, 26-29.

[24] Mallineni, S. K., Nuvvula, S., Matinlinna, J. P., Yiu, C. K. & King, N. M. (2013). Biocompatibility of Various Dental Materials in Contemporary Dentistry: A Narrative Insight. *Journal Investment Clinic Dentisty*, 4, 9-19.

[25] Damestani, Y., Reynolds, C. L., Szu, J., Hsu, M. S., Kodera, Y., Binder, D. K., Park, B. H., Garay, J. E., Rao, M. P. & Aguilar, G. (2013). Transparent Nanocrystalline Yttria-Stabilized-Zirconia Calvarium Prosthesis. Nanomed: Nanotechnol. *Biol. Med*, 9, 1135-1138.

[26] Wei, Y., Xixin, W., Qingguo, T., Mei, G. & Jianling, Z. (2014). Reinforcement of Denture Base PMMA with ZrO_2 Nanotubes. *Journal of the Mechanical Behavior of Biomedical Materials*, 32, 192-197.

[27] Asar, N. V., Albayrak, H., Korkmaz, T. & Turkyilmaz, I. (2013). Influence of Various Metal Oxides on Mechanical And Physical Properties of Heat-Cured Poly Methyl Methacrylate Denture Base Resins. *J Adv Prosthodont*, 5(4), 241-247.

[28] Asopa, V., Suresh, S., Khandelwal, M., Sharm, V., Asopa, S. S. & Kaira L. S. (2015). A Comparative Evaluation of Properties of Zirconia Reinforced High Impact Acrylic Resin with That of High Impact Acrylic Resin. *Saudi J Dent Res*, 6(2), 146-151.

[29] Vallittu, P. K. (1996). A review of Fibre-Reinforced Denture Base Material, *Denture Base Resin*, 5(4), 270-276.

[30] Goguta, L., Marsavina, L., Bratu, D. & Topala, F. (2006). Impact Strength of Acrylic Heat Curing Denture Base Resin Re- inforced with E-Glass Fibers. *Temporomandibular Joint Disorders*, 56(1), 88-91.

[31] Jagger, D. C., Harrison, A. & Jandt, K. D. (1999). The Reinforcement of Dentures. *Journal of Oral Rehabilitation*, 26, 185-194.

[32] Unalan., F., Dikbas, I. & Gurbuz, O. (2010). Transverse Strength of Poly-Methylmethacrylate Reinforced with Different Forms and Concentrations of E-Glass Fibres. *OHDMBSC*, 9(3), 144-147.

[33] Yondem, I., Yucel, M. T., Aykent, F. & Ozturk, A. N. (2011). Flexural Strength of Denture Base Resin Reinforced with Different Fibers. *Journal of the SU Faculty of Dentistry*, 20(1), 15-20.

[34] Alsharif, S. O., Akil, H. B. M., El-Aziz, N. A. & Ahmad, Z. B. A. (2014). Effect of Alumina Particles Loading on the Mechanical Properties of Light Cured Dental Resin Composites. *Mater Des*, 54, 430-435.

[35] Zhang, S., Cao, X., Ma, Y., Ke, Y., Zhang, J. & Wang, F. (2015). The Effects of Particle Size and Content on the Thermal Conductivity and Mechanical Properties of Al_2O_3/High Density Polyethylene (HDPE) Composites. *eXPRESS Polymer Letters*, 5, 581-890.

[36] Alhareb, A. O. & Ahmad, Z. A. (2011). Effect of Al_2O_3/ZrO_2 Reinforcement on the Mechanical Properties of PMMA Denture Base. *Journal of Reinforced Plastics & Composites*, 30(1), 86-93.

[37] Alhareb, A. O., Akil, H. M. & Ahmad, Z. A. (2015). Mechanical Properties of PMMA Denture Base Reinforced by Nitrile Rubber Particles with Al_2O_3/YSZ Fillers. *Procedia Manufacturing,* 2, 301-306.

[38] Kantharia, N., Naik, S., Apte, S., Kheur, M., Kheur, S., & Kale, B. (2014). Nano-hydroxyapatite and its Contemporary Applications. *Journal of Dental Research and Scientific Development*, 1, 15-19.

[39] Dorozhkin., S. V. & Epple, M. (2002). Biological and Medical Significance of Calcium Phosphates. *Angewandte Chemie International Edition*, 41, 3130-3146.

[40] Tham, W. L., Chow, W. S. & Ishak, Z. A. M. (2010). Simulated Body Fluid and Water Absorption Effects on Poly(Methyl Methacrylate)/Hydroxyapatite Denture Base Composites. *Express Polymer Letters*, 4(9), 517-528.

[41] Zebarjad, S. M., Sajjadi, S. A., Sdrabadi, T. E., Yaghmaei, A. & Naderi, B. (2011). A Study on Mechanical Properties of PMMA/Hydroxyapatite Nanocomposite. *Scientific Research,* 3, 795-801.

[42] Hamizah, A. S., Mariatti, M., Othman, R., Kawashita. M. & Noor Hayati, A. R. (2012). Mechanical and Thermal Properties of Polymethylmethacrylate Bone Cement Composites Incorporated with Hydroxyapatite and Glass-Ceramic Fillers. *Journal of Applied Polymer Science*, 125(1), E661-E669.

[43] Hongquan, Z. & Brian, V. D. (2012). Mechanical Properties of Hydroxyapatite Whisker-Reinforced Bis-GMA-Based Resin Composites. *Dental Material,* 28, 824-830.

[44] Calabrese, L., Fabiano, F., Curro, M., Borsellino, C., Bonaccorsi, L. M., Fabiano, V., Ientile, R. & Proverbio, E. (2016). Hydroxyapatite Whiskers Based Resin Composite versus Commercial Dental Composites: Mechanical and Biocompatibility Characterization. *Advances in Materials Science and Engineering,* 1-9.

[45] Gibson, I. R., Akao, M., Best S. M. & Bonfield, W. (1996). Phase transformations of tricalcium phosphates using high temperature X-ray diffraction, in Proceedings of the 9th International Symposium on Ceramics in Medicine, T. Kokubo, T. Nakamura, and M. P. Fumiaki. *Quintessence Publication, Chicago, Ill, USA, Eds,* pp. 173-176.

[46] LeGeros, R. Z. (2002). Properties of Osteoconductive Biomaterials: Calcium Phosphates. *Clinical Orthopaedics and Related Research,* 395, 81-98.

[47] Al-Sanabani, J. S., Madfa, A. A. & Al-Sanabani, F. A. (2013). Application of calcium phosphate materials in dentistry. *International Journal of Biomaterials,* 1-12.

[48] Munoz-Corcuera, M., Bascones-Martinez, A. & Ripolles-de Ramon, J. (2015). Post-extraction Application of Beta Tricalcium Phosphate in Alveolar Socket. *J Osseointegr,* 7(1), 8-14.

[49] Shu-Hsien, H., Tuan-Ti, H., Tsui-Hsien, H., Cheng-Yao, L. & Ming-You, S. (2016). Fabrication and characterization of polycaprolactone and tricalcium phosphate composites for

tissue engineering applications. *Journal of Dental Science*. Sigma- Aldrich. (2017). Raw material products. Retrieved from http://www.sigmaaldrich.com/united-states.html.

[50] Sachiko, T., Jin-Yan, C., Hidee, I., Kasumi, S., Vincent, Z., Takatomo, S., Tetsuji, H., Emiko, S., Ken, Y. & Kouji, M. (2016). Effects of Beta-Tricalcium Phosphate Particles on Primary Cultured Murine Dendritic Cells and Macrophages. *International Immunopharmacology*, 40, 419-427.

[51] Rupita, G. & Ritwik, S. (2016). Synthesis and Characterization of Sintered Beta-Tricalcium Phosphate: A Comparative Study on the Effect of Preparation Route. *Materials Science and Engineering C*, 67, 345-352.

[52] Harrison, A. & Huggett R. (1992). Effect of the Curing Cycle on Residual Monomer Levels of Acrylic Resin Denture Base Polymers. *Journal Dent*, 20, 370-374.

[53] Stani′c, U., Dimitrijevi′c, S. & Anti′c-Stankovi′c, J. (2010). Synthesis, Characterization and Antimicrobial Activity of Copper and Zincdoped Hydroxyapatite Nanopowders. *Applied Surface Science*, 256(20), 6038-6089.

[54] Puri, G., Berzins, D. W., Dhuru, V. B., Raj, P. A., Rambhia, S. K. & Dhiret, G. (2008). Effect of Phosphate Group Addition on the Properties of Denture Base Resins. *J Prosthet Dent*, 302-308.

[55] Moussa, A. R., Dehis, W. M., Elboraey, A. N. & ElGabry, H. S. (2016). A Comparative Clinical Study of the Effect of Denture Cleansing on the Surface Roughness and Hardness of Two Denture Base Materials. *Journal of Medical Sciences*, 4(3), 476-481.

[56] Doğan, O. M., Bolayir, G., Keskin, S., Doğan, A., Bek, B. & Boztuğ, A. (2007). The Effect of Esthetic Fibers on Impact Resistance of a Conventional Heat-Cured Denture Base Resin. *Dent Mat*, 26, 232-239.

[57] Merin, M., Kamalakanth, S. & Ravishankar, K. S. (2014). Impact Strength of Polypropylene Fiber Reinforced PMMA. *International Journal of Scientific & Engineering research*, 5(9), 951-955.

[58] Ferran, M. F., Francisco, V., Amparo, R. G., Adolfo, B. B. & Concha, S. B. (2006). Flour Rice Husk as Filler in Block Copolymer Polypropylene: Effect of Different Coupling Agents. *Journal Application Polymer Science*, 99(4), 1823-1831.

[59] Richeton, J., Schlatter, G., Vecchio, K. S., Re′mond, Y. & Ahzi, S. (2005), A Unified Model for Stiffness Modulus of Amorphous Polymer Across Transition Temperature and Strain Rates. *Polymer*, 46(16), 6035-6043.

[60] Munoz, E. & Manrique, J. A. G. (2015). Water Absorption Behaviour and Its Effect on the Mechanical Properties of Flax Fibre Reinforced Bioepoxy Composites. *International Journal of Polymer Science*, 1-10.