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Study the Effect of Nano Ceramic Particles on Some Physical Properties of Acrylic Resins

Abstract- *In the present research, study the effect of adding two different types of reinforcing particles, which included: nano-alumina (nano-Al_2O_3) and nano-silica (nano-SiO_2), that added with different volume fractions of (1%, 2% and 3%), on some physical properties of composite prosthesis complete denture base materials by using self (cold) cure poly methyl methacrylate (PMMA) resin as new fluid resin matrix. In this research, the composite prosthetic dentures specimens consist of two groups were prepared by using (Hand Lay-Up) method according to the types of reinforced particles, which includes: the first group consists of PMMA resin reinforced by nano-alumina particles, and the second group consists of PMMA resin reinforced by nano-silica particles. The physical tests were performed on these specimens include (water absorption test and thermal behaviors test). The result of this study showed the values of (thermal conductivity and thermal diffusivity) properties increased with increasing the volume fraction of both (nano-Al_2O_3 and nano-SiO_2) particles in PMMA complete denture base materials. While, the values of (water absorption and specific heat) properties decreased. In addition, the addition of (nano-Al_2O_3) particles has a noticeable effect on the all properties of composite material for prosthetic denture base specimens more than the (nano-SiO_2) particles.*

Keywords-*PMMA, Nano-Al_2O_3 particles, Nano-SiO_2 particles, Water Absorption, Thermal Properties.*

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1. Introduction

Many biomaterials are available in medicine and dentistry fields. Biomaterials can be classified as metals, polymers, ceramic and composites materials. Polymeric materials have a many applications for implantation since they are available in a wide variety of compositions and properties [1]. The most commonly polymers used in biomedical and dentistry application are acrylic resin. In the 20th century, acrylic resin and other plastic materials were used as denture base materials due to their attractive properties. Acrylic resins are the most widely used in dentistry application and accepted among all denture base materials, and it was estimated that they represent (95%) of the polymer in prosthodontics applications. Poly (methyl methacrylate) is favored for its good properties such as satisfactory mechanical properties, except the impact and fatigue strength, dimensional stability and it has high Tg temperature, the color which can similar to the human's internal skin. PMMA can be fabrication and processed by many methods such as casting, extrusion, injection and thermoforming method [2] .

Poly (methyl methacrylate) properties are modified when reinforced by adding many particles or fibers, this is approach the scientist to study the effected of reinforced materials on the mechanical and physical properties for the composite material. The literature surveys include some researches, which are accomplished in this field, it's:

Schajpal et al. investigates the effect of adding the (silver, copper and aluminum) powders to acrylic denture base resin in different volume fraction. They found when increased, all these types of metal fillers lead to increased compressive strength, but decrease in tensile strength, also the fillers increased thermal conductivity but did not proportionally as the filler concentration increased [3].

Panyayong et al. investigates the effect of adding the mixture of titanium dioxide (TiO_2) powders and Zirconium dioxide (ZrO_2) powders, on the some mechanical and physical properties of PMMA resin with different volume fraction (1%, 2%, and 3%) in ratio of 1:1, 1:2, 2:1. The results showed that addition of (TiO_2) and (ZrO_2) particles in these ratio combinations, lead to decreasing the water absorbed, but increasing flexural strength as well as the fracture toughness of PMMA resin [4]

Azlan et al. investigate the effects of adding the hydroxyapatite (HA) with different volume fraction (5%, 10%, 15%, 20%), on the flexural properties, fracture toughness and thermal properties of heat cure PMMA resin to form PMMA/HA composites. The results showed the flexural modulus and thermal conductivity of PMMA was increased by increasing the volume fraction of HA particles this is attributed to the reinforcement effects of HA particles [5].

Ayman et al. investigates the effect of adding the alumina (Al2O3) particles with different weight fraction (5%, 10%, 15%, and 20%), on the flexural strength and thermal diffusivity of heat-polymerized acrylic resin. It was found increased significantly the flexural strength and thermal diffusivity when increasing the weight percentage of alumina (Al2O3) particles. Increasing the flexural strength and heat transfer characteristics of the acrylic resin base material could lead to more patient satisfaction [6].

2. Aim of Research

In order to withstand against any denture fracture and avoid or reduce the incidence problems in denture base materials. In this research, using new type of denture base materials as fluid resin matrix, and studying the effect of some reinforcing by (nano-Al_2O_3 and nano-SiO_2) particles with selected volume fractions on the (compression, impact, hardness and thermal behavior) tests of the composite materials for prosthetic complete denture base.

3. Materials Used

I. Acrylic Resin Denture Base Material

In this research the composite prosthetic complete dentures specimens consist of polymer matrix and reinforced particles materials. Matrix material included cold curing PMMA that used as fluid resin matrix, type (Castavaria), made from (Vertex–Dental Company), to preparation specimens of composite prosthetic denture base. Vertex™ Castavaria is a multifunctional self-polymerizing acrylic which is perfectly useable as a pouring, relining, rebasing and as a repair acrylic.

This type of materials distinguishes by many properties compared with other type of PMMA polymer such as: softer feel, low molecular weight, color stable in the long run, minimized shrinkage, stable polymerization cycle with a perfect end result, the acrylic is long pourable and modelable for a long period of time. But have some disadvantage properties such as: low strength, low hardness and more difficult using during fabrication [7]. Table 1 shows some physical and mechanical properties of self-cure PMMA resin, type (Castavaria), which used in this study.

II. Particles Reinforcement Materials

Two types of ceramic particles were used in this study as reinforces materials with selected volume fraction of (1%, 2% and 3%) it was added to the acrylic powder including:

A. Nano Aluminum Oxide (Al_2O_3 99.9%) Particles

Aluminum oxide is usually called (alumina), and represented one of the most cost effective and widely used of ceramic materials. Aluminum oxide is supplied as (nano-particles), also it is possesses excellent size, shape and high purity about (99.9%). The structure of aluminum oxides have strong ionic bonding which gives its high strength, stiffness, hardness, wear resistant, and good thermal conductivity of alumina [8].

The result of particle size and particle size distribution of (nano-Al_2O_3) particles is obtained by using atomic force microscopy (AFM), which shows the average diameter was (57.48 nm). Table 2 shows some physical and mechanical properties of (Al_2O_3) particles that used in this study.

B. Nano Silicon Oxide (SiO_2) Particles

Silicon oxide has another name for the chemical compound is usually called (silica) and represented one of the most complex and most abundant families of ceramic materials. Silicon oxide is supplied as (nano-particles), each unit of silicon oxide includes one atom of silicon and two atoms of oxygen. Silicon oxide has a high chemical resistance, good thermal shock resistance, excellent strength, good transparent and good electrical insulation [8].

The result of particle size distribution of (nano-SiO_2) particles is obtained by using atomic force microscopy (AFM), which shows the average diameter was (24.29 nm). Table 2 shows some physical and mechanical properties of (SiO_2) particles that used in this study.

Table 1: Mechanical and Physical Properties of Self Cure PMMA Resin

Young's Modulus (GPa)	Impact Resistance (KJ/m^2)	Flexural Strength (MPa)	Water Absorption (%)	Density (gm/cm^3)
1.63-3	8.3	79	2.5	1.19

Table 2: Some Mechanical and Physical Properties of (Al_2O_3) Particles and (SiO_2) Particles

Material	Compressive Strength (MPa)	Thermal Conductivity (W/m.K)	Water Absorption (%)	Density (gm/cm^3)
Al_2O_3	2600	35	0	3.9
SiO_2	1108	1.38	0	2.3

4. Preparation of Test Specimens

I. Proportioning and Mixing of Acrylic

The PMMA denture base materials consist of polymer powder and monomer liquid (methyl methacrylate, MMA). The standard proportion in mixing ratio for cold cure (self-cure) acrylic resin is usually about (17 g) polymer powder (PMMA) and (9.5 g) monomer liquid (MMA) (1.7 g / 0.95g). When mixing powder and liquid many changes will take place due to solution of polymer in the monomer. This ratio was effect on the workability of the mixture, dimensional changes and toxicity of acrylic resin specimens [9].

This type of cold cure acrylic resin is mouldable for a long period time, where the mixture was mixed of liquid (MMA) in the clean and dry glass beaker, then slow addition of dry powder (PMMA) to liquid (MMA), the mixture was stirred at room temperature continuously by using mechanical mixing at speed (20 r.p.m.) until reached to the dough stage and poured mixture in the center of opening mould with maximum time about (4.5 min). During mixture pouring inside the glass mould, the mould must be slow rocked and vibrated from side to side to remove any gas bubbles from the specimens, and reminder of the mixture was poured into mould hole until the glass mould filling and left mould to stand on the bench top at room temperature for (8-13 min) from beginning of mixing process as working time to increase the viscosity of mixture and surface of casting become hard.

II. Curing Cycle Process

Polymerization curing all specimens after casting process was placed inside the oven at (60 ºC) and let them for (30 min). The advantage of this technique is polymerization may be accomplished

in short time, post cured of specimens and give minimum level of residual monomer. The castings composite prosthetic dentures specimens outside the oven at room temperature to complete the cooling and complete hardening of specimen as shown in Figure 1.

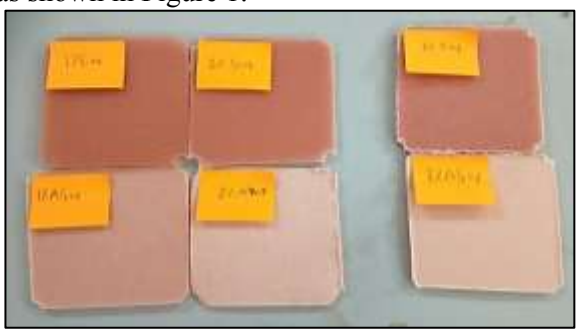


Figure 1: Composite prosthetic dentures specimens after curing process

5. Physical Tests

I. Water Absorption Test

The water absorption test is performed according to (ASTM D570). In this test, weighing the specimens before immersing them in distilled water and then immerse the specimens completely in container of distilled water at room temperature for about (24hr), after that the specimens were removed from distilled water. Then, all surfaces water of specimens wiped off with dry cloth and weighed by digital balance and water absorption was obtained by calculated the difference between two weights over original weight [10].

II. Thermal Behavior Test

This test is performed according to apparatus manual that depended on the standard specifications instrument, by using (Hot Disk Thermal Constant Analysis) which supplied by heating power was (0.022 w), then the specimen was placed inside device to measure of thermal transport properties (thermal conductivity, thermal diffusivity and specific heat per unit volume).

The basic hot disk operation include place the hot disk sensor as sandwiched between two pieces of the same composite material specimen are prepared at the same dimensions of the standard specifications instrument, and should be larger than the sensor diameter to ensure stable values of the thermal properties from outside boundaries influence on the test specimen. The specimen that used in this study have dimensions (20mm × 20mm), thickness (5mm), and must be clean both surface and free from oil, grease and other foreign matters. The sensor acts both as a heat source of specimen, then heated by passing an electrical current for a short period of time about (80 Sec), at same time recording the temperature increase as a function of time. As finally results, the values of thermal conductivity, thermal diffusivity and specific heat are read from the computerize gauge, the basic hot disk sensor operation as shown in the Figure 2 [11, 12].

All these tests carried out in air at room temperature (23 $\pm$ 2) $^{\circ}C$ after complete finishing and polishing processes, and immersion the specimens in distilled water at (37 $\pm$ 1) ºC for (48 hr), in order to remove any residual monomer and release residual stress, also to ensure that the denture base materials remains in semi oral environment [13].

6. Results and Discussions

I. Water Absorption Test for Modified Composites

Figure 3, shows the effect of adding both types of ceramic particles (nano-alumina, nano-silica) with different volume fractions on the water absorption of PMMA matrix. From this Figure can be noticed how the water absorption percentage decreased with increasing the volume fraction for both types of these particles in both groups of PMMA composite materials, because of when increasing the concentration of these fine particles, that lead to filled or diminished any spaces and porosities which were inside the PMMA resin. Finally, result the water absorption percentage will be decreased of prepared composite specimens.

It can also be noticed that the addition of nano-silica particles has a noticeable effect on the water absorption percentage of PMMA composite specimens more than the nano-alumina particles; therefore, water absorption percentage values for first group specimens (PMMA-nano-Al_2O_3) composite are more decreasing than the values of water absorption percentage for second group specimens (PMMA-nano-SiO_2) composite. This is due to the nano-alumina particles have large diameter (57.48 nm) and low penetration to filled or diminished any spaces and porosities which were inside the PMMA resin as compared with nano-silica particles which have small diameter (24.29 nm) and high penetration to filled or diminished any spaces and porosities inside the PMMA resin, which that evidenced by (AFM test).

Thus, the water absorption percentage decreased from (0.01092 %) for PMMA specimen (as referenced) to reach to the lower value of water

absorption (0.003852 %) for (PMMA - 3% nano-Al_2O_3) composite materials [14, 15].

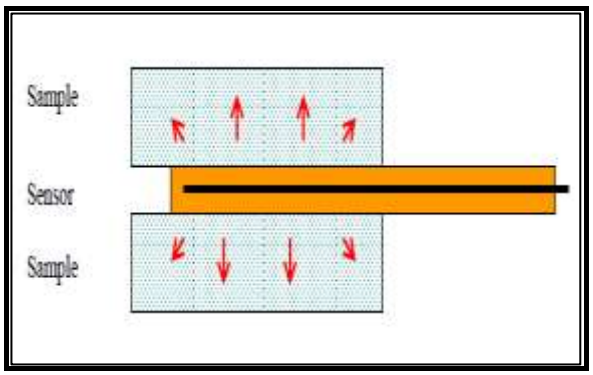


Figure 2: Hot disk sensor operation [12]

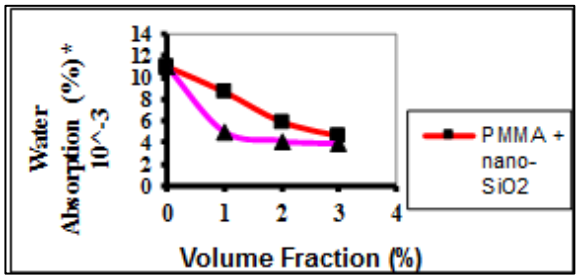


Figure 3: Shows Water Absorption Percentage of PMMA Composite Materials as Function of (Nano-SiO_2 - Nano-Al_2O_3) Particles (Vol %) in Composite

II. Thermal Behavior Test for Modified Composites

A. Thermal Conductivity for Modified Composites

In general, the composite materials, the thermal properties depend on the amounts and properties of the components in composite specimens. Also, is depend on the nature and strong of interface and spaces size between these components. Figure 4, shows the effect of adding both types of the ceramic particles, which include (nano-alumina or nano-silica) with different volume fractions on the thermal conductivity of PMMA matrix.

From this Figure can be noticed how the thermal conductivity values increased with the increasing of the volume fraction for both types of these particles in both groups of PMMA composite materials. This is due to the high thermal conductivity of the (alumina and silica) particles as compared with PMMA resin, thermal conductivity for first group specimens (PMMA - nano-Al_2O_3) composite is higher than the values of thermal conductivity for second group specimens (PMMA - nano-SiO_2) composite. This is due to the higher thermal conductivity of Al_2O_3 particles as compared with SiO_2 particles [16].

Thus, the thermal conductivity values increased from (0.2294 W/m.k) for PMMA specimen (as referenced) to reach to the higher value of thermal conductivity (0.3715 W/m.k) for (PMMA - 3% nano-Al_2O_3) composite materials.

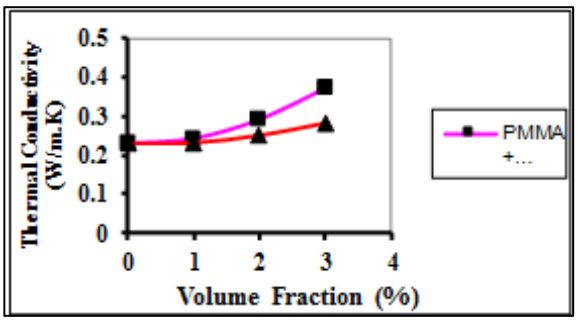
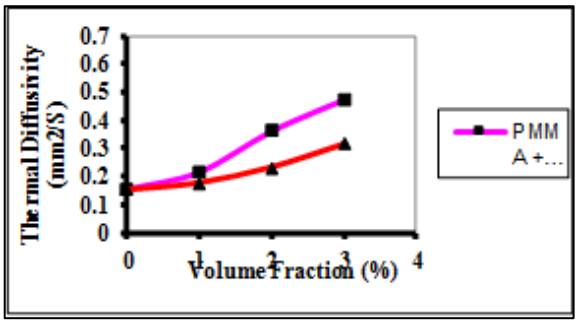


Figure 4: Shows thermal conductivity of PMMA composite materials as function of (Nano-SiO_2 - Nano-Al_2O_3) particles (Vol %) in composite

B. Thermal Diffusivity for Modified Composites

The same explanation is mentioned for the thermal conductivity values can be said and application for the thermal diffusivity values as shown in the Figure 5, which shows the effect of adding both types of the ceramic particles, which include (nano-alumina or nano-silica) with different volume fractions on the thermal diffusivity of PMMA matrix. From this Figure can be noticed how the thermal diffusivity values increased with the increasing of the volume fraction for both types of these particles in both groups of PMMA composite materials. This is due to the high thermal diffusivity of the (alumina and silica) particles as compared with PMMA resin alone.

It can also be noticed that the addition of nano-alumina particles has a noticeable effect on the thermal diffusivity of PMMA composite specimens more than the nano-silica particles; therefore, thermal diffusivity for first group specimens (PMMA-nano-Al_2O_3) composite is higher than the values of thermal diffusivity for second group specimens (PMMA-nano-SiO_2) composite. This is due to the higher thermal conductivity of Al_2O_3 particles as compared with SiO_2 particles [16]. Thus, the thermal diffusivity values increased from (0.1508 mm^2/S) for PMMA specimen (as referenced) to reach to the higher value of thermal conductivity (0.4752 mm^2/S) for (PMMA - 3% nano-Al_2O_3) composite materials.



C. Specific Heat for Modified Composites

Figure 6, shows the effect of adding both types of ceramic particles (nano-alumina or nano-silica) with different volume fractions on the volumetric specific heat of PMMA matrix. From this Figure can be noticed how the volumetric specific heat decreased with increasing the volume fraction for both types of these particles in both groups of PMMA composite materials, also these values are inversely proportional to the thermal conductivity values and thermal diffusivity values. This is due to the natural of these particles, which have high thermal conductivity value and low specific heat value as compared with the PMMA resin. At finally result, the decreases in values of volumetric specific heat.

It can also be noticed that the addition of nano-alumina particles has a noticeable effect on the volumetric specific heat of PMMA composite specimens more than the nano-silica particles, therefore, volumetric specific heat values for first group specimens (PMMA-nano-Al_2O_3) composite

Figure 5: Shows thermal diffusivity of PMMA composite materials as function of (Nano-SiO_2 - Nano-Al_2O_3) particles (Vol %) in Co

7. Conclusions

According to the experimental results of composite prosthetic complete denture base materials, can be the conclusions the following sentences:

1- Some physical properties values such as (thermal conductivity and thermal diffusivity) of PMMA composites prosthetic denture (PMMA - nano-Al_2O_3), (PMMA-nano-SiO_2), were increased with increasing of the volume fractions of (nano-Al_2O_3 and nano-SiO_2) particles.

2- Other physical properties values such as (water absorption and volumetric specific heat) of PMMA composites prosthetic denture (PMMA - nano-Al_2O_3), (PMMA-nano-SiO_2), were decreased with increasing of the volume fraction of (nano-Al_2O_3 and nano-SiO_2) particles.

are more decreasing than the values of volumetric specific heat for second group specimens (PMMA-nano-SiO_2) composite, because of the high conductivity and low volumetric specific heat of the Al_2O_3 particles as compared with SiO_2 particles [17]. Thus, the volumetric specific heat decreased from (1.691 MJ/m^3.K) for PMMA specimen (as referenced) to reach to the lower value of volumetric specific heat (0.679 MJ/m^3.K) for (PMMA - 3% nano-Al_2O_3) composite materials.

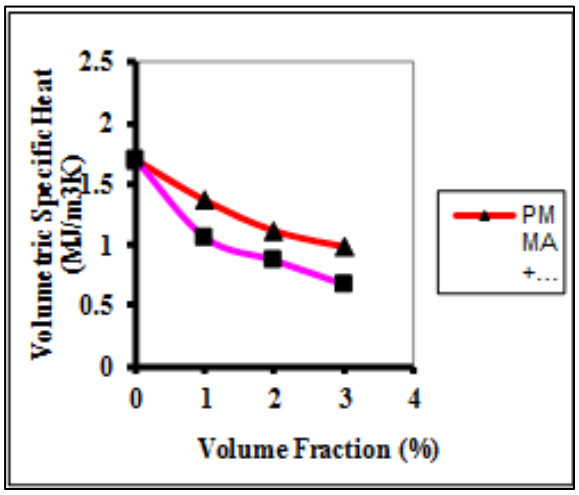


Figure 6: Shows volumetric specific heat of PMMA composite materials as function of (nano-SiO_2 - nano-Al_2O_3) particles (Vol %) in composite.

3- The addition of (nano- alumina) particles has a noticeable effect on the most physical properties of composite prosthetic complete denture base specimens more than the nano-silica particles.

4- The maximum values for properties (thermal conductivity and thermal diffusivity) were obtained in PMMA composites prosthetic denture (PMMA - nano-Al_2O_3),

5- The minimum values for properties (water absorption and specific heat) were obtained in PMMA composite prosthetic denture (PMMA - nano-Al_2O_3).

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