MECHANICAL PROPERTIES OF COMPOSITES MATERIALS REINFORCED IN CERAMIC PARTICLES

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Abstract- The complete dentures are made from different acrylic resins by various technologies. These materials are fragile and frequently appear cracks that lead to fractures of prosthetic dentures. Many studies are done to develop the properties of PMMA resin that is used for upper and lower complete denture base materials, by using composite materials consists of poly methyl methacrylate (PMMA) resin as reference material, reinforcement with different weight fractions of ZrO2 particles (1%, 3%, 5%,7%) wt%. Acrylic resin (PMMA) and composite materials were prepared by Hand lay-up molding and investigated. The investigated the mechanical properties were hardness, tensile properties (ultimate tensile strength (UTS), elongation at break), impact properties (impact strength, fracture toughness), and flexural strength& shear stress. The resulting composites of mechanical properties, composite materials with (Acrylic +7% ZrO2) has the maximum hardness of (72.4) shore D, The ultimate tensile strength of 33.75MPa was obtained for (Acrylic +7% ZrO2), while the elongation at break decreases with increase in filler concentration of 5 % was obtained for (Acrylic +7% ZrO2) is lower than other composites . The highest impact strength with (Acrylic +3% ZrO2) (83 J/m2) than with other composites. The fracture toughness of the composites increases with increase in the ZrO2 has the maximum value 1.998 MPa.m-1/2. Flexural strength & shear stress of the composite materials increased with increasing of the weight fraction of ZrO2 particles at 7wt % (81)Mpa &(1.8)Mpa respectively .

Index Terms- Acrylic resin, Zirconium Oxide, , mechanical properties.

I. INTRODUCTION

Composite materials play an important role in modern industry through the design and manufacture of advanced materials capable of attaining higher stiffness/density and strength/density ratios. These ratios allow composite materials to be used in various applications where the weight and strength of the structure are highly significant design parameters (e.g. aircraft, cars, and aerospace shuttle industries). Composite materials dramatically enhance the performance and increase the efficiency of such structures [(1).] Acrylic resins are the most commonly used polymeric materials in denture dentistry, majority of which comprise the Poly methyl methacrylate (PMMA).

This is due to their acceptable aesthetics, ease of handling, good thermal conductivity, low permeability to oral fluids and color stability. Inherent drawbacks of these materials are fracture as a result of fatigue when subjected to intra-oral forces and failure to withstand extra-oral impact forces. [(2)]. Arezou Sezavar et.al. (2015), had studied PMMA matrix nanocomposite reinforced with different wt% of alumina (i.e., 5, 10 and 15) were fabricated using the compression molding technique. Tensile properties of produced nanocomposites were studied using Zwick Z250 apparatus at cross head speed of about 5 mm/min. It is found that addition of nano alumina to PMMA causes an increase in modulus but not tensile strength or amount of elongation at break. Also, it is observed that the amount of deboning between the matrix and the granules has increased due to addition of nanoparticles[(3)].

II. EXPERIMENTAL WORK

A. *Materials Used*

The basic materials used in the preparation of samples are Acrylic resin (PMMA) resin as matrix, Zirconium oxide ZrO2 as reinforcement material. Matrix Material included PMMA cold curing that used in this project. 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.

Table (1): Some Mechanical and Physical Properties of Pour PMMA Polymer used in this Study According to (Vertex – Dental Company).

Young's Modulus (GPa)	Impact Resistance (KJ/m2)	Flexural Strength (MPa)	Density (gm/cm2)	Water Absorption (%)
1.63-3	8.3	79	1,19	2.5

Table (2): Some Mechanical and Physical Properties (ZrO2) Material used in this Study according to (ZIRCONIA SALES-GUL 185 SS-UK Company).

Young's Modulus (GPa)	Tensile strength (MPa)	Flexural Strength (MPa)	Density (gm/cm2)	Compression Strength (MPa)
205-210	800-1500	900-1200	5.7-6.1	2000

But have low strength, low hardness and more difficult using during fabrication. Table (1) shows the physical and mechanical properties of PMMA used in this study. The zirconium oxide represents the most widely

used ceramic oxide in medical application. ZrO2 is supplied as partially stabilized micro-particles form, which made by (ZIRCONIA SALES-GUI 185 SS-U.K Company). Table (2) shows the mechanical and physical properties of this material.

B. Preparation of Composites

The method used in the preparation of the samples, in this research is the (Hand lay-Up Molding) because it is simple to use and can make different shapes and sizes of composites. Relations between the weight fraction and the volume fraction for each of reinforced material and matrix materials relations illustrated below [4].

$$vp = \frac{\rho c}{\rho p} \times Wp \times 100\% \quad (1)$$

$$vm = \frac{\rho c}{\rho m} \times Wm \times 100\% \quad (2)$$

Where

ρc , ρm ,ρp: Density of composite material , matrix materials and reinforced material respectively (gm / cm3).

Wp, Wm: Weight fraction of reinforced material and matrix materials respectively.

Vp, Vm: Weight fraction of reinforced material and matrix materials respectively.

Note that the total the weight fraction and the volume fractions are illustrated below:

$$Wp + Wm = 1 \quad (3)$$

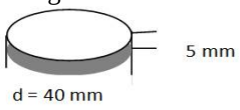
$$Vp + Vm = 1 \quad (4)$$

C. Mechanical Tests

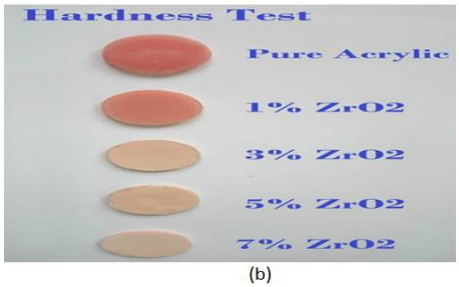
Hardness Test (Shore D)

This test is performed by using hardness (Shore D) and according to (ASTM DI-2242) standard. Samples have been cut into a diameter of (40mm) and a thickness of (5mm). Figure (1) shows standard specimens for this test [5].

For each specimen five hardness measurements were taken and the average hardness is calculated.



(a)

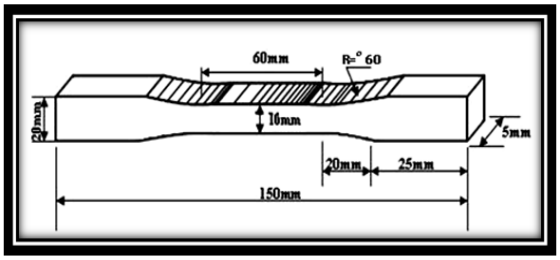


(b)

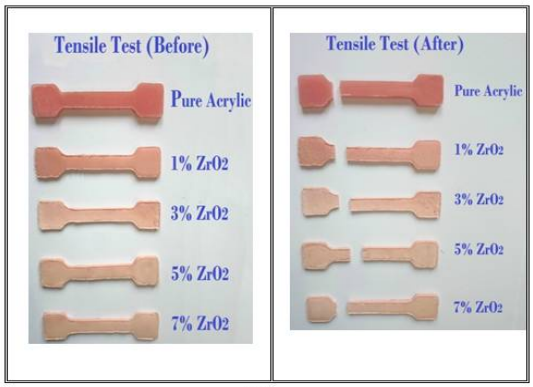
Figure (1): (a) Hardness (Shore D) standard specimens [6]. (b) Experimental specimens test.

D. Tensile Test

This test is performed according to (ASTM D638) at room temperature. Figure (2) shows standard specimens for tensile test [6].



(a)



(b)

Figure (2): (a) tensile test standard specimen [7], (b) Experimental specimens.

E. Impact Test

Impact resistance is calculated for samples from the following relationship [7].

$$Gc = \frac{Uc}{A} \quad (5)$$

Where

Gc: impact strength of material (J/m2).

Uc : impact energy (J).

A: cross- sectional area of specimen (m2).

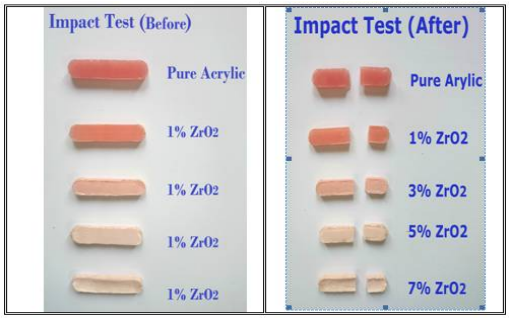
Fracture toughness can be expressed as [8].

$$Kc = \sqrt{Gc\,E} \quad (6)$$

Where:

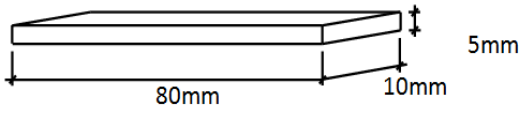
Kc: fracture toughness of material (MPa.m1/2).

E: elastic modulus of material (MPa).



(b)

Figure (3): (a) impact test standard specimen [8], (b) Experimental specimens.



(a)

This test is performed according to (ISO- 180) at room temperature. Samples have been cut into the dimensions (80*10*5) mm. Figure (3) shows standard specimens for impact test [9].

F. Flexural Strength& Shear Stress

This test is performed according to (ASTM D790) at room temperature by three- point bending test machine (Lybold Harris No.36110).Samples have been cut into the dimensions(100*10*5)mm. Figure (4) shows standard specimens for this test.

The flexural strength & maximum shear stress are calculated according to the equations [10].

$$F.S = \frac{3PL}{2bd^2} \quad (7)$$

$$\tau = \frac{3P}{4bd} \quad (8)$$

Where

F.S: flexural strength (MPa).

P: force at fracture (N).

L: length of the sample between Predicate (mm).

b:thikness(mm).

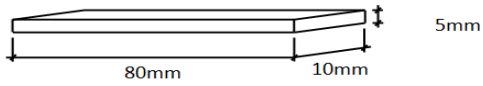
d:width(mm).

τ:maximum shear stress (MPa)

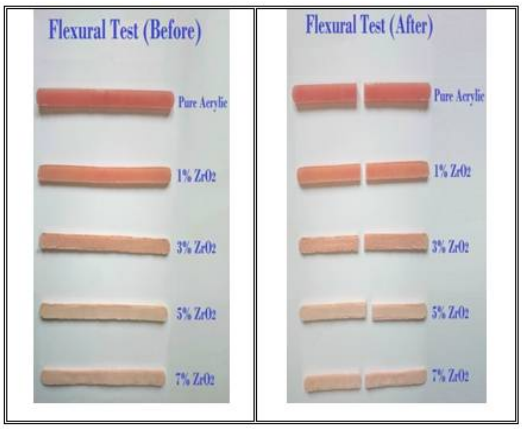
P: force at fracture (N).

b:thikness (mm).

d:width (mm).



(a)



(b)

Figure (4): (a) Flexural strength standard specimen (10), (b) Experimental specimens before & after test.

G. Results and Discussion

Hardness shore (D)

The results of Shore (D) hardness for the Acrylic resin (PMMA) reinforced with (B_1, B_2, B_3, B_4 and B_5) groups are illustrated in Table (3) and Figures (5). It can be noticed that the values of hardness increased with increasing ZrO2 particles. This is related to the high hardness and brittleness that have these particles as compared with PMMA matrix. Furthermore, related to the wettability and the bonding strength between the matrix and these particles, which lead to make the harder surface by impeding the matrix motion along the stress direction [11].

Table (3): Hardness shore (D) for Acrylic resin (PMMA) reinforced with groups (B_1, B_2, B_3, B_4 and B_5).

Type of composite	Hardness Shore (D)
B1	
Pure Acrylic (PMMA)	61.2
B2	
Acrylic +1% ZrO2	64
B3	
Acrylic +3% ZrO2	65.2
B4	
Acrylic +5% ZrO2	69.2
B5	
Acrylic +7% ZrO2	72.4

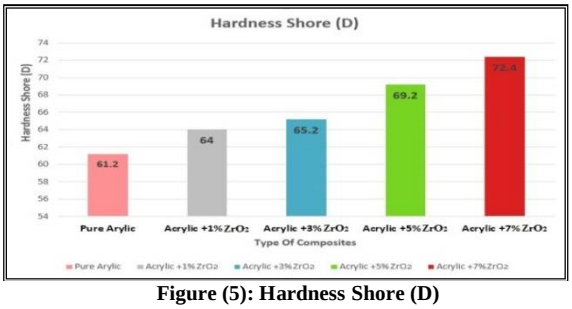


Figure (5): Hardness Shore (D)

H. *Tensile strength*

Table (4) and Figures (6) and (7) shows the resulted values of ultimate tensile strength (UTS) and elongation at break for the Acrylic resin (PMMA) reinforced with (B_1, B_2, B_3, B_4 and B_5) groups' .Figure (6) shows the effect of filler ZrO2 on tensile strength of PMMA/ ZrO2 composites. The tensile strength of the composites decreased with addition of 3wt% and 5wt% filler content and then started to increase with increasing filler content. The decreased of tensile strength in composites with 3wt% and 5wt% filler content maybe due to the insufficient of fillers to reinforce the matrix of the composites. As the filler content used is increases, the tensile strength of the composites increases. This is due to the addition of fillers has strengthen the interface of resin matrix and filler materials where it increases the ability of the filler to support stress transferred from the matrix. The Figure (7) shows the relationship between the weight fraction of ZrO2 particles in PMMA resin and the elongation percentage of the specimens. It can be noticed that the values of elongation percentage decreased with increasing of the weight fraction of particles. This is because of any increasing in the particle; it will be act as localized stress concentration regions. Therefore, the elongation percentage will be decreased. Also the decreasing in the elongation percentage depends upon the interfaces bonding between the

PMMA matrixes and reinforcing material ZrO2 particles therefore the decreasing in the elongation percentage may be attributed to the formation of a strong structure of the PMMA composite material for specimen [12, 13].

Table (4): Tensile strength for the Acrylic resin (PMMA) reinforced with (B_1, B_2, B_3, B_4 and B_5) groups.

Type of composite	σ UTS (MPa)	Elongation at break (%)
B1		
Pure Acrylic	30.5	7.7
B2		
Acrylic +1% ZrO2	31.6	7.7
B3		
Acrylic +3% ZrO2	24.8	6.1
B4		
Acrylic +5% ZrO2	24.8	5.8
B5		
Acrylic +7% ZrO2	33.75	5

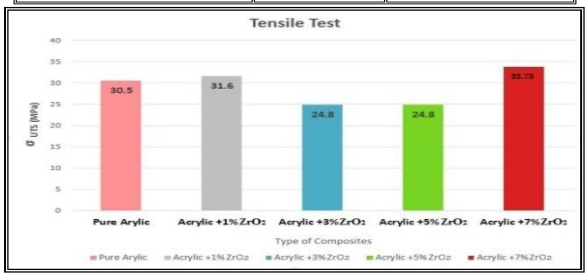


Figure (6): ultimate tensile strength (UTS)

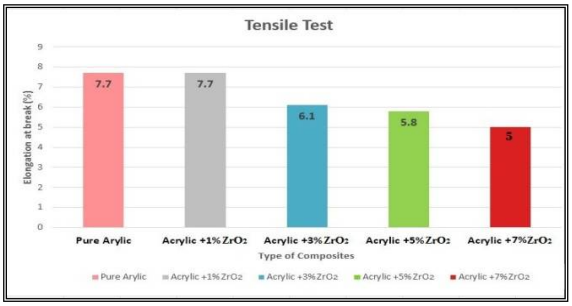


Figure (7): Elongation at break (%)

I. Impact energy

Table (5) shows the values of impact strength (Gc) & fracture toughness (Kc) for the Acrylic resin (PMMA) reinforced with (B_1, B_2, B_3, B_4 and B_5) groups. Figures (8) show the impact strength (Gc) for each composite materials. The results of impact strength test showed that the addition of ZrO2 particles increased the value of the impact strength, 3wt% group has the highest impact strength, but increasing the percentage of ZrO2 to 7wt% lowered the impact strength. The increase in impact strength due to the interfacial shear strength between filler and matrix is high due to formation of cross-links or supra molecular bonding which cover or shield the fillers that in turn prevents propagation of crack. Also the crack propagation can be changed by good bonding between filler and resin matrix. The aggregation of modified ZrO2 at 7wt%, that lead to the reduction in impact strength because of higher surface area of the fillers, stress concentration around this aggregation which lead to crack proportion. Also the increase in percentage of ZrO2 particles affects the interface region lead to lowering of energy dissipation per unit volume and consequently lowers the impact strength [14]. While the fracture toughness appear in Figure (9). It can be noticed that the values of fracture toughness increased with increasing of the weight fraction of particles. Therefore, when added of these particles in the PMMA composite lead to hindering and obstacle the crack propagation inside the materials [15].

Table (5): Impact strength of material & fracture toughness for the Acrylic resin (PMMA) reinforced with (B_1, B_2, B_3, B_4 and B_5) groups.

Type of composite	impact strength of material (GC) J/m2	Fracture Toughness (KC) MPa.m-1/2
B1		
Pure Acrylic	50	1.523
B2		
Acrylic +1% ZrO2	50	1.574
B3		
Acrylic +3% ZrO2	83	1.844
B4		
Acrylic +5% ZrO2	58	1.846
B5		
Acrylic +7% ZrO2	25	1.998

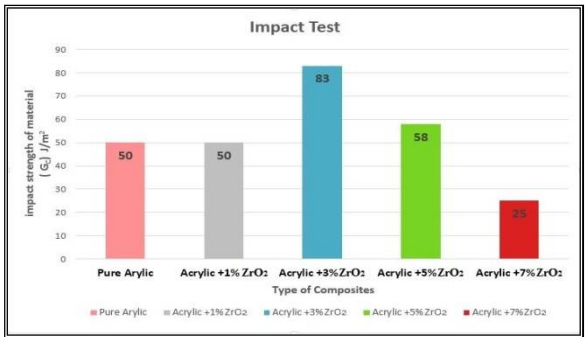


Figure (8): Impact strength (Gc)

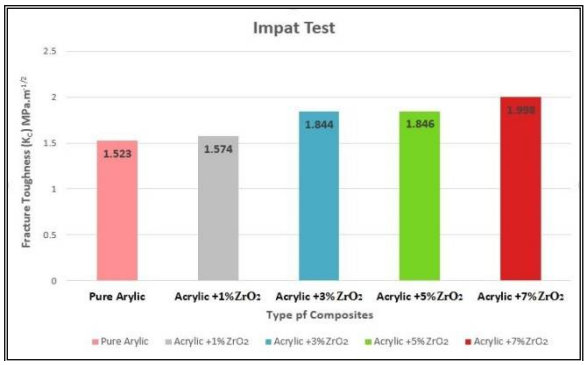


Figure (9): Fracture toughness (Kc)

J. Flexural Strength& Shear Stress

Table (6) and Figures (10) to (11), show the values of flexural strength & shear stress for the Acrylic resin (PMMA) reinforced with (B_1, B_2, B_3, B_4 and B_5) groups. It can be noticed that the values of flexural strength and shear stress increased with increasing of the weight fraction of particles. This is due to the ability of these particles to hinder the crack

propagation inside PMMA matrix according to strengthening mechanism additionally to the strong bonding between the PMMA matrix and these particles. Furthermore, this increasing may be due to the fact the flexural strength and shear stresses of ZrO2 particles are much higher than PMMA matrix [15].

Table (6): Flexural strength & shear stress for the Acrylic resin (PMMA) reinforced with (B_1, B_2, B_3, B_4 and B_5) groups.

Type of composite	Flexural strength (MPa)	Shear Stress (MPa)
B1		
Pure Acrylic	24	4
B2		
Acrylic +1% ZrO2	27	1.2
B3		
Acrylic +3% ZrO2	36	1.35
B4		
Acrylic +5% ZrO2	44	1. 5
B5		
Acrylic +7% ZrO2	81	1.8

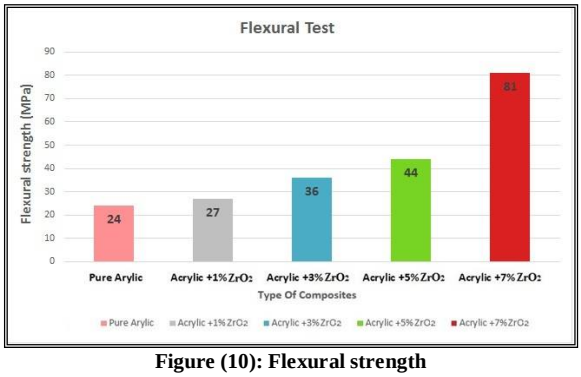


Figure (10): Flexural strength

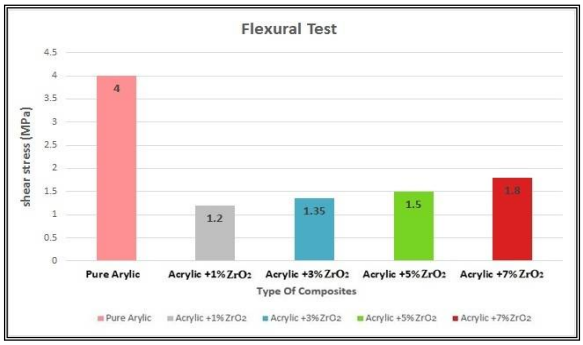


Figure (11): Shear stress

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