RESEARCH PAPER

Influence of Nanofillers on Mechanical Properties of the PMMA Matrix for Denture Applications

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ABSTRACT

In the present work, mechanical properties of polymethyl methacrylate (PMMA) polymer that is used for denture materials are studied and developed, the study done by preparing composite materials consists of resin matrix material (PMMA) which reinforced by two types of nano fillers (zirconia and silica) in (1%, 2%, and 3%) weight fractions. Some mechanical tests, like (tensile, impact, flexural, and hardness) are included in this work. The results of this work showed that using the reinforcing nanofillers have a good effect on the performance of composite materials that prepared for using as acrylic denture material so that all values of the studied properties increased with increasing of the concentration of nanofillers in these composite materials, except the elongation property, the values of these properties showed the maximum rates at 3 % ratio of nano fillers. Also, all obtained results showed the silica-PMMA composites exhibited higher mechanical properties compared to zirconia-PMMA composites.

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INTRODUCTION

The materials are selected, designed, and fabricated for use in dentistry are termed as dental materials; there are vary in types, characteristics according to their future purpose as dental material. It must be biocompatible, non-irritating, non-toxic,and non-allergenic, also the most essential characteristics of these materials are high durability to reset the predictable fracture, and stable over time, temperature change, and solvents. [1].

There are many types of dental materials as dental implant, restorations materials (fillings, bridges, and crowns), impression materials, and dentures (prosthetic materials), which are defined as part which are adhere to oral tissues and replaces missing natural teeth [2].

Polymethylmethacrylate PMMA polymeric material has more popularity in dental applications for the fabrication of both whole and partial denture parts due to its efficient properties [3].

The functional properties of PMMA include light weight, aesthetically preferring, easy preparing, and fabrication, biocompatibility, and stability in the oral conditions, so PMMA continues the favored option for denture base applications [4,5].

On the other hand, the conventional PMMA dentures are almost weak and brittle, and have a probability for suddenly failure, which leads to fracture with a more risk [6].

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Frequently, the failure of PMMA denture base materials occurs in the human mouth in normal function as the mastication process leads to fatigue phenomena through heavy occlusal force or by external sudden force [7].

Consequently, several attempts were made to develop the mechanical properties of PMMA composites [4,8]. Numerous researchers consistently study the means to solving the problems of PMMA denture bases, such as chemical modification of polymeric chemistry by the use of polymer blends or other useful method, including applying different fillers as reinforced materials in polymers like fibers and particles [9,10].

Many investigators have studded how the use of particle fillers, such as oxide's metal (TiO_2, ZrO_2, SiO_2, Al_2O_3), can increase the mechanical behavior of PMMA denture base [11].

In recent times, many studies has focused on promising nanoparticles, because they are generally having important features owing to their chemistry, size, and their ability to develop the current properties of matrixes [12]. Zirconia is one of the new materials that has attracted significant interest and exhibits excellent durability, high flexural strength, and fracture toughness, along with offering excellent biocompatibility and good aesthetics because of its white color, which is less likely to change appearances [13].

Silica nanopowder is also a broadly used material for strengthening denture base polymer because of its distinctive and favorable characteristics [14]. Silica nanomaterial is commonly used in this field due to its good antimicrobial properties and rigidity [15].

This study will help researchers who search for the modification of the properties of PMMA resin denture base material by showing the influence of addition two types of strong nano-powder, which include silica and zirconia, in order to reinforce it to reduce the sources of fracture dentures. This research also studies the effect of two factors of adding fillers (weight fraction and filler types), on the tensile, flexural, impact, and hardness of specimens of denture base composite materials.

MATERIALS AND METHODS

In this study cold-curing poly methyl methacrylate (PMMA) resin was the matrix that is used for preparing denture base materials, type (super acryl plus), produced by (SpofaDental) company. Fig. 1a shows PMMA resin.

Nano powders of silicon oxide and zirconia have particle sizes in the range (25-75) nm were inserted in acrylic powder to prepare specimens as denture base materials. These two groups of specimens are divided according to weight fraction, and filler types of the reinforcement materials, shown the Table 1.

Glass plates with dimensions of (200×200×5) mm were required for preparing the moulds of specimens, the walls and base of moulds covered with transparency film to prevent sticking between them and the cast material.

Hand lay–up manner used for preparing the samples of PMMA composite, this method includes calculating and weighing the PMMA acrylic resin in powder to liquid standard ratio about 2.25:1 to mix the monomer (MMA) and acrylic powder (PMMA). Then the powder (PMMA) was continuously mixed with the reinforcing powder until a homogenous mixture was formed, and then mixed quickly with the PMMA liquid. After that,

Table1. Type and weight fraction of filler materials used in this work

Type of materials	Acrylic Resin	Weight fraction of SiO_2 powders (Wt.)	Weight fraction of ZrO_2 powders (Wt.)
Pure	100%	-----	------
Group A	99% 98% 97%	1% 2% 3%	------
Group B	99% 98% 97%	-----	1% 2% 3%

this mixture was uniformly poured into the mould from one corner of it, to avoid the cast damage caused by bubbles formation. After the casting process was completed and the mould was let cool, the samples were removed from the cavities of the moulds with flat upper and lower surfaces. Then the cracks and edges present in the sides of specimens, generate due to the sticking between the mould cavity and specimen, were removed and handily finished by a special grinder. The used mould before and after casting is shown in Fig. 1b and Fig. 1c.

Mechanical Tests

Tensile Test

Tensile testing was done based on (ASTM D 638) standard, and was carried out by using a tensile machine (Universal tensile machine) type (LARYEE) with (50 KN) load, and the strain rate (the cross head speed) about 2mm/min at room temperature [16]. Fig. 2a displays the experimental tensile test specimen used in this study.

Flexural Test

The same device that was used in the tensile test, the universal test instrument used in the flexural test by the method of three-point bending experiment. In this test, the composite specimens were gradually subjected to vertical load at the mid of it at a cross head speed (2 mm/min) and waiting for they fractured in order to find the curve of load-displacement for all prepared specimens. The flexural strength and flexural modulus were can get from the flexural test according to ASTM D 790 [17]. The flexural specimens are cutting in the form as shown in Fig. 2b.

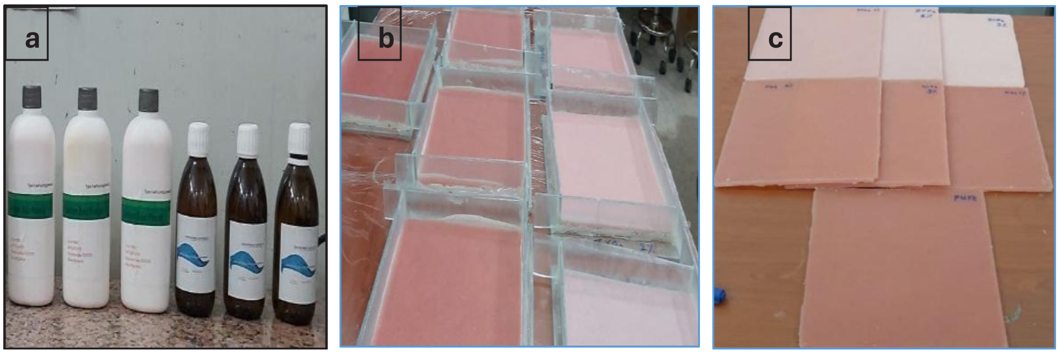

Fig. 1. The materials and mould used in this study.

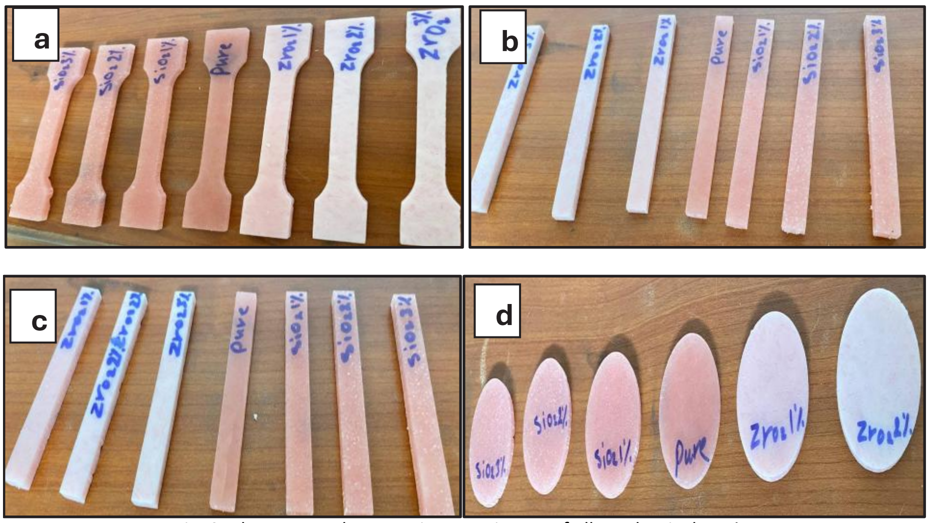

Fig. 2. The prepared composites specimens of all mechanical testing.

Impact Test

The machine type of (XJU series pendulum) for Izod Impact test was employed to test the prepared specimens according to ISO180. The specimen with a notch was vertically held at one end with the free other end, and it was broken by a moving pendulum that has (5.5 J) energy and velocity (3.5 m/s) [18]. Fig. 2c shows the impact specimen utilized in this study.

Hardness Test

Hardness test was conducted by Dorumeter hardness tester, type (Shore D), according to ASTM D2240 by applying a force about 50 N, and the pressed time was 15seconds [19].

PMMA specimens before and after reinforcing were tested by Shore D at different position five times, then the average of these value was collected for all specimens to obtain accurate results, hardness specimens are shown in Fig. 2d.

RESULTS AND DISCUSSION

Tensile Test

The samples of Polymethylmethacrylate PMMA are weak more than the samples with reinforcing powder, the pure resin is incompetent to withstand the load of applied tensile and breaks easily [20]. The prepared composite specimens that were reinforced with both powders exhibited a better tensile strength than the specimen of the pure PMMA. This is because the existence of reinforcing material in resin thus as sure carrying the loads to powder and make to with stand the tensile load that is applied on it.

Fig. 3a and Fig. 3b) illustrate the change of the tensile strength and modulus of elasticity with the weight percentage of zirconia and silica powders in PMMA matrix.

The values of tensile strength and elastic modulus raised with the adding and the increase in the amount of the two types of powders. So, the addition of (3 wt.%) of nanopowder show the most elevated value for these properties for the PMMA matrix reinforced with both fillers. This behavior belong to the strengthening mechanism occur by these fillers which act as restrictor the slipping of the PMMA chains, the manner of PMMA resin and the solid powders bonding also effect the strengthen mechanism efficacy, as the bonding between the matrix and reinforced fillers was strong that achieve the good wettability between solid powders particles and lead to give high strength to final composites materials [20]. Also, the strength of composites is affected by the presence of stiff ceramic particles, which always have higher strength and stiffness than matrix that caused more improved stiffness of these materials. Also, these particles act as a stress transferor and with the increase in the particle's weight fraction, cause a rise in effectiveness of stress transmission

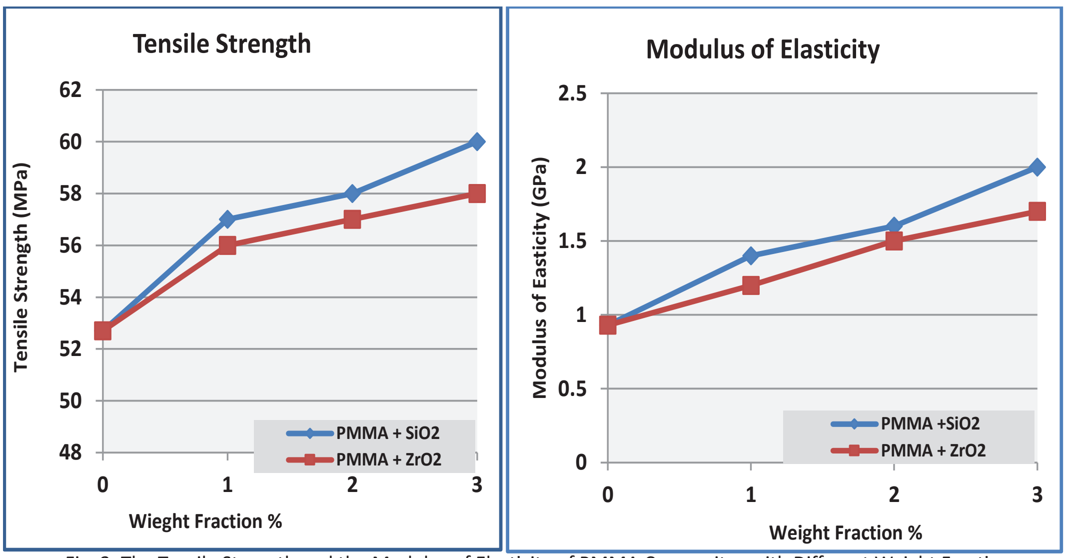

Fig. 3. The Tensile Strength and the Modulus of Elasticity of PMMA Composites with Different Weight Fraction.

from PMMA phase to the filler phase [21].

From this figure, it can also be observed that silica particles increase the elastic modulus and the tensile strength more than zirconia powder fillers. This is because these particle fillers have better stiffness than the matrix [22]. Where the modulus of elasticity for the composites reinforced with fillers of (SiO_2 and ZrO_2) at (3 wt.%), reaches (2 GPa) and (1.7 GPa) respectively, while for pure PMMA was (0.93 GPa).

The elongation percentage of composite when reinforced by both silica and zirconia fillers was lower than that of the pure matrix of PMMA, which has the maximum elongation percentage

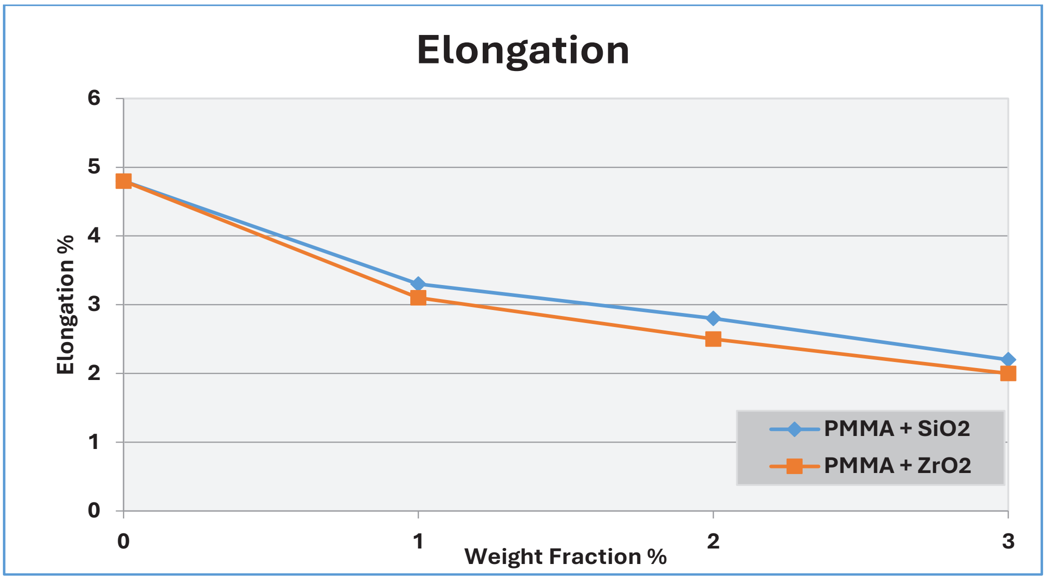

Fig. 4. The Elongation of PMMA Composites with Different Weight Fraction.

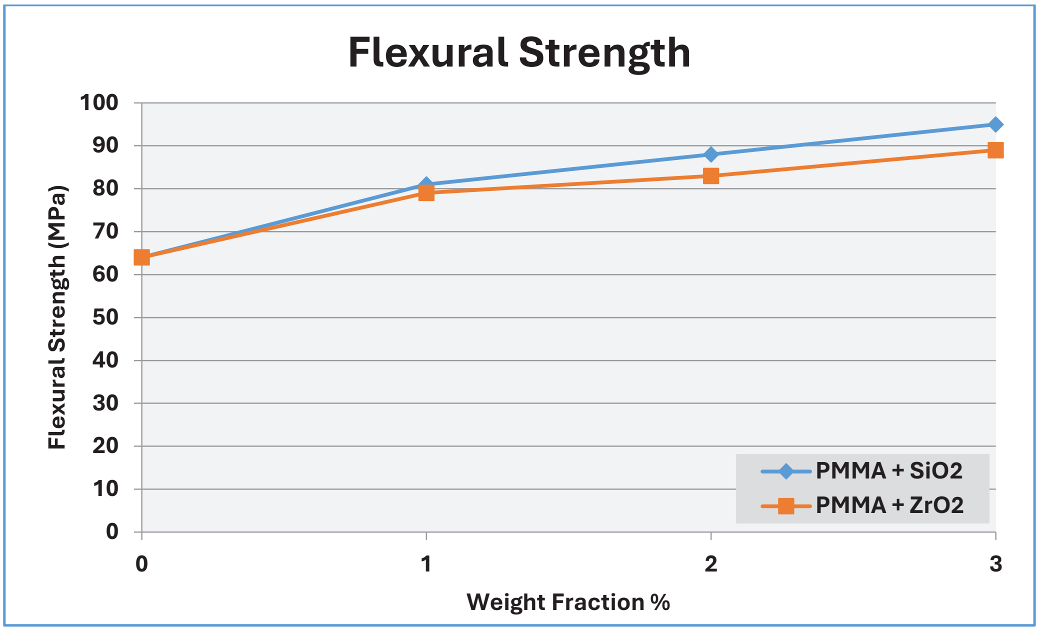

Fig. 5. The Flexural Strength of PMMA Composites with Different Weight Fraction.

equivalent to (4.8 %), although the lower value obtained at the specimen included 3 %wt of filler particles of zirconia reaches to 2 %., as shown in Fig. 4. This is because of the better properties of reinforced particles as compared with pure PMMA.

Flexural Strength

Fig. 5 showing the flexural strength values of prepared composites according to the weight percent of the strengthening filler (SiO_2, and ZrO_2) in these materials, (1, 2 and 3 wt. %) were included into the PMMA matrix.

As seen from this figure flexural strengths of two types (SiO_2 and ZrO_2) fillers composite specimens are higher than the specimen of PMMA matrix. The PMMA specimen has a flexural strength equal to (64 MPa), this value will increase with the increasing addition of fillers until reaching the maximum value (95 MPa) at 3% filler content of silica.

The increase in flexural strength in the prepared composites at 3% filler content may have occurred due to the homogeneous distribution of nanofillers at this concentration [23].

Impact Strength

Fig. 6 displays the relationship between the impact strength of PMMA composites and the weight fraction of nanofillers that were added to the pure resin.

In this figure, the impact strength of PMMA matrix can be seen to increase as the amount of fillers (weight fraction) increases. It can also be noted that the strengths value of composite, including silica powders, was higher than these of zirconia composites. The behavior of increasing the impact strength of composites may be due to the development of strong bonding of crosslinking between the resin and nanofillers, which inhibits the crack propagation through the PMMA matrix. Further because of the using tough solid ceramic fillers in a matrix caused a rise in the toughness of the PMMA composite materials [24]. Where the properties of the acrylic matrix were more controlled by the amounts and distribution of inserted particle in the matrix, along with the strength of the interface region between the PMMA and reinforced particles.

Hardness Test

Fig. 7 displays the hardness shore D related to the amount (weight percent) of both kinds of filler in the matrix. The hardness values were increase with the rise in the weight fraction for both powders that are included in the prepared

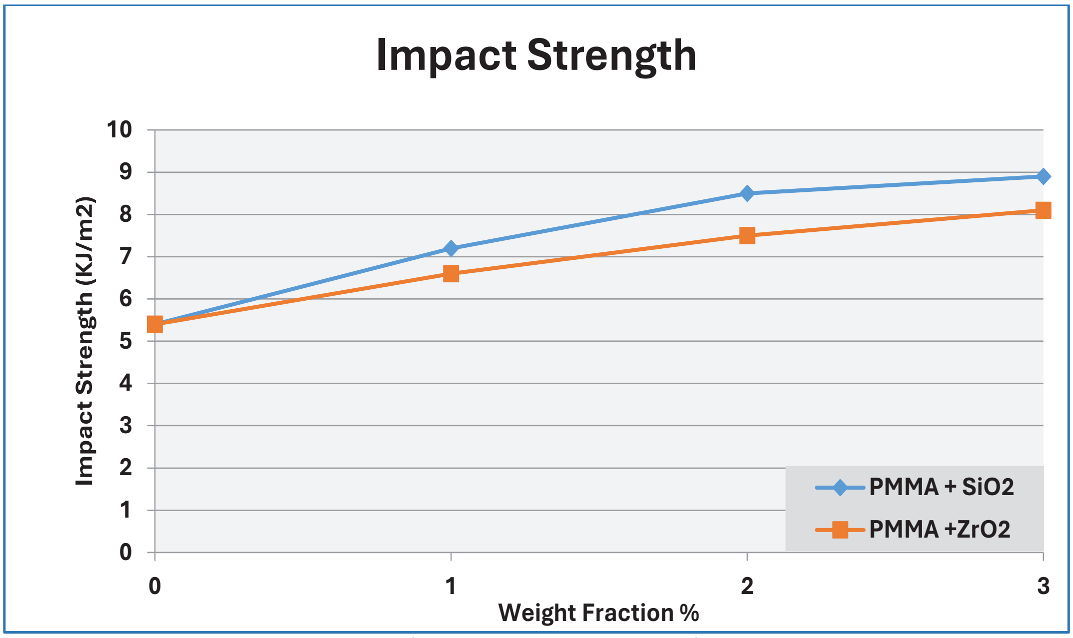

Fig. 6. Impact Strength of the PMMA Composites with Different Weight Fraction.

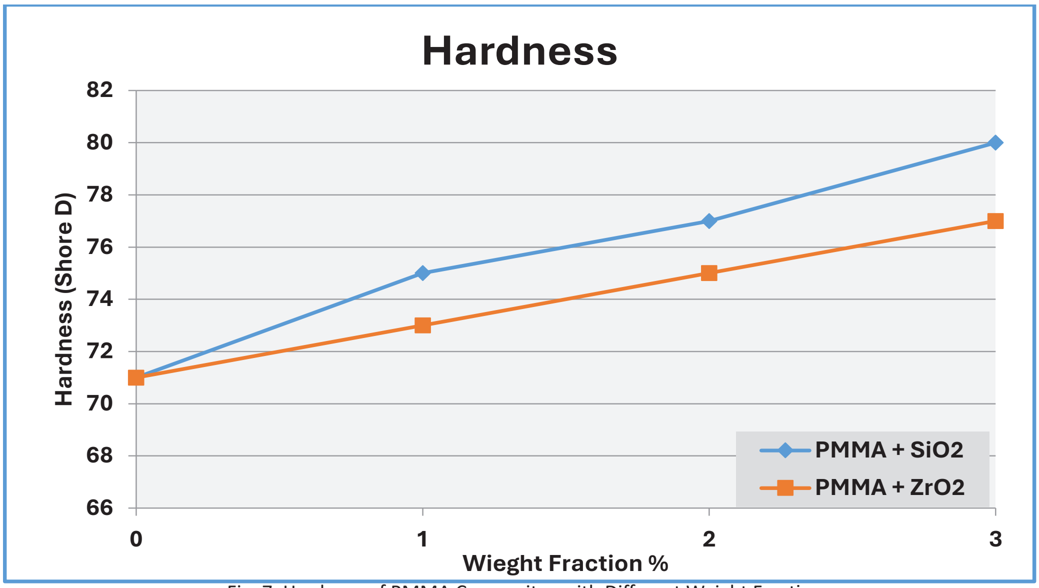

Fig. 7. Hardness of PMMA Composites with Different Weight Fraction.

composites.

The hardness of the PMMA composite containing nanosilica powders is higher than the hardness of the composites with zirconia powder. The used of reinforced powders, which have good mechanical properties e.g. hardness, yield strength, and elastic modulus, make the composite materials harder than the matrix. When the powder ratio increases causes a development in the hardness of the PMMA composite materials.

The presence of these powders resulted in considerable modifications in hardness values better than the pure PMMA matrix, this result could be associated to the reduction in the mobility of polymer chains caused by the presence of the nanoparticles, which might be caused an enhance in adhesion between matrix and particles [25].

CONCLUSION

The experimental results for nanocomposite materials that were prepared for this research leads to the important conclusion that nanopowder has a remarkable effect on all properties of the composite, all tested properties as tensile strength, elastic modulus, impact strength, flexural strength, impact strength, and hardness have been developed by the use of (SiO_2, and ZrO_2) nano particles, and continues in increasing with increase the weight fractions of powders (silica and zirconia), while only the elongation will be decreased. Also, silica powders have a clear effect on the properties of the prepared composite more than zirconia powder.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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