An Investigation of the Mechanical Properties of PMMA-based Composites Reinforced with PZT Ternary Nanoparticles

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Abstract

This study investigated the effects of Nano Lead Zirconium Titanium (PZT) on the mechanical properties of poly (methyl methacrylate) (PMMA) using tensile and compression tests, three-point bending, fracture toughness tests, and hardness tests. The results revealed that the addition of PZT has promising effects on the composite, except with respect to elongation, which deteriorated with the addition of PZT. The results show clearly that PZT has a significant effect on PMMA quality.

Key Words: PZT, PMMA, Three-point Bending, Fracture Toughness, Polymer Nano Composites.

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Introduction

Poly (methyl methacrylate) (PMMA) is one of the most popular polymers used in the polymer composites industries. Polymers are materials with large (macromolecule) molecules, and consist of repeating units that are typically connected by covalent bonds. The type of bond by which these molecules are bonded together is normally a hydrogen bond (Buthaina A. Ibrahim, 2010). The composites can be prepared from polymers with a variety of special fillers, common reinforcements, and modifiers to produce specific properties that have a wide range of applications (Dong et al., 2011). Polymer blends are materials consisting of two or more polymers that have been mixed together to yield a material with new characteristics (A., 1984, Michele et al., 2008). Polymers are commercially important because of a number of valuable structural features they possess, such as high ductility, high mechanical strength, high melting points, a very high resistance to dissolving in solvents, abrasion and fatigue (ASKELAND).

The amount of energy that a material can absorb before it breaks is called the material toughness (Ahmed, 2009). PMMA has many attractive properties, such as: it is lightweight, it has a high transmittance, it is transparency, it is highly resistant to chemicals, it has good insulating properties, and it is highly resistant to corrosion from weathering. Reinforcing PMMA can improve its resistance to fracture, as well as the stiffness of the polymer (Askeland and Phule). Reinforced PMMA was chosen for all these positive effects, as well as for other beneficial properties, including its low cost, toughness, strength and resistance to dissolving.

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The matrix material can be reinforced during the manufacturing stage of the composite (Hameed et al., 2007). In spite of the large body of research on PMMA composites, no one has thus far used Nano Lead Zirconate Titanate (PZT) as a reinforcement material for PMMA. Earlier studies have revealed that PZT film may contribute to applications involving the fabrication of micro-devices due to its good ferroelectricity, piezoelectricity and dielectricity (Xiuying et al., 2017). However, other studies have shown that PZT is highly efficient when used for mechanical applications such as polymer composite reinforcement (Paik et al., 2016).

The main disadvantage of PMMA is its brittleness in the dental applications it is commonly used for. When it is used alone, PMMA breaks when conducting patients' dental prints. Therefore, this study has reinforced PMMA with PZT nanoparticles in an attempt to lower its brittleness in a way that can improve its dental applications. The new reinforcement aims to improve fracture toughness while keeping patients safe from chemical hazards. The physical tests and measurements on the composites in this study are designed to simulate real-time dental activities. Therefore, the study is devoted to providing a good reference point for researchers in different fields to proceed from, be that in the academic or manufacturing sectors.

Materials and Methods

Cold curing of PMMA was undertaken using Castavaria made by Vertex-Dental, with ertex™ Castavaria being used as a matrix. A powder of nanoparticles (PZT) of radius 40-100 nm, with a spherical shape, and an assay of 99.999%, made by Chendgu Haoxuan Technology Co., China, was used as the reinforcement material. Samples were prepared according to the mass fractions shown in table (1):

Table 1. Experimental materials ratios

PMMA %	PZT %
100	0
99.75	0.25
99.5	0.5
99.25	0.75
99	1
98.75	1.25
98.5	1.5

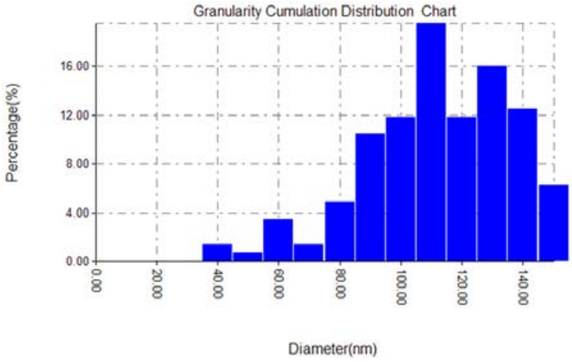
Twenty-four hours after the samples was prepared from the mold they were inserted into the electric furnace at 55°C for 55 minutes to produce the best crosslinking in the treatment process, as well as to eliminate the stresses produced during the industrial process. Different structural tests were applied to the samples, including tests for tensile strength, flexural strength, impact perforation, hardness, and response to a compressive load. All tested samples were prepared in accordance with ASTM standards.

Results and Discussion

An atomic force microscope (AFM) was used to identify the practical size distribution of PZT nanopowder. This revealed a mean value practical size distribution of 107nm, as summarized in table (2) and figure (1), and an average diameter of 68.91nm.

Table 2. Practical size distribution of PZT.

Diameter (nm)<	Volume (%)	Cumulation (%)	Diameter (nm)<	Volume%	Cumulation (%)	Diameter (nm)<	Volume (%)	Cumulation (%)
40.00	1.39	1.39	80.00	4.86	11.81	120.00	11.81	65.28
50.00	0.69	2.08	90.00	10.42	22.22	130.00	15.97	81.25
60.00	3.47	5.56	100.00	11.81	34.03	140.00	12.50	93.75
70.00	1.39	6.94	110.00	19.44	53.47	150.00	6.25	100.00



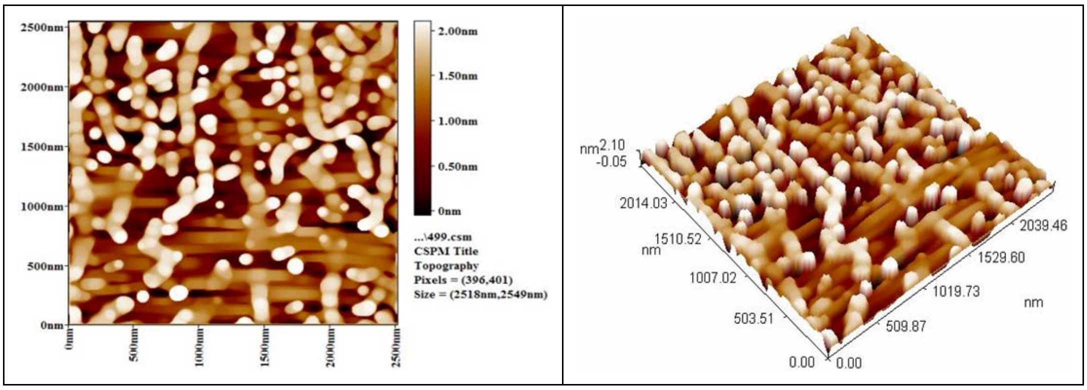


Fig. 1. AFM test of Nano PZT

Tensile Test Result

The stress-strain curves show that the deformation zone is flexible, and suggests linear stress-strain behavior, as illustrated by the slope of the straight line in the figure. The polymer material undergoes flexible deformation caused by tensile and polymeric chain stretching. The curve then exhibits deviation from this linear behavior as a consequence of internal cracks in the polymer internal, which grow and accumulate significantly with increased stress. The metal region that is showing larger deformation and cracks continue to grow with stress, leading to sample failure. In other cases, there was breakage on the top shells of the deformation locations, or faults were produced in a way similar to that of scratches in the bond or internal cracks in the working zones under increased stress, and when these finally exceeded the limits of the force for internal bonds to hold, breakage occurred (Salih et al., 2015).

It was found that the flexural stress value of the reinforced PZT nanoparticles was greater than without reinforcement. The explanation for this can be attributed to the strong bonding between PZT particles and the polymer matrix, which does not allow internal effect to the stress procedure as fast as minor subdivisions. The spaces between the interfaces inside the metallic reinforcement system cannot cause any faults to develop within the composite. This arises the possibility squeeze reinforcements in combined parts and, hence, to an increase in the interaction interfaces zone within the matrix and reinforcements. Consequently, the increase in strength among connections in the composite components of the overlay materials, as well as in the reinforcements, lead to them having greater flexibility than the matrix. (Kaiser and Karbhari, 2001).

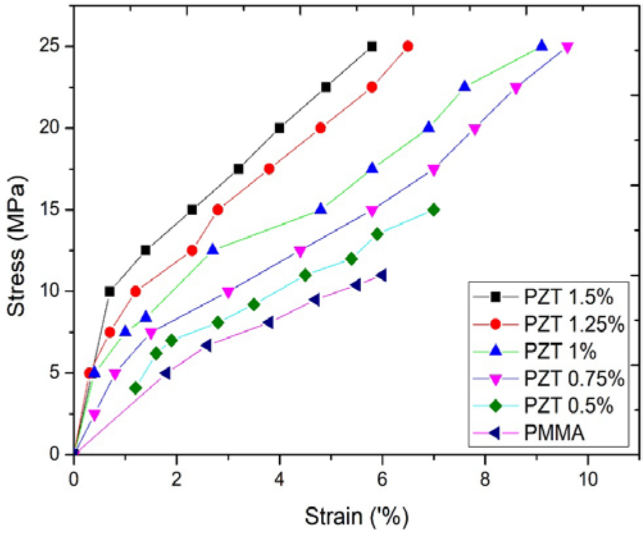


Fig. 2. Stress-strain curves of the PZT content in PMMA: PZT composite

Figure (3) shows the flexural strength curves of PMMA: PZT in relation to the PZT added. The figure shows how the flexural value increases with increases in the percentage of PZT.

Figure (4) shows the curves of Young's modulus of PMMA: PZT in relation to the proportion of PZT added to PMMA, and reveals that the value of Young's modulus increases with increases in PZT nanoparticles. Bending strength was significantly affected by the increase in reinforcement (Nanko and Kurtis, 2005).

Figure (5) shows the elongation curve for PMMA: PZT in relation to the proportion of PZT added. The elongation value decreases when PZT nanoparticles increase. The can be explained by the nature of the rigid nanoparticles, as an increase in the weight ratios of these particles, working to reduce the distance between the matrix molecules, leads to reduced fragility.

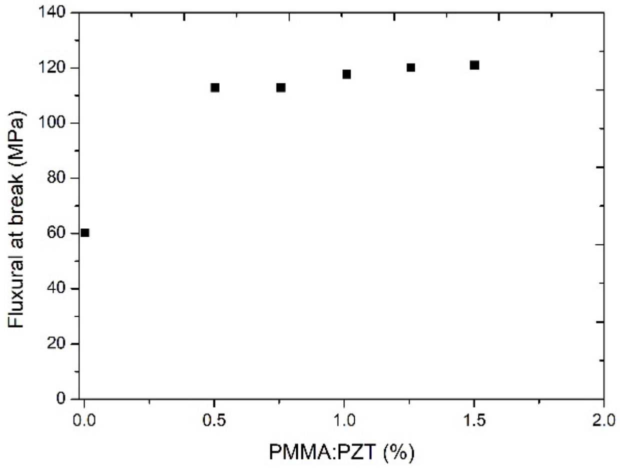


Fig. 3. The flexural strength values for different contents of the PZT in PMMA: PZT composite

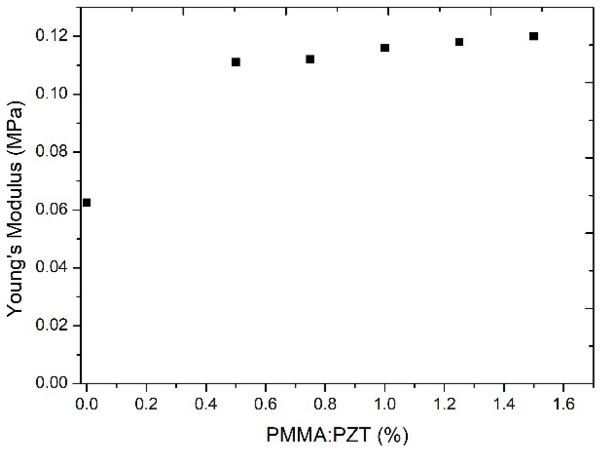


Fig. 4. Young's modulus for different contents of the PZT in PMMA: PZT composite

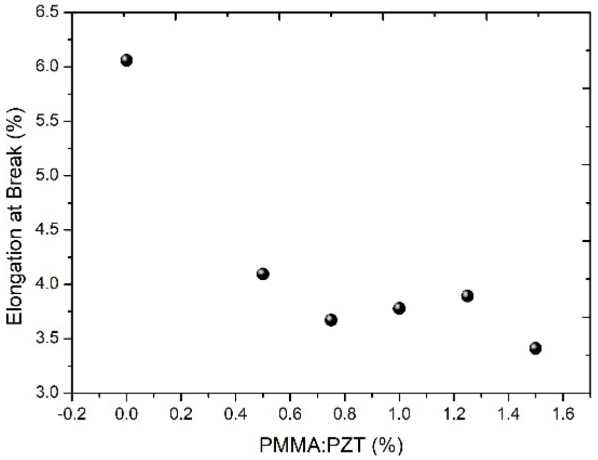


Fig. 5. Elongation at break for different contents of the PZT in PMMA: PZT composite.

Impact testing

Figure (6) shows the impact strength curve for PMMA: PZT in relation to the proportion of PZT added to PMMA, revealing that the impact value increases with increasing percentages of PZT. Some polymer materials, including PMMA, have high bonding chains, which are brittle, and this in turn makes them break easily. The penetration of nanoparticles into the matrix material increases the strength of the internal bond between the base material and the particles, thus increasing the impact values.

The particles act to disperse the stress on the area of influence. In addition, they reduce the concentration of stresses in a particular area, and prevent the growth of small cracks that occur as a result of trauma (ASKELAND).

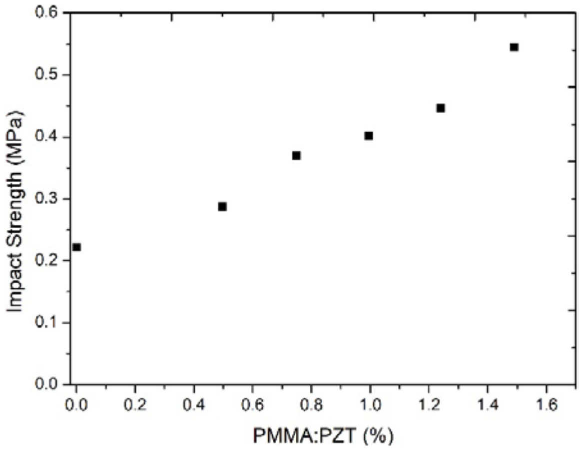


Fig. 6. Impact strength for different contents of the PZT in PMMA: PZT composite

Figure (7) shows the curve of PMMA: PZT in relation to the proportion of PZT added, and reveals that fracture toughness increases with increases in PZT percentage.

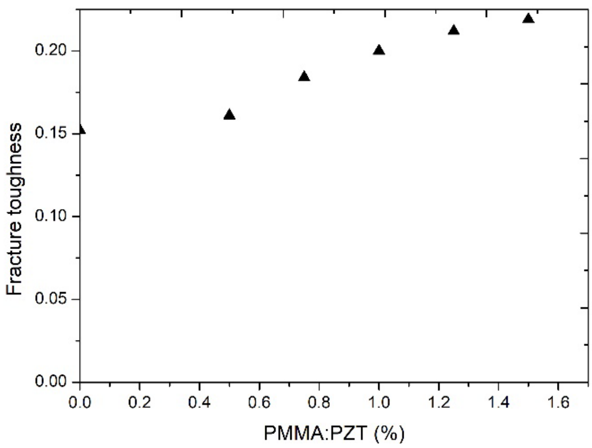


Fig.7. Fracture toughness data for different contents of the PZT in PMMA: PZT composite ent

Figure 7 shows that fracture toughness slightly improves with the addition of PZT. This positive effect may be attributed to the PZT characterizations that were mentioned in the introduction. However, this improvement is not significant with lower concentrations of PZT (>=0.5), but increase gradually at higher concentrations.

Hardness test

Figure (8) shows the hardness curve of the PMMA: PZT in relation to the proportion of PZT. It should be noted that the hardness values of nano PZT samples increase when the nano PZT content increases.

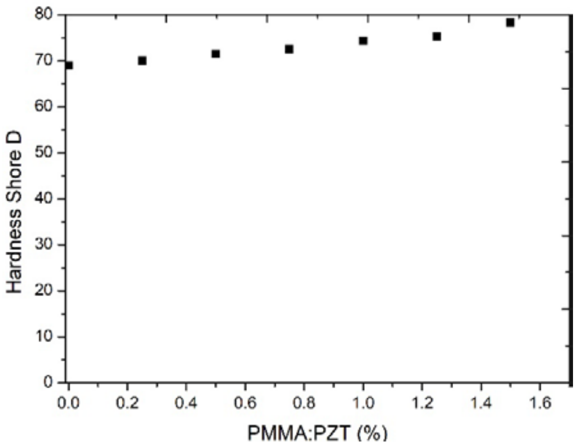


Fig. 8. The hardness test data for different contents of the PZT in PMMA: PZT composite

Because of this relationship, it has been found that the addition of PZT reduces gaps between molecules and hence increases the hardness of the matter, producing easy penetration into the spaces and pore boundaries in the composite material, which leads to a reduction in the gaps inside it (Varadharajan et al., 2005, Najeba A. Al-hamadany 2016).

Compression tests

Figure (8) shows the hardness curve of the PMMA: PZT in relation to the proportion of PZT. Figure (9) illustrates the compression behaviour of the PMMA: PZT in relation to the content of PZA. The figure shows that the compression value increases with increases in PZT nano content.

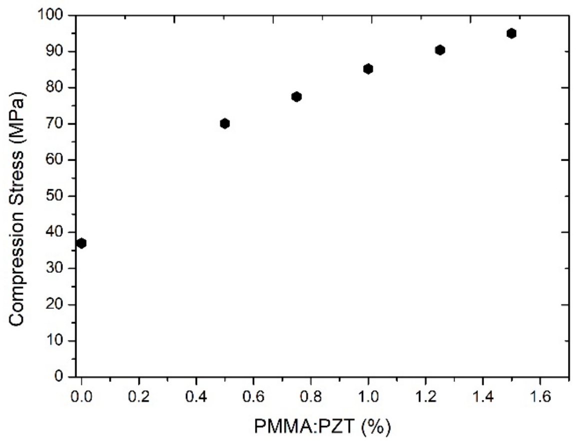


Fig. 9. The compressive strength for different contents of the PZT in PMMA: PZT composite

The reason for this increase may be explained by the reinforcement with PZT, which allows it to attain its rigidity even with a large compressive force in comparison to the matrix with the addition of polymeric content. Then, as mentioned earlier, the diffusion of PZT into the gaps between the polymeric chains will happen much more easily. This will lead to a decrease of space within the matrix, and hence an increase in its compressive strength (2004).

Conclusion

Mechanical tests were performed to investigate the effectiveness of using Nano Lead Zirconium Titanium (PZT) as reinforcement particles for Poly (methyl methacrylate) (PMMA) composites. The results revealed that the addition of PZT improves a number of the composite's characteristics, such as hardness, tensile strength, and compression. Fracture toughness and impact strength also increased with increases in PZT content. Overall, the mechanical properties of PMMA composite increased, with the exception of elongation, which showed deterioration with the increase of metallic nanoparticles.

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