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Experimental Study on the Effect of Adding Glass waste to Pmma Polymer to Improve Mechanical and Optical Performance

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Abstract
The composites has been prepared by hand lay-up method from the addition of glass waste powder to the polymer (pmma) polymethyl methacrylate .The particle size of ordinary glass powder (soda-lime) used as a reinforcing material was 231 nm and weight fractions are (0% ، 1% ، 3% ، 5%). X-ray diffraction test is used to observe crystal structure of pmma and glass powder which showed amorphous nature .Particle sizing test has been used to indicate size of glass powder grinding by mechanical method. Optical examinations were performed using a spectrometer (UV-Visible 1800 double) to analyze the optical properties. The results showed that the reinforced material slightly affected the transparency of the polymer in exchange for a decrease in the energy gap from 2.5 to 2.1ev. Mechanical examinations were performed, such as hardness, impact, bending, modules of elasticity, tensile, fracture toughness and compression .The results showed an improvement in mechanical properties as a result of these additives.
Keywords: Pmma/glass powder ,Composite, Optical properties, Energy gap, Mechanical properties, Bending strength, Impact strength, Tensile and compression.

1.Introduction

Materials science strives to obtain new materials with properties lightweight, good mechanical, good optical, uncomplicated manufacturing process and low cost. Therefore, many researchers have added different ceramic materials to pmma to improve its mechanical, optical and thermal properties [1-7] .Theses ceramic materials which have added as fillers are syntheses by chemical or green methods that mean a somewhat expensive process. The added reinforcing materials don't restrict the pmma but rather improve the other polymer matrix, such as polyester and epoxy as some researchers have demonstrated [8-11].Some studies have focused on using blend to improve the properties of the polymer [12-14] .Other studies have focused extensively on using agricultural and industrial waste as reinforcing materials added to polymers to improve their properties, on the other hand it is inexpensive and cleans the environment [15-16]. The silica SiO_2 has good optical and mechanical properties. It has high transmission and low absorption characteristic in the visible region and presence of SiO_2 enhances the mechanical strength of the composite thus are widely used as a filler in polymers [17-21]. Quartz glass powder, after being mixed with clay or other materials, was used as reinforced additives for polymers [22,23]. Poly (methyl methacrylate) (pmma), is a non-crystalline thermoplastic polymer commonly called acrylic glass with a melting point of 160 °C and it is used in dental laboratories ,medical and industry. This is characterized by light weight, good optical, mechanical properties and non-toxic and low cost. The glass is a non-crystalline contains typically 75% silica. So we aim in this work for preparing and studying a optical and mechanical properties of composites consisted of polymer pmma reinforced with ordinary glass instead of silica by using simple and inexpensive method.

2. Materials and Methods

Polymer pmma has used as the matrix, while ordinary glass powder has used as the filler for preparing four weight fractions (0,1,3,5)% of glass in pmma/glass composite. A piece of window glass waste was taken, cleaned, and dried in an oven. It was then mechanically ground to obtain glass powder with a particle size of 231 nm according to particle size analyzer analysis. The polymer powder and glass were then weighed according to the specified weight ratios using a sensitive four-digit balance. The polymer pmma was dissolved using pure benzene solvent with proportion 5:4, then the glass powder was added and thoroughly mixed using ultrasonic waves for 15 mints to ensure even distribution. After the mixing is complete, it is poured into suitable molds according to the shape of the sample required for mechanical and optical testing, and then left to dry at room temperature for 48 hours to ensure that the sample is completely hardened . X-ray diffraction (type Philips with wave length of cu kα λ=1.5405Ȧ. has been carried for pmma and glass. The optical properties using UV-Vis (300 -1000)nm have been studied for all samples as a function of wave length , weight fraction . The optical constants can be calculated using Lamberts law, where the absorption coefficient (α) is given by [4]

$$\alpha = \frac{2.303}{d} A \qquad \textbf{(1)}$$

The absorbance (A= absorbed light I_A / incident light intensity I_0) for sample with thickness d=3mm . Transmittance (T) is obtained using the relation[4]

$$T = 10^{-A} \qquad \textbf{(2)}$$

The reflectance (R) is calculated from transmission and absorption data according to law of the energy conservation using the relation

$$R + T + A = 1 \qquad \textbf{(3)}$$

The Refractive index (n) for (pmma-glass) composites is given by[4]

$$n = (1+R^{1/2}) / (1-R^{1/2}) \qquad \textbf{(4)}$$

The transitions insert material due to the falling photon with energy hυ are given by [4]

$$\alpha h\nu = C(h\nu - E_g)^{r} \qquad \textbf{(5)}$$

C is a proportional constant, r=2 and 3 for allowed and forbidden indirect transitions respectively.

The mechanical properties such as bending, elasticity modulus, tensile, hardness, impact and compression strength carried out according to ASTM-D790 test using the following laws [1,3].

$$B.S. = \frac{3fS}{2wt^2} \qquad \textbf{(6)}$$

Where: B.S.is bending (Flexural) strength (MPa). f=m*g: maximum applied Force at fracture (N). S is Spacing between supports (mm). w is Sample width (mm). t is Sample thickness (mm).

$$E = \frac{\delta S^3}{4wt^3} (Mpa) \qquad \textbf{(7)}$$

E is elasticity modulus; δ is the slope of the linear portion of the load/deflection curve for each test sample

Impact strength expresses the material's ability to resist breakage under a sudden load and is a measure of the strength of the material. It has measured by Charpy test using the following formula.

$$I.S. = \frac{U_f}{A}\left(\frac{kJ}{m^2}\right) \qquad \textbf{(8)}$$

Where: A is the of cross-sectional sample's area in m² and U_f is the energy of fracture (KJ). Compression strength σ of samples with area A is given by

$$\sigma = \frac{f}{A} \; (Mpa) \qquad \textbf{(9)}$$

Fracture toughness (K_{IC}) was calculated in MPa $m^{1/2}$ for samples using the following equation

$$K_{IC} = (I.S \times E)^{1/2} \qquad \textbf{(10)}$$

3. Results

The particle size of the glass powder used as a pmma reinforced filler have determined to be 231 nm , as shown in **Figure 1.** X-ray diffraction technology was used to study the crystal structure of glass powder and pmma. **Figure 2** showed that glass powder and pmma are a non-crystalline where it exhibits broad amorphous hump which is match with ASTM. The composite materials were cast into molds with dimensions determined by optical and mechanical specifications, as shown in the **Figure 3**.

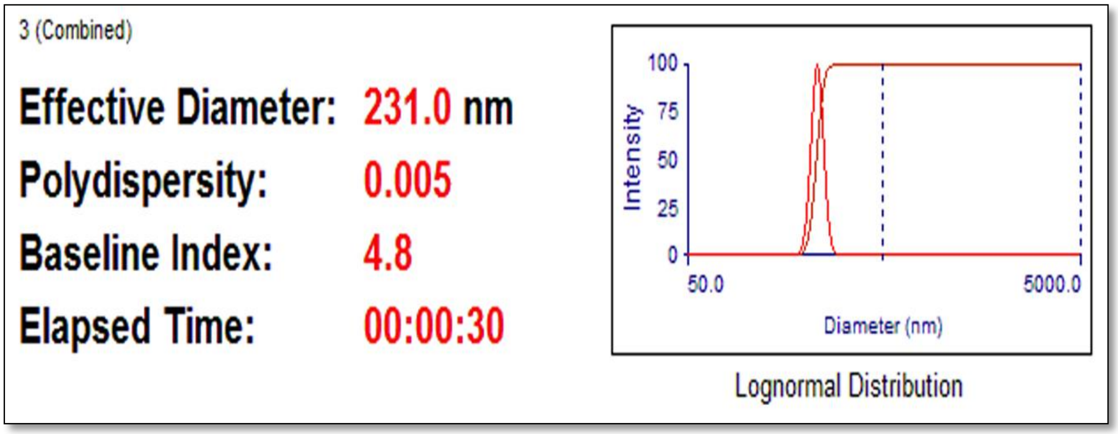

Figure 1. Particle size average of glass powder.

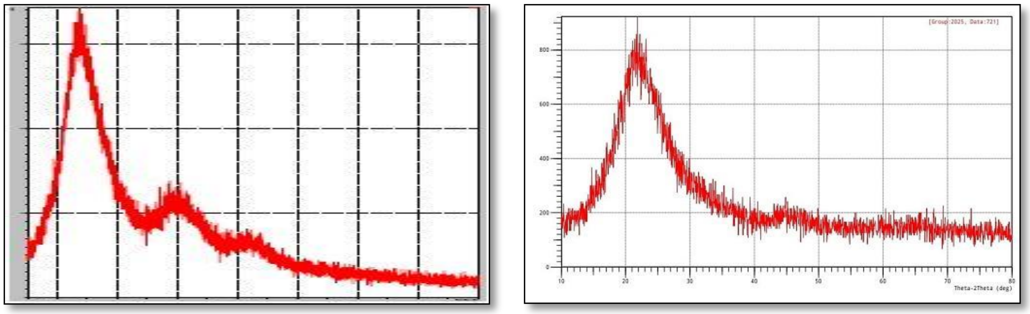

Figure 2. X-ray Diffraction pattern for PMMA (left) and glass powder (right).

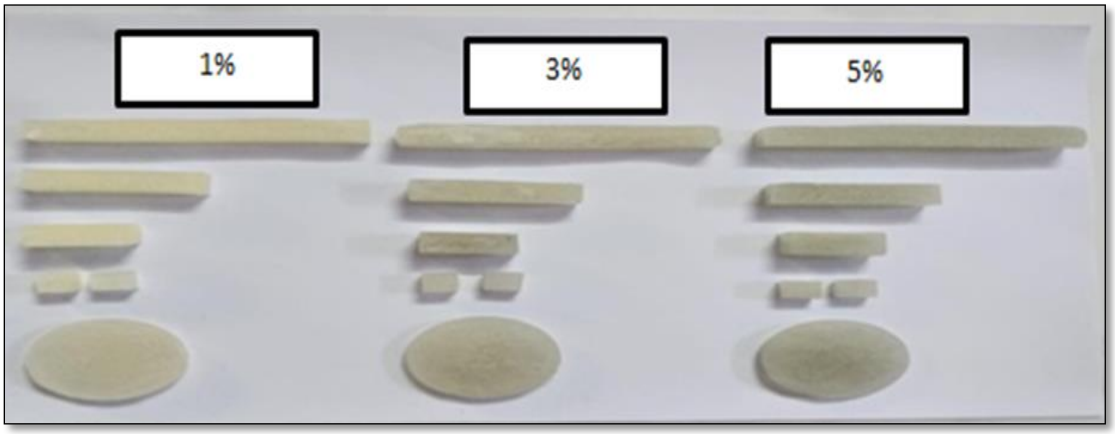

Figure 3. Photograph of the prepared samples

Figure 4 shows the absorption spectrum of (pmma/glass) composites at different weight ratios as a function of the incident photon wavelength within range (300–1000) nm. **Figure 5** shows decreasing the transmittance spectra of composite with increasing of fillers concentration in the wavelength range (400-1000 nm).

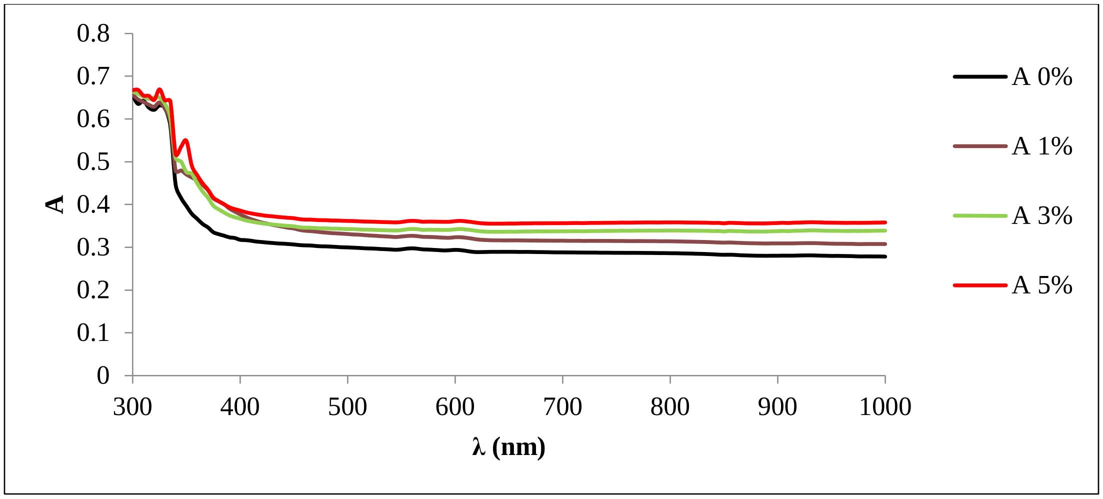

Figure 4. Absorption versus wavelength for (pmma/glass) composite at different wt%.

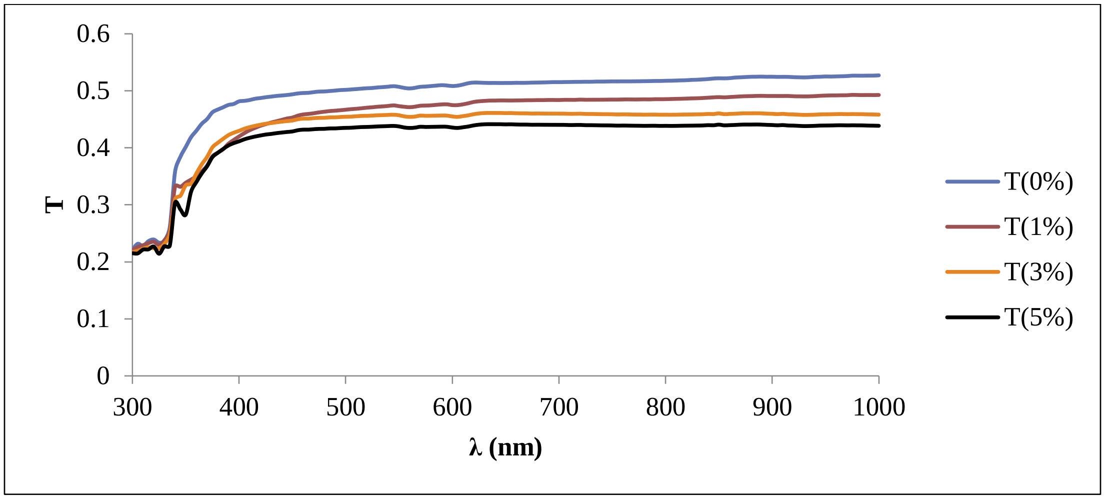

Figure 5. Transmittance versus wavelength for (pmma/glass) composite at different wt%.

The relationship between the absorption coefficient of (pmma/glass) composites and photon energy at different weight fractions of glass powder is shown in **Figure 6**. The energy gap for allowed indirect transitions of composites decreases with the increase of the glass concentrations as shown in **Figure 7**.

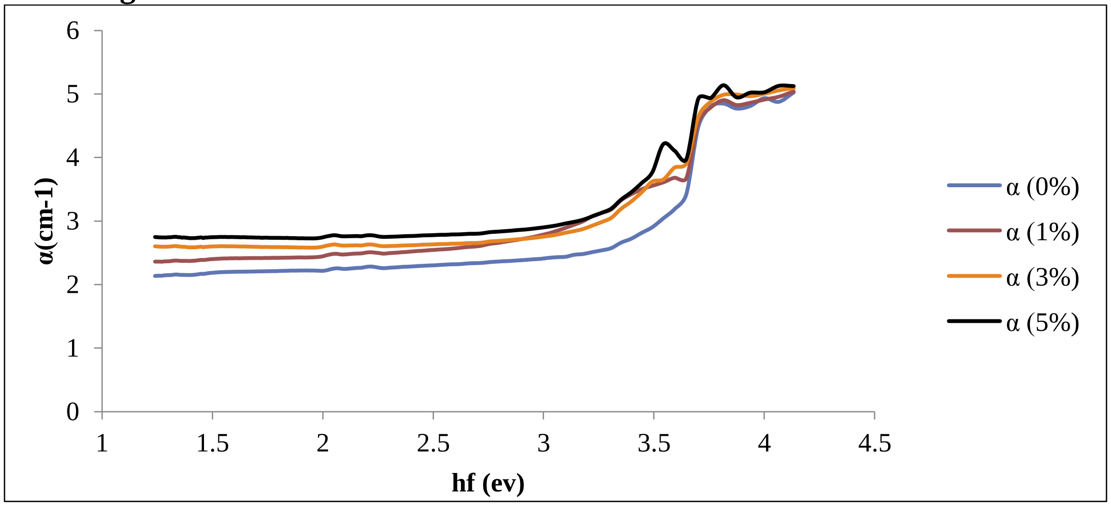

Figure 6. Absorption coefficient versus wavelength for (pmma/glass) composite at different wt%.

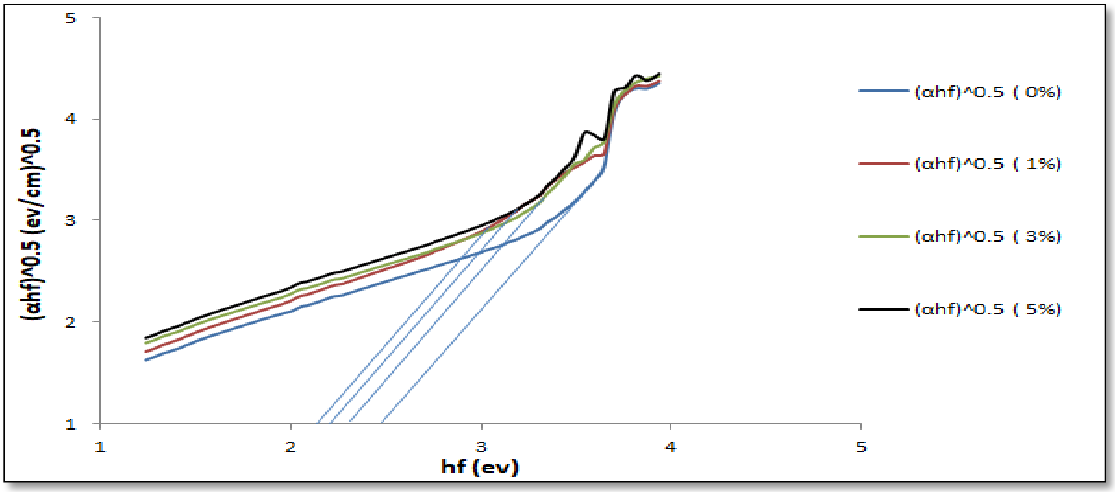

Figure 7. Energy gap versus wavelength for (pmma/glass) composite at different wt%.

Figure 8 shows the refractive index versus wavelength for composites. It clearly shows that the refractive index increases at weight ratio 1% compared to what it was in pure pmma, then becomes almost constant at ratios 3% and 5%. The results showed that the reinforced material slightly affected the transparency of the polymer in exchange for a decrease in the energy gap from 2.5 to 2.1ev.

The mechanical properties results of the glass reinforced composites and pmma which measured experimentally show that the presence of the reinforcing glass powder strengthens the composite. It is observed through **Figures 9, 10** decreasing of deflection versus load and thus increasing bending strength of composite due to the reinforcing glass. Also **Figure 10** shows increasing the elasticity modules as a function of weight fraction of glass after calculating slope of a load to deflection according to **Equation (7).**

Figure 11 shows improvement in impact strength and compression with increasing weight ratio of glass in pmma polymer.

A hardness and tensile test was conducted to evaluate the effect of adding ordinary glass on the surface strength of composite. The results show through **Figure 12** that increasing glass to polymer significantly improved the hardness and tensile strength. Incorporation of glass powder in polymer can enhance interphase and bonding between two systems.

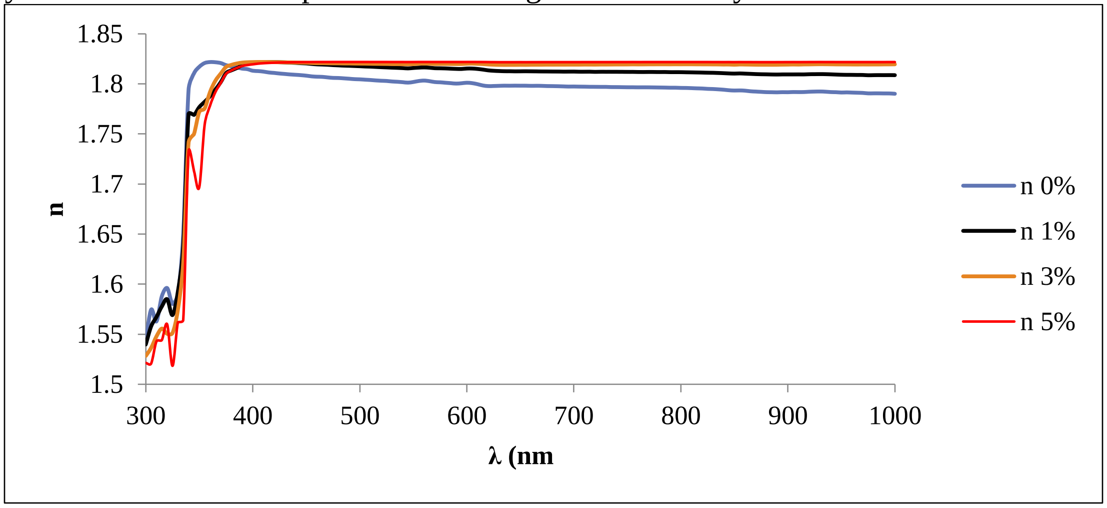

Figure 8. Refractive index versus wavelength for (pmma/glass) composite at different wt%.

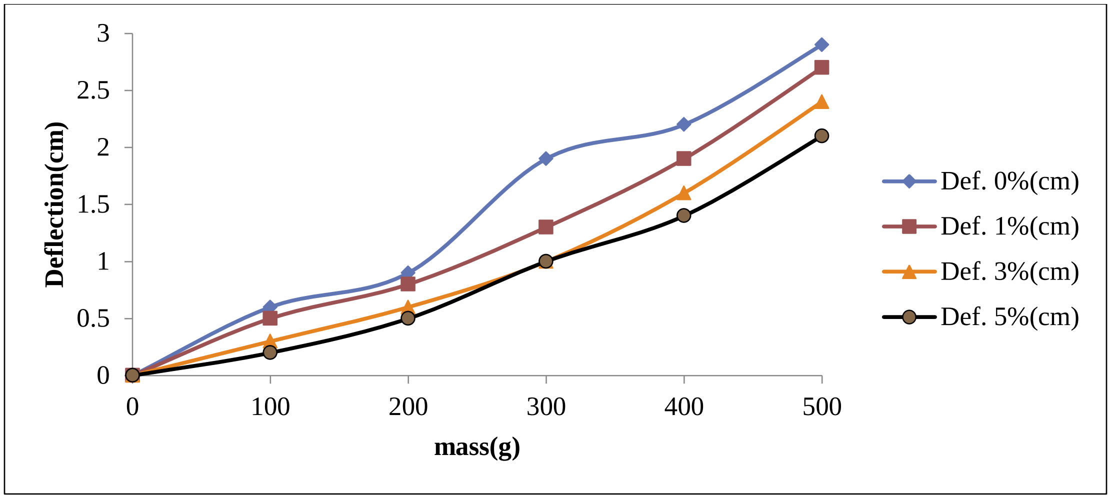

Figure 9. Deflection versus mass for (pmma/glass) composite at different wt%.

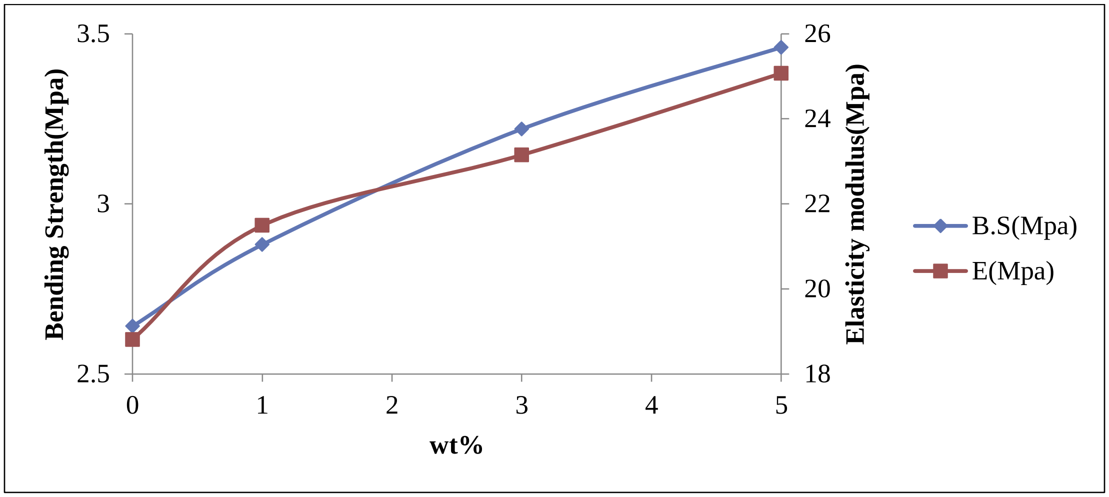

Figure 10. bending and elasticity modulus for pmma/glass composite at different wt%.

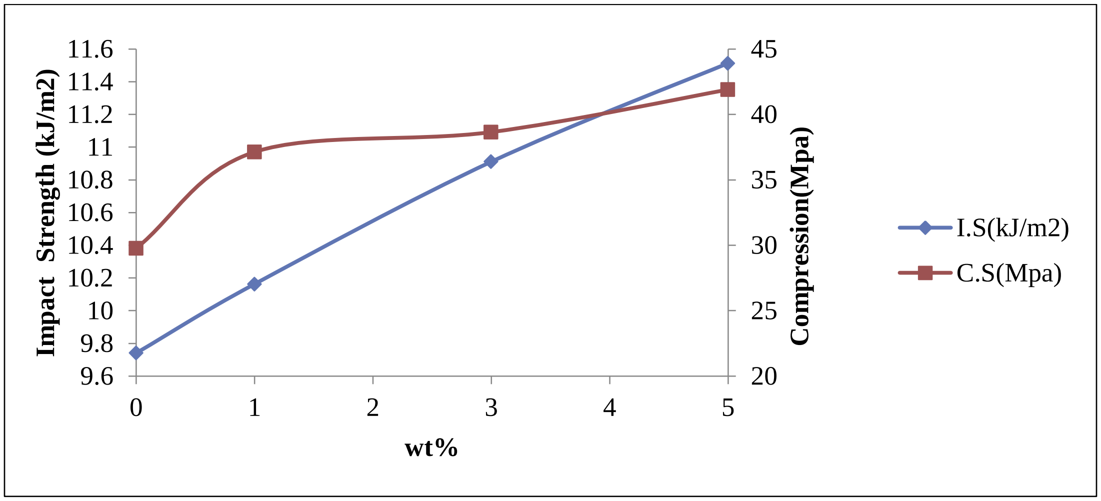

Figure 11. Impact and compression for (pmma/glass) composite at different wt%.

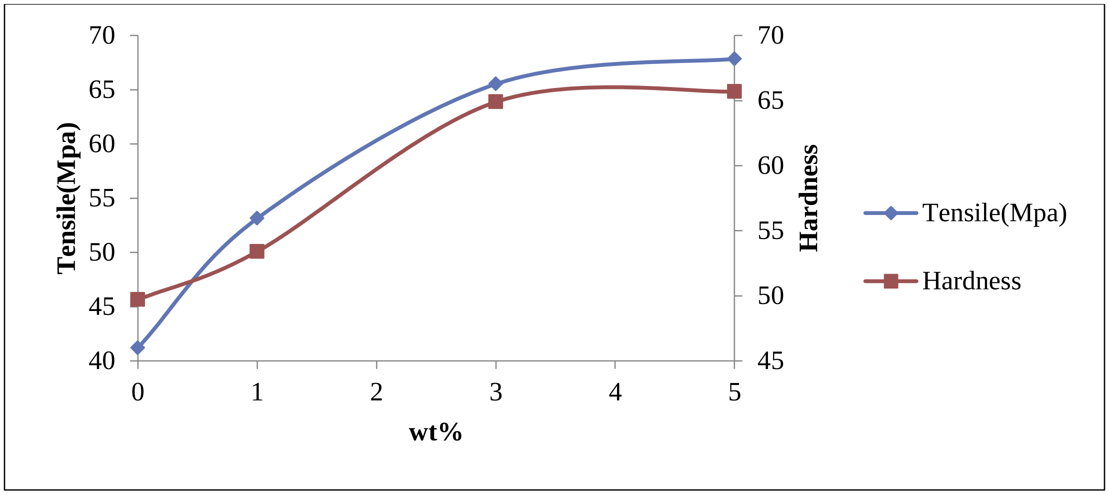

Figure 12. Tensile and hardness for pmma/glass composite at different wt%.

Fracture toughness is important test because it provides information on crack formation and the ability of a material to resist crack propagation. The fracture toughness tests were calculated using **Equation (10)** that showed increasing in its values of prepared composites due to adding of glass in pmma as shown in **Figure 13**.

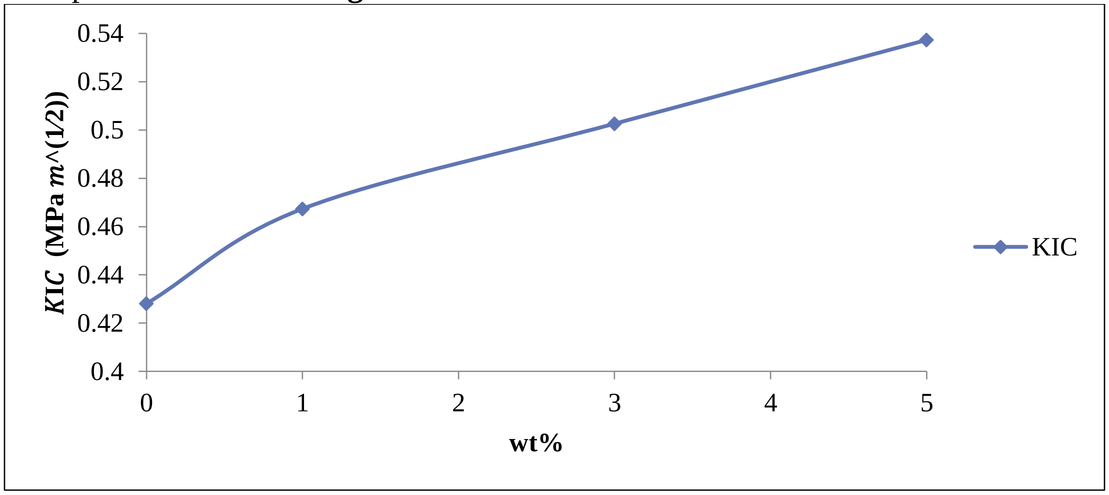

Figure 13. Fracture toughness for (pmma/glass) composite at different wt%.

4. Discussion

The mechanical ground has achieved to obtain glass powder with a particle size of 231 nm according to particle size analyzer analysis .glass powder and pmma are a non-crystalline where it exhibits broad amorphous hump which is match with ASTM[24]. The absorbance decreases with increasing wavelength in the ultraviolet region. It then stabilizes almost in the visible and near-infrared regions[25]. Conversely, absorption increases slightly with increasing weight fraction of the glass powder because it absorbs less incident light than other materials. It's showed increasing the absorption coefficient with the increase of glass concentrations[26]. Its values are less than 10^4 cm^{-1} so, the samples have indirect transitions as is evident in previous studies[4]. The energy gap decreases with the increase of the glass concentrations attributed to the increase of the localized level in energy band gap[27]. The mechanical properties such such as hardness, impact, bending, modules of elasticity, tensile, fracture toughness and compression in improvement .It can be explained by the fact that the glass particles distributed within the polymer matrix help to absorb and disperse the impact energy throughout the internal structure, withstand vertical loads and delaying the onset of cracking. Incorporation of glass powder in polymer can enhance interphase and bonding between two systems[28].

5. Conclusion

A particle distribution, agglomeration in the matrix, the type of solvent used, the type and size of the particles, the concentration of the added particles, preparation method and reactions between the particles and polymer are factors play an important role in determining the mechanical and other properties of polymer-based composites. The results in this study showed that adding different percentages of ordinary glass (0%, 1%, 3%, and 5%) to pmma polymer improve the mechanical properties such as hardness, impact, bending, modules of elasticity, tensile, fracture toughness and compression of the composite. They were increasing statistically significant. In addition, the reinforced material slightly affected the transparency of the polymer in exchange for a decrease in the energy gap from 2.5 to 2.1 ev. This improvement is due to adding glass powder waste that grounded by simple and cheap process in addition to cleaning environment from glass waste. So preparation of composite pmma/glass by casting method represents successful alternative method. It don't use expensive or complex materials such as fiber-glass or chemically synthesized substances, etc.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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