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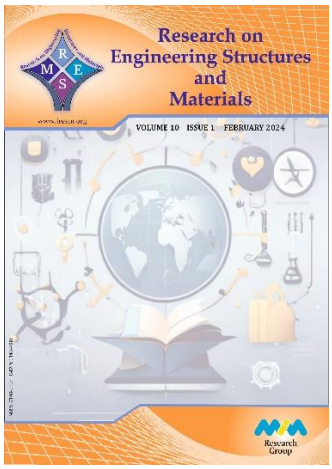

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Mohamed Ismail, Mohamed Bayoumi, Sayed Akl

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Research Article

Influence of incorporation carbon nanoparticles CNP on the mechanical properties of polystyrene composite

Mohamed Ismail[1, a], Mohamed Bayoumi[2, b], Sayed Akl[1, c]

[1]*Department of Mechanical Engineering, The British University in Egypt, Egypt*
[2]*Department of Mechanical Engineering, Al-Azhar University, Cairo, Egypt*

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Abstract

Polymer nanocomposites have recently received a lot of attention as they are anticipated to be used in a variety of applications. In this study, the effect of adding carbon nanoparticles to polystyrene and using Injection molding technique are investigated. The impact of adding different weight fractions of carbon nanoparticles (CNP) on tensile properties, impact strength and hardness performance of polystyrene polymer were measured. Tensile and impact strength increased with the addition of nanoparticles (CNP). The polymer composites with 0.025 wt.% CNP demonstrated maximum tensile and impact strength compared to pure polystyrene. Also, the maximum value of hardness appeared at 0.1 wt.% of CNP finally cracks are found in higher CNP concentration compared with lower percentages of CNP.

1. Introduction

Nanotechnology has attracted more attention throughout the last years. Nanoparticles are a key component of nanotechnology. Nanoparticles could be with a diameter ranging from one to one hundred nanometers and could be made of carbon, metal, metal oxides, or organic substances [1]. At the nanoscale, the particles have different mechanical and chemical properties than their larger counterparts. This is due to a larger surface area relative to volume, improved chemical compound stability, increased mechanical strength, and other factors [2-5].

Due to these characteristics, nanoparticles are now used in a wide range of applications. The traditional fillers for polymer composites are either reinforcement or particles. Popular reinforcements for fiber-reinforced composites include glass fiber, metal fiber, and carbon fiber. Particle-reinforced composites frequently use reinforcement materials including metal, silicon, and graphite. [6].

Metal Matrix Composites (MMCs) are materials made by adding (ceramic or metallic) particles, fibers, whiskers, or even sheet metal to the base material to produce an alloy or metal matrix. MMCs are exceptional materials that perform much better than their homogeneous parent substances in a variety of ways, including strength, wear resistance, corrosion resistance, and other characteristics. [7]. The success of MMCs in industry depends heavily on their ability to be produced into components and structures. They can only be connected in this way if they use welding and associated techniques. The presence

*Corresponding author: mohamed.elzareef@bue.edu.eg
[a] orcid.org/0009-0001-0526-8263; [b] orcid.org/0009-0007-3656-3154; [c] orcid.org/0009-0006-1967-9318
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of strengthening particles, which should have been advantageous to the MMCs, instead makes it more difficult for them to weld. [8] Many researchers investigated the mechanical characteristics of nanocomposites strengthened with just one type of reinforcement [9:13]. Others, on the other hand, investigated the effect of mixing two distinct types of reinforcement into a matrix of polymers with fiber reinforcement. Ayatollah et al. [14] investigated the effects of MWCNT's and nano-silica on the tensile performance of epoxy reinforced with woven carbon fabric-strengthened composites.

The addition of 0.5 wt.% of both nanoparticles greatly enhanced tensile performance; nevertheless, adding 0.9 wt.% results in a decline in the general pattern of tensile characteristics. Jun Rong Li [15] The development of crystalline polymer-based composites of polystyrene reinforced with CNP as prospective gas-sensing materials has been studied. Through polymerization filling, which is in-situ polymerization of styrene in the presence of CNP, the composites were given a low percolation threshold. The findings of the experiments demonstrated the composites' selective sensitivity, as seen by their great electrical reactivity to the vapors of nonpolar and low polar solvents and their weak reactivity to the vapors of high polar solvents. In addition to conductivity, the fillers' and matrix's absorption properties significantly affect the composites' sensitivity to gases. Also S. Hernández-López [16] investigated Experimental investigation of electrical resistivity variations in polystyrene and CNP-based mixes 22 wt.% CNP composite sheets were subjected to thermal heating-cooling cycles from room temperature to 100°C, only slightly above the Tg of the composite, at thicknesses of 0.030 mm, 2mm, and 10mm. For each cycle change in electrical resistivity, a hysteresis loop based on sample thickness forms. Marius et al. [17] examined how the mechanical characteristics of composite materials were affected using natural resources (Dammar gum) and wastepaper. The outcomes showed that the matrix's characteristics had changed significantly.

In the present study the effect of using carbon nanoparticles (CNP) as a reinforcement material is investigated to enhance the mechanical properties of the polystyrene used in injection molding industry.

2. Experimental Works

2.1 Materials

The polymer used in the present study is Polystyrene (PS) and carbon nanoparticles (CNP) were used as reinforcement was supplied from Sigma-Aldrich® company, the properties of polymer and reinforcement material according to the manufacturers are shown in [18-19].

2.2 Sample Preparation

Polystyrene polymer granules and carbon nanoparticles were prepared according to the required amount of reinforcement particles inside the matrix.

Table 2. Samples code with CNP weight percent

#	Sample code	Wt. % for CNP
1	PS 0000	0.000
2	PS 0.025	0.025
3	PS 0.050	0.050
4	PS 0.100	0.100

Then the mixture was directly injected using an automatic Vertical Small Plastic Injection Molding Machine "DAHOMETER Bench Model [20]" Figure 1 to start the forming process for the polymer composite test specimens Figure 2 and 3, each sample has a given code as shown in Table 2.

Fig. 1. Automatic vertical small plastic injection molding machine "DAHOMETER bench model" [20]

Fig. 2. Tensile specimen mold

Fig. 3. Impact specimen mold

2.3 Mechanical Properties

The impact of CNP weight percent on mechanical characteristics was assessed. Using a Computer Control Universal Testing machine/universal testing machine UTES-20 (FIE, India), tension tests were performed in accordance with ASTM D3039. Using an injection mold with an interior cavity dimension as illustrated in figure 4, samples were created as a single homogenous material.

An automated computer data collecting system generated the stress-strain curves. At room temperature, all experiments were conducted. For each sample, five specimens were tested under tension, and the average value was computed. This value was then chosen to represent the test result.

The impact strength and absorbed energy were measured by the Charpy test according to ASTM 256. Impact tests were carried out on impact machine type AVERY Denison, England. Samples were formed as a single homogeneous material by using injection mold with internal cavity with a dimension equal to 55 mm as a length, and 10 x10 mm as a cross section and V-notch angle equal 45o.The energy absorbed per unit area of the fractured cross-section is the measure of the impact strength of a specimen.

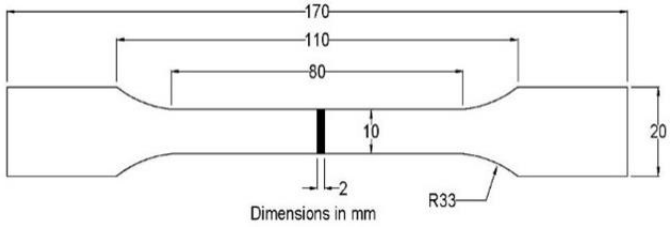


Fig. 4.Dimensions and geometry of the tensile test

Microstructure examination was performed on some polymer composites using scanning electron microscope (SEM) to study the interfacial junction between matrix and reinforcements and the fracture surface of the nanocomposites.

3. Results and Discussion

3.1 Tensile Tests

Figure 5 shows stress-strain curves at different wt.% contents of CNP. The figure shows the influence of nanoparticle reinforcements on the tensile strength of polymer matrix. The additives of CNP 0.025 wt. % content shows maximum ultimate tensile strength and maximum elongation. The figure shows also that all specimens failed quickly after the tensile load reached their maximum value. The ultimate tensile strength values of pure polystyrene and reinforced composite with carbon nanoparticles are shown in Figure 6. Tensile strength was significantly increased with the decrease in the wt.% content of CNP and the ideal wt.% content of CNP in PS is 0.025. This is due to the low number of nanoparticles which leads to reducing agglomeration between CNP. However, increasing the amount of CNP concentration to 0.1% reduces this gain due to the large agglomeration of CNP and the non-uniformed distribution of the reinforcement CNP's.

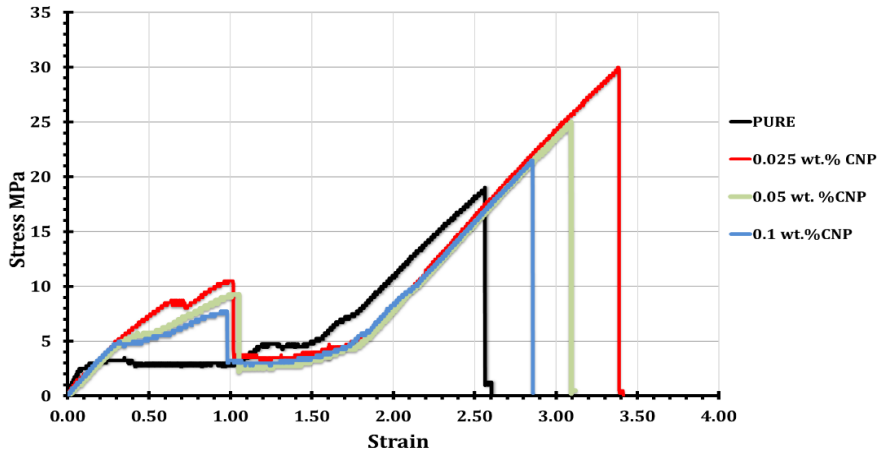


Fig. 5. Stress strain curves of polymer composites at different contents of CNP

SEM images are obtained to examine the failure reaction of the tensile samples and to verify the dispersion of the particles in the matrix. The fracture surfaces' SEM pictures at various CNP concentrations are shown in Figure 7. Images make it quite evident that CNP was evenly distributed throughout the polystyrene.

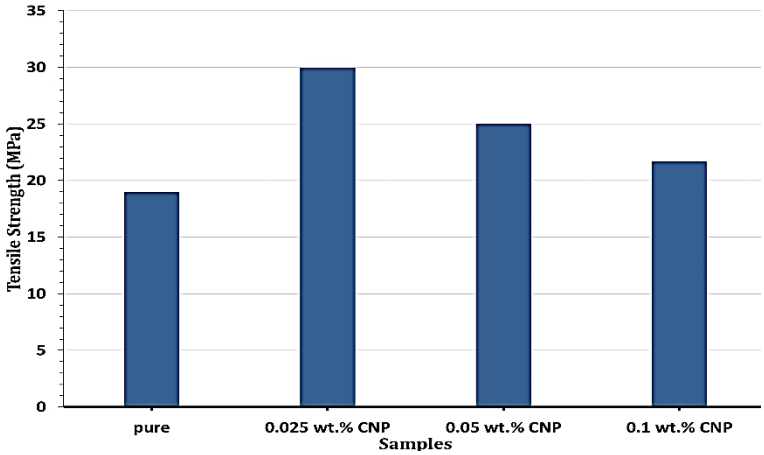
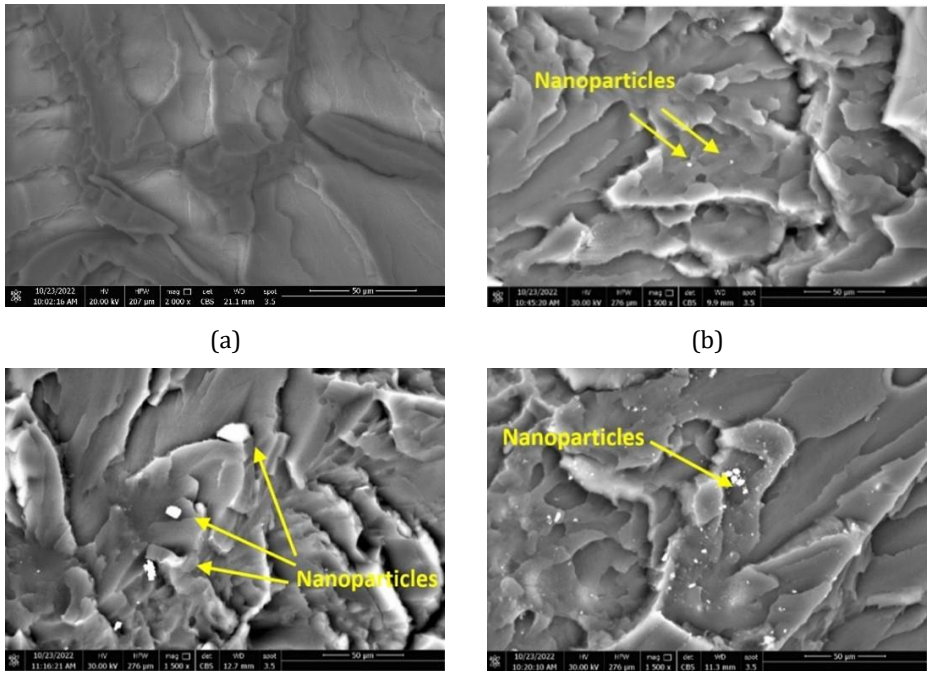


Fig. 6. Obtained tensile strength for Produced specimen according to CNP wt. %

The picture also demonstrates effective matrix and reinforcement mixing, showing the effectiveness of the injection molding technique in reducing porosity development and improving nanoparticle dispersion. However, it is also clear from the microphotographs that the 0.025 weight percent of CNP (figure 7.b) appears to be distributed uniformly with relatively small amount of agglomeration. This improvement could be because of the low CNP concentration, which decreased the likelihood of CNP agglomeration.



(a) (b)

(c) (d)

Fig. 7. Scanning electron photographs of tensile fracture surfaces a) pure polystyrene, b) 0.025 wt. 0 %, c) 0.05 wt. % and d) 0.1 wt.%

3.2 Crack Formation

The higher addition of CNP weight percentage increases the amount of microporosities connected to the agglomerations that are generated, and these microscopic pores might create channels at the interface that serve as debonding starting points [21]. The matrix's particle bonds were weakened as a result of the CNP, leading to a significant degree of propagating transversal cracking. Figures 8 and 9 demonstrate how the high concentration of the crack develops surrounding agglomerated CNP at 0.1 weight percent.

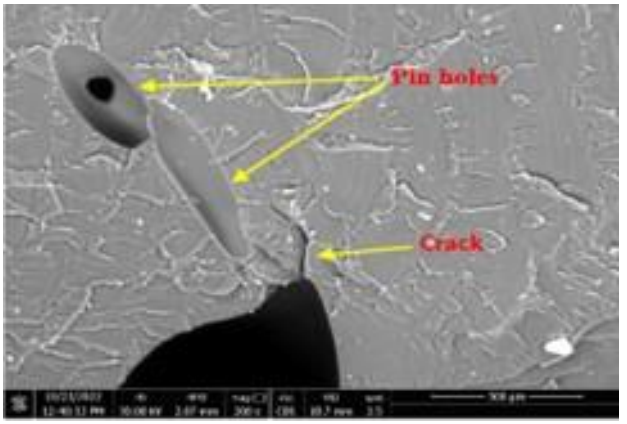


Fig. 8. Pin hole crack propagation on polystyrene reinforced by 0.1 wt.% CNP

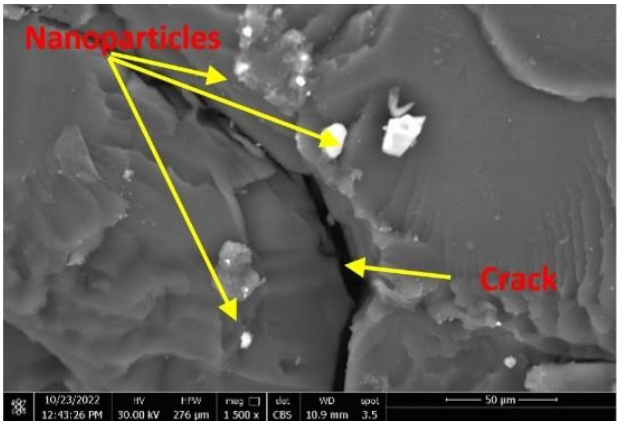
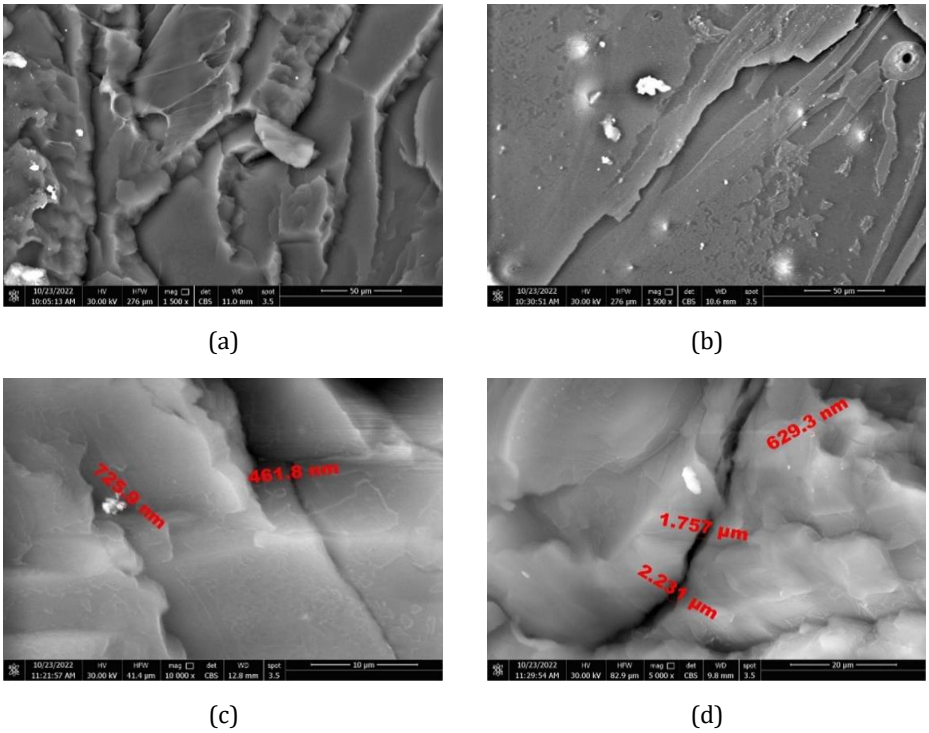


Fig. 9. Crack propagation on polystyrene reinforced by 0.1 wt.% CNP

Figure 10 shows the different weight percentage of CNP reinforcing polystyrene and crack formation and as mentioned before the greater the weight percentage of CNP, the greater cracks formation found on reinforced samples.



(a) (b)

(c) (d)

Fig. 10. SEM photomicrograph of crack formation on a) pure polystyrene, b) 0.025 wt. 0 %, c) 0.05 wt. % and d) 0.1 wt.%.

3.3 Impact Test

The impact strength behavior of CNP's composite is shown in Figure 11. When the weight percentage of the CNP grows up to (0.025%wt), the impact energy increases, then decreases as more carbon nanoparticles are added.

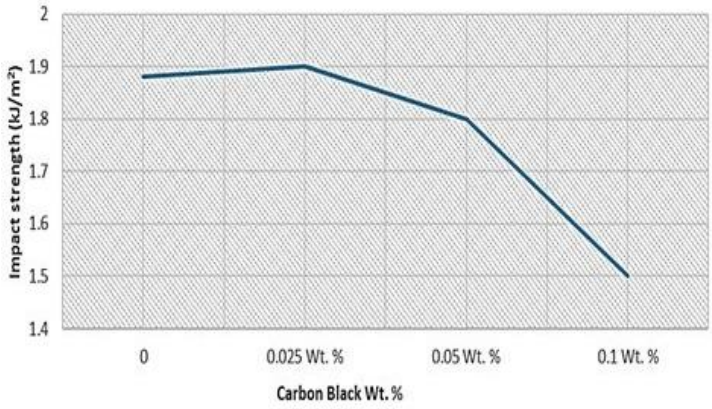


Fig. 11. Impact strength due to CNP wt. % content

The matrix may be deformed more easily because of the little particles that are dispersed throughout it. As a result, when a well-dispersed nanoparticle composite breaks, more

force is required to start a microcrack in the nanocomposite, and most of the impact energy is used by the plastic deformation that is easily seen surrounding the nanoparticles.

Figure 12 depicts a SEM photomicrograph of a fracture that formed following an impact test at various CNP weight percentages. It demonstrates the improved CNP dispersion, which leads to less agglomeration and higher impact strength in the nanocomposites. Agglomerates can occur when the amount of carbon nanoparticles in a material surpasses 0.025 weight percent. These agglomerates can operate as stress concentrations and as a microcrack activator. Because of this, a larger agglomeration weakens the composite's tensile strength and the impact strength of its nanocomposites. [22-23].

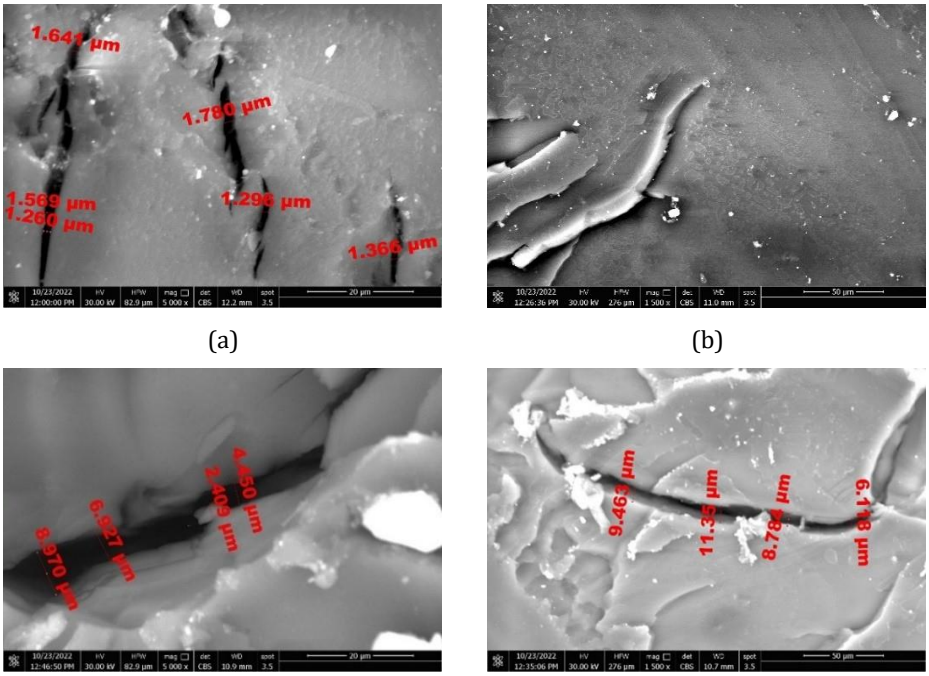


Fig. 12. SEM photomicrograph of crack formation during impact test on a) pure polystyrene, b) 0.025 wt. 0 %, c) .05 wt. % and d) 0.1 wt.%

3.4 Hardness Measurement

Hardness is measured on the specimen's flat surface. The hardness values at different wt.% of CNP were plotted Figure 13, the point is average of three readings for all samples. It is clear from the figure that the hardness values is increased with the increasing in the wt.% content of CNP. The maximum value of hardness appeared at 0.1 wt.% of CNP. This is due to the hardness value is dependent on the amount of CNP and resistance to plastic deformation, and excellent bonding between polymer matrix and nanoparticles reinforcement.

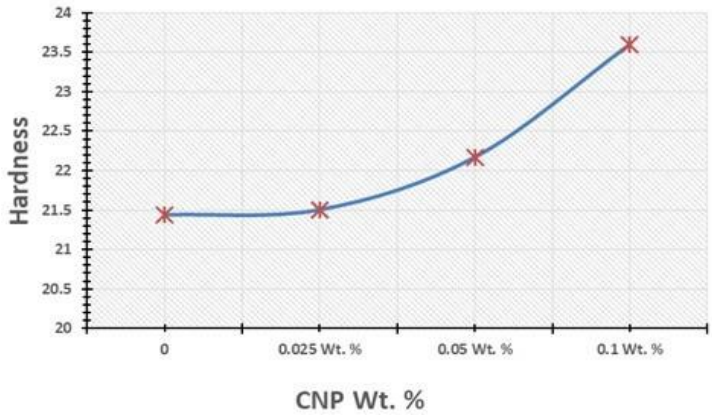


Fig. 13. Hardness values versus different wt.% of CNP

4. Conclusions

Through the investigation of the reinforcement of polystyrene by adding different weight percentage of CNP. Analysis of their mechanical properties and microstructure has led to the following conclusions.

- The stress–strain curves were recorded automatically by a computer data acquisition system. All tests were performed at room temperature. Tensile strength was significantly increased with the decrease in the wt.% content of CNP and the ideal wt.% content of CNP in PS is 0.025. This is due to the low number of nanoparticles which leads to reducing agglomeration between CNP, also good distribution among the polymer particles. However, increasing the amount of CNP concentration to 0.1% reduces this gain due to the large agglomeration of CNP and the non-uniformed distribution of the reinforcement CNP's.
- The microstructure study shows Scanning electron photomicrographs are taken to confirm the dispersion of the particles in the matrix and to study the failure response of the tensile sample's good mixture between matrix and reinforcement, which confirms the success of the injection mold technique in preventing porosity formation and enhances the distribution of nanoparticles. On the other hand, it is also evident from the microphotographs that the distribution of the 0.025 wt.% of CNP appears to be homogeneous with almost no agglomeration. This improvement could be due to the low CNP content, which reduced the possibility of agglomeration occurring between the CNP.
- cracks are found in higher CNP concentration compared with lower percentages of CNP. CNP weakened the bonding between particles in the matrix, resulting in a substantial amount of propagating transversal cracking at 0.1 wt.% CNP that the high concentration of the crack formed around agglomerated CNP.
- Also impact strength behavior of CNP's composite. It is obvious that the increase of the impact energy increases with the CNP's increased weight percentage up to (0.025%wt), then reduced with further addition of carbon nanoparticles. The presence of tiny particles scattered throughout the matrix facilitates plastic deformation.
- The maximum value of hardness appeared at 0.1 wt.% of CNP. This is due to the hardness value is dependent on the amount of CNP and resistance to plastic deformation, and excellent bonding between polymer matrix and nanoparticles reinforcement.

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