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Mechanical Characteristics of Epoxy Nanocomposites Reinforced with ALUMINA Nanoparticles and Multi-wall Carbon Nanotubes

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Abstract. : In the present investigation, the effect of addition of multi-wall carbon nanotubes (MWCNTs) and Al_2O_3 nanoparticles on the mechanical properties of epoxy was investigated. The results revealed that increasing the volume fraction of MWCNTs and Al_2O_3nanoparticles reduce the tensile strength and impact resistance, however, they increase microhardness of the nanocomposites. The pure epoxy exhibited higher tensile strength and impact resistance but lower microhardness when compared with epoxy/MWCNTs and epoxy/Al_2O_3 nanocomposites.

Keywords Nanocomposites, Epoxy, Mechanical Properties, MWCNTs, Alumina.

1. INTRODUCTION

The need for advanced materials with enhanced characteristics to meet new requirements, or to replace current materials, has been progressively increasing. Among the advanced materials, polymer matrix nanocomposites acquire good mechanical properties such strength, stiffness, toughness, and hardness when compared with the properties of metallic materials[1,2].

At Present, polymer nanocomposites are being investigated for use in a wide range of industrial applications, especially in automotive, and aerospace industries [3,4]. Amongst the polymer matrix resins being used in such nanocomposites, epoxy resin is an important polymer matrix with superior chemical resistance, mechanical properties, adhesion properties and thermal stability. The epoxy nanocomposites are widely used in a various of industrial applications, especially for automobile and aircraft components, as well as in electronic components, for instance transistors and supercapacitors [5,6].

However, the epoxy resin-based nanocomposites generally have excellent properties, they also are brittle and have low strength when compared with other resins nanocomposites. To solve these problems, it has become a common practice to add fillers to enhance the properties of the epoxy nanocomposites. Several nanofillers have been used as additives, such as nanoclay, Al_2O_3, graphene, MWCNTs and SiO_2, to epoxy nanocomposites to achieve high performance [7].

In the present investigation, the effect of the dispersion of MWCNTs and Al_2O_3 nanoparticles on the microhardness, tensile strength and impact resistance of epoxy was studied. These nanofillers were dispersed with several volume fractions up to 1.5 vol.-% using mechanical stirring technique.

2.EXPERIMENTAL PROCEDURES

In the present investigation, epoxy resin was used as a matrix material. The used epoxy resin has a commercial name of KEMAPOXY 150 and manufactured by Chemicals for Modern Buildings (CMB) Company, Egypt. Two types nanofillers were used as reinforcing agents, namely, aluminum oxide (Al_2O_3) nanoparticles and multi-walled carbon nanotubes (MWCNTs). The MWCNTs have outer diameters less than80 nm. The Al_2O_3 nanoparticulates have an diameters less than 50 nm. Nanocomposites having up to 1.5% volume fraction of the aforementioned nanofillers were fabricated.

The epoxy nanocomposites were fabricated using mechanical stirring method as follows: first, the epoxy resin and the desired volume fraction of the nanofillers were mixed in plastic mould using mechanical stirrerat 200rev/min for 20 minutes in ambient temperature. After that, the hardener solution was added to the epoxy/nanofiller mixture by ratio 1:2 by volume and then again stirred mechanically for 3 minutes. The epoxy/nanofiller slurry was poured in silicon dies have different shapes according to the required tests. Finally, the mixture was allowed to fully harden at room temperature. Nanocomposites were prepared by dispersing 0.25 vol.-%, 0.5 vol.-%, 0.75 vol.-%, 1 vol.-%, 1.25 vol.-% and 1.5 vol.-% of MWCNTs and Al_2O_3 nanoparticles.

Tensile tests of the epoxy/MWCNTs and epoxy/Al_2O_3nanocomposites were performed according to ASTM D 638-03 standard (Standard Test Method for Tensile Properties of Plastics) [8]. The tensile tests were conducted using a universal testing machineat constant crosshead speed of 1 mm/min. The tensile specimen is shown in Fig. 1. The microhardness of the nanocomposites was measured using Vickers indenter at a load of 200 g for 10 seconds. Ten readings were taken for each sample and the average value was determined.

Charpy Impact testing was performed using impact tester according to DIN-ISO179 at room temperature. Figure 2 shows a schematic illustration of a typical notched impact specimen. From each material, five impact specimens were tested, and the average value of the impact energy is calculated.

Scanning electron microscope (SEM) was used to investigate the fracture surfaces of the failed tensile and impact specimens.

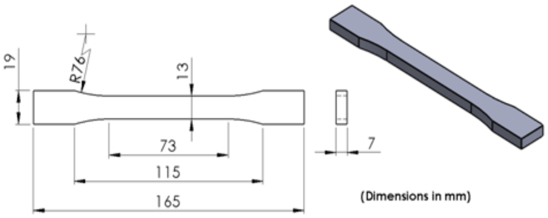

Fig 1. A schematic illustration of the tensile specimen. (Dimensions are in mm).

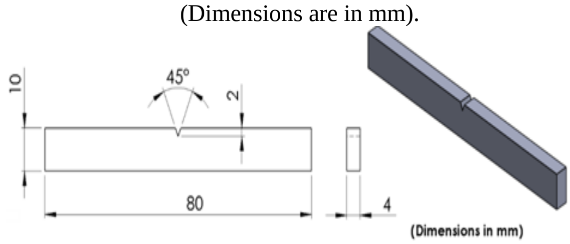

Fig 2. A schematic illustration of the impact specimen. (Dimensions are in mm).

3.RESULTS AND DISCUSSION

3.1. Tensile Properties

Figure 3 shows the variation of the tensile strength with the volume fraction of MWCNTs and Al_2O_3 nanofillers. The results revealed that both epoxy/MWCNTs and epoxy/Al_2O_3 nanocomposites showed tensile strength lower than the neat epoxy. The epoxy/MWCNTs nanocomposites exhibited slightly higher tensile strength when compared with the epoxy/Al_2O_3 nanocomposites. Increasing the volume fraction of MWCNTs and/or Al_2O_3 nanofillers reduce(s) the tensile strength of the nanocomposites. The reduction of the tensile strength with increasing the volume fraction of the MWCNTs and Al_2O_3 nanofillers may attribute to the increase of the discontinuities in the epoxy matrix and the voids formation.

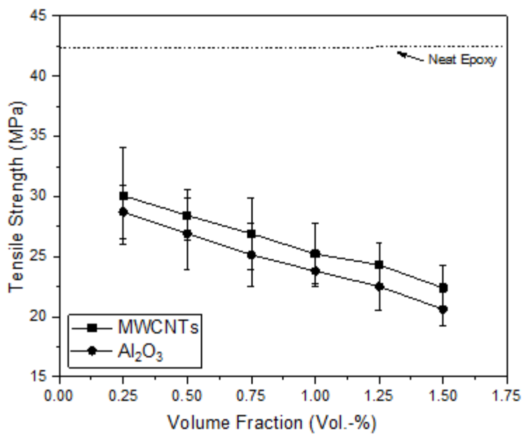

Fig 3. The variation of the tensile strength with the volume fraction of MWCNTs and Al_2O_3 nanofillers.

The neat epoxy and the epoxy/MWCNTs and epoxy/Al_2O_3 nanocomposites tensile specimens were broke immediately after the stress reached the maximum point. No yielding was observed for any of the tensile specimens. These results may be attributed to the brittleness of epoxy resin. Figure 4 shows SEM micrographs of the tensile fracture surfaces of 1 vol.-% epoxy/Al_2O_3 andepoxy/ MWCNTs nanocomposites. Typical brittle fracture was observed in both nanocomposites. It is possible to see the MWCNTs and Al_2O_3 nanofillers (indicted by the arrows) and its crack deflection. It can be also seen that the Al_2O_3 and MWCNTS nanofillers may stop and deflected the matrix crack.

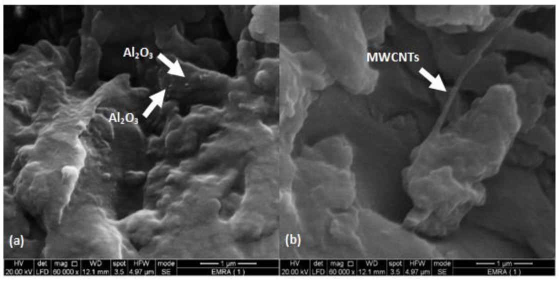

Fig 4. SEM micrograph of the tensile fracture surfaces of (a) 1 vol.-% epoxy/Al_2O_3 and (b) 1 vol.-% epoxy/ MWCNTs nanocomposites.

3.2. Microhardness

Figure 5 shows the variation of the microhardness with the volume fraction of MWCNTs and Al_2O_3 nanofillers. The results revealed that the epoxy/MWCNTs and epoxy/Al_2O_3 nanocomposites exhibited higher hardness when compared with the neat epoxy. The neat epoxy exhibited average microhardness of 15.4 VHN. While the minimum average microhardness was about 16.1 VHN for epoxy/0.25 Vol.-% MWCNTs nanocomposites.

Increasing the MWCNTs and/or the Al_2O_3 nanofillers volume fraction increase(s) the microhardness of the nanocomposites. For example, for nanocomposites containing 0.50 vol.-% of MWCNTs and Al_2O_3 nanofiller, the microhardness values were 16.9 VHN and 17.2 VHN, respectively. The epoxy/Al_2O_3 nanocomposites exhibited higher microhardness when compared with the epoxy/MWCNTs nanocomposites. This may attribute to the higher hardness of the Al_2O_3 nanoparticles when compared with the MWCNTs. The maximum microhardness values for the epoxy/MWCNTs and epoxy/Al_2O_3 nanocomposites, observed for nanocomposites containing 1.5 vol.-%, were about 20.1 and 20.5 VHN, respectively.

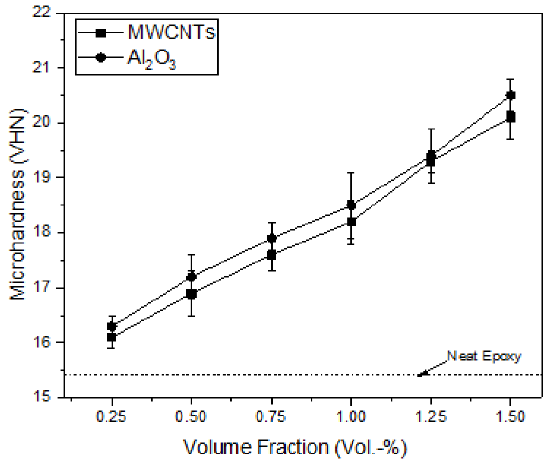

Fig 5. The variation of the microhardness with the volume fraction of MWCNTs and Al_2O_3 nanofillers.

3.3. Impact Resistance

Figure 6 shows the variation of the average impact energy with the volume fraction of MWCNTs and Al_2O_3 nanofillers. The results revealed that the epoxy/MWCNTs and epoxy/Al_2O_3 nanocomposites exhibited lower impact resistance than the neat epoxy matrix. For example, the neat epoxy showed average impact resistance of 58 J, while the maximum average impact resistances for epoxy/MWCNTs and epoxy/Al_2O_3 nanocomposites containing 0.25 vol.-% nanofiller are 55 and 57 J, respectively. The epoxy/Al_2O_3 nanocomposites exhibited slightly higher impact resistance when compared with the epoxy/MWCNTs nanocomposites. For example, at constant volume fraction of 0.5 vol.-%, the epoxy/$Al_2O_3$and epoxy/MWCNTs nanocomposites exhibited impact energies of 56.9 and 53 kJ, respectively.

Figure 7 shows SEM micrographs of the fracture surfaces of impact specimens for epoxy/Al_2O_3 and epoxy/MWCNTs nanocomposites containing 0.5 vol.-% of the nanofillers. It is clear that, groves, crack and pedals-like structure appeared on fracture surfaces of both epoxy/MWCNTs and epoxy/Al_2O_3 nanocomposites. Furthermore, the facture surface of the epoxy/Al_2O_3 nanocomposite specimens exhibited larger smoother fractured surface area when compared with epoxy/MWCNTs nanocomposites. This may attribute to the weak interaction bonding between the MWCNTs and epoxy matrix.

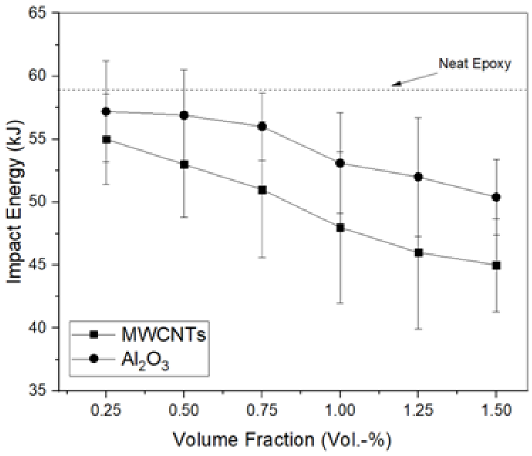

Fig 6. The variation of the impact energy with the volume fraction of MWCNTs and Al_2O_3 nanofillers.

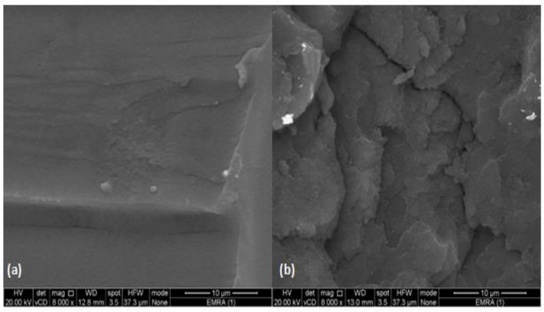

Fig 7. SEM micrographs of the fracture surfaces of impact specimens for (a) epoxy/0.5 vol.-% Al_2O_3 and (b) epoxy/0.5 vol.-% MWCNTs nanocomposites.

4. CONCLUSIONS

Based on the aforementioned results, the following conclusions can bedrawn: -

1. The neat epoxy showed higher tensile strength and impact resistance but lower microhardness when compared with epoxy/MWCNTs and epoxy/Al_2O_3 nanocomposites containing up to 1.5 vol.-% of the nanofillers.
2. The epoxy/MWCNTs nanocomposites exhibited slightly higher tensile strength when compared with the epoxy/Al_2O_3 nanocomposites. In contrast, epoxy/Al_2O_3 nanocomposites showed higher microhardness than the epoxy/MWCNTs nanocomposites.
3. Increasing the volume fraction of MWCNTs and Al_2O_3 nanofillers reduce the tensile strength and impact resistance but increases microhardness of the nanocomposites.

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