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INVESTIGATIONS ON THE MECHANICAL PROPERTIES OF THE NANO SiO_2 EPOXY NANOCOMPOSITE

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Abstract:
In this study, dispersion of nano SiO_2 and its effect on mechanical properties were studied by preparing epoxy nanocomposites. Ultrasonic and mechanical mixes were used to disperse the SiO_2 nanoparticles in to the epoxy resin. Having been produced with five different weight percentage ratios of SiO_2, nanocomposites fracture surfaces were characterized by Scanning Electron Microscopy, optical microscope on tensile tests and bending tests. The results of experimental tests showed that the optimum values of strength for both test were acquired for (2 wt. %) of nano SiO_2 epoxy nanocomposites. Scanning Electron Microscopy and optical microscopy analysis techniques were used to understand the toughening mechanisms of the nanocomposites.

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1. INTRODUCTION

Epoxy resins commonly used in adhesives, coatings, electronic, medical devices, optical components and structural composites due to their superior properties and low cost [1,2]. Additionally, in order to enhance mechanical performance of epoxy resin, there are several toughening procedures such as adding combination of rubber particles, shell particles, inorganic particles, plastic particles, nano particles etc. in to epoxy resin [2-4]. Aims of these strategies are intended to improve the performance of epoxy structure. Besides, of all combinations, adding nanoparticle has more serious effect on composite material. There are many studies about this subject in literature. A study was performed that investigate the influence of Carbon Nanotube (CNT) on the mechanical properties of epoxy matrix composites. As a result, having been produced nanocomposites behaved with more strength and stiffness [5]. In another study, it was found that adding nanoparticle increased the scratch resistance [6]. In addition to mechanical performance, nanocomposites have been investigated in terms of thermal and electrical properties [7]. It has also been observed that the nanoclay particles have effect on fracture behaviour in nanocomposites [8]. In the literature, Boron nitride CNT [9], nano clay [10], silica [11], graphene [12] nanoparticles are widely used to improve material properties.

2. MATERIAL AND METHODS

2.1 Production of nano SiO_2 epoxy composites

The nanocomposites were produced by adding different weight percentages of nano SiO_2 in to epoxy matrix which varies from 0–5 wt. %. Epoxy and powder nano SiO_2 (seen in Fig.1) were stirred at approximately 30 min with an ultrasonicator. After dispersing process curing agent was added in to epoxy and the mixture was degassed at 25 °C and 0.6 bar at approximately 20 min. Steel mold was covered with release agent and the mixture was poured into the preheated mold in (Fig.2.a). Curing was performed firstly at 80 °C for approximately 1 h, then at 120 °C at approximately 2 h. After that it was slowly cooled to room temperature in the oven. Then, specimens were removed from steel mold, which made according

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to the methods (ASTM D7264/ D7264M-07) standards for bending test and (ASTM D4762 - 11a) for tensile test in (Fig.2.b). All samples conventionally polished with SiC sandpapers with grit numbers of 800 to minimize effect stress concentration caused by sharp edges.

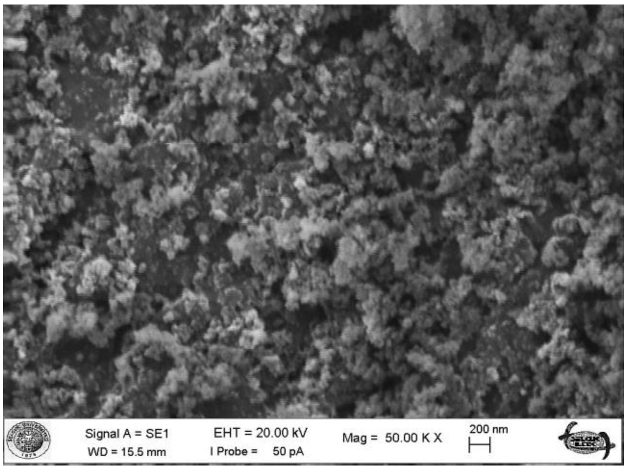

Fig.1. SEM image of powder SiO_2

(a)

(b)

Fig.2. Steel mold (a) and tensile test specimens (b)

2.2 Test procedure

The produced nanocomposite specimens were exposed to tensile and bending tests using Shimadzu test machine which has 1 kN load cell. Tensile tests were carried out with 2 $mm \cdot min^{-1}$ tensile speed and bending tests were performed under 1 $mm \cdot min^{-1}$ in accordance with ASTM standards. The fracture surfaces of samples and toughening mechanisms were observed via Leica DM2700M optical microscope and Zeiss Evo LS10 Scanning Electron Microscope (SEM).

3. RESULTS AND DISCUSSION

This chapter is consisting of three headings. The first title of part is related to tensile stress-strain properties of epoxy and SiO_2 added epoxy samples. Second part is about bending strength results of the samples. The other part consists of microstructure analysis, optical microscope and (Scanning Electron Microscopy) SEM images.

3.1 Tensile properties of nano SiO_2 added nanocomposites

Stress-strain curves of different weight percentage of nano SiO_2 containing epoxy composites are shown in (Fig.3). It can be seen highest enhancement of the tensile strength and strain is achieved with the 3 wt. nano % SiO_2 adding. Also this figure shows that the tensile properties are getting worse in case of over 3 wt. % nano SiO_2 addition. We believe that tensile properties decrease occurs due to the agglomerations of nano SiO_2. Also agglomerations of nano SiO_2 particles make the composite more brittle.

The fracture damage surfaces caused by bending were examined by optical microscope. The optical micrographs of different samples are depicted also in (Fig.3). Nanocomposite has bumpier surface than pure epoxy. Bumpy surface indicates that more energy absorption occurred. It is evidence that by adding 3 wt. % of nano SiO_2 increase plastic deformation capability of epoxy.

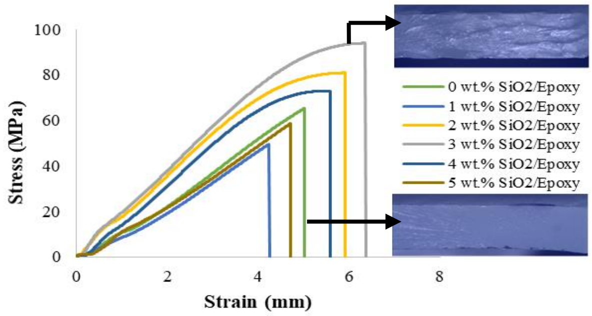

Fig.3. Tensile stress-displacement curves of nano SiO_2 epoxy composites and cross section images

3.2 Bending results

Flexural tests were carried out to understand the effect of nano SiO_2 matrix modification on flexural behavior. Nanocomposites contain various weight percentages of nano SiO_2, bending load-deflection curves are showed in (Fig.4). It can easily see that modified epoxy gives better bending results in case of adding nano SiO_2 up to 3 wt. %. However, by adding nano SiO_2 more than 3 wt. % results in decreasing carrying capacity. This drop in the carrying capacity is associated with the nanoparticle agglomerations in nanocomposites. The fracture cross section areas of neat epoxy and 3 wt. % nano SiO_2 added nanocomposites were given in (Fig.4). Surface roughness of nano SiO_2 added epoxy composites is significantly different. Neat epoxy specimens have less surface roughness which this indicates brittle fracture. On the contrary 3 wt. % SiO_2 added nanocomposites have maximum surface roughness which makes the composite more ductile.

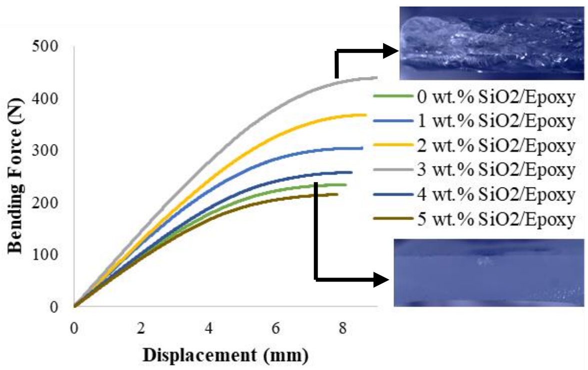

Fig.4. Bending force-displacement curves of nano SiO_2 epoxy composites and cross section images

3.3 SEM investigations

Fig.5 illustrates SEM images of the epoxy composite. As shown in (Fig.5), the 0 wt. % of nano SiO_2 epoxy display a fractured area, indicating smooth surface but in the 3 wt. % nano SiO_2 epoxy composite, there are toughening mechanisms cause of nano particle like deboning and crack deflection. It can be seen these mechanisms in (Fig.6). In addition to this, fracture surface of 3 wt. % nano SiO_2 epoxy composite has large plastic deformation areas. So, it can be easily understand that why adding nano SiO_2 improve the strength and strain of composite materials.

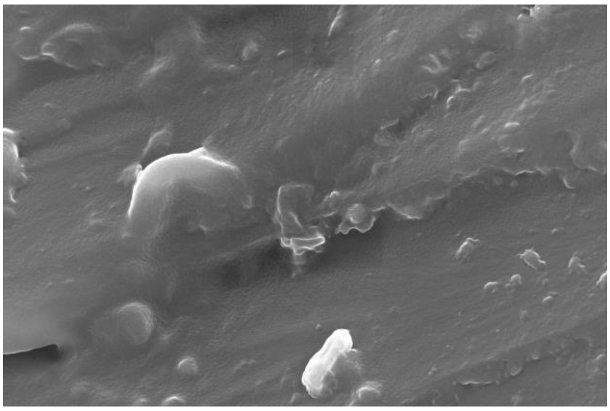

Fig.5. 0 wt. % nano SiO_2 epoxy composite

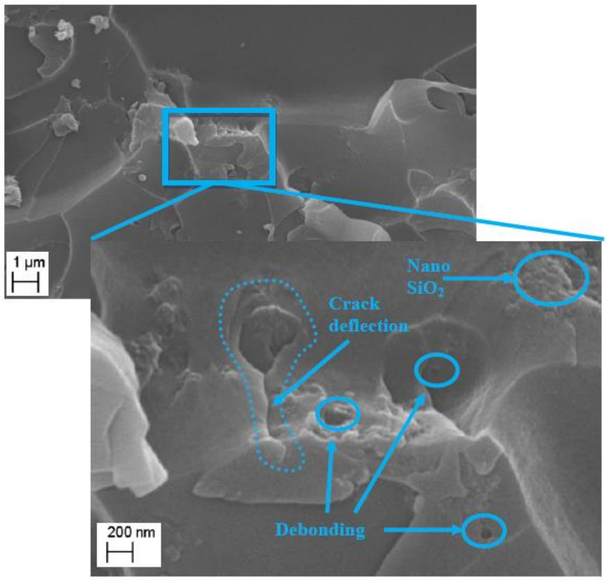

Fig.6. 3 wt. % nano SiO_2 epoxy nanocomposite

Agglomerated nano particles of 5 wt. % nano SiO_2 epoxy nanocomposite are shown in (Fig.7). This undesirable situation may be presented in nanocomposite materials with high nano particle content. For this reason, nano composite may show poor mechanical properties.

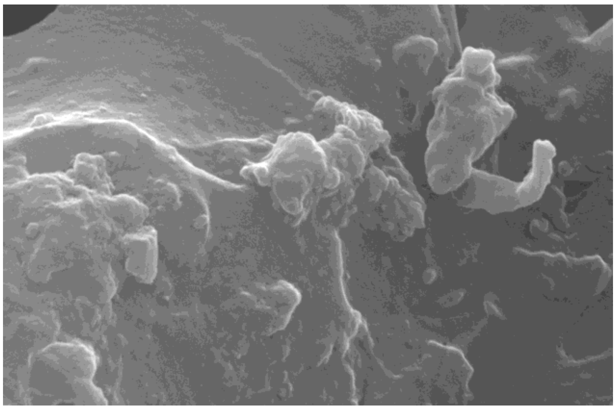

Fig.7. 5 wt. % nano SiO_2 epoxy nanocomposite

4. CONCLUSION

Adding nano SiO_2 loading resulted in an increase strength in epoxy nanocomposite. Besides, maximum enhancement of the tensile strength and strain was achieved with the 3 wt. % nano SiO_2 loading.

With adding more nano SiO_2 from 3 wt. %, well distributed mixture could not be achieved. Thus agglomerations of nano SiO_2 were seen.

As a result of tensile test of nano SiO_2 added nanocomposites, 3 wt. % nano SiO_2 loading was determined as an optimum level for maximum tensile strength. Similarly, this result was obtained in the bending test.

Up to 3 wt. % nano SiO_2 loaded epoxy resin, exhibited ductile behavior. In case of adding more SiO_2 than 3 wt. %, no more ductility was observed due to agglomerations.

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