

# **Characterization of Tensile Properties And Toughness Mechanisms on Nano- $\text{Al}_2\text{O}_3$ Epoxy Nanocomposites**

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**ABSTRACT:** In this paper, the effects of adding nano- $\text{Al}_2\text{O}_3$  particle (alumina) were investigated for epoxy modification with several weight ratios from 1 wt% to 5 wt%. Also, contribution of epoxy modification was studied on epoxy nano composites and carbon fiber reinforced laminated nano composites' tensile properties. Nano- $\text{Al}_2\text{O}_3$  epoxy nanocomposites were prepared by conventional casting in stainless steel mold. The carbon fiber reinforced nano- $\text{Al}_2\text{O}_3$  laminated nanocomposites were manufactured by using two different methods which are hand lay-up process and Vacuum Assisted Resin Infusion Method (VARIM), respectively. Experimental results showed that tensile properties both of nano- $\text{Al}_2\text{O}_3$  epoxy composites were affected from addition of nano- $\text{Al}_2\text{O}_3$  particles. Scanning Electron microscopy (SEM) and optical microscope were utilized in order to designate toughness mechanism and damage information of nanocomposite specimens. The experimental results illustrated that the highest values of tensile strength were obtained 2 wt%  $\text{Al}_2\text{O}_3$  nanoparticle epoxy modifications. Tensile strength increment values of nano- $\text{Al}_2\text{O}_3$  epoxy and nano- $\text{Al}_2\text{O}_3$  added carbon fiber reinforced laminated nanocomposites were determined around 34 % and 50 %, respectively. The data tend to support that using nano- $\text{Al}_2\text{O}_3$  particle would be a new approach to increase tensile properties due to strong matrix-fiber interface adhesion of carbon fiber reinforced nano- $\text{Al}_2\text{O}_3$  epoxy.

**KEYWORDS:** Alumina ( $\text{Al}_2\text{O}_3$ ) nanoparticle, epoxy modification, nanocomposite, tensile strength, toughness mechanism.

## **I. INTRODUCTION**

Carbon fiber reinforced epoxy polymer composites have been broadly used in various fields such as military and defense industries, automobiles, marine, aerospace industries, sports goods, civil engineering and an increasing number of other technical applications. They generally have many advantages like lightweight, good corrosion resistance, high stiffness, flexible thermal and electrical properties and high strength. Epoxy resins are commonly used as matrix materials to manufacture of carbon fiber composites because of their excellent wetting power, high mechanical properties, thermal and chemical resistance [1-3].

Recently, nanoparticles are used as reinforcements in epoxy to develop mechanical performance of composites, such as BNNP/Epoxy [4], nano- $\text{SiO}_2$ /Epoxy [5], nano-clay/Epoxy [6], CNT/Epoxy [7-10] and nano  $\text{Fe}_2\text{O}_3$ /Epoxy [11]. In literature research, it was found that many studies have tried to find some kind of solutions and new approaches to develop of nanocomposite materials. Le et al. investigated effect of the ratio of fillers, such as carbon nanotube and graphene on the tensile strength of epoxy composite [12]. Vaisakh et al. conducted highly competent design by using nano  $\text{SiO}_2/\text{Al}_2\text{O}_3$  particulate ceramics. Also, the effect of glass transition temperature, composite microstructure, thermal conductivity, mechanical properties, micro hardness and tribology properties were studied [13]. Asi tried to understand the mechanical properties of glass fiber reinforced epoxy composite filled with different proportions of  $\text{Al}_2\text{O}_3$  nanoparticles [14].

In the present paper, experimental studies have been performed to investigate the tensile strength of epoxy composites adding from 1 wt% to 5 wt% of nano- $\text{Al}_2\text{O}_3$  particles. For this purpose, firstly modifications of epoxy resin

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were investigated with tensile tests as dog bone specimens and then laminated composites were produced via VARIM (Vacuum Assisted Resin Infusion Method) to examine the effect of fiber-matrix interface adhesion.

## II. EXPERIMENTAL SETUP

The epoxy matrix as commercially available diglycidylether of bisphenol-A (DGEBA) purchased by Momentive Hexion Inc. Nano- $\text{Al}_2\text{O}_3$  was procured from MKNano Co. The grain sizes of nano- $\text{Al}_2\text{O}_3$  were 40 nm. Carbon fiber fabric and the all other vacuum infusion equipments were supplied by Dost Kimya Inc., Turkey. The area density of carbon fiber was  $300 \text{ g/m}^2$  and each bundle consisted of 12000 filament.

### A. Preparing Nano- $\text{Al}_2\text{O}_3$ -Epoxy Composites

The nano- $\text{Al}_2\text{O}_3$  weight content was varied from 1 wt% to 5 wt%. The epoxy and powder nano- $\text{Al}_2\text{O}_3$  (seen in Fig.1) were stirred for 30 min with ultra sonicator. Curing agent was added after dispersing process in epoxy and degassed at  $25^\circ\text{C}/0.6 \text{ bar}$  for 20 min. The steel mold covered with release agent and mixture was poured into preheated mold Fig.2. (a). Curing was performed at  $80^\circ\text{C}$  for 1 h, at  $120^\circ\text{C}$  for 2 h and then it was slowly cooled to room temperature in the oven. Then, specimens were unmolded from steel mold, which made according to ASTM D4762 - 11a Fig.2 (b). All samples were removed from mold and conventionally polished with SiC sandpapers with grit numbers of 800 to minimize effect stress concentration caused by sharp edges.

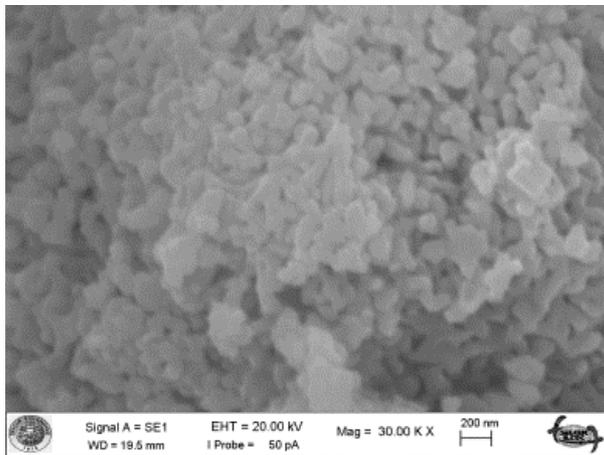


Fig.1. SEM image of powder  $\text{Al}_2\text{O}_3$

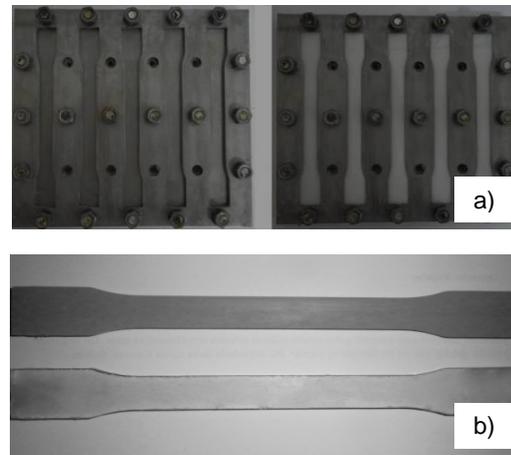


Fig.2. (a) Steel mold and covered with epoxy  
(b) Tensile test specimens

### B. Preparing Nano- $\text{Al}_2\text{O}_3$ -Epoxy/CF Composites

Similarly the nano- $\text{Al}_2\text{O}_3$  weight content of epoxy carbon fiber laminated composites was varied from 1 to 5 wt%. Carbon fiber reinforced epoxy matrix laminated nanocomposites were prepared by means of VARIM. Six layers of woven carbon fabrics ( $350 \text{ mm} \times 500 \text{ mm}$ ) were cut and the fiber preform was stacked on VARIM loom. In contrast to the standard VARIM methods, firstly hand lay-up method applied on each woven carbon fabric layers, and the resin impregnated woven fiber were put into a vacuum bag. In this way, filtering of nanoparticles by fiber was also prevented. After degassing, the temperature was increased to  $80^\circ\text{C}$  for 1 h, at  $120^\circ\text{C}$  for 2 h. After curing process, the system was cooled gradually down to the room temperature, so as to avoid the unwanted shrinkage in the laminates. Finally, the cured panel was taken out and specimens were cut according to ASTM D3039/D3039M-00 standards. All samples polished with SiC sandpapers identically.

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### C. Test Procedure

The manufactured nano composite specimens were fixed to tensile tests using Instron 8801 adorned with a load cell of 100 kN. Tests were carried out on samples (3,5 mm\*25 mm\*250 mm) and tensile speed was configured 2 mm/min accordance with standards.

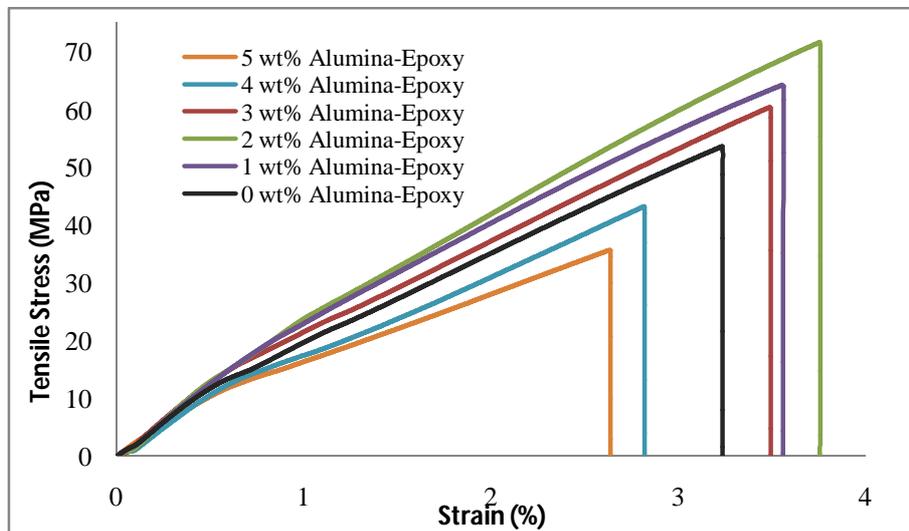
The fracture surfaces of samples and pull out of fiber were observed via Leica DM2700M optical microscope and Zeiss Evo LS10 Scanning Electron Microscope (SEM).

### III.RESULT AND DISCUSSION

This section divided two different parts which one (Part A) is related to tensile stress-strain curves of nano composites and the other one (Part B) is about microstructure analysis by using scanning electron microscopy (SEM) and optic microscopy to make more understandable for all results.

#### A. Tensile Properties of Nano Al<sub>2</sub>O<sub>3</sub> Epoxy Composites and Carbon Fiber Reinforced Nano Al<sub>2</sub>O<sub>3</sub> Composites

Stress-strain curves of different weight percentages of nano-Al<sub>2</sub>O<sub>3</sub> epoxy have shown in Fig.3. It can be seen the highest increasement of the tensile strength and strain is observed at the 2 wt% Al<sub>2</sub>O<sub>3</sub> loading. Also this figure has showed that tensile properties deteriorated in case of over 2 wt% Al<sub>2</sub>O<sub>3</sub> loading due to the agglomerations of nano Al<sub>2</sub>O<sub>3</sub>particle.



**Fig.3.** Tensile curves of Al<sub>2</sub>O<sub>3</sub> nanoparticle/epoxy composites

Fig.4 illustrates tensile tests results of fiber reinforced epoxy laminated composites. It is seen that the tensile behavior is consistent with Fig. 2. Optimum nano Al<sub>2</sub>O<sub>3</sub> concentration was determined by 2 wt% in terms of strength and stress due to enhancement of fiber-matrix interface adhesion. As same as, additions of Al<sub>2</sub>O<sub>3</sub> nanoparticle in excess of 2 wt% caused a decrease on tensile properties due to the nanoparticle agglomerations.

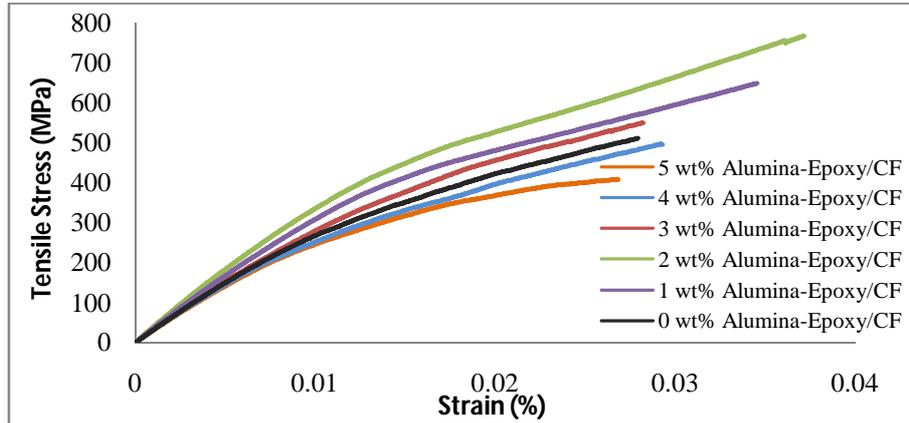


Fig.4. Tensile curves of carbon fiber reinforced Al<sub>2</sub>O<sub>3</sub> nanoparticle/epoxy composites

### B. Microstructure Analysis of Fracture Surface

To better understand the toughening effect of nano Al<sub>2</sub>O<sub>3</sub>particle on the nanocomposite, tensile fracture surfaces of the nano-epoxy and carbon fiber reinforced nano-Al<sub>2</sub>O<sub>3</sub> composites were observed with SEM and optical microscope. The optic micrograph of the neat epoxy sample displayed smooth fracture surface due to their inherent the poor toughness as shown in Fig.5 (a). The optic micrograph of Al<sub>2</sub>O<sub>3</sub> modified nanocomposites have showed roughly fracture surface with evidence of relatively plastic deformation and ductility compared to neat epoxy samples (Fig. 5 (b),(c),(d),(e),(f)). These differences clearly indicate that the fracture toughness of Al<sub>2</sub>O<sub>3</sub> modified epoxy resin higher than neat epoxy resin. The roughly surface and region of plastic deformation on fracture surface increased with addition of 2 wt% Al<sub>2</sub>O<sub>3</sub>nanoparticle compared to other fracture surfaces.

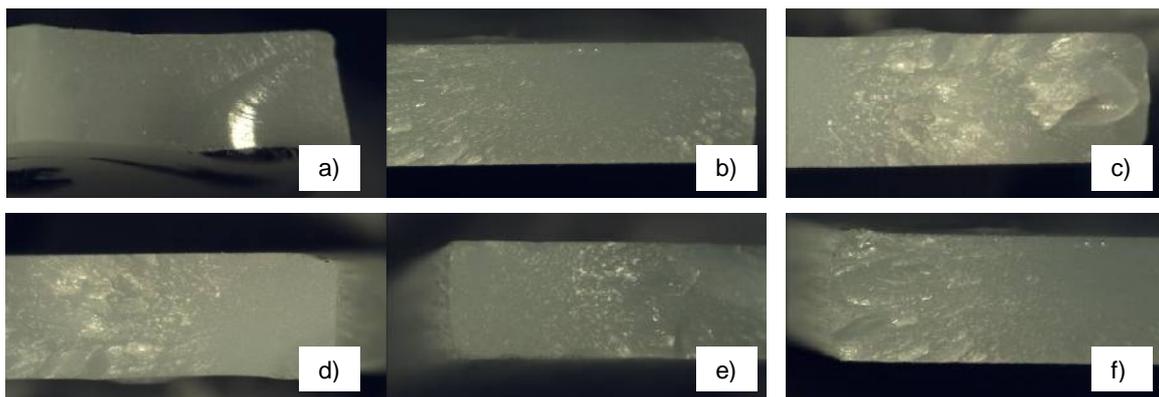
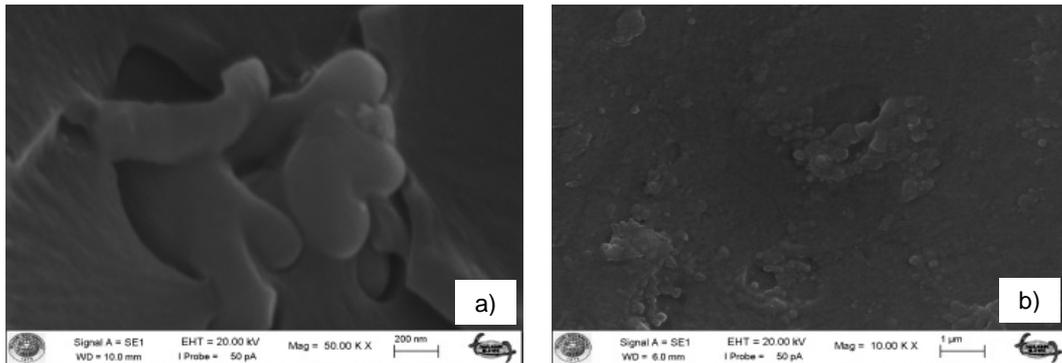


Fig. 5. Optic micrographs of epoxy specimens after tensile tests with different Al<sub>2</sub>O<sub>3</sub>nanoparticle concentrations: (a) 0 wt%, (b) 1 wt%, (c) 2 wt%, (d) 3 wt%, (e) 4 wt%, (f) 5 wt%.

The SEM images of the fracture surfaces for the 2 wt% nanoAl<sub>2</sub>O<sub>3</sub> epoxy composites haveshown in Fig. 6 and it is possible to see nano-Al<sub>2</sub>O<sub>3</sub> and its crack deflection[12]. It is can be seen that the Al<sub>2</sub>O<sub>3</sub>nanoparticlecould stop and deflected the matrix crackFig. 6(a). Additionally, toughness increasement of epoxy nanocomposites were associated with crack pinning, crack deflection mechanisms. Toughness of nano-Al<sub>2</sub>O<sub>3</sub> epoxy composites higher than neat epoxy composites because of that neat epoxy doesn't have this kind of toughening mechanisms. On the other hand, the 2 wt% nano-Al<sub>2</sub>O<sub>3</sub> epoxy composite indicated in Fig. 6(b) and it can be seen that nano-Al<sub>2</sub>O<sub>3</sub> particles were homogeneously dispersed in epoxy matrix.

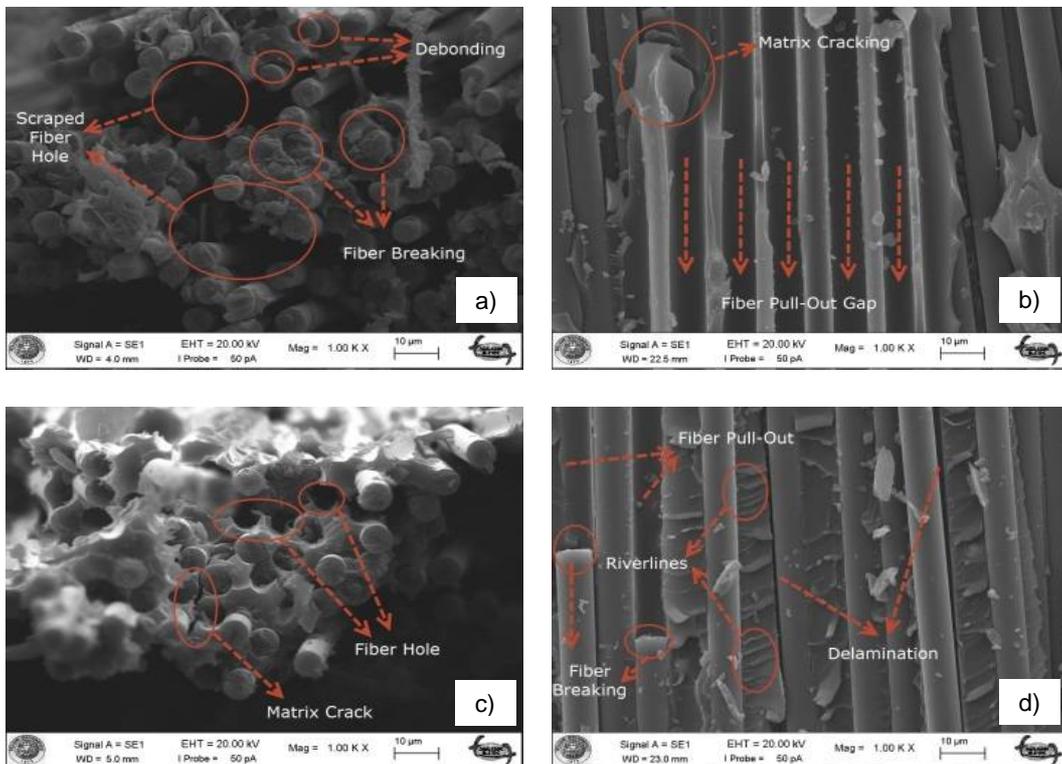
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**Fig.6.** SEM analysis of nano- $\text{Al}_2\text{O}_3$  after tensile test; a) Nano effect on the crack propagation  
b) Homogeneous distribution of  $\text{Al}_2\text{O}_3$  nanoparticles

Fig. 7 present SEM images of the carbon fiber reinforced neat and 2 wt% nano- $\text{Al}_2\text{O}_3$  epoxy composites after tensile test. Scraped fiber holes and debonding are seen a lot in neat epoxy matrix (Fig. 7(a)). Also, fibers readily pulled out from epoxy matrix (Fig. 7(b)). In contrast to neat epoxy composites, 2 wt% nano- $\text{Al}_2\text{O}_3$  epoxy composites have been exhibited a few fiber hole (Fig. 7(c)). Moreover, delamination, riverlines [12] which indicated that interfacial adhesion between fiber and matrix of 2 wt% nano- $\text{Al}_2\text{O}_3$  laminated nanocomposites stronger than carbon fiber reinforced neat epoxy composites (Fig. 7(d)).



**Fig.7.** SEM images of carbon fiber reinforced epoxy composite after tensile test;  
(a)-(b) Neat epoxy, (c)-(d) 2 wt%  $\text{Al}_2\text{O}_3$  nanoparticle/epoxy

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## IV. CONCLUSION

- i. Highest increment of the tensile strength and strain was achieved with the 2 wt%  $\text{Al}_2\text{O}_3$  loading in epoxy nanocomposites.
- ii. Excess amount of 2 wt%  $\text{Al}_2\text{O}_3$  ratios agglomerated into epoxy resin. For this reason, tensile properties decreased at excess amount of 2 wt%.
- iii. As a result of tensile test of carbon fiber reinforced laminated nanocomposites found that 2 wt%  $\text{Al}_2\text{O}_3$  loading was determined the highest tensile strength being optimum level.
- iv. Nano- $\text{Al}_2\text{O}_3$  modified epoxy nanocomposites exhibited relatively ductile behaviour. Also, this phenomenon is the highest in 2 wt%  $\text{Al}_2\text{O}_3$  loading.
- v. Fiber-matrix interface adhesion of carbon fiber reinforced nano- $\text{Al}_2\text{O}_3$  epoxy composite stronger than carbon fiber reinforced neat epoxy composite.
- vi. Tensile strength increment was determined around 34 % for nanocomposites and 50 % for laminated nanocomposites.

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