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Improvement in the Flexural Properties of Basalt Fibers/Epoxy-Aluminum Laminate Composites using Multi-Walled Carbon Nanotubes

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ABSTRACT: Recently, to improve the mechanical properties of polymeric composites, the inclusion of nanoparticles into the matrixes has received much attention. However, it is not well established whether nanoparticles can enhance the mechanical properties of fiber metal laminates. The present study aims to investigate the effect of multi-walled carbon nanotubes on the flexural behavior of a fiber metal laminates made up of alternating layers of Al2024 along with basalt fibers reinforced epoxy. Results showed that the flexural strength and flexural modulus of samples have an upward trend up to 0.5 wt.% loading, but beyond that, a downward trend was observed. Therefore, in this research, the optimal content of multi-walled carbon nanotubes for the best flexural properties was the 0.5 wt.% and compared to the samples without multi-walled carbon nanotubes; the flexural strength and flexural modulus values were found to 36.62% and 60.16% improvement, respectively. Furthermore, scanning electron microscope observations showed that the mechanisms of carbon nanotube-pull-out and carbon nanotube-bridging were the main reasons for these findings.

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1- Introduction

Fiber Metal Laminates (FMLs) are a class of hybrid composites consisting of metal and fiber reinforced polymer layers. These composites combine the advantages of both metals and polymers. The main advantages of FMLs include high wear strength, impact resistance, and the fatigue and corrosion properties [1].

To date, improvement in the mechanical properties of polymeric composites through the inclusion of the various nanoparticles has been investigated by many researchers. Before the introduction of graphene in 2004, to modify the properties of polymer composites, use of Carbon Nanotubes (CNTs) owing to their unique mechanical, electrical and thermal properties was attracted the most attention by researchers. It is well-known that the effectiveness of CNTs on improving the mechanical properties of composites is significantly affected by various factors such as type and dispersion condition of CNTs within the polymers [2, 3].

The effect of CNTs on the mechanical behavior of epoxy 862 was studied by Zhou et al. [2]. The positive effects of CNTs were confirmed by their results; for example, the flexural strength of composites containing 0.3 wt.% was about 28.3% higher than that for neat epoxy. These results were confirmed by the most performed studies. However, the negative effects of CNTs were also reported in little studies. In this regard, for example, Godara et al. [3] studied the mechanical properties of carbon fiber/epoxy composites through the application of the three types of CNTs. They showed that the tensile strength of samples decreased using the CNTs.

However, contrary to the effect of nanofillers on the conventional composites, the characteristics of nanofillers in the FMLs have not been dealt with in depth. There are few studies regarding the effect of nanofillers on the mechanical behavior of the metal/ polymer bonding. In one of the pioneering studies, the adhesive strength of epoxy resin/ steel by the addition of nano-Al2O3 was investigated by Zhai et al. [4]. They reported that the modification of epoxy resin with nano-Al2O3 has a significant effect on improving the adhesive strength of the epoxy/steel interfaces.

The present study aims to investigate the effect of Multi-Walled Carbon Nanotubes (MWCNTs) on the flexural behavior of a FML made up of alternating layers of Al2024-T3 sheets along with basalt fibers reinforced epoxy.

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2- Materials and Methods

The materials that used for fabrication of the samples were aluminum alloy grade 2024-T3 with 0.5 mm thickness, woven basalt fibers (BAS 350.1270.A, Basaltex, Belgium) and epoxy resin (Epon 828, with hardener TETA). The resin to hardener ratio was 100:13 by weight, as recommended by the manufacturer. Carboxyl functionalized MWCNTs (COOH-MWCNTs, 10-20 nanometer in outer diameter and 10-30 micrometer in length) were provided by Cheap Tubes Inc., USA.

To achieve the good dispersion of MWCNTs into the epoxy resin, the mixture of epoxy and MWCNTs at different weight percentages (0, 0.1, 0.25, 0.5 and 0.75) were ultrasonically homogenized at 320 W for 60 min (Ultrasonic homogenizer 400 W, 24 kHz, FAPAN Co., Ltd., Iran). Moreover, to improve the adhesion of the polymers to the aluminum, the Al2024-T3 sheets were anodized in sulfuric acid solution for 20 min.

The FMLs with 2/1 configuration were fabricated by hand lay-up method. The interlayer consisted of 4 basalt fibers reinforced epoxy layers. After laminating, the samples were placed into a mold for the curing step. The samples were kept for 7 days at room temperature for the complete curing process.

To investigate the mechanical properties of FMLs, a 3-point flexural bending test was conducted at the ambient temperature according to ASTM D790 on the samples with a size of 150 × 25 × 1.9 mm3 (length, width, thickness). In addition, the fracture surface of samples was investigated by analyzed using Scanning Electron Microscopy (SEM). The analysis was accomplished using TESCAN microscope.

3- Results and Discussion

Figs. 1 and 2 respectively show the flexural strength and flexural modulus of samples as a function MWCNTs content. It is clear that, with increasing the MWCNTs content up to 0.5 wt.%, the flexural strength and modulus of samples are increased. However, it seems that the low contents of MWCNTs (i.e. 0.1 and 0.25 wt.%) have not considerable effects on enhancing the mechanical properties of samples.

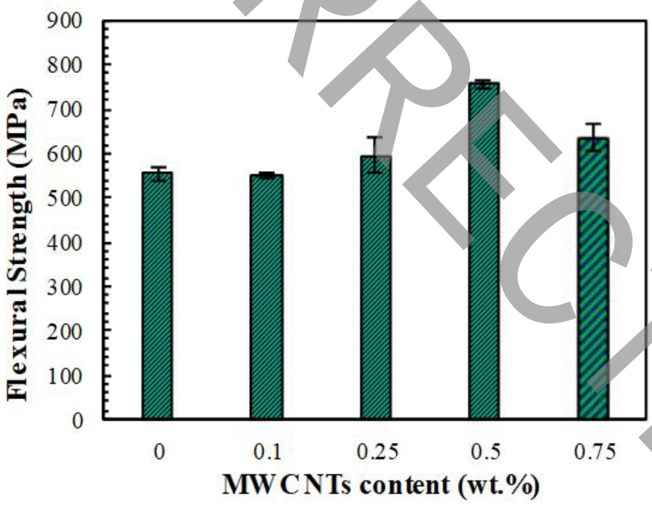

Figure 1. The flexural strength of basalt fibers/ epoxy/ aluminum 2024 laminates as a function of MWCNTs content.

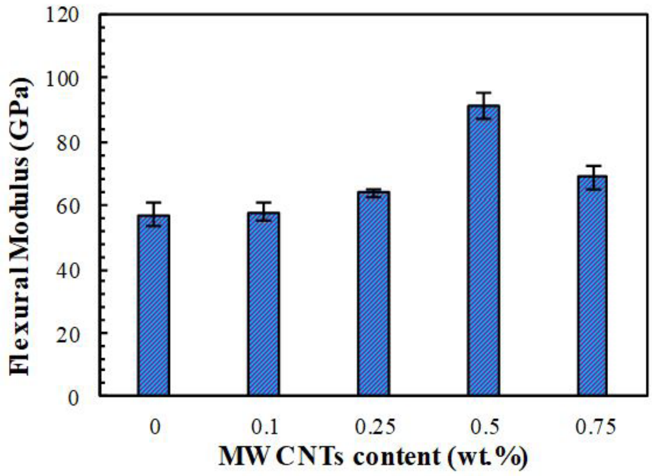

Figure 2. The flexural modulus of basalt fibers/ epoxy/ aluminum 2024 laminates as a function of MWCNTs content.

Accordingly, the flexural strength and modulus of samples with 0.25 wt.% MWCNTs are respectively about 594.37 MPa and 63.88 GPa which these values are about 7.26% and 11.65% higher than those for neat samples. The archived results are in good agreement with the mixtures law. According to the mixtures law, it can be said that the mechanical behavior of composite is depended on the amount of MWCNTs.

Among all samples, the maximum flexural strength is about 757.06 MPa for the FMLs with 0.5 wt.% MWCNTs. It is straightforward to verify that in the case of FMLs with 0.5 wt.% MWCNTs, compared with the base sample, the flexural strength and modulus values are improved to 36.62%, 60.16%, respectively. However, by increasing the MWCNTs content beyond the 0.5 wt.%, the downward trends are observed. Therefore, it can be concluded that the optimal content of MWCNTs is 0.5 wt.%.

The improvement in flexural properties of samples can be attributed to the microstructural evaluations. In the case of CNTs based nanocomposites, the CNTs pull-out, CNTs bridging, CNTs debonding and plastic void growth are introduced as the main strengthening mechanisms for improving the mechanical properties. When a crack appears in the CNTs nanocomposites, the CNTs through the bridging mechanism prevent from crack opening. However, after increasing the mechanical stress, the CNTs relative to their adhesion to the polymer, can be pulling out or ruptured. Due to this fact that the mentioned mechanisms consume high energy, the addition of CNTs can improve the mechanical properties of polymeric composites.

Fig. 3 shows the SEM micrographs of basalt fibers/epoxy composite containing 0.5 wt.%. In the Fig. 3 (a) the mechanism of pull-out is clearly visible. In addition, the proper dispersion and distribution of the MWCNTs which can be attributed to the functionalized group of them is also visible.

In the Fig. 3 (b) along with the MWCNTs pull-out, the MWCNTs bridging is also indicated. As mentioned earlier, the MWCNTs bridging contributes to hindering of the crack opening occurrence, leading to the overall mechanical improvement. On other hands, the decrement of the flexural properties of samples containing 0.75 wt.% MWCNTS can be related to various reasons such as increasing the chance of agglomeration and increasing the polymer's viscosity.

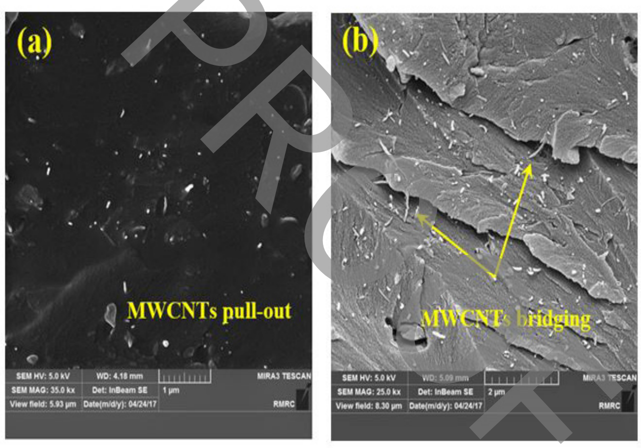

Figure 3. SEM images of strengthening mechanisms of basalt fibers/epoxy composite containing 0.5 wt.% MWCNTs (a) pull-out and (b) bridging.

4- Conclusions

In this paper the results show that:

1. By the addition of MWCNTs up to 0.5 wt.% an increasing trend for flexural strength and the flexural modulus of basalt fibers/ epoxy/ aluminum 2024 laminate composite was observed, but beyond that, a downward trend was observed.
2. SEM observations showed that the MWCNTs pull-out and MWCNTs bridging were the main mechanisms for improving the mechanical properties of nano modified-FMLs. However, increasing the polymer's viscosity and the chance of agglomeration were introduced as the probable reasons for the adverse effect of MWCNTs at high loadings.

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