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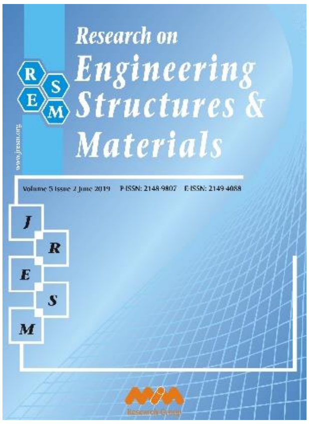

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Research Article

Flexural properties of glass fiber/epoxy/MWCNT composites

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Abstract

Glass fiber/epoxy resin/multi-walled carbon nanotubes (MWCNTs) were used to fabricate the nano materials integrated thermoset composite materials in this study. Thermoset composites with and without nano materials were fabricated using resin transfer molding (RTM) methods. In order to characterize fabricated samples, three-point flexural tests were used. The best improvement of the flexural modulus and strength with 19% and 7% were obtained by the samples in the 90° direction and MWCNTs compared to the samples without MWCNTs. An increase in interfacial adhesion between glass fibers and epoxy matrix due to the existing of the carbon nanotubes was the reason of the improvement of the flexural properties of carbon nanotubes integrated composites.

1. Introduction

The using of thermoplastics and thermosets polymeric composite materials were considerably developed in recent years. Nano materials can be used as an assistant factor for strengthening of the composites. Carbon nanotubes (CNTs) have superior properties such as, strength and stiffness, with high aspect ratio. Because of unique properties of CNTs (such as Young's modulus of ca. 1 TPa and tensile strength of ca. 200 GPa), CNTs has become an ideal candidate for polymer reinforcement [1]. In the literature, some articles were found addressing the flexural properties of CNT modified laminates [2-10].

Agnihotri et al. [2] studied effect of carbon nanotube grafting on the wettability and average mechanical properties of carbon fiber/polymer multiscale composites. They found that CNT grafting leads to a significant improvement in interfacial shear strength as well as flexural and tensile response of carbon fiber/polymer composites with the epoxy resin. Prusty et al. [3] studied mechanical, thermomechanical, and creep performance of CNT embedded epoxy at elevated temperatures. They recorded higher flexural strength and modulus of carboxylic functionalized CNT (FCNT) embedded epoxy nanocomposites over pristine CNT (UCNT) embedded epoxy nanocomposites and neat epoxy at room temperature environment. Avcı et al. [4] studied preparation and mechanical properties of carbon nanotube grafted glass fabric/epoxy multi-scale composites. They reported that

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the multi-scale composite laminates prepared with CNT grafted glass fabric represent increasing resistance to applied load after primary load fall occurred. Rahaman et al. [5] studied epoxy-carbon nanotubes as matrix in glass fiber reinforced laminated composites. They found that flexural strength, flexural modulus and storage modulus of carbon nanotubes/glass fiber/epoxy composite were considerably improved by the addition of MWCNTs. Coelho et al. [6] studied glass fiber hybrid composites molded by RTM using a dispersion of carbon nanotubes/clay in epoxy. They reported that the low clay content used and, especially, the very low MWCNT content, did not significantly alter the studied flexural properties. Zhouo et al. [7] studied fabrication and characterization of carbon/epoxy composites mixed with multi-walled carbon nanotubes. They found that the glass transition temperature, decomposition temperature, and flexural strengths were improved by infusing CNTs. Tensile behavior of MWCNT enhanced glass fiber reinforced polymeric composites at various crosshead speeds was investigated by Mahato et al. [8]. They reported that addition of 0.1% CNT and 0.3% CNT enhanced the tensile strength by 6.11% and 9.28% respectively than control GFRP composite. Panchagnula et al. [9] studied improvement in the mechanical properties of neat GFRPs with multi-walled CNTs. They found that the tensile and flexural strengths of MWCNT-GFRPs increased nearly 36.04% and 39.41% with the addition of 0.3% of MWCNTs. Interface enhancement of glass fiber fabric/epoxy composites by modifying fibers with functionalized MWCNTs was reported by Shen et al. [10]. They found that the interlaminar shear, tensile and flexural strengths of MWCNTs-grafted glass fiber fabric/epoxy composites were enhanced by 24.0%, 24.9% and 21.1%.

In the literature, it was found some researchers who they coated the surface of the reinforcements using nano materials. Lagoudas et al. [11] studied effect of carbon nanotubes on the interfacial shear strength of T650 carbon fiber in an epoxy matrix. They found that randomly oriented MWCNT and aligned MWCNT coated fibers demonstrated a 71% and 11% increase in interfacial shear strength over untreated, unsized fibers due to the presence of the nanotubes. Kim et al. [12] studied tensile strength of glass fibers with carbon nanotube–epoxy nanocomposite coating. They reported that the single fibers coated with the 0.3 wt% CNT–epoxy nanocomposite exhibited larger strength improvement than fibers with a neat epoxy coating, compared to fibers without coating. Epoxy matrix composites with carbon fiber/selectively integrated graphene as multi-scale reinforcements was investigated by Zanjani et al. [13]. They found about 51% improvements in the flexural strength in their fabricated composite materials by using nano materials. Interfacial shear strength of a glass fiber/epoxy bonding in composites modified with carbon nanotubes was reported by Gorbatikh et al. [14]. They obtained 90% improvement in interfacial shear strength by using carbon nanotubes in the fiber sizing. Demircan et al. [15] reported mechanical properties of thermoplastic and thermoset composites reinforced with 3d biaxial warp-knitted fabrics. They found about 97% and 58% improvements in the flexural modulus and strength of composites by using carbon nanotubes in the fiber sizing.

It was found little work about the three-point flexural properties of the MWCNTs integrated glass fiber epoxy thermoset composites reinforced with the non-crimp fabrics in the literature. The aim of this research was to study the effect of the MWCNTs integration on the three-point flexural properties of the thermoset composites. In this study, the flexural properties of 0.0 wt% and 0.4 wt% MWCNTs integrated specimens in the 0° and 90° directions were investigated. In order to design of the new thermoset composite materials, the results from our research can be used.

2. Experimental procedure

2.1. Constituents of Thermoset Composites

In order to fabricate nano materials integrated thermoset composites, the non-crimp fabrics (NCF) with glass fibers (Metyx Composites Ltd., Turkey), epoxy resin (DTE 1200, Duratek, Turkey) and hardener (DTS 1155, Duratek, Turkey) were used. The properties of the NCF are shown in Table 1.

Table 1 Properties of non-crimp fabric (NCF) of composites

E glass samples	Biaxial yarn 0° (warp) fibers, tex	Biaxial yarn 90° (weft) fibers, tex	Area weight of 0° warp fibers (gr/m^2)	Area weight of 90° weft fibers (gr/m^2)	Fabric weight (warp, weft and binding fibers) (gr/m^2)
LT1200E 05B 0/90	2400	1200	566	614	1187

The MWCNTs were supplied from Ege Nanotek Kimya Sanayi Limited Sirketi, Izmir, TURKEY. The properties of the MWCNTs were: 10–20 nm (the outer diameter), 5–10 nm (the interiour diameter), 10–30 micro m (length of the MWCNTs) and >200 m^2/g (the surface area of the MWCNTs). Figure 1 shows the SEM images of the MWCNTs.

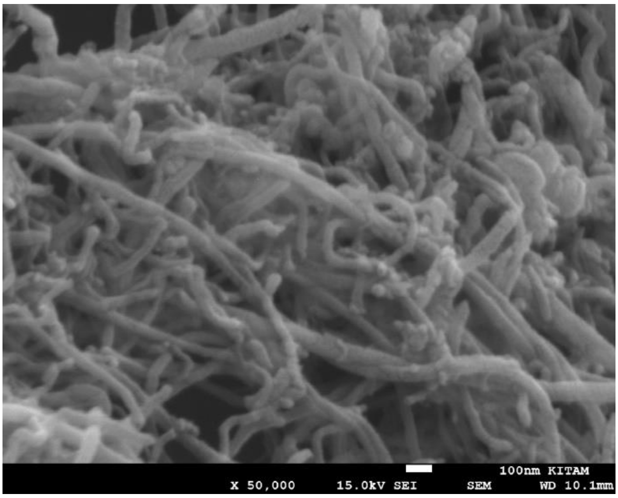

Fig. 1 SEM images of MWCNTs

2.2. Fabrication Method of Thermoset Composites

In order to fabricate the thermoset composites with nanomaterials, the resin transfer method (RTM) was chosen to manufacture four layers biaxial warp-knitted (BWK) reinforced composites plates as shown in Figure 2.

At first ethanol and MWCNTs solutions were prepared to coat each faces of the NCFs. MWCNTs were dispersed in ethanol using a magnetic stirrer device. After that the solution of MWCNTs and ethanol were stayed in an ultrasonic bath. Later, each faces of the NCFs were coated using of the solution of MWCNTs and ethanol. After coating of the NCF with the MWCNTs solution, the specimens were left for two days in the room temperature to ensure the full evaporation of the ethanol. Then, MWCNTs coated four layers fabrics were laid in mold cavity in a symmetrical stacking sequence ($[90_{wa}/0_{we}/90_{wa}/0_{we}]_s$) of the RTM system (Figure 3).

Fig. 2 The RTM apparatus

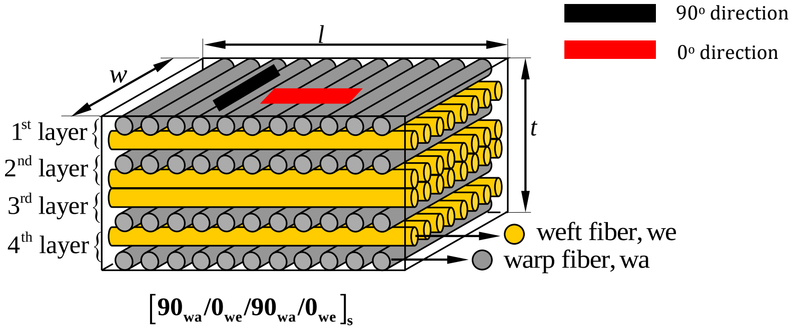

Fig. 3 Schematic drawing of the thermoset composites. Here, l: length, w: width and t: thickness of the fabricated composite plate

In the fabricated composite plates, the carbon nanotubes weight percentages were 0.4 wt %. After fabricating of the composites, burn off method in a muffle furnace was performed in order to determine the percentages of each of the constituents in the thermoset composites. The burn off process of the composites was conducted according to the ASTM D3171–99 standards. Table 2 shows the fiber volume fraction and thickness of the fabricated composites.

Table 2 Fiber volume fraction and thickness of fabricated composites

Composites	Weft Vf (%)	Warp Vf (%)	Binding Vf (%)	Total (warp, weft and binding) Vf (%)	Thickness (mm)
0.0 wt % MWCNT	17.4	16.1	0.66	34.2	5.4
0.4 wt % MWCNT	16.8	18.2	0.28	35.3	5.0

2.3. Characterization of Thermoset Composites

The ASTM-D790 test standards were used to prepare the specimens and test conditions for the the three-point flexural tests. The INSTRON 5982 100KN universal testing machine type with flexural tests apparatus was used to perform the three-point flexural tests. The tests speeds and the sample dimensions were 1 mm/min and 110 x 15 x 5.0–5.4 mm^3 for the three-point flexural tests. The test span lengths were 74 mm and 90 mm. Three specimens from each type of the composite panels were tested both in the 0° and 90° directions. The 0° and 90° directions of the specimens were cut after fabricating of the composite panels. The 0° and 90° directions of the specimens can be seen in Figure 3 (0° direction was shown by red color and 90° was shown by black color).

The flexural strength, modulus and strain were calculated using following Equations (1-3) [16].

$$\sigma_f = 3PL/bd^2 \tag{1}$$

$$\epsilon_f = 6Dd/L^2 \tag{2}$$

$$E_B = L^3 m/4bd^3 \tag{3}$$

Where, σ_f is the flexural strength (MPa); P is the flexural load (N); L is the support span length (mm); b is the sample width (mm); d is the sample thickness (mm); E_B is the flexural modulus (GPa); m is the slope of the tangent to the initial straight-line portion of the load-deflection curve; ε_f is the flexural strain (%); D is the maximum displacement of the centre of the sample (mm).

3. Results and Discussion

The results of the flexural properties of the specimens are shown in Figure 4. The flexural modulus and strength of the specimens with 0 wt% and 0.4 wt% MWCNTs were 12.8 GPa, 375.2 MPa, 15.9 GPa and 403.7 MPa in 90° direction and these were 17.2 GPa, 503.3 MPa, 20.1 GPa and 525.5 MPa in 0° direction. CNT integrated specimens showed 19% and 7% improvement of flexural modulus and strength against specimens without CNTs in 90° degree direction. That was 14% and 4% in 0° degree direction.

The specimens with 0 wt% MWCNT had a higher flexural modulus and strength in the 0° direction (17.2 GPa and 503.3 MPa) than those in the 90° direction (12.8 GPa and 375.2 MPa) due to the higher volume fraction of the weft fibers (17.4%) than the warp fibers (16.1%). Additionally, composite materials reinforced with thin plies showed higher mechanical properties than that was with thick plies [17-20]. The weft fibers (thin plies) of the specimens are aligned with the length of specimen in the 0° direction. The warp fibers (thick plies) of the specimens are aligned with the length of specimen in the 90° direction. Because of the alignment of thin fibers with the length of specimen in the 0° direction, the results of flexural modulus and strength were higher in the 0° direction compared to the 90° direction.

Since the volume fraction of the warp fibers (18.2%) is higher than the weft fibers (16.8%) with 0.4 wt% MWCNT, one will expect the specimens had a higher flexural modulus and strength in the 90° direction than those in the 0° direction. The fact that flexural modulus and strength in the 0° direction was higher than those in the 90° direction with 0.4 wt% MWCNT. As mentioned earlier, because of the alignment of thin fibers with the length of specimen in the 0° direction, the results of flexural modulus and strength were higher in the 0° direction compared to the 90° direction.

The flexural properties of the thermoset composites were improved by integrating of the MWCNTs on the surface of the NCF. The best improvement of the flexural modulus and strength with 19% and 7% were obtained from the samples in the 90° direction and 0.4 wt% MWCNTs. The interfacial properties between fiber and epoxy matrix could be improved by coating of the fiber surface with CNTs nano particles and this might be the possible reason of the enhancement of the flexural properties of composites. Since the CNTs having superior mechanical properties with large surface area, they improve mechanical properties of composites.

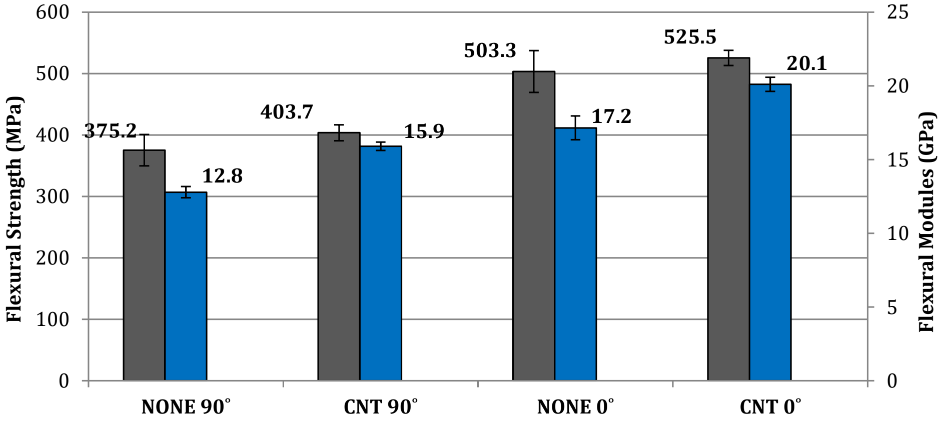

Fig. 4 Results of flexural properties of thermoset composites

Comparing these results with others found in the literature, 11% and 4.7% increase in flexural strength and modulus for addition of 0.1% pristine CNT (UCNT) in epoxy was reported by Prusty et al. [3]. About 14% increase in flexural strength for addition of 0.3% oxidized MWCNTs in epoxy was reported by Avcı et al. [4]. 27% increase in flexural modulus for carbon nanotubes/glass fiber/epoxy laminates containing 0.5% MWCNT was reported Rahaman et al. [5]. 11.7% increase in flexural modulus for addition of 0.4% MWCNT and 28.3% in flexural strength in epoxy was reported by Zhouo et al. [7]. The good agreement between our results and literature supported our mechanical tests.

4. Conclussions

The addition of the carbon nanotubes on the surface of the reinforcements enhanced the flexural modulus and strength of the thermoset composites.

From the results of this study, the following conclusions can be drawn:

- The results of flexural properties were higher in the 0° direction compared to the 90° direction.

- Composite materials reinforced with thin plies showed higher mechanical properties than that was with thick plies in the same volume fraction.
- The best improvement of the flexural modulus and strength with 19% and 7% were obtained from the specimens in the 90° direction and 0.4 wt% MWCNTs due to the superior properties of carbon nanotubes.
- The highest results of flexural modulus and strength were achieved with 0.4 wt% MWCNTs in 0^o direction.
- There was a good agreement of results of flexural tests of nano materials integrated composites from literature and from us.

In future study, we will try to investigate the impact properties of the nano materials integrated composite materials with the NCFs reinforcements.

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