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Experimental Investigation of Fatigue and Mechanical Properties of Unidirectional Composite Plates Filled Nanoparticles

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In this study, epoxy-based composite materials reinforced with unidirectional glass fiber (GFRP) fabric were manufactured by adding nanosized multi-walled carbon nanotube (MWCNT) and nanoclay to epoxy resin during production process. The effects of those additives on fatigue strength of the composite materials were investigated experimentally. In this context, both nanoparticles by adding 0.5 wt% of epoxy resin were mixed with ultrasonic homogenization mixer. To examine the contribution of nanoparticles, composite plates were produced as MWCNT and nanoclay filled and unfilled. Mechanical properties and fatigue behavior (S–N diagram) were obtained and the results were compared with each other. From the results obtained, fatigue and tensile strength of composite specimens with MWCNT filled were found higher than unfilled specimens.

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PACS/topics: MWCNTs, nanoclay, nanocomposite, epoxy resin

1. Introduction

The increased demand of fibre reinforced composites in recent years on aeronautics, automotive and marine industries caused an increasing research need in these materials in order to better understand their properties and achieve improved engineering products [1–3]. Glass fiber/epoxy composites 10 wt% of silica nanoparticles were added and the effect of these particles on fatigue strength was investigated. As a result of this research, they state that the contribution of silica increased fatigue strength by 3 times [4]. For glass fiber/epoxy composites, 2 wt% of nanoclay was added and the fatigue behavior of composite plates was investigated.

In study, it was found that the contribution of nanoclay increases the fatigue strength by 50% at minimum load [5]. By examining the effect of fatigue strength on delamination in carbon fiber/epoxy composites it was stated that delamination also increases effectively by increasing the tensile ratio during the fatigue test [6]. Fatigue behaviors under bending of two types of glass fiber/epoxy composites, one-way and random fiber lined, were compared and it was found that the crack propagation resistance of glass fiber reinforced composite material was better than random composition and the random fiber composite of unidirectional glass fiber was better [7]. A new composite fatigue analysis consisting of carbon fiber/linen/epoxy was used for the treatment of bone fractures and they were subjected to fatigue test with classical fatigue and thermography in analyses. When the tests were carried out, the load was carried with 50% of the tensile strength and the test result resulted in a crack density of only 0.48% of the composite at 2×10^6 load repetition. These test results concluded that the composite material had sufficient fatigue resistance to be applied in bone fracture treatments [8]. The fatigue behaviors of the carbon fiber/epoxy composites at different orientation angles were investigated and the fatigue behavior of the 0° layers was better than the fatigue behavior of the 45° layers [9].

The main objective of this work was to investigate the effects of MWCNT and nanoclay to addition epoxy resin on fatigue behaviour of GFRP composites. Three types of matrix compositions namely plain, enhanced with nanoclay and MWCNT were used in manufacturing GFRP composites. Also for this work, tension–tension fatigue loading modes were preferred.

2. Experimental studies

The materials used were glass-reinforced composites based on epoxy resin. The epoxy resin was a standard diglycidyl ether of bisphenol A (DGEBA) and Araldite LY 1564 supplied by Huntsman, Switzerland. The E-glass fibre fabric was a unidirectional fabric pattern with an areal weight of 330 g/m^2 and 1200 TEX from Huntsman, Switzerland. The COOH functionalized MWCNTs had an outer diameter of 10–20 nm and length of 0.5–2 μm. Nanomer NCs Esan nano 1–140, was provided by Eczacibasi Inc. from Istanbul, Turkey. All composite materials used in this study were produced by the hand lay-up method. To improve the mechanical properties of composite materials, nanoparticles were dispersed homogeneously in epoxy resin. Otherwise, nanoparticles dispersed non homogeneously causes stress concentrations and decrease strength of composites. Therefore, sonication method was used in this study. Nanoparticles (Clay, MWCNTs) were added to resin weighed on precision balance with 0.5 wt%. Cooling system was shown in Fig. 1a

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and the mixture of MWCNTs and epoxy resin was sonicated using Hielscher UP 400S at 70% amplitude and 0.6 cycles shown in Fig. 1b. Sonication was performed for 45 min at 35 °C.

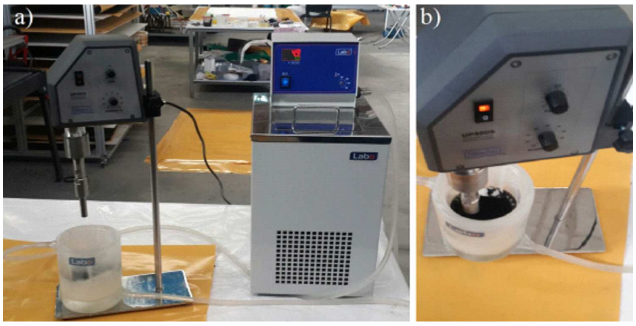

Fig. 1. (a) Cooling system and (b) homogenization of nanoparticles.

Epoxy resin impregnated glass fabrics were left in a wet gel state. Epoxy resins unfilled, filled with 0.5 wt% MWCNTs and NCs 0.5 wt% were prepared and fabricated with woven glass fibers (330 g/m^2 in density). Firstly, prepreg fabrics were prepared as seen in Fig. 2a. They were allowed to rest for 10 days to make smooth interfaces removed from air bubbles. The waxed papers were used to avoid sticking prepregs with press jaws, as seen in Fig. 2b. Prepreg fabrics in wrapping papers were hot pressed at 6 bar pressure and 120 °C temperature and cured for 2 h, as seen in Fig. 2c. After manufacturing of composite plates, Fig. 2d, they were cut in the form of test samples by water jet, as seen in Fig. 2e, tensile and a fatigue test sample, Fig. 2f.

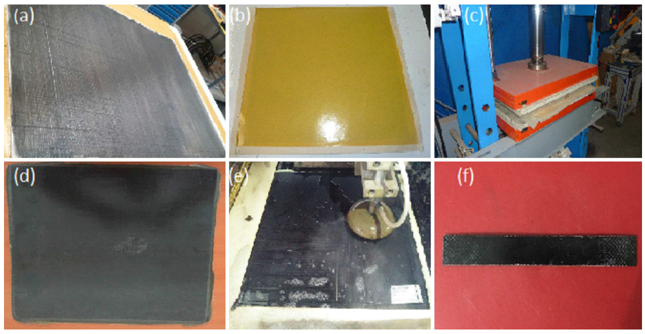

Fig. 2. Manufacturing of composite plates: (a) resin impregnation, (b) resin impregnated fabric 400 × 400 mm^2, (c) resin impregnated fabric hot pressed and cured, (d) composite plates (GF/epoxy/MWCNT) manufactured, (e) cutting with water jet, (f) a test specimen (GF/epoxy/MWCNT).

Figure 3 shows weight ratios of glass fibers and epoxy resing enhanced with MWCNT and NC for GF/epoxy/MWCNT, GF/epoxy/NC and GF/epoxy composite plates schematically.

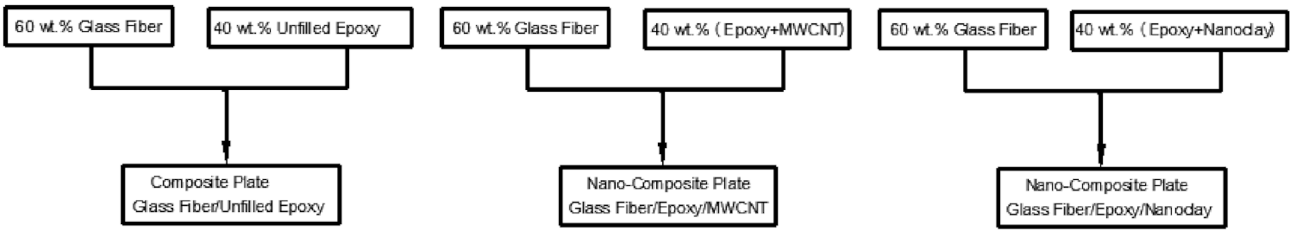

Fig. 3. Weight ratios of glass fibers and epoxy resin enhanced with MWCNT and NC.

Fatigue test samples were cut from composite plates manufactured in size of 400 × 400 mm^2 with longitudinal directions and, fatigue test, tension–tension were performed with Instron 8801 servohydrolic fatigue testing machines as shown in Fig. 4b.

2.1. Tensile testing

Tensile tests were performed according to the ASTM D3039 standards [10] with computer-controlled servo-hydraulic Instron 8801 tensile testing machine. Composite specimen was prepared as shown in Fig. 4a. Test speed was preferred as 0.5 mm/min. Axial strains were measured by video extensometer mounted on the testing machine. Mechanical properties obtained from tensile tests were presented in Fig. 5.

From Fig. 5a, the tensile strength of composite specimens were increased from 650 MPa to 779 MPa with addition 0.5 wt% of NC and also increased up to 795 MPa with addition 0.5 wt% of MWCNT. Additions of NC and MWCNT affected positively on the strength of composites. Elasticity modules of composite specimens increase from 42 GPa to 47 GPa with addition 0.5 wt% of MWCNT but decreased from 42 GPa to 41 GPa with addition 0.5 wt% of NC. The tensile strength increased by about 19% and 22%, whereas the modulus decreased by about 2% and increased by about 12% in the NC and MWCNT filled GFRP composite, respectively. Addition of MWCNT affects positively on the elasticity modulus whereas addition of NC affects negatively, as seen in Fig. 5b. Strain to failure of composite specimens was increased from 1.90% to 2.00% with addition 0.5 wt% of MWCNT and also increased up to 2.01% with addition 0.5 wt% of NC. The addition of nanoparticles increased the elastic deformation property of the composite material, as seen in Fig. 5c. The tensile test results of the

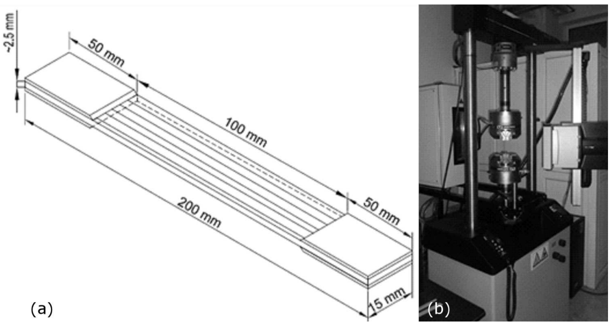

Fig. 4. (a) Specimen geometry tension and fatigue (b) tensile and fatigue test equipment (Instron 8801).

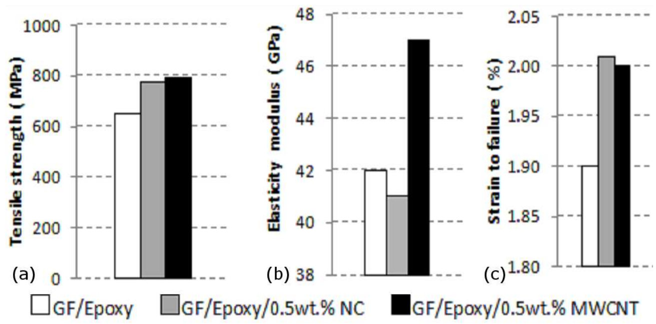

Fig. 5. Comparison of mechanical properties of GF/epoxy, GF/epoxy/NC and GF/epoxy/0.5 wtMWCNT: (a) tensile strength, (b) elasticity modulus, (c) strain to failure.

specimens were also shown in Fig. 6 as tensile stress and axial strain. All specimens showed linear elastic behavior up to failure. During failure, they fractured suddenly.

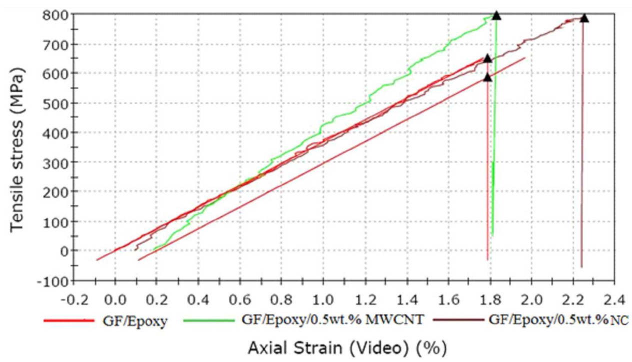

Fig. 6. A typical tensile-deformation graphs of composites (GF/epoxy, GF/epoxy/0.5 wt%MCNT, GF/epoxy/0.5 wt%NC).

2.2. Fatigue testing

Fatigue tests were performed according to the ASTM D3479M standards [11] with computer-controlled servo-hydraulic Instron 8801 tensile testing machine. Fatigue test specimens were also prepared as similar to tensile tests as seen in Fig. 4a. Fatigue tests were conducted at a stress ratio, $R = \sigma_{min}\sigma_{max} = 0.1$ with a sinusoidal waveform at a frequency, $\nu = 10$ Hz. All tests were performed at standard conditions of 24 °C and 50% humidity. Fatigue test results obtained under tension–tension loading, analysed in terms of the stress range of the load cycle against the number of cycles to failure, are shown in Fig. 7. For both 0.5 wt% NC and 0.5 wt% MWCNTs enhancement of GFRP composites improves the fatigue strength.

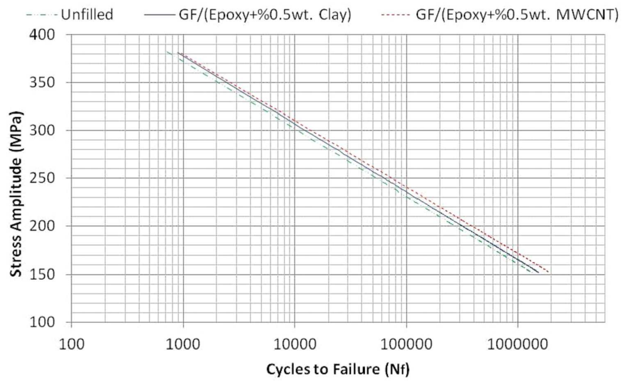

Fig. 7. *S*–*N* curves (log) of GFRP shows the increments in fatigue life by addition of nanoparticles.

3. Conclusion

In the present study, the effects of addition of NC and MWCNT fillers into epoxy matrix to mechanical properties and fatigue behaviour of glass fibre composites were investigated experimentally. The optimal GFRP content was 0.5 wt% MWCNTs, which produced the highest improvement in tensile and fatigue strength as compared to the unfilled GFRP. Composites manufactured with addition of 0.5 wt% MWCNT showed 22% improvement in tensile strength and 12% improvement in elasticity modulus. It is also clearly seen in Fig. 7 that, for a given maximum cyclic stress, the fatigue lives of the nanoparticle filled GFRP are greater than those of the unfilled ones. The fatigue life enhancement of about 10% and 20% with NC and MWCNT fillers is observed over the entire range of stress levels as seen at *S*–*N* curves in Fig. 7.

Acknowledgments

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