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INTERNATIONAL ADVANCED RESEARCHES and ENGINEERING JOURNAL

Journal homepage: www.dergipark.gov.tr/iarej

e-ISSN: 2618-575X

International Open Access

Volume 02
Issue 03

December, 2018

Research Article

On the effect of nano particle inclusion in fiber reinforced composite tensile and flexural behavior

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ARTICLE INFO

Article history:
Received 02 April 2018
Revised 17 April 2018
Accepted 18 April 2018

Keywords:
Composite
Epoxy
Glass
Graphene
Nanoplatelets Mechanic

ABSTRACT

This study aimed to investigate the effect of graphene nanoplatelets (GnPs) on the tensile and flexural properties of fiber reinforced composite material. For this purpose; an experimental study was conducted using composite materials which were manufactured with $[(0/90)_6]_s$ glass fiber and epoxy matrix by vacuum assisted resin transfer method. Glass fiber reinforced (GFR) epoxy composite plates were manufactured with various graphene nanoplatelets content such 0, 0.1, 0.25 and 0.5 wt% inclusion. Maximum tensile and flexural strength values were obtained in 0.1 wt% GnPs filled composites. After this weight content, decreasing trend in the strength values was observed. When fractured specimens were examined, failure modes were supported the test results also. Higher contents of GnPs were resulted as agglomeration in matrix mixture lead to impurities and stress concentrations, thus lower strength values were obtained in composite.

1. Introduction

In past few decades, fiber reinforced polymer composites (FRP) have attracted a great interest in material science and engineering applications because of their advanced strength and stiffness to weight ratios compared to conventional engineering materials. In FRP materials, material properties can be tailored by many processes like changing type of fiber/matrix material, fiber hybridization, stitching, z-pinning, adding particulate materials to matrix or fiber, etc. [1-7]. Unfortunately, poor fracture resistance of FRP composites has limited the usage area of these materials. Currently, composite modification by using inorganic nano particles has become a very popular research topic and incorporation of nano particle in matrix offers a significantly improved mechanical properties, thus has extended the limit of application area. Particularly, carbon based nano materials such as carbon nanotubes (CNTs) and graphene nano platelets (GnPs) have an important potential in this research topic. The main reason of this interest is their outstanding physical properties as large specific surface area, thermal/electrical conductivity and Young's modulus [8, 9]. In many studies, CNTs have proved their magnificent improvement in conductivity and toughness of composite material [10-15]. However, high cost of CNTs makes GnPs more favorable for tailoring process of FRP materials. GNPs are short stacks of individual graphite layers, a newly developed, lower cost material that generally increases the composite tensile strength [16]. Large specific surface of GnPs results larger contact area with polymer matrix and increases the stress transfer from matrix to nano particle. However, agglomeration problem arises in higher content of GnPs due to strong van der Waals forces [17].

In this study, researchers produced glass reinforced/epoxy composite samples at four different rates of inclusion of GnPs with the control sample. Tensile and flexural behaviors characterized with respect to GnPs amount of inclusion.

2. Materials and Procedures

2.1 Materials

Plain woven E-glass fabric with areal density of 202 g/m2 and epoxy resin (MOMENTIVE-MGS L285) and hardener (MOMENTIVE-MGS H285) were supplied from DOST Chemical Industrial Raw Materials Industry, Turkey. GnPs with a high purity of a purity of 99.5%, bulk density of ~ 0.05 g/cm3, 5 μm diameter, thickness of 5-8 nm and 150 m2/g surface area was obtained from Grafnano CSO, Turkey.

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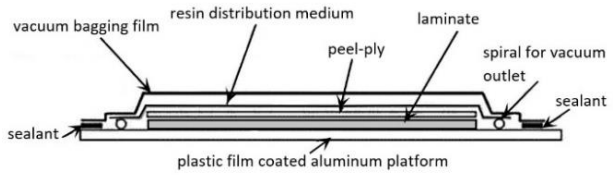

Figure 1. Schematic illustration of VARTM process.

2.2 Manufacturing process

The laminates were manufactured by vacuum assisted resin transfer method (VARTM) in Figure 1. Matrix phase was prepared by mixing the epoxy with hardener in the 100:40 weight ratio as well as different amounts of GnPs (0.1, 0.25 and 0.5 wt%). After epoxy was mixed with GnPs filler, the mixture was stirred by the help of homogenizer at 8000 rpm for 10 min to reach a good dispersity, then hardener was added, and stirred for 10 min. Twelve plies of glass fabric were cut into a certain size and laid by [0/90] lay-up sequence. During composite production, first ply was laid on to a thin release agent, and the resin mixture was distributed uniformly, the same procedure was repeated for each layer. Then peel ply and resin infusion mesh were laid on the fabrics. Finally, vacuum bag was sealed onto mesh. When the resin mixture impregnated, the composite material subjected vacuum under temperature of 45 °C for 1 h curing time and then left under vacuum for another 4-5 h under room temperature.

Table 1. Material properties

Material	Density	Thickness
Glass Fabric	202 g/m^2	0.15 mm
Graphene Nano Platelets	50 kg/m^3	5-8 nm
Epoxy Resin	1.18 g/m^3	-

2.3 Tensile Tests

To determine the effect of GnPs on the tensile behavior of glass fiber reinforced composite, uniaxial tensile tests were conducted at room temperature according to ASTM D 638 [18] standard. Shimadzu AG-x series universal testing machine with Epsilon Tech. 3542 axial extensometer was used in the experiments. Specimens in Figure 2 were prepared in the dimensions of 165 x 13 mm with a gauge length of 50 mm.

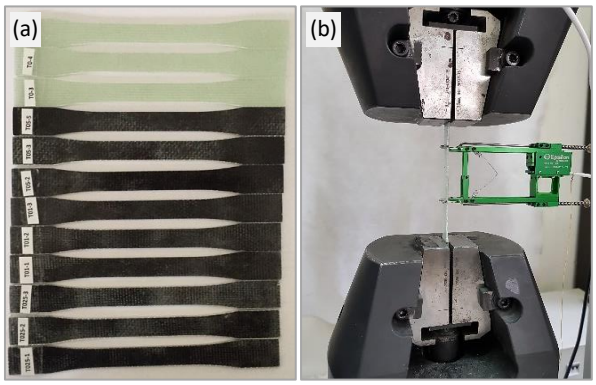

Figure 2. (a) Tensile test specimens, (b) tensile test set-up.

2.4 Flexural Tests

Three-point bending tests were performed following ASTM D 790 [19] standard using Shimadzu testing machine AG-X series (Kyoto, Japan) to determine the flexural properties of the prepared composite specimens. Specimens were cut in the size of 185 x 12.7 mm and the test was carried out at 3.6 mm/min crosshead speed according to Equation 1.

$$R = ZL^2/6d \quad (1)$$

where R is rate of crosshead motion (mm/min), L is support span (mm), d is depth of specimen (mm) and Z is rate of straining of the outer fiber (0.01).

Also, following equations [19] are adopted to calculate flexural stress (σ_f) and strain (ε_f) from test data using following equations:

$$\sigma_f = \frac{3PL}{2bd^2}\left[1 + 6\left(\frac{D}{L}\right)^2 - 4\left(\frac{D}{L}\right)\left(\frac{d}{L}\right)\right] \quad (2)$$

$$\varepsilon_f = \frac{6Dd}{L^2} \quad (3)$$

where P is the load at a given point on the load-deflection curve (N), L, b and d are the span (mm), width (mm) and depth (mm) of the specimen, respectively, D is the maximum deflection before failure (mm) and $\Delta P/\Delta x$ is the slope of the linear region of the load–deflection curve (N/m).

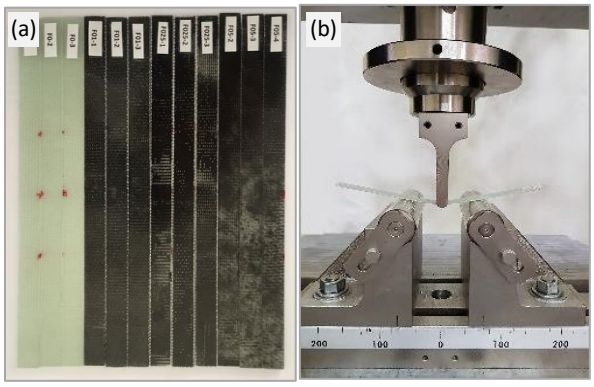

Figure 3. (a) 3-point bending test specimens, (b) 3-point bending test set-up.

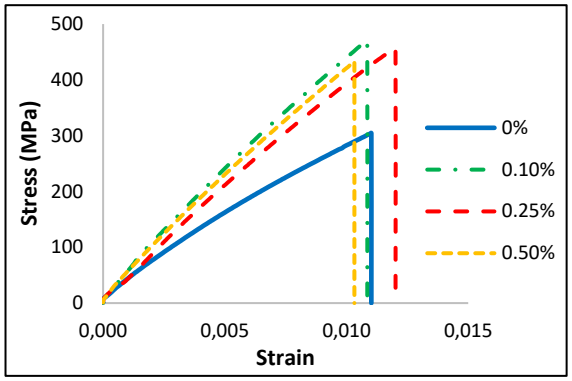

Figure 4. Stress-strain curves of test specimens.

3. Results and Discussions

3.1 Tensile Tests

To characterize the material under tensile load the strength, modulus and strain were recorded during experiments. The variation of tensile properties with varying content of GnPs were presented in Table 2, and stress-strain curves are displayed in Figure 4. The specimens have shown brittle behavior according to stress-strain curve and have increasing trend until 0.1 wt% in terms of strength and modulus. As seen in Table 2, tensile strength values were recorded as 304 MPa in control specimen, 471, 455 and 433 MPa for 0.1, 0.25 and 0.5 wt% specimens respectively. Enhancement in tensile strength values were measured as 54.9%, 49.67%, 42.43% in 0.1, 0.25 and 0.5wt% GnPs filled specimens respectively compared with control specimen. These considerable improvement is indicated that homogeneous dispersion of particle in matrix and successful load transfer between matrix/fiber interface. Previous studies [20-22] reported that up to a certain amount of graphene content, composite material shows better mechanical properties such as tensile strength, flexural strength and fracture toughness after that amount decreasing trend was reported.

At higher GnPs contents (0.25 and 0.5 wt%), a decreasing trend was recorded for tensile strength values compared to specimens with 0.1 wt% GnPs. These conclusions were attributed to agglomeration in graphene particles at high particle contents hence inhomogeneous particle dispersion and stress concentration in matrix material which can lead to crack initiation/propagation and consequently lower strength values in composite material [23-25].

Table 2. Tensile test results of test specimens

Nano Content (wt%)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Tensile Strain (%)
0, control	304	13.5	0.026
0.1	471	21.56	0.0255
0.25	455	18.46	0.039
0.5	433	20.42	0.0275

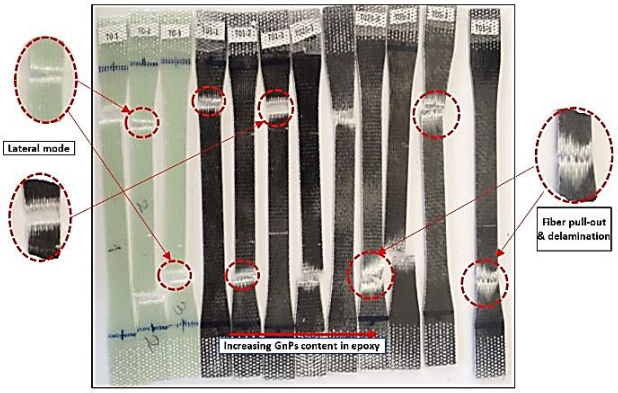

Figure 5. Failure modes of tensile test specimens.

Fractured specimens under axial tensile loading shown in Figure 5, the failure mode was formed in the lateral mode in 0, 0.1 wt% specimens, followed by damage in the mode of fiber pull-out with the delamination failure in matrix following the increasing amount of particle content. Delamination damage proves that the matrix/fiber bonding decreases as the content of particles in the material increases.

3.2 Flexural Tests

To characterize the produced material under bending moment, 3-point bending tests were conducted, force-displacement data were recorded for varying content of GnPs. According to the different additive contents, the flexural properties of the produced material are presented on the Table 3 and force-displacement curves of test specimens are given in Figure 5. Flexural strength values were recorded as 374.7, 662.5, 613.5 and 609.2 MPa for the control, 0.1, 0.25 and 0.5 wt% specimens respectively. Maximum enhancement in flexural strength was measured as 76.8% in 0.1 wt% and 63.7% in 0.25 wt%, 62.6% in 0.5 wt% test specimens compared with control specimen. As seen in the tensile test results, after 0.1 wt% GnPs content, decreasing trend was seen in terms of flexural strength compared to specimens with 0.1 wt% GnPs.

Fractured specimens under bending loading are shown in Figure 7, the failure mode was formed as fiber breakage in lower particle content, and then delamination failure in matrix following the increasing amount of particle content. Similarly, delamination damage proves poor matrix/fiber bonding at high content of particles in the material.

Table 3. Flexural properties of test specimens.

Nano Content (wt%)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Flexural Strain (%)
0, control	374.7	15.69	0.023
0.1	662.5	23.32	0.0284
0.25	613.5	21.98	0.0279
0.5	609.2	23.16	0.0263

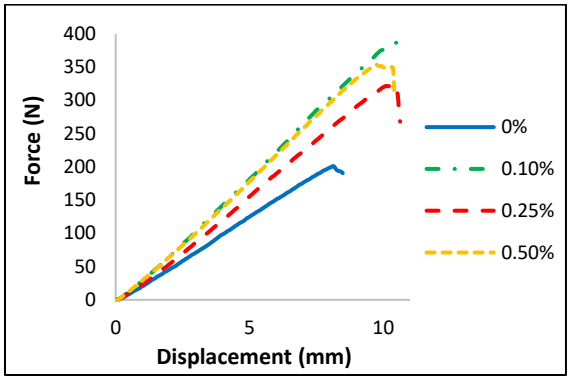

Figure 6. Force-displacement curves of test specimens.

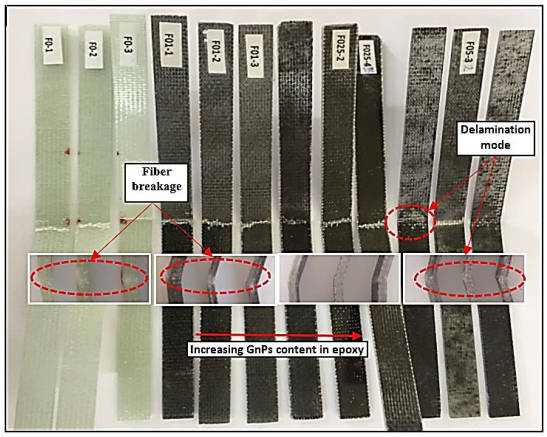

Figure 7. Failure modes of 3-point bending test specimens.

4. Conclusions

This work investigated the effect of GnPs inclusion on the mechanical properties of GFR epoxy composites. The results were revealed that addition of GnPs particles resulted as better mechanical properties in terms of tensile and flexural strength. Particularly, GnPs content of 0.1 wt% was resulted maximum enhancement in strength values compared to control material. Maximum enhancement was 54.9% in tensile strength and 76.8% in flexural strength value. After this filler content, decreasing trend was observed, but these strength values were also found to be higher than control sample values. In addition to the obtained strength values, it was evaluated that after the examination of the photographs of the fractured surface, the filler in the samples caused a decrease in fiber-matrix bonding and stress concentration in matrix due to agglomeration after 0.1 wt% of the GnPs filler content. This work has shown that a significant improvement in the tensile and flexural strengths of the glass fiber/ epoxy composite material at a certain filler content can be achieved.

Nomenclature

GnPs : Graphene nanoplatelets
FRP : Fiber reinforced polymer
GFR : Glass fiber reinforced
CNTs : Carbon nanotubes

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