

A strategy for enhancing shear strength and bending strength of FRP laminate using MWCNTs

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Abstract: Multi-wall carbon nanotubes (MWCNTs) promises to enhance mechanical properties exceptionally when it is doped with fiber reinforced polymer (FRP) composite. Glass fiber symmetrical laminate with eight layers of 4.0 mm thickness was fabricated by hand lay-up technique assisted by vacuum bagging method. Ply orientations for symmetrical laminate used [(0,90)/(+45,-45)/(+45,-45)/(0,90)/(90,0)/(+45,-45)/(+45,-45)/(90,0)]. MWCNTs reinforced three different samples (0 wt. %, 0.5 wt. % and 0.75 wt. % by weight) were tested on universal testing machine (UTM). Short beam strength test and inter laminar shear strength (ILSS) calculation have been done according to ASTM D2344 and ASTM D7264. UTM having maximum load capacity of 50 KN with loading rate of 0.1 mm/min to 50 mm/min was used for mechanical testing. Testing results justified that by adding 0.50 wt. % MWCNTs in symmetrical GFRP laminate can enhance inter laminar shear strength by 13.66 % and bending strength by 44.22 %.

1. Introduction

Carbon nanotubes (CNTs) offers extra ordinary properties like mechanical, thermal and electrical properties [1, 2]. After the discovery of carbon nanotubes in 1991 [1] several researchers used CNTs for enhancing material properties in various aspects [3, 4, 5]. High strength, stiffness, light weight and versatile applications of glass fiber epoxy composite makes it perfect advanced structural material for aircraft, marine, automobile industries [2]. In FRP composites reinforcement carries high proportion of applied load as compare to matrix [6]. Mechanical properties of polymer composite depends on type of fiber (continuous, short, chopped etc.), fiber layup and fiber material (glass fiber, carbon fiber, Kevlar etc.). When fiber materials are mixed with epoxy and hardener as result we have fiber reinforced polymer laminates [6]. H. Saito et al [7] justified that thickness of laminate affect energy absorption in CFRP laminate plate. P. Costa et al [5] studied mechanical, thermal, electrical and electromechanical properties of CNT based composites.

Epoxy is commonly used matrix material for fiber reinforced polymer composites due to good mechanical and/or chemical features and suitability with most of fiber materials. The only limitation of epoxy is the brittle nature which is unfavourable for interlaminar properties. Addition of nanoparticles like CNTs have capability to eliminate this limitation remarkably [4]. Y. Iwahori et al [8] calculated static strength test to define mechanical properties of cup stacked nanofiber (CSNF) composites and found dispersion of CSNF in epoxy can improve mechanical properties. Zhou et al [9] concluded that by adding 2% of carbon nanofibers may increase ILSS by 23%, F. H. Gojny et al [10] in 2005 improved 20% inter laminar shear strength by adding 0.3 wt.% double walled CNTs. Z. Fan et al [11] researched on GFRP laminates fabricated by injection based double vacuum assisted resin transfer moulding (IDVARTM) process and concluded that by adding up to 2 wt% of OMWNT in GFRP laminates 33% improvement in ILSS is possible.



In this paper, multi wall carbon nanotubes (MWCNTs) were used as secondary reinforcing agent in order to enhance bending strength and shear strength of symmetrical GFRP composite laminate. GFRP composite plates were prepared by hand layup technique assisted by vacuum bagging at 650 mm of Hg pressure.

2. Material fabrication

MWCNTs were prepared in house facility using 'AC arc discharge' method of graphite electrode with high purity (figure 1) as reported previously [12, 13].

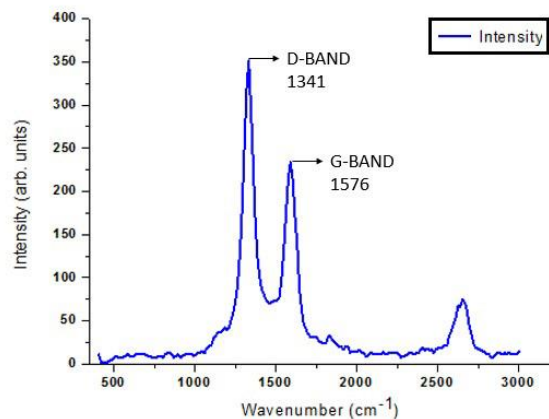


Figure 1 a. Raman testing of prepared MWCNTs

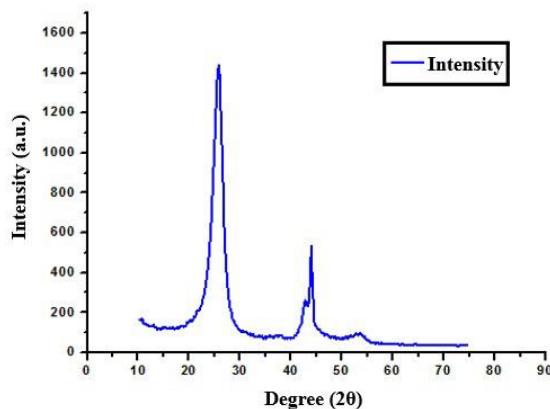


Figure 1 b. XRD plot

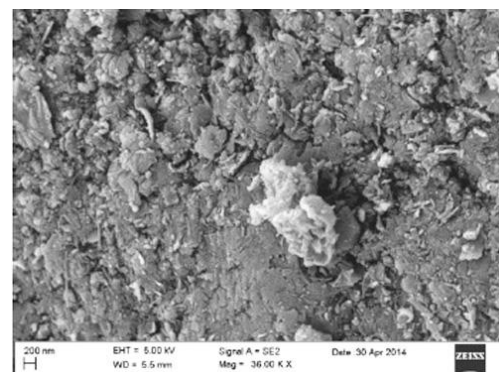


Figure 1 c. FE-SEM Image to show growth of MWCNTs

Glass fiber bidirectional woven of eight layers were cut in two different orientations as four layers of (0°/90°) and four layers of (+45°/-45°), in this way eight layered symmetric laminate [(0,90)/(+45,-45)/(+45,-45)/(0,90)/(90,0)/(+45,-45)/(+45,-45)/(90,0)] (shown in figure 2) was manufactured by hand layup technique assisted by vacuum bagging method at 650 mm of Hg. pressure.

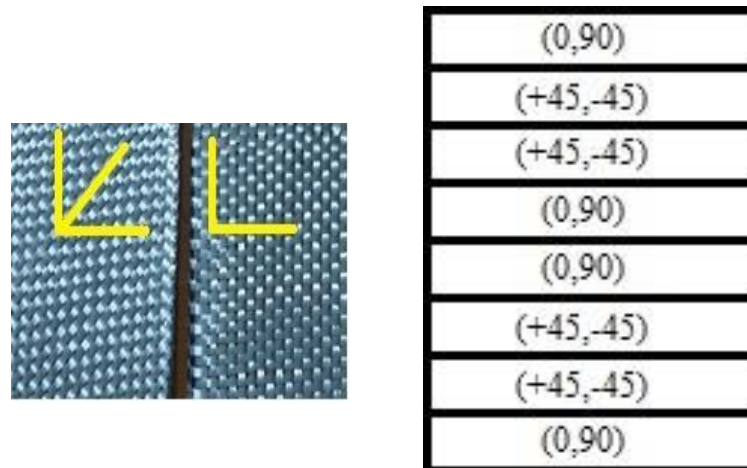


Figure 2. Glass fiber woven with (+45°/-45°) and (0°/90°) orientation with layup design

MWCNTs were mixed in epoxy (Bisphenol- A) using ultrasonic bath for 1 hr. and then hardener (K6) (manufactured by Atul Ltd., Balsad, Gujarat, India) mixed and further solution was mixed for 15 minutes using high speed hand stirrer at 1200 rpm. Epoxy and hardener were mixed in 10:1 proportions.

In order to prepare composite laminate glass woven sheet was kept on a flat surface and then adhesive resins were applied on glass fiber woven sheet using a brush. In next step second fiber layer was kept on first layer and brushing process was repeated. When two layers were combined to squeeze extra resin a heavy iron roller was rolled over wet woven surfaces. This process was repeated up to eight layers of proposed design laminate. As a final step to squeeze maximum amount of resins eight layered wet laminate was kept inside vacuum bag and 650 mm of Hg pressure was achieved using vacuum pump as shown in figure 3. This constant pressure was applied for 1 hr. and then pressure was released and heavy weights were applied for next 24 hrs. and curing was done in normal atmospheric conditions.



Figure 3. Vacuum bagging set-up

Seven different laminates were prepared for each type (i) neat epoxy GFRP laminate, (ii) GFRP laminate with 0.5 wt% MWCNT and (iii) GFRP laminate with 0.75 wt% MWCNT. Different samples were cut for ILSS testing and three point bending as shown in figure 4 a, b.

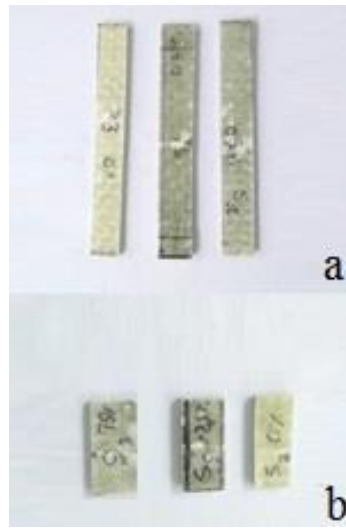


Figure 4. Testing samples for (a) three point bending and (b) ILSS

3. Testing Methods

Experiments were conducted on Hounsfield machine with maximum load carrying capacity of 50 KN and loading rate varied from 0.1mm/min to 50 mm/min. This machine is fully computerized UTM machine of DUCOM, Bangalore (India) shown in figure 5. Before performing experiments seven specimens for each case were cut from laminates. Specimen dimensions were considered according to ASTM standards ASTM D2344 for short beam shear strength test and ASTM D7264 for three point bending test of GFRP laminates.



Figure 5. UTM (Hounsfield) machine with bending test fixture

a. Short beam shear strength (SBSS) testing:

According to ASTM D2344 for a symmetrical laminate (laminate in which plies are identical above and below mid plane) inter laminar shear strength (ILSS) can be determined by using equation 1.

$$ILSS = \frac{0.75 P}{b \times h} \quad (1)$$

Where,

P = Maximum load observed during test (N)

b = width of beam (mm)

h = thickness of beam (mm)

Specimen Dimensions:

Thickness = 4 mm

Length = thickness X 6 = 24 mm

Width = Thickness X 2 = 8 mm

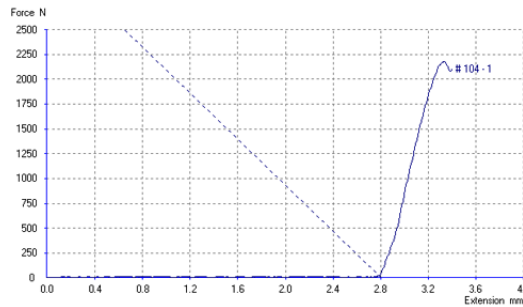


Figure 6. Graph for neat GFRP sample for ILSS test (F=2185N)

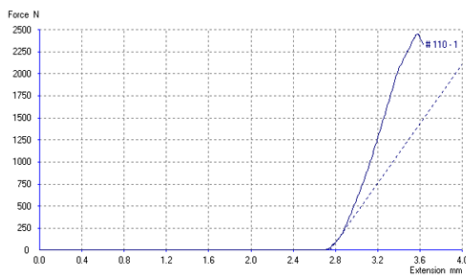


Figure 7. Graph for 0.50 wt% MWCNT doped GFRP sample for ILSS test (F=2434N)

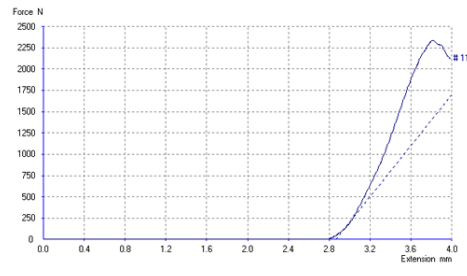


Figure 8. Graph for 0.75 wt% MWCNT doped GFRP sample for ILSS test (F=2330N)

b. Three point bending testing:

ASTM D7264 standard was followed for this testing procedure, specimen dimensions with 20:1 ratio was selected for testing. Maximum flexural stress or bend strength were compared on the basis of equation 2. Applied force (P) calculated by UTM machine and results were compared for investigating relative maximum flexural stress of all three samples i.e. GFRP neat laminate, 0.5 wt. % MWCNT reinforced GFRP laminate and 0.75 wt. % MWCNT doped GFRP laminate.

$$\sigma = \frac{3 PL}{2 bh^2} \quad (2)$$

Where,

σ = stresses at the outer surface at mid-span (MPa)

P = applied Force (N)

L = support span (mm)

b = width of beam (mm)

h = thickness of beam (mm)

Specimen Dimensions:

Support span (L) = 80 mm

Width of beam (b) = 13 mm

Thickness of beam (h) = 4 mm

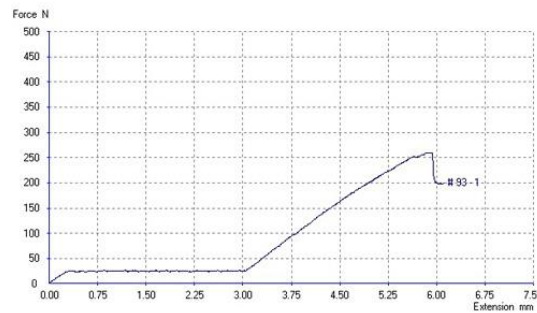


Figure 9. Graph for neat GFRP laminate for 3-point bend test (F=260N)

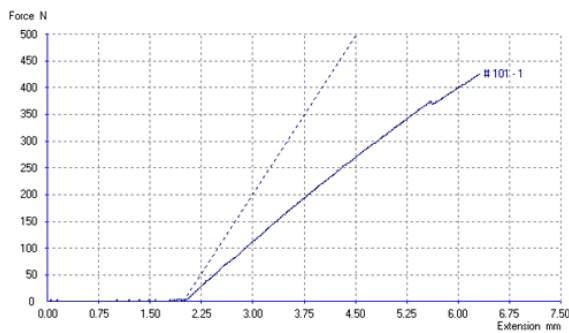


Figure 10. Graph for 0.50 wt% MWCNT doped GFRP laminate for 3-point bend test (F=375N)

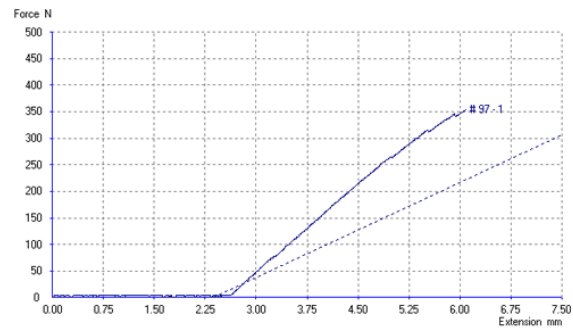


Figure 11. Graph for 0.75 wt% MWCNT doped GFRP laminate for 3-point bend test (F=314N)

4. Result and discussion

ILSS test provide accurate measurement of interlaminar shear strength of prepared GFRP laminates with and without MWCNT. Comparative testing of shear was done and it was observed that 0.5 wt. % of MWCNT have maximum improvement of 13.66% in shear strength. The main limitation of this method is specimen failure by other loading [14, 15] rather than pure shear, to avoid this drawback seven different samples were tested. SEM image (shown in figure 12) represents shear failure of matrix material from glass fiber. Based on all specimen testing final conclusions have been made to get optimum results. Interlaminar shear strength for pure GFRP was observed 51.21 MPa, 0.50 wt. % MWCNT doped GFRP has 58.21 MPa which is 13.66 % higher than neat GFRP laminate while 0.75 wt.% doped MWCNT GFRP laminate showed shear strength of 54.60 MPa. 0.75 wt. % doping enhanced ILSS by 6.60% but maximum improvement observed for 0.50 wt.% reinforced GFRP laminate.

Maximum flexural stress were also calculated, in order to find maximum possible augmentation by doping MWCNTs. In order to find maximum flexural strength maximum load capacity of specimen was calculated. This was done by performing three point bending test of GFRP laminate samples with and without MWCNTs. Fiber breakage and pattern of fiber fracture due to bending test are shown in figure 13 and figure 14. GFRP sample without MWCNT had bending strength of 150 MPa while 0.50 wt% MWCNT doped laminate showed highest bending strength of 216.34 MPa, this improvement was relatively 44.22% higher. While sample with 0.75 wt.% MWCNT doping had 20.76% improvement i.e. 181.15 MPa in bending strength as compare to neat GFRP laminate. Thus, for bending test similar results were observed i.e. maximum improvement in flexural stress was obtained at 0.5 wt% doping.

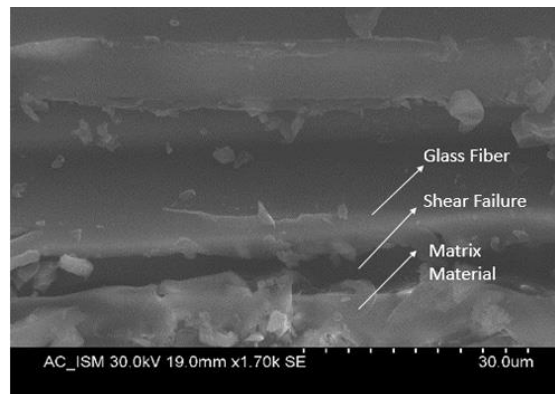


Figure 12. Shear failure in ILSS testing

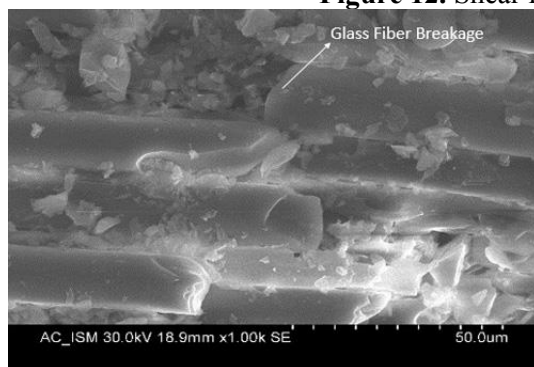


Figure 13. Fiber cracking in three point bending test

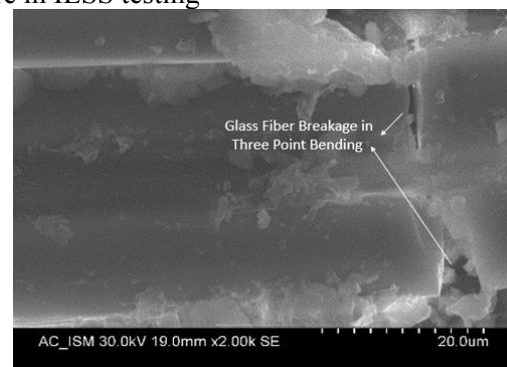


Figure 14. Fiber cracking pattern in three point bending

Conclusion

Experimental study was done in order to find out if we could enhance ILSS and maximum flexural strength of symmetric GFRP laminates beyond its natural limits. Literature review justified that it is possible to further enhance mechanical properties of FRP laminates by using carbon nanotubes. The main challenge was to find out an optimum value of MWCNT in order to get maximum improvement in ILSS and bending strength. In this research, a novel method is also proposed for fabricating MWCNT reinforced FRP composite laminates. The research finding of this work can be expressed as:

- It is possible to enhance ILSS and flexural properties of FRP composite by reinforcing MWCNT.
- 0.5 wt. % MWCNT reinforced GFRP composite showed highest improvement of 13.66% for interlaminar shear strength.
- 0.5 wt. % MWCNT reinforced GFRP composite had 44.22% higher bending strength as compare to neat glass/epoxy laminate.

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