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Flexural and Short beam shear strength analysis of symmetrical GFRP composites reinforced with MWCNTs having notches

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Abstract. The background of the work is experimental and micromechanical investigation of specimen samples having notch at a particular location from the central axis on Short Beam Shear Strength (SBSS) and Flexural strength of prepared Glass fiber reinforced polymer (GFRP) composites doped with Multi-wall carbon nanotubes (MWCNTs). The GFRP used is fabricated using hand lay-up technique assisted by vacuum bagging method and is symmetrical with eight layers of 4.0 mm thickness in total. The doping wt.% of MWCNTs used were 0 (neat), 1, 2, 3 and 4. The testing was carried out in Universal Testing Machine (UTM) using ASTM D2344 and ASTM D7264 standard samples for SBSS and Flexural strength test respectively. Test results show an increase in ILSS by 207.58% and Flexural strength by 63.82% respectively of samples with notches at 3 wt.% doping of MWCNTs. From the FESEM images the failure initiation and propagation could be observed for the different tests which are investigated in this experiment.

1. Introduction

In the recent years, Carbon nanotubes (CNTs) have become an important topic of study for many researchers. With their excellent mechanical, electrical and physical properties they are being widely used in many fields. Their application in aerospace industries [1], marine industries [2] etc. is immense. These can combine high Young’s modulus [3], tensile strength [3], stiffness [3-6] and flexibility [7]. The tensile strength and elastic modulus ranging from 50 to 100 GPa and 500 to 1000 GPa respectively, [3] along with small size (d= 1-50nm) and high specific surface area (SSA) up to 1315 m^2/g [8] make it a potential nanoparticle for composite materials. Glass Fiber Reinforced Plastics (GFRPs) are excellent composite materials which offer exceptional applications in aerospace, automotive industry [9], marine industries, shafts for golf sport [10], turbine blades [11] etc.. Its light weight, high specific strength, stiffness and extraordinary impact resistant properties [12] make it a centre of attraction for scientists. Among such benefits, the brittle nature of GFRP may limit its performance [13]. Therefore, it becomes important to modify the properties of GFRPs to enhance and widen its application areas.

The embedding of nanoparticle into polymer composites allows its properties to be enhanced. One such nanoparticle which holds the potential to modify and optimize the properties of GFRP is the

CNTs. Several articles have shown that a good dispersion of CNTs tend to improve the physical properties of composites [14, 15]. CNTs have shown to act as good toughening agents for different epoxies due to their high aspect ratio and mechanical properties [16]. Chandrasekaran et al. [17] worked on the Interlaminar shear strength of doped MWCNT in GFRP (epoxy) at 0.5 wt.% and found the strength of doped to be higher than neat specimen by 41%. Allaoui et al. [18] studied about the elastic modulus and yield strength and concluded that both doubled at 1 wt.% doped MWCNTs and quadrupled at 4 wt.% of MWCNTs doping in GFRP. Chang [14] investigated about the tensile strength and flexural strength and found that, both increased with the addition of MWCNTs to epoxy/FRP composite laminates. There was slight increase the tensile strength with increasing doping of MWCNTs. Gojny et al. [19] in his study with MWCNT contents of 0.1%, 0.3% and 0.5% by weight in GFRP, found that there is an increase in mode I fracture toughness with increasing doping. Lili et al. [20] made a comparative study of five different MWCNTs with different morphologies in terms of characteristics like diameter, length, surface morphology and improved the ILSS by 8.16%..

Despite so many articles stating the modification of composites using CNTs, none of them discussed the effect of doping CNTs in a particular notched area of composites. To transfer load from the matrix to the fiber more efficiently, an interface needs to be formed between the resin and the fiber fabric, which can happen if there is dispersion of CNTs in the thickness direction of the composite in the fiber fabric, which can lead to the interpenetration of those CNTs with the fiber fabric, that are preferentially oriented in between the glass fiber layers in the thickness direction.

The investigation here compares the ILSS and bending strength of the notched laminate specimen with the notch free laminate specimen at different weight percentages of MWCNT dopings. Additionally, the fracture initiation and propagation is studied under Field Emission Scanning Electron Microscopy (FESEM) and presented in this paper.

2. Materials, fabrication and processes

In this experimental investigation, the glass fabric (600GSM) is bi-directionally woven and is bought from M.S Industries, Kolkata, India. Bi-directional glass woven fabric was used as primary reinforcement bought from M.S Industries, Kolkata, India. It has a stacking sequence of $0^0/+90^0$, $+45^0/-45^0$, $+45^0/-45^0$, $0^0/90^0$ // $0^0/+90^0$, $+45^0/-45^0$, $+45^0/-45^0$, $0^0/+90^0$ as depicted in the figure 1. The MWCNTs used are purchased from United Nanotech Innovations pvt. Ltd,, Bangalore, India and has length of 1-10 microns, thickness of 5-20 nm and is 98% pure**.** An eight layered symmetrical design of MWCNTs/epoxy/GFRP is made with dopings of 0 (neat sample), 1, 2, 3 and 4 wt.% of MWCNTs in the resin. The MWCNTs used acts as a secondary reinforcement, which helps in enhancing the mechanical properties of the matrix. At first, the epoxy (Bisphenol-A) and MWCNTs are mixed using a probe ultrasonicator for 40 minutes, the unwanted heat produced is dissipated by keeping it in an ice bucket. The solution formed is mixed with a hardener (K-6, bought from Atul Ltd., Gujarat, India), in the ratio of 10:1, followed by sonication for 10 minutes. In the next step, the glass woven fabric layer is kept on a flat surface and then the mixture (resin) is applied on the fabric using a brush. The step is followed by placing another fabric layer over the first and the brush application process is repeated. Then, a heavy iron roller was rolled over the sandwich layer in order to squeeze out extra resins out from the wet glass woven surfaces. Similar process is continued till eight layers of proposed stacking sequence. The technique is then followed by vacuum bagging method at 700 mm Hg pressure in order to squeeze out extra resins from the prepared laminate, which is done by using vacuum pump. The pressure is applied continuously for 45 minutes and after releasing the pressure, the prepared laminate is kept in open atmosphere for curing for 24 hrs. with the application of heavy load.

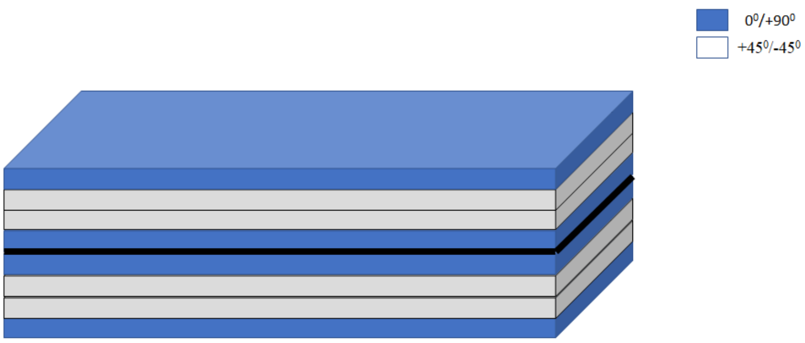


Figure 1. Ply stacking sequence of the laminate.

Seven different samples were prepared each for 0 (reference), 1, 2, 3 and 4 wt.% dopings of MWCNTs in GFRP as shown in figure 2 (a) and (b). The specimens were cut according to ASTM D2344 and ASTM D7264 for flexural and short beam strength respectively as depicted in the figure 3 and 4.The standardised samples were gripped in the Universal Testing Machine (UTM) fixture. The machine is fully computerised with load rate varying from 0.1 to 50 mm/min and maximum load carrying capacity of 50KN

Figure 2. Sample laminates of neat laminate composite for Short Beam Shear Test (a) without pre-crack (b) with pre-crack.

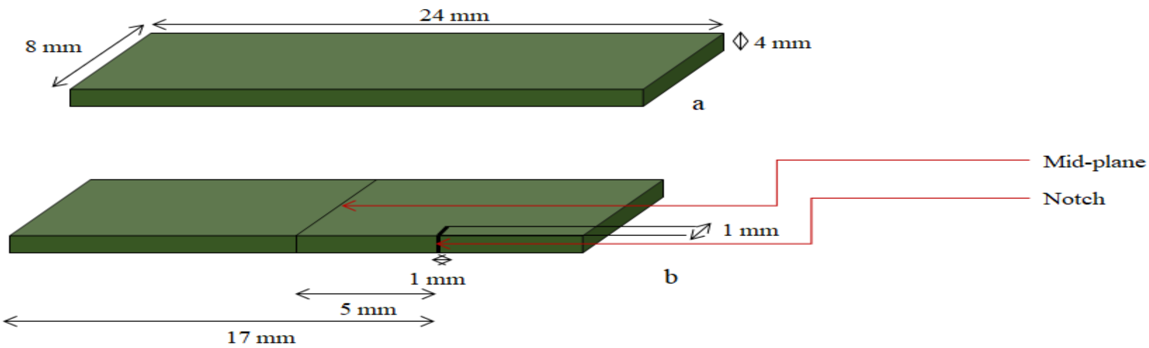


Figure 3. Specimen dimensions for Short-Beam Shear (SBS) test as per ASTM D2344

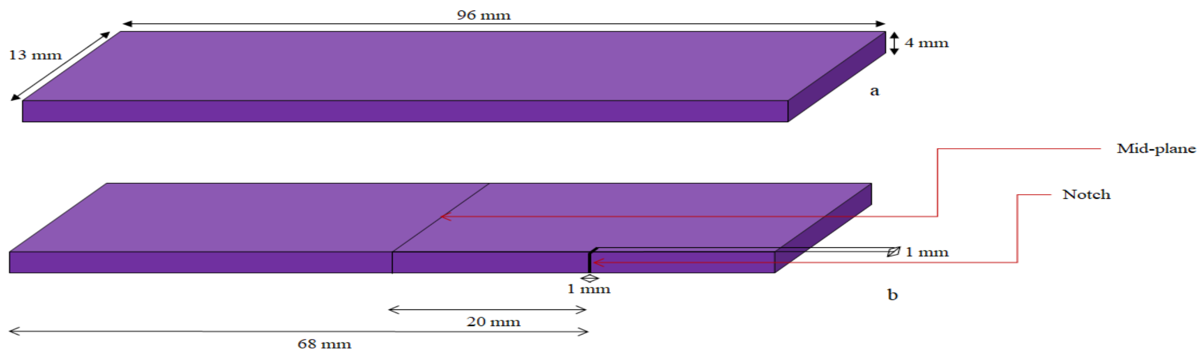


Figure 4. Specimen dimensions for Three Point Bend (TPB) test as per ASTM D7264

3. Testing

(a) Short Beam Shear Strength Testing (SBS)

The Inter Laminar Shear Strength (ILSS) for the symmetrical MWCNTs/GFRP laminate is calculated using the formulae in equation 1, as per ASTM D2344. The fixture setup for the test is shown in figure 5 (a) and (b). Then, the specimens are tested in Hounsfield UTM and graphs between Force and extension are plotted as shown in figure 6 and 7. A table is drawn to compare the ILSS of various wt.% of MWCNTs samples for both notched and un-notched samples (Table 1).

$$F^{*}=0.75 \times (P/(b \times h)) \qquad (1)$$

Where,

F* = ILSS or Short beam strength (MPa)

P = Max. Load observed during the test

b = Specimen width (mm)

h = Specimen thickness (mm)

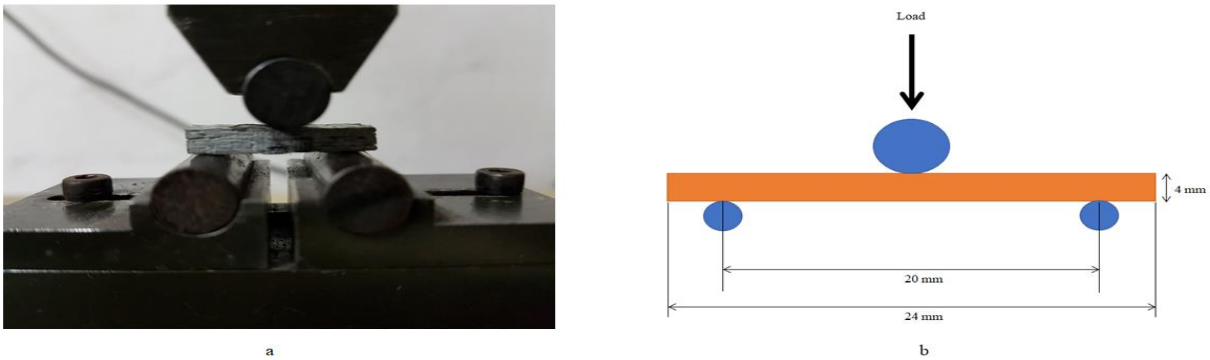


Figure 5: Fixture setup for short beam shear strength testing (ILSS) as per ASTM D2344

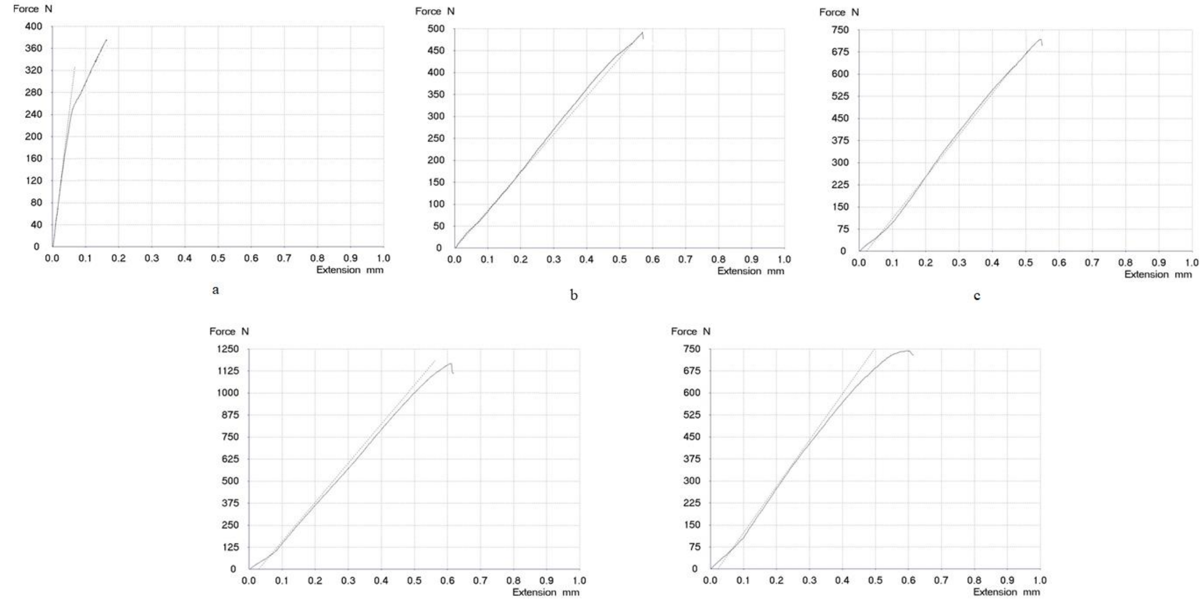


Figure 6: Graph between Load Vs. Extension of Short Beam Shear test for different MWCNTs dopings with pre-crack (a) 0 wt. % (reference), (b) 1 wt. % (c) 2 wt. % (d) 3 wt. % (e) 4 wt. %

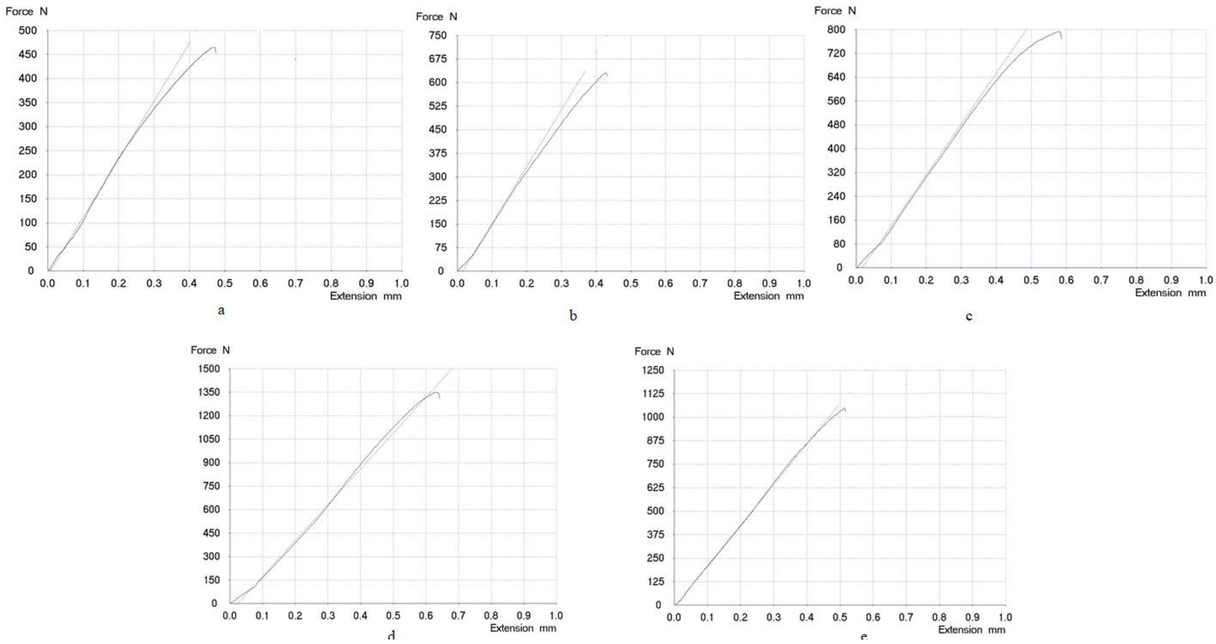


Figure 7: Graph between Load Vs. Extension of Short Beam Shear test for different MWCNTs dopings without pre-crack (a) 0 wt. % (reference), (b) 1 wt. % (c) 2 wt. % (d) 3 wt. % (e) 4 wt. %

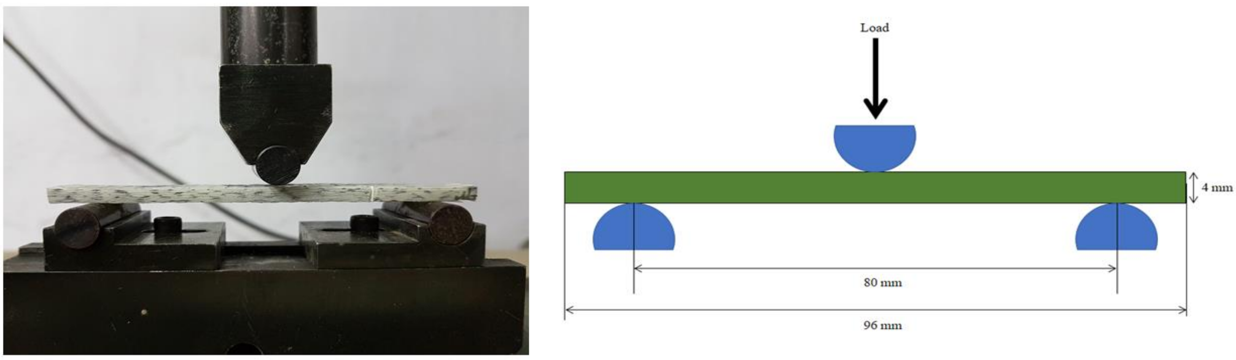
Table 1: Table representing the percentage reduction in ILSS of the pre-cracked specimen from that without pre-crack

MWCNTs doping(wt.%)	Maximum Load (N)		ILSS (F*) in MPa		% Reduction in strength
	With pre-crack	Without pre-crack	With pre-crack	Without pre-crack	
0	377.02	465.85	8.83	10.76	17.93
1	491.36	629.93	11.35	14.55	21.99
2	720.87	792.15	16.65	18.29	8.96
3	1175.93	1360.29	27.16	31.42	13.55
4	742.63	1053.62	17.15	24.33	29.55

(b) Flexural Strength Test (Three point bend test):
The maximum flexural strength was calculated using equation (2) using ASTM D7264. The support span length to thickness ratio is taken as 20:1 for testing purpose. The fixture setup for the test is shown in figure 8. Specimens are tested in Hounsfield UTM and graphs between Force and extension are plotted as shown in figure 9 and 10. A table is drawn to compare the maximum flexural strength of both notched and un-notched samples for various MWCNTs samples taken as shown in table 2.

$$\sigma^* = \frac{3 \times P \times L}{2 \times b \times h^2} \quad (2)$$

Where,
σ^* = Stress at the outer surface of mid-span (MPa)
P = Applied Load (N)
L = Support span (mm)
b = width of the beam (mm)
h = thickness of the beam (mm)



a b

Figure 8: Fixture setup for Flexural test (three-point bend test) according to ASTM D7264

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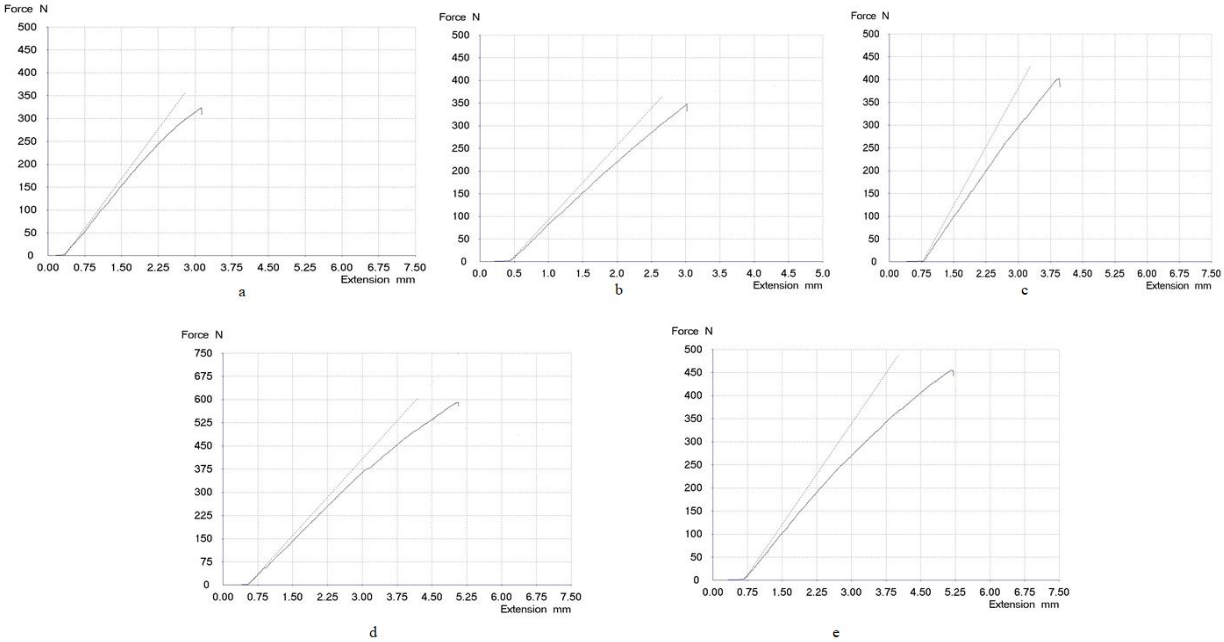

Figure 9: Graph between Load Vs. Extension of Three point bend test for different MWCNTs dopings without pre-crack (a) 0 wt. % (reference), (b) 1 wt. % (c) 2 wt. % (d) 3 wt. % (e) 4 wt. %

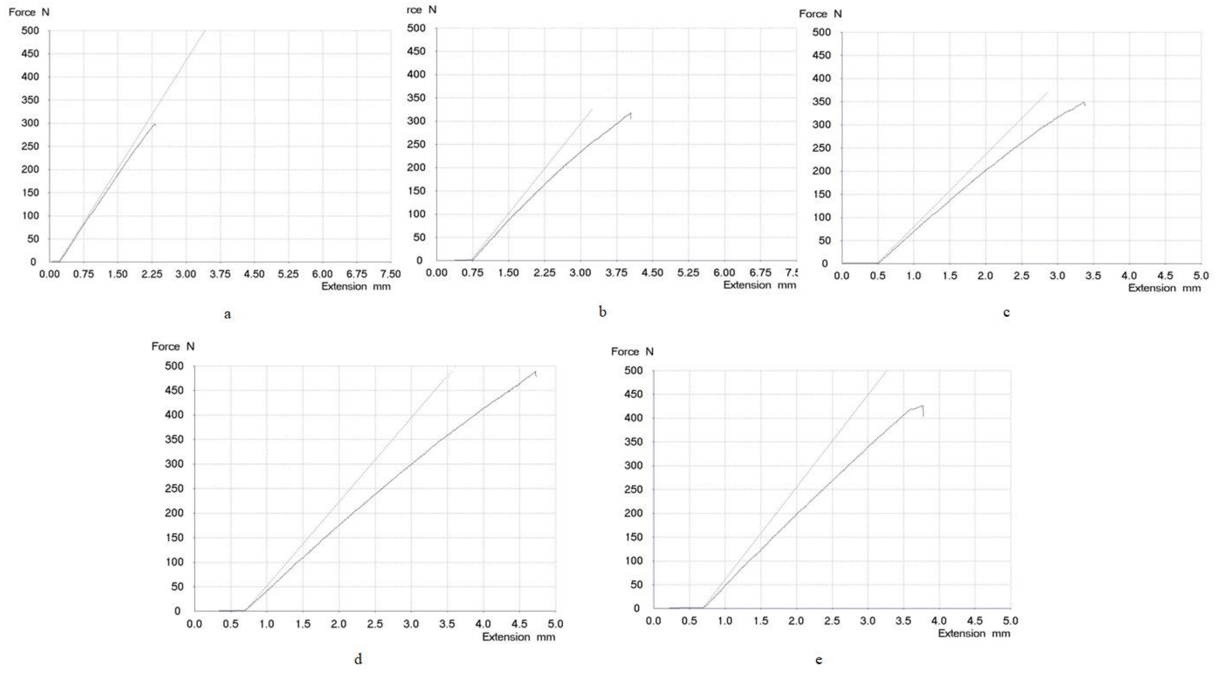

Figure 10: Graph between Load Vs. Extension of Three point bend test for different MWCNTs dopings with pre-crack (a) 0 wt. % (reference), (b) 1 wt. % (c) 2 wt. % (d) 3 wt. % (e) 4 wt. %

Table 2: Table representing percentage reduction in Flexural strength of the pre-cracked laminate from that without pre-crack

MWCNTs doping (wt.%)	Maximum Load (N)		Flexural Strength (max.) in MPa		% Reduction in strength
	With pre-crack	Without pre-crack	With pre-crack	Without pre-crack	
0	299.5	320.73	172.79	185.04	6.62
1	318.5	347.66	183.75	200.57	8.38
2	350.23	405.23	202.06	233.79	13.56
3	490.19	589.15	282.80	339.90	16.76
4	426.79	456.68	246.23	263.45	6.54

4. Results and discussion

In Short Beam Shear (SBS) test, there is continuous increase in the inter-laminar shear strength with increase in doping percentage, this is due to alignment of MWCNTs in the thickness direction [20]. As the doping value reaches 3 wt.%, the value of ILSS is maximum, this is due to the good dispersion of MWCNTs at this wt.%. The CNTs tend to form a bond between two adjacent layers in the laminate which strengthens the shear properties and increases load carrying capacity along shear direction. With further increase in doping value, the ILSS strength decreases due to strong attraction between CNTs which is known to be agglomeration. The samples with pre-crack carry stress concentration in them. The ILSS at 0 wt.% of the pre-crack is 8.83 MPa as compared to 10.76 MPa of the sample without pre-crack, thereby showing a percentage decrease of 17.93%. With further increase in the doping value of MWCNTs the value increases till 27.16 MPa of the pre-crack as compared to the 31.42 MPa of the sample free from crack. This shows that even if the specimen is levied to stress concentration previously, with increase in doping of MWCNTs the inter-laminar strength increases. With further increase in doping value the ILSS decreased to 17.15 MPa of the pre-cracked sample as compared to the 24.33 MPa of the defect crack free sample, the reason being agglomeration of CNTs at high doping values.

Flexural stress values were calculated which showed maximum augmentation upon doping MWCNTs in the matrix. Three point bend test was performed for the five different weight percentages. A similar pattern was observed in the flexural test, the flexural strength value increased from 185.04 MPa to 339.90 MPa with increasing doping percentage of MWCNTs from 0 to 3 wt.% of the laminates free from crack. A similar enhancement of flexural strength of laminates with pre-crack was observed from 172.79 MPa to 282.80 MPa with doping value increasing from neat to 3 wt.%. This shows that even in three point bend test, when Shear, tensile and compressive contribute to the failure of the laminate, the MWCNTs particles enhance the flexural strength of the composite of both types of laminates, The effect of doping CNTs dominates the effect due to previously present stress concentration by enhancing the properties along the thickness direction thus increasing the flexural strength. A drop to 246.23 MPa is observed of the pre-crack and 263.45 MPa without pre-crack, the reason being addressed to agglomeration.

The FESEM (Field Emission Scanning Electron Microscopy) images shown in figure 11 (a) and (b) show the different mechanisms of failure of the laminate of the Short Beam Shear test and the three point bend test respectively.

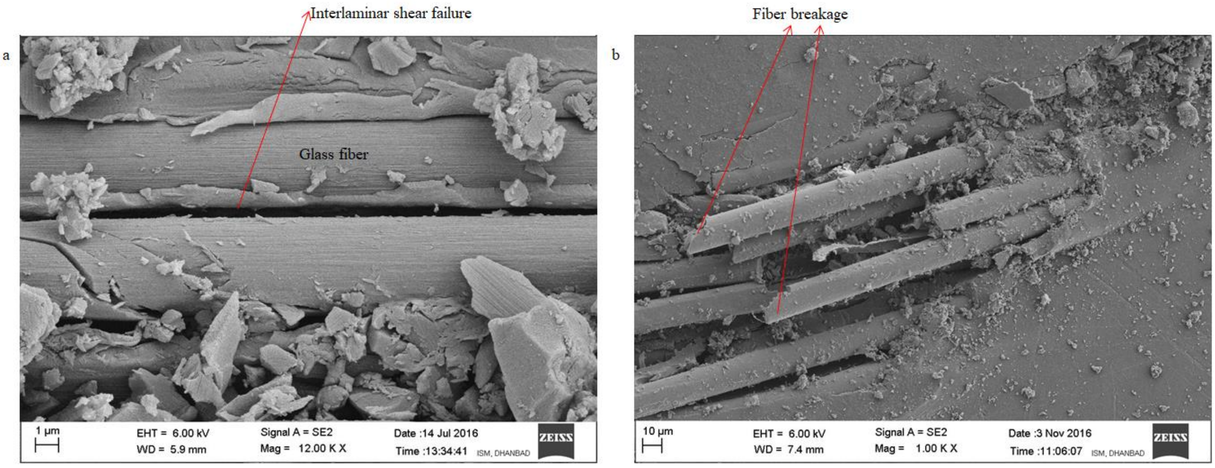

Figure 11: FESEM images representing failure mechanisms of (a) Short Beam Shear test (b) Three point bend

5. Conclusions

Experimental testing was conducted to find out the effect of doping MWCNTs on GFRP laminate specimens having pre-crack and without pre-crack. Two tests were conducted to (i) Short Beam Shear test and (ii) Three point bend test and the following results were drawn;

1. Both ILSS and flexural strength increased for notched and un-notched specimens till doping value of 3 wt.% MWCNTs.
2. Optimum balue of doping for ILSS and flexural test was observed to be at 3 wt.% of MWCNTs in GFRP laminate. ILSS value invreased by 207.58% and flexural strength by 63.82% for pre-crack sample
3. The value of both ILSS and Flexural strength dropped at 4 wt.% by 36.85% for pre-crack sample and 22.56% for sample without pre-crack sample and by 12.98% for pre-crack and by 22.56% for sample without pre-crack sample..
4. Doping MWCNTs in the pre-crack sample increased the ILSS and Flexural strength which shows dominancy of MWCNTs characterization over stress concentration.

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