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Evaluation of Interlaminar Toughness of Smart Laminate Composites: An Experimental Study

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Abstract: - Glass fiber-based composite materials are most popular nowadays in many industries such as aerospace, military, automobile, sports, etc. These materials have exotic mechanical properties and characteristics required for a structural component. Because of that, these materials are frequently and successfully used instead of other materials like steel, etc. In today's manufacturing industry, the basic requirements for the material are toughness, hardness, and stiffness together so that they can serve human needs. It should also be noted that composite materials constitute two or more components in the form of lamina and after manufacturing we get a new kind of material. The properties of these materials may vary from either of the components. Although these composite materials have good mechanical properties like strength, stiffness, corrosive resistance, fatigue life, wear resistance, light in weight, very good thermal conductivity and isolation, etc. one of the major problems with these materials is weak in shear. Therefore, the purpose of this study was to improve the interlaminar shear strength of the reinforced polymer by using carbon nanotubes (CNT) embedded in the layers with epoxy. CNT has a diameter of 20 nm and length of 940 nm, concentration of 0.50 wt.% mixed with epoxy to enhance the interlaminar shear strength (ILSS) of the composite material. The experimental study shows that the reinforcement of CNT into structural material like glass fiber reinforced polymer (GFRP) leads to improved shear strength of composites.

Keywords*:* Structural material, Carbon nanotube, Glass fiber reinforced polymer, smart composites.

1. Introduction

The enhanced specific mechanical properties of glass fibre-reinforced polymers (CFRPs) make them attractive for structural applications in the aerospace, civil as well as the defence industry. However, the effective use of these qualities necessitates a thorough understanding of both the mechanisms that cause composite failure and the associated strengthening mechanisms. Conversely, the breakdown of composite materials is a multifaceted event that might involve fiber breakage, matrix cracking, and delamination [1]. One important process that contributes significantly to the cumulative deterioration of a load-bearing composite structure is delamination, also known as interlaminar debonding. The early matrix cracks at shear discontinuities have a negligible impact on the composite's capacity to support weight [2]. Many research studies have presented numerous techniques and technologies of interphase bonding between reinforcing fiber and resin matrix, in order to effectively convey stress and improve the interlaminar adhesive strength of the composite laminates. To create high-performance composite laminates, high interfacial strength including transverse tensile strength or interfacial shear strength is necessary [3].

In order to enhance the interlaminar adhesive strength of the composite laminates, many authors have proposed various methods and technologies of interphase bonding between reinforcement fiber and resin matrix, in order to transmit stress effectively. High interfacial strength, including interfacial shear strength or transverse tensile strength, is essential for producing high-performance composite laminates. However, addition of carbon nanotube into GFRP may improve the shear strength of composites. Zhou et.al., [4] have studied the Fabrication and evaluation of carbon nanofibers filled carbon/epoxy composite found that by adding 2 wt. % carbon nanofibers (CNF) into glass fibre reinforced epoxy composites increased the ILSS by 22.3%. Fan et.al., [5] have studied the interlaminar shear strength of glass fiber reinforced epoxy composites enhanced with multi-walled carbon nanotubes and found that after adding 0.5 wt. % OMWNT (Oxidised multi-walled carbon nanotubes), 1 wt. % OMWNT, and 2 wt. % OMWNT the interlaminar shear strength (ILSS) values were improved by 9.7%, 20.5%, 33.1% respectively. Gojny et.al., [6] have studied about the influence of nano-modification on the mechanical and electrical properties of conventional fibre-reinforced composites and gained 20% improvement in ILSS by adding 0.3 wt.% double-walled carbon nanotubes into fibre reinforced epoxy composites. Boger et.al., [7] also got similar enhancement of ILSS, as well as electrical conductivity by using the double-walled carbon nanotubes. Zhu et.al., [8] have studied the processing and properties of polymer composites reinforced by functionalized SWNTs (Single-walled carbon nanotubes) and proposed an innovative way to create CNT/fiber/polymer composites by coating SWNTs on the surface of glass fibres before filling the mold with vinyl ester and got 35% enhancement in ILSS. Yokozeki et.al., [9] have studied the matrix cracking behaviours in carbon fiber/epoxy laminates and found that carbon fiber reinforced composites can benefit from dispersion of cup-stacked carbon nanotubes between fiber mats and these can delay the onset of matrix cracking. Siddiqui et.al., [10] have studied about Mode 1 interlaminar fracture behaviour and mechanical properties of CFRPs with nanoclay-filled epoxy matrix and found that adding organoclay nanoparticles increase both crack growth resistance and fracture toughness in carbon fiber reinforced polymer composites.

2. Objectives

From the above literature review based on glass fiber reinforced composites, it is observed that, the addition of carbon nanotubes into structural material can improve their strength and can be utilized for strengthening of structure or structural health monitoring. Towards this direction a lot of researches have gone over the past few decades. However, there is still some scope for improvement for investigating the effect of carbon nanotubes on the shear strength in glass fiber reinforced composites. Therefore, the purpose of this study was to improve the interlaminar shear strength of the reinforced polymer by using carbon nanotubes (CNT) embedded in the layers with epoxy.

3. Fabrication of smart laminate composites

The smart laminate composites are fabricated using glass fiber, carbon nanotubes (CNTs) and epoxy materials. To fulfil the objective of this study, the reinforced polymer composites are fabricated by using CNT embedded in the layers with epoxy. CNT having diameter of 20 nm and length of 940 nm was used. The concentration of CNT was 0.50 wt.%. In the present study, vacuum assisted hand lay-up technique was used for manufacturing the smart laminate composites. A brief fabrication procedure is listed here:

3.1. Applying the mould release agent

The specific size of mold has been prepared for testing purpose. After preparation of mold, it is heated and a release agent was applied for cleaning purpose. After that, considerable period of time was allowed for release agent to "set-up" or "flash off". Then buff with clean cloth repeat application (Particularly for first cycle). The same procedures should be done for alternating patterns that are going to be used. Curing the mould is done in this way.

3.2. Wet Lay-up process with Get Coat

Typically polyester, mineral filled (clays and carbonates), pigmented (different than mould colour), non-reinforced layer or coating is used. This produces decorative, high protective, glossy and coloured surface other than the mould colour, thus little or no additional finishing is required. One can do paint on, roll on, or spray on. Then allow gel coat to set.

3.3. Cutting the fabric materials

Fabric cutting should be done with extreme prejudice as the fibre is not tightly held and there is a chance of slipping of the fibre from their place. Figure 1 show the glass fiber reinforced polymer with different alignment.

(a) **(b)**

Figure 1: GFRP mat (a) $0^0/90^0$ (b) $0^0/45^0$

3.4. Weighing the resin materials

The resin should be weighed out in specified proportions to achieve desired resin content. Epoxy curing agents/hardener expressed in parts per hundred by weight of the epoxy resin or part by weight should be measured and mixed thoroughly with the resins. Resin content expressed as percent by weight is typically 25% - 35% by weight of the fibre volume. It depends on ability to wet out fiber, amount of resin bleeding out, during cure etc. There is a need to account for process waste like resin bleeding out, remaining on brushes, also dependent on size of part. Take quantity of resin components, in separate containers and thoroughly mix resin components. Tools generally used are containers, stirrers etc.

3.5. Apply the resin to fabric

Apply resin to fabric on mould surface or, preferably, wet out fabric with resin on separate surface and transfer to mould. Resin may be sprayed, poured or brush on, and spread with brush and/or squeegee. Applying resin on mould surface prior to laying of fabric facilities removal of entrapped air during compaction process in this case resin is forced up through the fabric along with the air which is trapped in. Applying resin to fabric on separate surface prevents resin rich and resin starved areas to be formed. General tools used are paint brush, spray equipment, squeegee etc. The fabrication of smart laminate composites is shown in Figure 2.

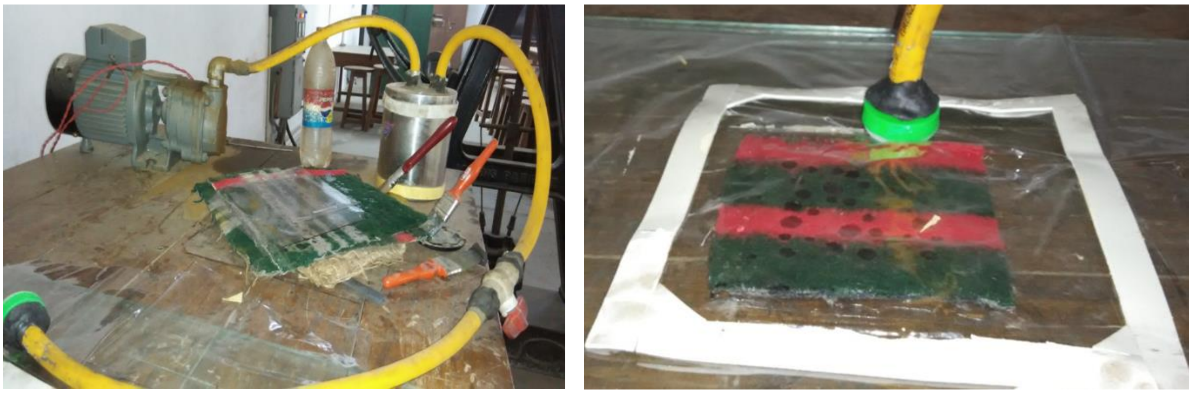


Figure 2: Fabrication of smart laminate composites

3.6. Compaction

Seal the setup with transparent sheet after covering the composite with "Bleed-off" fabric. This fabric will absorb excess of the resin if flowing. Apply the pressure using a vacuum pump with one way nozzle. After reaching the required pressure close the valve and keep the sample for curing. The smart laminate composite after curing is shown in Figure 3.

Figure 3: Smart laminate composite after curing.

4. Experimental Study

In the present study, MWCNT (Multi wall carbon nano tube) embedded GFRP (Glass fiber reinforced polymer) based smart laminate composite was fabricated using Vacuum Assisted Hand Lay-up technique. The layer was oriented in 0/90, 0/45, 0/45, 0/90 // 0/90, 0/45, 0/45, 0/90. In this study, the interlaminar toughness of MWCNT embedded GFRP was investigated thoroughly. A comparative study for effect of MWCNT was also done. For this purpose, “Short Beam Shear test” was conducted in which specimen was held over two cylindrical supports of diameter of 8 mm and one cylindrical head was moving downward at speed of 1 mm/min at mid span of the specimen to apply the load as shown in Figure 4. This test is almost similar to “Three Point Bend Test” but differs only in size of the specimen.

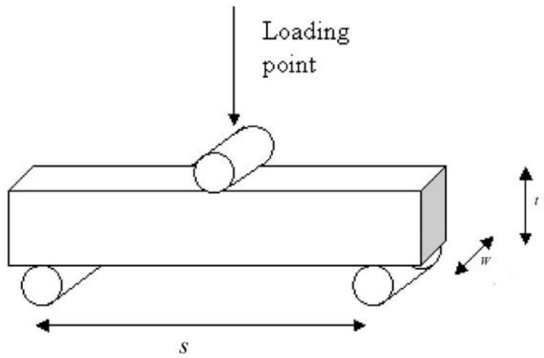


Figure 4: Short Beam Shear Test

4.1. Size of the specimen

The size of the specimen for “Short Beam Shear Test” should be small as compare to the specimen for “Three Point Bend Test”. The size of the specimen was taken as per ASTM D2344 in which length of the specimen was 25 mm, width 10 mm and thickness 3.6 mm. As per ASTM D2344 the span length between two cylindrical supports should be taken from $\frac{s}{t} = \frac{4}{1}$. The samples for experimental study with and without CNT are shown in Figure 5:

(a) **(b)**

Figure 5: (a) CNT embedded GFRP laminates, (b) GFRP base laminates

4.2. Test setup

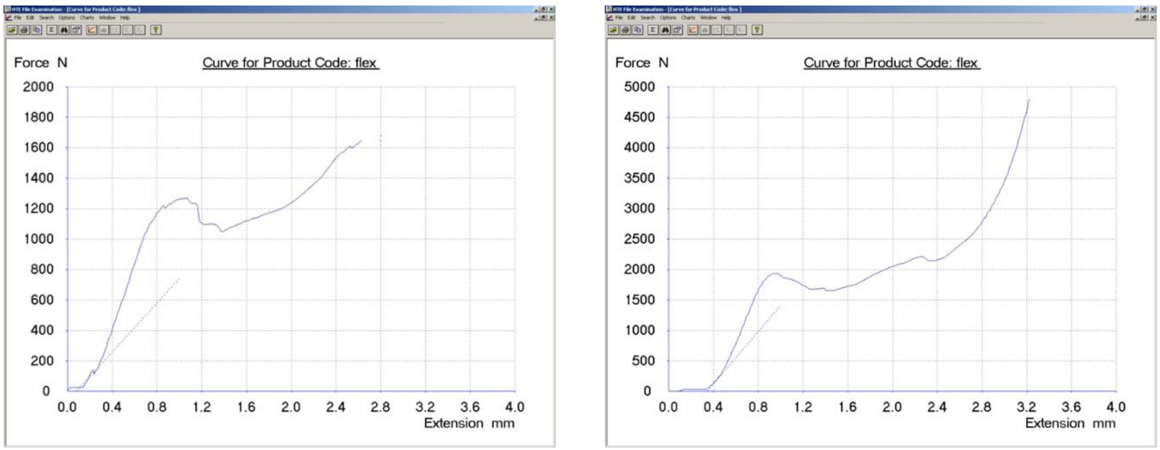
The test was conducted on HOUNSFIELD Universal Testing Machine. This electromechanical test machines are ideal for tension, bend and compression testing at forces up to 50 kN. Higher force capability and more test space provides increased testing versatility. The universal testing machine and experimental set up is shown in Figure 6.

(a) **(b)**

Figure 6: (a) Universal testing machine, (b) experimental set up

5. Results and Discussion

Short beam shear test of the specimen of GFRP based laminate and MWCNT embedded GFRP laminate tests were conducted using universal testing machine. At least four specimens were tested and average values of them was considered for the evaluation of strength. The relationship between load and deformation with and without CNT is shown in Figure 7. From the figure, it is found that with the addition of CNT into GFRP lead to increase the shear strength of GFRP composites.



(a) **(b)**

Figure 7: Experimental results with and without CNT

The shear strength of specimen with and without CNT is shown in table during the experimental study in table 1 and 2.

Table 1: Shear strength of specimen with CNT

Specimen	Width (mm)	Thickness (mm)	Max^m Load (N)	Shear Strength (MPa)
I	10	3.6	1860	38.75
II	10	3.6	1750	36.45
III	10	3.6	1800	37.5
IV	10	3.6	1700	35.41

Table 2: Shear strength of specimen without CNT

Specimen	Width (mm)	Thickness (mm)	Max^m Load (N)	Shear Strength (MPa)
I	10	3.6	1320	27.5
II	10	3.6	1350	28.125
III	10	3.6	1300	27.083
IV	10	3.6	1280	26.67

6. Conclusion

The interlaminar toughness of composite is very essential property to make it as a good structural component. The smart laminate composites were fabricated by reinforcing CNT into GFRP using vacuum assisted Hand Lay-up technique. After the fabrication of composite was cut into specific size. The stacking sequence of the material was [0/90, 0/45, 0/45, 0/90// 0/90, 0/45, 0/45, 0/90], which is symmetrical. The main conclusions of the experimental investigation of flexural analysis of glass fiber laminated composite material are as follows:

- After experimental analysis by doing "short beam shear test" of four different specimens of MWCNT (Multi wall carbon nano tube) embedded GFRP laminates, the average shear strength is found as 37.02 MPa, whereas the average shear strength of GFRP base laminates is found as 27.34 MPa. This shows that the interlaminar toughness of GFRP laminates is enhanced after MWCNT impregnated in the interlayer.
- Addition of CNT into GFRP may lead to increase the shear strength of composites.
- It was noticed that the interlaminar shear strength of the specimen with MWCNT embedded in the layer was improved by 35%.

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