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Exploration of Nano Fillers (Multi Walled Carbon Nano Tubes and Graphene Powders) in the Reinforcement of Epoxy/Glass Fibre Polymers (GFRP)

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Abstract*: *Variations in the mechanical properties of the glass fibre reinforced polymers were seen when exploring nano fillers such as Multi Walled Carbon Nano Tubes (MWCNTs) and graphene powders for reinforcement. GFRP composites when fabricated with increase in percentage weights of MWCNTs and graphene get better interfacial bonding with the matrix. Nano fillers improve the performance of the composites. This paper deals with the examination and experimental investigations carried out for the prediction of the enhancement of mechanical properties on GFRP reinforced with MWCNTs and graphene powders. GFRP composites were fabricated with variations in the amount of nano fillers in percentage weights of 2%, 4%, 6%, 8% and 10% wt. MWCNTs and graphene powders. The method used for reinforcement of resin with nano fillers was ultrasonication method meant for avoiding voids. A tendency for the mechanical properties to deteriorate was observed when nano fillers added were beyond certain weights of MWCNTs and graphene powders. This could be due to the agglomeration of nano fillers that change the fibre/matrix interface. Graphene nano fillers opts to be better compared to MWCNTs since the fabricated graphene reinforced glass fibre specimens have a better performance than GFRP specimens reinforced with MWCNTs.

Keywords* : *Nano fillers, MWCNTs, Graphene, Glass fibre reinforced Polymers.

I. INTRODUCTION

Extensive use of GFRP composites are seen in sports equipments and aircraft engine blades due to their high strength and fracture toughness. Rathinasabapathi et al [1] have explored the use of nano fillers and predicted an increase in the mechanical properties of fibres reinforced at suitable weights. Mostefa Bourchak et al. [2] have studied the impact of nano particles when added to GFRP specimens that led to an increase in fatigue strength. Dinesh kumar Rathore et al. [3] tested the flexural behaviour on epoxy/glass fibre composites filled with carbon nano tubes (CNTs) and found the yield of higher modulus and strength with addition of 0.1% wt. of MWCNTs. G K Arun et al.

[4] investigated GFRP specimens added with nano fillers and found GFRP specimens doped with nano fillers tends having a better strength with low weight and resistant to wear. P.S.Shivkumar Gouda et al. [5] have compared the usage of nano fillers with glass fibres and found experimentations with graphene having a smaller effect on fibre pull out and formation of voids. Pin-Ning Wang and Ming-Chuen yip et al. [6] made a study of nano fillers such as MWCNTs and graphene powders and found entanglement of the gap between the interlayers and acting to suppress or deter the crack propagation in the composite specimen. Ultrasonicatior is used for a good and better dispersion of nano fillers with epoxy resin. Mostefa Bourchak et al. [7] found enhancement in the fatigue strength and the fatigue life which was thrice that of neat GFRP. There was an increase with a suitable increase in the weight of graphene with fibres. Swetha chandrasekaran et al. [8] experimented with composite specimens reinforced with graphene and found a better adhesion of Nano fillers with in GFRP specimens following an increase in filler loadings. The objective of this study is to examine the mechanical properties of glass fibre epoxy polymers reinforced with multi walled carbon nano tubes and graphene powders with an appropriate weight percentage through investigation.

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II. EXPERIMENTAL METHODS

The materials used for the fabrication are listed below:
Standard bidirectional woven glass fibres were bought from Sakthi Glass Fibres, Chennai for fabrication of composite specimens. Multi walled carbon nano tubes (MWCNTs) with outer diameter of less than 8 µm, length of 10-30 µm and with a density of 0.15 – 0.35 g/cm^3 were used as received from Mahalakshmi Chemicals, Chennai. Graphene powder with 99.5% carbon, thickness of 6.8 µm, with a surface area of 150 m^2/g and APS of 15 microns was used as received from Mahalakshmi Chemicals, Chennai. Epoxy resin type Araldite LY556 bisphenol - A and hardener type HY951 was used to enable getting a good performance for encapsulation.
The composite specimens were prepared in a step by step manner as detailed below.

First the epoxy resin with suitable percentage weights of MWCNTs and Graphene powders were ultrasonicated for 1 hour at the highest speed for achieving uniform dispersion. Subsequently hardener was added for the solidification of the resin and stirred by an ultrasonicator for 50 minutes at a high speed. The epoxy resin reinforced with nano fillers was poured into a mould made of bi-directional woven glass fibre. At the end, the composite specimens reinforced with nano fillers were solidified through reduction to room temperature. Glass fibre composite specimens were reinforced with MWCNTs and Graphene powders with weight fractions ranging from 2% wt., 4% wt., 6% wt., 8% wt., 10% wt. Hand lay up method was used for the fabrication of the composite specimens. A rubber mould with standard dimensions 210x190 mm and fabricated with 4 layers of fibres and epoxy resin with the thickness ranging from 2.8 mm to 3.0 mm was used. They were cured at 155^{0}C for 45 minutes a 120 kN pressure and finally post cured at 90^{0}C for 12 hrs.

Various techniques were adopted for the characterization of the nano composites. A Universal testing machine was used for carrying tensile and flexural tests. ASTM D-638 standard was followed for cutting the specimen as per dimensions. Three identical specimens in each composition were fabricated and cut to test. The mechanical properties and average of three test results were obtained. For flexural test, the specimens were cut to dimensions of 140 mm x 15 mm x 3 mm following the ASTM D790 standard. The strength of the composite specimen in three point bending was expressed as the stress on the outermost fibres of composite specimens. Standard formulations were used for the computation of fracture toughness and flexural strength of nano filler reinforced GFRP specimens.

III. RESULTS AND DISCUSSIONS

Fabrication of glass fibre reinforced polymers was carried out by incorporating suitable weight fractions of multi walled carbon nano tubes and graphene powders. Mechanical properties were tested through various experiments in a universal testing machine under different loading conditions. The influence of various parameters that had an effect on the mechanical properties of GFRP is listed below:

A.Tensile strength of the composite specimen

The fabricated composite specimens were cut following the ASTM standards. The cut specimens were tested with the aid of computerised digital universal testing machine which associates software for recording the load and specimen extensions. Various parameters namely fracture toughness, ultimate tensile strength, Young's modulus and percentage elongation were found. A comparison in the matter of the mechanical properties between composite specimens reinforced with MWCNTs and Graphene powders have been depicted in a graph.

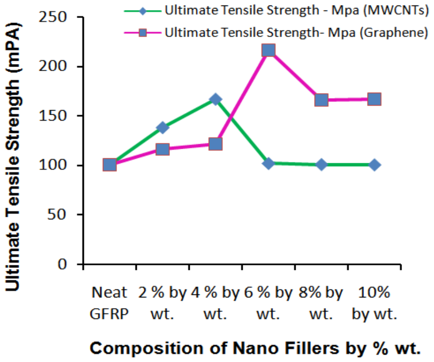

Figure 1. Ultimate Tensile Strength of Nano Fillers reinforced Glass Fibre Composites

Figure 1 shows the ultimate tensile strength of MWCNTs and graphene reinforced composite specimens. The ultimate tensile strength interpolated with respect to varying composition in % wt of MWCNTs and Graphene powders with GFRP is displayed. The composite laminate with 4% wt. of MWCNTs and 6% wt. of Graphene powder is seen exhibiting a higher tensile strength.

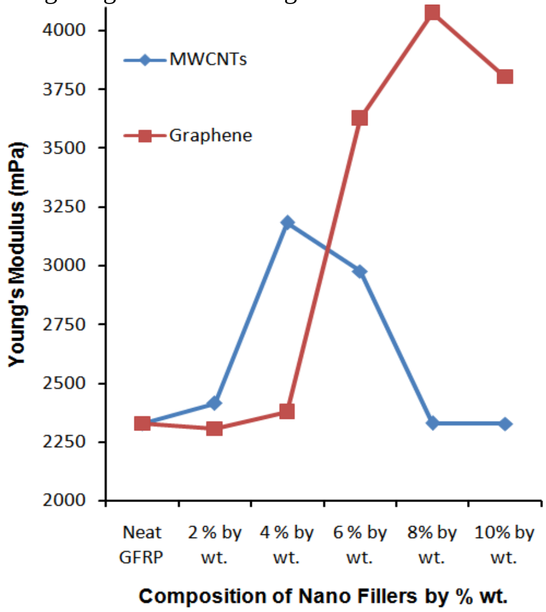

Figure 2. Young's Modulus of Nano Fillers reinforced Glass Fibre Composites

Figure 2 depicts the Young's modulus of MWCNTs and Graphene powders reinforced composite laminate plotted with respect to varying compositions in % wt. of Nano fillers. The composite specimen with 6% wt. of MWCNTs and 8% wt. of Graphene powder shows the highest Young's modulus. Irrespective of other mechanical properties, the young's modulus increases following an increase in the percentage weight of nano fillers.

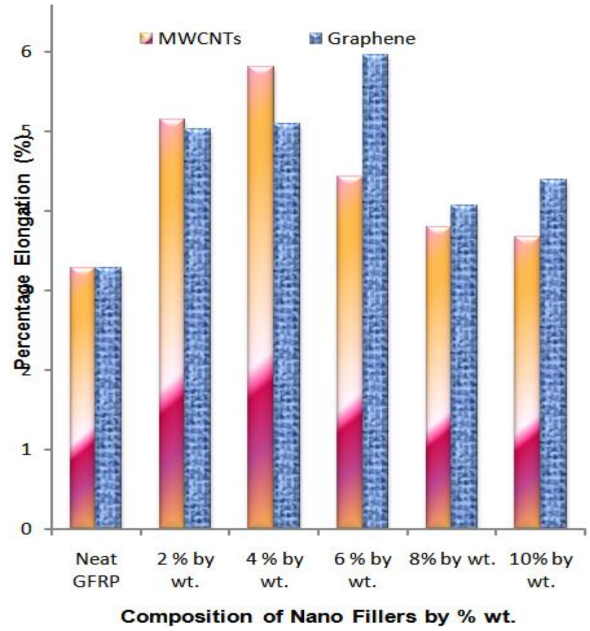

Figure 2. Percentage Elongation of Nano Fillers reinforced Glass Fibre Composites

Figure 3 depicts the percentage elongation of glass fibre composite specimen reinforced with nano fillers (MWCNTs and Graphene powders).

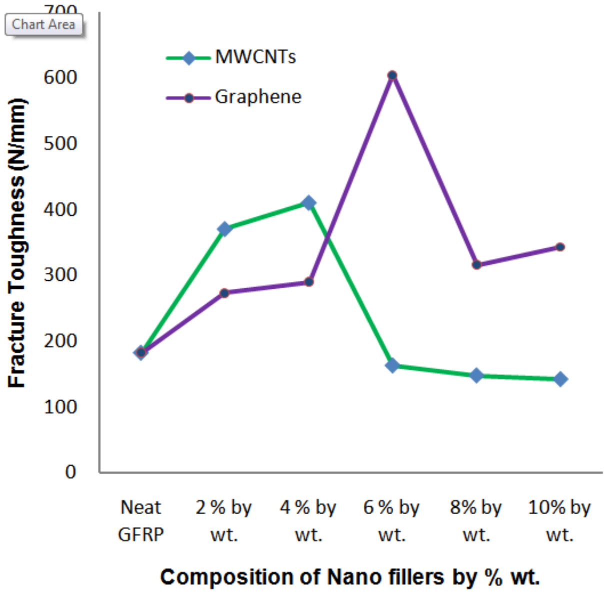

Figure 2. Fracture Toughness of Nano Fillers reinforced Glass Fibre Composites

Figure 4 shows the fracture toughness plotted with respect to varying percentage compositions of MWCNTs and Graphene powders. The major drawback in Neat GFRP (without Graphene) is its fracture toughness. Researchers have eliminated it through addition of suitable weight composition of MWCNTs and Graphene powders. Composite specimens on increase in the percentage weights of nano fillers, exhibited good mechanical properties. This could be due to dispersion of MWCNTs and Graphene powders with the epoxy resin in a homogeneous manner. Increase in Young's modulus exhibited the dominance of fibres. Nano reinforcement of glass fibres was enhanced by the presence of nano fillers.

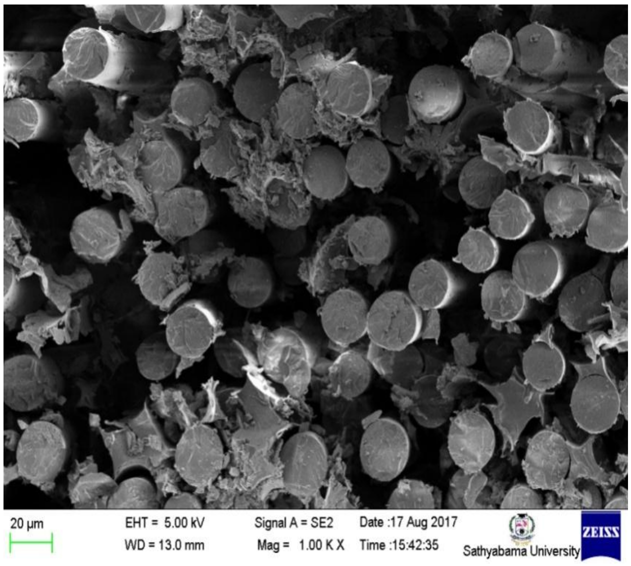

Figure 5.SEM image of GFRP specimen containing 4% wt. of MWCNTs

Figure 5 shows the SEM image of GFRP specimen containing 4% wt. of MWCNTs. It is clear from the SEM image that fibres have a good interfacial bonding with the matrix.

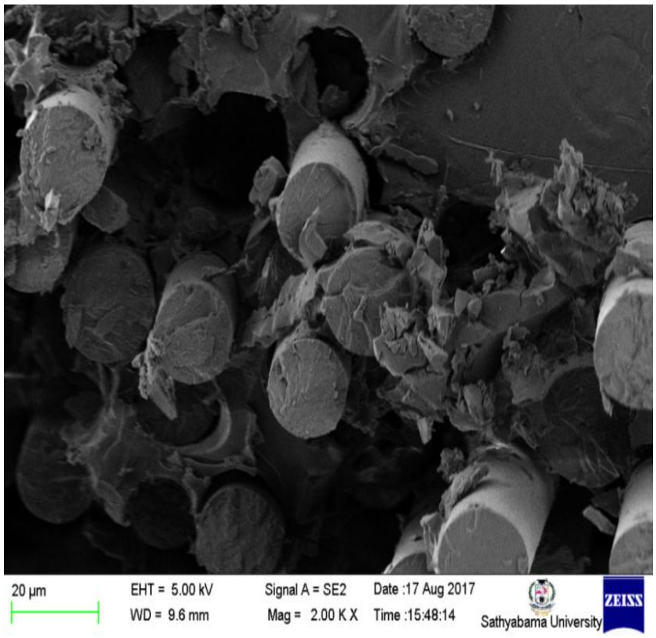

Figure 6.SEM image of GFRP specimen containing 6% wt. of MWCNTs

Figure 6 shows SEM image of 6% wt. of MWCNTs. Decrease in the tensile strength and other mechanical properties following an increase in the percentage weight of nano fillers beyond a certain limit can be seen. The percentage increase in nano fillers tends to increase viscosity leading to poor mixing with resin.

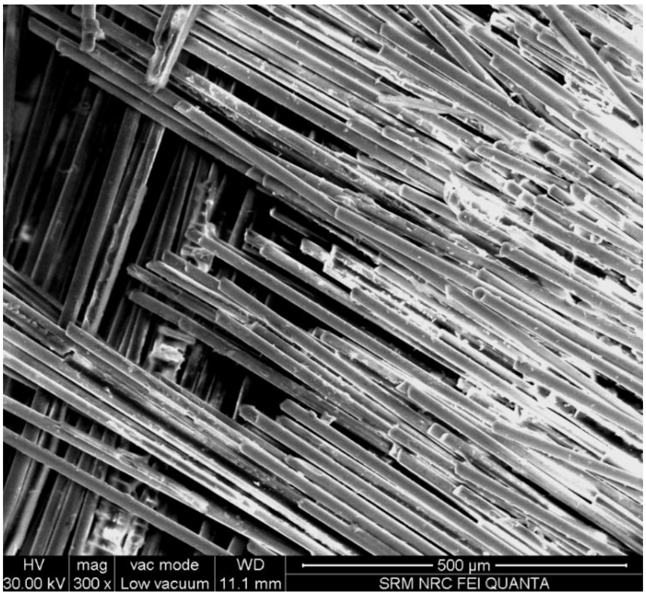

Figure 7.SEM image of GFRP specimen containing 6% wt. of Graphene

Figure 7 shows the SEM image of specimen containing 6% wt. of Graphene and the interface of nano fillers with resin and the matrix.

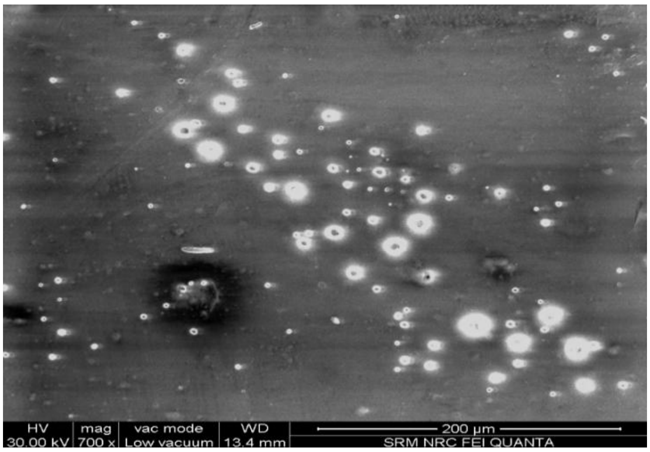

Figure 8.SEM image of GFRP specimen containing 10% wt. of Graphene

Figure 8 shows the SEM image of 10% wt. of graphene reinforced glass fibre polymer specimen. The nano voids formed can be seen as also the agglomeration in the specimen causing deterioration in the mechanical strength of composites.

B. Flexural strength of the composite specimen

Material stiffness can be evaluated by flexural test experimentation. Glass fibre composite specimens fabricated with varying % wt. of nano fillers were tested for measurement of flexural strength. A graph has been plotted for flexural strength with respect to varying % composition of MWCNTs and graphene powder. Modification in the matrix interface by addition of nano fillers can be seen is reflected in figure no.9.

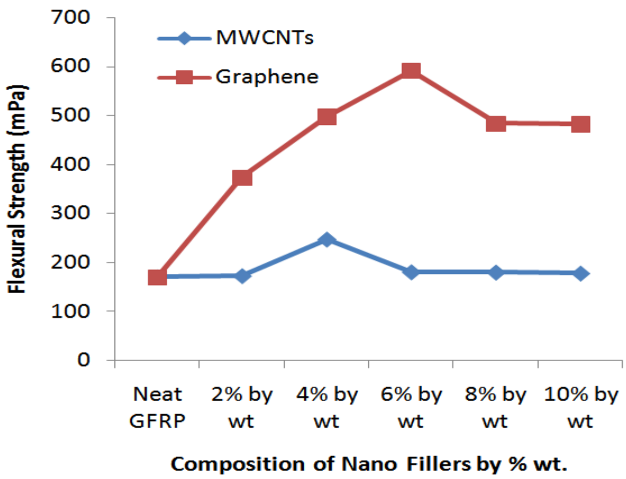

Figure 9. Flexural Strength of Nano Fillers reinforced Glass Fibre Composites

The figure depicts the composite specimens with 4% wt. of MWCNTs and 6% wt. of Graphene powder exhibiting a higher flexural strength. Nano fillers (MWCNTs and Graphene powder) receive the load transferred from the matrix and this, in turn anables active participation of Nano fillers in carrying the load. Homogeneous dispersion of MWCNTs and graphene powders into the resin imparts a stress transfer from the matrix to fibres. When the percentage weight of MWCNTs and graphene added are beyond a certain limit, these nano fillers agglomerate in a certain region of matrix causing non uniform transfer of stress along the composite laminates leading to a drop in the flexural strength.

C. Crystalline material (Graphene) identification by XRD

To predict the intensity of the crystalline material in each specimen X-ray diffraction analysis was used. The samples of graphene reinforced polymer composites were analyzed using XRD to identify the primary solid state structural information namely, the degree of cyrstallinity. The effect of various mechanical properties was known on the polymer formulation and processing in the presence of crystalline material (Graphene) with relative quantity. The degree of crystallinity is a primary mechanical property to enable fortitude of composites with accuracy. XRD aids in the recognition of crystalline polymers using the position and absolute intensities of crystalline phases in the polymer composite. Polymers are processed into fibres and composite films with crystalline material while the orientation of molecules is predicted using diffraction.

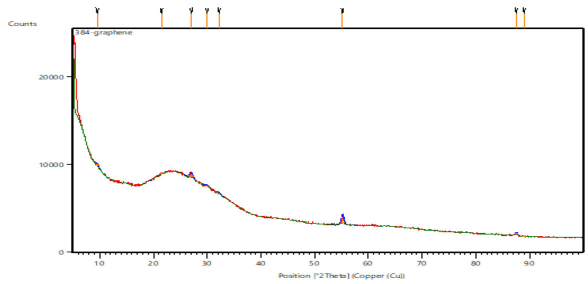

Figure 10. XRD image of Graphene Powder

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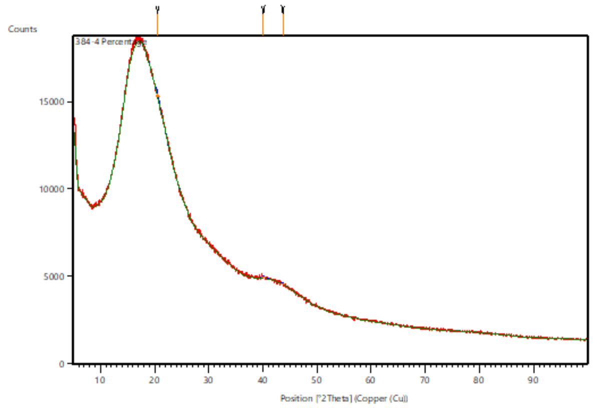

Figure 11. XRD image of GFRP + 4% Wt. Graphene

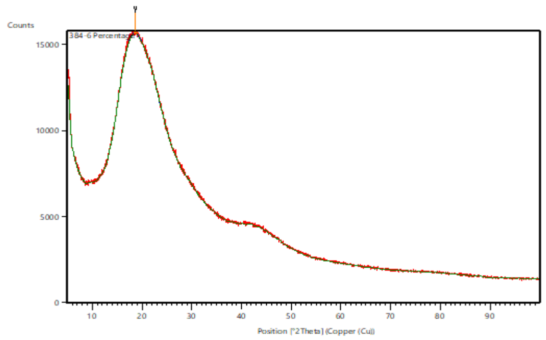

Figure 12. XRD image of GFRP + 6% Wt. Graphene

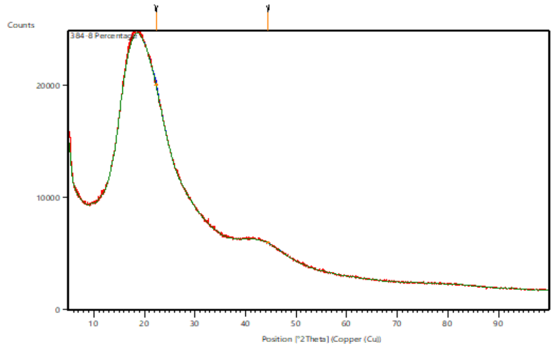

Figure 13. XRD image of GFRP + 8% Wt. Graphene

XRD pattern of pure Graphene powder was documented and used as an allusion for composition of different composite.

X ray diffraction patterns of GFRP/ Graphene (4%, 6%, 8 %) composite system are shown in Figure. The presence of crystalline behaviour is visible in the XRD pattern of the pure Graphene powder. The amorphous nature of composites is identified in the XRD images of Graphene wt by 2%, 4% and 6%. By increasing the Weight percentage of Graphene, the crystalline structure of the Polymer vanishes. Complete amorphous state of the composites can be seen in the curves with the absence of peak in the intensity versus 2θ. Indication of peak to peak in curve led to the inference of the formation of phase or phases in the composite during polymerization process. All the spectra for 4, 6, 8 % wt. Graphene reveal an amorphous halo in the low 2θ region. This is due to short-range order and indicating these composite films as amorphous. XRD pattern showed the semi-crystalline nature of composites.

IV. CONCLUSION

The glass fibre polymer composites with epoxy resin reinforced along with nano fillers (MWCNTs and Graphene powder) in varying compositions of 2% wt., 4% wt., 6% wt., 8% wt., and 10% wt. were fabricated using the ultrasonication method with minimum voids. Glass fibres doped with nano fillers exhibited a better performance than neat GFRP compared with various mechanical properties.

Experimental investigations showed the optimal characteristics in the mechanical properties of GFRP when MWCNTs and Graphene were added in suitable percentage weights. The composite laminates with 4% wt. MWCNTs and 6% wt. Graphene showed the most significant improvement in their mechanical properties showing the firm bond of the nano fillers onto the surface interface of glass fibres. The entire load was transferred from resin to nano fillers. This triggered improvement in various properties.

Mechanical properties such as tensile strength, young's modulus, flexural strength and fracture toughness get reduced on increasing the percentage weights of Multi walled carbon nano tubes (MWCNTs) and Graphene beyond 4% wt. of MWCNTs and 6% wt. of Graphene. A correlation observed could be due to voids in the resin and viscosity when ultrasonicated. A agglomeration of Nano fillers caused a change in the fibre and matrix interface. The Graphene nano filler reinforced polymer composites opts to be the best nano filler compared to MWCNTs reinforced GFRP due to their higher performative analysis when tested for various mechanical properties.

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