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The Mechanical Properties of Carbon Fiber Reinforced Epoxy Polymer Composites

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Abstract: Carbon Fiber Reinforced Polymer (CFRP) Composite Materials are Comes Under the Advanced Class Composite Materials, Are Commonly Preferred in Strategic Applications. However, the brittleness, air bubbles formed during the preparing of reinforcement resin, crack-prone matrix, and Fiber-matrix interface with a weak adhesion usually contribute to the failure of composite structures in terms of delamination and catastrophic failure. So, in the current work, Epoxy matrix CFRP composites are made using a hand lay-up process with varied amounts of Graphene Oxide (GO) (0%,0.25%,0.5%, and 1%) as a Nano Filler with Epoxy Polymer and nearly 90% of air bubbles are removed with the help of vacuum pump and desiccator. The samples will be Prepared According to the ASTM Standards and Tested Under Tension and 3 Point Bending Conditions. The maximum tensile strength, maximum flexural strength of 866.67MPa and 761.22MPa were observed for the 0.25%, 1% GO reinforced composites respectively.

Key Words: Composites, CFRP, Epoxy Resin, Carbon Fiber, Tensile test, Flexural test, Graphene Oxide (GO), Epoxy, Hardener

I. Introduction

Carbon Fibers (CF) are Fibers that are largely made up of carbon atoms and have a diameter of 5-10 Micrometres. Carbon Fibers are developed as the one of the prominent reinforcement materials used in the manufacturing of the high performance FRP composites for critical applications [1,2]. Carbon Fiber reinforced (CFRP) has the tremendous potential attraction as an emerging

structural material due to their high stiffness, high strength to weight ratio, low weight, Corrosive resistance, Chemically Stable, good electrically conductive, high temperature tolerance, and minimal thermal expansion, **Non-Poisonous [3-6].**

These aspects have made it widely used in aircraft, civil engineering, the military, motorsports, and other competitive sports. They are, however, more expensive than comparable Fibers such as glass or plastic Fibers. But the interfacial bonding that

exists between the untreated carbon Fiber and resin matrix is weak due to the significant surface inertia of the carbon Fiber, which is an inherent feature of material, which impacts the promising performance of composites materials with carbon Fiber.

The recent invention of two-dimensional hetero-structures has led to an interest in graphene and graphene oxide(GO) as potential additive to the CFRP Composites[7-9].Due to the distinct physical characteristics and Nano size ,GO is recognised as a particularly interesting alternative for reinforcing fillers in polymer composites[10,11].The edges and basal planes of GO are covered with variety of oxygen functional groups such as hydroxyl, epoxide, carboxylic and carbonyl groups. GO is primarily hydrophobic with hydrophilic edges, making it as an amphiphilic material even though it has been referred as the hydrophilic. It is anticipated that the GO will dissolve easily in resin polymers with varying polarities due to its amphiphilic nature. However, GO hasn't been investigated as a possible nanoparticle addition for interlaminar change in composites reinforced with carbon Fiber [12,13].

2.Experimental Details

2.1. Materials

Carbon Fiber

Here I had used the Carbon Fiber 400 GSM Plain Weave Bidirectional. Carbon Fiber 400 gsm refers to a carbon Fiber fabric with a weight of 400 grams per square meter. GSM is a typical unit of measurement for fabrics that indicates the material's density. Simply greater GSM indicates a heavier and thicker fabric. Carbon Fiber fabric is a material composed of long, thin strands of carbon Fibers. These Fibers are extremely strong and stiff, yet relatively lightweight. Bidirectional fabric offers strength in two primary directions (usually 0 and 90 degrees), making it good for applications requiring multi-directional stress handling. From Aadimaata Enterprises Mumbai (India) we had acquired Carbon Fiber (400 GSM Plain Weave Bidirectional).

Fig 1. Carbon Fiber

Table1. Specifications of Carbon Fiber

Property	Unit	Value
Areal Weight	g/m^2	400
Standard Width	mm	1000
Dry Fabric Thickness	mm	0.42
Density	g/cm^3	1.8
Filament Diameter	μm	7
Tensile Strength	MPa	4900
Tensile Modulus	GPa	240
Elongation	%	2.1

Epoxy

In our present work,I had used the Lapox-12 commonly known as L12 as a epoxy polymer. L-12 is a liquid, unmodified epoxy resin with a medium viscosity. It's a type of diglycidyl ether of bisphenol A (DGEBA, $C_{21}H_{24}O_4$). It is Commonly used with various hardeners for creating Fiber-reinforced composites. We Purchased this from Solind Services Pvt.Ltd Bengaluru (India) of Atul Brand.

Fig 2. Epoxy

Table 2. Specification of Lapox L-12[14]

Property	Unit	Value
Epoxide Equivalent	gm/eq	182-192
Epoxy Value	eq/kg	5.2-5.5
Viscosity at 25^0 C	mPa.s	9000-12000

Hardener

In Present work I had used the Hardener as Lapox K6. Lapox K-6 is a light-yellow aliphatic polyamine hardener. Its chemical name is Tri ethylene tetra amine($C_6H_{18}N_4$). It can cure epoxy resin at ambient temperatures. Epoxy resin cures quickly, resulting in a shorter pot life. Its low viscosity and low dosage make it ideal for applications such as adhesives, cement, and casting of small electrical components. We Purchased this also from Solind Services Pvt.Ltd Bengaluru (India) of Atul Brand.

Fig 3. Hardener

Table 3. Specification of K6[14]

Property	Value
Refractive Index at 25^0 C	1.4940-1.5000
Water Content	1% max

Graphene Oxide(GO)

In Our Current work,I had used 99.5% Pure GO having a 0.5 to 2 nm Thickness. Graphene oxide is a remarkable substance with unique features. The chemical formula of graphene oxide is $C_{140}H_{42}O_{20}$. Oxidizing graphite (common pencil lead) results in a single-atom-thick carbon sheet with oxygen-containing groups attached. Compared to normal graphene, it disperses well in water and is strong and lightweight, making it a promising material for composites [15]. CFRPs may suffer from weak bonding between carbon Fibers and polymer matrix. GO's oxygen-containing functional groups can help to bridge this gap. These groups exhibit strong chemical interactions with both the Fibers and the matrix, resulting in increased stress transmission and mechanical properties [16]. Graphene oxide (C, Purity 99.5%, Research Grade) was acquired from the Nano Research Laboratory in Gopalpur, Jharkhand (India).

Fig 4. Graphene Oxide (GO)

Table 4. Specifications of GO

Property	Units	Value
Color	-	Amber
No.of layers	-	2-6
Diameter	μ	1-5
Thickness	nm	0.5-2
Bulk Density	g/cc	0.241

Peelply

I had utilized the Peelply of 85GSM having the red stripes made of Nylon fabric. Peel ply serves a variety of purposes. First, it creates a Textured surface on the composite, which is great for secondary bonding since it improves adhesion. Second, it allows excess resin and trapped air to escape during the curing process, resulting in a stronger, lighter finished product. Finally, it shields the laminate's surface from contaminants. We had procured the Peel ply from HAYAEL AEROSPACE INDIA PVT LTD Chennai (India).

Fig 5. Peelply

Table 5. Specifications of Peelply

Property	Units	Value
Material	-	Nylon 6
Thickness	mm	0.15
Arial Weight	g/m^2	84.95
Fabric Type	-	Plain Weave
Base Color	-	White/Off white

Mild Steel Plates

I had used the two mild steel plates each having the 6mm thickness and 300mm x 250mm Area.The Purpose of these plates are to apply load on the composites under UTM after the preparing the laminate using the Hand layup Proccess. We Purchased the Plates From Local Market.

Fig 6. Mild Steel Plates

2.2.Preparation Methods

Preparing of CFRP Laminates Without GO

In the present work, I had produced the samples using the Hand Layup Process. Initially, I took two MS steel plates, cleaned their surfaces with ethanol, and applied the releasing agent to the surface of one plate and left it for a while. After some time, I attached the plastic sheet to the plate and cut the carbon Fiber down to 200mm x 200mm measurements. After that, I took a 250ml disposable plastic glass and placed it on the Electronic Composite Scale Weighing Machine, then pressed the Tare button to display '0'. After that, we put 200 grams of epoxy to the glass and tared it off. Then, holding a spatula, add 20 grams of Hardener (K6) to it (at a 1:10 ratio of epoxy to hardener). Then added the 20grams of Hardener(K6) to it(which is ratio of 1:10 of epoxy to hardener) and mixed it well with help of spatula.
After that, I placed the peel ply and poured some resin mixture and distributed it well on the peel ply with the help of a wiper, then placed the initial layer of carbon Fiber and applied pressure on the carbon Fiber with the help of a roller, and then added some resin mixture and spread it with a wiper before applying pressure with a roller by moving forward and backward. Repeat the process up to 6 layers, then add another peel ply on top, then another MS plate on top, and then place the laminate under the UTM and apply a mild load, allowing it to cure for up to 12 hours before removing the loads and the laminate by removing the peel ply. Finally, I cut the samples according to ASTM standards.

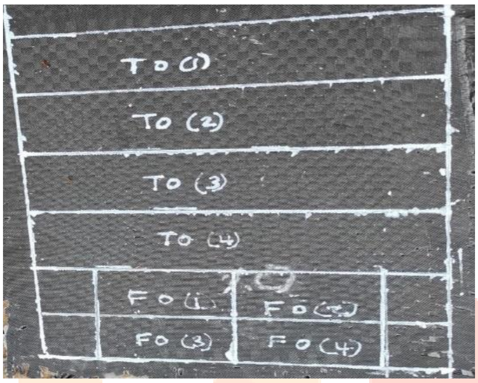

Fig 7. Laminate prepared with Neat Epoxy

Preparing of CFRP Laminates With GO

I had used the hand layup method to reinforce the carbon Fiber with graphene oxide (GO) and resin mixture, but I used a mini stirrer to ensure uniform mixing of GO powder in epoxy and created a vacuum chamber to remove air bubbles in the GO and Epoxy mixture using a vacuum pump and vacuum desiccator prepared the MS plates in the same way that was explained before. Then, a disposable plastic glass was placed on the electronic weighing machine and set to zero. Then, add 170 grams of epoxy and 0.45 grams or 0.25% graphene oxide (GO) and mix the mixture uniformly with a mini stirrer at 1000-1200 rpm for 10-15 minutes.

After that, place the mixture in the vacuum desiccator, turn on the vacuum pump, and wait until the bubbles in the mixture have been eliminated. After that, add the hardener at a 10:1 ratio to the epoxy mixture and stir it with a spatula. The procedure for preparing laminates without GO is the same mentioned previously. Finally, after curing, the samples were cut according to ASTM standards for tensile, flexural tests.

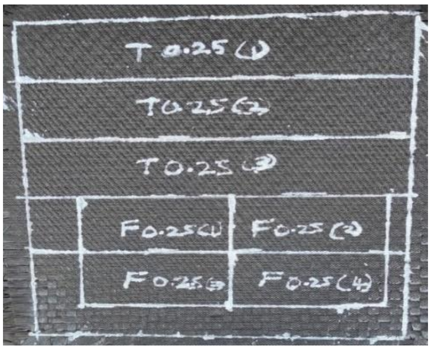

Fig 8. Laminated prepared with 0.25% GO reinforcement

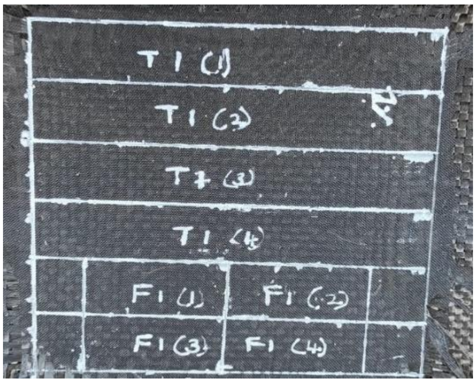

Fig 9. Laminated prepared with 1% GO reinforcement

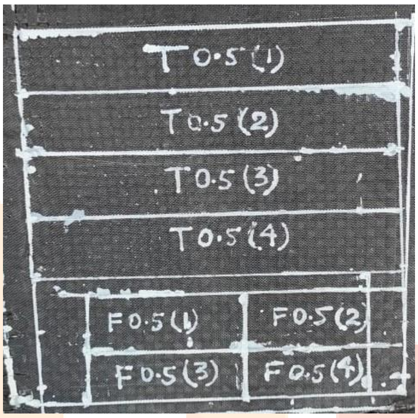

Fig 10. Laminated prepared with 0.5% GO reinforcement

3.Charcterization

The Mechanical Performance of Pure Epoxy and both epoxy and Graphene Oxide(GO) composites laminates are investigated from tensile,flexural and fracture tests conducted under the Universal Testing Machine (UTM) having capacity of 200 Kn load cell at a 1mm/min. The tensile test for laminates was prepared according to the ASTM D3039 with dimensions of 180mm x 24mm x2.9mm. the flextural test was conducted according to the ASTM D790 having dimensions of 60mm x 12mm x 2.9 mm.

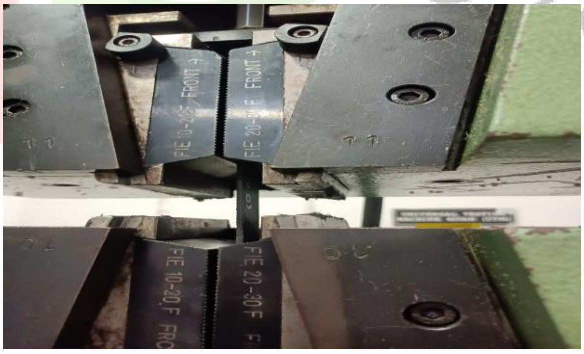

Fig 11. Sample in UTM

4.Results and Discussion

The tensile properties of GO/Epoxy reinforced composites prepared using different quantities were investigated to compare the role of GO as nanofiller for the CFRP composites preparation.the tensile properties of with and without GO reinforced composites are summarized in Table 5.The representive Tensile Stress vs strain plots of samples are shown in fig 12.It has to be found that the sample reinforced with the 0.25% of GO had given the maximum tensile strength and maximum percentage strain was found at Neat Epoxy. It also found that addition specific quantity of GO with epoxy as reinforcement,uplifts the mechanical performance of composites as compared to NE.The 0.25% GO CFRP Sample shows the high tensile strength,showing around~3.6% enhancement with respect to NE sample and ~21% with respect to 0.5% GO reinforced composite. It is worth noting that 0.25% GO reinforced composite shows better performance than other GO reinforced composites.
The highest tensile modulus were found to be 6.03 for 0.25%GO reinforced composite.the highet flextural was found to be 761GPa for 1%GO reinforced composite.The variation of tensile properties with GO as nano filler at different prcentages fig and also depicted in Table 5.

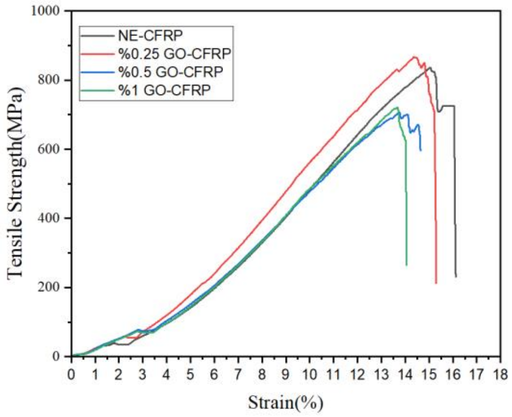

Fig 12. Tensile strength vs Strain

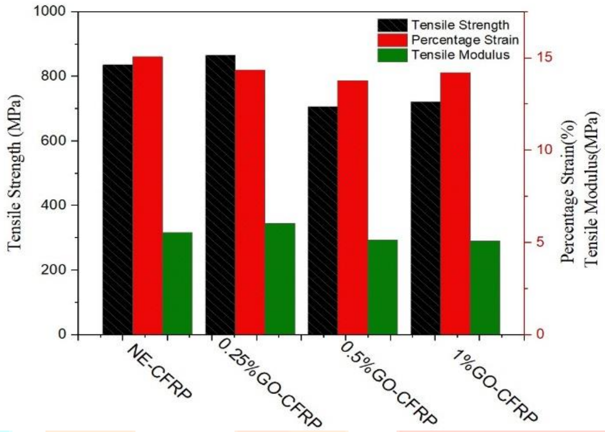

Fig 13. Variation of Tensile strength, Tensile modulus, and Percentage strain

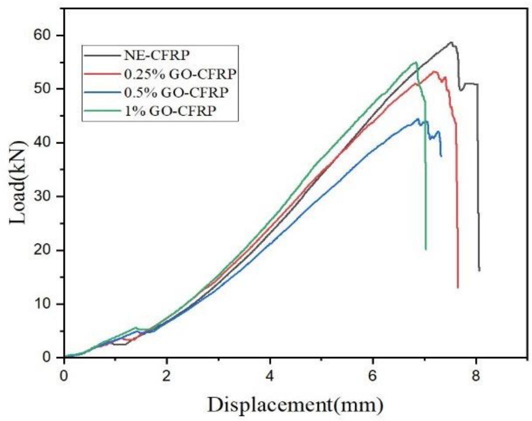

Fig 14. Load vs Displacement.

Sample Code	Tensile Strength(MPa)	Tensile strain (%)	Tensile Modulus(MPa)	Flexural Strength(GPa)
NE-CFRP	835.90	15.06	5.55	612.87
0.25%GO-CFRP	866.67	14.36	6.03	516.15
0.5% GO-CFRP	707.29	13.78	5.14	707.22
1% GO-CFRP	721.40	14.22	5.07	761.22

Conclusion

I had Prepared the CFRP Composites by using th Graphene Oxide(GO) as nanofiller.the tensile strength and modulus were enhanced ~3.6% and ~8.3% for 0.25% GO reinforced composite with respect to NE. The tensile strength and modulus were decreased by ~16.7% and ~8.9% for 0.5% GO reinforced composite,~14.7% and ~5.8% for 1% GO reinforced

Composite with respect to NE. the maximum flexural strength were observed as761.22 GPa for 1% GO reinforced composite.However,Comparing the Mechanical properties of GO reinforced composites with NE, the 0.25% GO reinforced composites are preferrable for the place were high tensile strength is required and 1% GO reinforced composites are preferrable for High flextural strength applications.

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