Investigation on Mechanical Properties of Graphene Oxide reinforced GFRP.

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Abstract. Graphene and E-glass fibres individually find a very wide field of applications because of their various mechanical and chemical properties. Recently graphene has attracted both academic and industrial interest because it can produce a dramatic improvement in properties at very low filler content. The primary interest of this venture is to investigate on Graphene reinforced polymer matrix nanocomposites and finding the mechanical properties. The composites were fabricated by Hand Lay Process and have been evaluated by the addition of Graphene with 1, 1.5, 2, 2.5 and 3 by weight% as reinforcement in composites. The theoretical and experimental results validate the increase in properties such as tensile strength, hardness and flexural strength with increase in weight proportions from 1% to 3% of graphene powder. It was observed that the composite material with 2.5% weight fraction of graphene yielded superior properties over other weight percentages. Graphene reinforced polymer matrix nanocomposites finds its major applications in the manufacture of aircraft bodies, ballistic missiles, sporting equipment, marine applications and extra-terrestrial ventures.

1. Introduction

P. Noorunnisa Khanam [1] has carried out a nano level technique of dispersing graphene in the matrix of polymer. A detailed study has been carried out on the aspects of methods of processing, factors affecting the conductivity under electrical load, the methods adopted to improvise the conductivity and possible applications in electronic industry. Minh-TaiLe and Shyh-ChourHuang [2] have employed the application of graphene platelets of nano size to enhance the mechano-thermal properties of epoxy based hybrid composites. The surface morphology of the composites has been analysed. The research showed that with an incremental increase of filler of nano size there was a remarkable change in strength and material behaviour tends towards brittleness. The hybrid matrix polymer based composites can be used in PCB industries due to their light weight, superior quality and thermal stability. Apart from structural enhancements, the graphene has improved the machinability of epoxy based composites. There has been a considerable decrease in the delamination of the composites under the effect of drilling under reinforcement of graphene [3]. The advancement of a nano level scattering of graphene particles in a polymer based composites has opened another and fascinating range in materials science [4-5]. Its exceptional properties make it reasonable to enhance the electrical
properties of polymer composites. It additionally talked about the threshold in view of filler volume, aspect ratio and material orientation. Sung-Chiu Shiu and Jia-Lin Tsai,[6] have incorporated graphene in forms of flakes and particles. Various properties like modulus of elasticity, thermal coefficient of expansion has been analysed under the addition of graphene oxide and flakes. The density of composites increased and the efficiency of reinforcement increased due to high energy of interaction in modified oxide of graphene. The oxide of graphene exhibited superior properties in comparison to the flakes. Tapas Kuilla, et.al.,[7] have reviewed all the advances carried out in the area of fabrication of graphene reinforced nano composites. The preparation, structure, properties and dispersion of graphene in the composites has been articulated. Further a lower content of graphene yields better properties in comparison to other nano fillers. D J Akshaykumar, et.al.,[8] have studied the wear behaviour of GFRP in two body condition. The graphene content as filler was varied from zero to one weight percentage, load was increased in increment of 10kN up to 30N and sliding distance was varied from 500m to 1500m with a constant 200rpm speed. It was seen that there was an increase in the resistance against wear with increase in contents of filler weight percentage. The authors have combined Carbon and Nomex to form a laminate that has resulted in a composite which can be used in applications where high strength with low weight and good wear resistance is needed [9].

2. Methodology
2.1 Fabrication of Laminates
The composites were fabricated by Hand Lay Process and have been evaluated by the addition of Graphene with 1, 1.5, 2, 2.5 and 3 by weight% as reinforcement in composites. A stir bar mixes the solution on a combined hot plate magnetic stirrer. Stirring is done for the reduction of graphene lumps with the application of heat to lower the viscosity of the resin. The speed is varied from 300 to 1150 rpm. The stirring is done till a uniform swirl motion appears. Then sonication which is the application of sound energy to agitate particles in the sample is carried in order to get the even breakdown of the molecules Ultrasonic Frequency of 600Hz is maintained for a time period of 45 minutes to facilitate the breakdown of graphene particles in the resin.

A glass of size 300*300 mm is used as base upon which wax is applied and a plastic sheet is placed to facilitate easy removal of the laminate after curing. E-Glass fibre is cut into size of 300*300 mm. According to the calculation, 13 layer of E-Glass fibre is used for each laminate. Resin and hardener are mixed in the desired ratio and the mixture is then applied uni-directionally using blades. Hand Lay-up process is adopted, fibres and resin are alternatively layered one after the other. After completing lay up of laminates, a pressure of 5kg/sq. ft. is applied onto the laminate and it is then left to cure for 2 days. After the adequate curing, the laminate is taken off from the glass.

![Figure 1. Stirring of graphene reinforced epoxy resin](image1.png)

![Figure 2. Ultrasonication of graphene reinforced epoxy resin.](image2.png)
2.2 Experimentation

The laminates were tested for tensile properties, hardness, flexural strength and percentage elongation according to the ASTM standards. The tensile and flexural test was carried out on Instron make Universal testing machine at Raghavendra Metallurgical testing, Bengaluru. 3 samples were tested and an average of 3 readings has been taken. The tensile test was carried out according to ASTM D3039/3039M – 08 and the specimen dimensions are shown in figure 3.

![Figure 3. Tensile testing Specimen Dimension](image1)

The flexural test was carried out according to ASTM D790 under 3 point loading condition. The specimen dimension is as shown in the figure 4 below.

![Figure 4. Flexural Testing Specimen Dimension](image2)

The hardness testing was carried out on a Rockwell hardness tester on a B scale with 100kgf load using a 1.58mm ball indenter.

3. Results And Discussions
3.1 Tensile Strength and Percentage of Elongation

The tensile test was conducted on the composites fabricated according to ASTM standards using the Universal Testing Machine (UTM). Tensile load in a gradually increasing manner was applied on the composite and slowly extending it until it fractures. Throughout the tests the control system and its associated software record the load and extension of the specimen. A graph as shown in figure 5 was plotted for tensile strength against the different percentages of reinforcement added to the base material.
Table 1. Tensile Strength for different Wt. % of Graphene

| Wt. % of Graphene | Peak Load(kN) | Tensile Strength(MPa) |
|-------------------|---------------|-----------------------|
| 1                 | 42.30         | 354.23                |
| 1.5               | 41.16         | 366.93                |
| 2                 | 38.20         | 346.15                |
| 2.5               | 42.76         | 407.06                |
| 3                 | 40.32         | 343.27                |

Figure 5. Tensile Strength vs Wt. % of Graphene in PMC

From the fig. 5.1, it was found that the laminate with 2.5 wt. % of graphene is exhibiting higher tensile strength. It is inferred that the laminate with 2.5 wt. % of graphene is much ductile when compared to the other laminates of different weight percentage of graphene. The decrease in the tensile strength of the laminate of 3% weight of graphene is due to the uneven distribution and improper breakdown of graphene powder particles in the resin. This occurs because the increase in the percentage of graphene resulted in poor mixing with the resin due to its viscosity. Figure 6 shows the elongation of the laminate containing 2.5 weight % of graphene is 15.84 mm and higher when compared to the other laminates. Thus it can be concluded that the laminate with 2.5 wt. % of graphene exhibits ductile property.

Table 2. Elongation at Peak for different Wt. % of Graphene

| Wt. % of Graphene | Peak Load(kN) | Elongation at Peak Load(mm) |
|-------------------|---------------|----------------------------|
| 1                 | 42.30         | 10.91                      |
| 1.5               | 41.16         | 10.53                      |
| 2                 | 38.20         | 11.42                      |
| 2.5               | 42.76         | 15.84                      |
| 3                 | 40.32         | 11.88                      |
3.2 Flexural Test

The fig.5.3 shows the range of variation of the load values from 1399 N to 1601 N. The highest displacement. The highest load is withstood by the laminate of 1.5% of graphene while the lowest is exhibited by the laminate of 3% of graphene.

Table 3. Different values of load and displacement for the Wt. % of Graphene

| Wt.% of Graphene | Load N  | Displacement (mm) | Flexural Strength(MPa) |
|------------------|---------|-------------------|------------------------|
| 1%               | 1559.3  | 5.295             | 21.650                 |
| 1.50%            | 1601.833| 4.935             | 23.362                 |
| 2%               | 1464.5  | 5.547             | 23.727                 |
| 2.50%            | 1408.933| 5.669             | 24.523                 |
| 3%               | 1399.133| 5.196             | 22.468                 |

Figure 6. Elongation at Peak vs Wt. % of Graphene in PMC

Figure 7. Load Vs Wt. % of Graphene
From the figure 8 laminate of 1% of graphene is displaced to a larger value and the lowest is exhibited by the laminate of 3% of graphene. From the figure 9 flexural strength for the laminate of 2.5% of graphene is larger and lowest for the laminate of 1% of graphene.

3.3 Hardness Test

From fig.5.6 the laminate of 2.5% weight of graphene exhibited as the hardest material amongst other laminates and the lowest possible hardness was exhibited by laminate of 3% of weight of graphene.
CONCLUSION

- In present work, the changes in the various mechanical properties of the Graphene reinforced polymer matrix nanocomposites fabricated have been reported.
- The addition of Graphene and E-Glass fiber as reinforcement for the laminate has proved to be effective in increasing the mechanical properties of the laminate.
- The Laminate of 2.5 weight % of graphene was found to exhibit superior properties in contrast to the other laminates of different weight percentages.
- The dispersion of the matrix in the laminate has been found to be good.
- The interfacial bonding and the energy of interaction is also found to be high.

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