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Graphene Nano Powder Embedded Glass Fiber Composites for Enhanced Multifunctional Performance

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ABSTRACT

Graphene is the most lucrative choice for automotive and aerospace industries due to its magnificent increase to strength of a composite and lightweight which ultimately lead to enhanced durability and performance. In this study, graphene nano powder (GNP) was added into hybrid glass fiber mixed with epoxy composites at different percentages for each grouping (0, 0.3, and 0.6 wt.% total) to see what effect it is having on various mechanical properties. Whereas most of the previous work done before focuses on graphene oxide (GO) or reduced graphene oxide (rGO) as the filler, this study highlights how to achieve the balanced improvements in various mechanical properties such as tensile strength, impact resistance, and hardness using GNP as a dispersion substitute: namely, at which level of the internally dispersed phase of the composite. Due to low cost and durable strength, glass fiber mixed with epoxy composites are common in structural design. Their wide adoption is limited by brittleness, low impact resistance, and weak fiber-matrix adhesion. These weaknesses were addressed by dispersing GNP in epoxy resin using magnetic stirring to prevent agglomeration, adding hardener, and consolidating with glass chopped strand mats using hand lay-up method. After fabrication, specimens underwent several tests i.e tensile strength test (ASTM D638), hardness test (ASTM D2240), and impact resistance test (ASTM D256). Compared to neat glass fiber mixed with epoxy composite, reinforced specimens showed significant enhancement. 0.6 wt% GNP produced optimum results with tensile strength, hardness and impact strength increasing by 256.25%, 49.4%., and 60.83% respectively. The results validate the hypothesis that moderate GNP loading improves mechanical properties in a significant percentage. To summarize, it is observed that moderate amounts of GNP incorporated into glass fiber/epoxy composites improved composite's mechanical properties significantly using a hand lay-up method.

Keywords: Glass fiber, Graphene nano powder, Mechanical properties, Mechanical characterization

1. Introduction

The limitations of conventional glass fiber composites have been brought to light by the growing necessity for lightweight, robust, and ballistic materials in the automotive industry, electronics, and aerospace industries[1]. This has prompted the incorporation of various kinds of graphene, such as graphene oxide, reduced graphene oxide, and graphene nano powder, to simultaneously enhance mechanical strength, thermal stability, and electrical performance. Graphene has gained much attention for use in composites because it is about 200 times stronger than steel[2]. Glass fiber composites are widely used for their strength. Because of sp2 hybridization, graphene provides a high amount of tensile strength. However, they have drawbacks such as low electrical conductivity, poor thermal stability, and insufficient fracture toughness. Their applicability in multifunctional engineering applications is hampered by these lacking. One intriguing way to get over these restrictions is to incorporate graphene nano powder. While graphene reinforcement in glass fiber composites has been studied in the past to improve mechanical, electrical, and thermal properties. Most of the studies have focused on single-function enhancement, leaving a gap in the ability to achieve simultaneous multifunctional performance through optimized dispersion and incorporation of graphene nano powder (GNP).

Various studies showed that by adding only 0.25wt% of GNP ensure 29% improvement in flexural strength[3]. It is found that the GO coating on the glass fiber surface successfully increases the tensile and flexural strengths[4]. Moreover, studies have shown that among glass fiber reinforced composite S type of glass fiber ensure overall better performance than others[5]. Incorporating graphene nano powder into glass fiber reinforced epoxy composites significantly improves tensile, flexural, and impact strength up to 6wt%, while also revealing that higher graphene content leads to agglomeration and voids, ultimately deteriorating mechanical performance. According to the results of the thermal characterization, the addition of graphene nanoplatelets (GNPs), graphene oxide (GO), reduced graphene oxide (rGO), and multi-walled carbon nanotubes (MWCNTs) improved thermal conductivity. Fiberglass/epoxy modified with MWCNTs 0.3%, GNP 1%, GO 2%, and rGO 0.042% improved thermal conductivity by 8.8%, 12.6%, 8.2%, and 4.1% respectively, as compared to the glass fiber epoxy composites. It was determined that, in comparison to other nanoparticles, the thermal conductivity

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improvement in graphene nanoplatelets-modified composites is more noticeable for the same volume fraction of nanoparticles[6].
Moreover researches have shown that the tensile, flexural, impact, water absorption, machinability, and FTIR test are done over the incorporation of graphene in the natural fiber composites showed an increase in the tensile, flexural and water absorption by 27.7%, 53% and 15% on average[7].
It is found earlier that the flexural modulus of laminates does not suffer any apparent change in its reference value and the glass transition temperatures was negligibly increased in the 1wt% GNPs[8]. Again, the recent researches found out that, the flexural strength shift from 500 MPa to 150 MPa with the addition of 1% GNPs[9].
Previous studies have extensively explored the incorporation of graphene nanoplatelets (GNPs) into natural fiber and glass fiber/epoxy composites to enhance their mechanical, thermal, and electrical properties. For instance, previous observations have demonstrated improvements in fracture toughness, flexural strength, and electrical conductivity using GNPs. However, challenges arise due to the agglomeration of GNPs, processing difficulties, and limited multifunctional performance persist. While significant advancements have been made in enhancing individual properties of glass fiber/epoxy composites using GNPs, a comprehensive approach of graphene nano powder embedded with glass fiber is still unexplored. Additionally, the effective dispersion of Graphene nano powder and the optimization of their content to achieve balanced multifunctional properties are areas that require further investigation. Despite extensive research on graphene-reinforced glass fiber/epoxy resin composites, most studies have focused on graphene, reduced graphene oxide and graphene oxide improving any single properties, leaving a gap in achieving simultaneous mechanical, thermal, and electrical properties enhancement. This work aims to develop graphene nano powder embedded glass fiber composites to overcome the shortcomings of previous works. Key parameters investigated include the tensile strength, impact test, and hardness test.

2. Materials and Methods

In this study, the materials utilized include glass fiber chopped strand mat, epoxy resin, PVA(Polyvinyl Alcohol), PET(Polyethylene Terephthalate) film sheet, and a low-cost hand lay-up technique is employed for the fabrication of the composite.

2.1 Glass fiber

Glass chopped strand mat were received from the department of mechanical engineering, Military Institute of Science and Technology which has 1.5mm thickness. Because of its unique mechanical, thermal, and chemical properties, glass fiber is chosen as the primary reinforcement material of the composite.

2.2 Graphene Nano powder

Graphene Nano powder was collected with average particle size of 5-10 mm (MW-12.01g/mol) with more than 99% purity. Graphene Nano powder was supplied by Ultra nanotech, Bengaluru, India.

2.3 Matrix

The hardener and epoxy resin were provided by Shenzhen Little Sparrow New Material Co. LTD. In China which has a resin and hardener of 3:1 ratio was collected. The experimentally determined density of epoxy resin was $1.18 g/cm^3$.

2.4 Mold

Acetone being a strong cleaning solvent was used for surface cleaning and dispersion. The molds were prepared by 3D printing and PET (Poly vinyl Alcohol) were used to prevent the surface of the composite from being rough.

2.5 Composite Fabrication

The composite was developed using a low-cost hand lay-up method. PVA (Polyvinyl Alcohol) and a PET film were applied as mold releasing agents. Figure 1 completely illustrates the step-by-step procedures briefly for the fabrication of our composite. For the laminate specimen of 3 mm thickness, the resin volume ratio is 0.2686 and the fiber volume ratio is 0.7314[10]. The mold area is calculated as $26{,}940.14 mm^2$, and the density of the resin is $1.18 g/cm^3$.

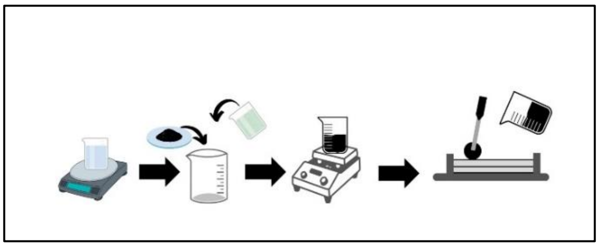


Figure 1: Schematic of preparation of the composite.

Total total composite volume of fibre is given by

$$= \frac{Fiber\ Volume\ ratio}{Total\ Composite\ Volume} \quad (1)$$

The number of fiber layer is given by

$$= \frac{One\ layer\ fiber\ volume}{Total\ composite\ volume\ of\ fiber} \quad (2)$$

Similarly, total composite volume of resin is expressed as:

$$Total\ Composite\ volume\ of\ resin = \frac{Resin\ volume\ ratio}{Total\ Composite\ Volume} \quad (3)$$

The corresponding resin weight is obtained from:
(Density of Resin × Total composite volume of resin)
For a configuration consisting of five fiber layers, six resin layers are required. Therefore, the resin weight per layer is calculated as:

$$Each\ layer\ weight = \frac{\mathbf{Weight\ of\ Resin}}{\mathbf{6}} \quad (4)$$

Figure 2: Magnetic Stirring

Figure 2 depicts the magnetic stirring of the key materials so that no agglomeration takes place in the composite. From the calculation, 5 layers of glass fiber and 2.82 g of resin were used for the 0% graphene nano powder–glass fiber composite. Similarly, composites were manufactured with 0.3% and 0.6%. Initially, the glass fiber sheets were cut with a laser beam according to the mold dimensions. The epoxy resin, hardener, and graphene nano powder were mixed using a magnetic stirrer for 15 min for 1500 rpm at 40°C[11]. PVA was applied on the mold surface as a releasing agent, and then fiber layers and resin were placed alternately in the mold. After placing all the layers and resin, a PET film sheet was placed on top of the composite, and a 20 kg weight was applied on the mold to avoid any voids in the composite. The sample was allowed to cure at room temperature for 24 hours. Figure 3 is herewith providing the measurements of the specimen prepared for mechanical characterization.

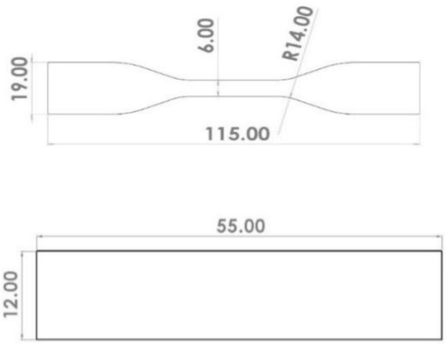


Figure 3: Dimension of specimen prepared for mechanical characterization.

2.6 Mechanical Characterization

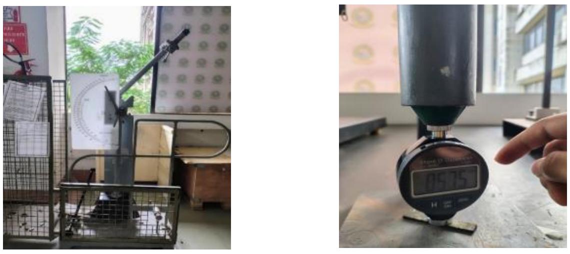
2.6.1 Tensile characteristics

The tensile test determines the composite's resistance to tensile loading, providing insight into its ultimate tensile strength and overall performance under uniaxial stress conditions. For tensile testing, a dog-bone shape specimen was prepared following ASTM D638 using laser beam A Universal Testing Machine with Merlin Software, model number 5590-HVL series, was used to perform this test.

Figure 4: (a) Universal Testing Machine

2.6.2 Hardness characteristics

The Hardness test is an indication of material's resistance to surface indentation or deformation. It determines its surface strength and wear resistance. The hardness test was done as per ASTM D2240 standards by shore D durometer.



(b) (c)

Figure 4: (b) Charpy test (c) Shore D Durometer test

2.6.3 Impact Characterization

The impact test is used to measure the ability of a material to absorb energy and resist fracture when subjected to sudden force, load, or shockwave. An AIT 300 EN pendulum was used to conduct Charpy impact tests, and ASTM D256 was followed. They were mounted horizontally at both ends, forming a simple beam.

$$Impact\ Strength = \frac{Aborbed\ Energy}{Width\ X\ Lenght} \qquad (5)$$

Above stated figure- 4 has shown all the equipment and tools for mechanical characterization. All the specimens were laser cut for individual tests. And each of tests were done twice for different percentages of GNP. Figure 5 and 6 clearly shows various specimen with different loadings of graphene nano powder laser cut as per our dimensions for mechanical tests.

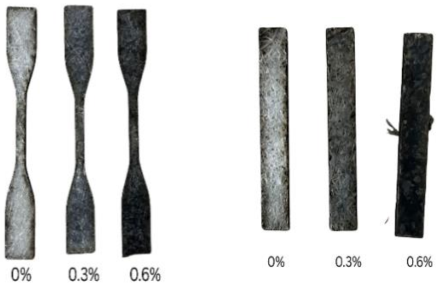


Figure 5 and 6: Specimen for tensile test and Specimen for impact test and hardness test

3. Results and Discussion

3.1 Tensile Test

In the tensile test, the neat glass fiber mixed with epoxy resin composite has shown a maximum tensile strength (RM) of 16 MPa, with a corresponding maximum load (Fm) of 0.292 kN. Modulus of elasticity was measured at 3.44 GPa with uniform elongation of 0.86%. Just addition of 0.3% GNP has increased the ultimate tensile strength by 81.25% i.e. 29 MPa. Maximum load capacity has increased to 0.518 kN. The stress-strain curve showed a linear rise to 57 MPa with the addition of 0.6% GNP Figure 7 shows how the ultimate tensile strength increases with increase of graphene loadings. Contrarily in figure 8 it is shown that after the peak, the curve sharply dropped, however the elongation was more than the neat composite with 0%GNP. The composite has gained a maximum load capacity of 1.025 kN along with the modulus of elasticity of 3.64 GPa.

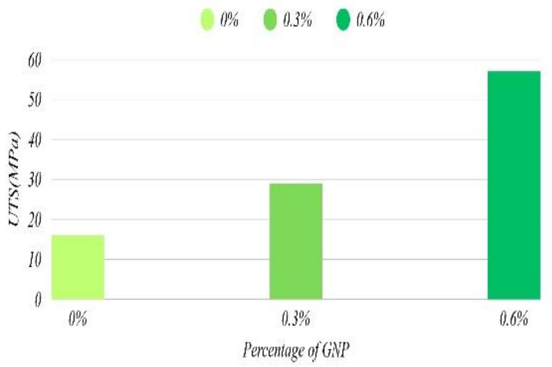


Figure 7: Comparison of Ultimate Tensile Strength of different loadings of GNP

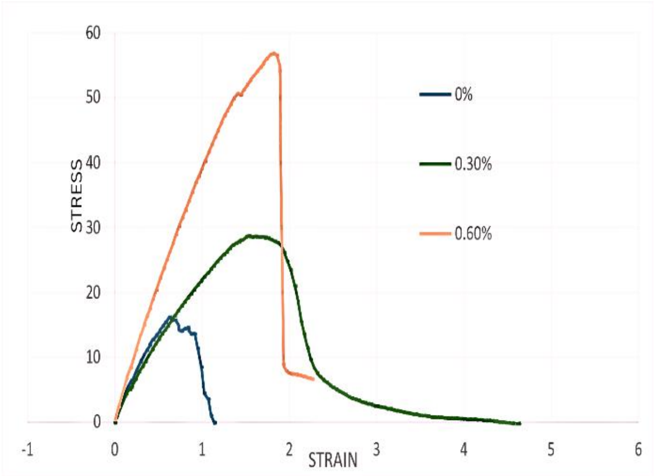


Figure 8: Comparison of stress-strain of different loadings of GNP

3.2 Hardness Test

In the hardness test with shore D durometer the neat glass fiber/epoxy resin loaded with 0% GNP has shown a hardness value of 41. 5 Shore D, whereas the glass fiber loaded with 0.3% GNP has shown a change by 27.71%i.e., 53 Shore D and loading of 0.6% has shown a rise by 49.4%i.e., 62 Shore D from the neat glass fiber/epoxy.

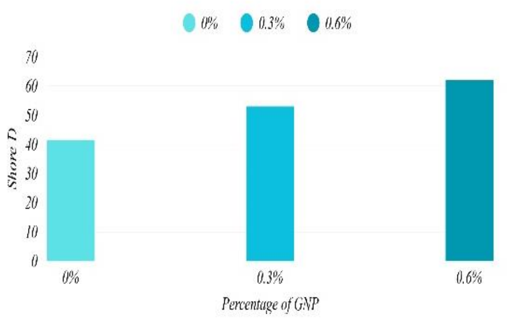


Figure 9: Comparison of hardness test of different loadings of GNP

3.3 Impact Test

In the Charpy impact test, the neat glass fiber/epoxy has shown an impact strength of 1.818 kJ/m^2, reflecting its brittle nature whereas with the addition of 0.3% GNP impact was shown 2.202 kJ/m^2 and 2.924 kJ/m^2 with the addition of 0.6% respectively. Figure 9 and 10 illustrates the improved hardness and impact strength of increased percentage of graphene nano powder.

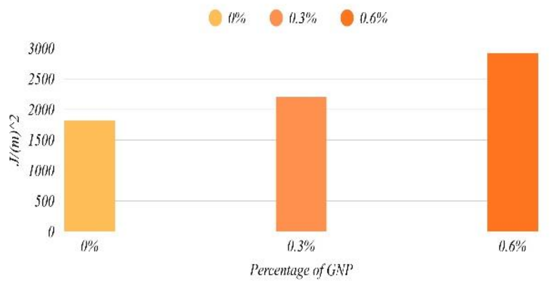


Figure 10: Comparison of impact strength of different loadings of GNP

4. Conclusion

The study focused on the mechanical effects of addition of various percentage (0%, 0.3%, and 0.6%) of graphene nanopowder to glass fiber/epoxy composites. Though an age-old hand layup method was used for preparing our specimen, but the dispersion of GNP was uniform, and agglomeration did not take place. From our test with different loadings, it is evident that the 0.6% GNP has shown significant improvement in tensile strength, impact resistance and hardness test as well, so 0.6% loading of graphene nano powder can be an optimized choice for future applications. The interfacial bonding, effective reinforcing network and better load transfer capability among the molecules has made this dispersion of GNP better than others. Thus, the composite has shown significant improvement in mechanical tests. With the addition of 0.3% and 0.6% graphene nano powder the tensile strength increased by 81.25% and 256.25% respectively. In the impact test, the loading of 0.3% and 0.6% showed an improvement of 21.03% and 60.83% respectively. Lastly in hardness test, the loading of 0.3% and 0.6% showed the improvement of 27.71% and 49.4% respectively.

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