Mechanical Characterization of TiO$_2$ nanoparticles based on Glass Fiber Reinforced Polymer Composite

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Abstract. Nanotechnology has become the best truly developing innovation in the field of engineering science. Numerous examinations have been completed by different exploration researchers in the prior many years. In my examination work research, the impact of cross breed E-glass built up fiber with epoxy Nano composite. The Nano composite covers overlays were set up by hand layup procedures by shifting layers of Titanium Dioxide (TiO$_2$) nanoparticles of 0.6% individually. The nano added substances are utilized to improve the strength from destroy opposition, hardness of the polymer composite and high strength to weight ratio. The Nano composite laminates this prepared are characterized by the compression and flexural test. The flexural properties of the glass fiber built up plastic improved with expansion of nanoTiO$_2$ filler particles. At 0.6 wt% of TiO$_2$ and having 12 layers the force at yield is 327.99N and bending stiffness 63.11 N/mm and in 9 layers force at yield is 149.06 and bending stiffness 36.22 N/mm. True interfacial bonding b/w the fiber and epoxy turned into the primary motive for reaching higher flexural properties.

Keywords. Nanoparticles, flexural strength, compression test, E-glass fiber, hand lay-up

1. Introduction

A composite material is made of two materials with different physical and chemical properties. When the two materials are got mixed, they create a material. Which is specialized for a specific job. It becomes stronger, lighter or resistant to electricity. It can improve the strength & stiffness. This new era there is a large growth in the material of composite. The composite material is a real venture for the fibers. The composite is made of epoxy base material. Epoxy base composite matrix has brilliant potential to supernumerary the conventional steel substances. Polymer matrix is the alternate procedures to growth new elegance of polymer structural substances. This modification can be completed with the aid of addition of various ceramic powders of varied sizes to reap the desired mechanical property [1]. In recent years, the incorporation of nanoparticles into polymers has been attracting great interest. Numerous studies deal with the outcome of nanoparticles on the mechanical properties of composite materials. Composites are moreover known as Fiber-Reinforced Polymer (FRP) composites. It is made-up of polymer matrix. This is bolstered with an engineering material. The man-made fiber (like glass, carbon or aramid) or particular reinforcing fiber. The matrix protects the fibers from environmental or outer damage and transmissions of the load on numerous fibers. The fibers, in turn, offer electricity and stiffness to enhance the matrix—and assist it resist cracks and fracture. Amit Chatterjee et. al. [2] investigated the property of the matrix of nanoparticles size fillers into epoxy resin. The ultrasonic mixing process via sonic cavitation was employed to disperse the
particle into resin system. The nanoparticles are spread evenly throughout the entire volume of resin. The nano composite stronger the storage modulus, Tg, tensile modulus, and flexural modulus from neat epoxy resin. The mechanical performance and thermal stability of the nano composites epoxy are based on the dispersion of the TiO2 within the epoxy matrix. Pallabi Bhuyan et.al. [3] investigated the effect of Cu powder and nanostructured Cu powder on the property of Cu-E-glass fiber composites changed into examined.

The file show pinnacle interplay among the matrix and the reinforcement and there can be comparable distribution of the reinforcement within the matrix. The Cu-E-glass fiber composites hardness turn out to be determined to boom from 0.8GPa to 2.7GPa. As the volume weight percentage of fiber glass is increased for unmilled case. As in milled case it also increases. Chandra Shekar et. al. [4] the use of filament winding technique there are few polymers matrix composite was manufactured. The glass fiber reinforced epoxy, carbon fiber reinforced epoxy matrix polymer composites and hybrid fiber reinforced polymer composites are manufactured successfully. And it is found that fracture toughness value for carbon reinforced polymer composite is higher as compared to E-glass fiber reinforced polymer composite. Mahavir Choudhary et. al. [5] build marble dust in various weight percentage by the used of vacuum-assisted resin transfer molding (VARTM) technique. It filled with glass fiber with epoxy resin composite materials. The thermo mechanical and erosive wear property of glass fiber composite was determined. The tensile strength and modulus of the not filled polymer composite is around 430.76 MPa and 3.85 GPa. Mawarnie Ismail et. al. [6] investigated the composite material which is made by reinforcing the bidirectional glass fibre and RH short fiber with epoxy resin. The best combinations result of hybrid composite is having 5 wt% of RH fiber and 25 wt% of glass fiber gives best mechanical properties like tensile test, flexural test and impact test. M. Sreenivasan et. al. [7] concluded the analysis of a coil spring which is composed of a polymer matrix composite material and performing analysis of the coil spring on Ansys 16.0 software he proposed that the equivalent stress, strain, deformation on applying a load of 5000 N on coil spring there is lesser change as compared to the carbon fibre and Kevlar fibre on applying the same load on it. S. Nallusamy et. al. [8] studied the effect of nanoparticles of titanium oxide as glass fibre is reinforced with it. The outcome of hybrid E-glass bolstered fiber with epoxy nanocomposite. The nanocomposite laminate is prepared with the aid of hand lay-up technique with the aid of various the composition of titanium oxide. It is observed that at 3 wt % of TiO2 the most flexural power become attained because of true interfacial bonding b/w the fibre and epoxy. Raut et.al [9] The analytical and experimental investigation on Automotive outdoor door deal with. The production of Handle the use of composite material with Glass fiber as reinforcement and Polyamide as a matrix turned into successful. We examine the experimental test as well as theoretical test and there may be infrequently any difference in load sporting capability. Hence, we can conclude that most reliable amount of fabric is used to fabricate the Handle no any extra material is used.

1.1 Classification of composites:

Composite are classified in two main terms as they are mentioned below:

1. **Matrix phase**: The primary segment, having a non-stop character, is referred to as matrix. Usually, high ductile and lots much less hard segment is the nature of matrix. It holds the scattered portion and offers a heap with it.

2. Dispersed (reinforcing) phase: The second phase is embedded within the matrix in a discontinuous shape. This secondary segment is known as moreover as dispersed section.
1.2 **Classification of composites based totally on matrix material:**

a). **Metal Matrix Composites (MMC):** MMC are group of materials incorporated with various reinforcing phases such as whiskers or continuous fiber or particulate fibers.

b). **Ceramic Matrix Composites (CMC):** CMC are special type of composite material in which both the reinforcement and matrix material are ceramics.

c). Polymer Matrix Composites (PMC): PMC is the material consist of a polymer (resin) matrix combined with a fibrous reinforcing dispersed phase.

1.3 **Polymer Matrix Composite (PMC):** Polymer Matrix Composite (PMC) is the material consisting of polymer (resin) matrix combine with a fibrous reinforcing dispersed phase Polymer matrix composite are very popular due to their low cost & simple fabrication method. PMCs are currently the most widely utilized composite of the available composites. Ceramic fibres are used to reinforce the matrix in PMCs because they have a higher strength than the matrix material. The matrix, reinforcement, process parameters, microstructure, composition, and interphase all have an impact on the capabilities of PMCs. PMCs are well-known for their low cost and simple manufacturing process. PMC producers can use a variety of manufacturing strategies to generate cost-effective items. Each manufacturing process contains structures that define the type of product that will be produced. The manufacturer is able to provide this knowledge as the best option for the customer. Matrix of polymer the thermoplastic or thermosetting plastic serves because the matrix, with one or greater reinforcements including carbon, glass, metal, and herbal fibres. Polymers produce correct components because they can be treated effectively. Lightweight is the most significant attribute of polymers. PMCs (polymer matrix composites) have a wide range of characteristics. High strength, super impact, compression, and fatigue characteristics; value-effective production and tooling strategies; first rate chemical and corrosion resistance; chemical inertness and superior mechanical features are only a few of them. PMCs are used in rockets, planes, and other vehicles, safety equipment and helmets.

2. **Materials and Methodology**

2.1 **Materials**

a) **E-glass fiber:** In present paper work E-glass fiber was chosen for the matrix material. This fiber is 300 gsm it has a good strength than the other glass fibers as it shows in below figure 3. It has a large application in automobile, aerospace, structural, paper industry, defence, food processing, chemical industry and cooling towers, fireproof suits and due to its fabulous properties, such as high strength to weight ratio, light weight and high tensile strength. It is cheaper than the other polymer matrix composite material. From the diverse varieties of glass fiber. This fiber is drastically used due to maximum regularly used fibers due to its immoderate electricity, low weight and has nicely warmth stiffness, cold resistance, moisture and rust resistance [10].

| Property          | Minimum value | Maximum value | Units   |
|-------------------|---------------|---------------|---------|
| Density           | 2.55          | 2.6           | Kg/m³   |
| Young modulus     | 72            | 85            | GPa     |
| Compressive Strength | 4000        | 5000          | MPa     |
| Hardness          | 3000          | 6000          | MPa     |
| Tensile strength  | 1950          | 2050          | MPa     |

**Table 1**: Properties of E-glass fibre
b) **Titanium dioxide nanoparticle (TiO$_2$):** Titanium dioxide is an inorganic chemical with a white tint that has been utilized in an extensive variety of merchandise for over a century. It is valued for its non-poisonous, non-reactive, and luminous houses, which effectively lighten the whiteness and brightness of a massive range of substances. It's the brightest and whitest. It has a numeral of particular dispositions which make it perfectly suited to various unique applications. It has a virtually immoderate melting problem of 1843°C and boiling trouble of 972°C, so appear virtually as a robust. It is far un-dissolvable in water. It works as an insulator. Another critical asset of titanium dioxide is that it may show photocatalytic interest beneath UV mild. Which makes it most operative for environmental purification, for specific styles of protecting coating layers, sterilisation and anti-fogging surfaces, or even in maximum cancers therapy for maximum cancers affected character.

c) **Copper oxide (CuO):** Copper nanoparticles are generally proper away available in most volumes. Researchers have furthermore endorsed the use of silver and copper ions as superior disinfectants chemical factors for wastewater generated from hospitals containing infectious micro-organism. The antibacterial property of copper nanoparticles, which show that copper nanoparticles have a extraordinary capacity as bacterial agent. Copper non-public immoderate ductility and actually excessive thermal and electric conductivity. Copper particles are in brown to black powder.

![Copper Oxide](Fig 1)

![Titanium dioxide nanoparticles (TiO2)](Fig 2)

![E-glass fiber of 300 gsm](Fig 3)
2.2 Bonding Material: The resin epoxy it truly is used have become Araldite (LY-556) epoxy resin and chemically belongs to ‘epoxide’ circle of relatives and hardener (HY -951), aliphatic 951 are provided through Ashwani Composite GIDA, Uttar Pradesh, India. Araldite, which, is used to bind the glass fiber layers collectively. Hardener is picked to decorate the strong point and grip to the composite. Epoxy resin is highly viscous and is mixed with a chemical substance to make curing substance which is called as hardner. Araldite LY556 is notable property like mechanical, dynamic, thermal & chemical resistance at temperatures under 75°C. Nature of hardener is colourless. Its aroma like ammonia with its pH value 13 [9]. The individual layers of composite the mild steel roller is used to roll on the layers of composite to remove the air which is present inside layer during coating of epoxy and preserve uniform thickness of epoxy inside the layers of fiber. Protects are cured at room temperature for as a minimum 48 hours earlier than characterization. Bonding material figure is shown as in fig 4.

Fig 4 Araldite LY556 and Harder 951

2.3 Fabrications of composite material

The work material was fabricated by hand lay-up method. This method is the moulding method. In this method the fibers are fabricated from reinforcement and covered with the matrix epoxy resin by using laying down. The coating is applied on the layer of each fabric and according to our required thickness the layers are used. It is more time-consuming method and it required more labour for productions. The important disadvantage of this method is undesirable shaped products are made. Such advantages are utilized in low performance composite including fiber-glass boat and bath tub manufacturing. The ultrasonication of TiO₂ with acetone is performed at 36 KHz frequency for 60 minutes. Afterward the TiO₂ nanoparticles is keep to cool for one hours. The proper mixing of titanium dioxide (TiO₂) nanoparticles with epoxy LY 551 by the stirrer at 800 rpm for 1 hours. And then the mixture of TiO₂ with epoxy is ready to apply the paste on the glass fiber. The titanium dioxide nanoparticles are present in 0.6 wt % and glass fiber with epoxy resin and coating of glass fiber with copper oxide. The steps involved in Hand lay-up method.

Hand –Lay-Up method is also called as manual method. The following are the steps involved in the preparation of glass fiber (FRC laminates).
Step 1: Cut the glass fiber polymer of 300gsm into 210 mm X 297 mm size.

Step 2: Preparation of the sample is done by cutting the glass fiber, placing the glass fibre of the size of A4 sheet paper.

Step 3: Then, prepare the matrix by mixing of titanium dioxide nanoparticles (TiO$_2$) with epoxy LY556 and hardener HY 951 in the ratio of 10:3.

Step 4: The A4 sheet is placed on the wooden plate by placing the weight of 40 kg.

Step 5: After placing the OHB sheet in the mould, the matrix is placed above OHB sheet in the mould and spread evenly.

Step 6: Once the Epoxy is placed, the glass fibre is placed above the OHB sheet with Epoxy.

Step 7: After placing the cotton fibre in the mould, the epoxy should be poured on the cotton fibre in the mould and the fibre should be immersed in the epoxy resin.

Step 8: OHB sheet is placed over the immersed glass fibre and it should be free of voids otherwise the desired strength should not be achieved.

Step 9: The laminate is allowed for curing in atmospheric condition for 48 hours.

Step 10: The specimen should be taken out from the mould and after that the OHB sheet is also removed after the time period is over that is 2 days.

![Image](image.png)

**Fig 5** Glass fiber with epoxy titanium dioxide

### 3. Result and Discussion

#### 3.1 Compression Test

Compression test are conducted by applying loads on the specimen. The specimen is kept in b/w the two plates and then the suitable load is applied to know the effect occurred on the specimen. Specimens are prepared according to ASTM D 638 Standards. The dimension is 260 mm x 24 mm x 5 mm. This composite sample is made of having 0.6% of titanium dioxide nanoparticles with glass fibers with epoxy resin and coating with copper oxide. This composite specimen is made of having 9 layers. The composite specimen A is compressed as it is shown in fig-6 and it is found the composite is break when
the force is applied of 6.87 KN and compressive displacement at break is 0.50 mm. This composite specimen C is made of 12 layers but the titanium percentage is fixed and during the testing it is found that the composite is break when force is applied of 10.50 KN and compressive displacement at break is 0.49 mm. This composite sample B having 9 layers specimen is compressed and it is found the composite is break when the force is applied of 2.31 KN and compressive displacement at break is 0.50 mm. The composite specimen D is made of 12 layers but the titanium percentage is fixed and during the testing it is found that the composite is break when force is applied of 3.72 KN and compressive displacement at break is 0.50 mm as shown in fig-7. Compression test result of all the sample is as mentioned below in tabulated form:

Table 2 Compression results of all four specimen

| S.No. | Sample | Fiber layers | With filler/without filler | Force at break [KN] | Compressive displacement at break [mm] | Coefficient of correlation at Modulus |
|-------|--------|--------------|---------------------------|---------------------|----------------------------------------|--------------------------------------|
| 1.    | A      | 9L           | With filler               | 6.87                | .50                                    | 1.00                                 |
| 2.    | B      | 9L           | Without filler            | 2.31                | .50                                    | 1.00                                 |
| 3.    | C      | 12L          | With filler               | 10.50               | .49                                    | 1.00                                 |
| 4.    | D      | 12L          | Without filler            | 3.72                | .60                                    | 1.00                                 |

3.2 Flexural strength
A flexural test is easier than the tensile test. Specimens are prepared according to ASTM D 638 Standards. The dimension is 150 mm x 15 mm x 3 mm. The sample is made of having 0.6% of titanium dioxide nanoparticles with glass fibers with epoxy resin and coating with copper oxide. This composite specimen is made of having 9 layers of glass fiber. The composite specimen is flexural and it is found that composite is bend when the force at yield of 149.09 and flexural displacement at 4.51 mm in sample A as shown in fig 8. The sample C is made of 12 layers the composite is flexible when force at yield point is 327.29 N and flexural displacement at 5.70 mm. The composite sample B is made of glass fibers with epoxy resin and coating with copper oxide as shown in fig 9. The specimen is made of having 9 layers. The composite specimen is flexural and it is found the composite is bend when the force at yield of 112.11 N and flexural displacement at yield is 4.96 mm and bending stiffness 25.29 N/mm. In sample D specimen is made of 12 layers and during the testing it is found that the composite is bend when force at yield 130.03 N and displacement at yield is 3.28 mm.

Flexural test of all the four sample is shown in tabulated form:
Table 3 flexural test result of all four samples.

| Sr. No. | Samples | Fiber layers | With filler/without filler | Force at yield (offset 0.2%) [N] | Displacement at yield (offset 0.2%) [mm] |
|---------|---------|--------------|-----------------------------|----------------------------------|------------------------------------------|
| 1.      | A       | 9 L          | With filler                 | 149.06                           | 4.51                                     |
| 2.      | B       | 9L           | Without filler              | 112.11                           | 4.96                                     |
| 3.      | C       | 12L          | With filler                 | 327.99                           | 5.70                                     |
| 4.      | D       | 12L          | Without filler              | 130.03                           | 3.28                                     |

Fig-6 Compression sample A

Fig-7 Compression sample D

Fig-8 flexural sample A

Fig-9 flexural sample B
Fig 10 Compression test of composite sample

Fig 11 Flexural test of composite samples

4. Conclusion

In this paper work the glass fiber epoxy titanium dioxide nanoparticles with copper coating consist of 0.6 weight percent of nanoparticles of TiO$_2$ with different no. of fiber layers specimen is prepared. The different composite specimen shows tremendous mechanical property.

There is two testing were performed for the prepared composite material such as flexural test (three point bending) and compression test. On the comparision of the compression test sample having 9 layers and 12 layers respectively with filler TiO$_2$ nanocomposite. The strength to weight ratio of this composite is higher. The result of compression test of the sample the force at break in 9 and 12 layers are 6.87 KN and 10.50 KN respectively. As we found that in 12-layer composite is more stronger than
the 9-layer composite sample. As the layer is increased, the strength increases but filler material remains constant. But during the neat (without filler material) composite, the compression test of the 9 layers and 12 layers is performed. It is found that the force at break is 2.31 KN and 3.27 KN respectively. There is a little increase in force at break. In the flexural testing of this composite material with filler material, it shows an excellent flexural strength. The composite which is made of glass fiber with reinforcement TiO2 epoxy composite. The composite with 9 layers and 12 layers, the force at yield are 149.06 N and 327.99 N respectively. The composite sample with neat (without TiO2) shows flexural strength.

The composite sample with neat (without TiO2) the testing of sample flexural test. The force at yield in 9 layers and 12 layers are 112.11 N and 130.03 N respectively.

Acknowledgments

It gives me great pleasure to express my thanks and indebtedness to my supervisor, Prof. S.C. Jayswal, for his counsel and direction from the beginning of this study. I am also grateful to Vibronics Medical Pvt Ltd Kundli, Sonipat Haryana, for allowing me to test my composite samples there.

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