Mechanical properties and evaluation of glass fiber reinforced polymer/ TiO_2 nano composite laminates

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Abstract

My graduate studies have centered on the fascinating field of advanced composite materials, specifically the integration of inorganic nanoparticles into thermosetting epoxy polymers. I've been particularly drawn to this area due to the inherent brittleness of epoxy matrices, a well-known limitation that hinders their broader application. My research has explored how incorporating nanoparticles can significantly enhance fracture resistance, improving both toughness and brittleness – crucial properties for structural integrity. The potential applications of these lightweight, high-performance materials are vast and exciting, ranging from robotics and aerospace to the demanding environments of space shuttles, missiles, and wind turbine blades. My work has also considered the current research emphasis on glass fiber reinforced composites. While these materials offer excellent longitudinal mechanical properties, their transverse weakness presents a significant challenge. To address this, my research has focused on reinforcing the matrix system of glass fiber reinforced polymer laminates with varying concentrations (0-5%) of titanium dioxide (TiO_2*) nanoparticles. These composites were meticulously fabricated using a compression molding method. A key part of my graduate work involved a thorough assessment of* *the mechanical characteristics of these nano particle-enhanced epoxy matrix laminated composites. Furthermore, I employed Scanning Electron Microscopy (SEM) to analyze the fracture surfaces of tensile test samples, providing valuable insights into the failure mechanisms and the impact of Tio$_2$ nano particle reinforcement. This microscopic analysis has allowed me to directly correlate the observed mechanical property improvements with the micro structural features of the fractured composites.*

Keywords: *composites, Nano-particles, Titanium dioxide (Tio$_2$), Scanning Electron Microscope*

1.Introduction

Throughout my studies, composite materials have expanded considerably. According to what I've learned, these materials are an intriguing class of constructed structures that integrate two or more different constituents at the macroscopic level. The important thing here is that these components don't dissolve, preserving their individual identities while adding to the composite's overall characteristics. In particular, I've learned to value how the two main phases—the matrix and the reinforcing phase—interact. The continuous matrix phase contains the reinforcing phase, which can be fibers, particles, or flakes, among other forms. Unlike single-phase materials, this combination enables us to customize the material properties. Strong examples of composites can be found in nature itself, such as bone, where calcium and phosphate ions strengthen the collagen matrix, and wood, where the lignin matrix gives the cellulose fibers structural

These examples from nature demonstrate the underlying ideas at work. According to my understanding, the matrix fulfills a number of vital purposes. It does more than just give the composite its shape; it also shields the reinforcement from the elements and is essential for transferring loads to the reinforcing phase. Additionally, the matrix works in concert with the reinforcement to increase the material's overall toughness. In contrast, the reinforcement is principally in charge of improving the composite's strength, stiffness, and other mechanical characteristics. It can also affect other important properties including conductivity, thermal transport, and the coefficient of thermal expansion. By carefully choosing and combining reinforcement and matrix, we can create materials with particular qualities that are suited to a variety of uses. Nano composites are currently the main focus of composite materials research. One kind of composite in which one of the materials is at the nano scale is called a nano composite. Researchers are looking into adding nano materials to the matrix of conventional composite materials to enhance their mechanical and other qualities. Achieving a uniform distribution of the nano material within the matrix and managing the matrix's increased viscosity when the nano material is introduced are two major obstacles in this procedure, though. Particles having nano scale dimensions, usually between 1 and 100 nanometers, make up nano materials. One-, two-, and zero-dimensional versions of these materials are all possible. Nanoparticles and other zero-dimensional materials are the most prevalent, but nano rods, nano tubes, and nano wires are examples of one-dimensional materials. Nano films, nano layers, and nano coatings are examples of two-dimensional nano materials. Additionally, nano materials can be divided into groups according to their composition, including metal, dendrites, composites, and carbon. Excellent mechanical and thermal properties are demonstrated by zero-dimensional nano materials in combination with polymer matrices. In composites, nano tubes and nano rods are frequently employed to improve reinforcing or provide polymers electrical conductivity. Nano silica, aluminum oxide, titanium oxide, silicon carbide, graphene, carbon nano fibers, and multi-wall carbon nano tubes are examples of common commercially accessible nano materials.

In some applications, fiber-reinforced polymer (FRP) composites frequently surpass high-strength steel due to their exceptional strength-to-weight ratio. Because of this, they are especially well-suited for sectors like aerospace and automotive where weight is a crucial consideration. Because of their adaptability, qualities can be customized by changing the fibers' kind and orientation, guaranteeing peak performance for particular needs. Many FRPs have outstanding corrosion resistance and durability, which makes them ideal for harsh settings like maritime applications. Furthermore, certain FRPs have exceptional dampening properties that successfully lower noise and vibrations, which is particularly advantageous in applications like wind turbines.

2.Materials

Material selection plays a crucial role in the design and development of any physical product. The goal of this process is to minimize cost while ensuring the product meets the necessary performance criteria. As the cornerstone of all engineering applications and designs, material selection is essential to creating functional and durable products. This process involves several key factors: understanding the application requirements, considering possible materials, applying physical principles, and ultimately making the final material selection. The first step in material selection is determining the application requirements. These requirements are specific to the function or purpose of the part or product. For instance, a bicycle cannot be constructed from fabric because the application requires materials that are structurally strong and durable. Once the application requirements are clear, the next step is to identify the possible materials that can meet those criteria. These materials are constrained by the application’s needs; for example, you cannot use a material with inadequate tensile strength for a structural component that bears heavy loads.

2.1Glass Fiber Reinforced Polymer (GFRP) is a composite material that combines a polymer matrix with glass fibers, resulting in a material with excellent mechanical properties. These include high tensile strength, stiffness, and impact resistance, which make GFRP suitable for a range of industries, such as automotive, aerospace, and construction. The lightweight nature of GFRP, coupled with its corrosion resistance and low thermal conductivity, enhances its applicability in various engineering applications. When utilized in friction stir casting, GFRP contributes to improved structural integrity, as the glass fibers efficiently distribute loads and enhance impact resistance. The composite material also demonstrates good fatigue resistance, making it ideal for applications subjected to repetitive loading cycles.

Titanium Dioxide (Tio_2) nanoparticles are renowned for their excellent photo catalytic properties and high chemical stability. When incorporated into GFRP composites, Tio_2 nanoparticles offer enhanced mechanical properties and increased thermal stability. The small size of these nanoparticles facilitates better dispersion within the polymer matrix, which ensures a more even distribution of reinforcement throughout the composite. Besides strengthening the material, the inclusion of Tio_2 nanoparticles also provides UV protection, which is crucial for applications exposed to outdoor environments. The combination of GFRP and Tio_2 nanoparticles results in advanced composite materials that deliver superior performance in a variety of applications, particularly when used in friction stir casting processes.

Fig.1 Titanium oxide nano particles

L12 resin is a specific type of epoxy resin that is frequently used in combination with compatible hardeners for various manufacturing processes, such as hand lay-up, filament winding, and pultrusion. Known for its medium viscosity, L12 resin allows for excellent fiber impregnation while maintaining manageability during processing. This resin can be cured using a range of hardeners, which enable customization of the final material properties. Factors such as cure speed, operating temperature, and mechanical characteristics are influenced by the choice of hardener. When cured with the appropriate hardener, such as K-12, L12 resin systems display outstanding thermal stability, allowing them to withstand higher temperatures without significant degradation, making them suitable for demanding applications.

Fig.2 L-12 Resin

K6 hardener is a widely used hardener, especially in combination with epoxy resins such as L12. It is known for its rapid curing abilities, even at room temperature, making it an excellent choice for time-sensitive projects. K6 hardener has a low viscosity, which ensures easy mixing with epoxy resins and efficient penetration into intricate molds or fiber reinforcements, promoting a uniform, void-free final product. However, due to its high reactivity, K6 has a short pot life, meaning it requires quick application after mixing before it begins to cure. This characteristic, while limiting in terms of working time, also contributes to the fast curing speed that is desired in many applications. K6 is commonly used in hand lay-up applications, where composite parts are manually created by layering resin-soaked fibers. When paired with L12 resin, it is important to follow the manufacturer’s recommended mixing ratios (typically 10-12 parts of K6 per 100 parts of L12) to achieve optimal material properties. The combination of fast curing and low viscosity makes K6 hardener a versatile and essential component in many composite fabrication processes.

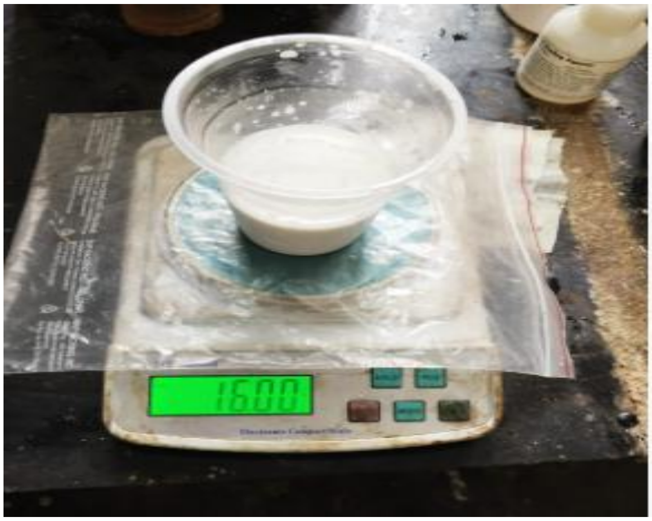


Fig.3 Resin L12+hardener K6+ Tio$_2$ mixture

Peel ply is a lightweight, loosely woven fabric applied to the surface of a composite layup during the curing process. Its primary purpose is to create a textured surface, making it ideal for secondary bonding or painting without the need for additional sanding or surface preparation. A 95 gsm (grams per square meter) peel ply refers to the fabric's weight, indicating that one square meter weighs 95 grams. This weight is common, but peel plies are available in a range of densities to cater to specific needs. Lighter peel plies might be used for smooth finishes, while heavier options are chosen for more aggressive textures. The appropriate gsm is selected based on factors such as the resin system, the desired surface finish, and the bonding or painting requirements. The manufacturer's data sheet will often recommend the ideal gsm to ensure optimal results. In composite manufacturing, peel plies are a valuable tool for achieving the desired surface characteristics and improving the overall efficiency of the production process.

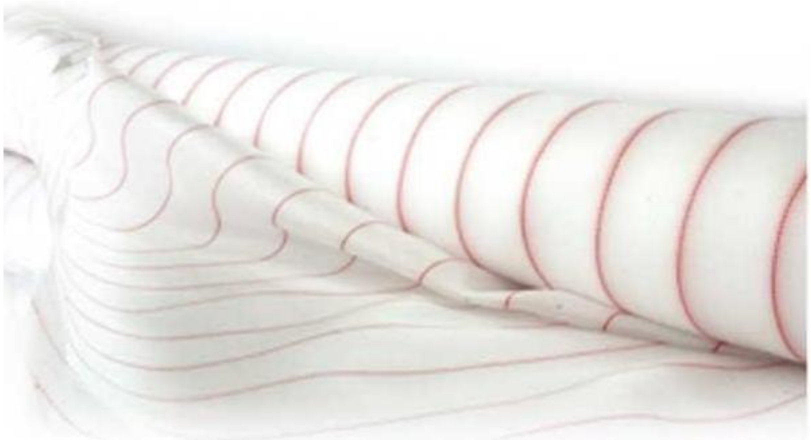


Fig.4 peel ply

Mold releasing agent In friction stir casting with Glass Fiber Reinforced Polymer (GFRP) reinforcement, selecting the right mold release agent is essential for achieving a smooth and efficient production process. It should be compatible with the resin system used in the GFRP composite (such as epoxy, polyester, or vinyl ester) and the mold material (such as aluminum, steel, or silicone), ensuring no chemical reactions or residue that could affect the product quality. The release agent should be easy to apply uniformly to the mold surface, whether by spraying, brushing, or wiping.

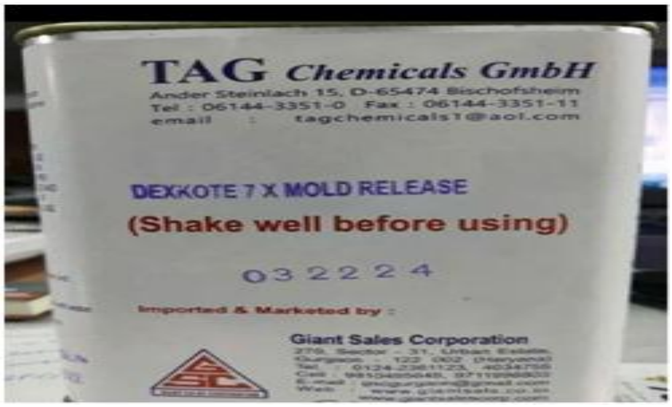


Fig.5 Mold release

Fig.6 Silicon rubber for Rubber mold (10:1) ratio

Fig.7 Aluminum patterns for making rubber mold preparation

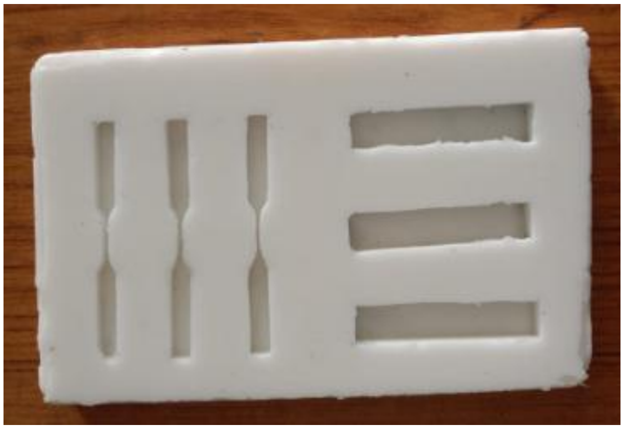


Fig.8 Rubber mould for nano particle composites

Glass fiber cloth is a woven fabric made from glass fibers, which are known for their strength, lightweight nature, and excellent mechanical properties. When combined with a resin matrix such as epoxy or polyester, glass fiber cloth forms a durable composite material. The weight of the cloth is expressed in GSM (grams per square meter), which indicates the fabric’s density. A 380 GSM glass fiber cloth means that one square meter of the material weighs 380 grams.

Fig.9 Glass fiber of 380 GSM

A vacuum desiccator is a sealed container designed to remove air using a vacuum pump. It is primarily used for eliminating moisture from substances or for storing materials that are sensitive to moisture. Vacuum desiccators also play a key role in removing air bubbles from mixtures, such as epoxy resin, by creating a vacuum within the container. When a motor is used in conjunction with the vacuum desiccator, it helps in drawing out air, causing the bubbles to rise to the surface of the mixture and escape.

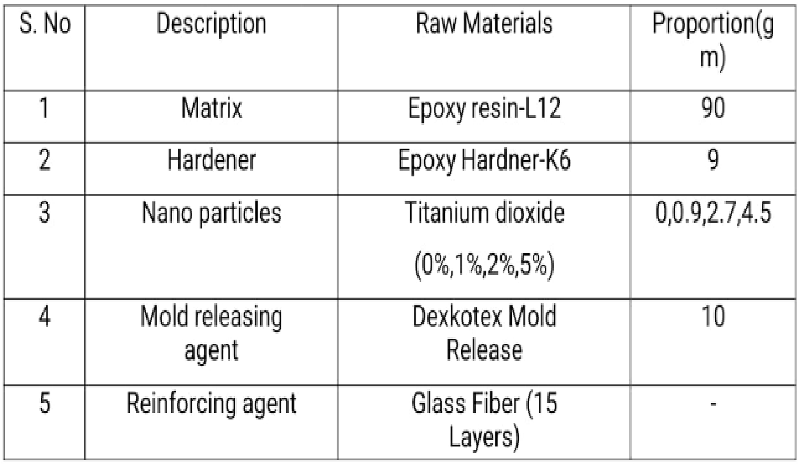
Fig.10 Vacuum desiccators and motor

These tools are versatile and find applications across a range of fields. Some common uses of vacuum desiccators and motors include:

- Removing moisture from substances to prevent degradation or contamination
- Storing moisture-sensitive materials in a controlled, dry environment
- Removing air bubbles from mixtures, enhancing the quality and consistency of materials like epoxy resin
- Drying samples in preparation for analysis, ensuring accurate results
- Preparing samples for microscopy by eliminating any unwanted moisture or air interference
- Storing electronic components in moisture-free conditions to avoid damage
- Packaging food products to extend shelf life and maintain freshness

3.Preparation of FRP composites

The hand-lay-up method id a best way for processing composite materials. It requires minimal infrastructure, making it an accessible and practical choice for various applications. Enhance the mechanical-properties of fiber-resin composites produced by this method, the standard test procedure ASTM-D790M-86 is typically employed for measurements. The process begins with the preparation of the mold, which is constructed on a smooth, clear film. Two-way tape is applied along the edges of the mold to maintain the correct dimensions. Once the mold surface is prepared with the tape on the clear film, long fibers—cut to match the size of the mold—are placed onto the surface of the thin plastic sheet. These fibers serve as the reinforcement for the composite.



S. No	Description	Raw Materials	Proportion(gm)
1	Matrix	Epoxy resin-L12	90
2	Hardener	Epoxy Hardner-K6	9
3	Nano particles	Titanium dioxide (0%,1%,2%,5%)	0,0.9,2.7,4.5
4	Mold releasing agent	Dexkotex Mold Release	10
5	Reinforcing agent	Glass Fiber (15 Layers)	-

Table.1 FRP composites of Epoxy + Hardener +TIO_2+Glass Fiber

Then, using the proper ratios, a thermosetting polymer in liquid form is fully combined with the suggested hardener or curing agent. Using a brush to ensure the polymer is equally distributed across the surface, this mixture is poured onto the fiber layer. After that, the mold is allowed to cure at room temperature for a full day, which allows the polymer to solidify. Following the curing process, specimens are prepared for additional testing and assessment by cutting them from the sheets in compliance with ASTM guidelines. Because of its ease of use, affordability, and comparatively low equipment requirements, this process is frequently employed to create composite materials.

The hand lay-up procedure is the first step in the fabrication of composite material specimens. Glass fibers are first carefully cut from a roll and then weighed to determine the exact quantity needed. A precise amount of epoxy resin L-12 is measured and put into a container to create a composite plate devoid of filler. To achieve the proper consistency, the hardener K-6 is heated in a parallel process to change its solid state into a liquid. After heating, the hardener is weighed and moved in the designated quantity to a different container. Weighing the right amount of epoxy resin and putting it in a container are the steps involved in creating laminates with filler.

Additionally, the same quantity of preheated hardener K-6 is weighed and put in a different container. Furthermore, measuring epoxy resin precisely and then pouring it into a container is the first step in making laminates with filler. Additionally, an equivalent amount of liquid hardener K-6 is measured and put into a different container. Furthermore, the necessary quantity of silica powder is weighed out individually.

In order to create the matrix phase, the silica powder is first mixed equally with the epoxy resin. The hardener is gradually added to the resin-silica mixture once the silica has completely incorporated. Using a glass rod to stir guarantees the blend's uniformity. This phase needs to be done carefully because using too much heat during mixing could degrade the composite and compromise its ultimate qualities. First, a precise amount of silica powder is weighed in order to start the process of creating composite materials. After that, the silica is added to the epoxy resin and completely mixed to form the matrix phase. The mixture is then mixed with the heated hardener once the silica has been evenly dispersed throughout the resin.

To guarantee even blending, this mixture is gently swirled with a glass rod. Care must be taken not to overheat the hardener during this procedure, since this could degrade the quality of the composite material. Following the preparation of the resin mixture, the hand lay-up technique is used to build the composite plates. For this operation, a clean, smooth surface is selected. In the first phase, a polythene sheet larger than the glass fiber mesh to be used is covered with a thin layer of wax. Next, the wax-coated sheet is covered with a single layer of glass fiber mesh, which is then covered with epoxy resin. To guarantee that there are no air gaps, the resin is evenly distributed throughout the fiber mesh using a roller brush and light pressure. The procedure is repeated, pouring epoxy and spreading it uniformly after another glass fiber mesh has been placed on top of the first. Until all eight glass fiber meshes are placed, this stacking process is repeated. The hand lay-up process is finished by placing a final polythene sheet coated with wax on top. This procedure is carried out for three different compositions:

- Glass FRP 0% Tio_2 + Epoxy + Resin + Hardener
- Glass FRP 1% Tio_2 + Epoxy + Resin + Hardener
- Glass FRP 2% Tio_2 + Epoxy + Resin + Hardener
- Glass FRP 5% Tio_2 + Epoxy + Resin + Hardener

4.Preparation of Tio_2 nano particles

Tio_2 is mixed in the ratio of 0 % weight ratio of resin: The effects of adding Tio_2 (titanium dioxide) to a resin system, specifically when no Tio_2 is added (0% weight ratio). This is essentially a baseline or control sample. The resin will exhibit its inherent properties, such as its strength, flexibility, hardness, and chemical resistance, in its unmodified state. These properties will serve as the benchmark against which the effects of adding Tio_2 can be compared. Without Tio_2, the resin will not exhibit photo catalytic activity, meaning it won't be able to catalyze chemical reactions when exposed to light. All testing as per standards are prepared.

Tio_2 is mixed in the ratio of 1 % weight ratio of resin: The consequences of incorporating titanium dioxide (Tio_2) into a resin system, particularly in the absence of Tio_2 (1% weight ratio). In essence, this is a control or baseline sample. The resin will exhibit its intrinsic features, such as its strength, flexibility, hardness, and chemical resistance, in its unmodified state. These qualities will serve as the baseline against which the impacts of adding Tio_2 can be compared. In the absence of Tio_2, the resin will not be able to accelerate chemical reactions when exposed to light, a phenomenon known as photo catalytic activity.

Tio_2 is mixed in the ratio of 2 % weight ratio of resin: The effects of adding Tio_2 (titanium dioxide) to a resin system, specifically when no Tio_2 is added (2% weight ratio). This is essentially a baseline or control sample. The resin will exhibit its inherent properties, such as its strength, flexibility, hardness, and chemical resistance, in its unmodified state. These properties will serve as the benchmark against which the effects of adding Tio_2 can be compared. Tio_2 nanoparticles can act as reinforcing agents, improving the mechanical properties of the composite.

Tio_2 is mixed in the ratio of 5% weight ratio of resin: Titanium dioxide (Tio_2) into a resin system, particularly in the absence of Tio_2 (5% weight ratio). In essence, this is a control or baseline sample. The resin will exhibit its intrinsic features, such as its strength, flexibility, hardness, and chemical resistance, in its unmodified state. These qualities will serve as the baseline against which the impacts of adding Tio_2 can be compared. By serving as reinforcing agents, Tio_2 nanoparticles can enhance the composite's mechanical qualities. All testing as per standards are prepared.

5.Tensile test

In a project focused on GFRP/Tio_2 nano composite laminates, bending tests are plays a critical role in understanding the influence of Tio_2 nanoparticles on the mechanical-properties of GFRP composites. The bending test allows for the comparison of the structural properties of GFRP laminates with and without Tio_2, revealing the effect of nano particle addition on the material's overall strength and performance.

Fig.11 universal testing machine

Tensile testing also aids in determining the optimal percentage of Tio_2 nanoparticles to achieve the desired balance of strength and stiffness within the composite. By analyzing the data obtained from these tests, valuable insights can be gained into the material's behavior under stress. This information is key to ensuring that the manufactured composite laminates maintain consistency and reliability, which is essential for practical applications. Ultimately, the results of tensile testing help refine the design of GFRP/Tio_2 nano composite laminates, optimizing them for specific uses.

6.Flexural test

For the flexural testing of GFRP/Tio_2 nano composite laminates, rectangular specimens are prepared following ASTM D790 standards, with precise measurements taken to ensure consistency. The test uses a three-point bending fixture on a Universal Testing Machine (UTM), where a constant rate of load is applied. Throughout the process, the load cell and extensometer record the force and deflection of the sample. The load-deflection data gathered is crucial for calculating the bended strength, while the bended modulus is determined from the linear portion of the load-deflection curve. These tests are more helpful to understand the materials. This comparison contributes to a deeper understanding of how the addition of Tio_2 affects the material's performance under bending stress.

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Fig.12 Flexural test machinery

7.Impact test

The Charpy impact test process for GFRP/Tio_2 nano composite laminates involves preparing specimens, either notched or unnotched, in accordance with ASTM D6110 standards, ensuring precise dimensions for consistency. These specimens are then placed on the Charpy impact testing machine, where a pendulum with a known potential energy is released to strike the specimen. During the fracture, the energy absorbed by the specimen is measured, which reflects the material's impact resistance.

Fig.13 Charpy Impact test machinery

8.Scanning electron microscopy (SEM)

The SEM process for GFRP/Tio$_2$ nano composite laminates begins with preparing small sections of the laminate, which are then mounted on SEM stubs and coated with a conductive material to facilitate electron flow. Once the specimen is prepared, an electron beam scans the surface, and the resulting signals are used to produce high-resolution images.

Fig.14 Scanning electron microscopy apparatus

These images are then carefully analyzed to evaluate various aspects of the composite, including the fiber distribution and orientation, the dispersion and any potential defects present within the material. Key findings from SEM:

- Particle geometry

- Surface topography
- Agglomeration and particle packing
- Composition analysis (with EDS)

9.Tensile test nano particle specimens

Fig.15 before & after 0%TiO_2 Tensile Specimens prepared by Nano particles

Fig.16 before & after 1%TiO_2 Tensile Specimens prepared by Nano particles

Fig.17 before & after 2%Tio_2 Tensile Specimens prepared by Nano particles

Fig.18 before & after 5%Tio_2 Tensile Specimens prepared by Nano particles

10.Flexural and impact test nano particles specimens

Below is the standard ASTM size for testing of the flexural and impact specimens made for all compositions used like 0% Tio_2 glass Epoxy + Resin + Hardener, 1 % Tio_2 glass Epoxy + Resin + Hardener, 2% Tio_2 glass Epoxy + Resin + Hardener, 5% Tio_2 glass Epoxy + Resin + Hardener are developed based on the given standard values.

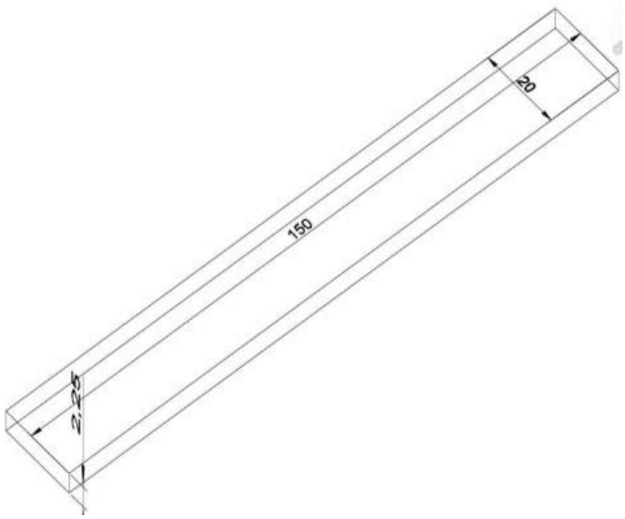


Fig.19 flexural test specimens dimensions

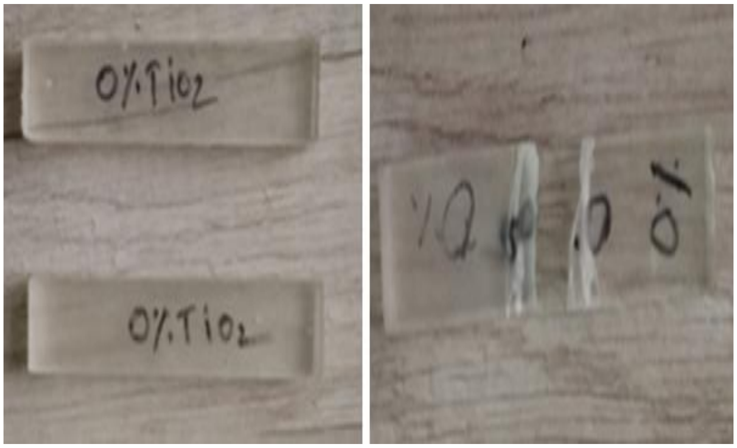


Fig.20 before & after 0%TiO_2 Flexural Specimens prepared by Nano particles

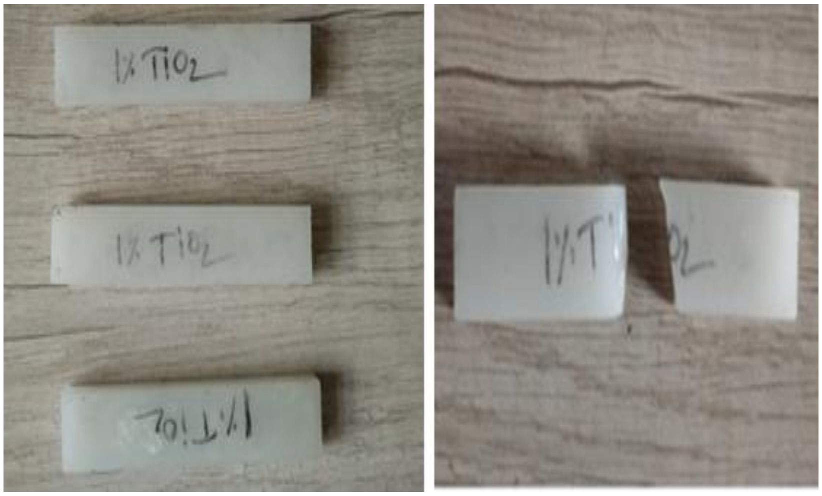


Fig.21 before & after 1%TiO_2 Flexural Specimens prepared by Nano particles

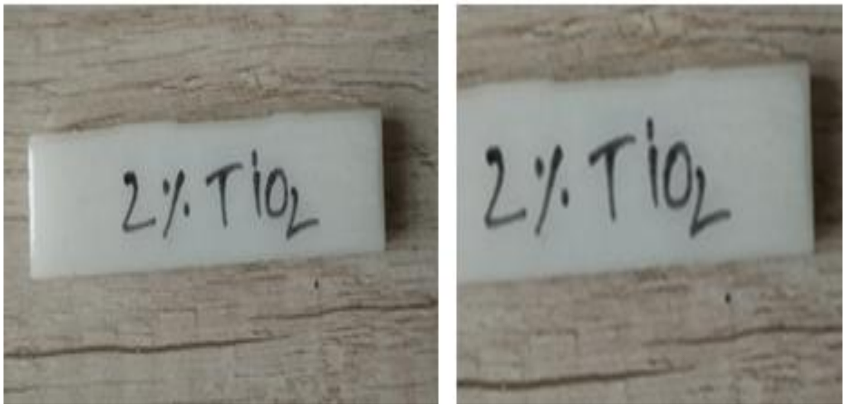


Fig.22 before & after 2%Tio$_2$ Flexural Specimens prepared by Nano particles

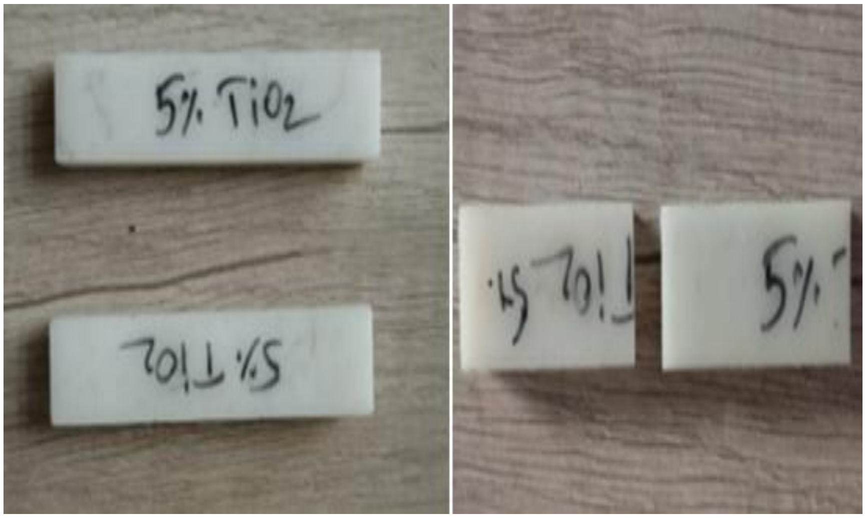


Fig.23 before & after 5%Tio$_2$ Flexural Specimens prepared by Nano particles

11.Tensile test on GFRP specimens

Below is the standard ASTM size for testing of the tensile and flexural specimens made for all compositions used like 0% Tio$_2$ glass Epoxy + Resin + Hardener, 1 % Tio$_2$ glass Epoxy + Resin + Hardener, 2% Tio$_2$ glass Epoxy + Resin + Hardener, 5% Tio$_2$ glass Epoxy + Resin + Hardener are developed based on the given standard values.

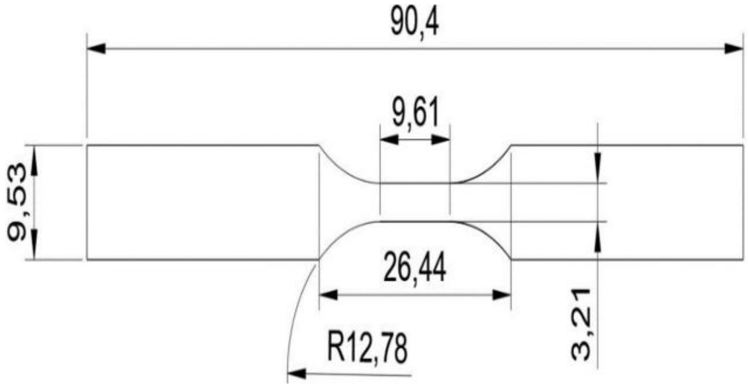


Fig.24 Tensile test specimen’s dimensions

The following specimens are Tensile and Flexural Specimens with 0% Tio$_2$ glass Epoxy + Resin + Hardener, 1% Tio$_2$ glass Epoxy + Resin + Hardener, 2% Tio$_2$ glass Epoxy + Resin + Hardener, 5% Tio$_2$ glass Epoxy + Resin + Hardener. Following are the specimens prepared by the Glass fiber reinforced with hardener and resins using Hand layup process.

Fig.25 before & after 0% Tio$_2$ glass Epoxy + Resin + Hardener specimens

Fig.26 before & after 1% Tio$_2$ glass Epoxy + Resin + Hardener Specimens

Fig.27 before & after 2% Tio_2 glass Epoxy + Resin + Hardener Specimens

Fig.28 before & after 5% Tio_2 glass Epoxy + Resin + Hardener Specimens

12.Impact test GFRP specimens

Below is the standard ASTM size for testing of the charpy impact specimens made for all compositions used like 0% Tio_2 glass Epoxy + Resin + Hardener, 1 % Tio_2 glass Epoxy + Resin + Hardener, 2% Tio_2 glass Epoxy + Resin + Hardener, 5% Tio_2 glass Epoxy + Resin + Hardener are developed based on the given standard values.

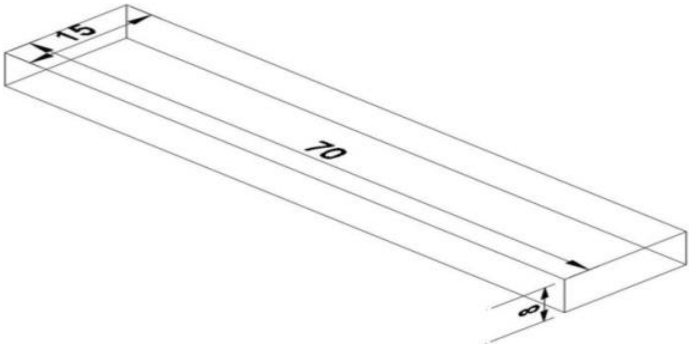


Fig.29 Impact test specimens dimensions

Fig.30 before and after 0%TiO_2 Impact FRP specimen

Fig.31 before and after 1%TiO_2 Impact FRP specimen

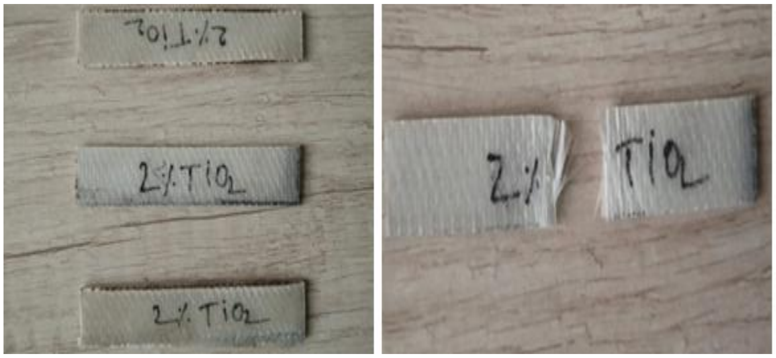
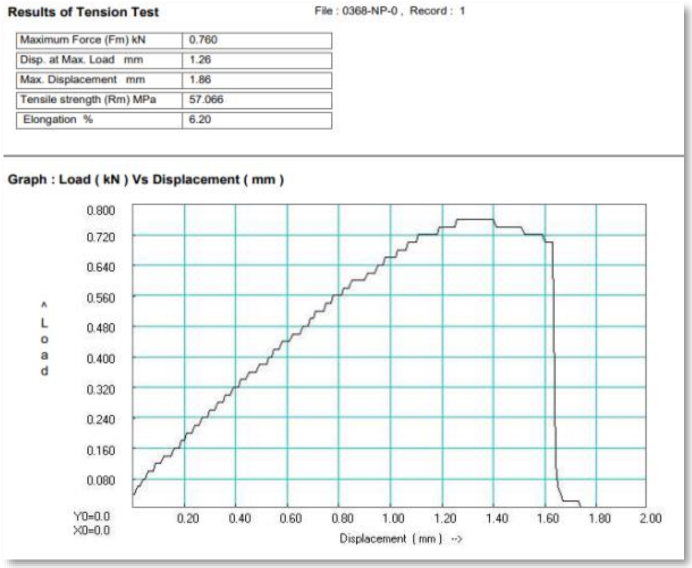


Fig.32 before and after 2%TiO_2 Impact FRP specimen

Fig.33 before and after 5%TiO_2 Impact FRP specimen

13.Results

Tensile test on 0% Tio_2- nano particles



Results of Tension Test File : 0368-NP-0 , Record : 1

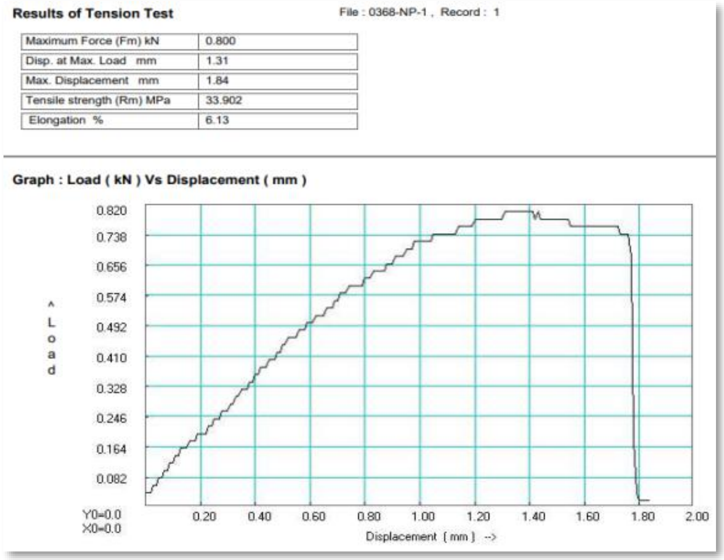
Maximum Force (Fm) kN	0.760
Disp. at Max. Load mm	1.26
Max. Displacement mm	1.86
Tensile strength (Rm) MPa	57.066
Elongation %	6.20

Graph : Load (kN) Vs Displacement (mm)

Graph.1 Load Vs Displacement for 0% Tio_2 -Nano particles

The above Graph is about 0% Tio_2 -Nano particles tensile test report. it shows the maximum displacement about 1.86 mm at 1.26 KN of load with a tensile strength of 57.066 MPa.

Tensile test on 1% Tio_2- nano particles



Results of Tension Test File : 0368-NP-1 , Record : 1

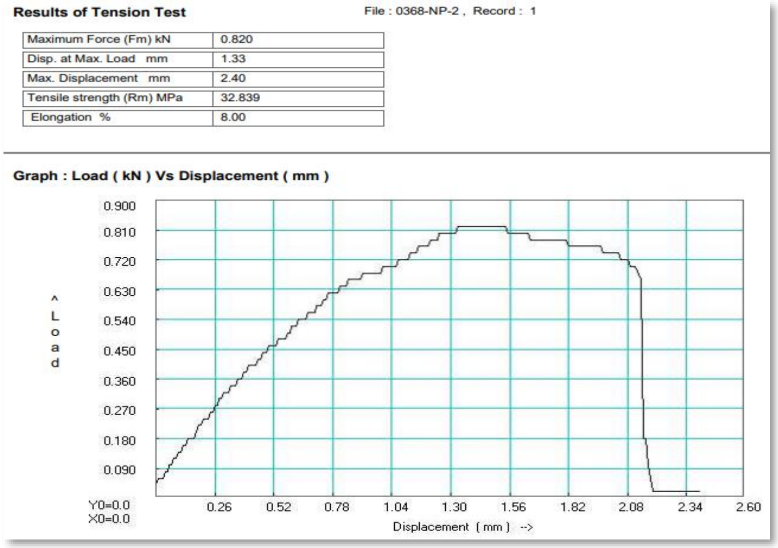
Maximum Force (Fm) kN	0.800
Disp. at Max. Load mm	1.31
Max. Displacement mm	1.84
Tensile strength (Rm) MPa	33.902
Elongation %	6.13

Graph : Load (kN) Vs Displacement (mm)

Graph.2 Load Vs Displacement for 1% Tio_2-Nano particles

The above Graph is about 1% Tio_2 -Nano particles tensile test report. It shows the maximum displacement about 1.84 mm at 1.31 KN of load with a tensile strength of 33.902 MPa.

Tensile test on 2% Tio_2- nano particles



Results of Tension Test File : 0368-NP-2 , Record : 1

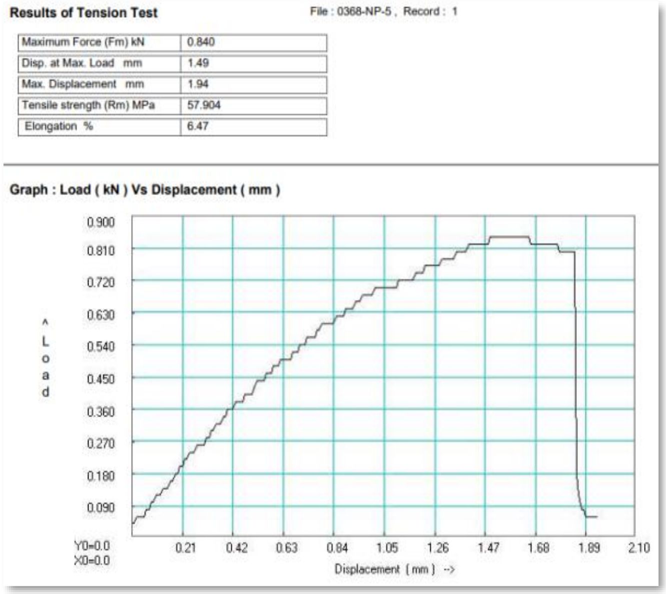
Maximum Force (Fm) kN	0.820
Disp. at Max. Load mm	1.33
Max. Displacement mm	2.40
Tensile strength (Rm) MPa	32.839
Elongation %	8.00

Graph : Load (kN) Vs Displacement (mm)

Graph.3 Load Vs Displacement for 2% Tio_2-Nano particles

The above Graph is about 2% Tio_2 -Nano particles tensile test report. It shows the maximum displacement about 2.40 mm at 1.33 KN of load with a tensile strength of 32.839 MPa.

Tensile test on 5% Tio_2- nano particles



Results of Tension Test File : 0368-NP-5 , Record : 1

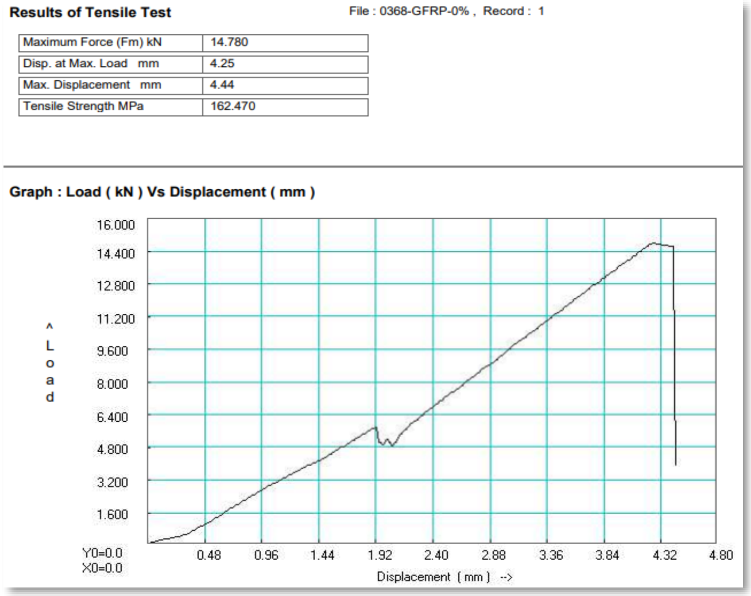
Maximum Force (Fm) kN	0.840
Disp. at Max. Load mm	1.49
Max. Displacement mm	1.94
Tensile strength (Rm) MPa	57.904
Elongation %	6.47

Graph : Load (kN) Vs Displacement (mm)

Graph.4 Load Vs Displacement for 5% Tio_2-Nano particles

The above Graph is about 5% Tio$_2$ -Nano particles tensile test report. It shows the maximum displacement about 1.94 mm at 1.49 KN of load with a tensile strength of 57.904 MPa.

Tensile test on GFRP-0%



Results of Tensile Test

File : 0368-GFRP-0% , Record : 1

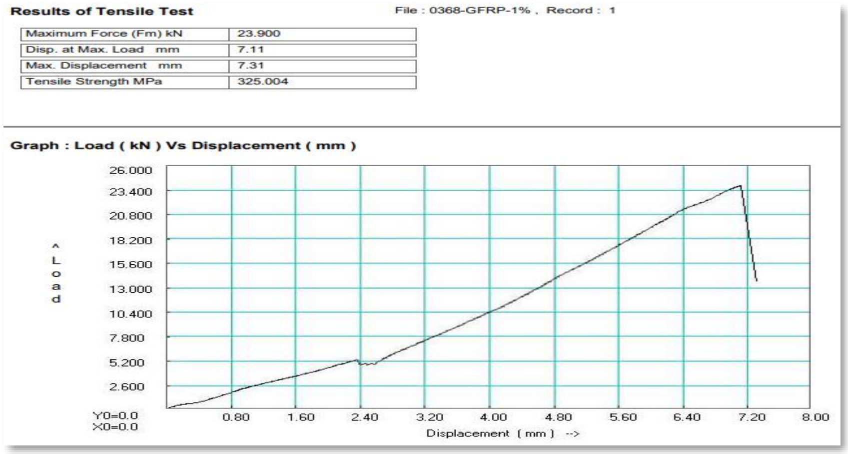
Maximum Force (Fm) kN	14.780
Disp. at Max. Load mm	4.25
Max. Displacement mm	4.44
Tensile Strength MPa	162.470

Graph : Load (kN) Vs Displacement (mm)

Graph.5 Load Vs Displacement 0% GFRP

The above Graph is about 0% Glass fiber reinforced plastics specimens tensile test report. It shows the maximum displacement about 4.44 mm at 4.25 KN of load with a tensile strength of 162.470 MPa.

Tensile test on GFRP-1%



Results of Tensile Test

File : 0368-GFRP-1% , Record : 1

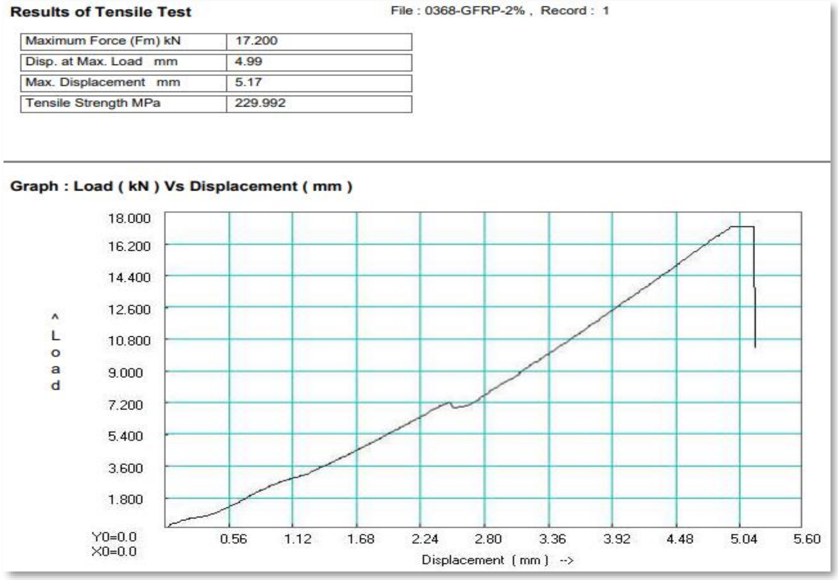
Maximum Force (Fm) kN	23.900
Disp. at Max. Load mm	7.11
Max. Displacement mm	7.31
Tensile Strength MPa	325.004

Graph : Load (kN) Vs Displacement (mm)

Graph.6 Load Vs Displacement 1% GFRP

The above Graph is about 1% Glass fiber reinforced plastics specimens tensile test report. It shows the maximum displacement about 7.31 mm at 7.11 KN of load with a tensile strength of 325.004 MPa.

Tensile test on GFRP-2%



Results of Tensile Test

File : 0368-GFRP-2% , Record : 1

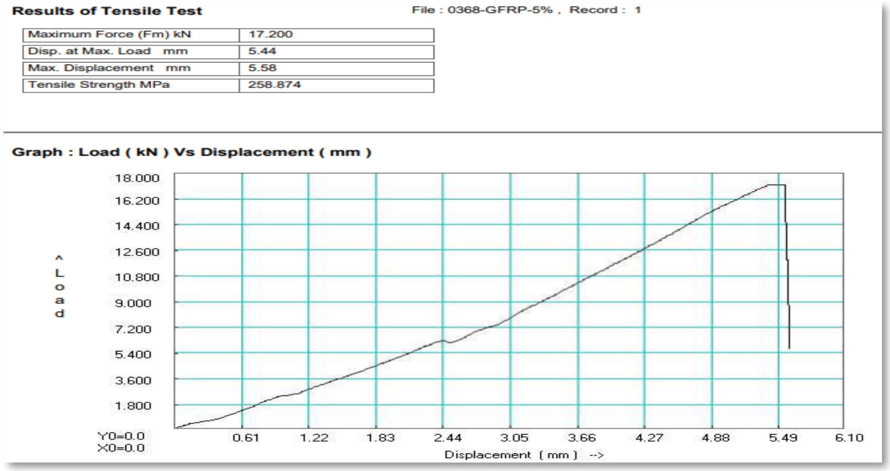
Maximum Force (Fm) kN	17.200
Disp. at Max. Load mm	4.99
Max. Displacement mm	5.17
Tensile Strength MPa	229.992

Graph : Load (kN) Vs Displacement (mm)

Graph.7 Load Vs Displacement 2% GFRP

The above Graph is about 2% Glass fiber reinforced plastics specimens tensile test report. It shows the maximum displacement about 5.17 mm at 4.99 KN of load with a tensile strength of 229.992 MPa.

Tensile test on GFRP-5%



Results of Tensile Test

File : 0368-GFRP-5% , Record : 1

Maximum Force (Fm) kN	17.200
Disp. at Max. Load mm	5.44
Max. Displacement mm	5.58
Tensile Strength MPa	258.874

Graph : Load (kN) Vs Displacement (mm)

Graph.8 Load Vs Displacement 5% GFRP

The above Graph is about 5% Glass fiber reinforced plastics specimens tensile test report. It shows the maximum displacement about 5.58 mm at 5.44 KN of load with a tensile strength of 258.874 MPa.

SEM analysis results for Nano Particles (NP)

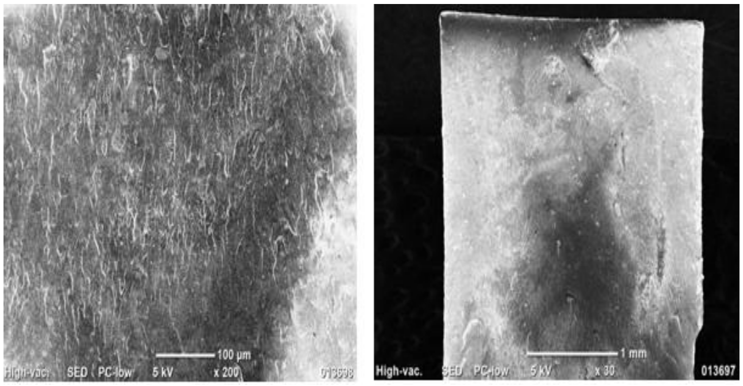


Fig.34 Nano particles – 0% TiO_2

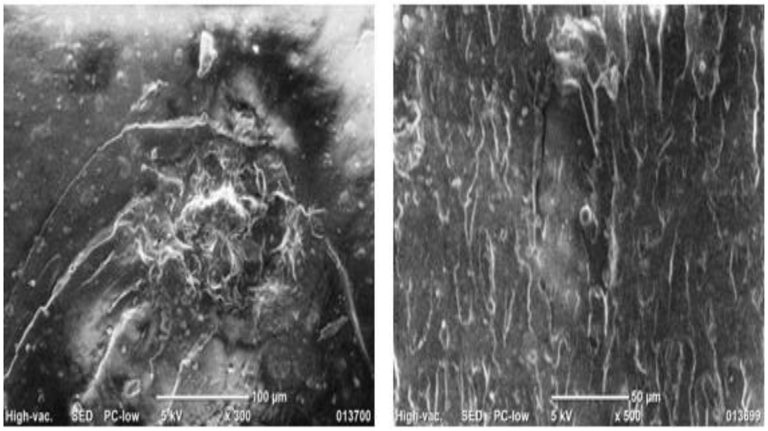


Fig.35 Nano particles – 1% TiO_2

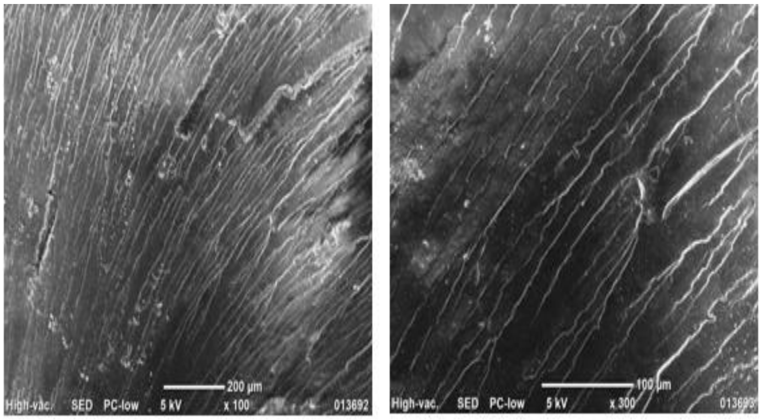


Fig.36 Nano particles – 2% TiO_2

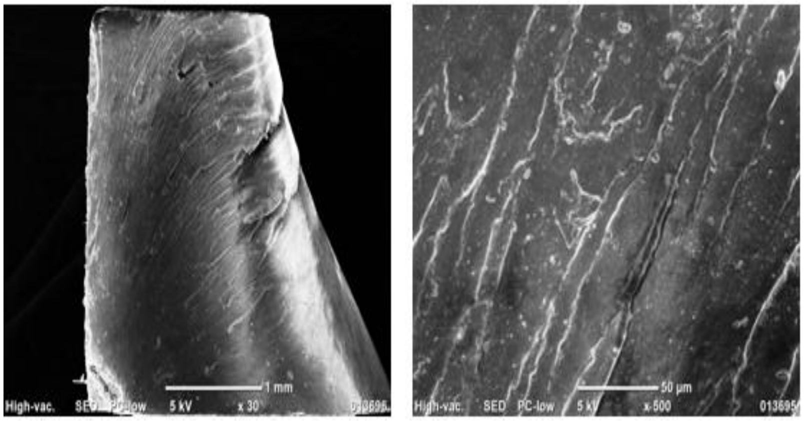


Fig.37 Nano particles – 5% TiO_2

SEM analysis for GFRP specimens

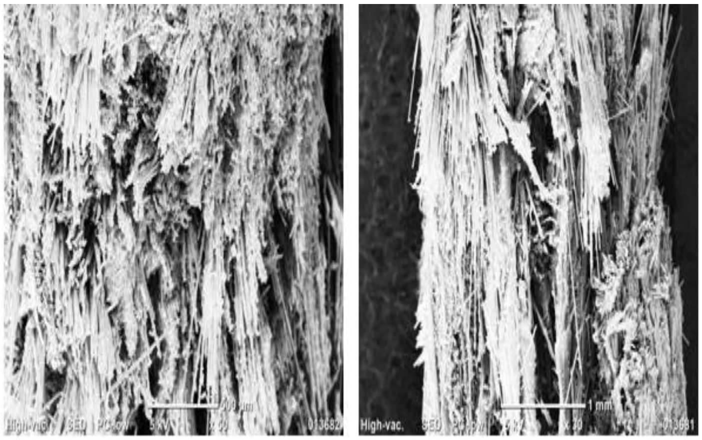


Fig.38 GFRP-0%

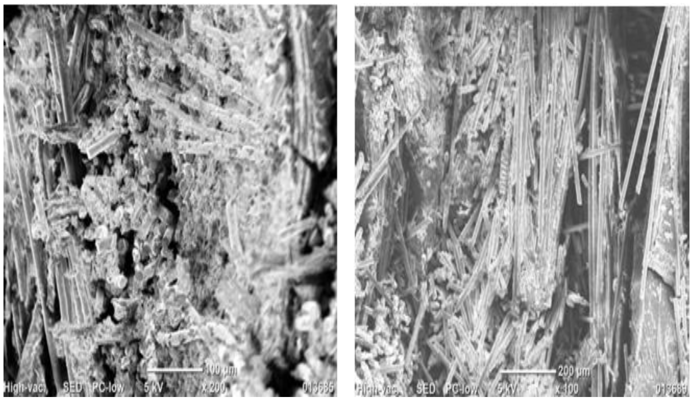


Fig.39 GFRP-1%

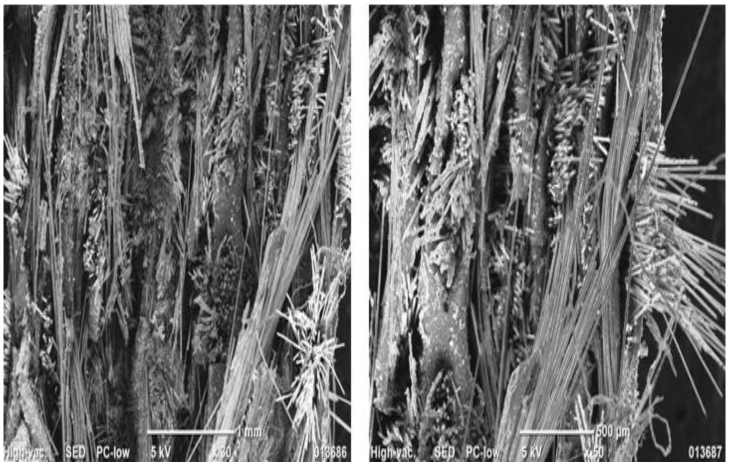


Fig.40 GFRP-2%

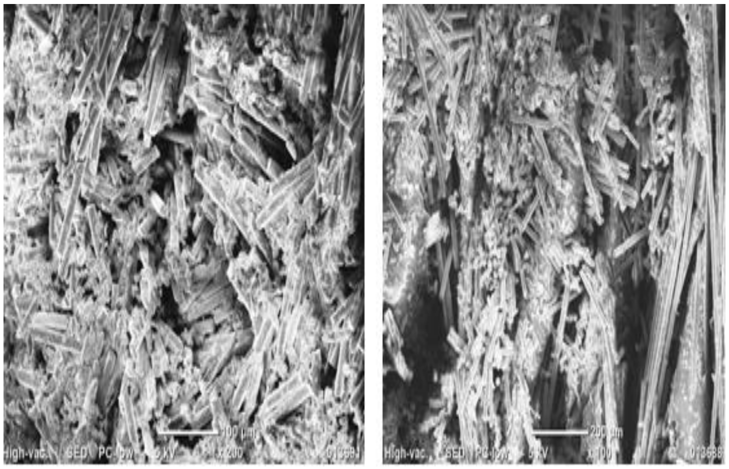
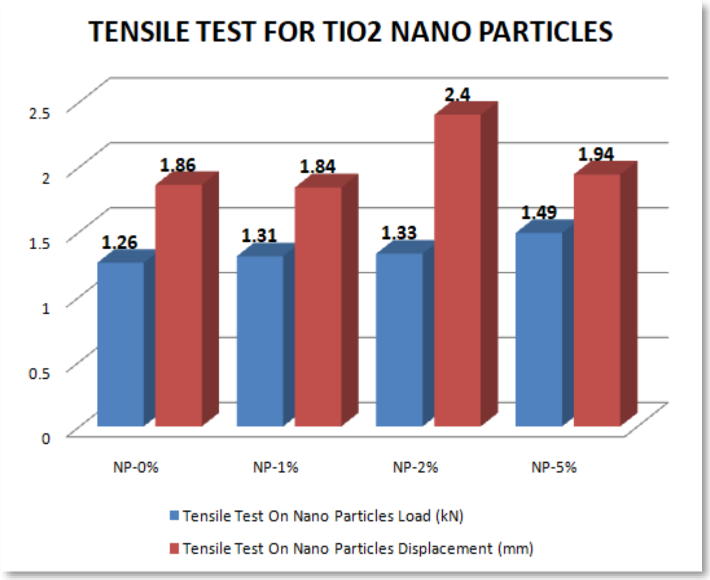


Fig.41 GFRP-5%

Graphs for Tio$_2$-nano particles testing's

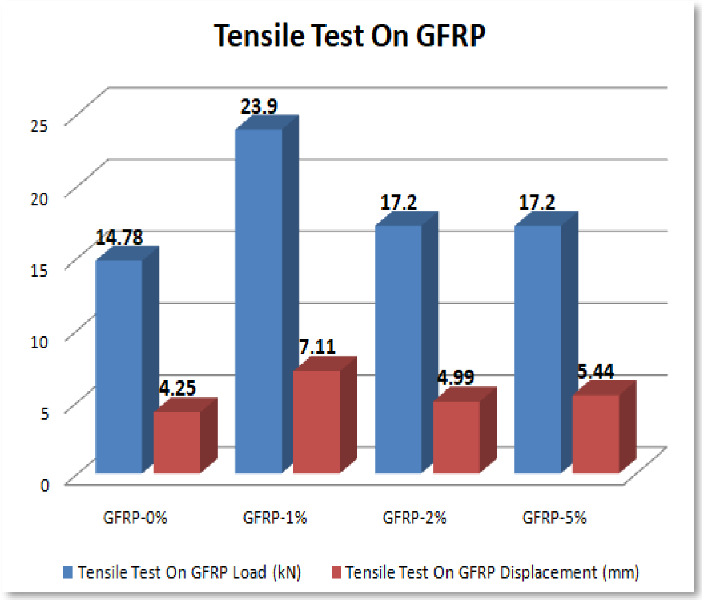
Nano Particles with different compositions of Titanium oxide nano particles with 0%, 1%, 2% and 5%. The following results clearly shows that minimum load at 1.26 KN for Nano Particles with -0% and have high maximum load Nano Particles with -5% and have better results for Nano Particles with -1%& 2%. So finally on observing all the results for Titanium oxide Nano Particles with -5% specimens are showing better mechanical properties.



Graph.9 tensile test on Tio_2 nano particles

Graphs for GFRP testing's

Glass Fiber Reinforcement Particles (GFRP) composites with different compositions 0%, 1%, 2% and 5%.



Graph.10 Tensile tests on GFRP

The following results clearly shows that minimum load at 14.78 KN for Glass Fiber Reinforcement Particles with -0% and have high maximum load Glass Fiber Reinforcement Particles with -1% is 23.9 KN and have better results for Glass Fiber with - 2% & 5%. So finally on observing all the results for Glass Fiber Reinforcement Particles GFRP-1% shows better results specimens are showing better mechanical properties.

Conclusion

Following are the results I investigate on my thesis work about mechanical properties and evaluation of glass fiber reinforced polymer/ Tio_2 nano composite laminates.

- Nano particles with Tio_2 particles mechanical properties are evaluated through testing made on the respective machineries like ultimate tensile machine, charpy impact test and scanning microscope analysis on different compositions like Nano particles with NP-0%, NP-1%, NP-2% and NP-5% respectively.
- On analyzing all the results in point 1, finally get into a conclusion Titanium oxide Nano Particles with -5% specimens are showing better mechanical properties among all other reaming compositions.
- Glass Fiber Reinforced particles (GFRP) specimens’ mechanical properties are evaluated through testing made on the respective machineries like ultimate tensile machine, charpy impact test and scanning microscope analysis on different compositions like epoxy, resins, glass fiber with GFRP- 0%, GFRP- 1%, GFRP- 2% and GFRP- 5%respectively.
- On analyzing all the results in point 3, finally get into a conclusion So finally on observing all the results for Glass Fiber Reinforcement Particles GFRP-1% shows better results specimens are showing better mechanical properties.
- Scanning electron microscope results are also more favorable morphology shape and size of nanoparticles, including their surface features, particle size distribution, and agglomeration patterns, providing a visual representation of the nanoparticles' overall structure and appearance on a sample surface, is more clear and homogeneous structure for 1% Tio_2 combination.
- Finally in my final conclusion about the thesis work of mech-prop. and evaluation of GFRP/ Tio_2 nano composite laminates testing on Glass FRP and Tio_2 Nano particles with various combinations, performing all testing’s like tensile, impact, flexural and impact analysis results, which are clearly show case best mechanical properties for the 1% variation of Titanium oxide nano particles. Clearly it dominates in impact, SEM and Bending tests respectively.

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