A Study on Effect of Variation of Thickness on Tensile Properties of Hybrid Polymer Composites (Glassfibre-Carbonfibre-Graphite) and GFRP Composites

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ABSTRACT

Increase in demand of advanced materials to satisfy the requirements of aerospace and automotive industry viz. high modulus to density ratio, leads to the research in composite materials where an attempt is made to study the properties of composite materials by composing the different materials together to obtain the desired properties by reducing the weight as much as possible. Here an attempt is made to study the behavior and tensile properties of Hybrid polymer composite material by composing *E-glass fibres, carbon fibres and graphite with epoxy resin 5052.* By the variation of thickness. Tensile strength of hybrid composite is observed for each thickness and is optimized and compared with the properties of standalone glass fibre reinforced composites for the same variation of thickness. The comparison represents the enhancement of tensile strength and cost effectiveness by the introduction of multiple materials (Hybrid composites).

***Keywords*–**Comparison of GFRP and hybrid composites, Hybrid composites, E- glass-carbon-graphite composite, Graphite-fibre composites.

1. Introduction

Composite materials are new generation materials developed to meet the demands of rapid growth of technological changes of the industry. Composite materials or composites are engineering materials made from two or more constituents' materials that remain separate and distinct on macroscopic level while forming a single component. It consists of short and soft collagen fibres embedded in a mineral matrix called apatite. [1]

Since early 1960s, there has been an increasing demand for materials that are stiffer and stronger yet lighter in fields as aerospace, energy and civil construction. By choosing an appropriate combination of reinforcement and matrix material, manufactures can produce properties that exactly fit the requirement for a particular structure for a particular purpose. Composite material systems result in a performance unattainable by the individual constituents and they offer the great advantages of flexible design. Most of efficient design of, say an aerospace structure, an automobile, a boat or an electric motor, we can make a composite material that meets the need.

Glass fibre reinforced resins have been in use since about the 1940s. Glass fibre reinforced resins are very light and strong materials, although their stiffness is not very high. Composite materials are engineering materials made from two or more constituents that remain separate and distinct on a macroscopic level while forming a single component. It consists of a matrix and reinforcement; matrix is bulk of a material holding the reinforcement together in position and help in transferring the loads. Matrix materials surround and support the reinforcement materials by maintaining their relative positions. Most composites have been created to improve combinations of mechanical characteristics such as stiffness, toughness, ambient and high temperature strength, wear resistance and aesthetic properties. Reinforcement is the load bearing material and also provides additional properties like wear resistance, corrosion resistance, impact strength lubricating property damping properties to the composite. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties.

1.1 Fibres

Fibreis a rope or string used as a component of composite materials, or matted(disambiguation needed) into sheets to make products such as paper or felt. Fibres are often used in the manufacture of other materials. The strongest engineering materials are generally made as fibres, for example carbon fibreand Ultra-high-molecular-weight polyethylene.
Synthetic fibres can often be produced very cheaply and in large amounts compared to natural fibres, but for clothing natural fibres can give some benefits, such as comfort, over their synthetic counterparts.

1.1.1 Natural fibres

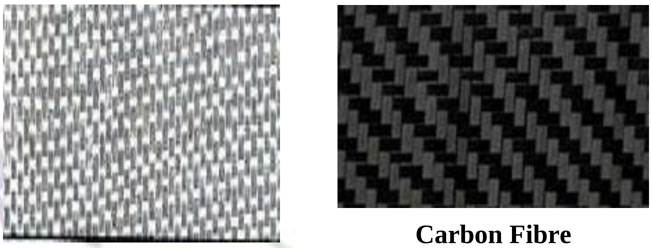
Natural fibres include those produced by plants, animals, and geological processes. They are biodegradable over time.
They can be classified according to their origin:

Figure1.1: Different types of natural fibres

- Vegetable fibres are generally based on arrangements of cellulose, often with lignin: examples include cotton, hemp, jute, flax, ramie, sisal and bagasse. Plant fibres are employed in the manufacture of paper and textile (cloth).
- Wood fibre, distinguished from vegetable fibre, is from tree sources. Forms include groundwood, thermomechanical pulp (TMP) and bleached or unbleached kraft or sulfite pulps. Kraft and sulfite, also called sulphite, refer to the type of pulping process used to remove the lignin bonding the original wood structure, thus freeing the fibres for use in paper and engineered wood products such as fibreboard.
- Animal fibres consist largely of particular proteins. Instances are silkworm silk, spider silk, sinew, catgut, wool, sea silk and hair such as cashmere wool, mohair and angora, fur such as sheepskin, rabbit, mink, fox, beaver, etc.
- Mineral fibres include the asbestos group. Asbestos is the only naturally occurring long mineral fibre. Six minerals have been classified as "asbestos" including chrysotile of the serpentine class and those belonging to the amphibole class: amosite, crocidolite, tremolite, anthophyllite and actinolite. Short, fibre-like minerals include wollastonite and palygorskite.

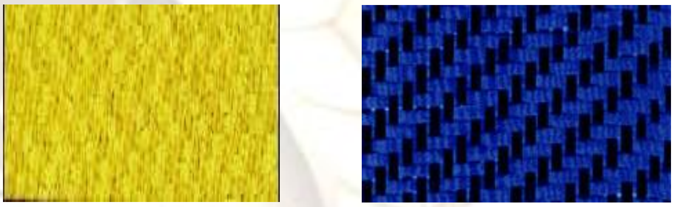
1.1.2 Synthetic fibres:

- Synthetic generally come from synthetic materials such as petrochemicals but some types of synthetic fibres are manufactured from naturalcellulose, including rayon, modal, and Lyocell. Cellulose-based fibres are of two types, regenerated or pure cellulose such as from the cupro-ammonium process and modified cellulose such as the cellulose acetates.
- Fibreclassification in reinforced plastics falls into two classes:
- (i) short fibres, also known as discontinuous fibres, with a general aspect ratio (defined as the ratio of fibrelength to diameter) between 20 to 60.
- (ii) long fibres, also known as continuous fibres, the general aspect ratio is between 200 to 500.



Carbon Fibre

Glass Fibre



Kevlar Fibre **Kevlar/ Carbon Hybrid**

Figure 1.2: Different types of Synthetic fibres

Carbon fibre composites are becoming widely adopted in the transportation, sporting goods and wind energy sectors, among others. This is because carbon-fibre composites weigh about one-fifth as much as steel, but can be comparable or better in terms of stiffness and strength, depending on fibre grade and orientation. In addition, carbon fibre show good creep resistance and good compatibility with epoxy matrix. However, the main drawbacks of carbon fibre composites for industrial use are rather susceptible to stress concentration and impact damage due to the brittleness of carbon fibre. The other major factor that is prohibiting the use of carbon fibre in common use is the high price.

To overcome both of these problems and to make carbon fibre more adaptable, hybridization is done. In the process a more ductile and low priced fibre is introduced in certain proportions to improve the mechanical properties. Hybrid composites normally contain a high modulus, high strength and costly fibre such as graphite or carbon fibre. The second fibre is usually a low modulus fibre and cheap fibre like Kevlar, PE or Basalt fibres. The intrinsic mechanical properties of both reinforcement material gives rise to unique structural materials in terms of toughness and strength. Glass fibre may also be a good candidate for the preparation of hybrid composites of this type. It has good toughness properties, low price and relatively good interfacial adhesion to the matrix. In this study hybrid composites have been prepared with glass fibre and carbon fibre as reinforced materials and epoxy resin as matrix. The aim of this study is to find out how the tensile and the impact strength of the hybrid composite varies with varying ratios of component fibre reinforcements. Theoretically, the hybridization of brittle carbon fibres with ductile glass fibres may improve the mechanical properties stated above [1].

1.2 Laminated composites:

A laminate is a material that can be constructed by uniting two or more layers of materials together. A laminate is a stock of limina orientation in a specific manner to achive a desired result. Individual limina are bonded together by a curing procedure that depends on the material system used. The mechanical response of a liminate is different from that of the individual lamina that form it. The Laminate's response depends on the properties of each lamina as well as the order in which the lamina are stocked.

Laminated composite materials consist of layers of atleast two different materials that are bonded together.If layers of such composite are stacked and bonded together in such a way that successive layers have their fibres alligned in different directions, thecomposite on the whole will have high strength and uniform properties in all directions.

A laminate is constucted by stacking a number of lamina in the thickness (z) direction. Delamination at ply drops in composites with thickness tapering has been a concern in applications of carbon fibres. This study explored the resistance to delamination under fatigue loading of carbon and glass fibre prepreg laminates with the same resin system, containing various ply drop geometries, and using thicker plies typical of wind turbine blades. Applied stress and strain levels to produce significant delamination at ply drops have been determined, and the experimental results correlated through finite element and analytical models. Carbon fibre laminates with ply drops, while performing adequately under static loads, delaminated in fatigue at low maximum strain levels except for the thinnest ply drops. The lower elastic modulus of the glass fibre laminates resulted in much higher strains to produce delamination for equivalent ply drop geometries. The results indicate that ply drops for carbon fibres should be much thinner than those commonly used for glass fibres in wind turbine blades [2]

Examples of few special types of laminates are below:

1.2.1 Unidirectional laminate:- in a Unidirectional laminate, fibreorientation angles are the same in all laminas.I unidirectional 0^0 laminates, for $\Phi=0^0$ in all laminas.

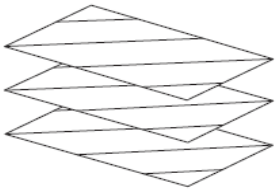


Fig 1.3: Unidirectional Laminate.

1.2.2 Angle ply laminate:-In an angle-ply laminate, fibreorientation angles in alternate layers are $/ \Phi/- \Phi/ \Phi/- \Phi/$ when $\Phi \neq 0^0$ or 90^0.

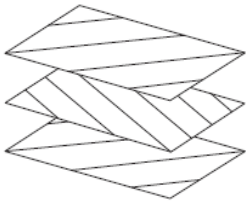


Fig 1.4: Angle Ply Laminate.

1.2.3 Cross ply laminate:- In a cross ply laminate, fibreorientation angles in alternative layers are $0^0/90^0/0^0/90^0$.

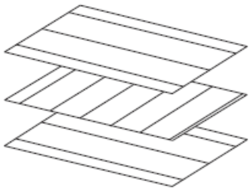


Fig 1.5: Cross Ply Laminate.

1.3 Polymers

Polymers are particularly attractive as matrix materials because they are easily process able and their density is comparatively low when compared to other materials. They exhibit excellent mechanical properties. High-temperature resins are used as composite materials are currently used in the manufacture of high-speed aircrafts, rockets and other related space and electronics. The reinforcements share the major load especially when a composite consists of fibre reinforcements dispersed in a weak matrix (e.g., carbon/epoxy composite), the fibres carry almost all the load. The strength and stiffness of such composites are, therefore, controlled by the strength and stiffness of constituent fibre. Carbon and graphite are superior high-temperature materials with strength and stiffness properties maintainable at temperature up to 2500^0 K. carbon fibre composites have been used for various aeronautical, biomedical, defense, industrial and space applications. Originally, these materials were produced for applications where hardware was exposed to extreme temperatures requiring high performance standards, such as solid rocket motors. Today carbon composites are used in commercial as well as military applications.[3]

1.4 Hybrid Composites

Hybrid composite fabricated from glass fibre and carbon fibre is made in an epoxy called DGEBA (Di-Glycidyl-Ether of Bisphenol A). The tensile strength and the impact strength of the hybrid composite were evaluated over a range of glass: carbon ratios. It was found that the mechanical properties increased as the relative proportion of carbon decreased. The carbon fibres and the glass fibre present in the epoxy showed multiple failure modes particularly at lower carbon proportions. It was noted that the overall failure did not occur until a considerable portion of fibre strands were fractured. Failure is thus progressive, and the material is effectively "tougher" than equivalent all-carbon fibre composites. This is precisely the Hybrid Effect [1].

Glass and Carbon fibre reinforced epoxy composites are 'widely used in a number of aerospace and non-aerospace applications. Selection of reinforcements and matrix systems, as well as the fibre fraction is crucial in structural designing of the composite product for specific applications. On the other hand, thermal stability and hot wet property retention are the matrix dominated deciding factors that govern the long term performance capabilities of the composites. Glass fibres are better known for their toughness, medium modulus, strength and stability, but are unsuitable for use in fatigue resistant composites, while carbon fibres are characterized by high modulus, brittleness, low density and superior fatigue properties. However, carbon fibres are thermally less stable and have lower toughness when compared to glass fibres. Hence, to tailor the properties for balanced performance requirements, fibre hybridization has recently become an attractive approach. Hybrid fibre reinforced composite materials can be made in two ways.

1. By mixing the fibres (co-mingling) in a common matrix
2. By laminating alternate layers of each type of reinforcement [4]

2. Methodology

The basic engineering properties of a composite material can be determined by either experimental stress analysis (testing) or theoretical mechanics (micromechanics). The micromechanics approach utilizes knowledge of the individual fibre and resin properties, and the proportionality of fibres to the resin in the lamina. A rule of mixtures approach can best be used to derive the majority of the composite lamina properties. For example the lamina axial modulus is derived from:

$\mathbf{E_x = E_fV_f + E_mV_m}$

Where: $\mathbf{E_f}$ is the fibre modulus of elasticity
$\mathbf{E_m}$ is the matrix (resin) modulus of Elasticity
$\mathbf{V_f}$ is the fibre volume ratio
$\mathbf{V_m}$ is the matrix volume ratio
$V_f + V_m = 1$ with zero voids

The fabrication of composite material includes the selection of the required fibre and matrix material, and collects the appropriate amount of matrix (Resin). (For example, the called-out ratio of say 70:30, requires a ratio of 70% fibre weight to 30% resin weight)

2.1 Fibre volume and weight ratio relationship

While the fibre weight ratio is easily determined by simple weighing, the fibre volume ratio is quite difficult to determine. Typically, an ASTM test method is employed which requires destruction of a small sample. However, the determination of fibre volume ratio can be derived from the fibre/resin weight ratio. The approach is as follows:

Data:
Carbon Fibre: 300 gsm
Glass Fibre: 140 gsm
Carbon Fibre Thickness: 0.17mm
Glass Fibre Thickness: 0.32mm

Specimen calculation for the preparation of Lamina					
Required thickness of the Lamina	**Number of carbon fibrelayers (gsm: 0.17)**		**Number of glass fibre layers (gsm: 0.32)**		**Total Thickness**
2mm	4 Layers	0.17*4=0.68mm	4 Layers	0.32*4 =1.28	0.68+1.28 =1.96mm
3mm	6 Layers	0.17*6=1.02mm	6 Layers	0.32*6 =1.92	1.02+1.92 =2.94mm
4mm	8 Layers	0.17*8=1.36mm	8 Layers	.32*8= 2.56	1.36+2.56 =3.92mm

Table 2.1: Calculation for specimen preparation

To achieve the appropriate structural performance for a composite material, the fibre volume ratio plays a crucial role. The engineering designer uses the fibre volume ratio to derive the lamina properties and thus after lamination, structural properties. But to achieve the required fibre volume ratio in wet lay-up processes the fabricator requires the fibre (Reinforcement) weight to resin (Matrix) weight ratio. The expression is dependent on the ratio of the fibre and resin densities. This relationship clearly identifies the importance of low fibre densities when compared with the resin density.

3. Experimental procedure

3.1 Pre fabrication: Before the fabrication, the fabrics and matrix (appropriate quantity of resin with its hardener to be taken) has to be kept in oven setting the temperature at 60^{0}C so that the moisture from resin and fabric (if present) will be removed, then and the resin and hardener is mixed together and gently stirred, so that the resin and hardener is properly mixed.

3.2 Fabrication: For the fabrication of polymer matrix composite the required fibres (Reinforcement media) and Epoxy resin (Matrix material) are to be collected then by applying releasing agent on the work table mount the releasing layer (Teflon sheet) then again apply the releasing agent and place the first layer of fabric and wet it then apply the next layer and again wet that follow the same procedure for all remaining layers, the wetting should be done in such a way that the resin should be distributed equally on the lamina, care should be taken that there should be no starvation or excess of resin on the lamina. After the last layer again the resin is applied and covered with Teflon sheet and then the dead weight is applied over the mold.
As the mold is ready it is left to reach the gel time of the resin, as it reaches the gel time, vacuum is applied by covering the mold by vacuum bag, and is left for some time to get set so as the resin should be spread equally on mold and excess of resin can be drawn outside. After the vacuum time it is left as it is at room temperature for 24hrs to cure. Therefore it is also called as *Room Temperature Vacuum Bag Molding (RTVBM).*

3.3 Post curing:

As the laminate is ready, it has to be subjected to post curing so the all the layers of the lamina bond together. This can be achieved by keeping the lamina in oven and set the oven to increase the temperature gradually to 50^{0}C in 15 minutes from room temperature and hold the temperature for 30 minutes again ramping up to 80^{0}C in next 15 minutes and hold the temperature for 30 minutes again ramp up to 90^{0}C in 15 minutes and hold for 30 minutes then ramp up to 120^{0}C in 30 minutes and hold for 60 minutes then let the oven cool down slowly to room temperature.

3.4 Testing:

Tensile Test

Tensile test is one of the fundamental mechanical tests which is required to evaluate the strength of any material, where a carefully prepared specimen is subjected to tensile load in a controlled manner. Tensile properties can be measured by the relation of load applied on the material to deflection (Strain) experienced against the applied load. Tensile tests are used to determine the modulus of elasticity, elastic limit, percentage of elongation in length and percentage of reduction in area, tensile strength, yield strength, other tensile properties.

The Tensile test specimen is prepared according to the ASTM standards, the specimen for tensile test is as shown below:

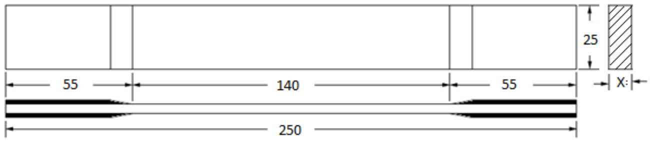


Figure 3.1: Tensile test specimen

Tensile test specimen is fixed between the two jaws of fully automated and closed loop computerized Universal Testing Machine (UTM) and tensile load is applied on specimen by pulling the one jaw and fixing the other jaw. The process is recorded and the each pulse values of load applied and deformation in specimen is collected in computer *and load vs deflection* and *stress vs strain* graphs are generated and all the data is stored in the computer.

Figure 3.2: Universal Testing Machine

This is closed loop computer controlled servo-hydraulic Universal Testing Machines of 1300 series, Instron make. All the tests were carried out in a closed loop computer controlled servo-hydraulic test machine. Principle of operation involves pumping oil at high pressure through hydraulic power pack, to displace an actuator at a specified rate, through a servo valve.

4. Testing and Evaluation

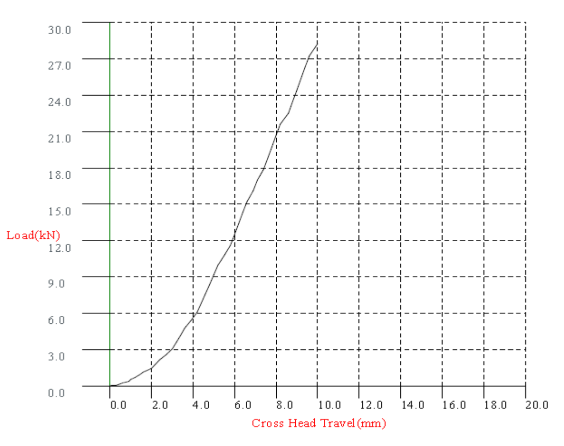
Tensile test results of carbon fibre, glass fibre and graphite hybrid polymer composite laminates:

The test was conducted on three samples of 2mm, 3mm and 4mm each. The data measured from the mechanical testing was used to calculate the elastic properties and strength of the laminates. Tensile strength, yield stress, peak load breaking load, load at yield, Young's modulus and percentage of elongation were determined. The table 4.1 shows the average tensile properties of multiple specimens for each thickness.

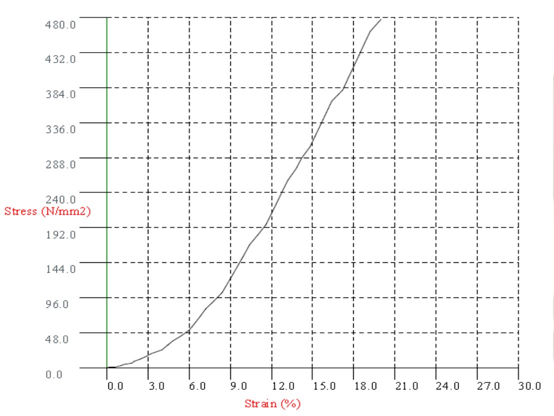
Sl. No	Thickness (mm)	Yield stress (N/mm2)	Tensile strength (N/mm2)	Ultimate Load (kN)	% Elo ati
1	2	413.11	460.32	27.17	8.
2	3	335.59	429	34.72	11
3	4	370.85	404.87	43.4	9.

Table 4.1: Tensile test data of carbon fibre, glass fiber and graphite Hybrid Composite laminates

4.1 The graphical representation of tensile properties of one of the samples of 2mm thickness is as shown below



Graph 4.1(a): Load v/s Displacement graph for one of the samples of 2mm thickness



Graph 4.1(b): Stress v/s Strain relationship for one of the samples of 2mm thickness

The load v/s displacement graphs of the tensile test of the 2mm thickness hybrid laminates the curve shows a steep linear increase up to a point where the specimens tends break suddenly

In case of the stress v/s strain curve of the 2mm thickness carbon and glass fiber laminates, the curve shows a linear variation up to the maximum stress where the component breaks.

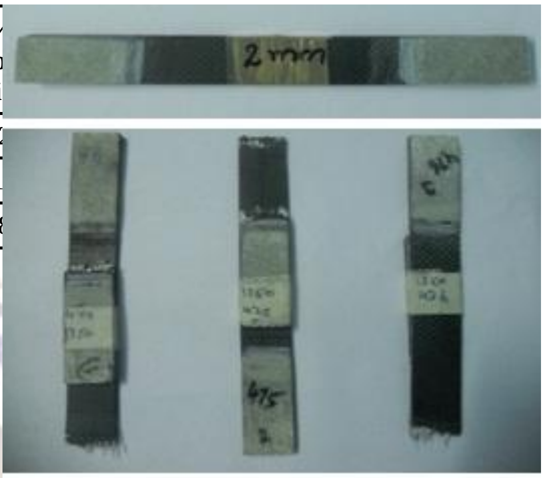
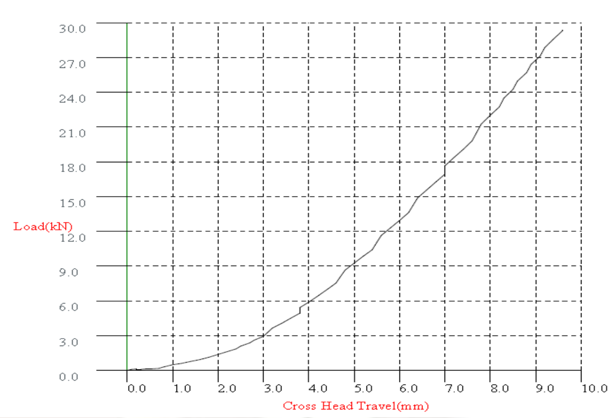
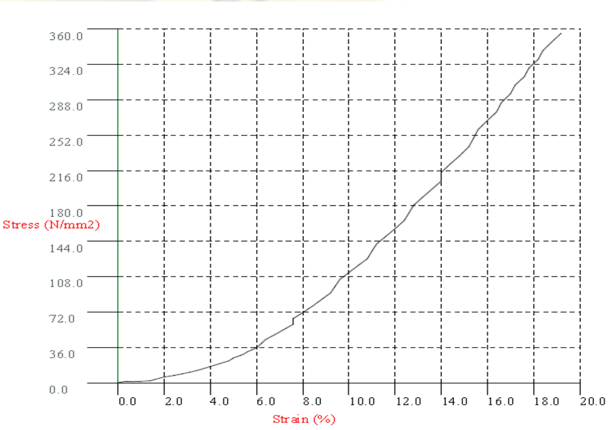


Figure 4.1: Test specimens of 2mm thickness before and after tensile test

4.2 The graphical representation of tensile properties of one of the samples of 3mm thickness is as shown below



Graph 4.2(a): Load v/s Displacement graph for one of the samples of 3mm thickness



Graph 4.2(b): Stress v/s Strain relationship for one of the samples of 3mm thickness

The load v/s displacement graphs of the tensile test of the 3mm thickness hybrid laminates the curve shows a gradual and approximate linear increase up to a point where the specimens tends break suddenly.

In case of the stress v/s strain curve of the 3mm thickness carbon and glass fiber laminates, the curve shows an initial increase in the strain and there is no considerable amount of increase in the stress value. Beyond a certain point there is a linear increase in curve up to the maximum stress where the component fails.

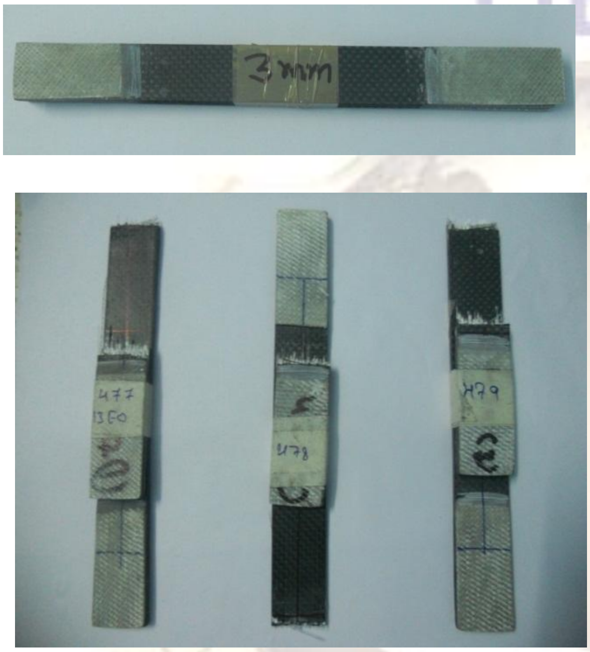
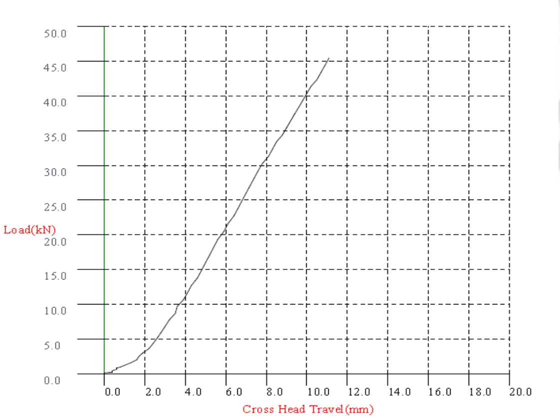
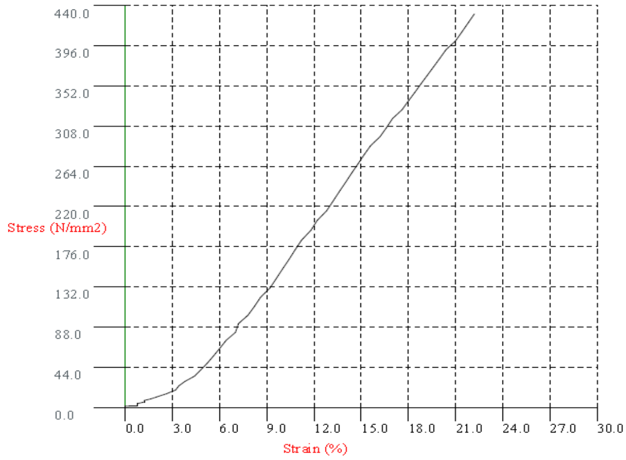


Figure 4.2: Test specimens of 3mm thickness before and after the tensile test

4.3 The graphical representation of tensile properties of one of the samples of 4mm thickness is as shown below



Graph 4.3(a): Load v/s Displacement graph for one of the samples of 4mm thickness



Graph 4.3(b): Stress v/s Strain relationship for one of the samples of 4mm thickness

The load v/s displacement graphs of the tensile test of the 4mm thickness hybrid laminates the curve shows more increase in the strain value when compared to stress up to a certain value. Beyond this value there is a linear increase up to the maximum load.

In case of the stress v/s strain curve of the 4mm thickness carbon and glass fiber laminates, the curve shows an initial increase in the strain and there is no considerable amount of increase in the stress value. Beyond a certain point there is a linear increase in curve up to the maximum stress where the component fails.

Figure 4.3: Test specimens of 4mm thickness before and after tensile test

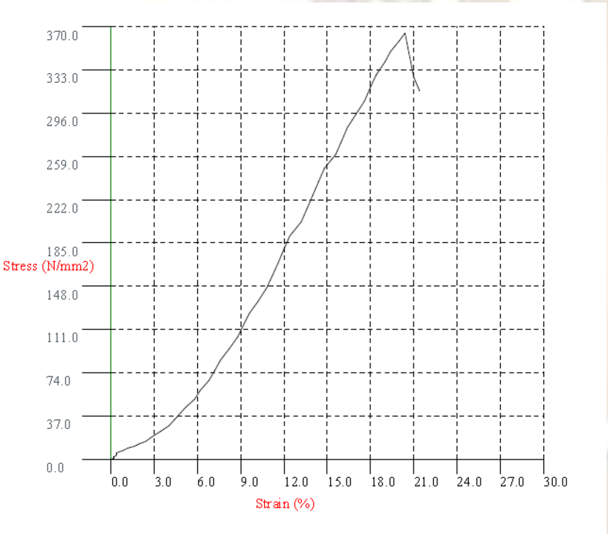
4.4Tensile test of Glass Fiber Reinforcement Composite laminates:

The test was conducted on 2mm, 3mm and 4mm glass fiber (GFRP) laminates. The data measured from the mechanical testing was used to calculate the elastic properties and strength of the laminates. Tensile strength, yield stress, peak load, load at break, load at yield, Young's modulus and percentage of elongation were determined. The table 4.2 shows the average tensile properties of multiple specimens for each thickness.

Sl. no.	Thickness (mm)	Yield stress (N/mm2)	Tensile strength (N/mm2)	Ultimate Load (kN)	El at
1	2	306.72	364.56	24.2	4
2	3	307.78	341	27.9	6
3	4	321.63	383.33	34.72	7

Table 4.2: Tensile test data of Glass Fiber (GFRP) laminates

4.4.1 Glass fiber laminate of 2mm thickness

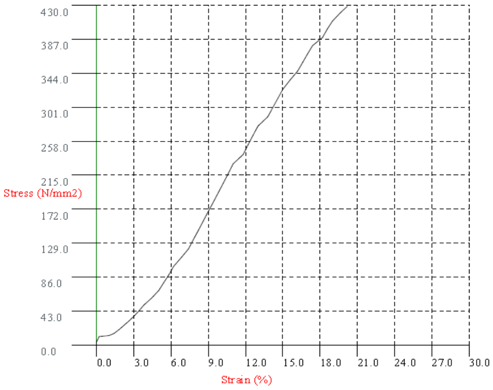


Graph 4.4.1: Stress v/s Strain relationship for GFRP Laminate of 2mm thickness

Figure 4.4.1: Test specimens of 2mm thickness before and after the tensile test

In case of the stress v/s strain graph 4.4.1 of 2mm thickness glass fiber laminates there is a linear increase in the curve up to the maximum load where the rupture occurs and the specimens tend to break. Beyond this point there is a steep decrease in the curve indicating the fall in the load withstanding capacity of the specimen after the rupture.

4.4.2 Glass fiber laminate of 3mm thickness

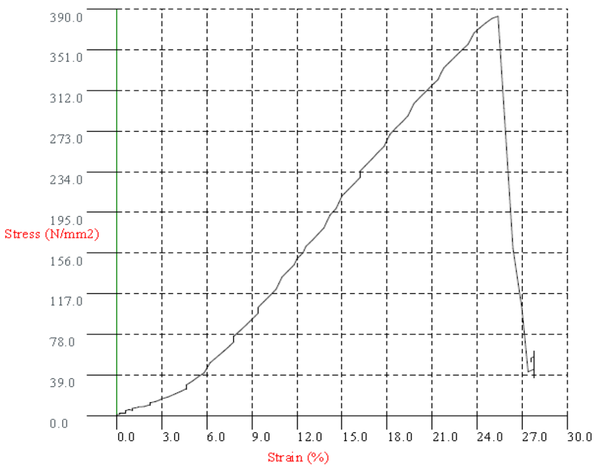


Graph 4.4.2: Stress v/s Strain relationship for GFRP Laminate of 3mm thickness

Figure 4.4.2(a): Test specimens of 3mm thickness before and after the tensile test

In case of the stress v/s strain graph 4.4.2 of 3mm thickness glass fiber laminates there is a linear increase in the curve up to the maximum load where the rupture occurs and the specimens tend to break.

4.4.3 Glass fiber laminate of 4mm thickness

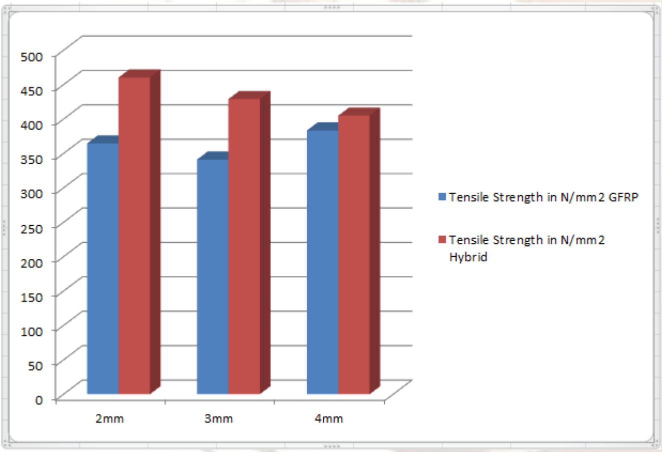


Graph 4.4.3: Stress v/s Strain relationship for GFRP Laminate of 4mm thickness

Figure 4.4.3: Test specimens of 4mm thickness before and after the tensile test

In case of the stress v/s strain graph 4.4.3 of 4mm thickness glass fiber laminates there is a linear increase in the curve up to the maximum load where the rupture occurs and the specimens tend to break. Beyond this point there is a steep decrease in the curve indicating the fall in the load withstanding capacity of the specimen after the rupture.

5. Results and Discussions



Graph5.1: Variation of Tensile strengths by for different thicknesses of Hybrid Composites and GFRP Composites laminates.

- The average tensile strengths of the thicknesses 2mm, 3mm & 4mmof Hybrid Composite laminates are**460.32Mpa, 429Mpa & 404.87Mpa** and for the Glass fiber (GFRP) Composite laminate are **364.56Mpa, 341Mpa and 383.33Mpa** respectively.
- The average % elongation of the thicknesses 2mm, 3mm & 4mmof Hybrid Composite laminates are**8.22%, 11.5%&11.89%** and for the Glass fiber (GFRP) Composite laminate are **4.26%, 6.04% & 7.6%** respectively.
- The ultimate load of the thicknesses 2mm, 3mm & 4mmof Hybrid Composite laminates are**27.17kN, 34.72kN & 43.4kN** and for the Glass fiber (GFRP) Composite laminate are **24.20kN, 27.9 & 34.72kN** respectively.

6. Conclusion

From the experimentation and results obtained after testing the following conclusion are drawn.

- It is found that the Hybrid Composite exhibited more tensile and mechanical properties when compared to the Glass Fibre composites irrespective of their thickness.
- When the comparison was carried out between the hybrid & GFRP composites of the different thicknesses, the difference between the tensile strengths of hybrid & GFRP composites of 4mmthickness is less when compared to the difference of strengths of 2mm & 3mm thick composites, which shows the weak bond of 4mm thick hybrid composite lamina, this may be because of starvation of resin or improper molding of lamina.
- By the addition of graphite powder tensile strength is enhanced as it mixes up with the resin and acts as the reinforcement with in the resin.
- Addition of graphite in composite enhances the thermal properties of the composite as graphite is the good conductor.
- With this study it is concluded that composition of multiple materials leads to the improvement in mechanical, and thermal properties.

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