International Research Journal of Education and Technology
ISSN 2581-7795

Analysis of Composite Material Plate for Tensile and Compression Loading Condition

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Abstract - *The analysis of plane composite plate under tensile & Compression loads with simply supported one side and boundary conditions are used to predict the deflection. The composite plate made with mixed layer of glass epoxy & carbon fiber material. In each boundary condition there is one side having fixed support and other end for tensile force & Compressive force. We are using 6 layers and 2 different material of each sample; hence we get 2 type of combination in plate. The adequacy of these modified fracture models were examined by considering the fracture data of specimen made of composite material.The objective function was to minimize cost and weight with the maximization of the stiffness. All plates are study in ANSYS workbench under given loading condition. Find out best of those plates.*

Key Words: *Composite material, Ansys, Stress analysis, Carbon fibre etc.*

1. INTRODUCTION

With the increasing demand for improved performance, which may be specified by less weight, increased strength, and stiffness, there is a need to use light weight composite materials replacing conventional metallic materials. A composite material is produced using at least two constituents with altogether different physical or chemical properties that when combined create a materialwith propertiesthat are unique in relationto the individual constituents. This project work therefore focuses on innovative ways of making different types of composite materials available for designing automotive industry production equipment by introducing a design and material concept that combines flexibility, relatively low costs and high functionality. Traditional materials are easy to use and there is good knowledge about how to build and maintain them. Problems that we are facing with new materials are mainly how to design and to assembly them. Non-metal material cannot be welded together, and bolts require that we have to drill holes in the material. If we use one of the composite materials like carbon fiber, drilling will cut the carbon fiber and weaken the design. Gluing is an alternative for composite materials, but leads in turn to new challenges. For example, delamination after gluing to pieces of composites is a major problem, and tests have shown that delamination is the first and most serious problem to handle. After some tensile tests, it was clear that the glue was stronger than the composite itself. This demands a new design of the joints. To be able to glue composite plates together we had to choose a different path of the assembly, mechanical locking turned out to be best solution.

2. TYPES OF MATERIAL

2.1 Reinforcements

Reinforcement sincomposites provide the necessary strength and stiffness. Inmanycases, reinforcements can be fibers or particulates. Particulate reinforcements are weaker, and brittle compared to the fiber reinforcements. Fiber salone cannot be used instructure seven though they possess high tensile strength because they cannot lone support the compressive loads.

2.2 Glass Fibre

Glass fibers are the most common type of fibers in the fiber reinforced polymers.Glass fiberprimarily consists of Silica (SiO_2-Silicon dioxide) apart from the other metallic oxides in minor portions.The raw ingredients are initially fed into a hopper where they are melted and this molten liquid is then fed through electrically heated platinum bushings consisting of 200 small orifices at its base. The molten liquid flows through these orifices because of the gravity thus forming fine continuous filaments. Glass fibers are easily damaged due to the presence of the surface flaws.This can be minimized by providing a proper sizing treatment to the extruded fibers.

2.3 Carbon Fibre

Carbon fibers and Graphite fibers are commonly used reinforcements that are generally used inapplications which require higher strength and stiffness and higher modulus. The basic differencebetween the Carbon and Graphite fibers is the Carbon content within the fiber and the process offabricating the fibers. There are quiet few disadvantages with the Carbon fiber like a low strain to failure, poor impact resistance, and very high electrical conductivity. The Carbon fibers have amorphous Carbon and a Graphitic blend of carbon in almost equa lcompositions because of which the carbon fibers are usually stronger.The crystal structure of Carbon generally has the carbon atoms arranged in parallel planes and these planes are held together by the Van der Waals forces, and adjacent Carbon atoms in the same plane are held together by a strong covalent bond, thus strengthening the entire Carbon crystal.

2.3 Armed Fibre

Aramid fibers are generally produced under the trade name of Kevlar.There are two distinct types of fibers in Kevlar: Kevlar 29 which is used in tires and the other is Kevlar 49 which is usedin structural applications that demand high strength and stiffness. Kevlar has a low density buthas a better specific strength compared to other reinforcement fibers. Kevlar also possessessuperior toughness, good damping characteristics, and impact resistant properties compared to the structural composites.

2.3 Boron Fibre

Boron fibers are usually a coating of Boronon a sub strate. Boron is usually brittle in nature.Boronis deposited on to the substrate usually by chemical vapor deposition. Since this process involves higher temperatures, a suitable substrate material like a Tungsten wire or Carbon may be usedbecause of the superior thermal characteristics of the substrate materials. Because of the higher density, higher strength and stiffness than the Graphite fibers, Boron fibers are preferred forbuilding Aerospace structures. However, the cost of the boron fibers is a major setback that prevents the use of the min a variety of structural applications.

3. LITERATURE REVIEW

The purpose of this research paper is to provide previous information on the issues to be considered in this thesis and to emphasize the relevance of the present study. Composite materials are playing an important role in a wide range of application fields and replacing many traditional engineering materials. Carbon fiber composite materials are a class of materials used in various products including aerospace, automobile, sporting goods, marine bodies, plastic pipes, storage containers, etc. The aim is of the present work is to present optimization aspects of machining of carbon fibre for improving material removal rate (MRR) and surface roughness of the finished product.

Melin and Asp [1] experimentally investigated the strain rate dependency on Carbon fiber/Epoxy composite laminates. It was found that the transverse modulus is not dependent on the strain rate. However, the stress and strain-to-failure slightly increased with strain rate when the composite test coupons were subjected to transverse tensile loading. In this investigation, dog bone specimens were tested using a split hopkin son pressure bar with tensile testing fixtures.

Harding and Welsh [2] conducted high strain rate tensile testing on Carbon/Epoxy, Glass/Epoxy, and Kevlar/Epoxy. It was determined that thestress at failure and strain are rate independent. High strain rate tensile test on unidirectional Carbon/Epoxy composites was experimentally investigated by Daniel and Hsiao and it was found that the tensile modulus increased with the rate of loading, however, the stress and strain to failure did not vary significantly.The high strain rate tensile behavior of woven Carbon/Epoxylaminate under shear and tensile loading was studied by Chiem and Liu Here, an increase instrength and strain to failure with the increasing loading rate was reported.

Norihiko [3] experimentally investigated the high strain rate loading of unidirectional Carbon fiber reinforcedcomposites and found that the tensile properties are independent of the strain rate. They reportedthat there are many factors that influence the high strain rate mechanical behavior of fiberreinforced composites. Staab and Gilat experimentally investigated the tensile mechanicalbehavior of Glass/Epoxy laminates and found that these materials experience a higher tensile modulus at higher strain rates when compared to quasi static loading conditions.

Tarfaoui [6] studied the influence of fiber orientation on the mechanical properties of Glass/Epoxy composite laminate ssubjected to high rates of strain. Inthisinvestigati on, fibers with different orientations of 0°, 20°, 30°, 45°, 60°, 70° and 90° were experimentally tested and it was found that the modulus, maximum stress and strain to failure arestrongly dependent on the fiber orientation.

4. SELECTION OF COMPOSITE MATERIAL

Nowadays, the composite industry is still evolving, with much of the growthnow focused around renewable energy. Wind turbine blades, especially, are constantlypushing the limits on size and require advanced composite materials, forexample, the engineers can design to tailor the composite based on the performancerequirements, making the composite sheet very strong in one direction by aligningthe fibers that way, but weaker in another direction where strength is not soimportant. The engineers can also select properties such as resistance to heat, chemicals, and weathering by choosing an appropriate matrix material.

The following are some of the reasons why composites are selected for certain applications:
1. High strength to weight ratio (Low density high tensile strength)
2. High creep resistance
3. High tensile strength at elevated temperatures
4. High toughness.

International Research Journal of Education and Technology
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Hence following types of composite material selected for our project work.

4.1 Carbon Fibre

Carbon fibers generally have excellent tensile properties, low densities, and high thermal and chemical stabilities in the absence of oxidizing agents, good thermal and electrical conductivities, and excellent creep resistance.

Fiber reinforced composites are considered to replace metallic components in many industries for past several years. Because, compared to conventional metals fiber reinforced composites have low density, high specific strength and stiffness, highercorrosion resistance and improved fatigue performance

Properties of Carbon Fiber:

1. Carbon Fiber has High Strength to Weight Ratio (also known as specific strength)-Strength of a material is the force per unit area at failure, divided by its density. Any material that is strong and light has a favorable Strength/weight ratio
2. Carbon Fiber is very rigid:-Rigidity or stiffness of a material is measured by its Young Modulus and measures how much a material deflects under stress.
3. Carbon fiber is Corrosion Resistant and Chemically Stable:-Although carbon fiber they do not deteriorate, Epoxy is sensitive to sunlight and needs to be protected.
4. Carbon fiber is electrically Conductive; Carbon fiber conductivity can facilitate Galvanic Corrosion in fittings.
5. Fatigue Resistance is good-Resistance to Fatigue in Carbon Fiber Composites is good.

Table -1: Mechanical Properties of Carbon Fibre

Sr. No	Properties		Values
1	Young's Modulus	E_x(GPa)	127.7
		E_y=E_z(GPa)	7.4
2	Piossion's Ratio	V_{xy}=V_{xz}	0.33
		V_{yz}	0.188
3	Shear Modulus	G_{xy}=G_{xz} (GPa)	6.9
		G_{yz}(GPa)	4.3
4	Tensile strength	X_t(Mpa)	1717
		Y_t=Z_t(MPa)	30
5	Compression Strength	X_c(Mpa)	-1200
		Y_c=Z_c(MPa)	-216
6	Shear Strength	S_{xy}=S_{yz}=S_{xz}(MPa)	33

4.2 Glass Epoxy

Glass fibers are silica based (=50-60% sio2) and contain a host of the other oxides of calcium and iron. Glass fibers are the earliest known fibers used to reinforce materials. Ceramic and metal fibers were subsequently found out and put to extensive use, to render composites stiffer more resistant to heat.

Over 95% of the fibers used in reinforced plastics are glass fibers, as they are inexpensive, easy tomanufacture and possess high strength and stiffness with respect to the plastics with which they are reinforced.glass fiber–reinforced epoxy composites in which glass fiber is the primary load carrying element, are being increasingly used in military and aerospace applications owing to several desirable properties including high specific strength, high specific stiffness, and controlled anisotropy.

Properties of Glass epoxy

1. Density is quite low and the strength is quite high. Young's modulus is moderate.
2. Thus strength to weight ratio is high but the modulus to weight ratio is only moderate.
3. Moisture decreases the strength.
4. Glass fiber are also susceptible is called static fatigue that is, when subjected to a constant load for an extended time period, glass fibers can undergo subcritical crack growth. This leads to failure over time at loads that might be safe when considering instantaneous loading.

Table -2: Mechanical Properties of Glass Epoxy

Properties	Values	Unit
density	2.55	g/cm^3
Tensile strength	1750	MPa
Young's modules	72.3	GPa
Co-efficient of thermal expansion	$4.7*10^{-6}$	K^{-1}

5. EXPERIMENTAL SETUP & STRESS ANALYSIS

5.1 Specimen Preparation

Composites laminated were fabricated at room temperature in shape of rectangle plates by hand layup technique proper care was taken during fabrication of laminates to ensure uniform thickness minimum voids in the material and maintain homogeneity. The laminates were fabricated by placing the Carbon fiber one over the other with a matrix in between the layers. Tools were used to distribute resin uniformly, Compact plies and to remove entrapped air the surfaces of the laminated were covered with 25 micron Mila film to prevent the layup form external disturbances. After layup, curing is done at room temperature for 24 hrs. Once the sample is ready, specimens are cut from laminate to appropriate dimensions using abrasive cutter mounted on a hand-held saw.

Later, we have machined to their exact dimensions using milling machine with carbide coated end mills at a speed of 80 rpm. Wooden backing plates are used to avoid edge delamination.

Fig -1: Test Specimen

5.2 Experimental procedure

Generally, two types of tests are carried out

1. Tensile Test

Tensile test is a commonly used material science test, in which the specimen is subjected to a controlled tension until it fails. For the composite materials biaxial tensile testing is used. The test pieces of required dimensions are placed in the jaws of the electromechanical UTM; slowly, the tensile load is applied. The ASTM standard is D3039, the gauge length is 150 mm, and the cross head speed is 2.5 mm\min. During the test, an extensometer of gauge length 25 mm is used, to measure the strain of the laminate. The laminates, before and after the tensile test, are shown in Figure no 3.

Fig -2: Tensile Testing Machine (UTM)

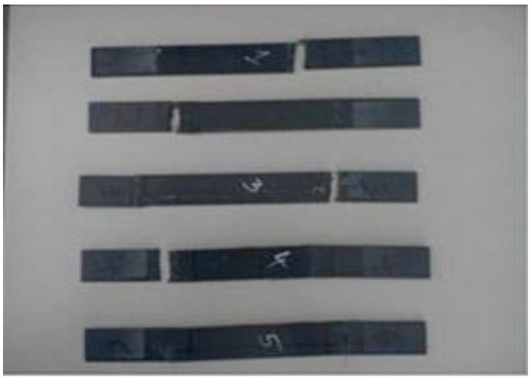

Fig -3: Specimen after Tensile Test

The scheme of tensile test and result analysis

The test uses a microcomputer to control the universal material mechanics testing machine to adjust different loading rates. The mechanical properties of the specimens with loading rates ranging from 0mm/min to 6mm/min were studied by group test. Three groups of specimens, 2mm/min, 4mm/min and 6mm/min, were taken to exclude accidental factors. And three specimens were taken from each group for testing. When the first obvious failure occurs, the test is stopped. The maximum tensile force of each specimen under each loading rate is recorded. The tensile strength under this loading rate is calculated by following formula .The average value is taken as the tensile strength under this loading rate.

Table -3: Tensile Test Data

Dimensions, Wxt (mmxmm)	Max. Displacement (mm)	Max. Load (kN)	Tensile Strength (MPa)
25×2.5	6.9	38.12	609
25×3	9.58	51.62	688

$$\text{Tensile strength} = \frac{\text{Maximum load}}{\text{W x t}}$$

The average tensile strength of the laminate are found to be 648.5 Mpa

2. Compression Test

Fig -4: Compression Testing

The goal of compression testing is to determine the behavior or response of a material while it experiences a compressive load by measuring fundamental variables, such as, strain, stress, and deformation. By testing a material in compression the compressive strength, yield strength, ultimate strength, elastic limit, and the elastic modulus among other parameters may all be determined. With the understanding of these different parameters and the values associated with a specific material it may be determined whether or not the material is suited for specific applications or if it will fail under the specified stresses.

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ISSN 2581-7795

Table -4: Compression Test Data

Dimensions, Wxt (mmxmm)	Max. Load (kN)	Compression Strength (MPa)
25×2.5	39.33	366
25×3	51	413

5.3 Stress Analysis

A. MODELLING OF THE PLATE

The laminate orientations of all the laminae are 0°, 45° and 90° as the composite is woven-Fabric Orthotropic Carbon/epoxy is the material is taken as input material with the properties of Young's Modulus as in *x,y, z* directions EX= 70.03Mpa EY = 70.03 Mpa EZ = 12.65 Mpa

B. ANALYSIS OF COMPOSITE LAMINATE USING ANSYS

SHELL281 is suitable for analyzing thin to moderately-thick shell structures. The element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes. (When using the membrane option, the element has translational degrees of freedom only.) SHELL281 is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. The element accounts for follower (load stiffness) effects of distributed pressures.SHELL281 may be used for layered applications for modeling composite shells or sandwich construction. The accuracy in modeling composite shells are governed by the first-order shear-deformation theory (usually referred to as Mindlin-Reissner shell theory).The element formulation is based on logarithmic strain and true stress measures. The element kinematics allow for finite membrane strains (stretching). However, the curvature changes within a time increment are assumed to be small. A single-layer shell section definition provides flexible options. For example, you can specify the number of integration points used and the material orientation.The shell section commands allow for layered shell definition. Options are available for specifying the thickness, material, orientation, and number of integration points through the thickness of the layers. You can designate the number of integration points (1, 3, 5, 7, or 9) located through the thickness of each layer when using section input. When only one, the point is always located midway between the top and bottom surfaces. If three or more points, two points are located on the top and bottom surfaces respectively and the remaining points are distributed at equal distances between the two points. The default number of integration points for each layer is three; however, when a single layer is defined and plasticity is present, the number of integration points is changed to a minimum of five during solution.

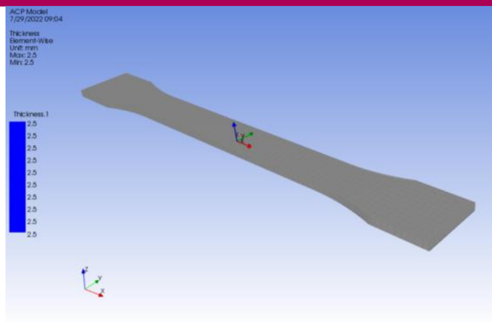


Fig -5: Composite Plate

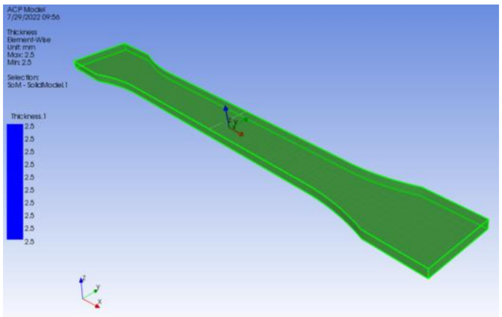
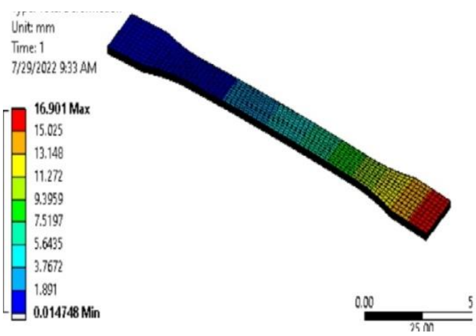


Fig -6: Boundary condition and load applied on the specimen

6. RESULT & DISCUSSION

The simulations were undertaken on two samples of carbon fibre parameters as detailed in Table 3 & 4. The magnitude of the load for each simulation is from 50 KN to 100 KN. For the first simulation, the orientation angle for composite plate is 0° for ply-1, 45° for ply-2 and 90° for ply-3 and the plies will be symmetric that made 6 plies. After the first simulation is successfully done, it was repeated by changing the values orientation angle which is 0° for each ply. Results and data from analysis are able to obtain from the completed analysis. Figure no 7(A) & (B) show the contour plot for carbon with orientation angle 0 °for ply-1, 45° for ply-2 and 90° for ply-3.



(a)

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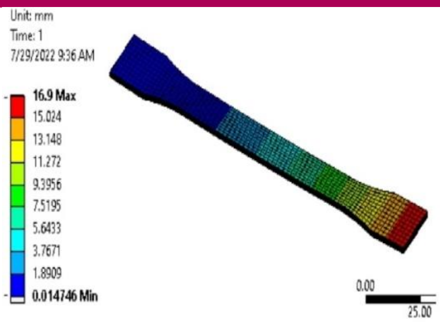
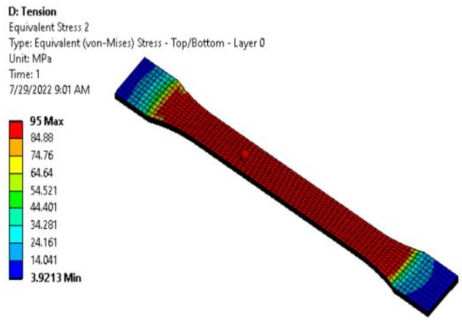


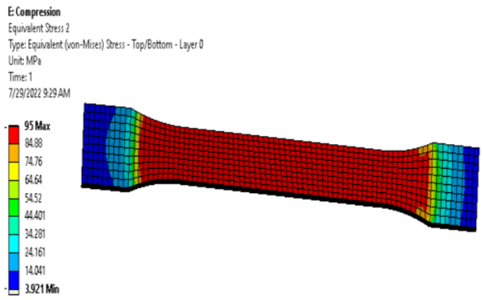
(b)

Fig-7: Carbon Fibre with orientation angle 0°, 45° and 90° A) Contour plot of Mises stress B) Countour plot of E11 strain.

Figure no 8 show the result of Von-mises stress for carbon fibre plate 2.5mm 3mm thickness with orientation angle 0°, 45° and 90°.



(a)



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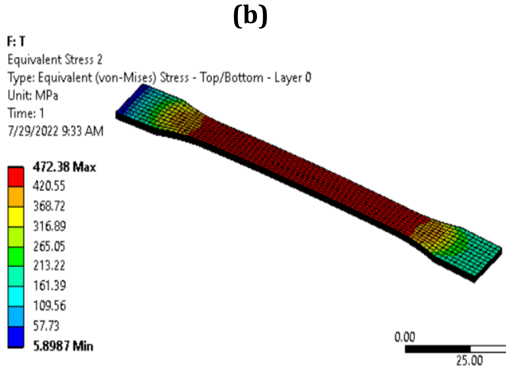

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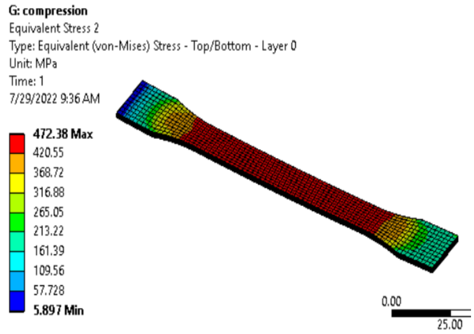
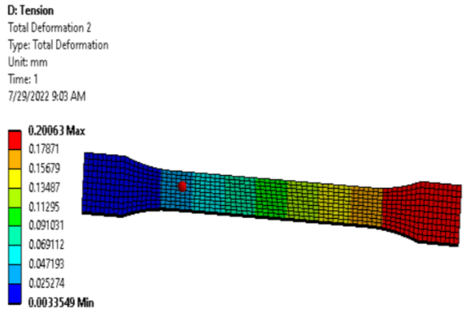


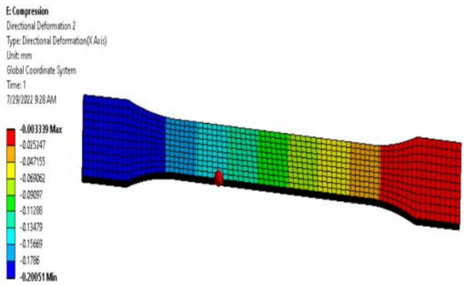
(d)

Fig-8: Carbon Fibre with orientation angle 0°, 45° and 90° (contour plot of Von-mises Stress)

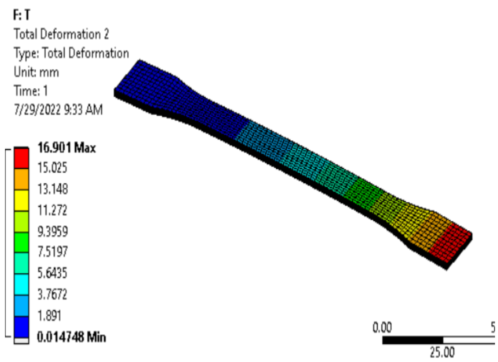
Figure no8 show the result of total deformation for carbon fibre plate 2.5mm 3mm thickness with orientation angle 0°, 45° and 90°.



(a)



(b)



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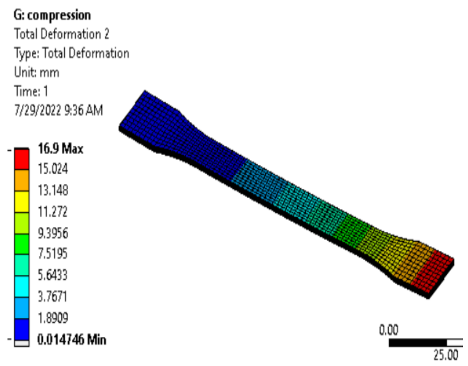

(d)

Fig-9: Carbon Fibre with orientation angle 0°, 45° and 90° (contour plot of Total deformation)

Following graph shows the stress vs strain relation of carbon fibre plate for Tension Test

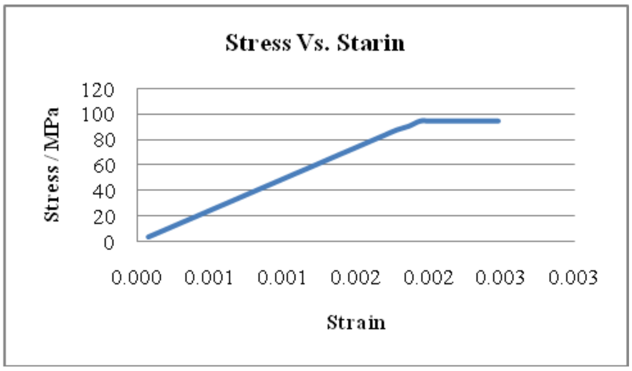

Chart -1: Stress vs Strain (2.5mm Plate)

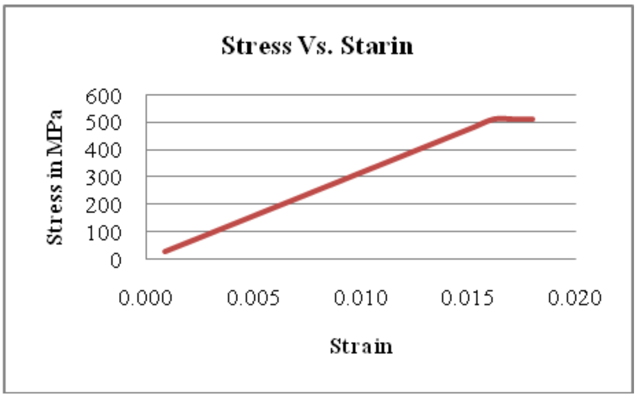

Chart -2: Stress vs Strain (3mm Plate)

Following graph shows the stress vs strain relation of carbon fibre plate for Compression Test

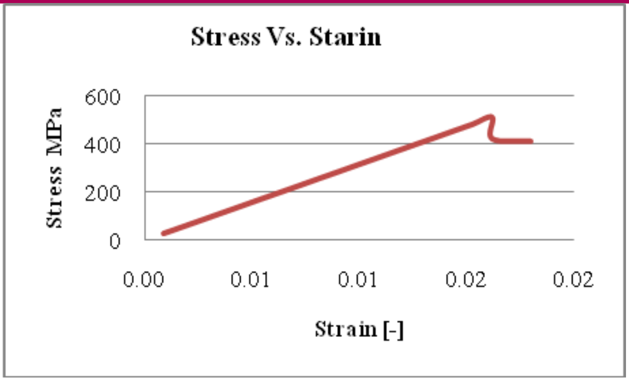

Chart -3: Stress vs Strain (2.5mm Plate)

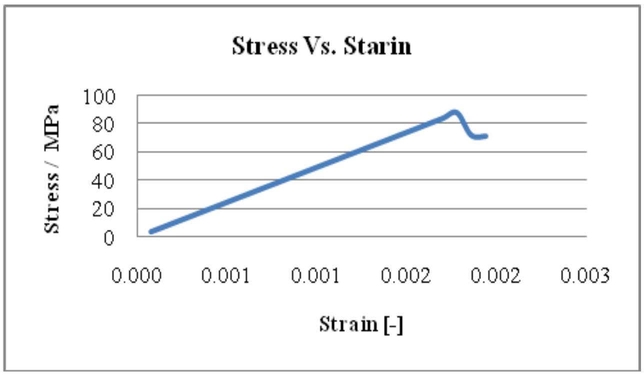

Chart -4: Stress vs Strain (3mm Plate)

Table -4: Compression Test Data

Test	**Test Specimen**	**Dimensions, Wxt (mmxmm)**	**Tensile Strength N/mm²**	**Ansys Result (Mpa)**
Tensile Test	Plate1	25×2.5	609	684.80
	Plate2	25×3	688	773.64
Compression Test	**Test Specimen**	**Dimensions, Wxt (mmxmm)**	**Comp. Strength N/mm²**	**Ansys Result (Mpa)**
	Plate3	25×2.5	592	665.68
	Plate4	25×3	674	757.89

7. CONCLUSION

The test results is shown in above Table 5 the requisite test results obtained on ANSYS workbench are compared with the testing results obtained from actual testing, considering various test parameters. From Table 5 it is observed that the values of Testing conducted on digital platform are higher than the results obtained from actual of the laminate. Hence, the laminates can be used in many industrial and commercial applications as a composite material.

ACKNOWLEDGEMENT

This project would have been a distant reality if not for the help and encouragement from various people. We take immense in thanking Dr.Mane V.V Principal of College of Engineering osmanabad, for having permitted us to carry out this project work.

I would like to express our heartfelt gratitude to Prof.P.H Jain (Project Guide) & Dr.D.D.Date (HOD) for supporting us & guiding us to prepare this detailed project work.

We are also thankful to the entire friend who directly & indirectly inspired & helped us for completion of this project and report.

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