Finite Element Analysis of the Carbon Fiber Reinforced Polymers (CFRP) With Epoxy Resin

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Abstract: The class of materials known as carbon fibre or graphite reinforced polymers is one in which carbon fibre is most frequently employed to strengthen composite materials. The matrix for carbon fibres can also be made of non-polymer materials. Carbon has had very modest success in metal matrix composite applications because of the development of metal carbides and concerns about corrosion. In high-temperature applications, reinforced carbon-carbon (RCC), which is made of graphite reinforced with carbon fibres, is employed structurally.

The use of CFRP has grown since its inception because it provides classic metals like cast iron with considerably improved characteristics at a lower weight. Due to its unparalleled potential, this discovery has emerged as the new spearhead of material technology. In this study, the relationship between variations in the fibre mass and CFRP characteristics is examined. The test is conducted using ASTM standard test specimens and software from Ansys 2022 R1. Evaluating equivalent stress, strain, and total deformation of the composite under the same load is the main goal of this research.

Keyword*s: FEA, Ansys ACP pre, carbon fibers, Epoxy resin, Total Deformation, Von –mises stress,*

I. INTRODUCTION

In one way or another, composite materials have been adopted into practically every sector. We'll look at a few benefits of employing composites and talk about some of the sectors that have employed them.

Composites were around long before they were technically discovered. Long cellulose fiber linked together by lignin make up the composite material that is a chunk of wood. The mixture of two or more materials is known as a composite. Reinforcement, matrix, and interface are the three essential components of a composite, with reinforcement serving as the load-bearing component and the interface serving as the contact surface between the matrix and the reinforcement. Sometimes, hardeners and accelerators are utilised to bond the ingredients. Polymer matrix composites (PMCs), metal matrix composites, ceramic matrix composites, and carbon/carbon composites are the four categories into which composites may be divided based on their matrix medium.

II. LITERATURE REVIEW

For the first time, Joseph Swan created carbon fibres in 1860 for use in light bulbs. In order to create an all-carbon fibre filament for one of the earliest incandescent light bulbs to be powered by electricity, Thomas Edison baked cotton threads or bamboo slivers at high temperatures in 1879. For the electrically heated incandescent light bulb, Lewis Latimer created a dependable carbon wire filament in 1880.

Chandra Kishore et al.[2022] examined the GFRP hybrid material's comparable stress, strain, and overall distortion under a 10N load. Due to its significantly improved qualities, theuse of GFRP has expanded since the past. Due to its unparalleled potential, this development has emerged as the new organise of material technology. Epoxy resin has various industrial uses for a wide variety of specialised objectives, but glass fibres are recognised to be a very adaptable material for industry and they demonstrate valuable bulk as well as fibre qualities. Their overall properties are significantly improved when reinforced in various variations. Thisstudy examines how changes in the fibre mass % affect the GFRP's physical characteristics. With the aid of the Ansys Academic testing programme, an ASTM standard test specimen is used.
Ritesh Bhat et al. [2019] In this work, the contingency of mechanical property over the material thickness is investigated on the glassfiber reinforced isophthalic polyester composite material. The specimens are made using simple hand lay-up method. The mechanical tests are conducted as per the relevant ASTM standards. ANOVA is carried out to determine the significant contribution of

material thickness on the tensile strength, flexural strength, and Barcol hardness. The mode of failure in the tensile specimen is studied in comparison to the ASTMD3039 standards and reasons are validated using the scanning electron microscopic analysis

Subrata Debnath et al. [2022] In the research, the effects of processing parameters on the tensile properties of Carbon Fibre Fabric/Polypropylene CFF/PP composites have been studied. Composites were fabricated under varying levels of compression pressure and temperature. The temperature was varied to 180 °C, 160 °C, and 157 °C, while compression pressure was varied in 100 kg/cm2, 80 kg/cm2, and 60 kg/cm2.

Naveen Jesuarockiam et al. [2019] observed that in the past few years, natural fibres, whichare readily accessible in nature, as well as natural additives-reinforced polymeric materials, have been employed extensively in nonload-bearing constructions. The laboratory-basedassessment of the characteristics exhibited by natural composites made with fibres is less genuine with a large degree of variance in the parameters that were measured due to human oversight and the precision of the testing machine's findings. To get around these restrictions, finite element analysis is used to evaluate the mechanical, thermal, and other characteristics ofnatural fibres and natural nutrients-reinforced composites made of polymer.

Brundaban PatroSami et al. [2017] recommended carbon fibres as an important material forthe twenty-first century because of its low weight, outstanding endurance, and great mechanical qualities. Due to their important vitality to weight characteristics, these materials are utilised for constructional uses in a variety of industries, including aviation, aeronautical, recreational applications, automotive, and medical devices. As a high achievement and high asset material,they are now widely known. Precursor polyacrylonitrile fibre is the source of the majority of carbon fibres. Due to the presence of smoke, heat, and electrical short circuits, such substanceshave the ability to ignite fires.

III. GEOMETRY SETUP AND MODELLING

To ensure quality, it becomes necessary to use standard test specimens; for this reason, test specimen of the specimen is in accordance with ASTM standard with name specified in figure. Each specimen's utilisation with a polymer matrix & a fiber-reinforced matrix has yielded validated results. The Table 1 gives thorough information about the specimen's dimensions and physical characteristics. Additionally, because the study is entirely simulation-based, maintaining an ISO cross sectional is simpler than it would be for a real equivalent.

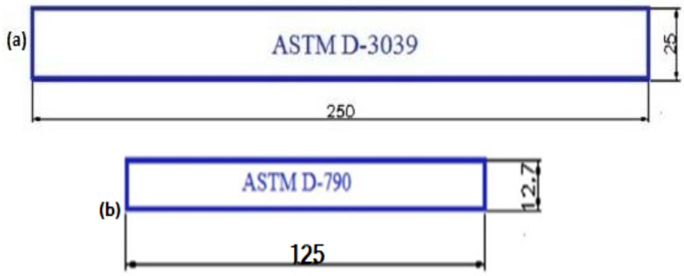


Figure 3.1: Test Specimen (a) tensile (b) banding

Modelling ply is creating for both test sample specimen and after that we are create the solid model using number of modelling ply. The following figure shows that carbon fiber and epoxy resin. Carbon fiber having two modelling ply and one epoxy resin ply between them.

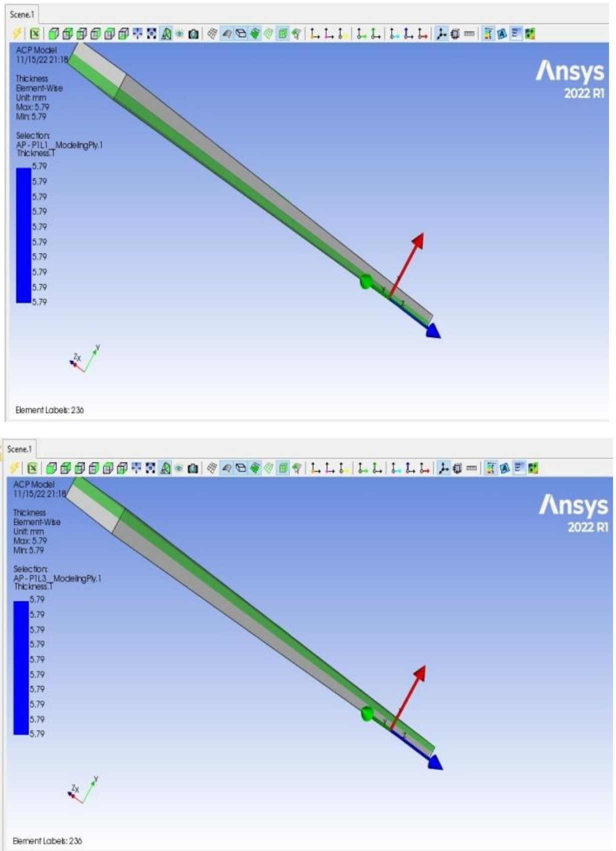


Figure 3.2: Modelling ply of carbon fiber (Bottom & top)

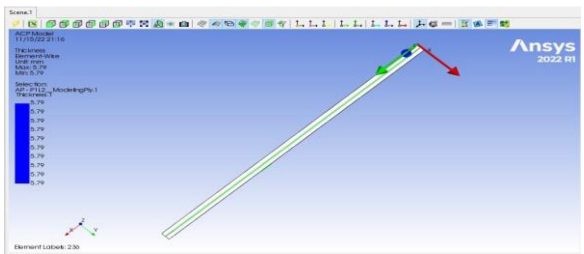


Figure 3.3: Modelling ply of Epoxy resin (Middle)

3.1 Geometry Setup

3.1.1 Test Specimen for Tensile Test

Here we are using the standard specimen of the composite material using carbon fiber (395 GPa) and epoxy resin. We are creating the test specimen for tensile test (for dimension Refer table 3.1)

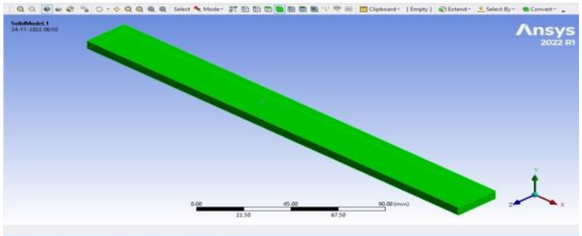


Figure 3.4: Geometrical model of test specimen for tensile (250x25).

Rosettes are important measurement devices that are used extensively in Fibersim to specify fibre orientations on the composite component. These "datum" or reference features determine the 0-degree direction at any place on the laminate using one of four mapping approaches

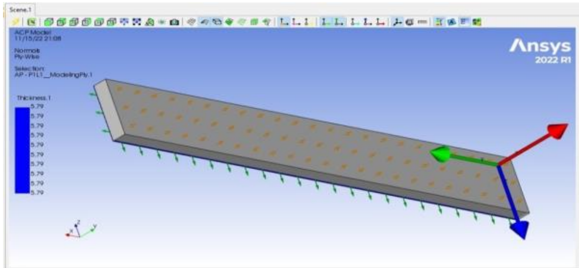


Figure 3.5: Rosette view of Geometrical model of test specimen for tensile test.

Green arrow are shows that carbon fiber orientation and the epoxy resin fiber orientation. And the epoxy resin fibers are perpendicular to the carbon fiber orientation. Another orange arrow shows the stackup direction of the modelling ply.

3.1.2 Test Specimen for Banding Test

Here we are using the standard specimen of the composite material using carbon fiber (395 GPa) and epoxy resin. We are creating the test specimen for the banding test (for dimension Refer table 3.1).

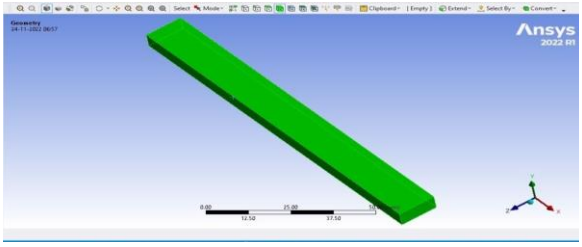


Figure 3.6: Geometrical model of test specimen for banding (125x12.7).

Table 3.1: Geometry of model specification

S.N.	Object Name	Geometry for tensile test specimen	Geometry for the bending specimen
1	State	Fully Defined	Fully Defined
2	Directional length of X axis	250. mm	125. mm
3	Directional length of Y axis	25. mm	12.7 mm
4	Directional length of Z axis	5.79 mm	5.79 mm
5	Volume of the Specimen	36187 mm3	9298.8 mm3
6	Mass of the Specimen	0.28407 kg	7.2995e-002 kg
7	Total object	1	1
8	Total number of Junction/Nodes	416	416
9	Total number of Elementary parts	225	220
10	Mesh Metric	None	None
11	Analysis Type	3D	3D

3.2 MESHING

Meshing is a critical operation in FEM in this process the CAD geometry is divided into numbers of small pieces. The small pieces are called mesh.

The analysis accuracy and calculation duration depend on the mesh size and orientations. By, default, a coarse mesh is generated by ANSYS software. Mesh contains mixed cells per unit area (ICEM Tetrahedral cells) having triangular faces at the boundaries.

Curvature- On and Smooth – Fine meshing.

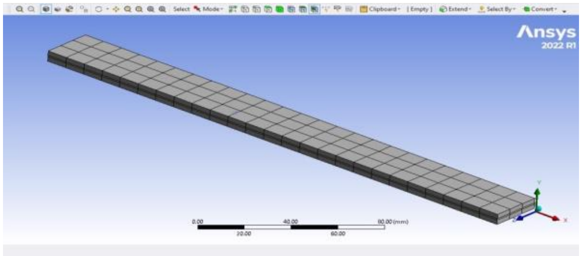


Figure 3.7: Meshing of test specimen

3.3 Boundary Condition

Here, the thickness of the components is adjusted to manage the weight proportion. After a stable generation, the test specimen generation is finished. The mechanical characteristics of the specimen under tension and under bending are listed in the table. Materials that were used in the testing are Resin Epoxy as a Matrix Reinforced with Carbon Fiber at a 395GPa (Refer to Material Property Section).

Following that, the test specimen is loaded to the necessary levels for equivalent stress, equivalent strain, and total deformation. Here, the parameters of the test specimen are used to create the FEA results in the ANSYS solver. Details on the physical and environmental restrictions are given. To avoid impact loading, the load is applied gradually and linearly.

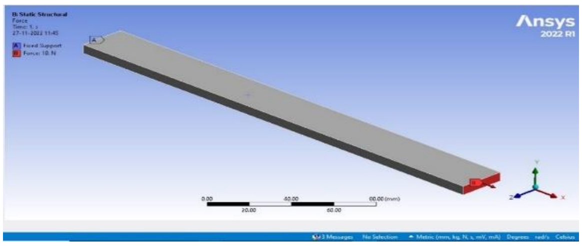


Figure 3.8: Boundary condition for tensile specimen

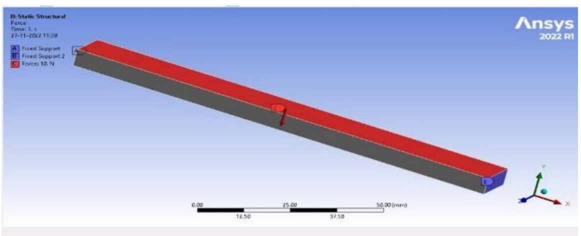


Figure 3.9: Boundary condition for banding specimen

Table 3.2: Details of boundary conditions.

Constraints Provided	Fixed Support	Fixed Support	Force
Status of Constraints Completely Defined	Completely Defined	Completely Defined	-
Extension selection Method	(Via.) Geometry Selection [for tensile specimen]	(Via.) Geometry Selection [for bending specimen]	-
Faces of Geometry 2 (total) 1(selected)	2 (total) 1(selected)	2 (total) 1(selected)	-
Type of Constraints Provided	Fixed Support	Fixed Support	Force
Components of the axis Applied on	-	-	Surface
Force Comp. in Z direction	0. N (ramped)	0. N (ramped)	-
Force Comp. in Y direction	0. N (ramped)	-10. N (ramped)	-
Force Comp. in X direction	10. N (ramped)	0. N (ramped)	-

IV. RESULTS AND DISCUSSIONS

The simulation is run with the academic version of ANSYS. For composite analysis, Ansys offers specialised software called ACP Pre and ACP Post. The procedure starts by creating a shell shape of the required specimen in ANSYS' design modeller in accordance with ASTM standards. Shell geometry indicates that the modeller has not given any thickness.

The geometry is then converted to a mesh once the surface/shell geometry has been generated. To assure correct results across the specimen, quadrilateral mesh is guaranteed and created with face refinement. In ANSYS ACP Pre, which is opened after the mechanical step, the geometry is given a layer of fibre and matrix.

Table 4.1: Material property of the composite material

Materials Properties	**Carbon Fiber (395Gpa)**	**Epoxy Resin**
Tensile Modulus X direction MPa	2.3e + 005	3780
Tensile Modulus Y direction MPa	23,000	-

Tensile Modulus Z direction MPa	23,000	-
Coefficient de Poisson XY	0.2	0.35
Coefficient de Poisson YZ	0.4	-
Coefficient de Poisson XZ	0.2	-
Modulus of rigidity XY MPa	9000	1400
Modulus of rigidity YZ MPa	8214.3	-
Modulus of rigidity XZ MPa	9000	-
Modulus of elasticity MPa	-	4200
Tensile Yield Strength MPa	-	54.6
Density kg mm^3	9000 1.8e-006	1.16e-006

For the purpose of simulating the perfect scenario, the gravitational acceleration is assumed to be zero. Additionally, because of this gravitational acceleration, the specimen's bulk may interfere with the characteristic, leading to a little overhang. This simulation's goal was to determine the stress, strain, and overall deformation caused by pure bending, tensile, and compressive loads; as a result, gravitational loads were ignored.

A positive force component is applied for tensile loading to test specimens that were fastened at one end (in the X-axis direction) (refer table 3.2). Referring to Fig. 4.1 (Total Distortion during Tensile Load), the contour for tensile loading exhibits maximal deformation at the free end and minimal deformation at the fixed end. As there is no resistance at the free end, similar findings are also corroborated by the overall equivalent strain diagram (see Fig. 4.3: Equivalent Elastic Strain during Tensile Loading (Layer 0)). The fixed end is also where the most stress is generated (see Fig. 4.2, "Equivalent (von-Mises) Stress under bending load (layer 0)").

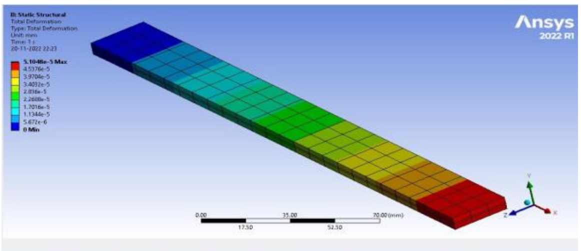


Figure 4.1: Test results (Total Deformation) of Specimen under Tensile Load.

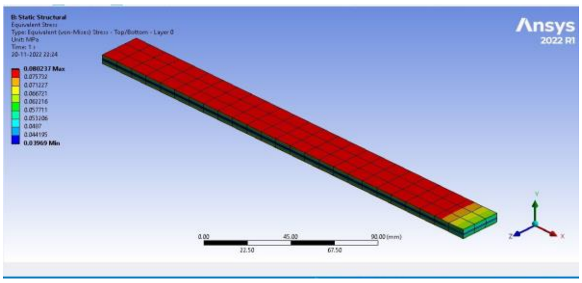


Figure 4.2: Test results (Equivalent Stress) of Specimen under Tensile Load.

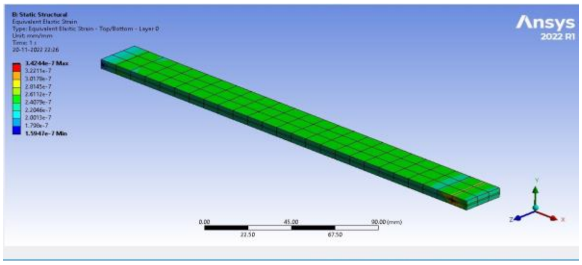


Figure 4.3: Test results (Equivalent Strain) of Specimen under Tensile Load.

Table 4.2: Result Summery (Tensile load)

Solution type	Total Deformation (mm)	Equivalent Elastic Strain	Equivalent Stress (MPa)
Generate with respect to	Time	-	-
Status of solutions	Solved	-	-
Minimum	0	1.5967 e^{-7}	0.03969
Maximum	0.0000510 48	3.4244 e^{-7}	0.080237
Average	0.0000255	2.5105 e^{-7}	0.059963
Time	1s	-	-
Load Step	1	-	-
Sub step	1	-	-

Iteration Number	1	-	-

The test subject was fastened at both ends. Faces in the direction of the Y-axis are required to be fixed. On the specimen's top face, a force is applied in the direction of the Z-axis. Due to response at the fixed support, the extremity of the structure had the most stress, whilst the centre experienced the lowest stress. Fig. 4.5 ("Equivalent (von-Mises) Stress under bending load (layer 0)") is a reference. Referring to Fig. 4.4 (Total Deformation under bending load), the total distortion contour likewise demonstrates the supporting outcome, with maximal deformation occurring in the middle and little deformation at the ends. The greatest strain is found at the fixed ends of the test specimen, according to the equivalent elastic strain diagram in Fig. 4.6 (Equivalent Elastic Strain under Bending Load, Layer 0).

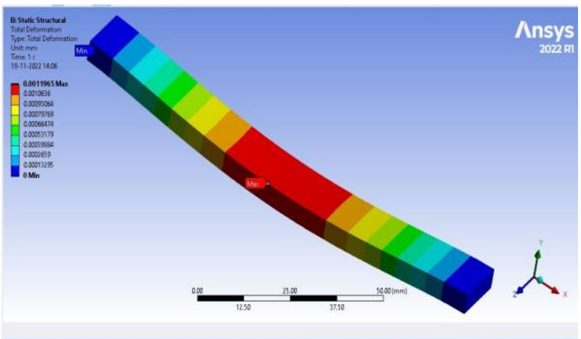


Figure 4.4: Test results (Total Deformation) of Specimen under Bending Load.

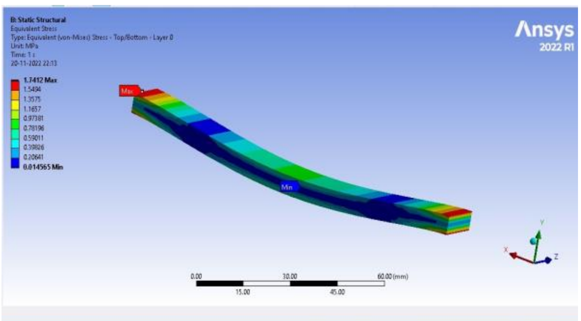
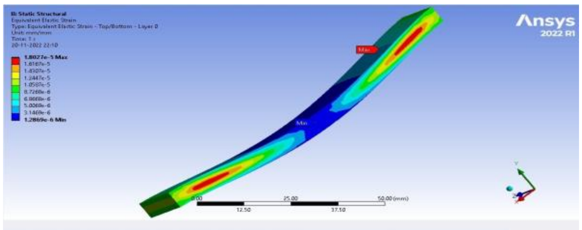


Figure 4.5: Test results (Equivalent Stress) of Specimen under Bending Load.



. Figure 4.6: Test results (Equivalent Strain) of Specimen under Bending Load

Table 4.3: Result Summery (Banding load)

Solution type	Total Deformation (mm)	Equivalent Elastic Strain	Equivalent Stress (MPa)
Generate with respect to	Time	-	-
Status of solutions	Solved	-	-
Minimum	0	1.2869 e^{-6}	0.014565
Maximum	.0011965	1.8027 e^{-5}	1.7412
Average	0.00059825	9.65695 e^{-6}	0.87788
Time	1s	-	-
Load Step	1	-	-
Sub step	1	-	-
Iteration Number	1	-	-

Comparison result of carbon- epoxy resin composite material over E- glass-epoxy resin composite.

Here is the comparison result between the carbon-epoxy composite materials and E-glass epoxy resin composite material.

We are testing both standard specimens using tensile load and banding load. Here we are using carbon epoxy materials with standard test specimen & find out the Equivalent Strain, Equivalent Stress, and Total Deformation. We are comparing this result with E-glass epoxy composite materials result on the basis of Base paper.

Table 4.4: Comparing Result with Tensile Test

Composite materials		Total Deformation(mm)	Equivalent Elastic Strain	Equivalent Stress (MPa)
E-Glass Epoxy Resin	Min.	0	$4.2157e^{-4}$	0.05261
	Max.	0.066161	$7.100e^{-6}$	2.5116

Carbon Epoxy Resin	Min	0	1.2869 e^{-6}	0.014565
	Max.	0.0011965	1.8027 e^{-5}	1.7412

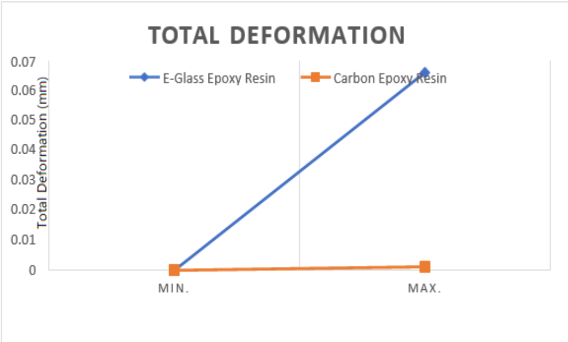


Figure 4.9 Comparison value of Total Deformation for Bending test.

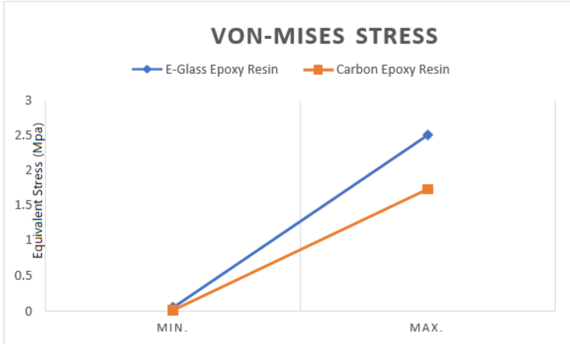


Figure 4.10 Comparison value of von-Mises stress for Bending test.

V. CONCLUSIONS

FEA Simulation of Carbon Fibre with Epoxy resin of standard test specimen and compare with E-glass fibre with epoxy resin (Base Paper) result concluded that the various results that are discussed below are fallowing:

- The Obtained results concluded that the von Misses stress occurring on the Carbon fiber are reducing as compared to E-Glass Fibre.
- When we do the banding test on a standard specimen, we see that the value of maximum stress is reduced by 30.67 % when we compare this value with that of the E-glass fiber.
- When we do the tensile test on a standard specimen, we find that the maximum stress value is lower when compared to that of E glass fibre by 85.29%.
- If we look at the total deformation of both the tests (tensile and banding) we find that carbon fiber has decreased by 96.9% and 81.9% respectively as compared to E-glass fiber.

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