# Analysis of Carbon Fiber and Glass Fiber Reinforced with PEEK

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***ABSTRACT:*** The potential use of carbon fiber reinforced and glass fiber reinforced with other materials enhances the material properties and it provides an upper hand in maintaining the high strength to the weight ratio. This paper offers an analytical study of the carbon fiber reinforced peek and glass fiber reinforced peek provided the values obtained after performing tensile, compression, and flexural tests of the materials using polyether ether ketone as binding material. However, the dimensions and the procedures for the testing materials are followed according to the different ASTM standards (D638, D3410, and D790) already specified for the tensile, compression, and flexural testing. The distinctive focus was on the mechanical behavior of the carbon fiber and glass fiber after its reinforcement with the peek. Also, the results obtained from the mechanical testing indicate high tensile, compression, and flexural strength under varying loading conditions. The results indicate that the material possesses excellent tensile, compression, and flexural strength with an advantage of a low weight ratio. These materials can be used in the automobile and aerospace industry.

***KEYWORDS:*** **Composites, Mechanical Testing, Structural Testing, ANSYS, FEA**

## I. INTRODUCTION

Composite materials are better than alloys and they possess better mechanical strength compared to them. The use of composites in the industry is on the rise because of the mechanical properties of composite materials. In this paper, we have analyzed the mechanical properties of two different composites but the binding material remains the same. The aim was to analyze each composite on the different volumetric composition of their fiber percentage with polyether ether ketone (Peek). We used Carbon Fiber and Glass Fiber as the matrix materials and the volumetric percentage was set to be 20%, 30%, and 40%. Carbon fiber and glass fiber both come under the same category of materials but differs in their strengths, carbon fiber possesses more strength compared to glass fiber. The idea to choose carbon fiber and glass fiber was due to their excellent high strength to less weight ratio. Its uses in the industry can help in designing heavy machinery with low body weight and high strength. Several tests were performed on the Ansys workbench from making the laminate to, giving boundary conditions to the laminates and executing the structural analysis. The paper discusses the material properties of carbon fiber, glass fiber, and peek, the design of the specimens taken according to ASTM standards, structural analysis on Ansys, and the overall discussion of the results obtained from the analysis. The results themselves claim that the carbon fiber reinforced with peek and glass fiber reinforced with peek have greater strength compared to and low weight ratio.

**Nomenclature**

1. Carbon Fiber (CF)
2. Glass Fiber (GF)
3. Polyether ether ketone (Peek)
4. Carbon Fiber Reinforced Peek (CFRP)
5. Glass Fiber Reinforced Peek (GFRP)
6. American Society for Testing and Materials (ASTM)
7. Polyacrylonitrile (PAN)
8. Tensile Testing Standards - D638
9. Compression Testing Standards - D3410
10. Flexural Testing Standards - D790
11. $\rho$ – Density (kg/m$^3$)
12. E - Young's Modulus (GPa or MPa)
13. $\upsilon$ - Poisson's Ratio
14. Giga Pascal (GPa) and Mega Pascal (MPa)
15. $\sigma$ - Stress (N/mm$^2$)
16. Strain (mm/mm)

## II. LITERATURE

The use of composite materials is increasing gradually in the industry as the heavy machinery requires high strength to less weight ratio which is provided by the composite materials and they are easy to manufacture. The history of CF is very rich. It was first used by Thomas Edition in 1897 and after that, the practical use of CF started in 1960. Dr. Akio Shindo from Japan developed the high mechanical strength of CF by increasing the carbon percentage to 55% using PAN which led to an increase in modulus to 6 times [1]. In 2020, I.A. Daniyan studied the development of mechanical strength of carbon fiber reinforced epoxy with silica additive. He did a numerical analysis using Response Surface Methodology (RSM). He made a model of tensile strength as a function of curing temperature and curing time [2]. In 2014, T.P. Sathishkumar, S. Satheeshkumar, and J Naveen discussed the mechanical, dynamics, thermal, tribological, and water absorption properties of Glass fiber reinforced polymer. They were used differently for preparing the glass fiber reinforced polymer with various environmental conditions. According to their observation, the UTS and flexural strength increased with an increase in the glass fiber [3]. In 2019, Vemu Vara Prasad and Maganti Pramila Devi did a study on the mechanical characterization of composites. They used epoxy basalt fiber as specimens and made specimens to reflect their properties under varying load conditions and the whole analysis was performed on Ansys 18.1 software. They performed several mechanical testing like tensile, compression, and flexural testing and compared the results with each specimen, and found the hybrid composite specimen to be having more UTS and flexural strength than other specimens [4]. In 2017, M. Rajesh and J. Pitchaimani did a study on composites and the change in their mechanical property (Tensile, Compression, and Flexural Strength), dynamic mechanical properties after the use of chemicals on their outer surface. They found that it enhances their mechanical property due to an increase in interfacial adhesion between fiber and matrix compared to other treatments [5]. In 2017, Rakesh Potluri, V. Diwakar, K. Venkatesh, and B. Srinivasa Reddy made a predictive model for the prediction of the mechanical property of the composites. They took epoxy carbon fiber as the composite and made several models for the prediction [6]. In 2020, Zahid Iqbal Khan, Agus Arsad, Zurina Mohamad, Unisa Habib, and Muhammad Abbas Ahmad Zaini did a work-study on the enhancement of the thermos-mechanical property of epoxy by preparing carbon fiber epoxy (CFE) and glass fiber epoxy (GFE) and tested on UTM [7]. In 1995, J.R. Sarasua and P.M. Remiro did a study on the mechanical behavior of glass fiber and carbon fiber reinforced peek. They choose two different methods classical unidirectional tensile test and an immersion ultrasonic technique [8]. In 2021, Marcin Malek, Mateusz Jackowski, Waldmer Lasica, Marta Kadela, and Marcin Wachowski worked on a project based on the mechanical and material properties of the mortar reinforced with glass fiber. They recycled glass fiber reinforced with mortar and as a result, its mechanical property got improved [9]. In 2021, Sun-ho Go, Alexandre Tugirumubano, and Hong-gun Kim did a study on impact strength for carbon composites at different fiber angle orientations, they performed a drop-weight impact test on the laminates at different fiber angles [10].

## III. DESIGN

### 3.1. Materials

The materials used in the present work are Carbon Fiber Reinforced Peek (CFRP) and Glass Fiber Reinforced Peek (GFRP). The aim was to observe the variation in the tensile strength, compression strength, and bending strength throughout the process by varying the volume percentage of the carbon fiber and glass fiber. Both materials when combined provides us the greater tensile, compressive, and flexural strength. On the contrary of their weight ratio [4].

Table.3.1. a. Property of Carbon Fiber Reinforced Peek

| Property | 20% | 30% | 40% |
|---|---|---|---|
| ρ | 1430 kg/m$^3$ | 1510 kg/m$^3$ | 1620 kg/m$^3$ |
| E | 8.8 GPa | 11.5 GPa | 14.2 GPa |
| υ | 0.37 | 0.39 | 0.41 |

Table.3.1. b. Property of Glass Fiber Reinforced Peek

### 3.2. Design of Ply

Different plies were made for performing the different tests on ANSYS software. Each ply was made according to the different ASTM standards. The necessity of mechanical testing of any material is to find out the strength at which components can withstand while working because different loads are applied to the materials [2]. The force applied for each testing was 10 kN.

| Property | 20% | 30% | 40% |
|---|---|---|---|
| ρ | 1370 kg/m$^3$ | 1400 kg/m$^3$ | 1440 kg/m$^3$ |
| E | 19.5 GPa | 28 GPa | 35 GPa |
| υ | 0.43 | 0.45 | 0.47 |

**Compression Test**

For the Compression test, ASTM D3410 testing standards are being followed and the specimen of CFRP and GFRP are prepared according to the dimension mentioned in the standards. Multiple uniform rectangular cross-section plies are made for the different volume percentages of the Carbon Fiber and Glass Fiber. The dimensions of the specimen are 155 mm x 25 mm x 4 mm. There is a total of 6 specimens were prepared for testing purposes.

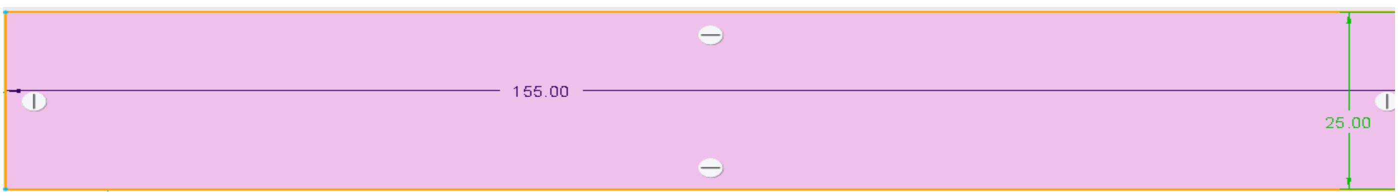



Fig.1. Dimension of Compressive Specimen

**Flexural Test**

For the Flexural test, we are following ASTM D790 testing standards and the dimensions of the specimen are 127 mm x 12.7 mm x 3 mm. the dimensions are taken following the D790 standards, and 6 different specimens were prepared according to the standards having 20%, 30% and 40% Carbon Fiber and Glass Fiber Volume percentage in the specimen.

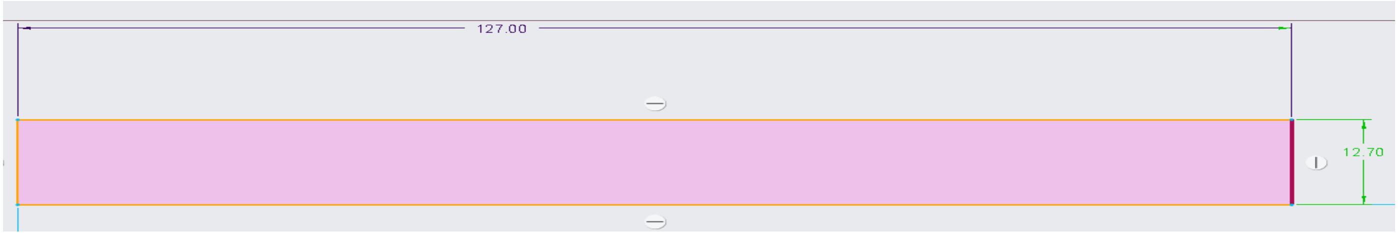



Fig.2. Dimension of Flexural Specimen

**Tensile Test**

For this particular tensile test, we follow ASTM D638 testing standards, and both CFRP and GFRP are tested accordingly. Tensile properties vary according to the specimen preparation. The test specimen for reinforced composites, including highly orthotropic laminates should be prepared according to the dimensions shown in Fig.3.

Table.3.2.a. ASTM Dimensions for Tensile Specimen

| Dimensions (see drawings) | For 3 mm |
|---|---|
| W—Width of the narrow section | 13 |
| L—Length of the narrow section | 57 |
| WO—Width overall, min | 19 |
| LO—Length overall, min | 165 |
| G—Gage length | 50 |
| D—Distance between grips | 115 |
| R—Radius of fillet | 76 |

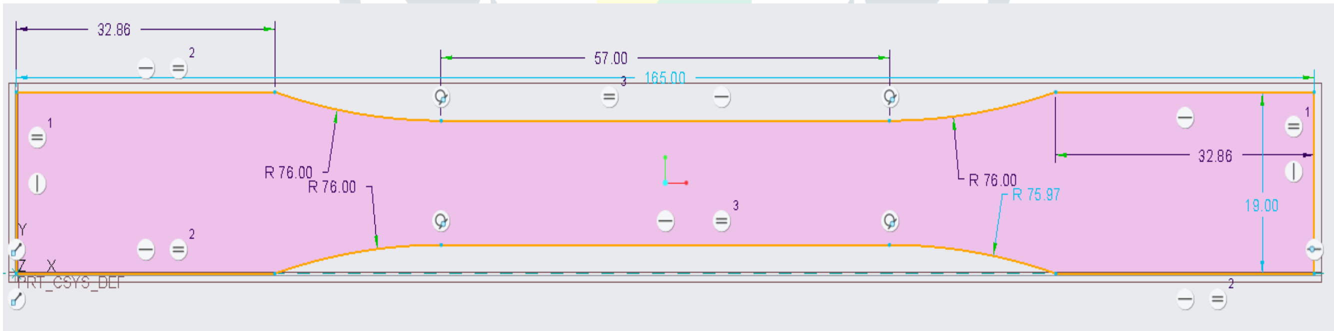



Fig.3. Dimension of Tensile Specimen

### 3.3. Meshing

Table.3.3.a. Meshing Details

| | NODES | ELEMENTS |
|---|---|---|
| **COMPRESSION** | 5515 | 4048 |
| **FLEXTURAL** | 2275 | 1536 |
| **TENSILE** | 3855 | 2740 |

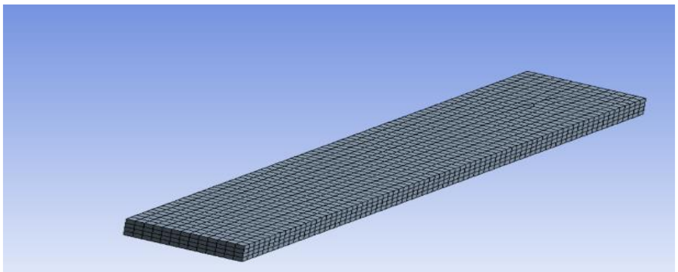


Fig.4. Compression Specimen

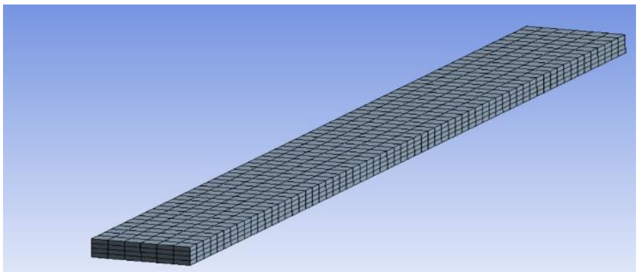


Fig.5. Flexural Specimen

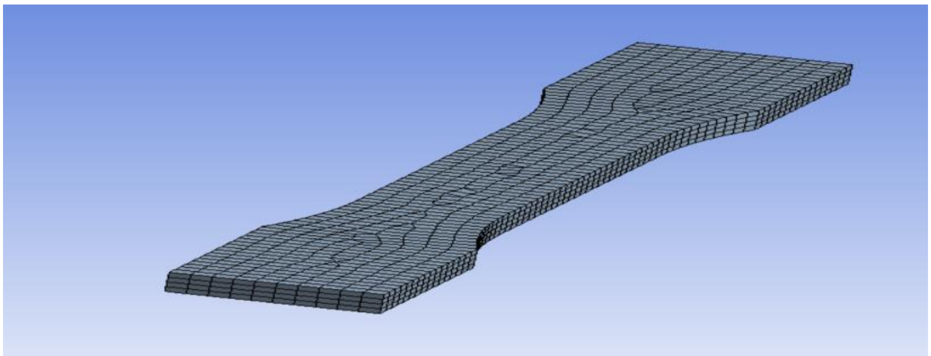


Fig.6. Tensile Specimen

**3.3.1. Boundary conditions:**

| | **Boundary conditions** | **Loading Conditions** |
|---|---|---|
| **Compression** | Fixed support | Force |
| **Flexural** | Fixed support.<br>Displacement.<br>Displacement 2. | Nodal Force |
| **Tensile** | Fixed support | Force |

**Boundary conditions & loading conditions:**

**For Compression:** According to the table or analysis in compression, we are using one boundary condition that is fixed support. We are giving this boundary condition at the side face of the compression specimen and the other is the loading condition that is force. We are applying force on the other face of the specimen.

**For Flexural:** According to the table or analysis in flexural, we are using three boundary conditions that are fixed support, displacement, and displacement 2. We are giving fixed support at the side face of the flexural specimen and displacement is given at the edge of the specimen and displacement 2 is also given at the edge of the specimen. Another is the loading condition that is force, we are applying the force at the center of the flexural specimen.

**For Tensile:** According to table or analysis in tensile, we are using one boundary condition that is fixed support. It is given at the side face of the tensile specimen. Another is the loading condition that is force, we are applying the force on the other face of the specimen.

**3.4. Fiber Angle Orientation**

A material is said to be isotropic if the properties are independent of direction within the material. Composites come under the category of anisotropic materials. If material is loaded along its 0˚, 45˚, and 90˚ directions. The modulus of elasticity or Young's modulus would be the same in all directions in the case of isotropic materials but it differs in the case of anisotropic. The moduli of the elasticity differ in each direction. When there is a single-ply or plies are stacked in the same orientation, that is called a lamina and When the plies are stacked at different angles, then it is called a laminate. Across the length, tension and compression loads are carried by the fibers, while the matrix stabilizes the fibers by distributing the loads between the fibers which are under tension and, and it prevents them from buckling in compression. Since the fiber orientation impacts the mechanical property of a material that much. So, we must orient as many layers as possible in the main load-carrying direction to balance the load throughout the material. In the present study, we have taken 4 different fiber angle orientations for the design of plies. These 4 fiber angles are 0˚, +45˚, -45˚ and +90˚. This combination of Fiber orientation maintains the balance of loads in each direction in the material. This type of laminate is also known as quasi-isotropic laminate because it carries equal loads in all four directions.

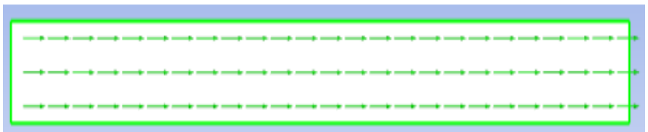


Fig.7. Fiber Orientations at zero degree

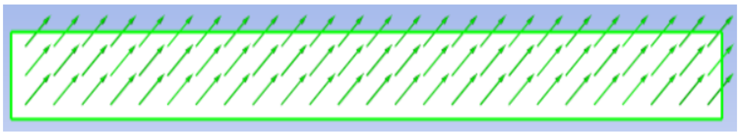


Fig.8. Fiber Orientations at + 45 degree

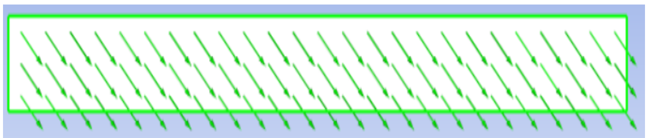


Fig.9. Fiber Orientations at – 45 degree

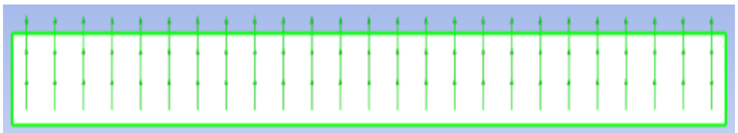
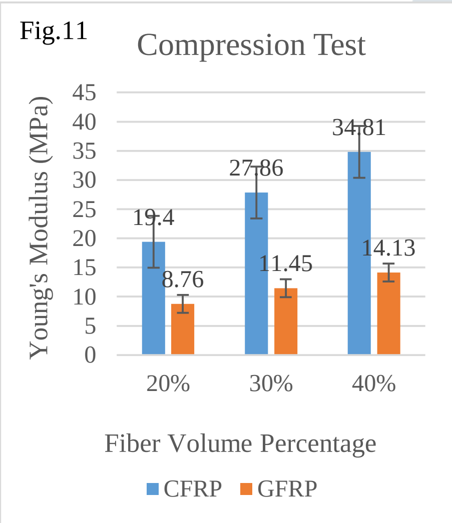
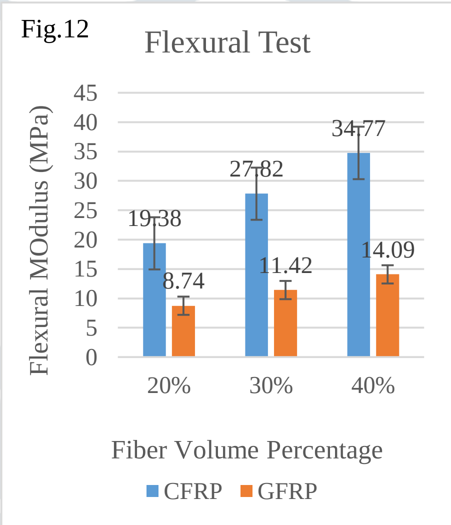


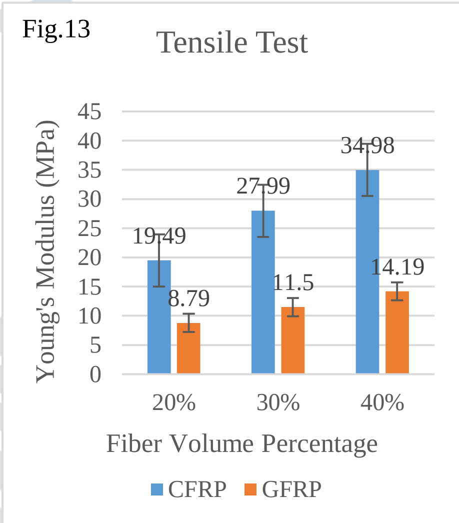
Fig.10. Fiber Orientations at + 90 degree

## IV. RESULTS

The structural analysis of the 18 specimens was done on ANSYS. Each specimen was prepared by different compositions of Carbon Fiber, Glass Fiber, and Polyether ether ketone (PEEK). Tabulated results are shown below.




The above three figures represent the variation of the value of Young's Modulus for Compression test, Tensile test, and flexural modulus for the flexural test. Blue bar represents the value of CFRP specimen at 20%, 30%, and 40% CF volume ratio. The orange bar represents the value of the GFRP specimen at 20%, 30%, and 40% GF volume ratio.

**Figures containing the variation in the values of Stress Vs Strain of CFRP are shown below**

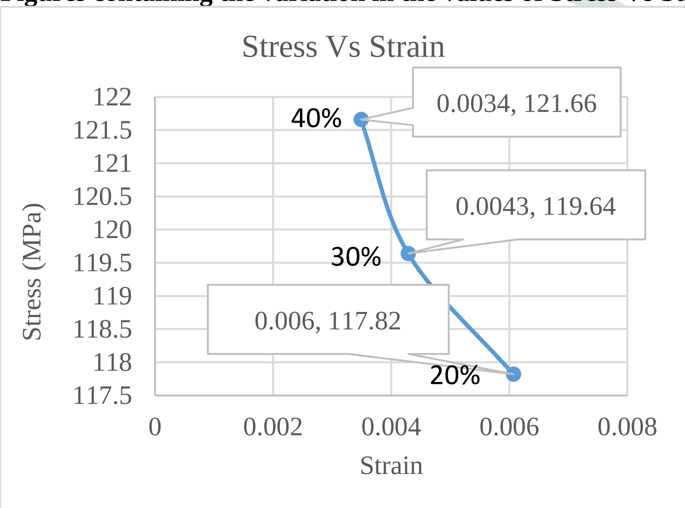



Fig.14. Compression Test of CFRP

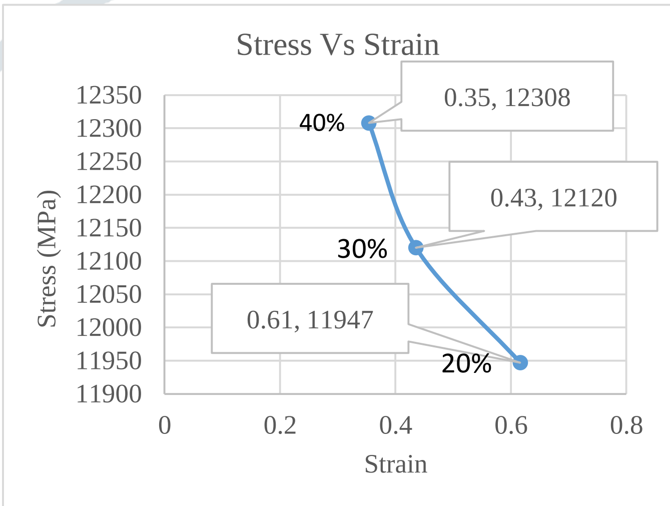



Fig.15. Flexural Test of CFRP

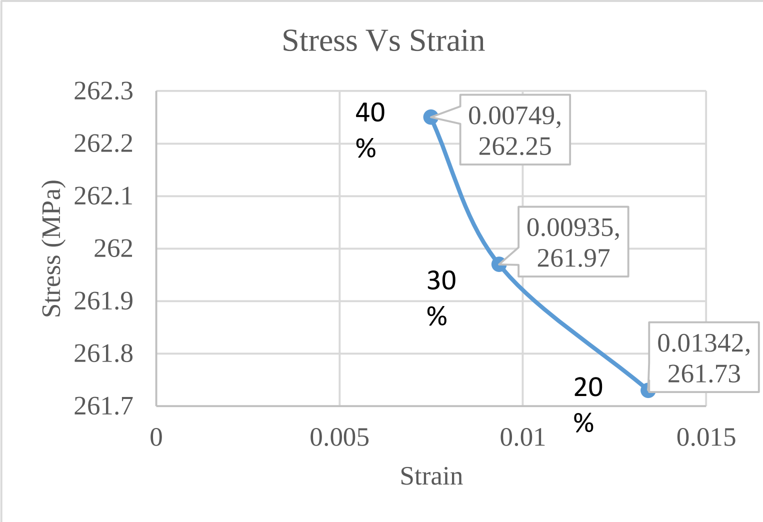



Fig.16. Tensile Test of CFRP

Fig. 11, 12, and 13 contain the different variation of Stress Vs Strain values for CFRP at 20%, 30%, and 40% volume percentage of CF. Figure '11', '12', and '13' represents the Figure of compression, flexural and tensile test respectively. The maximum stress value obtained from the Figure is 12308 MPa from the Flexural test and the minimum stress value is 117.82 MPa from the Compression test. Similarly, the maximum strain value obtained is 0.61 mm/mm from the Flexural test and the minimum stress value is 0.0034 mm/mm from the Compression test.

**Figures containing the variation in the values of Stress Vs Strain of GFRP are shown below**

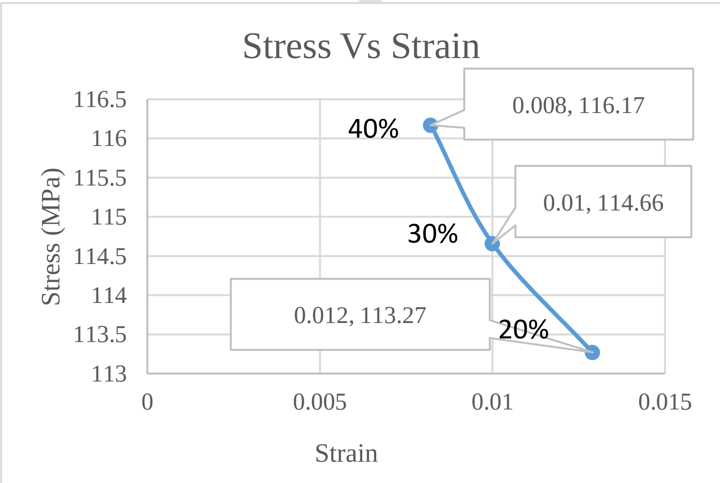



Fig.17. Compression Test of GFRP

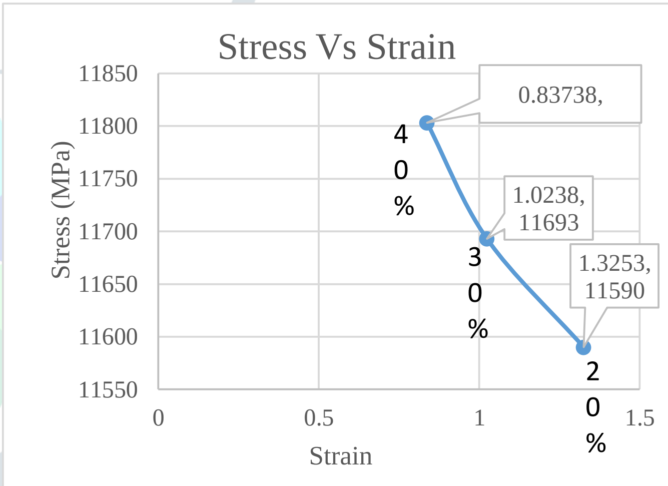



Fig.18. Flexural Test of GFRP

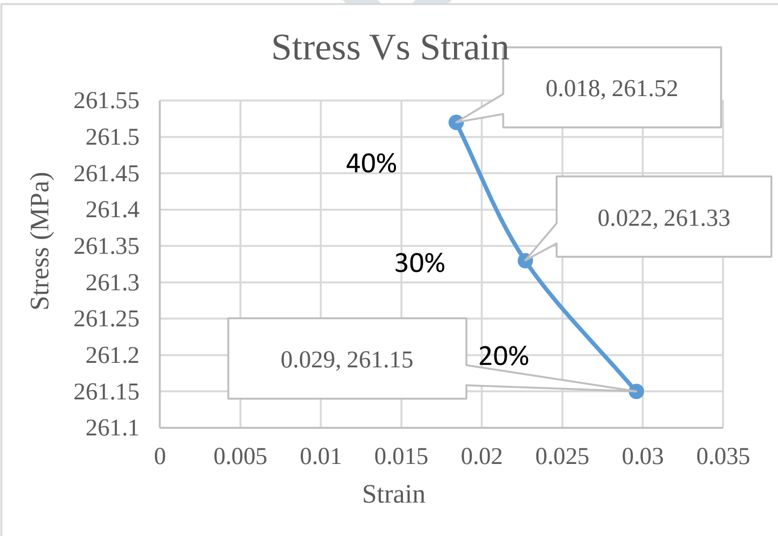



Fig.19. Tensile Test of GFRP

Figures 14, 15, and 16 contain three different figures representing the figures of values between stress vs strain for Compression, Flexural, and Tensile tests respectively. Each figure contains three points each represents the Stress Vs Strain value at different GF volume percentages in the GFRP. The maximum stress for GFRP is 11803 MPa and the minimum stress value is 113.27 MPa. Similarly, For Strain, the maximum and minimum values are 1.32 mm/mm and 0.008 mm/mm respectively.

### 4.1. ANSYS Analysis Results

**Static Structural Analysis of Carbon Fiber Reinforced Peek**

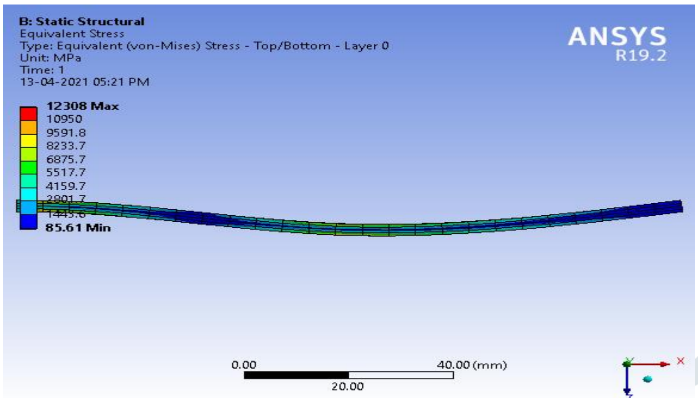


Fig.20. Equivalent Stress (Von-Mises)

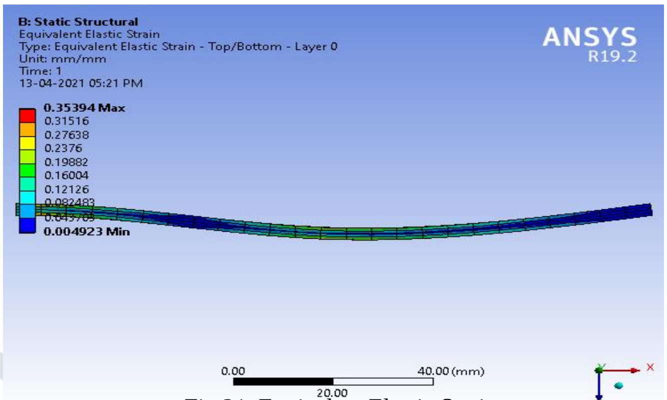


Fig.21. Equivalent Elastic Strain

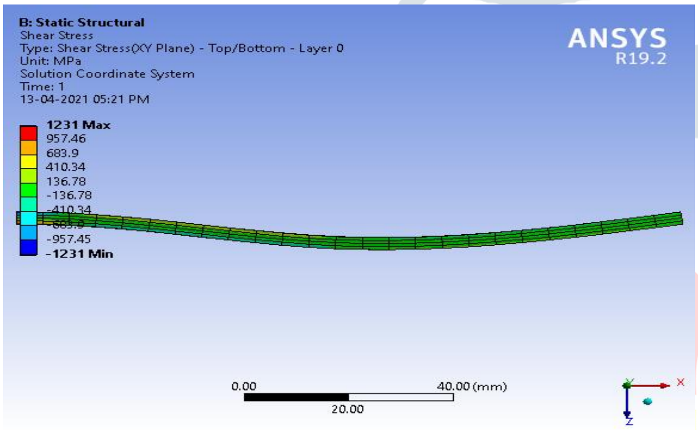


Fig.22. Shear Stress (XY Plane)

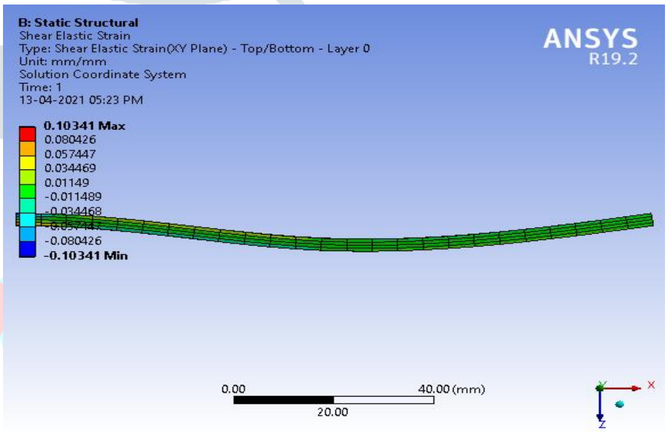


Fig.23. Shear Elastic Strain (XY Plane)

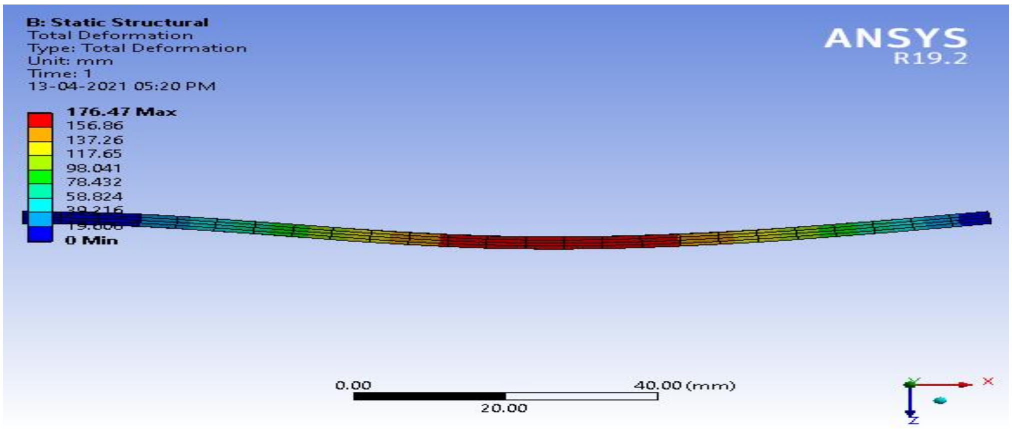



Fig.24. Total Deformation

### Static Structural Analysis of Carbon Fiber Reinforced Peek

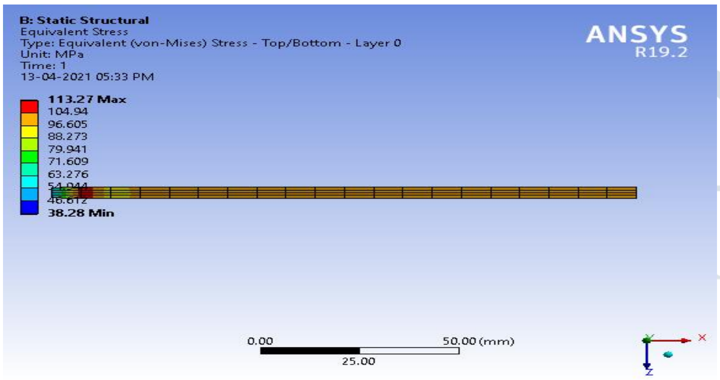



**Fig.25.** Equivalent Stress (Von-Mises)

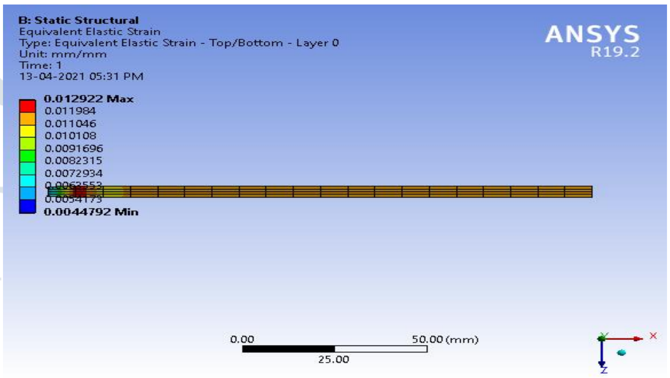



**Fig.26.** Equivalent Elastic Strain

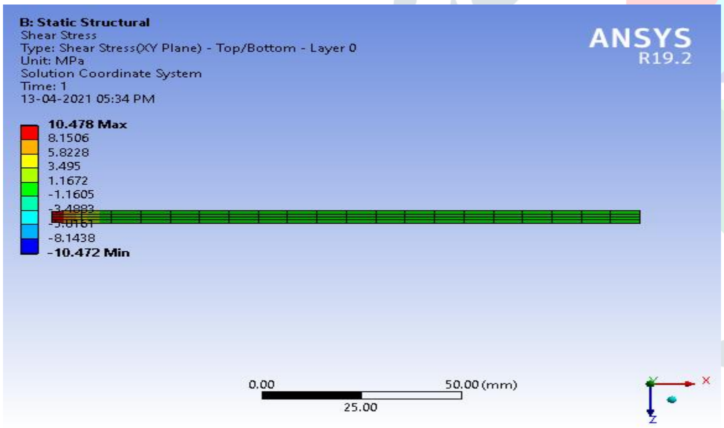



**Fig.27.** Shear Stress (XY Plane)

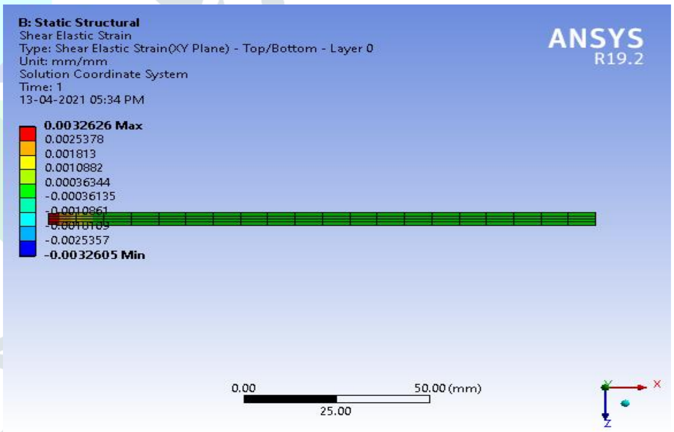



**Fig.28.** Shear Elastic Strain (XY Plane)

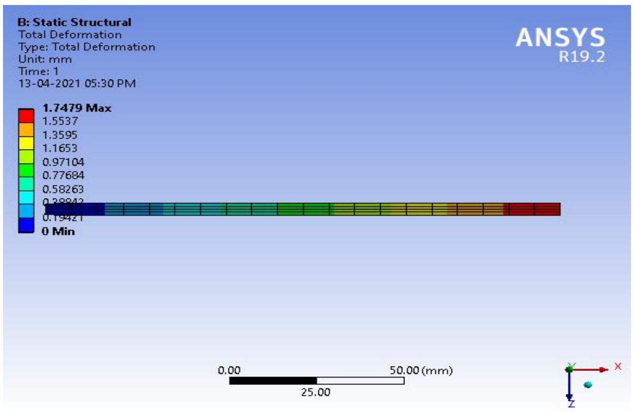



**Fig.29.** Total Deformation

### 4.2. Structural Analysis Results

We used Ansys Workbench for the analysis of the specimens. Each specimen was analyzed under the load of 10,000 N. The force can be applied to the face, edge, and center of the specimen. The loads were applied in the direction of the X, Y, and Z Coordinate axis. Shear Stress and Shear Strains have six components as Normal-X, Y, Z axis, and Shear-XZ, XY, YZ. Total deformation can be calculated from any axis as it is a scalar quantity.

**Carbon Fiber Reinforced Peek**

Fig.20 provides the maximum value of Equivalent Stress (Von-Mises) as 12308 MPa and the minimum value is 85.61 MPa. In Fig.21 Equivalent Elastic Strain has a maximum value of 0.35394 mm/mm and a minimum value of 4.923e-003 mm/mm. Fig.22 provides the value of maximum shear stress of 1231 MPa in the XY plane and mini. Fig.23 gives the maximum value of Shear Elastic Strain as 0.10341 mm/mm. From Fig.24 The total maximum deformation observed was 176.47 mm acting at the center and minimum deformation was 0 at the tip of the specimen due to both ends were fixed and the force was applied at the center of the upper face of the specimen.

**Glass Fiber Reinforced Peek**

Fig.25 gives the maximum value of Equivalent Stress (Von-Mises) is 113.27 MPa and the minimum value is 38.28 MPa. Fig.26 provides the maximum and minimum value of Equivalent Elastic Strain as 0.012922 mm/mm and 0.0044792 mm/mm respectively. Fig.27 states the value of Shear Stress in the XY plane, the maximum stress values are 10.478 MPa. From Fig.28 we can get the value of maximum Shear Elastic Strain as 0.0032626 mm/mm. The value of maximum Total Deformation, we got from Fig.29 is 1.7479 mm/mm and the minimum value is 0. The force of 10 kN was applied on the face which was opposite to the face fixed on the other end of the specimen which led to max deformation at the free end tip and the minimum occurrence at the fixed end of the specimen.

## V. DISCUSSION

The meshing images of the compression, flexural, and tensile specimen is shown in Fig.4, Fig.5, and Fig.6 respectively. The meshing is very fine and it helps to get the better outcomes of the analysis performed on the specimens. Each specimen is designed according to different ASTM standards specified for various tests. We have used these standards for the preparation of plies having different fiber volume percentages. The results indicate that the CFRP has more strength than GFRP in every tensile, compression, and flexural test. From Fig.13 we can illustrate that in the case of the tensile test, the specimen having the highest strength among others are 40% CFRP specimen. Similarly, from Fig.11 and Fig.12, for the compression and flexural test, 40% CFRP has the highest strength compared to other specimens. Fig.14,15,16 and Fig.17,18,19, demonstrate the correlation between the fiber percentage is increasing in a specimen Young's modulus of the specimen is decreasing from 40% to 20%, which defines that increasing the fiber percentage in the specimen increases its elastic property. The increase in fiber volume percentage for both the materials results in a significant increase in their mechanical strength. As the fiber percentage is increasing the load withstanding capacity of the material for a longer duration is increasing. The Figure shows a downward curve from 40% specimen to 20% which explains its increase in Young's Modulus throughout the experiment. The fiber angle orientation makes it easier for laminate to spread the load in each direction equally which protects the composite from sudden failure. The maximum elastic modulus is observed in the case of the 40% CFRP flexural test and the minimum is observed for the 20% GFRP compression test. During the Tensile Testing, The Carbon fiber reinforced peek (CFRP) having 20% Carbon Fiber (CF) volume percentage offers 121.72% greater Elastic Modulus than the Glass fiber reinforced peek (GFRP) having same 20% Glass Fiber volume percentage, because of which the CFRP 20% CF composition can withstand a higher amount of stress under the same strain value offered by the GFRP. Similarly, from figures which contain the variation of Young's Modulus to the fiber volume percentage we can see that for 30% it increases by 143.39% and for 40% it increases up to 146.51%. It increases as the volume percentage of CF/GF increases in the composite and the weight of the composite also decreases. we can see the variation in the Stress vs Strain in CFRP and GFRP with change in CF and GF volume percentage. The Figures illustrate that with an increase in Fiber percentage the stress enduring capacity of the composite is increasing because the extra fibers are providing the strength to withstand that load. For CFRP, the increase in CF percentage from 20% to 30% increases the tensile strength of the composite by 43.61%, and similarly for the 30% to 40% increases it by 25%. For GFRP, the increase is about 30.83% and 23.39 for 20% to 30% and 30% to 40% respectively. The average stress for CFRP is 12125 MPa and for GFRP is 11695.33 MPa. In the case of the compression test, the material has shown similar kinds of results compare to the tensile test and the composite is behaving similarly. The increase in value of Modulus of elasticity can be seen from Fig.11. Overall 27.27% hike is observed from the average compressive strength of the CFRP and a 23.51% hike is gained from the GFRP. The increase in compressive strength due to the increase in CF percentage for the composite is 43.60% from 20% to 30% and 24.94% from 30% to 40% respectively. The following composites used in the present study are having very high flexural strength, they can stand an immense amount of stress before going to get flex, our results show the same in Fig.12. Fig.15 and Fig.18 show the variation of stress to the strain of CFRP and GFRP in Flexural testing. The Figure shows the slow decrement in the strain value for the increase in fiber percentage but the stress value is increasing drastically which explains the composite is having high ultimate tensile strength which helps materials withstanding more stress than its yield limit. The composite having the 40% CF and 40% GF composition has the most excellent mechanical properties from the 18 specimens we have examined on the ANSYS software in the Static Structural model. The 40% CFRP has the 146.77% more Flexural modulus than GFRP. The experimental result shows a 43.55% increase in strength of the composite by increasing the Carbon Fiber percentage in CFRP by 20% to 30% and 24.98% for 30% to 40%. Similarly, for GFRP, it increases by 30.66% for 20 to 30% and 23.38% for 30 to 40%. Both the specimens showed more mechanical strength than the predicted strength. The increase in their strength is mainly due to the increase in fiber count as well as the stable fiber angle orientation pattern which helps the material when the load is applied to it.

## VI. CONCLUSION

An extensive experimental investigation of the effect of Fiber percentage at a fixed fiber angle orientation has confirmed that the Tensile, Compression, and Flexural strength depends upon the aforementioned parameters. In the investigation we made specimens having different Fiber percentage compositions with the polyether ether ketone (Peek). The higher the fiber percentage is present in a composite; its strength is becoming high. It is because of the High strength of the long fibers of carbon and glass. Nearly, 40% increase in strength is observed in each specimen after increasing the fiber percentage to only 10%. Fiber angle orientation also helped us in increasing the strength of the laminate. In our case, it helped to reduce the loads in the center and dividing them in each direction of the laminate equally. The stacking sequence of lamina helped in reducing the early stress on the laminate.
The compendium of this study is a step forward in the field of materials to design and analyze the composite materials by keeping in mind the aspect of failures. The excerpt of the findings can be utilized for research purposes.

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