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Implementation of Light Weight Carbon Composite Driveshaft for A Light Commercial Vehicle

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Abstract

The automotive drive shaft is a crucial component for power and torque transmission in vehicles, with a tubular shape that spins due to engine power. The current drive shaft is made of heavy-duty mild steel, increasing the vehicle's weight and fuel consumption. To reduce the weight, a composite material called carbon fiber was used. Carbon fiber showed better performance in driveshaft operation, and its properties were evaluated using universal testing machines and simulation software. The shear stress inside the drive shaft for mild steel and carbon fiber was found to be 3.2146 E+10 Pascal and 1.6254 E+10 Pascal, respectively. The torsion behavior of the prepared sample specimen showed a higher torque carrying capacity than the existing drive shaft, with a mass reduction of 77%. This suggests carbon fiber as an alternative material for drive shaft applications.

Highlights: *• Carbon fiber showed better performance in driveshaft operation. • Hand layup method is cheapest method for making composite material. • The main purpose of composite materials used in the automotive industry is weight reduction with better material properties. • Mild steel propeller shaft has more weight. • A bidirectional carbon fiber sheet is used to make a propeller shaft with the help of resins.*

Keywords: Fibers, Composites, Resins, Materials, and Mechanical Properties

INTRODUCTION

An automobile enterprise makes use of composites use of the interior and exteriors purpose like vehicle body, frame, engine block, clutch plate, transmission system, driveshaft etc. So, the composite materials used major role for automobile applications [1]. A quick advancement in engineering technology forced scientists and engineers to a point where they could no longer push past the limitations of the traditional materials to satisfy the needs of the designers [2]. The materials were unable to meet the demands of the designers since the technology's limitations were being stretched. In the field of materials technology, scientists are continually seeking a way to develop more robust, long-lasting materials that will meet the demands of their fellow engineers [2]. One of the most popular solutions to this issue in this industry is composite materials. Compromise solutions and alternatives are now being offered by composite materials in several engineering sectors [1, 3].

In comparison to its matrix, carbon fiber reinforced ceramic matrix/polymer composites offer superior physical-mechanical characteristics for their specific strength, high hardness, and exceptional fracture toughness. Additionally, they exhibit remarkable heat resistance, fracture resistance, ablation resistance, dimension stability,

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and wear resistance. The most popular ones are composite materials with a polymeric matrix and fiber reinforcements because of their high mechanical properties and lightweight [4]. When the relationship between mechanical qualities and weight significantly impacts the product's maintenance costs, these materials take the place of others (primarily metallic ones). Besides, it is possible to classify structural composite materials into sandwich structures and monolithic structures. Layers and a core make up sandwich constructions. They increase mechanical properties without appreciably adding to weight [5, 6]. They also improve thermal and acoustic insulation. Monolithic structures are components with intricate geometry created by layering fabrics in certain orientations to achieve particular properties. These qualities are designed to withstand the heaviest structural loads.

A drive shaft is a mechanical part that transmits rotation and torque. It is sometimes referred to as a cardan shaft or a propeller shaft. It is frequently used to attach other drive train parts that cannot be coupled directly due to their locations or the need for relative movement between them. Drive shafts are frequently composed of steel and are shaped like tubes. Drive shafts are used for the transmission of torque. They experience shear and torsion stresses equal to the discrepancy between the applied torque and the load. They must thus be sturdy enough to handle the pressure without adding too much weight, which would increase their inertia.

To move the car forward and backward, the torque generated by the engine and gearbox needs to be transferred to the back wheels. The drive shaft must ensure that the axles get a constant, steady flow of power. The driving shaft and differential convey this torque. The drive shaft is crucial for the vehicle's seamless and minimal power loss transmission from the gearbox to the final drive. The current drive shaft is made of soft steel with a big thickness and poor twisting characteristics, which affects the overall performance of the transmission system. So, the determination of the elective fabric for the drive shaft is exceptionally critical whereas creating any vehicle because its straight forwardly influences the effectiveness of the transmission work.

The selected material should have good structural characteristics in order to withstand the fluctuating load from the engine it possesses torque load which creates turbulences inside the material. By the literature papers the carbon epoxy material is selected for alternative composite materials for drive shaft applications which have low density as well as good structural characteristics when compared to the incumbent mild steel [7].

Because of their distinct physical and chemical characteristics, carbon materials are used as electrode and reinforcing materials. Fabricate the carbon composite fiber material with the hand layup method by applying epoxy resins [8, 16], Test the carbon composite fiber's mechanical behavior when the fabrication is finished, then compare the results with those of base materials. At that time, for more accuracy in the findings, we should use the ACP device to examine the flexural quality of the fiber fabric in the reenactment computer program. Finally, to conclude with the finest comes about.

MATERIALS AND METHODS

Carbon Fiber Material

Fig 2.1.1 shows us bi-directional carbon fiber cloth is cut into the necessary number of layers and placed on the mold's exterior. Thickness of each layer is 0.25 mm.

Open Mold

Fig 2.2.1 represented Hand layup method is the most seasoned strategy of woven composite fabricating. The samples are arranged by regarding some steps. At to begin with the shape surface is connected by wax to dodge the staying of the fiber to the surface.

Epoxy Resin and Hardener

The reinforcement that is already set up in the mold is coated with resin after being combined with hardener in a 9:1 ratio as shown in Fig 2.3.1. The mixture is spread evenly across the mold's surface.

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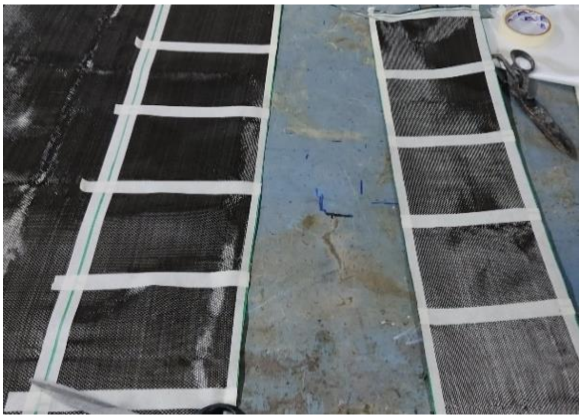

Figure 2.1.1: Carbon Sheet Material

Figure 2.2.1.: Open Mold

Figure 2.3.1: Resins and Hardener for Reinforcement Carbon Fiber.

Hand Layup Method

To achieve a smooth surface on the product, a thin plastic sheet is positioned at the top and bottom of the mold plate. Resin was applied to each layer and the pressure also applied each layer by the roller, which helps to remove the vacuum between the layers. The mold was closed, and a 5-kg load was applied throughout the surface of the lamination for 30 hours as shown in Fig 2.4.1. The mold was opened after room temperature curing and finally, the carbon fiber material was removed from the mold surface [9].

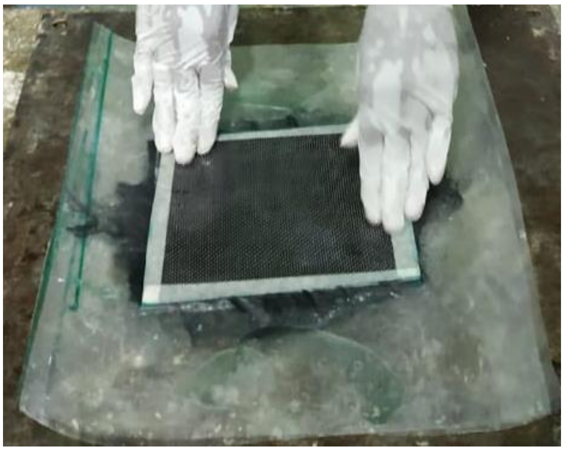

Fig. 2.4.1: Hand Layup.

Fig. 2.5.1. Fabricating of Drive Shaft.

Fig. 2.5.2. Final Shape of Drive Shaft.

Fabrication Of Carbon Fiber Drive Shaft (Test Sample Specimen)

Fig 2.5.1 & Fig 2.5.2 represented us the carbon fiber composite drive shaft is manufactured by hand layup method. As a mandrel, a 400 mm long, 10 mm diameter PVC pipe was employed. After cleaning the mandrel surface, a releasing agent (wax) is manually applied to the mandrel for a smooth surface on the product. Apply the epoxy resin-hardener mixture shown in “Fig. 2.5.1” in the ratio of 10:1. The layers of the shaft are oriented at 0 and 90 degrees with respect to the mandrel axis. Each layer has a thickness of 0.25 mm. so they need 12 layers of carbon fiber to make the composite drive shaft. After all, 12 layers have been wound; the mandrel is placed at room temperature for 48 hours. The shaft is cleaned on the inner surface with sandpaper, and the surface is cleaned with acetone as a degreasing agent [9].

EXPERIMENTAL SETUP

Tensile Testing of Carbon Fiber

The carbon fiber test specimen was 280 mm long, 25 mm wide, and 3 mm thick, in accordance with ASTM criteria, as illustrated in Fig. 3.1.1. The carbon fiber specimen had grasping zones at both ends and measurement zones in the middle for monitoring the specimen's deformation. The amount of the central zone measured 180 mm, while the gripping zone was 50 mm. In order to prevent slippage between the test specimens and the UTM's clamping grips during the tensile test and to ensure that the test specimens' failure occurred in the center zone, aluminum tabs were used in the test specimens' gripping zone [10].

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Fig. 3.1.1. Tensile Testing Rig for Composites.

Fig. 3.2.1. Three Point Flexural Test Rig.

Flexural Test Rig

The three-point bending flexural test yields data on the material's flexural stress, strain, and stress-strain response. It has employed to determine this composite material's bending strength. Flexural tests are carried out by UTM as shown in Fig 3.2.1. In this instance, the specimen is positioned bench side, and force will be applied to the specimen's center until it fractures [11].

Torsion Test of Carbon Fiber

With help of Fig 3.3.1 the torsion test is used to examine the carbon fiber material's behavior under shear stress and strain. The sample was evaluated by comparing the twist angle to the torque at rupture. On the tensional testing equipment, the shaft was put to the test. One end of the shaft was fixed to stay immobile while torque was applied to the other end. The output findings indicated the maximum torque that the shaft could withstand and the largest angle of twist before rupture. The maximum torque recorded on the carbon fiber is 75 Nm at 280 degrees [12].

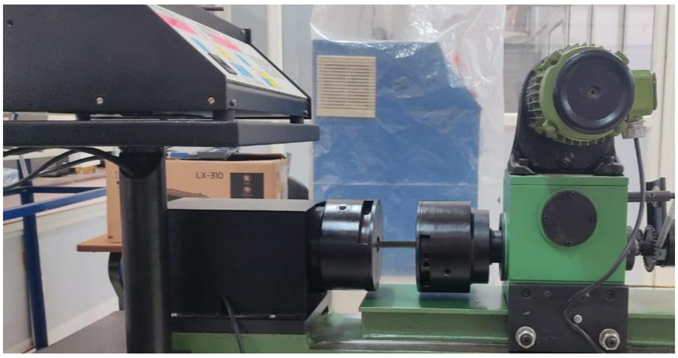

Fig. 3.3.1. Torsion Test Machine.

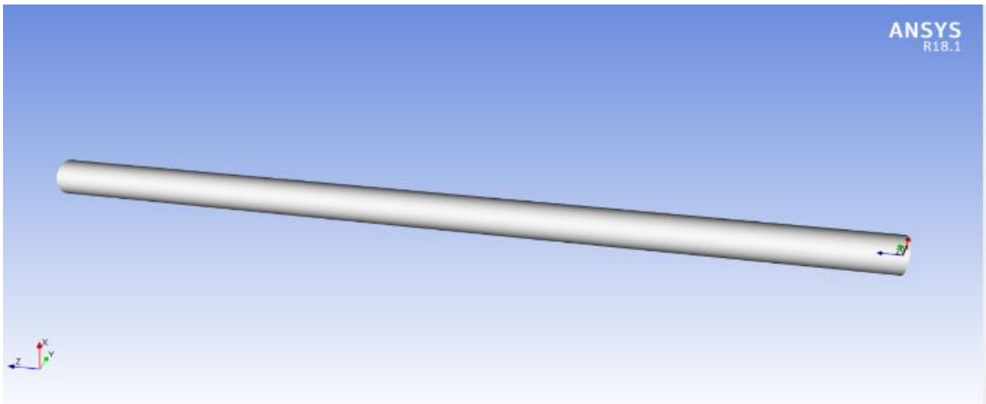

Fig. 3.4.1. Propeller shaft.

ACP Model

In this Ansys of composite precast (ACP), the composite material is made by layering multiple materials, each with a particular set of features. Standards for sturdy yet lightweight items have been established using these materials. Composites are sufficiently flexible to make it simple to create objects with complex shapes, such as boat hulls and surfboards. The design and modeling of a sample specimen of a driveshaft with carbon fiber are done by using the ANSYS workbench with ACP and static structural tools [13, 14, 15]. Initially, the shaft was created using the ACP model with a length of 200 mm as shown in Fig 3.4.1.

The length, outer diameter and inner diameter of the sample drive shaft are 200 mm, 13 mm and 10 mm respectively. With these details, the surface is imported into the ACP tool, and the following steps are taken to create the carbon fiber drive shaft. Using fabrics, a single layer of carbon fiber is created that is about 0.5 mm thick. The driving shaft has a thickness of 3 mm. Therefore, six layers of carbon fiber are required to achieve the drive shaft's 3 mm thickness 4.

RESULTS AND DISCUSSION

Tensile Strength Testing

A universal testing instrument controlled by a computer was used to inspect the materials. Its machine capacity is 100 kN. With the use of a digital vernier caliper, the thickness of each piece of equipment was measured. This test sample was modified to meet the proportions of the specimens and fitted to the UTM's mouth for the best possible grip as shown in Fig 4.1.1. After receiving measured dimensions, the material testing machine ran the tested materials until they failed. The measured data was automatically put onto a spreadsheet by the machine. The force at peak, the force at yield, the force at break, etc. were a few of the indicators that were measured. The goal of the testing apparatus was to identify the stress-strain curves of the materials being examined. These were used to evaluate the mechanical properties of the materials under consideration.

A simple uniaxial test comprises gradually increasing the amount of stress on a material specimen until it snaps. The tensile test was primarily used for engineering applications, among other things.

Graph 4.1.2 Represented us the tensile behavior of the carbon composite fiber material is depicted in this graph. As can be observed, up to a stress value of 281 MPa, Hooke's law was applied. According to this law, the relationship between a material's stress and strain is a direct one. Therefore, the yield strength of the carbon fiber can be taken as 287 MPa. The fiber was broken at 39700 N forces with a stress value of 332 MPa. Therefore, the ultimate strength of the carbon fiber can be taken as 332 MPa as shown in Table 4.1.3.

Flexural Strength Testing

Under a deflection or bending strain, the synthetic biomaterial's flexural strength was assessed using test specimen was 280 mm length, 25 mm width, and 3 mm thickness by ASTM standard by help of Fig 4.2.1. An appropriate universal testing device was used for this test and a three-point bend fixture with a rate corresponding to the specimen sample's depth.

Fig. 4.1.1. Tensile Test Specimen.

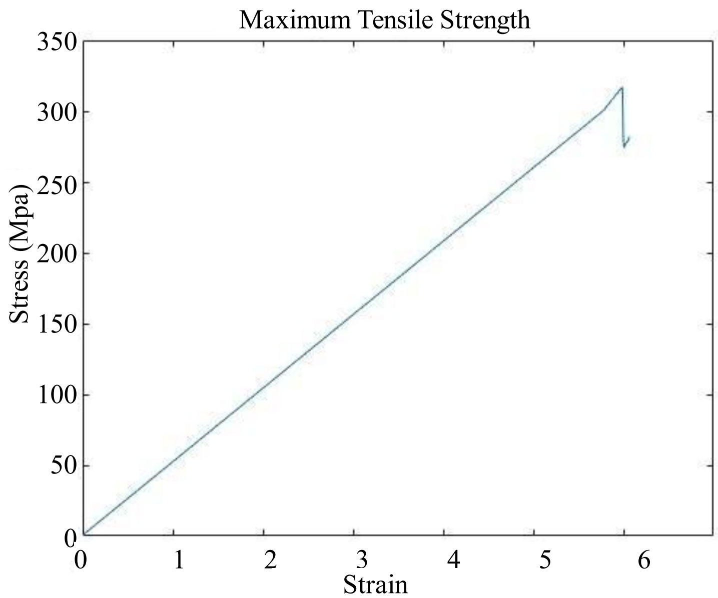

Fig. 4.1.2. Carbon Fiber Stress Strain Curve.

Table 4.1.3. Tensile Strength of Carbon Fiber.

Specimen	Ultimate Tensile Strength MPa	Yield Strength MPa	Breaking Point MPa
Carbon Fiber	332	287	254

Fig. 4.2.1. Flexural Test Specimen.

This Graph 4.2.2 shows the flexural behavior of the carbon fiber material. It can be seen that the material had sustained up to the load value of 839 N, which was induced at a maximum stress of 435 MPa. At peak load, strain is also increased, and stress is decreased. After that, the material was broken, so that the flexural strength or bending strength of the material can be taken as 435 MPa.

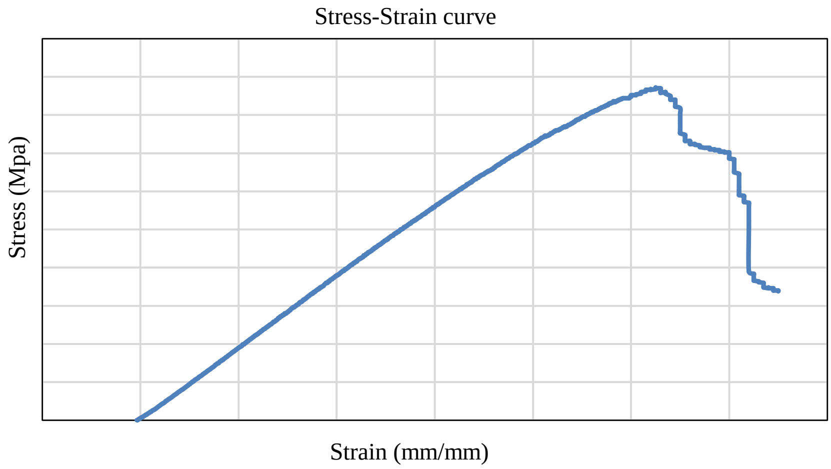

Fig. 4.2.2. Flexural strength of Carbon Material.

Table 4.3.1. Mechanical Properties of Carbon Fiber Material.

Properties	**Carbon Fiber**
Density(kg/m^3)	1490
Tensile Ultimate Strength (Mpa)	332
Tensile Yield Strength (Mpa)	281
Bending strength (Mpa)	435
Young’s Modulus (Gpa)	178
Poisson’s Ratio	0.3

This graph shows the flexural behavior of the carbon fiber material. It can be seen that the material had sustained up to the load value of 839 N, which was induced at a maximum stress of 435 MPa. At peak load, strain is also increased, and stress is decreased. After that, the material was broken, so the flexural strength or bending strength of the material can be taken as 435 MPa.

Input Data

Material Properties

Experimental Static Structural Values

Calculating Shear Stress and Strain Using Well-Known Equations are given below.

$$\frac{\tau}{r} = \frac{G\theta}{L} \tag{1}$$

$$G = \frac{\tau}{\gamma} \tag{2}$$

τ = Shear stress

γ = Shear strain

r = Radius of the outer diameter of shaft

G = Modulus of rigidity

Θ = Angle of twist

L = Length of the shaft

Variation of Shear Stress

The Graph 4.2.3 demonstrates how, at a torque value of 20 Nm in the torsion testing machine, shear stress is generated inside the shaft material. Here, we see that the stress developed in the carbon composite fiber material has lower than the existing mild steel material. On comparing this performance of the experimental values of shear stress of the mild steel and carbon composite drive shafts, they are 4.254E+10 Pascal and 2.431E+10 Pa, respectively. The carbon epoxy drive shaft the stress value is 42% lower than the mild steel drive shaft.

Variation of Shear Strain

The Graph 4.2.4 demonstrates how, when a force of 20 Nm was applied in a torsion testing machine, shear strain formed within the shaft material. Here see that the strain developed in the carbon composite fiber has lower than the existing material. On comparing this performance of the experimental values of shear stress of the mild steel and carbon composite drive shaftsis 0.55246 and 0.3575. The shear strain developed in the drive shaft with carbon epoxy is 39% lower than mild steel.

FEA Based Static Structural Analysis

In this study, shear stress and shear strain were calculated using the FEA-based Ansys analytical tool to analyze the structural behavior of the carbon composite material in drive shaft applications. The drive shaft sample specimen utilized for this research is 200 mm long, with a big diameter of 13 mm and a small diameter of 10 mm. The opposite end of this shaft, which generates a 20 Nm torque, has a fixed end.

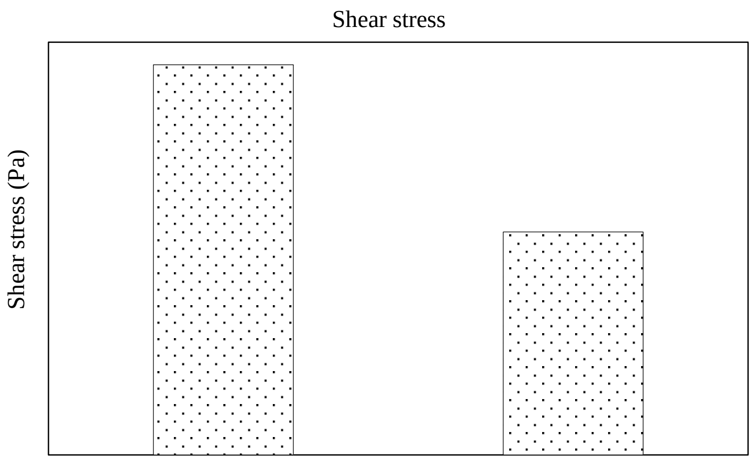

Fig. 4.2.3. Comparisons of Shear Stress for Mild Steel and Carbon Fiber Composites.

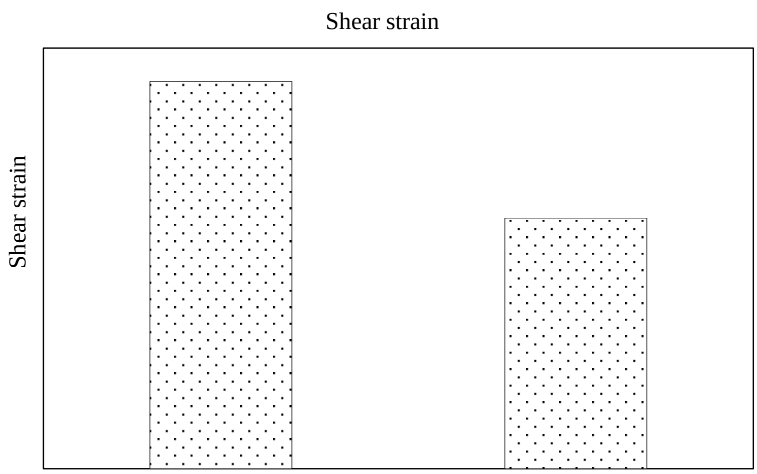

Fig. 4.2.4. Comparisons of Shear Strain for Mild Steel and Carbon Fiber Composites.

Shear Stress of Carbon fiber Drive Shaft

Fig 4.3.2 represented us carbon fiber's maximum shear stress is calculated to be 1.6254 e10 Pa and its minimum shear stress to be 1.4531 e6 Pa, respectively.

Shear Strain of Carbon Fiber Drive Shaft

The findings of calculating the carbon fiber's higher shear strain reveal that the highest and lower shear stresses are, respectively, 0.20451 and 0.000018284 with help of Fig 4.3.3.

Shear Stress of Mild Steel Drive Shaft

Calculating the maximum and minimum shear stresses for mild steel yields values of 3.2146 Pa and 2.8739 Pa, respectively, for the maximum shear stress with help of Fig 4.3.4.

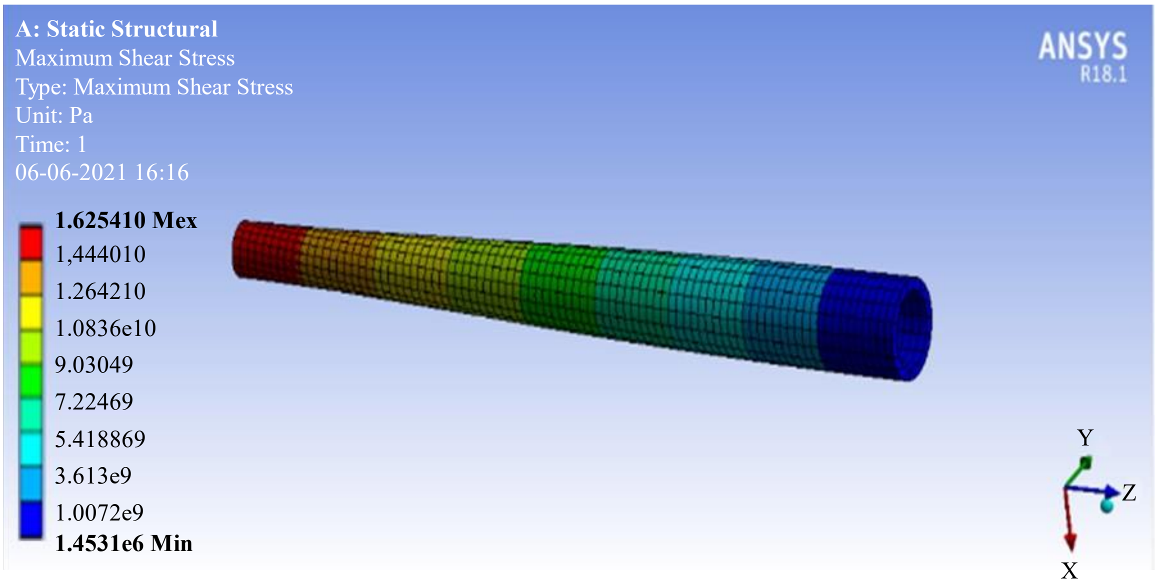

Fig. 4.3.2. Maximum and Minimum Shear Stress of carbon composite Fiber Drive Shaft

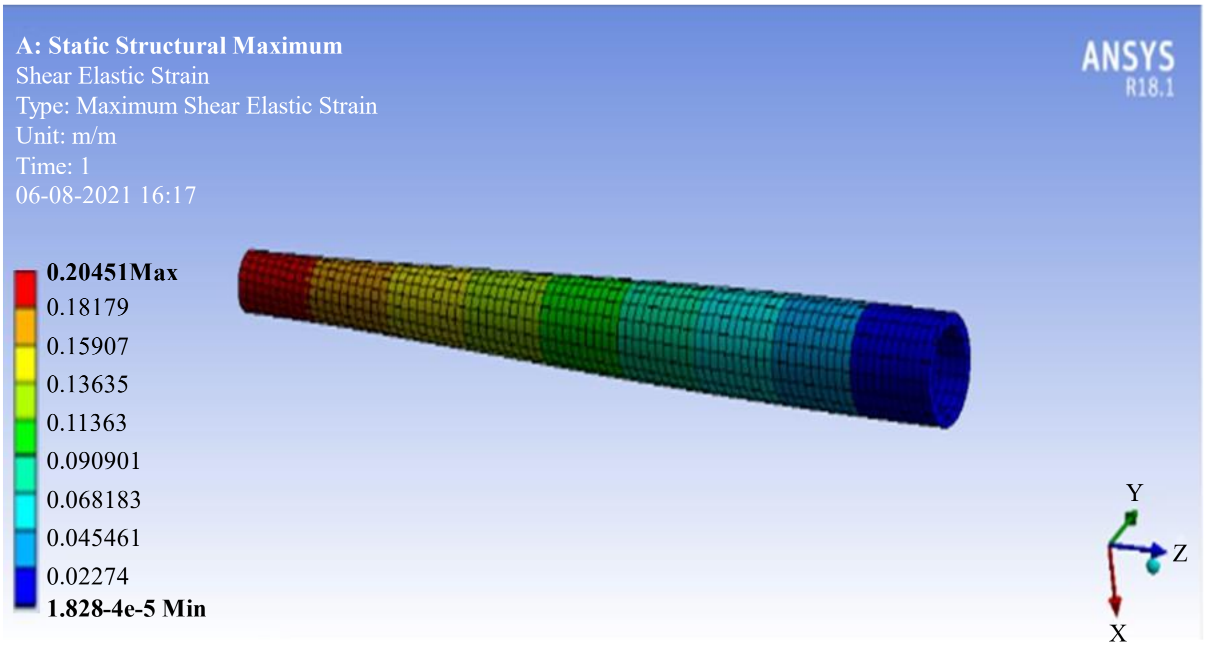

Fig. 4.3.3. Maximum and Minimum Shear Strain of carbon composite Fiber Drive Shaft.

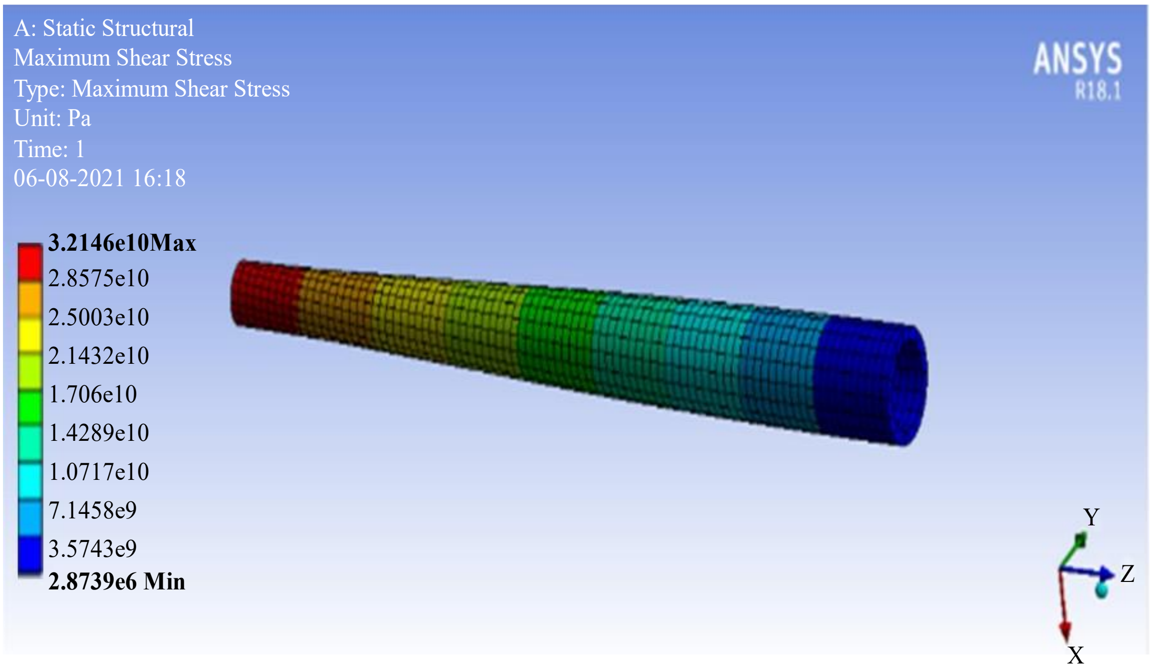

Fig. 4.3.4. Maximum and Minimum Shear Stress of Mild Steel Drive Shaft.

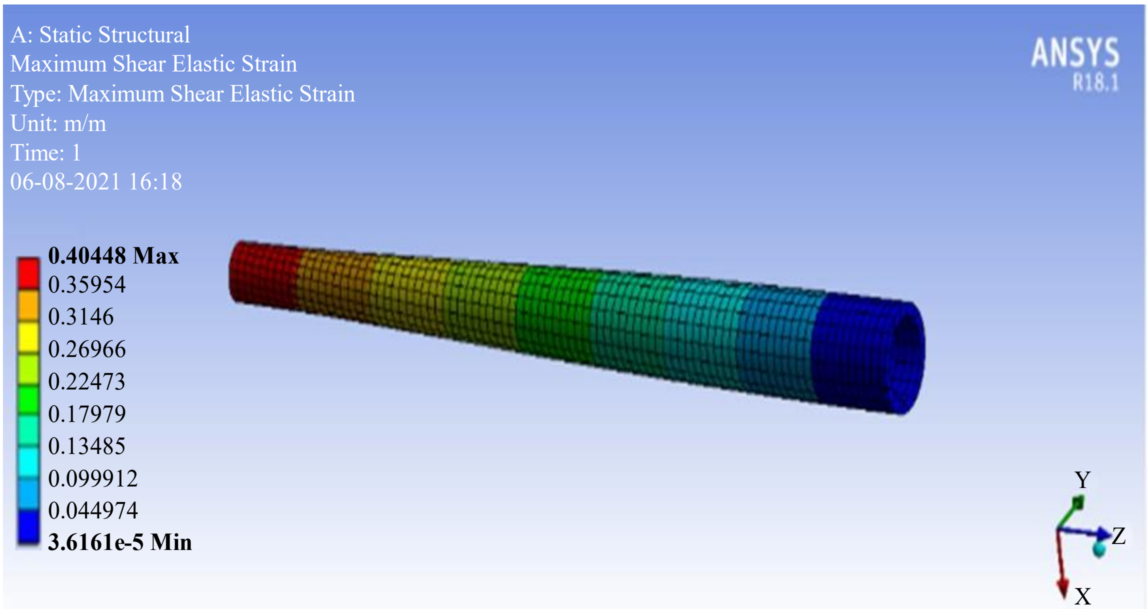

Fig. 4.3.5. Maximum and Minimum Shear Strain of Mild Steel Drive Shaft.

Table 4.3.6. Comparison of Maximum and Minimum Shear Stress and Shear Strain Value of Mild Steel and Carbon Fiber.

Material	Maximum shear stress (Pa)	Maximum shear strain (Pa)
Carbon fiber	1.6254e10	0.20451
Mild steel	3.2146e10	0.55246

Shear Strain of Mild Steel Drive Shaft

Calculating the mild steel's maximum shear strain yields maximum and minimum shear strain values of 0.40448 and 0.000036161, respectively by Fig 4.3.5.

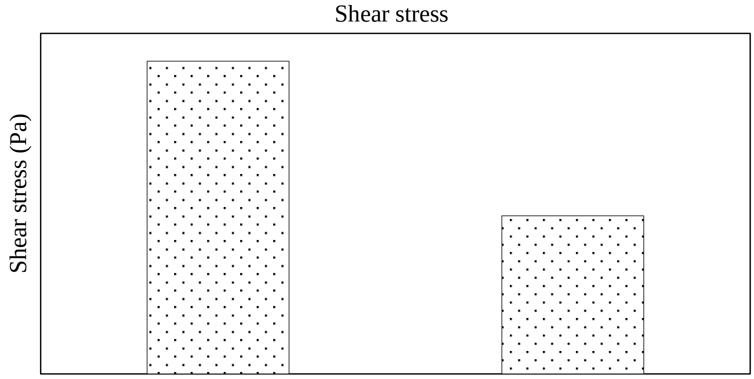

Fig.4.3.7. Shear Stress for Mild Steel and Carbon Fiber.

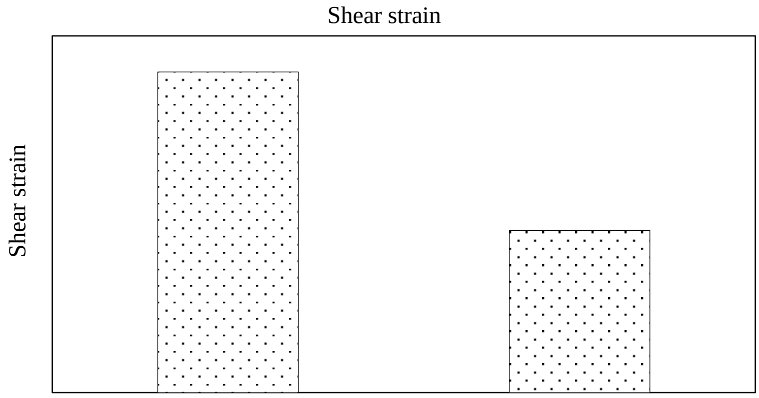

Fig. 4.3.8. Shear Strain for Mild Steel and Carbon Fiber.

Shear Stress Variation

The Table 4.3.6 represented us shear stress that affected the carbon epoxy and mild steel components can be seen in the above. It is evident that carbon epoxy performs better than mild steel. When steel and carbon epoxy were simulated, the carbon epoxy drive shaft experienced a shear stress of 1.6254E+10 Pascal, while mild steel experienced a shear stress of 3.2416E+10 Pascal. The stress value of the carbon epoxy drive shaft is 36% lower than that of the mild steel drive shaft has shown in Fig 4.3.7.

Shear Strain Variation

The Fig 4.3.8 shown us drive shaft's shear strain is shown in the figure above for the materials composed of mild steel and carbon epoxy. It is an evident that carbon epoxy performs better than mild steel. When mild steel and carbon epoxy simulation results are compared, the shear strain created in the carbon epoxy drive shaft is 0.20451, while the shear strain developed in the mild steel drive shaft is 0.40448. The strain on the carbon epoxy drive shaft is 34% less than that on the mild steel drive shaft.

COMPARISON OF FEA AND EXPERIMENTAL RESULTS

Comparison of Shear Stress

This Graph 4.3.9 compares the drive shaft's shear stress development between experimental and analytical results. According to simulation research, the drive shaft with mild steel experienced 3.2146E+10 Pascal of stress, while actual testing revealed 4.254E+10 Pascal. According to simulation study and testing, the drive shaft stress in carbon fiber was 1.6254E+10 Pascal and 2.431E+10 Pascal, respectively. The shear stress of mild steel and carbon fiber in the experimental value is, respectively, 22% and 30% greater than that in the simulation value. Here see that the stress developed in the carbon fiber material was lower than the existing mild steel material.

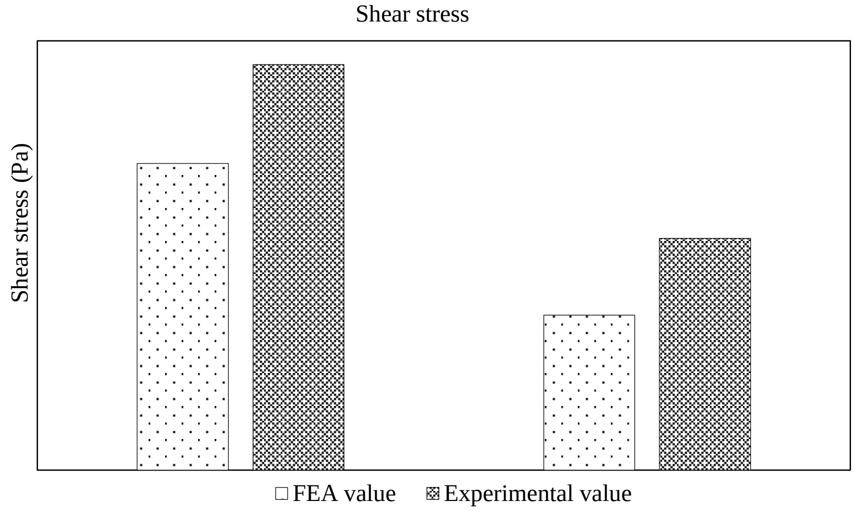

Fig. 4.3.9. Experimental Comparison of Shear Stress for Mild Steel and Carbon Fiber Material.

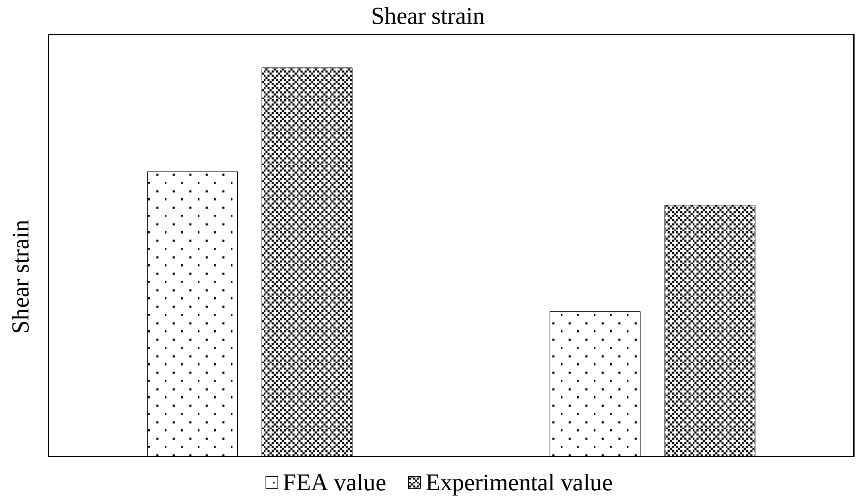

Fig. 4.3.10. Experimental Comparison Shear Strain for Mild Steel and Carbon Fiber Material.

Comparison of shear strain

The Graph 4.3.10 compares the shear strain that the drive shaft experienced based on analytical and experimental measurements. In the simulation study and the experiment, the drive shaft's strain created using mild steel was 0.40448 and 0.55246, respectively. In carbon fiber, the drive shaft's developed strain was 0.3575 in the experiment and 0.20451 in the simulation study. In experimental value, the shear strain of the mild steel and carbon fiber is, respectively, 26% and 34% higher than the simulation value. Here, we see that the strain developed in the carbon fiber material was lower than that of the existing mild steel material.

CONCLUSION

The hand layup method was used to prepare the carbon fiber sample specimen. The carbon fiber's qualities were assessed using the prepared samples. Using currently used conventional procedures; the carbon fiber's structural characteristics were assessed. Universal testing equipment was used to assess the material's flexural and tensile strengths. The torsion behavior of the identical test specimen was examined using simulation software for comparison purposes. The drive shaft sample specimen was created using carbon fiber and mild steel. The torsion behavior of the prepared test specimens was examined by a torsion testing machine. The performance of the existing mild steel and selected carbon fiber was compared both in simulation analysis and experimental analysis.

The torque carrying capacity of carbon fiber was found to be greater than that of mild steel, with values of 75 Nm and 63 Nm, respectively. So that the drive shaft made of carbon fiber can bear more load than mild steel. In simulation, the stress developed inside the shaft was 3.2146E+10 Pascal for mild steel and 1.6254E+10 Pascal for carbon fiber. In the experiment, the shear stress that developed inside the shaft was 4.254E + 10 Pascal for mild steel and 2.431E + 10 Pascal for carbon fiber. Then these drive shafts are made of mild steel and carbon fiber, and both weigh 1.81 kg and 0.45 kg, respectively. They have an 875 mm length, a 45 mm outer diameter, and a 40 mm inner diameter. A weight reduction of 77% is possible, which is helpful for vehicle performance. All of the aforementioned findings demonstrate that the chosen carbon fiber composite material is the best alternative material for drive shaft applications in the automotive sector.

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