

Design and Optimization of Drive Shaft with Different Composite Materials

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Abstract

This study investigates the torsional performance of a fully composite drive shaft manufactured using CFRP laminates with different, stacking sequences, and laminate thicknesses. The objective is to evaluate how fiber orientation and layup design influence the shaft's maximum static torsion capacity. A comprehensive finite element analysis (FEA) was conducted in ANSYS Workbench, modeling the CFRP structure as an orthotropic laminate to accurately capture directional stiffness and shear behavior. The result shows that torsional performance is highly sensitive to laminate configuration, with $\pm 45^\circ$ fiber orientations delivering the highest shear strength and torque-carrying capability. Increasing the number of CFRP layers further enhances stiffness while maintaining a low structural mass. Comparative analysis confirms that CFRP shafts outperform traditional metal-based and hybrid aluminum/composite shafts in both strength-to-weight ratio and static torsional capacity. These findings demonstrate that optimized hybrid construction significantly enhances torsional performance compared to conventional shafts, making it a viable candidate for lightweight, high-strength power transmission systems.

Keywords: Drive shaft, Ansys, Composite materials

1. Introduction

A drive shaft is a mechanical device for transferring power from the engine or motor to the point where useful work is applied. Most engines or motors deliver power as torque through rotary motion. This is extracted from the linear motion of pistons in a reciprocating engine. From the point of delivery, the components of power transmission from the drive train. The drive shafts are carriers of torque which are subject to torsion and shear stress, which represents the difference between the input force and the load. They thus need to be strong enough to bear the stress, without imposing too great an additional inertia by virtue of the weight of the shaft.

1.1 Purpose of Drive Shaft

The torque generated by the engine and transmitted through the gearbox must be delivered to the rear wheels to propel the vehicle forward or backward. This task is accomplished by the drive shaft, which ensures a smooth and continuous transfer of power to the axles. Together, the drive shaft and differential play a crucial role in delivering this torque efficiently.

1. Transmitting torque from the transmission to the differential gear box.
2. Handling maximum torque produced by the engine, particularly at low gears during acceleration.
3. Operating at high rotational speeds required by the vehicle's performance demands.

4. Accommodating varying operating angles between the transmission, differential, and axles. As the vehicle encounters road irregularities, the differential and axles move vertically, causing continuous changes in alignment.

1.2 Drive shaft arrangement in automobile

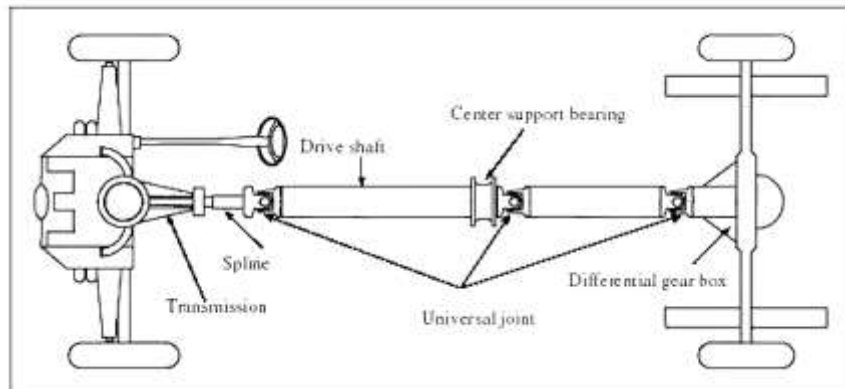


Figure 1: Two piece drive shaft arrangement in automobile

2. Literature Review

This section presents a comprehensive survey of previous research conducted on composite drive shafts.

- Arun Ravi developed a high-strength carbon/epoxy hollow composite drive shaft using SolidWorks and ANSYS, achieving about 24% weight reduction compared to steel shafts.
- Sagar Dharmadhikari analyzed composite drive shafts using Genetic Algorithm and ANSYS, showing that fiber orientation significantly affects shaft deflection and performance.
- V. S. Bhajantri performed modal analysis on carbon/epoxy composite shafts and reported nearly 50% weight savings compared to conventional steel shafts.
- Harshal Bankar studied different composite materials and stacking sequences, concluding that proper layer arrangement reduces stress and shaft weight.
- Dai Gil Lee designed a one-piece hybrid aluminum/composite drive shaft with an internal carbon/epoxy layer to improve impact resistance and reduce moisture absorption.
- T. Rangaswamy optimized one-piece automotive composite drive shafts using E-glass/epoxy and high modulus carbon/epoxy materials.
- Mahmood M. Shokrieh investigated the shear buckling behavior of composite drive shafts through analytical and finite element analysis methods.
- S. A. Mutasher studied the torsional strength of hybrid aluminum/composite shafts and examined the effects of winding angle, layer number, and stacking sequence.
- A. R. Abu Talib developed hybrid carbon/glass fiber epoxy drive shafts and analyzed their structural behavior using finite element analysis.
- M. A. Badie evaluated the influence of fiber orientation and stacking sequence on torsional stiffness, buckling resistance, fatigue life, and failure modes.
- Mohammad Reza Khoshnavan carried out design and modal analysis of automotive composite drive shafts to study vibration characteristics and structural performance.
- M. Arun and K. Somasundara Vinoth developed laminated aluminum–glass fiber drive shafts and found that increasing composite layers improves fatigue strength.

3.1 Problem Statement

The drive shaft is an important component used to transmit torque and rotational motion in automotive power transmission systems. Conventional steel drive shafts provide high strength but increase vehicle weight, which reduces fuel efficiency and overall performance. To overcome these limitations, light-weight composite materials such as carbon epoxy and E-glass epoxy are being considered due to their high strength-to-weight ratio, corrosion resistance, and fatigue strength.

This research focuses on the design and analysis of composite drive shafts using different material combinations and layer configurations. Finite Element Analysis (FEA) in ANSYS is used to evaluate stress, strain, deformation, and strength characteristics under static loading conditions. The results are compared with conventional steel shafts to determine the suitability of composite materials for automotive applications.

3.2 Objectives

1. To design and analyzed drive shaft with composite material which are glass fiber and CFRP.
2. To design and analyzed a composite drive shaft with different number of layers for an automobile.
3. To analyze the static torque capacity of the composite drive shaft for an automobile

4. Selection of Material

A composite material is formed by the combination of two or more distinct constituent materials, typically possessing significantly different physical and mechanical properties. These constituents work synergistically to impart enhanced and unique characteristics to the resulting composite.

1. GFRP

Glass Fiber Reinforced Polymer (GFRP) is chosen as the material for the drive shaft owing to its superior mechanical and physical properties. It exhibits a high strength-to-weight ratio, which contributes to reduced mass and improved fuel efficiency. Additionally, GFRP provides enhanced fatigue life and corrosion resistance compared to traditional metallic materials.

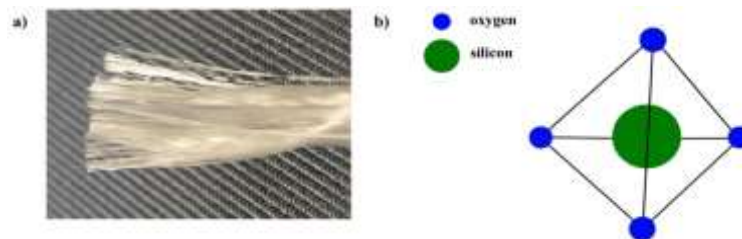


Figure 2: a) Bundle of glass fibers; b) Molecular Structure of Glass

2. Carbon epoxy

In this study, carbon fiber reinforced epoxy composite (carbon epoxy) is selected as the material for the drive shaft. This selection is primarily based on its outstanding mechanical properties, such as high specific strength and stiffness, which enable significant weight reduction compared to conventional materials like steel.

3. Structural Steel

In this study, **steel** is selected as the reference material for the drive shaft. The purpose of choosing steel is to establish a baseline for comparison with the composite materials, namely GFRP and carbon epoxy.

Table 1-Material Properties

Material	Steel	CFRP	GFRP
Modulus of Elasticity (GPa)	210	200	90
Poisson's Ratio	0.3	0.1	0.3
Modulus of Rigidity (GPa)	70	33	56
Density (Kg/m ³)	7830	1600	2000

This table indicates the properties of composite materials such as CFRP (carbon fiber reinforced plastic), GFRP (glass fiber reinforced plastic) and conventional steel. As per these properties the values are assigned for the analysis in the Ansys software.

5. Design and Modelling of Drive Shaft

In the design considerations, either a solid or a hollow circular shaft can be selected. For the present study, a hollow circular shaft has been chosen. This selection is based on the fact that hollow shafts exhibit a more uniform stress distribution across the cross-section, resulting in reduced stress variation compared to solid shafts.

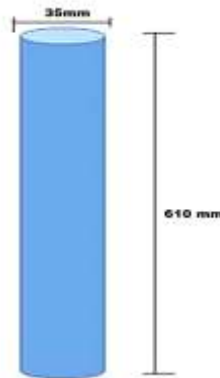


Figure 3: the rough sketch and 3D modeling figure of composite shaft

5.1 Dimensions of the propeller shaft

Length of the shaft : 610 mm

Mean radius of the shaft: 35 mm

Thickness of the hollow shaft : 4.578 mm (Carbon/epoxy shaft) : 5.110 mm (Glass/epoxy shaft)

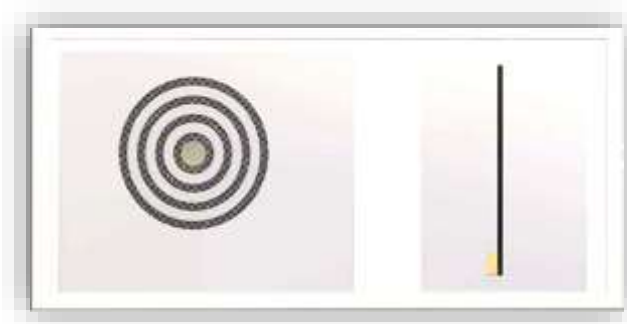


Figure 4: 3D Modeling

The 3D model has been developed and subsequently divided into multiple layers to represent the composite structure. In this model, the black regions correspond to the CFRP (Carbon Fiber Reinforced

Plastic) layers, while the white regions represent the GFRP (Glass Fiber Reinforced Plastic) layers. The respective thicknesses of each layer are specified in the above image.

6. Analysis of Drive shaft

The analysis of the drive shaft is carried out to evaluate the stresses, strains, and forces generated due to braking torque. In this study, static structural analysis is performed using ANSYS to determine the displacement, stress, strain, and force distribution within the shaft under applied loading conditions.



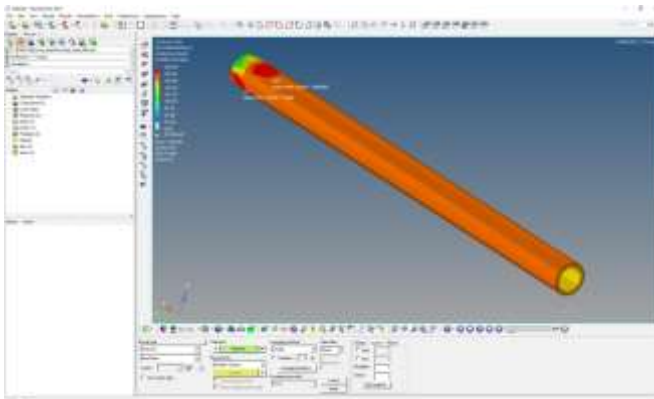
Figure 5: FEA model of the composite propeller shaft

6.1 Loads/Boundary Conditions

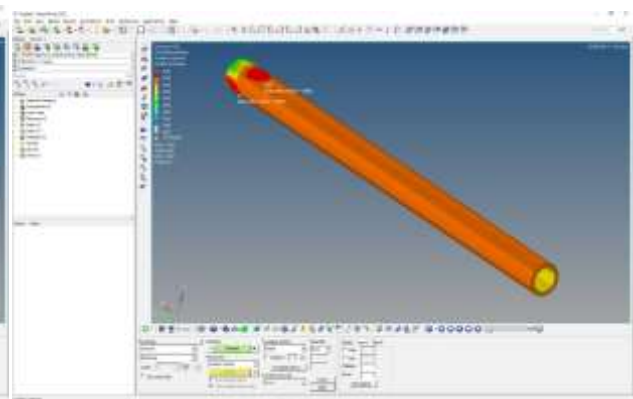
The gearbox is analyzed under maximum loading conditions, where the differential (wheel) movement is completely restrained. Three boundary conditions were applied during the analysis, with an applied moment of 900Nm-1300Nm acting on the shaft.

6.2 Results

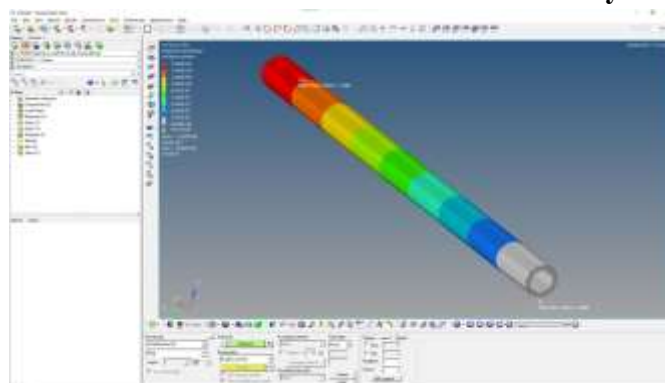
1. Results for Conventional Steel



Stress analysis of conventional steel

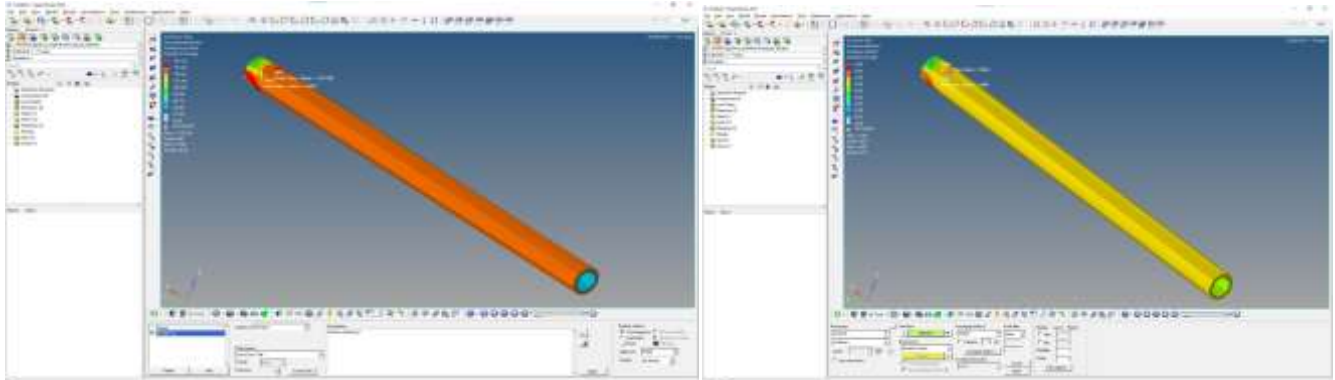


Strain analysis of conventional steel



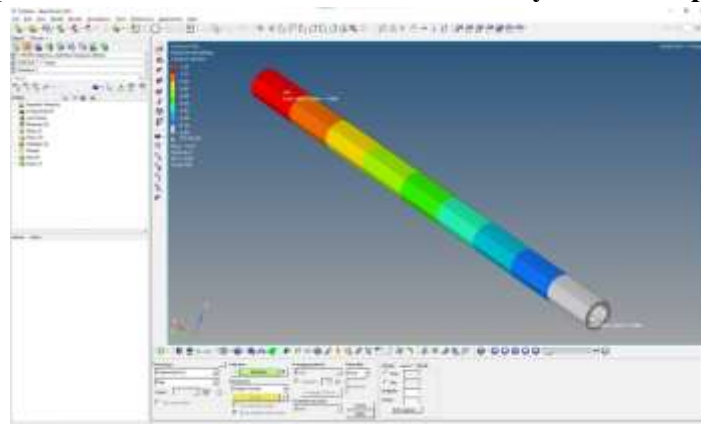
Deformation of conventional steel

2. Results for Composite structure



Stress analysis of Composite Structure

Strain analysis of Composite Structure



Deformation of Composite Structure

7. Results and Discussion

After the completion of the design and analysis, the obtained data were systematically evaluated to determine the final results of stress, strain, and deflection. The analyzed data were then presented in the form of tables and graphical representations for better interpretation.

7.1 Obtained Result

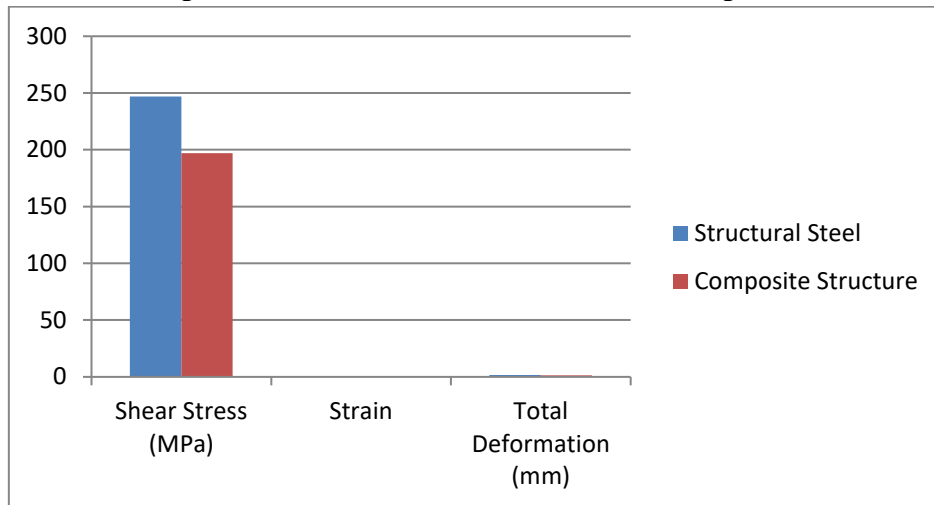
After assigning load to drive shaft and fixing the support, stress analysis is performed in ANSYS workbench and the following results were observed in chassis analysis.

Table 2-Table Obtained Result

Material	Torsional Strength T, (Nm)	Shear Stress (MPa)	Strain	Total Deformation (mm)
Structural Steel	1300	246.95	0.002	1.630
Composite Structure	900	197	0.002	1.246

From the above results, it is observed that the composite structure is having less shear stress than conventional steel. The drive shaft made by structural steel is having same strain i.e. 0.002 and different deformation.

Graph 1- Stress, strain & deformation Comparison



Conclusion

Static structural analysis was carried out to study the behavior of the shaft under steady loading conditions. The obtained results indicate that the composite material shafts exhibit higher strength and better performance compared to the conventional steel shaft. Based on the stress analysis and weight comparison, it is observed that the composite shafts are more efficient and suitable for replacing conventional steel shafts.

The following conclusions were drawn from the present study:

1. The weight of the composite material drive shaft is significantly lower than that of the conventional steel shaft.
2. The stress induced in the composite material shaft is lower compared to the conventional steel shaft.
3. Composite materials such as carbon epoxy and E-glass epoxy provide improved strength-to-weight ratio, making them suitable alternatives for conventional shaft materials.

Future scope

The present work on the analysis of composite drive shafts can be further extended in several directions to improve the performance, reliability, and efficiency of automotive transmission systems. The following points highlight the future scope of the study:

1. The study can be extended by considering different types of composite materials such as Kevlar fiber, boron fiber, and hybrid composites to evaluate their mechanical performance and weight reduction capabilities.
2. Further research can be carried out by optimizing the layer stacking sequence, fiber orientation angle, and number of layers to obtain maximum strength with minimum weight.
3. Dynamic and fatigue analysis of the composite drive shaft can be performed to investigate its behavior under cyclic loading and real-time operating conditions.
4. Experimental validation can be carried out to compare the analytical and simulation results with practical testing data for improved accuracy and reliability.

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