



# Design and Vibration Analysis of Hybrid Natural/Synthetic Fibre-Reinforced Composite Automotive Drive Shaft

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**ABSTRACT:** The growing demand for lightweight and sustainable automotive components has driven interest in composite materials as alternatives to conventional metallic drive shafts. This project focuses on the design and vibration analysis of a hybrid natural/synthetic fibre-reinforced composite automotive drive shaft. The proposed configuration consists of an aluminium core, externally reinforced with a combination of natural and synthetic fibres, achieving an optimal balance between strength, stiffness, weight reduction, and eco-friendliness. The hybrid structure enhances torsional rigidity while maintaining lower density compared to traditional steel shafts. Finite Element Analysis (FEA) is employed to evaluate structural behaviour, with emphasis on modal and vibration analysis to determine natural frequencies, critical speeds, and mode shapes. The study assesses the effectiveness of hybrid reinforcement in suppressing vibration amplitudes and improving dynamic stability while ensuring durability under operating loads. Outcomes demonstrate the potential of hybrid fibre-reinforced aluminium composite shafts as sustainable, high-performance alternatives in the automotive industry.

**KEYWORDS:** Hybrid Composite Drive Shaft, Natural Fibre Reinforcement, Synthetic Fibre, Aluminium Core, Finite Element Analysis, Modal Analysis, Vibration Analysis, Automotive Drivetrain.

## I. INTRODUCTION

The drive shaft is a critical component in automotive powertrain systems, responsible for transmitting torque from the engine or transmission to the differential with minimal loss and maximum structural integrity. Traditional drive shafts made from steel or aluminium alloys offer high strength but add significant weight to the vehicle, contributing to increased fuel consumption, reduced efficiency, and higher noise, vibration, and harshness (NVH) levels. With increasing demand for lightweight construction, improved dynamic performance, and sustainable materials, advanced composite materials are becoming viable alternatives [10] to conventional metallic shafts.

Composite drive shafts, especially those made from carbon, glass, or hybrid fibre systems, have demonstrated superior specific stiffness, higher critical speeds [3], and improved damping characteristics compared to metallic shafts. These properties allow composite shafts to operate at higher rotational speeds while reducing vibration transmission and improving overall vehicle NVH performance. Hybridization of natural fibres with synthetic fibres [10] has gained interest as an approach to balance mechanical performance, cost efficiency, and environmental sustainability. Natural fibres such as flax, jute [10], and hemp provide low density and inherent damping, while synthetic fibres such as glass or carbon contribute strength and stiffness. Combining them with a lightweight metallic core, such as aluminium, offers a promising hybrid structure with enhanced mechanical and vibration characteristics.

Despite this potential, the dynamic behaviour of hybrid natural/synthetic fibre-reinforced drive shafts, especially those incorporating a metallic core, remains insufficiently explored. [7] The interaction between multiple material phases, fibre orientations, and composite lay-ups introduces uncertainties in predicting natural frequencies, mode shapes, and critical speed behaviour. Accurate vibration and modal analysis is therefore essential to ensure structural safety, avoid resonance, and evaluate feasibility in real automotive environments. [1]

This research aims to design a hybrid composite drive shaft using an aluminium core reinforced with natural and synthetic fibres, and to investigate its dynamic behaviour through finite element-based modal and vibration analysis. The study focuses on evaluating weight reduction potential, improvement in natural frequencies, and vibration damping characteristics relative to conventional metallic shafts.



Fig.1. Drive shaft

## II. PROBLEM STATEMENT

- Conventional steel driveshafts add significant weight to vehicles, reducing fuel efficiency, raising emissions, and increasing noise and vibration, which affects ride comfort and lifespan. [2]
- Single-fiber composites have limitations, such as low strength in natural fibers and higher costs for synthetics. [10]
- Developing a lightweight, high-performance hybrid composite driveshaft with a natural-synthetic fiber blend around an aluminum core can overcome these drawbacks, making it essential to systematically design and analyze such shafts for sustainable automotive applications.

### OBJECTIVE

- To develop 3D CAD model using SOLIDWORKS and perform FEA analysis using ANSYS Workbench on a four-wheeler drive shaft using static loading.
- To reinforce synthetic fibres over natural fibres over aluminium core drive shaft for better performance and weight optimization.
- To perform torsional and vibration analysis of four-wheeler drive shaft using ANSYS Workbench.
- To perform modal analysis on the composite reinforced driveshaft.

## III. METHODOLOGY

The research methodology follows a systematic approach beginning with design and modeling of the existing conventional drive shaft and the proposed hybrid composite drive shaft. The entire process uses SOLIDWORKS for 3D CAD modeling and ANSYS Workbench for Finite Element Analysis. [3]

The first stage involves creating a detailed 3D CAD model of the existing drive shaft as a baseline for comparing performance of the new hybrid composite design. The geometry is accurately modeled with relevant dimensions typical of a four-wheeler automotive drive shaft. The material assigned is SM45C steel, with properties such as density, Young's modulus, Poisson's ratio, yield strength, and ultimate tensile strength defined in the ANSYS material library. Following baseline modeling, the hybrid composite reinforced drive shaft geometry is developed, consisting of an inner aluminium alloy core with multiple outer layers of composite reinforcement. The reinforcement comprises layers of natural sisal fibre and synthetic glass fibre applied over the aluminium core. Aluminium alloy material properties are assigned to the core, while orthotropic material properties of glass fibre and sisal fibre, including Young's modulus in different directions, shear modulus, and Poisson's ratio, are defined in the engineering data module.

Once both geometries are modeled and materials assigned, meshing is performed. The continuous geometry is divided into finite elements connected at nodes. A fine mesh is generated for both shafts to ensure accuracy, with mesh quality

checked using parameters such as element size, number of nodes, and number of elements. Finer mesh is used in areas where higher stress gradients are expected.

After meshing, boundary conditions and loading are applied to simulate real-world operating conditions. Three main types of analyses are performed on both shafts. First, static structural torsional test, where one end is fixed and a torsional moment is applied at the other end, evaluating torsional stiffness, total deformation, and equivalent stress distribution. Second, modal analysis determines natural frequencies and corresponding mode shapes for the first six modes, with the shaft supported at both ends, ensuring operating speed does not coincide with natural frequencies to avoid resonance. [1] Third, static structural bending test, where the shaft is supported at both ends and a transverse load is applied at the center, evaluating bending stiffness, total deformation, equivalent stress, and force reaction. Results from all three analyses are systematically compared to evaluate performance of the hybrid composite drive shaft relative to the conventional steel drive shaft.

**FINITE ELEMENT ANALYSIS:**

Finite Element Analysis (FEA) is a numerical simulation technique used to analyze behaviour of structures and components under different physical conditions such as loads, vibrations, temperature, and pressure. It helps predict stresses, deformation, strain, and dynamic characteristics before actual manufacturing or experimental testing. In FEA, a complex geometry is divided into smaller elements connected at nodes through meshing. Mathematical equations governing behaviour of each element are solved simultaneously to obtain an approximate solution for the entire structure. Accuracy depends on mesh quality, material properties, boundary conditions, and loading conditions. FEA is widely used in engineering design and research because it reduces repeated physical testing, saves development time, and improves design optimization.

**FEA OF EXISTING DRIVESHAFT:**

**Geometry:**

The geometry of the existing drive shaft is modeled as a hollow cylindrical shaft with dimensional accuracy representing a standard four-wheeler automotive drive shaft.

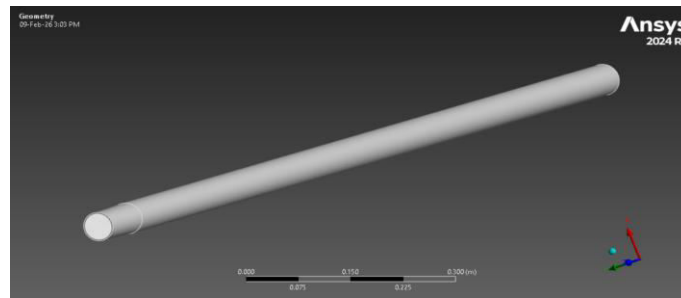
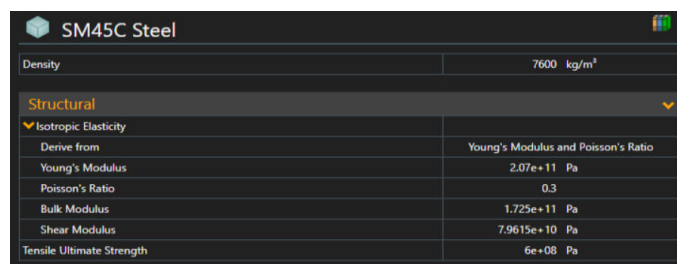


Fig.2.Geometry of Existing Driveshaft

**Material Properties:**

The existing drive shaft is made of SM45C steel. Material properties including density, Young's modulus, and Poisson's ratio are defined in the ANSYS engineering data module.



SM45C Steel	
Density	7600 kg/m <sup>3</sup>
<b>Structural</b>	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	2.07e+11 Pa
Poisson's Ratio	0.3
Bulk Modulus	1.725e+11 Pa
Shear Modulus	7.9615e+10 Pa
Tensile Ultimate Strength	6e+08 Pa

Fig.3. Material Properties of Existing Driveshaft

**Meshing:**

Meshing divides the geometry into a large number of small finite elements. Mesh details including number of nodes and elements are recorded.

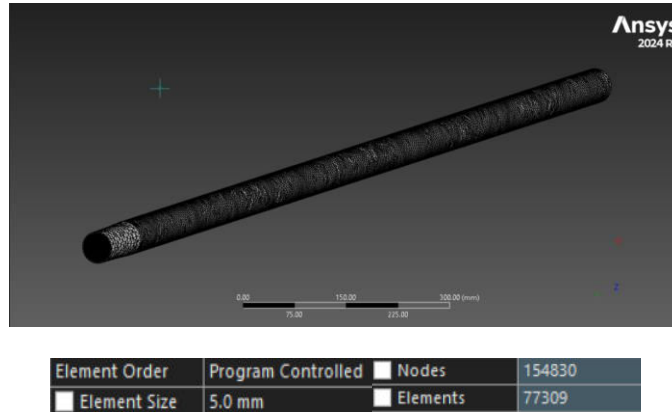


Fig.4. Meshing Details of Existing Driveshaft

**IV. RESULTS**

**Total Deformation:**

The total deformation contour plot shows maximum deformation experienced by the existing steel drive shaft under applied torsional load.

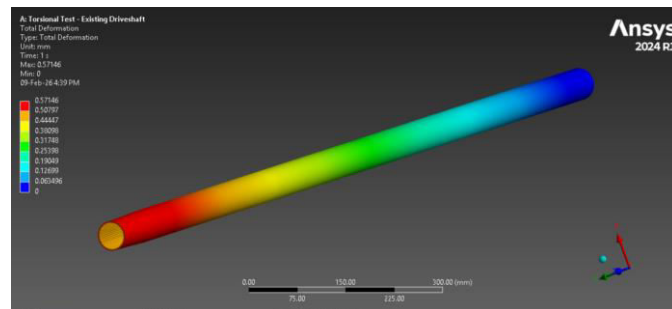


Fig.5.Total Deformation of Existing Driveshaft

**Equivalent Stress:**

Equivalent stress (von Mises stress) distribution is obtained from torsional analysis. Maximum equivalent stress value and location are identified.

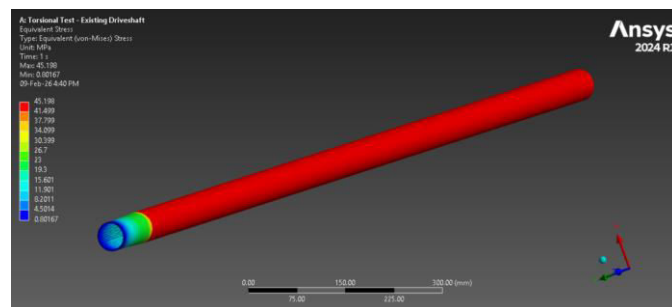


Fig.6. Equivalent Stress of Existing Driveshaft

#### FEA RESULTS:

Under torsional loading, the existing SM45C steel drive shaft exhibited a maximum total deformation of 0.57146 mm and a maximum equivalent stress of 45.198 MPa. In comparison, the hybrid drive shaft showed a higher deformation of 1.2183 mm, which is expected due to the lower shear modulus of composite materials. However, the maximum equivalent stress in the hybrid shaft was significantly lower at 33.061 MPa, indicating improved stress distribution and enhanced torsional load-carrying efficiency.

Modal analysis revealed that the steel drive shaft had higher natural frequencies across all modes, with the first mode occurring at approximately 94.45 Hz, while the hybrid drive shaft exhibited a slightly lower first natural frequency of approximately 86.74 Hz. [1] Although reduced, the natural frequencies of the hybrid shaft remain well above the minimum design requirement, ensuring safe operation away from resonance conditions. [3] The paired nature of mode shapes observed in both shafts confirms structural symmetry and consistent dynamic behavior.

In bending analysis, the conventional steel shaft experienced a maximum deformation of 5.0007 mm and a high equivalent stress of 361.91 MPa, approaching critical material limits. In contrast, the hybrid drive shaft showed comparable deformation of 5 mm but a substantially lower equivalent stress of 174.83 MPa, representing a reduction of more than 50%. Additionally, the maximum reaction force in the hybrid shaft of 1407.9 N was considerably lower than that of the steel shaft at 2929.5 N, indicating reduced load transmission to supports and improved vibration isolation.

#### V. MANUFACTURING OF THE COMPONENT

The manufacturing of the hybrid composite drive shaft was carried out in multiple stages involving machining, surface preparation, fibre reinforcement, [9] and curing processes. Initially, the aluminium shaft was prepared according to required dimensions using a turning operation on a lathe machine. The turning process ensured accurate outer diameter, proper surface finish, and dimensional uniformity along the shaft length. After machining, the aluminium surface was cleaned and prepared to improve bonding between the metallic surface and composite layers.



Fig.7. Aluminium shaft after machining

Following machining, reinforcement layers of sisal fibre and glass fibre were applied over the aluminium shaft. A suitable resin solution along with hardener was prepared and uniformly applied on the shaft surface. Sisal fibre layers were first wrapped around the aluminium shaft, followed by glass fibre reinforcement [9] to enhance strength and stiffness. Additional resin was applied between successive layers to ensure proper impregnation and bonding of fibres.



Fig.8. Reinforcement of Glass fibre and sisal fibre layers

After completion of the fibre wrapping process, the reinforced shaft was allowed to cure at room temperature for the required duration to achieve sufficient hardening and structural integrity. The cured specimen was then inspected visually for uniformity and proper bonding before being used for experimental testing and finite element validation.

## VI. EXPERIMENTAL TESTING

A Universal Testing Machine (UTM) [6] is a mechanical testing device used to determine strength and deformation characteristics of materials under different loading conditions such as tension, compression, and bending. It applies a gradually increasing load to a test specimen and measures corresponding deformation or displacement until failure occurs. The working principle of a UTM is based on controlled loading through a movable crosshead driven either mechanically or hydraulically. Applied load is measured using a load cell, while deformation is recorded using extensometers or displacement sensors. From the obtained load and deformation data, important mechanical properties such as tensile strength, yield strength, modulus of elasticity, flexural strength, and elongation can be determined. UTMs are widely used in material testing laboratories, research applications, and quality control processes because they provide accurate and reliable evaluation of material behavior under various loading conditions.

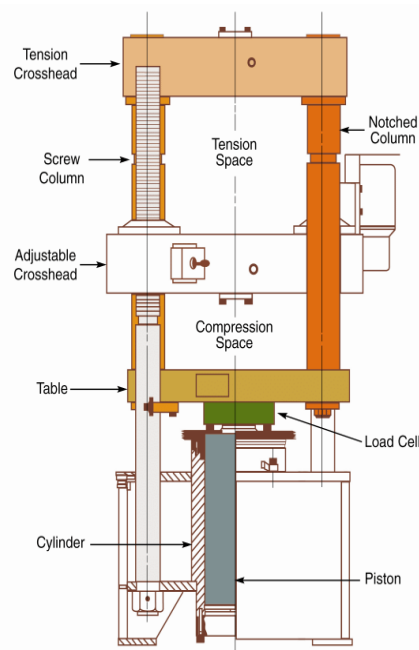


Fig.9. Schematic diagram of a UTM

**EXPERIMENTAL PROCEDURE**

The specimen was placed horizontally on the support rollers of the testing fixture with a specified span length between supports. A central loading arrangement was used to apply the load gradually at the midpoint of the specimen. The load was applied continuously at a constant crosshead speed until noticeable deformation or failure occurred. During the test, applied load and corresponding deformation were recorded automatically by the UTM. Maximum load, displacement, and bending behavior were observed and noted. After completion of the test, the specimen was examined for crack formation, delamination, or failure patterns. The obtained experimental results were then compared with finite element analysis results for validation of the numerical model.



Fig.10. Specimen under Flexural test using UTM

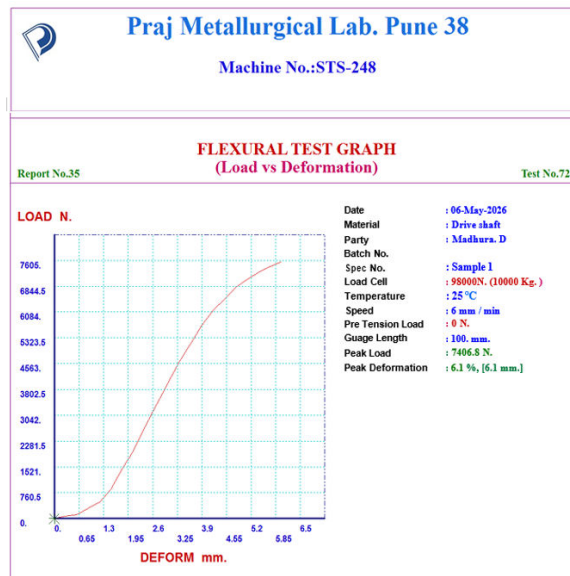


Fig.11. Flexural test graph of Specimen using UTM

**EXPERIMENTAL FEA:**

**Geometry:**

The geometry of the specimen used for experimental FEA is modeled to match dimensions of the physical test specimen.

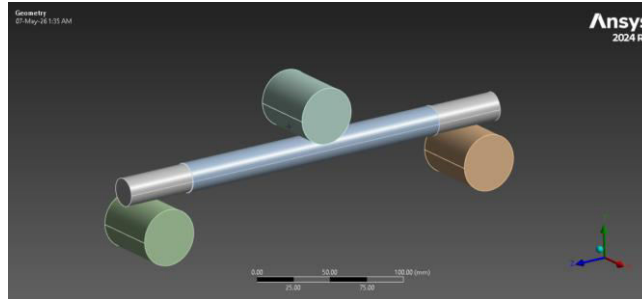
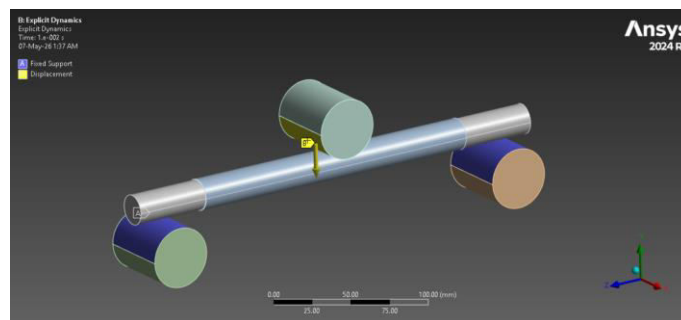


Fig.12. Geometry of specimen

**Boundary Conditions:**

Boundary conditions applied in experimental FEA replicate the support and loading conditions used in the physical flexural test.



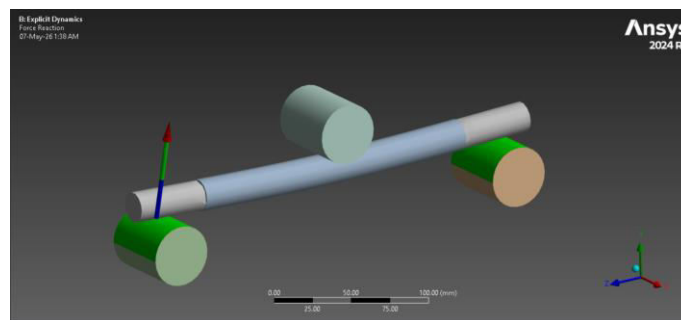
Type	Displacement
Define By	Components
Coordinate System	Global Coordinate System
X Component	0, mm (ramped)
Y Component	-6,1 mm (ramped)
Z Component	0, mm (ramped)

Fig.13. Boundary conditions on specimen

**Results:**

**Force Reaction:**

The force reaction obtained from experimental FEA is compared with experimental results from the UTM test.



Maximum Value Over Time	
X Axis	1486,8 N
Y Axis	7466,6 N
Z Axis	306,35 N
Total	7621,3 N

Fig.14. Force reaction of specimen

The experimental testing and experimental FEA results both show good agreement, [3] hence validating the study.

## VII. CONCLUSION

The comparative FEA and experimental results demonstrate that the hybrid natural/synthetic fibre-reinforced composite drive shaft provides improved structural and dynamic performance compared to the conventional SM45C steel drive shaft. Although the hybrid design exhibits a moderate increase in torsional deformation, it significantly reduces stress levels under both torsional and bending loading conditions, thereby improving fatigue resistance and durability. The slight decrease in natural frequencies remains within safe operating limits, while the inherent damping characteristics of composite materials contribute to better vibration behavior.

The manufacturing of the hybrid composite specimen was successfully completed, and experimental testing was carried out to validate the numerical analysis. The experimental results showed good agreement with FEA predictions, confirming the accuracy and reliability of the developed finite element model. Overall, the hybrid drive shaft demonstrates a favorable combination of lightweight characteristics, structural efficiency, vibration performance, and sustainability, making it a promising alternative for modern automotive drivetrain applications.

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