International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 3, May-Jun-2026, ISSN (Online): 2395-566X

Design And Finite Element Analysis Of Composite Drive Shafts: A Comprehensive Review On Materials, Modelling Techniques, And Performance Optimization

S,Shiva Kumar[1], P.V.R.Ravindra Reddy[2]
[1]Student, M.E (CAD/CAM), Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology, Hyderabad.
[2]Professor, Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology, Hyderabad.

Abstract: The drive shaft is a critical mechanical component responsible for transmitting torque from the transmission system to the wheels or other rotating components in automobiles, aerospace systems, and industrial machinery. Conventional steel drive shafts possess high strength but contribute significantly to the overall system weight, resulting in increased fuel consumption and reduced efficiency. In recent decades, fiber-reinforced polymer (FRP) composite materials such as carbon fiber reinforced polymers (CFRP), glass fiber reinforced polymers (GFRP), and hybrid composites have emerged as promising alternatives due to their superior specific strength, high stiffness-to-weight ratio, corrosion resistance, and improved damping characteristics. The advancement of finite element analysis (FEA) tools has enabled researchers to accurately predict the structural behavior of composite drive shafts under torsional, bending, buckling, vibration, and fatigue loading conditions. This review presents a comprehensive study of the design methodologies, material selection criteria, finite element modeling approaches, failure theories, optimization techniques, and recent developments in composite drive shaft technology. A critical comparison of different composite materials and FEA approaches is discussed, highlighting their advantages, limitations, and future research opportunities.

Keywords: Composite drive shaft, Finite Element Analysis, Carbon fiber reinforced polymer, Glass fiber reinforced polymer, ANSYS, Optimization, Torsional strength.

I. INTRODUCTION

A drive shaft is a critical mechanical element used for transmitting torque and rotational motion between different components of a power transmission system. Conventional drive shafts are generally manufactured using steel due to their high strength and reliability. However, the high density of steel contributes to increased vehicle weight, resulting in higher fuel consumption and reduced energy efficiency. Therefore, the automotive and aerospace industries have focused on developing lightweight alternatives with equivalent or improved mechanical performance [1].

Composite materials, particularly carbon fiber reinforced polymers (CFRP) and glass fiber reinforced polymers (GFRP), have emerged as suitable replacements for metallic drive shafts because of their excellent strength-to-weight ratio, corrosion resistance, and superior fatigue characteristics [2]. The low density of composite materials enables the development of single-piece drive shafts, replacing conventional multi-piece steel assemblies and reducing the number of mechanical joints and associated losses [3].

The mechanical behavior of composite drive shafts depends on several factors, including fiber type, matrix material, fiber orientation, laminate stacking sequence, shaft dimensions, and manufacturing method. Due to the anisotropic nature of composites, analytical approaches alone are insufficient for accurate performance prediction. Consequently, finite element analysis has become an essential tool for evaluating stress distribution, deformation, natural frequencies, and failure characteristics before experimental fabrication [4].

II. EVOLUTION OF COMPOSITE DRIVE SHAFT TECHNOLOGY

The development of composite drive shafts began with the objective of reducing rotating mass while maintaining adequate torsional strength and dynamic stability. Early investigations concentrated on graphite/epoxy and glass/epoxy composites owing to their superior specific mechanical properties. Later, hybrid composite systems combining carbon and glass fibers were introduced to achieve an optimal balance between performance and manufacturing cost [1].

Several researchers demonstrated that properly designed composite shafts can achieve weight reductions of 50–70% compared with conventional steel shafts while maintaining comparable torque transmission capability [5]. The improved damping characteristics of composite materials also provide reduced noise and vibration levels, making them suitable for modern high-speed automotive applications [6].

III. MATERIALS USED IN COMPOSITE DRIVE SHAFTS

3.1 Carbon Fiber Reinforced Polymer (CFRP): CFRP is among the most widely used materials for high-performance drive shafts due to its high elastic modulus, excellent fatigue strength, and low density. The high specific stiffness of carbon fibers enables the design of shafts with higher critical speeds and reduced deformation under torsional loading [2]. Studies on CFRP shafts have reported significant improvements in dynamic performance and weight reduction compared with conventional steel shafts [7].

3.2 Glass Fiber Reinforced Polymer (GFRP): GFRP provides an economical alternative to carbon fiber composites. Although its stiffness is lower than CFRP, it possesses good impact resistance, corrosion resistance, and ease of fabrication. GFRP-based shafts are therefore considered suitable for medium-load and cost-sensitive automotive applications [8].

3.3 Hybrid Composite Materials: Hybrid composite shafts combine different reinforcement fibers, such as carbon and glass fibers, to exploit the advantages of each material. Carbon fibers provide high stiffness and strength, while glass fibers reduce the overall manufacturing cost and improve impact resistance. Abu Talib et al. [1] investigated carbon/glass epoxy hybrid drive shafts and reported that appropriate stacking sequences can significantly improve torsional strength and buckling resistance.

IV. DESIGN CONSIDERATIONS FOR COMPOSITE DRIVE SHAFTS

The design of composite drive shafts involves satisfying multiple performance criteria, including torsional strength, bending stiffness, critical speed, fatigue life, and buckling resistance.

4.1 Torsional Strength: The primary function of a drive shaft is to transmit torque safely without failure. The torsional capability of a composite shaft depends on fiber orientation, laminate thickness, and material properties. Fiber angles close to ±45° are generally preferred because they provide maximum resistance to shear stresses generated during torque transmission [9].

4.2 Bending and Critical Speed Analysis: Drive shafts must operate below their critical speeds to avoid resonance and excessive vibration. Due to their high stiffness-to-weight ratio, composite shafts can be designed with higher natural frequencies than metallic shafts, enabling the replacement of two-piece steel shafts with a single-piece composite design [3].

4.3 Buckling Behaviour: Thin-walled composite shafts subjected to high torque may fail due to torsional buckling. The critical buckling torque is influenced by shaft geometry, laminate thickness, fiber orientation, and stacking sequence. Finite element methods are extensively used to predict buckling behavior and optimize the laminate configuration [6].

V. FINITE ELEMENT ANALYSIS OF COMPOSITE DRIVE SHAFTS

Finite element analysis has become a powerful numerical technique for investigating the structural and dynamic performance of composite drive shafts. Commercial software packages such as ANSYS, ABAQUS, and MSC NASTRAN are commonly employed to simulate composite structures.

A typical FEA procedure involves geometry development, material modeling, meshing, application of boundary conditions, and evaluation of structural responses. Composite materials are generally modeled as orthotropic laminates, and different ply orientations are assigned to predict realistic mechanical behavior [10].

VI. FEA-BASED INVESTIGATIONS

6.1 Static Structural Analysis: Static finite element analysis is performed to determine stress distribution, deformation, and safety factors under applied torque. Comparative studies have shown that CFRP and hybrid composite shafts exhibit lower weight and acceptable stress levels compared with steel shafts [5].

6.2 Modal Analysis: Modal analysis determines the natural frequencies and vibration modes of the shaft. Composite shafts generally exhibit higher natural frequencies due to their superior stiffness-to-weight ratio. The prediction of modal characteristics is essential for preventing resonance during operation [7].

6.3 Buckling Analysis: Linear and nonlinear buckling analyses are conducted to determine the maximum torque that a shaft can withstand before structural instability occurs. The finite element method provides a reliable approach for evaluating different laminate configurations and identifying optimal stacking sequences [6].

6.4 Fatigue Analysis: Since drive shafts are subjected to repeated torsional loading during their service life, fatigue analysis is essential for evaluating long-term reliability. Composite materials generally demonstrate superior fatigue performance due to their ability to dissipate cyclic loading energy effectively [2].

VII. OPTIMIZATION TECHNIQUES IN COMPOSITE DRIVE SHAFT DESIGN

The optimization of composite drive shafts aims to achieve minimum weight while maintaining required strength, stiffness, and stability. Important design variables include fiber orientation, layer thickness, number of plies, shaft diameter, and material selection.

Modern optimization methods such as genetic algorithms, particle swarm optimization, and multi-objective optimization integrated with finite element simulations have been employed to determine optimal laminate configurations [9]. These methods enable engineers to achieve improved mechanical performance with reduced material consumption.

VIII. CHALLENGES AND FUTURE RESEARCH TRENDS

Although composite drive shafts offer substantial advantages, their widespread implementation faces several challenges, including high manufacturing costs, complex failure mechanisms, delamination, difficulty in repair, and uncertainty in fatigue life prediction [10].

Future research is expected to focus on advanced hybrid composites, nanocomposite reinforcements, smart composite shafts integrated with sensors, artificial intelligence-based design optimization, and high-fidelity nonlinear finite element models for improved prediction accuracy.

IX. CONCLUSIONS

Composite drive shafts have emerged as promising alternatives to conventional steel shafts due to their high specific strength, low weight, excellent fatigue resistance, and superior damping properties. Finite element analysis has played a crucial role in understanding their structural behavior and optimizing design parameters. The selection of appropriate materials, fiber orientations, and stacking sequences significantly affects torsional strength, critical speed, and buckling resistance. Recent developments in hybrid materials, numerical optimization, and advanced manufacturing techniques are expected to accelerate the adoption of composite drive shafts in automotive, aerospace, and industrial applications.

X. CONCLUSIONS

Composite drive shafts represent a promising replacement for conventional metallic shafts due to their significant weight reduction, superior specific strength, and enhanced vibration damping characteristics. The use of finite element analysis has become indispensable for predicting the mechanical behavior of composite shafts under static, dynamic, buckling, and fatigue loading conditions. Carbon fiber composites provide the highest structural performance, whereas glass fiber and hybrid composites offer a balance between cost and mechanical properties. The selection of appropriate fiber orientation, stacking sequence, and geometric parameters is crucial for achieving an optimized design. Future advancements in computational modeling, intelligent optimization techniques, and advanced composite materials are expected to further improve the reliability and industrial adoption of composite drive shafts.

XI. REFERENCES (IEEE FORMAT)

[1] A. R. Abu Talib, A. Ali, M. A. Badie, N. Azida, and A. F. Golestaneh, "Developing a hybrid, carbon/glass fiber-reinforced epoxy composite automotive drive shaft," *Materials and Design*, vol. 31, no. 1, pp. 514–521, 2010.

[2] M. M. Shokrieh and H. Hasani, "Dynamic analysis of a composite drive shaft considering the effects of fiber orientation and stacking sequence," *Composite Structures*, vol. 90, no. 2, pp. 182–187, 2009.

[3] S. A. Mutasher, "Prediction of the torsional strength of the hybrid aluminum/composite drive shaft," *Materials and Design*, vol. 30, no. 2, pp. 215–220, 2009.

[4] T. Rangaswamy, R. Vijayarangan, and S. Chandrashekhara, "Optimal sizing and stacking sequence of composite drive shafts," *Materials Science*, vol. 11, no. 2, pp. 159–163, 2005.

[5] D. H. Cho, D. G. Lee, and H. S. Kim, "Manufacture and evaluation of a hybrid aluminum/composite drive shaft," *Composite Structures*, vol. 63, pp. 87–99, 2004.

[6] M. A. Badie, E. Mahdi, and A. M. S. Hamouda, "An investigation into hybrid carbon/glass fiber reinforced epoxy composite automotive drive shaft," *Materials and Design*, vol. 32, pp. 1485–1500, 2011.

[7] H. B. H. Gubran, "Dynamic analysis of rotating composite shafts," *Composite Structures*, vol. 84, pp. 220–226, 2008.

[8] S. Dharmadhikari, S. Mahakalkar, J. Giri, and N. Khutafale, "Design and analysis of composite drive shaft using ANSYS and genetic algorithm," *International Journal of Engineering Research and Applications*, vol. 3, no. 1, pp. 490–496, 2013.

[9] J. Searle et al., "FEA modelling and environmental assessment of a thin-walled composite drive shaft," *Sustainable and Circular Materials Research*, 2022.

[10] R. Jones, *Mechanics of Composite Materials*, 2nd ed., Taylor & Francis, 1999.