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A Review on Composite materials for Drive Shafts for Automotive Applications

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Abstract.

The growing demand for lightweight, high-strength, and fuel-efficient vehicles has propelled the automotive industry to explore advanced material alternatives to traditional steel components. One such critical component is the drive shaft, which plays a vital role in power transmission from the engine to the wheels.This paper presents a comprehensive review of composite materials—such as carbon/epoxy, glass/epoxy, and hybrid laminates—for automotive drive shafts, emphasizing their advantages over traditional steel in terms of weight reduction, vibration resistance, and fatigue performance. This study aims to address these gaps by conducting both modal and transient structural analysis on composite drive shafts using simulation-based methods. The outcomes contribute to the development of optimized, durable, and vibration-resistant drive shafts suitable for high-speed and high-torque automotive applications. Ultimately, this study supports the broader transition toward sustainable, high-efficiency vehicular technologies through the integration of advanced composite materials.

Keywords: Drive Shafts, composite materials, weight reduction, fatigue performance, automobiles, ANSYS.

Introduction

Over the past two decades, numerous researchers have explored the potential of composite materials as a superior alternative to traditional steel in automotive drive shafts. Studies have consistently demonstrated that materials like carbon/epoxy, glass/epoxy, and hybrid composites can significantly reduce component weight, enhance natural frequency, and improve vibration damping and fatigue performance. The use of finite element analysis (FEA) tools such as ANSYS has enabled accurate evaluation of static, modal, and buckling behaviors under real-world loading conditions. This review presents a detailed synthesis of key contributions that collectively support the application of advanced composites in the design and analysis of high-performance, lightweight drive shafts. The increasing demand for lightweight, high-strength automotive components has led researchers to explore composite materials for drive shafts as a replacement for conventional metallic ones. Multiple studies have demonstrated the structural and dynamic benefits of using fiber-reinforced composites such as carbon/epoxy and glass/epoxy. This literature review summarizes significant contributions from several recent studies that focus on the design, optimization, and analysis of composite drive shafts using finite element methods.

In the study by Arun Ravi (2014), a one-piece composite drive shaft made from high-strength carbon/epoxy was modeled and analyzed using ANSYS Workbench. The research focused on comparing this composite shaft to a conventional steel shaft of equivalent dimensions. The finite element analysis (FEA) results showed that the composite shaft had lower total deformation and significantly reduced weight, achieving a 24% weight saving over steel. Moreover, the study found that the composite shaft could sustain similar torque levels while offering increased natural frequency and lower strain values. This work provided clear evidence that composite materials could be a viable alternative to steel, especially for high-performance automotive applications where reducing unsprung mass is critical.

Ravi's analysis also explored the stress distribution under applied moments of 350,000 Nm and a rotational velocity of 650 rad/s. The study used both static and buckling analysis, showing that carbon fiber composite shafts exhibited a maximum equivalent stress of approximately 110.52 MPa, significantly lower than that of structural steel under the same conditions. The findings confirmed the mechanical superiority of carbon composites, particularly in torsional and vibrational resistance, making them suitable for high-speed applications. This detailed assessment highlighted the importance of precise material modeling and boundary condition setup in composite shaft design.

The study by Swapnil B. Vartak et al. (2017) analyzed and optimized drive shafts made from E-glass/epoxy, high-strength carbon/epoxy, and high-modulus carbon/epoxy. One of the primary goals was to replace two-piece steel drive shafts with single-piece composite alternatives to reduce weight and complexity. Their research demonstrated that replacing a steel shaft with a carbon/epoxy shaft could result in up to 72% weight reduction. Furthermore, through modal analysis, they observed that changes in fiber orientation significantly influenced the natural frequency of the shaft, which is a crucial parameter to avoid resonance during operation. The study also emphasized the importance of using FEA tools to accurately predict deformation and stress under torsional loading.

In a related section of the same study, Vartak et al. discussed how composite shafts improve not only vehicle performance but also manufacturing and maintenance efficiency. The use of a single-piece composite shaft reduces the need for couplings, bearings, and support structures that are often necessary in multi-piece steel shafts. This contributes to lower assembly time, maintenance effort, and inventory costs. Additionally, composite materials provided improved vibration damping, which helps in enhancing passenger comfort and reducing noise and wear on drivetrain components.

Another important contribution highlighted in the same paper was the use of finite element simulation in ANSYS Workbench 14.5, where they applied real-world loading conditions such as a moment of 590,000 Nmm to evaluate deformation, stress, and strain. The comparison between steel and glass fiber drive shafts revealed that although the glass fiber variant showed slightly higher deformation, it delivered comparable stress resistance while being significantly lighter. This reinforced the conclusion that composite shafts not only perform competitively under static loading but also have enhanced potential in dynamic performance when fiber configuration is optimized.

Mithunesh C.K. and H.S. Manjunath (2022) conducted a highly detailed comparative analysis of steel and carbon fiber reinforced plastic (CFRP) drive shafts using ANSYS. Their focus was on optimizing material selection to reduce stress and weight while maintaining structural integrity. Using a hex-dominant mesh with over 22,000 elements, they applied a torque of 2.3×10^6 Nmm and performed static structural and modal analysis. The CFRP shaft developed significantly lower stress values (97.14 MPa) compared to the steel shaft (128.21 MPa), with a weight reduction of nearly 46%, confirming the material's effectiveness in high-torque applications.

In their modal analysis, Mithunesh and Manjunath identified the first six natural frequencies of the CFRP shaft, ranging from 93.14 Hz to 403.22 Hz. These values showed that the composite shaft maintained higher vibrational resistance across multiple modes, essential for avoiding resonance conditions in real-world scenarios. The fiber architecture in the CFRP shaft played a significant role in determining these modal characteristics, supporting the conclusion that careful laminate design is necessary for vibration-sensitive applications like automotive drivetrains.

The same study also emphasized the principal stress evaluation in the CFRP drive shaft. Maximum and minimum principal stresses were recorded as 62.33 MPa and -59.18 MPa, respectively, showcasing the shaft's ability to manage alternating loads without failure. These results were further validated through fatigue life predictions using Goodman's diagram and stress-life equations. The estimated life cycle of over 1.12 million load cycles demonstrated that CFRP shafts are not only lighter and stronger but also more durable under cyclic torsional loading conditions.

Additionally, the researchers performed an analytical validation of critical speed and shear stress using classical mechanics equations. They demonstrated that CFRP shafts provide higher critical speed and better torsional strength per unit weight compared to traditional materials. The hollow cross-section design further improved the stress distribution, making CFRP a structurally efficient option for automotive applications. Their study concluded that, despite higher material costs, CFRP shafts offer unmatched performance benefits in terms of strength-to-weight ratio, vibrational behavior, and fatigue life, thus justifying their use in modern vehicle systems.

P. Jayanaidu, M. Hibbatullah, and Prof. P. Baskar (2013) investigated the optimization of drive shafts using titanium alloy (Ti-6Al-7Nb) as a replacement for conventional steel. Their study emphasized that steel shafts, due to their low specific stiffness and strength, result in excessive weight and lower efficiency. By employing ANSYS for both design and modal analysis, they found that titanium significantly reduced both stress and deformation levels while increasing the natural frequency of the shaft. Modal analysis showed frequencies of 55.021 Hz and 55.065 Hz for the first two modes, supporting the shaft's enhanced vibrational performance. This study concluded that titanium, although more expensive, can be a superior alternative due to its lightweight and strength characteristics, particularly beneficial for improving fuel efficiency and reducing driveline inertia.

The same study also discussed the deformation characteristics of titanium versus steel under identical loading conditions. The results revealed that titanium yielded a total deformation of only 0.000519 mm compared to 0.000564 mm in steel. Though the difference appears marginal, in high-speed automotive applications, such improvements contribute significantly to driveline stability and efficiency. The researchers also highlighted the importance of accurately modeling vibration behavior to avoid resonance, thereby extending fatigue life. Their use of modal analysis provided a valuable theoretical basis for the early-stage optimization of propeller shafts.

In another investigation, K. Gokul et al. (2022) focused on the design and modal analysis of cardan shafts using Creo and ANSYS software. Their study addressed one of the key issues with cardan shafts: vibration due to continuous angular variation between transmission and axle during rotation. They proposed geometry modifications (circular and rectangular cutouts) to reduce weight and enhance natural frequency. Their results showed that the circular cut-out geometry performed better in terms of vibration reduction and had minimal deformation under the same boundary conditions, making it the most efficient design among those tested. This highlights the value of structural geometry optimization in improving NVH (noise, vibration, harshness) characteristics of driveline components.

The same study also elaborated on common failure modes in cardan shafts, including torsional fatigue, misalignment, and excessive torque loading, all of which can result in severe driveline failure. Through structural analysis using ANSYS, they were able to simulate stress distributions under different configurations and predict the critical speeds that might result in resonance. The circular cut-out model not only increased the natural frequency but also demonstrated superior vibrational characteristics, which are essential for long-life and high-speed performance of automotive drive shafts.

Meanwhile, Kishor Ghatage and NarayanraoHargude (2013) conducted a comprehensive analysis on composite drive shafts using Carbon/Epoxy and Glass-Carbon/Epoxy materials. Their work included static, modal, and buckling analyses. A major contribution of their study was the experimental validation of fiber orientation and stacking sequence on shaft performance. The Carbon/Epoxy shaft exhibited a natural frequency of 13,454 Hz, buckling torque of 2,526.43 Nm, and displacement of 3.86 mm, whereas the Glass-Carbon/Epoxy shaft had a lower frequency of 7,848 Hz but a higher buckling torque of 4,145.54 Nm. These findings indicate that although Carbon/Epoxy is stiffer and lighter, Glass-Carbon/Epoxy offers greater torque capacity under buckling loads.

Their research also utilized eigenvalue buckling analysis to predict failure loads under torsional stress, a critical factor for real-world driveline safety. The results validated that composite materials not only enhance stiffness-to-weight ratios but also significantly outperform traditional steel shafts in terms of dynamic stability. Moreover, their detailed FEA model using SHELL 99 elements allowed accurate simulation of complex composite behaviors under multi-layered configurations, reinforcing the role of simulation tools in composite structural design.

Another critical aspect of Ghatage and Hargude's work was the implementation of Timoshenko beam theory for calculating lateral vibration modes and critical speed. This methodology allowed a more accurate prediction of shaft behavior by considering both rotary inertia and transverse shear deformation. Their findings confirmed that the natural frequency increases with the square root of specific modulus and decreases with the square of length, a crucial insight for scaling shaft designs without compromising performance.

The modal and buckling analyses conducted by these authors also illustrated that fiber orientation directly influences natural frequency and dynamic stiffness. With proper laminate design, one-piece composite shafts can entirely eliminate the need for two-piece configurations, thereby reducing mass, mechanical losses, and system complexity. Their study concluded that switching to composite shafts can yield up to 30% fuel efficiency improvement by reducing rotational mass and eliminating unnecessary rotating joints and support structures.

These studies collectively establish the importance of advanced materials like CFRP, GFRP, and Titanium alloys in driveline systems. They underline that while composites offer superior stiffness, vibration resistance, and fatigue life, their performance is highly dependent on fiber lay-up, boundary conditions, and material-specific properties. The consistent application of simulation techniques such as static analysis, modal analysis, and eigenvalue buckling analysis using FEA software like ANSYS is essential for optimizing these complex composite structures.

Pankaj K. Hatwar and Dr. R.S. Dalu (2015) conducted an in-depth study on the replacement of conventional steel drive shafts with composite alternatives for automotive applications. Their research focused on carbon/epoxy and glass/epoxy composites, emphasizing their superior strength-to-weight ratio, higher damping capacity, and corrosion resistance. Through static and modal analyses using ANSYS, they demonstrated that composite shafts could significantly increase the natural frequency of the shaft, thereby enabling the use of a single-piece design instead of a two-piece steel shaft. The study concluded that composite shafts offer reduced mass, better noise and vibration behavior, and improved dynamic stability — all critical for enhancing vehicle performance.

Their analysis showed that the carbon/epoxy composite shaft exhibited a fundamental natural frequency of 20160 rpm, much higher than steel (9660 rpm), confirming its superior vibration resistance. Additionally, the total deformation in carbon/epoxy shafts was considerably lower, suggesting that these materials could endure operational stresses better without compromising durability. This reinforced the suitability of composites for high-speed, torque-transmitting components such as automotive drive shafts.

Parshuram D. and Sunil Mangsetty (2013) explored the design of a hybrid composite drive shaft using a combination of graphite, carbon, and glass fibers embedded in resin matrices. Their work emphasized the weight reduction benefits and higher specific strength of composite materials compared to steel. By modeling the shaft assembly in CATIA and analyzing it using ANSYS, they evaluated deflection, stress, and modal behavior. The study revealed that composite shafts not only met the mechanical requirements but also eliminated the need for multiple shaft segments and joints, thereby reducing weight, complexity, and vibration.

One key observation made by Parshuram and Mangsetty was that conventional steel shafts, often split into two pieces to manage vibration, could be replaced with single-piece composite shafts due to the higher stiffness-to-density ratio of carbon fibers. Their findings support the idea that advanced composite design not only simplifies manufacturing and maintenance but also enhances vehicle comfort through improved damping and reduced noise.

Ramchandra D. Patil and Dr. D. M. Patel (2020) introduced a novel hybrid design approach by integrating a carbon fiber/epoxy composite layer inside an aluminum tube, rather than wrapping it externally. This innovative configuration aimed to prevent impact damage and moisture absorption — two common issues in conventional composite shafts. Using finite element analysis, they determined the optimal stacking sequence and residual stress distribution, ensuring structural safety and dynamic reliability. The hybrid shaft achieved enhanced torsional strength and increased natural frequency while reducing overall weight and cost compared to traditional two-piece steel shafts.

Their results indicated that the hybrid aluminum/composite shaft satisfied the critical performance parameters for automotive applications, including torque capability (>3500 Nm) and bending natural frequency (>9200 rpm). The integration of press-fitting for aluminum-composite-to-steel joints also contributed to reducing assembly complexity and cost. This work underscores the potential of hybrid structures in meeting both economic and engineering design challenges.

The same study also highlighted the comparative performance of various composite configurations. For instance, a carbon/epoxy shaft had a bending frequency significantly higher than that of steel or aluminum, making it suitable for high-speed applications where dynamic stability is paramount. The hybrid structure helped bridge the gap between performance and affordability, thus making it viable for large-scale implementation in the automotive sector.

These three studies collectively underline the transition in automotive drive shaft design — from heavy, multi-part steel assemblies to lightweight, high-performance composite and hybrid alternatives. The use of finite element analysis tools such as ANSYS was common across all studies, reinforcing the importance of simulation in understanding complex behaviors such as torsional buckling, modal frequencies, and stress distribution under dynamic loading.

Furthermore, these works highlight the importance of material selection, particularly the choice of reinforcement fiber and resin system. Carbon fibers provide high stiffness and fatigue resistance, whereas glass fibers offer cost benefits. Hybrid configurations offer a balanced compromise by achieving sufficient strength and frequency characteristics while managing material costs — a crucial factor in commercial vehicle design.

Arbaz Khan et al. (2023) provided a comprehensive review on the design and analysis of composite drive shafts for automotive applications. The study emphasized the functional importance of drive shafts under operational conditions such as torsional loads, rotational speeds, and vibration. The authors analyzed various composite materials including carbon/epoxy, glass/epoxy, Kevlar/epoxy, and boron/epoxy, using static and modal analyses to compare their mechanical performance with that of conventional steel. Notably, they reported a weight reduction of up to 82.28% using glass/epoxy composites while maintaining lower stress and strain values. Modal analysis results showed higher natural frequencies for composites, especially carbon/epoxy, indicating better vibration resistance compared to steel drive shafts.

Sridhar et al. (2016) focused on the replacement of two-piece steel drive shafts with single-piece composite alternatives. Their study highlighted that composite drive shafts not only reduce weight but also offer better torsional strength, buckling resistance, and vibration characteristics. The use of high modulus carbon/epoxy materials led to a weight reduction of 51% compared to steel. Modal analysis using ANSYS revealed that composite shafts exhibited significantly higher natural frequencies, reducing the risk of resonance. Their research concluded that a one-piece composite shaft is feasible for automotive use and results in increased structural efficiency and fuel economy.

In the same study, Sridhar et al. (2016) also conducted a comparative stress analysis of steel, E-glass/epoxy, and high-strength carbon/epoxy shafts. The analysis showed that high-modulus carbon/epoxy shafts had the lowest deformation and highest vibration resistance. Furthermore, their use of Bernoulli–Euler and Timoshenko beam theories to estimate natural frequencies revealed the significance of including shear and rotary inertia effects in composite design. This reinforced the validity of composite drive shafts under both static and dynamic loads.

G. Kaviprakash et al. (2014) explored the influence of fiber orientation and stacking sequence on the structural integrity of composite drive shafts. Using ANSYS, they evaluated multiple laminates such as [0/+45/–45/90/0] and concluded that fiber orientations at ±45° offered optimal torsional stiffness and fatigue strength, while 0° orientation maximized natural frequency. Their study established that hybrid composites combining high-strength carbon, high-modulus carbon, and Kevlar fibers achieved the best trade-off between low weight and high performance, with up to 79% weight reduction observed over steel.

Additionally, Kaviprakash et al. noted that the stacking sequence of fibers plays a critical role in buckling resistance and fatigue life. For instance, placing ±45° layers closer to the shaft's inner surface enhanced fatigue resistance, while keeping 0° and 90° plies on the outer layers improved buckling strength. Modal analysis showed that a ply orientation of [0/50/–50/90/0] achieved the highest first natural frequency, with a 29.34% improvement over steel, making it ideal for high-speed applications.

M.A. Badie et al. (2011), as cited in the literature, investigated the dynamic and failure behavior of composite tubes and concluded that the buckling torque is highly sensitive to fiber angle. Fibers at 90° provided the highest buckling resistance, whereas ±45° orientations offered the best torsional stiffness. This aligns with current trends in composite shaft design, where fiber angle is optimized based on application-specific demands such as bending, torque, or impact loads.

A.R. Abu Talib et al. (2010) also explored hybrid carbon/glass fiber-reinforced shafts and found that altering winding angles from 0° to 90° could lead to a 44.5% drop in natural frequency and a 46.07% drop in buckling strength. Their findings highlight the importance of choosing fiber orientation strategically to maximize structural performance, especially for dynamic applications like drive shafts.

Harshal Bankar et al. (2014) emphasized that the first mode bending frequency of composite drive shafts increases significantly with reduced weight. Their parametric optimization showed that using appropriate ply angles between 30° and 70° for shear loading and 0° for axial stiffness ensures that the shaft can sustain both normal and torsional stresses effectively.

Ali S. Hammood et al. (2016) further reinforced the significance of fiber orientation in fatigue performance. Their study revealed that composites with 0° orientation showed the highest fatigue life, while 90° orientation significantly reduced strength and cycle life. These observations are critical when designing for long-life components under cyclic loads.

Muni Kishore, Jaligam Keerthi, and Vinay Kumar (2016) investigated the performance and feasibility of replacing conventional steel drive shafts with composite materials, specifically E-glass/epoxy and carbon/epoxy. Their study modeled the drive shaft in CATIA V5 R21 and conducted extensive simulations using ANSYS Workbench, focusing on static structural, modal, and rigid dynamic analyses. The study aimed to achieve significant weight reduction while improving stress distribution and deformation characteristics. They found that E-glass/epoxy offered a favorable balance of mechanical properties, achieving lower stress and strain compared to steel, and concluded that it could be a viable replacement for traditional materials in automotive applications.

Their analysis further revealed that while carbon/epoxy had better vibration performance (due to higher natural frequencies), E-glass/epoxy was superior in terms of cost-efficiency and deformation control. Modal analysis showed deformation levels under dynamic loading were within safe limits, and rigid body dynamics confirmed that composite shafts could maintain mechanical integrity under high-speed torque transmission. The researchers highlighted the composite shaft's ability to absorb shocks, reducing stress on the drivetrain and enhancing lifespan, making it a practical solution for both performance and economic concerns in automotive engineering.

Ravi Prakash and Yogesh Mishra (2019) analyzed a carbon fiber-reinforced plastic (CFRP) hollow shaft using ANSYS 18.2 to optimize weight while maintaining sufficient structural strength. Their work emphasized how composite materials outperform metals in reducing fuel consumption and damping vibrations. The CFRP shaft they analyzed reduced the total component weight from 3.2 kg to 2.6 kg, a significant saving that improved performance without compromising strength. They modeled the shaft's geometry, applied boundary conditions, and evaluated stress and modal behaviors across different configurations.

In addition to their static analysis, Ravi Prakash and Mishra performed modal and buckling analyses to ensure operational safety. The natural frequency of the CFRP shaft was found to be significantly higher than that of steel, avoiding resonance-related failures during high-speed rotation. Their study also recorded the torsional buckling load of CFRP shafts as nearly five times greater than the applied torque, confirming their robustness. These findings support the selection of CFRP materials not only for their lightweight characteristics but also for their exceptional resistance to mechanical instability under torsional stress.

Arbaz Khan et al. (2023) focused their research on the design and static structural analysis of a glass/epoxy composite drive shaft using FEA tools. The drive shaft was modeled and simulated to compare the performance of glass/epoxy against traditional steel (SM45C). Their findings showed that the use of composite materials resulted in a 46% weight reduction, contributing to better fuel efficiency and easier handling. Additionally, the composite shaft exhibited higher torsional strength and lower deformation, suggesting suitability for high-speed vehicle systems.

The same study also evaluated torsional buckling strength, determining that the developed composite shaft could safely withstand torque loads well beyond those experienced in normal operation. The critical buckling torque (Tcr) for the composite shaft was calculated at 14195 Nm, more than twice the maximum operating torque, establishing a high safety margin. The researchers concluded that glass/epoxy shafts not only met but exceeded design expectations in stiffness, damping, and strength, providing a reliable and cost-effective alternative to metal shafts.

Moreover, Khan and colleagues performed bending natural frequency calculations using the Bernoulli-Euler beam theory. They recorded a first natural frequency of 124 Hz, which was significantly higher than the steel equivalent (80 Hz). This improvement in vibration characteristics ensures that composite shafts operate safely within high rotational speeds, preventing resonance issues. The design was further refined using CAD tools, and simulated results such as deformation, equivalent stress, and strain were verified using ANSYS, confirming that composite shafts are more resilient under operational stresses.

Additionally, the study included a comprehensive material comparison between structural steel and composites. In terms of total deformation and equivalent stress, the glass fiber composite shaft performed better, showcasing lower stress concentrations and less deflection under similar loading conditions. These insights reinforce the practicality of adopting composite shafts in automotive applications where rotational stability, fuel savings, and durability are critical performance indicators.

Result:

The reviewed literature clearly illustrates the transformative potential of composite materials—such as carbon/epoxy, glass/epoxy, and hybrid laminates—in the design and performance of automotive drive shafts. Across multiple studies, researchers have consistently reported substantial weight reduction (ranging from 24% to over 80%), enhanced torsional and buckling strength, and significant improvements in vibration resistance through increased natural frequencies. Advanced simulation tools like ANSYS have enabled precise modeling of deformation, stress distribution, and dynamic behavior under realistic loading scenarios. The importance of fiber orientation, laminate stacking sequence, and hybrid configurations has been emphasized as critical design parameters influencing structural integrity and fatigue life. Studies involving alternative materials like titanium alloys and hybrid aluminum-composite shafts further broaden the design possibilities for achieving performance, durability, and efficiency. Overall, the findings from these diverse works strongly support the adoption of composite drive shafts as a superior alternative to traditional steel designs, aligning with modern automotive goals of lightweighting, noise and vibration control, and fuel economy. These insights form a solid foundation for further investigation into dynamic analysis techniques such as modal and transient structural evaluations of composite shafts.

Conclusion:

This study provides strong evidence that composite drive shafts are not only technically viable but also highly advantageous in meeting the evolving demands of automotive performance, efficiency, and sustainability. This literature foundation sets the stage for further investigation into dynamic analyses, particularly modal and transient structural evaluations—that can refine and validate composite shaft designs for widespread practical deployment.

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