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# Design of Propeller Shaft Using Composite Materials

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**ABSTRACT**

Roadways automobiles, such as cars, trucks, buses, and land moving companies, share many mechanical elements, such as engine components, propeller shafts, thereby gearboxes, braking systems, grips, and tyres. To make a vehicle more fuel-effective, which in turn makes transportation more affordable, its weight must be decreased. The addition of composite substances to traditional metals used in automobile parts will save weight and enhance the mechanical qualities of those components because composite elements are lighter in weight with increased strength & stiffness. In order to meet the specifications for the current situation, the propeller shaft's minimum dimensions are designed in this article, and traditional steel material is replaced with composite material. The theoretical construction of the propeller shaft initially considers the safe dimensions of steel, carbon/epoxy, and glassy epoxy mixtures. Application called CREO 7.0 is used for modeling. After modeling, analysis of the propeller shafts can be done using the ABAQUS SOFTWARE to see if the results of the theoretical calculations and the analytical results are comparable. Following a comparison of the results between the three materials, a carbon epoxy composites product is chosen as a viable substitute for traditional SM45C steel in terms of a number of its mechanical qualities.

**Keywords-** Propeller Shaft, Composite Material, Carbon Epoxy, Glass Epoxy, SM45C, ABAQUS, Solidwork, Optimization, Analysis

## Introduction

An essential part of every automobile's energy gearbox is the propeller shaft. Standard steel shafts for drives are heavy and have low critical speeds. It is crucial to lessen the mass of the shaft that drives in order to attain the highest level of power transmission efficiency. Depending on the overall width of the vehicle, the shaft in a front-engine, rear-drive vehicle will limit the power. Longer rods naturally bend when used; to prevent this, they divide utilizing ubiquitous joints. The power transferring capacity of universal joints reduces as their number rises. Hybrid elements can endure great heat while maintaining great strengths and rigidity. Qualities like stretching, the von Mises stress, or stress due to shear are examined when the study is conducted using the ABACUS & SOLID WORK programme. The analysis includes composite materials including graphite epoxy, glassy epoxy resin, and traditional SM45C steel shafts. The use of universal joints will decline. The conventional approach makes use of two steel shaft sections connected by two universal joints. However, the standard connection intermediary is not utilized in cases of mixed elements. This is due to the composite material's less bending and distortion than traditional shafts. Power transmission has been improved and weight reduction has been achieved by using high strength materials.

## Propeller shaft

Figure 1 illustrates the application of a propeller shaft, also known as a drive shaft, to transmit energy among various rear driveshaft elements. The ability to move parts linked to one another is a benefit when employing propeller shafts. Construction equipment's connection between wheel axles may be the area of application while the machine is working on uneven terrain. A propeller shaft can accommodate variations in length and inclination. The function is made possible by the combination of many pieces. Accessory studs make it possible to link the driveline's components together.

Figure 1: Propeller shaft

The average propeller shaft has about 12 separate components. Figure 1 depicts every component of a propeller shaft. The components of the propeller shafts that connect to the matching hubs on the transmission or wheels axle are known as flange yokes. One of the propeller shaft joints is made up of a flange yoke, the journal spider, and the tube yoke. A bearing located inside the joint is secured in place by a circlip. The tube yoke and tube are welded together. To lessen noise, a cardboard roll may occasionally be inserted inside the tube. The tube and sleeve muff are both welded together. There are splines inside the sleeve muff that the yoke shaft's exterior spirals may slide along.

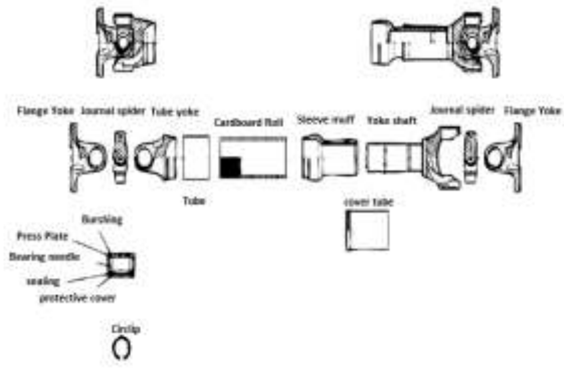


Figure 1.2: Propeller Shaft Parts

**Automotive Drive Shaft Vehicles**

When the torque reaches its wheels, an automobile may employ an axial shaft to transfer power from an engine or gearbox towards the other side of the vehicle. Power is frequently transferred from the main differential gearbox, to the wheels via two sets or long driving shafts.

## LITERATURE REVIEW

**Design and performance analysis of hybrid composite driveshaft**

Utilizing an evolutionary method, O. Montagnier et al. [1] optimized hybrid composite shafts of drive for aircraft tail rotor drivelines. Speeds under subcritical and supersonic operating states were taken into consideration. Used was a hybrid driveshaft made of extremely strong, high modulus carbon fiber reinforced with resin.

Yu-Chung TSENG et al. [2] investigated how long straight parts reacted to twisting motion. The aluminum shaft was wrapped in an epoxy glass fiber composite to create the root for the hybrid blade core. They created a sandwich-like construction by joining an aluminum shaft and epoxy glass fiber. The composite shaft was examined using a testing apparatus for torsional forces. Monitoring the tension on a composite shaft using a strain gauge yields its stress and bending angle.

According to Badie M. A. et al. [3], the researchers looked at how fiber and layer stack arrangement oriented angles affected the fundamental frequency, torsion discomfort, bending power, fatigue lifespan, and ways of breakdown in composites tubes. For the research of fatigue lifespan and linear static analysis of composites tubes for various stacking orders, they have used FEA. Scaled textile composite models are used to test the torsional stiffness experimentally. The basic frequency is growing with decreasing fiber orientation angles, as demonstrated by the FEM data.

A.R. Abu Talib et al. [4] constructed hybrids resins carbon with plastic glass fiber composites driveshafts using analysis of finite elements.

Authors have included epoxy-reinforced glass and carbon fibers. They employed crystal-epoxy in three layers and emissions-epoxy in a single layer with orientations angles of 00, 450, and 900 in their design. These four layers, as well as one that combined the two, were encased around an aluminum tube with measurements of 216 mm in length and 12.7 mm in outside diameter. For cleaning large LCD glass panels, Hak Sung Kim et al. [5] created a hybrid brush shaft with an interior co-cured joined carbon oxy sheet and an outside the material tube.

Compared to using an autoclave suction bag, using an adaptable vacuum tube approach saved manufacturing costs. The elastic tension tube approach produces a hybrid shaft with a good mechanical connection and adequate properties. According to research, compared to standard stainless steel brush shafts, hybrid brushing shafts have a 35% lower slope and deflection near to the bearing mounting position.

S. A. Mutasher et al. [6] examined the static power as well as torque transmission capacities of the produced shaft using the wetted filament winding process to fabricate a hybrid aluminum composite driveshaft. The materials used to make the driveshaft were carbon, the material, epoxy paint, and meshes. In their experimental study, they discovered that for both carbon and glass fibers, the stable and reactive strain capability is greater for a winding angle of 45° than for 90°. The aluminum tube failed in the dynamic tension test at the shaft's midpoint, according to the authors' observations. The longitudinally propagating break in the composite shaft eventually started a separation of the composites layer from the aluminum tube. In the power propagation test, the issue was seen in several places along the test specimen's length. The laminated shaft produced the same twist relation and torque angle with stacking orders of [90o/+45o/-45o/90o] and [+45o/-45o/90o/90o].

The mixture of aluminum and synthetic fiber was examined by Zorica Dordevic et al. [7] for fundamental resonances that were influenced by the wall width of the aluminum tube and the number of layers of carbon fiber. Authors have deduced from the results of the study that thinning the aluminum tube wall resulted in a rise in the shaft's fundamental frequencies. Once more, the simplest frequencies are at their highest values when the pointing angle for carbon fibers is 0o, while they decline as the point of orientation of the fibers increases.

Using FEA, S. A. Mutasher [8] forecasted the hybrid aluminum/composite driveshaft's torsional strength.

For a rear-wheel-drive vehicle, Hak Sung Kim et al. [9] created a single-piece hybrid drive shaft composed of aluminum and carbon-epoxy composite. Press-fit assembly was used to join the aluminum yoke to the hybrid shaft. Static torsion stiffness and push-fit joint breakdown mode have been improved by the developed design. The prototype single-piece vehicle hybrid aluminum-composite driveshaft has been constructed and studied. Compared to a traditional two-piece steel driveshaft, the mass of the single-piece automobile hybrid materials-composite drive shaft was 50% lower.

## Design methodology and performance analysis of composite driveshaft

Naveen Rastogi [10] presented a comprehensive method to design composite driveshafts for applications in the automotive sector. He used MS-EXCEL macros to design a composite driveshaft and the adhesively bonded cylindrical joint between the yoke and the pipe with the. Closed-form analytical solutions were used for initial design and developed tools for rapid design and analysis of composite driveshaft. Numerical analysis of carbon epoxy composite tube and joint of adhesively bonded tube concerning the yoke and the tube was performed in SDRC IDEAS to validate the preliminary design tools.

C. Sivakandhan et al. [11] have completed the numerical analysis of epoxy glass composite specimens using a solid 95 element, which has 20 nodes. In their research, the authors have analyzed three specimens of glass epoxy for torsion only and shown a significant amount of mass saving when relative to conventional steel driveshaft with the usage of composite materials and optimization techniques. These results are inspiring and suggest that glass-epoxy composite materials can be successfully used in engineering applications.

Porous hybrid driveshafts for automobiles were studied by B. James Prasad Rao et al. [12] using glass fiber reinforcement plastics (GFRP) and carbon fibre reinforced plastics (CFRP). The intended force level is much below the critical torque, according to the authors' failure study using the maximum stress hypothesis. The FEM-based programme ANSYS was used to analyze the designed driveshaft. 3D shell99 components and solid46 layer elements were used to model the driveshaft. Harmonic analysis, Eigenvalue buckling, or linear static analysis were used to examine the modes of failure. For the carbon, glass, and hybrid propeller shafts, authors have demonstrated static deflection values of 0.12, 0.25, and 0.2, respectively, under a torque of 2030 Nm. The ultimate torsional strength is about five times lower than the torsional buckling load. Once more, toughness may be increased if the structure of the composite rod is optimized. In this study, the authors did not test the conclusions through experiments. For orthotropic materials, the highest stress collapse theory has some restrictions.

A single-piece composite driveshaft was employed to replace a two-piece steel driveshaft by M. R. Khoshravan et al. [13]. The coupling-designed carbon epoxy composite driveshaft showed variations in static strain and critical velocity with fiber alignment. In ANSYS, the static and dynamic analysis was completed. The Tsai-Hill failure theory was used to evaluate the composite shaft's breaking resistance and revealed a 72% weight decrease. demonstrating the significant impact of stacking patterns on the dynamic characteristics of the composite shaft is motivating.

O. A. Bauchau et al [14] The discovered rotating buckled carry of the graphite epoxy shafts created on prevalent pay concept which consists of adaptable coupling impacts and side shearing distortions. The guidance of the power used and the layup arranging has up for 80% effect on buckled load. Transversal cutting stretching was found important for greater than 3 circumferential waves in the buckled pattern. The writers found the identical buckling manner structure but lowered the buckled load for the damaged specimen.

## Manufacturing techniques of the composite driveshaft

A separate-piece composite drivetrain was created by Durk Hyun Cho et al. [15]. An aluminum tube and a carbon fiber epoxy composites were used to make the shaft. The carbon fiber and aluminum pipe was co-cured to create this shaft. During the teamed up-curing functioning, a compression load is applied to the aluminum tube to eliminate any remaining thermal stress that had built up during manufacture as a result of the different thermal expansion values of aluminum and carbon fiber composite. The hybrid metal composites shaft underwent the whirling test, static torque checks, and dynamic torque checks. It was discovered that the fifty percent mass decrease of the hybrid shaft over a steel shaft boosted its lowest dynamic tension gearbox capabilities and fundamental bending frequency.

A separate-piece automobile hybrid aluminum composites driveshaft was created by Dai Gil Lee et al. [16] and is depicted in Fig. 2 The epoxy carbon fiber composites coating was teamed up-cured over the inside side of an aluminum pipe during the production of this shaft, as opposed to the exterior surface. This guards against external impact and moisture concentration damaging the composite layer. By taking into account the thermal residual stresses at the interface between the material and the aluminum pipe, the composite layer's organization was enhanced. The ideal stacking order was determined using the FEM. Press-fitting was used to link steel yokes to the aluminum composite tube, which has advantages over other joining techniques in terms of dependability and production costs.

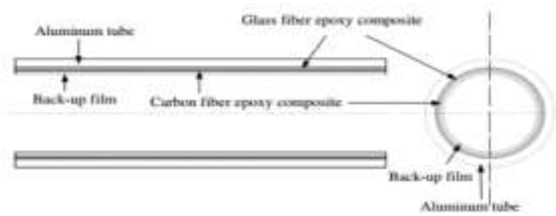


Figure 2: Hybrid composite driveshaft

The separate-piece automobile hybrid aluminum composites drive shaft, according to the authors' experimental examination, offers a 20% decrease in weight and a 120% improvement in torque capacity over a typical drive shaft composed of steel.For a rear-wheel-drive vehicle, Mohammad Reza Khoshravan et al.created a 2 m long HM-carbon epoxy composites driving shaft. Software from ANSYS was used to analyze the planned shaft. For the composite driveshaft, HM carbon epoxy material with 60% fiber volume is employed. Six was chosen as the safety factor. The ideal fibre configuration for the material's driveshaft is [900 /00 / +450 4].

Glass epoxy composite drive shaft manufacturing and design processes were detailed by M. Pallavi et al. for a light motor vehicle.

They discussed joining metals to composite materials, cutting, and oven curing. In the experimental study, it was discovered that in comparison with the standard steel shaft, the glass-based epoxy composite shaft had higher torque (10.5%), rigidity (25.69%), and frequency of natural (25%) values. The glass urethane composite shaft's weight decreased by 37.9%. They improved performance through lowering the diameter of the metal shaft from 15 mm to 9.5 mm of the hybrid shaft and came to the conclusion that the glass-epoxy combination is the best steel substitute.

## Comparative analysis of optimization techniques for the composite driveshaft

For the cross-sectional layout of a shaft that was subjected to simple twisting, Qing Li et al. used a progressive structure optimisation technique. Calculating the distribution of shear stresses over the shaft's cross-section was carried out using FEA. The least effective material was gradually eliminated from the cross-section, and the least strong component was gradually migrated from the toughest area to the weakest region. The fully stressed and least rigid models had the identical cross-sections, they found by contrasting the best forms produced by both strong and rigid criteria.

A simulation-based annealed approach was employed by H.B.H. Gubran et al. to minimize weight whilst optimizing or appropriately positioning the shaft's inherent frequency in relation to the conditions of operation. Torsional rigidity and bending force are limits applied. Design characteristics such as individual ply, its thickness, stack order, and thickness were retained. By switching from a uniform ply angle and equal thickness of wall to varied ply angle and variable wall thickness, the researchers discovered a considerable improvement in dynamic performance. The middle of the shaft has the highest first frequency and torsion stiffness, according to the results, which can be enhanced through lowering ply angles and employing the greatest thickness there.

With the aid of a genetic algorithm (GA), R. R. Ajith et al. optimized the layout characteristics of the composite driveshaft for automobile power trains. Numerous plies, their depth, and the order in which they were stacked were taken into consideration for optimisation. The authors' experimentation with two composite materials—E-glass epoxy and boron epoxy—had weight minimization as its goal. Basic speed torque delivery, torsional buckling load, and other restrictions were used. The stress and strain distribution along shaft thickness were found to be within permitted limits when they plotted the fluctuation of the goal function, emphasizes and stresses with the number of generations. The weight was reduced by 48% and 86%. The outcomes of the genetic algorithm encourage the employment of it for additional intricate and realistic designs.

The method of regulating stack order of laminated composites for the enhancement of buckling load was presented by M. H. Hajmohammad et al. They used genetic optimisation methods and neural networks. The multi-layer perceptron (MLP) and neural network designs are used to calculate the improved buckling load, and a genetic algorithm is then employed to find the best design. They established that combining genetic algorithms and neural networks is a successful way to optimize how to stack composite laminates.

For a thick laminate composite plate, A. R. Vosoughi et al. discovered the best stacking arrangements to maximize buckling strength. Particle swarm optimization (PSO), genetic algorithms (GAs), and FEM are all employed by the authors. Higher-order shear displacement theory (HSDT) was used to create the main governing equations for the plate, and the finite element method (FEM) was used to calculate the plate's buckling strength. Particle swarm optimization (PSO) and genetic algorithms (GAs) were combined to get the FEM-derived solution. The effects of several parameters on the optimisation, including the aspect ratio, the number of plies, thickness-to-length ratio, and boundary circumstances, were examined.

## Experimental setup development for the investigation of the driveshaft

Investigations into the cross-sectional distortion and bending of tube composites shafts under intense static loading were conducted by H.B.H. Gubran and K. Gupta. In the experimental analysis, the shaft was supported by self-aligning bearings while a static focused load was applied to its center. The eddy current probes were utilized to measure the changes of sites at the top and bottom of the centrally placed shaft cross-section. The beyond-of-plane movement obtained for a 45° ply angle shafts was found to be less than that of in-plane translation, according to the researchers. For 0° and 90° ply angles, there was no out of plane movement. Oblique ply shaft deflection (i.e. 45°)2 was less than single-layer shaft deflection (i.e. 45°), as well as the initial layer.

Glenn E. Vallee and colleagues created a cost-effective tension measuring device that could also determine the material's shear characteristics in accordance with ASTM standards. The created test arrangement has offered an affordable way to carry out the standard ASTM torsion test. The direction of twist under the applied torque is concurrently measured in a device for testing using material specimens with both solid and hollow round sections employed by the authors. The torque-twist diagram and the shear stress-strain diagram were both plotted using this data.

The failure mechanisms of the gearbox system on cars were investigated experimentally and numerically by H. Bayrakceken et al. Driveshaft and universal joint yoke failure analysis was done by the authors.

They came to the conclusion that the fracture is located where the joint yoke is since those are the areas under the most stress. The driveshaft's failure resulted from improper heating conditions, and the crack's starting points overlap with the areas that are under a lot of stress. Failure is accelerated by the slight stress concentration.

K. Saravanan et al. conducted an experimental vibration analysis of composite material shafts and beams using an accelerometer and laser vibration meter. According to the authors' findings, stacking and fibre orientation have an important effect on natural frequencies. The normal occurrence of the angle ply laminate is lower than the pass-ply lamination situations for the same number of layers. Compared to the speedometer and the laser vibrometer, the accelerometer is far more expensive.

The torsion test bed was created by Dongmei Yuan and colleagues to evaluate the torsion operation of a vehicle drive shaft. Through the angle-regulating device, this system completely mimicked the drive shaft's real operating condition. The driveshaft's rotational strength and rigidity might be determined using the test bed. An electronic control system and hydraulic loading device have been created by the authors.

According to the ASTM standard, Ibrahim M. E. et al. designed and built a manually operated torsion testing equipment. Pure iron, pure aluminum, and aluminum with 12% silicon alloy pieces of various radii and gauge widths have been manufactured and tested by the authors.

## Numerical simulation of the composite driveshaft

A. Boukhalfa et al. examined the rotating nanocomposite shaft's efficiency on rigid bearings over time. For evaluation, 10 layers of similar thickness and orientations (90°, 45°, -45°, 0°6, 90°) of the boron epoxy composite and the graphite epoxy composite were utilized. The framework was created by the authors using the hierarchy-based finite element approach with p-version. The authors have taken five bending modes from the analysis. Theoretical research was used to establish the axle's kinematic and strain energy, which is crucial for deriving the equations of motion. The binding effect, turning inertia, gyroscopic effects, and lateral deformation caused by shear during the production of hybrid layers have all been incorporated in this model.

To explore their behavior along with the contrast with practical and analytic results, Mahmood M. Shokrieh et al. estimated the buckling torque for composite driveshafts and verified their findings with finite element analysis. On the mechanical properties of composite driveshafts, the impact of support conditions, fiber position, and stack pattern has been studied. The authors came to the conclusion that a shaft's supporting circumstances do not significantly affect the buckling torque. Authors have demonstrated that the fiber direction and layer stacking arrangement for a shaft made of composites have a significant impact on the bending tension and that the square of the frequency spectrum reduces linearly as the force placed on the shaft's diameter increases.

In three different material combinations—metals (steel and aluminum), composites (CFRP and GFRP), and hybrids of metals and composites—H. B. H. Gubran examined the deformation of cross-section and dynamic performance of shafts. The transverse shear deformation and dynamic behavior were calculated using a layered degenerated finite shell element. Shafts with straightforward support with L/R or t/R ratios of 20 and 0.08 made of metals (steel and aluminum), composites (CFRP and GFRP), and plastics were taken into consideration. The mesh size employed was 6 4 for the shell finite element modeling (Fig. 3). Various shafts' dynamic behavior and section distortion were looked at.

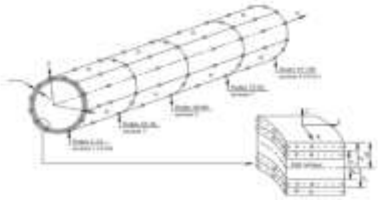

Figure 3: Finite element model of the laminated shaft

The writer came to the conclusion that the E1/ratio affects a shaft's inherent frequency. Steel and aluminum both behaved dynamically at the same level. With different fiber alignments, the ratio E1/ for composite fluctuates. It was highest at 0° and got smaller as it moved towards 90°. The basic frequencies of composite (CFRP or GFRP) shafts reached their highest value at a 0° fiber angle and decreased towards a 90° fiber position. For fibers aligned at 37°–38°, the dynamical efficiency of shafts made of (CFRP or GFRP) composite and (steel or aluminum) metal was the same. In comparison to metal, the motion efficiency of plastics (CFRP and GFRP) orientated at any angle was inferior.

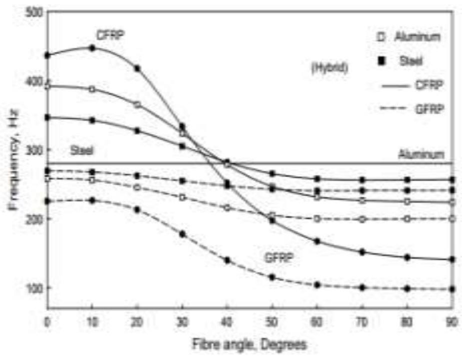


Figure 4: Dynamic performance of hybrid aluminum, steel, Various fiber orientations angles for CFRP and GFRP.

The outside and interior surfaces of these hybrid propellers were built using layers of metal made of aluminum or steel, while the middle surface was constructed using composite layers made of GFRP or CFRP. The initial frequency of a hybrid CFRP steel rod rose by 25% to 5%, respectively, depending on the fiber orientation angle (0°–36°). With a fiber orientation angle of 0°–36°, the default frequency of a hybrid CFRP aluminum shaft rose by 40% to 7%, respectively.The effects of fiber orientations, angles and plies stack pattern on the critical speed and crucial bending force were reproduced using a FE model created by M. A. Badie et al.

## Present theories and practices

An attempt was made by G. Raghavendra Rao et al. to anticipate the drive shaft's fatigue life using FEA technology. For a given piece of terrain, the load spectra operating on the driving shaft is estimated. The FE model of the drive shaft underwent structural analysis, and possible locations of significant stress concentration were identified. The outcomes of a fatigue study include Von Mises stress, tiredness harm, life under fatigue, factor of safety, and total deformation. The static study revealed that the provide a' roots are the places with the highest level of stress. The motor's shafts fail where there is an elevated level of anxiety, as predicted by fatigue analysis. The component's lifespan due to fatigue is discovered to be unbounded by design.The lifespan of the drive shafts is 69806 kilometers for a 40% overload and 20564 kilometers for a 50% overload, respectively. The current study can be utilized as an example in the automobile sector to forecast the lifespan of any part in the drivetrain of a car that is subject to quasi-constant frequency load.

The propeller's shafts, additionally referred to as the drive shaft, constitutes one of the most crucial parts of a car in its transfer of power, as stated by Nizam S. Sakeer et al. The shaft is split and linked to the main shafts at the rear axles. Power is transferred from the main shaft through a propeller shaft that rotates the back tyre, each time the primary axis rotates.

In order to attain an extended tyre base, automobiles employ long rotor shafts. At a certain speed, the shaft will begin to vibrate violently and create a horrific whirlwind. Its shaft's diameter was reduced as a result to diminish its intense vortices. Once a shaft's diameter is reduced, it can be separated, with the middle portion being positioned precisely using composite material. High strength and stiffness are characteristics of composite substances. Utilizing composite material, the propeller shaft of a "CHEVROLET TAVERA" vehicle is analyzed. $Al_2O_3$ and AlSiC alloys are used in this study, and SOLIDWORK and ANSYS are used for analysis.

The propeller shaft for the MARUTI OMNI was supplied by Salaisivabalan T. et al. in order to develop a shaft for its smallest size that meets the specifications for the present issue and then replace traditional steel materials by a composite material. The proposed design of the shaft for the propeller initially considers the safe dimensions for steel, carbon/epoxy, and glass/epoxy composite materials. The NX 8.5 software can then be used to produce them as part models for the right size. To determine that theoretic and analytical results are comparable, The torsional force buckling evaluation and modal analysis in the propeller shafts can be performed after modeling using NX NASTRAN. The three materials' outcomes are then compared, and a carbon/epoxy combination is chosen as a suitable substitute for traditional steel.

The proposals regarding the shaft propeller programme for Swedish Building Machinery, including guidelines for the use of modularization were provided by Annika Henrich and Nadja Suonperä. The effectiveness of decentralization depends, amongst other things, on specific documentation, regular interaction, and strong supplier cooperation. The goal of this project is to develop a separated shaft propeller programme for Volvo CE's wheeled loaders & haulers.

## Conclusions

Composite propeller shafts composed of glass and graphite resin are created to comply with the same safety standards as a regular iron shaft. The stretching, shear stress, Von-Mises stress, crucial velocity, bend frequency of nature, and weight are determined from the torsion buckling or modal analysis.  Glass adhesive and graphite epoxy have von Mises stresses that fall below safe levels, preventing breakage. The Deflection of carbon epoxy is lower. using composite materials Insignificant weight reductions of between 73 and 80% have been achieved using propeller shafts compared to steel shafts. Composites not only guarantee a reduction in vibration and noise, but also weight. As a result, an automotive propeller shaft made of carbon epoxy composite material will be used.

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