Analysis and Optimization of Composite Propeller Shaft for Automotive Applications

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Abstract. In the field of automotive engineering polymeric composites played vital role due to its outstanding properties such as high strength, low weight and high stiffness. The purpose of this research is to develop a single piece steel (Cr–Mo SCM440) drive shaft using computer aided modelling tool and finite element method was used for analysing static analysing and free vibration. These results were compared with the propeller shaft made by carbon and glass epoxy composites. ANSYS software is used for accomplish total deflection, natural frequency, and modal analyses. From this work it was noted that the propeller shaft made using carbon epoxy offered better results as compared with steel and glass epoxy composite propeller.

1. Introduction
In its most basic form, a composite material is a mix of two or more components. Advance composites have a long history, beginning in the aerospace industry in the 1970s, yet they are currently used in almost all industries after barely four decades [1]. It's possible that advancements in composite material properties, as well as new production technologies, have broadened its application range [2]. Metallic parts are being phased out in numerous sectors as technology progresses. The link between the transmission and the vehicle's rear axle is called a propeller shaft [3-5]. The car's complete driveline is made up of multiple components, each with its own rotational mass [6]. Three universal joints, a central supporting bearing, and a bracket make up the two-piece steel drive shaft, which adds weight to an automobile and reduces fuel economy. Because spinning larger pieces requires more energy, the power is lost [7].

The quantity of rotational mass can be lowered to reduce energy loss. To minimise weight and meet vibration requirements, a one-piece composite shaft can be made. The available power is transmitted more efficiently with a lower rotational weight [8]. This removes all assembly by joining the two-piece steel shafts, lowering overall weight, vibrations, and overall cost. Fuel usage will be lowered as a result of the weight loss. According to a report, the weight of the vehicle loses roughly 17-22 percent of the total energy produced by the engine.

As a result, several studies are being conducted to minimise vehicle weight by adopting light weight elements such as couplings, chassis, shafts with holes, and composite materials parts. This work is also linked to the same principle of reducing vehicle weight through the use of lightweight materials like carbon fibre and epoxy resin [9]. Steel or aluminium shafts have a shorter fatigue life than composite constructions. Composite materials may be designed to satisfy specific design requirements for strength and rigidity, and composite drive shafts are lighter than steel or aluminium drive shafts [10].

Most of the previous studies focus on only in weight reduction in propeller shaft using various metallic materials. In this current work automotive propeller shaft is made using modelling software. ANSYS software is used for analysing purpose. Total deflection, natural frequency, and modal analysis were done on the metallic propeller shaft made by steel (Cr–Mo SCM440). And these results were compared with the composite propeller shaft made by glass and carbon epoxy polymeric composite.
2. Materials and Methods

In this work three materials such as chromium molybdenum SCMM440 metallic material, carbon fibre reinforced epoxy composites and glass fibre epoxy composites were chosen for analysing the total deflection and natural frequencies in the propeller shaft [11,12]. Table 1 shows the chemical compositions and Table 2 shows the mechanical properties of SCMM 440 used for this research.

Table 1 Chemical compositions (wt. %) of SCMM 440

|     | C    | Si   | Cr   | Ni   | Mn   | Mo   | P    | Cu   | S    |
|-----|------|------|------|------|------|------|------|------|------|
|     | 0.43 | 0.35 | 0.90 | < 0.25 | 0.60 | 0.15 | 0.60-0.8 | 0.3  | < 0.03 |

Table 2 Mechanical properties of SCMM 40 material

| Description           | Properties |
|-----------------------|------------|
| Yield strength (MPa)  | 843        |
| Tensile strength (MPa)| 1020       |
| Elongation (%)        | 12         |
| Hardness              | 302-350    |

2.1 Polymer composite Material

Polymer matrix composites are the most often utilised advanced composites. These composites are prepared of a polymer and thin-diameter fibres (carbon, glass). They are most widely employed in the repair of aircraft structures because of their low cost, great strength, and easy production methods. Composite laminates are non-homogeneous, anisotropic material [13,14]. In this work carbon fibre and glass fibre reinforced polymer composites are used for comparing the metal propeller shaft. Table 3 shows the mechanical properties of carbon and glass fibre reinforced polymer composites used for this investigation.

Table 3 Mechanical properties of polymeric composites used for this investigation

| Specifications         | E- Glass fibre | Carbon fibre |
|------------------------|----------------|--------------|
| Poisons ratio          | 0.21           | 1.2          |
| Density (g/cm³)        | 1.75           | 4.1          |
| Youngs Modulus (GPa)   | 72             | 87           |
| Tensile strength (MPa) | 3440           | 3590         |

2.2 Basic Composite Theory

In recent years, laminate composites have become increasingly popular in lightweight, high-strength constructions including ground transportation vehicles, aeroplanes, and space structures. However, composite materials have certain major drawbacks. The reaction to impact loading is the most important of these. When a foreign item collides with a structure, it creates an impact force [15-17].

In its simplest form, a composite material is one that is made up of at least two components that interact together to provide material qualities that are distinct from those of the individual constituents. In practise, most composites are made up of a bulk material and some form of reinforcement, which is added to boost the matrix's strength and stiffness. Typically, this reinforcement is in the form of fibres.
2.3 Reinforcing

Reinforcement adds strength and rigidity, as well as regulating the thermal expansion coefficient. It also aids in the attainment of directional qualities. Fibres, particles, or flakes can be used as reinforcements. The body and yoke sections are built of a fibre reinforced composite material that consists of a filament and a plastic that is attached to the filament[18]. In general, the fibre reinforcing effect of a fibre reinforced composite material decreases as the filaments that make up the composite material are bent more sharply. When the rotational speed is modest or the required characteristics, such as torsional strength, heat resistance, and moisture resistance, are low, the reinforced fibre can be glass fibre or aramid fibre alone, and the matrix resin can be a resin other than epoxy resin [19].

2.4 Modelling of propeller shaft using Ansys

The distinction of the material is based on mechanical qualities, however there is no clear border between the two. Polyester resins reinforced with low-strength glass fibers are commonly used to make reinforced plastics. The development of the material itself is frequently included into the manufacturing process when fabricating and molding polymer matrix composites into final items [20]. Examples of these processes are Lay-up by hand, molding in a vacuum, Lay-up using a spray gun, pultrusion and filament winding. Table 4 shows the fiber system codes used for modelling the propeller shaft in Ansys.

| CODE | FIBER |
|------|-------|
| AIO  | Alumina |
| Ar   | Aramid |
| B    | Boron |
| C    | Carbon |
| GI   | Glass |
| DGI  | D-Glass |
| EGI  | E-Glass |
| GR   | Graphite |
| Li   | Lithium |

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The following parameters such as mean radius, length, thickness of hallow shaft, thickness of fibre and angle of fibre orientation. Propeller shaft was idealised as shaft for modelling the shaft as cylindrical tube. Layers were defined from bottom to top. In this work general shell 98 element was selected for meshing purpose. The shape of the element was ‘quadrilateral’. After creating FEM mesh of nodes and elements, nodes were merged. The geometric model was verified for geometric check, bad element check. The material used is glass fiber reinforced in epoxy matrix and carbon fiber reinforced in epoxy matrix. The pad command in the sketch-based features toolbar was used to pad this sketch by 22.5mm on both sides [24,25]. As indicated in Fig 1, tritangent fillet is now applied to both yokes. The contour between the yokes is created with the same tritangent fillet. Figure 2 shows the meshed view of composite propeller shaft used for this current investigation.

![Figure 2 Geometrical view of mesh covered shaft](image)

The propeller shaft is optimized using finite Element (FE) analysis with the help of ANSYS software. Figure 3 shows the total deflection obtained in the composite propeller shaft.

![Figure 3 Total deformation of stainless steel](image)
3. Result and Discussion

3.1 Static Analysis

Static load was analysed for the three different materials such as steel (Cr–Mo SCM440), glass and carbon fibre composites of the composite propeller shaft. Table 4 explained the influence of wall thickness of the propeller shaft on angle of twist. From the figure it was noticed that comparing with steel and glass propeller shaft, carbon fibre offered good angle of twist. In carbon fibre offered more resistance before get fractured.

![Wall thickness vs Angle of Twist](image1)

**Figure 4** Angle of twist in composite propeller shaft

3.2 Weight reduction over buckling torque

In Ansys software mass calculation was done for the three different materials used in propeller shaft. Figure 5 it was observed that the propeller shaft made with carbon fibre composite weight is less as compared with other two. From the above discussion it was noted that the propeller shaft made with carbon fibre composite weight is less.

![Mass of composite propeller shaft](image2)

**Figure 5** Weight comparison of propeller shaft for three different materials
4. Conclusion

An automobile's high-strength aluminium alloy-based drive shaft must be designed and replaced with a normal steel drive shaft. A one-piece composite drive shaft for rear-wheel-drive cars was built with ANSYS for high-strength aluminium alloy with the purpose of lowering shaft weight. The projected findings might be positive, implying that it can be employed successfully and efficiently in other complicated and realistic designs that are frequently encountered in engineering applications. When a composite shaft is utilised instead of a traditional hollow steel shaft as the propeller shaft of a vehicle, the weight of the shaft is decreased by 26%. Single-piece shafts can be created using composite materials. The power loss then goes down. The projected findings might be positive, implying that it can be employed successfully and efficiently in other complicated and realistic designs that are frequently encountered in engineering applications.

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Conflict of Interest

The authors declare no conflict of interest.

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