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Comparative Analysis of Conventional Steel and Composite Drive Shaft

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Abstract: *Nowadays, diverse engineering applications have been seeing an abundant usage of composite materials in various technologies. Since the drive shaft is a significant component of an automobile, its weight reduction can be crucial in fuel efficiency and more outstanding performance. The work involves substituting composite drive shafts instead of steel drive shafts. This research paper undertakes the investigation of advanced composite materials such as E-Glass/Epoxy, HM-Carbon/Epoxy, and HS-Carbon/Epoxy to evaluate the feasibility of composite material to fulfill the objective automobile drive shaft by evaluating stresses and deflection under subjected load using FEA software ANSYS for given composite material and compared with steel drive shaft to verify optimum results. The results indicate that the replacement of the steel shaft with HS-Carbon/Epoxy composite will yield weight savings of up to 78.94 %.*

Keywords: *Driveshaft, Weight optimization, Composites, ANSYS*

I. INTRODUCTION

A drive shaft is a rotating machine element that transmits the power generated by the engine to the differential from the transmission to effectively propel the vehicle in forward or backward motion. Often referred to as cardan or propeller shaft. Design characteristics have a hollow tubular design. Three different types of drive shafts are generally employed in an automobile, namely i) single piece, ii) double piece, iii) front wheel drive [1]. In established usage, steel is employed for manufacturing the drive shaft. Since drive shafts are subjected to torsion and shear stress while in rotation, they must be sufficiently strong enough to withstand combined loading without failure. Additionally, the drive shaft must be able to function accordingly during periods of fluctuating load, and the continually varying angles between the transmission and the axles require the drive shaft to perform accurately [2]. One of the most important considerations while designing the drive shaft is to account for the altercation in length due to braking and road deflection. Due to the low fundamental frequency of the metallic shaft, it is required to be manufactured in two pieces, thus increasing the overall weight [3]. Investigating the metallic drive shaft, we further get to know crucial constraints such as i) heavyweight, ii) poor corrosive resistance, iii) low specific modulus and strength [4]. Thus, it gives us the means to research and find alternate materials which can overcome these constraints and replace the steel drive shaft. Composites are alternative materials that have been in use extensively in automobile industries. Composites can be specifically altered respectively according to design requirements. Materials having perceptible macroscopic association (between two or more) can be exemplified as composites [5]. Composites are preferred due to their greater strength and high stiffness-to-weight ratio: increased fatigue resistance, better torque transmission capacity, and corrosion resistance [6]. The employment of composite results in the manufacturing of the drive shaft in a single piece, thus achieving weight reduction and design optimization.[7]

A. Aim and scope of the work

This study performs analysis on three different composite materials using FEA software Ansys for stresses, deformation, and weight, and the result is compared with conventional steel drive shaft to determine the most appropriate material for the shafting purpose and to create an adequate technological foundation for successfully designing, specifying, and manufacturing composite shafting in future automobiles, as well as to demonstrate the technology's feasibility.

II. METHODOLOGY

The methodology followed in this work is as follows:

1. A comprehensive examination of the driveshaft's loading and operation parameters.
2. Obtaining all the dimensions of existing driveshafts for automobiles.
3. Obtaining the boundary conditions required for analysis.
4. Development of 3-D model in PTC CREO 8.0.3.
5. The analysis of the above model has been performed in ANSYS 2022 R1, by considering the model material as a traditional steel drive shaft.
6. The drive shaft is analyzed for the composite materials using the same boundary condition.
7. Then we must compare the results for all the materials to determine which one is the best material for the drive shaft.

III. SOLID MODELLING & MATERIAL PROPERTIES

The model has been developed by utilizing the designing software PTC CREO 8.0.3 considering the dimensions mentioned in table 1. Mechanical properties of steel and different composite materials have been depicted in table 2 and table 3, respectively.

IV. DESIGN SPECIFICATION

Torsion is the principal load transmitted by the drive shaft. Therefore the drive shaft must be developed with adequate torsional strength to safely carry the torque. Due to space constraints, the drive shaft's outer diameter should not exceed 100 mm. The shaft's outer diameter is set to 90 mm in this example. The value of ultimate torque is defined as 2030 N-m; this value is obtained from a medium truck engine having an engine producing power higher than 260 KW or 350 HP, measured at a low speed of 1200 rpm.[10]

Table 1: Design parameters of the drive shaft.

S. No.	**Specification of the shaft**	**Notations**	**Value**	**Unit**
1	Outside Diameter	D	90	mm
2	Inside Diameter	d	83	mm
3	Length	L	1250	mm
4	Thickness	t	3.5	mm

Table 2: Mechanical properties of Steel SM45C. [8]

S.No.	**Mechanical Properties**	**Notations**	**Value**	**Unit**
1	Young's Modulus	E	207	GPa
2	Shear Modulus	G	80	GPa
3	Poisson's Ratio	μ	0.3	-
4	Density	ρ	7600	kg/m^3
5	Yield Strength	σ_y	370	MPa

Table 3: Mechanical properties of composite materials. [9]

S.No.	**Mechanical Properties**	**Notations**	**Units**	**E-Glass/ Epoxy**	**HS Carbon/ Epoxy**	**HM Carbon/ Epoxy**
1	Longitudinal Elastic Modulus	E_X	GPa	50	134	190
2	Transverse Elastic Modulus	E_Y	GPa	12	7	7.7
3	Shear Modulus	G_{XY}	GPa	5.6	5.8	4.2
4	Density	ρ	Kg/m^3	2000	1600	1600
5	Poisson's Ratio	μ	-	0.3	0.3	0.3

V. FINITE ELEMENT ANALYSIS (FEA)

Finite Element Analysis (FEA) is a computer-based numerical tool for quantifying the strength and behavior of engineering structures. It can be used to compute deflection, stress, vibration, buckling behavior, and other parameters. The FEA software ANSYS 2022 R1 was used to perform finite element analysis in this project. The static structural evaluation was carried out on both steel and composite driveshafts using the dimensions and material parameters listed in Tables 1, 2 & 3.

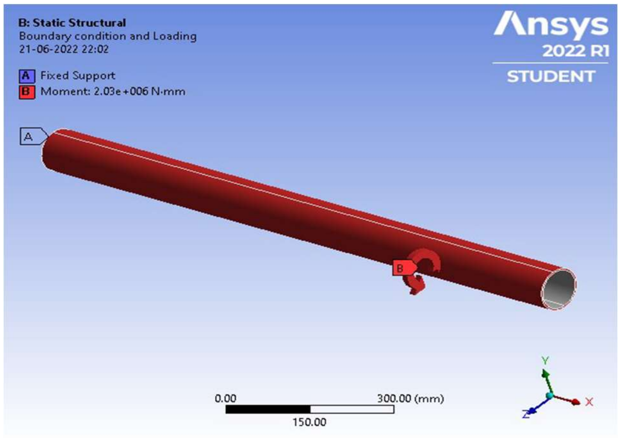

Figure 1: Boundary and loading parameters

The model has been developed by utilizing the designing software PTC CREO 8.0.3 as shown in Figure 1, considering the dimensions mentioned in Table 1. The boundary and loading conditions applied are shown in Figure 1.

A. Findings of Finite Element Analysis

The following mechanical properties have been analyzed for both the steel and composite material drive shaft:

1. *Equivalent Stress (Von Mises).*
2. *Maximum Shear Stress.*
3. *Total Deformation.*

1. Equivalent Stress (Von-Mises)

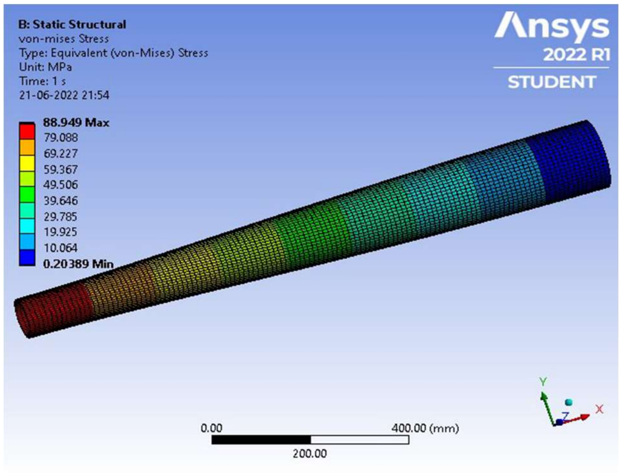

Figure 2:SM45C steel drive shaft

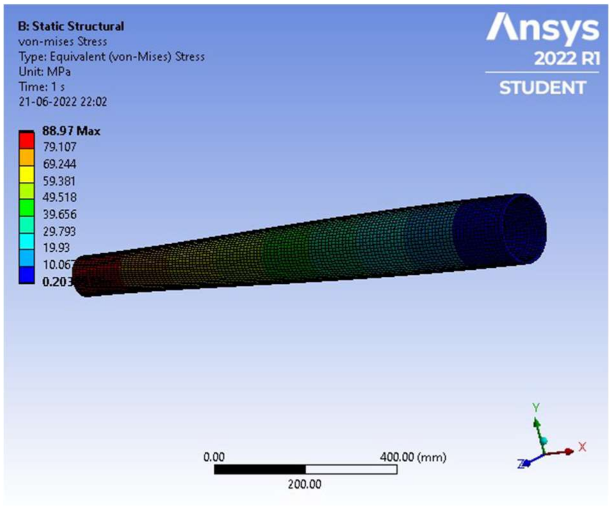

Figure 3: E-Glass/Epoxy drive shaft

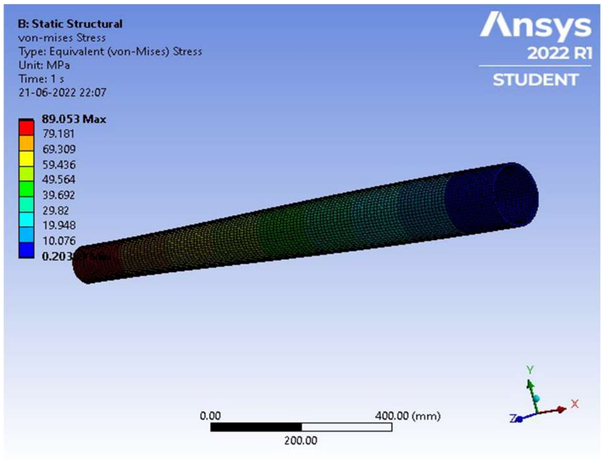

Figure 4: HS-Carbon/Epoxy drive shaft

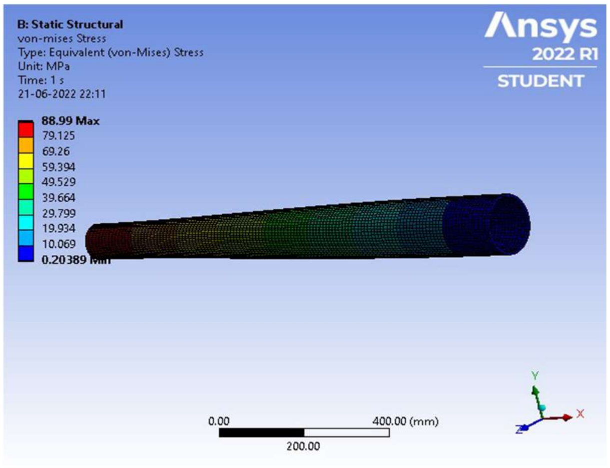

Figure 5: HM-Carbon/Epoxy drive shaft

2. Maximum shear stress

Figure: 6,7,8,9 represents the maximum shear stress induced in the respective materials

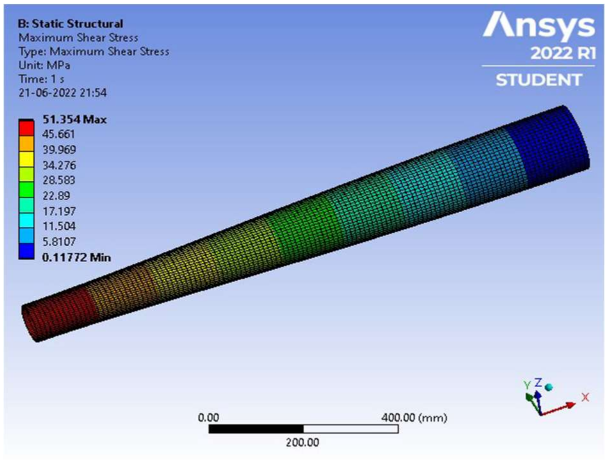

Figure 6: SM45C steel drive shaft

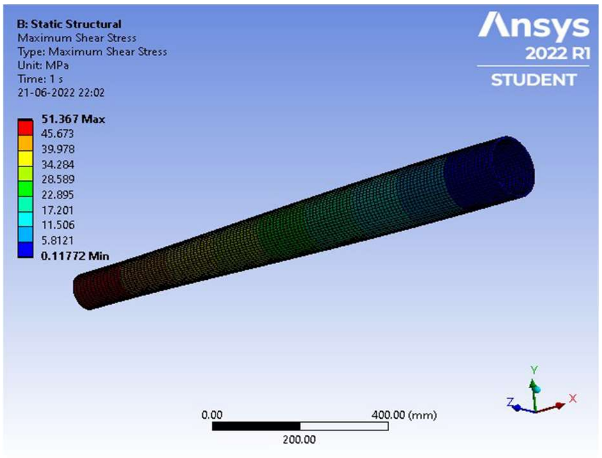

Figure 7: E-Glass/Epoxy drive shaft

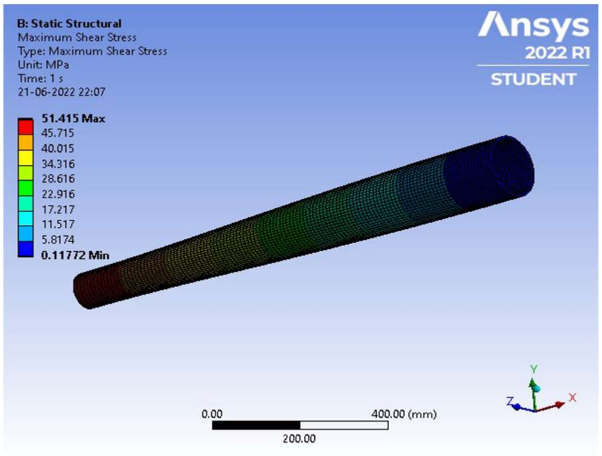

Figure 8: HS-Carbon/Epoxy drive shaft

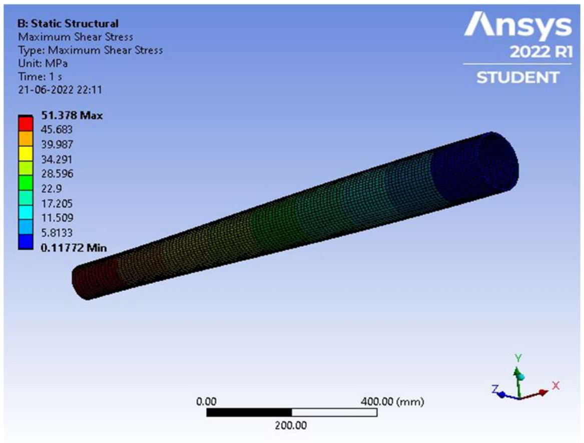

Figure 9: HM-Carbon/Epoxy drive shaft

3. Total deformation

Figure 10,11,12,13 represents the total deformation in the respective material when subjected to torsion.

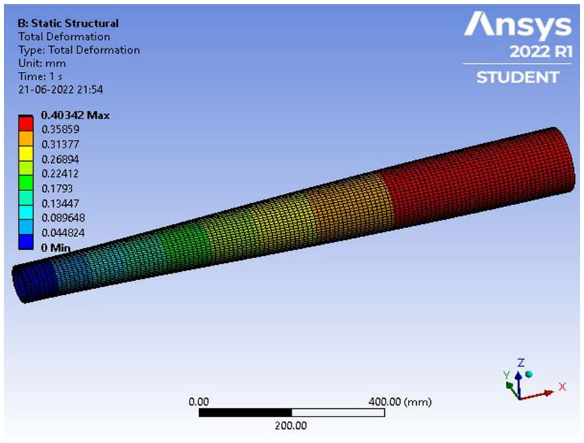

Figure 10: SM45C steel drive shaft

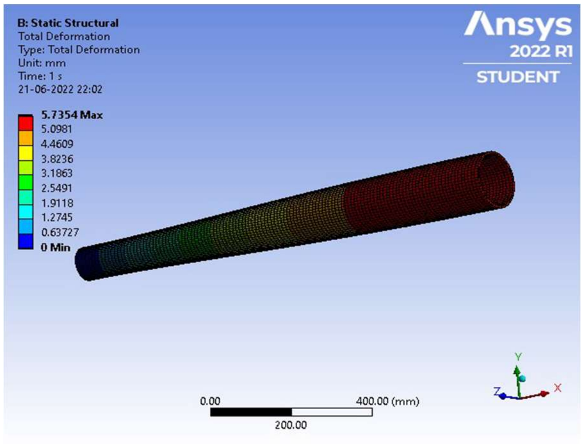

Figure 11: E-Glass/Epoxy drive shaft

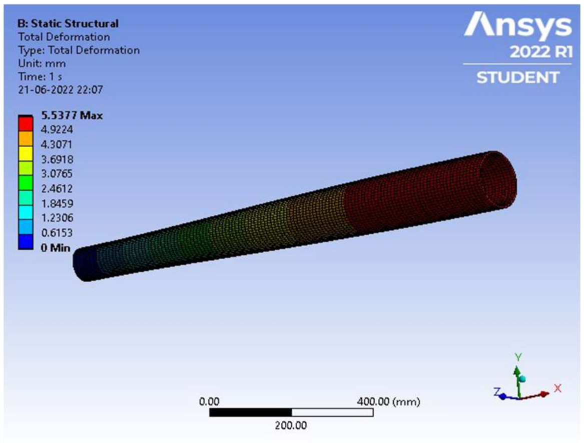

Figure 12: HS-Carbon/Epoxy drive shaft

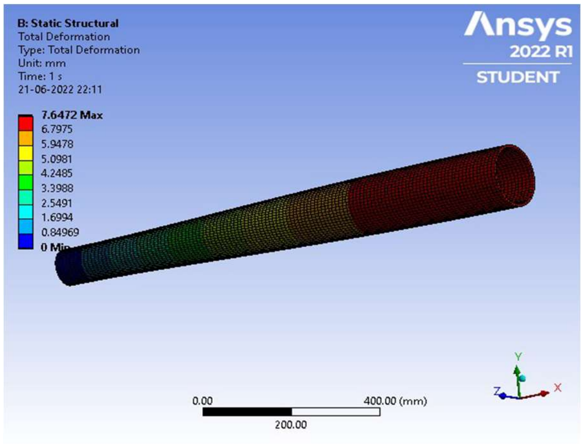

Figure 13: HM-Carbon/Epoxy drive shaft

VI. RESULTS

The results obtained from the FEA method by analyzing stresses and deformation induced in drive shafts when subjected to torsion for different materials are tabulated in Table 4. By observing the results obtained, it can be perceived that the stresses induced in the respective materials are well within their allowable limits; furthermore, composite materials demonstrate slightly increased deformation and a significant weight reduction in the shafts when either of the composite material is selected.

VII. COMPARISON OF RESULTS

1. The study corresponds to replacement of steel drive shaft with E-Glass/Epoxy, the results indicate maximum Von Mises stress of 39 MPa and a maximum weight reduction of 82 % [11].

Table 4: FEA results of steel and composite drive shafts

S.No.	Parameters	SM45C Steel	E-Glass/ Epoxy	HS-Carbon/ Epoxy	HM-Carbon/ Epoxy	Units
1	Equivalent Stress (Von Mises)	88.949	88.97	89.053	88.99	MPa
2	Maximum Shear Stress	51.354	51.367	51.415	51.378	MPa
3	Total Deformation	0.4032	5.7354	5.5377	7.6472	mm
4	Weight	8.9328	2.3507	1.8806	1.8806	Kg

2. The author's work studies the replacement of metallic shaft with the likes of composites namely; Carbon/Epoxy & Glass/Epoxy. The von Mises stress induced in the Carbon/ Epoxy is 35.56 MPa and in Glass/ Epoxy is 31.673 MPa, which is within the permissible stress limit both having factor of safety 2.81 and 2.36 respectively [12].

VIII. CONCLUSION

1) The premise of the project was to carry out weight optimization by substituting the steel drive shafts in an automobile to enhance fuel efficiency. Thus, we achieved a minimum weight saving of 73.69 % (E-Glass/Epoxy) and a maximum weight saving of 78.94 % (HS-Carbon/Epoxy) when replaced by the composite drive shaft.

2) By scrutinizing FEA results for the composite and steel shafts, considering the same boundary conditions, obtained data reflect stresses induced in the composite materials are in a similar range as that of the steel shaft.

3) Analyzing the FEA results obtained, the induced stresses are well within the allowable stress limits in all the materials.

4) The composite drive shaft can be manufactured as a single piece and are light weighted in comparison to the steel shaft, which needs to be manufactured in two pieces; hence we also achieve design optimization.

5) Finally, from the above discussions and result evaluation, we can conclude that the feasibility of replacing the steel drive shaft with an HS-Carbon/Epoxy composite shaft will have maximum advantage.

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