FEA SIMULATION OF COMPOSITE PROPELLER SHAFT OF AUTOMOBILE

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ABSTRACT
In the process of designing a vehicle, one of the most important objectives is the conservation of energy and the most effective way to obtain this goal is the reduction of weight of the vehicle. There is almost a direct proportionality between the weight of the vehicle and its fuel consumption, particularly in city driving. The advanced composite materials seem ideally suitable for long power drive shaft (propeller shaft) applications as their elastic properties can be tailored to increase the torque they carry as well as the rotational speed at which they operate. In this paper, the conventional drive shaft material has been replaced with advanced composites and hybrid materials to carry out a comparative analysis, thus determining the most suitable replaceable material.
Keywords: Composite material, Propeller shaft, Elastic properties, Conventional drive, Hybrid materials.

1. INTRODUCTION
Almost all automobiles which correspond to design with rear wheel drive and front engine installation use a drive shaft for the transmission of motion from the engine to the differential. The static torque transmission capability of the propeller shaft for passenger cars, and small truck and vans should be larger than 3500 Nm and the fundamental bending natural frequency should be higher than 8000 rpm to avoid whirling vibration, By using advanced composite materials, the weight of the drive shaft assembly can be tremendously reduced.

2. OBJECTIVE
The aims of the paper to reduce the weight of the drive shaft assembly by using advanced composite materials. For this project work, the drive shaft of a Toyota Qualis was chosen. The modeling of the drive shaft assembly was done using CATIA V5R16. A shaft has to be designed to meet the stringent design requirements for automobiles. A comparative study of five different materials was conducted to choose the best-suited material. Theory with the help of a code written in C language. The analysis was carried out using ANSYS 11.0 WorkBench for the following materials at three different ply orientations $[0/30]_{8S}$, $[\pm 45]_{8S}$ and $[0/90]_{8S}$, The first was Steel (SM45C) which was used for reference purpose Two Composites, Boron/Epoxy, Kevlar/Epoxy.

3. BACKGROUND
Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. The constituents are combined at a macroscopic level and are not soluble in each other.. One constituent is called reinforcing phase and the one in which the reinforcing phase is embedded is called matrix. Historical or natural examples of composites are abundant: brick made of clay reinforced with straw, mud wall with bamboo shoots, concrete, granite consisting of quartz, mica and feldspar, wood (cellulose fibers in lignin matrix), etc.

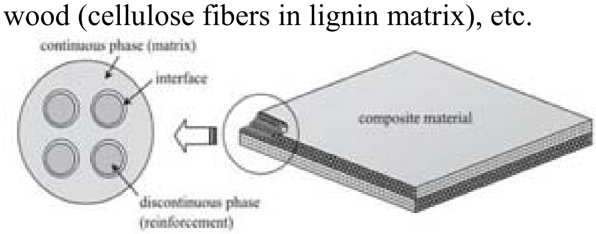


Fig 1 Composite Material

Advanced composite materials are refereed to those composite materials developed and used in the aerospace industries. They usually consist of high performance fibers as reinforcing phases and polymers or metals as matrices. Examples are carbon or graphite fiber/epoxy, glass fiber/epoxy, boron fiber/aluminum, boron fiber/titanium, etc. Hybrid composites are usually multi-layered (laminate) with mixed fibers.

4. Drive Shaft

The shafts, which propel (push the object ahead) are referred to as the propeller shafts. Propellers are usually associated with ships and planes as they are propelled in water or air using a propeller fan. The shaft is the primary connection between the front and the rear end (engine and differential) which performs both the jobs of transmitting the motion and propelling the front end.

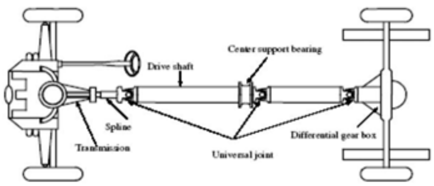


Fig 2.Schematic arrangement of Underbody of an Automobile

A propeller shaft is an assembly of one or more tubular shafts connected by universal, constant velocity or flexible joints. The number of tubular pieces and joints depends on the distance between the gearbox and the axle. The second propeller shaft is placed between a transfer gearbox and the front axle. The torque that is produced from the engine and transmission must be transferred to the rear wheels to push the vehicle forward and reverse. Vibration is the most common drive shaft problem. Small cars, short vans and trucks (LMV) are able to use a single drive shaft with a slip joint at the front end without experiencing any undue vibration. Transverse vibration is the result of unbalanced condition acting on the shaft for example, a critical whirling speed of 8000 rev/min is doubled in length, the critical whirling of the new shaft will be reduced to a quarter of this, i.e. the shaft will now begin to rotate at 2000 rev/min. Increasing the diameter of the shaft could solve the vibration problem, but this would increase its strength beyond its torque carrying requirements and at the same time increase its inertia, which would oppose the vehicle's acceleration and deceleration

5. THEORETICAL AND SIMULATED RESULTS CORRELATION

Fig 3: Torque applied to the Hollow shaft

A comparison between the results obtained based on theoretical calculations and the results obtained from the ANSYS 11.0 Work-Bench have been carried out. The drive shaft of the automobile has been idealized as a hollow cylindrical shaft. It is then subjected to the same load theoretically and in the finite element solver. The comparison of results shows a very close range conformance, which has been plotted.

5.1 Theoretical Calculations for Hollow Shaft

The Drive shaft, for simplicity has been first idealized as a hollow cylindrical shaft which is fixed at one end and on which a torque of 3500 Nm is applied as represented below.

For the hollow shaft, $R_o = 0.01$ m ; $R_i = 0.02$ m ; l = 0.5 m ; E = 207e9 pa and Torque=3500 Nm Where R_o = Outer Radius, R_i = Inner Radius, L = Length of the shaft , E = Young's Modulus of Steel (SM45C), T = Applied Torque

$$\text{Deflection} = Y_{Max} = \frac{M\,L^2}{2EI} = \frac{3500 \times (0.5^{2})}{2 \times (207e^{9}) \times (1.178e^{-7})}$$

$$= 0.0179\text{m}$$

Maximum Shear Stress :

$$\tau_{Max} = \frac{T \times R_o}{J}$$

$$= \frac{3500 \times 0.02}{[\Pi/2] \times [R_o^{4} - R_i^{4}]}$$

$$= \frac{70}{2.35626 \times 10^{-7}}$$

$$= 2.9708\text{ e }8\text{ Pa}$$

Maximum Von-Misses Stress:

$$= \frac{[T \times (d_o/2)]}{I}$$

$$= \frac{3500 \times (0.04/2)}{[\pi/64]\times[(0.04)^{4}-(0.02)^{4}]}$$

$$= 594178454.2$$

$$= 5.9417\text{ e }7\text{ Pa}$$

6. Simulated Results for Hollow Shaft

The derived theoretical results are now going to be compared to the simulated results. For which, a hollow shaft with the same specifications was created in CATIA V5R17. This CATIA model was then imported into ANSYS 11.0 Workbench, wherein the model was analyzed. Torsional load was applied by fixing one end of the shaft and applying torque on the other end. The results were found to be very close to the theoretically calculated values. The results are as follows.

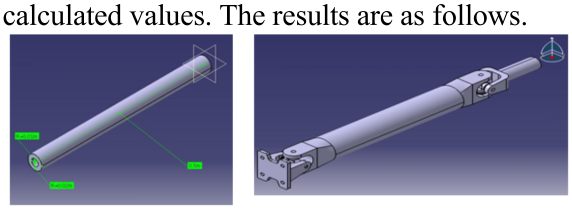
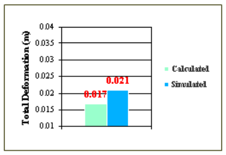


Fig 4: CATIA model of the hollow shaft& Assembly

Reality the drive shaft is not a simple hollow cylinder, but a complex assembly of a number of parts. Assembly of parts which makeup the drive shaft assembly was modeled using CATIA software. The drive shaft of Toyota Qualis was chosen for determining the dimensions. The entire assembly was created in CATIA V5R17.The hollow shaft is made-up using the same dimensions, which are R_o = 0.01 m ;R_i = 0.02 m , l = 0.5 m , E = 207e9 pa , and Torque=3500 Nm.

Comparison between theoretically calculated and simulated values:



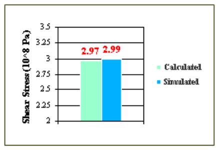


Fig 5: Comparison between theoretically calculated and simulated values:

Comparison of Total Deformation of the shaft & Comparison of Shear Stress of the shaft The fundamental natural bending frequency for passenger cars, small trucks, and vans of the propeller shaft should be higher than 6,500 rpm to avoid whirling vibration and the torque transmission capability of the drive shaft should be larger than 3,500 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations. The drive shaft of transmission system is to be designed optimally for following specified design requirements as shown in Table-1.

Mechanical properties	Symbol	Units	Steel
Young's Modulus	E	GPa	207.0
Shear modulus	G	GPa	80.0
Poisson's ratio	ν	-----	0.3
Density	ρ	Kg/m³	7600
Yield Strength	S_y	MPa	370
Shear Strength	S_s	MPa	--

Table 1: Design Requirements.

The material properties of the composite drive shaft are analyzed through the classical lamination theory. The linear elastic response of laminated composite incorporates the assumption of Kirchhoff for bending and stretching of thin plates beside the assumption that each layer is in state of plane stress. the first step is the construction of the reduced stiffness matrix. The expressions of the reduced stiffness coefficients Q_{ij} in terms of engineering constants are as follows.

For an angle-ply lamina, as shown in the figure, where fibers are oriented at an angle with the positive X-axis (longitudinal axis of shaft), and the stress strain relationship is different. Whenever the angle θ = 0° or θ = 90°, then Q_{16} = Q_{26} = 0. σ and ε represent normal stresses and strains in X, Y and XY directions

$$\begin{Bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{Bmatrix}=\begin{bmatrix}\frac{1}{E_1} & -\frac{\nu_{12}}{E_1} & 0\\ -\frac{\nu_{21}}{E_2} & \frac{1}{E_2} & 0\\ 0 & 0 & \frac{1}{G_{12}}\end{bmatrix}\begin{Bmatrix}\sigma_1\\ \sigma_2\\ \sigma_{12}\end{Bmatrix} \quad \begin{Bmatrix}\sigma_1\\ \sigma_2\\ \sigma_{12}\end{Bmatrix}=\begin{bmatrix}\frac{E_1}{1-\nu_{12}\nu_{21}} & \frac{\nu_{12}E_2}{1-\nu_{12}\nu_{21}} & 0\\ \frac{\nu_{21}E_1}{1-\nu_{12}\nu_{21}} & \frac{E_2}{1-\nu_{12}\nu_{21}} & 0\\ 0 & 0 & G_{12}\end{bmatrix}\begin{Bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{Bmatrix}$$

Or by the stiffness matrix [C] such that

$$[\sigma] = [C][\varepsilon]$$

$$[\varepsilon] = [S][\sigma]$$

respectively and bar over Qij matrix denotes transformed reduced stiffness. For a symmetric laminate, the B matrix vanishes and the in plane and bending stiffness are uncoupled, Where Nx, Ny, Nxy are referred

Property	Units	Stacking Sequence		
		$[0/30]_{8s}$	$[\pm 45]_{8s}$	$[0/90]_{8s}$
Longitudinal Modulus (E11)	Gpa	281.86	281.86	281.86
Transverse Modulus (E22)	Gpa	10.88	10.88	10.88
Shear Modulus (G12)	Gpa	4.124	4.1234	4.1234
Young's Modulus in X- Direction (Exx)	Gpa	281.86	33.66	155.7
Young's Modulus in Y- Direction (Eyy)	Gpa	10.88	27.12	137.59
Major Poisson's Ratio (Vxy)		0.2451	0.2451	0.2451
Minor Poisson's Ratio (Vyx)		0.0095	0.0095	0.0095
Shear Modulus in XY Direction (Gxy)	Gpa	4.1234	67.4925	4.1235

Property	Units	Stacking Sequence		
		$[0/30]_{8s}$	$[\pm 45]_{8s}$	$[0/90]_{8s}$
Longitudinal Modulus (E11)	Gpa	95.71	95.71	95.71
Transverse Modulus (E22)	Gpa	10.45	10.45	10.45
Shear Modulus (G12)	Gpa	4.03	4.03	4.03
Young's Modulus in X- Direction (Exx)	Gpa	95.71	14.12	56.33
Young's Modulus in Y- Direction (Eyy)	Gpa	10.46	14.14	50.59
Major Poisson's Ratio (Vxy)		0.34	0.34	0.34
Minor Poisson's Ratio (Vyx)		0.037	0.037	0.037
Shear Modulus in XY Direction (Gxy)	Gpa	4.03	25.08	4.03

Table:2 Material Properties of Boron/Epoxy Composite & Kevlar/Epoxy Composite

Kevlar/Epoxy with Ply Orientation: [0/30]$_{8\ s}$

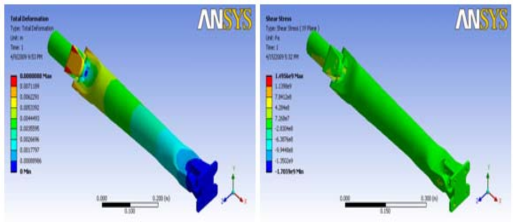


Fig 7: Deformation and shear stress of Kevlar/Epoxy.

Frequency Response of Boron/Epoxy, Ply Orientation: [0/30]$_{8\ s}$

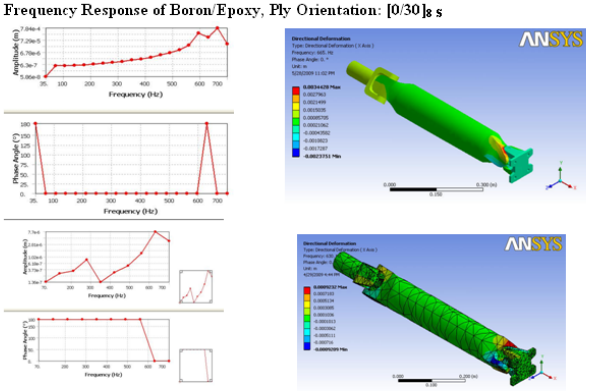
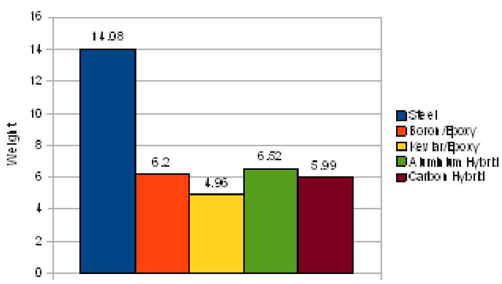
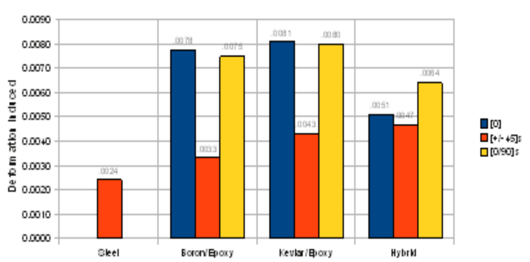


Fig 8: Frequency Response of Boron/Epoxy.

9.1 COMPARATIVE ANALYSIS & OBSERVATIONS:





The Kevlar/Epoxy Composite has shown the maximum reduction in weight followed by Carbon Hybrid, Boron/Epoxy Composite and finally Aluminium Hybrid. The percentage weight savings of each material is given as follows Kevlar/Epoxy Composite – 65 %, Carbon Hybrid – 57.5 %, Boron/Epoxy Composite – 55.9 %, Aluminum Hybrid – 54 %.

9.2 Deformation induced in the 5 materials due to torque

The following graph illustrates the total deformation caused in the assembly due to the application of a torque of 3500 Nm (the rated load for passenger cars).Two Conclusions can be drawn from the following graph. (1) It was found that though Steel had the minimum deflection and very closely by Boron/Epoxy Composite.(2) The Variation in ply orientations helps us to know that the ply orientation [+/-45]$_{8\ s}$ gives the least amount of deflection when compared to the other two orientations.

9.3 Shear Stress induced in the assembly due to the application of 3500 Nm Torque:

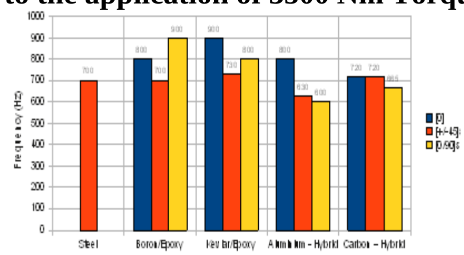


Fig 11. The Shear Stress distribution also confirms with the above conclusions,

The ply orientation [+/-45]$_{8\ s}$ gives the least amount of shear stress. After Steel, Boron/Epoxy shows the minimum induction of shear stress followed very closely by Kevlar/Epoxy. The graph shows the frequencies at which the maximum amplitude occurred in Harmonic Analysis. The resonant frequencies do not show any specific trend based on the changes of ply orientations, however Boron/Epoxy and Kevlar/Epoxy show a comparatively higher frequency range when compared to other materials, including steel.The observations that throughout the various parameters, analyzed for all the materials, Boron/Epoxy and Kevlar/Epoxy Composites have shown a remarkable similarity in their results. Kevlar/Epoxy has been found to be 1.24 kg lighter than Boron/Epoxy.

10. CONCLUSION

A total of five materials were chosen for the comparative analysis, including steel, which was used for reference. The usage of composite materials has resulted in considerable amount of weight saving in the range of 65% to 54% when compared to conventional steel shaft. Deformation, shear stress induced and resonant frequencies it is evident that Kevlar/Epoxy composite has the most encouraging properties to act as the replacement for steel out of the considered five materials. And the best suitable ply orientation is [+/- 45°].

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