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DESIGN AND STRUCTURAL ANALYSIS OF DRIVE SHAFT BY USING COMPOSITE MATERIALS

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ABSTRACT

Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of composite materials. This work deals with the replacement of conventional two piece shaft with a single piece composite shaft for an automotive application. The advanced composite materials such as Boron, Carbon, and Kevlar with suitable resins are widely used now a days for automotive and other industrial applications especially for rotor applications because of their high specific strength (strength/density) and high specific modulus (modulus/density). Polymer matrix composites were proposed for light weight shafts in drivelines for automotive, industries. Present work is conducted to analyze the composite drive shaft model of Toyota Quails, which is used for four wheel rear drive passenger cars. Boron/Epoxy, Kevlar/Epoxy, Aluminium-Boron/Epoxy and Carbon-Kevlar/Epoxy drive shafts are analyzed taking into consideration of the dimensional proportionality. Finally, considering the Density, Maximum Shear stress, Total Deformation from the analysis, Kevlar/Epoxy is acceptable to use instead of steel for the Toyota Qualis driveshaft.

1 DRIVE SHAFT

The term Drive shaft is used to refer to a shaft, which is used for the transfer of motion from one point to another. Whereas 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. However the drive shaft of the automobile is also referred to as the propeller shaft because apart from transmitting the rotary motion from the front end to the rear end of the vehicle, these shafts also propel the vehicle forward. 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. Thus, the terms Drive Shaft and Propeller Shafts are used interchangeably.

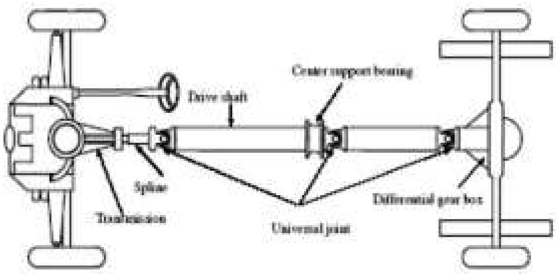

Fig 1Schematic arrangement of Drive shaft under body of an Automobile

In other words, a propeller shaft (Figure 1.3) is a longitudinal driveshaft used in vehices where the engine is situated at the opposite end of the vehicle to the driven wheels. 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. On some four-wheel drive vehicles one propeller shaft is used to power the rear wheels as with rear-wheel drive and a second propeller shaft is used to power the front wheels. In this case the second propeller shaft is placed between a transfer gearbox and the front axle. Hence, it can be observed that a drive

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shaft is one of the most important components, which is responsible for the actual movement of the vehicle once the motion is produced in the engine. The designing of such a critical component is usually stringent, as any fracture in this part could lead to a catastrophic failure of the vehicle when it is in motion.

2 SPECIFICATION OF PROBLEM

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. An automotive propeller shaft, or drive shaft, transmits power from the engine to differential gears of a rear wheel-driving vehicle. 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 8000rpm to avoid whirling vibration. The whirling of the propeller shaft, which is a resonance vibration, occurs when the rotational speed is equal to the fundamental natural bending frequency, which is inversely proportional to the square root of specific stiffness (E/).

When conventional materials such as Steel or Aluminium are used, the weight of the drive shaft assembly is considerably high, which has a certain role in increasing the overall weight of the vehicle. Also, due to the increased weight of the shaft there are more chances of whirling of the shaft. To avoid this in conventional drive shafts, which have a length exceeding 1.2m, the shafts are made in two pieces. However, the two piece steel propeller shaft has a complex and heavy configuration because three universal joints and a centre support bearing in addition to a spline are required,which produces noise and vibrations that are transmitted to vehicle through the centre support bearing.But by using advanced composite materials, the weight of the drive shaft assembly can be tremendously reduced. This also allows the use of a single drive shaft (instead of a two piece drive shaft) for lengths exceeding 1.2m. Apart from being lightweight, the use of composites also ensures less noise and vibration. However, the composite propeller shaft requires reliable joining of the composite shaft to the steel or Aluminium yoke of a universal joint.

3 AIM AND SCOPE OF THE WORK

The project aims 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 V5R20. A shaft has to be modeled to meet the stringent design requirements for automobiles. A comparative study of five different materials was conducted to choose the best-suited material. Steel (SM45C) was chosen for reference and the rest of the four composites were analyzed. The analysis was carried out using ANSYS 14.5 Work Bench for the following materials

4 LITERATURE SURVEY

. COMPOSITES

Agarwal B.D. and Broutman L. J. have extensively reviewed the theoretical details of composite materials and composite structures in “Analysis and performance of fibre composites”,1990[1]. Thimmagowda and sabhapathy vijayarangan studied the design optimization of one piece composite drive shaft for power transmission applications to replace conventional drive shafts of an automobile using E-glass/epoxy and high modulus carbon/epoxy composites using genetic algorithms technique, optimization of the composite drive shaft was done and also weight reduction of the shaft was attained subjected to constraints such as torque transmission, torsional buckling and fundamental lateral natural frequency. Raffi mohammed et al.[3] conducted analysis on three different composite materials E-glass, E-carbon, Kevlar aiming the reduction of the weight of drive shaft assembly to replace the conventional driveshaft without any decrease in the vehicle quality and reliability. Among those three composite materials E-carbon was concluded as the best suited composite to replace conventional material like steel. So that, weight and stresses are considerably decreased. The Spicer U-Joint Division of Dana Corporation for the Ford Econoline van models developed the first composite propeller shaft in 1985. The General Motors pickup trucks which adopted the Spicer product, enjoyed a demand three times that of projected sales in its first year Dai Gil Lee et al. [4, 5]. John. W. Weeton et al. [7]

briefly described the application possibilities of composites in the field of automotive industry to manufacture composite elliptic springs, drive shafts and leaf spumes in Engineers guide to composite materials, American Society for metal, 1986. Beard more and Johnson discussed the potential for composites in structural automotive applications from a structural point of view. Pollard [8] studied the possibility of the polymer Matrix composite usage in driveline applications. Faust et.al [10] described the considerable interest on the part of both the helicopter and automobile industries in the development of lightweight drive shafts. Procedure for finding the elastic moduli of anisotropic laminated composites is explained by Azzi .V.D and Tsai.S.W.

5 DESCRIPTION OF THE PROBLEM

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 3.1

Tab 1 Specifications of Drive shaft model of Toyota Qualis

S. No	Name	Notation	Units	Value
1	Ultimate Torque	T_{max}	Nm	3500
2	Maximum Speed of shaft	N_{max}	RPM	6500
3	Maximum Diameter of the shaft	D	mm	100
4	Length	L	M	1.2
5	Outer Radius	R_o	M	0.02
6	Inner Radius	R_i	M	0.01

6 MODELING OF DRIVE SHAFT ASSEMBLY

However, in reality the drive shaft is not a simple hollow cylinder, but a complex assembly of a number of parts. This 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. Using these dimensions, the entire assembly was created in CATIA V5R20. The important parts created in CATIA in this assembly are also shown along with the whole drive shaft assembly in Figures 4

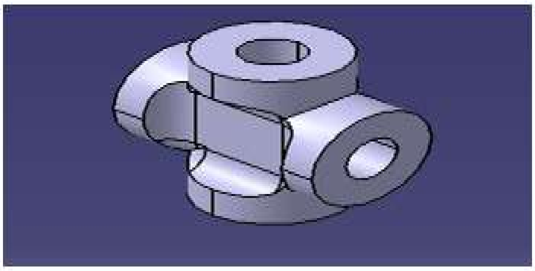

Fig 2 Drive Shaft Assembly in CATIA

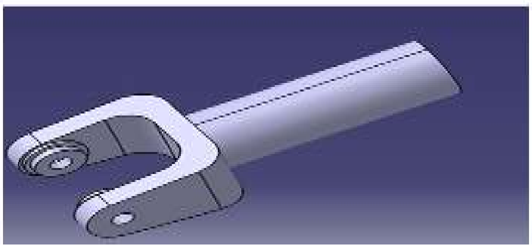

Fig 3 Sleeve-Yoke in shaft assembly

Thus the Toyota quails drive shaft assembly was created in CATIA software with the prescribed dimensions as shown in the above Figure

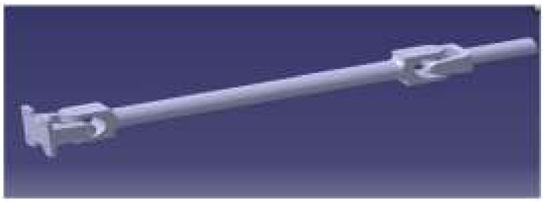

Fig 4 Drive Shaft Assembly in CATIA

7 MATERIAL PROPERTIES

Tab 2Material Properties of Steel (SM45C)

S.No	Material Properties	Units	Values
1	Young's Modulus	GPa	207
2	Shear Modulus	GPa	80
3	Poisson's Ratio	---	0.3
4	Density	Kg/m^3	7600
5	Yield Strength	MPa	370

Tab 3 Material Properties of Boron/Epoxy Composite

Density of Boron/Epoxy = 2249 kg/m^3

S.No	Property	Units	Values
1	Young's modulus in X direction	Gpa	281.86
2	Young's modulus in Y direction	Gpa	10.88
3	Young's modulus in Z direction	Gpa	10.88
4	Poisson's ratio in XY direction	—	0.2451
5	Poisson's ratio in YZ direction	—	0.0093
6	Poisson's ratio in XZ direction	—	0.2451
7	Shear modulus in XY direction	Gpa	67.4
8	Shear modulus in YZ direction	Gpa	67.4
9	Shear modulus in XZ direction	Gpa	67.4

Tab 4 Material Properties for Kevlar/Epoxy composite

Density of Kevlar/Epoxy = 1402 kg/m^3

S.No	Property	Units	Values
1	Young's modulus in X direction	Gpa	95.71
2	Young's modulus in Y direction	Gpa	10.45
3	Young's modulus in Z direction	Gpa	10.45
4	Poisson's ratio in XY direction	—	0.34
5	Poisson's ratio in YZ direction	—	0.37
6	Poisson's ratio in XZ direction	—	0.37
7	Shear modulus in XY direction	Gpa	25.08
8	Shear modulus in YZ direction	Gpa	25.08
9	Shear modulus in XZ direction	Gpa	25.08

Tab 5 Material properties of Aluminium-Boron/Epoxy Composite:

Density of Aluminium-Boron/Epoxy=2100 kg/m^3

S.No	Property	Units	Values
1	Young's modulus in X direction	Gpa	169.5
2	Young's modulus in Y direction	Gpa	7.28
3	Young's modulus in Z direction	Gpa	7.28
4	Poisson's ratio in XY direction	—	0.28
5	Poisson's ratio in YZ direction	—	0.28
6	Poisson's ratio in XZ direction	—	0.28
7	Shear modulus in XY direction	Gpa	4.823
8	Shear modulus in YZ direction	Gpa	4.823
9	Shear modulus in XZ direction	Gpa	4.823

Tab 6 Material properties of Carbon-Kevlar/Epoxy Composite

S.No	Property	Units	Values
1	Young's modulus in X direction	Gpa	125.6
2	Young's modulus in Y direction	Gpa	125.6
3	Young's modulus in Z direction	Gpa	125.6
4	Poisson's ratio in XY direction	—	0.328
5	Poisson's ratio in YZ direction	—	0.328
6	Poisson's ratio in XZ direction	—	0.328
7	Shear modulus in XY direction	Gpa	4.28
8	Shear modulus in YZ direction	Gpa	4.28
9	Shear modulus in XZ direction	Gpa	4.28

Thus, by using Ansys workbench, the model of drive shaft is imported into ansys and then it is applied with the material taken from the Engineering Data and then it is meshed as shown in the figure 5 The drive shaft model which is meshed is then fixed at the end yoke and then the sleeve yoke subjected to a torque of 3500 N-m and then with the given parameters, the model is solved. By solving, required results such as maximum shear stress, maximum deformation Von-misses stresses and several other things can be attained

8 STATIC AND MODAL ANALYSIS

Thus, the model which is meshed is subjected to a torque of 3500 N-m is analysed for the four different composite materials and also for the steel(SM45C). The results of maximum shear stress and deformations are shown below:

8.1 STATIC ANALYSIS RESULTS

8.1.1 STEEL(SM45C):

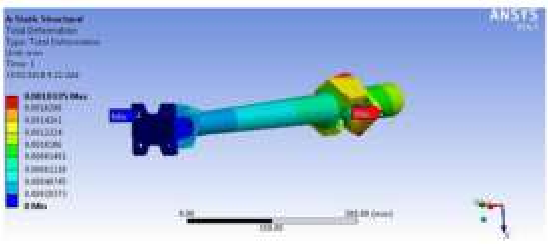

Fig 5 Maximum deformation of Steel

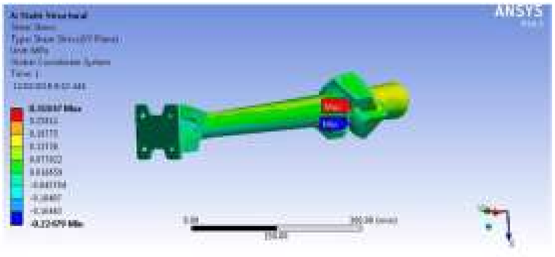

Fig 6 Maximum shear stress of Steel

8.1.2BORON/EPOXY:

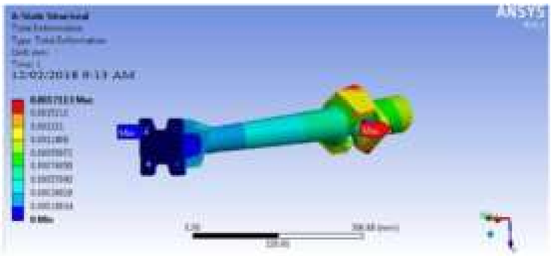

Fig 7 Maximum deformation of Boron-Epoxy

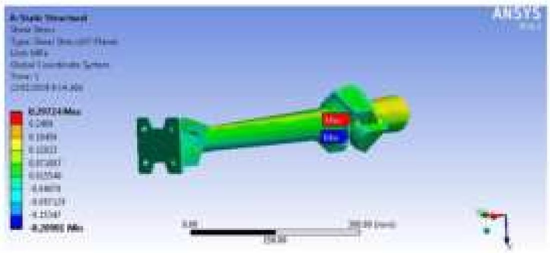

Fig 8 Maximum shear stress of Boron-Epoxy

8.1.3 KEVLAR/EPOXY:

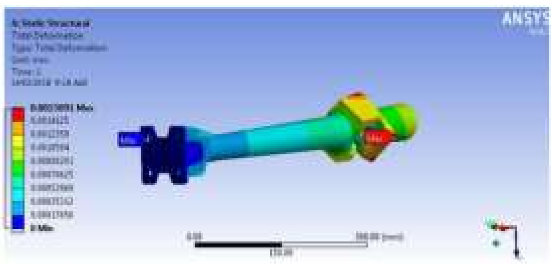

Fig 9 Maximum deformation of Kevlar/Epoxy

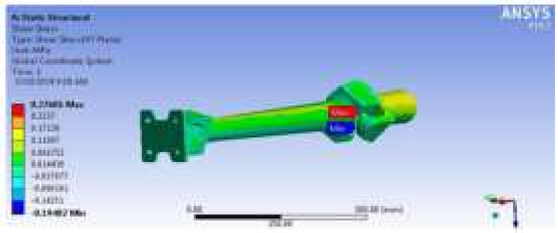

Fig 10 Maximum SHEAR STRESS of Kevlar/Epoxy

8.1.4 AL-BORON EPOXY COMPOSITE

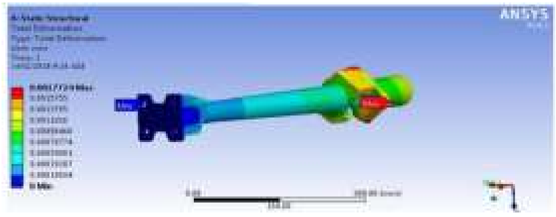

Fig 11 Total deformation of al-boron epoxy composite

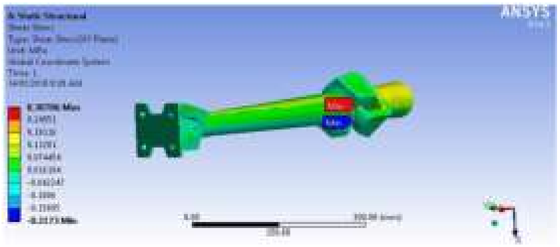

Fig 12 Shear stress of al-boron epoxy composite

8.1.5 CARBON-KEVLAR

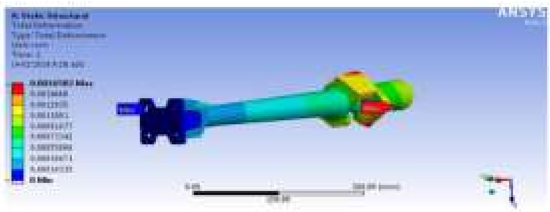

Fig 13 Total deformation of carbon-kevlar

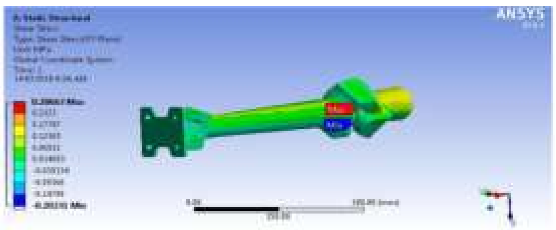

Fig 14 Shear stress OF carbon-Kevlar

Table 7 Maximum Deformation, shear stress and Density of steel and composites

S.no	Material	Maximum deformation(m)	Maximum shear stress(Mpa)	Density (Kg/m3)
1	Steel(SM45C)	0.0018335	0.31847	7600
2	Boron/Epoxy	0.0017113	0.29724	2249
3	Kevlar/Epoxy	0.0015891	0.27601	1402
4	Aluminium-Boron/Epoxy	0.0017724	0.30786	2100
5	Carbon-Kevlar/Epoxy	0.0016502	0.28663	1470

8.2 MODAL ANALYSIS

Modal analysis is one of the structural analysis which gives information about the vibrations created in the drive shaft model and also the corresponding maximum deformations that it will undergo modal analysis helps to analyse a body when it is in motion.Modal analysis of Toyota quails drive shaft for the four composite materials along with steel can be done at six modes of frequencies and the corresponding deformations are take in to consideration and then the best suited material among these four composite materials has been declared.

Tab 8 Modal analysis of steel

Modes	Frequency(Hz)	Total deformation(mm)
1	1.231	0.0025
2	12.142	1.752
3	28.314	3.216
4	56.12	6.823
5	110.14	9.242
6	171.22	17.14

Tab 9 Modal analysis of Boron epoxy

Modes	Frequency(Hz)	Total deformation(mm)
1	1.913	0.0013
2	9.132	1.101
3	25.31	2.155
4	53.76	4.661
5	111.333	12.136
6	159.83	17.25

Tab 10 Modal analysis of Aluminum boron epoxy

Modes	Frequency(Hz)	Total deformation(mm)
1	2.23	0.0021
2	10.36	1.21
3	29.58	3.214
4	61.183	5.631
5	100.241	9.139
6	161.135	18.132

Tab 11 Modal analysis of Carbon Kevlar epoxy

Modes	Frequency(Hz)	Total deformation(mm)
1	2.126	0.0011
2	8.781	1.132
3	26.618	2.212
4	58.126	6.131
5	106.11	8.142
6	166.12	16.13

Tab 7 Modal analysis of Kevlar Epoxy

Modes	Frequency(Hz)	Total deformation(mm)
1	2.12	0.001
2	11.132	1.106
3	30.183	2.131
4	57.262	5.231
5	113.307	9.732
6	180.262	15.73

9 CONCLUSION

The presented work was aimed at reducing the fuel consumption of the automobiles, which employs drive shafts. This was achieved by reducing the weight of the drive shaft with the use of composite materials. The Drive shaft of a Toyota Qualis was chosen and the model is created in CATIA V5R21. Being a complex assembly of a number of parts, it had to be analyzed in ANSYS 14.5 Workbench. A total of five materials were chosen for the comparative analysis, including steel, which was used for reference, these 4 materials were analyzed. The analysis shows that, considerable amount of weight can be saved when composite materials are used compared to conventional steel shaft. Taking into consideration of the weight saving, deformation, shear stress induced, maximum deformation in modal analysis, it is evident that Kevlar/Epoxy composite (Kevlar of 73% and Epoxy of 23%) has the most encouraging properties to act as the replacement for steel out of the considered four materials

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