

# A Study Paper On Analysis And Comparison Of Composite Drive Shaft With Conventional Steel Drive Shaft

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**Abstract**— Present study covers design, analysis and development of driveshaft for automobile applications. This covers dimension calculations of drive shaft based on engine power required. Accordingly shaft couplings e.g. universal joints, transmission gears for axle and axle design will be performed considering all static and dynamic loads acting upon it. All design process will be performed with aid of FE analysis using ANSYS software. Optimization will be followed after performing design which includes weight reduction of drive shaft and material selection.

**Keywords:** Drive shaft, Composite material, Steel shaft, Composite shaft, FE Analysis, ANSYS.

## I. INTRODUCTION

### A. Drive Shaft

Drive shafts are used widely in power transmission applications e.g. automobiles, aerospace, pumping industries etc. Present study is aimed towards study of automobile drive shafts. In automobiles drive shaft is connected at its two ends by universal joints to transmit power at angle. These shafts are subjected to torsion movement and dynamic loading due to transport acceleration of vehicle.

### B. Purpose of the Drive Shaft

- It must transmit torque from the transmission to the differential gear box.
- The drive shaft must also be capable of rotating at very fast speed required by the vehicle.
- The length of the drive shaft must also be capable of changing while transmitting torque. Length changes are caused by axle movement due to torque reaction, road deflection, braking load, and so on.
- The drives shaft must also operate through constantly changing the angles between the transmission, the differential and the axles.
- A slip joint is used to composite for this motion. The slip joint is made of an internal and external spline.
- The dive shaft should provide a smooth flow of power to the axles.

### C. Composite Materials

The advanced composite materials such as graphite, carbon, Kevlar and Glass with Suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/density). Advanced composite materials seem ideally suited for long, power driver shaft (propeller shaft) applications. Their elastic properties can be tailored to increase the torque they can carry as well as the rotational speed at which they operate. The drive shafts are used in automotive, aircraft and aerospace applications. The automotive industry is

exploiting composite material technology for structural components construction in order to obtain the reduction of the weight without decrease in vehicle quality and reliability. It is known that energy conservation is one of the most important objectives in vehicle design and reduction of weight is one of the most effective measures to obtain this result. Actually, there is almost a direct proportionality between the weight of a vehicle and its fuel consumption, particularly in city driving. 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 or not soluble in each other. The main difference between composites, where as in alloys, constituent materials are soluble in each other and form a new material which has different properties from their constituents.

### D. Classification Of Composite Materials

Composite materials can be classified as

- Polymer matrix composites
- Metal matrix composites
- Ceramic Matrix

Technologically, the most important composites are those in which the dispersed phase is in the form of a fiber. The Design of fiber reinforced composites is based on the Specific strength is the ratio between strength and density. Specific modulus is the ratio between modulus and density. Fiber length has a great influence on the mechanical characteristics of a material. The fibers can be either long or short. Long continuous fibers are easy to orient and process, while short fibers cannot be controlled fully for proper orientation. Long fibers provide many benefits over short fibers. These include impact resistant, low shrinkage, improved surface finish and dimensional stability. However short fiber provide low cost are easy to work with and have fast cycle time fabrication procedures.

The principal fibers in commercial use are various types of glass, carbon, graphite, Kevlar. All these fibers can be incorporated into a matrix either in continuous lengths or in discontinuous lengths. The matrix material may be a plastic or rubber polymer, metal or ceramic. Laminate is obtained by stacking a number of thin layers of fibers and matrix consolidating them to the desired thickness. Fiber orientation in each layer can be controlled to generate a wide range of physical and mechanical properties for the composite laminate.

### E. Properties Of Composite Materials

The physical properties of composite materials are generally not isotropic (independent of direction of applied force or load) in nature, but rather are typically orthotropic (depends

on the direction of the applied force or load). For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel.

In contrast, isotropic materials (for example, aluminum or steel), in standard wrought forms, typically have the same stiffness regardless of the directional orientation of the applied forces and/or moments. While, composite materials exhibit different properties in different directions. The relationship between forces/moments and strains/curvatures for an isotropic material can be described with the following material properties: Young's Modulus, the Shear Modulus and the Poisson's ratio, in relatively simple mathematical relationships. For the anisotropic material, it requires the mathematics of a second order tensor and up to 21 material property constants. For the special case of orthogonal isotropy, there are three different material property constants for each of Young's Modulus, Shear Modulus and Poisson's ratio--a total of 9 constants to describe the relationship between forces/moments and strains/curvatures.

#### F. Advantages Of Composites Over Conventional Materials

- High strength to weight ratio
- High stiffness to weight ratio
- Better fatigue resistance
- Improved corrosion resistance
- Good thermal conductivity
- Low coefficient of thermal expansion. As a result, composite structures exhibit a better dimensional stable over a wide temperature range.
- High damping capacity.

#### G. Manufacturing of Composite shaft

Shaft are manufactured by filament winding process, Fiber strands are unwound from the creels and passed continuously to the resin (matrix) Tank.

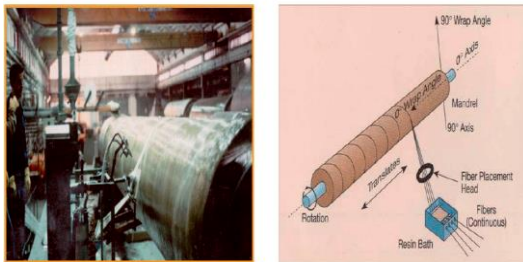


Fig. 1: Filament Winding Process Arrangement

- In the resin tank, the fiber strands are impregnated completely with resin.
- Resin impregnated strand are passed on to a rotating mandrel.
- Strands are wound around the mandrel in a controlled manner and in a specific fiber orientation.
- Curing of the composite is done with heat and final composite product is taken out from mandrel.
- To remove the metallic mandrel from the composite part hydraulic rams may be used.

#### H. Main Components Of Filament Winding Process

- Fiber creel

- Resin impregnation system
- Carriage
- Rotating Mandrel

#### I. Controlling Parameters

- Fiber tension
- Winding speed
- Design of resin bath
- Viscosity of Resin
- Fiber Orientation
- Carriage Movement

### II. DESIGN OF DRIVE SHAFT

#### A. Initial Diameter Of Shaft

- Considering material of shaft as steel, shear stress = 90 MPa
- Factor of safety for shaft design = 1.5
- Design shear stress =  $180/1.5$   
= 120 MPa
- Torque  $T = P \times 60 / (2\pi N)$  (P in W)

Standard values of Torque,

The fundamental natural bending frequency of drive shaft of passenger cars, small trucks, and vans should be higher than 6500 rpm to avoid whirling vibrations and the torque transmission capacity of the drive shaft should be larger than 3500 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations.

$$\frac{D_o^4 - D_i^4}{D_o} = \frac{16T}{\tau \pi}$$

Assuming initial diameters of drive shaft and by performing iterations, following diameter vales reflects shaft shear stress value = 110 MPa, which is less than allowable shear stress value as mentioned above.

$$D_o = 60 \text{ mm}$$

$$D_i = 40 \text{ mm}$$

#### B. Checking For Whirling Of Shaft

Critical speed of shaft:

$$N_c = (30/\pi) * \sqrt{(g/\delta st)}$$

$$\text{where, } \delta st = (5wL^3) / (384EI)$$

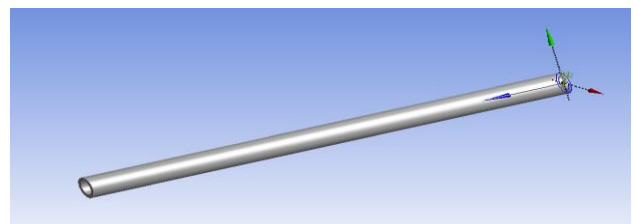
Substituting values in above parameters,

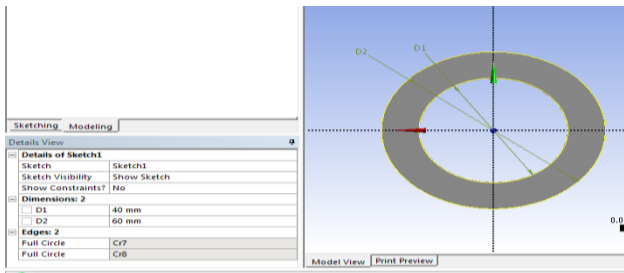
$$N_c = 6159 \text{ RPM}$$

Since critical speed of shaft is less than maximum speed (N = 6500 rpm), design of composite shaft is safe for critical speed.

### III. ANALYSIS OF SHAFT

#### A. Geometry





**B. Material Properties**

**1) Steel**

Properties of Outline Row 3: Structural Steel				
	A	B	C	D E
1	Property	Value	Unit	
2	Density	7850	kg m <sup>-3</sup>	
3	Isotropic Secant Coefficient of Thermal Expansion			
6	Isotropic Elasticity			
12	Alternating Stress Mean Stress	Tabular		
16	Strain-Life Parameters			
24	Tensile Yield Strength	2.5E+08	Pa	
25	Compressive Yield Strength	2.5E+08	Pa	
26	Tensile Ultimate Strength	4.6E+08	Pa	
27	Compressive Ultimate Strength	0	Pa	

**2) Glass fibre (Class G10)**

Glass fibre G10 is an orthotropic material, properties of which are as follows,

Properties of Outline Row 3: G10				
	A	B	C	D E
1	Property	Value	Unit	
2	Density	1900	kg m <sup>-3</sup>	
3	Orthotropic Instantaneous Coefficient of Thermal Expansion	Tabular		
10	Orthotropic Elasticity			
11	Young's Modulus X direction	3.05E+10	Pa	
12	Young's Modulus Y direction	2.67E+10	Pa	
13	Young's Modulus Z direction	1.59E+10	Pa	
14	Poisson's Ratio XY	0.29		
15	Poisson's Ratio YZ	0.32		
16	Poisson's Ratio XZ	0.06		
17	Shear Modulus XY	6.8E+09	Pa	
18	Shear Modulus YZ	5.7E+09	Pa	
19	Shear Modulus XZ	4.8E+09	Pa	
20	Tensile Ultimate Strength	4.14E+08	Pa	
21	Compressive Ultimate Strength	7.49E+08	Pa	

**C. Results Summary**

Material	Shear Stress	Mass	Natural Frequency (Hz)
Steel	107.87	12.33	50.65
Composite (G10)	106.88	2.98	39.89

Table. 1: Comparison between Steel Shaft and Composite Shaft

As shown in results above, with same geometry and less weight, for composite material stress value is less compared to steel material.

Further to above analysis, glass fiber composite materials are available with different resin types.

Comparison of different combinations are done as follows,

Sr No.	Property	Symbol	Unit	Value
1	Longitudinal Modulus	E11	GPa	79.2

2	Transverse Modulus	E22	GPa	7.25
3	Shear Modulus	G12	GPa	4.25
4	Poisson's ratio	v		0.34
5	Density	δ	Kg/m3	1384

Table. 2: Boron/Epoxy

Sr No.	Property	Symbol	Unit	Value
1	Longitudinal Modulus	E11	GPa	232.2
2	Transverse Modulus	E22	GPa	7.413
3	Shear Modulus	G12	GPa	4.05
4	Poisson's ratio	v		0.262
5	Density	δ	Kg/m3	2080

Table. 3: Kevlar /Epoxy

Sr No.	Property	Symbol	Unit	Value
1	Longitudinal Modulus	E11	GPa	123.6
2	Transverse Modulus	E22	GPa	7.4
3	Shear Modulus	G12	GPa	4.28
4	Poisson's ratio	v		0.328
5	Density	δ	Kg/m3	1470

Table. 4: Carbon-Kevlar/Epoxy Hybrid composite

Sr No.	Property	Symbol	Unit	Value
1	Longitudinal Modulus	E11	GPa	169.76
2	Transverse Modulus	E22	GPa	7.29
3	Shear Modulus	G12	GPa	4.625
4	Poisson's ratio	v		0.29
5	Density	δ	Kg/m3	2100

Table. 5: Aluminum-Boron/Epoxy Hybrid composite

Composite	Shear Stress (MPa)	Fundamental Natural Frequency (Hz)
Boron-Epoxy	107.23	73.83
Kevlar-Epoxy	107.83	119.2
Carbon Kevlar/Epoxy	107.54	90.74
Aluminum Boron/Epoxy	107.75	105.06

Table. 6: Comparison between different Composite Shaft

Angle	Maximum Shear Stress (MPa)	Maximum Principal Stress (MPa)	Minimum Principal Stress (MPa)	Natural Frequency (Hz)

0°	106.58	115.58	-115.58	28.76
25°	107.81	115.11	-114.23	26.58
45°	107.7	114.67	-113.67	26.32
90°	106.88	116	-116	39.89

Table. 7: Analysis of composite drive shaft for different stacking angle

#### IV. CONCLUSION

The usage of composite materials has resulted in considerable amount of weight saving in the range of 81 – 72 % when compared to conventional drive shaft.

Taking into account the weight saving, shear stress and resultant frequency it is evident that Kevlar/Epoxy composite has the most encouraging properties to act as replacement to steel. Moreover 90° angle of fibre for present application has proved improved fundamental natural frequency.

The present work was aimed at reducing the fuel consumption of automobiles in particular or any machine, which employs drive shaft, in general. This was achieved by reducing the weight of drive shaft with the use of composite materials.

By using advanced composite materials, the weight of 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 transmission of power to the differential part of the assembly.

Apart from being lightweight, the use of composites also ensures less noise and vibration.

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