iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** V **Month of publication:** May 2018

DOI: http://doi.org/10.22214/ijraset.2018.5254

Design and Analysis of Composite Drive Shaft

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Abstract: The advanced composites are resulted in great achievements in many fields including marine and automobile engineering, sports and medicine, in terms of corrosion and fatigue resistances, high specific modulus and specific Strength improvement and reduction in energy requirements owing to reduction in weight. The aim of this work is that to replace the conventional steel shaft of automobiles with an appropriate composite shaft. The conventional drives hafts are made in two pieces for reducing the bending natural frequency, whereas the composite shafts made as single-piece shafts, thus reducing the overall weight. E-Glass/Epoxy and Kevlar/Epoxy composites were design and analyze in terms of torsional strength, torsional buckling and bending natural frequency by compare them with the conventional steel driveshaft under the same grounds of design constraints and the best suited composite material was recommended. In this present work an attempt has been to estimate the deflection, stresses, and natural frequencies under subjected loads using FEA (Ansys).
Keywords: Propeller shaft,Drive shaft,composite material, composite drive shaft design etc.

I. INTRODUCTION

An automotive drive shaft transmits power from the engine to the differential gear of a rear wheel drive vehicle. The torque capability of the drive shaft for passenger cars should be larger than 3500 Nm and the fundamental bending natural frequency should be higher than 9200 rpm to avoid whirling vibration. Since the fundamental bending natural frequency of a one-piece drive shafts made of steel or aluminum is normally lower than 5700 rpm when the length of the drive shaft is around 1.5 m, the steel drive shaft is usually manufactured in two pieces to increase the fundamental natural frequency of bending because the natural frequency of bending of a shaft is inversely proportional to the square of beam length and proportional to the square root of specific modulus. The two-piece steel drive shaft consists of three universal joints, a center supporting bearing and a bracket, which increases the total weight of an automotive vehicle and decreases fuel efficiency. Since composite materials have more than four times specific stiffness ($E= \rho$) of Aluminum or steel materials, it is possible to manufacture composite drive shafts in one-piece without whirling vibration over 9200 rpm. The composite drive shaft reduced weight and less noise and vibration. However, because of the high material cost of E-Glass and Kevlar fiber epoxy composite materials, rather cheap aluminum materials may be used partly with composite materials such as in a hybrid type of aluminum/composite drive shaft, in which the aluminum has a role to transmit the require torque, while the E- Glass fiber epoxy composite increases the bending natural frequency above 9200 rpm.

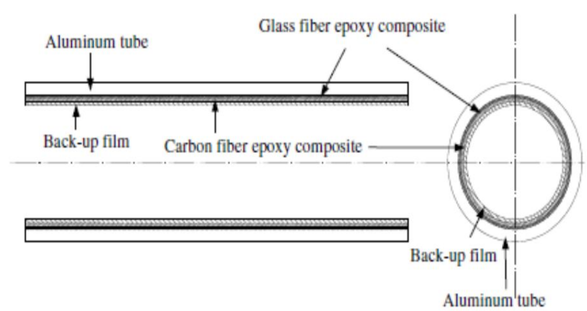

Fig.1 Schematic Diagram of the Co-Cured Aluminum/Composite Drive Shaft

II. MATERIAL SELECTION

A. Selection of Reinforcement Fiber

Fibers are available with widely differing properties. Review of the design and performance requirements usually dictate the fiber/fibers to be used. E-glass/ Kevlar fibers: Its advantages include high specific strength and modulus, low coefficient of thermal expansion, and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance, and high electrical conductivity. Glass fibers: Its advantages include its low cost, high strength, high chemical resistance, and good insulating properties. The disadvantages are low elastic modulus, poor adhesion to polymers, low fatigue

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue V, May 2018- Available at www.ijraset.com

strength, and high density, which increase shaft size and weight. Also crack detection becomes difficult.

B. Selection of Resin System

The important considerations in selecting resin are cost, temperature capability, elongation to failure and resistance to impact (a function of modulus of elongation). The resins selected for most of the drive shafts are either epoxies or vinyl esters. Here, epoxy resin was selected due to its high strength, good wetting of fibers, lower curing shrinkage, and better dimensional stability.

TABLE-I MATERIAL PROPERTIES OF STEEL(SM45C)

SN	Mechanical Properties	Symbol	Unit	Value
1	Young's Modulus	E	GPa	207.0
2	Shear Modulus	G	GPa	80.0
3	Poisson's Ratio	Y	-----	0.3
4	Density	P	Kg/m3	7600
5	Yield Strength	Sy	MPa	370
6	Shear Strength	Sx	MPa	275

III. DESIGN OF DRIVE SHAFT

A. Assumptions

1) The shaft rotates at a constant speed about its longitudinal axis.
2) The shaft has a uniform, circular cross section.
3) The shaft is perfectly balanced, i.e., at every cross section, the mass center coincides with the geometric center.
4) All damping and nonlinear effects are excluded.
5) The stress-strain relationship for composite material is linear & elastic; hence, Hooke's law is applicable for composite materials.
6) Acoustical fluid interactions are neglected, i.e., the shaft is assumed to be acting in a vacuum.
7) Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress.

B. Selection of Cross-Section

The drive shaft can be solid circular or hollow circular. Here hollow circular cross-section was chosen because:
1) The hollow circular shafts are stronger in per kg weight than solid circular.
2) The stress distribution in case of solid shaft is zero at the center and maximum at the outer surface while in hollow shaft stress variation is smaller. In solid shafts the material close to the center are not fully utilized.

TABLE-2 SPECIFICATION OF DRIVE SHAFT

SN	Name	Notation	Unit	Value
1	Ultimate Torque	T	Nm	3500
2	Max. Speed of shaft	N	Rpm	6500
3	Length of shaft	L	mm	1250
4	Outer Diameter of shaft	Do	mm	92
5	Inner Diameter	Di	mm	80
6	Thickness of shaft	T	mm	6

C. Mass of Drive Shaft

$$M= \rho AL = \rho\ (do2 - di2) \times \frac{L}{4}$$

Where, do = outer diameter (m)
di = inner diameter (m)

$$m = 8.58\ Kg$$

D. Torque Transmission Capacity of Drive Shaft

$$T = Ss\,\frac{\pi(do^4 - di^4)}{16do}$$

$$T = 123.33\ X\ 106 \times \frac{\pi(0.092^4 - 0.08^4)}{16\ X\ 3.32\ X\ 0.09}$$

Taking factor of safety as 3,

$$T = 4599.19\ Nm$$

E. Torsional buckling capacity of the drive shaft

$$\text{If } \frac{1}{\sqrt{1-\nu^2}}\frac{L^2 t}{(2r)^3} > 5.5,$$

For long shaft, the critical stress is given by,

$$\tau cr = \frac{E}{3\sqrt{2(1-\nu^2)^{3/4}}}(t/r)^{3/2}$$

For short & medium shaft, the critical stress is given by,

$$\tau cr = \frac{4.39\ E}{(1-\nu^2)}(t/r^2)\sqrt{1 + 0.0257\ (1-\nu^2)^{\frac{3}{4}}\frac{L^3}{(rt)^{1.5}}}$$

$$\tau cr = 1119.65\ N / mm2$$

The relation between thecritical stress and torsional Buckling Capacity is given by,

$$T\ cr = \tau\ cr\ 2\pi r2t$$

$$Tcr = 43857.9\ N\text{-}m$$

F. Lateral or Bending Vibration

The shaft is considered as simply supported beam undergoes transverse vibration. Thus the Natural Frequency can be found by using two theories.

G. Bernoulli-Euler Beam Theory- Ncrbe

It neglects the both transverse shear deformation and rotary inertia effects. Natural frequency is given by,

$$fnbe = \frac{\pi p^2}{2L^2}\sqrt{\frac{EI_x}{m_l}}$$

Where, p = 1, 2…

$$N\ crbe = 60f\ nbe$$

$$fnbe = 161.03\ Hz$$

$$N\ crbe = 9662.38\ rpm$$

H. Timoshenko Beam Theory-Ncrt

It considers both transverse shear deformation and rotary inertia effects. Natural frequency based on the Timoshenko beam theory is given by,

$$fnt = Ks\left(\frac{30\pi p^2}{L^2}\right)\sqrt{\frac{Er^2}{2\rho}}$$

$$N\ crt = 60f\ nt$$

$$\frac{1}{K_s^2} = 1 + \frac{n^2\pi^2 r^2}{2L^2}\left[1 + \frac{f_s E}{G}\right]$$

$$Ks = 0.964$$

fs= 2 for hollow circular cross-sections The relation between Timoshenko and Bernoulli-Euler beam theories is given by,

$$fnt = Ks\ f\ nbe$$
$$fnt = 0.962\ X\ 161.03$$
$$fnt = 155.32\ Hz$$
$$N\ crt = 9319.98\ rpm$$

TABLE-3
MATERIAL PROPERTIES OF CARBON/EPOXY COMPOSITE AND GLASS EPOXY COMPOSITE

SN	Properties	Symbols	Units	E-glass / Epoxy	Kevlar / Epoxy
1	Longitudinal Modulus	E11	GPa	134	170
2	Transverse Modulus	E22	GPa	7.0	10.0
3	Shear Modulus	G12	GPa	5.8	6
4	Poisson's Ratio	υ	----	0.3	0.3
5	Density	P	Kg/m3	2200	1450
6	Longitudinal tensile strength	St1	MPa	870	880
7	Transverse tensile strength	St2	MPa	60	70
8	Shear strength	Ss	MPa	97	100

Similarly, we can calculate the Torque transmission capacity, Torsional buckling capacity, Frequency for composite shaft. We get the design solution as,

TABLE-4 THE TORQUE TRANSMISSION CAPACITY OF THE SHAFT

Material	Steel	E-glass / Epoxy	Kevlar / Epoxy
Torque, T (N-m)	4599.19	5260.18	5570.26

TABLE-5EFFECT OF TRANSVERSE SHEAR ON THE FUNDAMENTAL NATURAL FREQUENCY

Material	Steel	E-glass / Epoxy	Kevlar / Epoxy
Ncrbe (rpm)	9662.3	9461.65	7663.31
Ncrt (rpm)	9319.9	9270.28	7495.42

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
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IV. ANALYSIS OF DRIVE SHAFT USING ANSYS

A. Modeling and simulation

In this section 3D FE Models along with the loads and boundary conditions will be presented.

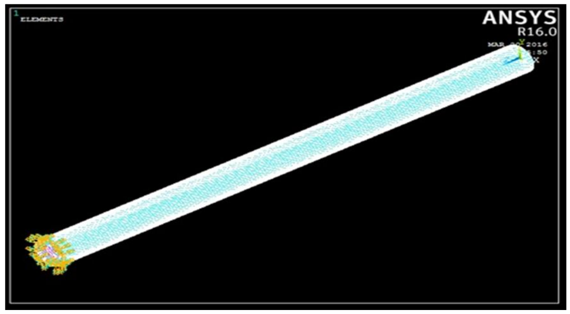

Fig. 2 Boundary Conditions for the Modal Analysis

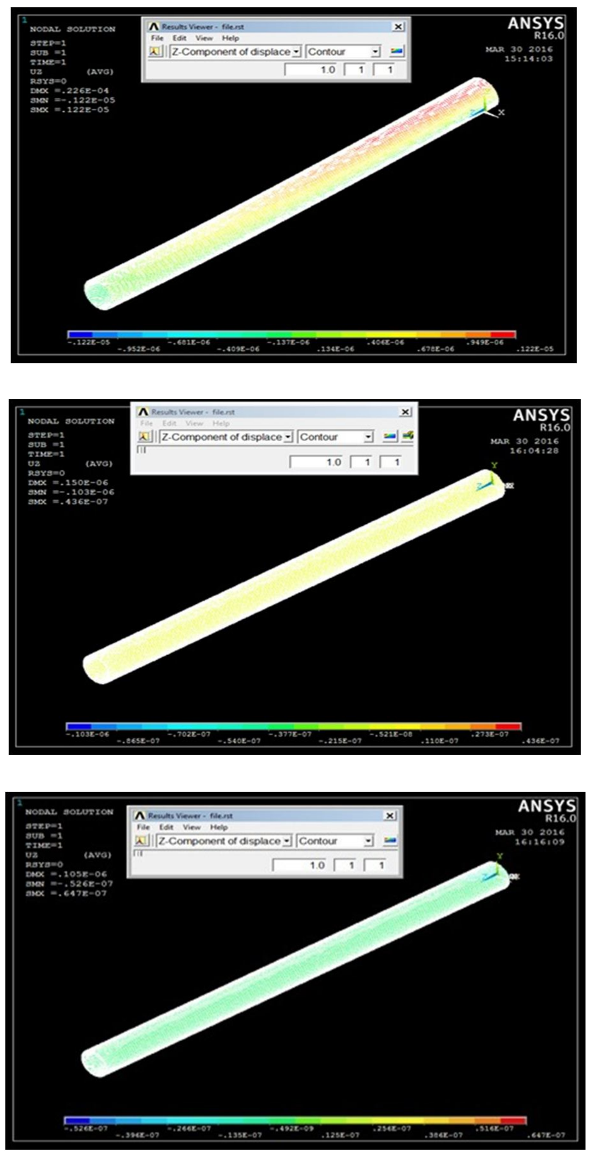

Fig.3 Maximum Deformation (a) Steel (b) E- Glass/ Epoxy (c) Kevlar/ Epoxy

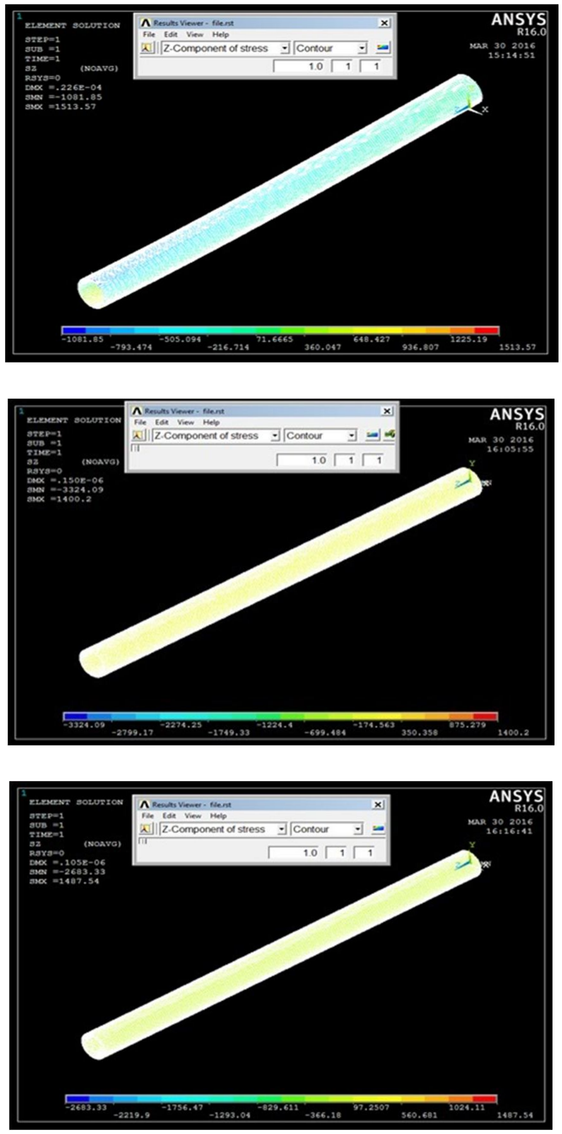

Fig.4 Maximum Stess (a) Steel (b) E- Glass/ Epoxy (c) Kevlar/ Epoxy

V. CONCLUSION

Taking into account the weight saving, deformation, shear stress induced and resultant frequency it is evident that composite has the most encouraging properties to act as replacement to steel. The present work was aimed at reducing the fuel consumption of the automobiles in particular or any machine, which employs drive shaft, in general. This was achieved by reducing the weight of the drive shaft with the use of composite materials. This also allows the use of a single drive shaft (instead of a two piece drive shaft) for transmission of power to the differential parts of the assembly. Analysis of both drive shaft shows that the composite drive shaft has capability to transmit more torque, has more buckling torque transmission capability and has much higher fundamental natural bending frequency which provides better margin of safety than the conventional composite drive shaft. The composite drive are safer and reliable than steel as design parameter are higher in case of composite. Natural frequency using Bernoulli-euler beam theory and Timoshenko's beam theory are compared. The frequency calculated by using Bernoulli-euler beam theory is high as it neglects rotary inertia and transverse shear.

VI. ACKNOWLEDGEMENT

Department of Mechanical Engineering, here knowledge is considered as the liable asset and it is proved that the power of mind is like a ray of sun; and when strenuous they illume.

First and foremost, we express our gratitude towards our guide Prof. Aher V.S. who kindly consented to acts as our guide. I cannot thank him enough; his patience, energy, an utmost contagious positive attitude, and critical comments are largely responsible for a timely and enjoyable completion of this assignment. I appreciate his enlightening guidance; especially his pursuit for the perfect work will help us in the long run.

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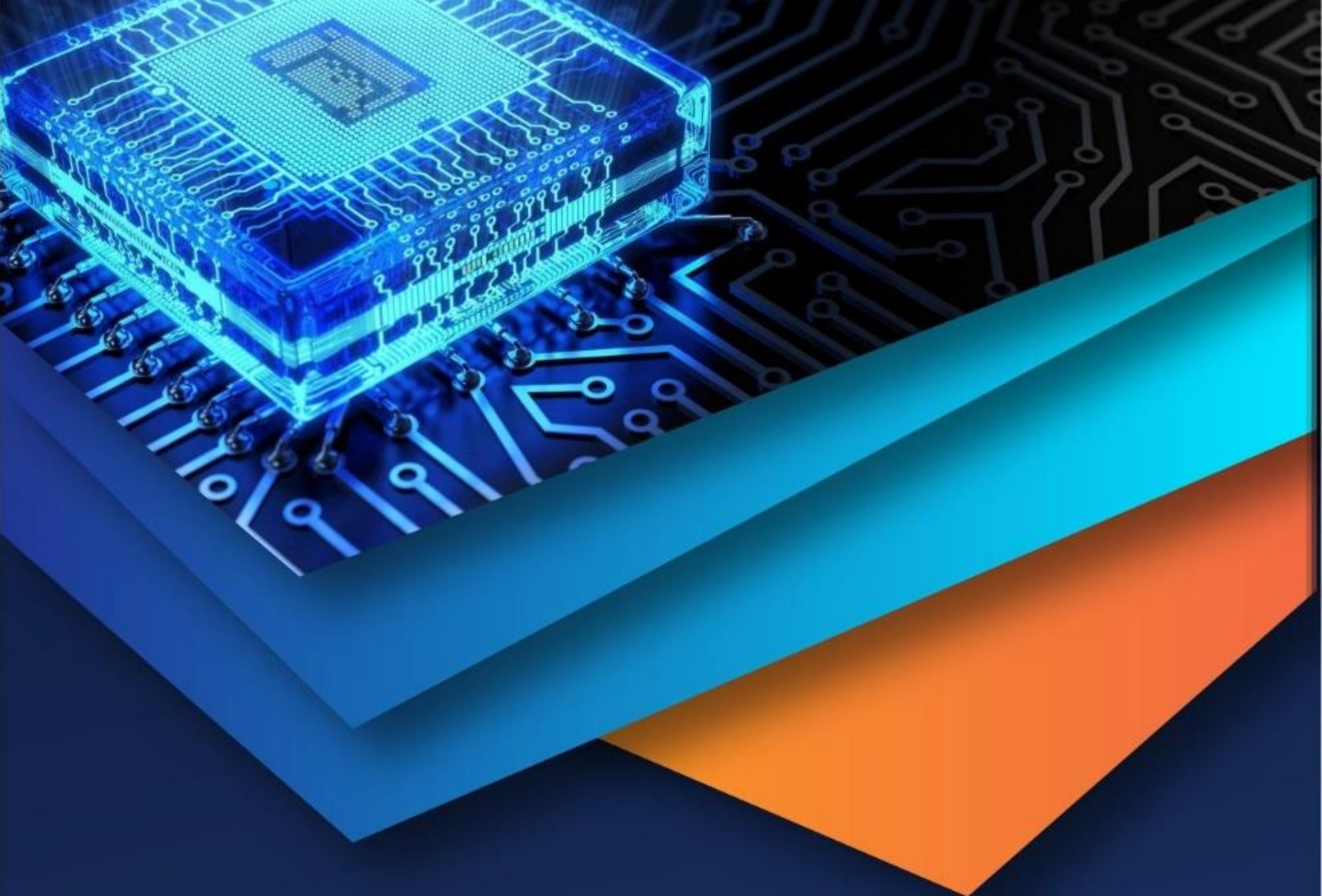

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