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Design and Analysis of Composite Propeller Shaft for Automotive Application

[#1]Dattatray S. Ghorpade, [#2]Kishor B. Kale

[1]dattatrayg218@gmail.com
[2]kishorkale.iisc@gmail.com

[#12]Mechanical Department, Savitribai Phule Pune University
PDVVP College of Engineering, Ahmednagar, India

ABSTRACT

This work deals with the experimental investigation of performance of conventional steel drive shafts with carbon epoxy composite drive shaft. A drive shaft for rear wheel drive automobile was designed using carbon epoxy composites. Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials. A composite shaft made of carbon epoxy composites is tested with the help of torque tester. The use of composite material reduces the weight of shaft significantly as the composite having lower density. The stacking sequence of the composite layer and fiber orientation are selected to maximize torsional shear strength. The design parameters are selected with the objective of minimizing the weight of composite drive shaft &increase in torque capability compared with a conventional steel drive shaft.By analysing performance conventional steel drive shaft can be replaced by composite drive shaft.

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I. Introduction

Fossil fuels used for automobile like petrol, diesel etc. are non-renewable source of energy. So, main intention in automobile sector is to improve mileage of vehicle. One of the ways to increase the mileage of vehicle is to reduce its weight. There are a variety of alternatives being explored by the automobile companies, there is more than one possible answer. At this point the only certainty is that no single material or type of material will dominant. The biggest questions the automotive industry faces today is which materials are to be used, to reduce the weight of the vehicle and save fuel.

The major amounts of non-renewable fuels are utilized in automotive sector for transportation. So, today's need is to develop energy efficient systems for power transmission applications. Almost all automobiles, which correspond to design with rear wheel drive and front engine installation, have transmission shafts [1]. An automotive drive shaft transmits power from the engine to the differential gear of a rear wheel drive vehicle. The weight reduction of the drive shaft can have a certain role in the general weight reduction of the vehicle and is a highly desirable goal, if it can be achieved without increase in cost and decrease in quality [2, 3]. The material which is being used today is high strength steel. Metallic drive shafts have limitations of weight and low critical speed. The fundamental bending natural frequency of a shaft is inversely proportional to the square of length and proportional to the square root of specific modulus [4].

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 6500 rpm to avoid whirling vibration [1, 2]. 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 bending natural frequency [5].

Polymer matrix composites are most common composite material being used in drive shaft. The most common are carbon epoxy, glass epoxy and carbon/glass epoxy hybrids. The advanced composite materials such as Graphite, Carbon and Glass with suitable resins are widely used because of their high specific strength and high specific modulus [6, 7].Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of

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composite materials [8]. Since, carbon fiber epoxy composite materials have more than four times specific stiffness of steel or aluminum materials, it is possible to manufacture composite drive shafts in one-piece without reducing whirling vibration over 6500 rpm[9].

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. In addition, the use of single torque tubes reduces assembly time, inventory cost, maintenance, and part complexity. Analytically it was proved that composite drive shaft has many benefits such as reduced weight and less noise and vibration. But experimental investigations regarding performance of composite drive shaft have not done to compare with conventional steel drive shaft. To decrease the bending stresses various stacking sequences can be used. By doing the same, we can maximize the torque transmission, static torque capability, buckling torque capability and bending natural frequency.

The objective of this work is, to analyse the comparative performance of carbon epoxy composite drive shaft with respect to conventional steel drive shaft for torque transmission capability. By analysing performance conventional steel drive shaft can be replaced by composite drive shaft.

I. LITERATURE REVIEW

Rangaswamy et. al presented a paper with objective to design and analyze a composite drive shaft for power transmission applications. A one-piece drive shaft for rear wheel drive automobile was designed optimally using E-Glass/Epoxy and High modulus (HM) Carbon/Epoxy composites. They had successfully applied a Genetic Algorithm (GA) to minimize the weight of shaft which is subjected to the constraints such as torque transmission, torsional buckling capacities and fundamental natural frequency [1]. Lee et. al had discussed design and manufacture of an automotive hybrid aluminum/composite drive shaft. In his work, one-piece automotive hybrid aluminum/composite drive shaft was developed with a new manufacturing method, in which a carbon fiber epoxy composite layer was co-cured on the inner surface of an aluminum tube. The mass of the manufactured hybrid aluminum/composite drive shaft was 3.3 kg, which was only 25% of the conventional steel drive shaft[2]. Rangaswamy et. al have performed design optimization of E-glass / epoxy and high modulus (HM) carbon/epoxy composites drive shaft using genetic algorithms. Aluminum material used in combination with composite may lead to increase in natural frequency of shaft[3].

Mutasher have investigated the maximum torsion capacity of the hybrid aluminum/composite shaft for different winding angle, number of layers and stacking sequences. The finite element method has been used to analyze the hybrid shaft under static torsion [4]. A.R. Abu Talib have studied design of composite drive shafts incorporating carbon and glass fibers within an epoxy by using matrix a finite element analysis. The present finite element analysis of the design variables of fiber orientation and stacking sequence provide an insight into their effects on the drive shaft’s critical mechanical characteristics and fatigue resistance [5].

Khoshravan et. al presented the design method and vibrational analysis of composite propeller shafts. Composite shaft design some parameters such as critical speed, static torque and adhesive joints are studied; the behavior of materials is considered nonlinear isotropic for adhesive, linear isotropic for metal and orthotropic for composite shaft [6].Schola et. al have designed High Strength Carbon composite drive shafts have been to replace the steel drive shaft of an automobile. The weight savings of the HS Carbon is 24 % (100-50) compared to same dimensions of steel shaft [7]. Dinesh et. al have designed A composite drive shaft for wheel drive automobile optimally by using Genetic Algorithm for E – Glass/ Epoxy, High Strength Carbon/ Epoxy and High Modulus Carbon/ Epoxy composites with the objective of minimization of weight of the shaft. The weight savings of the E – Glass/ Epoxy, High Strength Carbon/ Epoxy and High Modulus Carbon/ Epoxy shafts were equal to 48.36%, 86.90%, and 86.90% of the weight of steel shaft respectively [8]. Patil et.al discusses the results of Analytical Analysis are used to perform Torsional Buckling analysis using ANSYS software. The results show the stacking sequence and fiber angle orientation of shaft strongly affects Buckling strength of shaft [9].

Parvathi et. al have performed A Static and Dynamic analysis, composite shaft is analyzed using Finite Element Analysis Software for composites with the objective of minimizing the weight of the shaft. He concluded that results we can conclude that 75 diameter with 12 mm wall thickness shaft with carbon fiber as inner and outer and fiber as middle core is suitable for drive shaft due to low stress, less weight and less manufacturing cost[10]. Ghatage et. al have done analysis for finding out the suitability of composite structures for automotive drive shaft application the parameters such as; ply thickness, number of plies and stacking sequence are optimized for carbon/ Epoxy and Glass/ Epoxy shafts using Genetic Algorithm as an optimization tool with the objective of weight minimization of the composite shaft[11].

Suryawanshi et. al presented a review of design of hybrid aluminum/ composite drive shaft for automobile. Press fitting method for the joining of the aluminum/ composite tube and steel yokes was devised to improve reliability and to reduce manufacturing cost, compared to other joining methods such as adhesively bonded, bolted or riveted and welded joints. The joining of the aluminum - composite tube and steel yoke with improved reliability and optimum manufacturing cost is done by press fitting. In order to increase the torque transmission capacity protrusion shape is provided on the inner surface of steel yoke which will fit on Universal joints [12].Belawagi et. al have made an attempt is made to evaluate the suitability of composite material such as E-Glass/Epoxy and HM-Carbon/Epoxy for the purpose of automotive transmission applications. In this paper comparison of drive shaft for steel and composite is carried out based on maximum deformation, maximum and minimum stresses induced in the shaft [13].O. Montagnier et. al have studied the optimization of hybrid composite drive shafts operating at subcritical or supercritical speeds, using a genetic algorithm. They have concluded as $\pm 45^0$ HS carbon/epoxy plies should be used in order to maximize the torque resistance, 0^0 HM carbon/epoxy plies should be used in order to maximize the axial stiffness and minimize the axial damping involved in bending oscillations, 90^0 HM carbon/epoxy plies should be used far from the shaft middle surface in order to maximize the torsional buckling Torque [14].

Chopde et. al have designed the composite drive shaft made of high modulus carbon / epoxy multilayered composites. Modal analysis was conducted to obtain natural frequencies of the composite shaft. The effect of changing the carbon fiber orientation angle on natural frequency was also studied [15]. Bankar et. al have made the aim to replace a two-piece metallic drive shaft by a composite drive shaft. The following materials can be chosen Steel, Boron/Epoxy Composite, Kevlar/Epoxy Composite, Aluminum – Glass/Epoxy Hybrid, Carbon – Glass/Epoxy Hybrid. The analysis was carried out for three different ply orientations of the composites in order to suggest the most suitable ply orientation of the material that would give the maximum weight reduction [16].

Bhirud et. al presented the analysis of drive shaft by Substituting composite structures for conventional metallic structures which has many advantages because of higher specific stiffness and strength of composite materials. The intention of work is to minimize the weight of drive shaft. In this present work an attempt has been to estimate the deflection, stresses, and natural frequencies under subjected loads using FEA (Ansys) [17]. Moorthy et. al were designed Carbon/Epoxy and Kevlar/Epoxy composites. They had analyzed for their appropriateness in terms of torsional strength, bending natural frequency and torsional buckling by comparing them with the conventional steel driveshaft under the same grounds of design constraints and the best-suited composite was recommended [18].

Driveshaft must operate through constantly changing angles between the transmission and axle. High quality steel (Steel SM45) is a common material for construction. Steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft which is inversely proportional to the square of beam length and proportional to the square root of specific modulus. Hence, 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 bending natural frequency. The two piece steel drive shaft consists of three universal joints, a cross center supporting bearing and a bracket, which increase the total weight of a vehicle. Power transmission can be improved through the reduction of inertial mass and light Hook's weight. Substituting composite structures for conventional is metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials.

Comparison of drive shaft for steel and composite is carried out based on maximum deformation, maximum and minimum stresses induced in the shaft using finite element analysis. They have concluded as $\pm 45^0$ carbon/epoxy plies should be used in order to maximize the torque resistance, 0^0 carbon/epoxy plies should be used in order to maximize the axial stiffness and minimize the axial damping involved in bending oscillations, 90^0 carbon/epoxy plies should be used far from the shaft middle surface in order to maximize the torsional buckling Torque.

After review of above papers, it is observed that work is limited to optimization using genetic algorithm and analysis of drive shaft using FEA software. But experimental investigation of composite drive shaft has not done to analyse performance with conventional steel drive shaft.

II. Methodology

A. *Problem Specification*

The application selected for this project is TATA207. It has max torque output 180Nm @ 1500rpm. The following specifications were selected for automobile drive shaft:

1. The torque transmission capacity of the driveshaft (T) = 180 N-m.
2. The shaft needs to withstand torsional buckling (Tb) such that Tb > T.
3. The minimum bending natural frequency of the shaft f_{nb}(min) = 25 Hz.

B. *Design of Steel Drive Shaft*

The material most widely being used for conventional drive shaft is steel. The steel selected was SAE 4130. The properties of SM45C steel are:

- Young's modulus (E) = 200GPa,
- Poisson's ratio (ν) = 0.3,
- Density of steel (ρ) = 7850 kg/m3
- Ultimate shear strength τ_{ult} = 80 MPa

Outside diameter of the Steel as well as composite drive shaft is taken as 35mm since, for performance comparison purpose.

1) *Torsional strength:* The primary load in the drive shaft is torsion. The maximum shear stress, τm, in the drive shaft is at the outer radius (ro), and is given as,

$$\frac{\tau_{max}}{F.O.S.} = \tag{1}$$

Since, $r_o = 17.5\ m$

$ri = 11.5\ m$.

t = 6 mm

2) *Torsional buckling:* This requirement asks that the applied torsion be less than the critical torsional buckling moment. For a thin, hollow cylinder made of isotropic materials, the critical buckling torsion, Tb is given as follows,

A shaft is considered as a long shaft, if:

$$\left[\frac{1}{\sqrt{1-\nu^2}}\right]\frac{L^2 \times t}{(2r)^3} > 5 \tag{2}$$

And critical stress for a Short & Medium shaft is given by,

$$T_{cr} = \left[\frac{4.39E}{(1-\nu^2)}\right]\left(\frac{t}{r}\right)^2 \sqrt{1\left(1 + 0.0257(1-\nu^2)^{3/4}\frac{L^2}{(rt)}\right.} \tag{3}$$

For long shaft, the torsional buckling capacity:

$$T_b = \tau_{cr}(2\pi r^2 \tag{4}$$

Where critical stress is given by,

$$\tau_{cr} = \left[\frac{E}{3\sqrt{2}(1-\nu^2)^{3/4}}\right]\left(\frac{t}{r}\right)^{3} \tag{5}$$

$\tau_{cr} = 13247.77\ N/mm^2$

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$T_b = 112371.6\ N \quad (\quad T_b >$

3) *Natural frequency*: The lowest natural frequency for a rotating shaft is given by,

$$f_n = \frac{\pi}{2}\sqrt{\frac{I}{m}} \qquad (6)$$

$$f_{nb} = 26\ Hz\ or\ \ N_{nb} = 1560\ rpm$$

C. Design of composite shaft

The specifications of the composite drive shaft of an automotive transmission are same as that of the steel drive shaft for comparison of performance. Outer diameter of composite drive shaft is taken 35mm same as that of steel drive shaft.

1) *Assumptions:*

- The shaft rotates at a constant speed about its longitudinal axis.
- The shaft has a uniform, circular cross section
- The shaft is perfectly balanced, i.e., at every cross section, the mass and center coincide with geometric center.
- All damping and nonlinear effects are excluded.
- Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress [19].

2) *Material Selection:*

A composite material is defined as a material composed of two or more constituents combined on a macroscopic scale by mechanical and chemical bonds. Composites are combinations of two materials in which one of the material is called the "matrix phase" is in the form of fibers, sheets, or particles and is embedded in the other material called the "reinforcing phase".

- Fiber Selection: The commonly used fibers are carbon, glass, Kevlar etc. Among these, the carbon fiber has been selected based on the strength and stiffness. This is used as standard reinforcement fiber for all mechanical property requirements. Thus, Carbon fiber was found appropriate for this application.

- Resin Selection: In a FRP, interlaminar shear strength is controlled by the matrix system used. Since these are reinforcement fibers in the thickness direction, fiber do not influence inter laminar shear strength. Therefore, the matrix system should have good inter laminar shear strength characteristics compatibility to the selected reinforcement fiber. Many thermo set resins such as polyester, vinyl ester, epoxy resin are being used for fiber reinforcement plastics (FRP) fabrication. Among these resin systems, epoxies show better inter laminar shear strength and good mechanical properties.

3) *Torsional strength:* Since the nature of loading is pure torsional shear, ply orientation angle should select in such manner that it should have higher shear strength. Fig. 1 shows variation of elastic modulus along X & Y direction. Fig. 2 shows variation of shear modulus along XY plane.

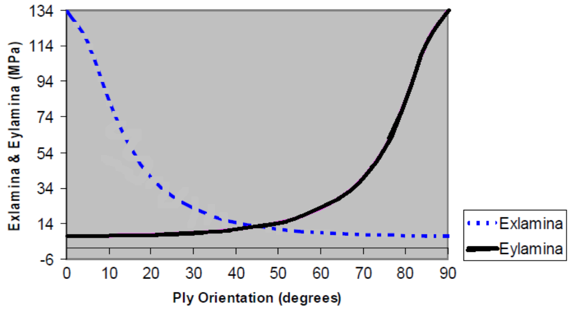

Fig.1 $E_{xlamina}, E_{ylam}$ with ply orientation for carbon epoxy [16]

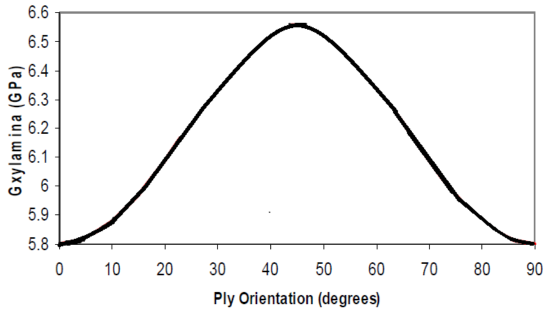

Fig.2 G_{xylam} with ply orientation for carbon epoxy [16]

Only 0°, ±45° and 90° were considered for the composite ply orientations, because of their specific advantages. 60% fiber volume fraction Carbon/Epoxy shaft (Vf =60%) with standard ply thickness of 0.13 mm was selected. [18]

Assuming that the drive shaft is a thin, hollow cylinder, an element in the cylinder can be assumed to be a flat laminate.

$$\frac{\tau_{max}}{F.O.S.} = \frac{T}{2\pi r} \qquad (7)$$

Where, r is the mean radius of the shaft

Since the nature of loading is pure torsional shear, 70% of the plies can be set at ±45° and the remaining 30% at 0º and 90º orientations.

From fig 3,

$\tau_{max} = 293$ Mpa

$r^2 t = 0.586 \times 10^{-6}$mm

Consider factor of safety as 6

$t \geq 2.1782$ mm

Thickness of each ply is ,

$$t = 0.13m$$

$$n =$$

4) *Torsional buckling:* Since long thin hollow shafts are vulnerable to torsional buckling, the possibility of the torsional buckling of the composite shaft was checked by the expression for the torsional buckling load of a thin walled orthotropic tube.

An orthotropic thin hollow cylinder will buckle torsionally if; the applied torque is greater than the critical torsional buckling load. This can be given as,

$$T_c = (2\pi r^2 t)(0.272)\left(ExE_y^3\right)^{\frac{1}{4}}\left[\frac{t}{r_m}\right]^{3/2}$$

$$T_c = 2635.37\ Nm \quad (T_c > \qquad (8)$$

5) *Natural frequency:*The shaft is considered as simply supported beam undergoing transverse vibration.

Natural frequency be found using Bernoulli-Euler Beam Theory.

It neglects the both transverse shear deformation as well as rotary inertia effects. The minimum natural frequency based on the Bernoulli-Euler beam theory for a rotating shaft is given by,

$$f_{nb} = \frac{\pi p^2}{2}\sqrt{\frac{E}{m}} \quad (9)$$

$m' = 0.3905\ kg/m$

$f_{nb} = 36Hz$

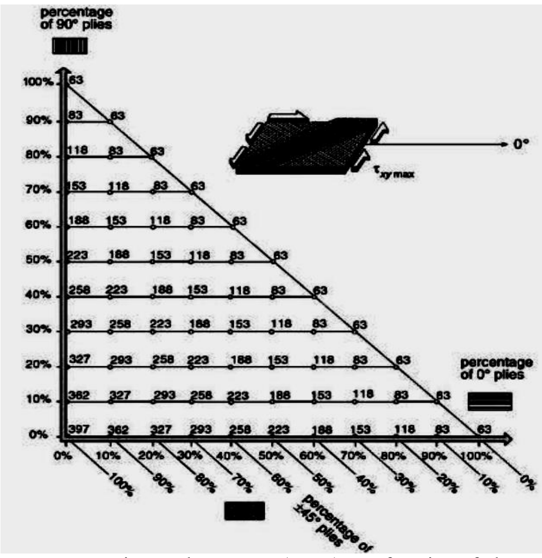

Fig.3 Maximum shear stress (τmax) as a function of ply percentages for Carbon/Epoxy Laminate (Vf = 60%; Ply thickness = 0.13 mm) [19]

D. NUMERICAL ANALYSIS

The Finite Element Method (FEM) is practical application often known as Finite Element Analysis. Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. Thus, a complex engineering problem with non-standard shape and geometry can be solved using finite element analysis where a closed form solution is not available.

A Structural analysis can be linear or non-linear. The static analysis deals with the condition of equilibrium of bodies acted upon by forces. A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those carried by time varying loads. A FEA analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads.

1) *FEA of steel shaft:* To perform analysis of steel shaft, 3-dimensional model is created using Design Modeler. Meshing of the prepared model is done using appropriate method. Boundary conditions are provided as per the application. All degree of freedom are restricted for one end and at the other end of shaft model, moment is applied as 180Nm.The moment was applied in successive interval as 30, 60, 90, 120, 150, 180, 210 Nm.

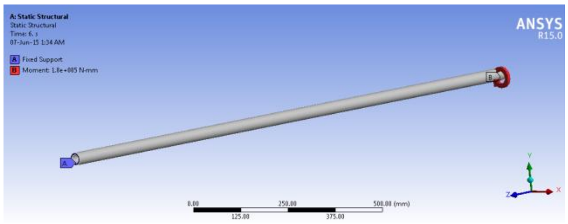

Fig.4 boundary condition for FEA model

2) *FEA of composite shaft:* FEA of composite drive shaft is done by Ansys workbench 2015 with Ansys Composite Prepost. Procedure to solve composite drive shaft is quite different than that of steel material. In addition to conventional structural solution it needs pre-processing and post processing. Different ply groups are provided in ansys composite pre-processing as per design. This layered geometry is directly feed to the structural solution as a section data, where it can be solved.

3) *Fabrication of carbon epoxy composite drive shaft:* In case of composite shaft, there are number of variable for design. One of them is as ply orientation angle. When angle orientation of ply is 0 and 90, laminates possesses lowest shear modulus. The laminate configuration ± 45; laminates possess the highest shear modulus and hence these laminate type is used in purely torsional application. On another hand ± 45 laminate possess lower modulus in axial direction. To increase natural frequency of shaft, the shaft must have and adequate axial modulus. Hence, 0° layer must be added to the lay up to improve the resonance frequency.

4) *Experimentation:* The experimentation is performed by using Torque Testing Machine. The specimen was mounted on torque testing machine.After mounting specimen on torque testing machine, torque was applied incrementally. The observations were recorded as the applied torque and the corresponding angle of twist. For a circular cross-section, in the absence of the other loads, pure shear stress state exists at each point. Torsional elastic shear stresses vary linearly from zero at the axis of twist to a maximum at the extreme fibers

TABLE I
EXPERIMENTAL RESULTS FOR STEEL AND CARBON EPOXY COMPOSITE DRIVE SHAFT

Sr. No.	Torque Nm	Experimental Angular Deflection for	
		Steel drive shaft	carbon epoxy composite drive shaft
1	30	0.0270	0.0349
2	60	0.0397	0.0547
3	90	0.0523	0.0610
4	120	0.0592	0.0775
5	150	0.0681	0.0883
6	180	0.0777	0.0998
7	210	0.0922	0.1092

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TABLE III
STRESSES FOR STEEL AND CARBON EPOXY COMPOSITE DRIVE SHAFT

Sr. No.	Torque Nm	Von-mises stress for	
		Steel drive shaft Mpa	carbon epoxy composite drive shaft Mpa
1	30	7.9404	4.0496
2	60	15.881	8.0993
3	90	23.821	12.149
4	120	31.761	16.199
5	150	39.702	20.248
6	180	47.642	24.298
7	210	55.583	28.348

5)FEA Results

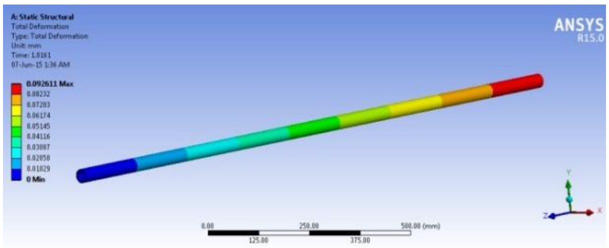

Fig.5 Total deformation for steel shaft

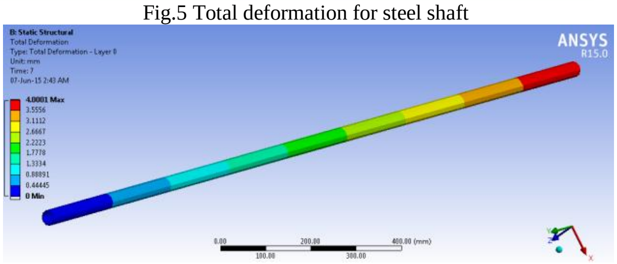

Fig.6 Total deformation for carbon epoxy composite shaft

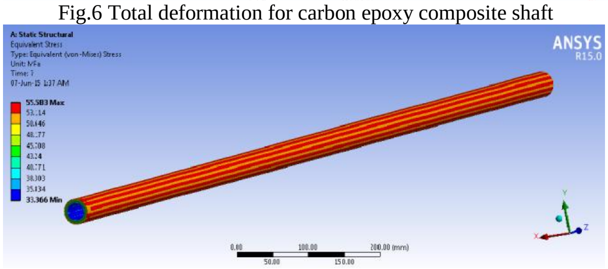

Fig.7 Max Stress for steel shaft

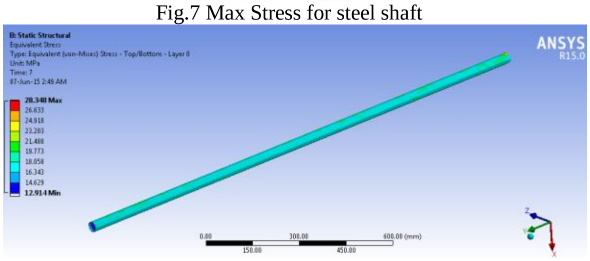

Fig.8 Max Stress for carbon epoxy composite shaft

6)Weight Reduction

Some amount of power generated by engine is wasted due to rotating masses in power transmission system. Power is lost because a part of energy is needed to rotate heavy parts. Drive shaft is one of the rotating members of power transmission system. So reduction in amount of rotating masses leads to energy saving.

TABLE III
MASS COMPARISON

Shaft Material	Mass (kg)
Steel	7.47
Carbon epoxy composite	0.900

III. CONCLUSIONS

In this paper, the composite drive shaft made up of carbon epoxy multilayered composites has been designed. Based on maximum deformation, maximum and minimum stresses induced in the shaft, the performance comparison of steel drive shaft and carbon epoxy composite drive shaft is carried out. The replacement of composite materials has resulted in considerable amount of weight reduction when compared to conventional steel shaft. Also, the results were obtained, which shows

1. The presented work was aimed to replace conventional two piece steel drive shaft with carbon epoxy composite shaft.
2. It also leads to reduce the fuel consumption of the automobile in the particular or any machine, which employs drive shafts; it is achieved by considerable amount of weight reduction.
3. By taking into considerations the weight saving, deformation, shear stress induced, it is evident that carbon/Epoxy composite has the most encouraging properties to act as replacement for steel.

NOMENCLATURE

E	Young's modulus of elasticity	Pa
m	Mass per unit length	Kg/m
L	Length of drive shaft	mm
I	Area moment of inertia	mm4
n	Number of ply	
t_k	Ply thickness	mm
t	Total thickness	mm
f_{nb}	Natural frequency	Hz
τ_{max}	Maximum shear stress	Pa
J	Polar moment of inertia	mm4
ν	Poisons ratio	
E_x	Young's modulus along x direction	Pa
E_y	Young's modulus along y direction	Pa

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REFERENCES

[1] T. Rangaswamy, S. Vijayarangan, R. A. Chandrashekar, T.K. Venkatesh and K.Anantharaman,"Optimal Design And Analysis of Automotive Composite Drive Shaft", International Symposium of Research Students on Materials Science and Engineering, December 2002-04.

[2] Dai Gil Lee, Hak Sung Kim, Jong Woon Kim, Jin Kook Kim, "Design and manufacture of an automotive hybrid aluminum/composite drive shaft", Composite Structures 63, 2004, pp.87–99.

[3] Thimmegowda Rangaswamy, Sabapathy Vijayarangan, "Optimal Sizing and Stacking Sequence of Composite Drive Shafts", MATERIALS Science, Vol. 11, No. 2. 2005, pp.133-139.

[4] S.A. Mutasher, "Prediction of the torsional strength of the hybrid aluminum/composite drive shaft", Materials and Design 30 (2009), pp.215–220.

[5] A.R. Abu Talib, Aidy Ali, Mohamed A. Badie, Nur Azida Che Lah, Golestaneh, "Developing a hybrid, carbon/glass fiber-reinforced, epoxy composite automotive drive shaft", Materials and Design 31 (2010), pp.514–521.

[6] Mohammad Reza Khoshravan, Amin Paykani, Aidin Akbarzadeh, "Design And Modal Analysis Of Composite Drive Shaft For Automotive Application", International Journal of Engineering Science and Technology, Vol. 3, No. 4, April 2011, pp.2543-2549.

[7] PG Schola, "Design, Comparison and Analysis of a Composite Drive Shaft for an Automobile", International Review of Applied Engineering Research, Volume 4, 2014, pp.21-28.

[8] D. Dinesh, F. Anand Raju, "Optimum Design And Analysis Of A Composite Drive Shaft For An Automobile By Using Genetic Algorithm And Ansys", International Journal Of Engineering Research And Applications, Vol. 2, Issue4, July-August 2012, Pp.1874-1880.

[9] Sagar D. Patil, Prof. D.S.Chavan, Prof. M.V.Kavade, "Investigation of Composite Torsion Shaft for Torsional Buckling Analysis using Finite Element Analysis", Journal of Mechanical and Civil Engineering, Volume 4, Issue 3 (Nov-Dec. 2012), pp.26-31.

[10] K. V. N. Parvathi, CH. Prabhakara Rao, "Structural Design of Composite Drive Shaft For Rear-Wheel Drive Engine", International Journal of Advanced Engineering Research and Studies, Vol. II/ Issue I, Oct.-Dec.,2012, pp.85-89

[11] Ghatage K.D, Hargude N.V, "Optimum Design of Automotive Composite Drive Shaft with Genetic Algorithm as Optimization Tool", International Journal Of Mechanical Engineering And Technology, Volume 3, Issue 3, September - December (2012), pp.438-449.

[12] Bhushan K. Suryawanshi, Prajitsen G.Damle, "Review of Design of Hybrid Aluminum/ Composite Drive Shaft for Automobile", International Journal of Innovative Technology and Exploring Engineering, Volume-2, Issue-4, March 2013, pp.259-266.

[13] Belawagi Gireesh, Sollapur Shrishail B, V. N. Satwik, "Finite Element & Experimental Investigation of Composite Torsion Shaft", International Journal of Engineering Research and Applications, Vol. 3, Issue 2, March -April 2013, pp.1510-1517.

[14] O. Montagnier, Ch. Hochard, "Optimization of hybrid high-modulus/high-strength carbon fibre reinforced plastic composite drive shafts", Materials and Design 46 (2013), pp.88–100.

[15] Chopde Pandurang V., "Vibration Analysis of Carbon Epoxy Composite Drive Shaft for Automotive Application", International Journal of Engineering Research & Technology, Vol. 2 Issue 4, April – 2013, pp.65-69.

[16] Harshal Bankar, VirajShinde, P. Baskar, " Material Optimization and Weight Reduction of Drive Shaft Using Composite Material", Journal of Mechanical and Civil Engineering, Volume 10, Issue 1, Nov. - Dec. 2013, pp.39-46.

[17] Bhirud P. Prakash,Bimlesh Kumar Sinha, "Analysis of Drive Shaft", International Journal of Mechanical and Production Engineering, Volume- 2, Issue- 2, Feb.-2014, pp.24-29.

[18] R. Srinivasa Moorthy, Yonas Mitiku & K. Sridhar, "Design of Automobile Driveshaft using Carbon/Epoxy and Kevlar/Epoxy Composites", IJER, Volume-02, Issue-10, pp-173-179.

[19] Autar K. Kaw, "Mechanics of composite material", second edition Taylor & Francis Group, 2006.

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