THE INTERNATIONAL JOURNAL OF
SCIENCE & TECHNOLEDGE

Structural Analysis of Composite Material Drive Shaft Using FEM

Esakkimuthu N.
PG Student, Department of Mechanical Engineering
Regional Centre of Anna University, Tirunelveli, India
Dr. Rajakumar S.
Assistant Professor, Department of Mechanical Engineering
Regional Centre of Anna University, Tirunelveli, India

Abstract:
Replacement of conventional metallic structures with the composite structures have many advantages because of high specific stiffness and strength of composite materials This work deals with the Substituting single piece composite drive shaft for conventional two piece steel drive shaft with the aim of minimization of rotating mass in drive line application for increasing the fuel efficiency. Firstly, a finite element model of drive shaft made of steel, Kevlar/Epoxy, and Boron/Epoxy composites are developed to analyze for static, modal and buckling analysis. From the results obtained, it is observed that composites are having better torque transmission capacity and bending natural frequency compared to steel. Boron/Epoxy has good buckling strength capability as compared with other composites. These finite element analysis results are compared with analytical values and it is observed that the single piece composite drive shaft is suitable for driveline application.

***Key words** : Automotive ,Drive shaft, Composite material, Finite element*

1. Introduction

In the drive line application the torque produced in the engine has to be transferred to the rear wheels to move the vehicle. In the recent years research is going on to replace a two piece drive shaft with a single piece shaft without compromising on functional requirements. As the single piece drive shaft is long and thin walled, the failure mode is torsional buckling rather than material failure. Sagar R.Dharmadhikari, et al [1] have measured the deformation of steel and composite drive shaft. The deflection of steel, HS Carbon/Epoxy, HM Carbon/Epoxy shafts were 0.00016618mm, 0.00032761mm, 0.0003261mm respectively. Finally, single piece high strength Carbon/Epoxy composite drive shaft has been proposed to design to replace the two piece conventional steel drive shaft of an automobile.

Parshuram D and Sunil Mangsetty [2] They studied the usage of composite materials has resulted in considerable amount of weight saving in the range of 81% to 72% when compared to conventional steel The usage of composite materials has resulted in considerable amount of weight saving in the range of 81% to 72% when compared to conventional steel drive shaft. Taking into account the weight saving, deformation, shear stress induced and resultant frequency it is evident that Kevlar/epoxy composite has the most encouraging properties to act as
replacement to steel. Their 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. 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 transmission of power to the differential parts of the assembly. Apart from being lightweight, the use of composites also ensures less noise and vibration.

Bhushan K, et al [3] have designed the hybrid aluminium /composite drive shafts with the objective of minimization of weight of the shaft which was subjected to the constraints such as torque transmission, torsional buckling capacities and natural bending frequency. The mass of the hybrid aluminum/composite drive shaft will be very less compared to the conventional steel drive shaft. The static torque capability and the fundamental natural frequency were 4320 Nm and 9390 rpm, which exceeded the design requirements. A press fit joining method between the steel yoke with protrusions on its surface and the aluminium tube was developed to increase the reliability of joining and to reduce manufacturing cost.

Mohamed Reza Khoshravan et al [4] have suggested that composite material has been resulted in considerable amount of weight reduction about 72% when compared to conventional steel shafts and also reveal that the orientation of fiber has great influence on the dynamic characteristic of the composite shafts.

Madu K.S. et al [5] have concluded that the optimized composite drive shafts designed using particle swarm optimization technique is safe under the peak torque loading of 3500Nm and rotational speed of 6500rpm. Kevlar/Epoxy and HM Carbon/ Epoxy shafts are good in shear strength and bending natural frequency and are excellent from vibration point of view. Kevlar/Epoxy has good buckling strength capability as compared with other composite material. The obtained Finite element analysis results are compared with analytical values and observed that the single piece composite drive shaft is suitable for driveline applications. Thus the designed single piece composite drive shafts can be employed in the automobiles to result for considerable weight savings, thereby increasing the fuel efficiency. However, high material processing cost together with its limited availability is a major limitation of the composite materials which need to be addressed, to make the employment of composite drive shaft in the automobile economical.

R.P.Kumar Rompicharla and Dr.K.Rambabu [6] have concluded that the usage of composite material has resulted to inconsiderable amount of weight saving in the range of 28 % when compared to conventional steel shaft. Taking into considerations of weight saving, deformation, shear stress induced and resonant frequencies, it is evident that Kevlar/Epoxy composite has the most encouraging properties to act as replacement for steel out of the considered two materials . The presented work was aimed to reduce the fuel consumption of the automobile in the particular or any machine which employs drive shaft, in general it is achieved by using light weight composites like Kevlar/Epoxy. The presented work also deals with design optimization. i.e. converting two piece drive shaft (conventional steel shaft) in to single piece light weighted composite drive shaft. In this case study a drive shaft of Toyota Qualis is considered. The geometrical model is developed and various structural analysis are performed.

D.Dinesh et al [7] have designed the E- Glass/Epoxy, High strength Carbon/Epoxy and High Modulus Carbon/Epoxy composite drive shaft to replace the steel drive shaft of an automobile. A composite drive shaft for automobile has been designed optimally by using genetic algorithm for E- Glass/Epoxy, High strength Carbon/Epoxy and High Modulus Carbon/Epoxy with the objective of minimization of the weight of the shaft which was subjected to the constraints such as torque transmission, torsional buckling capacities and natural frequency. The weight savings of 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. The deflection of steel, E- Glass/Epoxy, High Strength Carbob/Epoxy and High Modulus Carbon/Epoxy shaft were equal to 0.012407, 0.025262, 0.019288 and 0.012919 mm respectively. The fundamental natural frequency of steel , E- Glass/Epoxy, HS Carbon/Epoxy and HM Carbon/Epoxy shafts were 9319.98, 6514.56, 7495.42 and 9270.28 rpm respectively. The torsional buckling capacity of steel, E- Glass/Epoxy, HS Carbon/Epoxy and HM Carbon/Epoxy shafts were 43857.96, 29856.45, 3772.11 and 3765.75 N-m respectively.

Anup A. Bijagare et al [8] have concluded that the high strength carbon/epoxy composite drive shaft has been designed to replace conventional steel drive shaft of an automobile. A one piece composite drive shaft for rear wheel drive automobiles has been designed optimally by using Genetic Algorithm (GA) for high strength carbon/epoxy composites with the objective of minimization of weight of shaft, & analyzed using ANSYS for better torque transmission capacity and bending vibration characteristics when the value of tk= 0.31 and n = 8 then the weight of composite drive shaft is 1.36 kg i.e. the weight saving by the composite drive shaft as compared to steel drive shaft is about 83.47 %. These results are encouraging and suggest that GA can be used effectively and efficiently in other complex and realistic designs often encountered in engineering applications.

Ghatage K.D and Mr.Hargude N.V [9] have designed optimally with genetic algorithm as optimization tool that a one-piece composite drive shaft made of Carbon/Epoxy and Glass-Carbon/Epoxy with the objective of minimization of weight of drive shaft which is subjected to constraints such as Maximum torque transmission capacity, Buckling torque transmission capacity and critical speed. About 28.01 % of weight saving is achieved with Carbon/Epoxy shaft with increase in critical speed enabling manufacturing of shaft of length 1.8m to 2 m as compared to steel shaft by experimentation. About 15.75% weight saving is achieved with Glass-Carbon/Epoxy composite shaft with increasing critical speed enabling manufacturing of shaft of length 1.7 m to 2m as compared to steel shaft by experimentation. The results reveal that the orientation of fibers has great influence on the dynamic characteristics of the composite material drive shafts in a positive direction genetic algorithm is suggested as an effective optimization tool.

Hargude N.V and Ghatage K.D[10] have presented that a procedure to optimum design of composite drive shaft made up of E-Glass/Epoxy and high modulus carbon/Epoxy multilayered composites. GA is suggested as an effective optimization tool for optimal design of composite drive shaft for better sequence, transmission capacity and bending vibration characteristics. The usage of composite material and optimization techniques have resulted in considerable amount of weight saving in the range of 48 to 86% when compared to conventional steel shaft. Result obtained are encouraging and GA can be suggested effective efficient tool for other complex and realistic designs often encountered in engineering application.

2. Specification of the Problem

The torque transmission capability of the drive shaft for passenger cars, small trucks, and vans should be larger than 3500 Nm (T_{max}) and fundamental natural bending frequency of the drive shaft should be higher than 6500 rpm (N_{max}) to avoid whirling vibration. The drive shaft outer diameter *do* should not exceed 100 mm due to space limitations. Here outer diameter of the shaft is taken as 95 mm. A drive shaft is the connection between the transmission and the rear axle of the car. Power generated by the engine is transferred to the transmission via a clutch assembly. The transmission is linked to the driveshaft by a yoke and universal joint assembly. The drive shaft transmit the power to the rear end through another yoke and U- joint assembly.

3. Methodology

- The literature of the drive shaft for its loading and operating conditions are considered.
- Steel drive shaft to meet the functional requirements of automobile is designed and composite drive shaft is also designed with the same geometry as that of steel drive shaft
- Preparation of 2D FE model using ANSYS and applying loading condition from design specification and boundary condition for required analysis

- The following analysis using ANSYS solver are performed on the shaft model created by the material of steel,
  - Kevlar/Epoxy and Boron/Epoxy composites.
  - Static Analysis
  - Modal Analysis
  - Buckling Analysis
- The results obtained for steel and composites based on theoretical calculation and the results obtained from

ANSYS solver are compared and validated for torque transmission capacity shear stress distribution, shear elastic strain, deflection, and natural frequency.

4. Design and Analysis of the Drive Shaft for an Automobile

Maximum torque (T) = 3500 N-m and Maximum speed of shaft (N) = 6500 rpm are considered based on the literature and available standards of automobile drive shafts The drive shaft can be solid circular or hollow circular. Here hollow circular cross section is chosen. Because, The hollow circular shafts are stronger in per kg weight than solid circular shaft. The stress distribution in case of solid circular is zero at the centre and maximum at the outer surface . In hollow shaft stress variation is smaller. In solid shafts, the material close to the centre are not fully utilized. Due to space factor , the outer diameter and length of the shaft is taken as 95mm and 1250mm respectively.

Design constraints are given as

- Torque transmission capacity of the shaft . T > Tmax
- Torsional buckling capacity of the shaft . T > Tmax.
- Lateral fundamental natural frequency of the shaft. Ncrt > Nmax

Specification of shafts are given in Table. 1

S. No.	Parameter	Symbol	Size	Unit
1.	Outside diameter of shaft.	d_o	95	Mm
2.	Inner diameter	d_i	84.36	Mm
3.	Length of the shaft	L	1250	Mm
4.	Weight of steel shaft	W_s	14.24	Kg
5.	Weight of composite shaft (Kevlar/Epoxy).	W_k	2.62	Kg
6.	Weight of composite shaft(Boron/Epoxy)	W_b	4.21	Kg

Table 1: Specification of Shafts

4.1 Finite Element Analysis

In finite element method, a structure is broken down into small elements. The behavior of an individual element can be described with relatively simple set of equations. Just as the set of element would be joined together to build the whole structure, the equations describing the behaviors of the individual elements are joined into an extremely large set of equations that describe the behavior of the whole structure. In this work finite element model of steel and various composites drive shaft is developed using ANSYS solver. The material properties of steel and composite drive shaft considered are shown in table 2. Since the geometry of the model is simple, an assumption of linear isotropic material for steel and linear orthotropic material for composite is made. The element considered for modeling steel and composite shaft are pipe 20. Each element is having 20 nodes and each node is having all degrees of freedom. .Material properties of shaft is presented in Table.2

Material / Parameter	Steel	Kevlar/Epoxy	Boron/Epoxy
E_x [Pa]	2.07e11	95.71e9	281.86e9
E_y [Pa]	-	10.45e9	10.88e9
E_z [Pa]	-	10.45e9	10.88e9
G_{xy} [Pa]	-	25.08.e9	67.49e9
G_{yz} [Pa]	-	25.08e9	67.49e9
v_{xy}	0.3	0.34	0.2451
v_{yz}	-	0.37	0.0095
v_{xz}	-	0.34	0.2451
Density [kg /m^3]	7600	1402	2249

Table 2: Material Properties

4.1.1. Static Analysis

Static analysis deals with the condition of equilibrium of the bodies acted upon by forces and the results obtained from static analysis for structure or component caused by loads will give a clear idea about whether it will withstand for the applied maximum forces or not. If the stress values obtained in this analysis crosses allowable values, it will result in the failure of the structure in the static condition itself. To avoid such a failure, this analysis is necessary. For this case the 2D FE model is developed and typical meshing is generated by using pipe 20 element. The shaft is fixed at one end and the other end a torque of

3500 N-m is applied and it rotates at a constant speed about its longitudinal axis. Hook's law is applicable for steel and composite materials.

4.1.2. Model Analysis

When an elastic system free from its external forces can disturbed from its equilibrium position and vibrates under the influence of inherent forces and is said to be in the state of free vibration. It will vibrate at its natural frequency and its amplitude will gradually become smaller with time due to energy being dissipated by motion. The natural frequency and the mode shapes are important parameter in the design of a structure for dynamic loading condition. In this case, model analysis is performed on 2D model created by using pipe 20 element in ANSYS solver It does not involve any computation of response due to any loading, but yields the natural frequencies and corresponding mode shapes. Theoretical natural frequencies for steel and composite material are calculated by using formula given below.

Natural Frequency [fn] = $C \times \sqrt{\frac{gEI}{wl4}}$ Value of constant c for different mode.c_1=0.56, c_2=3.51, c_3=9.82

- Critical Speed Analysis
  The relationship between shaft's length and the critical speed for both materials of drive shaft are shown in Figure 1 It is evident that for a specific application where the critical speed is about 8000 rev/min, the longest possible steel shaft is 1250 mm, while the composite one can have a length 1650 mm [4]. The main point that attracts manufacturers to use composite materials in the drive shafts is that they make it possible to increase the length of the shaft

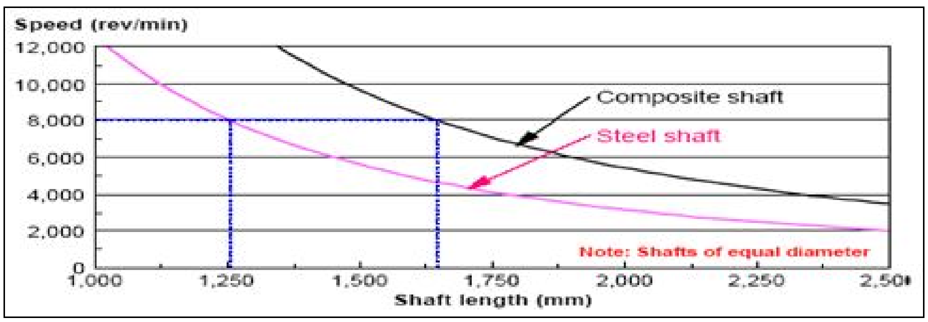

Figure 1: The effect of shaft length on critical speed [4]

4.1.3 Buckling Analysis

Buckling analysis is a technique used to determine buckling loads (critical load) at which structure becomes unstable, and buckled mode shapes. For thin walled shafts, the failure mode under an applied torque is torsional buckling rather than material failure. For a realistic drive system, improved lateral stability characteristic must be achieved together with improved torque carrying capabilities. The following general procedures are followed for performing the buckling analysis.

- 2D FE model is created as per the design specification
- Obtain the static solution
- Obtain the eigen value buckling analysis.
- Expand the solution
- Review the results

5. Results and Discussion

5.1 Static Analysis of Steel and Composite Drive Shaft

Static analysis is carried out with one end is fixed and a torque of 3500 N-m is applied at the other end. The shear stress obtained from ANSYS solver is 52.1M.Pa. and it is obtained from theoretical calculation is 54.9M.Pa. The results obtained from FEA solver for deflection of steel and composite materials are tabulated in Table 3 and it is more in Kevlar/Epoxy than Boron/Epoxy and conventional steel shaft. Figure 2, 3 & 4 are showing that the X component rotation for conventional steel shaft, Kevlar/Epoxy, and Boron/Epoxy composite shafts respectively.

Material	X Component of rotation (in radian)
Steel	0.018873
Kevlar/Epoxy	0.057884
Boron/Epoxy	0.02151

Table 3: Deflection of Steel

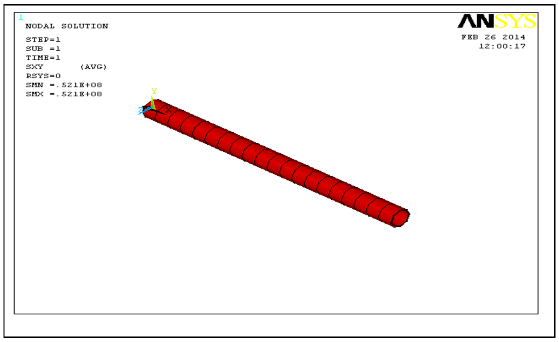

Figure 2: Shear stress of steel drive shaft

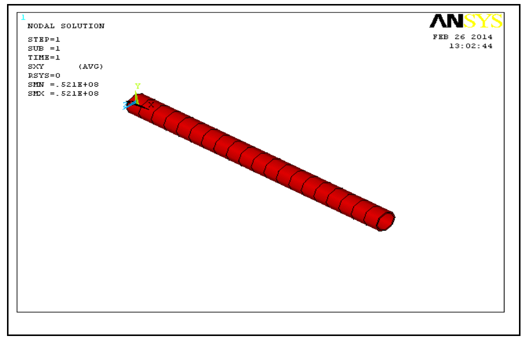

Figure 3: shear stress of Kevlar/Epoxy drive shaft

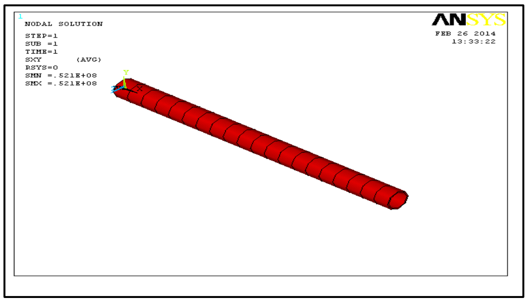

Figure 4: Shear stress of Boron/Epoxy drive shaft

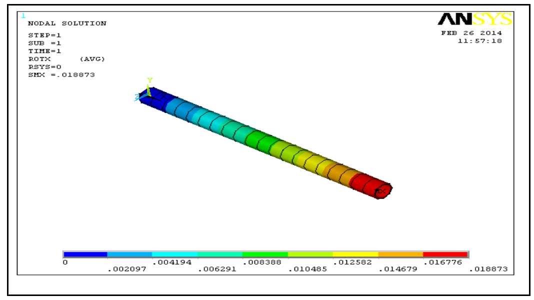

Figure 5: X Component of rotation of steel drive shaft

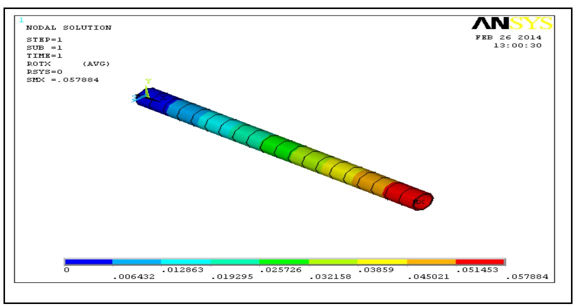

Figure 6: X Component of rotation of Kevlar/Epoxy shaft

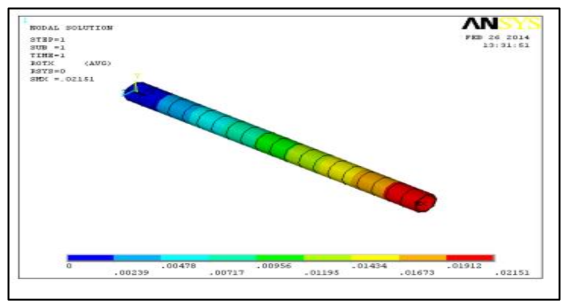

Figure 7: X Component of rotation of Boron/Epoxy

5.2. Model Analysis of Steel and Composite Rive Shaft

The model analysis is performed to find the natural frequencies in lateral direction. The natural frequency obtained from the theoretical calculations and from the ANSYS solver for conventional steel shaft, Kevlar/Epoxy, and Boron/Epoxy composite shafts are compared in table 4. It is evident from the comparison that there is small variation in between the value obtained from theoretical calculation and from the ANSYS solver. It is observed from this analysis that conventional steel shaft has low value of natural frequency. So that steel shaft will achieve the critical speed in lower operating speed while compare with composite shaft. It is also observed that Boron/Epoxy has the maximum value of natural frequency than the Kevlar/Epoxy. It is clearly shows that Boron/Epoxy having better torque carrying capability. .

Frequency No	**Natural Frequency of Steel**		**Natural Frequency of Kevlar /Epoxy**		**Natural Frequency of Boron/Epoxy**	
	Theoretical Result [Hz]	**ANSYS Result [Hz]**	**Theoretical Result [Hz]**	**ANSYS Result [Hz]**	**Theoretical Result [Hz]**	**ANSYS Result [Hz]**
1	58.39	57.719	94.07	92.63	127.47	125.39
2	366.04	343.32	589.63	540.82	798.99	728.15
3	1024.08	1026.2	1649.63	1652.9	2235.35	2239.22

Table 4: Comparison of Results

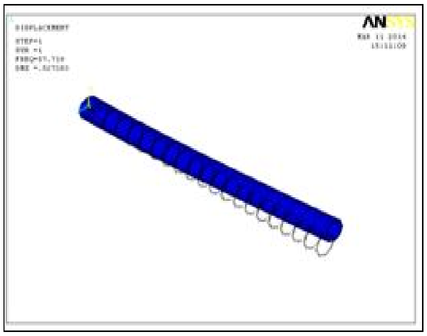
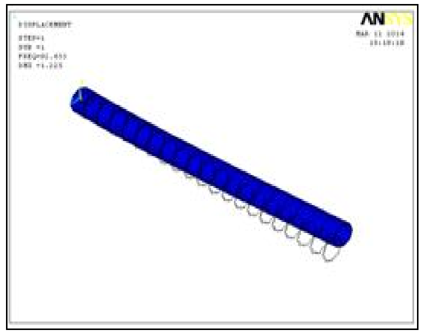
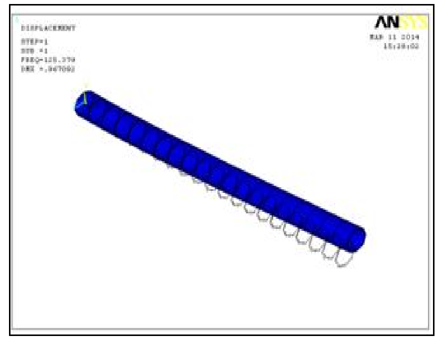

Figure 8: Modal Analysis of steel shaft
Figure 9: Modal Analysis of Kevlar/Epoxy shaft
Figure 10: Modal Analysis of Boron/Epoxy.

5.3. Buckling Analysis Of Steel And Composite Drive Shaft

The critical buckling torque obtained from ANSYS solver for steel, Kevlar/Epoxy and Boron/Epoxy are tabulated in table 5. It is observed from this analysis that Boron/Epoxy has higher buckling torque capability while compare conventional steel shaft and Kevlar/Epoxy composite shaft.

Sl. no	Material	Torsional buckling capacity (in N-m)
1	Steel	471990
2	Kevlar/Epoxy	216939
3	Boron/Epoxy	658897

Table 5: Value of Critical Buckling Torque

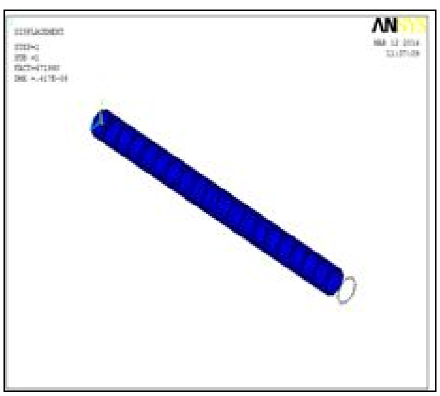
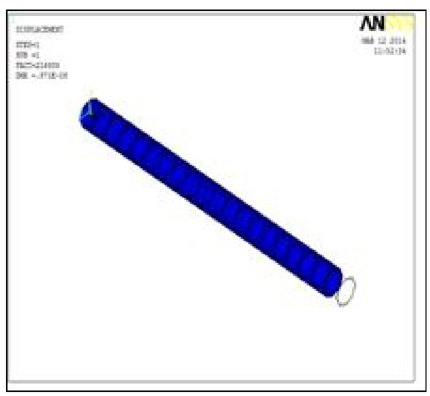
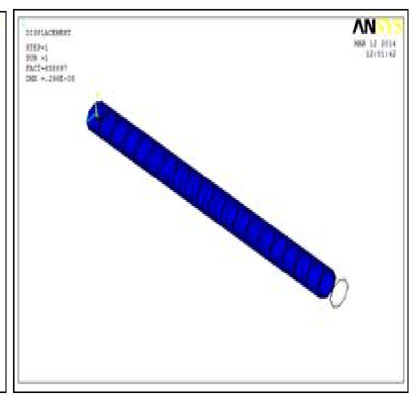

Figure 11:Buckling analysis of steel shaft
Figure 12: Buckling analysis of Kevlar/Epoxy
Figure 13: Buckling analysis of Boron/Epoxy

6 Conclusion

A Finite element model made of steel, Kevlar/Epoxy and Boron/Epoxy composite shafts are developed and analyzed for static, model and buckling analysis using ANSYS solver. The results reveal that

- The usage of composite material having considerable amount of weight saving.
- Static analysis indicates that deformation of steel has low value while compare with composites. However, Boron/Epoxy can be replaced in the place of conventional steel shaft.
- Natural frequency values obtained from ANSYS solver are compared with theoretical value for validation purpose and found that small variation in between both analysis and it is evident that Boron/Epoxy has the higher natural frequency value and more suitable for driveline application.
- Analysis of steel shaft and composite shaft indicate that Boron/Epoxy has more buckling torque transmission capability. Hence A two piece steel drive shaft can be replaced by one piece Boron/Epoxy composite drive shaft resulting into increase in fuel efficiency.
- While taking into account that the weight saving, deformation, resonant frequency and buckling strength, It is clearly reveals that Boron/Epoxy composite material drive shaft has most encouraging properties for replacement of conventional steel shaft.

7. References

1. Sagar R Dharmadhikari, Sachin G Mahakalkar, Jayant P Giri,& Nilesh D Khutafale, “Design and Analysis of composite drive shaft using ANSYS and Genetic algorithm”, A Critical Review International Journal of Modern Engineering Research ,3 (1) (2013) pp 490-496.
2. Parshuram D and Sunil Mangsetty ,“Design and Analysis of Composite/Hybrid Drive shaft for Automotives”, The International Journal of Engineering and science , 2(01) (2013) pp 160-171.
3. Bhushan K Suryawanshi and Prajitsen G Damle,” Review of Design of Hybrid Aluminium / Composite Drive shaft for Automobile”, International Journal of Innovative Technology and Exploring Engineering, 2 (04) (2013) SSN2278-3075
4. Chopde Pandurang V ,“Vibration Analysis of Carbon Epoxy Composite Drive Shaft For Automotive Application”, International Journal of Engineering Research & Technology, 2 (04)(2013) ISSN 2278-0181.
5. Madhu K.S, Darshan B.H and Manjunath K, “Buckling Analysis of Composite Drive Shaft For Automotive Application”, Journal of Innovative Research and Solution, 1A (02) (2013) pp63-70.
6. R.P. Kumar Rompicharla and K. Rambabu, “Design and Optimization of Drive Shaft with composite materials”, International Journal of Modern Engineering Research, 2 (05) (2012) pp3422-3428.
7. D.Dinesh and 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, 2 (04) (2012) pp 1874-1880.
8. Anup A. Bijagare, P.G.Mehar and V.N.Mujbaile, “Design Optimization & Analysis of Drive Shaft”,VSRD International Journal of Mechanical,Automobile & Production Engineering, 2 (06) (2012) pp 210-215.
9. Ghatage K.D. and Hargude, “Optimum Design Of Automotive Composite Drive Shaft With Genetic Algorithm As Optimization Tool”, International Journal of Mechanical Engineering And Technology, 3 (03) (2012) pp 438-449.
10. Hargude N.V and Ghatage K.D, “An Overview Of Genetic Algorithm Based Optimum Design Of An Automotive Composite (E-glass/epoxy and HM-carbon/epoxy) Drive Shaft” ,International Journal of Mechanical Engineering and Technology, 3 (01) (2011) pp 110-119