FEA Based Vibration Characteristic Analysis of Conventional and Composite Material Single Piece Drive Shaft

Ashwani Kumar, Neelesh Sharma, Pravin P Patil

***Abstract*—The main objective of this research work is vibration analysis of transmission drive shaft of a heavy vehicle. The research work is concern with the modal analysis of single piece drive shaft made from conventional and composite materials. Based on modal results select the best suited material for drive shaft. Three different materials Steel SM45C, HS Carbon Epoxy Composite and E Glass Polyester Resin Composite were selected from literature study. The main advantage of using composite material is that it has higher specific strength, less weight, high damping capacity, longer life, high critical speed and greater torque carrying capacity. The main function of drive shaft is to transmit torque from transmission to the rear wheel differential system. Heavy vehicle truck transmission drive shaft was selected as research object. Ansys 14.5 was used as an analysis tool for numerical simulation to find the vibration response of composite material drive shaft. FEA simulation result shows that the natural frequency of free vibration varies from 0 Hz to 919 Hz.**

***Index Terms*—Drive shaft, Composite Material, Fundamental Frequency, Modal Analysis**

I. Introduction

Conventionally it is manufactured using Steel material in two-piece and used for transmitting torque and rotation, at the same time it is also used to connect mechanical components of drive train that are not directly connected from transmission or engine to rear end of vehicle. This type of transmission drive shaft is known as propeller shaft. Two-piece drive shaft consists of two or more universal joints with jaw coupling which increases the total weight of drive shaft and decreases the fuel efficiency. Heavy vehicle truck

transmission longitudinal drive shaft is subjected to shear stress, torsion, lateral vibration and torsional vibration. The strength and weight are two technical indexes for drive shaft failure. Researchers have done various studies on drive shaft.

Zhenguo Zhang et al. [1] have studied the self-excited vibration of a propeller shaft. The excitation is caused due to friction induced instability. The shaft is supported on rubber bearing lubricated by water. The system was modeled in consideration with torsional vibration of continuous shaft and tangential vibration of rubber bearing. The authors have determined the stability and vibrational characteristics using complex eigenvalues analysis method. Balazs Trencseni at al. [2] have studied the driving comfort of heavy vehicle. The vehicle drivability performance is evaluated by driveline. Authors have investigated the reasons of failure for drive shaft [3-5].

S. A. Mutasher [6] this research work present study of advanced composite, aluminum/ composite for hybrid shaft having high torque transmission, high natural bending frequency with less noise and vibration. Ansys and FEM have been used for numerical simulation. The linear and nonlinear properties of materials were considered. The maximum torque transmitted through hybrid shaft is 295Nm. The numerical result was verified with experimental results. Composite material drive shaft was studied in this study and author has highlights the importance of composite material over conventional materials [7].

In advance stage of material study hybrid shaft has been introduced [8-10]. Durk Hyun Cho et al. [11] have studied the composite material single-piece drive shaft. The shaft was manufacture using fiber epoxy composite and aluminum tube for obtaining high natural bending frequency and torque transmission capability. The results shows that the shaft sustain for 107 cycles with dynamic load of + 500 Nm. Ashley R. Crowther et al. [12] have studied the automatic transmission system for impulsive response for the abrupt change in mean torque excitation and system load change. Composite material use in aerospace industry and method for reducing residual stresses is studied [13-15].

Manuscript received Feb11, 2017; revised April 14, 2017. This research work has been carried out at Advanced Modelling and Simulation lab sponsored by Department of Science and Technology (DST) and research cell of Graphic Era University, Dehradun. Authors are thankful to DST, New Delhi and GEU, Dehradun for the necessary funding.

F. A. Dr. Ashwani Kumar is with Directorate of Technical Education, Uttar Pradesh, Kanpur, India (Phone: +91-992-772-3380; E-mail: kumarashwani.geu@gmail.com).

S. B. Neelesh Sharma is with Department of Mechanical Engineering, AKG Engineering College, Ghaziabad U.P. India (E-mail:neeleshksharma@yahoo.com).

T. C. Prof. (Dr.) Pravin P. Patil is with Department of Mechanical Engineering, Graphic Era University, Dehradun, India (E-mail: dr.patil@geu.ac.in).

II. SOLID MODELLING AND MATERIAL PROPERTIES

Single-piece drive shaft was designed using the Solid Edge and Pro-E [16-17] software. FEA based analysis was done using ANSYS 14.5 [18]. The result of this study provides the reference work for the structure optimization and performance evaluation of single-piece drive shaft aims at reducing vibration and strength problem. Free vibration study of heavy vehicle, single-piece composite material drive shaft was performed to evaluate the inherent natural frequency and vibration mode shape to prevent the resonance. Figure 1 shows the single-piece drive shaft with universal joint. The ANSYS 14.5 program solver works on meshing concept of nodes and elements (nodes- 87718, elements- 453477).

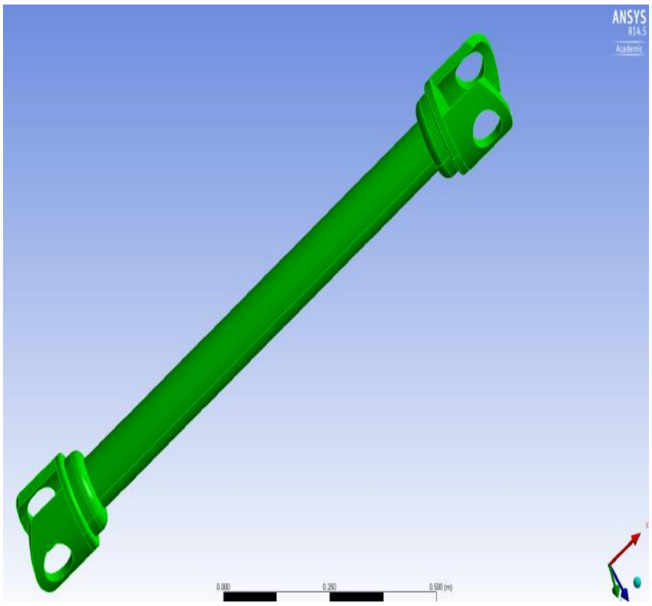


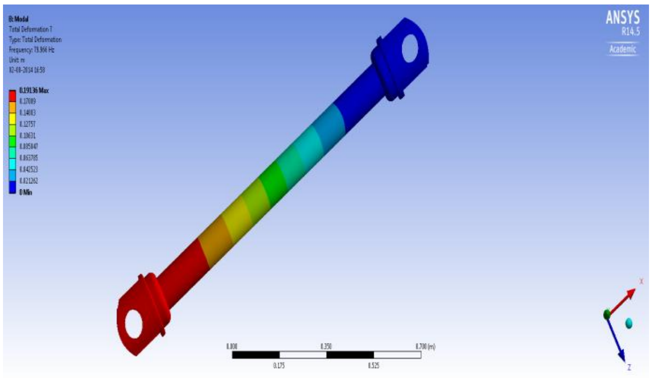
Figure 1 CAD solid model of drive shaft

One of the main features of composite material is damping property, which reduces the noise and vibration. Steel SM45C, HS carbon epoxy and E-glass polyester resin were selected as material for drive shaft analysis. Nonlinear effect of material properties were considered for structural and free vibration analysis. The geometric properties of the drive shaft are length of shaft 1250 mm, Outer Diameter-90 mm, inner diameter-83.36mm. Young’s Modulus, Material Density and Poisson’s Ratio is required as material mechanical properties for FEA based modal analysis. Steel SM45 C (Young’s Modulus-2.07e11 Pa, Material Density 7600 kg/m3 and Poisson’s Ratio-0.3), HS Carbon Epoxy Composite (Young’s Modulus-2.1e11 Pa, Material Density 1600 kg/m3 and Poisson’s Ratio-0.3) and E Glass Polyester Resin Composite (Young’s Modulus-3.4e10 Pa, Material Density 2100 kg/m3 and Poisson’s Ratio-0.366).

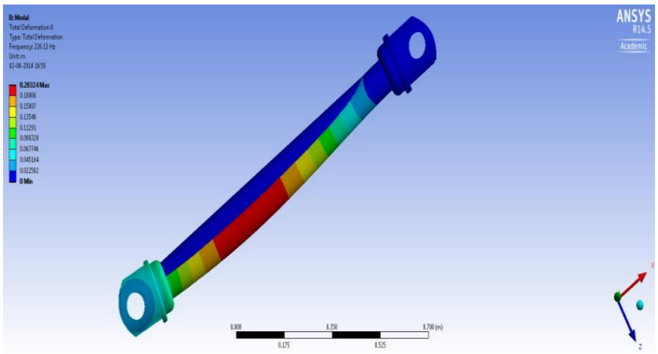
III. FEA SIMULATION

FEA based numerical simulations evaluate the results of free vibration analysis for steel and composite material. Inertia and damping effects was not considered for analysis. Rotational and moments values are applied in form of loading. Automobile drive shaft is subjected to torque transmission, no direct load value act on it. Rotational and moment effects caused failure of drive shaft. So only these two parameters were considered for modal analysis.

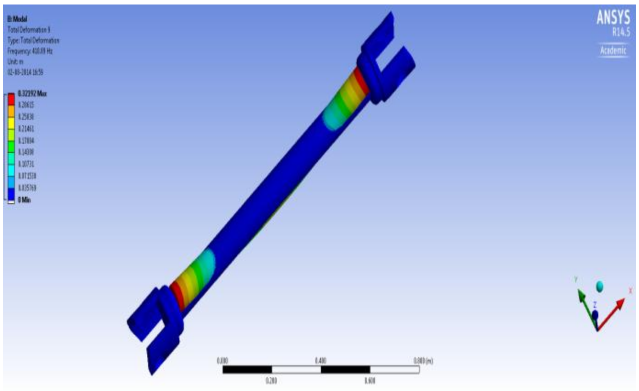
A. Modal Analysis of Steel SM45 C Material Drive Shaft



Mode 7 f7=79.966 Hz.



Mode 8 f8=226.13 Hz.

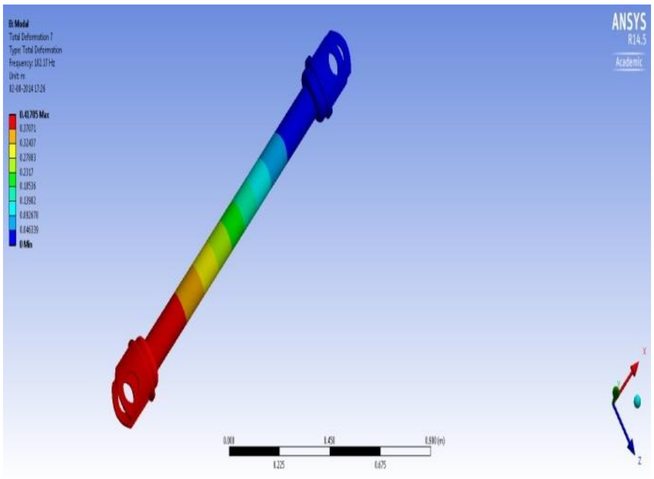


Mode 9 f9=418.89 Hz.

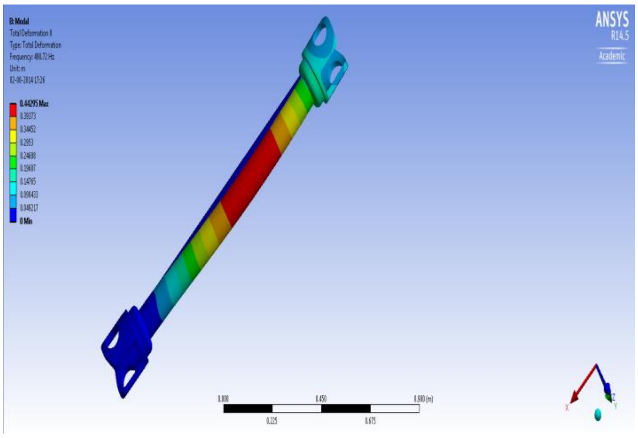
Figure 2 Modal analysis of Steel SM45C single piece drive shaft.

Figure 2 shows the vibration mode shapes and corresponding natural frequency for steel Sm45C. The mode 1 and 2 is rigid mode having frequency 0 Hz. The FEA analysis shows the first valid frequency is 79.966 Hz (mode 7) and the critical speed is equal to 4797 rpm that is nearer to whirling speed. Mode 7 shows the deformation at the transmission end side. Mode 8 shows lateral vibration with bending effect. The bending frequency is 226.13 Hz and critical speed is 13567 rpm. Table 1 shows the frequency variation for steel and composite materials.

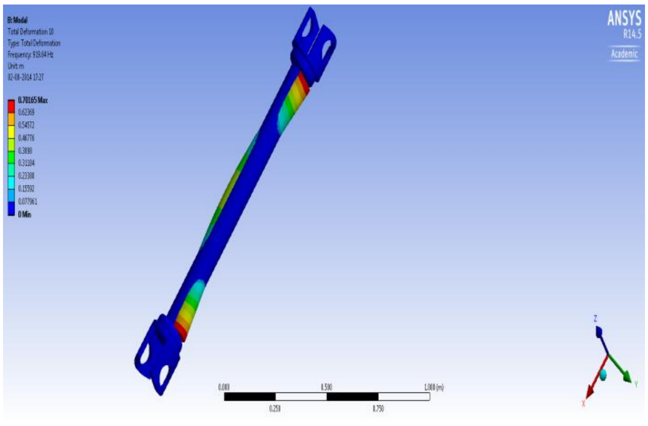
B. Modal Analysis of HS Carbon Epoxy Composite Material Drive Shaft



Mode 7 f7=182.17 Hz

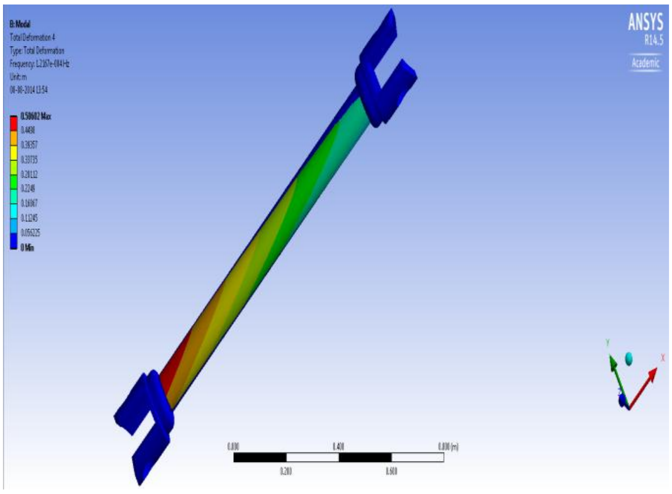


Mode 8 f8=498.72 Hz

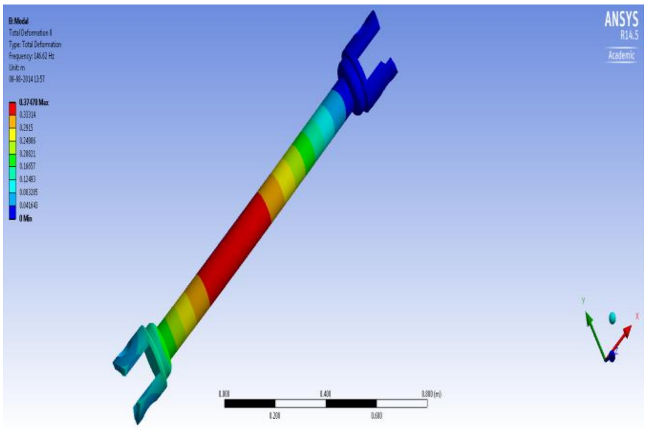


Mode 10 f10= 919.64 Hz

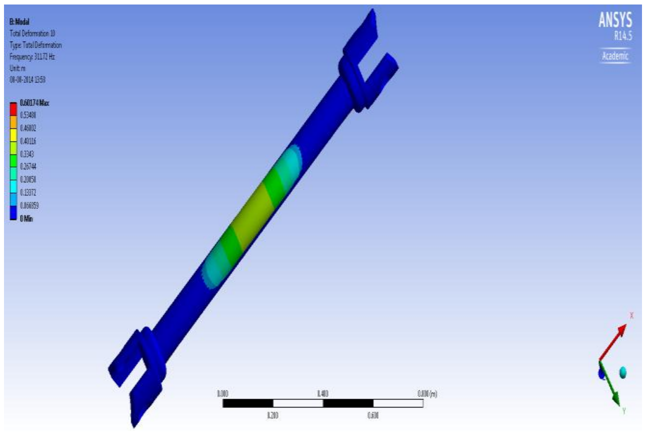
Figure 3 Modal analysis of HS Carbon Epoxy composite material single piece drive shaft.



Mode 4 f4=1.2167e-004 Hz



Mode 8 f8=146.62 Hz



Mode 10 f10=311.72 Hz

Figure 4 Modal analysis of E Glass Polyester Resin composite material drive shaft.

Figure 3 shows the vibration mode shapes and natural frequency for HS carbon epoxy composite material. Mode 1, 2 and 3 shows 0 Hz natural frequency. Mode 4, 5 and 6 shows very less natural frequency in range of e-004 (Table 1).

The first valid frequency is 182.17 Hz and critical speed 10930 rpm which is much higher than 2400 rpm resonance critical speed preventing the resonance condition. The external excitation causes resonance. Mode 8 has deformation at centre portion due to axial bending vibration.

Mode 10 shows torsional vibration at 919.64 Hz. The single-piece drive shaft deformed at end points.

A. Modal Analysis of HS Carbon Epoxy Composite Material Drive Shaft

Polyester resin composite material shows bending and torsional vibration mode shapes (figure 4). Mode 1 and 2 has 0 Hz natural frequency. Mode 4, 5 and 6 shows very less natural frequency in range of e-004 (Table 1). The first valid frequency is 48.127 Hz and critical speed is 2887 Hz. This critical speed is nearer to whirling critical speed of 2400 rpm. Therefore E-glass polyester resin composite material has resonance problem. Mode 8 has large deformation at centre portion of drive shaft. Mode 10 shows minimum deformation at 311.72 Hz having 18703 rpm critical speed much higher than 2400 rpm critical speed. The relation between critical speed and natural frequency is given as ($N_{cr} = 60\ f_{nt}$).

Table 1 Modal frequency variation for steel and composite materials.

Mode/ Valid Mode	Modal Frequency Steel SM45 C	Modal Frequency HS-Carbon Epoxy	Modal Frequency E Glass Polyester Resin
1	79.966	182.17	48.127
2	226.13	498.72	146.62
3	418.89	919.53	288.09
4	498.72	919.64	311.72

IV. RESULTS AND DISCUSSION

Variation of natural frequencies for steel and composite materials is shown in Figure 5. HS carbon epoxy composite material shows the excellent material properties for the design of single-piece composite drive shaft to meet the stringent design requirements for heavy vehicles. In order to avoid the whirling or resonance vibration the bending frequency should be higher than (2400-4000) rpm for trucks and vans and the transmission capability should be higher than 154 Nm. The HS carbon epoxy composite material fulfills these technical requirements. The bending natural frequency is 10930 rpm much higher than 2400 rpm, so it reduces the chances of whirling or resonance. The torque transmission capability of single-piece drive shaft was considered as 245 Nm.

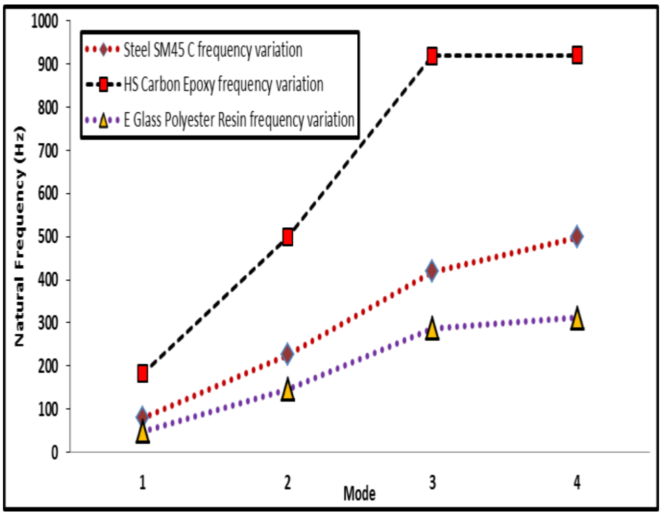


Figure 5 Natural frequency comparison graph for different materials

V. CONCLUSION

The results of this research work have theoretical significance in design stage of single-piece composite material drive shaft for heavy vehicles. The two-piece drive shaft design was replaced with single-piece composite material drive shaft. The vibration characteristic analysis was performed for single-piece composite drive shaft. Vibration response of driving shaft shows that HS carbon epoxy composite is suited for single-piece drive shaft. The research work concludes the following points-

- The study has investigated the use of composite materials for heavy vehicle truck, single-piece lightweight drive shaft. HS carbon epoxy composite material suited on design and vibration criteria. The maximum deflection is 0.1 mm, bending natural frequency is 182.17 Hz and critical speed is 10930 rpm much higher than whirling vibration critical speed.

- The modal analysis results show the first 10 natural frequency and corresponding mode shape for steel and composite materials. The critical speed for all materials are- steel Sm45 C- 4797 rpm (79.96 Hz), HS carbon epoxy composite-10930 rpm (182.17 Hz) and E-glass polyester resin composite-2887 rpm (48.12 Hz). The whirling critical speed for heavy vehicles vary (2400-4000)rpm which signifies that HS carbon composite is best suited for single-piece drive shaft of heavy vehicle.

- Vibration mode shapes (axial bending vibration, torsional vibration) were identified for steel and composites material single-piece drive shaft.

FEA based analysis tool Ansys 14.5 has been used for structural and modal analysis. The FEA result shows that on design and vibration index HS carbon epoxy composite can be used as single-piece drive shaft material. FEA results are in good agreement offering satisfactory results.

ISBN: 978-988-14048-3-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

REFERENCES

[1] Z. Zhang, Z. Zhang , X. Huang, H. Hua. "Stability and transient dynamics of a propeller-shaft system as induced by nonlinear friction acting on bearing-shaft contact interface." *Journal of Sound and Vibration*, vol. 333(12), pp. 2608-2630, 2014.

[2] B. Trencséni , L. Palkovics. "Driveline torque observer for heavy duty vehicle." *Periodica polytechnic, Transportation Engineering* 39/2 91–97 doi: 10.3311/pp.tr.2011-2.08 (9), 2011.

[3] M. Aleyaasin, M. Ebrahimi, R. Whalley. "Flexural vibration of rotating shafts by frequency domain hybrid modelling." *Computers & structures*, vol. 79 (3), pp. 319-331, 2001.

[4] K. Solanki, M. Horstemeyer. "Failure analysis of AISI 304 stainless steel shaft." *Engineering Failure Analysis*, vol. 15, pp. 835–846, 2008.

[5] Y. Wei, Y. Wang, S. Chang, J. FU. "Numerical prediction of propeller excited acoustic response of submarine structure based on CFD, FEM and BEM." *Journal of Hydrodynamics*, vol. 24 (2), pp. 207-216, 2012.

[6] S. Mutasher. "Prediction of the torsional strength of the hybrid aluminum/ composite drive shaft." *Materials & design*, vol. 30 (2), pp. 215-220, 2009.

[7] N. Rastogi. " Design of composite drive shafts for automotive applications." *SAE, Technical Paper Series*, 2004-01-0485, 2004.

[8] H. Kim, S. Park, H. Hwang, D. Lee. "Effect of the smart cure cycle on the performance of the co-cured aluminum/ composite hybrid shaft." *Composite Structures*, vol. 75 (1-4), pp. 276-288, 2006.

[9] H. Baryrakceken. "Failure analysis of an automobile differential pinion shaft." *Engineering Failure Analysis*, vol. 13 (8), pp. 1422-1428, 2006.

[10] A. Talib, A. Ali, M. Badie, N. Lah, Golestaneh A. F ."Developing a hybrid, carbon/glass fiber-reinforced, epoxy composite automotive drive shaft." Materials & Design, Vol. 31 (1), pp. 514–521, 2014.

[11] D. Cho, D. Lee, J. Choi. "Manufacture of one-piece automotive drive shafts with aluminum and composite." *Composite Structures*, vol. 38(1-4), pp. 309-319, 1997.

[12] A. Crowther, R. Singh, N. Zhang, C. Chapman. "Impulsive response of an automatic transmission system with multiple clearances: Formulation, Simulation and experiment." *Journal of Sound and Vibration*, vol. 306 (3-5), pp. 444-466, 2007.

[13] R. Ingle, B. Ahuja. "An experimental investigation on dynamic analysis of high speed carbon-epoxy shaft in aerostatic conical journal bearings." *Composites Science and Technology*, Vol. 66 (3-4), pp. 604-612, 2006.

[14] D. Cho, and D. Lee. "Manufacturing of co-cured aluminum composite shafts with compression during co-curing operation to reduce residual thermal stresses" *Journal of Composite Material*, vol. 32, pp. 1221–41,1998.

[15] E. Sevkat, H. Tumer. "Residual torsional properties of composite shafts subjected to impact loadings." *Materials & Design*, vol. 51, pp. 956-967, 2013.

[16] SOLIDEDGE .Version 19.0. 2006.

[17] Pro-E 5.0. Designing guide manual , 2013.

[18] ANSYS R14.5 Academic Structural Analysis Guide 2013.