INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY
ISSN: 0974 – 3154 Volume 6, Number 2 (2013), pp. 137 - 142

DEVELOPMENTS IN DESIGN OF COMPOSITE DRIVE SHAFT FOR AUTOMOTIVE APPLICATIONS

Rajaram M. Shinde[1], Prof. Dr. Suresh M. Sawant[2]

[1] Research Scholer, Rajarambapu Institute of Technology, Rajaramnagar,Tal- Walwa, Dist- Sangli-415414 (M.S.), India,

[2] Professor, Departent of Mechnical Engineering, Rajarambapu Institute of Technology, Rajaramnagar,Tal- Walwa, Dist- Sangli- 415414 (M.S.), India

ABSTRACT

Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials. Composite materials can be tailored to efficiently meet the design requirements of strength, stiffness. Weight of composite drive shaft is less compared with steel or aluminum for similar strength. It is possible to manufacture one piece composite drive shaft which reduces number of parts from the assembly required for conventional two piece steel drive shaft. Also, composite materials typically have a lower modulus of elasticity. As a result, when torque peaks occur in the driveline, the driveshaft can act as a shock absorber and decrease stress on part of the drive train extending life.

INTRODUCTION

Rapid technological advances in engineering brought the scientists and engineers to a point, where they became limited by the capabilities of traditional materials. With the limits of the technology pushed, the materials failed to answer the requirements of the designers or manufacturers. Researchers in materials technology are constantly looking for solutions to provide stronger, durable materials which will answer the needs of their fellow engineers. Composite materials are one of the most favored solutions to this problem in the field. Problems born from material limitations like heavy weight, structural strength, and thermal resistance are being solved by the composite material alternatives, and many more alternatives are being introduced to readily use engineering applications.

Strength of composite material depends on 1. The mechanical properties of fiber and matrix which are constituent materials of shaft. 2. Mechanical bond strength of fiber and matrix interface. 3. Fiber volume fraction and fiber distribution in matrix.

The main issue in designing of the composite material is the understanding the orthotropic nature of composite material. The possibility of different fiber matrix system combined with variables such as fiber volume fractions. Then laminae can be placed at an angle and at particular distances from midplane in the laminate. The material system and stacking sequence then determines the stresses and strains in the laminate. Laminate section is computationally intensive and repetitive task due to many possibilities of fiber-matrix combinations, material systems and stacking sequence.

Almost all automobiles which correspond to design with rear wheel drive and front engine installation have transmission shafts. The weight reduction of drive shaft have certain role in the general weight reduction of the vehicle and is highly desirable goal, if it can be achieved without increase in cost and decrease in quality and reliability. The replacement by composite materials has resulted in considerable amount of weight reduction up to 72% when compared to conventional steel shaft. Also, the results reveal that the orientation of fibers has great influence on the dynamic characteristics of the composite shafts.

Torsional buckling more critical in the design of composite shafts, because one-piece composite drive shafts required to made longer. Although increasing the length of drive shaft does not change the static torsional stress, it can decrease the torsional buckling load capacity of the shafts. Therefore, the optimization for the torsional buckling load of composite drive shafts is needs more insight in it.

Second, the stacking sequence of the layers affects the torsional buckling capacity of drive shafts. Therefore, selection a suitable stacking sequence can increase the torsional buckling load of the composite shafts.

LITERATURE SURVEY

C. Sivakandhan and P. Suresh Prabhu (2012) concluded in their research that the epoxy/glass fiber composite can be employed in the drive shaft. Moreover, authors believed that the real ANSYS analysis can be done to verify the stability of developed composite material. The usage of composite materials and optimization techniques has resulted in considerable amount of weight saving when compared to conventional steel drive shaft. Researchers have used two equations for calculation of torsional buckling load.

$$T_{buckling} = \frac{1.854}{\sqrt{L}} \times E_1^{0.375} \times E_2^{0.625} \times t^{2.25} \times D^{1.25} ----1.$$

$$T_{buckling} = \frac{2.289}{\sqrt{L}} \times E_1^{0.375} \times E_2^{0.625} \times t^{2.25} \times D^{1.25} ----2.$$

In these equations t is the thickness, D is the average diameter, L is the length of the shaft and E1 and E2 are the longitudinal and transverse stiffness of the shaft, respectively. To evaluate the accuracy of Equations (1) and (2), the torsional buckling load of a shaft is calculated using these equations. The results are compared with results obtained by experimental and finite element methods using ANSYS software. Researchers in this research have tested composite shaft for different boundary conditions and by changing fiber orientations and stacking sequence. Conclusion from this research is the boundary conditions of the shaft do not have much effect on the buckling torque. The fiber orientation of a composite shaft strongly affects the buckling torque. The stacking sequence of the layers for a composite shaft also strongly affects the bucking torque.

Mohammad Reza Khoshravan et al. (2011) presented design method and vibration analysis of composite propeller shafts. Composite drive shaft is studied to meet the torque transmission capacity, critical speed and natural frequency. Relation between the critical speed and length of shaft for steel and composite shaft has been studied. It is plotted as shown in figure.

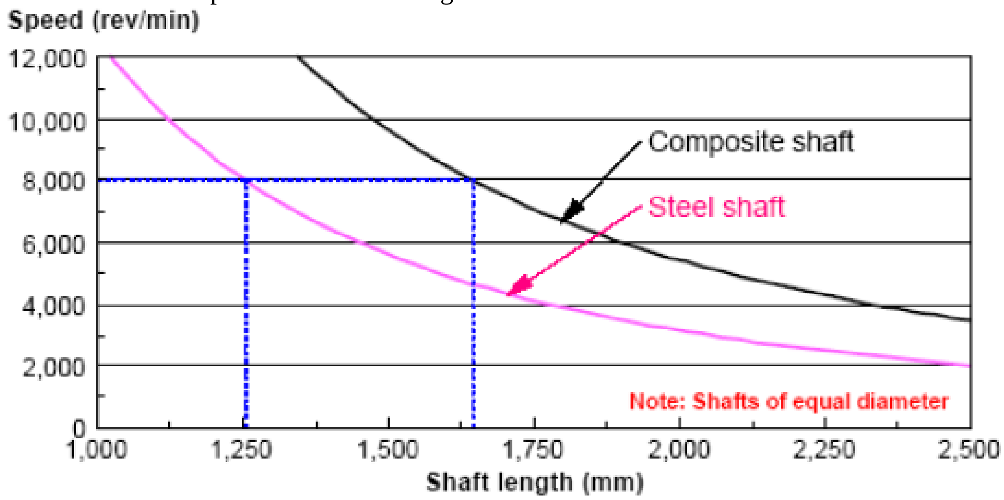

Fig. 1. Effect of shaft length on critical speed.

In modal analysis first five natural frequencies are calculated and results are plotted for getting variation of natural frequency. Considering the equations and design correlations researchers have been concluded that the optimum fiber arrangement of the composite drive shaft is obtained as [90^0 / 0^0 / $45^0{}_4$].

M.A.K. Chowdhuri *et al.* (2010) have focused on the design of automotive composite drive shaft. He has replaced two piece drive shaft by single piece composite shaft. However, the main advantage of his design is only one piece of composite drive shaft is possible that fulfill all the requirements of drive shaft. He proposed two different designs, one is purely from Graphite/Epoxy lamina and other is using Aluminum with Graphite/Epoxy. The basic requirements considered here are torsional strength, torsional buckling and bending natural frequency. Results obtained for two designs in his analysis are shown in table 1& 2.

Table 1. Failure loads, torques and frequency for graphite /epoxy composites

Staking Sequence	No of Plies	N_{xy}, (N/m)	T_b (N-m)	f_n (Hz)
$[\pm 45]_s$	4	175974.4	53.51	64.20
$[90/0/90/0/90/\bar{45}]_s$	11	142597.7	2612.73	111.28
$[0/90/0/90/0/\bar{45}]_s$	11	142597.7	2198.08	132.28
$[0/90/0/45/90/-\bar{45}]_s$	11	193377	2211.27	116.54

From the above analysis author concluded that the last three designs of drive shaft fulfilled the requirements. Among these three best designs of drive shaft using only graphite /epoxy is the best one ecause for the first two cases the laminate fails catastrophically. So the best design is [0 / 90 / 0 / 45 / 90 / 45]s.

Table 2. Failure loads, torques and frequency for graphite /epoxy and Aluminum

Staking Sequence	No of Plies	N_{xy}, (N/m)	T_b (N-m)	f_n (Hz)
Pure Al	1	379481	2915.9	83.59
[Al/0]	2	336234	3238.6	89.46
[0/Al/0]	3	395065	4052.6	94.50
[0/Al/90/0]	4	356104	5103.1	93.38

From table 2. combination of aluminum and 0° ply is sufficient for peak torque, buckling torque and bending natural frequency. If 90° lamina was added with aluminum and 0° lamina it will increase buckling torque but decreases bending frequency.

Zorica Dordevic *et al*. (2008) analyzed that the values of fundamental natural frequencies of the shaft obtained by a combination of aluminum and composite material, depending on the number of carbon fibers layers and the thickness of the wall of the aluminum tube. It was concluded, by the analysis that the reduction of the thickness of the aluminum tube wall leads to the increase of fundamental natural frequencies of the shaft. In addition, it was seen that the fundamental natural frequencies have the largest values if the orientation angle of carbon fibers is 0^o, while the increase of the angles of orientation of fibers leads to the decrease of the fundamental natural frequencies values.

Table 3. Comparison of critical speed.

Critical speed, *rpm*	
Al/USN carbon fiber epoxy composite Al/[0_8]	9996
Steel	8472
Aluminum	8496

Table 3. gives the comparative analysis of critical speeds of steel, aluminum and hybrid aluminum/carbon fibers/epoxy composite shafts this comparison between the critical speeds leads to the conclusion that the advantage of the composite shaft over the classical metal shaft is in biased limits for the critical value of fundamental natural frequencies and the critical speed. This means that composite shaft may operate at higher speeds and at higher frequencies compared to steel shafts.

S. A. Mutasher et al. (2006) in this research a static torque and power transmission capacities of a hybrid aluminum/composite drive shaft, fabricated by a wetted filament winding method, were investigated. Special mechanisms for static torsion and power transmission test setups were designed and fabricated. Carbon, glass, one epoxy, and hardener were used. The static and dynamic characteristic of the hybrid aluminum/composite drive shaft with respect to the fiber types, stacking sequences, winding angle and number of layers were investigated. From the experiments, researcher has concluded that the static and dynamic torque capacity for a winding angle of 45^0 is higher than 90^0 for both glass and carbon fibers. In addition, in the static torsion test, the shaft's being laminated with a stacking sequence of [90/ + 45/-45/90] and [+45/-45/90/90] resulted in the same behavior in the torque–angle and the twist relation. The power transmission capacities were lose to each other and this in turn satisfied the lamination theory. The finite-element method was used to analyze the hybrid shaft under static torsion and ANSYS software was used to perform the numerical analysis for the hybrid shaft. A full scale hybrid specimen analysis was done. Elasto-plastic properties were used for the aluminum tube and linear elastic for composite materials. Good agreement was obtained between the finite-element predictions and experimental results.

Table 4: Review of Past Researches on composite drive shafts for Automotive Applications

Author	Year	Title of Research	Composites used	FEA/Optimization Technique/s Used	Remark
C. Sivakandhan and P. Suresh Prabhu	2012	Composite Drive Shaft is a Good Strength and Weight Saving to Compare Conventional Materials Design and Analysis of E-Glass/Epoxy Composite Drive Shaft for Automotive Applications	E-glass/epoxy	• Analyzed using ANSYS	
M.A.K. Chowdhuri et al.	2010	Design Analysis of an Automotive Composite Drive Shaft	Graphite/Epoxy Aluminum with Graphite/Epoxy.	The Maximum Stress Failure Theory PROMAL soft ware is used for the progressive failure analysis.	
Zorica Dordevic et al.	2008	Dynamic Analysis of Hybrid Aluminum/Composite Shafts	Aluminum and carbon fibers/epoxy composites	Finite element method is used to predict the fundamental natural frequency of hybrid shaft and compared with steel and aluminum shaft.	
A. Boukhalfa et al.	2008	Free Vibration Analysis of a Rotating Composite Shaft Using the *p*-Version of the Finite Element Method	_____	___________	
S. A. Mutasher et al.	2006	Static and dynamic characteristics of a hybrid aluminum/composite drive shaft	Aluminum with carbon, glass, one epoxy, and hardener.	• Carried Experimental investigations. • Numerical analysis using ANSYS	
S.A. Mutasher et al.	2005	Static Torsion Capacity of a Hybrid Aluminum Glass Fiber Composite Hollow Shaft	Aluminum glass-fiber	Classical laminated theory	
T.Rangaswamy, *et al.*	2005	Optimal Sizing and Stacking Sequence of Composite Drive Shafts	E-glass/ epoxy carbon/epoxy composites.	• Optimized using Genetic Algorithm • Analyzed using ANSYS	
M. A. Badie, et al.	2004	Automotive Composite Drive shafts: Investigation of The Design Variables Effects	carbon-epoxy glass-epoxy	• Finite element analysis • Torsional buckling analysis. • Fatigue analysis	
Mahmood M. Shokrieh *et al.*	2004	Shear buckling of a composite drive shaft under torsion	E-glass/ epoxy carbon/epoxy composites.	• Finite element analysis using ANSYS software. • Torsional buckling analysis.	
R. R. Ajith, et al.	2004	Genetic Algorithm Based Optimum Design of Composite Drive Shaft	E-Glass/Epoxy Boron/Epoxy	• Genetic Algorithm • C programming	

CONCLUSION

It becomes evident from the literature review that some research has been carried out in the area of design of composite material for automotive applications. For better performance and saving of material cost this application area has to explore to the depth and there lies ample scope for further investigations.

The research has identified following parameters which influence the optimum design of composite drive shaft. These are:

i) Material composition in composite
ii) Volume fraction of matrix and fiber material
iii) Orientation and stacking sequence of fiber material.

In case of hybrid shafts the static torque capacity for winding angle of 45^0 is higher than 90^0. For [+45/-45]3s laminates, the maximum static torsion approximately 7.5 times higher than the pure aluminum tube. In case of composite shaft torsional buckling strength can be increased by designing proper stacking sequence. Fundamental natural frequency can also be improved by designing optimum composite shaft.

In past researches it has been observed that the hybrid composite drive shafts are good for torsional strength but they have not achieved required strength to weight ratio again bending frequency will be reduced by using composition of only fiber and epoxy materials. However to reduce to the amount of rotating mass in the drive train of a lightweight drive shaft should be constructed. Researchers have not been explored applications of composite drive shafts for a heavy automobile for which wheelbase is comparatively large. The researchers have made attempts to optimize the composite drive shafts; however, strength to weight ratio of these shafts remains to be low and should be increased to the possible extent. They have advocated necessity for better transmission efficiency may require design modifications.

REFERENCES

1. Mahmood M. Shokrieh , Akbar Hasani, Larry B. Lessard’ Shear buckling of a composite drive shaft under torsion’ Elsevier Composite Structures 64 (2004) 63–69
2. S.A. Mutasher, B. B. Sahari, ‘Static Torsion Capacity of a Hybrid Aluminum Glass Fiber Composite Hollow Shaft’ American Journal of Applied Sciences (Special Issue): 67-71, 2005
3. M.A.K. Chowdhuri, R.A. Hossain, ‘Design Analysis of an Automotive Composite Drive Shaft’ International Journal of Engineering and Technology Vol.2(2), 2010, 45-48
4. R.R Ajith, T. Rangaswamy, ‘Genetic Algorithm Based Optimum Design of Composite Drive Shaft’ International Symposium of Research Students on Material Science and Engineering December 20-22,2004,Chennai.
5. T.Rangaswamy, S. Vijayarangan ‘Optimal Sizing and Stacking Sequence of Composite Drive Shafts ’ MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 11, No. 2. 2005
6. M. A. Badie, A. Mahdi, A. R. Abutalib, E. J. Abdullah and R. Yonus ’Automotive Composite Driveshafts: Investigation Of The Design Variables Effects’ International Journal of Engineering and Technology, Vol. 3, No.2, 2006, pp. 227-237
7. S A Mutasher1, B B Sahari1, A M S Hamouda1,2_, and S M Sapuan1 Static and dynamic characteristics of a hybrid aluminium/composite drive shaft Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials Design and Applications 2007 221: 63 DOI: 10.1243/14644207JMDA63
8. Zorica Dordevic, Stevan Maksimovic, Ivana Ilic, ‘Dynamic Analysis of Hybrid Aluminum/Composite Shafts’ Scientific Technical Review,Vol.LVIII,No.2,2008 UDK: 621.824:66:624.042.3 COSATI: 13-09, 11-04, 20-11
9. Mohammad Reza Khoshravan, Amin Paykani ‘Design And Modal Analysis Of Composite Drive Shaft For Automotive Application’ International Journal of Engineering and Technology Vol.3(4), 2011, 41-49