HYBRID AND NON HYBRID COMPOSITE AUTOMOTIVE TUBULAR SHAFT

M. A. BADIE, E. Mahdi and A.M.S. Hamouda

Mechanical and Industrial Engineering Department, College of Engineering, Qatar University

Introduction

Weight reduction, fatigue resistance, vibration damping and design flexibility to meet critical vibration characteristics are offered by substituting fibrous composites for conventional metals in power transmission shafts, which utilized in many engineering applications including automotive. Strongly related to stiffness, the optimal design constrained by rotational frequency, torsional frequency and applied torque, which are to be traversed by increasing the critical speed, torsional stiffness and critical torque, respectively [1-4]. However, composite drive shaft design is a problem of prescribed stiffness with the variables of layers material, thickness and stacking sequence. Least cost can be achieved by using a hybrid of carbon/epoxy and E-glass/epoxy as carbon fibers with their higher specific stiffness, have comparatively high price. This paper examines the effect of fiber orientation angles and stacking sequence on the natural frequency, buckling strength and fatigue life. Besides, the study of the torsional stiffness and failure modes of composite tubes, are investigated.

Finite Element Modeling

Finite element analysis (FEA) has been used to predict the fatigue life of composite automotive tubular shaft after linear dynamic analysis for different stacking sequence. Eigenvalue analysis used to investigate the effect of two design variables, namely the fiber orientation angle and layers stacking sequence on the bending natural frequency and buckling torque.

Table 1 lists the FEA and analytical solution. Based on FEA results, it was found that the natural frequency increases with decreasing fibers angles. The composite automotive tubular shaft has a reduction equal to 54.3% of its frequency when the orientation angle of carbon fibers at one layer, among other three glass ones, transformed from 0º to 90º. On the other hand, the critical buckling torque has a peak value at 90º and lowest at a range of 20º to 40º when the angle of one or two layers in a hybrid or all layers in non-hybrid changed in sameness. The layers stacking sequence has no effect on the critical speed (natural frequency) of composite automotive tubular shaft but significantly affect buckling torque and fatigue resistance. Fig. 1 shows the first mode of buckling.

Table 1: Comparison between analytical and FEA results

	Analytical	**FEA**
Specimen		
Buckling Torque (Nm)	59.12	54.22
Natural Frequency (Hz)	375.27	377.33
Drive Shaft		
Buckling Torque (Nm)	2030	1830.9
Natural Frequency (Hz)	91.17	93.45

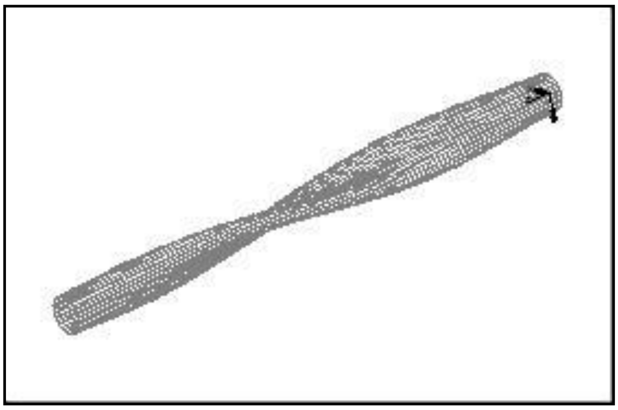

Fig.1: Buckling shape of full-scale shaft by Eigenvalue solution.

Concerning the buckling, the measuring factor for the goodness of stacking sequence is a component in the bending stiffness matrix [D]. This component D_{22} is the normal bending stiffness along the hoop direction. Therefore, D_{22} specify the ability of drive shaft material to deflect in radial direction or to (buckle). In addition, the coupling between twist moment and normal curvature appears as D_{16} and D_{26} components, has a substantial effect on both the buckling torque and natural frequency. Concerning fatigue, longer life of drive shaft realized by locating ±45º layers together and inner mostly while locating 0º/90º layers together with 90º layer exposed to outside. Indeed, the stacking sequence of [±45,0,90] is the best for both fatigue and buckling resistance. Figure 2 shows the effect of fiber orientation on the drive shaft critical speed.

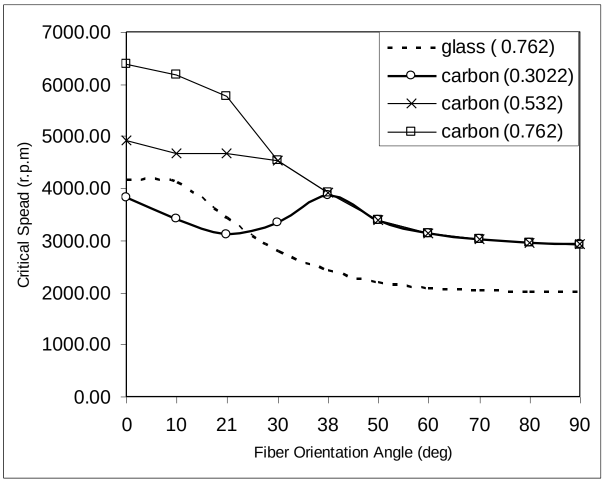

Fig 2: Critical speed- fiber orientation angle curves. Numbers in parentheses indicate total thickness in millimeters

Experimental Program

Experimental study on scaled woven fabric composite models was carried out to investigate the torsional stiffness. Six specimens were fabricated to study the torsional stiffness of each one. Woven-roving fabrics of both carbon and glass fibers were impregnated with epoxy to fabricate the tubes. These layers stacked at two fiber orientation angles as ±45 and 0/90. The static torsion test for the previous six structures was carried out by applying the torque manually and gradually. The results of this test indicate the rigidities of different composite structures utilizing different materials and fibers orientation angles. Fig 3 shows torque-twisting angle curves. Figs. 4 and 5 show failure mode of glass and carbon /epoxy tubes. It is evident that composite tubes of fiber orientation angles of ±45º experience higher load carrying capacity and higher torsional stiffness. Specimens of carbon/epoxy or glass/epoxy composites with fiber orientation angles of ±45º show catastrophic failure mode.

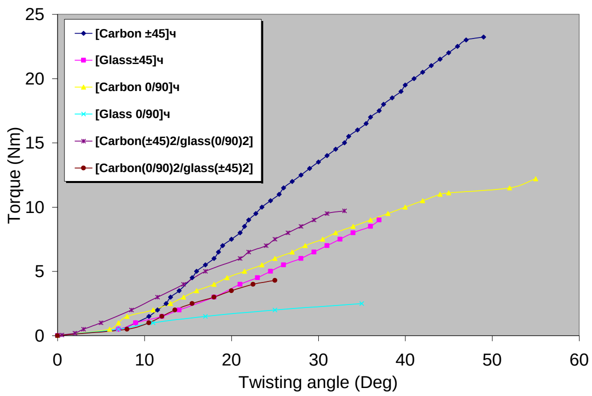

Fig 3: Torque-angle of twist curves for different configurations.

Fig 4: Static test specimen showing failure mode for glass/epoxy tube with ±45º stacking sequence.

Fig 5: Static test specimen showing failure mode for carbon/epoxy tube with [0/90º] stacking sequence.

Conclusion

1. Carbon fibers have the major contribution over glass in increasing the torsional stiffness.
2. The fiber orientation angle of 45º is the best in increasing the torsional stiffness.
3. Laminates containing fabric fibers placed at ±45º experienced sudden failure whatever the material is. On the other hand, the stacking of 90/0 experienced a gradual failure.
4. Carbon/epoxy tubes experience higher fracture strain than that of glass/epoxy
5. In hybridized tubes, the severe difference in torsional stiffness of the layers leads to initially suppressed twisting.
6. For hybridized tubes, the severe difference in torsional stiffness of the layers leads to contain the matrix cracks at outer plies not to extend towards the tubes ends.
7. For all hybrid tubes, their failure mode was dominated by carbon fiber layer.

References:

1. Traylor, John W., "Graphite Drive Shaft Assembly" U.S. Patent Number 4952195, 1990.
2. Shinohara, Y., et al. "Production of Drive Shafts from Reinforced Plastics Pipes," European Patent EP0511843, 1992.
3. Bauchau, O. A., et al. "Torsional Buckling Analysis and Damage Tolerance of Graphite/Epoxy Shafts," Journal of Composite Materials, Vol. 22, March 1988, 258–270.
4. Zinberg, H., Symonds, M., "The Development of an Advanced Composite Tail Rotor Driveshaft," American Helicopter Society 26th Annual Forum, June 1970.