



# An investigation into hybrid carbon/glass fiber reinforced epoxy composite automotive drive shaft

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## ABSTRACT

This paper examines the effect of fiber orientation angles and stacking sequence on the torsional stiffness, natural frequency, buckling strength, fatigue life and failure modes of composite tubes. Finite element analysis (FEA) has been used to predict the fatigue life of composite drive shaft (CDS) using linear dynamic analysis for different stacking sequence. Experimental program on scaled woven fabric composite models was carried out to investigate the torsional stiffness. FEA results showed that the natural frequency increases with decreasing fiber orientation angles. The CDS 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 0° to 90°. On the other hand, the critical buckling torque has a peak value at 90° and lowest at a range of 20–40° when the angle of one or two layers in a hybrid or all layers in non-hybrid changed similarly. Experimentally, composite tubes of fiber orientation angles of ±45° experience higher load carrying capacity and higher torsional stiffness. Specimens of carbon/epoxy or glass/epoxy composites with fiber orientation angles of ±45° show catastrophic failure mode. In a hybrid of both materials, [±45°] configuration influenced the failure mode.

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## 1. Introduction

Power transmitted from the engine to the final drive where useful work is applied through a system consists of a gearbox, clutch, drive shaft and a differential in the rear-drive automobiles [1]. Different from the conventional metallic, in composite drive shaft there are many parameters to be altered, namely the fibers orientation angles, stacking sequences, layers thicknesses and number of layers [20]. These parameters, due to the tailorability of elastic constants, could provide a large number of possible designs, which must satisfy optimally the performance characteristics of the composite drive shaft (critical speed, critical buckling torque and load carrying capacity). Leslie et al. [2] studied four designs of a drive shaft 50" long and 3" diameter with material consideration of carbon fiber, aluminum, steel and titanium. It is well-known that the steel drive shaft is usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely proportional to the square of beam length and proportional to the square root of specific modulus [3]. There are many design studies but the information about the design variables and their effect on the performance characteristics is not comprehensive [4]. It is misunderstood that carbon fiber shafts were "too stiff". Indeed, what meant by too stiff is the

torsional stiffness rather than the flexural stiffness. Both the torsional stiffness and flexural stiffness could be tailored due to the type of application. Rastogi [5] used a hybrid of carbon/epoxy and glass/epoxy to optimize the cost versus performance requirements. He analyzed and designed a composite drive shaft using two approaches. The first approach is closed-form analytical expressions for the critical speed, torsional strength and buckling strength, which utilized to develop a preliminary design tool. The effect of fiber orientation angle on the fatigue strength of composite tubes was discussed by many researchers [6–8] but, on the other hand, the effect of stacking sequence on the torsional fatigue strength is not available. Bert and Kim [9] carried out an analytical solution to compute torsional buckling of composite drive shafts. They calculated the torsional buckling load of composite drive shafts with various lay-ups with good accuracy by considering the effect of off-axis stiffness and flexural moment. Their theory can predict the torsional buckling of composite drive shafts under pure torsion and combined torsion and bending. Chen and Peng [10] performed numerical simulation using a finite element method to study the stability of composite shafts under combined loading conditions. They predicted the critical axial load of a thin-walled composite drive shaft under rotation.

Generally, all accessed design studies were not including the fatigue consideration, which may be needed to be explored in relation to composite shafts design. Therefore, the aim of this work is to investigate numerically the effect of stacking sequence and

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