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Effect of hybrid reinforcement on the performance of filament wound hollow shaft

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ABSTRACT

Previous studies have shown that composite materials can replace metals as the material of construction in shafts. Composite material shafts are normally made up of polymer matrix composites as they are easy to design and economical to manufacture. This paper investigates the effect of hybrid reinforcement on the performance of filament wound hollow shaft. The hybrid shafts are composed of hybrid filaments including a combination of carbon, glass and aramid fibers. The initial stage involved development and verification of FEA model in order to establish grounds for further experimentation. Afterwards, a design of experiments model was established and experiments were performed using FEA. After the design phase, the shafts were manufactured using filament winding processing technique employing suitable matrix and reinforcement systems. Lastly, the shafts were tested for torsional characteristics, hardness, density and chemical reactivity. The results showed that carbon fiber reinforcement shows best results in terms of torsional characteristics. In terms of chemical reactivity, carbon-glass hybrid reinforcement exhibited minimum degradation. Furthermore, it was also found that hybrid reinforcements containing carbon-aramid fibers showed better results in terms of density and surface hardness.

1. Introduction

The quest for better material to improve engineering design has led to the development of high strength and light weight composite materials which are progressively impacting the daily life of humans. Modern research is exploiting the use of composite materials in order to design efficient systems especially in aerospace and automotive sector.

Composite materials made by filament winding technology are preferred over their metallic counterparts due to their high strength at a much lower weight. This property of filament wound composites makes them ideal in circumstances where weight saving is required such as applications for aerospace and automotive. Shafts are used to transmit the rotary load from one component to another and they are usually cylindrical in nature. Filament winding technology can be employed to manufacture shafts that are hollow and symmetrical. Previous researchers [1–5] have shown that shafts made up of composite material are advantageous to the overall efficiency of a system.

Researchers have studied the effects of hybrid fibers in a varied manner. Sevkat et al. [6] examined the effect of torsional strain-rate and lay-up sequences using hybrid fibers. Findings of the research study revealed that with the change in lay-up sequence, there is a change in torsional properties. In another research, Abu Talib et al. [7] conducted a numerical study on stacking sequence hybrid fibers with a combination of glass and carbon fibers. The researchers claimed that worst stacking sequence results in 46.07% less strength than a shaft with best stacking sequence. Among other researchers, Badie et al. [8] also investigated hybrid glass/carbon fiber shafts with changing stacking and orientation and its effect on various parameters. They concluded that an orientation angle of 45° is best in order to achieve the maximum stiffness.

Composite shafts can also be manufactured using a combination of metallic and composite parts. Lee et al. [9] developed a shaft in which a combination of composite and metallic parts was utilized. The results of the study revealed that a hybrid shaft offers 75% mass reduction and 160% increase in torsional strength compared to the full metallic shaft. Mutasher [10] also examined the hybrid aluminum/composite shaft with the prediction of torsional strength using analytical techniques. The study inferred that an increase in a number of composite layers

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leads to an increase in torsional strength with a compromise on weight.

Apart from filament winding technology, few researchers have used alternate techniques to manufacture the shafts. Capela et al. [11] utilized molding technique to fabricate all carbon fiber tubular shaft by vacuum bagging to investigate the effects of torsional stress. The study showed that fatigue and static strength decrease with an increase in shear stress during the torsional moment. Additionally, Pater et al. [12] produced a hollow drive shaft by using rotary compression. The study claimed that this process is an alternate to the fabrication of composite shafts from conventional methods.

Apart from torsional properties, Shokrieh et al. [13] and Bert et al. [14] analyzed shear buckling properties of composite shafts by applying tensile loads. The research study found that the natural frequency of composite shaft decreases with an increasing torque. Among other factors that affect the buckling torque is the stacking sequence of composite laminates.

Adding various additives or natural fibers can also alter the performance of composite shafts. Misri et al. [15] fabricated composite shafts using natural fiber such as kenaf and employing the process of filament winding. The torsional test on fabricated samples found that sample with kenaf fiber and aluminum reinforcement have the highest torsional strength and the highest degree of rotation. Siddiqui et al. [16] studied the effect of carbon nanotubes on torsional properties of carbon fiber composites. Samples were fabricated using various percentages of CNTs. The results indicated that test specimens with 0.5% CNT showed 17% increase in torsional modulus and 19% increase in torsional strength.

Previous researchers have [6–8] conducted studies on hybrid shafts using more than one type of reinforcement. The term hybrid shafts referred to fabrication technique using multiple type of reinforcement layers. However, no study has been conducted utilizing hybrid reinforcement in a single layer to fabricate filament wound hollow shafts. This study incorporates multiple type of fibers within a single layer. Moreover, Glass and aramid fibers are known for their low cost and high flame resistance respectively and hence a hybrid fiber with carbon fiber not only provides strength but also add up other advantages. This paper investigates the effect of hybrid reinforcement on the performance of hollow shafts. The purpose of the research is to deduce information on hybridization of shafts as compare to pure carbon fiber counterparts. The research explicitly provides an explanation on effects incurred by hybrid fiber reinforcements including carbon-glass and carbon-aramid hybrids. This investigation bridges the gap between the use of hybrid fibers for specialized application such as aerospace and marine. Furthermore this research enhances the knowledge in use of hybrid reinforcements as suitable material for multipurpose application as provided by each incorporated fiber.

The shafts were first modeled through finite element commercial based software ABAQUS. After verification of the model by comparing three pilot experimental and simulated results, the design of experiments was performed in order to check various combinations. The rationale for performing design of experiments was to study variables such as lamination sequence and layer type as manufacturing of each design is not cost effective. Afterwards, the design of shaft based upon an optimal combination of layup sequence and layer type was selected and manufactured using filament winding technology. Manufactured shafts were then tested on the torsional testing machine to examine torsional characteristics. Furthermore, shafts were also tested for supplementary properties such as surface hardness, chemical reactivity, and density. Another factor of the study was the effect of a hot and cold curing resin.

2. Design and analysis

The approach for design and analysis for this study is based on three phases. The first stage involves the development of a model and its validation while the second phase comprises of the design of experiments. The third stage includes the selection of shafts for manufacturing and testing based on the optimal design provided by design of experiments.

Table 1
Mesh sensitivity analysis.

SNo	Approximate Element Size (m)	Created Elements	Calculated Stress (Pa)
1	0.1	160	7.85E+07
2	0.01	360	7.74E+07
3	0.009	429	7.66E+07
4	0.008	570	7.53E+07
5	0.007	731	7.42E+07
6	0.006	1000	7.28E+07
7	0.005	1440	7.14E+07
8	0.0049	1440	7.15E+07
9	0.0048	1575	7.12E+07
10	0.0046	1690	7.12E+07

2.1. Model generation and validation

For finite element analysis, ABAQUS software version 6.0 was used. For composite materials, structures may be assumed as composed of several layers and each layer have orthotropic properties. For the study, CAD model was developed using part generation module in ABAQUS.

For analysis purpose, a twisting moment was generated within the material. The boundary conditions coincided with the actual experimental settings. One end of the shaft was fixed for movement in all degrees of freedom while another end was assigned to a rotation of 5 degrees. Assumptions of the FE model includes the use of orthotropic material model and each reinforcement holds half the volume in hybrid shafts. Displacement in rotation direction develops twisting moments which causes stress throughout the material. The model was developed using composite continuum shell element S8R. Mesh sensitivity analysis was performed on the developed model for validation of the mesh. The values of mesh size and their response value of stress are given in Table 1. Fig. 1 shows a meshed model used for the study along with boundary conditions whereas Fig. 2 shows a deformed model.

Part geometry was a simple hollow cylinder with a length of 300 mm and a diameter 20 mm. The outer diameter of the part is defined by thickness and the number of laminas as per design, given in Table 2.

Developed CAD model replicates actual samples fabricated for Realtime testing. As Torque depends upon length and diameter of the shaft, similar CAD model was used to perform each 378 experiments in order to achieve comparative results.

Orthotropic material type for composite materials was chosen for the material design. Material properties used for simulation purposes are given in Table 3.

Initially, three different FE models were developed and validated

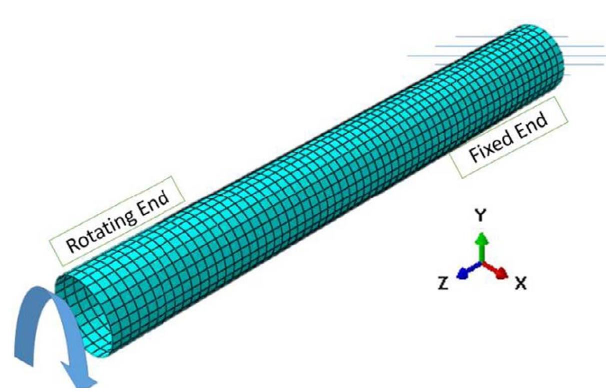

Fig. 1. CAD representation of Mesh Model.