Design and analysis of Composite Shaft

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ABSTRACT

Propeller shaft is common component used in all king of power transmission machines. They undergo various torsional loads during their operational life cycles. Steel shaft due to higher durability are used for manufacturing of drive shaft on a wider scale. Weight of steel shaft is heavy as compared to overall weight drive mechanism. This form basis of replacement of steel shaft with hybrid composite shaft. Light weight aluminum shaft with glass/carbon fiber epoxy coating will be manufactured with dimension of steel shaft. Finite element analysis of both shaft will be done under Torsional loading using Ansys FEA package. CATIA V5 will be used for CAD modeling/Design of both shafts. Experimental investigation will be done using fixture and Torsion Machine. Comparative analysis of FEA and Experimental will be done for validation of work. Conclusion and future scope will be suggested.

Keyword : - *ANSYS, Composite Material, Drive Shaf*

1. Introduction

Since the 1970s, composite materials have been regarded as potential candidates for manufacturing drive shafts because of their high specific stiffness and strength. Previous studies on this topic have dealt mainly with composite shaft design in the subcritical case that is when the first critical speed is never exceeded. However, when a long driveline is required (in the case of helicopters, tilt-rotors, tailless aircraft with twin turboprops, etc.), an additional means of increasing the drive shaft length consists in operating above the first critical speed, in the so-called supercritical regime. The main advantage of long shafts is that they reduce the number of bearing supports required, and thus greatly decrease the maintenance costs and the weight of the driveline. The design process is more complex, however, because the shaft has to cross a critical speed, and dynamic instabilities due to rotating damping can occur in this regime. Aeronautic applications lend themselves well to operating in the supercritical regime because the driveline always rotates at the nominal speed during flight, since they undergo acceleration and deceleration processes on the ground. The aim of this paper is to optimize a supercritical drive shaft in this practical case.

An efficient fixation device must stabilize the fracture by keeping detrimental fragments' motions to a minimum, while allowing for some level so axial movements between fracture ends. To fulfill this requirement, the fixation device must bear Torsional and bending loads (i.e. has high bending and Torsional stiffness's) while being axially flexible (i.e. has a moderately low axial stiffness). Designing such a structure are technically impractical using isotropic materials (e.g. metallic alloys) since axial, bending, and Torsional stiffness's of anisotropic material depend on the elastic modulus which is identical in all directions. On the other hand, fiber -reinforced composites can be customized to obtain desired stiffness and strength in different directions by changing the composition of fibers or the stacking sequence of plies.

It is well accepted that among the main advantages of using plastic materials are their Light weight, low cost and superior properties reported that about 21% of waste plastics are burnt and 33% are wasted in landfill, thus creating adverse effects on the environment, especially in terms of disposal; this is becoming a serious global issue in terms of the green world environment. Among the potential solutions is using composites, which are derived from renewable resources. Up-to-date, natural fibers are becoming the main focus amongst researchers. These help to increase the mechanical properties for composite applications, as well as to reduce the amount of synthetic fibre composite usage. Despite the current fact that synthetic fibre performs better in structural composite applications compared to natural fibre; natural fibres can be the best candidate materials to replace and decrease the usage of synthetic fibres especially in non-structural applications where a lower mechanical performance is often accepted. Many researchers have studied new ways to utilize resources derived from natural fibres such as banana, water hyacinth and kenaf. Their studies involve a variety of manufacturing methods to produce composites for product application such as hand lay-up, resin transfer mouldings, and filament winding. In the present study, new hybrid natural fibre composite materials were fabricated using the filament winding method to increase the mechanical properties.

The filament winding process, to some extent, can improve the production speed, volume, size and shapes of the products. Filament winding also offers other advantages such as the ease of production of composite structures with a thick cross-section, and flexibility in design. The filament winding process of fibre-reinforced thermosetting components can be applied to make simple components like pipes, tubes and rods such as those found in sailboard masts, lamp posts, and fishing rods, or high tech components such as high pressure vessels and aerospace components. Few studies had been carried out to investigate the torsional behaviour of drive shaft composites produced by filament winding technique.

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 fiber orientation angle on the performance of drive shaft. The numerical results were validated by results obtained from analytical solutions. Separately, a study of the torsional stiffness, torque – angle of twist behavior and failure modes was experimentally performed in order to enable the observation and discussion of the different failure modes. The specimens used in the experiment were hand lay-up fabricated from woven roving fiber. This fabrication technique is limited to study the behavior of composite tubes rather than to study applicability of this technique to drive shafts. Replacing existing drive shaft with composite drive shaft will be tried by using experimental stress analysis technique. Single piece E-glass fiber-epoxy drive shaft will be replaced by existing shaft. Finite element analysis will be used to achieve strain vector with elastic limit of material. Torsional buckling load setup will be designed to perform experimental analysis using Torsion machine. FEA will be performed with Ansys software packages. Strain gauge will be mounted on shaft and measured strain will be validated with FEA results.

1.1 Problem Statement

Machinery results to higher efficiency and power. Substitute's metallic structure with composite can help in achieving higher stiffness and light weight components. This is basis of experimenting composite reinforced steel shaft over existing shaft. Since we want to increase the strength of an already existing shaft without much increase in cost and weight. Therefore we have selected steel shaft reinforced with epoxy glass fiber.

1.2 Objectives

1. Modeling of steel shaft.
2. Analyzing for stresses, deformation and reaction moments.
3. Preparing epoxy reinforced steel shaft.
4. Analyzing for stresses, deformation and reaction moments on composite shaft.
5. Experimental testing on Torsion Testing Machine and correlating results.

1.3 Scope

It is proposed to do torsion analysis on drive shaft as per following.

1) Theoretical Analysis:- Running the problem in FEA software and comparing the results with experimental analysis.

2) Experimental Analysis:- Testing the propeller shaft under actual conditions to know the model is able to withstand the actual loads.

2. LITERATURE REVIEW

[1] O. Montagnier, et al.

This study deals with the optimisation of hybrid composite drive shafts operating at subcritical or supercritical speeds, using a genetic algorithm. A formulation for the flexural vibrations of a composite drive shaft mounted on visco elastic supports including shear effects is developed. In particular, an analytic stability criterion is developed to ensure the integrity of the system in the supercritical regime. Then it is shown that the torsional strength can be computed with the maximum stress criterion. A shell method is developed for computing drive shaft torsional buckling. The optimisation of a helicopter tail rotor driveline is then performed. In particular, original hybrid shafts consisting of high-modulus and high strength carbon fibre reinforced epoxy plies were studied. The solutions obtained using the method presented here made it possible to greatly decrease the number of shafts and the weight of the driveline under subcritical conditions, and even more under supercritical conditions. This study yielded some general rules for designing an optimum composite shaft without any need for optimisation algorithms.

[2] Saeid Samiezadeh, et al.

Intramedullary nails are the golden treatment option for dia physeal fractures. However, their high stiffness can shield the surrounding bone from the natural physiologic load resulting in subsequent bone loss. Their stiff structure can also delay union by reducing compressive loads at the fracture site, there by inhibiting secondary bone healing. Composite intramedullary nails have recently been introduced toad dress these draw- backs. The purpose of this study is to evaluate the mechanical properties of a previously developed composite IM nail made of carbon-fibre/epoxy whose structure was optimized based on fracture healing requirements using the selective stress shielding approach. Following manufacturing, the cross-section of the composite nail was examining dunderan optical micro scopeto find the porosity of the structure. Mechanical properties of the proposed composite intramedullary nail were determined during standard tension, compression, bending, and torsion tests. The failed specimens were then examined to obtain the modes of failure. The material showed high strength in tension (403:977:8 MPa), compression (316:9710:9 MPa), bending (405:378:1 MPa), and torsion (328:577:3 MPa). Comparing the flexural modulus (41:170:9 GPa) with the compressive modulus (10:070:2GPa) yielded that the material was significantly more flexible in compression than in bending. This customized flexibility along with the high Torsional stiffness of the nail (70:772:0Nm2) has made it ideal as a fracture fixation device since this unique structure can stabilize the fracture while allowing for compression of fracture ends. Negligible moisture absorption (0:5%) and low porosity of the laminate structure (0.3%) are other advantages of the proposed structure. The findings suggested that the carbon-fibre/epoxy intramedullary nailis flexible axially while being relatively rigid in bending and torsion.

[3] S. Misri, et al.

Synthetic fibre is of higher strength in composites and is a low cost material, but the problem is that it does not degrade in the environment. Studies on single yarn natural fibre have been reported, especially those concerned with improving its mechanical properties. This can be used for lower end applications such as furniture and automotive dash board to reduce the utilization of synthetic fibre. Continuous yarn fibres are required to increase the strength for engineering applications and filament winding is a method to produce aligned technical composites which have high fibre content. This paper presents an experimental and simulation studies to investigate the behaviour of composite hollow shafts, with a specific focus on the maximum torsion capacity of the composite hollow shaft for different winding angles and aluminum reinforcement. The conventional filament winding machine was modified and added to a new resin bath mechanism in order to produce a new natural fibre composite hollow shaft using kenaf yarn fibre reinforced with unsaturated polyester resin. The results show that the torsion capacity is significantly affected by changing the winding angle and the presence of aluminum in the static torque test capacity properties. The maximum static torsion capacity of kenaf yarn fibre reinforces unsaturated polyester composite shaft at a winding angle of 45º was higher strength than 90º orientation while the presence of aluminum enhanced the torsion property significantly. Finite element analysis (FEA) using Abaqus software was carried out and showed a good agreement with the experimental results.

[4] M.A. Badie, et al.

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.

[5] Y.A. Khalid, et al.

Throughout this experimental study, a bending fatigue analysis was carried out for hybrid aluminum/composite drive shafts. The hybrid shafts used were fabricated using filament winding technique. Glass fiber with a matrix of epoxy resin and hardener were used to construct the external composite layers needed. Four cases were studied using aluminum tube wounded by different layers of composite materials and different stacking sequence or fiber orientation angles. The failure mode for all the hybrid shafts was identified. The macroscopic level tests indicate that the cracks initiating in the zones free of fibers or in the outer skin of resin and increase with increasing number of cycles until the failure of specimen. It has also been noticed that there is no fiber breakage from the rotating bending fatigue test. Results obtained from this study show that increasing the number of layers would enhance the fatigue strength of aluminum tube up to 40%, for [±45].

3. Computer Aided Design (CAD):

Around the mid 1970s, as CAD systems began to provide more capability than a manual drafting with electronic drafting, the cost benefit for companies to switch to CAD became apparent. During this transition, calculations were still performed either by hand or by those individuals who could run computer programs. CAD was a revolutionary change in the engineering industry, where draftsmen, designers and engineering roles begin to merge. It can also be used to design objects. Many CAD applications now offer advanced rendering and animation capabilities so engineers can understand their product designs.

4. Computer Aided Engineering

It is the broad usage of computer software to aid in engineering analysis tasks. It includes Finite Element Analysis (FEA), Multi-body-dynamics (MBD), and optimization.

CAE in the automotive industry

CAE tools are vastly used in the automobile industry. In fact, their use has enabled the automakers to reduce product development cost and time while improving the safety, comfort, and durability of the Machineries they produce. Even there have been tremendous advances in CAE, it is widely used in the engineering field, for final confirmation physical testing is preferred for subsystems because CAE cannot predict all variables in complex assemblies (i.e. metal stretch, thinning).

Finite Element Method (FEM)

It is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. FEM uses methods from the calculus of variations to obtain a solution by minimizing an associated error function.

Mesh Generation

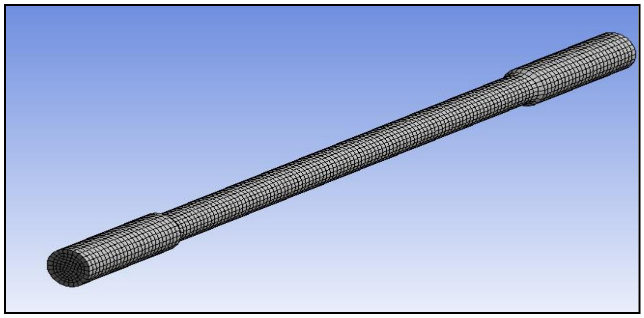

Fig.ure4.1.3.Mesh Generation

Element type- Hexahedron
No. of Elements-15600
No. of Nodes- 68183
Larger diameter satisfies both strength and stiffness
Static Structural Analysis
Analysis of Steel Shaft

The Finite Element Method is a numerical approximation method, in which the complex structure is divided into number of small parts that is pieces and these small parts are called as finite elements. The structures response and loads are assumed to vary slowly with respect to time. There are various types of loading that can be applied in this analysis which are externally applied forces and pressures, and temperatures.

A) FEA Pre Processing

The pre-processing of the steel shaft is done for the purpose of the dividing the problem into nodes and elements, developing equation for an element, applying boundary conditions, initial conditions and for applying loads.

Table 1 Properties of steel.

Property	Value	Unit
Density	7850	Kg/m3
Young's modulus	200000	MPa
Bulk modulus	166700	MPa
Shear modulus	76900	MPa
Ultimate tensile strength	207	MPa
Poisson's ratio	0.3	

Table 2 Properties of epoxy.

Property	Value	Unit
Density	1910	Kg/m3
Young's modulus	3780	MPa
Bulk modulus	4200	MPa
Shear modulus	1400	MPa
Ultimate tensile strength	26-85	MPa
Poisson's ratio	0.35	

Constraints: The rigid element connects the nodes around the steel shaft to the centre, which has fixed degree of freedom.

Shaft is rotated at 1 deg, 2 deg and 3 deg rotation from other end as shown in following Figure.

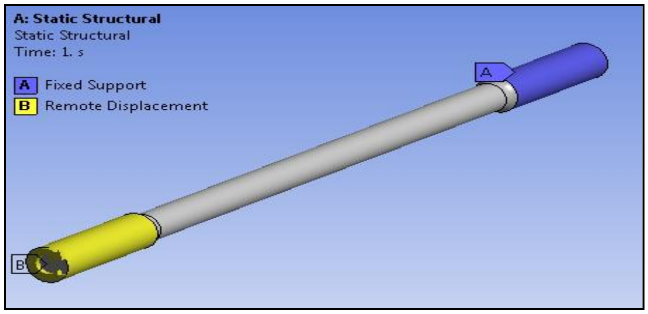

Fig. 4.3 Boundary Condition

Static Structural Analysis

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A) FEA Pre Processing

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a) Von-mises stress

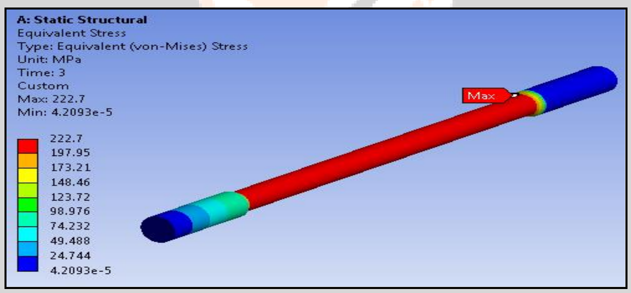


Fig. 4.4 Von- Mises stress of steel steel shaft

Maximum von-mises stress is 222.7 MPa.

b) Deformation:

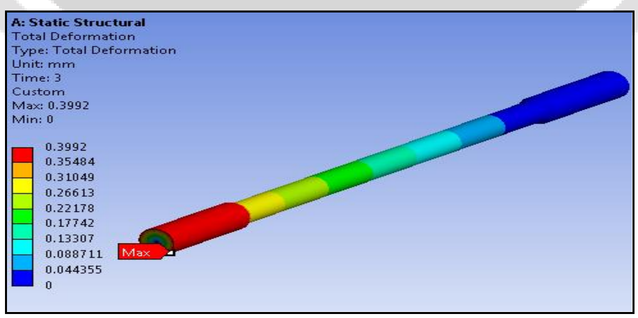


Fig. 4.5 Deformation of steel shaft

Maximum Deformation is 0.3 mm

C) Shear Stress:

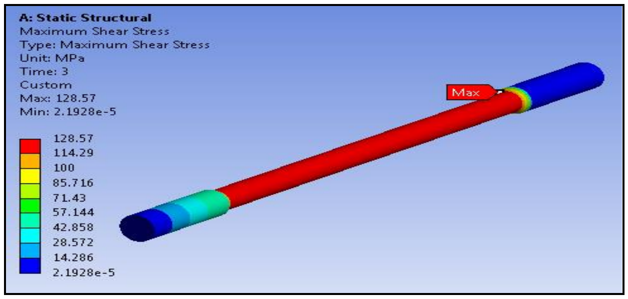
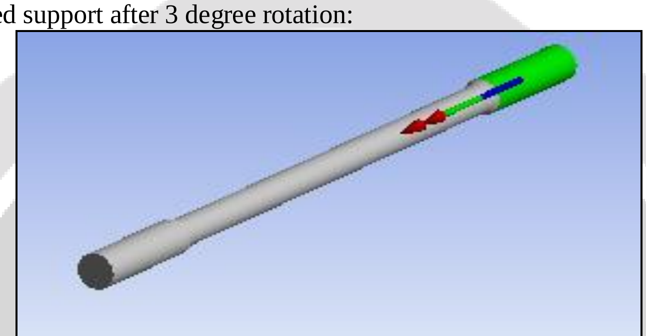


Fig. 4.6 Shear stress of steel shaft

Shear stress in Steel shaft is 128.57 MPa.

d) Reaction moment at fixed support after 3 degree rotation:



Time [s]	Moment Reaction (Z) [N·m]
1.	-13.263
2.	-26.526
3.	-39.788

Fig. 4.7 Moment reaction is 39.78 Nm after 3 deg rotation

Moment reaction is 39.78 Nm after 3 deg rotation

Composite Epoxy glass fiber reinforced Steel Shaft Analysis:

Boundary Conditions:

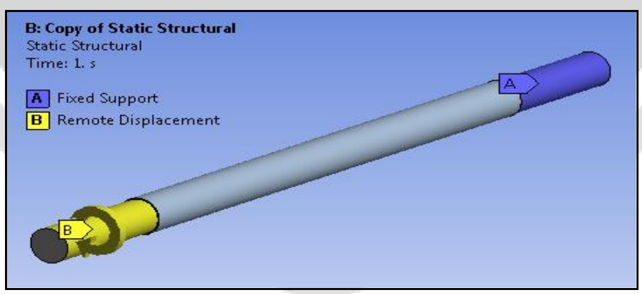


Fig. 4.8 Boundary Condition of composite epoxy reinforced steel shaft

a) Von- Mises:

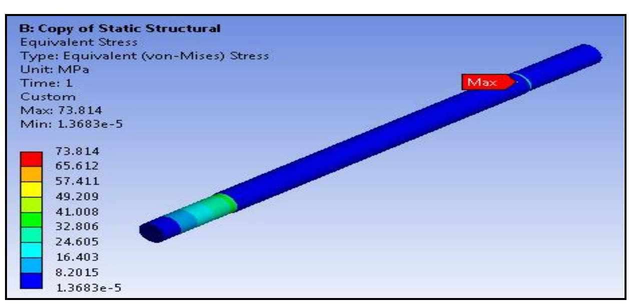


Fig. 4.9 Von- Mises stress of composite steel shaft

Maximum von-mises stress is 78 MPa.

b) Deformation:

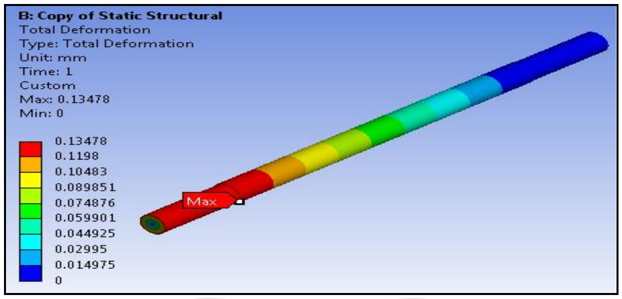


Fig. 4.10 Deformation of composite steel shaft

Maximum Deformation is 0.13mm.

C) Shear Stress:

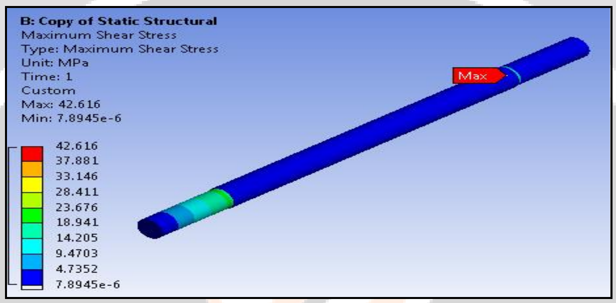
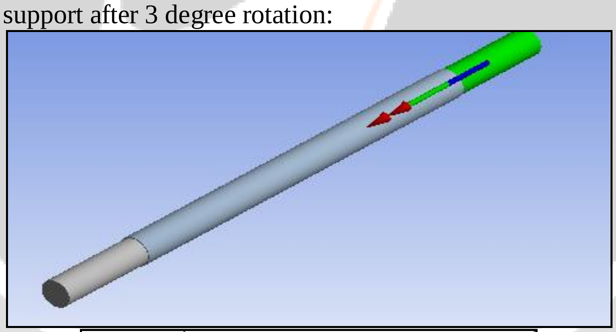


Fig. 4.11 Shear stress of composite steel shaft

Shear stress in reinforced steel shaft is 42.6 MPa.

d) Reaction moment at fixed support after 3 degree rotation:



Time [s]	☑ Moment Reaction (Z) [N·m]
1.	-13.763
2.	-27.527
3.	-41.29

Fig. 4.6 Moment reaction is 41.29 Nm after 3 deg rotation

4. CONCLUSIONS

By using steel shaft reinforced with epoxy glass fiber we can increase the strength of an already existing shaft without much increase in cost and weight.

5. REFERENCES

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