MODAL ANALYSIS FOR THE DESIGN OF GLASS/EPOXY HOLLOW SHAFT FOR MISALIGNMENTS

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Abstract- **In the present work an attempt is made to evaluate the suitability of composite material such as E-Glass/Epoxy composite hollow shaft with grooves inclination for the purpose of automotive transmission applications. The glass/epoxy shaft was made flexible by introducing grooves. With this the torsional stiffness of the shaft reduces. The grooves inclined at 45^0 is first introduced in the shaft and checked for misalignments. This is followed by the introduction of perpendicular grooves. Then the misalignment is checked for varying groove angles. A one-piece composite drive shaft for automobile is designed and analyzed using ANSYS software respectively for E-Glass/ Epoxy with the objective of reducing axial misalignment which is subjected to the constraints such as torque transmission, torsional buckling strength capabilities with weight benefits.**
Finite element models of the drive shaft will be generated and analyzed using ANSYS version 11 commercial software. Cylindrical local coordinate dataset has been defined to align the material direction of the composite lay-up and to apply ends supports and loading.
Keywords: E-Glass/Epoxy Composite, Hollow Shaft.

1. INTRODUCTION

The problem of misalignment is encountered wherever there are rotating shafts, which is of great concern to designers and maintenance engineers. Higher the speed, more accurate alignment is required. If an application is generating vibrations, one should always check the alignments. Misalignments are the deviation of relative shaft position from collinear axis of rotation when equipment is running at normal operating conditions. During the transmission of Torque between two shafts there might be some axial and lateral misalignments these misalignments should also be taken care. The composite materials are well known by their excellent combination of high structural stiffness and low weight. The advanced composite materials such as Graphite, Carbon, Kevlar and Glass with suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/ density).Their inherent anisotropy allows the designer to tailor the material in order to achieve the desired performance requirements. Advanced composite materials seem ideally suited for long, power driver shaft (propeller shaft) applications. Their elastic properties can be tailored to increase the torque they can carry as well as the rotational speed at which they operate. The drive shafts are used in automotive, aircraft and aerospace applications. The automotive industry is exploiting composite material technology for structural components construction in order to obtain the reduction of the weight without decrease in vehicle quality and reliability.

2. LITERATURE SURVEY

S Vijayarangan, R A Chandrasekhar [1] designed and analyzed a composite drive shaft for power transmission applications. A one piece drive shaft for rear wheel drive automobile was designed optimally using E-glass /epoxy and high modulus carbon/Epoxy composites. In this paper a Genetic Algorithm has been successfully applied to minimize the weight of shaft which is subjected to constrain such as torque transmission, torsional buckling capacities and fundamental natural frequency. The results of Genetic Algorithm are used to perform static and buckling analysis using ANSYS software. The results show the stacking sequence of shaft strongly affects buckling torque.

Lien –Wen Chen [2] studied the stability behavior of a rotating composite shaft subjected to axial compressive loads using finite element method. The laminated composite shaft is modeled as a Timoshenko shaft by applying the equivalent modulus beam theory. Numerical results correlate well with the reported beam models. The critical speed of the thin walled composite shaft is dependent on the stacking sequence, the length-radius ratio and the boundary conditions and the rotational speed has little effects on the critical loads of a rotating thin walled shaft.

Filiz Civigin [3] investigated the torsional deflections and stress analysis of the composite bars in torsional. In the Experiment study, Epoxy/E glass composite bars were manufactured by filament winding process in order to determine mechanical properties of the composite bars. The Experiment was carried out on a torsional test machine, which was built specifically to investigate the static and dynamic characteristics of composite shafts. The torsional deflections were obtained experimentally and also by FEA. Inspection of the static behavior of the composite bar under torsional loading are made by both Experimental and theoretical analysis.

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3. AIMS AND SCOPE OF WORK

The main aim of the present study is to design and analyze a glass/epoxy composite hollow shaft, so as to take up axial misalignment of a given value for pre specified static torsion stiffness and torque, with weight benefits. This is achieved by introducing helical grooves along the circumference of the shaft similar to that of isotropic flexible couplings. The dimensions, orientation and number of grooves are optimized to take up required misalignment, without violating any given design parameters. Also the torsional buckling load and critical speed of the designed shaft is calculated to evaluate the effect of the grooves on these design parameters.

4. DESIGN OF COMPOSITE DRIVE SHAFT

4.1. Specification of the Problem

Design, analysis and optimization of the glass/epoxy composite hollow shaft subjected to following specifications:
1 .Composite hollow shaft should transmit a torque of 1000 NM
2. Torsional stiffness should be greater than 5700 Nm/rad
3. Misalignment of +-5mm in axial direction must be obtained.
4. Weight of the designed shaft should be less than 3.0 Kgs

4.2 Selection of Cross-Section

The drive shaft can be solid circular or hollow circular. Here hollow circular cross-section was chosen   because; the hollow circular shafts are stronger in per kg weight than solid circular. The stress distribution in case of solid shaft is zero at the center and maximum at the outer surface while in hollow shaft stress variation is smaller. In solid shafts the material close to the center are not fully utilized.

4.3. Selection of Reinforcement Fiber

Fibers are available with widely differing properties. Review of the design and performance requirements usually dictate the fiber/fibers to be used.

Carbon/Graphite fibers: Its advantages include high specific strength and modulus, low coefficient of thermal expansion, and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance, and high electrical conductivity.

Glass fibers: Its advantages include its low cost, high strength, high chemical resistance, and good insulating properties. The disadvantages are low elastic modulus, poor adhesion to polymers, low fatigue strength, and high density, which increase shaft size and weight. Also crack detection becomes difficult.

Kevlar fibers: Its advantages are low density, high tensile strength, low cost, and higher impact resistance. The disadvantages are very low compressive strength, marginal shear strength, and high water absorption. Kevlar is not recommended for use in torque carrying application because of its low strength in compression and shear here, both glass and carbon fibers are selected as   potential materials for the design of shaft.

4.4 Selection of Resin System

The important considerations in selecting resin are cost, temperature capability, elongation to failure and resistance to impact (a function of modulus of elongation). The resins selected for most of the drive shafts are either epoxies or vinyl esters. Here, epoxy resin was selected due to its high strength, good wetting of fibers, lower curing shrinkage, and better dimensional stability.

4.5 The Materials and their Properties

Mechanical properties of E-glass fibers

Material properties	Values
Density (pf)	2500Kg/m3
Modulus of elasticity (Ef)	72.5GPa
Shear Modulus (Gr)	28.1GPa
Poisson's ratio (vn2)	0.22
Ultimate Tensile strength (Sf)	3.45GPa
Shear strength	35 MPa
Axial and Transverse Tensile strength	2150 MPa
Axial and transverse compressive strength	1450 MPa

Properties of Thermo set epoxy resins

Material properties	Values
Density	1200Kg/m3
Modulus of elasticity (Gm	24GPa
Tensile strength (Sm)	140 MPa
Elongation	4%
Poisson's ratio (Vm)	0.35
Flexural yield strength	240 MPa
Compressive strength	225 MPa
Shear strength	35 MPa
Maximum work temperature	200oc

Mechanical Properties of the E Glass/Epoxy

Mechanical Properties	Symbol	Units	E-Glass Epoxy
Longitudinal Young's Modulus	E_{11}	Gpa	52.36
Transverse Young's Modulus	E_{22}	Gpa	8.02
Major Poisson Ratio	v_{12}		0.24
Inplane Shear Modulus	G_{12}	Gpa	3.097
Ultimate Longitudinal Tensile Strength	$(\sigma_1)_{u/t}$	Mpa	954.8
Ultimate Longitudinal Compressive Strength	$(\sigma_1)_{u/t}$	Mpa	69.2
Transverse Tensile Strength	$(\sigma_2)_{u/t}$	Mpa	27.29
Ultimate Transverse Compressive Strength	$(\sigma_2)_{u/t}$	Mpa	38.66
Inplane shear strength	$(\tau_{12})_{u/t}$	Mpa	12.72
Density	P	Kg/m^3	1980

5. FINITE ELEMENT ANALYSIS
5.1. Finite Element Analysis
Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It also can be used to analyze either small or large- scale deflection under loading or applied displacement. It uses a numerical technique called the finite element method (FEM). The primary unknowns in this structural analysis are displacements and other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements.

5.2. Modeling linear layered shell
Composites are somewhat more difficult to model than an isotropic material such as iron or steel. Because each layer may have different orthotropic material properties, we must exercise care when defining the properties and orientations of the various layers.
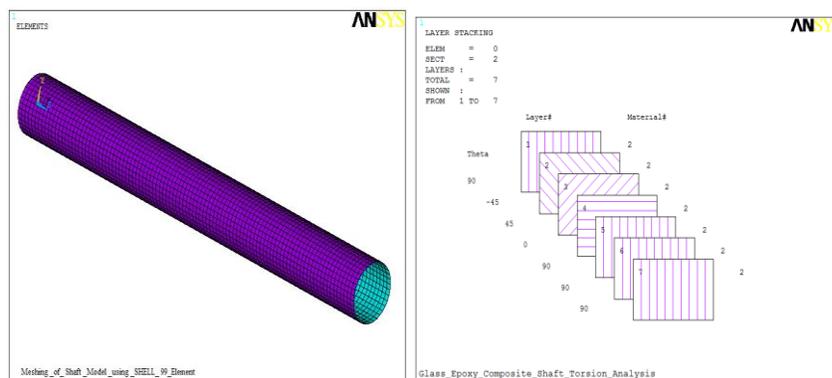
Build a 3D parametric part from a 2D sketch by combining basic and advanced features, such as extrusions, sweeps, cuts, holes, slots, and rounds. Finally, Part Modeling Help provides procedures for modifying part features and resolving failures.

5.3. Boundary conditions for static analysis
One end of the hollow composite shaft is fully fixed by constraining all degree of freedom and at another end only torque in terms of tangential force is applied.
Torque applied=1000N/m
Force=torque/mean radius=1000/(R0+Ri/2)
Force per node=force/no of nodes
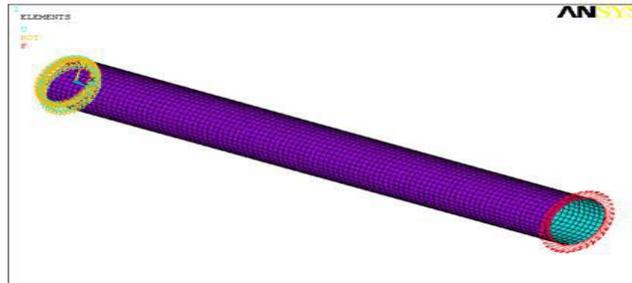
Finite element model of Glass/Epoxy shaft

5.4. Modal Analysis
The modal analysis is performed to find the natural frequencies in lateral directions. The mode shapes for all material combinations are obtained to their corresponding critical speeds. A number of fundamental modes, which all are critical frequencies, are obtained. If the shaft's frequencies correspond to these ones, it may be collapsed.

5.5. Boundary conditions for modal analysis
The selection of element type and the meshing quality has to be validated first before proceeding with the problem. So, the analysis of simple glass/epoxy shaft is initially carried out. The torque to be transmitted by the shaft is 1000Nm and its torsional stiffness should not be lesser than 5700Nm/rad. The weight of the shaft should not exceed 3kgs and its length is fixed at 1225 mm. At both the ends of the shaft, 112.5mm is left free for the rigid couplings.
The dimensions of the shaft are as given
Length of the shaft L=1225mm, Inner diameter, Di=59mm, Lamina thickness Ti=0.15mm,
Layer Orientation= $(45^0, ^- 45^0, 45^0)$

6. METHODOLOGY
The methodology adopted involves the following steps:
1)   Finite Element Analysis of simple glass/epoxy shaft
     a)   Study of torsional stiffness and stresses with increasing number of layers.
     b)   Decide on maximum number of layers, such that the weight of the shaft does not exceed 3 kgs, to obtain the required torsional stiffness and stresses within limits.
2)   Finite Element Analysis of the shaft with multiple grooves of width 1mm and groove angle with respect to the longitudinal axis at 45^0.
     a)   Decide the length of grooves in the shaft for which torsional stiffness and failure index values are satisfied.
     b)   Check for maximum axial and lateral misalignment obtained.
3)   Finite Element Analysis of the shaft with multiple grooves by increasing the grooves width by 1mm until the optimum width is achieved.
     a)   Optimize the width of the grooves in the shaft to obtain the required minimum torsional stiffness and stresses within limits.
     b)   Check for maximum axial and lateral misalignment obtained.
4)   Finite Element Analysis of Glass/Epoxy shaft with multiple perpendicular grooves (i.e. the grooves inclined at 90^0 with respect to the longitudinal axis).
     a)   Decide the length of grooves in the shaft for which torsional stiffness and failure index values are satisfied.
     b)   Check for maximum axial and lateral misalignment obtained.
5)   Finite Element Analysis of the shaft with multiple perpendicular grooves by increasing the groove width by 1mm until the optimum width is achieved.
     a)   Optimize the width of the grooves in the shaft to obtain the required minimum torsional stiffness and stresses within limits.
     b)   Check for maximum axial and lateral misalignment obtained.
6)   Finite Element Analysis of the shaft with single groove of 360^0

Groove length and optimized width at different groove angles.

7) Finite Element Analysis of the shaft with multiple grooves of optimized groove length and width at different groove angles.
   a) The behavior of the shaft with multiple grooves is analyzed.
   b) Check for maximum axial and lateral misalignment obtained at different angles.
8) Finite Element Analysis of the shaft with miscellaneous groove positioning for maximizing the misalignments.
   a) Shaft with alternate grooves. Thus, increased torsional stiffness and reduced stresses are obtained since the pitch length is reduced to half(as the no is reduced to half)
   b) Shaft with alternate grooves over 2pitches (the pitch length is still 360^0). In this design, the number of grooves is the same as that for 1 pitch but the circumferential distance between the grooves is increased.
   c) Shaft is designed with half the pitch length i.e. all the grooves lie on one half of the shaft.
   d) Shaft is designed with longitudinal grooves.
9) Evaluating the first natural frequency and critical speed of the Glass/epoxy shaft.
   a) The first natural frequency and critical speed is calculated theoretically. Finite Element Analysis of the shaft with and without the grooves is done.
10) Calculating the Torsional Buckling load of the glass/epoxy shaft.
   a) The torsional buckling load is calculated from the simple shaft without grooves theoretically and referred using Finite Element Analysis. Then the torsional buckling load is calculated for the shaft, with Optimized groove length and width.

7. RESULT & DISCUSSION

XY Shear Strain

YZ Shear Strain

XZ Shear Strain

Stress Intensity
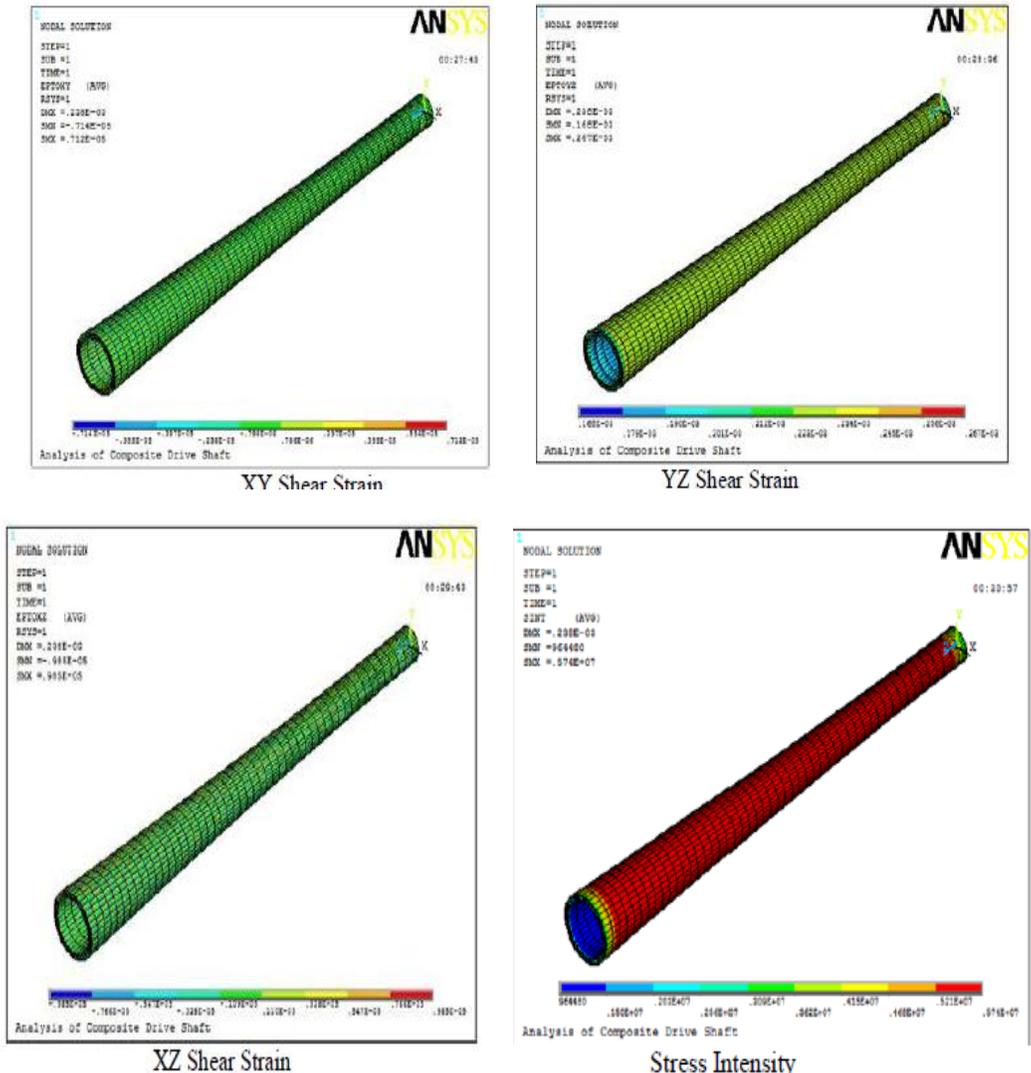
Fig-Static Stress Analysis of Composite shaft with 45-45-45-45 Orientation
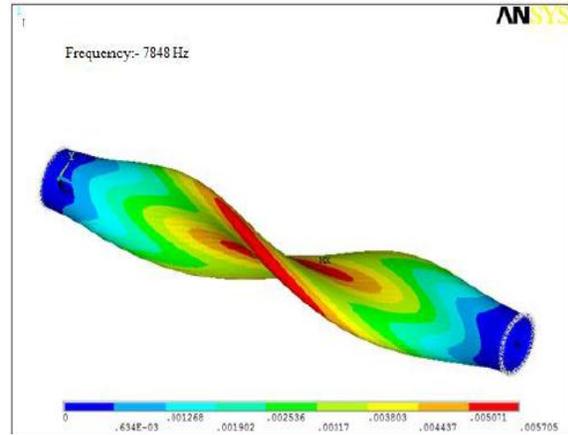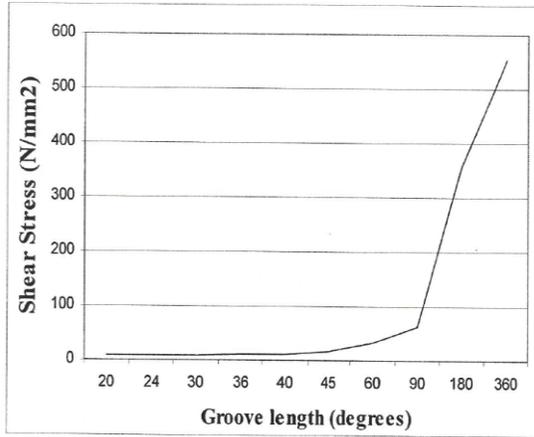
Buckling mode shapes of glass/epoxy composite shaft
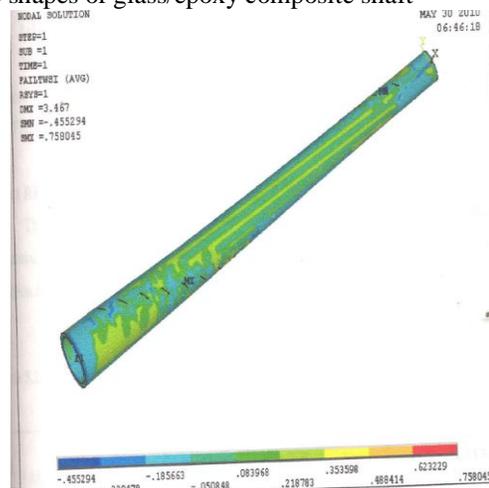
Contour plot for failure index of the shaft with 18 grooves inclined at 45^0
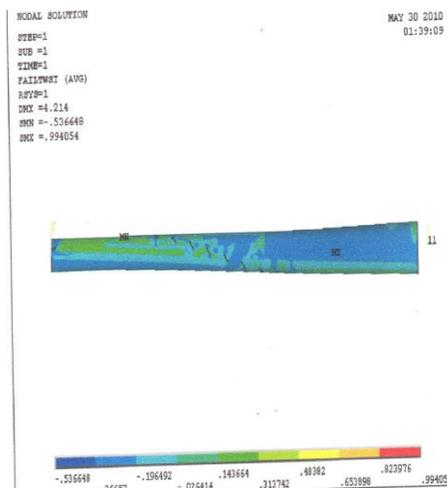
Contour plot for failure index of the Shaft with 18 grooves of length 20^0 and width 1mm

8. CONCLUSIONS

The present thesis outlines the methodology, design and analysis of a composite hollow shaft to take up axial and lateral misalignments. The hollow shaft made up of E-glass/epoxy multilayered composites has been designed for the purpose of introducing misalignments.

The analysis of the shaft, with some miscellaneous arrangements of grooves, is carried out. It was observed that with the increase in groove width, the axial misalignment in the shaft increases but the lateral misalignment in the shaft remains nearly same. Also, at different groove angles between 45^0 and 90^0 the lateral misalignment remains nearly the same, whereas there is increase in the axial misalignment as the angle increases from 45^0 to $90^{0.}$

The critical speed and torsional buckling capacity of the composite shaft are not reduced drastically when the grooves are introduced in the shaft. The shaft with perpendicular grooves gives less reduction in torsional buckling capacity compared with the shaft with grooves inclined at other angles. But the shaft with grooves inclined at 45^0 gives less reduction in critical speed compared to the shaft with perpendicular grooves.

9. REFERENCES

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