"Fatigue Analysis Of Epoxy Composite Material Reinforcement On Propeller Shaft"

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Abstract
Propeller shaft, also known as propeller shaft is the most important component to any power transmission application; automotive propeller Shaft is one of this. A propeller shaft is a mechanical part that transmits the generated torque by a vehicle's engine into motive force which is usable to propel the vehicle. Substituting composite structures for metallic which is structures has many advantages because of higher specific stiffness and strength of composite materials. This work deals with the conventional replacement of steel propeller shafts with fiberglass epoxy composite propeller shaft for an automotive application. The parameters of design were optimized with the objective of minimizing the weight of a propeller shaft. The design optimization also improves the performance of propeller shaft. Present work deals with FEA analysis of composite shaft with different degree of orientation of glass fibers. It includes the modeling of shaft in CATIA. The meshing and boundary condition application will be carried using Hypermesh, Fatigue analysis of composite shaft will be carried out using ANSYS.
Keywords- Propeller Shaft, fiberglass epoxy composite propeller shaft, Catia V5R19, Hypermesh 12.0, Ansys 13

Introduction:

The advances of rapid technological in engineering design field which results in finding the alternate solution for the conventional materials. The main task for engineers to finding the materials which have more reliable than conventional materials. Researchers and designers are looking constantly for the solutions to provide stronger and durable materials which may answer the needs of fellow engineers. Propeller shafts are used as power transmission tubing in so many applications, which are including cooling towers, pumping sets, aerospace, trucks and automobiles. The design of metallic shaft, knowing the torque and the shear stress allowable which are for the material, the size of the shaft's cross section will be determined. In the today's days there is requirement for light weight materials vehicle.

Functions of Propeller shaft:

- Transmit the power from gear box
- To compensate for change in length: The length of the propeller shaft must also be capable of changing while transmitting torque. Length changes are caused by torque reaction of axle movements, road deflections, braking load and so on. For this motion slip joints are used. The

slip joint are usually made of an internal and external spline. It is located on front end of the propeller shaft and is connected to the transmission.

- Transmit motion at an angle which is varying frequently: The propeller shaft must also operating through constantly changing angles between the transmission and the differential and the axles. As the rear wheels roll over bumps in the road, the differential and the axle move up and down
- The propeller shaft must also be capable of rotation at the very fast speeds required by the vehicle.

It consists of the following components:

1. **Shaft:**

a) Shaft is made of steel tube with suitable diameter and length to withstand stresses developed during transmission

b) It is made of strong steel tube, but light and well balanced so that vibration will not occur.

2. **Universal joint:**

a) The gear box which is attached to the chassis and rear axle is attached to the frame by spring. This spring compress or expands and is in continuous movement due to road irregularities. This results in vibration of angle propeller between gearbox and differential.

b) Hence a propeller shaft is required to transmit power between two points at varying vertical and horizontal distance. Thus two universal joints are necessary in propeller shafts to take care of variation in the angle of propeller.

Strength Characteristics:

Structural properties, which may be stiffness, dimensional stability, and strength of a composite laminate, depend on the sequence of the plies which is stacking. The stacking sequence describes the distribution of ply orientations by the laminate thickness. If the number of plies with chosen orientations increases, more stacking sequences is possible. For example, a symmetric eight-ply laminate with four different ply orientations has 24 different stacking sequences.

Fiber Orientation:

The strength and stiffness of a composite buildup depends on the orientation sequence of the plies. The practical range of strength or stiffness of carbon fiber extends from values as low as those provided by fiberglass to as high as those provided by titanium. This range of values is determined by the orientation of the plies to the applied load. Proper selection of ply orientation which is in advanced composite materials have necessary to provide a structurally efficient design. The part might require 0° plies to react to axial loads, 45° plies to react to shear loads, and which is 90° plies to react to side loads. Because the strength design requirements will be a function of the applied load direction, ply orientation and ply sequence have to be correct. It is critical during a repair to replace each damaged ply with a ply of the same material and ply orientation.

Problem statement:

- They have less specific modulus and strength. It's corrosion resistance is less as compared with composite materials.
- Increased weight
- Steel propeller shafts have less damping capacity.
- Conventional steel propeller shafts are usually manufactured in two pieces to increase the fundamental bending natural. Therefore the steel propeller shaft is made in two sections connected by a support structure, bearings and U-joints and hence overall weight of assembly will be more.

Objectives:

The main objective of the project is to carry out design and Optimization on structure under static and dynamic loads.

a) To design a propeller shaft using CATIA CAD Software,
b) To conduct design analysis using Hypermesh and Ansys Simulation software.
c) Interpreting the Ansys results
d) Optimization of structure.
e) Fabrication, testing and validation

Literature Survey:

Bhirud Pankaj Prakash, Bimlesh Kumar Sinha[1] The overall objective of this work is to analyze a composite propeller shaft for power transmission. Substituting composite structures which is for conventional metallic structures has many advantages because of higher specific stiffness and or strength of composite materials. The work deals with the replacement of conventional steel propeller shafts with an Kevlar or epoxy or E glass polythene resin composite propeller shaft for an automotive application. The intention of work is to minimize the weight of propeller shaft. In this present work an attempt has been to estimate the deflection, stresses, and or natural frequencies under subjected loads using FEA (Ansys). The usage of composite material are resulted to inconsiderable amount of weight saving which is in the range of 24% to 29% when compared to conventional steel shaft. By considerations of the saving weight, deformation, shear stress induced and resonant Frequencies it is evident that Kevlar or Epoxy composite are the most encouraging properties to act as replacement for steel out of the considered two materials. The presented work which is also deals with design optimization i.e converting two piece propeller shaft (conventional steel shaft) in to single piece light weighted composite propeller shaft.

Pandurang V Chopde, Prof. R.B.Barjibhe [2] In this study, experimental and theoretical, torsional and vibration analysis is done on conventional SM45C steel propeller shaft, carbon epoxy and glass epoxy composite propeller shaft. The parameter like deflection, stresses, and or natural frequencies which is under subjected loads using FEA will be studied. Modal analysis is carried to find out natural frequency, deflection, stresses under subjected loads.

Bhimagoud Patil1, Fayaz Kandagal2, Vinoth M.A [3], The main concept of this project is to reduce the weight of automotive propeller shaft which are done through the fabrication of Al-Si matrix reinforced with SiC-Cenosphere composite material by stir casting with varying percentage of Cenosphere. The modeling of the propeller shaft assembly was created by using

CATIA software. In present work an attempt has been to estimate deflection, stresses which are under subjected boundary conditions, analysis are carried out by Abaqus.

Sagar D. Patil, Prof. D.S.Chavan, Prof. M.V.Kavade[4], The overall objective of this paper is to design and analyze a composite propeller shaft for power transmission applications. A one-piece propeller shaft for rear wheel propeller automobile was designed optimally using E-Glass or Epoxy and High modulus (HM) Carbon/Epoxy composites. In this paper an Analytical and ANSYS Software have been successfully applied to minimize the weight of shaft which are subjected to the constraints such as torque transmission, Static Structural capacities.

S V Gopals Krishna, B V Subrahmanyam, and R Srinivasulu [9], The present work includes, analysis done on propeller shaft of Toyota quails with different composite materials and or concludes that the use of composite materials for propeller shaft would induce less amount of stress which are additionally reduces the weight of the vehicle. In present work, analysis done on dive shaft with different composite materials and concludes that the use of composite materials which is for propeller shaft may induce less amount of stress which additionally reduces the weight of the vehicle.

Project overview:

In our project, we are going to work over a propeller shaft of a bolero car. By reverse engineering (hand calculation) dimensions of the propellershaft will be found out. Currently, propeller shaft is made of MS material. 3D modeling will be done in CatiaV5.Meshing and analysis will be carried out in Hypermesh and Ansys respectively. Stress and deformation will be the output of analysis. By following the same procedure for 3D modeling, meshing, re-analysis of propeller shaft by using composite material will be done. But this analysis will include propeller shaft made of fiber glass or epoxy material with different orientation. Stress values must be below critical value to ensure that the new design which is safe.

Once we get the results from analytical solutions, we make a prototype of the propeller shaft and carryout experimental testing on it. The values which are experimental should be in-line with the analytical values.

Tools Used:

Cad Software – CatiaV5R19

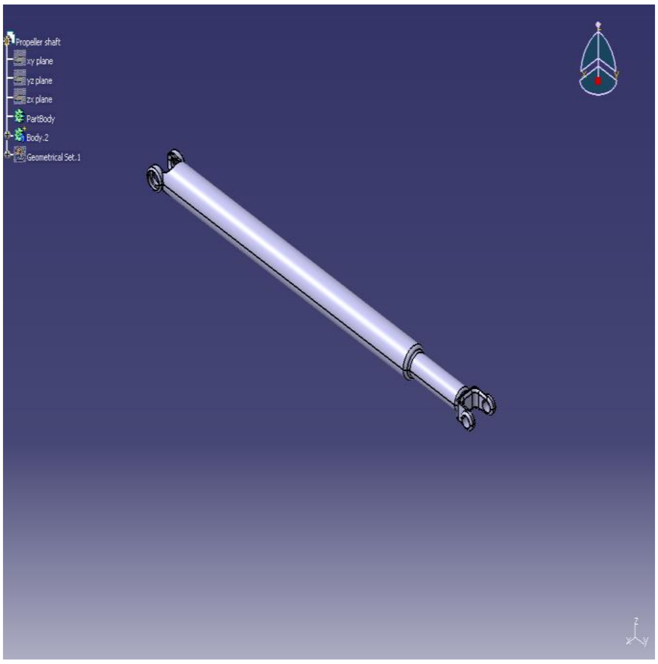
CAE software – Hypermesh 12.0, Ansys 13.

Experimental testing – UTM

Design And Analysis Of Propeller Shaft

Dimensions are required for calculating of boundary conditions. Hence its CAD model is necessary. The conventional model used in Bolero vehicles is used. Dimensions are taken through reverse engg i.e through hand calculations. CAD model then is made by the commands in CATIA of Pad, pocket, fillet, and geometrical selections in part design module. Parametric generation of drawings will help to get the dimensions useful in forces calculations in static and dynamic loading conditions on composite shaft.

(Figure: 1 Hand Measurement Image)



(Figure : 2 CAD Model of propeller shaft)

Finite Element Analysis of propeller shaft:

- The results of finite element analysis for propeller shaft are discussed. FE models are used for static analysis considering the boundary conditions.
- A general-purpose commercial finite element code, Hyper-Mesh and Ansys is applied to conduct the static simulations

Analysis:

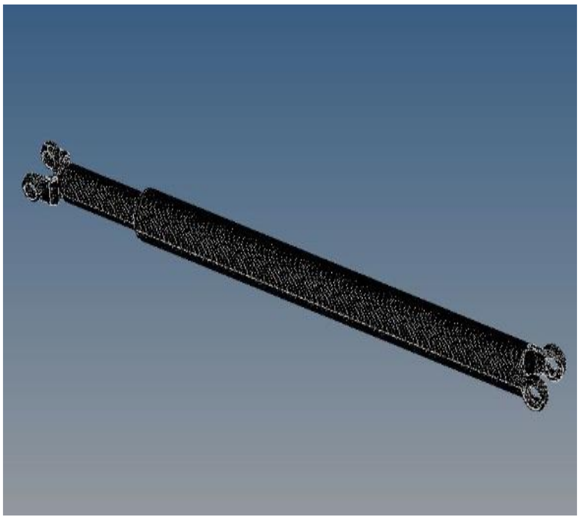
Analysis is carried out by selecting appropriate solver and carrying out the operations in various stages to obtain solution. Particularly analysis have been carried out in three stages by performing various operations in software.

Stage-I

In this stage igs files are imported to the meshing software like Hypermesh. The CAD data of the propeller shaft structure is imported and the surfaces were created and meshed. Since all the dimensions of propeller shaft are measurable (3D), the best element for meshing is the tetra-hedral.

Meshing:

A structure or component consists of infinite number of particles or points hence they must be divided in to some finite number of parts. In meshing we divide these components into finite numbers. Dividing helps us to carry out calculations on the meshed part. We divide the component by nodes and elements. We are going to mesh the components using 3D elements. As all dimension of propeller shaft are in proportion we use the tetra-hedral elements for meshing.

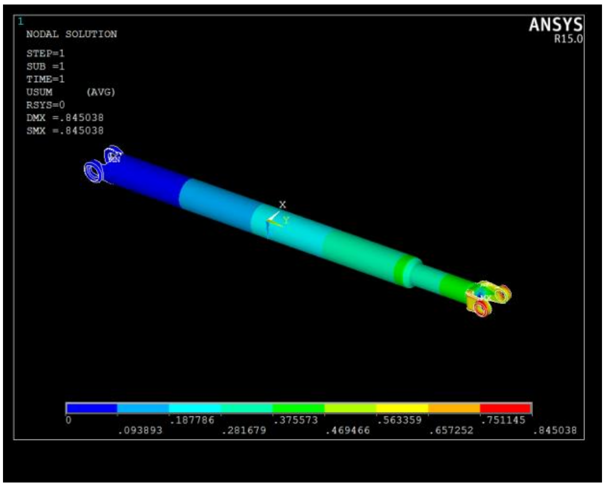


(Figure: 3 tetra-hedral meshing on propeller shaft)

While meshing mesh size of an element is to be taken into consideration because all software's have some limits for the number of elements. Less the mesh size more will be the number of elements and coarse the mesh size less will be the number of elements. As the number of elements increases the run time increases. After meshing elements are to be checked for Quality i.e. elements have some definite quality criteria which should be met by all elements. A quality criterion consists of minimum and maximum angles of the elements, jacobian, warpage etc.

Number of nodes: 59934
Number of elements: 249508
Element size = 4 mm

Deformation Result of Propeller shaft

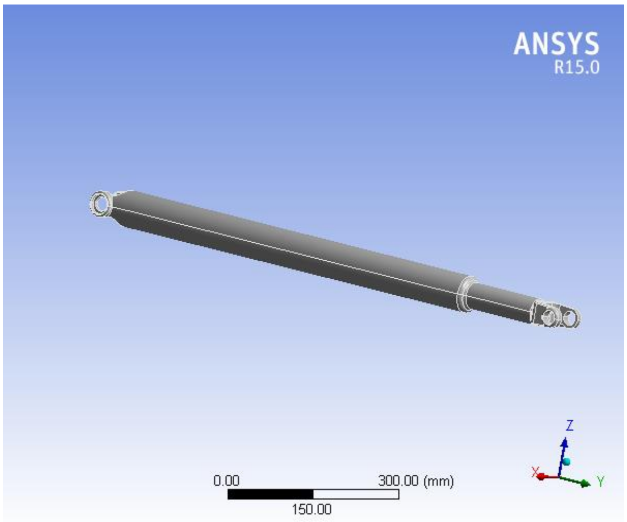


(Figure: 4 Deformation of propeller shaft)

Above figure shows Deformation plot for propeller shaft whose value is 0.84mm.

Fatigue Analysis

CAD model:



(Figure: 5 CAD model of propeller shaft)

Meshing Details:

Sizing	
Use Advanced Size Function	Off
Relevance Center	Medium
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	1.749e-002 mm
Defeaturing	
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	11407
Elements	4781
Mesh Metric	None

(Table No: 2 Meshing Details)

Material

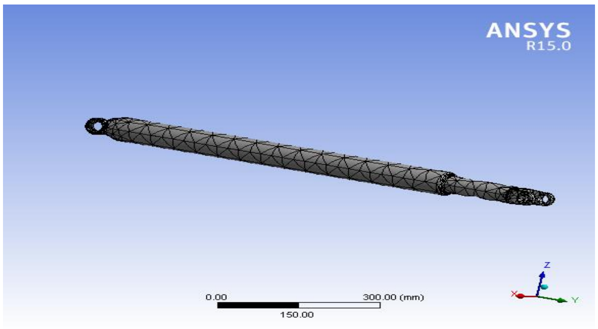
Structural Steel > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999	10	0
2827	20	0
1896	50	0
1413	100	0
1069	200	0
441	2000	0
262	10000	0
214	20000	0

138	1.e+005	0
114	2.e+005	0
86.2	1.e+006	0

(Table No: 3 Alternating stresses and cycles)

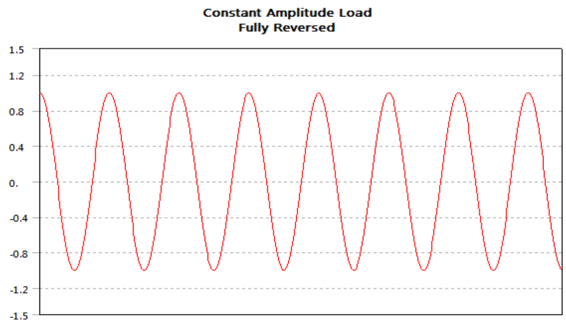
Meshed Model of Propeller Shaft



(Figure:5 Meshed model of propeller shaft)

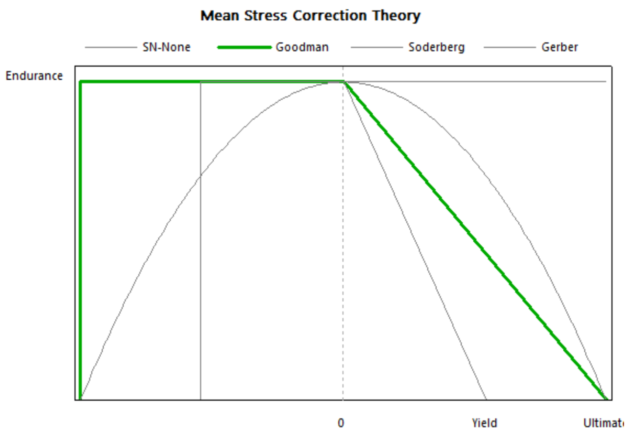
Fatigue Boundary conditions

Cyclic loading



(Figure: 6 Cyclic loading)

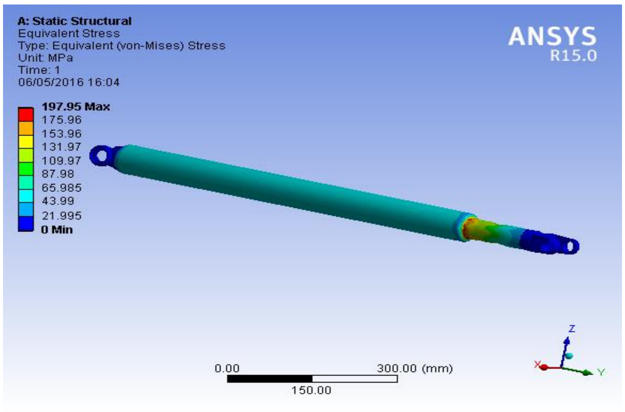
Mean Stress Correction Theory:



(Figure: 7 mean stress correction theory)

Results:

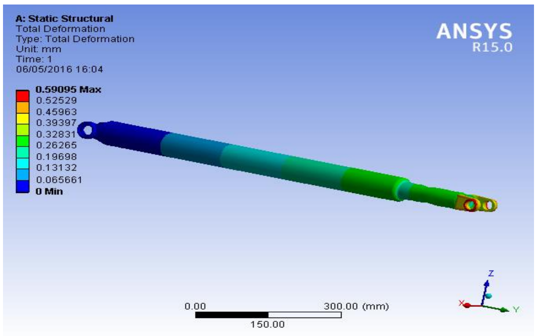
Equivalent stress:



(Fig: 8 von mises stress of propeller shaft)

Above figure shows von mises stress for propeller shaft which is coming as 197.95 N/mm2. This stress value is below permissible, hence it is safe.

Deformation:

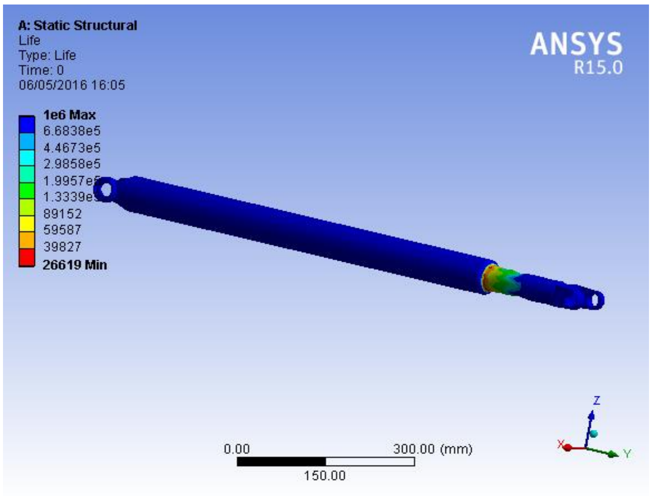


(Fig: 9 deformation of propeller shaft).

Above figure shows deformation of propeller shaft which is 0.59mm, which is very less.

Damage and Fatigue life:

Fatigue life



(Figure: 10 Life of a propeller shaft)

Above figure shows life of a propeller shaft which is 1 e6 cycles.

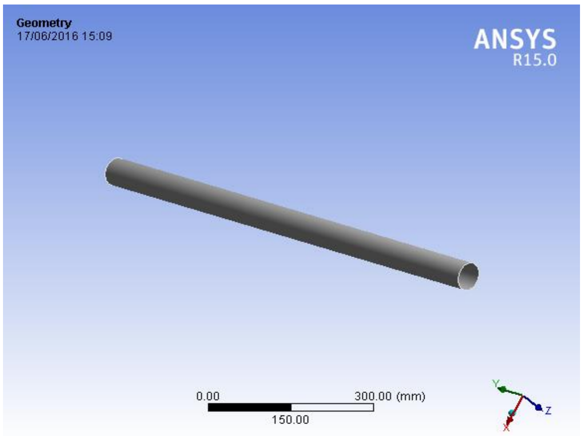
Torque calculation:

Specifications of a car engine:

Displacement = 2523 cc
Max power = 46.3 KW
Max. torque = 195 Nm
Transfer gear ration = 3.78
Torque Calculation
Velocity, V = 120 Km/h = 2000 m/min
Tire Diameter, D = 27.6 in = 703 mm = 0.703 m
Vehicle RPM = Speed of Vehicle / Circumference of tire
Nv = V/ (π*D)
= 2000/ (π*0.703)
Nv = 905.57 rpm
Propeller shaft rpm,
N = Nv*gear Ratio
= 905.57*3.78
N = 3423.05 rpm
Power, P = 2*π*N*T/60
$46.3*10^3 = 2*\pi*2053.8*T/60$
T = 129.16 Nm
Abuse torque by considering FOS= 3.5
T applied = 129.16 * 3.5 = 452.07 Nm

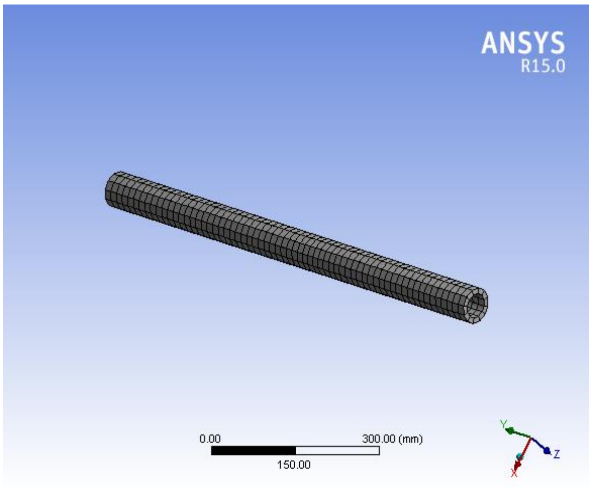
Static Analysis Of Glass Fiber Composite Shaft

CAD model



(Figure: 8 CAD model of glass fibre composite shaft)

Meshed model



(Figure:9 Meshed Model)

No of elements and nodes-

Statistics	
Nodes	780
Elements	768

The layups of glass fiber are arranged in order of 45 and -45 degree alternatively till 10mm thickness

Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
10	Epoxy_EGlass_UD	1	45
9	Epoxy_EGlass_UD	1	-45
8	Epoxy_EGlass_UD	1	45
7	Epoxy_EGlass_UD	1	-45
6	Epoxy_EGlass_UD	1	45
5	Epoxy_EGlass_UD	1	-45
4	Epoxy_EGlass_UD	1	45
3	Epoxy_EGlass_UD	1	-45
2	Epoxy_EGlass_UD	1	45
1	Epoxy_EGlass_UD	1	-45
(-Z)			

Results:

Total deformation:

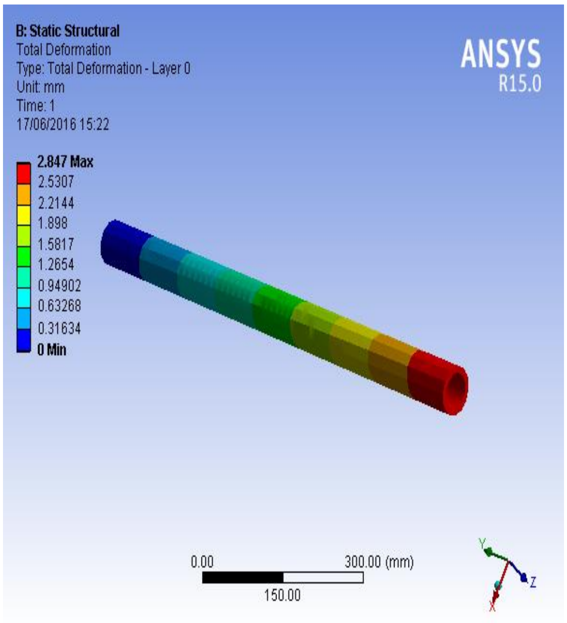


Figure: 10 Total deformation of composite material

The max deformation is 2.84mm

Von-mises stresses:

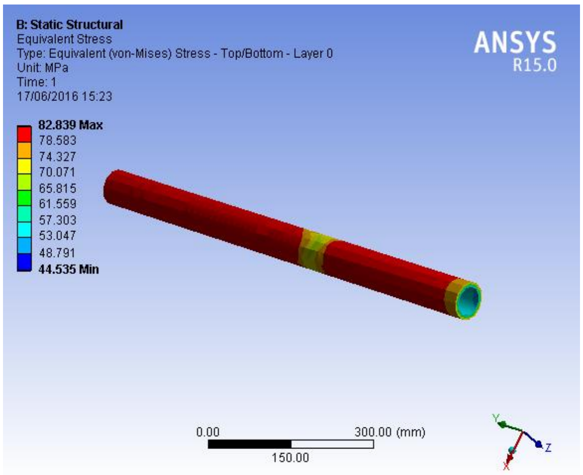


Figure: 11 Von-mises stresses

Above figure shows von mises stress analysis for propeller shaft. Maximum stress value is 82.86 N/mm^2 which is less than permissible limit .Hence our design is safe.

Fatifue Testing:

MACHINE USED	*1)* *2) 8872 Servohydraulic Fatigue Testing System (INSTRON)*

LITERATURE	The Instron® 8872 is a compact tabletop servohydraulic testing system that meets the challenging demands of various static and dynamic testing requirements. With the actuator in the upper crosshead and a lower t-slot table, the 8872 makes an ideal platform for a variety of medical devices, biomaterials, advanced materials, and other component testing.
DESCRIPTION	The 8872 fatigue testing system is ideal for fatigue and static testing of biomedical, advanced materials, and manufactured components. The servohydraulic actuator is conveniently located in the crosshead for easy table mounting. The T-slot base makes it easy to secure orthopedic specimens, automotive components, and manufacturing assemblies. The adjustable crosshead, actuator mounted load cell, and corrosion resistant Tslot base with unique drain channel are essential for testing biomedical specimens immersed in a saline bath. Combined with the advanced features of the 8800 digital controller and Instron's patented Dynacell™, these table model systems are compact and flexible enough to be located anywhere in your laboratory, saving valuable space. Console software provides full system control from a PC: including waveform generation, calibration, limit setup, and status monitoring. Add WaveMatrix™ block loading

	software for simple and advanced cyclic tests on materials or components, or add Bluehill® software for static tests.
FEATURES	• Up to ±25 kN (5620 lbf) axial force capacity • Patented Dynacell load cell featuring compensation for inertial loads caused by heavy grips and fixtures • Standard or extraheight frame options • Wide range of grips, fixtures, and accessories

Experimental Setup of Propeller shaft.

Fixture: Shaft is supported by two V block fixtures for proper resting and is been locked so as not to rotate. A cantilever beam bolt is fixed and load is applied at 10mm distance in order to produce torque of 452Nm.

Result Discussions

Von misses stresses

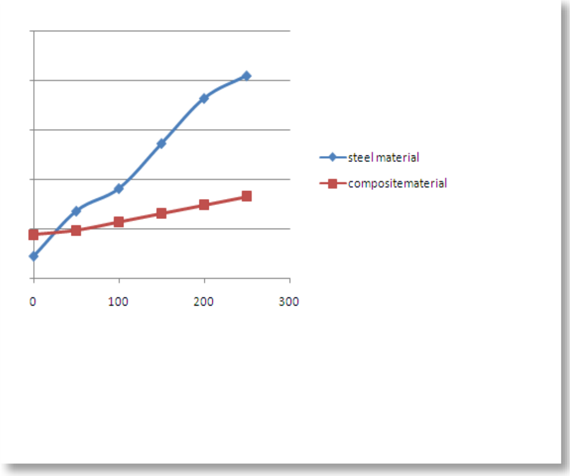


Figure 12 : von misses stresses for steel and composite material

Length of shaft	Steel material(stress in MPa)	Composite material(stress in MPa)
0	22.8086	44.53
50	68.4259	48.79
100	91.2345	57.303
150	136.85	65.815
200	182.469	74.327
250	205.278	82.83

Table 4 : length and stress details

Deformation

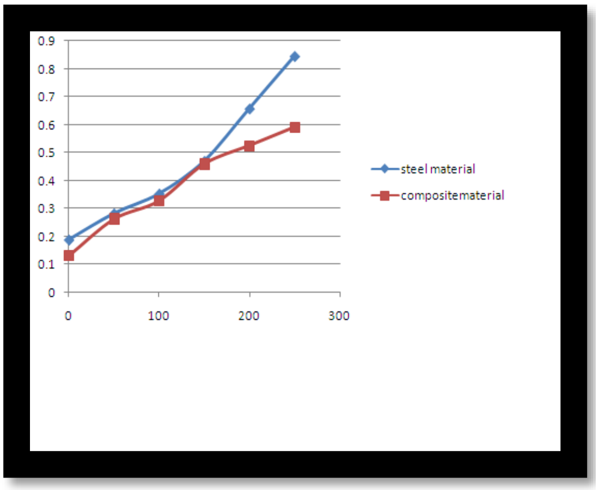


Figure 13: Deformation for steel and composite material shaft

Length of shaft	Steel material(deformation in mm)	Composite material(deformation in mm)
0	0.1877	0.1313
50	0.2816	0.2626
100	0.3526	0.3283
150	0.4694	0.4596
200	0.6572	0.5252
250	0.845	0.5909

Table 5: deformation details

Fatigue life

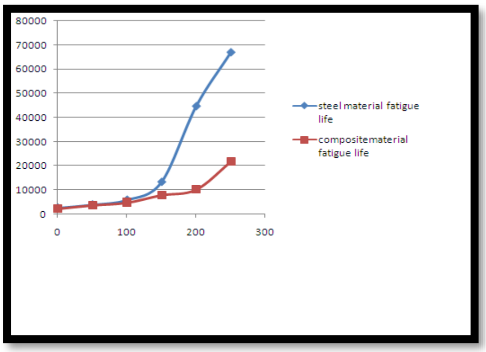


Figure 14: Fatigue life of steel and composite material shaft

Length of shaft	Steel material(deformation in mm)	Composite material(deformation in mm)
0	0.1877	0.1313
50	0.2816	0.2626
100	0.3526	0.3283
150	0.4694	0.4596
200	0.6572	0.5252
250	0.845	0.5909

Table 6: Fatigue life details for steel & composite material

Conclusion:

- In the present work the fatigue analysis of composite shaft is carried out and the cycles of failure are calculated.
- Composite shaft is fabricated and tested for fatigue life.
- While doing the analysis we are getting the Maximum stress value **is 205.27 N/mm^2** for steel material which is more than the composite material which is Maximum stress value is **82.80 N/mm^2** .
- Also the deformation takes place for the conventional material is **0.84 mm** which more than the **0.59 mm** for composite material.
- After applying the gradual load we observe that no crack is coming after **22100 cycle** for the composite material as compare to conventional material.
- Ultimately strength of the composite material propeller shaft is more than the conventional propeller shaft.

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