Design and Analysis of Propellar Shaft

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Abstract- *Fuel efficiency and weight of automobile are the two important parameters to be considered. The most suitable way to increase the efficiency of automobile without sacrificing the safety of passengers is by using composite materials. Most of the automobile industries are using composite materials for manufacturing components of an automobile to reduce the weight without compromising quality and reliability. The main objective of this paper is to reduce the weight of an automobile drive shaft assembly by using the composite materials such as Epoxy/E-glass and Epoxy carbon. Conventional Drive shaft has having less strength, less specific modulus and increased weight. Composite materials are having advantages like high strength, free corrosion resistance, high specific modulus, high impact energy and reduced weight.*

Keywords- Composite material, FEA Analysis, Drive Shaft, Non-liner

I. INTRODUCTION

The main purpose of the diving shaft or propeller shaft is to transmit torque from the gear box to differential gear box, it has to withstand high rotational speeds required by the vehicle and the drive shaft has to change its length while transmitting the torque. Propeller shaft consists mainly of three parts those are shaft, universal joint and a slip joint. The shaft has to withstand mainly torsional loads. It has to be well balanced to avoid whirling at high speeds. Depending upon the rear axle drive the number of universal joints may be varied as one or two. When the vehicle is running the universal joint accounts for up and down moment of rear axle. The slip joint serves to adjust the length of the propeller shaft when demanded by the rear axle moments.

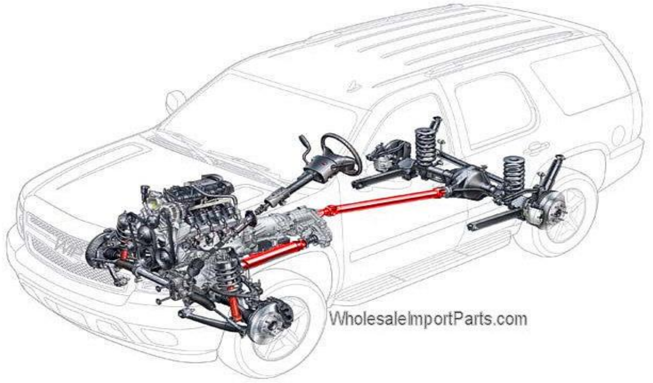

Fig.1:drive shaft

weight. Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials. Composite materials can be tailored to efficiently meet the design requirements of strength, stiffness and composite drive shafts weight less than steel or aluminum. Composite materials are used in large volume in various engineering structures including spacecraft's, airplanes, automobiles, boats, sports equipment, bridges and buildings. Widespread use of composite materials in industry is due to the good characteristics of its strength to density and hardness to density. The possibility of increase in these characteristics using the latest technology and various manufacturing methods has raised application range of these materials. Application of composite materials was generally begun only at aerospace industry in 1970s, but nowadays after only three decades, it is developed in most industries. Meanwhile, the automotive industry considered as a mother one in each country, has benefited from abilities and characteristics of these advanced materials. Along with progress in technology, metallic automotive parts are replaced by composite ones. One of them is drive shaft (propeller shaft), which numerous researches have been done on it in recent decades. Drive shafts are usually made of solid or hollow tube of steel or aluminum. Over than 70% of single or two piece differentials are made of several-piece propeller shaft that result in a rather heavy drive shaft shows a photographic view of two-piece steel and a sample composite drive shaft. Composite drive shafts were begun to be used in bulk in automotive since 1988.

1.1)COMPOSITE MATERIAL

A material composed of two or more constituents is called composite material. Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. The constituents are combined at a macroscopic level and or not soluble in each other. The main difference between composite and an alloy are constituent materials which are insoluble in each other and the individual constituents retain those properties in the case of composites, where as in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents

A) Basic Concepts of Composite Materials

Composite materials are basically hybrid materials formed of multiple materials in order to utilize their individual structural advantages in a single structural material. The constituents are combined at a macroscopic level and are not soluble in each other. The key is the macroscopic examination of a material wherein the components can be identified by the naked eye. Different materials can be combined on a microscopic scale, such as in alloying of metals, but the resulting material is, for all practical purposes, macroscopically homogeneous, i.e. the components cannot be distinguished by the naked eye and essentially acts together. The advantage of composite materials is that, if well designed, they usually exhibit the best qualities of their components or constituents and often some qualities that neither constituent possesses. Some of the properties that can be improved by forming a composite material are strength, fatigue life, stiffness, temperature-dependent behavior, corrosion resistance, thermal insulation, wear resistance, thermal conductivity, attractiveness, acoustical insulation and weight. Naturally, not all of these properties are improved at the same time nor is there usually any requirement to do so. In fact, some of the properties are in conflict with one another, e.g., thermal insulation versus thermal conductivity. The objective is merely to create a material that has only the characteristics needed to perform the designed task. There are two building blocks that constitute the structure of composite materials. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix. The reinforcing phase material may be in the form of fibers, particulates, flakes. The matrix phase materials are generally continuous. Examples of composite systems include concrete reinforced with steel, epoxy reinforced with graphite fibers,etc A composite material can be defined as a material consisting of two or more phases embedded in a continuous phase. The discontinuous phase is reinforcement and continuous phase is the matrix. Materials form an integral part of the way composite structures perform. They are broadly categorized into three types

1. Reinforcements
2. Resins
3. Core materials

The various types of fibers currently in use are

1. Glass Fibres
2. Carbon Fibres
   Aramid Fibres
3. Boron Fibres
4. Silicon Carbide Fibres

B) Matrix

In a composite material the fibres are surrounded by a thin layer of matrix material that holds the fibres permanently in the desired orientation and distributes an applied load among all the fibres. The matrix also plays a strong role in determining the environmental stability of the composite article as well as mechanical factors such as toughness and shear strength. The matrix binds the fibres together, holding them aligned in the important stressed directions. The matrix must also isolate the fibres from each other so that they can act as separate entities. The matrix should protect the reinforcing filaments from mechanical damage (e.g. abrasion) and from environmental attack. A ductile matrix will provide a means of slowing down or stopping cracks that might have originated at broken fibres; conversely, a brittle matrix may depend upon the fibres to act as matrix crack stoppers. Through the quality of its “grip” on the fibres (the interfacial bond strength), the matrix can also be an important means of increasing the toughness of the composite.

Because the reinforcing fibres can be oriented during fabrication of item, composites can be tailored to meet increased load demands in specific directions. The combined fiber-matrix system is an engineered material designed to maximize mechanical and environmental performance. Fibres are the principal constituent in a fiber-reinforced composite material. They occupy the largest volume fraction in a composite laminate and share the major portion of the load acting on a composite structure. Proper selection of the type, amount and orientation of fibres is very important, because it influences the following characteristics of a composite laminate.

C) Classification of Composites

Composite materials in general are categorized based on the kind of reinforcements or the surrounding matrix. There are four commonly accepted types of composite materials based on Reinforcements-

1. Fibrous composite materials that consist of fibres in a matrix.
2. Laminated composite materials that consist of layers of various materials.
3. Particulate composite materials that are composed of particles in a matrix.
4. Combinations of some or all of the first three types.

And the major composite classes based on structural composition of the matrix are-

1. Polymer-Matrix Composites
2. Metal- Matrix Composites
3. Ceramic- Matrix Composites
4. Carbon- Carbon Composites
5. Hybrid Composite

In general, carbon, aramid fibres and other specialty reinforcements are used in the marine field where structures are highly engineered for optimum efficiency. Architecture and fabric finishes are also critical elements of correct reinforcement selection. Resins are the bonding materials which are used to attach the core materials with reinforcements. They are of two types, viz. Orthophthalic and Isophthalic of which the latter exhibits better mechanical resistance, chemical properties and increased resistance to water permittivity. Core materials form the basis for sandwich composite structures that have promising prospects in marine construction. The dynamic behaviour of a composite structure is integrally related to the characteristics of the core material used.

D) Selection of Fibre

Fibres are available with widely differing properties. Review of the design and performance requirements usually dictate the fiber to be used. So in our analysis we will consider the Carbon fibres because its advantages include high specific strength and modulus, low coefficient of thermal expansion, and high fatigue strength which is ideal fiber for torque transmitting shaft .Fibres are selected on below given parameters:

1. Specific gravity
2. Tensile strength and modulus
3. Compressive strength and modulus
4. Fatigue strength and fatigue failure mechanisms
5. Electric and thermal conductivities
6. Cost

a) Glass fibres:

Glass fibres are widely used in practice. The advantages of glass fibres over other materials are the easy and cheap production, possibility to produce very long fibres, high resistance to impact, good machine ability, etc. The basic disadvantages of glass-fiber-reinforced composites lie in the fact that they have a low modulus of elasticity and that they lose resistance at elevated temperatures.

b) Carbon Fibres:

The need for stronger materials led to greater application of carbon fiber/epoxy resin composite. Carbon fibres have high strength, high modulus of elasticity, low density excellent machinability, resistance to elevated temperature, low thermal expansion coefficient, Inertness to most reagents etc. Their main advantages are low toughness and high anisotropy, which causes additional problems to constructors and high production compared to glass fibres.

E) Selection of Resin

The important consideration in selecting resin is cost, temperature capability, and elongation to failure and resistance to impact. The resins selected for most of the drive shafts are either epoxies or vinyl esters.For the manufacture of construction composites, the most widely used are the following: - matrices based on epoxy resins, matrices based on phenolic resins, matrices based on polyester resins, and metal based matrices. The properties of composites mainly depend on: - the strength and chemical stability of the matrix, the strength and elasticity of the reinforcing fibres, the strength of the bond between the matrix and the reinforcing fibres. Epoxy resins are polyether resins containing more than one epoxy group capable of being converted into the thermoset form. These resins, on curing, do not create volatile products in spite of the presence of a volatile solvent. The epoxies may be named as oxides, such as ethylene oxides (epoxy ethane), or 1,2-epoxide.

F) Carbon Epoxy Composite

Following are the features of carbon epoxy composite, the reason for which it is chosen.

1. Carbon epoxy composite gives high tensile strength, high modulus of rigidity as compared to other composites.
2. Carbon epoxy composite has unique damping characteristic.
3. Carbon epoxy composite has positive coefficient of thermal expansion i.e. tensile strength of this composite increases with temperature.
4. Carbon epoxy composite is fatigue, wear and corrosion resistant.

G) Materials used in analysis and their properties:

The material used in the analysis is structural steel, E-glass and E-carbon

Table-1: Properties of Structural Steel.

Sr.No	**Properties**	**Value**
1	Young's modulus 2.07e+011pa	2.07e+011pa
2	Poisson ratio	0.3
3	Density	7600 kg/m3
4	Allowable Stress	370e+006pa
5	Shear modulus	77.9 e+009pa

Table-2: Properties of E-carbon

Sr.No.	**Properties**	**Value**
1	Young's modulus	1.9e+011pa
2	Poisson ratio	0.3
3	Density	1600kg/m3
4	Allowable Stress	440e+066pa
5	Shear modulus	4.2e+009pa

Table-3: Properties of E-glass

Sr.No.	**Properties**	**Value**
1	Young's modulus	5.e+010
2	Poisson ratio	0.3
3	Density	2000 kgm3
4	Allowable Stress	400e+006 pa
5	Shear modulus	5.6e+009pa

II. DESIGN CALCULATIONS

A) Selection of Cross-Section

The shaft can be solid circular or hollow circular. Here hollow circular cross-section was chosen because:

I. The hollow circular shafts are stronger in per kg weight than solid circular shafts.
II. The stress distribution in case of solid shaft is zero at the centre and maximum at the outer surface while in hollow shaft stress variation is smaller. In solid shafts the material close to the centre are not fully utilized.

a) Design calculation for structural steel shaft

Engine Specification :
Max. power (P) =75kW
Max. Torque (T) = 200N-m
Speed (N) =1400-3400rpm
Length (L) =900mm
Steel Drive Shaft
Power $P=2\pi NT/60$
$T=p\times 60/2\pi N$
$T=75\times 10^3 \times 60/2\pi\times 1400$
$T=511.94\times 10^3$ N-mm
Assume that, Using PSG Design data book
$D/d=1.25$
$D=1.25d$
$T=\pi/16\times\tau\times(D^4-d^4/D)$
Taking, Hear =50N/mm for steel
$511.94\times 10^3=\pi/16\times 50\times((1.25d^4)-d^4)/(1.25d)$
$511.94\times 10^3=\pi/16\times 50\times 1.153d^3$
d=35.66mm
D=1.25d=1.25×35.66
D=44.58mm
Stiffness of shaft
L=length of the shaft
L=900mm
Angle of twist 1°to1.5° =1°× /180 =0.01745rad
$T/J=G\Theta/L$
Where,
T= maximum torque applied in drive shaft(N-mm)
J = polar moment of inertia (mm^4)
$J=\pi/32(D^4-d^4)$
$J=\pi/32((1.25d)^4-d^4)$
$J=0.141d^4$ mm^4
$511.94\times 10^3/0.141d^4=80\times 10^3\times 0.0174/900$
d=42mm
D=1.25×42
D =52.50mm
Larger diameter satisfies both strength and stiffness Torsional buckling:
Where,
t= thickness of the hollow steel shaft
$t=r_o-r_i=26.25-21$
t=5.25mm
Radius of the shaft
$r=r_o+r_i/2$

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$=26.25+21/2$
r= 23.62mm
For long shaft the torsional buckling capacity
$T_b=\tau_{cr}2\pi r^2\times t$
Where critical stress is given by,

$$\tau_{cr}=\frac{E}{\sqrt[3]{2(1-y^2)\wedge\frac{3}{4}}}\times\left(\frac{t}{r}\right)^{\frac{3}{2}}$$

$$\tau_{cr}=\frac{207000}{\sqrt[3]{2(1-0.3^2)^{\frac{3}{4}}}}\times\left(\frac{5.25}{23.62}\right)^{\frac{3}{2}}$$

$\tau_{cr}=17628.19$ N/mm^2

For long shaft the torsional buckling capacity
$T_b=\tau_{cr}2\pi r^2t$
$T_b=324.419$ KN-m
$T_b>T$ hence design is safe
Natural frequency for composite material
$f_{nb}=\pi/2\sqrt{EI/mL4}$
E =210 Gpa longitudinal young's modulus x
$I=\pi/64(D^4-d^4)$
$=\pi/64(0.05250^4-0.042^4)$
$I=2.2\times 10^{-7}m^4$
Mass of shaft
$m=\varrho\times(\pi/4)[D^2-d^2]$
$=7600\times(\pi/4)[0.05250^2-0.042^2]$
m=5.92kg/m
Natural frequency of shaft
$f_{nb}=\pi/2\sqrt{EI/mL4}$
$f_{nb}=56.70Hz$

b) Composite material carbon/Epoxy

Stiffness of shaft
L=length of the shaft
L=900mm
$T/J=G/L$
Where,
T= maximum torque applied in drive shaft(N-mm)
J = polar moment of inertia (mm^4)
$J=\pi/32(D^4-d^4)$
$J=\pi/32((1.25d)^4-d^4)$
$J=0.141d^4$ mm^4
$511.94\times 10^3/0.141d^4=33\times 10^3\times 0.0174/900$
d=52.40mm
D=1.25×52.40
D =65.57mm

Larger diameter satisfies both strength and stiffness Torsional buckling:
Where,
t= thickness of the hollow steel shaft
$t=r_o-r_i$
t=7 mm

Radius of the shaft
$r = r_o + r_i / 2$
r= 29.47mm
For long shaft the torsional buckling capacity
$T_b = \tau_{cr} 2\pi r^2 \times t$

Where critical stress is given by,

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$$\tau_{cr} = \frac{E}{\sqrt[3]{2(1-y^2)\wedge\frac{3}{4}}} \times \left(\frac{t}{r}\right)^{\frac{3}{2}}$$

$$\tau_{cr} = \frac{190000}{\sqrt[3]{2(1-0.3^2)^{\frac{3}{4}}}} \times \left(\frac{7}{28.5}\right)^{\frac{3}{2}}$$

$\tau_{cr} = 1663.03\ N/mm^2$

For long shaft the torsional buckling capacity

$$T_b = \tau_{cr} 2\pi r^2 t(0.272)(E_x E y^3)\wedge\frac{1}{4} \times \left(\frac{t}{r}\right)^{\frac{2}{3}}$$

T_b =106.46 KN-m
$T_b > T$ hence design is safe

Natural frequency for composite material
$f = \pi / 2\sqrt{E\,I/mL4}$
E =190 Gpa longitudinal young's modulus x
$I = \pi / 64\ (D^4 – d^4)$
$= \pi / 64\ (0.06557^4 – 0.05240^4)$
$I = 5.37 \times 10^{-7} m^4$
Mass of shaft
$m = \varrho \times (\pi / 4)\ [D^2 - d^2]$
$= 1600 \times (\pi / 4)\ [0.06557^2 - 0.05240^2]$
m=1.55kg/m
Natural frequency
$f = \pi / 2\sqrt{E\,I/mL4}$
f_{nb} =41.7 Hz
.

III. FEA

3.1) INTRODUCTION TO FEM

Finite element analysis (FEM) is a way to simulate loading conditions on a design and to determine the design response to those conditions. The FEM represents one of the most significant developments in the history of computational methods. Finite Element Analysis (FEA) is a computer -based numerical technique for calculating the strength and behaviour of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behaviour and many other phenomena. It can be used to analyze either small or large- scale deflection under loading or applied displacement. It can analyze elastic deformation, or "permanently bent out of shape" plastic. Deformation The computer is required because the astronomical number of calculations needed to analyze a large structure. The power and low cost of modern computers has made Finite Element Analysis available to many discipline and companies.

In the Finite Element Method, a structure is broken down into many small simple blocks or elements. The behaviour of an individual element can be described with a relatively simple set of equations. Just as the set of elements would be joined together to build the whole structure, the equations describing the behaviors of the individual elements are joined into an extremely large set of equations. From the solution, the computer extracts the behaviour of the individual elements. From this, it can get the stress and deflection of all the parts of the structure.

Steps in FEA:
a) Discretization: It is a process of sub dividing a domain of continuum into a number of sub-structures or sub-domain. Each sub-domain is called a finite element. Each finite element establishes continuity with the adjacent elements through the points called nodes. The behaviour of a continuum under given loading is the sum of total of the behaviour of the individual finite elements.
b) Selection of the displacement field: The displacement field is selected based on the requirement of the accuracy of the result. An unknown displacement field could be interpolated using a linear polynomial or a nonlinear polynomial, for example:

u= a0+ a1x

The assumed displacement functions or models represent only approximately the actual or exact distribution of the displacement model. First, the type and degree of the displacement model must be chosen. Then a polynomial is chosen and only the degree of polynomial is open to decision. Second, the displacement function should be in terms of nodal displacement but may also include derivatives of the displacements at some of or all of

c) To derive element equations: If a structure is discredited into a number of finite elements, for each element of structure we have to determine the stiffness, displacement vector and load vector. The stiffness of the element of the coefficients of the equations derived from the material and geometric properties of an element obtained by the use of the principle of minimum potential energy. The stiffness relates displacements at the nodal points to the applied forces at the nodal points. The distributed forces applied to the structure are converted into the concentrated forces at the nodes. The equilibrium equation between the stiffness matrix (K), nodal force vector (F), and the nodal displacement vector (Q) IS expressed as a set of simultaneous linear algebraic equation.
[K][Q]= [F]
The element stiffness matrix for an element depends on the displacement model geometry of an element and the local material properties.

d) Assembly of elements: Individual elements could be assembled with respect to their stiffness, displacement and forces. Similarly

load vector can be assembled to get final FEM equation KQ=F, where 'K 'is called global stiffness matrix, 'Q' is called global displacement vector and 'F' is called global load factor. The process includes the assembly of the overall or global stiffness matrix, for the entire body from the individual stiffness matrix and global force from the element nodal force vector. The relationship between the local and global element displacement is as follows:
[U]= [T] [U g]

This is a simple displacement transformation involving direction cosine, which relates local and global system.

$$[T] = \begin{bmatrix} t & 0 & 0 \\ 0 & t & 0 \\ 0 & 0 & t \end{bmatrix}$$

e) Application of boundary condition:

Geometric or essential boundary condition: Geometric boundary conditions are those, which correspond to the prescribed displacements or rotation at node in a structure. Homogeneous and non-homogeneous boundary condition: If the prescribed displacements are zero, then we call them as homogeneous boundary condition. If a value other than zero is specified at some points in the structure, we call them as non-homogeneous boundary condition. Natural or forced boundary condition: If a force or moment is applied at a particular node, then we call them as natural or forced boundary conditions. The boundary conditions could be applied by two basic methods Elimination approach. Penalty approach

f) Solution of equations: The finite element equation KQ=F is solved by various standard approaches as for example Gaussian elimination approach.

g) Calculation of stresses and strains: The displacement vector is computed in the previous step and the elemental stresses and strains can be computed using these displacement values at the nodes

3.2) ANALYSIS OF STEEL SHAFT

Table NO.4

Sr.No	Material	Properties	
1	Sm45C	Volume	7.0138e+005mm^3
2	Sm45C	Mass	5.3305 Kg
3	Sm45C	Centroid X	4.4886e-016mm
4	Sm45C	Centroid Y	-1.0779e-015mm
5	Sm45C	Centroid Z	450mm
6	Sm45C	Moment of inertia Ip1	3.5947e+005 Kg.mm^2
7	Sm45C	Moment of inertia Ip2	3.5947e+005 Kg.mm^2
8	Sm45C	Moment of inertia Ip3	2981.4 Kg.mm^2

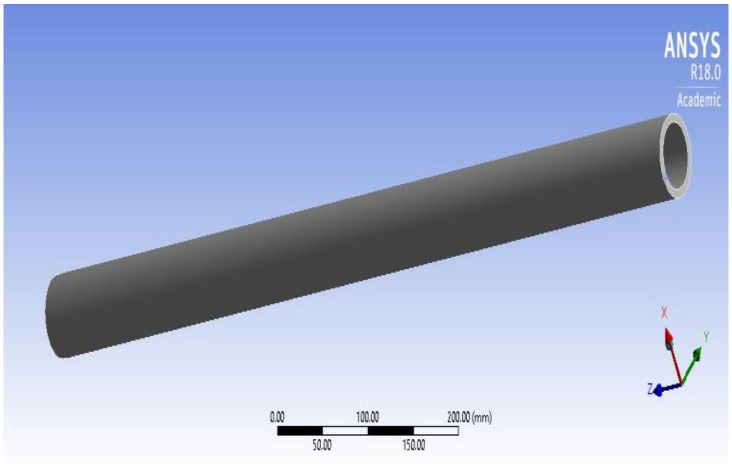


Fig.No2:Design model of steel propeller shaf

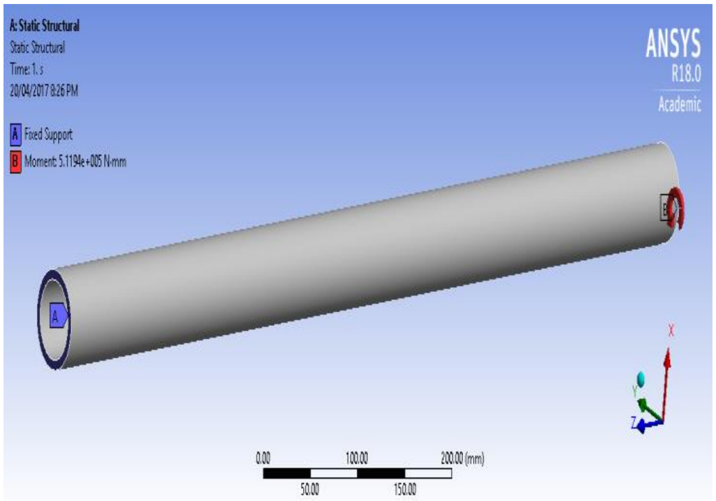


Fig.No.-3:Boundary conditions apply on steel shaft

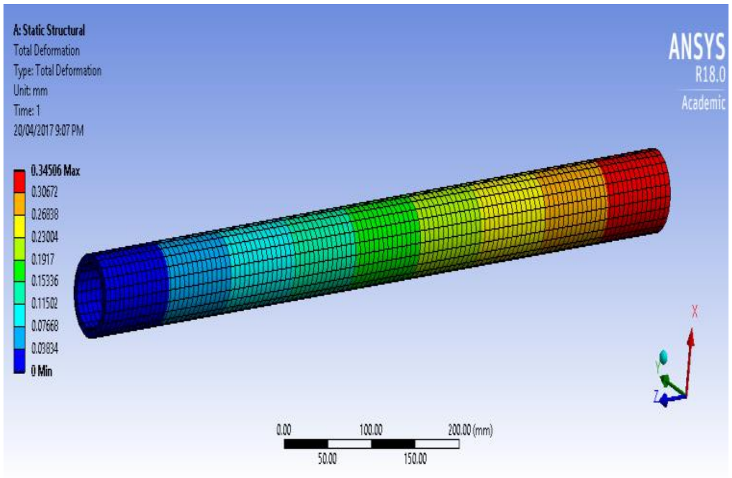


Fig.No.-4:Total deformation on steel shaft

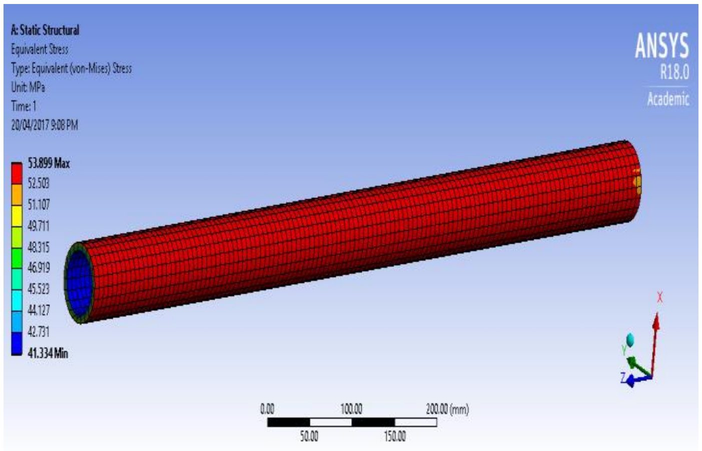


Fig.No.-5:Eqivalant stress on steel shaft

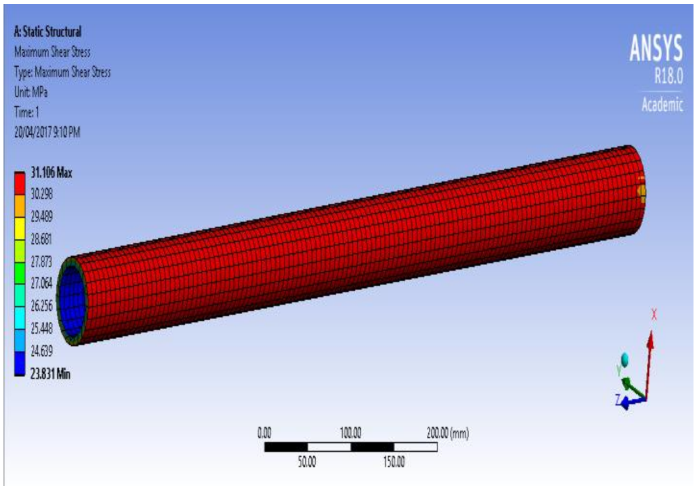


Fig.No.-6:Shear stress on steel shaft

3.3) ANALYSIS OF CARBON-EPOXY SHAFT

A good design solution can be delivered only when the function of the component being designed, is known before hand with proper working condition specifications. Ability of different methodologies in solving for these conditions can be appreciated based on the complexity of the problem, though. Presently, Comparison is made between the composite and the conventional steel shaft for maximum shear stress induced in the shafts and maximum deflections in the shafts. Finally modal analysis is carried out to study the variation in natural frequency by changing the fiber angle orientation of different layer of the composite shaft.

Table No 5

Sr.No.	Material	Properties	
1	Carbon Epoxy	Volume	9.7043e+005mm^3
2	Carbon Epoxy	Mass	1.5527 Kg
3	Carbon Epoxy	Centroid X	1.5055e-015mm
4	Carbon Epoxy	Centroid Y	416.89mm
5	Carbon Epoxy	Centroid Z	9.159e-017mm
6	Carbon Epoxy	Moment of Inertia Ip1	1.052e+005Kg.mm^2
7	Carbon Epoxy	Moment of Inertia Ip2	1059.1Kg.mm^2
8	Carbon Epoxy	Moment of Inertia Ip3	1.052e+005Kg.mm^2
9	Carbon Epoxy	Surface Area	1.4816e+005mm^2

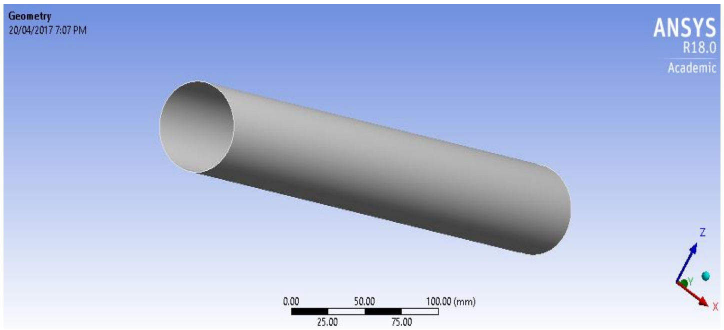


Fig.No.-7Design of composite material propeller shaft of orientation $\pm 45^0$

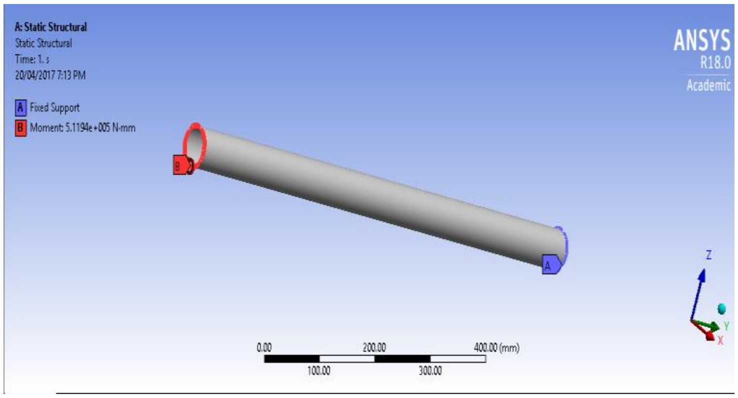


Fig.No.-8:Boundary conditins apply on composite propeller shaft of orientation $\pm 45^0$

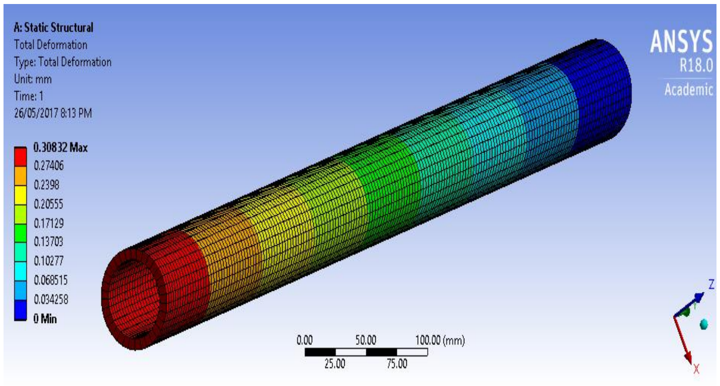


Fig.No.-9Total deformation on composite propeller shaft of orientation $\pm 45^0$

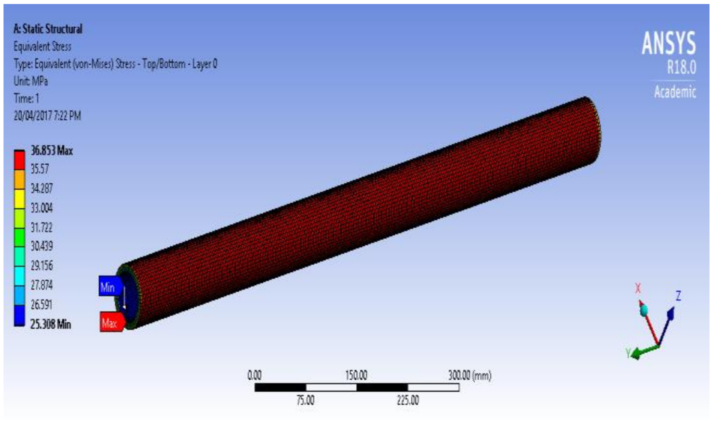
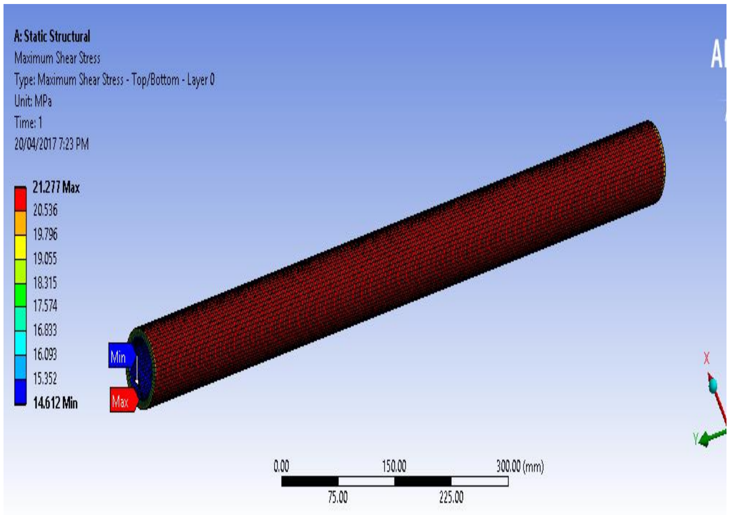


Fig.No.10:Eqivalant stress on composite propeller shaft of orientation ±45



3.3) RESULTS AND DISCUSSION

On the basis of above analytical design and analysis data, we have resulted out the table below.

Sr.No.	Parameters	Unit	SM45	Composite
1	Torque	Nm	511.94	511.94
2	Thickness	mm	5.25	6.55
3	Deformation	mm	0.345	0.30832
4	Max. Equivalent Stress	MPa	53.9	36.70
5	Max. Shear stress	MPa	31.11	20.11
6	Natural frequency	Hz	60.41	40.98
7	Weight	Kg	5.33	1.55

IV.CONCLUSION

Following conclusions are drawn from the results obtained from these analyses-

1. The High Strength Carbon/Epoxy and High Modulus Carbon/Epoxy Composite drive shafts have been designed to replace the steel drive shaft of an automobile.
2. The weight savings of the High strength carbon/epoxy and high modulus carbon/epoxy shafts were equal to 50 % approximately of the steel shaft .
3. Optimum fibre angle orientation will play important role in composite shaft which depends on requirement of composite shaft .
4. The design procedure is studied and along with finite element analysis some important parameter are obtained. The composite drive shaft made up of HM carbon / epoxy multi-layered composites has been designed. The results reveal that the orientation of fibres has great influence on the static characteristics of the composite shafts and offers advantages such as
    a. Lower weight
    b. Higher strength
    c. Progressive failure mechanism (offers warning before failure)
    d. Lower power consumption
5. The present finite element analysis of the design variables provide an insight of their effects on the drive shaft's critical mechanical characteristics and fatigue resistance. A model of hybridized layers was generated incorporating carbon-epoxy. The buckling, which dominates the failure mode, have a value which not increases regularly with increasing the winding angle.
6. Regression Analysis was done to obtain relations between fibre angle orientation and parameters like stresses induced in each layer, deflection in each layer and natural frequencies of the composite shaft.

This relation helps in finding the above mentioned parameters at any fibre orientation; which will help to optimization.

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