"Finite Element & Experimental Investigation of Composite Torsion Shaft"

Belawagi Gireesh, Sollapur Shrishail B, V. N. Satwik
4th Sem CIM Branch Gogte Institute of Technology Belgaum
Asst. Professor Department of Mechanical Engineering Sinhgad Academy of Engineering, Pune
Associate Professor Department of Mechanical Engineering Gogte Institute of Technology Belgaum

ABSTRACT:-*In the present work an attempt is made to evaluate the suitability of composite material such as E-Glass/Epoxy and HM-Carbon/Epoxy for the purpose of automotive transmission applications. A one-piece composite drive shaft for automobile is designed and analyzed using ANSYS software respectively for E-Glass/ Epoxy and HM-Carbon/Epoxy composites with the objective of minimization of weight of the shaft which is subjected to the constraints such as torque transmission, torsional buckling strength capabilities and natural bending frequency. Finite element models of the drive shaft will be generated and analyzed using ANSYS version 13 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. Comparison of drive shaft with steel material and composite shaft shows that composite shaft gives advantages in terms of strength, weight reduction and ultimately power consumption in automobile.*

I. Introduction

The advanced composite materials such as Graphite, Carbon and Glass with suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/ density). 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. It is known that energy conservation is one of the most important objectives in vehicle design and reduction of weight is one of the most effective measures to obtain this result. Actually, there is almost a direct proportionality between the weight of a vehicle and its fuel consumption, particularly in city driving.

In metallic shaft design, knowing the torque and the allowable service shear stress for the material allows the size of the shaft's cross-section to be determined. In order to satisfy the design parameter of torque divided by the allowable shear stress, there is unique value for the shaft's inner radius because the outer radius is constrained by the space under the car cabin. Metallic drive shafts have limitations of weight, low critical speed and vibration characteristics. 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.

C. Sivakandhan & P. Suresh Prabhu [1] have investigated that usage of composite materials and optimization techniques has resulted in considerable amount of weight saving when compared to conventional steel drive shaft. By this analysis we conclude that composite shaft having the certain amount of torque transmitting capability. M. A. Badie [2] have investigated 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. By this investigation they found that bending natural frequency increase by decreasing the fiber orientation angle. Decreasing the angle increase the modulus in the axial direction. Carbon fibers have the major contribution over glass in increasing the torsional stiffness. And also in another paper they observed that the composite drive shaft of carbon-epoxy and glass-epoxy have good mechanical characteristics and fatigue resistance. The result shows that, in changing carbon fibers winding angle from 0^0 to 90^0 the stacking sequence has an effect on fatigue properties and loss in natural frequency of 44.5% [3]. M. M. Shokrieh[4] In this research, the effect of boundary conditions and the stacking sequence of the composite layers on the strength of the drive shaft is studied. It shows that increasing of applied torque on the shaft reduces the natural frequency. The result was boundary conditions of the shaft do not have much effect on the buckling torque. The fiber orientation of a composite shaft strongly affects the buckling torque.

II. Design and Analysis of Composite Drive Shaft

2.1. Design procedure

The material properties of the drive shaft analyzed through the classical lamination theory. This theory, which deals with the linear elastic response of laminated composite, incorporates the assumption of Kirchhoff-love for bending and stretching of thin plates beside the assumption that each layer is in state of plane stress. From the properties of the composite materials at fibers direction, the first step is the construction the reduced stiffness matrix. The expressions of the reduced stiffness coefficients Q_{ij} in terms of engineering constants are as follows:

$$Q_{66} = G_{12}$$

$$Q_{11} = \frac{E_1}{1 - \upsilon_{12}\upsilon_{21}}$$

$$Q_{12} = \frac{\upsilon_{12} E_2}{1 - \upsilon_{12}\upsilon_{21}}$$

$$Q_{22} = \frac{E_2}{1 - \upsilon_{12}\upsilon_{21}}$$

$$\upsilon_{21} = \frac{E_2}{E_1}\upsilon_{12}$$

The second step is to construct the extensional stiffness matrix [A]. This matrix is the summation of the products of the transformed reduced stiffness matrix of each layer and the thickness of this layer as:

$$[A] = \sum_{K=1}^{N} [\overline{Q}]^K (z_K - z_{K-1})$$

The matrix is in (Pa.m) and the thickness of each ply is calculated in reference of their coordinate location in the laminate. The A matrix is used to calculate and, which are the average moduli in the axial and hoop directions, respectively from: $A\,E_x$ E_h

$$E_x = \frac{1}{t}\left[A_{11} - \frac{A_{12}^2}{A_{22}}\right]$$

$$E_h = \frac{1}{t}\left[A_{22} - \frac{A_{12}^2}{A_{11}}\right]$$

2.2 Materials and Production of laminates Composite Shaft

Assumptions

1. The shaft rotates at a constant speed about its longitudinal axis.
2. The shaft has a uniform, circular cross section.
3. The shaft is perfectly balanced.
4. All damping and nonlinear effects are excluded.
5. The stress-strain relationship for composite material is linear & elastic; hence, Hooke's law is applicable for composite materials.
6. Acoustical fluid interactions are neglected, i.e., the shaft is assumed to be acting in a vacuum.
7. Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress.

2.3 Selection of fibers:

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.

2.4 Selection of Resin:

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

2.5 Specimens fabrication:

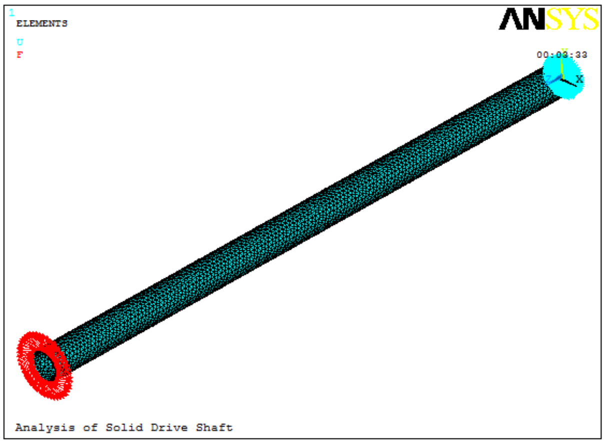
Glass fiber is used as reinforcement in the form of bidirectional fabric (Standard E-Glass Fiberglass) and polyester with catalyst addition as matrix for the composite material. The mechanical properties of the composite are calculated

analytically using the mixture rule. Through hand lay-up process followed by a cure process under pressure, five sets of symmetrical
Laminates with a total of five layers each one are produced:
Set1: [0/0/0/0/0],
Set2: [0/30/0/30/0],
Set3: [0/45/0/45/0]
Set4: [0/60/0/60/0] and
Set5:[0/90/0/90/0].

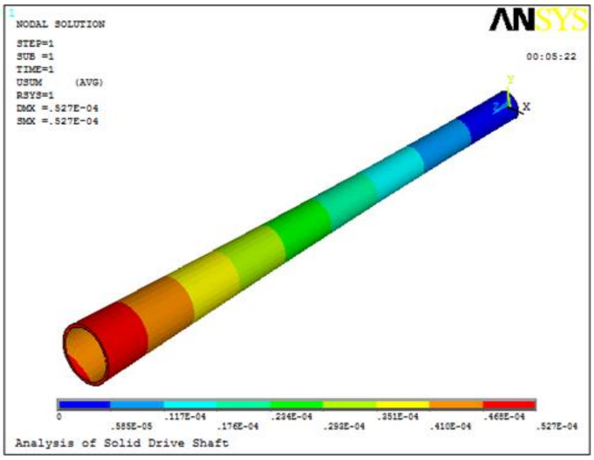
The numbers mentioned in the above sets indicates the angle of fiber inclination measured by degrees. After the cure process, the laminated composite shaft dimensions with length of 1 m and 25 mm diameter with 5 mm thickness. A typical specimen made from fiber reinforced plastic (FRP) composite shaft formed from five plies with 1mm thickness for each ply. Three composite levels were selected for each code number. These are specimens with low fiber volume fraction ***Vf* = 25%** and two level of average fiber volume fraction ***Vf* = 45 %** and **65%**. In order to study the effect of lamina orientation and staking sequence on the modal parameters, five code numbers of the specimens were fabricated and stated for each fiber volume fraction.

2.6 Static Analysis of Conventional Drive Shaft with Steel as material

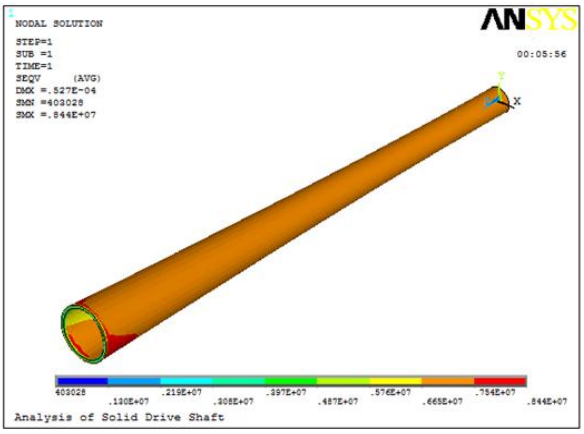
Conventional drive shaft is made up of steel material for most of the automobile, but some times aluminum also used. To compare the capability of composite material steel shaft strength is compared with composite. In present analysis conventional shaft was modeled in ANSYS with solid45 element and its length is considered as 1 m and diameter of the shaft is 25 mm with 5 mm thickness. Similar dimensions are used in composite shaft analysis also and described in next section. Steel material has young's modulus of E_x = 210 GPa and possion ratio equal to 0.3. Comparison is carried out based on maximum deformation, maximum and minimum stresses induced in the shaft. ANSYS has capability of APDL programming and its code was developed. Proposed drive shaft is considered fixed at one end and other end torque is applied, as drive shaft transmits power and does not take a vertical bending load. ANSYS has a capability to apply toque with simple APDL command nrotat, which applies tangential force on end nodes by rotation of co-ordinate system. Figure 1 shows results of analysis of static shaft with steel material. Next section explains about composite material analysis.

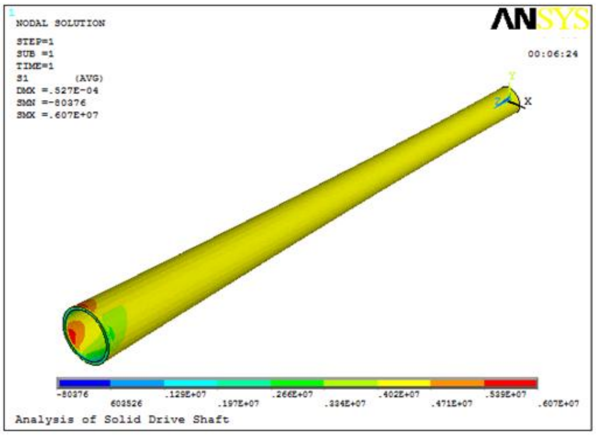


Boundary Condition

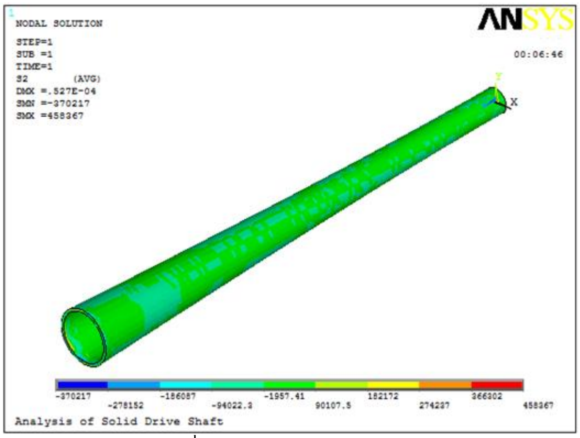


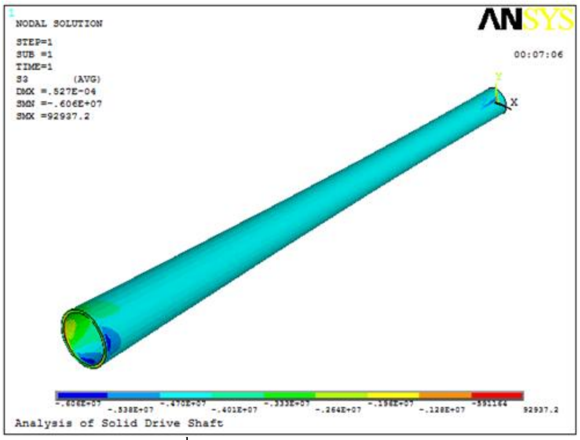
Deformation



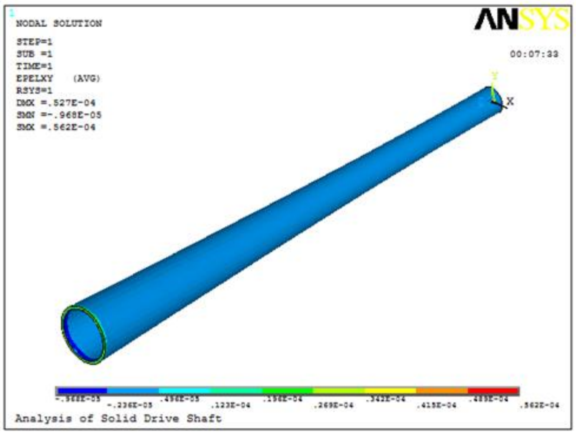


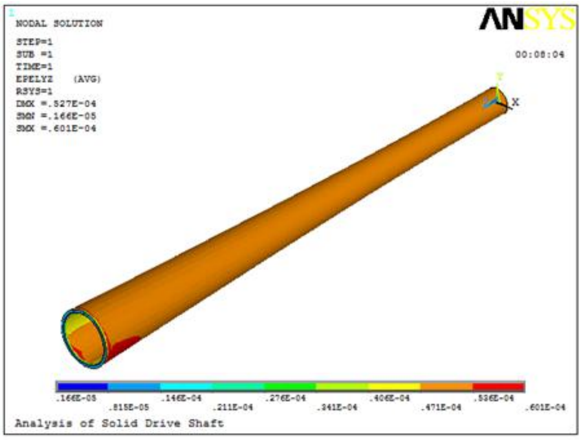
Von Misses Stress | 1st Principal Stress



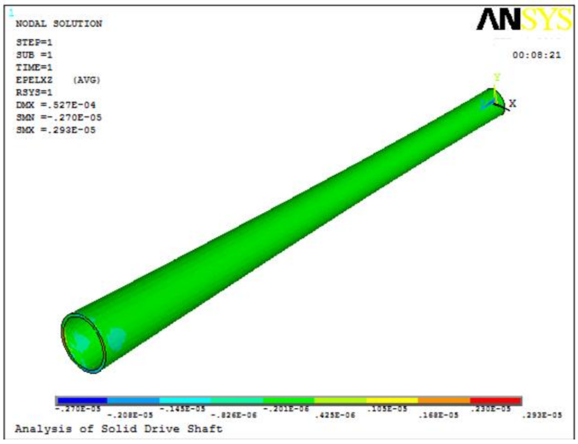


2nd Principal Stress | 3rd Principal Stress





XY Shear Strain | YZ Shear Strain



XY Shear strain | Stress Intensity

Figure 1 Static Stress Analysis of Solid shaft with Material as Steel

2.7 Static Analysis of Composite Shaft

The Static analysis deals with the conditions of equilibrium of the bodies acted upon by forces. A static analysis can be either linear or non-linear. All types of non-linearity's are allowed such as large deformations, plasticity, creep, stress stiffening, contact elements etc. this section focuses on static analysis of composite shaft. A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those carried by time varying loads. A static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. A static analysis can however include steady inertia loads such as gravity, spinning and time varying loads. In static analysis loading and response conditions are assumed, that is the loads and the structure responses are assumed to vary slowly with respect to time. The kinds of loading that can be applied in static analysis includes,

1. Externally applied forces, moments and pressures
2. Steady state inertial forces such as gravity and spinning
3. Imposed non-zero displacements

A static analysis result of structural displacements, stresses and strains and forces in structures for components caused by loads will give a clear idea about whether the structure or components will withstand for the applied maximum forces. If the stress values obtained in this analysis crosses the allowable values it will result in the failure of the structure in the static condition itself. To avoid such a failure, this analysis is necessary. Figure 3 shows results of static analysis carried out on shaft fixed at one end and torque at other end.

ANSYS 13 APDL code was developed for static analysis of composite drive shaft with layer orientation sequence as 45-45-45-45 and is shown in figure below. ANSYS has a capability of modeling a composite material as layered elements such as shell282. In present study shell282 element was used to model proposed drive shaft and static analysis is carried out. SHELL281 is suitable for analyzing thin to moderately-thick shell structures. The element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes. (When using the membrane option, the element has translational degrees of freedom only.)

SHELL281 is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. The element accounts for follower (load stiffness) effects of distributed pressures. SHELL281 may be used for layered applications for modeling composite shells or sandwich construction. The accuracy in modeling composite shells is governed by the first-order shear-deformation theory (usually referred to as Mindlin-Reissner shell theory).

Material Properties are listed in table as below

E-Glass Epoxy	Carbon Fiber
E_x = 40.3 E 9 N/m^2	E_x = 126.9 E 9 N/m^2
E_y = 6.21 E 9 N/m^2	E_y = 11 E 9 N/m^2
E_z = 40.3 E 9 N/m^2	E_z = 126.9 E 9 N/m^2
μ_{xy} = 0.2	μ_{xy} = 0.2
μ_{xz} = 0.2	μ_{xz} = 0.2
μ_{yz} = 0.2	μ_{yz} = 0.2
G_{xy} = 3.07 E 9 N/m^2	G_{xy} = 6.6 E 9 N/m^2
G_{xz} = 2.39 E 9 N/m^2	G_{xz} = 4.23 E 9 N/m^2
G_{yz} = 1.55 E 9 N/m^2	G_{yz} = 4.88E 9 N/m^2
Density=1910Kg/m^3	Density =1610 Kg/m^3

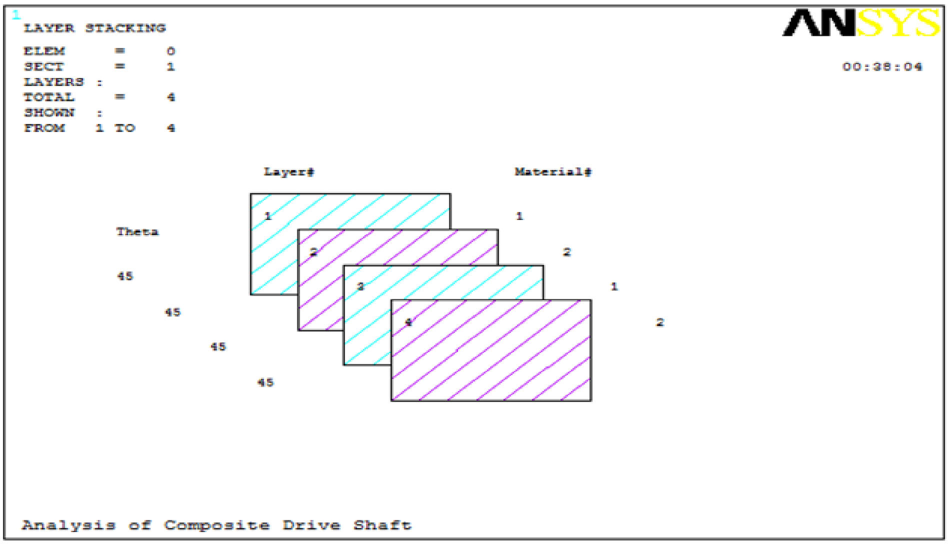
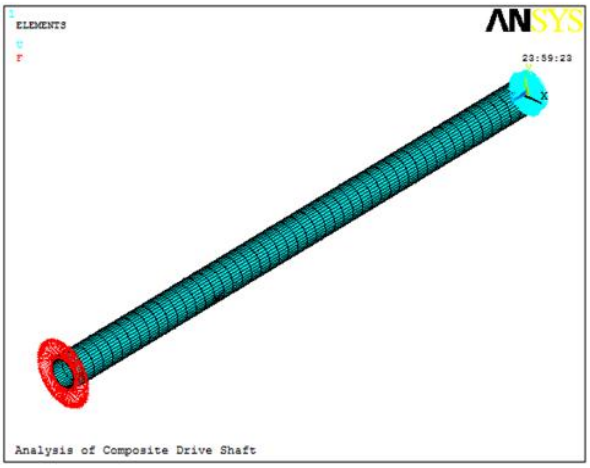
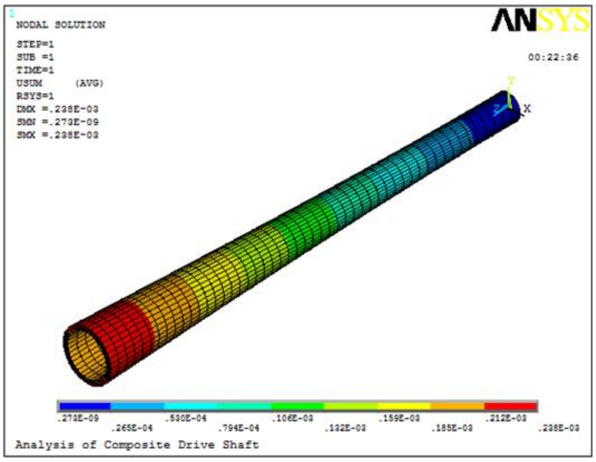


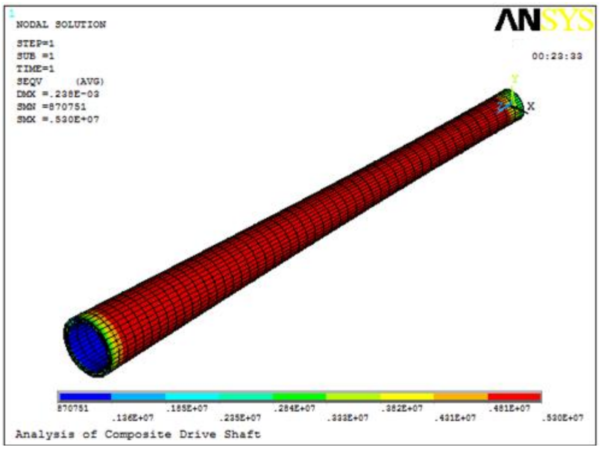
Figure 2 Layered Element Configurations in ANSYS 13



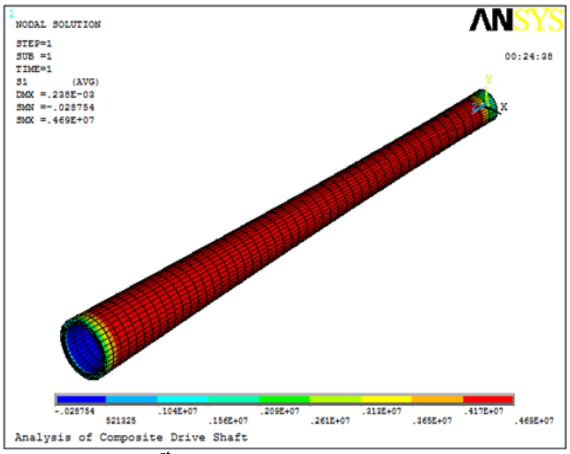
Boundary Condition



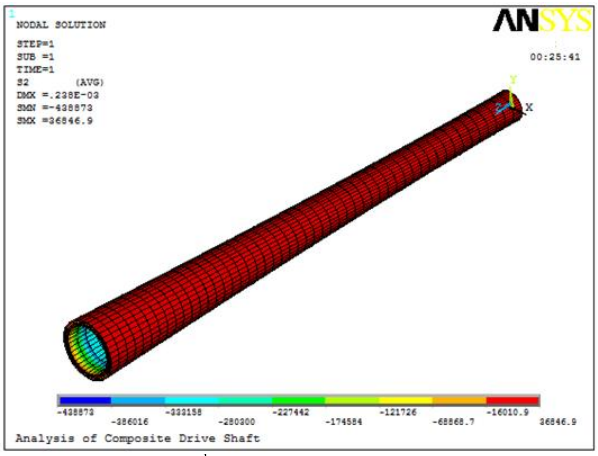
Deformation



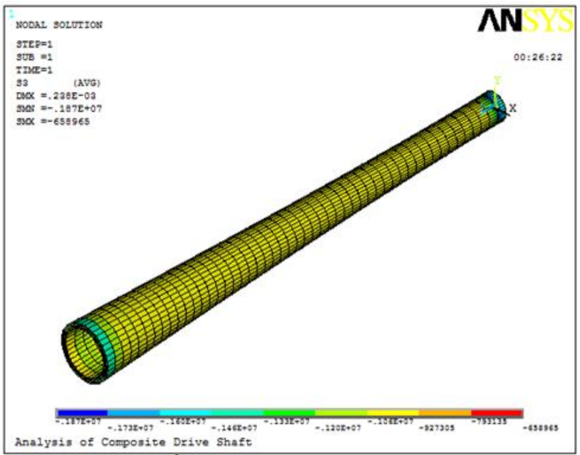
Von Misses Stress



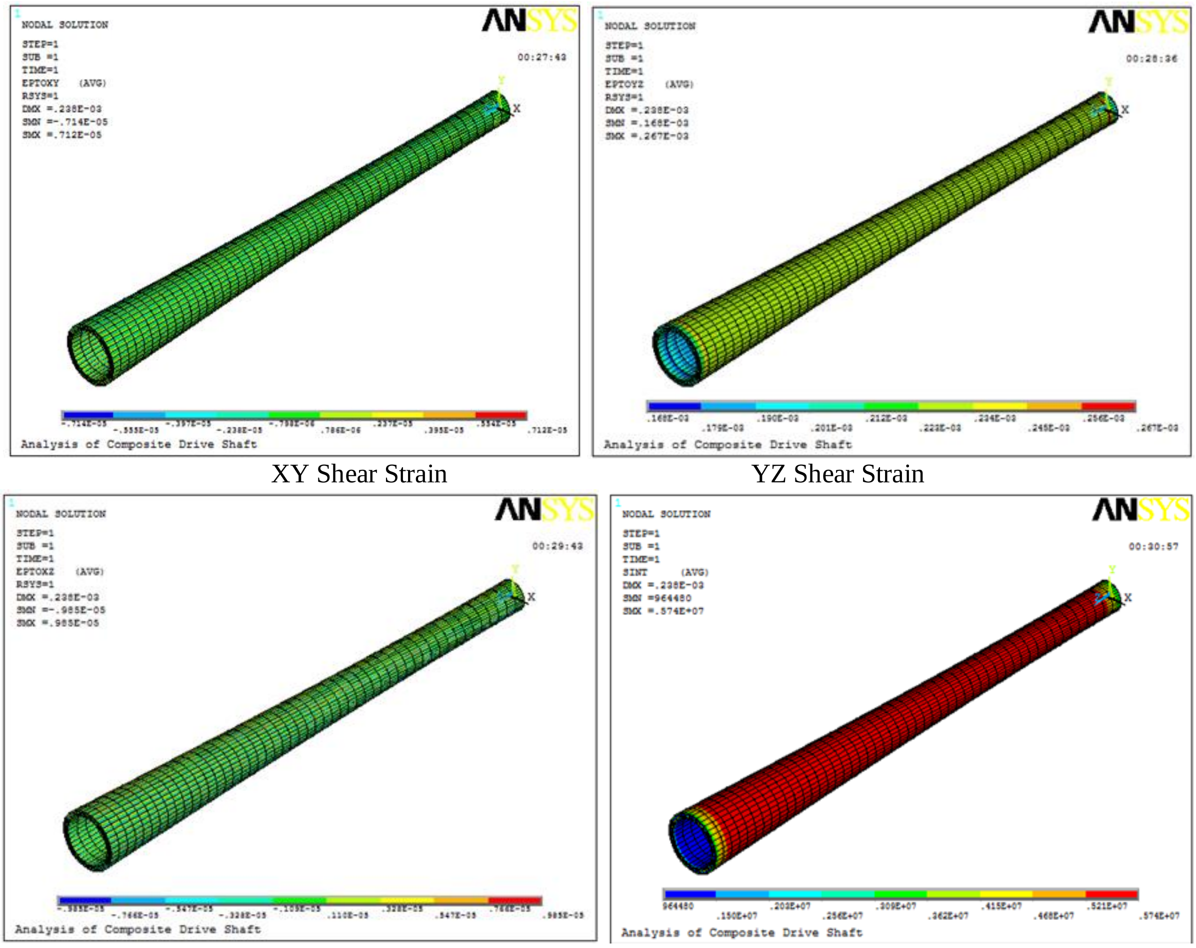
1st Principal Stress



2nd Principal Stress



3rd Principal Stress



XY Shear Strain

YZ Shear Strain

XZ Shear Strain

Stress Intensity

Figure 3 Static Stress Analysis of Composite shaft with 45-45-45-45 Orientation

III. Conclusions

In this paper comparison of drive shaft for steel and composite is carried out based on maximum deformation, maximum and minimum stresses induced in the shaft. Its design procedure is studied and along with finite element analysis some important parameter are obtained. The composite drive shaft made up of high modulus carbon / epoxy multilayered composites has been designed. The replacement of composite materials has resulted in considerable amount of weight reduction about 72% when compared to conventional steel shaft. Also, the results reveal that the orientation of fibers has great influence on the static characteristics of the composite shafts and offers advantages such as

- Lower weight
- Higher strength
- Progressive failure mechanism (offers warning before failure)
- Lower power consumption

References

[1] C. Sivakandhan, P. Suresh Prabhu: Composite drive shaft is a good strength and weight saving to compare conventional materials design and analysis of E Glass/Epoxy composite drive shaft for automotive application. ISSN 1450-216X Vol. 76 No.4 (2012), pp. 595-600.

[2] M. A. Badie, E. Mahdi, A. M. S. Hamouda : An investigation into hybrid carbon/glass fiber reinforced epoxy composite automotive drive shaft. Materials and Design 32 (2011) 1485-1500.

[3] M. A. Badie, A. R. Abutalib, E. J. Abdullah and R. Yonus: Automotive composite driveshaft: Investigation of the design variables effects. International Journal of Engineering and Technology, Vol. 3, No.2, 2006, pp. 227-237.

[4] M. M. Shokrieh, Akbar Hasani, L. B. Lessard: Shear buckling of a composite drive shaft under torsion. Composite structures 64 (2004) 63-69

[5] Nitin Gokhale, Sanjay Deshpande, Anand Thite, Practical Finite Element Analysis, Finite to Infinite, India.

[6] A.R. Abu Talib, Aidy Ali, Mohamed A. Badie, Nur Azida Che Lah, A.F. Golestaneh: Developing a hybrid, carbon/glass fiber-reinforced, epoxy composite automotive drive shaft. Materials and Design 31 (2010), pp 514–521.

[7] R. Sino, T.N. Baranger, E. Chatelet, G. Jacquet: Dynamic analysis of a rotating composite shaft. Composites Science and Technology 68 (2008), pp 337–345.

[8] Mahmood M. Shokrieh, Akbar Hasani, Larry B. Lessard: Shear buckling of a composite drive shaft under torsion. Composite Structures 64 (2004) 63-69.

[9] Y. A. Khalid, S. A. Mutasher, B. B. sahari, A. M. S. Hamouda: Bending fatigue behavior of hybrid aluminum/composite drive shafts. Materials and design 28 (2007) 329-334.

[10] Chih-Yung Chang, Min-Yung Chang, J. H. Huang: Vibration analysis of rotating composite shafts containing randomly oriented reinforcements. Composite structures 63 (2004) 21-32