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DESIGN AND ANALYSIS OF PROPELLER SHAFT BY USING COMPOSITE MATERIAL

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Abstract—a drive shaft is the one of the most important part that transmits power from the motor to the differential component of a rear wheel drive vehicles. The steel drive shaft is used as a part of car, now days this steel drive shaft is replaced by composite material drive shaft. The propeller shafts are used in automobile applications, aircraft and aerospace applications. The automobile industry is manufacturing composite material in order to obtain their reduction of the weight without decrease in vehicle quality and reliability. The drive shafts are utilized as a part of racing car, air ship applications. The steel material shaft fails due to only torsional loading, Because of this the steel material is replaced by the composite material. This composite material consists of Kevlar and Graphite which has good strength to weight ratio as compared steel material. Its design and analysis have done by CATIA and ANSYS software respectively. It is tested on Universal Testing Machine (UTM).

Index Terms—ANSYS, CATIA, Drive Shaft, Flexible Properties, Quality and Reliability, Torsional loading, UTM

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1 INTRODUCTION

THEdriveshaft is a rotating shaft that transmits power drive to wheels. Driveshaft is used to operate on regularly changing angles between the axle and transmission. High quality steel (SteelSM45) is a most widely used material for propeller shaft. Nowadays there is a heavy requirement for lightweight materials in automobiles. The conventional steel material is replaceable by most efficient composite materials. Composite materials are a most widely used material in the automobiles because of its high specific strength and high stiffness. Composite materials can fulfill the design requirements of strength, stiffness and composite drive shafts weightless than steel or aluminum of same strength. Also, composite materials have lower young's modulus.

2 PROBLEM STATEMENT

The weight reduction of propeller shaft can be a certain roll in the general weight reduction in the application and is a most desirable goal and if it can be achieved without increase in cost and without decrease in quality and reliability. The steel propeller shaft becomes the reason of increasing the weight of the vehicle specially racing cars as compared to composite propeller shaft. Strength and stiffness of the steel shaft is less than composite shaft.

3 WORKING

Filament winding can be explained as the manufacturing of parts with high fiber volume fractions and controlled fiber orientation. Fibers are submerged in a resin bath and coated with low or medium molecular weight reactants. The submerged fibers are then wound around a mandrel in a controlled pattern to form the shape of the part. After winding, the resin is cured by using heat. The mold core may be removed as an integral component of the part. This process is primarily used for hollow propeller shaft, generally circular components, such as pipes. Pressure vessels, pipes and Shafts have all been manufactured using filament winding. It has been combined with other fiber such as hand layup, pultrusion, and braiding methods. Mixture of fiber is through fiber tension and resin content is primarily metered. The fibers may be saturated with resin before winding, pre-saturated or post-saturated. This winding has the advantages of using the low-cost materials with long life and low viscosity. The pre-saturated systems produce parts with more continuous resin content and can be wound fast.

On the basis of desired properties of the materials, winding patterns such as helical and polar can be developed. Filament winding is commonly used to produce such structures as pressure vessels, power transmission shafts, piping. Variations on the filament winding process have produced a number of structures such as propeller shaft for automobiles and a band of continuous resin-saturated monofilament is wounded around a rotating mandrel and cured to produce symmetric hollow propeller shaft. Within the application of filament winding are automobile Shafts, helicopter blades, pipe lines, spherical pressure vessel and large underground gasoline storage tank. The filament winding is also used to manufacture paper sheets or continuous fiber reinforced sheet molding compounds. The sheet is found by slitting the wound shape parallel to the mandrel axis.

A greater number of fiber monofilaments are pulled from a series of creels in to a liquid resin bath containing liquid resin, catalyst and other ingredients, such as pigments and ultraviolet absorber. Fiber tension is controlled by using the fiber guides located between each creel and the resin bath.

Before entering the resin bath, the monofilament usually gathered on to a band by passing them through a stainless-steel comb.

At the end of resin tank, the resin saturated monofilaments are pulled through a wiping mechanism that removes the excess resin from the monofilaments and manage the resin coating thickness around each monofilament. The most commonly used wiping mechanism is a set of squeeze rollers in which the position of top roller is adjusted to control the resin content as well as the tension in fiber rovings. Another technique for wiping the resin saturated monofilaments is to pull each filament separately through an orifice, just like the procedure in a wire drawing process. This process provides fine control of resin content. However, it becomes difficult to rethread the broken roving line through its orifice, due to fiber breakage during a filament winding operation.

Once the roving's have been saturated and wiped, they are combined together on a flat band and positioned on the mandrel band formation can be achieved by using a straight bar, a comb. The band former is generally mounted on a carriage, which traverses back and forth parallel to the mandrel like a tool stock in a lathe machine. The traversing speed of the carriage and the winding speed of mandrel are managed to gain the desired winding angle patterns.

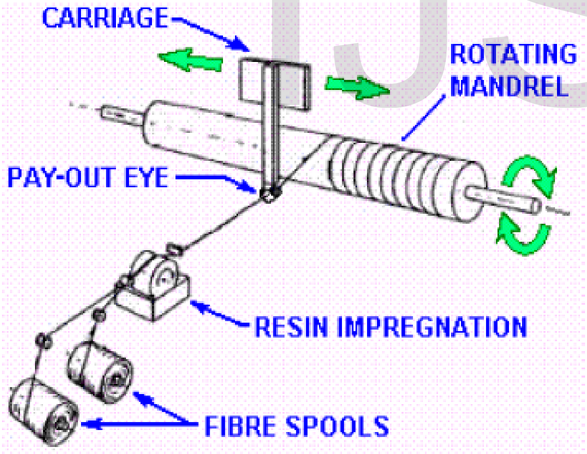

Fig.1: Filament Winding Machine

TABLE 1
Properties of Composite Materials

Material	Kevlar	Graphite
Young's Modulus	76 GPa	4.1 GPa
Yield Strength	1240 MPa	4.8 MPa
Poisson's ratio	0.35	0.2
Density	1460 kg/m^3	2098 m^3

4 DESIGN

Steel Material: Steel material has more weight and less strength as compare to composite material. Steel is ductile material. It has good thermal conductivity.

Steel Material:
Material: Hot rolled annealed steel
Shaft length (L) = 0.75 m
Diameter (D) = 54.6 mm
Density (ϱ) = 7.87gm/cm3
Modulus of elasticity (E) = 206 GPa
Maximum torque transmission (T) = 2500 N.m
Allowable Shear strength (τ_{allow}) = 356 MPa (Safety factor =1.4)

Stress calculation of shaft

Von-misses stress,

$$\tau = \frac{16T}{\pi D^3}$$

$$\tau = \frac{16 \times 2500}{\pi \times 0.0546^3}$$

$$\tau = 78.22 \text{ MPa.}$$

Shaft subjected to bending moment only,

$$\sigma_b = \frac{32M}{\pi d^3}$$

$$\sigma_b = \frac{32 \times 1000}{3.14 \times 0.054^3}$$

$$\sigma_b = 64.72\text{MPa}$$

$$\sigma_{max} = K_t \frac{32M}{\pi d^3} = 1.82 \times \frac{32 \times 1000}{3.14 \times 0.054^3} = 117.7904\text{MPa}$$

By considering, $K_t = 1.824$ from DME-1

…… (k_t is stress concentration factor)

$$\tau_{max} = K_t \frac{32M}{\pi d^3} = 1.824 \times \frac{32 \times 1000}{3.14 \times 0.054^3} = 118.0493 MPa$$

Maximum principle stress:

$$\sigma_1 = \frac{\sigma_b}{2} + \sqrt{(\frac{\sigma_b}{2})^2 + (\tau)^2} = \frac{117.7904}{2} + \sqrt{(\frac{117.7904}{2})^2 + (118.0493)^2}$$

$$\sigma_1 = 190.2782 MPa$$

$$\sigma_2 = \frac{\sigma_b}{2} - \sqrt{(\frac{\sigma_b}{2})^2 + (\tau)^2} = \frac{117.7904}{2} - \sqrt{(\frac{117.7904}{2})^2 + (118.0493)^2}$$

$$\sigma_2 = -73.238 MPa$$

Corresponding shear stress is,

$$\tau = \frac{\sigma_1 + \sigma_2}{2} = \frac{190.2782 - 73.238}{2} = 131.7581 MPa$$

$$\sigma_{equivalent} = \sqrt{(\sigma_1)^2 - \sigma_1\sigma_2 + (\sigma_2)^2}$$

$$\sigma_{equivalent} = \sqrt{(190.2782)^2 - (190.2782 \times (73.238) + (73.238)^2}$$

$$\sigma_{equivalent} = 166.235 \text{ MPa}$$

Torsional buckling (T_b) for the composite material:

$$T_b = 2\pi r^2 t \times 0.272 \times ((E_x E_y{}^3)^{0.25}) (\frac{t}{r})^{1.5}$$

T_b= $2\pi \times 27.3^2 \times 10 \times 0.272 \times ((190 \times 10^3 \times$
(7.7×103)0.25) (1027.3)1.5

T_b= 2.44×10^6N-mm.

Composite Material: In this manufacturing, we are using Kevlar and graphite material composition. Kevlar has high tensile strength, high toughness. Kevlar is widely used as friction material. Graphite is brittle material which is crystalline form of the carbon. Graphite is an excellent conductor of the heat and electricity, stable over a broad range of temperatures and a highly refractory material with high melting point.

Composite Material:

Shaft length (L) = 0.75 m
Diameter (D) = 0.0675 m
Max Torque (T) = 3500 Nm
Shear stress = 358 MPa (FOS= 1.5)
Shaft subjected to torsional moment,

Von-misses stress,

$$\tau = \frac{16T}{\pi D^3}$$

$$\tau = \frac{16 \times 2500}{\pi \times 0.0675^3}$$

$$\tau = 57.95 \text{ MPa.}$$

Shaft subjected to bending moment only,

$$\sigma_b = \frac{32M}{\pi d^3}$$

$$\sigma_b = \frac{32 \times 1000}{3.14 \times 0.0675^3}$$

$$\sigma_b = 33.11 \text{ MPa}$$

$$\sigma_{max} = K_t \frac{32M}{\pi d^3} = 1.82 \times \frac{32 \times 1000}{3.14 \times 0.0675^3} = 60.27 \text{ MPa}$$

By considering, $K_t = 1.824$ from DME-1

…… (k_t is stress concentration factor)

$$\tau_{max} = K_t \frac{32M}{\pi d^3} = 1.89 \times \frac{32 \times 1000}{3.14 \times 0.0675^3} = 62.59 \text{ MPa}$$

Maximum principle stress:

$$\sigma_1 = \frac{\sigma_b}{2} + \sqrt{(\frac{\sigma_b}{2})^2 + (\tau)^2}$$

$$= \frac{60.27}{2} + \sqrt{(\frac{60.27}{2})^2 + (62.59)^2}$$

$$\sigma_1 = 99.60 \text{ MPa}$$

$$\sigma_2 = \frac{\sigma_b}{2} - \sqrt{(\frac{\sigma_b}{2})^2 + (\tau)^2}$$

$$= \frac{60.27}{2} - \sqrt{(\frac{60.27}{2})^2 + (62.59)^2}$$

$$\sigma_2 = -39.33 \text{ MPa}$$

Corresponding shear stress is,

$$\tau = \frac{\sigma_1 + \sigma_2}{2} = \frac{99.60 - 39.33}{2} = 30.13 \text{ MPa}$$

$$\sigma_{\text{equivalent}} = \sqrt{(\sigma_1)^2 - \sigma_1\sigma_2 + (\sigma_2)^2}$$

$$\sigma_{\text{equivalent}} = \sqrt{(99.60)^2 - (99.60 \times (39.33) + (39.33)^2}$$

$$\sigma_{\text{equivalent}} = 86.88 \text{ MPa}$$

Torsional buckling (T_b) for the composite material:

$$T_b = 2\pi r^2 t \times 0.272 \times ((E_x E_y{}^3)^{0.25}) (\frac{t}{r})^{1.5}$$

$$T_b = 2\pi \times 33.75^2 \times 10 \times 0.272 \times ((4.1 \times 10^3 \times$$
(76×103)0.25) (1033.75)1.5

$$T_b = 2.13 \times 10^6 \text{N-mm.}$$

4.1 Modelling of the Solid Shaft

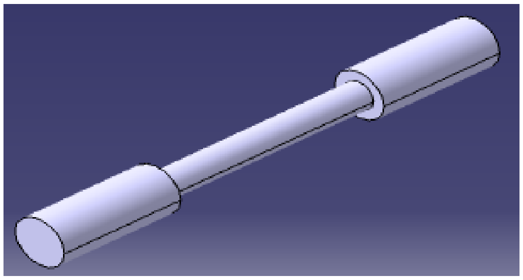

Fig.2: Modelling of Solid Shaft

TABLE 2
Parameters of Solid Shaft

Material	SM45C
Diameter	10 mm
Grip Diameter	17 mm
Length	70 mm
Grip Length	40 mm

4.2 Modelling of the Solid Shaft

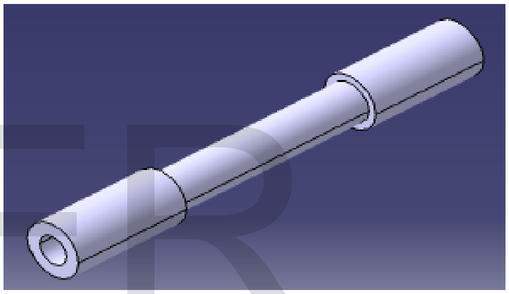

Fig.3: Modelling of Hollow Shaft

TABLE 3
Parameters of Hollow Shaft

Material	Composite
Outer Diameter	14 mm
Inner Diameter	10 mm
Grip Diameter	19 mm
Thickness	2 mm
Length	70 mm
Grip Length	40 mm

4.3 Angle of orientation

TABLE 4
Angle of Orientation

Set	Orientation Sequence	Number of layers
1	±45°	4
2	90°/0°/90°/0°/90°/45°	8
3	0°/90°/0°/90°/0°/45°	8
4	0°/90°/0°/45°/90°/−45°	10

5 ANALYSIS

5.1 Steel Shaft

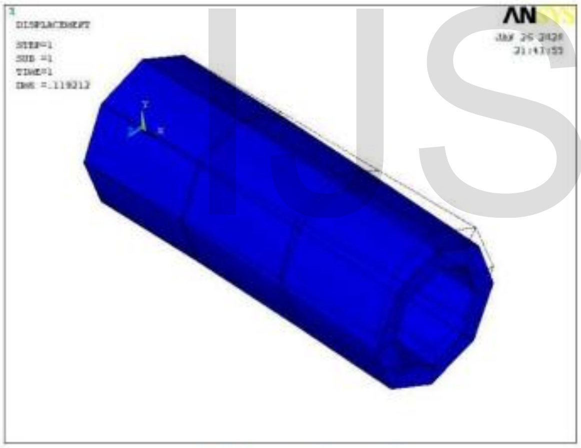

Fig. 4 : n of Steel Shaft

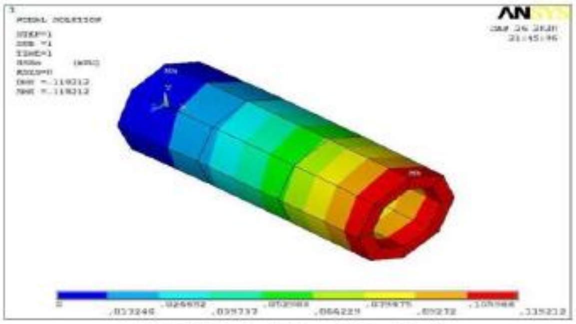

Fig.5: Nodal solution of steel shaft

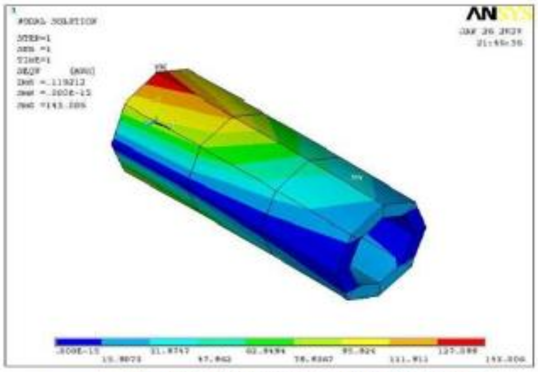

Fig.6: Element Solution of steel shaft

5.2 Composite Shaft

Fig.7: Deformation of composite material

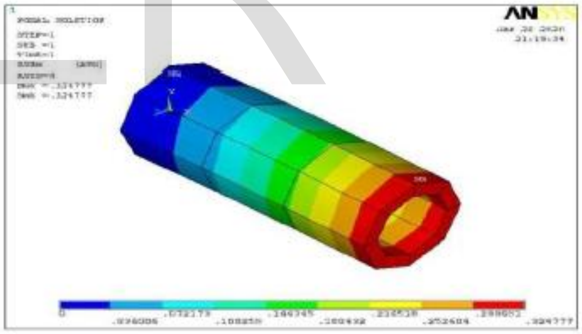

Fig.8: Nodal solution of composite material

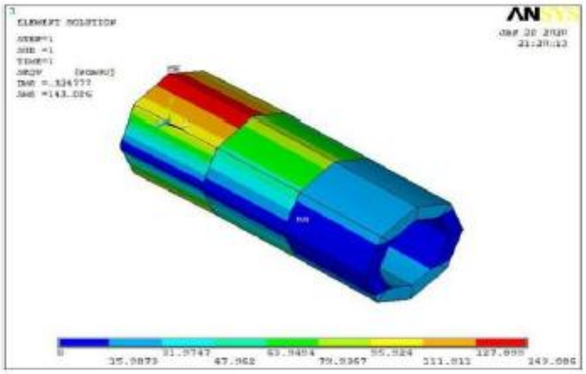

Fig.9: Element solution of comp. material

According to above analysis, by using ANSYS software we analyze that Steel Shaft having deformation of 0.1192 and deformation of Composite Shaft having 0.32477. By studying above figures we observe that, the composite shaft is more flexible and durable than steel shaft. As compared to steel propeller shaft the composite propeller shaft can sustain in high stress. The deformation of the steel propeller shaft is less so there are more chances of breakage of the steel propeller shaft than composite propeller shaft.

6 CONCLUSIONS

From the above research it has been concluded that the one-piece composite drive shaft is considered to be replaced a two-piece steel drive shaft. Its design procedure is studied and along with ANSYS software some important parameters are obtained. The composite drive shaft made up of high modulus graphite Kevlar multilayered composites has been designed. The replacement of composite materials has resulted in considerable amount of weight reduction when compare to conventional steel shaft.

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