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Design and Analysis of Composite Drive Shaft for Automotive Application

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Abstract: To design and analyze a composite drive shaft for power transmission in automobiles. The composite shaft have high specific stiffness and high specific strength when compared to ordinary steel shaft. In this present work the conventional two-piece steel drive shafts is replaced with a single composite drive shaft. Attempt has been carried out to estimate deflection, stresses under subjected loades & natural frequencies using FEA and the results are compared with steel shaft to validate our project.

Key words: Drive shaft · Different composite materials · Ansys13.0 · Material saving

INTRODUCTION

Drive shaft is a mechanical instrument which is used in automobiles. Most popularly this drive shaft is known as the propeller shaft, while coming to the construction it was long cylindrical structure consists of thee universal joints. Drive shaft is used to transfer the rotary motion to the differential by using the helical gear box. This rotary motion is used to run the rear wheels. In many cases we use stainless steel shaft for the fabrication of drive shaft. This drive shaft has wide applications in automobile world, used in the vehicles like trucks, buses, aero planes etc [1].

Problem Description: Stainless steel was mainly used because of its high strength. But this stainless steel shaft has less specific strength and less specific modulus. Stainless steel has less damping capacity. Because of its higher density of molecules of stainless steel, its weight is very high. Because of increase in weight fuel consumption will in increase, the effect of inertia will be more [2-4]. Because of increase in weight of the propeller shaft we are replacing the stainless steel with the composite materials, which are very less weight when compared to that of stainless steel. The cost of composite materials is less when compared to that of stainless steel.

Composite Materials and its Classification: A material composed of 2 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, whereas in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents [5-7].

Classification Of Composite Materials: Composite materials can be classified as;

- Polymer matrix composites
- Metal matrix composites
- Ceramic Matrix.

Advantages of Composites over the Conventional Materials:

- High strength to weight ratio
- High stiffness to weight ratio
- High impact resistance
- Better fatigue resistance
- Improved corrosion resistance
- High damping capacity.

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Types of Drive Shaft: There are various type of transmission shaft among them following are important
1. Transmission shaft.
2. Machine shaft.
3. Spindle.
4. Automobile drive shaft.
5. Ship propeller shaft.
6. Helicopter tail rotor shaft.

These drive shafts can be manufactured by replacing the stainless steel with the composite materials.

Functions Of The Drive Shaft:

- First, it must transmit torque from the transmission to the differential gear box.
- During the operation, it is necessary to transmit maximum low-gear torque developed by the engine.
- The drive shaft must also operate through constantly changing angles between the transmission, the differential and the axles. As the rear wheels roll over bumps in the road, the differential and the axle move up and down. This movement changes the angle between the transmission and the differential [8].
- The length of the drive shaft must also be capable of changing while transmitting torque. Length changes are caused by axle movement due to torque reaction, road deflections, braking load and so on. A slip joint is used to composite for this motion. The slip joint is usually made of an internal and external spline. It is located on front end of the drive shaft and is connected to the transmission.

Demerits of A Conventional Drive Shaft:

- They have less specific modulus and strength.
- Increased weight.
- Conventional steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely proportional to the square of beam length and proportional to the square root of specific modulus. [9]. Therefore the steel drive shaft is made in two sections connected by a support structure, bearings and U-joints and hence overall weight of assembly will be more.
- Its corrosion resistance is less as compared with composite materials.
- Steel drive shafts have less damping capacity.

Comparison of Stainless Steel with Composite Materials:

Property	Stainless Steel	Composie Materials
Specific strength	Low	High
Specific modulus	Low	High
Weight	High	Low
Cost	High	Low
Corrosion	High	Low
Damping capacity	Medium	High

Methodology: Modeling and analysis of 3-Dimensional models of the drive shaft were carried out using catia & solid words and analysis is carried out using Ansys software structural analysis of composite drive shaft and steel drive shaft are carried out. The results are compared with steel shaft to validate our project.

- Study of cause of failures in drive shaft
- Selection of composite material
- Preparation of CAD model
- Analysis the CAD model with existing material with Ansys
- Analysis of drive shaft by using different composite materials
- The results are compared with validate our project

Material Selection: Composite material

HS Carbon/Epoxy and HM carbon/Epoxy:

S.No	Mechanical properties	Symbol	Units	Value
1	Young's modulus	E	Gpa	210
2	Shear modulus	G	Gpa	70
3	Shear strength	Ss	Mpa	420
4	Density	ρ	Kg/m^3	1600
5	Poisson's ratio	υ	----	0.3

Material properties of steel SM45C:

S.No	Mechanical properties	Symbol	Units	Value
1	Young's modulus	E	GPa	207
2	Shear modulus	G	GPa	80
3	Poisson's ratio	υ	----	0.3
4	Density	ρ	Kg/m^3	7600
5	Yield strength	Sy	MPa	370
6	Shear strength	Sx	MPa	275

6.3 Material Properties Of Kevlar/Epoxy

Sl. No	Property	Symbol	Units	Values
1	Longitudinal Modulus	E11	GPa	79.2
2	Transverse Modulus	E22	GPa	7.25
3	Shear Modulus	G12	GPa	4.25
4	Poisson's Ratio	υ	-----	0.34
5	Density	ρ	Kg/m^3	1384

Design Calculation of Drive Shaft

Engine Specification

H-Series Ashokleyland Engine, Truck model -6DT120:

Max. power (P) =132kW

Max.Torque (T) = 660N-mm

Speed (N) =1200-1600rpm

Length (L) =1800mm

Steel Drive Shaft [10]:

Power $P=2\pi NT/60$

$T=p\times 60/2\pi N$

$T=132\times 10^3\times 60/2\pi\times 1200 =1050.42$N-m

$T=1050.42\times 10^3$ 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 $\tau=50N/mm^2$ for steel

$1050.42\times 10^3= \pi/16\times 50\times ((1.25d)^4-d^4)/ (1.25d)$

$1050.42\times 10^3= \pi/16\times 50\times 1.153d^3$

=45.26mm

d=46mm

$D=1.25d=1.25\times 46=58$

D=58mm

Stiffness of shaft

L=length of the shaft

L=1800mm

θ =Angle of twist 1°to1.5°

$\theta =1°\times\pi/180$

θ =0.01745rad

$T/J=G\theta/L$

Where,

T= maximum torque applied in drive shaft(N-mm)

J = polar moment of inertia (mm4)

$J=\pi/32(D^4-d^4)$

$J= \pi/32((1.25d^4)-d^4)$

$J=0.141d^4mm^4$

$1050.42\times 10^3/0.141d^4=80\times 10^3\times 0.0174/1800$

d=56mm

$D=1.25\times 56=70$mm

D=70mm

Larger diameter satisfies both strength and stiffness

Torsional buckling:

Where,

t= thickness of the hollow steel shaft

$t=r_o-r_i=35-28$

t=7mm

Radius of the shaft

$r= r_o+r_i/2=35+28/2=$

r=31.5mm

For long shaft the torsional buckling capacity

$T_b=\tau_{cr}(2\pi r^2t)$

Where critical stress is given by,

$\tau_{cr}=[E/3°2(1-\upsilon^2)^{3/4}] (t/r)^{3/2}$

$[207\times 10^3/3v2 (1-0.3^2)^{3/4}] (7/31.5)^{3/2}$

$\tau_{cr}=5482.76N/mm^2$

$T_b=5482.76(2\pi\times 29.5^2\times 6.5)$

$T_b=239.27$KN-m

Natural Frequency:

$f_{nb}= \pi/2\ vEI/mL^4$

where,

E = Young's modulus of elasticity (Pa)

m = mass per unit length (kg/m)

L = length of drive shaft (mm)

I = areamoment of inertia (m^4)

$I=\pi/64 (D^4-d^4)$

$= \pi/64 (0.07^4-0.056^4)$

$I=6.958\times 10^{-7}m^4$

m=mass per unit length of shaft is given by

$m=\rho (\pi/4) [D^2-d^2]$

$=7600\times (\pi/4) [0.07^2-0.056^2]$

m=10.529kg/m

$f_{nb}= \pi/2 \sqrt{}207\times 10^9 \times 6.958\times 10^{-7}/10.529\times 1.8^4$

f_{nb}=56.70Hz

Composite material carbon/Epoxy

$T_b=\tau_{cr}(2\pi r^2t)$

Where critical stress is given by,

$\tau_{cr}=[E/3\sqrt{2}(1-\upsilon^2)^{3/4}] (t/r)^{3/2}$

$[210\times 10^3/3v2(1-0.3^2)^{3/4}] (7/31.5)^{3/2}$

$\tau_{cr}=5563.51N/mm^2$

$T_b=5563.51(2\pi\times 31.5^2\times 7)$

$T_b=242.79$KN-m

Natural frequency for composite material

$f_{nb}= \pi/2 \sqrt{}E_x I/mL^4$

E_x=210Gpa longitudinal young's modulus

$I=\pi/64 (D^4-d^4)$

$= \pi/64 (0.07^4-0.056^4)$

$I=6.958\times 10^{-7}m^4$

$m=\rho a (\pi/4) [D^2-d^2]$

$=1600\times (\pi/4) [0.07^2-0.056^2]$

m=2.216kg/m

$f_{nb}= \pi/2 \sqrt{}210\times 10^9 \times 6.958\times 10^{-7}/2.216\times 1.8^4$

$f_{nb\,=}$124.49Hz

Dimensions of Drive Shaft:

S.No	Description	Notations	Value
1	Outer diameter	D	70mm
2	Inner diameter	d	56mm
3	Thickness of the shaft	t	7mm
4	Length of the shaft	L	1800mm
5	Radius of the shaft	r	31.5mm

Software

Finite Element Analysis: Finite element analysis is a computer based numerical technique is used to for calculating the strength and behavior of the engineering structures. The structure on which the analysis can be done is divided into large number of finite elements and required stress at the desired point can be calculated. The accuracy of the structure depends on the no of finite elements made.

Static Analysis: Static analysis deals with the conditions of equilibrium of the bodies acted upon by the forces.

Types of static analysis

- Linear
- Non linear

Kinds of loads that can be applied in static analysis includes

1. Pressures, moments and externally applied forces.
2. Non-zero displacements imposed.
3. Inertial forces such as gravity.

Ansys Evaluation: ANSYS is a complete FEA simulation software package developed by ANSYS Inc – USA. It is used by engineers worldwide in virtually all fields of engineering.

- Structural
- Thermal
- Fluid (CFD, Acoustics and other fluid analyses)
- Low-and High-Frequency Electromagnetic.

Procedure: Every analysis involves three main steps's

- Pre-processor
- Solver
- post processor.

Structural Analysis: Structural analysis is probably the most common application of the finite element method. The term structural (or structure) implies not only civil engineering structures such as bridges and buildings, but also naval, aeronautical and mechanical structures such as ship hulls, aircraft bodies and machine housings, as well as mechanical components such as pistons, machine parts and tools.

Analysis Results:

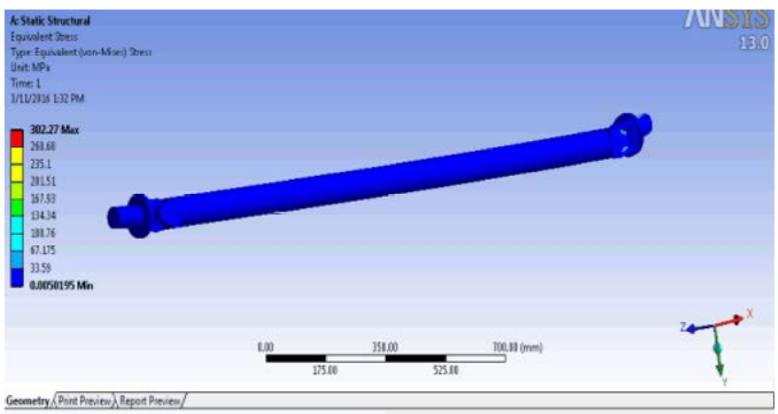


Fig. 1: Von mises stress Steel SM45

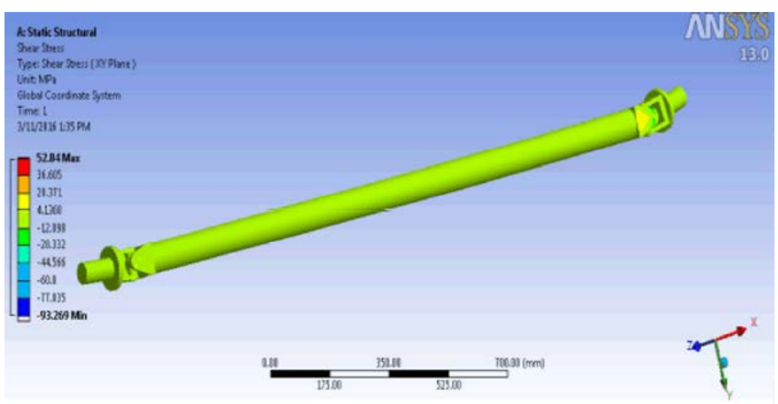


Fig. 2: Shear Stress

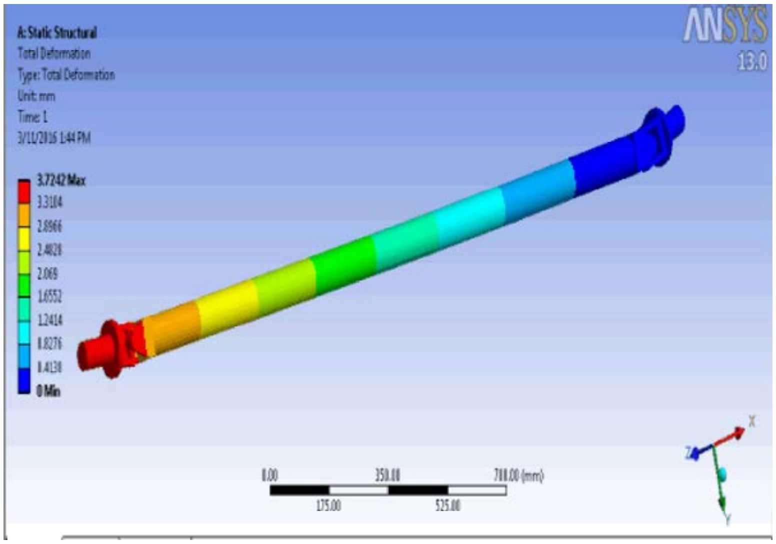


Fig. 3: Total Deformation

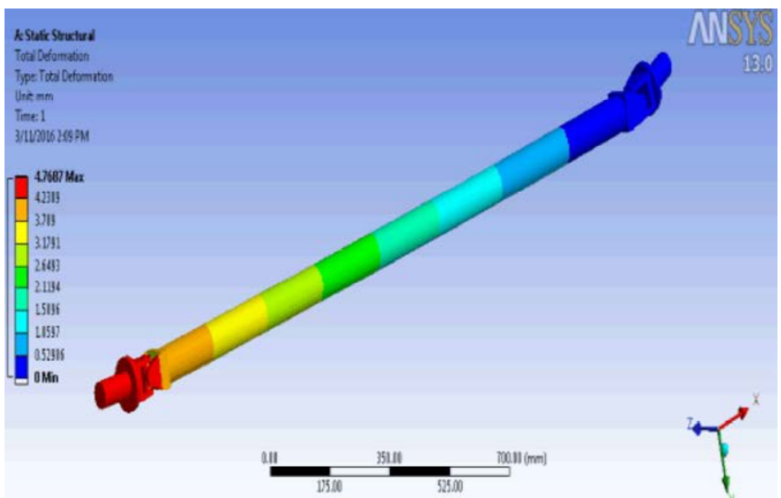


Fig. 4: Composite drive shaft Boron/Epoxy Total Deformation

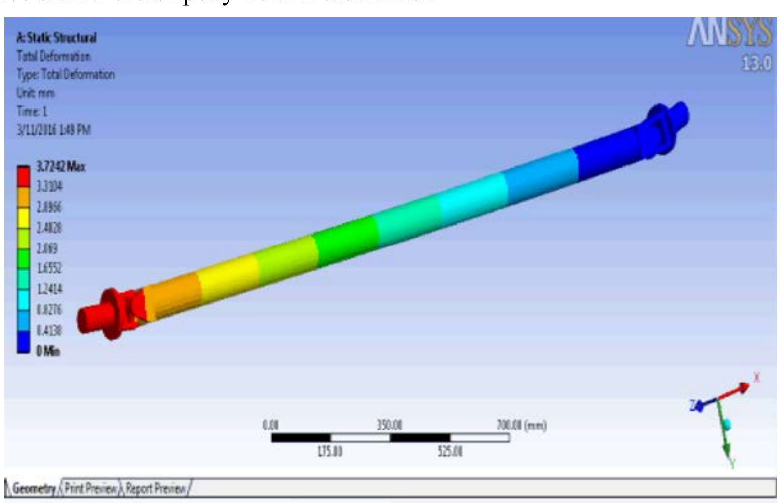


Fig. 5: Total Deformation Carbon/Epoxy

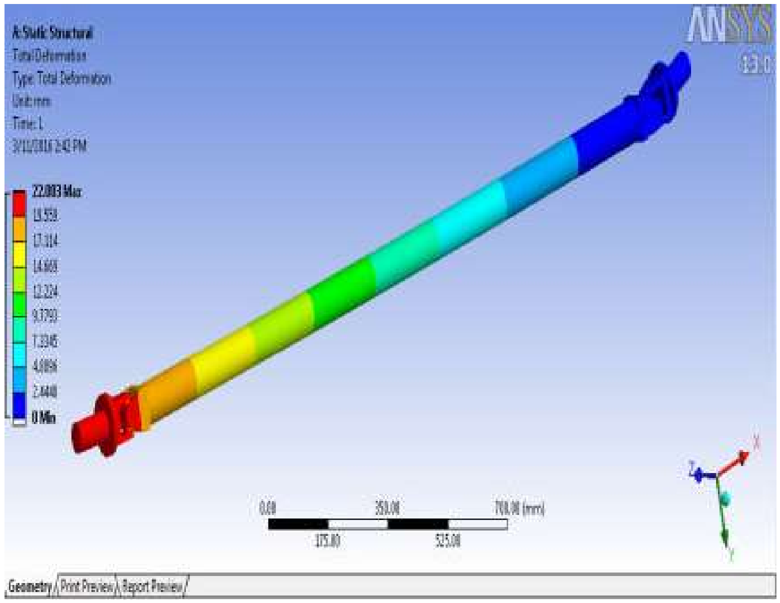


Fig. 6: Kevlar/Epoxy Total Deformation

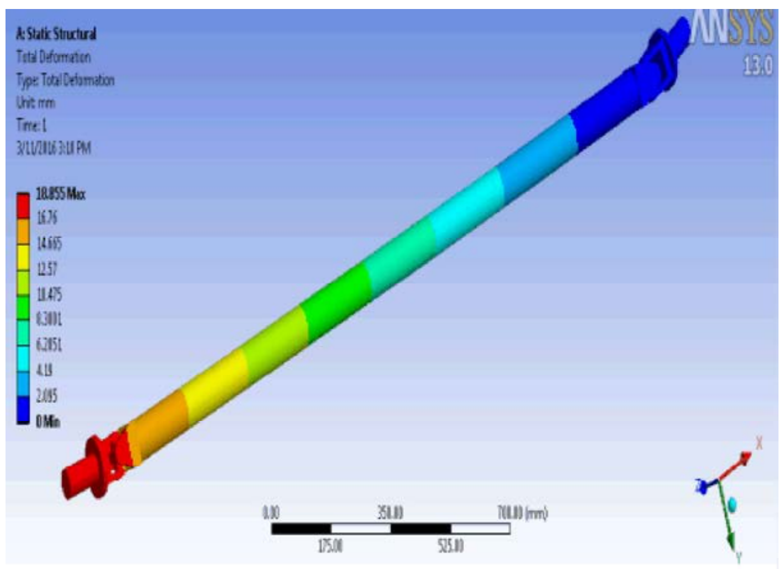
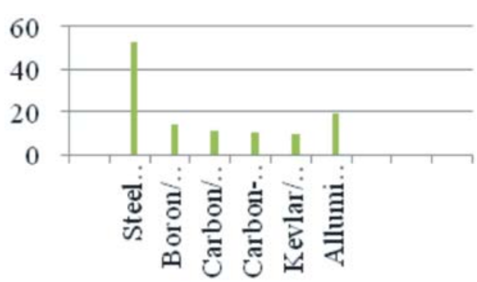


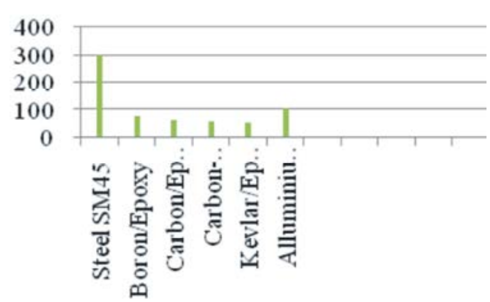
Fig. 7: Alluminium-Boron/Epoxy Total Deformation

Comparison Of Results

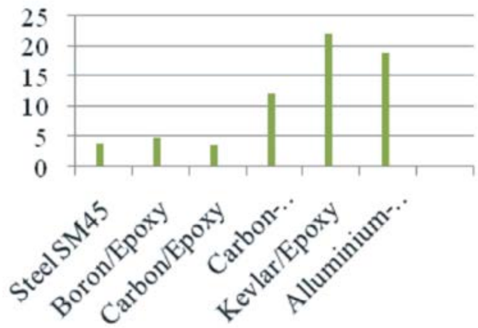
Shear Stress:



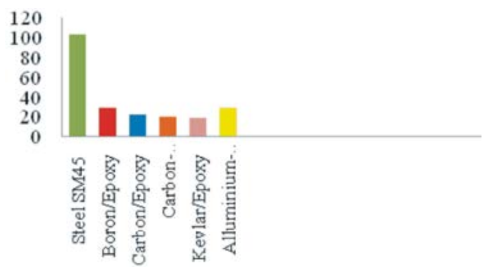
Von-Mises Stress:



Total Deformation



Weight Comparison Between Steel &Composite Drive Shaft:



CONCLUSION

The High Strength Carbon composite drive shafts have been designed to replace the steel drive shaft of an automobile. A one-piece composite drive shaft for rear wheel drive automobile has been designed with High Strength Carbon composites with the objective of minimization of weight of the shaft which was subjected to the constraints such as torque transmission, torsional buckling capacities and natural bending frequency. The High Strength Carbon composite drive shafts have been analysed to replace the steel drive shaft of an automobile. The usage of composite materials has resulted in considerable amount of weight saving in the range of 70% to 63% when compared to conventional steel drive shaft. In finally suggestion, the cost of composite material compare boron to HS Carbon/Epoxy is low and best one.

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