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Static and Modal Analysis of Propeller Shaft of LMV

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***Abstract:** The propeller shaft is the very important component in a vehicle,motion of any the vehicle can be done by the propeller shaft. i.e. transmission of torque from the engine to wheels is performed by a shaft. This shaft is known as a propeller shaft. The automobile like cars having various mechanical elements are built to create the vehicle fuel efficient that in result make the transportation economical, the weight of that vehicle ought to be reduced. the overall objective of this work is to design and weight optimization of propeller shaft of the light motor vehicle. This project deals with drive shaft of MARUTI OMNI to design the shaft for its minimum dimensions and satisfy current drawback with specification then replace typical steel material with composite material. The composite materials are lightweight with additional strength & stiffness, replacement of composite materials to traditional steel materials utilized in automotive vehicle components can scale back the weight and improve the mechanical properties of these parts. Here a part model created for individual dimensions in CATIA V5R19 software. Than modeling, Torsional buckling analysis and Modal analysis will be applied for propeller shafts using ANSYS R14.5 to validate the theoretical calculations and analytical results. The obtained results are compared with Carbon/Epoxy composite material which are chosen as better replacement material for regular steel material in terms of many mechanical properties for light motor vehicle.*

***Keywords:** Drive shaft, Composite material, Carbon/ Epoxy fibre, CATIA V5R19, ANSYS R14.5*

I. INTRODUCTION

Drive Shaft is a rotating shaft that transmits power from the engine to the differential gear of a rear wheel drive vehicles Driveshaft must operate through constantly changing angles between the transmission and axle. Automotive drive Shaft is a very important component of vehicle. The present project focuses on the design of such an automotive driveshaft by composite materials, the main advantages of the present design are only one piece of composite driveshaft is possible that fulfil all the requirements of drive shaft. The basic requirements considered here are torsion strength, torsion buckling and bending natural frequency. An optimum design of the draft shaft is done, which is cheapest and lightest but meets all of the above high load is the most requirements.

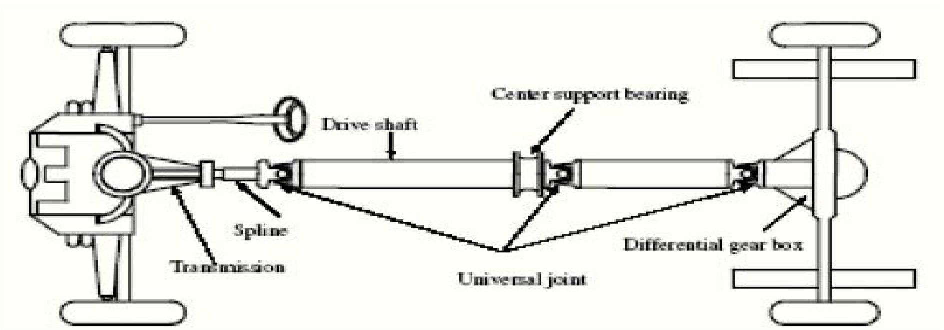

Fig-1 Propeller shaft and component

Drive shafts are used as power transmission tubing in many applications, including cooling towers, pumping sets, aerospace, trucks and automobiles. In the design of metallic shaft, knowing the torque and the allowable shear stress for the material, the size of the shaft's cross section can be determined. In the today's days there is a heavy requirement for lightweight materials vehicle.

1) *Composite Materials:* A new kind of material which is formed due to combination of two or more metals or non metals is known as composite materials. Generally composite materials are lighter and stronger than conventional metals. The usages of composite materials were started from early 20th century itself. Concrete is one of the most famous composite material which is widely used in building bridges, houses, skyscrapers, etc., There are many types of composite materials like carbon epoxy, glass epoxy, Kevlar, etc.,

II. LITRATURE REVIEW

V Jose Ananth Vino et al [1] This paper deals with the replacement of conventional propeller shaft with the composite shaft. Design parameter was optimized for optimizing the weight of the shaft. the modeling is done by SOLIDWORKS software. He evaluated stress under subjected load, defection and natural frequency using ANSYS.

S Dharmadhikari J P Giri et al [2] Study deals with design and analysis of composite drive shaft using Ansys and genetic algorithm.

S Shinde et al [3] This paper deals with Design of propeller shaft For Mahindra considering torque capacity, Shear stress, and critical rpm requirement. And epoxy and aluminum material used for replacement of conventional shaft.

Bhirud P.P et al [4] This paper deals with the replacement of steel shaft with E glass resign composite drive shaft. ANSYS is used as analysis software.

Salaisivabalan T et al [5] This paper deals with propeller shaft of MARUTI OMNI to design shaft for its minimum dimension. then part can be created in NX 8.5 and after modeling Torsional buckling analysis and model analysis can be carried out in NX NASTRAN. Obtained results can be compared.

Parshuram D et al [6] in this work studied weight optimization of the shaft by using the composite material. design of the shaft is carried out in CATIA and analysis is carried out in ANSYS.

S P Maske et al [7] This paper deals with Failure analysis and design optimization of propeller shaft of Bus. the SAE 1045 Steel shaft is replaced by Chromium steel SAE 3145 and analysis can be carried out in ANSYS.

D Khushwaha et al [8] this paper deals with optimal design and analysis of composite drive shaft for a light commercial vehicle. The design is carried out in PRO-E and analysis in ANSYS.

III. DESIGN OF PRPELLER SHAFT

Transmission of power can be improved through the reduction of mass inertia and light weight. In the design of SM45C steel shaft, knowing the torque and the allowable shear stress for the steel material.

A. Problem Specification

The specifications were assumed appropriately, supported the literature review and standards offered for automobile propeller shaft particularly Maruti Omni [3].

The torque transmission capacity of the drive shaft (T) = 59 Nm

The shaft has to stand up to buckling torque (Tb) specified Tb > T

The minimum bending natural frequency of the shaft (fnb min) = 80 Hz

Maximum diameter of the propeller shaft (**do**) = 0.051 m

Length of the propeller shaft (l) = 0.562 m

First the traditional steel shaft was designed to facilitate comparison in terms of mass savings. Be it the traditional shaft or the composite one, the design ought to be supported the subsequent criteria

1) Torsional strength
2) Buckling torque
3) Bending Natural frequency

The mechanical properties of steel and composite material are taken from the literature available mentioned in the Table 1.

Table-1. Mechanical properties of materials for propeller shaft

Mechanical Properties	Units	Steel (SM45C)	Carbon epoxy
Young's Modulus	GPa	207.0	131.6
Shear Modulus	Gpa	80.0	7.6
Poisson Ratio		0.3	0.281
Density	Kg\M3	7600	1550
Shear Stress	N\MM2	29.419	40

B. Torsional Strength

The maximum torsional strength of the Steel shaft is calculated by using torsion equation [7]

$$\tau/r = T/J = G\theta/l$$

Where, T is torque transmitted in Nm.
Polar moment of inertia (J) = $\pi/32\ (do^4 - di^4) = 1.43019 \times 10\ \text{-}7\ m^4$
Mean radius of shaft (rm) = $ro+ri^2 = 0.02475$ m
ro = is outside radius of hollow shaft in m
ri = inside radius of hollow shaft in m
G = Shear Modulus = 80 × 109 N/m2
Assume angle of twist in radians(θ) = 5 × π/180 radian
Shear stress (τ) = Gθrml= 307.45 × 10 6 N/m2
Now, τ/r = T/J , T = 1776.61 Nm > 59 Nm. Therefore design is safe

C. Bending Natural Frequency

Minimum bending natural frequency for Steel shaft (fnb min) = 80 Hz
Natural frequency (fnb) = π2√Ex Ixm, L4
Where, Ex = 207 × 109 N/m2
Moment of inertia in x direction(Ix)= $\pi/64\ (do^4 - di^4) = 7.1509 \times 10{-}8$ m4
The mass per unit length of the shaft (m,) = $\rho\pi/4(do^2 - di^2) = 1.8311$ Kg/ m
Where, density of steel (ρ) = 7850 Kg/m3
do = 0.051 m, di = 0.048 m
Therefore bending natural frequency (fnb) = 447.15 Hz >80 Hz

D. Critical Speed

N is the maximum speed of the transmission system = 5000 rpm
Critical speed of the Steel shaft (Ncr) = 60 × fnb = 51002.6 rpm > N

E. Weight of Steel Drive Shaft

Weight = Density ×Volume = 1.1478 Kg.

IV. DESIGN OF COMPOSITE SHAFT

A. Torsional Strength

The maximum torsional strength**, τ/r = T/J = Gθ/l**
T is torque transmitted in Nm
Polar Moment of Inertia (J) = $\pi/32\ (do^4 - di^4) = 5.16848 \times 10{-}7$ m4
Where, do = 0.051 m, di = 0.035 m
Mean radius of shaft (rm) = ro+ri2 = 0.0215 m
Shear Modulus (G) = 7.6 × 109 N/m2
Assume, angle of twist (θ) = 5 × π180 radians
l = length of shaft = 0.562 m
Shear stress (τ) = Gθ/rml= 25.37 × 106 N/m2
Hence, T = 609.94 Nm>59Nm.

B. Bending Natural Frequency

Minimum bending natural frequency for composite shaft (fnb min) = 80 Hz.
Natural frequency (fnb) = π2 (Ex Ixm, L4)12⁄
Ex = 177 × 109 N/m2
Moment of inertia in x direction(Ix)= π64 (do4− di4) = 2.5842 × 10−7 m4
The mass per unit length (m,) = ρ*π/4(D2− d2) = 1.67509 Kg/ m
Where, density of composite material (ρ) = 1550 Kg/m3
Bending natural frequency (fnb) = 821.82 Hz >80 Hz

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C. Critical Speed of Shaft

N = 5000 rpm

Critical speed of the (Ncr) = 60 × fnb = 49309.33 rpm > N

D. Weight of composite Drive Shaft

Weight (W) = Density ×Volume = $\rho \times \pi/4\ (D^2 - d^2) \times L$ = 0.9414 Kg

The design parameters for both the shafts are calculated and mentioned below in Table 2.

Properties	Units	Steel	Carbon/Epoxy
Inner Dia	Mm	48.434	35
Max. Shaer Stress	Mpa	307.45	25.37
Bending Natural	Hz	447.15	906.56
Critical Speed	N	26829.36	54939.6
Mass	Kg	1.1478	0.9348

V. FINITE ELEMENT ANALYSIS

The steel shaft model is imported from CATIA V5R19 software to ANSYS R14.5 and analyzed for the maximum deflection, maximum shear stress as well as the Von-Mises stress values. The ensuing values are placed in Table 3. The fastened constraint is applied at the one end of the shaft

Steel Drive shaft analysis result (Fig-2-7)

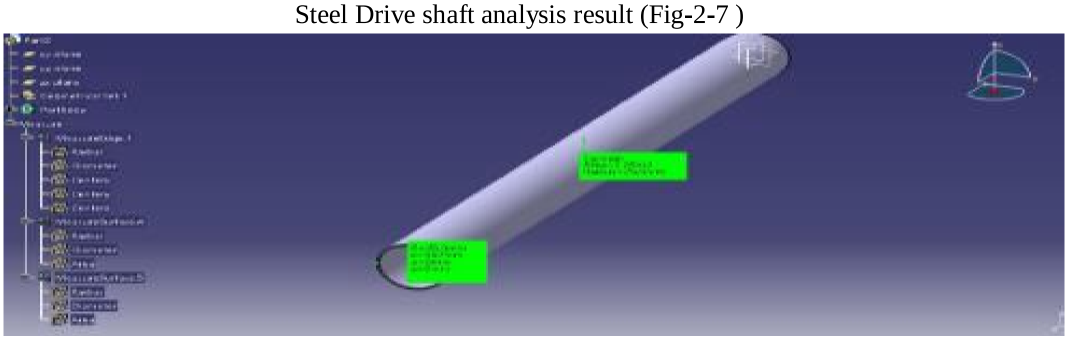

Fig-2 Part modal

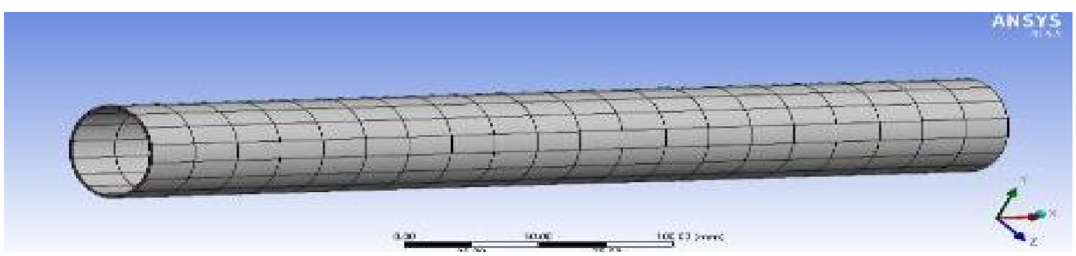

Fig-3 Meshing

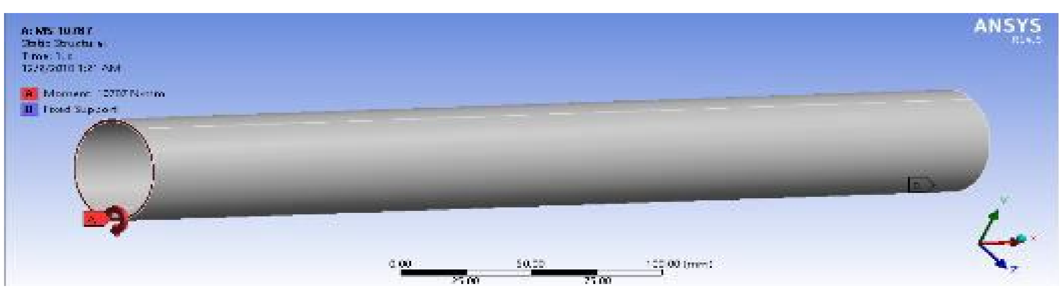

Fig-4 Boundary conditions

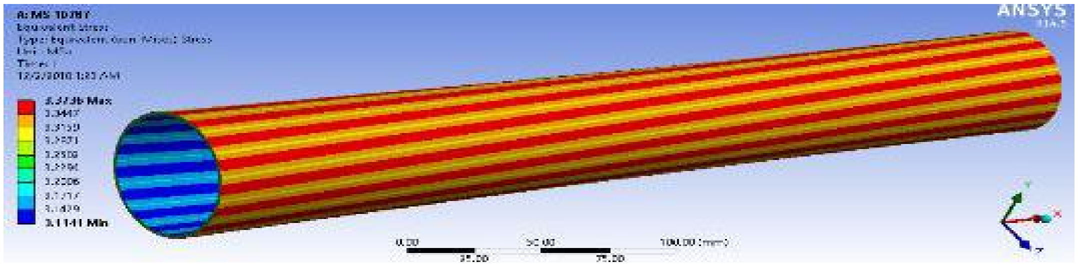

Fig-5 Von-Mises stress

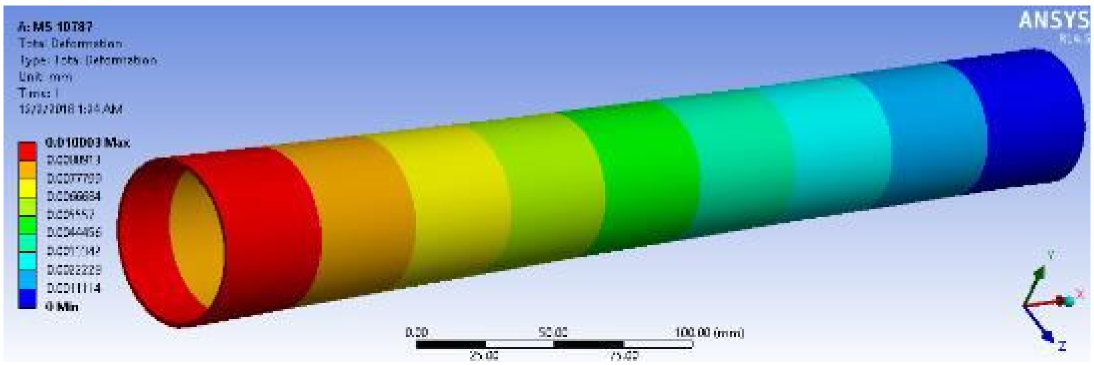

Fig-6 Total deflection

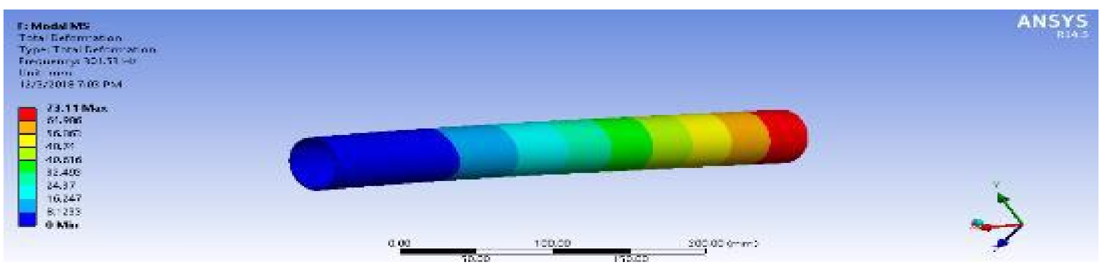

Fig-7 Modal analysis

Composite drive shaft analysis result(Fig 8-13)

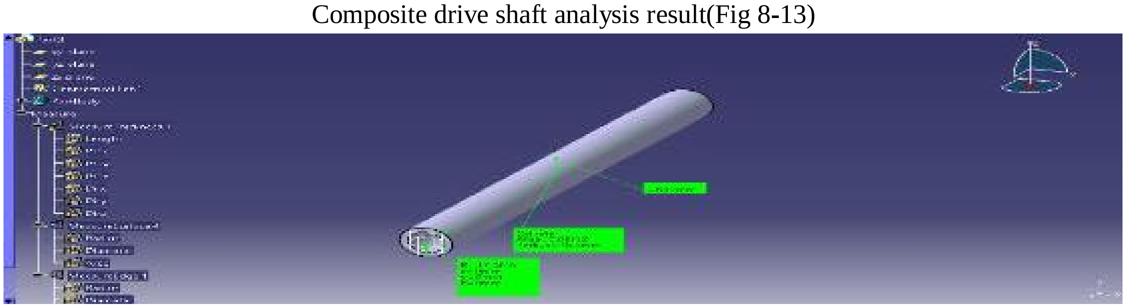

Fig-8 Part model

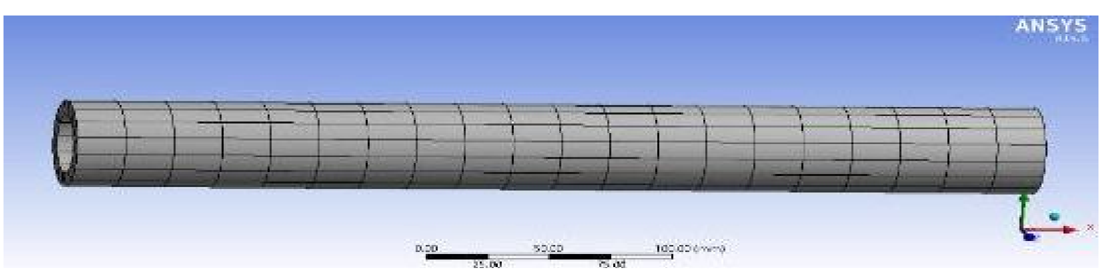

Fig-9 Meshing

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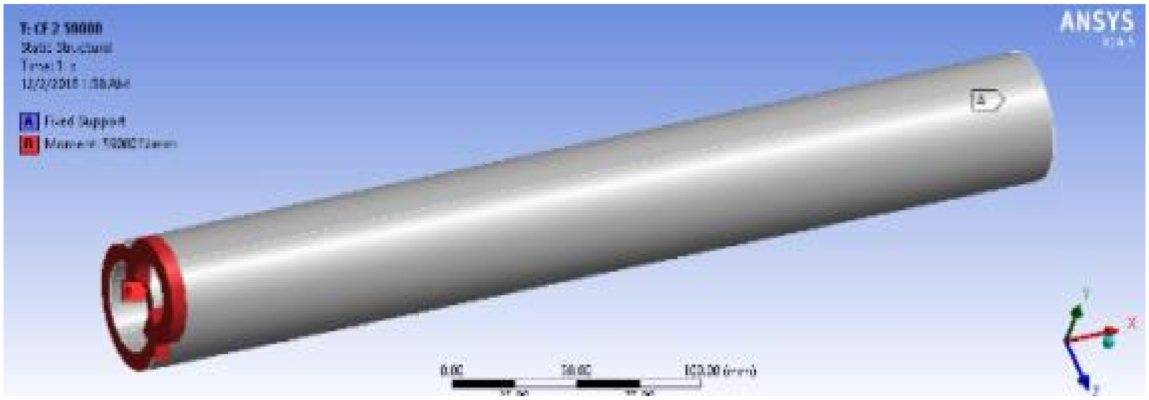

Fig-10 Boundary conditions

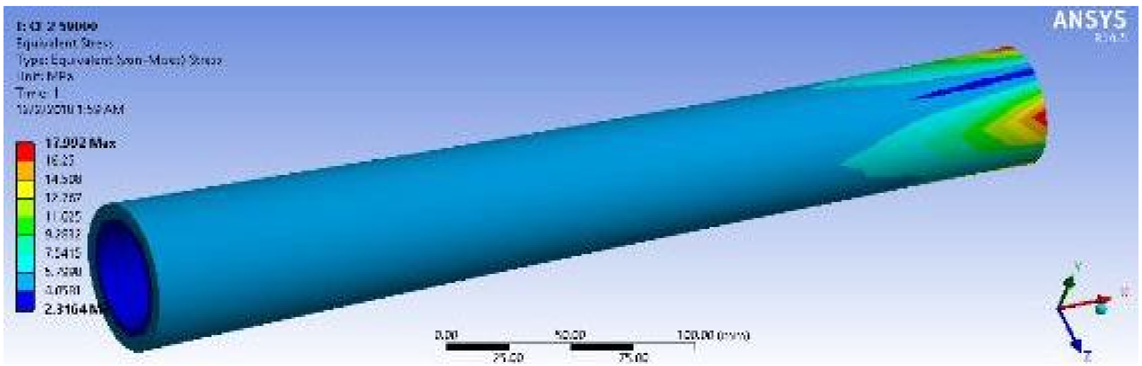

Fig-11 Von-Mises stress

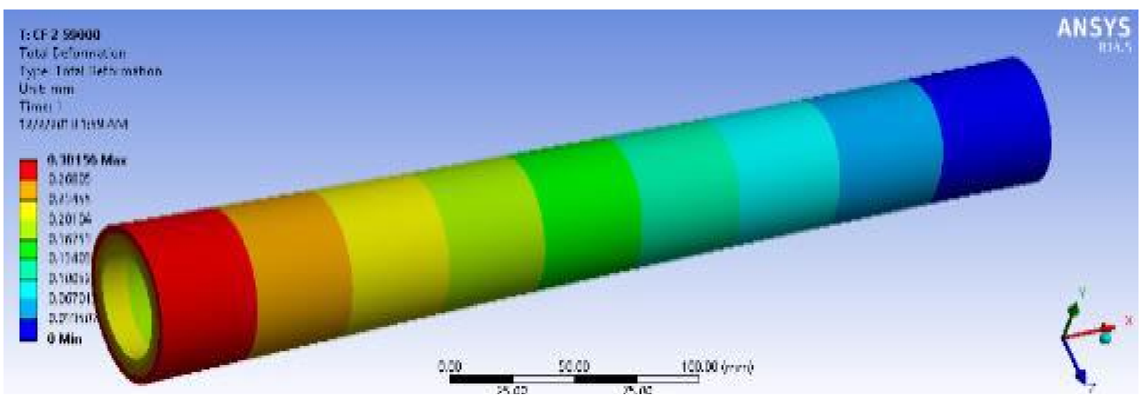

Fig-12 Total deflection..

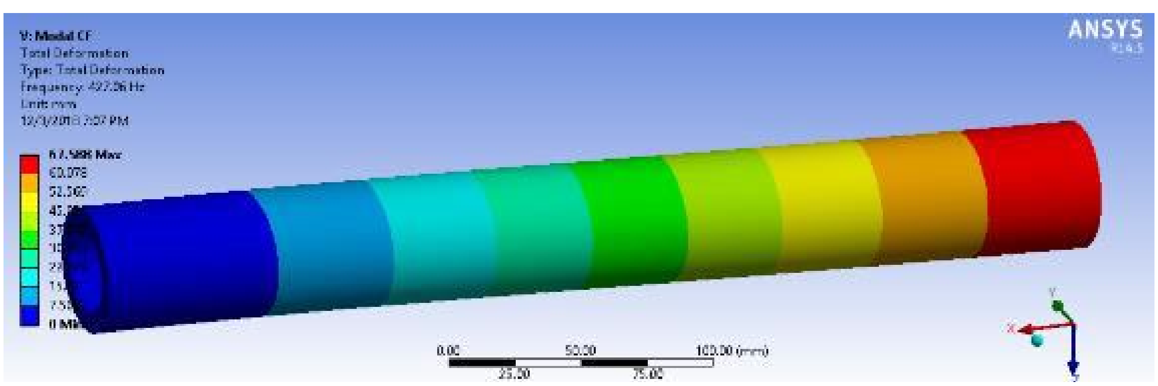

Fig-13 Modal analysis

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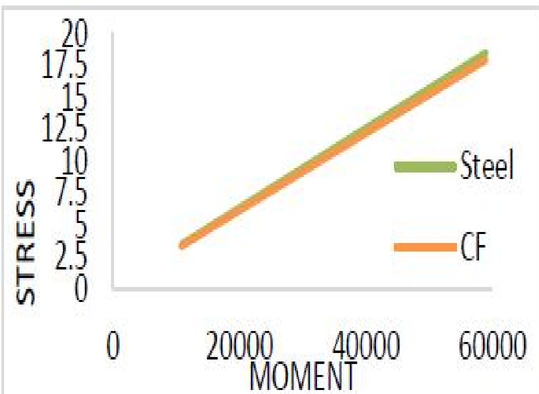
VI. RESULTS AND COMPARISON

A. *Torsional Buckling*

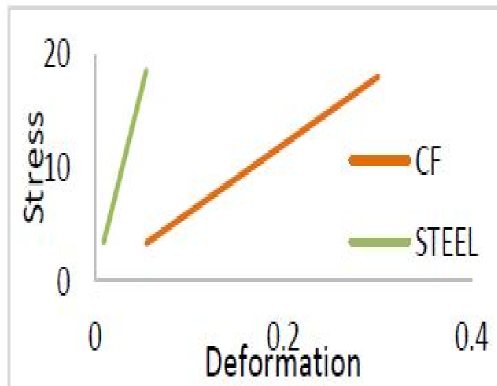
The steel shaft model has imported from CATIA V5R19 software to ANSYS R14.5 and analyzed for the maximum deflection, maximum shear stress as well as the Von-Mises stress value. The resulting values are tabulated as in Table 3. The fixed constraint is applied at the one edge of the shaft. The twisting moment is applied at the other edge of the shaft.

Table 3. Torsional Buckling analysis results and comparison

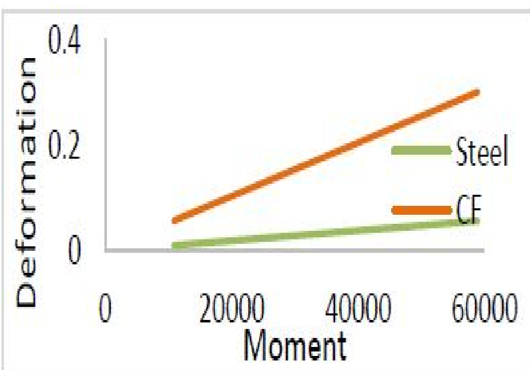
Material	Deflection(mm)	Von Misses Stress(Mpa)
Steel	0.05471	18.452
Carbon/Epoxy	0.30156	17.992



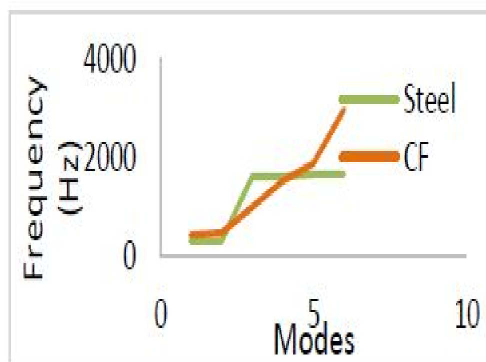
Graph- 1 Moment Vs Stress



Graph-2 Deformation Vs Moment



Graph- 3 Moment Vs Deformation



Graph-4 Modes Vs Frequency

B. *Modal Analysis*

When bending natural frequency is high then critical speed is also high. Therefore, the shafts have more range of speed if the natural frequency is high [3]. From comparison of natural frequency of both conventional Steel shaft and Carbon/ Epoxy composite shaft it is clear that composite shaft having higher values of natural frequency as shown in table 4. Result and Comparison of Modal Analysis which is more preferable for drive shaft in light motor vehicle.

Table 4. Result and Comparison of Modal Analysis

Material	Mode-1	Mode-2	Mode-3	Mode-4
Steel	301.53	3.01.53	1603.4	1660.2
Carbon/epoxy	427.06	476.13	984.08	1510.3

VII. CONCLUSION

From the torsional buckling and modal analysis the deformation, shear stress, Von-Mises stress, critical speed, bending natural frequency and weight are determined which gives better results as compare to Steel shaft. In comparison Carbon/Epoxy composite shaft is best solely in weight reduction which is 18.55% lesser than steel shaft. Carbon/Epoxy composite shaft is best in shear stress and Von-Mises stress is 41.63% larger and bending natural frequency of Carbon/Epoxy composite shaft is also larger than steel shaft. Therefore a Caron/Epoxy composite shaft can use as a propeller shaft for light motor vehicles like Maruti Omni.

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