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Design, Analysis and Comparison of Propeller Drive Shaft of an Automobile

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Abstract:- Most of the automobiles has Rear wheel drive and front engine installation consists a transmission shaft. Substitution of conventional metallic Propeller Drive Shaft with the composite structure has many advantages due to its less weight, high strength and higher specific stiffness. The reduction of weight of the Propeller Drive Shaft will lead to reduction in overall weight of the vehicle which will aid to achieve the desired goal. Because of the high specific strength and high specific modulus, the advanced composite materials such as Carbon and Glass Fibers with suitable resins are widely used. The advance Composite materials seem ideally suited for long power Propeller Drive Shaft applications. The main considerations are total deformation, stress and strain distribution in the modified model of the drive shaft. In this paper we analyze a composite Propeller Drive Shaft for power transmission, it demonstrates the favorable factors and identifies the suitable composite Propeller Drive Shaft that can replace the conventional steel drive shafts for an automotive application. The aim is to reduce the weight of drive shaft. This research paper basically deals with FEM analysis by using it we analyze and compare the design of various composite materials.

Keywords:- *Drive shaft; conventional shaft; Composites drive shaft; SM45C; Carbon Epoxy; Glass Epoxy; Kevlar49; CATIA ; ANSYS.*

I. INTRODUCTION

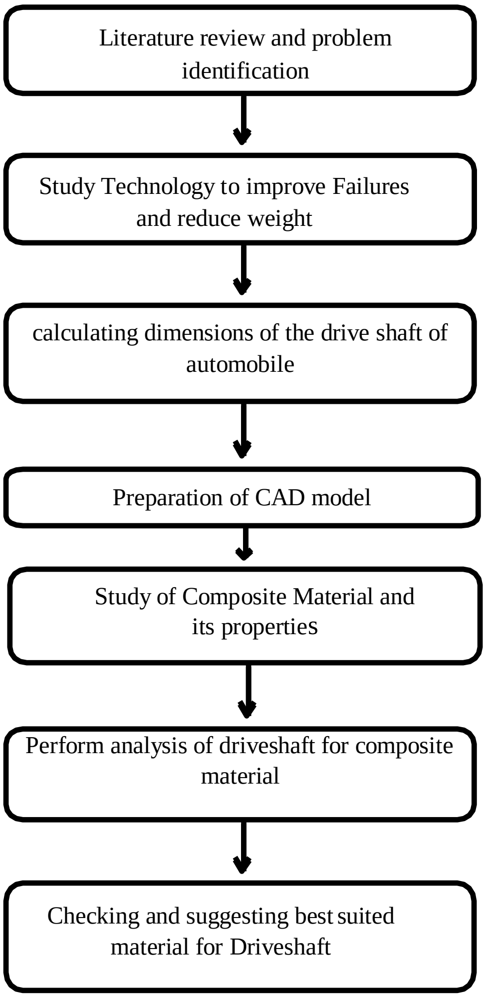
A driveshaft of an automobile is a mechanical component which transfer torque and rotation to the wheels. Due to the requirement of movement or the rotation at different angles and distance, the component of drive trains cannot be connected directly so to do that Propeller Drive Shaft is generally used. Usually High-quality steel (Steel SM45C) is a prevalent material for Propeller Drive Shaft fabrication. Many automobile industries still use the conventional Propeller Drive Shaft whose primary concern is cost reduction rather than overall weight of the vehicle.

John Weeton [1] clarified the possibilities of replacement of conventional steel material by composite material in automobile field. In recent years' composite materials have been used widely due to its advantages over the conventional materials. The composite Propeller Drive Shaft [2] has advantage such as high strength, weight reduction, electrically non-conductive, long fatigue life and also it reduces bearing and journal wear. Propeller Drive Shaft must possess the capability of transmitting power and rotation at different angles between the transmission and rear axle. Method of converting a constrained optimization problem to an unconstrained optimization problem proposed by Rajiv and Krishnamurthy [3] Because of their superiority, composites are increasingly employed in structural components and various other industrial use. Some common applications are helicopter rotor blades, aircraft wings in aerospace engineering, and bridge structures in civil engineering applications. Some basics of composite materials are discussed in further section for better familiarization of ourselves with the nature and properties of composite.

In automotive field Propeller Drive Shaft connects the transmission and real axle, also transfers motion and torque. As the torque is produced in the engine and it is transferred to rear axle to move the vehicle in forward and reverse direction, the purpose of the Propeller Drive Shaft is to provide uninterrupted flow of power to the axle. The Propeller Drive Shaft and differential are used to transfer this torque.

Composite materials are basically mixture of different materials it is manufactured with an aim to utilize advantage of individual structures in a single structure material. The components are blended together at macroscopic level but they are not soluble in each other [4]. The root factor is the microscopic examination of a material where the constituents can be analyzed by keen observation. Different materials will be combined on a microscopic scale, like in alloying of metals, however the produced material is, for all practical uses, microscopically homogeneous, i.e. constituents cannot be distinguished by the naked observation and acts as a single material. The advantage of composite materials is that, if properly designed, they usually have the best properties of their constituents and often some qualities that none individual has. Several properties such are strength, fatigue life, stiffness, temperature-dependent behavior, corrosion resistance, thermal insulation, wear resistance, thermal conductivity, attractiveness, acoustical insulation and weight can be enhanced but some of the properties are in contradiction with one another, e.g., thermal insulation versus thermal conductivity. So our objective is to create the composite with our required characteristics as per our design. There are two main components of composite materials. One is binder or matrix which surrounds the other material is reinforcement or 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.

II. METHODOLOGY



III. DESIGN AND SPECIFICATION OF DRIVE SHAFT

For this project we have considered FORD MUSTANG car and four different materials for the study and optimization of Propeller Drive Shaft and its effect on the vehicle.

- SM45C (Conventional steel shaft)
- E-Glass/epoxy
- Carbon/epoxy
- Kevlar 49

➢ *Assumptions:*

In the analysis of the composite Propeller Drive Shaft following assumptions are made.

- The shaft rotates at a constant speed about its longitudinal axis.
- The shaft has a uniform, circular cross section.
- The shaft is perfectly balanced, i.e., at every cross section, the mass center coincides with the geometric center.
- All damping and nonlinear effects are excluded.

The stresses-strain relationship for composite material is linear and elastic, i.e., Hooke's law is applicable for composite materials.

properties	Symbol	Unit	Steel (SM 45C)	Carbon /epoxy UD	E-glass/ epoxy UD	Kevlar /epoxy UD
Young's modulus (x-direction)	E_x	GPa	207	209	45	80
Young's modulus (y-direction)	E_y	Gpa	207	9.45	10	55
Ult.Tensile strength (x-direction)	σ_{ut}	MPa	650	1979	1100	1300
Poisson's ratio xy plane	M	-	0.29	0.27	0.3	0.34
Poisson's ratio yz plane	M	-	0.29	0.4	0.61	0.34
Poisson's ratio zx plane	M	-	0.29	0.27	0.3	0.4
Shear modulus xy plane	G	MPa	81395	5500	5200	2200
Density	P	Kg/m^3	8760	1600	2000	1400

Table 1. Properties of materials

IV. MATHEMATICAL ANALYSIS

The torque generated by the engine = 280lb-ft = 380N-m
Over all gear ratio = 4.23*2.55

Maximum torque transmitted to the shaft T = torque generated by engine x overall gear ratio = 4100 N-m (1)

Allowable stress is obtained by considering factor of safety, $\sigma_{allowable=} (\sigma_{ultimate})/FoS$ (2)

Torsional shear strength is 0.18 times the Allowable stress, $\tau=0.18\sigma_{allowable}$ (3)

The diameter, d is calculated by the relation, $d=[(16xT)/(\Pi x\tau)]^{1/3}$ (4)

After this we take the nearest diameter value of standard size from reference book.

For proper strength we take hollow shaft of 3.2mm thickness(t) and using this the outer and inner radius are calculated from relation, $r_o = d/2$ and $r_i = r_o - t$.

Mass of Propeller Drive Shaft is calculated by the product of density of material and volume of shaft $m = \rho AL$ (5)

To find the percentage mass reduction let us consider,
a = mass of the steel shaft
b = mass of the composite shaft therefore, percentage mass reduced = [(a-b)/a] x 100 (6)
d_o = outer diameter of shaft
d_i = inner diameter of shaft
L = length of the shaft = 1430 mm
A = cross sectional area of the shaft
factor of safety = 3

Fundamental Natural frequency of shaft is obtained by using Timoshenko's beam theory,

$$1/Ks^2 = 1 + [p^2 \times \Pi \times r_m/(2L^2)] \times (1 + [fs \times E_x/(G_{xy})] \quad (7)$$

$$Fnt = Ks \times [30 \times \Pi \times p^2 / L^2] \times [E_x \times r_m^2 /(2\rho)] \quad (8)$$

$$Ncrt = 60\ Fnt \quad (9)$$

Ks = shear coefficient of lateral natural frequency
p = 1, first natural frequency
r_m = mean radius of shaft
fs = 2 for hollow shaft
Fnt = natural frequency, Hz
Ncrt = critical speed, RPM

As long, thin and hollow shaft are vulnerable to torsional buckling so torsional buckling(Tcr) of composites are calculated as,

$$Tcr = (2 \times \Pi \times r_m \times t) \times (0.272) \times (E_x \times E_y^3)^{0.25} \times (t/r_m)^{1.5} \quad (10)$$

V. MODELLING AND MESH GENERATION

A. *Cad Modelling*

For geometry construction the length of propeller shaft is taken as 1430 mm and the calculated diameter is 90 mm.

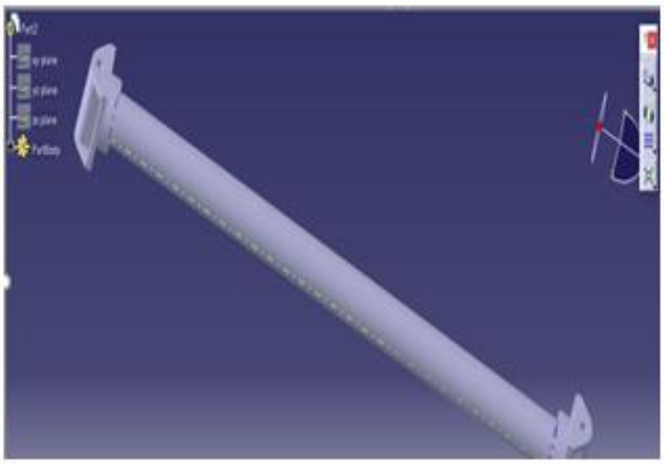


Fig 1:- Cad modelling

B. *Mesh Generation*

The complete structure analysis of the propeller drive shaft in present case follows three major steps. Preprocessor, solutions and post processor. Preprocessor involve CAD geometry, Meshing and Boundary conditions.

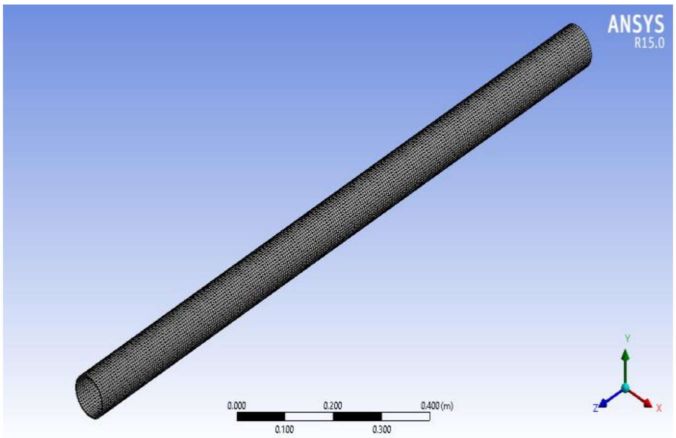


Fig 2:- Generated Mesh

VI. RESULT AND DISCUSSION

A. *Torsional Analysis*

The primary load carried by a Propeller Drive Shaft is torsion. The long thin hollow shafts are vulnerable to torsion. Externally applied forces, moments and state inertial forces such as gravity are imposed over the propeller drive shaft. 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.

B. *Boundary condition and Loading:*

- The one end of the Propeller Drive Shaft is constrained in all direction.
- The moment of 4100 N-m is applied at the other end.
- Material properties of SM45C alloy Steel and of the composites are from ANSYS library created during Analysis.
- The solver used for this FEM analysis is Mechanical APDL solver.

A. *Total Deformation Result*

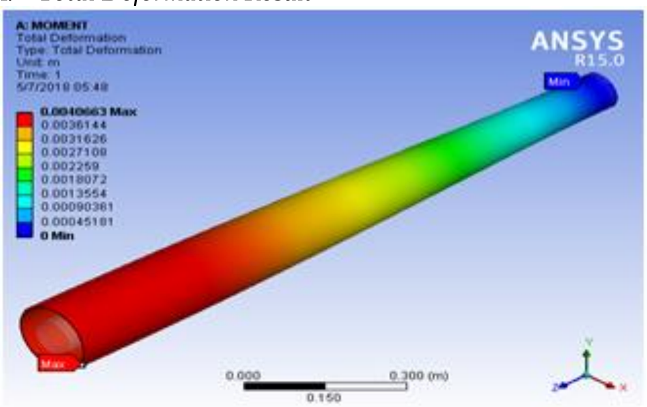


Fig 3 (a):- Carbon/Epoxy

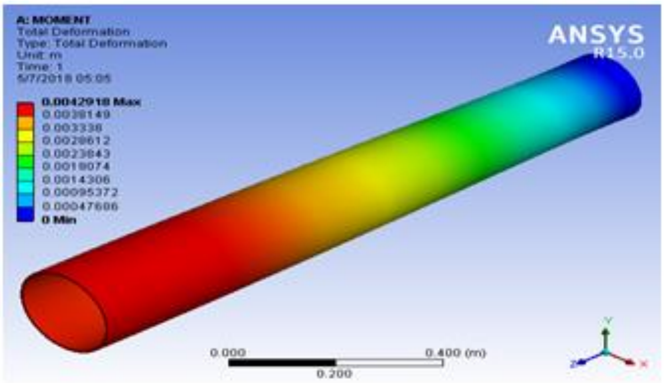


Fig 3(b):- Glass/Epoxy

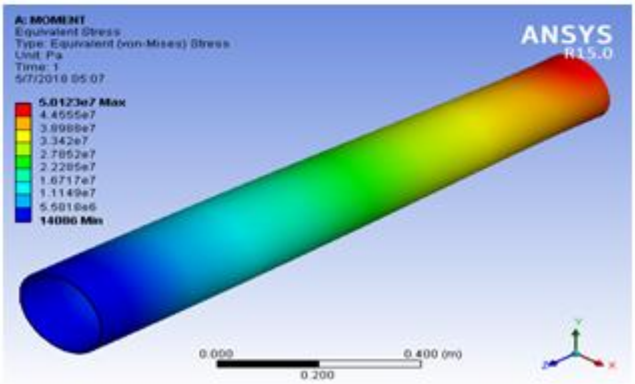


Fig 4(b):- Glass/Epoxy

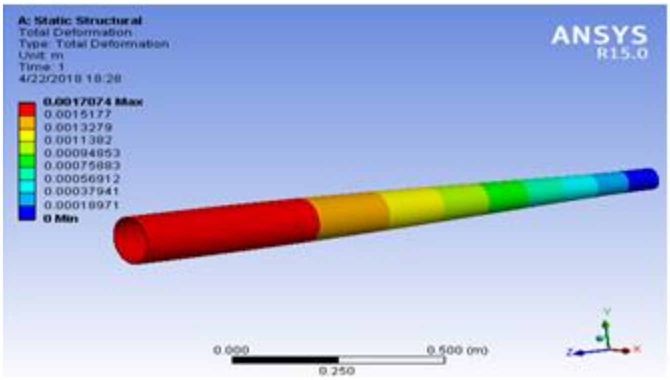


Fig 3 (c):- SM45C

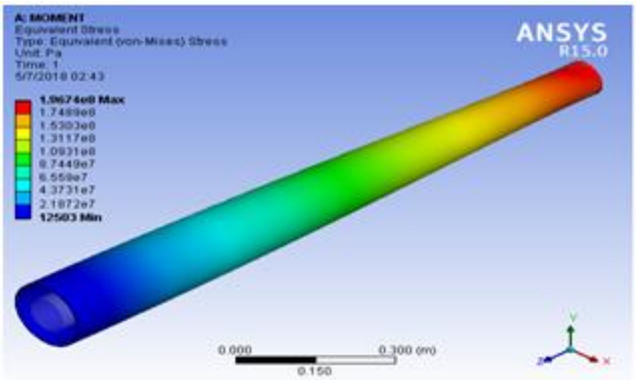


Fig 4(c):- SM45C

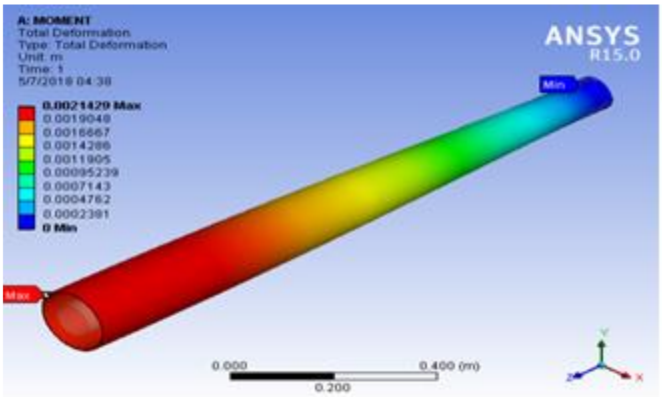


Fig 3(d):- Kevlar/Epoxy

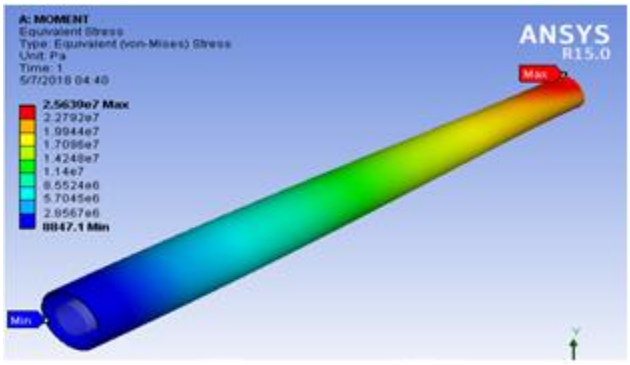


Fig 4(d):- Kevlar/Epoxy

B. Equivalent (Von-Mises) Stress Result

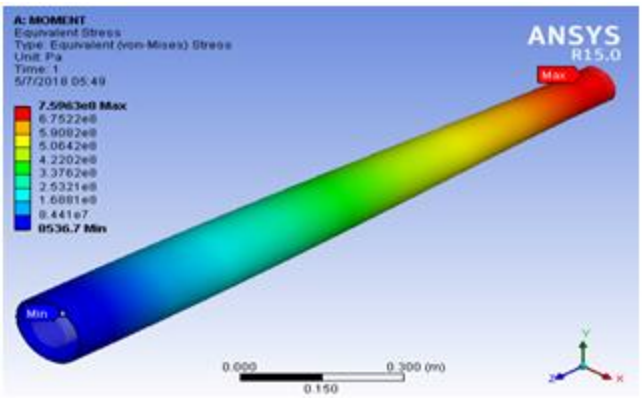


Fig 4(a):- Carbon/Epoxy

C. Equivalent Elastic Strain Result

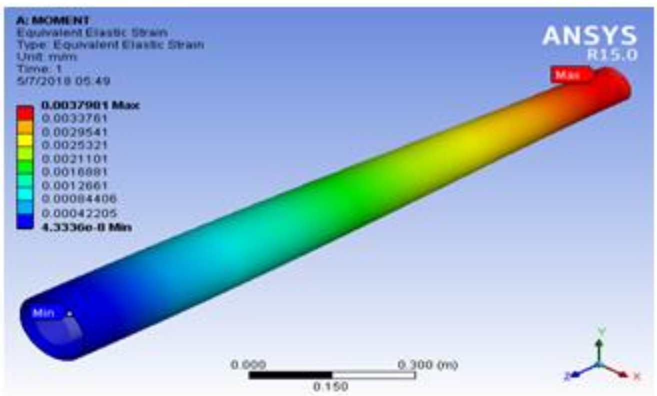


Fig 5(a):- Carbon/Epoxy

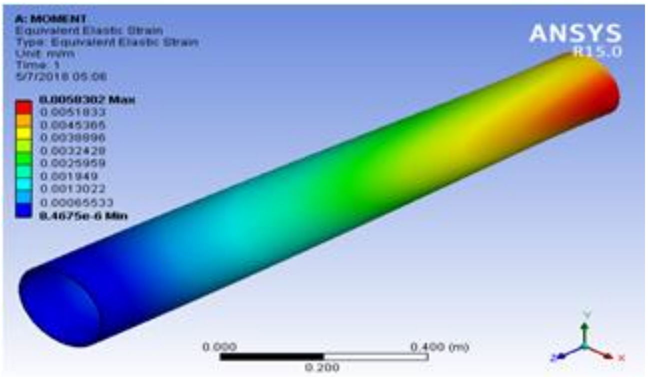


Fig 5 (b):- Glass/Epoxy

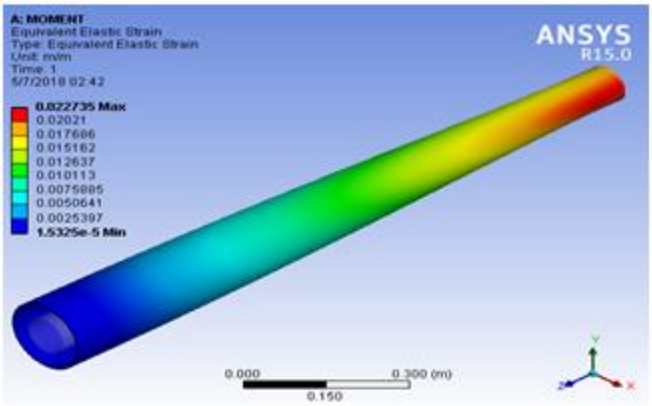


Fig 5(c):- SM45C

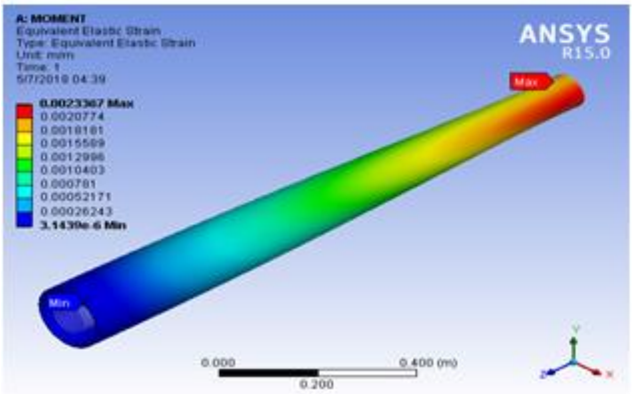


Fig 5(d):- Kevlar/Epoxy

➢ *Result Tables*

These results are obtained from the mathematical calculations as well as from the software we used for the analysis,

Parameter	Unit	SM45C	Carbon/epoxy	Glass/epoxy	Kevlar/epoxy
Natural frequency, Fnt	Hz	6893.7	13986.7	6468	9370.6
Critical speed, Ncrt	RPM	413623	839202	388080	562236
Torsional buckling load, Tcr	N	43076.7	4264.6	3030.9	12569.4
Mass, m	Kg	10.93	2	2.5	1.75
%mass reduced	-	-	81.7	77.12	83.98

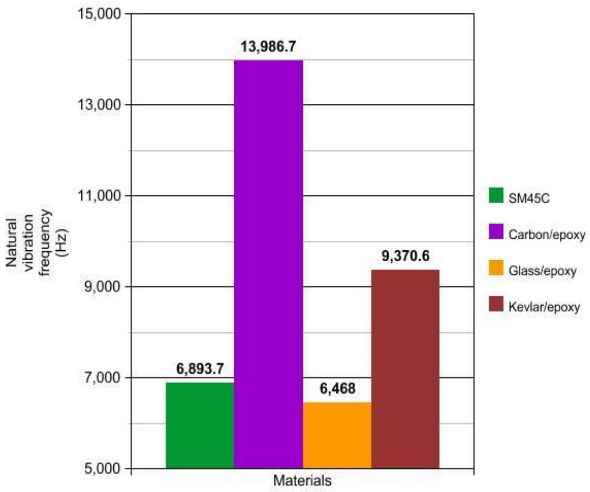
Table 2. mass result and comparison

Material	Total Deformation	Equivalent (Von-Mises) Stress	Equivalent Elastic Strain
Units	mm	MPa	m/m
Steel	17.99	196.7	0.002273
Carbon/Epoxy	4.066	759	0.00379
Glass/Epoxy	4.29	50.12	0.00583
Kevlar/Epoxy	2.14	25.63	0.00233

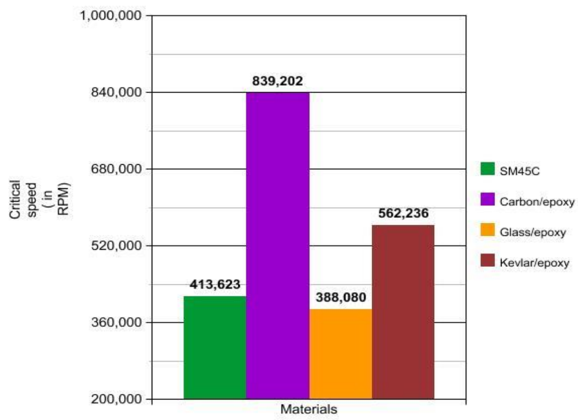
Table 3. Torsional analysis result comparison

➢ *GRAPH*

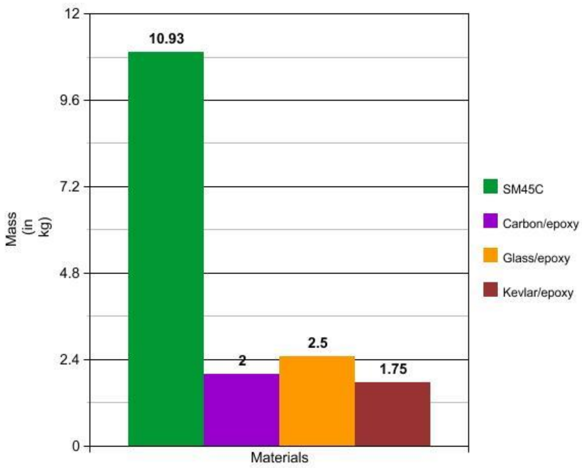
Following graph shows the variation of values of different factor among the materials we have taken for the propeller drive shaft,



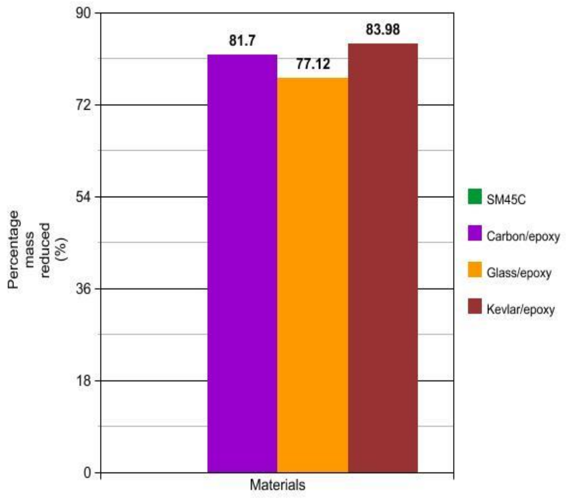
Graph 1. Natural vibration frequency



Graph 2. Critical speed of the shaft



Graph 3. Mass of the shaft



Graph 4. % reduction in mass, SM45C as reference

VII. CONCLUSION

- Kevlar/epoxy has better performance in weight than others but considering cost, carbon/epoxy works best.
- Carbon fiber possess high strength when combined with suitable resin and is comparatively easier to manufacture.
- Considering all the factors in mind the best suited composite for Propeller Drive Shaft fabrication is Carbon/epoxy.
- Torsional Buckling Capacity is best for epoxy reinforced carbon.
- Critical Natural Frequency is best for carbon epoxy
- Composite materials are used also for gears, automotive parts fiber Glass/Epoxy leaf springs for heavy trucks and trailers and many other mechanical transmission devices.

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