ANALYSIS AND COMPARISON OF AN AUTOMOBILE DRIVE SHAFT FOR DIFFERENT TYPES OF FIBER REINFORCED COMPOSITES

Suraj Kadam[1], Rameshwar Chavan[2]

[1]PG student, Deogiri Institute of Engineering and Management Studies, Aurangabad, Maharashtra, India.
[2]Professor, Dept. of Mechanical Engineering, Deogiri Institute of Engineering and Management Studies, Aurangabad, Maharashtra-431005, India.

---***---

Abstract - *The last few years have seen the increasing use of composite materials in many fields of engineering applications. Polymer composites are today widely used to design the automobile components in view of their outstanding specific stiffness and strength properties. Composite shafts for automotive applications are among the most current areas of investigation. Weight reduction can be primarily achieved by the introduction of better material. The conventional system uses metallic shaft, has inherent limitations like heavy weight, corrosion, flexibility problems, vibrations, which magnifies with increase in shaft diameter. Advanced composite materials offer the potential to improve propulsion shafting, by reducing weight, bearing loads, alignment problems, flexibility, and vibration damping characteristics.*

The present work deals in the evaluation of the suitability of fibers such as carbon, glass and jute with epoxy resin for the purpose of composite drive shafts for automotive application with the aid of commercial software ANSYS by virtue of FEM Analysis. The static structural and natural frequency analysis were made which are primitive requirement for rotating element like drive shafts. At long last, it is presumed that over all investigations there is a possibility of about 80% weight reduction is conceivable over steel drive shaft.

***Key Words*: Driveshaft, Composite, Weight Reduction, Carbon, Glass, Jute, Epoxy**.

1. INTRODUCTION

Composite material has been regarded as potential option for fabrication of drive shafts due to their high specific stiffness and specific strength, since 1970s. Drive shafts made of composites have used for many years by the militarily and aerospace sectors. Most popular example of this type of the driveshaft is the shaft for the Boeing Vertrol Model 234 helicopter[1]. In this shaft center portion of aluminum material is replaced by composites and this glass hybrid shaft reduces weight by 20-25 % and increases its life cycle period by almost three times. As composite shaft can be made in one piece of required length and advantage of these long shafts is that, they would reduce the number of bearing supports, which causes great reduction in maintenance costs and also the weight of the transmission system. The steel conventional shafts of long lengths are generally made up into two pieces with three hook joints and center support bearing with bracket, which causes increase in total weight of the transmission assembly and overall weight of the vehicle. Substituting required conventional metallic structures by composite material made structures provides many advantages like, higher specific stiffness, strength, fatigue life, thermal insulation, thermal conductivity, wear resistance, and corrosion resistance[2].

Composite materials can efficiently adapt, to meet the required aspects of design such as strength, stiffness. Simultaneously, composite shafts weight is less than that of steel or aluminum shafts of similar strength. It is feasible to manufacture composite drive shaft in one piece to avoid all complications of the two piece steel drive shaft assembly. Researchers have investigated about joining method of the shaft made up of composite to the yokes of constant velocity joints which are made up of a conventional material with the experiments and these experiments gives results of design analysis in many aspects. The composite materials such as Carbon, glass, and graphite with suitable resins are widely used because of their specific properties with respect to lower density. These advanced composite materials ideally fitted long, power propeller shaft applications[2].

Generally, not all of above mentioned properties are getting improved at the same time nor there is requirement for the same in each application considering the fact that some of the above properties conflict one another e.g., thermal conductivity versus thermal insulation. The objective is mainly to obtain a material that has only the characteristics required to meet the design requirements[3].

Composite materials have a long time history of its applications. Precise beginnings of their usage are unknown, but recorded history contains references about the use of some form of composite materials. For example, Israelites used a straw which was to strengthen mud bricks. Plywood was used by the ancient Egyptians when they found that wood could be modified by some minor processing to achieve superior strength, resistance to thermal expansion as well as to swelling caused by the absorption of moisture. More recently, fibre-reinforced, resin-matrix composite materials that have high stiffness-to-weight ratios and strength-to-weight ratio become very important in weight stringent applications like aircrafts, space vehicles, etc.[3].

1.1 Importance and Functions of the Drive Shaft

Driveshaft in an automobile is connected between the output shaft of transmission gear box and the input shaft of differential. Generally due to misalignment of engine gearbox and differential gearbox, drive shaft is mounted in inclined position with two universal joints. These two joints in pair act as a constant velocity joints and accommodate the angular movement with its associated fluctuation in speed. Driveshaft of an automobile must transmit required torque from engine gearbox to the differential gear box. The drive shaft must also be capable of rotating at a speed required by the vehicle. The drives shaft must accommodate constantly changing of angles caused by the movements of transmission, differential and axles. The drive shaft must also be capable to accommodate slight variation in length while transmitting torque. The drive shaft should provide a uninterrupted and smooth flow of power to the axles[4].

Fundamental purpose of the driveshaft is that it must transmit torque engine to the differential gear box. In running condition, it is required to transmit low-gear torque which is a maximum torque developed by the engine. When the rear wheels gets roll over the bumps in the road, the differential with axles move up and down. Due to this up and down movement of axles, angles between transmission gear box and differential gets changed and which is followed by variation in lengths also. Similarly length variations are caused due to torque variation and its reaction, deflections of roads, braking loads, etc. A slip joint which is also called a universal joint is used to compensate for these variations[2,4].

1.2 Basic concepts of Composite Materials

The word composite meaning is the material witch is formed by combination of two or more materials which are combined on macroscopic level to form another new useful material. In most of the composites the macroscopic signifies that their composition can be view by naked eye. The best advantageous part of the design of the composites offer is that they provides best quality of their constituents and sometimes gives new property that neither constituent possesses. We can mainly differentiate composite and an alloy based on the constituents. In the composites, constituent material are insoluble with each other and individual constituents used to retain their properties, where as in alloys, constituent materials are soluble and new material which is formed by alloying gives different properties than that of original constituents. Advanced composite materials are used to distinguish with ultrahigh strength and stiffness with use of fibers such as boron, graphite and some percentage of glass. These fiber materials give two to three times better performance over other conventional materials on a basis of weight comparison[5].

1.2.1 Classification of Composite Materials

Composite materials in general are categorized based on the kind of reinforcements or the surrounding matrix. There are four commonly accepted types of composite materials based on reinforcements[6]:

a) Fibrous composite materials that consist of fibres in a matrix.

b) Laminated composite materials that consist of layers of various materials.

c) Particulate composite materials that are composed of particles in a matrix.

d) Combinations of some or all of the first three types.

And the major composite classes based on structural composition of the matrix area[6].

a) Polymer-Matrix Composites.

b) Metal- Matrix Composites.

c) Ceramic- Matrix Composites.

d) Carbon- Carbon Composites.

e) Hybrid Composites.

1.2.2 Types of fibers

Generally, strands are chiefly delegated Natural filaments and Man-made or Synthetic filaments. There are such huge numbers of common filaments which are acquired from nature, for example, sisal, coconut, banana, fleece, coir, jute, flax, hemp, cotton, kenaf, abaca, ramie, silk, pineapple. Green composites are the unrivaled classes of composite materials wherein the parts (grid or fortification) are gotten from the nature Natural filaments are named creature cellulose strands and which are additionally isolated into bast, leaf, seed and organic product filaments.

The mechanical conduct of fiber-strengthened composites are basically reliant on their innate capacities to empower pressure exchange, which thusly relies upon the fiber quality, framework quality and the quality of interfacial bond between the fiber/lattice. A portion of the significant fiber can possibly fulfill the prerequisites of various applications in synthesis with epoxy sap and metals[7].

A. Glass Fiber:

Glass strands are a standout amongst the most generally utilized polymer fortifications with almost 90% of all FRPs made of glass filaments of which, the most established and the most well-known structure is the E-glass or electrical evaluation glass. Different sorts of glass strands incorporate A-glass or soluble base glass, C-glass or synthetic safe glass, and the high quality R-glass as well as S-glass. Under research facility conditions glass filaments can oppose elastic worries of around 7000 N/mm², though business glass strands achieve 2800 to 4800 N/mm[8].

B. Carbon Fiber:

Carbon filaments (GFs) are the new type of high quality materials made of graphitic and non-crystalline areas of all strengthening strands, carbon strands offer the most astounding explicit modulus and quality. Moreover, carbon strands can hold its elasticity even at high temperatures and are autonomous of dampness. Carbon strands don't really break under worry rather than glass and other natural polymer filaments. Carbon strands are adaptable, on account of their incredibly high solidarity to weight and firmness to weight proportions. In addition, they are artificially idle, electrically conductive and infusible. The firmness and modulus of flexibility of carbon strands can extend from glass to multiple times that of steel. The most generally utilized sorts have a modulus of 200-400 N/mm²[8].

C. Kevlar Fiber:

Kevlar is an aramid fiber of Poly-para-phenylen-terephtalamide (PPTA) with an inflexible atomic structure. Aramid like strands were first created in 1960s as another for steel fortifications in elastic tires. In any case, when built up the aramid strands were likewise discovered appropriate for ballistics and as surrogate for asbestos. Kevlar filaments are regularly utilized for elite composite applications where light weight, high quality and solidness, harm obstruction, and protection from weakness are of most extreme significance. Aramid strands are regularly utilized in those applications that requests high quality and low weight together with a high effect opposition. Probably the most successive uses of aramid materials incorporate slug evidence vests, cooling vehicles, transport bodies and recently towards basic fortifying of common structures[9].

D. Sisal Fiber:

Sisal can be effectively developed in a short estate time. The plant develops normally in the supports of fields and railroad tracks. Study showed that around 4.5 million tons for each year sisal fiber are removed all through the world. It is separated from the leaves of the sisal plant (Agave sisalana), which is at present planted in tropical countries of Africa, the West Indies and the Far East. By and large, any sisal plant contains 200–250 sisal leaves in which every leave can have at any rate 1000–1200 fiber groups. Altogether, a sisal plant has 4% fiber, 0.75% fingernail skin, 8% dry issue and 87.25% water[10].

Sisal fiber separated from the leaves is arranged into three kinds: mechanical, lace and xylem. Mechanical filaments are removed from the fringe of the leaf. They have appearance like horseshoe and can be isolated by the extraction procedure. The strip type is the longest fiber and could be part up longitudinally amid the fiber preparing. The xylem strands have sporadic shape and separate effectively amid the preparing[10].

E. Jute Fiber:

The utilization of jute strands as support for advancement of composite materials has expanded in these days on the grounds that the vexation appeared by the earth because of increment in fuel costs, exhaustion of non-renewable energy sources, an Earth-wide temperature boost are the significant concerns which power the scientists to work in the zone of green composites. The jute fiber strengthened composites additionally supplant old materials, for example, steel and wood. Because of the huge extension in the field of composites the need to locate an option in contrast to the glass fiber fortified composites is inevitable because of its non-biodegrading property. Advancement of a superior composite utilizing characteristic filament has been a noteworthy zone of concern. As principle focal point of this exposition is to check the reasonableness of Jute fiber for driveshaft application, in this way subtleties of jute fiber and assembling of strengthened composites from it are talked about in consequent segment[11].

1.2.3 Applications of Composite Materials

The common applications of composites are extending day by day. Nowadays they are used in medical applications too. Some other fields of applications are[6]:

Automotive : Drive shafts, clutch plates, fibre Glass/Epoxy leaf springs for heavy trucks and trailers, rocker arm covers, suspension arms and bearings for steering system, bumpers, body panels and doors.

Aerospace: Drive shafts, rudders, elevators, bearings, landing gear doors, panels and floorings of airplanes, payload bay doors, remote manipulator arm, high gain antenna, antenna ribs and struts etc.

Marine: Propeller vanes, fans & blowers, gear cases, valves &strainers, condenser shells.

Chemical Industries: Composite vessels for liquid natural gas for alternative fuel vehicle, racked bottles for fire service, mountain climbing, underground storage tanks, ducts and stacks etc.

Electrical & Electronics: Structures for overhead transmission lines for railways, Power line insulators, Lighting poles, Fibre optics tensile members etc.

2. METHODOLOGY

2.1 Computer Aided Design (CAD)

Computer aided design is the tool used by engineers and other professional to provide more capability and accurate tool than a manual drafting. It is also called as Electronic drafting or Digital drafting. Cost and time benefits are increased with the use of CAD technology. Major advantage of usage of CAD is the reduction in designed cycle time and low cost of new product development. It has merged the role of draftsman, designer and engineer. Animation and advanced rendering capabilities of CAD makes easy for designer and end customers to understand product and its design. There are many software of CAD which is popular in industrial and educational field are PTC Creo, Solid Edge, Solid Works, AutoCAD, etc. In this work, 3-D model of driveshaft is made by using Solid Works package.

For CAD geometry construction:

Dimensions for propeller shaft

- The length is taken as 1000 mm
- The outer Diameter is 80 mm
- The inner Diameter is 60 mm

Dimensions for End flanges

- The internal diameter is 60 mm
- The external diameter is 120 mm
- Thickness is 15 mm

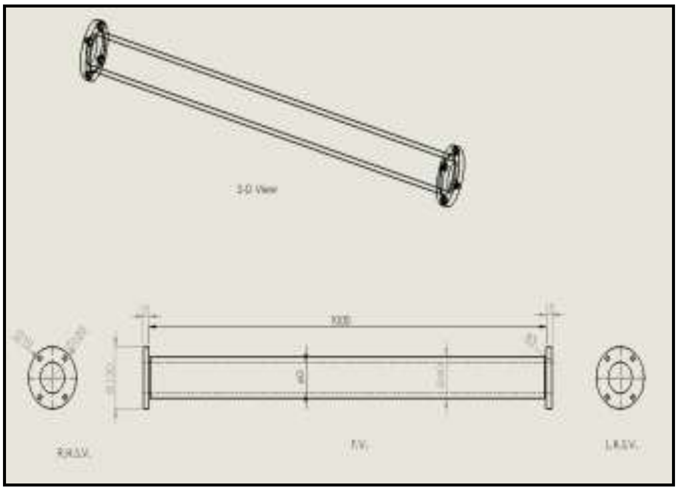


Fig - 1: Propeller shaft

2.3 Finite Element Method (FEM)

As explained earlier, it is one of the CAE tool, mostly used in every automotive industry for design verification. Explicit analysis technique of FEM is used for crash testing of vehicle. Similarly, other components of vehicle are analyzed individually for their design and performance. Static and dynamic analysis of each important component is carried out by FEA packages such as Ansys. For analysis of driveshaft Ansys 16.2 version is used where Static structural and Modal Analysis for natural frequency are performed.

2.3.1 Static Structural

In static structural analysis, loading and response conditions are assumed steady. This loads can be solve by ANSYS solver. It is used to find directional stress, equivalent stress, total deformation, strains, etc. This analysis can be of linear or non-linear type where, nonlinearities like plasticity, stress stiffening and deformations are allowed. Static structural analysis includes standard set of steps to be followed and these steps are used to vary depending on the type of analysis to be performed. Some steps of structure which are common in every static analysis are as follows:

1. Create analysis system
2. Define material: Engineering data
3. Import Geometry or build geometry through modeler.
4. Apply and control of mesh
5. Define boundary conditions and input loads
6. Solve and plot the results.

A. Torsional Analysis: In this analysis, torque of 300 N-m is applied at one end of shaft while other end treated as fixed support.

- **Inputs given:**
  a. Boundary condition: One end is fixed and torque at other end
  b. Torque : 300 N-m
  c. Mesh size: 0.005 m

B. Angular Deformation Analysis: In this analysis, same torque of 300 N-m is applied with given boundary conditions, but commands (APDL) and remote point is given to find out the angular deformation with respect to required axis.

Command used at given remote point:

Measure_pilot=_npilot

Similarly, to obtain the required rotation of the shaft with respect to the x-axis, below command (APDL) is inserted in solution of analysis.

my_rotx=ROTX (Measure_pilot)*57.25

2.3.2 Natural Frequency Analysis

In Finite element methods, a modal analysis is used to determine the natural frequencies and mode shapes of component or structure. It is also used as a starting analysis for other detail dynamic analysis, harmonic analysis and spectrum analysis. This analysis can be performed by ABAQUS, ANSYS or Samcef solver. Modal analysis is of two types depending on the application which are Pre-stress modal analysis and simple modal analysis. After import of geometry, boundary conditions are applied as fixed support or free support depending as per the application. In analysis settings, maximum number of modes can be defined as required. After solving the problem, we will obtain the frequencies for the defined modes and need to convert those frequencies in to deformation plots as mode shape results.

- **Inputs given:**
  - **a.** Max. number of modes = 6
  - **b.** Boundary conditions = Zero displacement at both ends

3. ANALYSIS RESULTS

3.1 Structural steel

- **Material property : Structural Steel**

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Density	7850	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
4	Coefficient of Thermal Expansion	1.2E-05	C^-1
5	Reference Temperature	22	C
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa
12	Field Variables		
13	Temperature	Yes	
14	Shear Angle	No	
15	Degradation Factor	No	
16	Alternating Stress Mean Stress	Tabular	
20	Strain-Life Parameters		
28	Tensile Yield Strength	2.5E+08	Pa
29	Compressive Yield Strength	2.5E+08	Pa
30	Tensile Ultimate Strength	4.6E+08	Pa
31	Compressive Ultimate Strength	0	Pa

Fig - 2: Material properties of Structural Steel

3.1.1 Max. Shear Stress

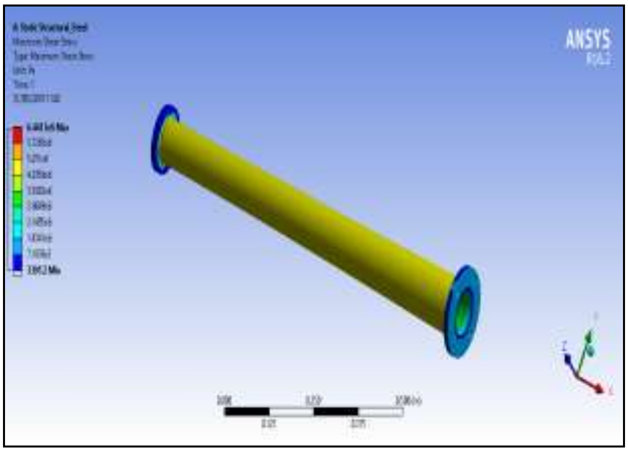


Fig - 3: Max Shear Stress plot of steel shaft

From the ANSYS analysis, maximum shear stress value for structural steel obtained is 6.4417 Mpa.

3.1.2 Equivalent (Von-mises) Stress

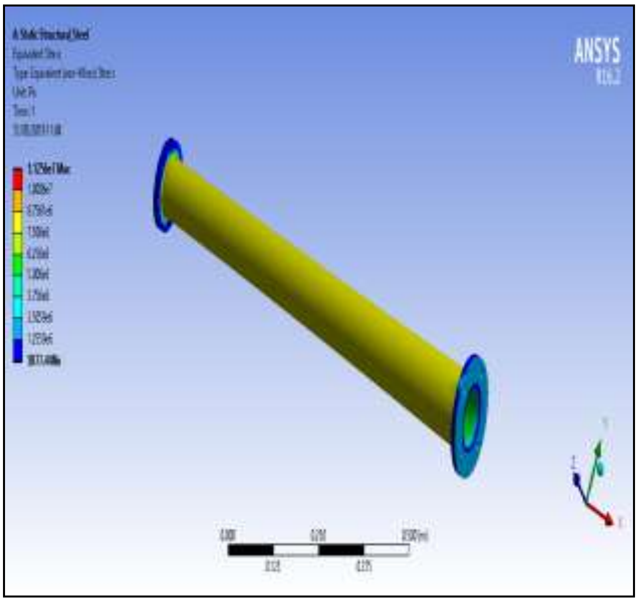


Fig - 4: Equivalent stress plot of steel shaft

Equivalent (Von-mises) Stress value for structural steel obtained is 11.256 Mpa.

3.1.3 Angular Deformation

After solving the problem, angular deformation obtained for structural steel shaft is 0.4095˚ as shown in below figure.

Details of "Commands (APDL)"

Suppressed	No
Output Search Prefix	my_
Invalidate Solution	No
Target	Mechanical APDL
Input Arguments	
ARG1	
ARG2	
ARG3	
ARG4	
ARG5	
ARG6	
ARG7	
ARG8	
ARG9	
Results	
my_rotx	4.0949e-002

Fig - 5: Result in terms of Angular deformation

3.1.4 Natural Frequency Analysis

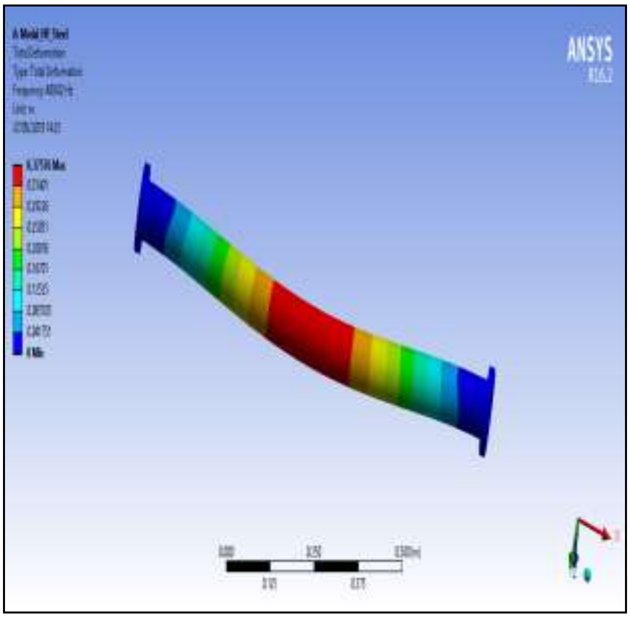


Fig - 6: Total deformation plot for natural frequency at mode 1

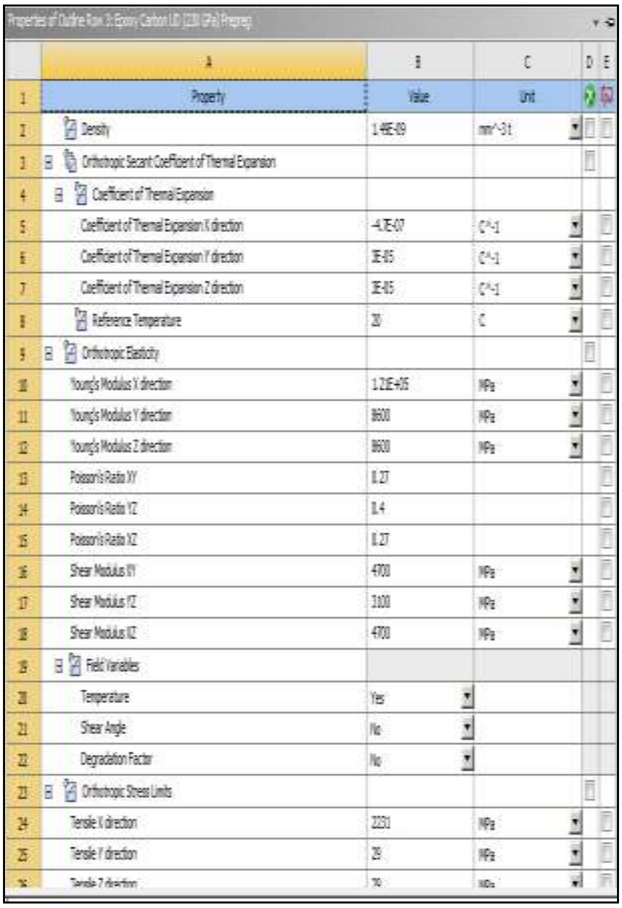
As, number of modes selected is six, it gives six number of frequencies in Hz for the same.

Table -1: Frequencies and deformations of all modes for structural steel

Mode No.	Frequency (Hz)
1	409.02
2	409.15
3	1048.6
4	1048.9
5	1543.5
6	1895.9

3.2 Carbon fiber

- **Material property : Carbon Fiber Reinforced Shaft**



Properties of Outline Row 3: Epoxy Carbon UD (230 GPa) Prepreg

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1.49E-09	mm^-3 t		
3	Orthotropic Secant Coefficient of Thermal Expansion				
4	Coefficient of Thermal Expansion				
5	Coefficient of Thermal Expansion X direction	-4.7E-07	C^-1		
6	Coefficient of Thermal Expansion Y direction	3E-05	C^-1		
7	Coefficient of Thermal Expansion Z direction	3E-05	C^-1		
8	Reference Temperature	20	C		
9	Orthotropic Elasticity				
10	Young's Modulus X direction	1.21E+05	MPa		
11	Young's Modulus Y direction	8600	MPa		
12	Young's Modulus Z direction	8600	MPa		
13	Poisson's Ratio XY	0.27			
14	Poisson's Ratio YZ	0.4			
15	Poisson's Ratio XZ	0.27			
16	Shear Modulus XY	4700	MPa		
17	Shear Modulus YZ	3100	MPa		
18	Shear Modulus XZ	4700	MPa		
19	Field Variables				
20	Temperature	Yes			
21	Shear Angle	No			
22	Degradation Factor	No			
23	Orthotropic Stress Limits				
24	Tensile X direction	2231	MPa		
25	Tensile Y direction	29	MPa		
26	Tensile Z direction	29	MPa		

Fig - 7: Material properties of Carbon Fiber

3.2.1 Max. Shear Stress

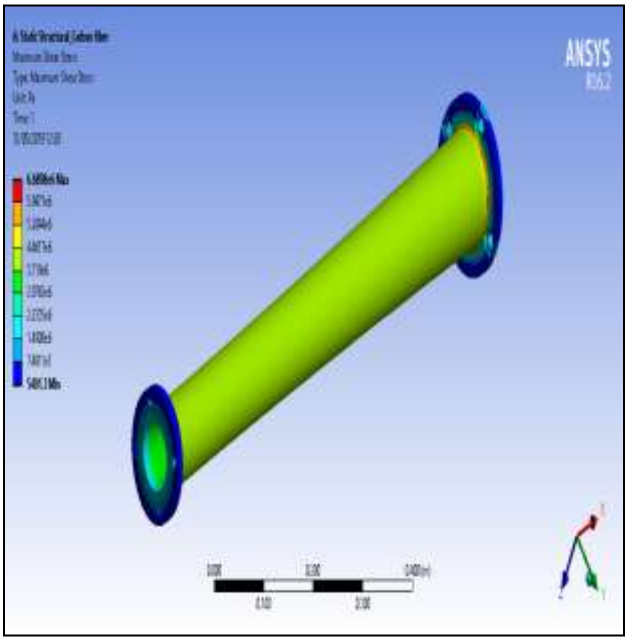


Fig - 8: Max. Shear Stress plot for Carbon fiber shaft

From the ANSYS analysis, maximum shear stress value obtained is 6.68 Mpa, which is close to the shear stress obtained for structural steel analysis.

3.2.2 Equivalent (Von-mises) Stress

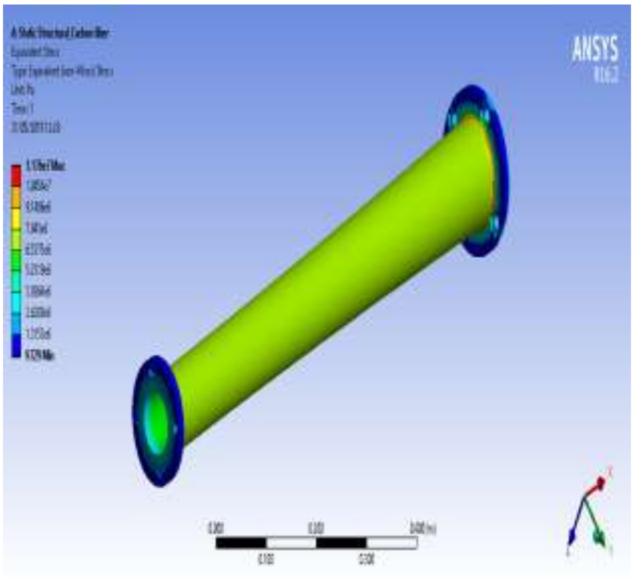


Fig - 9: Equivalent (Von-mises) Stress for Carbon fiber shaft

Equivalent (Von-mises) Stress value for carbon fiber reinforced shaft is 11.76 Mpa.

3.2.3 Angular Deformation

After solving the problem, angular deformation obtained for carbon fiber reinforced shaft is 0.6724° as shown in below figure.

Details of "Commands (APDL)"	
Suppressed	No
Output Search Prefix	my_
Invalidate Solution	No
Target	Mechanical APDL
Input Arguments	
ARG1	
ARG2	
ARG3	
ARG4	
ARG5	
ARG6	
ARG7	
ARG8	
ARG9	
Results	
my_rotx	0.67243

Fig - 10: Result in terms of angular deformation

3.2.4 Natural Frequency Analysis

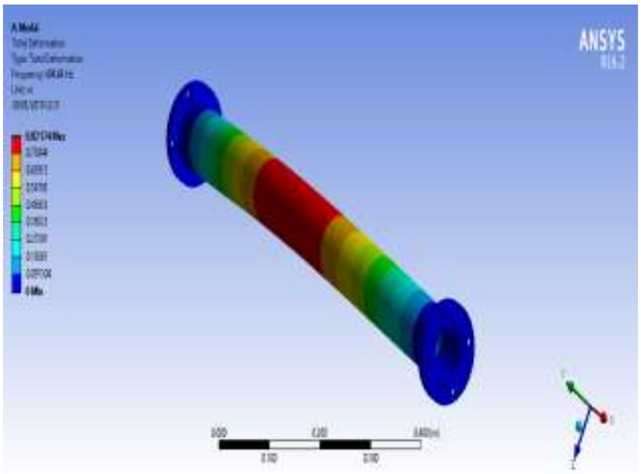


Fig - 11: Total deformation of natural frequency at mode 1

As, number of modes selected is six, it gives six number of frequencies. Frequencies in Hz obtained from analysis are shown in below,

Table -2: Frequencies at all modes for Carbon Fiber Reinforced material

Mode No.	Frequencies (Hz)
1	494.64
2	494.73
3	874.35
4	1057.4
5	1057.6
6	1704.5

3.3 Glass Fiber

- **Material property : Glass Fiber Reinforced Shaft**

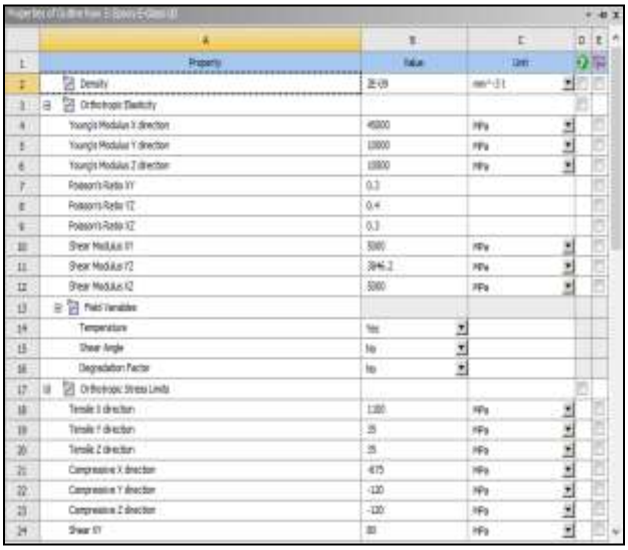


Fig - 12: Material properties of Glass Fiber

3.3.1 Max. Shear Stress

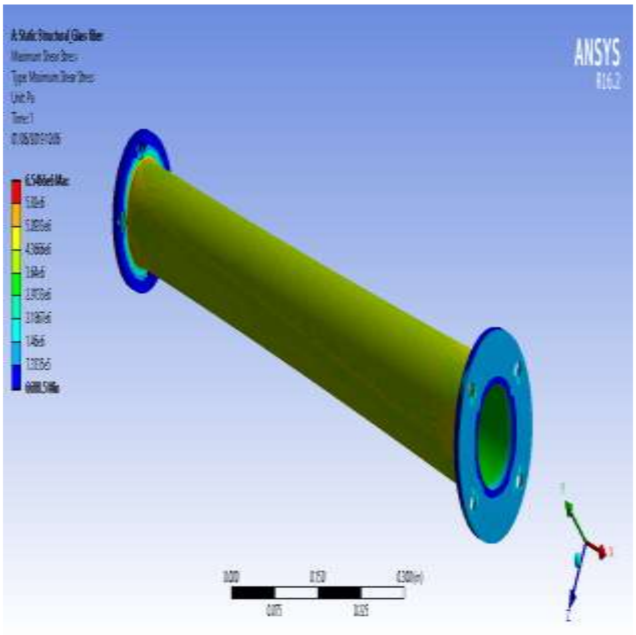


Fig - 13: Material properties of Glass Fiber

Maximum shear stress value obtained for glass fiber reinforced is 6.55 Mpa, which is more than structural steel but less than carbon fiber.

3.3.2 Equivalent (Von-mises) Stress

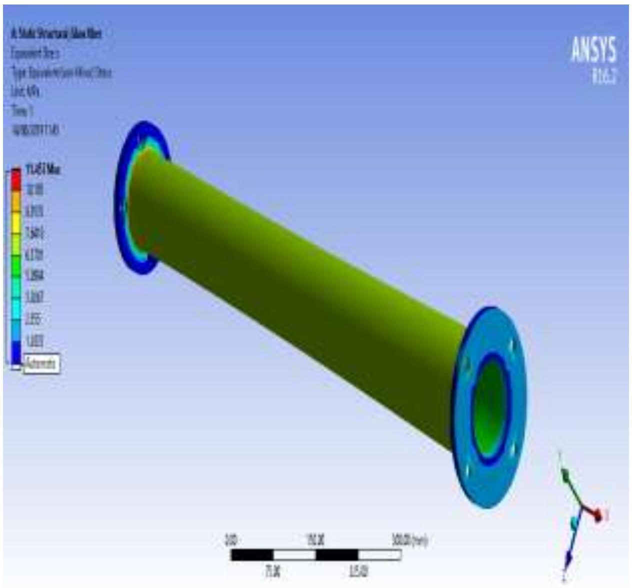
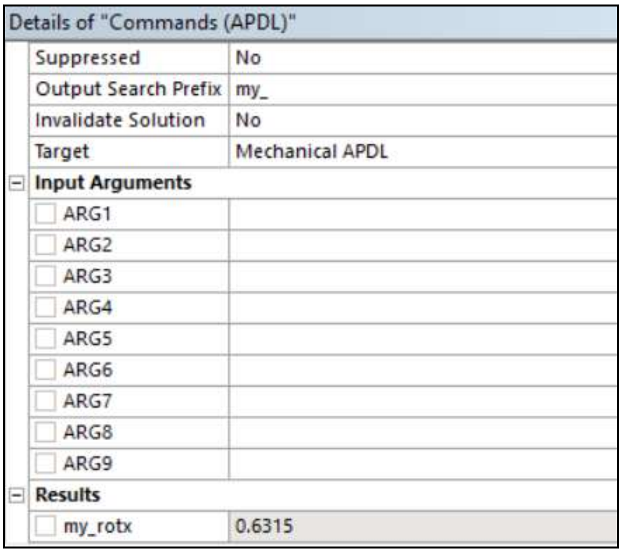


Fig - 14: Equivalent (Von-mises) Stress value for glass fiber

Equivalent (Von-mises) Stress value for glass fiber reinforced shaft is 11.45 Mpa, which is more than structural steel.

3.3.3 Angular Deformation

Angular deformation obtained for glass fiber reinforced shaft is 0.6315° as shown in below figure.



Details of "Commands (APDL)"	
Suppressed	No
Output Search Prefix	my_
Invalidate Solution	No
Target	Mechanical APDL
Input Arguments	
ARG1	
ARG2	
ARG3	
ARG4	
ARG5	
ARG6	
ARG7	
ARG8	
ARG9	
Results	
my_rotx	0.6315

Fig - 15: Result of Angular deformation for glass fiber composite

3.3.4 Natural Frequency Analysis

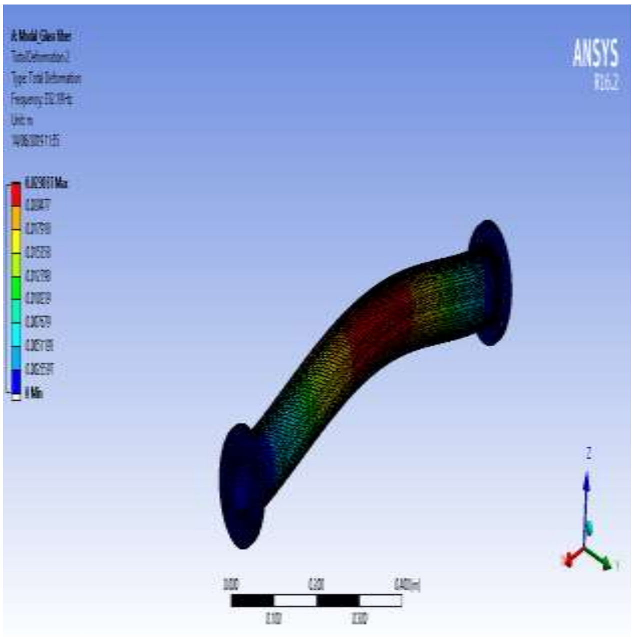


Fig - 16: Total deformation of natural frequency at mode 1

Table -3: Natural frequencies of all modes for glass fiber composites

Mode No.	Frequency (Hz)
1	332.12
2	332.19

3	775.31
4	775.44
5	778.77
6	1306.2

3.4 Jute Fiber

- **Material property : Jute Fiber Reinforced Shaft**

	A	B	C
1	Property	Value	Unit
2	Density	1450	kg m^-3
3	Orthotropic Elasticity		
4	Young's Modulus X direction	26500	MPa
5	Young's Modulus Y direction	8000	MPa
6	Young's Modulus Z direction	8000	MPa
7	Poisson's Ratio XY	0.27	
8	Poisson's Ratio YZ	0.4	
9	Poisson's Ratio XZ	0.27	
10	Shear Modulus XY	4000	MPa
11	Shear Modulus YZ	3650	MPa
12	Shear Modulus XZ	4000	MPa
13	Field Variables		
14	Temperature	Yes	
15	Shear Angle	No	
16	Degradation Factor	No	

Fig - 17: Material properties of Jute Fiber

3.4.1 Max. Shear Stress

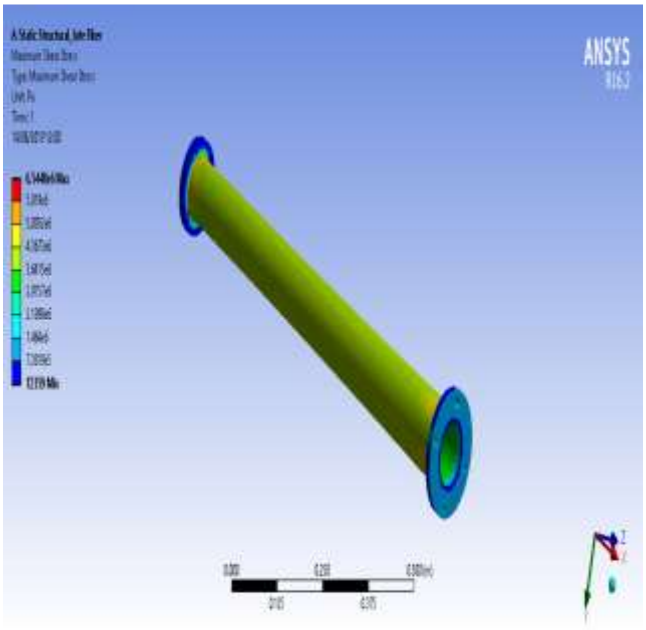


Fig - 18: Max. Shear Stress plot for Jute fiber shaft

Max. Shear Stress for jute fiber composite is 6.54 which are nearly equal to glass fiber.

3.4.2 Equivalent (Von-mises) Stress

Equivalent (Von-mises) Stress value for jute fiber reinforced shaft is 11.45 Mpa, which is same as glass fiber reinforced shaft.

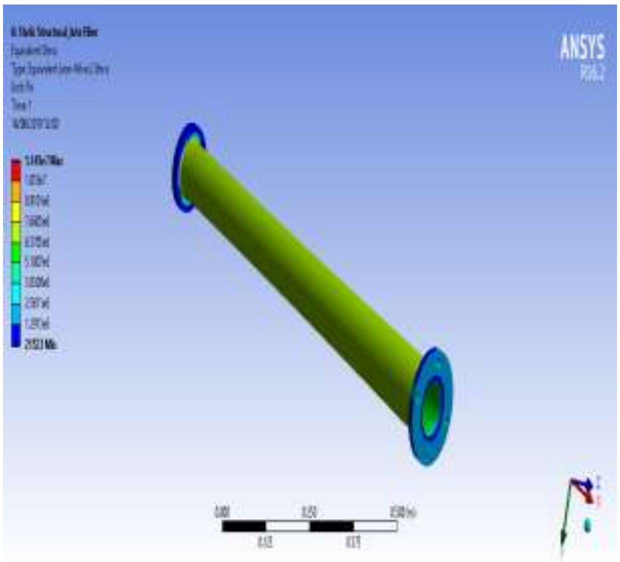


Fig - 19: Equivalent (Von-mises) Stress value for jute fiber

3.4.3 Angular Deformation

After solving the problem, angular deformation obtained for structural steel shaft is 0.7888˚ as shown in below figure.

Details of "Commands (APDL)"

Suppressed	No
Output Search Prefix	my_
Invalidate Solution	No
Target	Mechanical APDL
Input Arguments	
ARG1	
ARG2	
ARG3	
ARG4	
ARG5	
ARG6	
ARG7	
ARG8	
ARG9	
Results	
my_rotx	0.78884

Fig - 20: Result of angular deformation for Jute fiber composite

3.4.4 Natural Frequency Analysis

Natural frequencies for jute fiber reinforced shaft for six numbers of modes in Hz obtained from analysis are shown in below table.

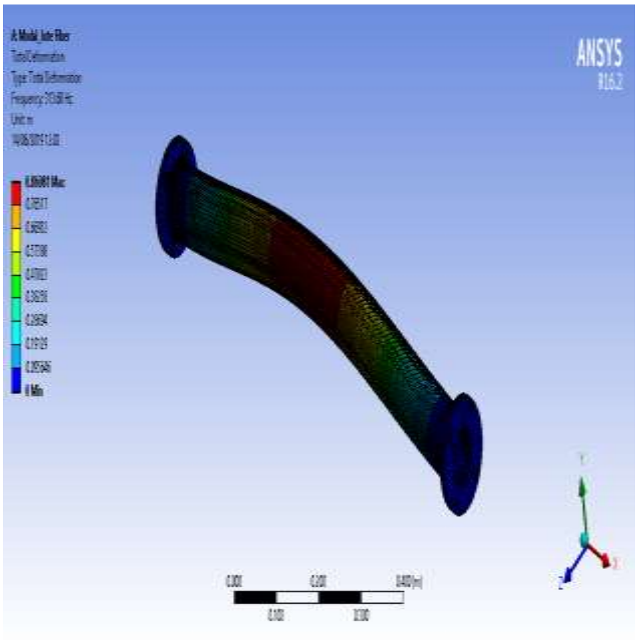


Fig - 21: Total deformation of natural frequency at mode 1

Table -4: Natural Frequencies of all modes for Jute fiber composites

Mode No.	Frequency (Hz)
1	313.68
2	313.75
3	752.18
4	752.33
5	818.37
6	1289.1

4. DISCUSSION

4.1 Based on Torsional Analysis

As analysis is carried out with one end is fixed and torque of 300 N-m is applied at other end. Then, results from ANSYS solver and theoretical calculations are compared, which are found within acceptable range of error. Shear strength is nothing but the strength of shaft where material fails in shear. Results of torsional analysis for all four types of materials are compared by using below graph.

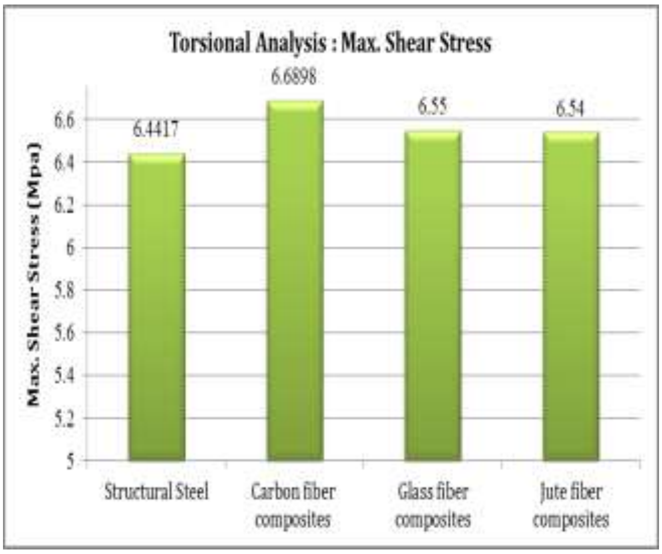


Chart - 1: Comparison of materials on the basis of max. Shear stress

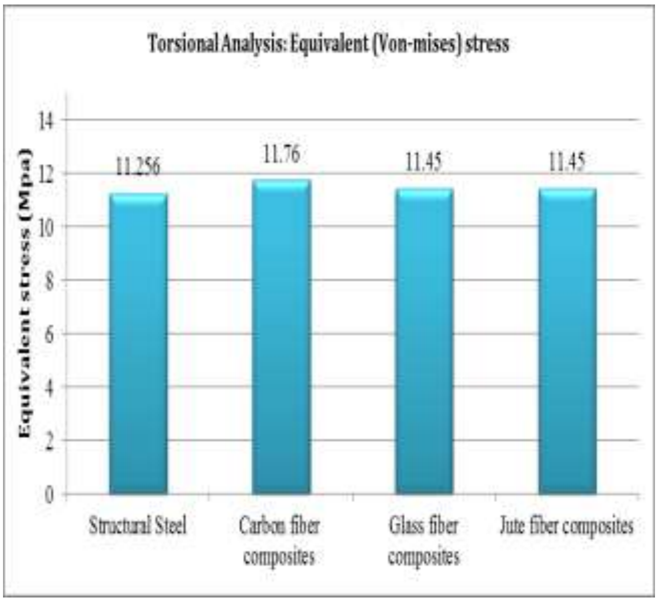


Chart - 2: Comparison of materials on the basis of equivalent stress

It is observed from above graphs that all four materials give maximum shear stress and equivalent stress values nearly equal. On specific basis, maximum shear stress is generated in the carbon fiber composites and minimum is in conventional structural steel.

Angular deformation analysis performed separately, which has given the degree of rotation of shaft with respect to orientation axis after application of required torque.

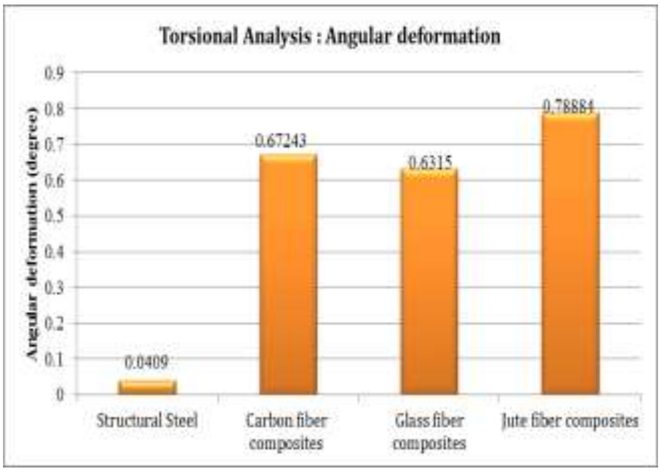


Chart - 3: Comparison on the basis of angular deformation

Rotation of shaft, in case of conventional steel material is lower as compared to that of fiber reinforced composite materials, whereas all three fibers reinforced composite gives the angular deformation in equal range and jute fiber composite has the highest value as obtained. It can be observed that on the basis of angular deformation criteria, jute fiber does not give better results than other used materials.

4.2 On the basis of Natural Frequency Analysis

As discussed earlier, modal analysis is used to find the natural frequencies and corresponding mode shapes. From the analysis of solver below results are extracted for different materials, which are represented in the form of Figure 26.

The Natural frequency and mode shapes are two important modal parameters in the free vibration for dynamic loading. In simulation inertia and damping effects was neglected. It is observed that frequencies obtained in all the cases are well above the critical frequency of the driveshaft, which is around 44 Hz.

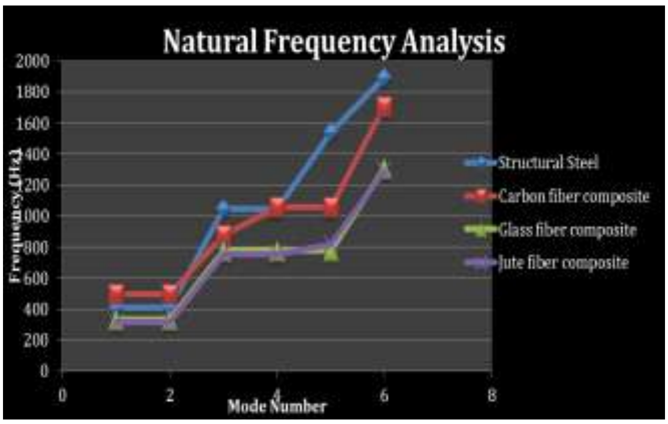


Chart - 4: Graph of natural frequencies for all four materials

Inverse pattern is obtained with reference to the angular deformation analysis i.e., structural steel gives frequencies of higher range and jute fiber composite gives lower range of frequencies in comparison of all four analyzed materials.

If the driveshaft frequency is nearer to the critical frequency then the resonance may occurs and simulation has proved that in all four cases the shaft rotates well above the zone of critical frequency and no chances of resonance condition.

4.3 On the basis of weight saving

After satisfying all requirements as static torsional, natural frequency and random vibration and comparison for Structural steel, E-Glass/Epoxy, Carbon/Epoxy and Jute/Epoxy composite driveshaft from FEA and validation are now ready for comparison on mass.

% mass saving = ((Steel mass – composite mass)/steel mass) x 100

1. **Carbon/Epoxy composite:**
   - % mass saving = ((20.59-3.91)/20.59) x 100
     = 81.01 %
2. **E-Glass/Epoxy composite:**
   - % mass saving = ((20.59-5.48)/20.59) x 100
     = 73.38 %
3. **Jute/Epoxy composite:**
   - % mass saving = ((20.59-3.80)/20.59) x 100
     = 81.54 %

It is observed from above calculation that, Jute/Epoxy composite gives best weight optimization about 81% and with further development in dynamic aspects of design of driveshaft may provide better replacement to conventional steel shaft.

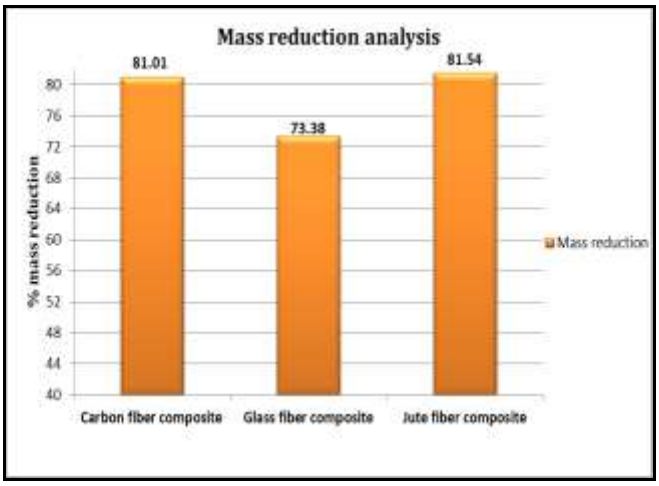


Chart - 5: Graph of % weight saving

5. CONCLUSIONS

Table -5: Analysis results of all materials

Material Name	Weight (Kg)	Max. Shear Stress (Mpa)	Equivalent (Von-Mises) Stress (Mpa)	Angular Deformation (Degree)	Natural Frequencies (Hz)
Structural Steel	20.59	6.4417	11.26	0.0409	1. 409.02 2. 409.15 3. 1048.6 4. 1048.9 5. 1543.5 6. 1895.9
Carbon Fiber	3.91	6.6898	11.76	0.6724	1. 494.73 2. 494.73 3. 874.35 4. 1057.4 5. 1057.6 6. 1704.5
Glass Fiber	5.48	6.55	11.45	0.6315	1. 332.12 2. 332.19 3. 775.31 4. 775.44 5. 778.77 6. 1306.2
Jute Fiber	3.80	6.54	11.45	0.7888	1. 313.68 2. 313.75 3. 752.18 4. 752.33 5. 818.37 6. 1289.1

It is seen from the above study that the fibers reinforced with epoxy resin can be the best alternate to the conventional material in case of automotive driveshaft application because of the following aspects:

1. Nearly 80 % weight reduction is possible with the use of fiber reinforced composite materials.

2. All structural results are in permissible limits with respect to the application for composite materials, which are studied.

3. It provides torsional stiffness equivalent to that of conventional steel.

4. Frequencies obtained for first six modes are well above the critical frequency range of selected application of drive shaft. Therefore composite materials are best suited for driveshaft application.

5. Composite materials are completely free from corrosion.

6. As values of equivalent stress and directional deformation are lower in fiber reinforced composites than steel, which proves that these composite materials will give more life as compared to conventional materials.

Jute is one of the natural fibers which are easily available and cheaper. It will provide good mechanical properties with the help of different chemical treatments, fiber orientations, by varying fiber fraction and fiber orientation angles as a scope of further developments.

As natural fibers are prone to moisture, so removal of moisture leads to improve the fiber/matrix interface and thus rests in improving the mechanical strength. Optimum heat treatment of fibers and matrix material could be a way to improve the mechanical strength.

ACKNOWLEDGEMENT

The author expresses gratitude towards Dr. Ulhas Shiurkar (Director of Deogiri Institute of Engineering And Management Studies) and Prof. P.G.Taur (Head of Mech. Department) for their continues motivation and encouragement. Authors are also thankful to Kalpesh Kakulite, Pankaj Londhe and Nilesh Zhade for the technical discussion and support.

[1] Y.A. Khalid, S.A. Mutasher, B.B. Sahari, A.M.S. Hamouda, Bending fatigue behavior of hybrid aluminum/composite drive shafts, Mater. Des. 28 (2007) 329–334. doi:10.1016/j.matdes.2005.05.021.

[2] L. Gong, X. Gao, H. Yang, Y. Liu, X. Yao, Design on the driveshaft of 3D 4-Directional carbon fiber braided composites, Compos. Struct. 203 (2018) 466–473. doi:10.1016/j.compstruct.2018.06.103.

[3] L. Jones, Front Matter, 2017. doi:10.5406/j.ctt1v2xsbz.1.

[4] R.P.K. Rompicharla, K. Rambabu, Design and Optimization of Drive Shaft with composite materials, Int. J. Mod. Eng. Res. 2 (2012).

[5] D.B. Miracle, S.L. Donaldson, Introduction to composites, ASM Handb. 21 (2001) 3–17.

[6] N.RAJENDAR, N. KUMAR, Design And Analysis Of Composite Drive Shaft, Int. J. Sci. Eng. Technol. Res. 6 (2017) 51–59.

[7] S.T. Peters, Handbook of composites, Springer Science & Business Media, 2013.

[8] P. S, S. KM, N. K, S. S, Fiber Reinforced Composites - A Review, J. Mater. Sci. Eng. 06 (2017). doi:10.4172/2169-0022.1000341.

[9] P.K. Mallik, Fiber-Reiforced Composites - Materials, Manufacturing, and Desing, 2007. doi:13:978-1-4200-0598.

[10] K. Senthilkumar, N. Saba, N. Rajini, M. Chandrasekar, M. Jawaid, S. Siengchin, O.Y. Alotman, Mechanical

properties evaluation of sisal fibre reinforced polymer composites: A review, Constr. Build. Mater. 174 (2018) 713–729. doi:10.1016/j.conbuildmat.2018.04.143.

[11] H. Singh, J.I.P. Singh, S. Singh, V. Dhawan, S.K. Tiwari, A Brief Review of Jute Fibre and Its Composites, Mater. Today Proc. 5 (2018) 28427–28437. doi:10.1016/j.matpr.2018.10.129.