# Design And Optimization Of Automobile Propeller Shaft With Composite Materials Using Fem Analysis

**Apurva D. Diwekar,**
P G Student, Department of Mechanical Engineering,
G H Raisoni University, Amravati, Maharashtra , India.
**Dr. Prashant Singh**
Asst. Professor , Department of Mechanical Engineering, G H Raisoni University, Amravati, Maharashtra, India.

**Abstract:** The Roadway vehicles like cars, buses, trucks and land movers having many mechanical parts in common like Engine parts, Propeller shafts, Gearbox, Brakes, Clutches, Wheels, etc., To make the vehicle fuel efficient which in result make the transportation economical, the weight of that vehicle should be reduced. Since the composite materials are light weight with more strength & stiffness, inclusion of composite materials to conventional steel materials used in auto parts will reduce the weight and improve the mechanical properties of those components. This paper deals with propeller shaft of heavy vehicle to design the shaft for its minimum dimensions to satisfy current problem specification and then replace conventional steel material with composite material. The design of the propeller shaft is first theoretically designed for steel, Carbon/Epoxy and Glass/Epoxy composite material for its safe dimensions. Then they can be created as a part model for respective dimensions in CREO software. After modeling, Torsional buckling analysis can be carried out in the propeller shafts using ABAQUS software to check whether theoretical calculations and analytical results are similar. Then obtained results are compared among those three materials and Carbon/Epoxy composite material is selected as suitable replacement material for conventional steel material in terms of several mechanical properties.

***Keywords:*** Propeller Shafts, Abaqus,Solidworks, Analysis, Composite Material, Conventional Steel, Mechanical Properties

## 1. Introduction

The propeller shaft is an important component in the power transmission of any vehicle. Conventional steel drive shafts have weight and low critical speed limits. If the maximum efficiency of the power transmission is to be achieved, it is most important to reduce the weight of the drive shaft. The shaft in the front engine rear-drive vehicle will reduce the power according to the length of the vehicle. Natural bends occur when long shafts are used, to avoid this they are split using universal joints. When the number of universal joints increases its power transmitting capability decreases. The overall objective of this work is to control the power loss using composite material. Composite materials have high strength and stiffness and they can also withstand high temperature. When the analysis is done by ABACUS & SOLIDWORK software's, properties like Strain energy, Equivalent elastic strain, Total deformation, Von-misses stress are analysed.

## 2. Related Work

Virendra V. Maheta et. al (2015) presented study involves the design, analysis and development of a driveshaft for automobiles Application. This involves calculating the dimensions of the drive shaft based on the required engine power. Accordingly, shaft couplings e.g. universal joints, transmission gears for axle and axle design will be performed considering all static and dynamic loads acting upon it. All design process will be performed with aid of FE analysis using ANSYS software. Optimization will be followed after performing design which includes weight reduction of drive shaft and material selection. It has been observed from results of study that by using composite material in place of steel material, weight reduction of up to about 80% is obtained. When study is carried out for different epoxy materials of composites, it has been observed that Kevlar/Epoxy composite has proved maximum strength compared to the others. When study has been carried out for different fiber angles for composite layers, it has been observed that 90o angle of fibers is providing better fundamental frequency compared to other angles.

Kiran A, Jagtap et. al. (2015) presented the design the driveshaft for heavy duty trucks based on their ability to transmit maximum torque, maximum stress has been produced and perfect component analysis software has been used to evaluate the product by virtual simulation as per the required speed requirements. The power from Transmission shaft should be transmitted to the Rear axle of the vehicle. The axis of the Transmission and the connecting member of Rear axle are at an angle, which changes with the variation in load or the road condition. To facilitate the power transmission at a variable angle a Propeller shaft is used. With respect to the geometrical construction the Propeller shafts are categorized into single piece two-piece and three-piece propeller shafts. In case of two or multi stage propeller shaft length of the rear propeller shaft is subjected to variation while the remaining propeller shafts are rigid members i.e., do not change in length. The variation in the length of rear propeller shaft is allowed using a splined shaft. Generally, length of the propeller shaft is decided after freezing the remaining aggregates.

V. Jose Ananth Vino et. al. (2015) suggested the concept to reduce the weight of automotive drive shaft with the utilization of composite material. Composite materials have been used in automotive components because of their properties such as low weight, high specific stiffness, corrosion free, ability to produce complex shapes, high specific strength and high impact energy absorption etc. As the automotive drive shaft is a very important component of vehicle. The modeling of the drive shaft assembly was done using SOLIDWORKS software. A shaft has to be designed to meet the stringent design requirements for automotives. In automobiles the drive shaft is used for the transmission of motion from the engine to the differential. An automotive propeller shaft, or drive shaft, transmits power from the engine to differential gears of rear wheel-driving vehicle. In present work an attempt has been to estimate deflection, stresses under subjected loads & natural frequencies using Ansys software.

Salaisivabalan T. et. al. (2016) presented the propeller shaft of MARUTI OMNI to design the shaft for its minimum dimensions to satisfy current problem specification and then replace conventional steel material with composite material. The design of the propeller shaft is first theoretically designed for steel, Carbon/Epoxy and Glass/Epoxy composite material for its safe dimensions. Then they can be created as a part model for respective dimensions in NX 8.5 software. After modeling, Torsional buckling analysis and Modal analysis can be carried out in the propeller shafts using NX NASTRAN to check whether theoretical calculations and analytical results are similar. Then obtained results are compared among those three materials and Carbon/Epoxy composite material is selected as suitable replacement material for conventional steel material in terms of several mechanical properties.

Annika Henrich and Nadja Suonperä, [7] presented the recommendations regarding to Volvo Construction Equipment's propeller shaft program included guidelines for modularization. The success of modularization is based on among other factors, on particular documentation, continuous communication and close cooperation with the suppliers. This study can be defined as the first step towards a modularized propeller shaft program for Volvo CE's haulers and wheel loaders.

## 3. Proposed Methodology

- First task was to design procedure of propeller shaft according to standard which is used.
- Next step was to create a model of the propeller shaft with the help of design calculation of propeller shaft which we had calculated in ABAQUS.
- In next step, we are taking the material as which is used standard wise for propeller shaft i.e., Steel SM45 and we had developed an analysis report taking proper torque as per standard .
- Next step is to take the composite material i.e., Carbon Epoxy and Glass Epoxy, take the required result of analysis.
- Last step is to take the comparative analysis in between Steel and Carbon Epoxy and glass Epoxy result are shown.

### 3.1 Objectives

- To investigate the existing design of automotive/automobile propeller shafts.
- To check the design of propeller shaft mathematically with a conventional material.
- To check also design of propeller shaft mathematically with composite material.
- To perform FEM analysis with conventional as well as composite materials.
- Finally optimize the design of propeller shaft which should be compatible and cost effective.
- Interprets the results of all conditions and analysis.

### 3.2 Finite Element Analysis

Finite element analysis process involves following steps.

Preprocessing is carried out in ABAQUS Software. Following steps involved in preprocessing.

- Geometry import & cleanup.
- Component collector creation.
- Material & property definition.
- 2D shell meshing of propeller tube & 3D meshing of solid parts.
- Joint's creation using 1D rigid RBE2 elements.
- Applying boundary conditions.
- Preparation of analysis Deck for ABAQUS.

### 3.4 Solution

- Applying boundary conditions
- Running ABAQUS solution sequence for static analysis
- Running ABAQUS solution sequence for modal analysis

### 3.5 Post Processing

In this part results are analyzed, applied for visualization of the behavior of the component in the actual practice in all respects e.g., stresses displacement.

.

### 3.6 Description of Composite Material

A composite material is a combination of two materials with different physical and chemical properties. When they are combined, they create a material which is specialized to do a certain job, for instance to become stronger, lighter or resistant to electricity. They can also improve strength and stiffness.

#### A. Carbon Epoxy

Carbon fibre reinforced composites have exceptional mechanical properties. These strong, stiff and lightweight materials are an ideal choice for applications where lightweight & superior performance are important, such as components for aircraft, automotive, rail and high-quality consumer products.

The range offered is based upon composite sheets produced by stacking carbon fibre fabrics one upon another and then infusing the stack with resin under vacuum.

**Constituents of carbon epoxy**

Carbon fibres are produced from polymer fibres such as polyacrylonitrile and from pitch. The initial fibre material is drawn under tension whilst it is heated to around 1000°C causing 2-dimensional carbon-carbon crystals (graphite) to be formed when hydrogen is driven out. The carbon-carbon chain has extremely strong molecular bonds and this is what gives the fibres their high strength.

**B. Glass epoxy**

Laminated material in sheets, made from modified glass fabric as a reinforcement and epoxy resole resin. Besides good mechanical and electrical insulating properties has high climate resistance. It is used in production of components with good mechanical and electrical properties, for electrical equipment at higher temperatures or in humid environments, for stressed electrical insulating components, such as chassis, body equipment, housing parts of distribution boards, transformers, switchgears, electrical machines. It is used in the production of components with good mechanical and electrical properties, for electrical equipment at higher temperatures or in humid environments, for stressed electrical insulating components, such as chassis, body equipment, housing parts of distribution boards, transformers, switchgears, electrical machines.

It is characterized by excellent mechanical and electrical insulating properties, which keeps even at higher temperatures. It is characterized by resistance to tracking. It is used in the production of components with good mechanical and electrical properties, for electrical equipment at higher temperatures or in humid environments, for stressed electrical insulating components, such as chassis, body equipment, housing parts of distribution boards, transformers, switchgears, electrical machines.

**3.7 Mechanical Properties of Material used for propeller shaft**

Table 3.1: Mechanical Properties of Material used for propeller shaft

| Mechanical Properties | Units | Steel (SM45C) | Carbon Epoxy | Glass Epoxy |
|---|---|---|---|---|
| Young's Modulus (E) or Modulus of Elasticity | GPa | 207 | 131.6 | 43.3 |
| Shear Modulus (G) or Modulus of Rigidity | GPa | 80 | 3.5 | 3.5 |
| Poisson's Ratio | | 0.3 | 0.281 | 0.3 |
| Density | Kg/m3 | 7600 | 1550 | 2100 |
| Shear Stress | MPa | 29.419 | 40 | 65 |

### 3.8 CAD Modeling

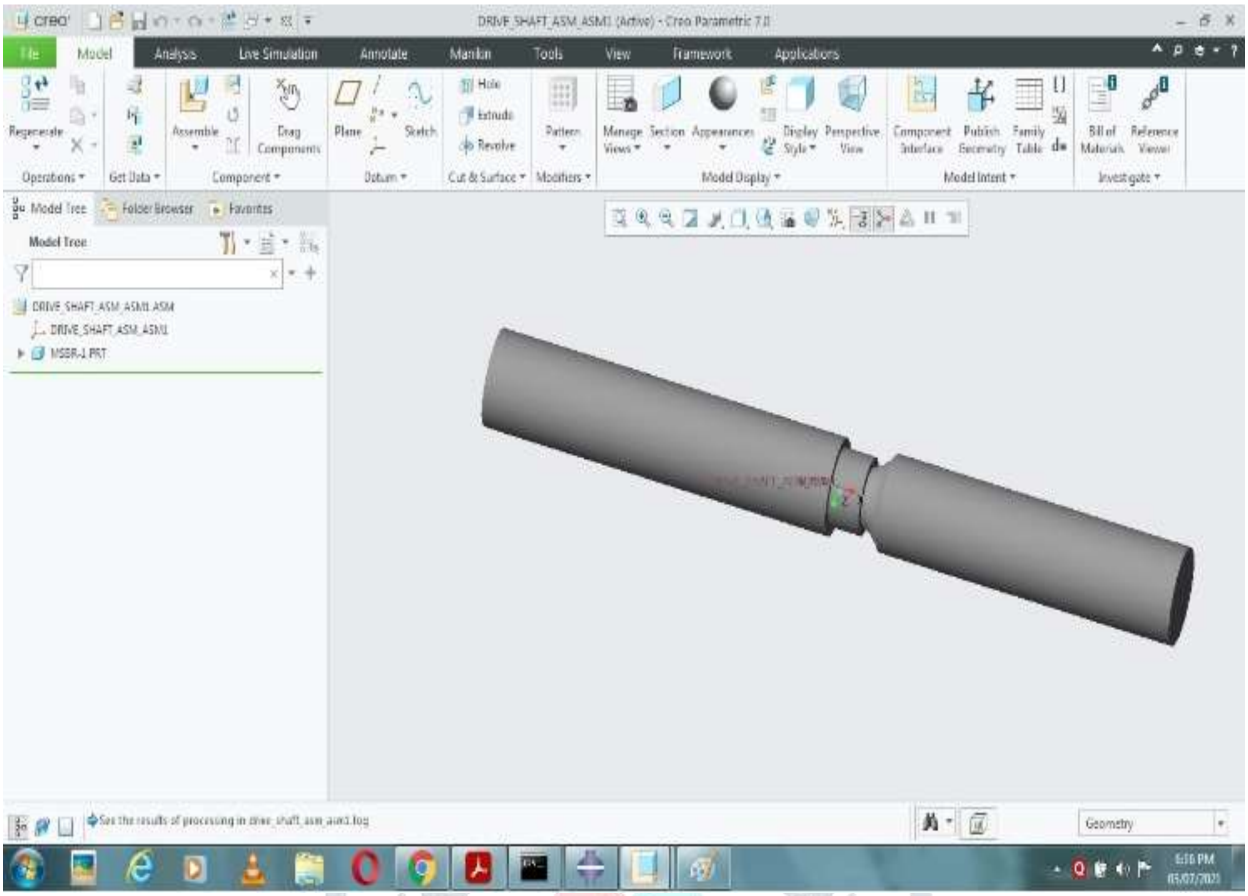


Figure 3.1: CAD Model of Propeller Shaft

### 3.9 Drafting of Propeller Shaft

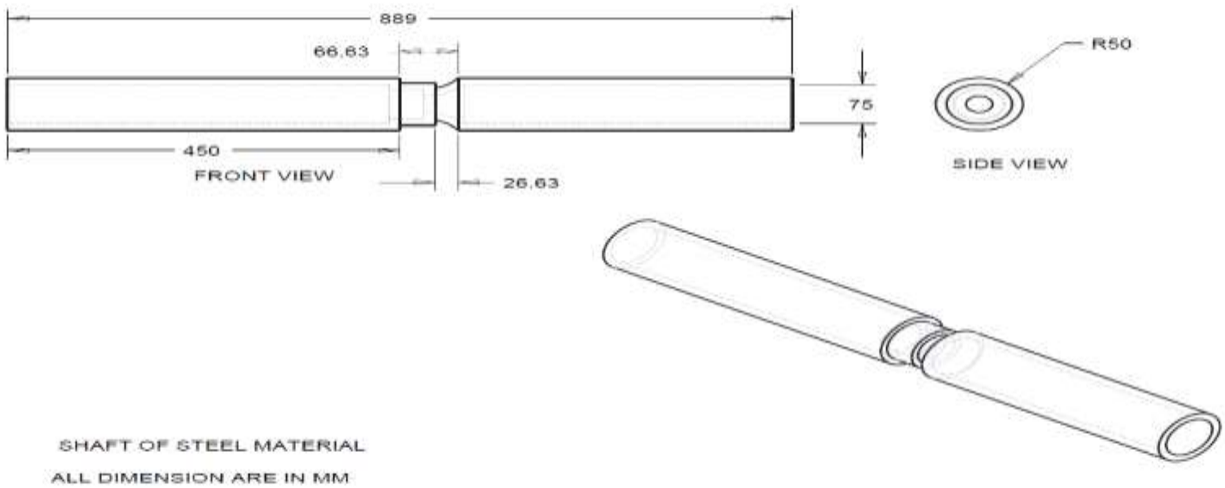


Figure 3.2: Drafting Model of Propeller Shaft for SM45C

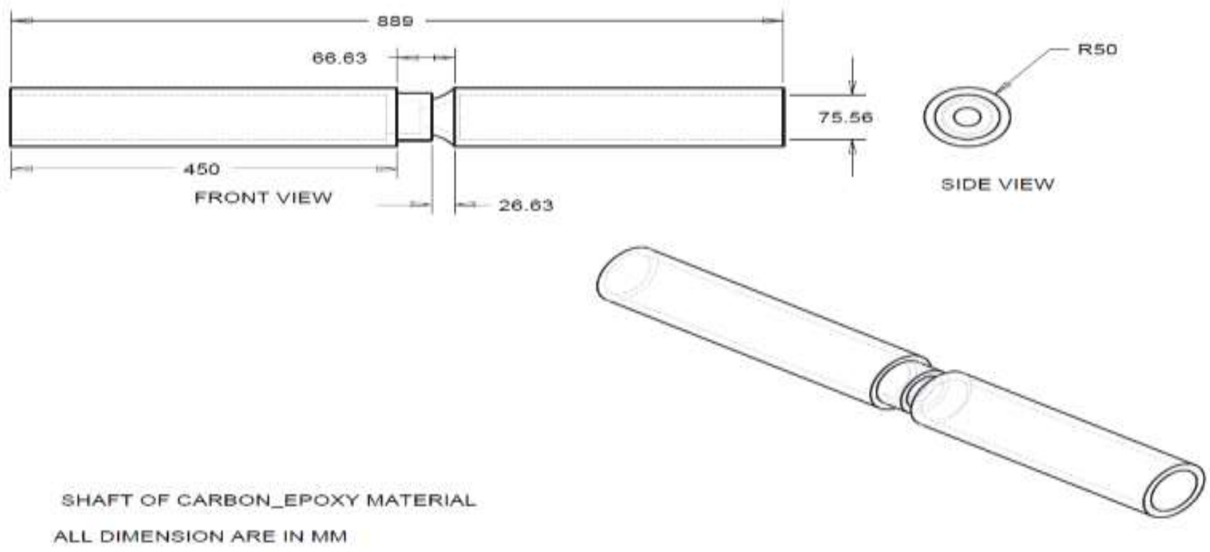


Figure 3.3: Drafting Model of Propeller Shaft for Carbon Epoxy

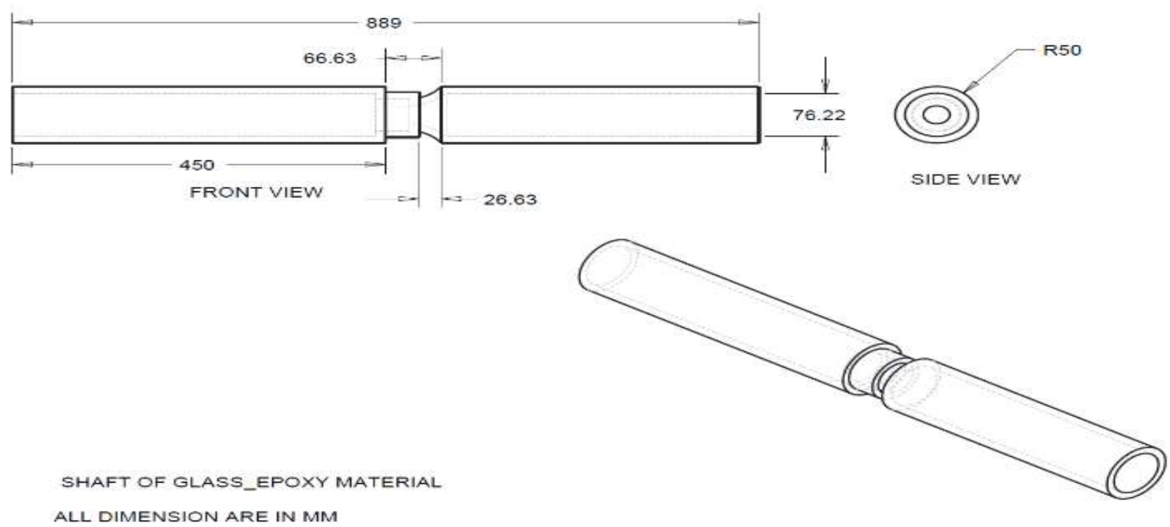


Figure 3.4: Drafting Model of Propeller Shaft for Glass Epoxy

**3.10 Software used for Modeling and Analysis**

**Modeling**

**CREO 7.0 Software**

This software is used for modeling i.e., making CAD model of proposed multipurpose fiber extraction machine and for simulation purpose. Proper designing & modeling of fiber extrzction machine using a CAD Modeling Software like CREO.
Creo is a suite of design software supporting product design for discrete manufacturers and is developed by PTC. The suite consists of apps, each delivering a distinct set of capabilities for a user role within product development. Creo Element and Creo Parametric compete directly with CATIA, Simens NX/solidedge, and solidworks. The Creo suits of apps replace and supersede PTC's product formally known as Pro/ENGINEER, Cocreat, and productive. Creo has many different software package Solution and features.

**Procedure for Modeling**

**Step 1:** First open the CREO and then select the file menu and select New in file menu.
**Step 2:** Then select the part drawing from the left side menu and in that we have
1. Top plane
2. front plane
3. Right plane

Select the top plane and x-y axis is displaced on the screen

**Step 3:** From the right-side menu select the sketch command and select the circular cross section (Circle)

**Step 4:** Next select the smart dimension and set the dimensions in mm and gives the value of outer diameter as 100 mm

**Step 5:** Now go on to the screen and based on the dimensions, draw a circle with outer diameter and draw another circle with inner diameter 75 mm as the given thickness in 25 mm

**Step 6:** Now select the Extrude command and apply it on the part cross section and extrude it from center to a length of 450 mm towards right and left.

**Step 7:** Now finally click sketch and save the model and select print. The required model of specified dimensions is obtained.

**ABAQUS Software**

FEM based Analysis was done using Abaqus.

**Steps Involved in Analysis**

**Step1: Part Module**
Import the model of CREO which is in IGS format as Part
Section Assignment
According to the given geometry we define a 3D deformable solid model.
**Step 2: Property Module**
We will define the mechanical properties such as density, Young's Modulus, Poisson Ration according to the material used (SM45C, Carbon Epoxy and Glass Epoxy)
**Step 3: Assembly Module**
In this Step we should bring the model in the assembly module.
**Step 4: Step Module**
In this step we follow the below path
Create>>Static General
**Step 5: Interaction Module**
In this step we define the reference point. We select constraint and in it we select the reference point and the surface on which coupling is there.
**Step 6: Load Module**
Now, we need to define the specified Torque on the model, to do that we follow this:
Create Load>>Shell Edge Load>>Selecting Shell Edges>>Entering the Torque Magnitude>>Press Ok!!!
**Step 7: Mesh Module**
As you see the color of the module is yellow. It says that we can use the sweep mesh in this model
To generate sweep mesh on the part we follow this procedure:
Seed Part Instance>>Choose Approximate Global Size(10)>>Press OK>>Mesh Part Instance>>Select the Geometry>>Press Yes
After that model is meshed
**Step 8: Job Module**
In this step we should only create a job to start analysis of the model. To do this the only work we have to do is:
Press Create Job >> Press Ok >> Press Continue Now with pressing the SUBMIT button the analysis starts.
If there is no problem in previous Steps, after sometime the complete message is seen in status column.
**Step 9: Visualization Module**
After analyzing the model, in this module we see the results.

## 4. Design Calculation

We have designed propeller shaft for Automobile
Therefore, standard torque transmission capacity required for the most of the Automobile is,
$T_p$ = 610 Nm
Outside diameter of propeller shaft for our design purpose, $d_o = 100\ mm$
Length of the propeller shaft, L = 889 mm

### 4.1 Torsional Strength

$T_p = \frac{\pi}{32} \times \tau \times d_0^3 \times (1 - K^4)$
Where,

$$\tau = allowable\ shear\ stress\ for\ the\ given\ material$$
$$K = Stress\ Factor$$

$610 \times 10^3 = \frac{\pi}{32} \times 29.419 \times 100^3 \times (1 - K^4)$

$$K^4 = 0.316$$
$$\frac{d_i^4}{d_0^4} = K^4$$
$$d_i^4 = 0.316 \times d_0^4$$

Therefore, $d_i = 75\ mm$

Thus, wall thickness can be calculated by

$$t = (do - di)/2$$

$$t = \frac{100 - 75}{2}$$

$$t = 12.5\ mm$$

For our designed purpose we had taken t = 13 mm

Maximum Shear stress of shaft is given by,

$$\tau_{max} = \frac{T_p r_o}{\frac{\pi}{32} \times \left[d_0^4 - d_i^4\right]}$$

$\tau_{max} = 4.54\ N/mm^2$ or MPa

**4.2 Torsional Buckling**

A shaft is considered as short shaft if the following condition satisfies; otherwise, the shaft is considered as long shaft

$$\left(\frac{1}{\sqrt{(1 - \upsilon^2)}}\right) \times \frac{L^2 t}{(2r)^3} > 5.5$$

Where r is the mean radius, such that

$$r = \frac{r_i + r_o}{2}$$

$$\left(\frac{1}{\sqrt{(1 - 0.3^2)}}\right) \times \frac{0.889^2 \times 0.013}{(2 \times 0.0875)^3} > 5.5$$

$$2.009 > 5.5$$

Therefore, here the shaft is a short shaft, then the formula to calculate critical stress (τcr) is

$$\tau_{cr} = \frac{4.39\ E}{(1 - \upsilon^2)} \times \left(\frac{t}{r}\right)^2 \times \sqrt{1 + 0.0257\ (1 - \upsilon^2)^{\frac{3}{4}} \times \frac{L^3}{(r.t)^{1.5}}}$$

$$\tau_{cr} = \frac{4.39 \times 207 \times 10^9}{(1 - 0.3^2)} \times \left(\frac{0.013}{0.0875}\right)^2 \times \sqrt{1 + 0.0257\ (1 - 0.3^2)^{\frac{3}{4}}} \times \frac{0.889^3}{(0.0875 \times 0.013)^{1.5}}$$

$$\tau_{cr} = 408.4 \times 10^9\ N/m^2$$

Or

$$\tau_{cr} = 408.4\ \text{GPa}$$

The relationship between torsional buckling and critical stress is given by,

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

$T_b = 255 \times 10^6$ Nm

$$if\ T_b > T_p$$

Then the design will be safe. As per our calculation the torque value of propeller shaft is less than Buckling Torque. The total mass of the shaft is

$$m = m_u L$$

Where, mu is mass per unit length in kg/m

$$m_u = \rho \frac{\pi}{4} (d_0^2 - d_i^2)$$

$m = 7600 \times \frac{\pi}{4} (0.100^2 - 0.075^2) \times 0.889$

$$m = 23.21\ kg$$

**4.3 Von-Mises Stress**
**Maximum Von-mises Stress**

$$= \frac{[T \times do]}{2 \times I}$$

$$= \frac{[T \times do]}{2 \times \frac{\pi}{64} \times (d_0^4 - d_i^4)}$$

$$= \frac{[610 \times 0.100]}{2 \times \frac{\pi}{64} \times (0.100^4 - 0.075^4)}$$

$$= 9.08 \times 10^6$$

$$= 9.08\ MPa$$

**Carbon Epoxy**

$$= \frac{[T \times do]}{2 \times I}$$
$$= \frac{[610 \times 0.100]}{2 \times \frac{\pi}{64} \times (0.100^4 - 0.07556^4)}$$
$$= 5.76 \times 10^5$$
$$= 0.576\, MPa$$

**Glass Epoxy**

$$= \frac{[T \times do]}{2 \times I}$$
$$= \frac{[610 \times 0.100]}{2 \times \frac{\pi}{64} \times (0.100^4 - 0.07621^4)}$$
$$= 5.876 \times 10^5$$
$$= 0.586\, MPa$$

Similarly, we had calculated the values for material Carbon Epoxy and Glass Epoxy, and the values are given in the table below

**4.4 Rotational Velocity**

At a speed 3000 RPM, the rotational velocity calculated is to be,

$$\omega = \frac{2\pi N}{60}$$
$$\omega = \frac{2 \times \pi \times 3000}{60}$$
$$\omega = 314\, rad/sec$$

**Mass Saving in %**

$$Mass\ Saving\ in\ \% = \frac{Mass\ of\ SM45C - Mass\ of\ Composite\ Material}{Mass\ of\ SM45C} \times 100$$

Table 4.1: Analytical Values of Propeller Shaft of Different Material

| Properties | Units | Steel SM45C) | Carbon/Epoxy | Glass/Epoxy |
|---|---|---|---|---|
| **Length (L)** | m | 0.889 | 0.889 | **0.889** |
| **Outer dia ($d_o$)** | m | 0.100 | 0.100 | **0.100** |
| **Inner dia ($d_i$)** | m | 0.075 | 0.07556 | **0.07621** |
| **Max. Shear Stress ($\tau_{max}$)** | MPa | 4.54 | 4.6 | **4.68** |
| **Von-Mises Stress** | MPa | 9.08 | 0.576 | **0.586** |
| **Critical Stress ($\tau_{cr}$)** | GPa | 408.4 | 243.80 | **80.15** |
| **Buckilng Torque ($T_b$)** | Nm | 255 x$10^6$ | 141 x$10^6$ | **46.9 x$10^6$** |
| **Frequency** | Hz | 458.94 | 807.39 | **400.81** |
| **Mass (m)** | kg | 23.21 | 4.64 | **6.14** |
| **Weight in Mass Saving** | **%** | **--** | **80** | **73.54** |

## 5. ANALYSIS AND RESULTS

The steel propeller shaft is imported to ABAQUS and is analysed for the maximum deflection, Maximum shear stress and the Von-Mises stress value. The resulting values are tabulated. The fixed constraint is given at the one edge of the shaft, where the shaft is connected to differential unit. The Torque T is given at the other edge of the shaft. The same procedure is repeated for E-Glass/Epoxy and Carbon/Epoxy leaf springs.

### 5.1 Result of SM45C

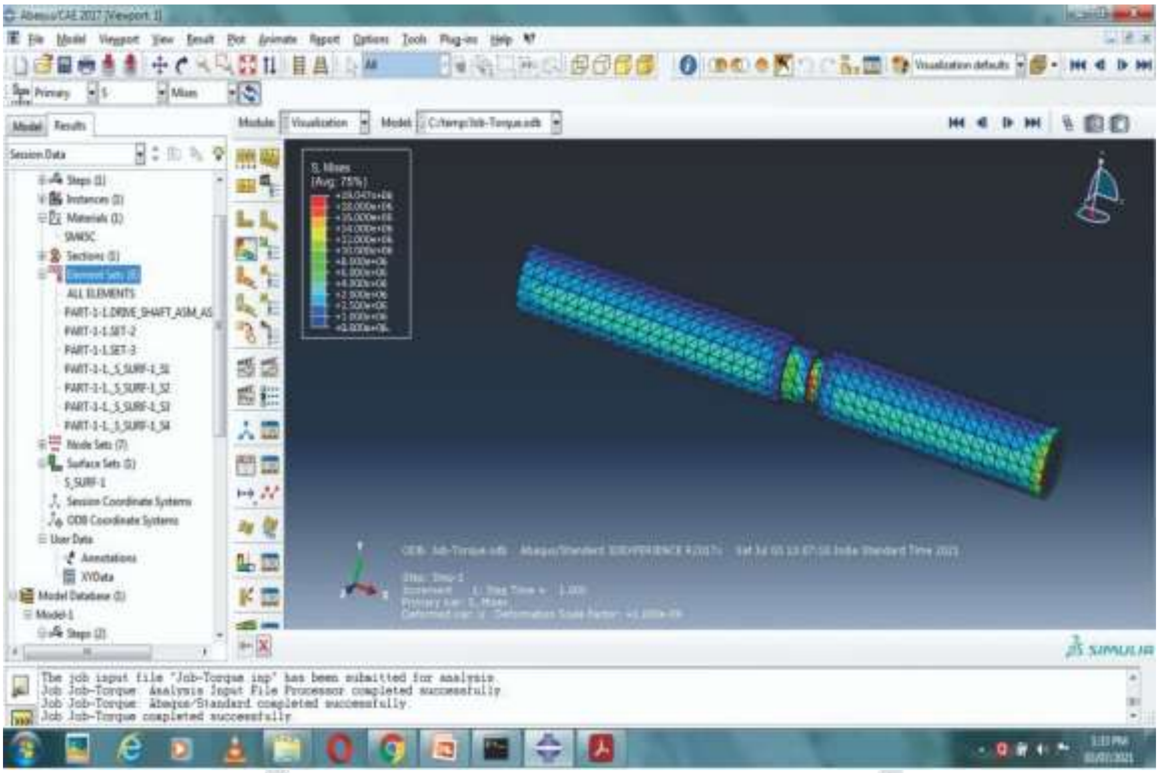


**Figure 5.1:** Von Mises Stresses of Propeller Shaft for SM45C

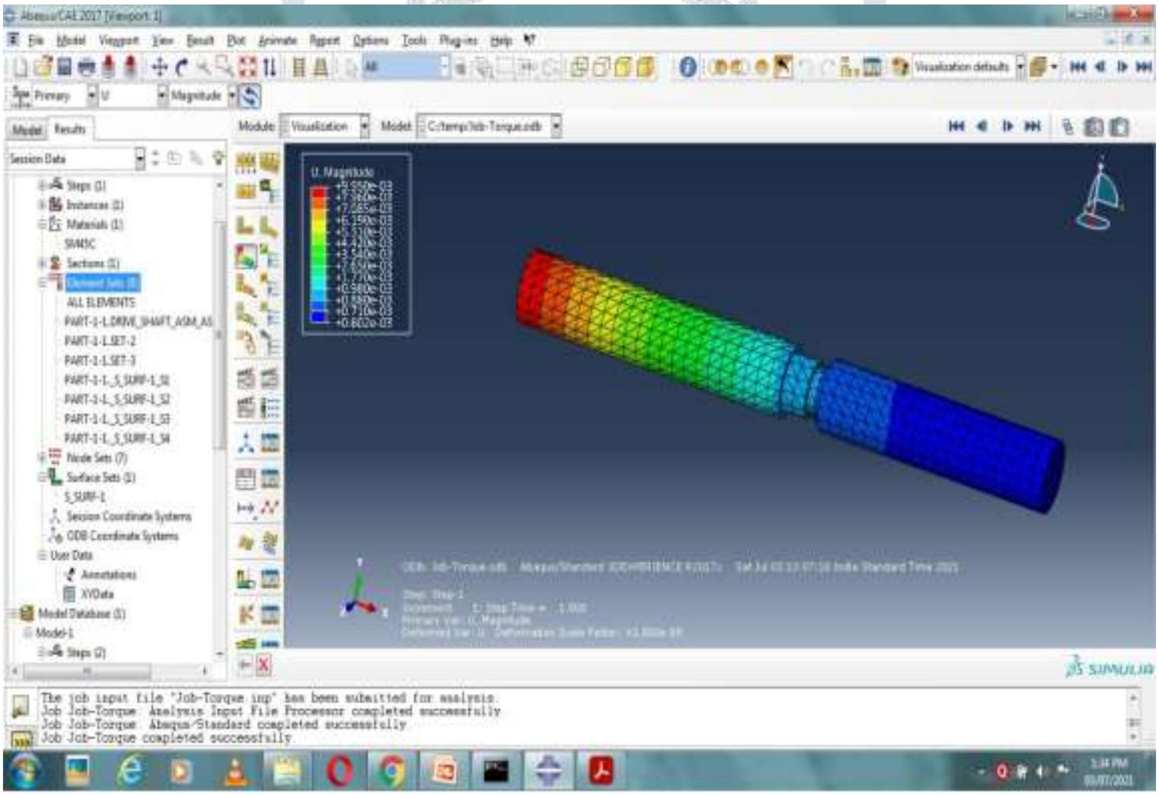


**Figure 5.2:** Displacement of Propeller Shaft for SM45C

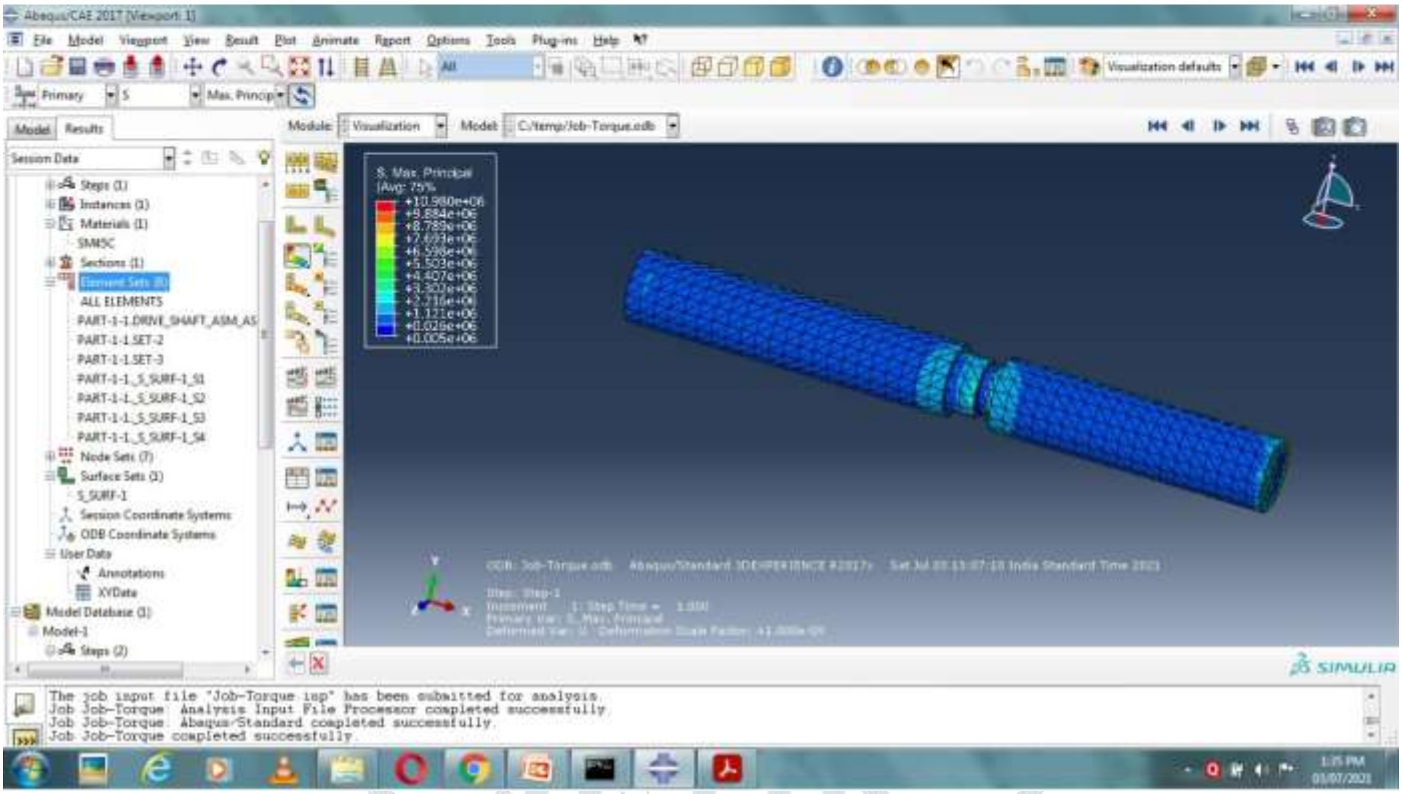


**Figure 5.3:** Maximum Shear Stress of Propeller Shaft for SM45C

**5.2 Result of Carbon Epoxy**

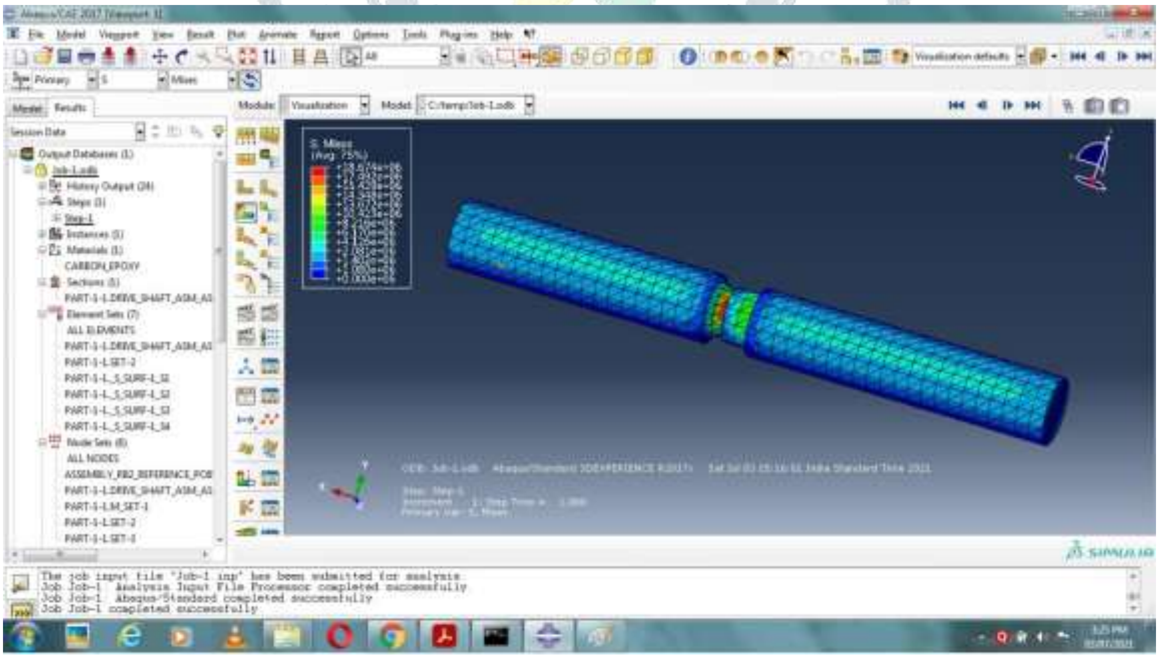


**Figure 5.4:** Von Mises Stresses of Propeller Shaft for carbon Epoxy

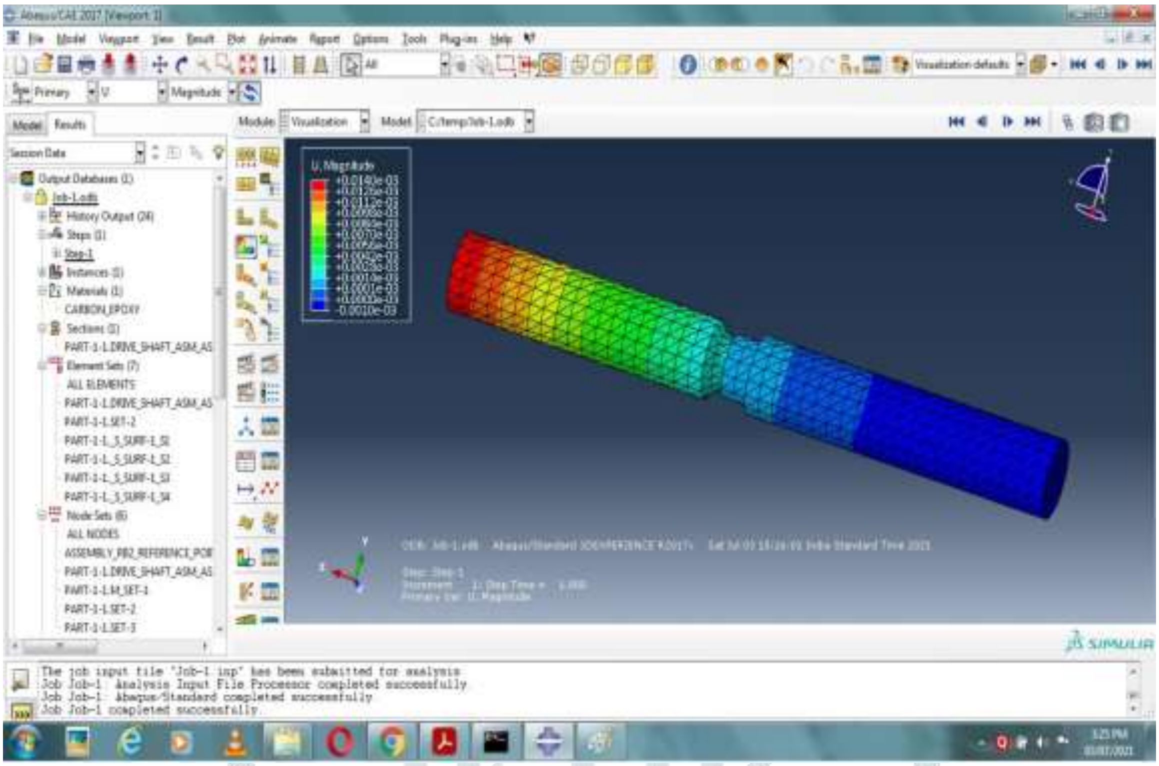


**Figure 5.5:** Displacement of Propeller Shaft for carbon Epoxy

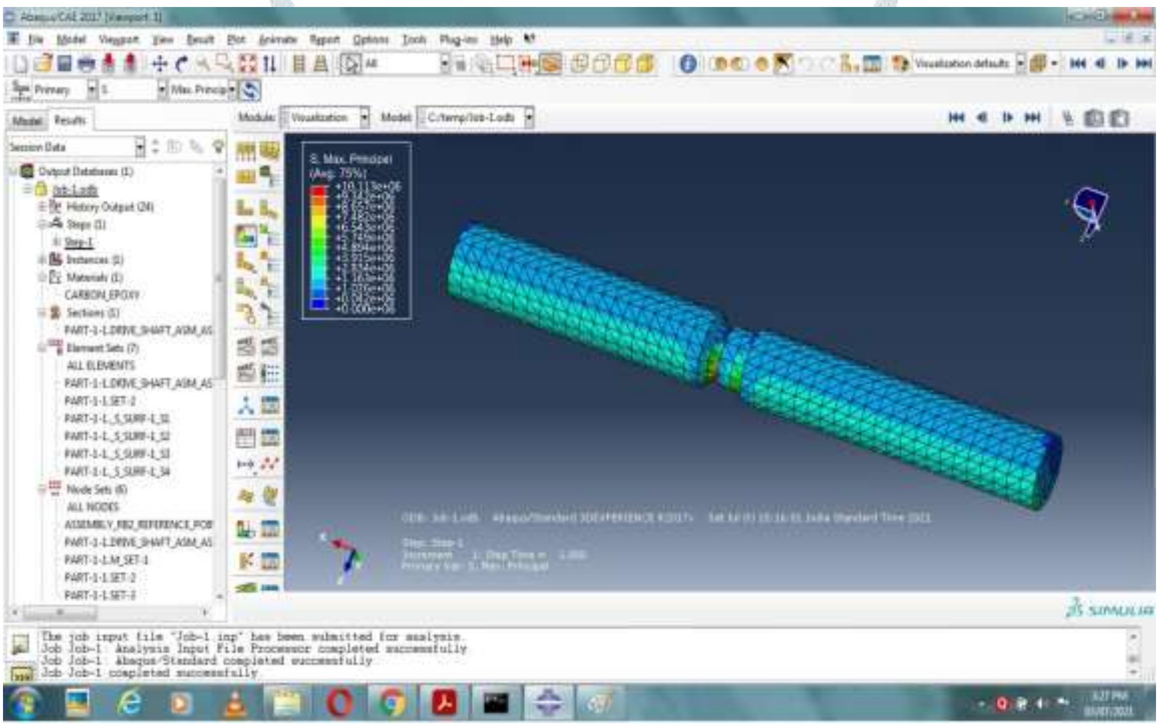


**Figure 5.6:** Maximum Shear Stress of Propeller Shaft for carbon Epoxy

### 5.3 Result of Glass Epoxy

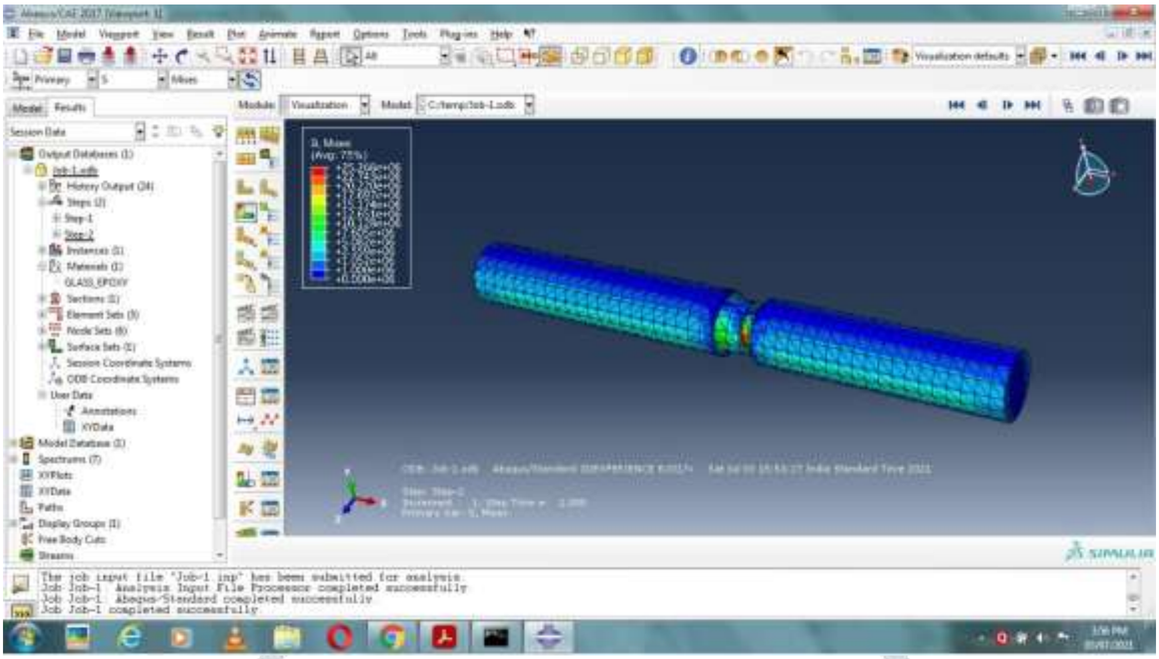

**Figure 5.7:** Von Mises Stresses of Propeller Shaft for Glass Epoxy

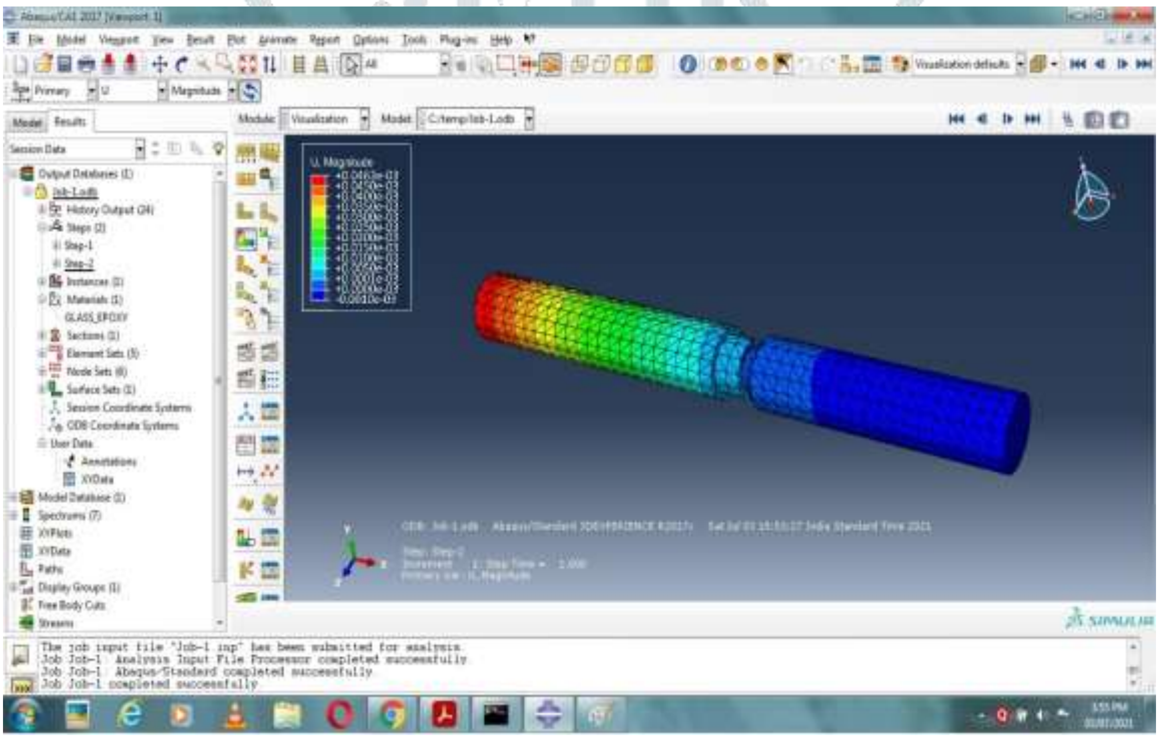

**Figure 5.8:** Displacement of Propeller Shaft for Glass Epoxy

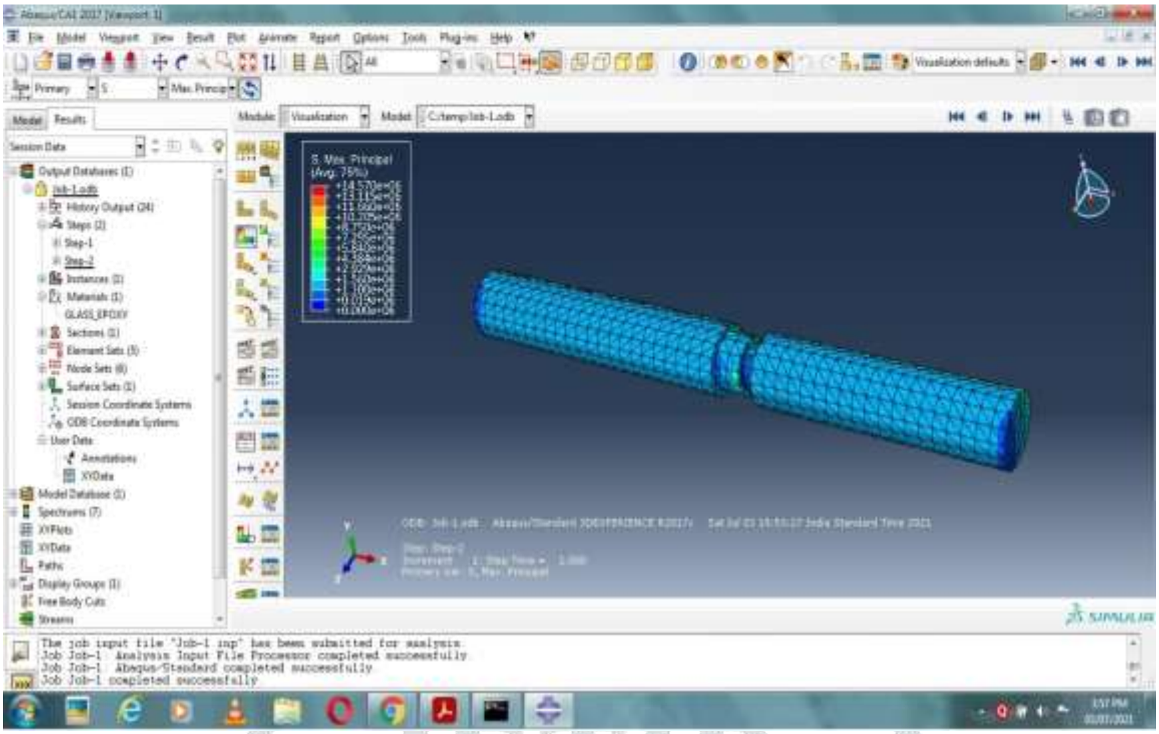

**Figure 5.9:** Maximum Shear Stress of Propeller Shaft for Glass Epoxy

## 6. RESULT AND COMPARISON

**Table 6.1:** Validation and comparison of analytical and ABAQUS results

| Result | SM45C | | Carbon Epoxy | | Glass Epoxy | |
|---|---|---|---|---|---|---|
| | ABAQUS | Analytical | ABAQUS | Analytical | ABAQUS | Analytical |
| Von-Mises Stress (MPa) | 19.04 | 9.08 | 18.67 | 0.576 | 25.26 | 0.586 |
| Shear Stress (MPa) | 10.98 | 4.64 | 10.113 | 4.60 | 14.57 | 4.68 |
| Mass (Kg) | 23.21 | 23.21 | 4.64 | 4.64 | 6.14 | 6.14 |

$$Percentage\ Mass\ Saving = \frac{Mass\ of\ SM45C - Mass\ of\ Composite\ Material}{Mass\ of\ SM45C} \times 100$$

When comparing Carbon Epoxy and Glass Epoxy composite shaft to conventional steel shaft the Carbon Epoxy composite shaft provides 80% in mass savings and Glass Epoxy composite shaft provides 73.54% of mass savings than steel shaft. If the weight of shaft is low, then more performance and fuel efficiency shall be obtained by the vehicle, so composite shafts shall be preferred. Also, the Shear stress and Von-Mises stress of Carbon Epoxy composite shaft and Glass Epoxy composite shaft are well placed under their safe values. Hence these composite shafts shall be preferred as suitable material for propeller shaft.

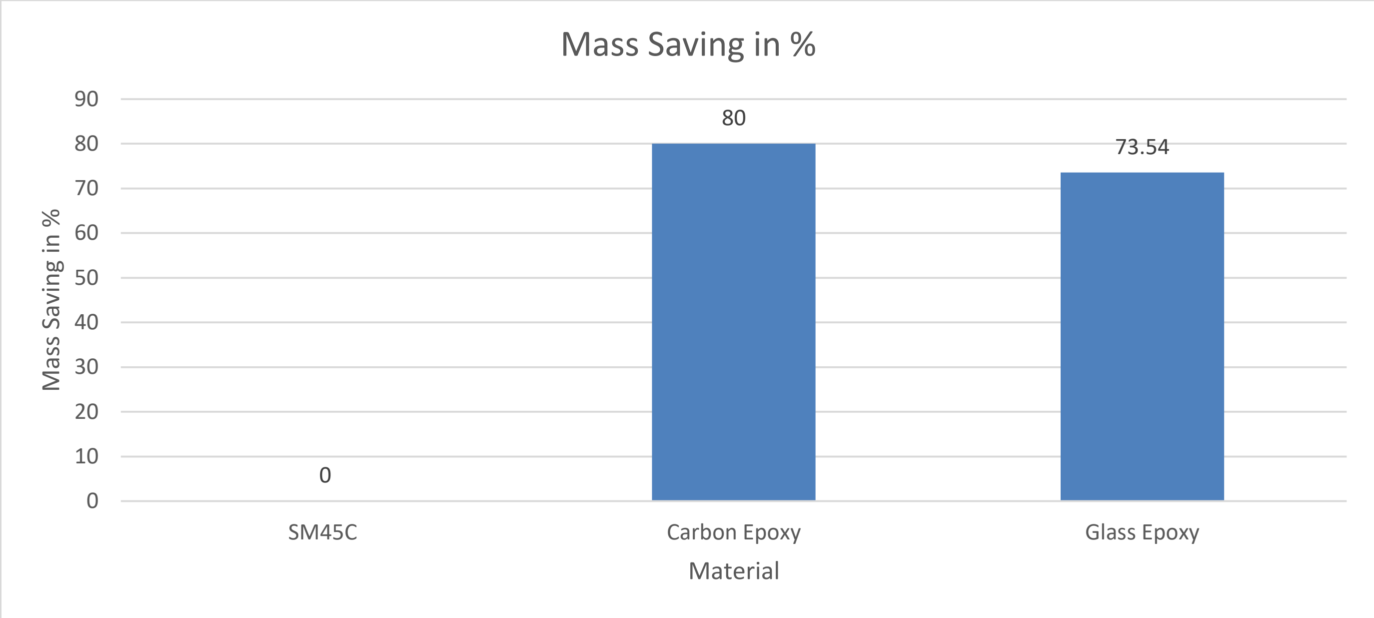


Figure 6.1: Graph of Percentage Mass Saving

**Comparison of Material on the basis of Equivalent Von-mises stresses**

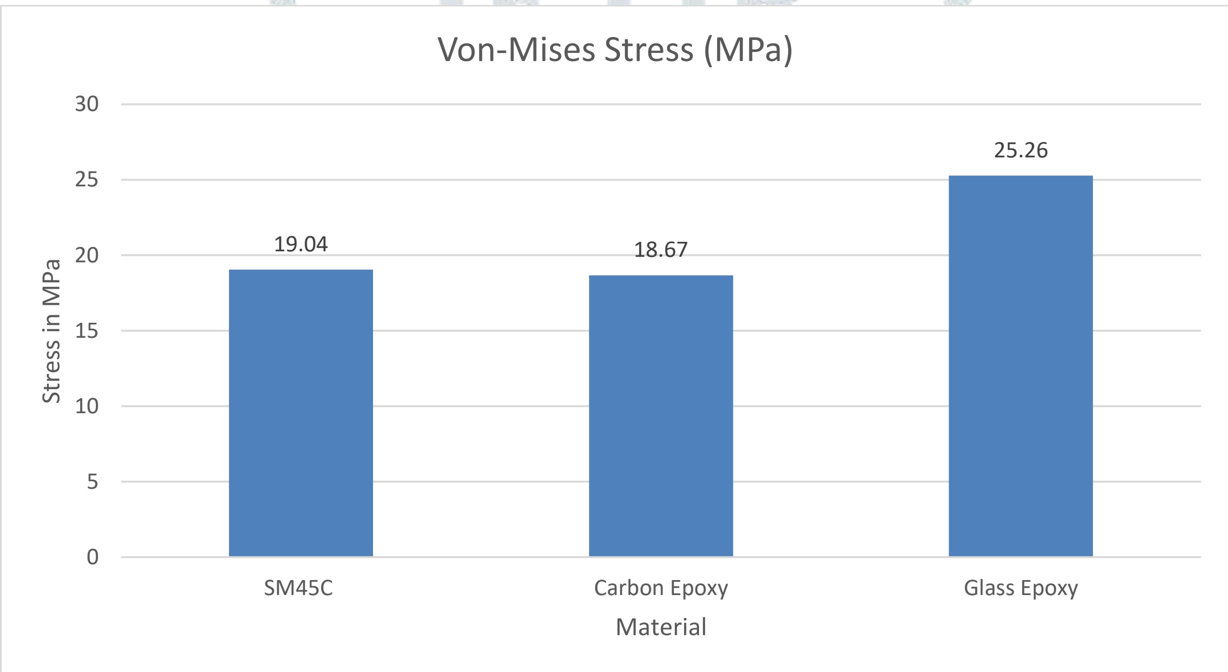


**Figure 6.1:** Comparison of Material on the basis of Equivalent Von-mises stresses

**Comparison of Material on the basis of Equivalent Shear stresses**

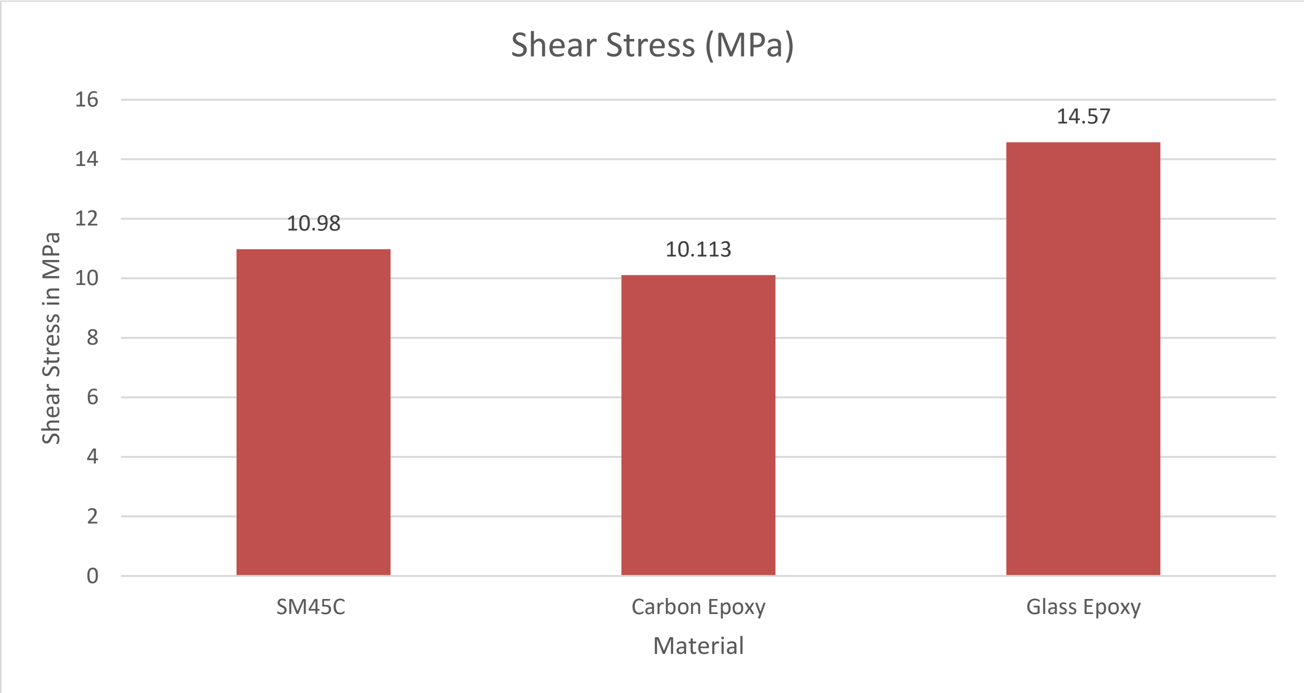


**Figure 6.2:** Comparison of Material on the basis of Equivalent Shear stresses

## CONCLUSION

The Carbon Epoxy and Glass Epoxy composite propeller shafts are designed to meet safe design requirements as the conventional steel shaft. From analysis Shear stress, Von-Mises stress, critical speed, Displacement, bending natural frequency and weight are determined.Von mises stress of Carbon Epoxy and Glass Epoxy drive shaft are under their safe values so fracture will not occur. Shear stress of Carbon Epoxy is nearly equal to Conventional Steel shaft. The usage of composite material drive shaft has resulted in inconsiderable amount weight saving in the range of 73 to 80% when compared to conventional steel shaft.Composite materials have higher specific stiffness to provide the required strength against less weight. Higher stiffness of composite material solves the problem of higher strength requirement for drive shaft and less weight solves the problem of inertia.. By reducing weight of propeller shaft, tyre wear will minimize, stability of vehicle body will increased, as the vehicle weight will be reduced. Light weight vehicle will greatly decreases the $Co_2$ production. Apart from being lightweight, the use of composites also ensures less noise and vibrations. Deflection is less in Carbon Epoxy shaft as compared to Glass Epoxy shaft. This study leaves wide scope for future investigation. It can be extended to newer composite using other reinforcing phases. The reduction in weight gives further advantage in the increases in the fuel economy of vehicle.

Since this work relies on pure theoretical calculation and simulation in analysis software, the future work is to fabricate the propeller shaft in Carbon/Epoxy composite material and test it in real time environment.

## References

[1] P. Parveen Sulthana, K. Aruna, T. Krishna Rao, H. G. Shivakumar, "Design and Analysis of Drive Shaft for Heavy Duty Truck", International Journal of Research in Engineering and Technology, Volume: 05, Issue: 01, Jan-2016.

[2] Nizam S Sakeer, Thoufeek A, Vyshak O R, Hallaj J, Mathews Thariyan, "Design, Analysis & Optimization of propeller shaft with composite materials by using software's", International Research Journal of Engineering and Technology (IRJET), Volume: 06, Issue: 05, May 2019

[3] Virendra V. Maheta, Anup B. Patel, "Design, Analysis and Optimization in Automobile Drive Shaft", International Journal for Innovative Research in Science & Technology, Volume 1, Issue 12, 2015

[4] Kiran A. Jagtap, P. M. Sonawane, "Design and Analysis of Drive Shaft for Heavy Duty Truck", International Journal of Engineering Research & Technology (IJERT), Vol. 4 Issue 02, February-2015

[5] V. Jose Ananth Vino, Dr. J. Hameed Hussain, "Design and Analysis of Propeller Shaft", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Issue 8, August 2015

[6] Salaisivabalan T, Natarajan R. "Design and Analysis of Propeller Shaft of an Automobile Using Composite Materials", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5, Issue 5, May 2016.

[7] Annika Henrich and Nadja Suonperä, "Analysis of the propeller shaft program at Volvo Construction Equipment", Master thesis, Product Development KPP305,

[8] Dr Porag Kalita," Propeller Shaft in Automobile: Review the Allocation Procedure in Front Axle and springs", International Journal of Computer Engineering in Research Trends, Volume 3, Issue 9, September-2016, pp. 454-460

[9] Atul Kumar Raikwar, Prof. Prabhash Jain & Rajkumari Raikwar, "Design and optimization of automobile propeller shaft with composite materials using FEM Analysis", International Journal of Engineering Development and Research, Volume 4, Issue 4, 2016

[10] Gubran, Hason & Gupta, Kshitij. (2014). Design Optimization of Automotive Propeller Shafts, Journal of Vibration Engineering & Technology.

[11] R. Harimaheswaran, N. Jeyakumar, R. Satheeshkumar, P. Viswabharathy, "Design Optimization and Analysis of Propeller Shaft", International Journal of Emerging Technologies in Engineering Research (IJETER), Volume 5, Issue 4, April 2017.

[12] Mr. Hucche Rohan Dilip, Dr. S. Y. Gajjal, Prof. V. K. Kulloli, "Design & Analysis of Composite Propeller Shaft", International Journal for Scientific Research & Development, Vol. 3, Issue 10, 2015.