DAYANANDA SAGAR COLLEGE OF ENGINEERING

Accredited by National Assessment & Accreditation Council (NAAC) with 'A' Grade
(AICTE Approved, an Autonomous Institute Affiliated to VTU, Belagavi)
Shavige Malleshwara Hills, Kumaraswamy Layout, Bengaluru-560111

DEPARTMENT OF MECHANICAL ENGINEERING

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A Mini-Project Report on

"To Study and Analysis of Carbon Fiber Composite Drive Shafts for Automotive Applications"

Submitted in partial fulfilment for the award of degree of

BACHELOR OF ENGINEERING

In

MECHANICAL ENGINEERING

2022-2023

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Certificate

Certified that the project report entitled **'To Study and Analysis of Carbon Fiber Composite Drive Shafts for Automotive Applications'** is a Bonafide work carried out by **Mallanna**, bearing USN**: 1DS20ME044**, **Naveenakumar Annennanavar**, bearing USN**: 1DS20ME420**, **Rakesha K P**, bearing USN**: 1DS21ME455**, **Sudarshan N D**, bearing USN**: 1DS21ME478**, under the guidance of **Dr. Vivek Bhandarkar V N** , **Assistant Professor** , Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru, in partial fulfilment for the award of Bachelor of Engineering in Mechanical Engineering of the Visvesvaraya Technological University, Belagavi.

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DECLARATION

We the below mentioned students hereby declare that the entire work embodied in the project report entitled '**To Study and Analysis of Carbon Fiber Composite Drive Shafts for Automotive Applications**' has been independently carried out by us under the guidance of Dr. **Vivek Bhandarkar V N**, Assistant Professor, Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru, in partial fulfilment of the requirements for the award of Bachelor Degree in Mechanical Engineering of Visvesvaraya Technological University, Belagavi.

We further declare that we have not submitted this report either in part or in full to any other university for the award of any degree.

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ABSTRACT

The drive shaft is a crucial component in power transmission applications, particularly in the automotive industry. Its purpose is to transfer the *torque* generated by the engine into motive force that propels the vehicle. The drive shaft's tubular design includes an outer and inner diameter that rotates at an engine output-driven frequency. However, the fluctuating load it operates under can cause it to fail and interrupt *power transmission*. Therefore, designing the shaft to withstand the load requirements is essential in avoiding failure. Composite material drive shafts have gained increasing attention in recent years due to their unique properties, which include *high strength, low weight*, and *resistance to fatigue and corrosion*. These properties make composite drive shafts well-suited for applications that require high specifications, such as in mechanical and marine industries.

This project aims to investigate the feasibility of using *carbon fiber* composite materials for automotive drive shaft applications. The volume fraction method is used to calculate the strength of carbon fiber reinforced materials, and an analytical approach is employed to design and analyze a carbon fiber composite drive shaft to replace the conventional metallic drive shaft in a passenger car. Static analyses were conducted using Finite Element Analysis software, aimed at minimizing the shaft's weight while meeting constraints such as torque transmission and critical buckling torque capacity. The results of the analysis will be presented, including the optimized design of the composite drive shaft, which exhibits a significant weight reduction, increased stiffness, and reduced static deflection. This study aims to provide valuable insights into the potential of carbon fiber composite materials for automotive drive shaft applications and may contribute to the development of more efficient and durable drive shafts for the automotive industry.

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

The drive shaft (also called propeller shaft or prop shaft) is a component of the drive train in a vehicle, with the purpose of delivering torque from the transmission to the differential which then transmits this torque to the wheels in order to move the vehicle. The drive shaft is primarily used to transfer torque between components that are separated by a distance, since different components must be in different locations in the vehicle. A front-engine rear-wheel drive car must have a long drive shaft connecting the rear axle to the transmission. The drive shaft of the car is as shown in the figure 1.1.

Drive shafts are used differently in different vehicles, varying greatly in cars with distinct configurations for front-wheel drive, four-wheel drive. Other vehicles also use drive shafts, like motorcycles, locomotives, and marine vessels. Below is the drive shaft configuration for a common front-engine rear-wheel drive vehicle (some cars have the transmission at the back).

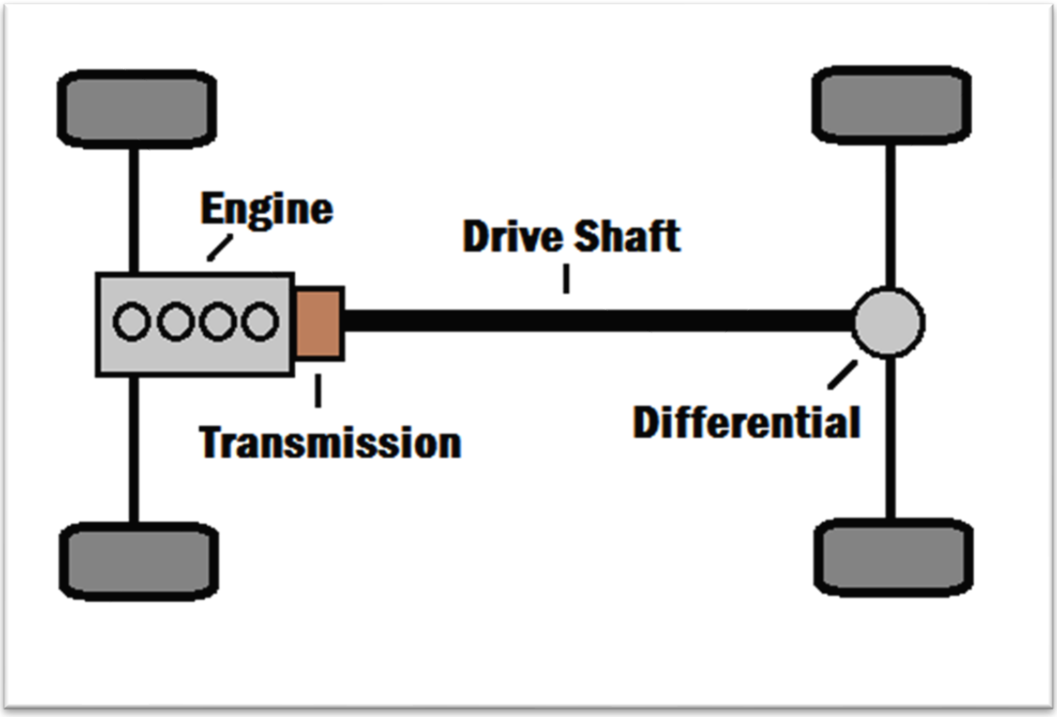

Figure1.1: Drive Shaft [1]

A shaft that is used to convey motion from one location to another is referred to as a "drive shaft." The propeller shaft, on the other hand, is the shaft that propels. Propellers are often linked with ships and aeroplanes because they employ a propeller shaft to propel themselves through the air or water in addition to delivering rotational motion from the front to the back of the moving object. The shaft serves as the main link between the front and back ends and is responsible for both motion and pushing the front end. As a result, the phrases When the engine is located at the other end of the vehicle from the driven wheels, a longitudinal drive shaft called the propeller shaft is employed. An assembly of one or more tube shafts joined together by universal, constant velocity, or flexible joints forms a propeller shaft. The distance between the gearbox and the axle affects both the number of tubular sections and the joints. As with rear wheel drive, some four-wheel drive vehicles employ one propeller shaft to power the back wheels and a second propeller shaft to power the front wheels. In this instance, the front axle is replaced between a transfer gear box and the second propeller shaft. As a result, it is clear that a drive shaft is among the most crucial parts since it is it that really moves the car after the engine generates motion. A key component of this importance is often designed with great care since even a little crack might cause the vehicle to crash catastrophically while it is moving.

Drive shafts are typically made from metals such as steel. Metal drive shafts are limited by their weight and low critical speed. As metals have low specific stiffness, the length of metal drive shafts is limited. Composite materials are generally used due to their high stiffness and low weight. Each reduction of 10% in the mass of a vehicle would reduce fuel consumption by 6%–8%, depending on the type of vehicle offering many benefits, including, (a) up to 80% mass saving comparing to steel drive shaft; (b) easy to achieve design specification like weight, strength, power consumption with careful lay-up strategy; (c) easy to achieve a higher. natural bending frequency than steel drive shafts and (d) can be used in extreme vibration conditions. The design specification of a drive shaft seeks to minimise three performance criteria: factor of safety (stress based), buckling torque and natural frequency. Due to the differing constituents in composite materials their failure modes differ from homogeneous materials, therefore, composite specific failure modes must be used to calculate the factor of safety (Fos). As composite materials are normally orthotropic, drive shaft performance is strongly dependent on the chosen lay-up. Composite manufacturing processes must also be considered in the design stages. The chosen manufacturing process can affect the final composite mechanical properties, cost, and environmental impact [1].

1.2 Purpose of Driveshaft

The torque that is produced from the engine and transmission must be transferred to the rear wheels to push the vehicle forward and reverse. The drive shaft must provide a smooth, uninterrupted flow of power to the axles. The drive shaft and differential are used to transfer this torque. Functions of Driveshaft are as follows: 1. First, it must transmit torque from the transmission to the differential gear box. 2. During the operation, it is necessary to transmit maximum low-gear torque developed by the engine. 3. The drive shafts must also be capable of rotating at the very fast speeds required by the vehicle. 4. The drive shaft must also operate through constantly changing angles between the transmission, the differential and the axles. As the rear wheels roll over bumps in the road, the differential and axles move up and down. This movement changes the angle between the transmission and the differential. 5. The length of the drive shaft must also be capable of changing while transmitting torque. Length changes are caused by axle movement due to torque reaction, road deflections, braking loads and so on. A slip joint is used to compensate for this motion. The slip joint is usually made of an internal and external spline. It is located on the front end of the drive shaft and is connected to the transmission.

A carbon fiber driveshaft is a component used in automotive and industrial applications to transmit torque from the engine or motor to the wheels or other driven components. It is made primarily of carbon fiber reinforced polymer, which combines the high strength and stiffness of carbon fiber with the lightweight and corrosion-resistant properties of polymers.

Carbon fiber driveshafts offer several advantages over traditional metal shafts, such as steel or aluminium. Here are some key features and benefits of carbon fiber driveshafts:

1. Lightweight: Carbon fiber is known for its exceptional strength-to-weight ratio. Carbon fiber driveshafts are significantly lighter than their metal counterparts, reducing the overall weight of the vehicle or machinery. This weight reduction improves performance in terms of acceleration, fuel efficiency, and handling.

2. High Strength and Stiffness: Carbon fiber composites possess excellent mechanical properties. They have a high tensile strength, allowing them to withstand high torque and rotational speeds without failure. Carbon fiber driveshafts also exhibit high stiffness, minimizing flex and torsional deflection, which results in more efficient power transfer.

3. Vibration Damping: Carbon fiber has inherent damping characteristics, which means it can absorb and dissipate vibrations and oscillations. This feature helps reduce drivetrain vibrations, leading to a smoother and more comfortable ride.

4. Corrosion Resistance: Unlike metal driveshafts that can corrode over time, carbon fiber is highly resistant to corrosion. This property makes carbon fiber driveshafts suitable for various environments, including humid or corrosive conditions.

5. Improved Drivetrain Response: The reduced weight and increased stiffness of carbon fiber driveshafts contribute to improved throttle response and faster acceleration. The lower rotational inertia allows the engine or motor to rev up more quickly, resulting in enhanced overall performance.

6. Customization: Carbon fiber driveshafts can be engineered and designed to meet specific performance requirements. They can be tailored to different vehicle types, power levels, and applications, ensuring optimal performance and reliability.

It's important to note that while carbon fiber driveshafts offer numerous advantages, they can be more expensive to produce compared to traditional metal shafts. However, their benefits in terms of performance, weight reduction, and durability often justify the higher cost, particularly in high-performance or specialized applications. Overall, carbon fiber driveshafts have revolutionized the drivetrain industry by providing lightweight, strong, and efficient alternatives to traditional metal shafts, offering improved performance [2].

CHAPTER 2: LITERATURE REVIEW

- Joseph Searle et al. [1] (2022) investigated the feasibility of replacing traditional structural steel with lightweight FRP (Fiber Reinforced Polymer) composites in a drive shaft. The study involved conducting experiments using three types of FRP composites: basalt/epoxy, carbon/epoxy, and CNT (Carbon Nanotubes) reinforced carbon/epoxy composites. The mechanical performance of the composites was analysed using Finite Element Analysis (FEA) and Classical Laminate Theory (CLT), while the environmental performance was evaluated using Life Cycle Assessment (LCA) methodology. The findings of the study indicate that, with careful design considerations, a composite drive shaft can surpass the mechanical performance of a steel shaft. The composite shaft exhibited significant advantages, including a mass saving of up to 90% compared to steel, and a 50% higher Factor of Safety. However, when considering embodied energy (the total energy required for the production and use of a material), the study found that steel shafts had a lower embodied energy of 150MJ, while the FRP composites had a higher embodied energy of +325MJ. Despite this, the weight savings achieved by the FRP composites resulted in reduced carbon emissions, making the carbon/epoxy composite shaft more environmentally preferable than a steel shaft.
- Pandurang V Chopde (2015) et.al [2] analysed Carbon/Epoxy Composite Drive Shaft for Automotive Application. The experimental and theoretical, torsional and vibration analysis is done on conventional SM45C steel drive shaft, carbon epoxy and glass epoxy composite drive shaft.
- T. Rangaswamy (2004) et.al [3] studied the Optimal Design and Analysis of Automotive Composite Drive Shaft a one-piece drive shaft for rear-wheel-drive automobile was designed optimally using E-Glass/Epoxy and High modulus (HM) Carbon/Epoxy composites.
- B. James Prasad Rao et al. 2016 [4] conducted a study on the application of Carbon Reinforced Plastics (CFRP) and Glass Fiber Reinforced Plastics (GFRP) composite hollow shafts in automobiles. The Experimental study indicates that, failure analysis conducted using the maximum stress criteria and found that the failure torque exceeded the design torque level. Finite Element Method (FEM) technique were utilised to

analyze the propeller shaft. The propeller shaft was modelled in the FEM using the "3D-shell99 element and solid46 layered element." The ANSYS package was utilized to carry out various analyses, including failure modes analysis, linear static analysis, vibration Eigen value analysis, buckling analysis, and harmonic analysis. The results revealed that the static deflection of the carbon propeller shaft was 0.120, while for the glass shaft it was 0.250, and for the hybrid shaft it was 0.20, all of which were lower than that of the conventional steel propeller shaft. The fundamental natural frequency of the carbon-epoxy propeller shaft was lower than that of the glass shaft and steel shafts. The stresses and displacement amplitudes of the propeller shafts reached their maximum values at frequencies that were significantly different from the operating frequency range. Furthermore, the torsional buckling load was approximately five times higher than the ultimate torque transmission by the shaft, indicating a safer design.

- Parshuram D, Sunil Mangsetty et al [5] (2013) analysed to reduce weight of automotive drive shaft with the utilization of composite material. The modelling of the drive shaft assembly was done using CATIA software. The outcome of this paper is to reduce the weight of 72% - 80%, to estimate deflection, stresses under subjected loads & natural frequencies using FEA.

CHAPTER 3: METHODOLOGY

3.1 METHOD AND METHODOLOGY

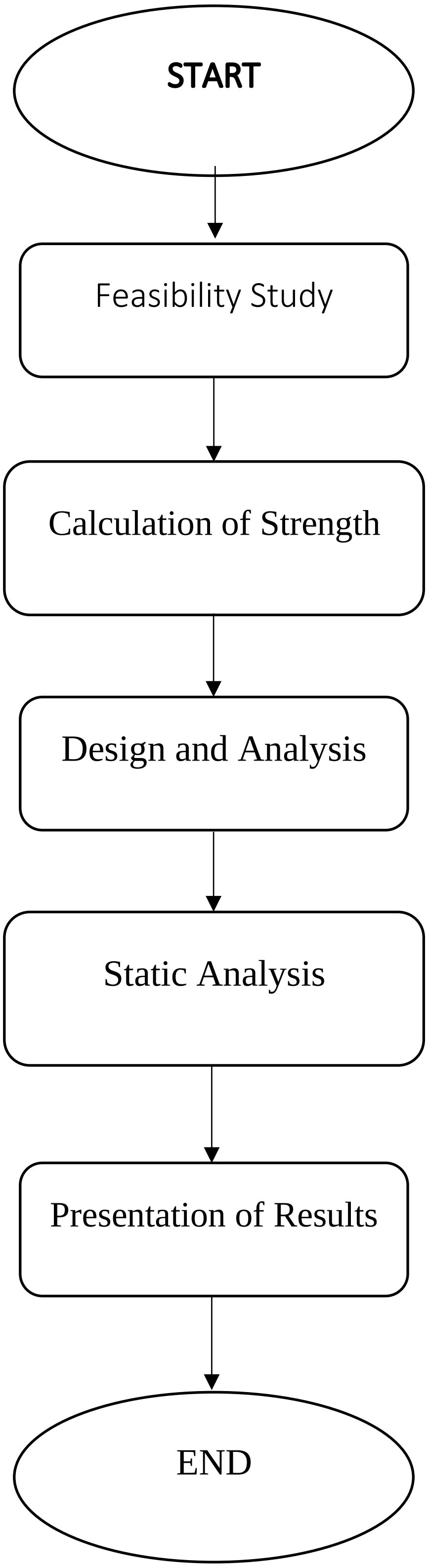

Figure 3.1- Steps for methodology

- **Feasibility Study:** The feasibility of using carbon fiber composite materials for automotive drive shaft applications will be investigated by reviewing the literature on composite materials, particularly carbon fiber composites, and their properties.
- **Calculation of Strength:** The volume fraction method will be used to calculate the strength of carbon fiber reinforced materials.
- **Analysis:** An analytical approach will be employed to design and analyse a carbon fiber composite drive shaft to replace the conventional metallic drive shaft in a passenger car.
- **Static Analyses:** Static and dynamic analyses will be conducted using FEA software to minimize the shaft's weight while meeting torque transmission and critical buckling torque capacity constraints.
- **Results Presentation:** The results of the analysis will be presented, including the optimized design of the composite drive shaft, which exhibits a significant weight reduction, increased stiffness, and reduced static deflection.
- **Contribution to Development:** The study aims to provide valuable insights into the potential of carbon fiber composite materials for automotive drive shaft applications and contribute to the development of more efficient and durable drive shafts for the automotive industry.

3.2 Specification of the Drive Shaft

The fundamental natural bending frequency for passenger cars, small trucks, and vans of the propeller shaft should be higher than 6,500 rpm to avoid whirling vibration and the torque transmission capability of the drive shaft should be larger than 3,500 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations. Here outer diameter of the shaft taken is 51 mm. The drive shaft of transmission system is to be designed optimally for following specified design requirements as shown in Table 3.2.1

Sl. No.	Name	Notation	Unit	Value
1.	Ultimate Torque	Tmax	Nm	3500
2.	Max. Speed of Shaft	Nmax	Rpm	5700
3.	Length of shaft	L	mm	660
4.	Outer Diameter of Shaft	Do	mm	51
5.	Inner Diameter of Shaft	Di	mm	47

Table -3.2.1: Design requirements and Specifications of Existing Model

Steel (SM45C) is used for automotive drive shaft applications. The material properties of the steel (SM45C) are taken from literature available. The steel drive shaft should satisfy three design specifications such as

1. Torque Transmission Capability.

2. Buckling Torque Capability.

3. Bending Natural Frequency.

3.2.1- Calculation for Stainless Steel [SM45C]

Properties	Stainless Steel
Shear modulus, G_{lt} (MPa)	8000 MPa
Poisson ratio, μ	0.29
Elastic Modulus in x direction, Ex (MPa)	2.5 MPa
Density, ρ (kg/m3)	7850 Kg/m^3

Table -3.2.1.1: Specification of stainless steel

3.2.2 Torque Transmission Capacity of Driveshaft

The maximum torsional strength of the shaft is calculated by using the following equation [From design data hand book],

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l}$$

Where,

T is Torque Transmitted in N-m.

J is Polar M.I in m^4.

$$J = \frac{\pi}{32} \times [do^4 \text{-} di^4] = 0.0982 \times [51^4 \text{-} 47^4] = 0.185 \times 10^{-6}\ m^4.$$

τ is Shear Stress in N/m^2.

r is mean radius of shaft in m.

$$r = \frac{ro + ri}{2} = \frac{25.5 + 23.5}{2} = 0.0245m$$

G is Shear Modulus in N/m2.

θ is angle of twist in radians.

l is length of shaft in m.

Now,

$$\tau = \frac{G\theta r}{l} = \frac{80 \times 10^9 \times \frac{5\pi}{180} \times 0.0245}{0.66}$$

$$\tau = 259.15 \times 10^6 \ \mathrm{N/m^2}$$

Thus, the torsional strength of the shaft will be calculated by

$$T = \frac{\tau \times J}{r} = \frac{259.15 \times 10^6 \times 0.185 \times 10^{-6}}{0.0245}$$

$$T = 1956.88 \ \mathrm{Nm}$$

The torque transmitted by the steel shaft is 1956.88 Nm.

3.2.3- Torsional Buckling Capacity of the Drive Shaft

$$\frac{1}{\sqrt{1-\mu^2}} \times \frac{l^2 t}{(2r)^3} > 5.5$$

$$7.6 > 5.5$$

Therefore, it is called as long shaft otherwise it is called as short & medium shaft.

For long shaft, the critical stress is given by,

$$\tau_{cr} = \frac{E}{3\sqrt{2} \times (1-\mu^2)^{3/4}} \times \left(\frac{t}{r}\right)^{3/2}$$

$$\tau_{cr} = 1221.37 \times 10^6 \ \mathrm{N/m^2}.$$

The relation between the torsional buckling capacity and critical stress is given by,

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

$$T_b = 1221.37 \times 10^6 \times 2 \times 3.14 \times (0.0245)^2 \times 0.007$$

$$T_b = 9212.74\ Nm$$

$$T_b > T$$

Therefore, the Design is Safe.

3.2.4- Bending Natural Frequency

The shaft is considered as simply supported beam undergoing transverse vibration or can be idealized as a pinned-pinned beam. Natural frequency can be found using the following equation,

$$f_{nb} = \frac{\pi}{2} \times \sqrt{\frac{E_x I_x}{mL^4}}$$

Here,

The moment of inertia of hollow shaft is given by,

$$I = \frac{\pi}{64} \times [do^4\text{-}di^4] = 0.0781 \times [51^4\text{-}47^4] = 0.0925 \times 10^{-6}\ m^4.$$

The mass per unit length of the shaft is given by,

$$m' = \rho \times \frac{\pi}{4} \times \left(d_o^2 - d_i^2\right) = 2.4168\ Kg/m$$

Therefore, upon substitution of above values we get,

$$f_{nb} = 1.57 \times \sqrt{\frac{2.5 \times 10^6 \times 0.0925 \times 10^{-6}}{2.4168 \times (0.007)^4}}$$

$$f_{nb} = 321.05\ Hz > 80\ Hz$$

Here, the fundamental bending natural frequency of steel shaft is greater than the minimum natural frequency of the shaft assumed. Therefore, the designed Steel Shaft is Safe.

3.2.5 - Critical Speed of Shaft:

The critical speed of the shaft is given by,

$$N_{cr} = 60 \times f_{nb}$$

$$N_{cr} = 19263.54\, rpm$$

Therefore, the critical speed of the shaft is 19263.54 rpm which is more than the maximum speed of the transmission system.

3.2.6- Weight of Steel Driveshaft:

Weight = Density ×Volume

$$W = \rho \times v$$

$$W = \rho \times \frac{\pi}{4} \times \left(d_o^2 - d_i^2\right) \times L$$

$$W = 7850 \times \frac{\pi}{4} \times (0.051^2 - 0.047^2) \times 0.66$$

$$W = 1.595\, Kg$$

3.3 - SPECIFICATION OF COMPOSITE DRIVE SHAFT

The specifications of the composite drive shaft of an automotive transmission are same as that of the steel drive shaft for optimal design. The driveshaft is to be design for the following design requirements.

3.3.1 - Assumptions

1. About longitudinal axis, the shaft rotates at a constant speed.

2. The shaft has a circular and the uniform cross section along the length.

3. The shaft is such that at every cross section, the mass centre coincides with the geometric centre due to which the shaft is perfectly balanced.

4. All the nonlinear and the damping effects are excluded.

5. The shaft is be made of composite material and (Hooke's law is applicable for composite material i.e., the stress strain relationship for composite material is linear and elastic.

6. The shaft is considered as it is under plane stress as the lamina is thin and out-of-plane loads are applied.

3.3.2 - Material selection and Mechanical Properties

The carbon is selected as the best suitable material for the design of composite driveshaft as they are available in market as compared to other materials. Epoxy resin is selected due to its strength, good wetting of fibres and lower curing shrinkage. Following Cases for fiber volume fraction were considered here,

60% Fiber volume fraction of Carbon shaft (V_{fc} = 60% & V_m = 40%).

The material properties of the above considered shaft were calculated using fiber volume fraction theory. Considering the first case for unidirectional ply properties can be calculated by using properties presented in Table 4.2 above as follows,

Properties	**Carbon Fiber**
Shear modulus, G_{lt} (MPa)	3,820 MPa
Poisson ratio, μ	0.34
Elastic Modulus in x direction, Ex (MPa)	10,200 MPa
Density, ρ (kg/m3)	1530 Kg/m^3

Table -3.3.2.1: Specification of Carbon fiber

The material properties of the composite material and its cases are given in Table 4.2. The composite drive shaft should satisfy three design specifications such as,

1. Torque Transmission Capability

2. Buckling Torque Capability

3. Bending Natural Frequency.

3.3.3 - Torque Transmission Capacity of Driveshaft

Considering the composite driveshaft is designed to meet the design requirements and specifications as mentioned above. The maximum torsional strength of the shaft is calculated by using the following equation,

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l}$$

Now,

$$\tau = \frac{G \times \theta \times r}{l} = \frac{3.82 \times 10^9 \times \frac{5\pi}{180} \times 0.0245}{0.66}$$

$$\tau = 12.38 \times 10^6 \ \mathrm{N/m^2}$$

Therefore, putting this value in shear strength in above equation, we get,

$$T = \frac{\tau \times J}{r} = \frac{12.38 \times 10^{6} \times 0.185 \times 10^{-6}}{0.0245}$$

$$T = 285.29 \text{ Nm}$$

The torque transmitted by the steel shaft is 285.29 Nm.

3.3.4 - Torsional Buckling Capacity of the Drive Shaft

Since long thin hollow shafts are vulnerable to torsional buckling, the possibility of the torsional buckling of the composite shaft was checked by considering the hollow composite shaft as anisotropic cylindrical shell the buckling torque is given by:

$$T_b = 2\pi r^2 t \times \frac{(E_x \times E_y^3)^{1/4}}{3\sqrt{2} \times (1-\mu^2)^{3/4}} \times (\frac{t}{r})^{3/2}$$

Where,

Ex = Young’s modulus in x direction.

Ey = Young’s modulus in y direction.

Here, we considered the composite driveshaft as orthotropic lamina. Therefore,

$$T_b = 2\pi(0.0245)^2(0.007) \times 0.272 \times (10200 \times 10200^3)^{1/4} \times (0.2857)^{3/2}$$

$$T_b = 11{,}186\ Nm$$

Here, **Tb** > **T**

Therefore, the design is safe. From the above equation, we can see that the torsional buckling capability of composite shaft is strongly dependent on the thickness of composite shaft and the average modulus in the hoop direction.

3.3.5 - Bending Natural Frequency

The shaft is considered as simply supported beam undergoing transverse vibration or can be idealized as a pinned-pinned beam. Natural frequency can be found using the following equation,

$$f_{nb} = \frac{\pi}{2} \times \sqrt{\frac{E_x I_x}{mL^4}}$$

Here, the moment of inertia of hollow shaft is given by,

$$I = \frac{\pi}{64} \times [do^4\text{-}di^4] = 0.0781 \times [51^4\text{-}47^4] = 0.0925{\times}10^{-6}\ \mathrm{m}^4.$$

The mass per unit length of the shaft is given by,

$$m' = \rho \times \frac{\pi}{4} \times \left(d_o^2 - d_i^2\right) = 2.10\ Kg/m$$

Therefore, upon substitution of above values we get,

$$f_{nb} = 1.57 \times \sqrt{\frac{10200 \times 10^6 \times 0.0925 \times 10^{-6}}{2.10 \times (0.007)^4}}$$

$$f_{nb} = 140.03\ Hz > 80\ Hz$$

Here, the fundamental bending natural frequency of composite shaft is greater than the minimum natural frequency of the shaft assumed. Therefore, the designed Composite Shaft is Safe.

3.3.6 - Critical Speed of Shaft:

The critical speed of the shaft is given by,

$$N_{cr} = 60 \times f_{nb}$$

$$N_{cr} = 60 \times 140.03$$

$$N_{cr} = 8420\ rpm$$

Therefore, the critical speed of the shaft is 8420 rpm which is more than the maximum speed of the transmission system.

3.3.7 - Weight of Composite Driveshaft:

$$\text{Weight} = \text{Density} \times \text{Volume}$$

$$W = \rho \times v$$

$$W = \rho \times \frac{\pi}{4} \times \left(d_o^2 - d_i^2\right) \times L$$

$$W = 1530 \times \frac{\pi}{4} \times (0.051^2 - 0.047^2) \times 0.66$$

$$W = 0.311\ Kg$$

The weight of the Composite Driveshaft is 0.311 Kg.

Chapter 4: RESULT AND DISCUSSION

4.1- FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behaviour of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behaviour and many other phenomena. It also can be used to analyse eithersmall or large scale deflection under loading or applied displacement. In this project finite element analysis was carried out using the FEA software ANSYS. Static, Modal andBuckling analysis was carried out using the mentioned dimensions and material properties in the table given above for both steel and composite driveshaft.

4.1.1- Stainless Steel [SM45C]

Static Modal and Buckling analysis were carried out as follows

1. Model was created in ANSYS by taking 51mm as O.D. and 47mm as I.D. and 660mm length. The loading and boundary condition applied to shaft is shown in Fig-

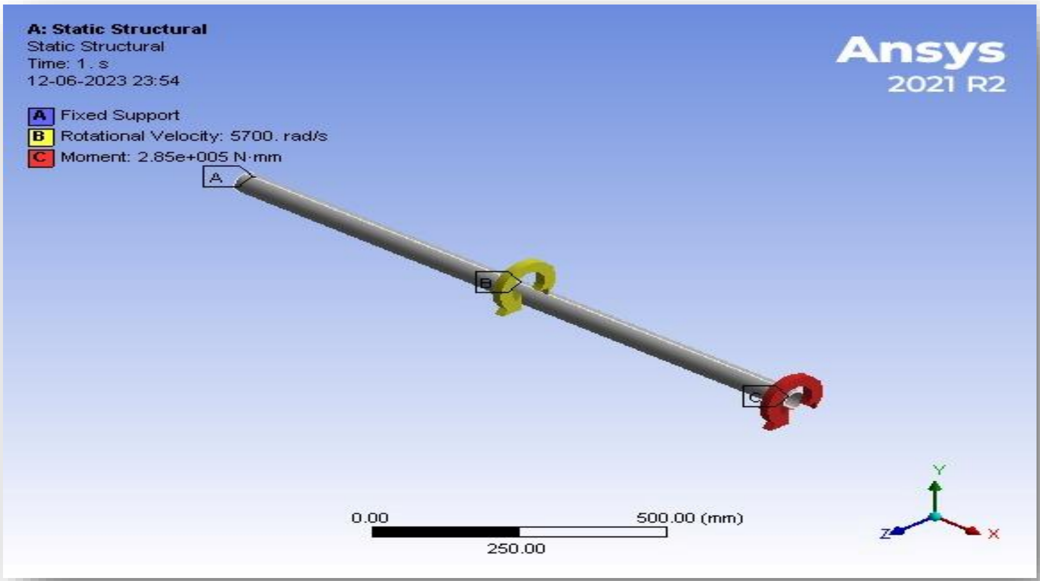

Fig -4.1.1.1- Boundary conditions

The finite element model of Carbon / Epoxy shaft is shown in Figure. One end is fixed and torque is applied at another end.

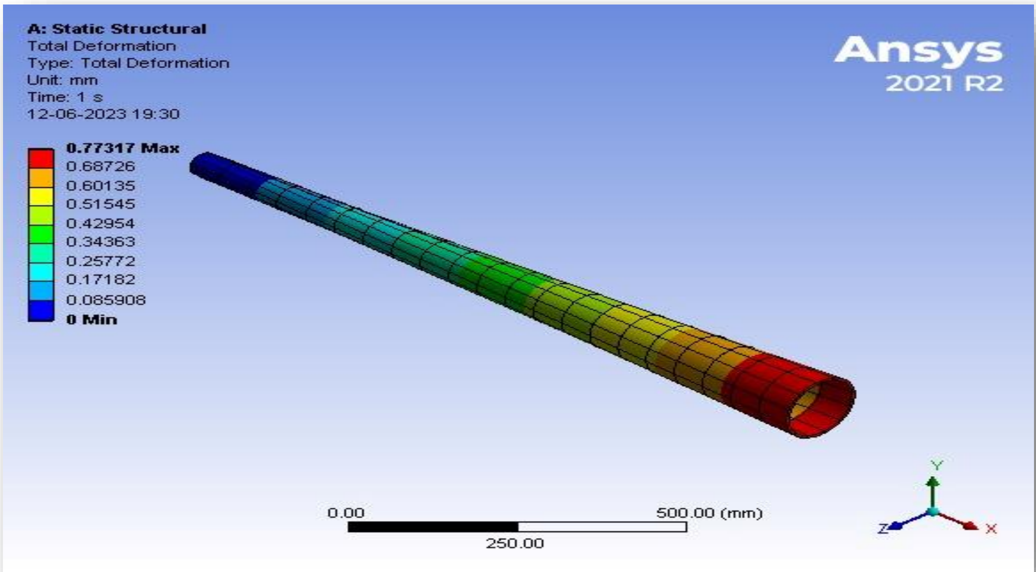

Figure 4.1.1.2: Static structural of total deformation

In this figure fixed support have minimum value of 0mm to at moment applied at the last which has deformation of 0.77317mm as shown in above figure.

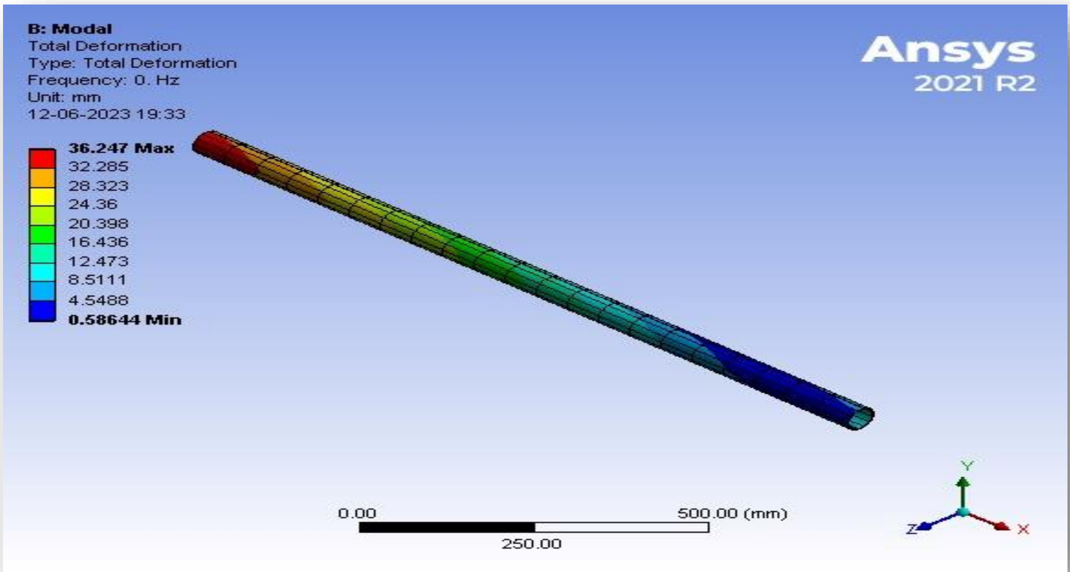

Figure 4.1.1.3: Static structural of modal total deformation

In this figure fixed support have minimum value of 068644 mm to at moment applied at the last which has deformation increases to 36.247 mm as shown in above figure.

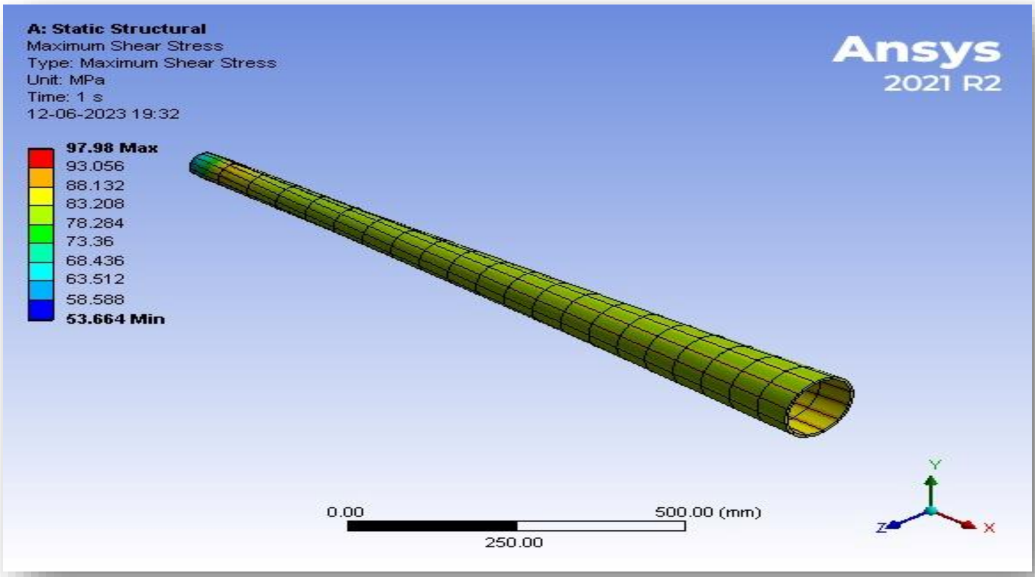

Figure 4.1.1.4: Static structural of maximum shear stress

In this figure fixed support have minimum value of 63.664 N/mm2 to at moment applied at the last which has of 97.98 N/mm2 as shown in above figure.

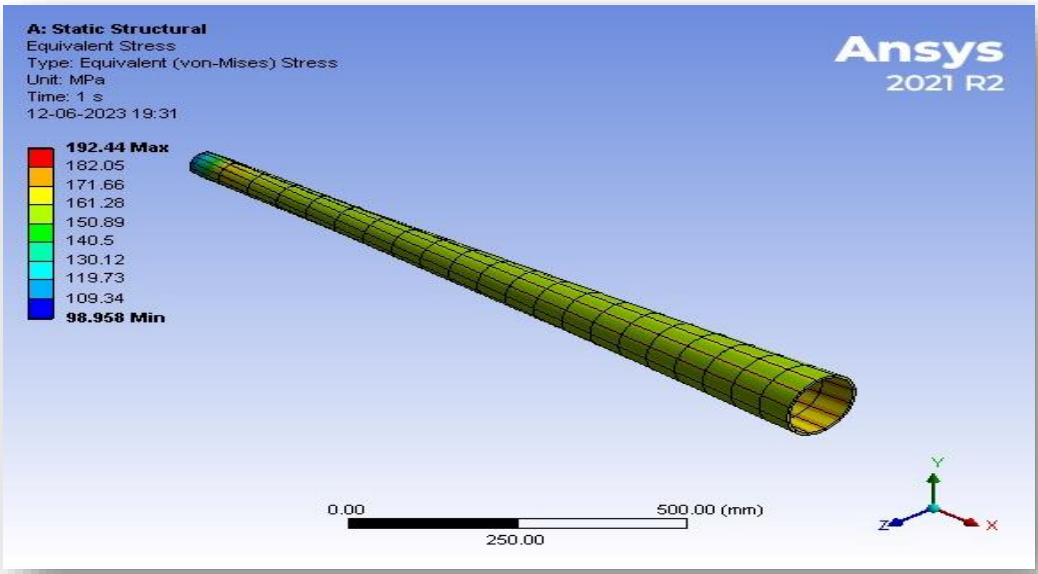

Figure 4.1.1.5: Static structural of maximum equivalent von - misses stress

In this figure fixed support have minimum value of 97.958 N/mm2 to at moment applied at the last which has of 182.44 N/mm2 as shown in above figure.

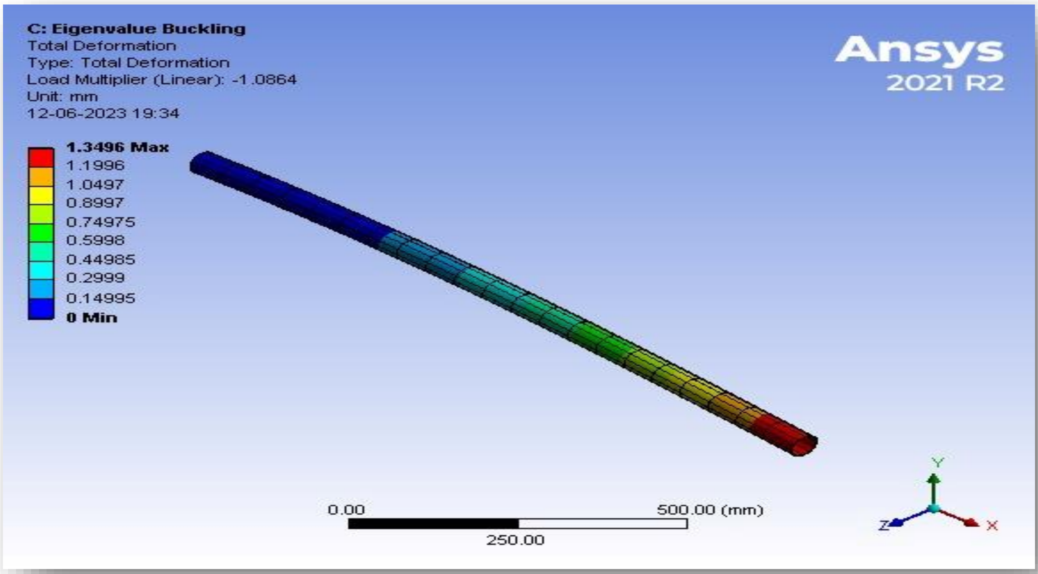

Figure 4.1.1.6: Buckling analysis

It is a technique used to determine buckling loads (critical loads) at which a structure becomes unstable, and buckled mode shapes. For thin walled shafts, the failure mode under an applied torque is torsional buckling rather than material failure. For a realistic driveshaft system, improved lateral stability characteristics must be achieved together with improved torque carrying capabilities.

4.1.2- Carbon Fibre

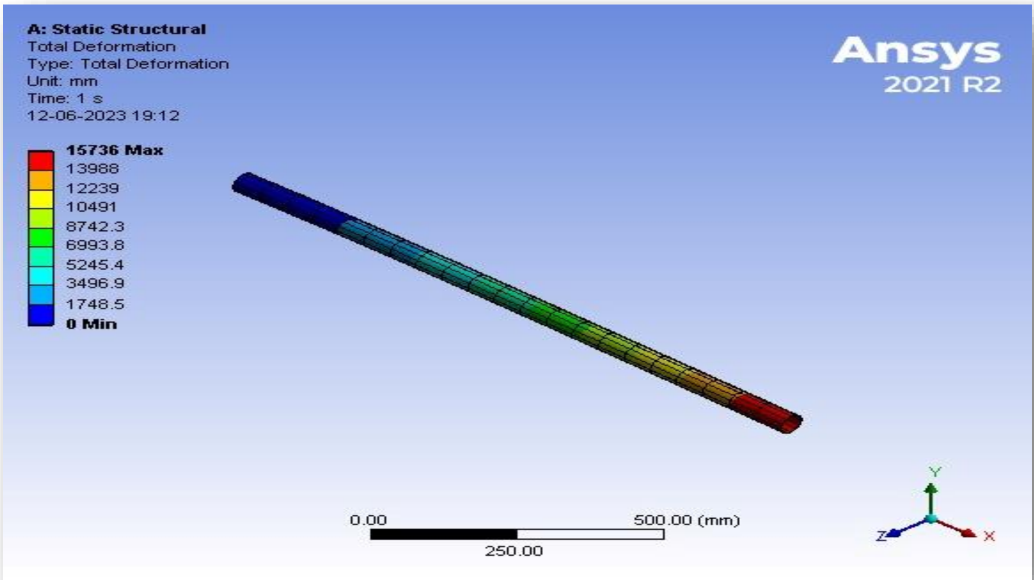

Figure 4.1.2.1: Static structural of total deformation

In this figure fixed support have minimum value of 0 mm to at moment applied at the last which has deformation of 15736 mm as shown in above figure.

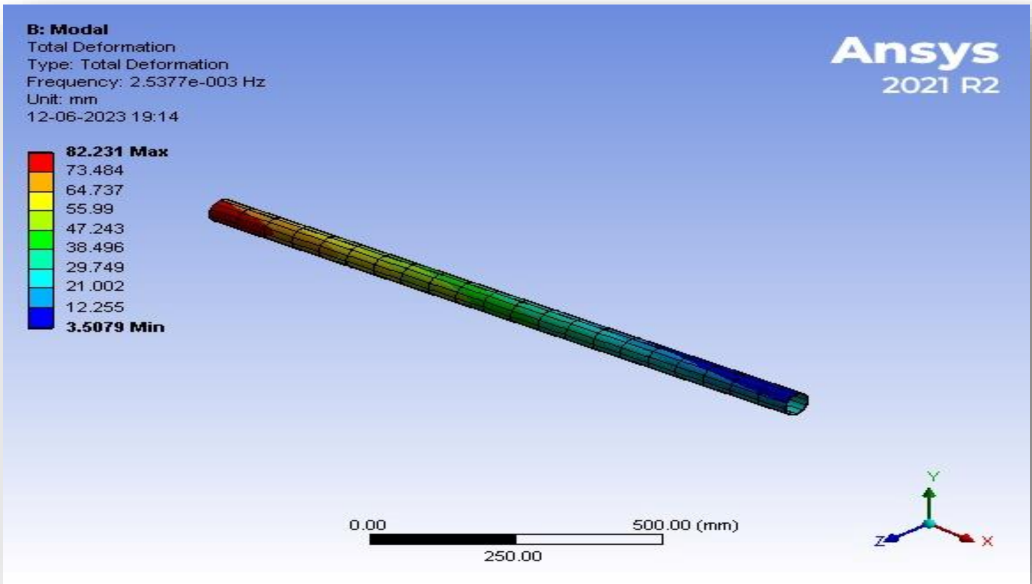

Figure 4.1.2.2: Static structural of modal total deformation

In this figure fixed support have minimum value of 3.6079 mm to at moment applied at the last which has deformation of 82.231 mm as shown in above figure.

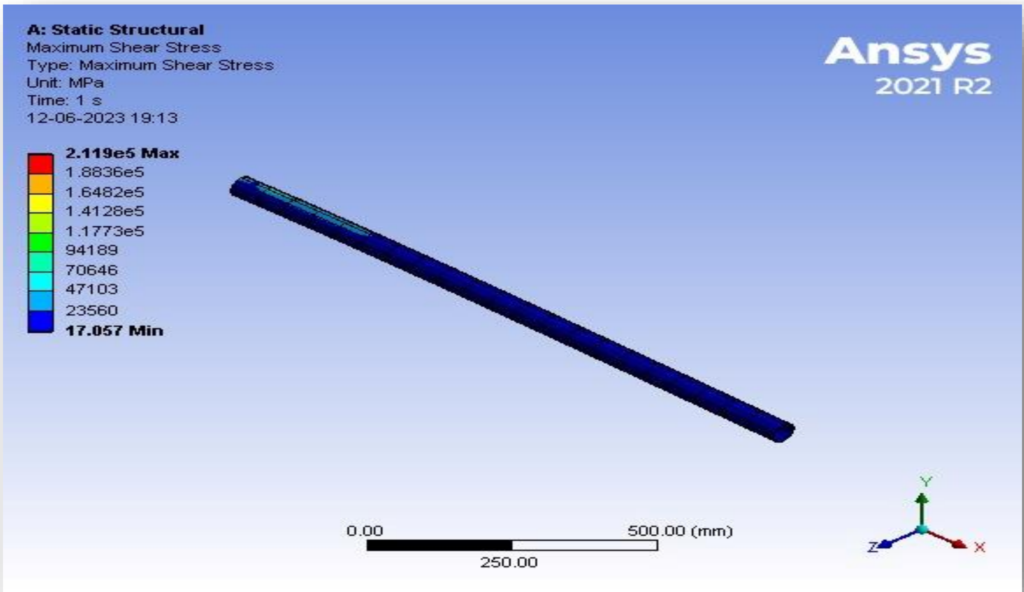

Figure 4.1.2.3: Static structural of maximum shear stress

In this figure fixed support have minimum value of 17.057 N/mm^2 to at moment applied at the last which has of 2.119×10^5 N/mm^2 as shown in above figure.

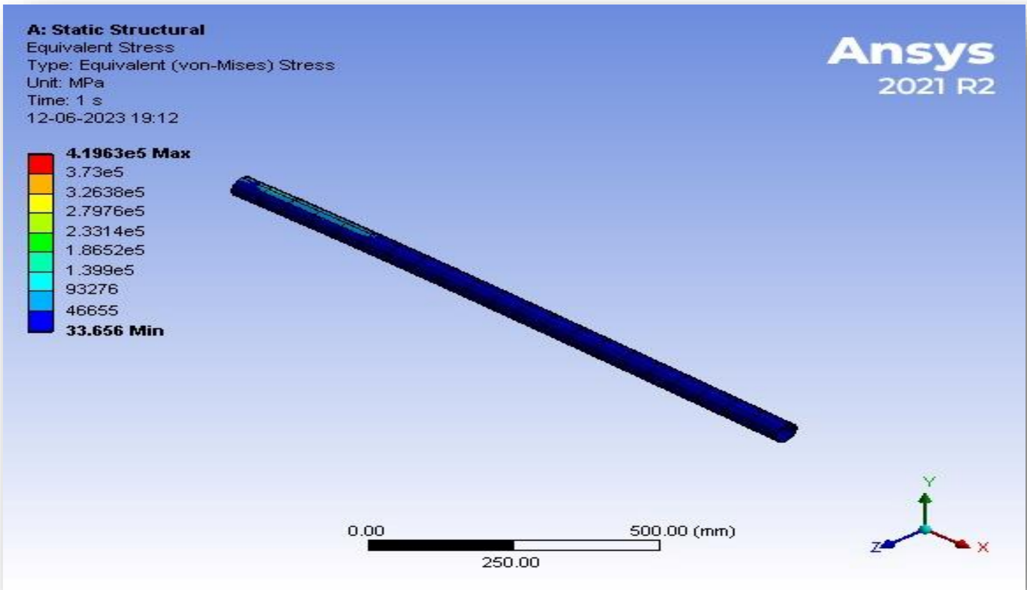

Figure 4.1.2.4: Static structural of maximum equivalent von - misses stress

In this figure fixed support have minimum value of 33.656 N/mm^2 to at moment applied at the last which has of 4.1963×10^5 N/mm^2 as shown in above figure.

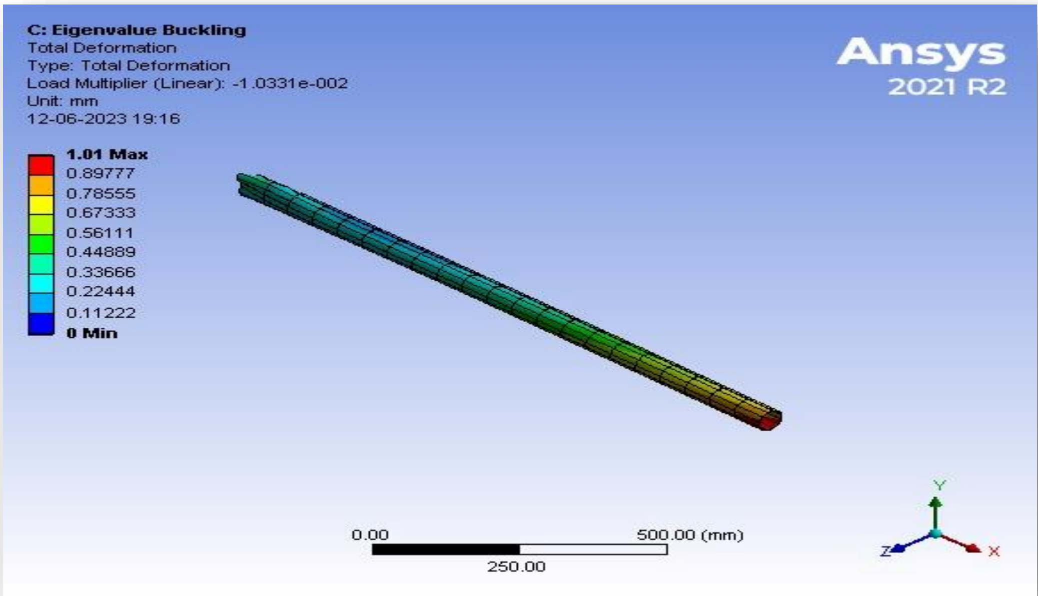

Figure 4.1.2.5: Buckling analysis

It is a technique used to determine buckling loads (critical loads) at which a structure becomes unstable, and buckled mode shapes. For thin walled shafts, the failure mode under an applied torque is torsional buckling rather than material failure. For a realistic driveshaft system, improved lateral stability characteristics must be achieved together with improved torque carrying capabilities.

4.1.3 Comparison of Stainless steel and Carbon fiber

Material / Properties	Stainless Steel	Carbon Fiber
Shear Stress (MPa)	259.15	12.38
Torque Applied (Nm)	1956.88	295.6
Buckling torque (Nm)	9,212.74	11,186
Natural frequency (Hz)	321.05	140.03
Critical Speed (rpm)	19,263.54	8,402
Weight of Driveshaft (Kg)	1.595	0.311

Table- 4.1.3.1: Comparison of Stainless steel and Carbon fiber

CHAPTER 5: CONCLUSIONS

From above comparison of carbon fiber composites offer significant advantages over traditional steel drive shafts.

Analysis using finite element analysis (FEA) and experimental testing has provided valuable insights into the structural behavior, stress distribution, natural frequencies, and critical speeds of carbon fiber composite drive shafts.

The study and analysis of carbon fiber composite drive shafts for automotive applications have laid the foundation for the development of lightweight, high-strength, and durable drive shafts that can enhance vehicle efficiency, performance, and sustainability.

1. The theoretical values of shaft design are nearly same to the analytical values of shaft obtain using analysis tool ANSYS software.
2. Hybrid driveshaft i.e., Carbon Fiber driveshaft with 60% fiber volume fraction; the torsional buckling strength of the hybrid composite driveshaft was 11,186 Nm which is more than the maximum torque applied to the shaft which is 3500 Nm. The fundamental bending natural frequency of the composite shaft is 140.03 Hz and the minimum required bending natural frequency is 80 Hz. The critical speed of the composite shaft is 8,402 rpm and is more than the maximum speed. Hence, the designed hybrid composite shaft is safe for torsional buckling, fundamental bending natural frequency and critical speed theoretically.
3. Torsional strength of the shaft with higher fiber volume fraction is higher. Thus, we can conclude that fiber volume fraction is the deciding factor in designing.
4. Hybrid composite driveshaft's have better mechanical properties than conventional composite driveshaft as it contains two fiber materials. Fiber materials having high cost can be used with less cost fiber materials in proportion so that it can obtain the mechanical properties of both the material and can be relief in cost reduction. Carbon fibers have the major contribution over glass fibers in increasing the torsional stiffness.

Compare to steel driveshaft more than 80% of weight can be reduced by using the composite driveshaft instead of steel driveshaft. The advantage is less weight and less power required for transmission from engine to driveshaft to rear wheel of the vehicle and it gives less noise and vibration while rotating shaft.

SCOPE FOR FUTURE WORK

Composite Shaft can be Manufactured using various combinations of materials and can be tested experimentally for torsional test of shaft, buckling capability of shaft, critical speed test and natural frequency.

- Advanced Manufacturing Techniques.
- Multi material Hybrid Design.
- Structural Optimization and Design.
- Failure Analysis and Durability Assessment.
- Environmental sustainability.
- System Integration Optimization.
- Cost reduction and Commercial Viability.
- Real world testing validation.

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