ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

Design and analysis of composite drive shaft for Rear wheel drive vehicle

A Thesis Submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering

By

Lelisa Gezu

Advisor: Mr.Mekonnen Liben (Asst.prof.)

Mechanical and vehicle Engineering Department

February 2019

Adama, Ethiopia

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

Design and analysis of composite drive shaft for Rear wheel drive vehicle

By

Lelisa Gezu

Approved By Examiners Board

____________________	______________	_____________
Advisor	Signature	Date
________________	______________	____________
Chairman person	Signature	Date
_________________	______________	___________
Internal examiner	Signature	Date
________________	_____________	____________
External examiner	Signature	Date

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this thesis entitled ''**Design and analysis of composite drive shaft for Rear wheel drive vehicle**'' in partial fulfillment of the requirement for the award of the degree of Master of Science in Automotive Engineering is an authentic record of my own work, with due reference to the literature, and carried out from November 2017 to February 2019 under the supervision of Mr.Mekonnen Liben (Asst.Prof), in the Department Mechanical System and Vehicle Engineering at Adama science and technology university, Ethiopia.

Lelisa Gezu	--------------	--------------
	Signature	date
Student		

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Mr.Mekonnen Liben	------------	------------
Advisor	signature	date

ACKNOWLEDGEMENT

First of all I thank God for his help to accomplish this thesis and stand by my side at times of challenges and difficulties.I express special gratitude to my advisor Mr.Mekonnen Liben (Asst.prof) for his inspiration, guidance, constant supervision, direction and discussion in successful completion of my project. I wish to express my sincere and obedient gratitude to Mr. Ramesh Babu, Mr.Idris Ilmi, Mr.Zewudie Alemayehu, Lealem , Meba all friends at ASTU and all the members of the department for their help. Similarly my great honor and respect goes to Adama science and Technology University for giving me the scholarship and Belayab Cables Plc for their willingness to test my sample in their workshop.

A special thanks to my family. Word cannot express how grateful I am to my mother, father for all the sacrifices that they have rendered me. The last but not the least is Adama science and Technology University for offering me this scholarship.

ABSTRACT

Currently in our world as the modern technology is becoming sophisticated the material utilized is also becoming the main focus for many researchers to search for efficient and reliable materials. Automotive driveshaft is one of the very important components of an automobile which draws attention to enhance its material from the point of view of its weight and strength. The objective of this paper is to design and analyze a composite driveshaft for power transmission to get maximum efficiency, weight reduction, increasing comfort, decrease noise and part complexity of the vehicle. This thesis deals with the replacement of two piece steel drive shaft with a composite material made of E-glass fiber/epoxy with one piece and to investigate mechanical properties like tensile, bending and compression strength test of composite material on experimental basis by preparing specimen of composite shaft as per ASTM using hand lay-up technique. The driveshaft selected is applicable to Mahindra xylo D2BS-III vehicle which is at present using steel driveshaft. The numerically designed drive shaft is first designed for steel, glass fiber/epoxy and hybrid/epoxy composite material for its safe dimensions, then part model created was for respective dimensions in CATIA V5R19 software. After modeling, the part is imported to ANSYS and modal analysis; buckling and harmonic response analysis is carried out using ANSYS R15.0 workbench. The result had shown a mass reduction of 46% and better mechanical property of the composite material. In conclusion the two-piece driveshaft can be replaced by single piece composite made resulted in weight reduction which can also eliminates part complexity.

Key Words: driveshaft, composite material, glass fiber, light weight, ANSYS

TABLE OF CONTENTS

CONTENTS **PAGES**

ACKNOWLEDGEMENT ……………………………………………………………………….i

ABSTRACT……………………………………………………………..………………....ii

LIST OF FIGURES ……………………………………………………………………..vi

LIST OF TABLES ………………….…………………………………………………….....viii

LIST OF ACRONYMS AND SYMBOLS….........………………….......................................ix

CHAPTER ONE………………………………………………….....………………......1

1. INTRODUCTION……………………………………………………….................1

1.1. Background ……….…………………………………………….......................1

1.2. Statement of the problem……..…………………………………………..............4

1.3. Objective of the study………………………………………………………...........5

1.4. Specific objective of the study……..………………………….............................5

1.5. Significance of the study………………………………….....................................5

1.6. Scope of the study…………………………………..6

1.7. Limitation……………………………………………………………………......6

CHAPTER TWO……………………………………………………………………...7

2. LITERATURE REVIEW…………………………………………………………...7

INTRODUCTION…..………………………………………………………...........7

2.1. Historical development of composite ……………………………………………..7

2.2. Previous works on composites ……………………..………………………………...8

2.3. Overviews of composites……………..……………………………………………11

2.3.1. Classification of composites……………………………………………………13

2.3.2. Reinforcement……………………………………………………………………..18

2.3.3. Definition of laminated structure……………....……………………………….....21

2.3.4. Critical speed analysis in composite driveshaft……..…….……………….........22

2.3.5. Limitation of the composite ………………………………… ……………...23

2.4. Schematic arrangement of underbody of an automobile …………….............................24

2.4.1. Operation principle …………………………………………………………..26

2.4.2. General characteristic of universal joint…………………………………………...27

2.5. Crash performance analysis of composite driveshaft ……………………………………30

CHAPTER THREE………………………………………………………………33

3. MATERIALS AND METHODS ………………………………………………………….33

3.1. Materials……………………………………………………………………........33

3.1.1. Glass fiber…………………………………………………………..…………34

3.1.2. Matrix…………………………………………………………………………..34

3.2. Methods……………………………………………………………………………......36

3.3. Method of manufacturing.………….…………………………………………….........37

3.4. Description of glass fiber /epoxy resin composite……...……………………...………..43

3.4.1. Tensile test ……………………………………………………………...………..43

3.4.2. Compressive strength test (ASTM D3410)……………………………………………45

3.4.3. Bending strength test (ASTM D790-2010)…………………………………............46

CHAPTER FOUR………………………………………………………………………47

4. DESIGN……………………………………………………………………………………47

4.1. Design of Steel Drive Shaft ……………………………………………………………..47

4.2. Design of composite driveshaft………………………………………………………......56

4.3. Selection of Cross-Section……………………………………………………………….56

4.4. Design and analysis of driveshaft…………………………………………………………..64
4.4.1. Modeling using catia V5…………………………………………………………64
4.4.2. Analysis of Propeller Shaft……………………………………………………....65
4.4.3. Meshing……………………………………………………………………………..66
4.4.4. Boundary condition….……………………………………………………………67
4.4.5. Analysis of composite driveshaft…….…………………………………………...69
CHAPTER FIVE……………………………………………………………………......71
5. RESULT AND DISCUSSION ……………………………………………………71
5.1. Tensile strength of sisal/glass fiber hybrid composite material…………………………72
5.2. Modal analysis……………………………………………………………...……73
5.3. Harmonic analysis ……………………………………………………………………75
CHAPTER SIX……………………………………………………………………………77
6. CONCLUSION AND RECOMMENDATION……………………………………....77
6.1. Conclusion…………………………………………………………………………...77
6.2. Recommendation for prospective Applications……………………………............78
6.3. Scope for the future work…………………………………………………………..79
REFERENCES……………………………………………………………………...….80
APPENDIX…………………………………………………………………………….....86
Appendix A ……………………… ………………………………………………….87
Appendix B ……………………………...……………………………………………...90
Appendix C………………………………………………………………………………...94

LIST OF FIGURES

Figure 2.1.Composite production in different industries...7

Figure 2.2.Garbage truck with composite driveshaft 8

Figure 2.3.Composite classification based on matrix materials……………………………...13

Figure 2.4.Composite classifications based on structure property..14

Figure 2.5. Idealized chemical structure of a simple Epoxy..17

Figure 2.6.Types of fibers..18

Figure 2.7. Glass fiber..20

Figure 2.8. Lamina, laminae and laminate..21

Figure 2.9. Critical speed-length curve for automotive drive shafts..22

Figure 2.10.Driveshaft arrangement in rear wheel drive 24

Figure 2.11.Two-piece drive-line with single intermediate support bearing............................26

Figure 2.12.Shaft operating angle……………………….……..……………….............28

Figure 2.13.Behaviour of propeller shafts in frontal crash……………………….....................31

Figure 2.14. A failed composite driveshaft……………………………………….................32

Figure 3.1. E- Glass Fibers (a) CSM and (b) WRM……………………………………...........34

Figure 3.2. General Purpose resin..35

Figure 3.3. Hardener..36

Figure 3.4. Hand layup method..38

Figure 3.5. Mould prepared in specified dimension..40

Figure 3.6. Mixing of epoxy with hardener………………………………………….............41

Figure 3.7. Removing of air using roller………..……………………………………............41

Figure 3.8. Flowchart of the manufacturing process...42

Figure 3.9. Universal testing machine (UTM)…………………………………………......44

Figure 3.10. Fracture of the specimen…………………………………………………….......44

Figure 3.11. Composite specimen mount……………………………………………..........45

Figure 3.12. Specimen under bending test...48

Figure 4.1. Transmission of torque by drive shaft..49

Figure 4.2.CATIA modelled driveshaft...64

Figure 4.3.Imported solid model of driveshaft from CATIA...65

Figure 4.4. Mesh of the driveshaft..66

Figure 4.5. Fixed support imposed on the shaft...67

Figure 4.6. Total deformation of steel driveshaft..68

Figure 4.7. Steel driveshaft elastic strain...68

Figure 4.8. Von-misses of steel driveshaft 69

Figure 4.9. Deformation of glass/epoxy fiber driveshaft...69

Figure 4.10. Elastic strain of glass/epoxy fiber driveshaft...70

Figure 4.11.Von-misses of glass/epoxy fiber driveshaft..70

Figure 5.1. Natural frequency variation graph for both materials……………………………..74

Figure 5.2. Variation of stress amplitude with different exciting frequencies…………………75

Figure 5.3. Chart representation of both driveshaft weights..76

LIST OF TABLE

Table 2.1.Maximum operating angle 30

Table 3.1.Materials used for the preparation of specimen composite......................................33

Table 3.2.Weight of the sample specimen..40

Table 4.1.Mechanical properties of Steel (SM45C)……………….…………………………..47

Table 4.2. Design requirements and Specifications of Existing Model……………………......48

Table 4.3. Mechanical Properties of E-Glass/Epoxy Composite (60/40%)..............................59

Table 4.4.Physical dimension of the composite drive shaft 59

Table 4.5. Steel isotropic elasticity property from ANSYS…………………………………..68

Table 4.6. Orthotropic elasticity property of E-glass fiber from ANSYS……………………69

Table 5.1.validation and Comparisons of analytical and ANSYS results for steel and composite material……………………………………………………...71

Table 5.2.Comparison of analytical result for torque and natural frequency............................71

Table 5.3. Mechanical property values experimental result 72

Table 5.4. Natural frequency of steel and E-glass/epoxy at different mode…………………......73

ACRONYMS AND SYMBOLS

do	Outer Diameter of hollow steel Shaft
di	Inner diameter of hollow steel Shaft
t	thickness of the hollow steel shaft
v	poisson's ratio
l	length of shaft
E	young's modulus
lbs	pound
μm	micrometer
T1	input torque
T2	output torque
ω	rotational angular Velocity
ϕ	rotational angle of driven shaft
Ө	operating angle
Ks	stiffness constant
ρ	Density
Sy	Yield strength
Ss	Shear strength
G	Shear modulus
ΔT	total deformation
J	Polar moment of inertia
τ	Shear Stress
r_m	mean radius
f_{nb}	natural frequency
Ix	Area moment of inertia
m	mass
σ	stress
Hz	hertz

NVH	Noise, vibration and harshness
METEC	Metal and Engineering Corporation
SEM	Scanning Electron Microscopy
TLBO	Teaching Learning Based Optimization Algorithm
FRP	Fiber-reinforced plastic
MMC	Metal matrix composite
CMM	Ceramic Matrix Materials
PMC	Polymer matrix composite
PRP	Particle reinforced polymer
ASTM	American Society of Testing & Materials
CV	Constant Velocity
GP	General Purpose
PVA	poly vinyl alcohol
UTS	ultimate tensile strength
UTM	universal testing machine
SBS	short beam shear
FOS	Factor of safety
CATIA	computer-aided three-dimensional interactive application
FEA	Finite Element Analysis
CSM	Chopped Strand Mat
WRM	Woven roving mat
MR	Modulus of rupture

CHAPTER ONE

INTRODUCTION

1.1. BACKGROUND

A drive shaft is mechanical component for transmitting torque and rotation, usually used to connect other components of a drive train that cannot be connected directly. Most engines or motors deliver power as torque through rotary motion. Transmission propeller shaft, a potential item for weight reduction, accounts for 7-15 percent of sprung weight, which is the weight of the propeller shaft without any reduction on the torque bearing capacity and stiffness in automobile transmission system [1].

Today12 % of the population owns a car. By 2020 this number could be 15 % [2]. Such a large number of cars have a negative impact on the planet on which we live. The aim is to reduce the weight of the car by using the material of lower density, or weight, and with better car design. Over the past 30 years the industry has reduced vehicle weight about 30 % .Every 10% of weight reduced from the average new car or light truck can decrease fuel consumption by around 7 % [3].

Traditionally, driveshaft is made from steel (SM45C) which transfer power from the transmission to the rear axle of the vehicle. As a direct response to industry demand, for greater performance and efficiency in light trucks, vans and high performance automobiles, the graphite, carbon, glass fiber, and aluminium driveshaft tube were developed. Glass fiber/epoxy resin composites are widely used in automotive and aviation industry. The advantages of glass fiber over other materials are: easy and cheap production, possibility to produce very long fibers, high resistance to impact and etc. The main reason for this is a significant saving in weight of the driveshaft. The composite driveshaft has a mass of about 2.7kg, while the amount for steel driveshaft is about 10 kg [4].

A one piece composite driveshaft can be manufactured so as to satisfy the vibration requirements. This eliminates all the assembly, connecting the two piece steel shaft and thus minimizes the overall weight, vibrations and cost. Due to weight reduction fuel consumption will be reduced. The entire driveline of the car is composed of several components, each with rotating mass. the rule of thumb is that 17-22% of the power generated by the engine is lost in rotating mass of the drive train [5].The power is lost because it takes more energy to spin heavier parts. This energy loss can be reduced by decreasing the amount of rotating mass.

Composite materials have high damping capacity and hence they produce less vibration and noise with the ability of good corrosion resistance. Lower rotating weight transmits more of available power. A composite driveshaft offers excellent vibration damping, cabin comfort, reduction of wear on drive train and increased tire traction. Also, composite materials typically have a lower modulus of elasticity. As a result, when torque peaks occur in the driveline, the composite driveshaft can act as a shock absorber and decrease stress on part of the drive train extending life it also sustains the torque transmitted. The term Drive shaft and propeller shafts are used interchangeably [6].

In this project an attempt has been made to replace two piece drive shaft with composite material single piece drive shaft. This composite material drive shaft have two universal joints and jaw coupling while the two piece drive shaft consists of three universal joint, a center support bearing and a bracket. Analysis of composite drive shaft is carried out to understand the effectiveness of composite material on load carrying capacity and toque transmission of drive shaft. Because of increase in weight of the propeller shaft replacing the stainless steel with the composite materials, which are very less weight when compared to that of stainless steel. The cost of composite materials is less when compared to that of stainless steel.

From different research it is clear about 20-25% of total greenhouse gas emission in industrialized countries is generated by transportation. Fossil fuels used for automobile like diesel, petrol, etc. are non-renewable source of energy. So, main intension in automobile sector is to improve mileage of vehicle. One of the ways to increase the mileage of vehicle is to reduce its weight. CO_2 emission by human activities is one of the major reasons for excessive greenhouse gases in earth's environment, which is causing global warming. To reduce CO_2emission due to transportation the focus be on decreasing fuel consumption of the vehicle used for transportation, one ways of achieving it is reducing the weight of the vehicle [7].

Solutions for reducing vehicle emissions

A number of measures are adopted in terms of their potential contribution to CO_2 reduction in passenger cars,

- Technical improvements to reduce fuel consumption at the vehicle level;
- Adoption of fuel efficient air conditioning systems;
- Strategies for application of alternative fuels based on fossil energy;
- Biofuels research;
- Fuel efficient driving;
- CO_2 based taxation schemes for passenger cars;
- Strategies for improved energy
- Public proposals;

Every 10% of weight reduced from the average new car or light truck can decrease fuel consumption by 7%.Noise, vibration and harshness (NVH) have become increasingly important factors in vehicle design as a result of the quest for increased refinement. Harshness, which is related to the quality and transient nature of vibration and noise, is also strongly linked to vehicle refinement [8].

1.2. Problem statement

Drive shafts are one of the most important components in vehicles. Because of two or three piece assembly of drive shaft consists of three universal joint, a center support bearing and a bracket which increases in weight of overall assembly has resulted which lead to increase in weight and complex mechanism. Recently limited number of vehicles are equipped with fiber composite reinforced fiberglass, graphite, and aluminum drive shafts. The advantages of using these materials are weight reduction, torsional strength, fatigue resistance, easier and better balancing, and reduced interference from shock loading.

It is also possible that if the steel drive shaft is broken as the vehicle is running it may pivot on the ground and subjects the car to roll-over. But if the composite drive shaft is broken it is divided into fine fibers that do not have any danger for the driver. Moreover, the breakage of composite drive shaft is less-risky when compared with the scattering of broken steel parts in various directions.

1.3. The objective of the study

The general objective of this thesis work is to design and analyze composite driveshaft of light vehicle in order to replacement of a conventional steel drive shaft with composite drive shafts to gain reduction in the weight of the vehicle.

1.4. Specific objectives

- Preparing composite specimen using hand lay-up method.
- Design the shaft and testing mechanical properties
- Graphical Modelling of composite drive shaft using CATIA V5R19 software.
- Analyzing the driveshaft using ANSYS R15.0workbench.
- To compare weight of designed composite with steel drive shaft in the literature review.

1.5. Significance of the Study

The outcome of this study would give input for driveshaft manufacturers. It would provide some guideline on how to design composite driveshaft and its performances analysis using ANSYS software. It is also give better understanding about the composite material advancement over the conventional driveshaft and emphasizes more on how to improve weight of a vehicle.

Apart from that, optimized fuel economy will be achieved; Furthermore, the result of this thesis can be used as a reference for any individual, researcher or manufacturer who are engaged in vehicle body design, to save foreign currency by reducing fuel consumption and reduction of weight by replacing it without reduced strength.

Beneficiary: automotive industries, society, researchers and the country as a whole.

1.6. Scope of the Study

This work is delimited to preparation of specimen of glass fiber composite and testing its properties, design using CATIA and analysis of composite drive shaft of automobile using ANSYS software.

1.7. Limitation

Limitation of local journals and relevant materials has urged me to depend on only materials from internet though its interruption was a challenge. Furthermore, difficulties of obtaining proper materials from the market, increased cost, and unavailability of proper laboratories for conducting material tests were some of the major limitations encountered.

CHAPTER TWO

2. LITERATURE REVIEW

INTRODUCTION

The main purpose of literature review is to emphasize the importance of previous work, present study and to provide overview of work done to date towards composites driveshaft. The most important topics included in this review are:-

- Historical development of composite material
- Previous work on composite driveshaft
- Overview of composite
- Schematic of driveshaft

2.1. Historical development of composite material

Composite materials have been in focus from a structural point of view recently; applications and correspondingly the literature of composite materials are growing for quite some time. Adoption of composite materials has been started by aerospace industries, however they are used much more widely in other industrial applications, such as sporting goods today, a fact which is obvious from Figure below [9].

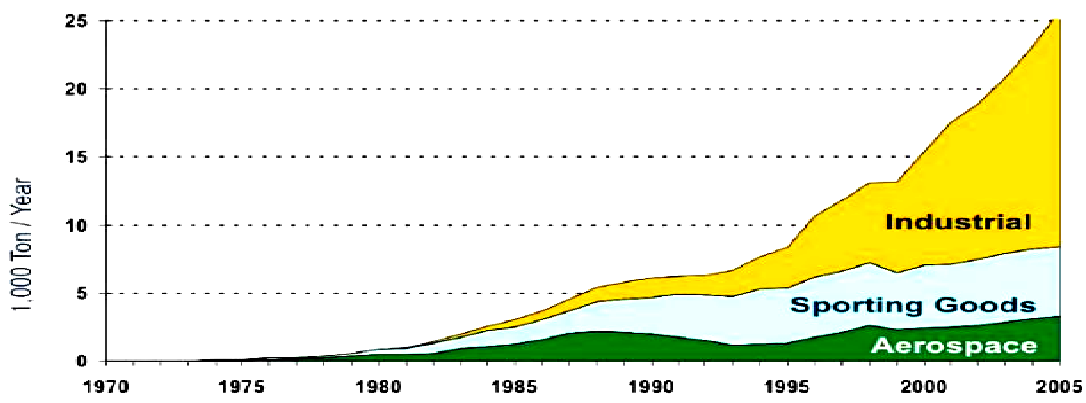


Figure 2.1. Composite production in different industries

2.2. Previous work on composite driveshaft

The Spicer U-Joint Division of Dana Corporation for the Ford Econoline van models developed the first composite propeller shaft in 1985. The General Motors pickup trucks, which adopted the Spicer product, enjoyed a demand three times that of projected sales in its first year. In a test started in August of 1994, a 1-piece carbon fiber driveshaft was installed in a Garbage truck operating in Texas, which is shown in Figure below. This shaft replaced a 2-piece steel shaft and a center bearing. The resultant weight savings was about 80lbs. The shaft had seen daily use for the last two years in what has been described as one of the most torturous commercial truck applications possible. Absolutely no problems have been recorded [10].

Figure 2.2. Garbage truck with composite driveshaft [10].

The characteristic of propeller shaft to substitute its material with composite material and suitability of material is analyzed by evaluating and comparing stress distribution and deformation within the shaft to replace the steel driveshaft with a piece a piece of E-glass/epoxy and E-carbon/epoxy with the help of material properties. The modeling and analysis is done using commercial software i.e. CATIA and ANSYS taking into considerations the weight saving, deformation, shear stress induced and frequencies it is evident that E-glass /Epoxy composite has the most encouraging properties to act as replacement for steel out of the considered three materials [11].

Design and analysis of composite driveshaft for power transmission. It also compares the convectional two piece drive shafts with different composite material like S-glass, E-glass, carbon epoxy and substitution of the best one to attain improved efficiency. The intension here is to increase mechanical properties such as deflection, weight reduction, natural frequencies of the shaft and stress under subjected load. It states the substitution of the composite material for convectional steel structures has many advantages because of higher specific stiffness and strength composite material. It also carried out design and analysis using CATIA and ANSYS software. According to this paper the replacement of convectional driveshaft results in weight reduction of automobile which contributes to fuel economy. It has been conclude that S-Glass epoxy composite material may be used as alternate material for propeller shaft [12].

The basic design requirements considered are torsional strength, torsional buckling and bending natural frequency. It takes four cases by wounding different layers of composite materials and carried out an experiment .as in which the steel has a role to transmit the required torque, while the E-glass epoxy composite increases the bending and natural frequency. Results obtained from this study show that increasing the number of layers would enhance the maximum static torsion 66 % for {+45/-45}3s laminates higher than the pure aluminum and mass reduction of 42% compared with steel driveshaft. A one-piece hybrid composite full driveshaft is optimally analyzed using finite element ANSYS software and results indicates that using composite materials, it is possible to reduce the weight up to 30 % when compared to structural steel. It is clearly stated that from the paper E-glass/epoxy composite has a good weight saving, deformation, shear stress induced and resonant frequencies properties compared to steel [13].

The fabricated composite driveshaft is tested for fatigue life and the design optimization improves the performance of propeller shaft. This paper deals with FEA analysis of composite shaft with different degree of orientation of glass fibers. It includes the modeling of shaft in CATIA software. The meshing and boundary condition application will be carried out using hyper mesh, Fatigue analysis of composite shaft carried out using ANSYS. After applying the gradual load and lastly concluded that no crack is coming after 22100 cycle for the composite material as compare to convectional material [14].

In replacing of the conventionally used steel driveshaft of automobiles with an appropriate composite driveshaft different orientation of fibers are taken into consideration such as 0^0, ±45 and 90^0 for the composite ply orientations, owning their specific advantages. The properties like torsional strength, bending natural frequency and torsional buckling were designed and analyzed for their appropriateness after made them from composites of carbon/epoxy and Kevlar/epoxy by comparing them with the convectional driveshaft under the same grounds of design constraints and they found that composite material takes prior advantage so it is recommended for usage. From this paper it is clearly stated the weight reduction percentage which saves 89.756 % when made from carbon/epoxy driveshaft with barely half of the wall thickness of convectional steel driveshaft [15].

The compressive, shear and flexural properties of E-glass/epoxy composite have an increasing trend when the strain rate is increasing; whereas the tensile strength decreases as the strain rate increases [16].

The substitution of convectional driveshaft material with other alternative composite material like E-glass/epoxy has considerable amount of weight reduction in the range of 28% when compared to structural steel shaft. Taking into considerations the weight saving, deformation, shear stress induced and resonant frequencies it is evident that E-Glass/Epoxy composite has the most encouraging properties to act as replacement for steel out of the considered two materials [17].

In this project work an attempt is made to evaluate the suitability of composite material such as E-Glass/Epoxy for the purpose of automotive drive shaft application. A one-piece composite shaft is optimally analyzed using Finite Element Analysis Software for E-Glass/Epoxy composites with the objective of minimizing the weight of the shaft, which is subjected to the constraints such as torque transmission, critical buckling torque capacity and bending natural frequency. By varying the diameter and length he studied and concludes that using minimum outer radius large amount of mass can be saved [18].

2.3. Overview of composite

Matrix and reinforcement together create a product that has properties not achievable by the constituent materials alone. Fiber-reinforced plastic (FRP) composite are now widely accepted as structural materials with aerospace and automotive industries. The advanced composite materials such as graphite, carbon, and glass with suitable resins are widely used because of their high specific strength and high specific modulus (modulus / density) [19]. The weight reduction of the drive shaft can have a certain role in the general weight reduction of the vehicle and is a highly desirable goal, if it can be achieved without an increase in cost and a decrease in quality and reliability. The fundamental natural frequency of the carbon fiber composite propeller shaft can be twice as high as that of steel or aluminum because the carbon fiber composite material has more than 4 times the specific stiffness of steel or aluminum which makes it possible to manufacture the propeller shaft of passenger cars on one piece.

The constituents are combined at a macroscopic level and or not soluble in each other. The main difference between composite and an alloy are constituent materials which are insoluble in each other and the individual constituents retain those properties in the case of composites, where as in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents. The reinforcement is usually a fiber or a particulate. Particulate composites have dimensions that are approximately equal in all directions. They may be spherical, platelets, or any other regular or irregular geometry. Particulate composites tend to be much weaker and less stiff than continuous- fiber composites, but they are usually much less expensive. Particulate reinforced composites usually contain less reinforcement (up to 40 to 50 volume percent) due to processing difficulties and brittleness. A fiber has a length that is much greater than its diameter. The length-to-diameter (L/d) ratio is known as the aspect ratio and can vary greatly [20]. Continuous fibers have long aspect ratios, while discontinuous fibers have short aspect ratios.

Continuous-fiber composites normally have a preferred orientation, while discontinuous fibers generally have a random orientation. Examples of continuous reinforcements include unidirectional, woven cloth and helical winding while examples of discontinuous rein-forcemeats are chopped fibers and random mat.

Composite drive shafts can solve many such automotive and industrial problems that accompany the usage of the conventional metal ones, because their performance is limited due to lower critical speed, weight, vibration, offers excellent vibration damping, cabin comfort, reduction of wear on drive train components and increasing tires traction. In addition, the use of a one piece torque tube reduces assembly time, inventory cost, maintenance, and part complexity.

Most composites have two constituent materials.

- Matrix
- Reinforcement

Matrix Interface / Interphase of Matrices

Matrix is the constituent of a composite in which other constituents are embedded. If the matrix is a metal, then it is called as a metal matrix and consecutively polymer matrix, if the matrix is a polymer and so on. Sometimes the matrix itself is a key strengthening element. It influences the mechanical properties, shear modulus and strength and its processing characteristics [21]. They are material component that surrounds the fiber. Usually ductile, or tough. Strength usually equal to 1/10 (or less) than that of fiber. Examples include: thermoplastic or thermoset. Thermo set most common (epoxy, phenolic).

Functions of a Matrix

In a composite material, the matrix material serves the following functions:

• Holds the fibers together.

• Protects the fibers from environment.

• Distributes the loads evenly between fibers so that all fibers are subjected to the same amount of strain.

• Enhances transverse properties of a laminate.

• Improves impact and fracture resistance of a component.

• Helps to avoid propagation of crack growth through the fibers by providing alternate failure path along the interface between the fibers and the matrix [22].

2.3.1. Classification of composites

Composite materials in general are categorized based on the kind of matrix. The major composite classes based on structural composition of the matrix area.

a) Polymer-Matrix Composites

b) Metal- Matrix Composites

c) Ceramic- Matrix Composites

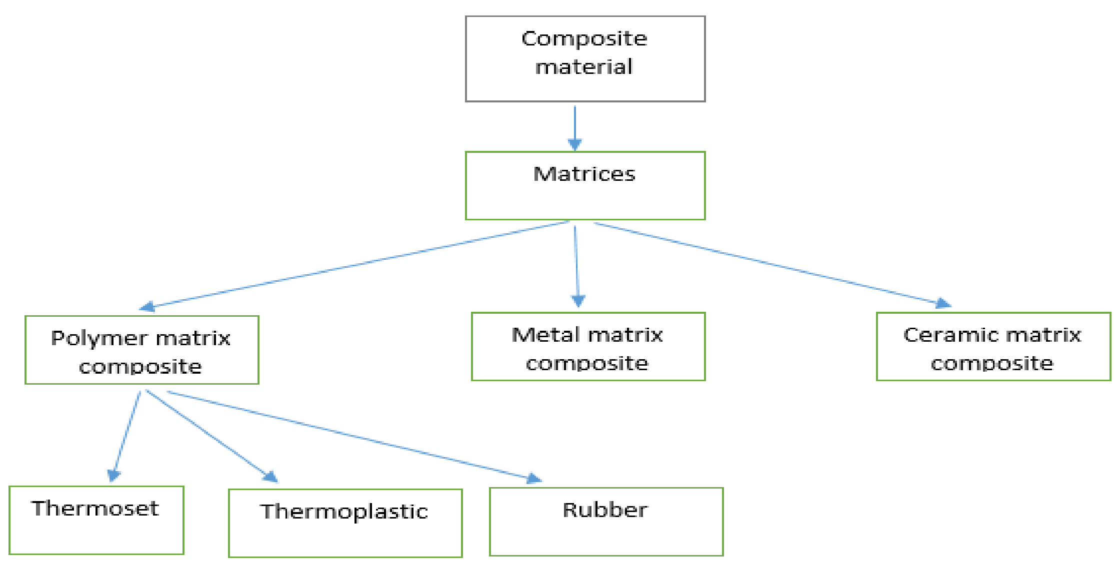


Figure 2.3. Composite classification based on matrix materials [23]

Unlike metals, composite materials are not prone to plastic deformation. This practically means that only elastic deformations will occur when the materials are subjected to the action of external forces. As for fatigue, composites are fundamentally different from metals. While metals show fatigue failure only in one way, composites fail in different failure modes. [24]

One of the essential properties of composite materials is their relatively high load carrying capacity even after a partial damage. This is due to the load transfer in a large number of fibers.

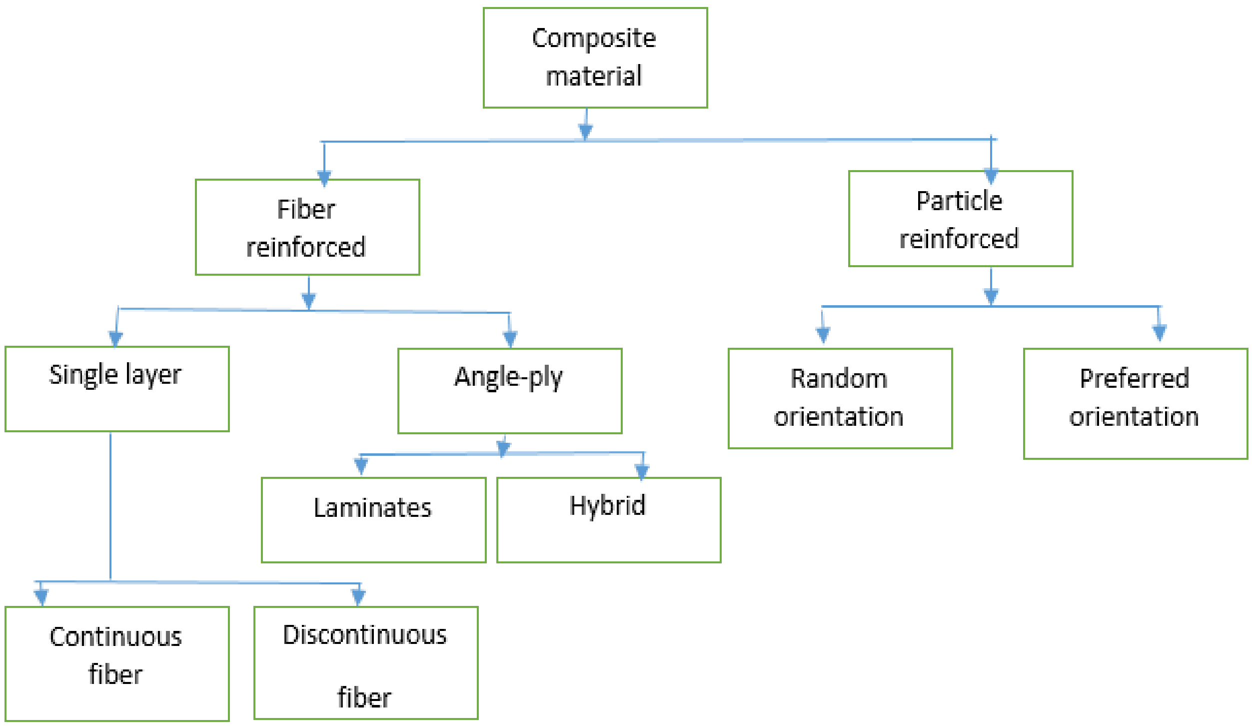


Figure 2.4. Composite classifications based on structure property [25].

A) Metal matrix composite (MMC)

In a composite material, when the matrix is a metal or an alloy. By altering the manufacturing method, the processing and the finishing, as well as by the form of the reinforcement components, it is possible to obtain different characteristic profiles, although the same composition and the amount of the components involved. Generally MMCs are classified according to type of used reinforcement and the geometric characteristics of the same. Normally, the main classification of composites can be made in the form of reinforcement groups into two basic categories [26].

a. Continuous reinforcement composites, constituted by continuous fibers or filaments;

b. Discontinuous reinforced composites, containing short fibers, whiskers or particles

B) Ceramic Matrix Materials (CMM)

Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favorite for applications requiring a structural material that doesn’t give way at temperatures above 1500ºC. Naturally, ceramic matrices are the obvious choice for high temperature applications.

High modulus of elasticity and low tensile strain, which most ceramics posses, have combined to cause the failure of attempts to add reinforcements to obtain strength improvement. This is because at the stress levels at which ceramics rupture, there is insufficient elongation of the matrix which keeps composite from transferring an effective quantum of load to the reinforcement and the composite may fail unless the percentage of fiber volume is high enough[27].

C) Polymer matrix composite (PMC)

Also known as fiber reinforced polymer or plastic. These material use a polymer based resin as the matrix, and a variety of fibers such as glass, carbon and aramid as a reinforcement.
Most commonly used matrix materials are polymeric. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and doesn't require high temperature. Also equipment required for manufacturing polymer matrix composites are simpler. For this reason polymer matrix composites developed rapidly and soon became popular for structural applications. Two types of polymer composites are:
(a) Fiber reinforced polymer (FRP)
(b) Particle reinforced polymer (PRP) [28].

Resins

Resin is a generic term used to designate the polymer, polymer precursor material, and/or mixture or formulation thereof with various additives or chemically reactive components. The resin, its chemical composition and physical properties, fundamentally affect the processing, fabrication and ultimate properties of composite materials. Variations in the composition, physical state, or morphology of a resin and the presence of impurities or contaminants in a resin may affect handle ability and process ability, lamina/laminate properties, and composite material performance and long-term durability. Resin matrix system acts as a binding agent in a structural component in which the fibers are embedded. When too much resin is used, the part is classified as resin rich. On the other hand if there is too little resin, the part is called resin starved. [21].

Epoxy

Epoxy is a general description of a family of polymers which are based on molecules that contain epoxide groups an epoxide group is an oxirane structure, a three-member ring with one oxygen and two carbon atoms. The polymers are available in a variety of viscosities from liquid to solid. Epoxies are used widely in resins for prepress and structural adhesives. The advantages of epoxies are high strength and modulus, low levels of volatiles, excellent adhesion, low shrinkage, good chemical resistance, and ease of processing. Epoxy system consists of Hardeners, plasticizers, and fillers are also added to produce epoxies with a wide range of properties of viscosity, impact, degradation, etc. Epoxy resin has greater bonding and physical strength than polyester resin. Their major disadvantages are brittleness and the reduction of properties in the presence of moisture.

The processing or curing of epoxies is slower than polyester resins. The cost of the resin is also higher than the polyesters.

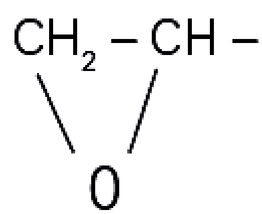


Figure 2.5. Idealized chemical structure of a simple Epoxy (Ethylene oxide) [29].

Although epoxy is costlier than other polymer matrices, it is the most popular PMC matrix. More than two-thirds of the polymer matrices used in aerospace applications is epoxy based.

The main reasons why epoxy is the most used polymer matrix material are

- High strength.
- Low viscosity and low flow rates, which allow good wetting of fibers and prevent misalignment of fibers during processing.
- Low volatility during cure.
- Low shrink rates, which reduce the tendency of gaining large shear stresses of the bond between epoxy and its reinforcement

2.3.2. Reinforcement

Reinforcing phase / Materials

The role of reinforcement in composite materials is primarily to add mechanical properties to the material such as strength and stiffness. Reinforcement phase is the principal load-carrying member in a composite. The reinforcing phase may be a particulate or a fiber, continuous type or discontinuous type. Some of the important particulates normally reinforced in composite materials are titanium carbide, tungsten carbide, silicon nitride, aluminum silicate, quartz, silicon carbide, graphite, fly ash, alumina, glass fibers, titanium boride etc. The reinforcements may be called by different names according to sizes such as Whisker (< 0.025 mm), (fiber 0.025 – 0.8 mm), Wire (0.8 – 6.4 mm), rod (6.4 – 50 mm) and bar (> 50 mm).

Reinforcements basically come in three forms:

- particulate
- discontinuous fiber
- continuous fiber

Reinforcements become fibers when one dimension becomes long compared to others. Discontinuous reinforcements (chopped fibers) vary in length from a few millimeters to a few centimeters**.**

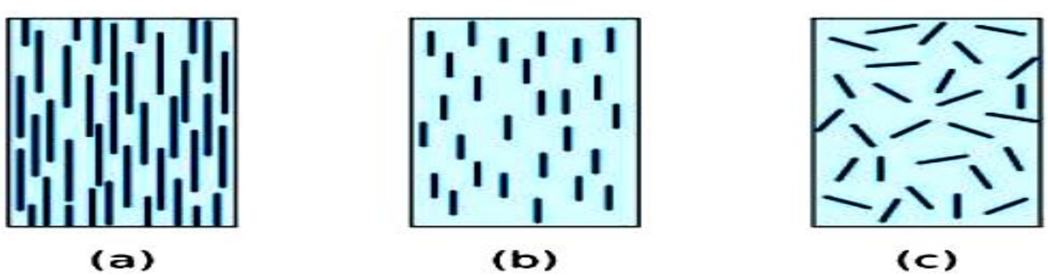


Figure 2.6. Types of fibers

Typologies of fiber-reinforced composite materials: (a) continuous fiber reinforced; (b) discontinuous aligned fiber-reinforced ;(c) discontinuous random oriented fiber reinforced [30].

Fibers

Fibers are the principal constituent in a fiber reinforced composite material. The main function of fibers within composite structures is as the load bearing component and, as such, they are generally significantly stiffer and stronger when compared to the matrix component. They occupy the largest volume fraction in a composite laminate and share the major portion of the load acting on a composite structure. Fibers, also known as filaments, have finite lengths of at least 100 times their diameter, and are prepared by drawing from a molten bath, by spinning, or by chemical vapor deposition on a substrate such as tungsten or carbon [31].

Classification of Fibers

(a) Natural fibers

These fibers are naturally available. As such they have inferior quality than the synthetic or man-made fibers. But, natural fibers are bio-degradable and there by ecofriendly. The lists of natural fibers are [32].

- Banana palm
- Coir pine apple
- Jute sisal

(b) Synthetic / Man-made fibers

These fibers are manufactured synthetically. So, they show superior qualities than the natural fibers. The list of man-made fibers includes

- Boron glass
- Carbon graphite
- Ceramic silica

Glass fibers

It is lighter than steel and aluminum, easy to be shaped and rust-proof. Amongst the reinforcing materials used in fiber-reinforced polymer (FRP) composites, glass fibers are the most widely utilized mainly due to their relatively low price, availability and reliability as well as their reasonably high strength when compared to carbon fibers. Glass fiber filaments are produced by forcing a molten glass through holes in the bottom of a platinum bushing. Following this, the glass filaments are collected, quenched by passing through a light water spray, coated with a protective binder, gathered to form a bundle (also known as a tow or strand), and finally wound onto a spool[33].

The types used for structural reinforcements are as follows

a. **E-glass (electrical)-**lower alkali content and stronger than A glass (alkali).good tensile and compressive strength and stiffness, good electrical properties and relatively low cost, but impact resistance relatively poor. E-glass is the most common form of reinforcing fiber used in polymer matrix composite. It is available in the form of strand, yarns and Rovings. Strand is a compactly associated bundle of filaments, yarns are closely associated bundle of twisted filaments and rovings are loosely associated bundle of untwisted filaments.
b. **C-glass(chemical)-**best resistance to chemical attack mainly used in the form of surface tissue in the outer layer of laminates used in chemical and water pipes and tanks.
c. **R, S or T-glass**-manufacturers trade names for equivalent fibers having higher tensile strength and modulus than E-glass, with better wet strength retension.The ‘S’in S-glass stands for higher content of silica. It retains its strength at high temperatures compared to E-glass and has higher fatigue strength [34].

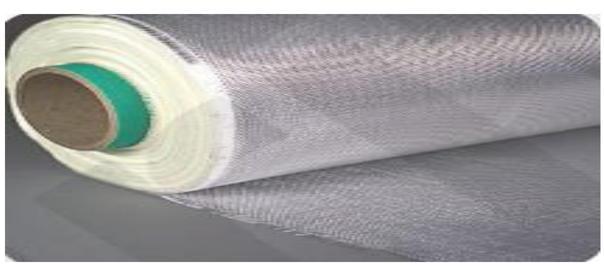


Figure 2.7. Glass fiber

E-glass fiber available in the following forms

i) Strand a compactly associated bundles of filaments.

ii) Yarns closely associated bundles of twisted filament or strands. Each filament diameter in a yarn is the same, and is usually between 4-13μm.

iii) Roving a loosely associated bundle of untwisted filament or strands. Each filament diameter in a roving is the same, and is usually between 13-24 μm.

.

E-glass has the lowest cost of all commercially available reinforcing fibers, which is the reason for its widespread use in the FRP industry. Although S-2-glass is manufactured with less-stringent nonmilitary specifications, its tensile strength and modulus are similar to those of S-glass [35].

2.3.3. Definition of laminated structures

A lamina is defined as a layer of a composite structure in which the fibers are all oriented in the same direction. A laminate is constructed by stacking a number of such lamina in the direction of the lamina thickness, which is illustrated in Figure below.

The design and analysis of such laminated structures demands knowledge of the stresses and strains in the laminate.

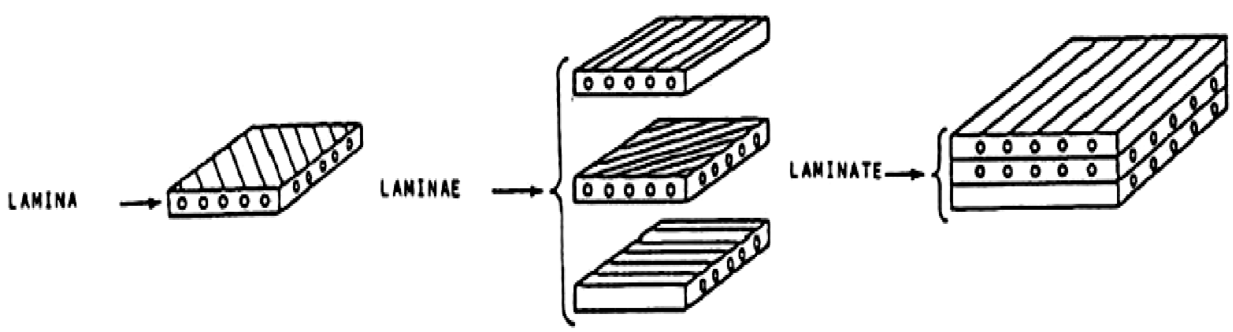


Figure 2.8. Lamina, laminae and laminate url: 2

Macro mechanical Analysis of Laminate

Macro mechanical analysis will be developed for a laminate. A real structure however will not consist of a one lamina but a laminate consisting of more than one lamina bonded together through their thickness. Based on in-plane loads of extension, shear, bending and torsion, stresses and strains will be found in the local and global axes of each ply. The strength, stiffness properties of laminate will depend on

1) Elastic modules.
2) Stacking sequence.
3) Thickness.
4) Angle of orientation of each lamina.

2.3.4. Critical speed analysis in composite drive shafts

Critical speed is the speed at which a spinning shaft will become unstable. There are several ways to raise the critical speed of a driveshaft. These ways are by making it lighter, stiffer, or increase diameter without increasing weight. This is the reason for composite fiber makes a good driveshaft; it is stiff and light and can be made to any diameter or wall thickness. The main point that attracts manufacturers to use composite materials in the drive shafts is that they make it possible to increase the length of the shaft. The relationship between shaft's length and the critical speed for both types of drive shafts are shown in Fig. below. It is evident that for a specific application where the critical speed is about 8000 rev/min, the longest possible steel shaft is 1250 mm, while the composite one can have a length 1650 mm.

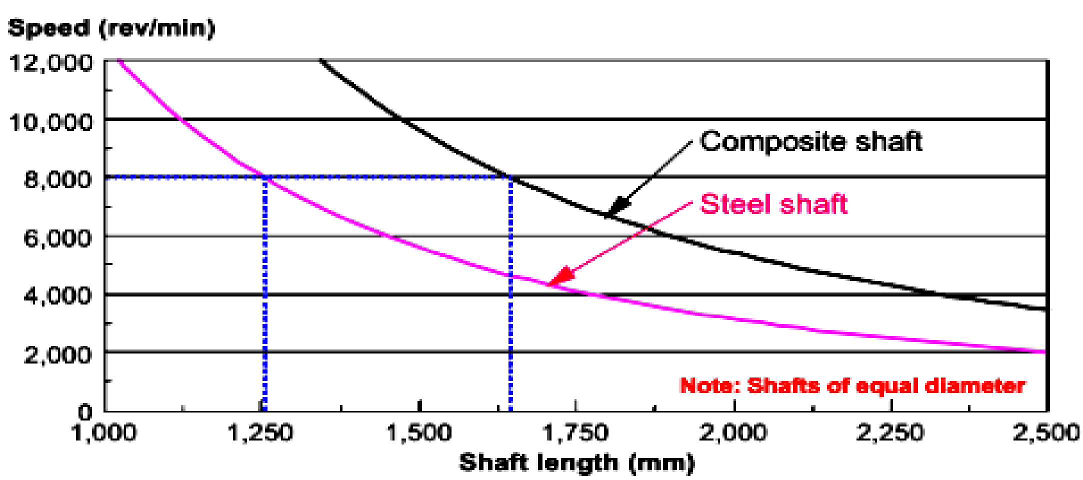


Figure 2.9. Critical speed-length curve for automotive drive shafts [36].

2.3.5. Limitations of Composites

Some of the associated disadvantages of advanced composites are as follows [37].

- High cost of raw materials and fabrication.
- Composites are more brittle than wrought metals and thus are more easily damaged.
- Transverse properties may be weak.
- Matrix is weak, therefore, low toughness.
- Reuse and disposal may be difficult.
- Difficult to attach.

2.4. Schematic arrangement of underbody of an automobile

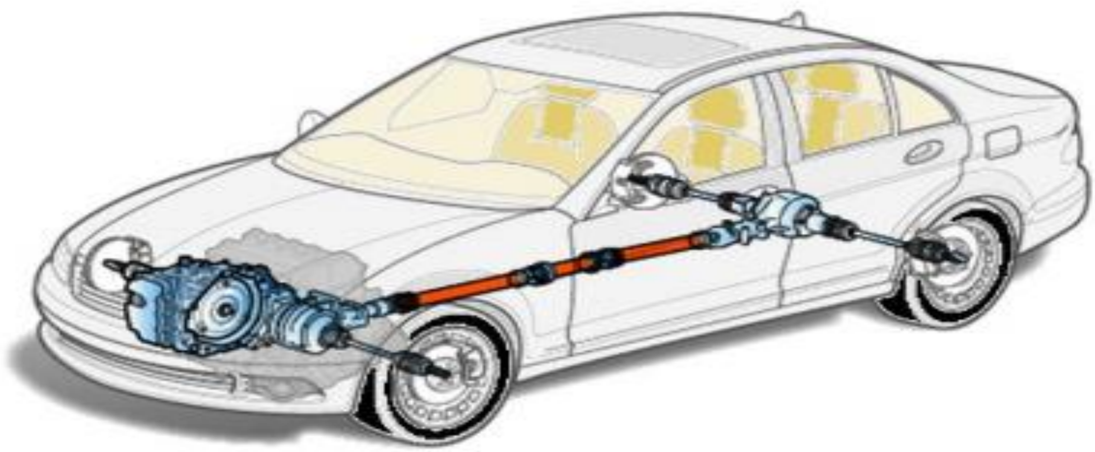


Figure 2.10. Driveshaft arrangement in rear wheel drive [38].

Power Flow in a Motor Vehicle (Automobile)

IC Engine → **Clutch** → **Gearbox** → **Propeller Shaft** → **Final Drive** → **Axle Shafts** → **Drive Wheels**

Parts of drive shaft and universal joint

Parts of drive shaft and universal joint are shown in figure 2.11.Parts of drive shaft and universal joints are:

1. U bolt nut
2. U bolt washers
3. U bolt
4. Universal joint journal
5. Lubrication fitting
6. Snap ring.
7. Universal joint sleeve yoke
8. Spline seal
9. Dust cap
10. Drive shaft tube

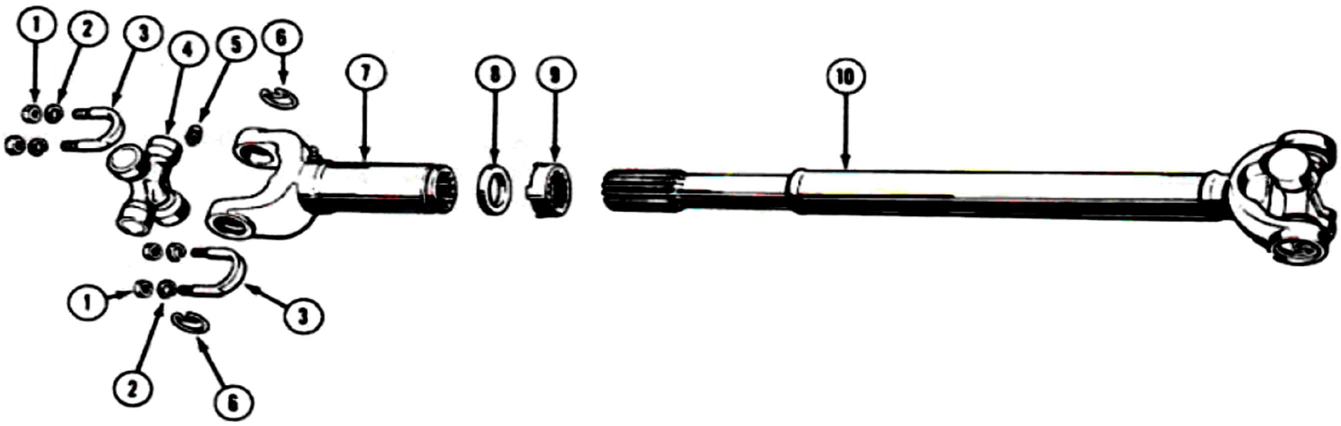


Figure 2.11. Parts of drive shaft and universal joint [39]

Steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely proportional to the square of beam length and proportional to the square root of specific modulus. The two piece steel drive shaft consists of three universal joints, a center supporting bearing and bracket, which increase the total weight of a vehicle [40].To increase the critical speed of the shaft during varying load conditions it needs to either decrease the span length or increase the bending strength because the bending natural frequency is inversely proportional to the square of the span length [41].

Demerits of a Conventional Drive Shaft

- They have less specific modulus and strength
- Its corrosion resistance is less as compared with composite materials.
- Increased weight
- Steel drive shafts have less damping capacity.
- Conventional steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural. Therefore the steel drive shaft is made in two sections connected by a support structure, bearings and U-joints and hence overall weight of assembly will be more.

2.4.1. Operating Principle

When universal joints are used to connect two units (e.g. gearbox and back axle) the driven shaft does not rotate with uniform velocity i.e. it does not turn at the same speed during each part of a revolution. In one revolution the driven shaft is accelerated twice and decelerated twice. This effect being increases as the angularity is increased. These velocity differences can be cancelled in the propeller shaft by the use of two correctly aligned joints, the acceleration of one being neutralized by the deceleration of the second. A sliding joint is used to allow the drive shaft to change its length as it rotates, to compensate for the small backward and forward movement of the rear axle caused by the action of the suspension system. It is simply a splined tubular portion built onto the forward universal joint and it slides in splines on the gearbox main shaft. 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. 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 [42].

Two-piece drive-lines, with two shafts and an intermediate support bearing are generally used on trucks with wheel bases from 3.4 to 4.8 m, but there is some overlap depending on the vehicle's work role.

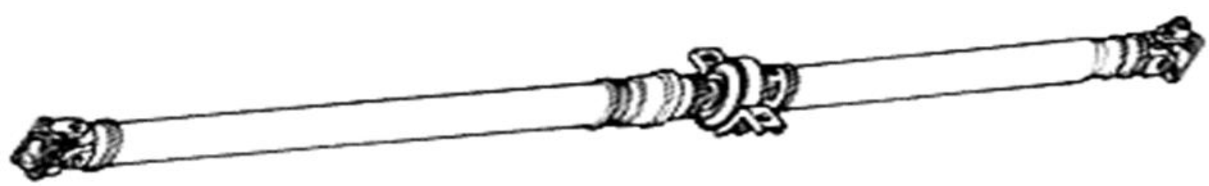


Figure 2.11. Two-piece drive-line with single intermediate support bearing [43].

The two-piece propeller shaft has three universal joints, and the primary propeller shaft is of the fixed-joints-and-tube assembly type, but the secondary propeller shaft has a slip-joint at the support-bearing end to accommodate any elongation due to suspension movement. Usually the primary shaft is in line with the gearbox main shaft axis, but the secondary propeller shaft is inclined slightly so that it intersects the rear-axle final-drive pinion shaft.
For vehicles with wheelbases over 4.8 m, a three-piece drive-line with two intermediate support bearings may be necessary. [44]

2.4.2. General Characteristic of Universal Joint

Can be called Cardan, Spicer, or Hooke joints. Allow for angle changes between the drive shaft, the transmission output shaft, and the rear axle housing U-joints speed up and slow down twice per revolution.

Single universal joint

The driving shaft and driven shaft intermediated by a universal joint has the following relationship between their rotational angles:

$$\tan\phi_2 = \cos\Theta \tan\phi_1 \qquad 2.1$$

Where: ϕ_1 = Rotational angle of driving shaft

ϕ_2 = Rotational angle of driven shaft

Θ = Shaft operating angle

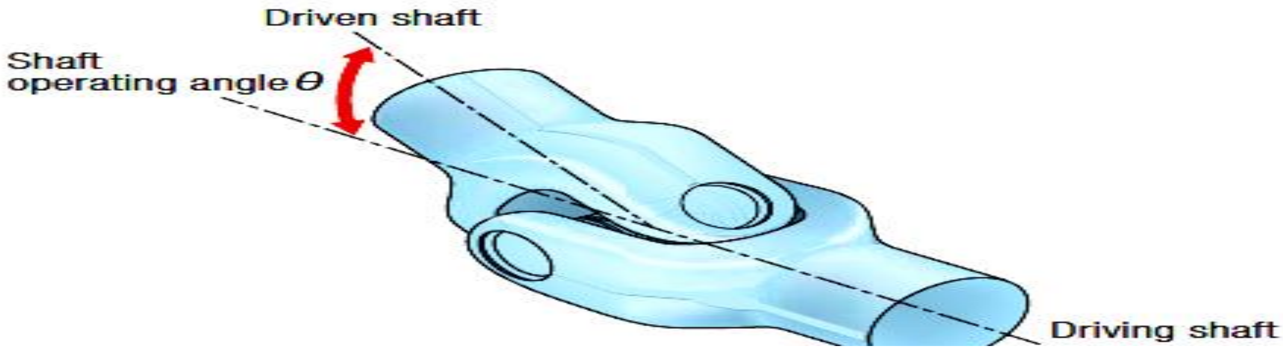


Figure 2.12. Shaft operating angle

This means that, even if the rotational speed and torque of the driving shaft are constant, the driven shaft is subject to fluctuation in rotational speed and torque. The speed ratio between the driving and driven shaft can be obtained by differentiating equation (2.1) with respect to time (t),

$$\frac{\boldsymbol{\omega_2}}{\boldsymbol{\omega_1}} = \frac{cos\theta}{1 - sin^2\emptyset 1 \cdot sin^2\theta} \qquad 2.2$$

$$\boldsymbol{\omega}_2 = \frac{\omega 1 cos\theta}{1 - sin^2\theta \cdot sin^2\theta} \qquad 2.3$$

Where, ϕ_1 is by $\omega_1 \cdot t$ and ϕ_2 by $\omega_2 \cdot t$:

The angular velocity equation can again be differentiated to get the relation between the angular accelerations a1 and a2

$$a_{2=} \frac{a1cos\theta}{1-sin^2\theta cos^2\phi 1} - \frac{w1^2 cos\theta sin^2\theta sin2\phi 1}{(1-sin^2\theta cos\,^2\phi 1)^2} \qquad 2.4$$

Where: $\boldsymbol{\omega_1}$ = Rotational angular Velocity of Driving shaft (rad/s)

$\boldsymbol{\omega_2}$ = Rotational angular velocity of Driven shaft (rad/s)

$\frac{\boldsymbol{\omega_2}}{\boldsymbol{\omega_1}}$ = angular velocity Ratio

The maximum value and minimum value of the angular velocity ratio can be expressed as follows:

$$\left(\frac{\boldsymbol{\omega_2}}{\boldsymbol{\omega_1}}\right) max = \frac{1}{cos\theta} \qquad when\ \phi 1 = 90^0$$

$$\left(\frac{\boldsymbol{\omega_2}}{\boldsymbol{\omega_1}}\right) min = cos\theta \qquad when\ \ \phi 1 = 0^0$$

The maximum fluctuation rate of angular velocity in a universal joint can be expressed by the following equation:

$$\frac{(\boldsymbol{\omega_2} max - \boldsymbol{\omega_2} \mathrm{min})}{\boldsymbol{\omega_1}} = \frac{1}{cos\theta} - cos\theta \qquad 2.5$$

The maximum value and minimum value of torque transmitted can be obtained as shown below, respectively:

$$(\frac{T_2}{T_1}) max = \frac{1}{cos\theta} \qquad when \quad \phi 1 = 0^0$$

$$\left(\frac{T2}{T1}\right) min. = cos\theta \qquad when \quad \phi 1 = 90^0$$

Where: T_1= input torque

T_2= output torque

$\frac{T2}{T1}$ = Torque ratio

The angles shown on this chart are the maximum universal joint operating angles recommended by Spicer Engineers and are directly related to the speed of the driveshaft. Any universal joint operating angle greater than 3 degrees will lower universal joint life and may cause a vibration.

Table 2.1. Maximum operating angle

Drive shaft RPM	Maximum operating angle	Interaxle parallel	Interaxle intersecting
5000	3.0^0	-	-
4500	3.7^0	-	-
4000	4.2^0	3.8^0	3.8^0
3500	5.0^0	4.4^0	4.4^0
3000	5.8^0	5.1^0	4.8^0
2500	7.0^0	6.0^0	4.8^0
2000	8.7^0	6.0^0	4.8^0
1500	11.5^0	6.0^0	4.8^0

2.5. Crash performance of composite propeller shafts

Increasing public interest in safe vehicles is encouraging car manufacturers and their suppliers to design components and systems that will perform well in a crash .The propeller shaft in rear- and four-wheel-drive cars is a good example of this. In a frontal crash, the propeller shaft transmits forces from the engine / gearbox unit to the rear axle. Many vehicles today have a two-piece propeller shaft that can buckle at the center bearing in any direction, depending on the joint position at impact. It is therefore virtually impossible to predict the axial force and the energy absorbed by the shaft in a crash.

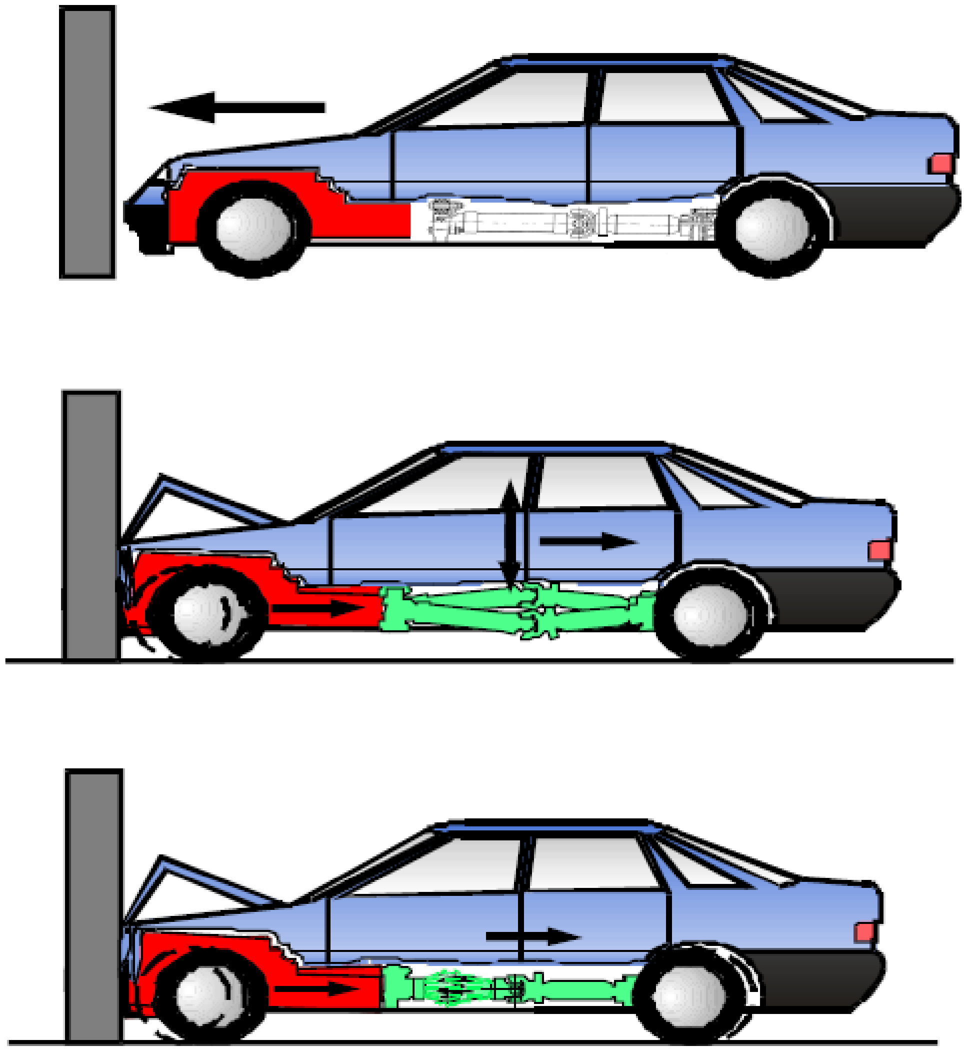


Figure 2.13. Behavior of propeller shafts in frontal crash [43]

The target for crash-optimized propeller shafts is to achieve a defined behavior of axial force and displacement during an impact, and consequently controlled energy absorption. Not all vehicle platforms require the same behavior; the Audi Quattro described earlier required collapse at very low axial force so that the differential was decoupled from the engine / gearbox unit. In other applications, the propeller shaft has been designed to meet a specific energy absorption characteristic so that loads in the front footwell area of the passenger cell are reduced.

One of the most useful new options is to make the tube end connection by a press-fit interference design. The steel or aluminum end part is inserted into the composite tube using a press to overcome a designed interference. Torques is transmitted during normal operation of the propeller shaft by friction alone, but axial loads cause slip of the connection at a known load. Other design features can be introduced to make the axial load progressively increase, stay constant, or progressively decrease with extended displacements.

Due to their fibrous nature embedded in a polymeric matrix, composites can absorb a fair amount of energy upon impact. Composite driveshaft would break apart rather than entering passenger compartment, catapulting vehicle or whipping a broken end through a tank or valuable cargo during an accident. A failed steel driveshaft may project shrapnel in all directions; however, a composite torque tube would break into smaller fiber a fragment, which is seen in Figure below, that constitute it, upon failure [24]. Composite tube construction has been shown to introduce new design options for achieving the desired energy absorption behavior.

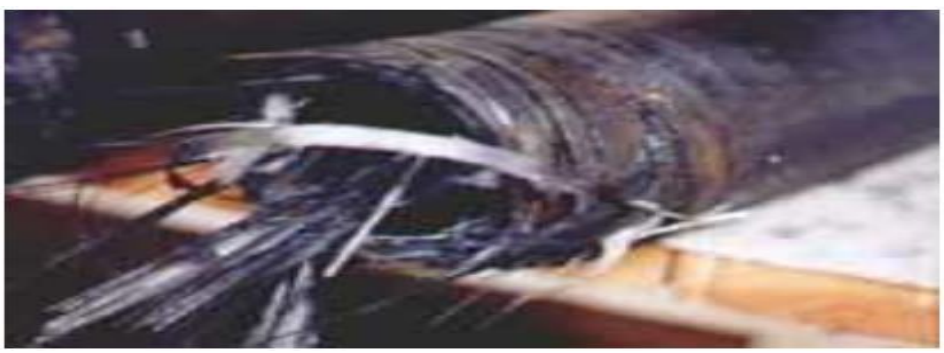


Figure 2.14. A failed composite drive shaft url 3

CHAPTER THREE

MATERIAL AND METHOD

3.1. Materials

In this research which aims to substitute mild steel by composite material several varieties of material and equipment are used for fabrication of composite materials and for testing in procedure was followed by achieving the goals.

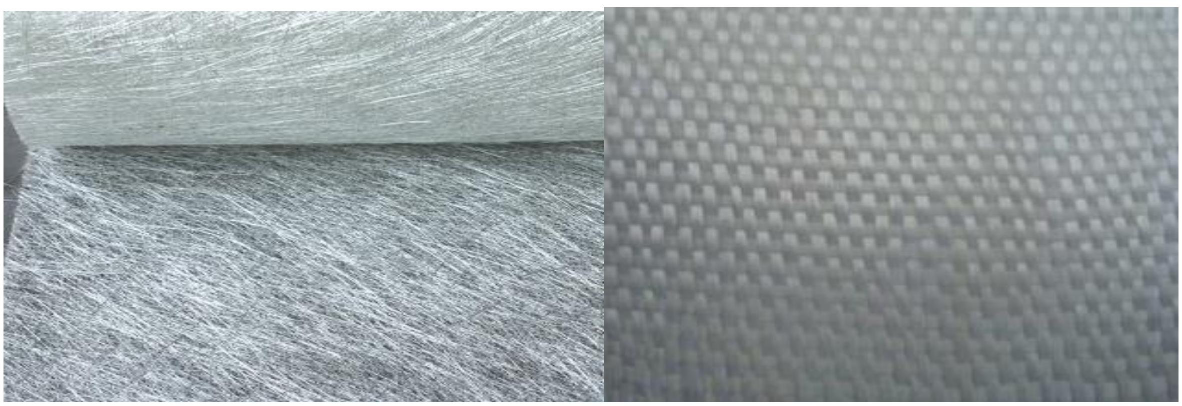
The materials and equipment used in this research work are listed in the table 3. 1

Table 3.1. Materials used for the preparation of specimen composite

No	Name	Quantity	No	Name	Quantity
1	Glass Fiber	5 Kg	8	Scissors	1 pcs
2	Epoxy Resin (GP)	6liter	9	Vernier caliper	1 pcs
3	Hardener (catalyst)	1liter	10	Steel Rule	1 pcs
4	Wax	1 Kg	11	Weighing machine	1 pcs
5	Aluminum foil	0.25 kg	12	Band saw	1 pcs
6	Roller brush	2 pcs	13	Measuring jar	2
7	Normal brush	4			

The present work is aims to design and fabricate a composite drive shaft which can replace the existing steel drive shaft. The fabrication of the composites is carried out by the hand lay-up technique. Maximum care has been taken to maintain uniformity and homogeneity of the composite. Glass fibers are readily produced from raw materials, which are now available in unlimited supply.

3.1.1. Glass fiber: Glass is the most common fiber used in polymer matrix composites. Its advantages include its high strength, low cost, high chemical resistance, and good insulating properties. The E-glass fibers were Chopped Strand Mat (CSM) and Woven roving mat (WRM) used as reinforcement (Figure 3.1). The composition of glass fiber consisted of oxygen (42.84%), silica (28.57%), calcium (17.27%) and aluminum (9.09%) in the highest concentration among constitutes, while the concentration of modifying and other oxides were below 1%. E- Glass is a low alkali glass with a typical nominal composition of SiO_2(54%) , Al_2O_3(14%) ,CaO+MgO(22%) , B_2O_3(10%) and Na_2O+K_2O less than 2 %. Some other materials are also present as impurity [45].



(a) CSM (b) WRM

Figure 3.1. E- Glass Fibers

3.1.2. Matrix

This phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. The commonly used resins for the composite driveshaft are either epoxies or the vinyl esters. Here, epoxy resin is selected due to its strength, good wetting of fibers and lower curing shrinkage.

Epoxy Resin

The resin used for this study is Epoxy Resin with brand name of Resin GP, which is purchased from the local market world fiber glass & water proofing engine in Addis Ababa, Ethiopia. Epoxy resins are the widespread polymer used with advanced composites. Their wide use is primarily due to their better mechanical properties, excellent adhesion, good option utilizing addition-type reactions, low cure shrinkage and low cost.

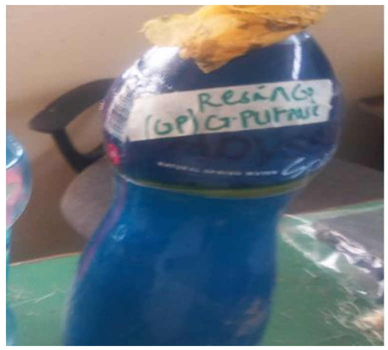


Figure 3.2. General Purpose resin

Hardener (catalyst)

Hardener is a curing agent for epoxy or fiberglass. Epoxy resin requires a hardener to initiate curing; it is also called as catalyst, the substance that hardens the adhesive when mixed with resin. The catalyst initiates the chemical reaction of the epoxy resin and monomer component from liquid to a solid state. The curing agent applied in this work for the liquid epoxy resin is hardener with brand name of system #2060 hardener which is purchased from the local market world fiber glass & water proofing engine in Addis Ababa, Ethiopia.

Figure 3.3. Hardener

3.2. Methods

The Steps involved in the methodology listed as follows:-

- Selection of raw material
- Preparation of composite material
- Testing of composite Material
- Modeling using catia V_5

Glass fiber is used as reinforcement in the form of chopped Stand mat E-Glass Fiberglass with catalyst addition as matrix for the composite material.

Raw materials used in hand lay-up method:

Matrix –epoxy

Reinforcement-glass fiber, chips of aluminum

3.3. Method of manufacturing

Hand lay-up technique

Hand lay-up technique is the simplest method of composite processing. The processing steps are quite simple. Hand layup process is chosen for manufacturing of laminates. Fibers and resin pre-mixed with curing agent are manually placed against the molding surface. First of all, a release gel (initially applied with poly vinyl alcohol (PVA) which is a releasing agent) is sprayed on the mold surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of chopped strand mats are cut as per the mold size and placed at the surface of mold after Perspex sheet. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with hardener (curing agent) and poured onto the surface of mat already placed in the mold. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present.

The process is repeated for each layer of polymer and mat, till the required layers are stacked. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing either at room temperature or at some specific temperature, mold is opened and the developed composite part is taken out and further processed.

Care is taken to ensure that resin is devoid of air bubbles, as it is applied to reinforcing fibers. For this, serrated rollers may be used, which help remove air bubbles, as well as ensure increased wetting of fibers. The time of curing depends on type of polymer used for composite processing.

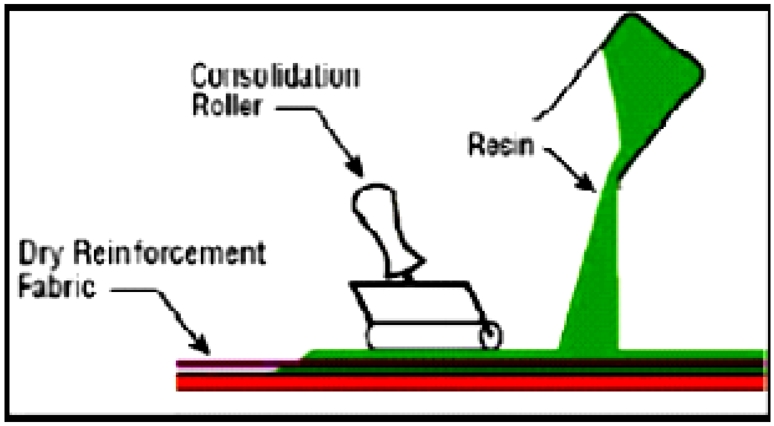


Figure 3.4. Hand layup method [46]

Tools for Lay-up:

1. Weighing balance - to weigh the chemicals.
2. Brushes - to apply resin for both gel coat application and for lamination.
3. Rollers - to remove the air bubbles and also for applying resin.

Solvents:

Solvents are required for cleaning the rollers and brushes during or after the lay-up sequence is over. Acetone or nitrocellulose thinner can be used as solvents.

Finishing surface mat layer / resin coat:

The glass fiber laminate provides a rough surface finish. In order to get a smoother surface, a surface mat layer or resin coat may be applied over the laminate layer and smoothened by placing a thin Mylar film layer.

Gel coat:

The gel coat gives the required finish of the product. It is usually a thin layer applied on the outer surface of the product. The color is obtained by adding appropriate pigments to the resin. The gel coat forms a protective layer that protects the glass fiber getting in contact with water and chemicals. If the gel coat is too thin, the fiber pattern will become visible. If it is too thick, crazing and star crack can appear on the gel coat.

Hand layup was chosen for manufacturing of laminates. The detailed procedure is explained below.

1. Place the metal plate on the plane surface.
2. Prepare the mixture of epoxy and hardener
3. Apply the mixture of epoxy and hardener on the wooden plate.
4. Calculate the weight of fiber particular volume fraction.
5. Place the first sheet of fiber glass and subsequent apply epoxy this process continues till required thickness maintains.
6. Place the supporting plates on each side of the laminate for maintaining the thickness.
7. Apply external pressure to remove the excessive epoxy resin.
8. Curing for 24 hour.
9. Cut the excess material.

Specimens fabrication

The test specimen is being fabricated using hand layup method as it was the simplest one to do. This method is commonly used production processes. Mould pattern was made up of mild steel of dimension of 400 x 320mm x 4mm.After the Post-cure, the composite laminate is ready to use. The marking were made on the laminate of the desired dimensions of various mechanical tests as per ASTM standards.

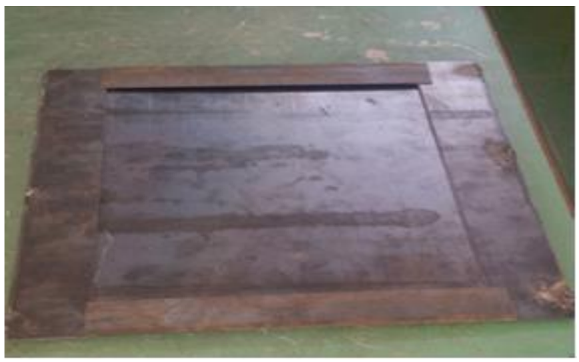


Figure 3.5. Mould prepared in specified dimension

This open mold is suitable for making a wide variety of composites products from very small to very large. Better mechanical properties with 50% of volume fraction, however further increase in fiber content increases mechanical properties but composites starts delaminating [47].

Table 3.2. Weight of the sample specimen

material	Quantity		
	Glass fiber (gm)	Epoxy(ml)	Hardener(ml)
60% fiber and 40 % epoxy	66.64	200	20

Preparation of epoxy Resin (General purpose resin) and hardener:

Epoxy of general purpose resin (GP) mixed with hardener is used to prepare the composite plate. The weight ratio for mixing epoxy and hardener is 100:10.Hardeners include anhydrides (acids), amines, polyamides, dicyandiamide etc. The mixer is strewed with stirrer for about one minutes continuously The mixing is performed in the mixing containers(Bowl) the bowl is made of Nickel to prevent melting of the Bowl during the exothermic reaction as shown in the figure:-

Figure 3.6. Mixing of epoxy with hardener

At first Applying wax/gel on the fiber side of the lower mold then a plastic was placed on bottom part of the mould for ease of removal. Start laying up the first ply and apply the matrix unit. Then using roller avoids the air bubble as shown in this picture.

Figure 3.7. Removing of air using roller

Pressure was then applied from the top and the mould was allowed to compress at room temperature for 24-48 hours. After 24 hours the samples were taken out of the mould after curing the laminate was cut into required size. The process of polymerization is called "curing", and can be controlled through temperature and choice of resin and hardener compounds. Manufacturing of composite material is an important step in manufacturing of composite driveshaft as it greatly affects the properties of composite material.

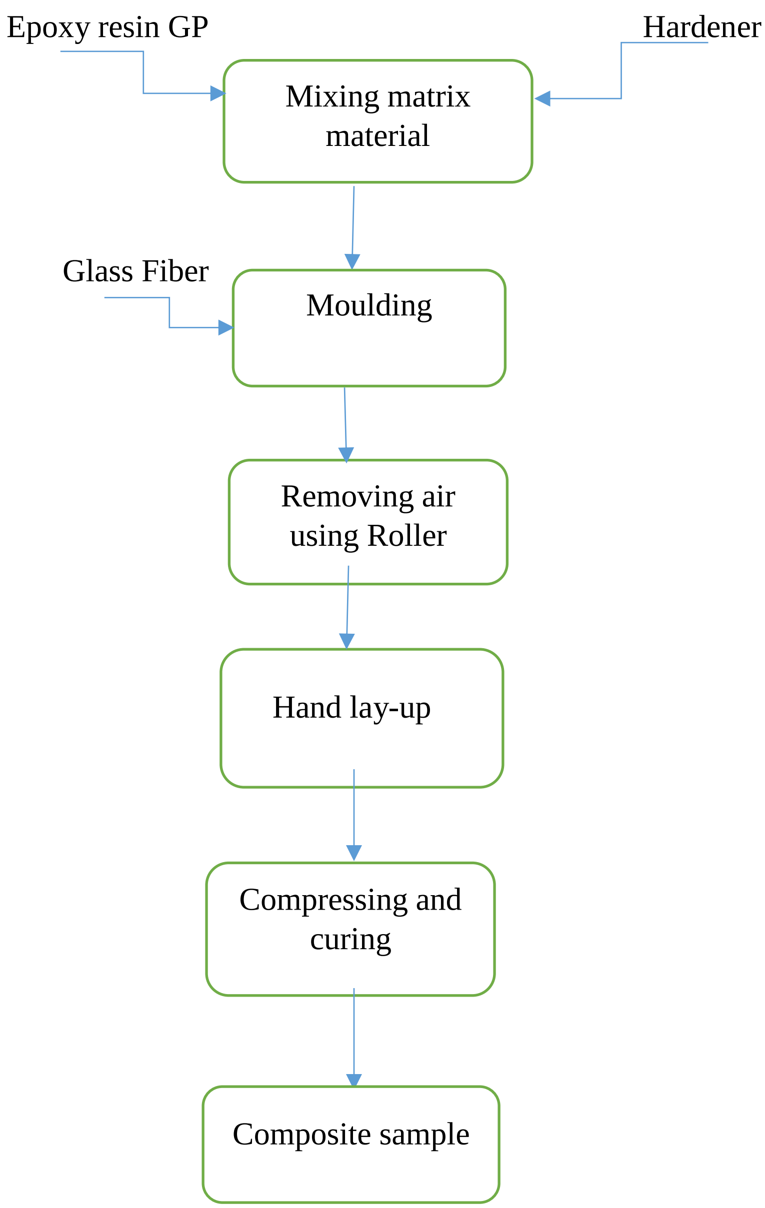


Figure 3.8. Flowchart of the manufacturing process

3.4. Description of glass fiber /epoxy resin composite

Glass fiber composite is a composite made of polymer reinforced with fiber made of glass. Glass fibers are made from extrusion of silica. It is a material formed from very fine strands of glass. The silica can be heated and drew in to fine strands of fibers. At least 3 replicate specimens were tested and the results were presented as an average of tested specimens. For each composite specimen the thickness were determined. The thickness measurements were performed at 3 places along the length of each specimen. Overall sample thickness was determined by averaging measurements for three specimens the tests were conducted at a room temperature.

3.4.1. Tensile Strength Test (ASTM D3039)

The different composite specimens are tested in universal testing machine (UTM) and the samples are left to break till the ultimate tensile strength occurs. The primary objective of this test was to evaluate the in-plane tensile properties of each sample composites. For each sample, 3 specimens were tested in each machine and cross-machine direction each specimen was 300 by 25 mm by during the test the specimens were placed in the grips of UTM and axial load is applied through both ends of the specimen. Typical points of interest when testing a material include: ultimate tensile strength (UTS) or peak stress; and gauge length was 200 mm.

Experiment Instructions

- Insert the test specimen.
    - Mount the specimen first in to the lower grip, and then in to the upper. Upper grip can be moved up or down (using Δ or ∇ buttons) to fit the specimen length.
    - Make sure the specimen is mounted deep and centered.
- Preload the specimen slightly (about 1 KN) to compensate the clearance in the gripping system.
    1. Performing the experiment
        - Set both displays (Force and Elongation) to zero by simultaneously pressing first and third buttons below the displays.

- Start software on PC, choose **Tensile Test** under "Performing experiment" menu, and fill in required data (diameter and gauge length of specimen, and type of material) in the computer window.
- Start measurement by clicking on the green field "I" on the computer Software Window.
- Start the test by pressing the up (Δ) button until specimen breaks.
- Remove the broken parts and observe them closely.

The composite laminates were subjected to various loads and computer controlled UTM as shown in figure 3.9. The specimens were clamped and tests were performed. The tests were closely monitored and conducted at room temperature. The load at which the completed fracture of the specimen occurred has been accepted as breakage load.

Figure3.9. universal testing machine (UTM)

The failure occurs due to decrease in the strength of the material with increase in load when it is subjected to load.

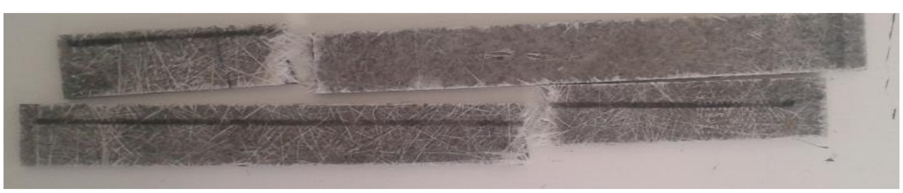
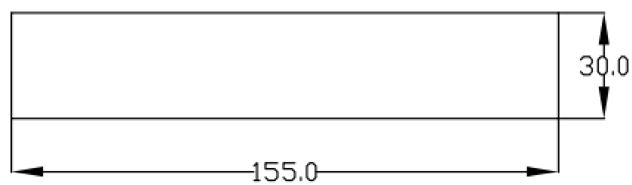


Figure 3.10. Fracture of the specimen

3.4.2. Compressive Strength Test

Compression testing is also a fundamental materials science test in which a sample is subjected to uniaxial compressive load. The results from the test are commonly used to select a material for an application, for quality control and to predict how a material will react under other types of forces. Laboratory experiment involved in subjecting glass fiber reinforced composite specimen to axial compression loading using the UTM .The dimension of the specimen is (155x30x4) mm. The samples the samples were then placed between the compression anvils to commence compression testing during testing; the maximum load attained was recorded by WP 310 Hydraulic Universal Testing Machine (UTM) testing system after the specimen failed. Specimens for compression using American Society of Testing Materials (ASTM) standards ASTM D 3410 is prepared.



A typical dimension of specimen

Figure 3.11. Composite specimen mount

3.4.3. Bending Strength Test (ASTM D-790)

Bending strength is defined as a materials ability to resist deformation under load. The short beam shear (SBS) tests are performed on the composites samples to evaluate the value of inter laminar shear strength (ILSS). It is a one point bend test, which generally promotes failure by inter laminar shear. This test is conducted as per ASTM standard using WP 310Hydraulic Universal Testing Machine (UTM**)** in Belay cable manufacturing plc laboratory. The loading arrangement is shown in figure. The dimension of the specimen is (127x30x4) mm. with. The flexural strength is expressed as modulus of rupture (MR).

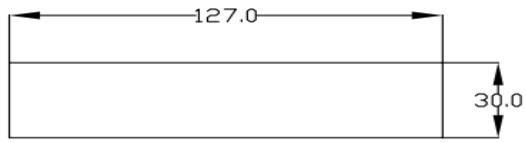


Figure 3.12. Specimen under bending test

CHAPTER FOUR

DESIGN OF DRIVESHAFT

4.1. Design of Steel Drive Shaft

The conventional material used in drive shaft for automobile applications is carbon steel of grades 40C8, 45c8, 50c4 etc. The conventional materials are more weight because of high density. Steel (SM45C) used for automotive drive shaft applications. The commonly used materials for manufacturing the propeller shaft is low carbon steel with 10-18 % , Chromium and 5-8 % Nickel.SM45C: It also known as S45C which is an unalloyed carbon mechanical structural steel belonging to ISD3752-1986 steel grade standard. It is widely used in ladder shaft, hollow shaft, crank shaft, mould base structural applications.

The material properties of the steel (SM45C) are given in Table below. The steel drive shaft should satisfy three design specifications such as torque transmission capability, buckling torque capability and bending natural frequency.

Table 4.1. Mechanical properties of Steel (SM45C) [48]

Mechanical properties	symbol	Values	units
Young's modulus	E	207	Gpa
Shear modulus	G	80	Gpa
Poisson's ratio	V	0.3	-
density	ρ	7600	Kg/m^3
Yield strength	Sy	370	Mpa
Shear strength	Ss	-	Mpa

First Natural Frequency of Conventional Steel Shaft:

All rotating shaft, even in the absence of external load, deflect during rotation. The combined weight of a shaft and wheel can cause deflection that will create resonant vibration at certain speeds, known as Critical Speed. The magnitude of deflection depends upon the following:

- Stiffness of the shaft and its support
- total mass of shaft and attached parts
- Unbalance of the mass with respect to the axis of rotation
- The amount of damping in the system

As per ASME code for design of shaft, the shear strength for the shaft or the maximum allowable shear stress is given by the following equation:

Shear Strength (Ssy) = 0.3 Syt

Ssy = 0.3 x 370 N/mm

Ssy = 111 N/mm

Therefore, the maximum allowable shear stress on the propeller shaft is = 111 N/mm.

SPECIFICATION OF THE PROBLEM

The torque transmission capability of the drive shaft for passenger cars, small trucks, and vans should be larger than 3,500 Nm and fundamental natural bending frequency of the propeller shaft should be higher than 6,500 rpm to avoid whirling vibration. The drive shaft outer diameter should not exceed 100 mm due to space limitations. Here outer diameter of the shaft is taken as 90 mm. The drive shaft of transmission system is to be designed optimally for following specified design requirements as shown in Table below.

Table 4.2. Design requirements and Specifications of Existing Model [48]

no	Name	Notation	value	unit
1	Ultimate Torque	Tmax	3500	Nm
2	Max. Speed of Shaft	Nmax	5700	Rpm
3	Length of shaft	L	1250	mm
4	Outer Diameter of a shaft	Do	90	mm
5	Inner diameter of a shaft	Di	86	mm

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.

One of the major roles of drive shaft is to transmit torque as follows

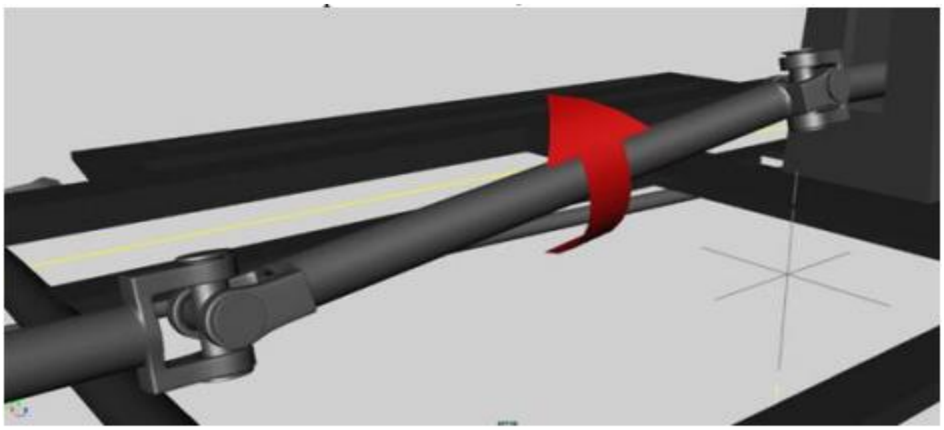


Figure 4.1. Transmission of torque by drive shaft [49]

As dynamic load is acting on drive shaft, natural frequency will be one of the essential factors for design; hence dividing drive shaft in two pieces using an additional universal joint at its Centre will raise fundamental natural frequency of the driveshaft. Vibration is the most common drive shaft problem. Increasing the diameter of the shaft could solve the vibration problem, but this would increase its strength beyond its torque carrying requirements and at the same time increase its inertia, which would oppose the vehicle's acceleration and deceleration. [50]

Also weight reduction is very important factor in automobile applications. By the use of composite materials for manufacturing of drive shafts will provide larger strength to weight ratio compared to metallic shafts. Also composites have bettered corrosion resistance, large damping capacity and low coefficient of thermal expansion which provides better dimensional stability.

Analytical calculations

For steel SM45C

Moment of inertia

$$I = \frac{\pi}{64} \times [do^4 - di^4] \qquad 4.1$$

$$I = \frac{3.14}{64} \times [0.09^4 - 0.086^4]$$

$$I = 5.341e^{-7}\ m^4$$

Polar moment of inertia J= 4 I 4.2

=4*5.341e^{-7}

=0.000002136 m^{4}

Maximum shear strain $\emptyset = \frac{TL}{GJ}$ 4.3

Substituting in the equation, $\emptyset = \frac{3500*1.25}{80\text{Gpa} *0.0000021364}$

=0.0255m/m

Total deformation, δ=$\emptyset * \ell$ 4.4

= 0.0255*1.25

=0.0318m

Maximum shear stress, $\tau = \frac{Tdo}{J}$ 4.5

$$\tau = \frac{3500 * 0.09}{0.0000021364}$$

$$\tau = 147Mpa$$

Where: T = Torque Transmitted in N-m.

J = Polar M.I in m^{4}.

τ = Shear Stress in N/m2.

r = mean radius of shaft in m.

For E-glass fiber /epoxy resin composite driveshaft

Moment of inertia

$$I = \frac{\pi}{64} \times [do^4 - di^4]$$

$$I= \frac{3.14}{64} \times [0.09^4 - 0.0764^4]$$

I=1.5847 x 10^{-6} m^{4}

Polar moment of inertia J= 4 I

=4*1.5847 x 10^{-6}

=0.00000618184 m^{4}

Maximum shear strain $\emptyset = \frac{TL}{GJ}$

Substituting in the equation, $\emptyset = \frac{3500*1.25}{5.6\text{Gpa}*0.00000618184}$

$= 0.126$ m/m

Total deformation, $\delta = \emptyset * \ell$

$= 0.126 * 1.25$

$= 0.157$ m

Maximum shear stress, $\tau = \frac{Tdo}{J}$

$$\tau = \frac{3500 * 0.09}{0.00000618184}$$

$$\tau = 50\ Mpa$$

The design should fulfill

The shaft needs to withstand critical torsional buckling (Tcr) such that Tcr > T.

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

Torque Transmission Capacity of Driveshaft

$$\frac{\tau}{r} = \frac{G\theta}{\ell} = \frac{T}{J} \qquad 4.6$$

$T = \frac{\pi \tau [d_o^4 - d_i^4]}{16}$ (for $hollowshaft$)

$J = \frac{\pi (d_o^4 - d_i^4)}{32}$ (for $hollow\ shaft$)

From equation (4.6) we can get the relation

$$\frac{T}{J} = \frac{\tau}{r}$$

The maximum torsional strength of the shaft is calculated by using the following equation from equation (4.6) above**,** [51].

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

$$J = \frac{\pi}{32} \times [do^4 - di^4]$$

$$J = \frac{\boldsymbol{\pi}(0.09^4 - 0.086^4)}{32}$$

$$J = 3.14 * 10.91 \times 10^{-6} / 32 \text{ m}^4$$

$$J = 1.07 \times 10^{-6} \text{m}^4$$

$$r = \frac{ro + ri}{2}$$

r=0.045+0.043/2

r=0.044m

Where: G = Shear Modulus in N/m^2.

Θ = angle of twist in radians.

L = length of shaft in m.

Now,

$$\tau = \frac{80 \times 10^9 \times \frac{5\pi}{180} \times 0.044}{1.250} \text{ N/m}^2$$

$$\tau = 245.61 \times 10^6 \text{N/m}^2$$

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

$$\frac{\boldsymbol{T}}{\boldsymbol{J}} = \frac{\boldsymbol{\tau}}{\boldsymbol{r}}$$

$$\mathrm{T} = \frac{\mathrm{J} \times \tau}{\mathrm{r}} \qquad 4.7$$

Therefore, putting this value in shear strength in above equation (4.7),

$$\mathrm{T} = \frac{245.61 \times 10^6 \times 1.07 \times 10^{-6}}{0.044}$$

T =5957.9Nm

Torsional Buckling Capacity of the Drive Shaft (Tcr)

As the shaft is designed based on static torque capacity, it is needed to calculate the buckling torque to verify shaft is safe under buckling with current torque following equation gives us value of torsional buckling capacity of shaft [52].

$$\text{If,} \frac{1}{\sqrt{1-v^2}} \frac{l^2 t}{(2r)^3} > 5.5 \qquad 4.8$$

Where, r is mean radius

r = (ri+ro)/2

r=0.044

t=0.045-0.043=0.002mm

Let substitute the values in the equation in equation (4.8)

$$= \left(\frac{1}{\sqrt{1-0.3^2}}\right) * \frac{(1.25)^2}{(2*0.44)^3} * 0.002 > 5.5$$

= 6.27 which is greater than 5.5.so, it is long shaft.

For short & medium shaft, the critical stress is given by,

$$\tau cr = \frac{4.39E}{(1-v^2)} (t/r^2) \sqrt{1 + 0.0257(1-v^2)^{\frac{3}{4}}} \frac{l^3}{(rt)^{1.5}} \qquad 4.9$$

For long shaft, the critical stress is given by,

$$\tau cr = \frac{E}{3\sqrt{2} \times (1-v^2)^{\frac{3}{4}}} \times (\frac{\boldsymbol{t}}{\boldsymbol{r}})^{\frac{3}{2}}$$

$$= \frac{207 \times 10^9}{3\sqrt{2}(1-0.3^2)^{\frac{3}{4}}} \times (\frac{0.002}{0.044})^{1.5}$$

$$= \frac{207 \times 10^9}{3.95} \times 0.00969$$

$$\boldsymbol{\tau} cr = 507.8 \times 10^6 \text{N/mm}^2$$

The relation between the torsional Buckling Capacity and critical stress is given by,

$$Tcr = \tau cr \times 2\pi r^2 t$$

$$= 507.8 \times 10^6 (2)(\pi)(0.044)^2(0.002)$$

=12,347.7N.m

Tcr >T. Hence the condition is satisfied.

Therefore, the design is safe.

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 bernoullis-Euler theories. It neglects the both transverse shear deformation as well as rotary inertia effects. Natural frequency based on the Bernoulli-Euler beam theory is given by [53].

$$f_{nb} = \frac{\pi p^2}{2l^2}\sqrt{\frac{EIx}{m1}} \qquad 4.10$$

Where: f_{nb} = natural frequency based on Bernoulli Euler theory, HZ

P =1, first natural frequency

r = mean radius of shaft

Ix =Area moment of inertia in x direction in m^4

m_1 = mass per unit length in kg/m

The moment of inertia of hollow shaft is given by,

$$I_x = \frac{\pi}{64}(do^4 - di^4)$$

$$I_x = 8.5147 \times 10^{-7} m^4$$

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

$$m_1 = (\frac{\pi}{4}) * \rho * (do^2 - di^2) \qquad 4.11$$

$$= (\frac{\pi}{4}) * 7600 \frac{kg}{m3}(0.90^2 - 0.086^2)$$

m_1= 6.881kg /m

Therefore, upon substitution of above values in equation 4.10,

$$f_{nb} = \frac{\pi p^2}{2l^2}\sqrt{\frac{EIx}{m1}}$$

$$= \frac{\pi p^2}{2(1.25)^2}\sqrt{\frac{207\times10^9\times8.5147\times10^{-7}}{4.2}}$$

$$f_{nb}=192.9\text{Hz}$$

Here, the fundamental bending natural frequency of steel shaft is greater than the minimum natural frequency of the shaft assumed that is 80Hz. Therefore, the designed Steel Shaft is Safe.

Mass of steel driveshaft

m= m_1*L
= 6.881kg/m*1.25m
= 8.661kg

The mass of spline-sleeve joint 2.402 kg

m= m+ mass of spline
m=8.661+2.402 kg
m=11.063 kg

Critical Speed of Shaft:-The critical speed of the shaft is given by,

Ncr=60*fnb
=60*192.9
=11,572 rpm

Therefore, the critical speed of the shaft is 11,572 rpm which is more than the maximum speed of the transmission system.

4.2. Design of composite driveshaft

The following assumptions were made in calculations:

1. The shaft rotates at a constant speed about its longitudinal axis.
2. The shaft has a uniform, circular cross section.
3. The shaft is perfectly balanced, i.e., at every cross section, the mass center coincides with the geometric center.
4. All damping and nonlinear effects are excluded.
5. The stress-strain relationship for composite material is linear & elastic; hence, Hooke's law is applicable for composite materials.
6. Acoustical fluid interactions are neglected, i.e. the shaft is assumed to be acting in a vacuum.
7. Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress.

First, the fibers are selected to provide the best stiffness and strength beside cost consideration.

Hooke's Law

Generalized Hooke's law for orthotropic material is given by:

$$\{\sigma\}=[Q]\{\varepsilon\} \tag{4.12}$$

Where: [Q] = material stiffness matrix.
σ =stresses and
ε = strains in material directions.

4.3. Selection of Cross-Section

The drive shaft can be solid circular or hollow circular. Here hollow circular cross-section was chosen because [54],

•The hollow circular shafts are stronger in per kg weight than solid circular.

•The stress distribution in case of solid shaft is zero at the center and maximum at the outer surface while in hollow shaft stress variation is smaller. In solid shafts the material close to the center are not fully utilized. Here is prove that a hollow shaft is stronger and stiffer than a solid shaft of same material, length and weight

Let,

D-diameter of solid shaft
D1-outer diameter of hollow shaft
D2-inner radius of hollow shaft
Since material, weight and length are same,
Weight of the solid shaft = weight of the hollow shaft

For solid shaft, torque resisted is,

Since material, weight and length are same,

Weight of the solid shaft = weight of the hollow shaft 4.13

$$\frac{\pi D^2.L.\rho}{4} = \frac{\pi(D1^2 - D2^2).L.\rho}{4}$$

$$D^2 = D1^2 - D2^2$$

For solid shaft, torque resisted is,

$$T_S = \frac{Js \times \tau}{R} = \frac{(\pi D^4/32)\tau}{D/2} \rightarrow Ts = \frac{\tau \times \pi D^3}{16}$$

For hollow shaft, torque resisted is,

$$T_{H} = \frac{JH \times \tau}{R} = \frac{[\pi(D1^4 - D2^4)/32] \times \tau}{\frac{D1}{2}} \rightarrow TH = \tau \times \frac{\pi(D1^4 - D2^4)}{16D1}$$

$$\text{Therefore,} \boldsymbol{\frac{TH}{TS} = \frac{D1^4 - D2^4}{D^3 \times D1}}$$

Substituting (4.13) in the above equation we have,

$$\frac{TH}{TS} = \frac{D1^4 - D2^4}{(D1^2 - D2^{2)3/2}.D1} \qquad [\, since\ D = (D1^2 - D2^{2)1/2}]$$

$$\frac{TH}{TS} = \frac{(D1^2 - D2^2)(D1^2 + D2^2)}{(D1^2 - D2^2)(D1^2 - D2^2)1/2.D1}$$

$$\frac{TH}{TS} = \frac{D1^2 + D2^2}{\sqrt{D1^2 - D2^2}(D1)}$$

$$\frac{TH}{TS} = \frac{D1^2(1 + (\frac{D2}{D1})^2)}{D1\sqrt{1 - (\frac{D2}{D1})^2}\ (D1)} = \frac{(1 + \left(\frac{D2}{D1}\right)^2)}{\sqrt{1 - 1 + \left(\frac{D2}{D1}\right)^2}} > 1$$

Hence hollow shafts are stronger than solid shafts of same material, length and weight.

To prove hollow shaft is stiffer:

Stiffness of shaft may be defined as torque required to produce unit rotation in unit length. Let this be denoted by K. Then from torsion formula

$$\frac{K}{J} = \frac{G \times \mathcal{L}}{\mathcal{L}}$$

$$kh = G\left[\frac{\pi(D14 - D24)}{32}\right]$$

$$\text{Ks} = \text{G}G \times JS = G\left[\frac{\pi D4}{32}\right]$$

$$\frac{KH}{KS} = \frac{D1^4 - D2^4}{D^4}$$

$$= \frac{D1^4 - D2^4}{(D^2)^2}$$

$$= \frac{(D1^2 - D2^2)(D1^2 + D2^2)}{(D1^2 - D2^2)2}$$

$$\frac{KH}{KS} = \frac{D1^2 + D2^2}{D1^2 - D2^2} > 1$$

$$K_{H > KS}$$

Hence hollow shafts are stiffer than solid shafts of same material, length and weight.

So, I prefer the hollow shaft for the design purpose depending on its both stiffness and strength as proved above.

Table 4.3. Mechanical Properties of E-Glass/Epoxy Composite (60/40%)

Properties	value	unit
Ex Longitudinal elastic modulus	10700	Mpa
Ey Transverse elastic modulus	10700	Mpa
Gxy Modulus of rigidity	5.6	Gpa
v Poisson ratio	0.3	-
σ_x Working stress in x-direction	800	Mpa
σ_y Working stress in y-direction	40	Mpa
τ_{xy} Shear stress	72	Mpa
ρ Density of the material	2040	Kg/m^3
Ply Thickness	0.13	mm

Let take fiber volume fraction of Glass/Epoxy shaft

(Vfg = 60% & Vm=40%).

Table 4.4. Physical dimension of the composite drive shaft

Dimensions	value	Unit
Length ,L	1250	mm
Outer diameter, do	90	mm
inner diameter,di	76.4	mm
Thickness ,t	6.8	mm

1. Torsional strength

Since the primary load on a driveshaft is torsion, the maximum shear stress (**τ**m**ax**) at the outer diameter (do) and inner diameter (di) of the shaft is given by:

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

$$\tau = \frac{G \times \theta \times r}{\ell}$$

$$\tau = \frac{3704Mpa * 5\pi/180 \times 0.0416}{1.250}$$

$=10.75\times 10^{6} N/m^{2}$

T is the maximum torque applied in N-m

Do and di are outer and inner diameters of the shaft respectively in m.

Factor of safety (FOS) of 6,

r =0.0416m

Thus the wall thickness of the hollow steel shaft:

t = **r**o−**r**i= 6.8mm

τm**a**x =10.75M pa

$$\frac{\tau max}{FOS} = \frac{T}{2\pi r^{2} t}$$

Shear stress max = 10.75 MPa

For a factor of safety FOS. of 6,

$r^2t = 4.44005\times10^{-6}m^3$

Thus,

$t \geq 1.06\times10^{-3}$m.

Since the thickness of each ply is 0.13 mm,

$n = 1.106\times10^{-3}/0.13\times10^{-3}$

= 7.94 = 8

2. **Torsional critical buckling (Tcr)**

Considering the hollow composite shaft as an isotropic cylindrical shell, the buckling torque is given by Equation

$T_{cr} = (2\pi r^2 t)\ (0.272)\ (E_x E_y^3)^{0.25} (t/r)^{1.54}$

$Tcr=2*3.14*0.0416^2*0.0068*(0.272)\ (10700*10700^3)^{0.25}(0.0068/0.0416)^{1.5}$

T_{cr}= 14,195 Nm

Where: t = the overall wall thickness,

r = the mean radius, and

Ex and Ey are the Young's moduli in 'x' and 'y' directions respectively.

$T_{cr} > T$ condition satisfied

3. **Bending natural frequency**

The drive shaft is idealized as a pinned-pinned beam. The lowest natural frequency is calculated using the Equation

$$f\text{nb}= \frac{\pi}{2}\sqrt{\frac{gExIx}{WL^4}} = \frac{\pi}{2}\sqrt{\frac{ExIx}{m1L^4}}$$

Here,

The moment of inertia of hollow shaft is given by,

$$I_x= \frac{\pi}{64}(do^4 - di^4)$$

$$Ix=3.14/64(0.09^4-0.076^4)$$

$$Ix = 1.5847 \times 10^{-6}$$

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

$$m_1=\rho\times\frac{\pi}{4}\times(do^2 - di^2)$$

$$m_1= (2040)\ (0.785)\ (0.09^2-0.076^2)$$

$$m_1=3.73 \text{ kg/m}$$

Bending natural frequency of E-glass/Epoxy Drive Shaft

$$f_{nb} = 124 \text{ Hz}$$

Where: f_{nb} = the lowest natural frequency in hertz.

W/g = the mass per unit length,

I= the moment of inertia and

L = the length of the drive shaft.

Upon substitution, f_{nb}=124Hz (> 80 Hz).

Thus the designed glass/Epoxy composite drive shaft meets all the requirements.

Mass of E-Glass/Epoxy driveshaft

$m = m_1 \times L$

$m=3.73 \times 1.25$

$= 4.66$ kg

Critical Speed of Shaft

The critical speed of the shaft (Ncr) and natural frequency (fnb) are related by using equation

$N_{cr}=60*f_{nb}$

N_{cr}=7,440 rpm

Therefore, the critical speed of the shaft is 7,440 rpm which is more than the maximum speed of the transmission system.

Percentage of Mass Saving

1. Mass of steel drive shaft = 8.661 kg

2. Total mass of composite drive shaft: 4.66 kg

$$= (1- \frac{mass\ of\ composite}{mass\ of\ \ steel}) \times 100 \qquad 4.14$$

$$= (1- \frac{4.66}{8.661}) \times 100$$

$$= 46\%$$

Engine Specification: Mahindra xylo D2BS III

Max. Power (P) =70 kW

Max.Torque (T) = 220 Nm

Speed (N) =1400-2600rpm

Length (L) =1250

Power P=2πNT/60

T= p×60/2 πN

=$70\times10^3 \times 60/2\pi \times 1400$

= 477 N-m ^{3}

T= 477×10^3 N-mm

T= maximum torque applied in drive shaft (N-mm**)**

4.4. Modeling and analysis of driveshaft

4.4.1. Modeling Using Catia V5

CATIA (an acronym of **computer-aided three-dimensional interactive application**) is a multi-platform software suite for computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), PLM and 3D, developed by the French company Dassault Systems: url 1

CATIA offers a solution to shape design, styling, surfacing workflow and visualization to create, modify. The drive shaft will be modeled using through CATIA V5. It enables the creation of 3D parts, from 3D sketches, sheet metal, composites, and molded, forged or tooling parts up to the definition of mechanical assemblies.

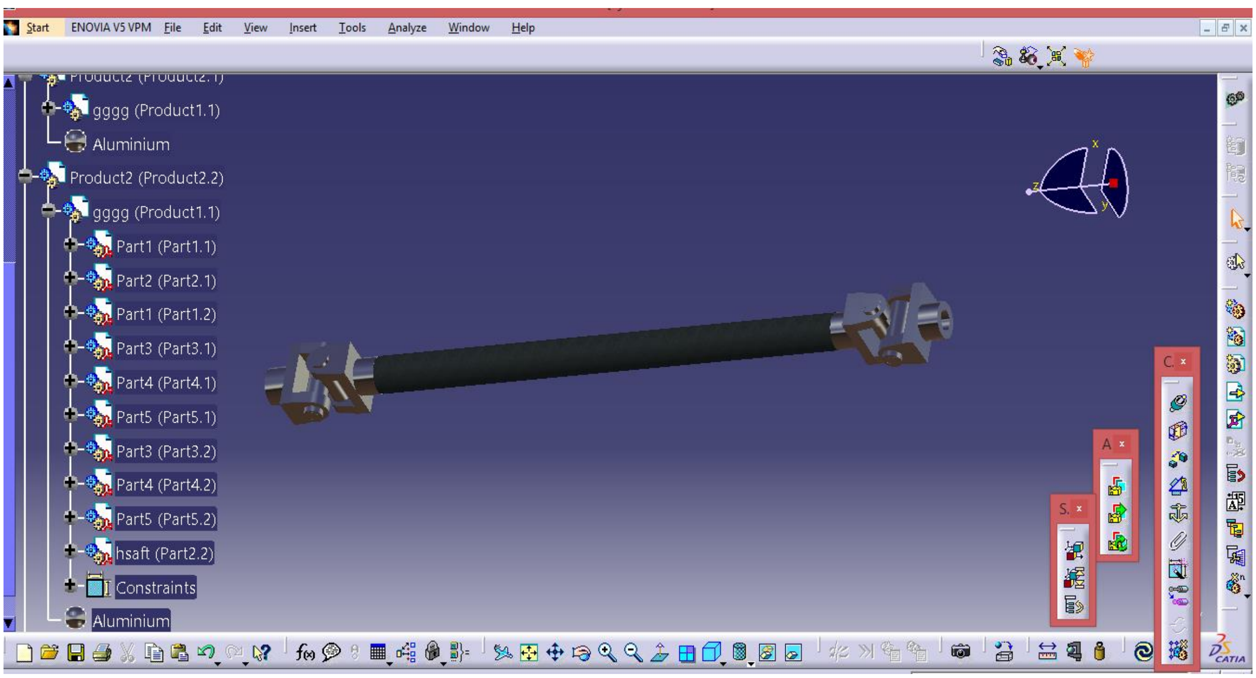


Figure 4.2. CATIA graphical modeled driveshaft

General procedure of FAE

There are three basic steps in formulating finite element analysis pre-processing, solution and post processing. The pre-processing step includes: define the geometric domain of the problem, the material properties of the element, the geometric properties of the elements (Length, area, and the like), the element connectivity (mesh the model), the physical constraints (boundary condition) and the loading. The next step is solution .The computed results are then used to determine like deformation and element stress which carried out by commercial software. The final step is post processing, the analysis and evaluation of the result is conducted in this step. Specific procedures of pre and post processing are different up on the program [55].

4.4.1. ANALYSIS OF PROPELLER SHAFT

ANSYS is an engineering simulation software (computer-aided engineering).In this project finite element analysis was carried out using the FEA software ANSYS. Finite element analysis is a computer based numerical technique is used to for calculating the strength and behavior of the engineering structures. Numerical model is developed using ANSYS ® Composite Prep Post (ACP) in Workbench environment and ANSYS Parametric Design Language (APDL) in Mechanical. The modeled drive shaft in CATIA V5 is imported into ANSYS in **igs.**format. Assumptions the shaft rotates at a constant speed about its longitudinal axis. The shaft has a uniform, circular cross section.

Geometry of the shaft

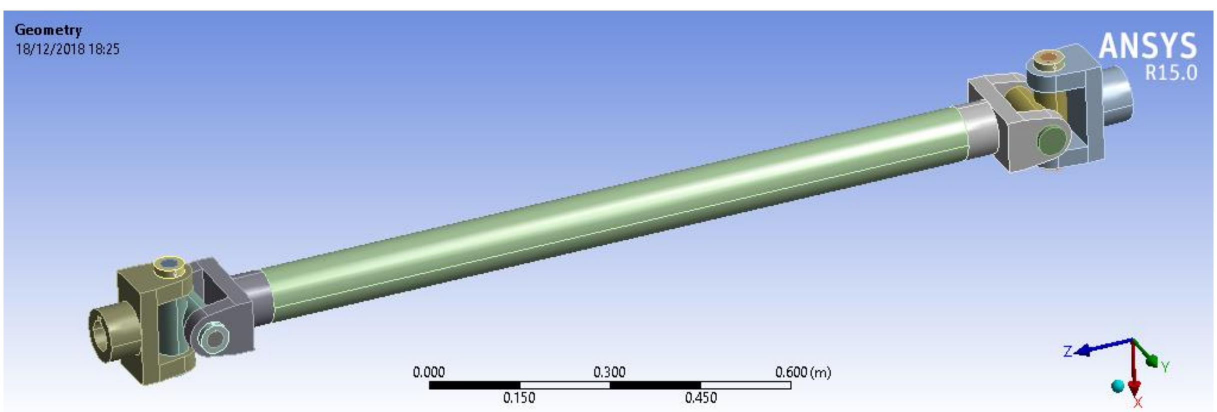


Figure 4.3. Imported solid model of driveshaft from CATIA

4.4.3. Meshing

The meshing is the method in which the geometry is divided in small number of elements.
A structure consists of infinite number of particles or points hence they must be divided in to some finite number of parts. In meshing components divided into finite numbers. Dividing helps to carry out calculations on the meshed part. The component by is divided by nodes and elements. The components are going to mesh using 3D elements. This meshing of propeller shaft is as shown in below figure 4.4.

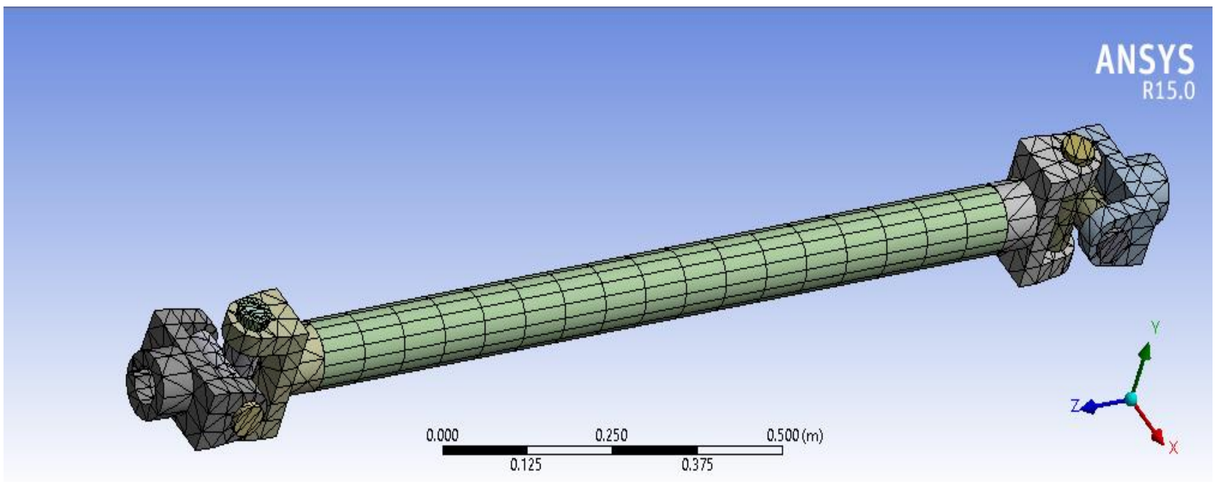


Figure 4.4. Mesh of the driveshaft

Transient analysis

Used to determine the response of structure to arbitrary time-varying loads. For transient analysis shaft is fixed at one end and torque is applied at the other end. The specification can be 477 Nm on the fixed rigid. The von misses stress distribution, total deformation and shear stress distribution of both material shafts are shown in figures 6 to 11.

Fixed support

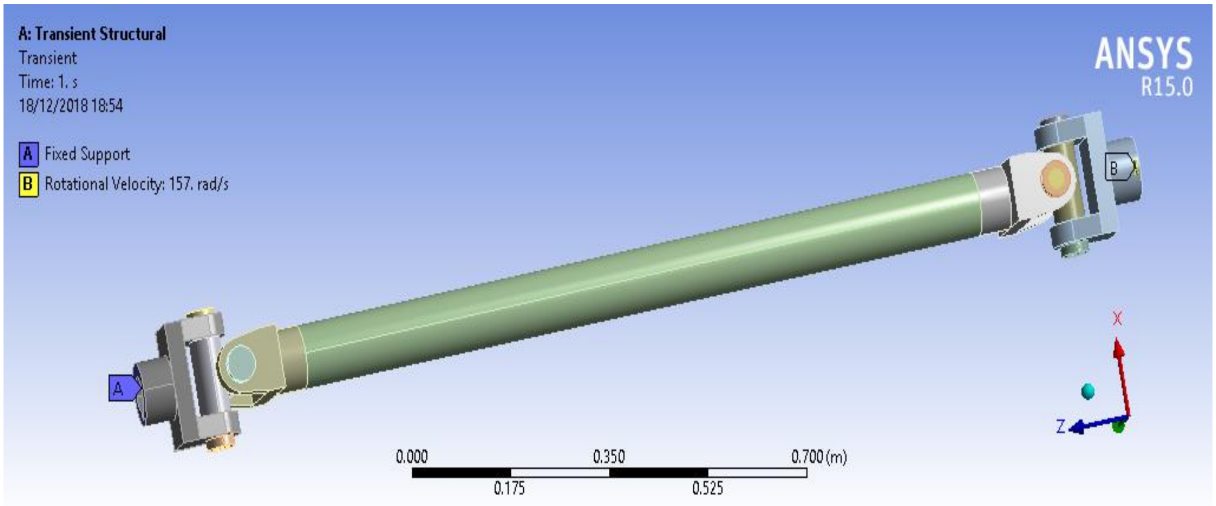


Figure 4.5. Fixed support imposed on the shaft

4.4.4. Boundary condition:

The boundary condition for the analysis of drive shaft are given as the one end is constrained with zero displacement in the both linear and rotational. At the other end of shaft torque is applied. To simulate the same working conditions real time boundary conditions, fixed support were applied on one side and rotational velocity and moment were applied on the other sides of the drive shaft assembly. Rotational velocity of 1500rpm (157 rad/sec) was applied for structural and vibration analysis. The rotational motion of drive shaft generates a torsional moment in whole body of drive shaft. This moment was applied on the opposite end having magnitude equal to 477Nm in the direction apposite to direction of rotational velocity.

Buckling analysis

Buckling analysis is a technique used to determine buckling loads (critical loads) at which a structure becomes unstable, and buckled mode shapes (the characteristic shape associated with a structure's buckled).

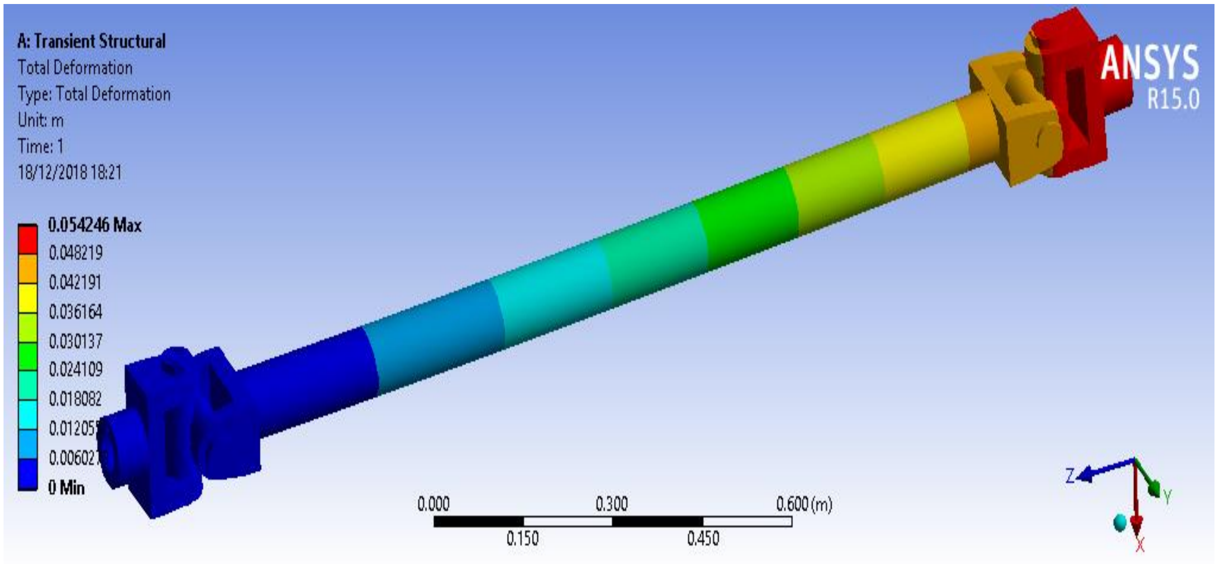


Figure 4.6. Total deformation of steel driveshaft

Table 4.5. Steel isotropic elasticity property from ANSYS

steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.01e+011	0.33	1.9706e+011	7.5564e+010

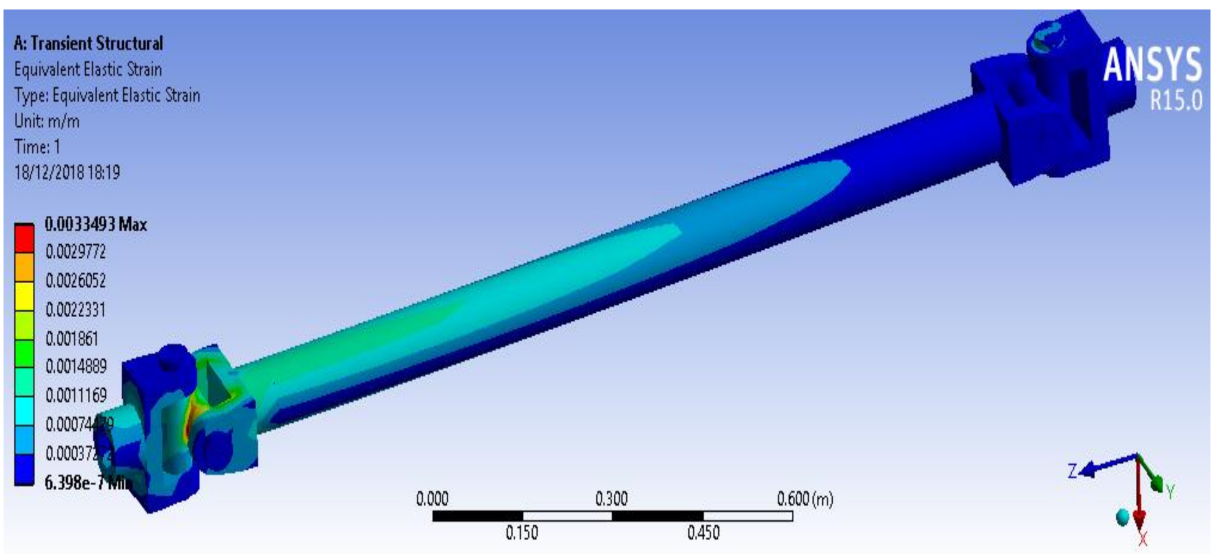


Figure 4.7. Steel driveshaft elastic strain

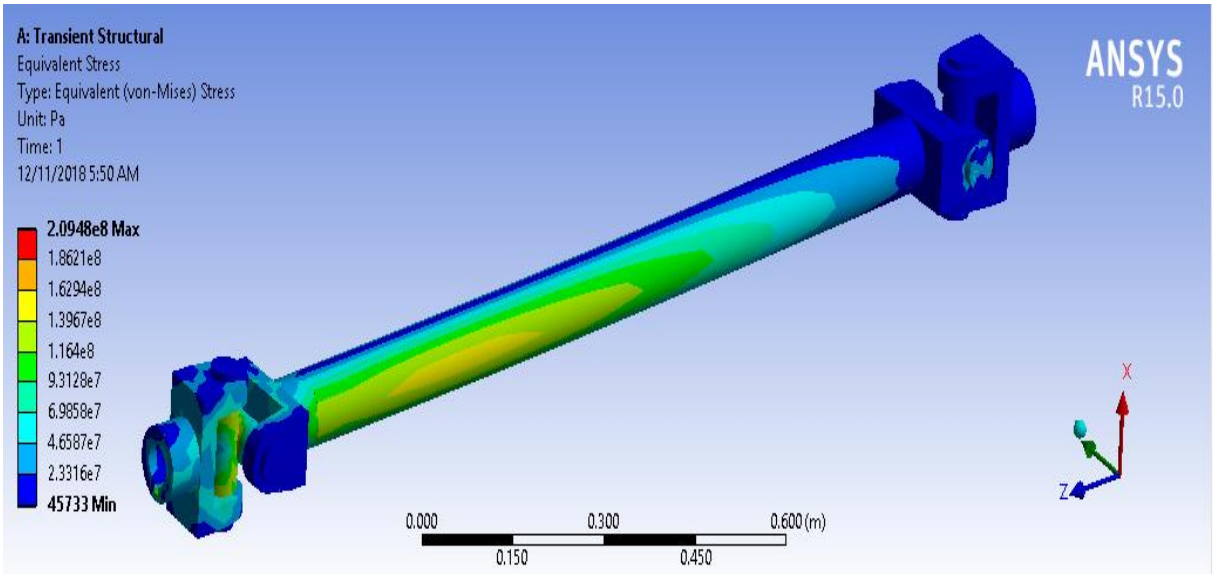


Figure 4.8. Von-mises of steel driveshaft

4.4.5. Analysis of composite driveshaft

Table 4.6. Orthotropic elasticity property of E-glass fiber from ANSYS

E-glass Fiber > Orthotropic Elasticity

Temperature C	Young's Modulus X direction Pa	Young's Modulus Y direction Pa	Young's Modulus Z direction Pa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY Pa	Shear Modulus YZ Pa	Shear Modulus XZ Pa
	4.5e+010	1.e+010	1.e+010	0.3	0.4	0.3	5.e+009	3.8462e+009	5.e+009

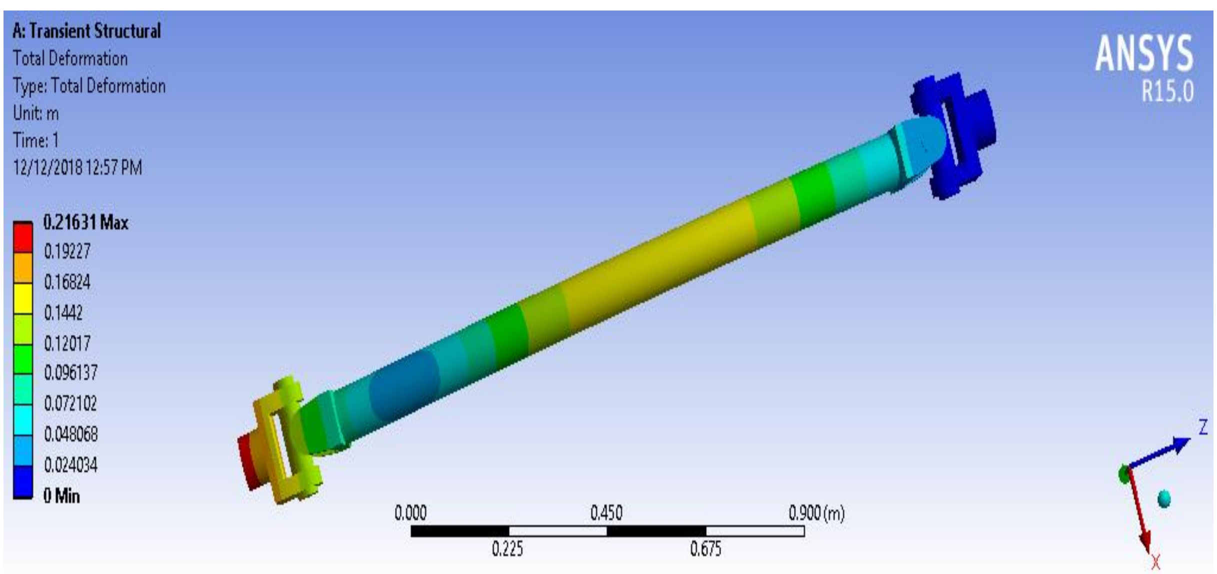


Figure 4.9. Deformation of glass/epoxy fiber driveshaft

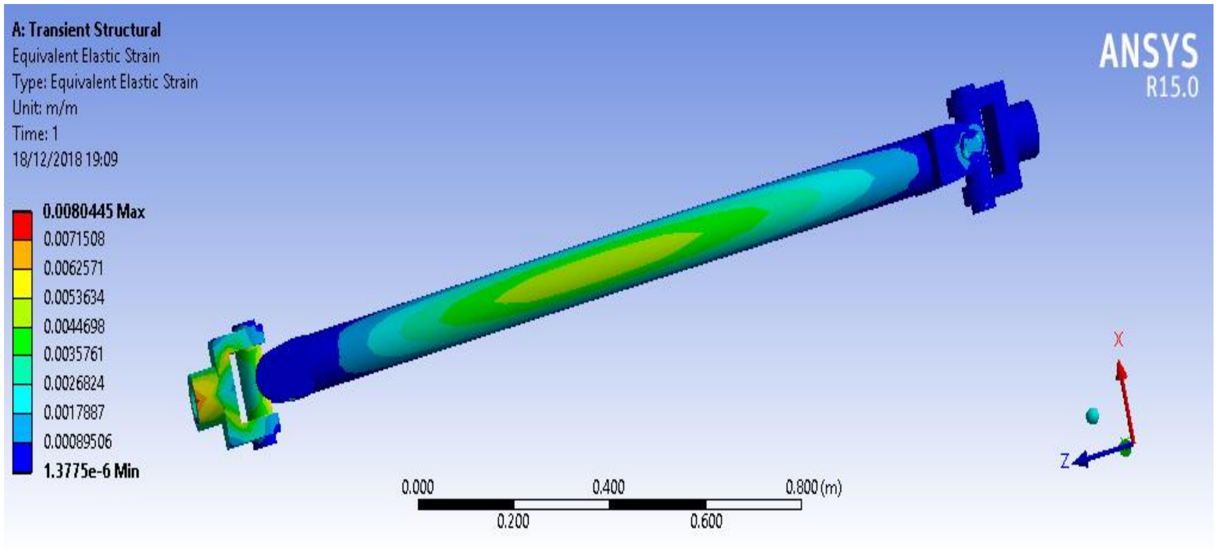


Figure 4.10. Elastic strain of glass/epoxy fiber driveshaft

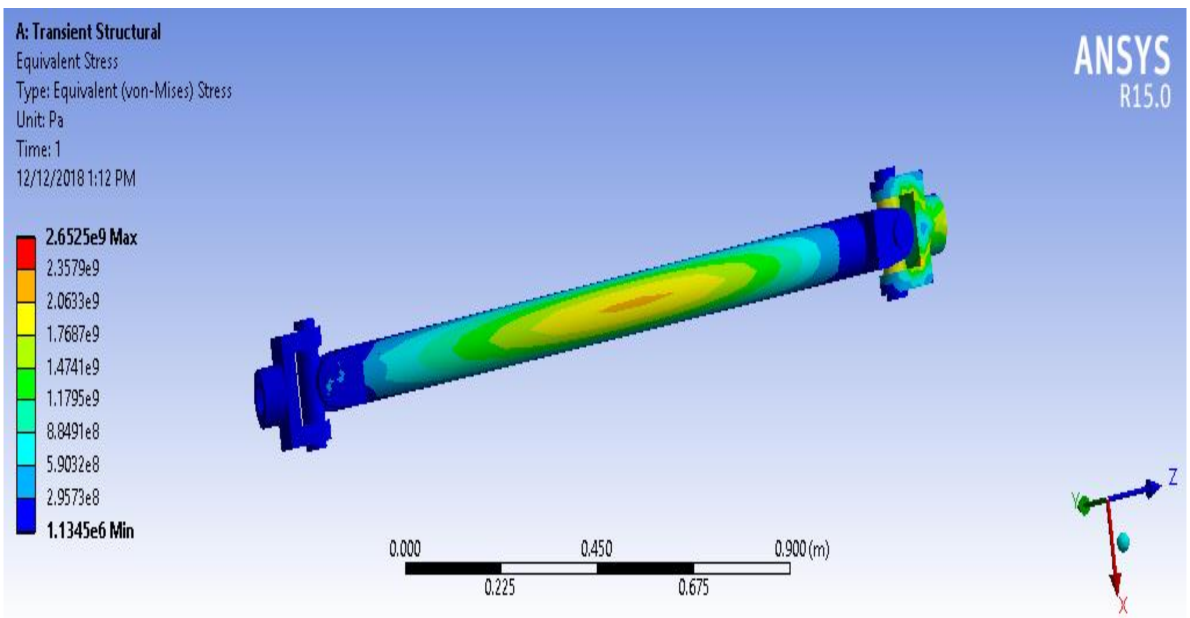


Figure 4.11. von-mises of glass/epoxy fiber driveshaft

Here total deformation, equivalent Stress and Equivalent strain are considered for evaluating the results using FAE.This shows that the convectional steel shaft produces the maximum shear and von-misses stress for the given transmission condition while the E-glass composite produces maximum stress for the given condition but have the maximum deformation.

CHAPTERFIVE

RESULTS & DISCUSSION

FEA based numerical simulations evaluate the results of structural analysis for steel alloy and epoxy composite material. In analysis inertia and damping effects was not considered. Rotational and moments values are applied in form of loading. The automobile drive shaft is subjected to torque transmission, no direct load value act on it. The result of this analysis evaluates the static failure condition of drive shaft.

Table 5.1.Validation and comparation of analytical and ANSYS results for steel and composite material

Results	**Steel**		**E- glass/ Epoxy**	
	Analytical	**ANSYS**	**Analytical**	**ANSYS**
Deformation(m)	0.0318	0.05	0.157	0.2
Maximum shear strain(m/m)	0.0255	0.0033	0.126	0.0080
Maximum shear stress(MPa)	147	83	50	97
Weight(kg)	8.661	8.661	4.66	4.76

Table 5.2.Comparison of analytical result for torque and natural frequency

	Torque transmission capacity(Nm)	Torsional buckling capacity(Nm)	Natural frequency (Hz)
specification	3500	3500	6500(rpm)
Steel SM45C	5957.9	12347.7	129.9
Glass/epoxy	3500	14195	124

The theoretical results from finite element analysis showed in a general a good agreement with the analytical values. Composite materials are analyzed taking into consideration of weight reduction, von-misses stresses and frequency. The replacement of composite materials has resulted in considerable amount of weight reduction about 46 % when compared to conventional steel shaft.

5.1. Tensile strength of sisal/glass fiber hybrid composite material

The test specimens for tensile test were cut as per specifications. The specimen was held in the grips of UTM and load was applied gently. As the load increases the fracture occurs in the gauge length portion of the test specimen. It is observed that the glass fiber composite is exhibiting higher tensile strength than sisal reinforced composite, tensile strength of sisal/glass fiber hybrid composite is higher than sisal reinforced composite but lower than glass fiber reinforced composite. The increase in tensile strength of hybrid composite is because of glass fiber content. The three samples were tested and the average value is tabulated.

The tensile strength of sisal/glass fiber hybrid composites is presented in table 5.3 it is observed that the glass fiber composite is exhibiting higher tensile strength than the sisal fiber composite. Tensile strength of sisal/glass fiber hybrid composite is higher than sisal reinforced composite but lower than glass fiber reinforced composite. The increase in tensile strength of hybrid composite is because of glass fiber content.

Fabricated material's specimen have been tested on Universal Testing Machine for find out the value of tensile strength, bending and Compressive strength with different material made up.

Table 5.3. Mechanical property values experimental result

	Tensile test(N/mm^2)	Compression test(Mpa)	Bending test (Mpa)
Al filler + glass fiber /epoxy	170	20	20.43
Sisal/glass fiber/epoxy	140	13	28
Glass fiber/epoxy	220	40	16.5

The effect of the glass fiber on the strength is shown in table 5.3. The increase in tensile strength with increasing in glass fiber can be attributed to good interfacial bonding between the glass fiber and the matrix.

5.2. MODAL ANALYSIS

When an elastic system free from external forces can disturbed from its equilibrium position and vibrates under the influence of inherent forces and is said to be in the state of free vibration. It will vibrate at its natural frequency and its amplitude will gradually become smaller with time due to energy being dissipated by motion. The main parameters of interest in free vibration are natural frequency and the amplitude. The natural frequencies and the mode shapes are important parameters in the design of a structure for dynamic loading conditions. Modal analysis is used to determine the vibration characteristics such as natural frequencies and mode shapes of a structure or a machine component while it is being designed. Modal analysis is to avoid the damage of resonance to mechanical structure before it works in reality, the modal analysis is necessary to judge whether there is a resonance. [56]

In modal analysis coarse mesh can be used because stresses are not taken into consideration. Natural frequency and different mode shapes are found by modal analysis. Natural frequency is a function of stiffness and mass. Fiber angle orientation affects natural frequency of system. For modal analysis one end of shaft is fixed.

Table 5.4. Natural frequency of steel and E-glass/epoxy at different mode

Mode	Frequency [Hz] Steel	Frequency [Hz] for E-glass fiber
1.	55.308	23.452
2.		23.497
3.	331.99	140.91
4.		141.95
5.	647.32	292.02
6.	875.3	371.81
7.		377.4
8.	1044.7	443.13
9.	1591.5	676.59

It depicts that Natural frequency and different mode shapes are found by modal analysis. The result shows that the frequency goes on increasing from first mode to last mode shape.

The rotational speed of the body is limited by the lateral stability. The drive shaft designed should rotate at the speed lower than the first natural bending frequency of in order to avoid whirling vibration.

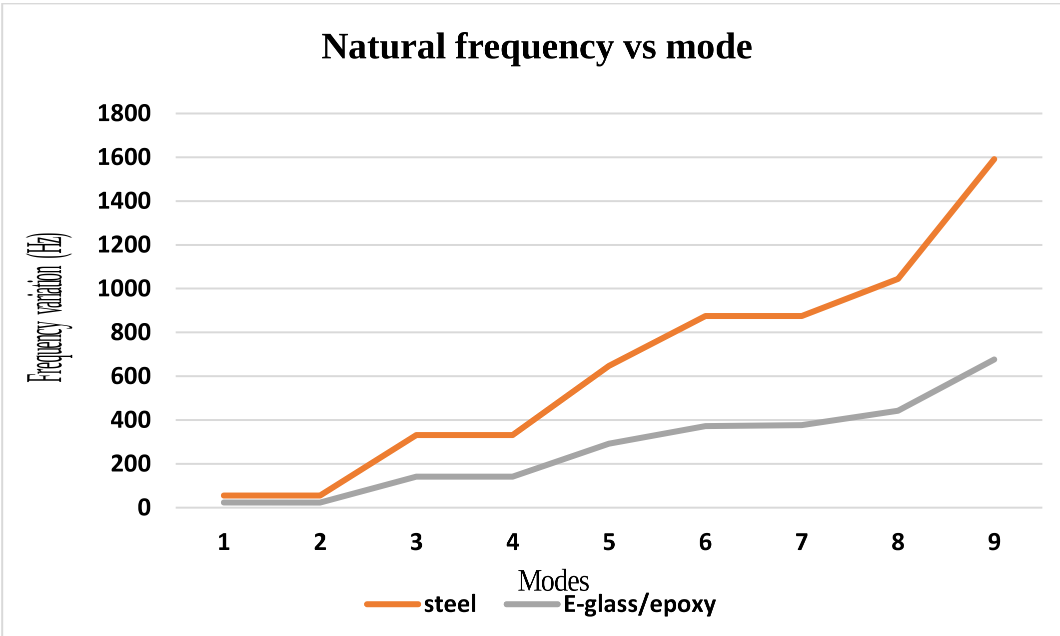


Figure 5.1. Natural frequency variation graph for both materials.

Figure 5.1 shows that variation of natural frequencies for steel and E-glass/epoxy composite material. The graph show that for both materials has natural bending frequencies with some value start with the 2^{nd} mode and as the mode increases the natural frequency increases correspondingly. It is found that natural frequency increases with increase in mode of vibration from software result.

5.3. Harmonic analysis

Harmonic analysis result is used to verify the steady-state response of a linear structure, enabling researchers, engineers and designer to determine whether in which the part can withstand resonance, fatigue or other structural problems related to vibration during its operation life. Simulation will automatically determine the number of modes n necessary for an accurate solution. Harmonic analysis calculates the response of a structure to cyclic loads over a frequency range and plot the response on amplitude vs. frequency graph as shown below.

Solution for frequency amplitude

The figure 5.2 shows that the highest amplitude recorded is at approximately 450Hz. Resonance is occurred at this frequency since it generated the highest amplitude frequency at the highest peak amplitude illustrated in the plot is similar with the last mode shape frequency of the driveshaft.

Harmonic of E-glass fiber

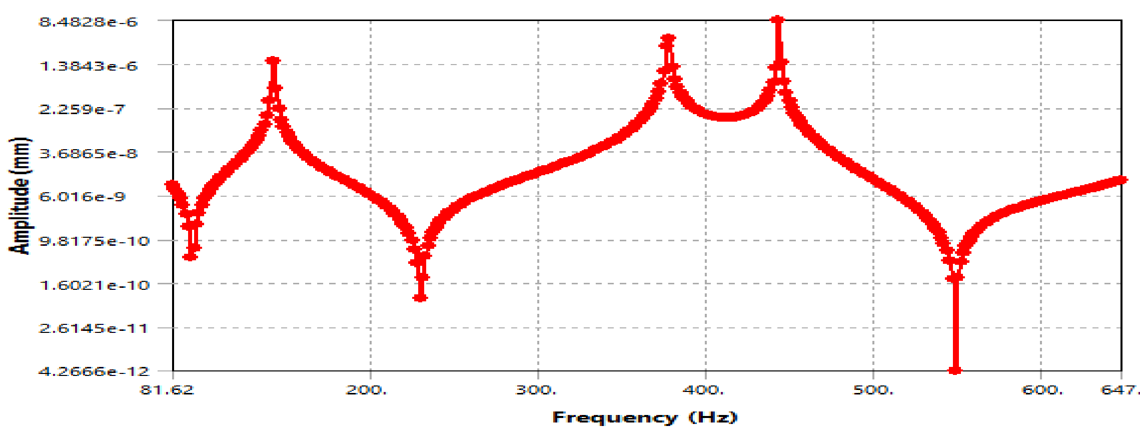


Figure 5.2.variation of stress amplitude with different exciting frequencies

As can be seen from the graphs the peaks correspond to the to the resonance condition. Taking into consideration the weight saving, resonant frequencies it is evident that E-glass/epoxy composite has the good encouraging properties to act as the replacement for steel.

In this research work three tests were carried out i.e. tensile test, bending and compression test. From this experimental evaluation of mechanical properties of glass fiber reinforced composite material is done. It is clearly observed that Short glass fiber reinforced epoxy composites with different volume were successfully prepared using hand layup method. It has been noticed that the mechanical properties of composites such as tensile strength and compression strength increases with increase in glass fiber content .

As it is clearly seen in figure 5.3 composite material preferably substitutes the convectional steel material by reducing it in almost half amount of percentage.

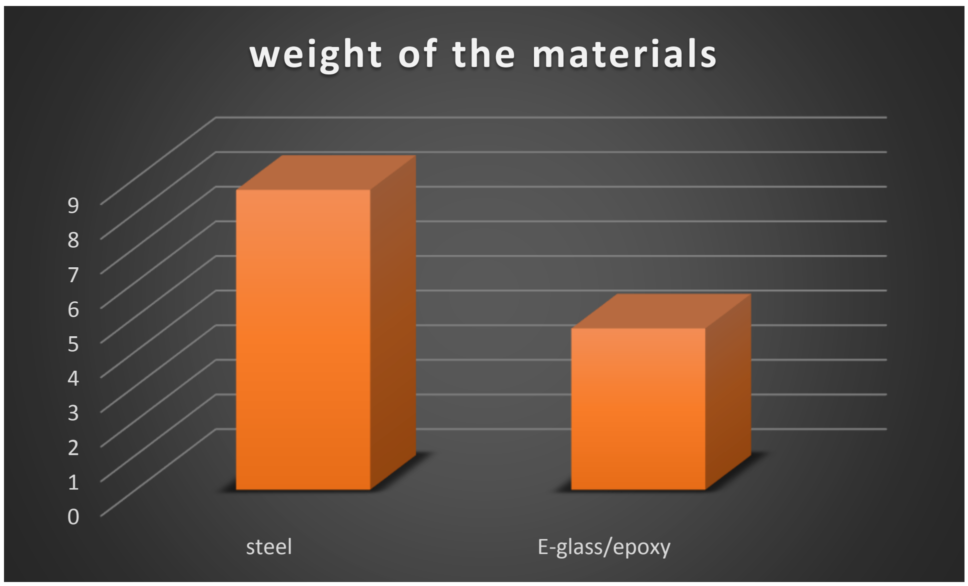


Figure 5.3.chart representation of both driveshaft weights

One-piece composite tubing may replace a two-piece steel setup due to tailorability of the material. Average vehicle can also be reduced by downsizing vehicles by using alternative material. Reduction in vehicle size and weight can significantly reduce fuel consumption. Reduction 100kg weight of vehicles, CO_2 emissions can be decreased about 5 g/km [57].

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

Summary

As aim of this project is to reduce the weight and decrease part complexity of the shaft. Some advantages of using composites over metals might be summarized as, anisotropic nature providing tailorability, production of both material and structure/component in a single operation, corrosion resistance and durability, damping and dimensional stability. Reduced corrosion and fatigue means less maintenance work and cost thus proven in-service durability. Recently, composite materials have been a trending topic so they have more potential for future development. In addition to these, they provide some additional convenience for production. Composite structures usually consist of fewer parts, so quicker assemblies are possible which means efficient production through reduced flow times.

6.1. Conclusion

In this paper, design and analysis of a single piece composite driveshaft that would replace a two-piece steel driveshaft for a light weight vehicle is achieved. A composite material is developed by means of hand lay-up technique to study materials mechanical property. Based on the finite element analysis and the analytical calculation done the following conclusions were drawn. The usage of composite materials has resulted inconsiderable amount of weight saving of 46% when compared to conventional steel drive shaft. Taking into account the weight saving, deformation, shear stress induced and resultant frequency it is evident that composite has the most encouraging properties to act as replacement to steel .The present work was aimed to enhance the fuel economy of the automobiles by reducing the weight of the drive shaft with the use of composite materials. Apart from being lightweight, the use of E-glass fiber/Epoxy resin also ensures less noise and vibration.

- One piece composite drive shaft was considered to replace the two piece conventional steel drive shaft.
- Taking into considerations the 46% weight saving, deformation, shear stress induced and frequencies it is evident that E-Glass/Epoxy composite has the most encouraging properties to act as replacement for steel.

6.2. Recommendation

Composite materials are appropriate for automotive application with their various advantageous and promising mechanical properties.

- From this study, it has been found that E-glass/epoxy resin composite materials shows sufficient potential application in the current era for manufacturing of the automotive interior and exterior part for sport vehicles, bicycle frames, different parts of aircraft and so on.
- The production of some vehicle parts like driveshaft, leaf spring, doors, bumper and dash board are showing better quality by replacing the convectional material by composite material in order to increase fuel efficiency and to bring better comfort by reducing vibration and noise.
- Ethiopian automobile assembly plants (car producers) and government to give attention toward the hybrid composite for different part manufacturing in order to fill the gap of foreign currency and technology transfer.
- ASTU should take pioneer action toward this area by doing a lot of research and fulfilling lab materials.

6.3. Scope of Future research

The area that must be done in continuous with this work is present in this sub topic .The following area is suggested for further study:

- Testing the properties of composite material by adding filler.
- Testing the specimen using torsional test and scanning electron microscope (SEM).
- Better if crush analysis is done.
- Modifying the E-glass/epoxy by hybridizing with natural fiber for different vehicle manufacturing part.
- Tribological assessment of glass fiber/epoxy resin composite material has been a much less studied area there is a very wide scope for future scholars to explore this area of research.

REFERENCE

1.M.pallavi,T.joel swaroop Raj,A.syam Prasad and M.madhavi (2015).Experimental Investigations on Static and Dynamic Parameters of Steel and Composite Propeller Shafts for a Light Passenger Vehicle, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE).

2.Andure M.W., Jirapure and S.C.,Dhamande, L.P. (2012). Advance Automobile Material for Light Weight Future, International Conference on Benchmarks in Engineering Science and Technology (ICBEST).

3.Anup B., Kristian B., Lynette C., Christopher E., Tiffany G., John H., Emmanuel K., Matthew K.and Malcolm W.(2008). Reducing Transportation's Petroleum Consumption and GHG Emissions, MIT.

4. Bhirud Pankaj P. and Bimlesh Kumar S (2014) Analysis of Drive Shaft: International Journal of Mechanical and Production Engineering, ISSN: 2320-2092,Vol 2.

5.Deepti kushwaha and Gaurav saxena (2014) optimal design and analysis of composite drive shaft for a light commercial vehicle,International Journal of Advance Engineering and Research Development(IJAERD).

6.Robert S. Salzar (1998) Design considerations for rotating laminated metal-matrix-composite Shafts, CUNY Graduate School of Civil Engineering, The City College of New York, NY 10031, USA.

7.H.P.J.de wilde and p.kroon (2012) policy options to reduce passanger car CO_2 emissions after 2020, energy research center of netherlands.

8.G.V.Mahajan and Prof. V.S.Aher (2012) A Review over Current Development and Automotive Application, International Journal of Scientific and Research Publication, India.

9.Lin,K.Y (2014) Composite Materials Overview for Engineers, University of Washington, Massive Open Online Course Notes.

10.Leslie, J.C.,Troung,L., Blank, B., & Frick, G. (1996). Composite driveshafts: technology and experience (No. 962209). SAE Technical Paper.

11. Muni kishore, JaligamKeerthi and Vinay kumar. (2016). Design and Analysis of Drive Shaft of an Automobile, IJETT,Volume 38.

12. Mohan.S. R, Balamuralikrishna.L, GowthamRam.G, KarthikSugumar.K, and Magesh.M. (2017). Design and finite element analysis of automotive propeller shaft using composite materials: SSRG International Journal of Mechanical Engineering.

13.S.Thennarasan, Bertram nirmalhilip, A.Prabhu and T.Arul Nicholas .(2017). Modeling and analysis of propeller shaft with universal joints: International Journal of Emerging Technologies in Engineering Research (IJETER), Volume 5.

14.Ganesh D. shined and K.H.Munde (2017) Fatigue Analysis of Epoxy Composite Material Reinforcement on Propeller Shaft, IJRESTs.

15.R.Srinivasa Moorthy, Yonas Mitiku and K.Sridhar.(2017). Design of Automobile Driveshaft using Carbon/Epoxy and Kevlar/Epoxy Composites: American Journal of Engineering Research (AJER), Ethiopia.

16.Esmael Adem, Er.Mukesh Didwania, Gurala Muralidhar R and Ermias G.Koricho .(2015).Experimental Analysis of E-Glass /Epoxy & E-Glass /polyester Composites for Auto Body Panel: American International Journal of Research in Science.

17.V.JoseAnanth Vino and Dr.J.Hameed Hussain (2015) Design and Analysis of Propeller Shaft.International Journal of Innovative Research in Science, Engineering and Technology,Vol. 4,India.

18.Asmamaw Gebresilassie (2012) Design and analysis of Composite Drive Shaft for Rear-Wheel Drive Engine, International Journal of Scientific & Engineering Research Volume 3, Issue 5,India.

19.J Narsaiah, K Venkatesh, and P Avinash. (2017). Design & Analysis of Composite Drive Shaft Made of Different Materials for Application in Automobiles ,International Journal for Scientific Research & Development(IJSRD) ,Vol. 5.

20.Chaitanya G Rothea and A.S.Bombatkar (2015) Design and Analysis of Composite Material Drive Shaft,International Journal of Innovative and Emerging Research in Engineering(IJIERE),volume 2.

21.Prof.Renno Veinthal (2010) Application of Materials,tallinna university of technology.

22.Venkata Naga Prakash (2017) Mechanical Behavior of Carbon and Glass Fiber Reinforced Composite Materials Under Varying Loading Rates, University of Michiga.

23.European Aluminum Association (2013) The Aluminum Automotive manual-Hang on parts.

24.American Chemistry Council (2006) Composite driveshafts can increase torque and can help prevent injuries.

25.Daniel E.Whitney (2008) Design and Manufacturing of Car Doors: Report on Visits Made to US, European and Japanese Car Manufacturers in 2007.

26.K. Shiva Shankar, Ch Harish, B. Praharshini Amulya and Rahul. (2016). Fabrication of Fiber Reinforced Composite, International Journal of Innovative Research in Science, Engineering and Technology(IJIRSET),india.

27.Kalaiyarasan A and Sankareswarann (2016) design and analysis of drive shaft by different reinforcement material in metal matrix composite, International Journal of Recent Scientific Research, 2016,india.

28.Dr.srikari S.composite and applications,ramaiah school of advanced studies,Bangalore.

29. Bhagwan D. Agarwal, Lawrence J. Broutman, K .Chandrashekhara, (2015). Analysis and performance of fiber composites,third edition.

30.L.E.Nielsen and R F.Landel (1994) Mechanical Properties of Polymers and Composites, Marcel Dekker, New York.

31. Brendan J. O'Toole (2005) Introduction to Composite Materials, University of Nevada Las Vegas.

32.M. R. Sanjay, G. R. Arpitha1, L. Laxmana Naikl, K. Gopalakrishna, B. Yogesha. (2016). Applications of Natural Fibers and Its Composites, scientific research publishing, India

33.Dr.Hossein Saidpour (2004) Lightweight High Performance Materials for Car Body Structures: NTI Technology Conference, CEME, Ford Motor Company.

34.Sabitra Subhadarsan .P and Pradipta Kumar .D (2007) Fiber reinforced polymer composites characterization by differential scanning calorimeter, National Institute of Technology, Rourkela.

35.P.K.Mallick,fiber reinforced composites Materials, Manufacturing, and Design,University of Michigan-Dearborn, third edition.

36.Pollard A.(1999).Polymer matrix composite in drive line applications. GKN Technology, Wolverhampton.

37.Miroslava Klárová (2015) Composite materials, Technical University of Ostrava, Ostrava .

38.Ketan S Patil and V.M.Chidri (2015) Optimisation of a Composite Material Automotive Driveshaft by Using FEM ,International Journal of Current Engineering and Technology .

39.Akula Jagadeesh Kumar (2007) Optimum Design and Analysis of a Composite Drive Shaft for an Automobile, Sweden.

40.R.P.Kumar Rompicharla (2012) Design and Optimization of Driveshaft with Composite Materials, International Journal of Engineering Research & Technology, Vol. 1.

41.Anirudha P. Jangam and Vishavjit L. Bhanavase (2015) Design and Analysis of Drive Shaft in Automotive Using Composite Material, ARDIJEET.

42.Gyadari Ramesh and Dr. G. Chandra Mohan Reddy (2015) Structural and Modal Analysis of Composite Material Shaft with Damping Material, International Journal for Innovative Research in Science & Technology(IJIRST),India.

43.Vinodh Kumar S, Sampath V and Baskar P.(2015). Analysis of Propeller Shaft for Composite Materials: School of Mechanical and Building Sciences, VIT University, Vellore, India.

44.Satendra Kumar (2017) Study of design parameters of propeller shaft of heavy duty trucks,national institute of technology Jamshedpur.

45.G.Devendhar Rao,K.Srinivasa Reddy, P.Raghavendra Rao, and P. Madusudana ,(2017). Mechanical Properties of E-Glass Fiber Reinforced Epoxy Composites with SnO2 and PTFE,International Journal of Emerging Research in Management & Technology.

46.M. S. EL-Wazery, M. I. EL-Elamy, and S. H. Zoalfakar.(2017). Mechanical Properties of Glass Fiber Reinforced Polyester Composites, International Journal of Applied Science and Engineering, Egypt.

47.Mr.Vishal S.and Prof. Laukik B (2016) Experimental investigation of mechanical properties of glass fiber/epoxy composites with variable volume fraction,IARJSET.

48.J Narsaiah, K Venkatesh and P Avinash (2017). Design & Analysis of Composite Drive Shaft Made of Different Materials for Application in Automobiles, International Journal for Scientific Research & Development (IJSRD) Vol. 5.

49.VirendraV.M. and Anup B.Patel (2015) Design, Analysis and Optimization in Automobile Drive Shaft, International Journal for Innovative Research in Science &Technology (IJIRST).

50. David,v (2004) fundamentals of finite element analysis.McGraw Hill.

51.Mr. A.R. Nadaf and Dr.V.A.Raikar (2017) design and Analysis of Composite Shaft of Passenger Vehicle, International Research Journal of Engineering and Technology (IRJET),India.

52.Timoshenko SP and Gere JM (1963) Theory of Elastic Stability. New York, McGraw-Hill, pp.500-509.

53.S.S.Rao (2002) Mechanical vibrations, Addision-Wesely publishing Company, pp.537-541.

54.V. S. Bhajantri, S. C. Bajantri, A. M. Shindolkar and S. S. Amarapure.(2014). Design and Analysis of Composite Drive Shaft, IJRET: International Journal of Research in Engineering and Technology.

55.M. Mahesh Babu and Dr. N.Ramesh (2018) FAE simulation of composite propeller shaft of automobile, international journal of current engineering and scientific research (IJCESR).

56.Tang,Y, and Yu,Y (2017) Modal and harmonic response analysis of key components of robotic arm based on ANSYS,zhenghou,450002,china.

57.sunwenlong,chenxiaokai and wang Lu (2016) Analysis of energy saving and emission reduction of vehicles using lightweight materials. School of mechanical engineering, Beijing institute of technology, Beijing and 100081, china.

From World Wide Web page

Url-1 <*http://www.wikipidea.com/catia*>

Url-2 <*http://navyaviation.tpub.com/14018/css/14018-596.htm*>

Url-3 <*http://www.acpt.com/Products/Composite-Driveshafts.aspx*>

Appendix

Material Data

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

E-glass fiber
E-glass fiber > Constants

Density	2040 kg m^-3

E-glass fiber > Orthotropic Elasticity

Temperature C	Young's Modulus X direction Pa	Young's Modulus Y direction Pa	Young's Modulus Z direction Pa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY Pa	Shear Modulus YZ Pa	Shear Modulus XZ Pa
	4.5e+010	1.e+010	1.e+010	0.3	0.4	0.3	5.e+009	3.846e+009	5.e+009

steel
steel > Constants

Density	7600 kg m^-3

steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.07e+011	0.3	1.725e+011	7.9615e+010

Appendix A (steel)

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\DE\AppData\Local\Temp\WB_DESKTOP-BNCDOCP_DE_3752_2\unsaved_project_files\dp0\SYS\DM\SYS.agdb
Type	DesignModeler
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	90. mm
Length Y	90. mm
Length Z	1250. mm
Properties	
Volume	1.9792e+006 mm³
Mass	13.042 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	31043
Elements	4719
Mesh Metric	None

Object Name	*Total Deformation*	*Total Deformation 2*	*Total Deformation 3*	*Total Deformation 4*	*Total Deformation 5*	*Total Deformation 6*	*Total Deformation 7*	*Total Deformation 8*	*Total Deformation 9*
State	Solved								
Scope									
Scoping Method	Geometry Selection								
Geometry	All Bodies								
Definition									
Type	Total Deformation								
Mode	1.	2.	3.	4.	5.	6.	1.	2.	3.
Identifier									
Suppressed	No								
Results									
Minimum	0. mm								

Maximum	16.261 mm	16.041 mm	12.323 mm	15.809 mm	16.261 mm	16.041 mm
Minimum Occurs On	Solid					
Maximum Occurs On	Solid					
Information						
Frequency	55.308 Hz	331.99 Hz	647.32 Hz	875.3 Hz	55.308 Hz	331.99 Hz

Modal

Object Name	*Solid*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Behavior	None
Material	
Assignment	steel
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	90. mm
Length Y	90. mm
Length Z	1250. mm
Properties	
Volume	1.9792e+006 mm³
Mass	13.042 kg
Centroid X	-1.5055e-015 mm
Centroid Y	-2.6884e-016 mm
Centroid Z	625. mm
Moment of Inertia Ip1	1.9619e+006 kg·mm²
Moment of Inertia Ip2	1.9619e+006 kg·mm²
Moment of Inertia Ip3	26400 kg·mm²
Statistics	
Nodes	31043
Elements	4719
Mesh Metric	None

Harmonic Response steel

Object Name	*Analysis Settings*
State	Fully Defined
Options	
Frequency Spacing	Linear
Range Minimum	80. Hz
Range Maximum	647. Hz
Solution Intervals	350
User Defined Frequencies	Off
Solution Method	Full
Variational Technology	Program Controlled
Rotordynamics Controls	
Coriolis Effect	Off
Output Controls	
Stress	Yes
Strain	Yes
Object Name	*Frequency Response*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Spatial Resolution	Use Average
Definition	
Type	Directional Deformation
Orientation	X Axis
Suppressed	No
Options	
Frequency Range	Use Parent
Minimum Frequency	80. Hz
Maximum Frequency	647. Hz
Display	Bode
Chart Viewing Style	Log Y
Results	
Maximum Amplitude	4.8102e-007 mm
Frequency	332.72 Hz
Phase Angle	180. °
Real	-4.8102e-007 mm
Imaginary	2.9972e-021 mm

Appendix B

E-glass Fiber

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\DE\AppData\Local\Temp\WB_DESKTOP-BNCDOCP_DE_3752_2\unsaved_project_files\dp0\SYS\DM\SYS.agdb
Type	DesignModeler
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	90. mm
Length Y	90. mm
Length Z	1250. mm
Properties	
Volume	1.9792e+006 mm³
Mass	4.76 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	31043
Elements	4719
Mesh Metric	None
Basic Geometry Options	
Parameters	Independent
Parameter Key	
Attributes	Yes
Attribute Key	
Named Selections	Yes
Named Selection Key	
Material Properties	Yes
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	Yes
Coordinate System Key	
Reader Mode Saves Updated File	No
Use Instances	Yes

Smart CAD Update	Yes
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\DE\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

Object Name	*Total Deformation*	*Total Deformation 2*	*Total Deformation 3*	*Total Deformation 4*	*Total Deformation 5*	*Total Deformation 6*	*Total Deformation 7*	*Total Deformation 8*	*Total Deformation 9*
State	Solved								
Scope									
Scoping Method	Geometry Selection								
Geometry	All Bodies								
Definition									
Type	Total Deformation								
Mode	1.	2.	3.	4.	5.	6.	1.	2.	3.
Identifier									
Suppressed	No								
Results									
Minimum	0. mm								
Maximum	31.385 mm	31.406 mm	30.975 mm	31.079 mm	23.798 mm	30.525 mm	31.385 mm	31.406 mm	30.975 mm
Minimum Occurs On	Solid								
Maximum Occurs On	Solid								
Information									
Frequency	23.452 Hz	23.497 Hz	140.91 Hz	141.95 Hz	292.02 Hz	371.81 Hz	23.452 Hz	23.497 Hz	140.91 Hz

Model

Object Name	*Solid*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Behavior	None
Material	
Assignment	e glass fiber
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	90. mm
Length Y	90. mm
Length Z	1250. mm
Properties	
Volume	1.9792e+006 mm^3
Mass	4.76 kg
Centroid X	-1.5055e-015 mm
Centroid Y	-2.6884e-016 mm
Centroid Z	625. mm
Moment of Inertia Ip1	5.266e+005 $kg \cdot mm^2$
Moment of Inertia Ip2	5.266e+005 $kg \cdot mm^2$
Moment of Inertia Ip3	7086.3 $kg \cdot mm^2$
Statistics	
Nodes	31043
Elements	4719
Mesh Metric	None

Harmonic Response for E-glass fiber

Object Name	*Frequency Response*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Spatial Resolution	Use Average
Definition	
Type	Directional Deformation
Orientation	X Axis
Suppressed	No
Options	
Frequency Range	Use Parent
Minimum Frequency	80. Hz
Maximum Frequency	647. Hz
Display	Bode
Chart Viewing Style	Log Y
Results	
Maximum Amplitude	8.4828e-006 mm
Frequency	442.88 Hz
Phase Angle	180. °
Real	-8.4828e-006 mm
Imaginary	0. mm

Appendix C

Xylo D2 BS-III Technical Specs

Dimensions & Weight	
Length	4520 mm
Width	1850 mm
Height	1895 mm
Wheelbase	2760 mm
Ground Clearance	186 mm
Kerb Weight	1875 kg
Capacity	
Doors	5 Doors
Seating Capacity	7 & 8 Person
No of Seating Rows	3 Rows
Fuel Tank Capacity	55 litres
Engine & Transmission	
Displacement	2489 cc
Valves per Cylinder	2 Valves
Valve Configuration	SOHC
Fuel Type	Diesel
Engine Type	4 cylinder mDI CRDe diesel engine
Max Power (bhp@rpm)	95 bhp @ 3600 rpm
Max Torque (Nm@rpm)	220 Nm @ 1400 rpm
Mileage (ARAI)	13.9 kmpl
Turbocharger/Supercharger	Turbocharged
Turbocharger Type	Fixed Geometry
No of gears	5 Gears

Transmission Type	Manual
Drive train	RWD
Dual Clutch	No
Sport Mode	No
Manual Shifting for Automatic	No
Driving Modes	No
Engine Start-Stop Function	No
Suspensions, Brakes & Steering	
Suspension Front	independent coil spring
Suspension Rear	Mulit-link coil spring
Front Brake Type	Disc
Rear Brake Type	Drum
Minimum Turning Radius	5.6 metres
Steering Type	Power assisted (Hydraulic)
Wheels	Steel Rims
Spare Wheel	Steel
Front Tires	205 / 65 R15
Rear Tires	205 / 65 R15