Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 5, Issue 01, January -2018

Design and Analysis of Carbon Fibre Drive Shaft Using Classical Theories

Akshay Shrishrimal[1], Pranav Patil [2], Ritesh Mane[3]

1, Dept. of Mechanical Engineering, MIT, Pune, India.
2, Dept. of Mechanical Engineering, MIT, Pune, India.
3, Dept. of Mechanical Engineering, MIT, Pune, India.

Abstract

In vehicles drive shaft is one of the important components. A drive shaft is a rotating shaft that transmits power from the engine to the differential gear of a rear wheel drive vehicles. Generally an alloy steel drive shaft is used in automotive, nowadaysthissteeldriveshaftisreplacedbycompositematerialdriveshaft.The advanced composite materials such as graphite, carbon, Kevlar and glass with suitable resins are widely used because of their high specific strength and high specific module. Due to replacement of composite material can results in considerable amount of weight reduction as compared to steel shaft. In this study composite shaft and genetic algorithm is successfully applied to minimize the weight of shaft which is subjected to the constraints such as torque transmission and fundamental natural frequency. Our main aim is to study its design procedure along with finite element analysis. Many researchers have been investigated about drive shaft.Thisworkdealswiththereplacementofconventionalsteeldriveshaftwithhighstrengthcarbon/epoxy composite drive shaft. The design parameters were optimized with the help of genetic algorithm (G.A) with the objective of minimizing the weight of composite drive shaft. The result of GAareused for modeling of Carbon/epoxy composite drives haft and steel drive shaft using CAD soft ware to perform static, buckling and modal analysis of both drive shaft using ANSYS software.

Keywords- *Drive shaft, composite material, ANSYS, Genetic Algorithmetc.*

I. INTRODUCTION

The advanced composite materials such as Graphite, Carbon, Kevlar and Glass with suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/density). Advanced composite materials seem ideally suited for long, power driver shaft (propeller shaft) applications. Their elastic properties can be tailored to increase the torque they can carry as well as the rotational speed at which they operate. The drive shafts are used in automotive, aircraft and aerospace applications. The automotive industry is exploiting composite material technology for structural components construction in order to obtain the reduction of the weight without decrease in vehicle quality and reliability. It is known that energy conservation is one of the most important objectives in vehicle design and reduction of weight is one of the most effective measures to obtain this result. Actually, there is almost a direct proportionality between the weight of a vehicle and its fuel consumption, particularly in city driving.

II. THE GENETICALGORITHEM

The design parameters are to be optimized for E-Glass/ Epoxy, High Strength Carbon/Epoxy and High Modulus Carbon/Epoxy composite drive shafts of an automobile using Genetic Algorithm. The purpose of using Genetic Algorithm is to minimize the weight of the shaft, which is subjected to the constraints such as torque transmission, torsional buckling capacities and fundamental lateral natural frequency.

The design parameters to be optimized are,

1. Plythickness
2. Number of pliesrequired

III. INTRODUCTION TO DRIVESHAFT

The torque that is produced from the engine and transmission must be transferred to the rear wheels to push thevehicleforwardandreverse.Thedriveshaftmustprovideasmooth,uninterruptedflowofpowertothe axles.The drive shaft and differential are used to transfer this torque.

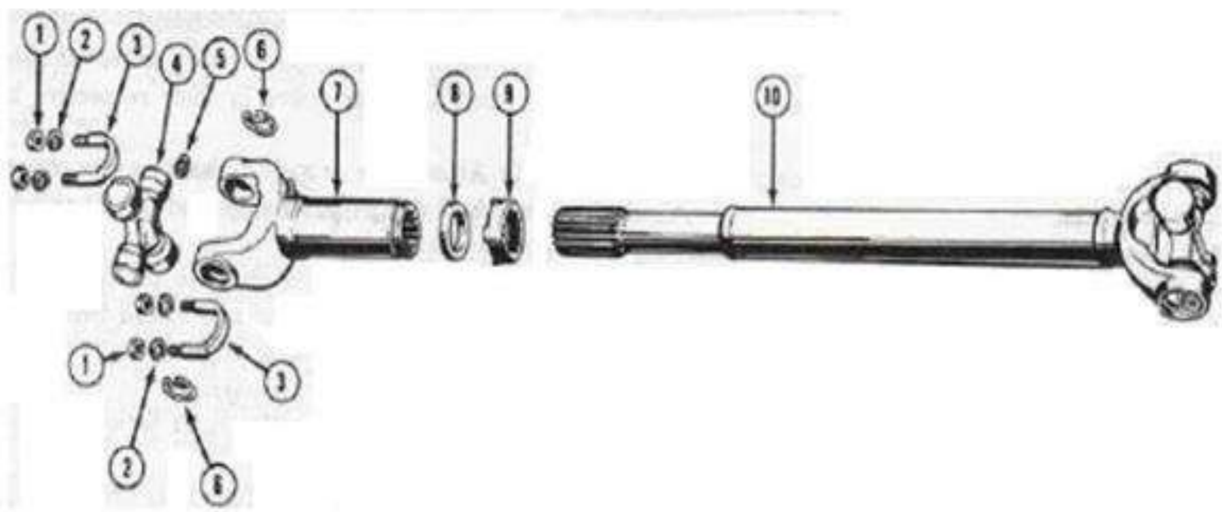
IV. FUNCTIONS OF THE DRIVE SHAFT

1. First, it must transmit torque from the transmission to the differential gearbox.
2. During the operation, it is necessary to transmit maximum low-gear torque developed by theengine.
3. The drive shafts must also be capable of rotating at the very fast speeds required by thevehicle.
4. The drive shaft must also operate through constantly changing angles between the transmission,the differential and the axles. As the rear wheels roll over bumps in the road, the differential and axles move up and down. This movement changes the angle between the transmission and thedifferential.
5. Thelengthofthedriveshaftmustalsobecapableofchangingwhiletransmittingtorque.Lengthchangesare caused by axle movement due to torque reaction, road deflections, braking loads and so on. A slip joint is used to compensate for this motion. The slip joint is usually made of an internal and external spline. It is located on the front end of the drive shaft and is connected to thetransmission.

V. PART OF DRIVE SHAFT AND UNIVERSAL JOINT

Parts of drive shaft and universal joint are shown in fig.1.Parts of drive shaft and universal joints are: -

1. U-boltnut
2. U-boltwashers
3. U-bolt
4. Universal jointjournal
5. Lubrication fitting
6. Snap ring.
7. Universal joint sleeveyoke
8. Splineseal
9. Dustcap
10. Drive shaft tube



1. Different Parts of Drive System

VI. INTRODUCTION OF COMPOSITES

Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. 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. 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. Continuous-fiber composites are often made into laminates by stacking single Sheets of continuous fibers in different orientations to obtain the desired strength and stiffness properties with fiber volumes as high as 60 to 70 percent. Fibers produce high-strength composites because of their small diameter; they contain far fewer defects (normally surface defects) compared to the material produced in bulk. As a general rule, the smaller the diameter of the fiber, the higher its strength, but often the cost increases as the diameter becomes smaller. In addition, smaller diameter high-strength fibers have greater flexibility and are more amenable to fabrication processes such as weaving or forming over radii. Typical fibers include glass, aramid, and carbon, which may be continuous or discontinuous. the chief engineer of aircraft structures for the U.S. Navy once told the author that he liked composites because “ They don’t rot [corrode] and they don’t get tired [fatigue].” Corrosion of aluminum alloys is a major cost and a constant maintenance problem for both commercial and military aircraft. The corrosion resistance of composites can result in major savings in supportability costs. Carbon fiber composites cause galvanic corrosion of aluminum if the fibers are placed in direct contact with the metal surface, but bonding a glass fabric electrical insulation layer on all interfaces that contact aluminum eliminates this problem.

VII. CLASSIFICATION OF COMPOSITES

Composite materials can be classified as

1. Polymer matrix composites
2. Metal matrix composites
3. Ceramic Matrix

Technologically, the most important composites are those in which the dispersed phase is in the form of a fiber. The design of fiber-reinforced composites is based on the high strength and stiffness on a weight basis. Specific strength is the ratio between strength and density. Specific modulus is the ratio between modulus and density. Fiber length has a great influence on the mechanical characteristics of a material. The fibers can be either long or short. Long continuous fibers are easy to orient and process, while short fibers cannot be controlled fully for proper orientation. Long fibers provide many benefits over short fibers. These include impact resistance, low shrinkage, improved surface finish, and dimensional stability. However, short fibers provide low cost, are easy to work with, and have fast cycle time fabrication procedures. The characteristics of the fiber- reinforced composites depend not only on the properties of the fiber, but also on the degree to which an applied load is transmitted to the fibers by the matrix phase

The principal fibers in commercial use are various types of glass, carbon, graphite and Kevlar. All these fibers can be incorporated into a matrix either in continuous lengths or in discontinuous lengths. The matrix material may be a plastic or rubber polymer, metal or ceramic. Laminate is obtained by stacking a number of thin layers of fibers and matrix consolidating them to the desired thickness. Fiber orientation in each layer can be controlled to generate a wide range of physical and mechanical properties for the composite laminate.

7.1 Processing of composite materials

Fiber composites are most commonly fabricated by the impregnation (or infiltration) of the matrix or matrix precursor in the liquid state in to the fiber preform, which can take the form of a woven fabric. In the case of composites in the shape of tubes, the fibers may be impregnated in the form of a continuous bundle (called a tow) from a spool and subsequently the bundles can by wound on a mandrel. Instead of impregnation, the fibers and matrix material may be intermixed in the solid state by commingling reinforcing fibers and matrix fibers, by coating the reinforcing fibers with the matrix material, by sandwiching reinforcing fibers with foils of the matrix material, and in other ways. After impregnation or intermixing, consolidation is carried out, often under heat and pressure.

7.2 Advantages of fiber reinforced composites

The advantages of composites over the conventional materials are

1. High strength to weight ratio
2. High stiffness to weight ratio
3. High impact resistance
4. Better fatigue resistance
5. Improved corrosion resistance
6. Good thermal conductivity
7. Low Coefficient of thermal expansion. As a result, composite
8. Structures may exhibit a better dimensional stability over a wide temperature range.
9. High damping capacity.

VIII. DESCRIPTION OF PROBLEM

Almost all automobiles (at least those which correspond to design with rear wheel drive and front engine installation) have transmission shafts. 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 increase in cost and decrease in quality and reliability. It is possible to achieve design of composite drive shaft with less weight to increase the first natural frequency of the shaft and to decrease the bending stresses using various stacking sequences. By doing the same, maximize the torque transmission and torsional buckling capabilities are also maximized.

IX. DESIGN OF STEEL DRIVE SHAFT

The fundamental natural bending frequency for passenger cars, small trucks, and vans of the propeller shaft should be higher than 6,500 rpm to avoid whirling vibration and the torque transmission capability of the drive shaft should be larger than 3,500 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations. Here outer diameter of the shaft 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 1.

Table 1. Design requirements and specifications

Sr. No.	Name	Notation	Unit	Value
1	Ultimate Torque	T_{max}	N-m	3500
2	Max. Speed of Shaft	N_{max}	Rpm	6500
3	Length of Shaft	L	Mm	1250

Table 2. Design Parameters of Steel Drive Shaft

Sr. No	Parameter of Shaft	Symbol	Value	Unit
1	Outer Diameter	d_o	90	mm
2	Inner Diameter	d_i	83.36	mm
3	Length of the Shaft	L	1250	mm
4	Thickness of shaft	T	3.32	mm

Steel(SM45C)usedforautomotivedriveshaftapplications.Thematerialpropertiesofthesteel(SM45C)are giveninTable3.Thesteeldriveshaftshouldsatisfythreedesignspecificationssuchastorquetransmissioncapability, buckling torque capability and bending naturalfrequency.

Table 3. Mechanical Properties of Steel (SM 45C)

Mechanical Properties	Symbol	Units	Steel
Young's Modulus	E	Gpa	207
Shear Modulus	G	Gpa	80
Poisson's ratio	ν	-	0.3
Density	ρ	Kg / M^3	7600
Shear Strength	Ss	MPa	370

9.1 Torque transmission capacity of the drive shaft

T = SS π(do4− di4)16do

T = 123.33 X 10 6 π(0.094− 0.085924)16 X 3.32 X 0.09

Taking factor of safety as 3.

T = 3599.19 N - m

9.2 Torsional buckling capacity of the drive shaft

If 1√1−ν2 L2t(2r)3 > 5.5,

It is called as Long shaft otherwise it is called as Short & Medium shaft.

For long shaft, the critical stress is given by,

τ cr = E3√2(1−ν2)3/4 (t/r)3/2

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

τ cr = 4.39 E(1−ν2) (t/r2) √1+0.0257 (1− ν2)34L3(rt)1.5

τ cr = 1119.65 N / mm2

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

T cr = τ cr 2πr2t

Tcr = 43857.9 N-m

9.3 Lateral or bending vibration

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

9.4 Bernoulli-Euler beam theory-

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 [38],

f nbe = π p2 2L2 √EIx ml

Where, p = 1, 2

N crbe = 60f nbe

f nbe = 161.03 Hz

N crbe = 9662.38 rpm

9.5 Timoshenko beam theory-

It considers both transverse shear deformation as well as rotary inertia effects. Natural frequency based on the Timoshenko beam theory is given by,

fnt = Ks (30πp2 L2) √Er2 2ρ

N crt = 60f nt

1 Ks2 = 1 + n2π2r2 2L2 [1 + fsE G]
Ks = 0.964

fs= 2 for hollow circular cross-sections

X. THE RELATION BETWEEN TIMOSHENKO AND BERNOULLI-EULER BEAM THEORIES

The relation between Timoshenko and Bernoulli-Euler beam theories is given by,

f nt = Ks f nbe
f nt = 0.962 X 161.03
f nt = 155.32 Hz
N crt = 9319.98 rpm

XI. DESIGN OF COMPOSITE DRIVE SHAFT

The specifications of the composite drive shaft of an automotive transmission are same as that of the steel drive shaft for optimal design

Assumptions

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.

11.1 Selection of cross-section

The drive shaft can be solid circular or hollow circular. Here hollow circular cross-section was chosen because:

1. The hollow circular shafts are stronger in per kg weight than solid circular.
2. 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.

11.2 Selection of materials

Based on the advantages discussed earlier, the High Strength Carbon / Epoxy and High Modulus Carbon / Epoxy materials are selected for composite drive shaft. The Table 4 shows the properties of the High Strength Carbon / Epoxy and High Modulus Carbon / Epoxy materials used for composite drive shafts. Table 4.Properties of HS Carbon / Epoxy and HM Carbon / Epoxy

11.3 Torsional buckling capacity (tcr)

Since long thin hollow shafts are vulnerable to torsional buckling, the possibility of the torsional buckling of the composite shaft was checked by the expression for the torsional buckling load Tcr of a thin walled orthotropic tube, which was expressed below.

Tcr = (2πr 2 t) (0.272) (E x E y 3) 0.25 (t / r) 1.5

This equation has been generated from the equation of isotropic cylindrical shell and has been used for the design of drive shafts. From the equation 5.22, the torsional buckling capability of composite shaft is strongly dependent on the thickness of composite shaft and the average modulus in the hoop direction.

11.4 Lateral or bending vibration

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

11.5 Bernoulli-euler beam theory-ncrbe

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,

11.6 Timoshenko beam theory- ncrt

It considers both transverse shear deformation as well as rotary inertia effects. Natural frequency based on the Timoshenko beam theory is given by,

fs= 2 for hollow circular cross-sections

Table 4.Properties of HS Carbon / Epoxy and HM Carbon / Epoxy

Mechanical Properties	**Units**	**HM - Carbon / Epoxy**	**HS - Carbon / Epoxy**
E_{11}	Gpa	190	134
E_{22}	Gpa	7.7	7.0
G_{12}	Gpa	4.2	5.8
ν_{12}	-	0.3	0.3
P	Kg / M	1600	1600
S_1	MPa	870	880
S_2	MPa	54	60
S_{12}	MPa	30	97

XII. FINITE ELEMENTANALYSIS

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It also can be used to analyze either small or large- scale deflection under loading or applied displacement. It uses a numerical technique called the finite element method (FEM). In finite element method, the actual continuum is represented by the finite elements. These elements are considered to be joined at specified joints called nodes or nodal points. As the actual variation of the field variable (like displacement, temperature and pressure or velocity) inside the continuum is not known, the variation of the field variable inside a finite element is approximated by a simple function. The approximating functions are also called as interpolation models and are defined in terms of field variable at the nodes. When the equilibrium equations for the whole continuum are known, the unknowns will be the nodal values of the field variable.

In this project finite element analysis was carried out using the FEA software ANSYS. The primary unknowns in this structural analysis are displacements and other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements.

12.1 Static analysis

Static analysis deals with the conditions of equilibrium of the bodies acted upon by forces. A static analysis can be either linear or non-linear. All types of non-linearities are allowed such as large deformations, plasticity, creep, stress stiffening, contact elements etc. this chapter focuses on static analysis. A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those carried by time varying loads. A static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. A static analysis can however include steady inertia loads such as gravity, spinning and time varying loads.

In static analysis loading and response conditions are assumed, that is the loads and the structure responses are assumed to vary slowly with respect to time. The kinds of loading that can be applied in static analysis includes,

1. Externally applied forces, moments and pressures

2. Steady state inertial forces such as gravity and spinning
3. Imposed non-zero displacements.

A static analysis result of structural displacements, stresses and strains and forces in structures for components caused by loads will give a clear idea about whether the structure or components will withstand for the applied maximum forces. If the stress values obtained in this analysis crosses the allowable values it will result in the failure of the structure in the static condition itself. To avoid such a failure, this analysis is necessary.

12.2 Boundary conditions

The finite element model of HS Carbon/Epoxy shaft. One end is fixed and torque is applied at other end.

12.3 Modal analysis

When an elastic system free from external forces is disturbed from its equilibrium position it 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. It can also be a starting point for another more detailed analysis such as a transient dynamic analysis, a harmonic response analysis or a spectrum analysis. Modal analysis is used to determine the natural frequencies and mode shapes of a structure or a machine component.

The rotational speed is limited by lateral stability considerations. Most designs are sub critical, i.e. rotational speed must be lower than the first natural bending frequency of the shaft. The natural frequency depends on the diameter of the shaft, thickness of the hollow shaft, specific stiffness and the length.

XIII. SUMMARIZATION OF ANYSISRESULT

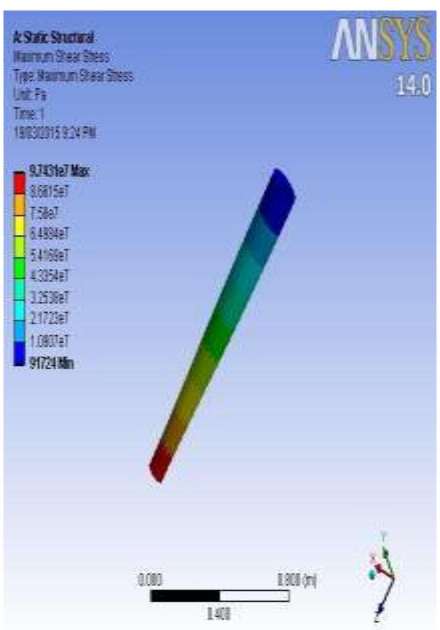


Figure 2. Maximum Shear Stress forSteelDrive

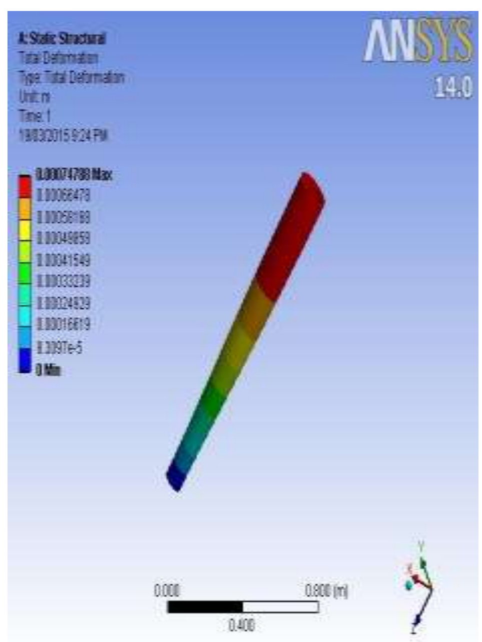


Figure 3. Maximum Deformation for Steel Drive

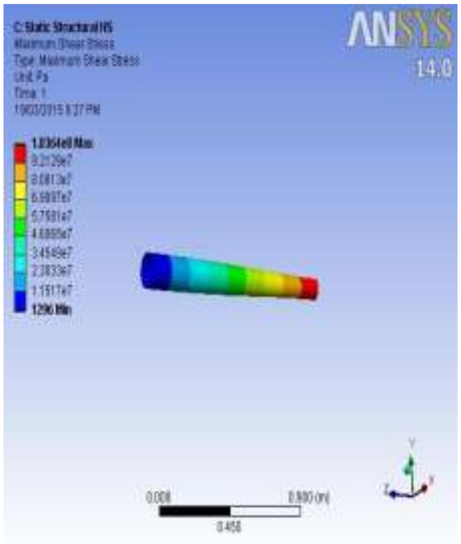


Figure 4. Maximum Shear StressforHS-Carbon/Epoxy

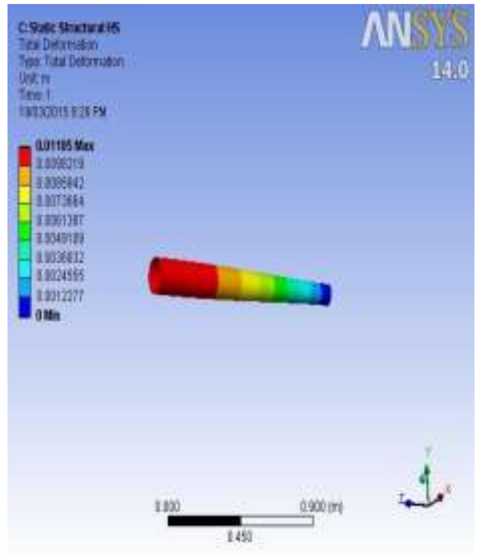


Figure 5. Maximum Deformation for HS-Carbon/Epoxy

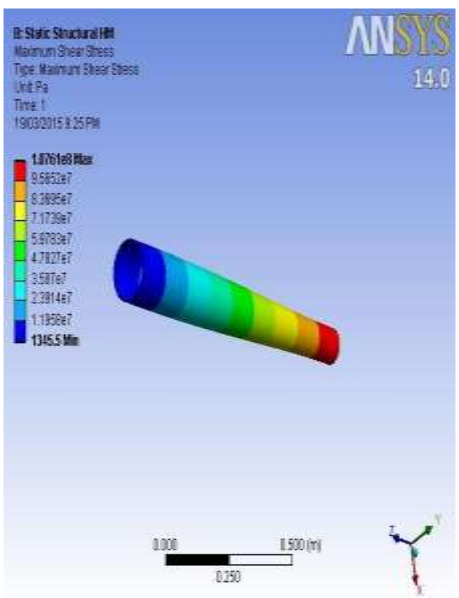


Figure 6. Maximum Shear StressforHM-Carbon/Epoxy

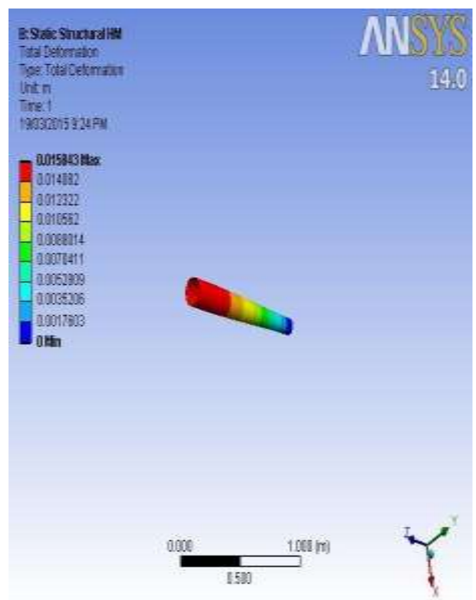
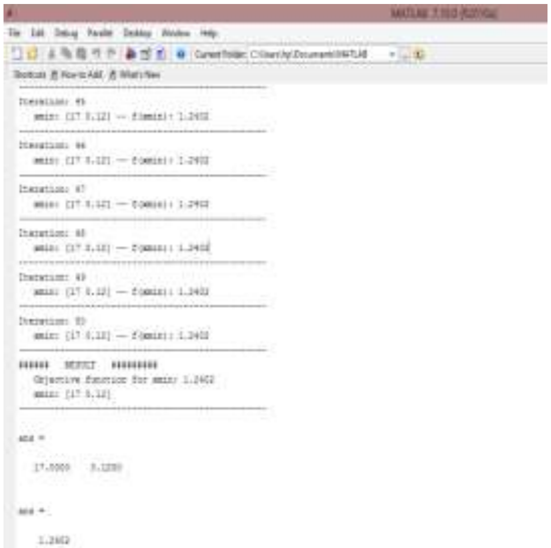


Figure 7. Maximum Deformation forHM-Carbon/Epoxy

XIV. RESULT OF GENETIC ALGORITHEM

A one-piece composite drive shaft for rear wheel drive automobile was designed optimally by using genetic Algorithm for High Strength Carbon / Epoxy and High Modulus Carbon / Epoxy composites with the objective of minimization of weight of the shaft which is subjected to the constraints such as torque transmission, torsional buckling capacities and natural bending frequency.

A simple Genetic Algorithm is designed to optimize the weight of the drive shaft by using the MATLAB. The different M files are written in MATLAB. Then the program is executed to solve the optimization and the results are shown in fig. 1 (a)(b)



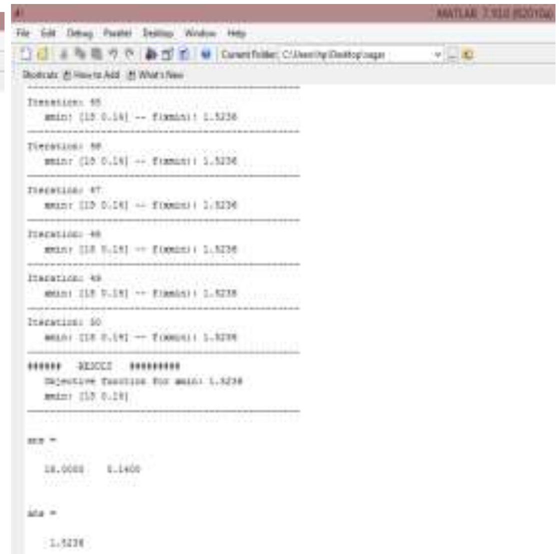


Fig.8 (a) Fig.8 (b)

Fig.8 (a) Output of GeneticAlgorithmfor for HM – Carbon/Epoxy

Fig.8(b) Output of Genetic algorithm HS – Carbon /Epoxy

Parameters	Steel	HS – Carbon / Epoxy	HM – Carbon / Epoxy
do (mm)	90	90	90
L (mm)	1250	1250	1250
t_k (mm)	3.318	0.12	0.14
Optimum no. of Layers	1	17	18
t (mm)	3.318	2.04	2.52
Weight (kg)	8.604	1.24	1.52
Weight saving (%)	-	85.20	82.26

XV. CONCLUSION

The following conclusions are drawn from the present work.

1. The High Strength Carbon / Epoxy and High Modulus Carbon / Epoxy composite drive shafts have been designed to replace the steel drive shaft of an automobile.
2. A one-piece composite drive shaft for rear wheel drive automobile has been designed optimally by using Genetic Algorithm for High Strength Carbon / Epoxy and High Modulus Carbon / Epoxy composites with the objective of minimization of weight of the shaft which was subjected to the constraints such as torque transmission, torsional buckling capacities and natural bending frequency.
3. The weight savings of the High Strength Carbon / Epoxy and High Modulus Carbon / Epoxy shafts were equal to 85.20% and 82.26% of the weight of steel shaft respectively.

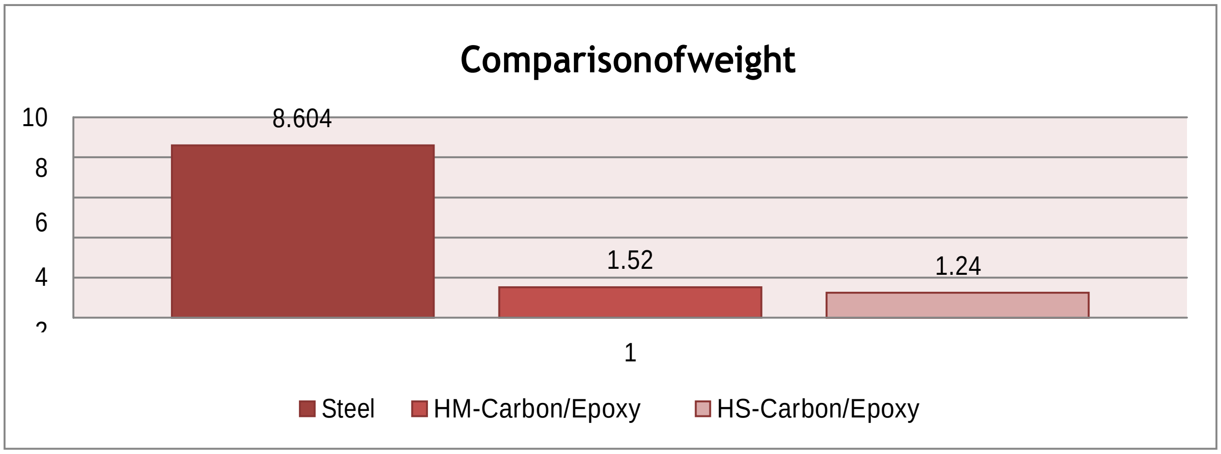


Fig.9. Bar chart of weight comparison acknowledgment

It is pleasure for me to present this paper where guidance plays an invaluable key and provides concert platform for completion of the paper.

XVI. REFERENCES

[1] Jones R.M., 1990, Mechanics of Composite Materials, 2e, McGraw- Hill Book Company, New York.
[2] J.H.Park, J.H.Hwang, C.S.Lee, W.Hwang, 2001, "Stacking Sequence Design of Composite Laminates for Maximum Strength Using Genetic Algorithms", Journal of Composite Structures, Vol.52, pp217- 231.
[3] Goldberg, D.E., 1989, "Genetic Algorithm in Search Optimization and Machine Learning", Addison-Wesley Publishing Company Inc., Reading Massachusetts.
[4] Johan.W.et.al .Engineers Guide to Composite Materials, American Society for Metals,1986
[5] T. RANGASWAMY , et.al. " optimal sizing and stacking sequence of composite Drive shafts."ISSN 1392-1320 Materials science Vol.11, no.2,2005.
[6] Belingardi.G, Calderale.P.M. And Rosetto.M, 1990, "Design Of Composite Material Drive Shafts for Vehicular Applications", Int. J. of Vehicle Design, Vol.11, No.6, pp. 553-563.
[7] Jin Kook Kim. Dai GilLee, and Durk Hyun Cho, 2001, "Investigation of Adhesively Bonded Joints for Composite Propeller shafts", Journal of Composite Materials, Vol.35, No.11, pp.999-1021.
[8] Azzi.V.D and Tsai.S.W, 1965, "Elastic Moduli of Laminated Anisotropic Composites", Journal of Exp. Mech, Vol.5, pp 177-185.
[9] Azzi.V.D and Tsai.S.W, 1695, "Anisotropic Strength of Composites", Journal of Experimental .Mech. Vol.5, pp.134-139.
[10] Pollard. A, 1989, "Polymer Matrix Composites in Driveline Applications", Journal of Composite Structures, Vol.25, pp.165-175.
[11] Ganapathi.M and Varadan.T.K. 1994, "Nonlinear Free Flexural Vibrations of Laminated Circular Cylindrical Shells", Journal of Composite Structures, Vol.No.30, pp.33-49.
[12] Review of Design of hybrid aluminum/ composite drive shaft for automobile Bushan K. Suryawanshi, G. DamleInternational journal of Innovative Technology and Exploring Engineering ISSN:2278-3075, vol-2, issue-4,March-2013
[13] "Design and Analysis of composite drive shaft using ANSYS and GA" A critical review International journal of modern engineering research (IJMER) www.ijmer.com vol.3, issue.1, Jan-Feb 2013 pp 490-496 ISSN:2249-6645 Sagar R. Dharmadhikari, 1 Sachin G. Mahakalkar, 2 Jayant P. Giri, 3 Nilesh D. Khutafale4.

