DESIGN & ANALYSIS OF COMPOSITE MATERIAL DRIVE SHAFT IN AUTOMOBILE

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ABSTRACT

This paper presents the characteristic details of propeller shaft to substitute its material with composite material and suitability of material is analyzed by evaluating and comparing stress distribution & deformation with in the shaft to replace the steel drive shaft with a piece of E-glass/ epoxy and E-carbon/epoxy with the help of material properties. The 3D modeling and assembly of Drive shaft was done using SOLIDWORKS software. Analysis is performed by using commercial FEA software ANSYS by considering static structural, Rigid dynamics and modal analysis to estimate deformation, stress under given loads and frequencies. The main objective of this paper is deduction of weight of an automobile transmission. Thus, in this project work the propeller shaft of a vehicle was chosen and analyzed by replacing it with different materials.

Keywords — Drive shaft, transmission, ANSYS, Structural Steel, rigid dynamics, frequencies.

1. INTRODUCTION

An automotive drive shaft transmits power from the engine to the differential gear of a rear wheel drive vehicle. The drive shaft is 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 which increases the total weight of an automotive vehicle and decreases fuel efficiency. So, a single piece drive shaft is preferred here and the material of it is considered to be Titanium alloy because of its high strength and low density. Drive shafts are carriers of torque and are subject to torsion and shear stress, equivalent to the difference between the input torque and the load. They must therefore be strong enough to bear the stress, whilst avoiding too much additional weight as that would in turn increase their inertia.

In large rear wheel drive automobile, drive shaft is manufacturing in two pieces. This two pieces drive shaft assembled and results in heavy assembled. The main agenda for two piece assembly is to increase its natural frequency. Nowadays, energy conservation is most important objective in the design of automobile and the effective measure is to reduce the weight of automobile.

Actually, there is direct relation between vehicle's weight and fuel consumption. Use of composite drive shaft leads to reduction in weight, also it is electrically non-conductive, long fatigue life. Composites have a lower modulus of elasticity, because of that it works as shock absorber when torque peaks are happened.
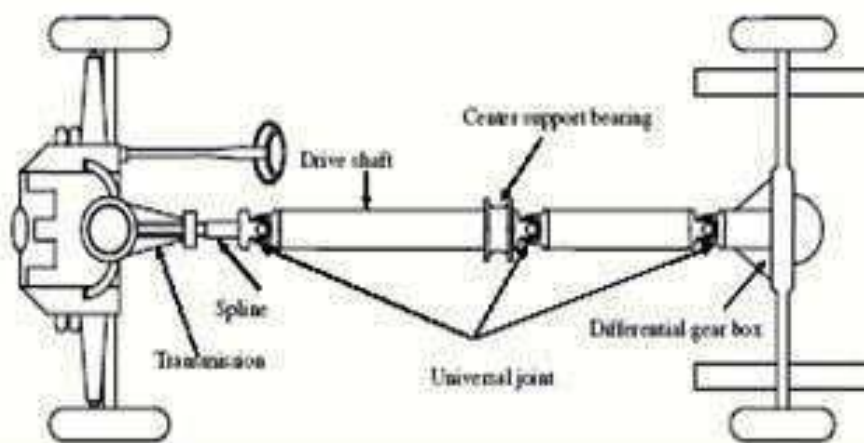
Figure 1.1: two piece drive shaft arrangement in automobile

2. Material used:

Nowadays, composite materials are used in large scale in various engineering structures including spacecraft's, aero planes, automobiles, boats, sports equipment, buildings, and bridges. The most widely use of composite materials in industry is due to the excellent characteristics such as, specific strength and specific hardness or strength-weight ratio and hardness-weight ratio. The application of composite materials started first at the aerospace industry in 1970s, but nowadays after only three decades, it has been developed in most industries. Meanwhile, the automotive industry, considered as a pioneer in every country, has been benefited from the properties and characteristics of these advanced materials. With the progress in technology, metallic parts have been replaced by composite materials in automobiles. Power transmission drive shafts are used in many applications, including cooling towers, pumping sets, aerospace, structures, and automobiles.
Composite materials can be classified as:

☐ Polymer matrix composites

☐ Metal matrix composites

☐ Ceramic Matrix

3. ANALYSIS TOOL (ANSYS WORKBENCH)

The ANSYS 14.0 Workbench platform is the framework upon which the industry's broadest and deepest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user through even complex multi physics analyses with drag-and-drop simplicity. With bidirectional CAD connectivity, powerful highly-automated meshing, a project-level update mechanism, pervasive parameter management and integrated optimization tools, the ANSYS Workbench platform delivers unprecedented productivity, enabling Simulation-Driven Product Development.

LITERATURE REVIEW

In today's era, composite materials are widely used in various fields like spacecraft's equipment, automobiles, structural components etc. main purpose of using composite material is to use their characteristics. By using this technology its application is also enlarged.
Generally drive shaft assemblies are made from pieces of shafts and u-joints, which lead to increase in weight and complex mechanism. Firstly In 1988, composite shaft was used in automobile.

Shaw D, Simitses DJ, Sheinman (1985) investigated about Imperfection sensitivity of laminated cylindrical shells in torsion and axial compression. They found that the linear analysis is considered satisfactory in comparison with nonlinear analysis due to the fact that cylindrical shells under torsion are less sensitive to imperfections.

Bhirud Pankaj Prakash, Bimlesh Kumar Sinha (2000) evaluated that by substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of composite materials. In the recent days, there is a huge demand for a light weight material such as fiber reinforced polymer composites seems to be a promising solution to this arising demand. These materials have gained attention due to their applications in the field of automotive, aerospace, sports goods, medicines and household appliances. The overall objective of this work is to analyze a composite drive shaft for power transmission. Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of composite materials. This work deals with the replacement of conventional steel drive shafts with a Kevlar/epoxy or E glass polythene resin composite drive shaft for an automotive application. The intention of work is to minimize the weight of drive shaft. In this present work an attempt has been to estimate the deflection, stresses, and natural frequencies under subjected loads using FEA (Ansys). Further comparison carried out for both loads using FEA. Further comparison carried out for both optimized and stress intensity factor found for both Steel and composite drive shafts.

Parshuram D, Sunil Mangsetty (2013) the main concept of our project is to reduce the weight of automotive drive shaft with the utilization of composite material. Composite materials have been used in automotive components because of their properties such as low weight, high specific stiffness, corrosion free, ability to produce complex shapes, high specific strength and high impact energy absorption etc. As the automotive drive shaft is a very important component of vehicle. The modeling of the drive shaft assembly was done using CATIA software. A shaft has to be designed to meet the stringent design requirements for automotive. In automobiles the drive shaft is used for the transmission of motion from the engine to the differential. An automotive propeller shaft, or drive shaft, transmits power from the engine to differential gears of rear wheel-driving vehicle. In present work an attempt has been to estimate deflection, stresses under subjected loads & natural frequencies using FEA.

Bhushan K. Suryawanshi, Prajitsen G. Damle, (2013) developed a new manufacturing method, in which a carbon fiber epoxy composite layer was co-cured on the inner surface of an aluminum tube rather than wrapping on the outer surface to prevent the composite layer from being damaged by external impact and absorption of moisture. Replacing composite structures with conventional metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials. By considering the thermal residual stresses of the interface between the aluminum tube and the composite layer, the optimum stacking sequence is calculated with the help of finite element analysis. Press fitting method for the joining of the aluminum/composite tube and steel yokes was devised to improve reliability and to reduce manufacturing cost, compared to other joining methods such as adhesively bonded, bolted or riveted and welded joints. The joining of the aluminum - composite tube and steel yoke with improved reliability and optimum manufacturing cost is done by press fitting. In order to increase the torque transmission capacity protrusion shape is provided on the inner surface of steel yoke which will fit on Universal joints.

Harshal Bankar, Viraj Shinde, P. Baskar (2013) proved the use of composite material in reducing the weight of shaft significantly as the composite has lower density in their work. The initial torque required to give rotation to the transmission system is large, as the weight reduces this surplus torque is utilized to propel the vehicle, at the same time inertial effect of rotating part decreases. Also the reduction in the weight of shaft increases the 1st modal frequency of bending; hence this shaft can be utilized for higher frequencies than steel. The reduction in weight gives further advantage in the increase in fuel economy of vehicle. The stress distribution and the maximum deformation in the shaft are the functions of the stacking of material. The optimum stacking of material layers can be used as the effective tool to reduce weight and stress acting on the

drive shaft. The design of drive shaft is critical as it is subjected to combined loads. The designer has two options for designing the drive shaft whether to select solid or hollow shaft. The solid shaft gives a maximum value of torque transmission but at same time due to increase in weight of shaft the 1st mode frequency decreases. Also shaft outer surface facing most of the stress coming on to it and the inner material layer experienced less stress, hence the inner layers increasing the weight of shaft and not utilized for stress distribution properly, that's why the hollow drive shaft is best option.

P. Jayanaidu, M. Hibbatullah, Prof. P. Baskar (2013) present the concept to deals with optimization of drive shaft using the ANSYS. Substitution of Titanium drive shafts over the conventional steel material for drive shaft has increasing the advantages of design due to its high specific stiffness, strength and low weight. Drive shaft is the main component of an automobile. It is used to transfer the motion from the engine to the wheel. Drive shaft is the assembly of many small components. Use of conventional steel for manufacturing of drive shaft has many disadvantages such as low specific stiffness and strength. Many methods are available at present for the design optimization of structural systems. This paper discusses the past work done on drive shafts using ANSYS and design and modal analysis of shafts made of Titanium alloy (Ti-6Al-7Nb).

M.R. Khoshravan, A. Paykani (**2014)** presents a design method and a vibration analysis of a carbon/epoxy composite driveshaft. The design of the composite drive shaft is divided into two main sections: First, the design of the composite shaft and second, the design of its coupling. Some parameters such as critical speed, static torque, fiber orientation and adhesive joints were studied. Tsai-Hill failure criterion was implemented to control the rupture resistance of the composite shaft and then its critical speed analysis and modal analysis were carried out using ANSYS. The behavior of materials is considered nonlinear isotropic for adhesive, linear isotropic for metal and orthotropic for composite shaft. The results showed significant points about the appropriate design of composite drive shafts. The substitution of composite drive shaft has resulted in considerable weight reduction about 72% compared to conventional steel shaft. Furthermore, results revealed that the orientation of fibers had great influence on the dynamic characteristics of the composite shaft.

4. METHODOLOGY

It deals with the analysis of drive shaft which is obtained by the following methods-

4.1. Mathematical analysis

In the mathematical analysis all the factors such as maximum deflection, maximum Von- misses stress, maximum shear stress etc. In it all the calculation done by manually. 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 Propeller shaft should be larger than 350 Nm. The Propeller shaft outer diameter should not exceed 100 mm due to space limitations.

Properties (mechanical) of Steel Shaft

Poisson's ratio = 0.27

Shear modulus = 82 Mpa

Tensile yield strength = 325 Mpa

Tensile ultimate strength = 385 Mpa

R = 0.108 m;   L = 1.48 m;   E = 207e9 pa   Density = 7870 kgm^3

Where,

R = Radius of shaft

L = Length of the shaft

E = Young's Modulus of Kevlar

T = Applied Torque

Engine Torque Calculation

Rotational speed = 2600 rpm   Max^m Power = 110 HP i.e. 82.03 KW

The torque transmission capacity of shaft is calculated by using torsional equation

Torque T = P/2πn

= (82.03KW) (1000W/KW)/2π (2600rev/min)/ (60sec/min)

= 301.28 Nm

Max^m Force = Torque/Length

= 301.28/1.48

= 203.568 N

$$\text{Deflection} = Y_{Max} = \frac{ML^2}{2EI}$$

= 1.492*10^{-5} m

$$I = \pi/64(d_0^4 - d_i^4) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

For hollow shaft, polar moment of inertia,

$$J = \frac{\pi}{32}(d0^4 - di^4) \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(2)$$

Where

J = polar moment of inertia,

τ_s = torsional shear stress,   r = d/2 where d is the diameter of shaft

Maximum Shear Stress: $\tau_{Max} = \dfrac{T * Ro}{J}$

$$= 2.436 * 10^6 \text{ Pa}$$

Maximum Von-Misses Stress:

$$= \dfrac{T * \left(\frac{do}{2}\right)}{I}$$

$$= 301721.6072$$

$$= 3.012 * 10^5 \text{ Pa}$$

Also mass is calculate of shaft for both material

 Area = π/4(d^2)

    A = 0.03665 m^2

Volume of shaft V= 0.03665*1.48 = 0.05424 m^3

Mass of shaft, m = **σ*V**= 7850*0.05424
        = **425.78 kg**

Properties (mechanical) of Composite Shaft

Now for composite material maximum shear stress is calculated

Density of Kevlar shaft   **σ** = 1470 kgm^3

Young Modulus of Kevlar   E = 990 Pa

                Length L = 1.48 m

Area = $\pi/4(d^2)$

A = 0.03665 m^2

Volume of shaft V= 0.03665*1.48 = 0.05424 m^3

Mass of shaft, m = **σ*V=** 1470*0.05424

= 79.73 kg

After analytical calculation analysis is carried out using ANSYS

Now ANSYS analysis is being carried out for the composite material shaft

4.2. Design Analysis

The finite element method is a powerful numerical tool widely used to solve nonlinear problems of elasticity, solids and structures. In this project, modeling was performed using the commercial code ANSYS. The finite element modeling's based on a 3D element. The ANSYS14.0 Workbench platform is the framework upon which the industry's broadest and deepest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user through even complex multi physics analyses with drag-and-drop simplicity. With bidirectional CAD connectivity, powerful highly-automated meshing, a project-level update mechanism, pervasive parameter management and integrated optimization tools, the ANSYS Workbench platform delivers unprecedented productivity, enabling Simulation-Driven Product Development.

In this study, a FEA was conducted by using ANSYS commercial software. The 3D model was developed and a typical meshing was generated. The drive shaft was fixed at both ends and it was subjected to torque in the middle. The torque transmission capability of the drive shaft was taken as 350 Nm, the length and the outer diameter here were considered as 2 meters and 120 millimeters respectively. The shaft rotates at a constant speed about its longitudinal axis. The shaft has a uniform, circular cross-section. The shaft was perfectly balanced, all damping and non-linear effects were excluded. The stress strain relationship for composite material is linear and elastic; hence Hook's law is applicable for composite material. Since lamina is thin and no out-of-plane loads were applied, it was considered as under the plane stress. Since the fiber volume of 60% is the standard fiber volume fraction for most industries, it was selected for composite drive shaft.

In the following analysis Kevlar and steel shafts were compared with each other in terms of their deformation, maximum Shear stress and Von-Misses stress under same conditions as in the previous journal. The Maximum stress undergone and the total deformation occur in Steel under the given conditions. Kevlar is better in terms of maximum stress and deformation as these parameters produced in this shaft are less when compared to steel.

Process of Structural Analysis

MODELING OF PROPELLER SHAFT IN SOLID WORKS:

In this work propeller shaft is selected for structural analysis using ANSYS. The various materials using finite element analysis software ANSYS 14.0.

The propeller shaft is designed by required dimensions into the modeling software SOLIDWORKS. The geometry of the propeller shaft is designed in SOLIDWORKS is imported to the analysis software in the IGES format. The designed propeller shaft is below

Propeller Shaft Model and Mesh

The modeling of propeller shaft using SOLIDWORKS and the same is used for structural analysis. In this work node elements selected for meshing. The finite element mesh of the piston model used in ANSYS is shown Figure.

Fig: 4.1. Model of Shaft Messing

5. Result and Discussion

5.1. Structural Analysis with different Material

Finite element analysis is a computer based analysis technique for calculating the strength and behavior of structures. In the FEM the structure is represented as finite elements. These elements are joined at particular points which are called as nodes. The FEA is used to calculate the deflection, stresses, strains temperature, buckling behavior of the member. In our project FEA is carried out by using the ANSYS 14.0. Initially we don't know the displacement and other quantities like strains, stresses which are then calculated from nodal displacement. A static analysis is used to determine the displacement, strain, von misses stress and force in structure or compounds caused by load that do not significant inertia and damping effects. The static analysis of drive shaft is done by ANSYS software 14.0.

Kevlar/Epoxy and Glass/Epoxy are having more deformation under tensile and flexure load hence it replaces the two pieces of steel drive shaft into single shaft with better transmission of power. Because of their elasticity, they decrease the stress and act as a best shock absorber when the torque is more. Also Kevlar/Epoxy and Glass/Epoxy having less deformation under impact load so that it can absorb more energy because of its toughness.

The difference between the structural steel and composite (Kevlar) material are as given below with the different conditions.

Structural steel   **Kevlar**

Here the total deformation of the material are as given with the proper conditions and comparison between the steel and composite are as given below.
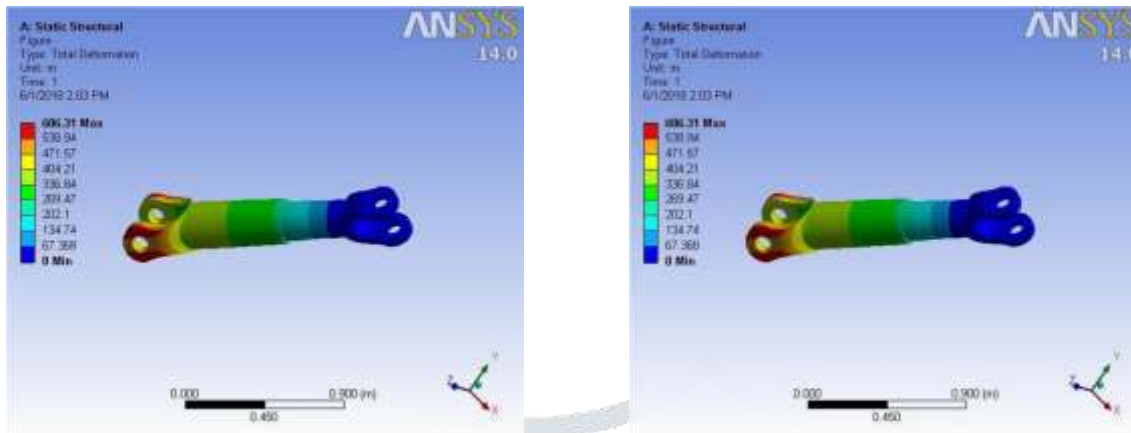

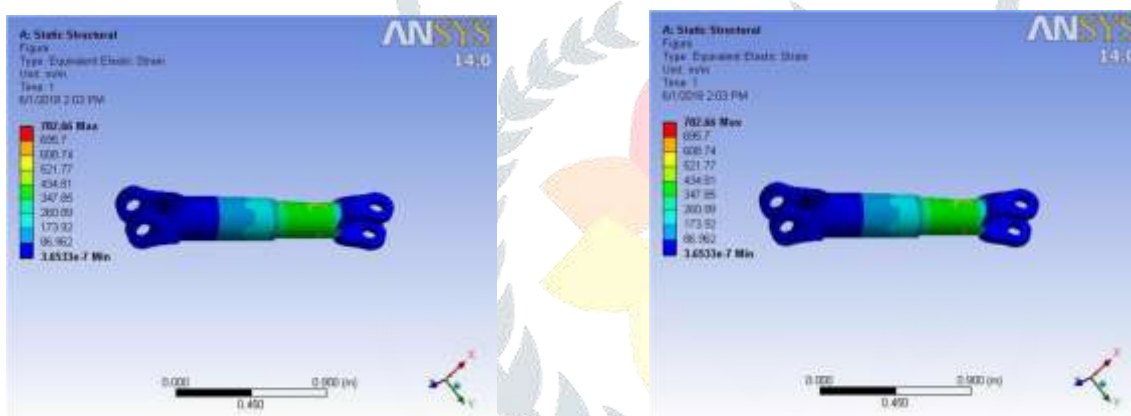Fig: 5.1. Comparison of total deformation for steel and composite

Fig: 5.2. Comparison of Equivalent Elastic Strain for steel and composite
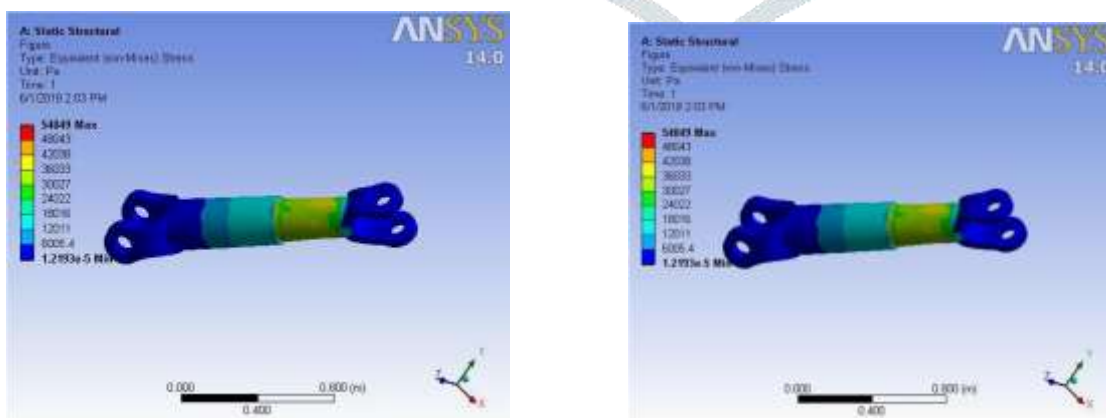

Fig: 5.3. Comparison of Maximum Shear Stress for steel and composite

5.2. Modal Analysis

Same steps were followed for Modal Analysis except for it was imported to ANSYS Workbench and total deformations were found out using the Modal Analysis at 6 different mode values. 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.
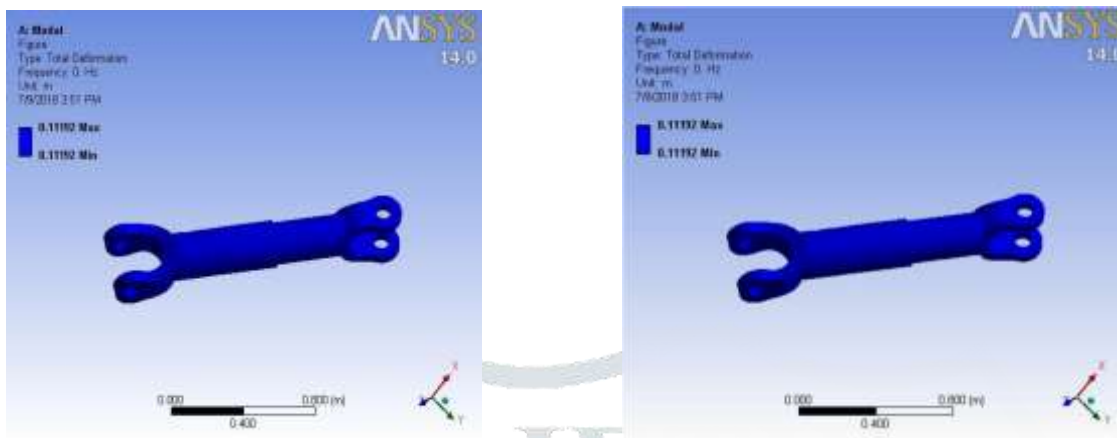
Fig: 5.4. Comparison of first set of natural frequency analysis for steel and composite

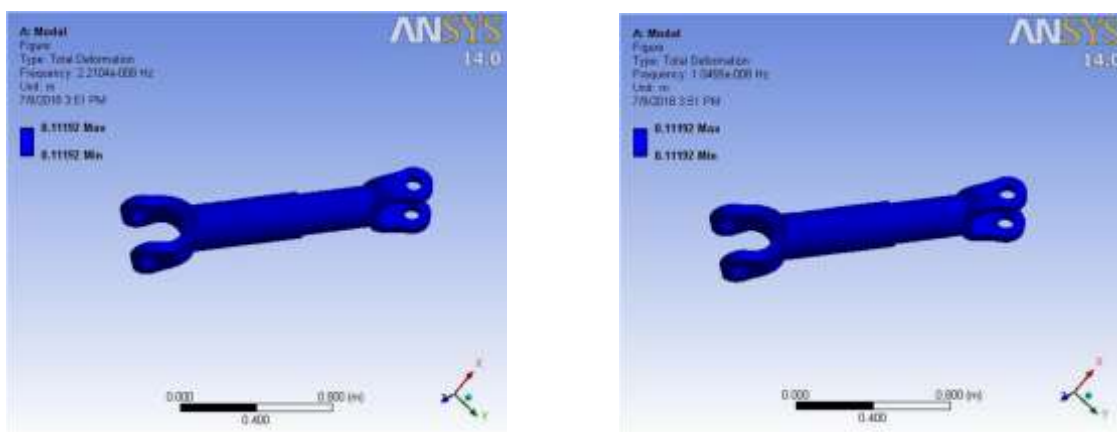Fig: 5.5. Comparison of second set of natural frequency analysis for steel and composite

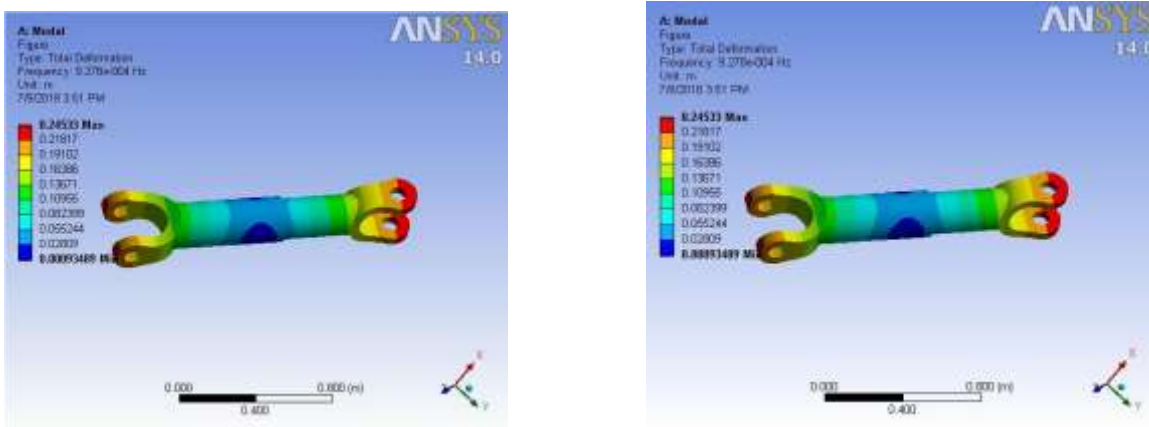Fig: 5.6. Comparison of third set of natural frequency analysis for steel and composite

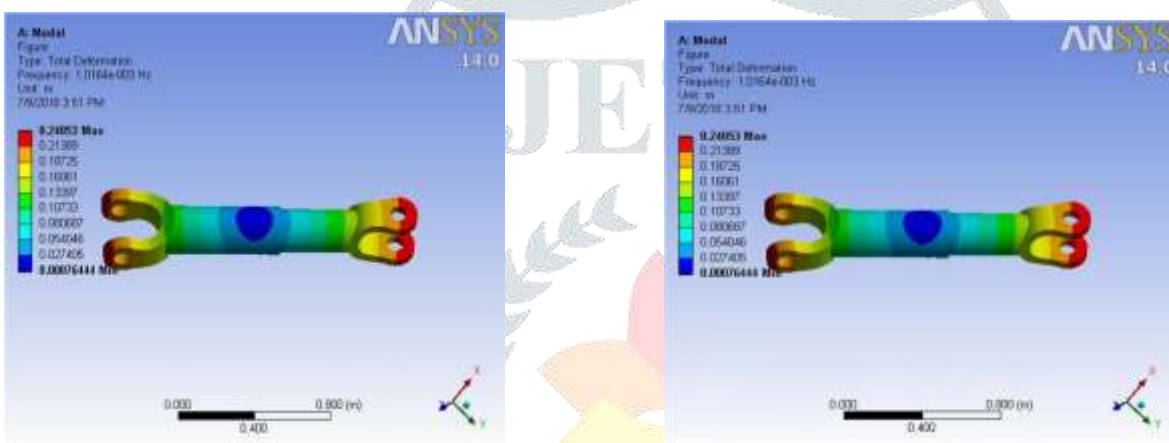Fig: 5.7. Comparison of fourth set of natural frequency analysis for steel and composite

Fig: 5.8. Comparison of fifth set of natural frequency analysis for steel and composite
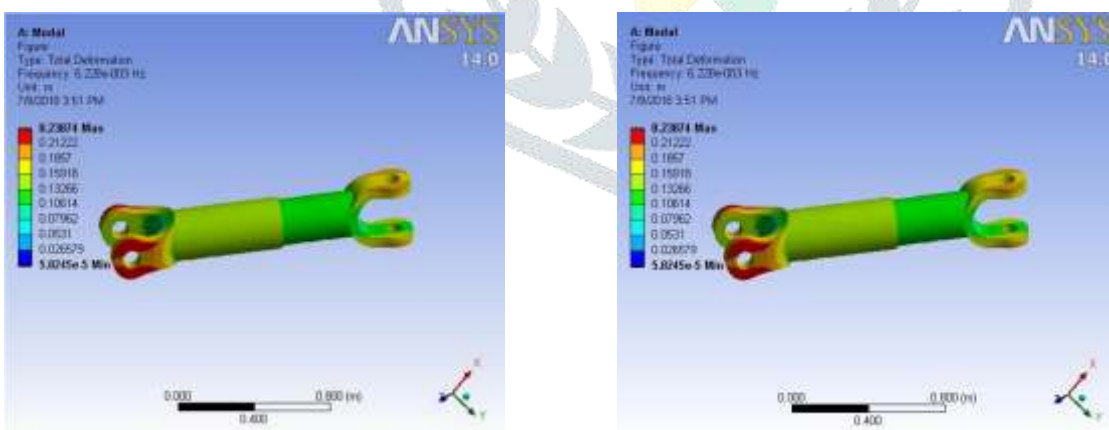

Fig: 5.9. Comparison of sixth set of natural frequency analysis for steel and composite

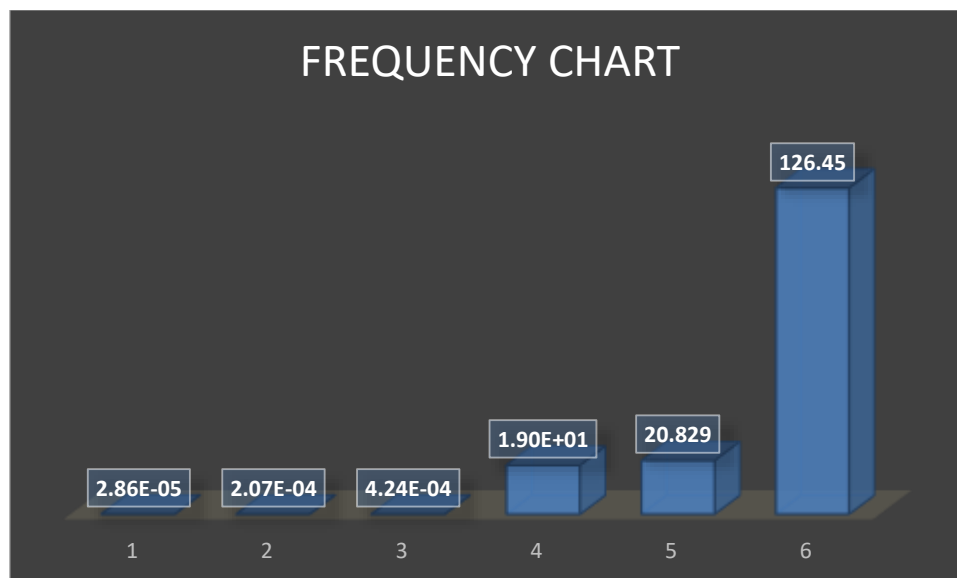**Model (A4) > Modal (A5) > Solution (A6) > Frequency**

Fig: 5.10. Graph of Frequency variation

6. CONCLUSION

The E-Glass/ Epoxy, High Strength Carbon/Epoxy and High Modulus Carbon/Epoxy composite drive shafts have been designed to replace the steel drive shaft of an automobile machine, which employs Propeller shafts, in general. This was achieved by reducing the weight of the Propeller shaft with the use of different composite materials. The Propeller shaft of a vehicle was chosen for determining the dimensions, which were then used for creating a model in SOLIDWORKS. Being a complex assembly of a number of parts, it had to be analyzed only for Propeller shaft in ANSYS 14.0. At the few materials were chosen for the comparative analysis, including steel, which was used for reference. Taking into consideration the weight saving, deformation, shear stress induced and resonant frequencies it is observed that composite material has the most encouraging properties to act as the replacement for steel out of all the materials.

Table 6.1 Result of both materials

- ✓ On the basis of stress calculation, report says that composite material shaft is advisable to replace conventional material shaft.

- ✓ Weight of shaft is reducing about 81% after using composite material.
- ✓ The torque transmission capacity of the composite drive shafts has been calculated by neglecting and considering the effect of centrifugal forces and it has been observed that centrifugal forces will reduce the torque transmission capacity of the shaft.

- ✓ The E-Glass/ Epoxy, High Strength Carbon/Epoxy and High Modulus Carbon/Epoxy composite drive shafts have been designed to replace the steel drive shaft of an automobile.

- ✓ The presented work also deals with design optimization i.e. converting two piece drive shaft (Structural steel shaft) in to single piece light weighted composite drive shaft.

- ✓ The drive shaft of the dimensions, which were used then used for the material properties of composites were used the stability of drive shaft is ensured by limiting the include values within the permissible range in ANSYS Workbench 14.0.

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