Driving shaft optimizations based on Static Analysis for various material Constriction

Ahmed Salim Naser Al-murshedi[1,a]
[1]Engineering Technical College-Najaf, Al-Furat Al-Awsat Technical University, 3200 Najaf, Iraq
[a]Ahmed.al-murshedi@atu.edu.iq

Header Ali A.[1,b]
[1]Engineering Technical College-Najaf, Al-Furat Al-Awsat Technical University, 3200 Najaf, Iraq
,[b] Header.ali.a@atu.edu.iq

Hussein Awad Kurdi Saad [1,c]
[1]Engineering Technical College-Najaf, Al-Furat Al-Awsat Technical University, 3200 Najaf, Iraq
[c] Husseinawad@atu.edu.iq

ABSTRACT

A significant problematic in the design of a rotating shaft of substantial span is the lateral stability. With light weight composite material it is comparatively simple to meet the strength and torsional stiffness desires utilizing a thin walled tube. The main purpose of this work is to achieve finite element method (FEM) analysis and to find an optimal design of an automobile driving shaft through investigating various composite materials and also to find out compatible and cost-effective. For that, it has been endeavored to recognize the most appropriate composite material which may the alternates instead of classical material of the driving shaft, for that five material have been examined for the same design pattern dimensions and load. These materials are steel alloy as traditional driving shaft material, Kevlar Epoxy, Epoxy carbon, and Epoxy E-Glass. The FEM examination has been prepared all the above material to find out the outstanding material as an alternate material of the driving shaft. The outcomes have discussed that material like Boron-Epoxy can be utilized as an alternate material for the vehicle driving shaft. It has been explored that the Boron-Epoxy is the most promising material instead of predictable material as a result of the maximum static deformation and weight is reduced in comparison to the classical driving shaft material. The weight of the shaft using that material is enhancing to reach about 3.146 kg.

Keywords:

1- Introduction:

Reducing engine loads is one of the most important purposes when designing a system. Transmission The most effective way to achieve this goal is to reduce the vehicle's transmission weight and static deformation. There is an almost direct match between the drive shaft mass and its fuel consumption, especially in city driving. Automobile manufacturing manipulates the technology of composite materials to create structural parts in order to obtain a reduction in weight, without compromising the vehicle's performance and reliability. The properties can be designed to step up the torque that it carries as well as the speed of rotation that controls it.

In this study, the predictable driving shaft was interchanged with different types of materials for comparative analysis, thus discovering the most suitable replaceable material [1, 2].

Stainless steel has been used to a large extent for manufacturing driveshaft due to its high strength performance, meanwhile, this material has less specific modulus and strength. The property of stainless steel material has less damping ability. Its weight is considered superior, due to the increased density of stainless steel material particles. The fuel consumption will increase, as the weight of the drive shaft increases, the inertia effect will be developed. The steel drive shaft can be interchanged with a composite material which can be considered less heavy when compared to the stainless steel drive shaft. Moreover, the processing cost of the shaft with composite materials is lower when compared to that of stainless steel. Carbon/epoxy and e-glass / epoxy materials for the combined drive shaft were filtered. Then, the specifications of the composite materials are strictly perpendicular [3, 16].

To perform FEM analysis using conventional and composite materials. To compare the result with mathematical analysis and FEM analysis. Finally, improve the design of the drive shaft which must be compatible and cost-effective. Interprets the results of all conditions and an'IJE

In this study, the authors aim to deal with a method that increase the 1st natural bending frequency of a hollow shaft. In any application this shaft would have to transmit an essential torque. The optimization of frequency associated only with the shaft bending stiffness and does not consider those torsional strength necessities. It is significant to contain those rations within the enhancement process otherwise meaningless results can be elevated. In other words shafts with a great bending frequency but with inadequate strength to convey the essential torque.

2- Literature Review

Durk Hyun Cho et al. [1] they investigated drive shaft made from a composite material of single-piece. The outcomes illustrated that the shaft can withstand for more than hundred cycles during subjected for a dynamic load of 500 N.m. M. Aleyaasin et al. [2] examined the case of flexural oscillation for a propeller shaft of marine. Ercan Sevkat et al. [3] introduced a situation of residual torsional specifications of composite driving shaft. It has been considered for 4 various impact energy stages (5, 10, 20 and 40 J energy). The studies examinations based on comparison between the impact and impact-less features of shaft for torsion. Balazs Trencseni at al. [4] considered a driving comfort of massive automotive. The automotive drivability achievement has been calculated through driveline. The study pointed that vibration damping, simplicity of gear shifting rises the drivability however it has some opposing influence on fuel economy. The study also concluded the significance of driveline torque amounts for drivability achievement.

Arun Ravi [5] demonstrated a high strength carbon/epoxy propeller shaft using Solidworks and solved utilizing ANSYS. Static examination that is included total deflection, equivalent elastic stress and strain, are associated among shafts made from composite and steel. The outcomes released that 24% weight savings of Great Strength carbon material if compared to that shafts made form steel of same sizes.

Sagar dharmadhikari et al. [6] implemented an investigations on propeller shaft made from a composite material utilizing ANSYS program and Genetic algorithm. Outcomes for deformation were compared between steel, ultra-modulus carbon/epoxy and ultra-strength carbon/epoxy. The dual portion conventional steel shaft is exchanged with single part composite drive shaft. The study detected that a Fibre angle alignments play a good effect on the driving shaft of composite material.

V.S. Bhajantri et al. [7] achieved modeling for a composite propeller shaft utilizing fibres of extra strength carbon and epoxy resin and also implemented modal examination for this case study. The outcomes show that for high deflection and ultra-stresses were compared with that one of steel driving shaft. Trough utilizing carbon epoxy of high-strength, the mass savings are approximately 50% versus steel driving shaft. Variable fibre angle alignment effected high shear stress and high deformation. The orientation of Fibre angle is considered significant in multilayered composite material of driving shafts and leads to reduce weight, developed strength, advanced failure (appear caution beforehand crash) and also reduce power consumption. The study pointed out that an appropriate layers stacking can make a reduction in stresses plus weight of the composite driving shaft.

Harshal Bankar et al. [8] Introduced an investigations on various driving shafts material, the study applied the lights on the shafts made from Boron-epoxy, Kevlar-epoxy, Glass-epoxy and steel and Aluminum materials through changing 3 diverse layers alignments. Most suitable ply alignment is designated to decrease the extreme mass of the driving shaft. The stress location and the maximum deflection are the keys of the assembling of materials in the driving shafts.

Asmamaw Gebresilassie [9] accomplished a simulation and an analytical solutions for 3 different composite propeller shafts made up of E-Glass-epoxy resin through changing the rotation and the critical velocity for dissimilar diameters and lengths. The study outcomes illustrated that a linear relationship exist between the torque and deformation, stress and torque in addition to the torque and strain results. Angle orientations of Fibre plus the stacking order has a better effect on the buckling strength.

Sagar D Patil et al. [10] carried out a modelling for a hollow composite propeller shaft utilizing 3 plys of Glass-epoxy and one ply of extra Modulus Carbon-epoxy ply. Examinations is achieved through changing the fibre angle alignment and the stacking arrangement. Consequences demonstrate that orientation of the fibre angle by 10/0 /90 /10 degree is favored with a stacking arrangement of Glass/Glass/Glass/Carbon correspondingly for gaining torsional buckling twisting. The investigations highlighted that the weight can be decreased approximately 80% when a comparisons implemented between the driving shafts made from composite and steel material, whereas, a reduction of about 43% for that one made from than Aluminium.

3. Theoretical Methodology:

3.1-Modeling And Analysis

In the existing study shafts of various composite materials are modeled utilizing ANSYS considering rotation in z direction (axis of rotation of shaft) is free and is zero in the y and z directions. The shafts is modeled as a shell having mean diameter 100 mm as shown in Fig. 1 and other parameters as mentioned below.

Shaft parameter	**Parameter value**
Diameter	100 mm
length	1650 mm
Fundamental Torque is	1250 N-mm
Maximum velocity	2500 rpm
Rotational speed	260 rad/sec

The material properties of the driving shaft that have investigated in this study are shown in Table 1 to table 5.

Table 1: Material property of Steel alloy	
Parameters	**Specifications**
Density	8760 kg/m3
Tensile Ultimate Strength	686 Mpa
Tensile Yield Strength	490 Mpa

Poisson's Ratio	0.290
Young's Modulus	210000 Mpa
Bulk modulus	166670 Mpa
Shear modulus	81395 Mpa

Table 2: Kevlar Epoxy Material Properties

Parameters	**Specifications**
Density	1400 kg/m3
Young's Modulus (X-direction)	80000 MPa
Young's Modulus (Y-direction)	55000 MPa
Young's Modulus (Z-direction)	80000 MPa
Poisson's Ratio XY	0.34
Poisson's Ratio YZ	0.34
Poisson's Ratio XZ	0.4
Shear modulus XY	2200 MPa
Shear modulus YZ	1800 MPa
Shear modulus XZ	2200 MPa

Table 3: E-Glass – Epoxy Material Properties

Parameters	**Specifications**
Density	2000 kg/m3
Young's Modulus (X-direction)	45000 MPa
Young's Modulus (Y-direction)	10000 MPa
Young's Modulus (Z-direction)	10000 MPa
Poisson's Ratio XY	0.3
Poisson's Ratio YZ	0.61
Poisson's Ratio XZ	0.3
Shear modulus XY	5200 MPa
Shear modulus YZ	3846.2 MPa
Shear modulus XZ	5000 MPa
Orthotropic Stress	**Specifications**
Tensile (X-direction)	1100 MPa
Tensile (Y-direction)	35 MPa
Tensile (Z-direction)	35 MPa
Compressive (X-direction)	675 MPa
Compressive (Y-direction)	-120 MPa
Compressive (Z-direction)	-120 MPa
Shear XY	80 MPa
Shear YZ	46-154 MPa
Shear XZ	80 MPa

Table 4: Epoxy- Carbon Material Properties	
Parameters	**Specifications**
Density	1540 kg/m3
Young's Modulus (X-direction)	2090 MPa
Young's Modulus (Y-direction)	9450 MPa
Young's Modulus (Z-direction)	9450 MPa
Poisson's Ratio XY	0.27
Poisson's Ratio YZ	0.4
Poisson's Ratio XZ	0.27
Shear modulus XY	5500 MPa
Shear modulus YZ	3900 MPa
Shear modulus XZ	5500 MPa
Orthotropic Stress	**Specifications**
Tensile (X-direction)	1979 MPa
Tensile (Y-direction)	26 MPa
Tensile (Z-direction)	26 MPa
Compressive (X-direction)	-893 MPa
Compressive (Y-direction)	-139 MPa
Compressive (Z-direction)	-139 MPa
Shear XY	100 MPa
Shear YZ	50 MPa
Shear XZ	10 MPa

Table 5: Thermoplastic Polyimide Material Properties	
Parameters	**Specifications**
Density	1410 Kg/m3
Young's Modulus	19000 Mpa
Poisson's Ratio	0.3
Bulk Modulus	15833 Mpa
Shear modulus	7307.7 Mpa
Tensile Yield strength	215 MPa
Tensile Ultimate strength	330 MPa

Table 6: Boron- Epoxy Material Properties	
Parameters	**Specifications**
Density	1970 kg/m3
Young's Modulus (X-direction)	200 Gpa
Young's Modulus (Y-direction)	19.6 Gpa
Young's Modulus (Z-direction)	19.6 Gpa
Poisson's Ratio XY	0.3
Poisson's Ratio YZ	0.28
Poisson's Ratio XZ	0.28
Shear modulus XY	7.2 Gpa
Shear modulus YZ	5.5 Gpa
Shear modulus XZ	5.5 Gpa

The displacement fields are given as follows:

$$u_x(x,y,z,t) = z\beta_x(x,t) - y\beta_y(x,t)$$
$$v_y(x,y,z,t) = v_0(x,t) \qquad \text{3-1}$$
$$w_z(x,y,z,t) = w_0(x,t)$$

To theoretically model the shaft, a beam formulation containing rotary inertia influences and shear distortions can be utilized. The Rayleigh quotient expression for the natural frequency can be expressed as follow:

$$\omega_1^2 = \min \frac{\int_o^L EI(n)\left(\frac{d\alpha}{dx}\right)^2 dx + \int_o^L GK(n)\left(\frac{dw}{dx} - \alpha\right)^2 dx}{\int_o^L TI(n)\, w^2\, dx + \int_o^L RI(n)\, \alpha^2\, dx} \qquad \text{3-2}$$

Where;

w1	is 1st natural bending frequency,
x	is coordinate lengthways the distance of the shaft of length L,
EI(n)	is bending stiffness as a function of a variable n,
GK(n)	is shear stiffness,
TI(n)	is transverse inertia,
RI (n)	is rotary inertia,
w(x)	is transverse deflection of the shaft,
a(x)	is rotation of an initially normal section.
da/dx	is curvature.
dw/ dx- a	is shearing angle.

Numerically, in the finite element analysis, the gradient of the strain and kinetic energy of the shaft can be predictable by summing up the involvement of every element. The process can be condensed to the summation of the impact for every Gaussian point when the numerical integration is utilized. The mathematical expressions should be as follow;

$$\text{const.} = U_s^*/V - U_k^*/V \qquad \text{3-3}$$

$$U_s^* = \int_o^L \left[\frac{\partial EI}{\partial n}\left(\frac{d\alpha}{dx}\right)^2 + \frac{\partial GK}{\partial n}\left(\frac{dw}{dx} - \alpha\right)^2\right] v(x)\, dx, \qquad \text{3-4}$$

$$U_s^* = \sum_i \left\{\left[\frac{\partial EI}{\partial n}\left(\frac{d\alpha}{dx}\right)^2 + \frac{\partial GK}{\partial n}\left(\frac{dw}{dx} - \alpha\right)^2\right] v(x)\right\}_{x=x_i} w_i$$

t of strain and kinetic energy density.

$$= \sum_i U_{si}^*$$

$$U_k^* = \omega_1^2 \sum_i \left\{\left[\frac{\partial TI}{\partial n} w^2 + \frac{\partial RI}{\partial n}\alpha^2\right] v(x)\right\}_{x=x_i} \overline{w}_i$$

4

$$= \sum_i U_{ki}^*$$

Several materials of steel, aluminum and composite have been theoretically investigated to model various shaft material utilizing the finite element program ANSYS, a static structural and dynamic analyses have been implemented to determine the optimal design of the shaft. In addition, the shaft masses based on its material types also have been demonstrated. The static structural analysis have for various shaft materials have been illustrated in figures 1 to figure 6.

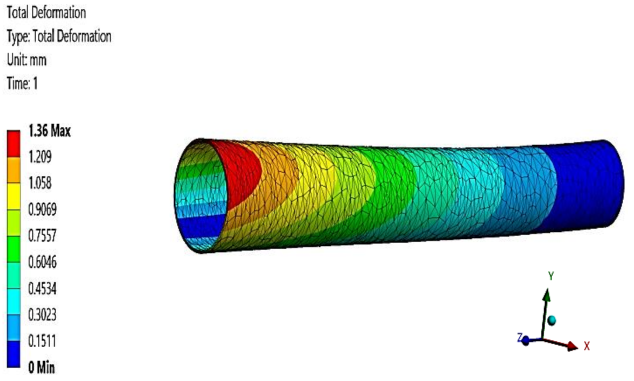

Figure1: Total deformation of the Steel shaft.

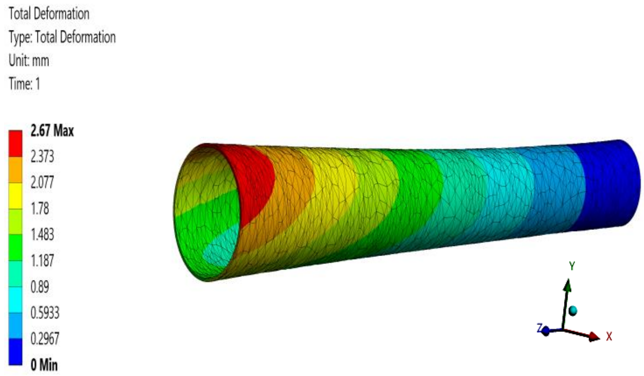

Figure2: Total deformation of the Aluminum shaft.

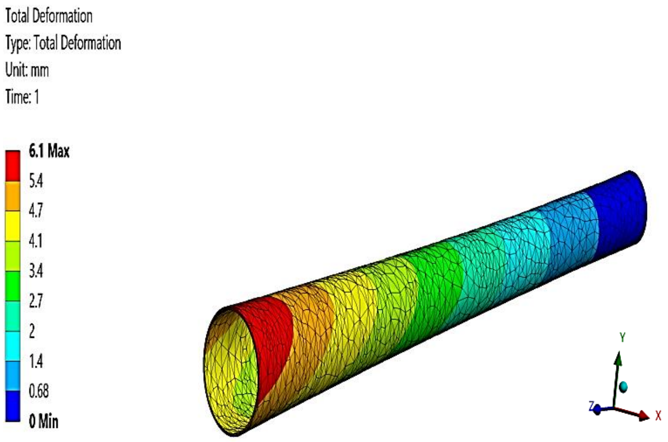

Figure3: Total deformation of the Kevlar Epoxy shaft.

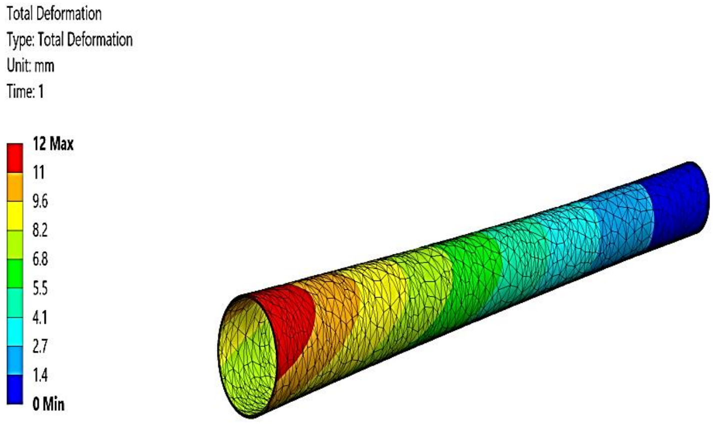

Figure4: Total deformation of the Glass fiber G10 shaft.

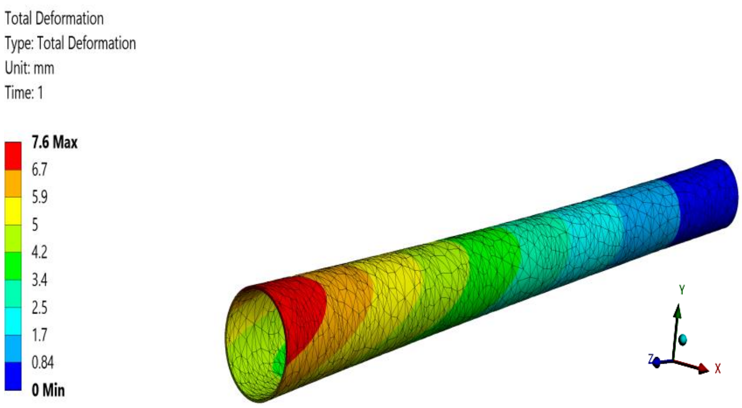

Figure5: Total deformation of the carbon Epoxy shaft.

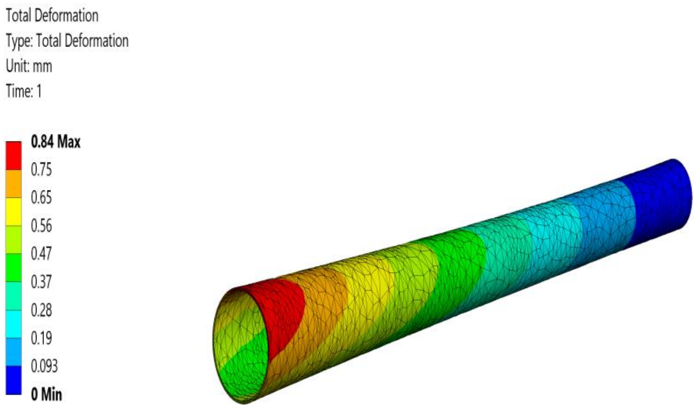

Figure6: Total deformation of the Boron Epoxy shaft.

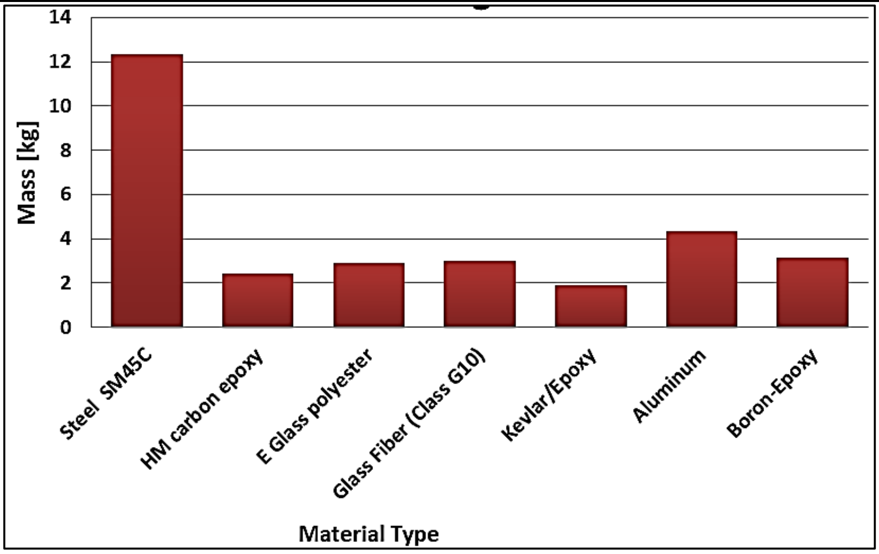

Figure 7: mass of various drive shaft materials.

As can be seen from the static structural analysis for the shaft material (Figures 1 -6), there are three varieties of materials that have been recognized and behaves with least stresses plus least static deformation compared to the anther kinds of materials that have been simulated, namely (steel, Aluminum and Boron-Epoxy) where the stress and deformation signifies a function of the range of kinds of stresses.

Some of the materials have the least mass compared to the anther kinds of materials that have been investigated (Figure 7). Thus, optimal design of the shaft should tend to be the least deformation and stresses and also, the shaft should be the least mass. As can be seen from figures 1-6 and figure 7, that the shaft material of Boron – Epoxy is matched that assumptions.

The strain energy, the stress distribution and the total static deformation of various rotating shafts were investigated (figure 8 to figure 10).

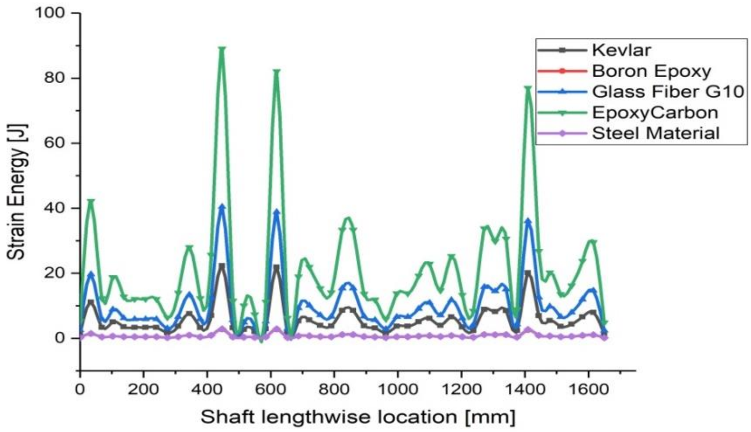

Figure 8: strain energy of various drive shaft materials.

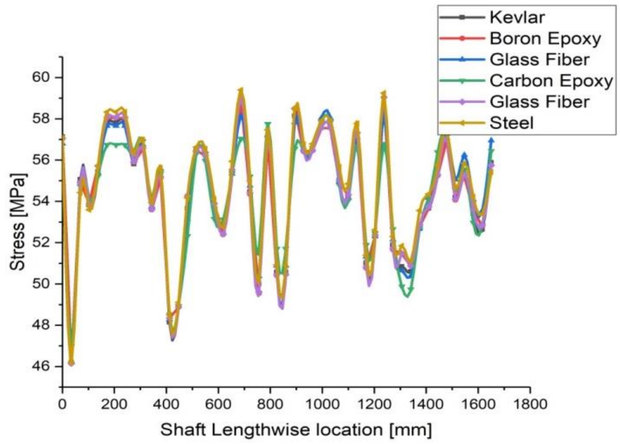

Figure 9: stress distribution of various drive shaft materials.

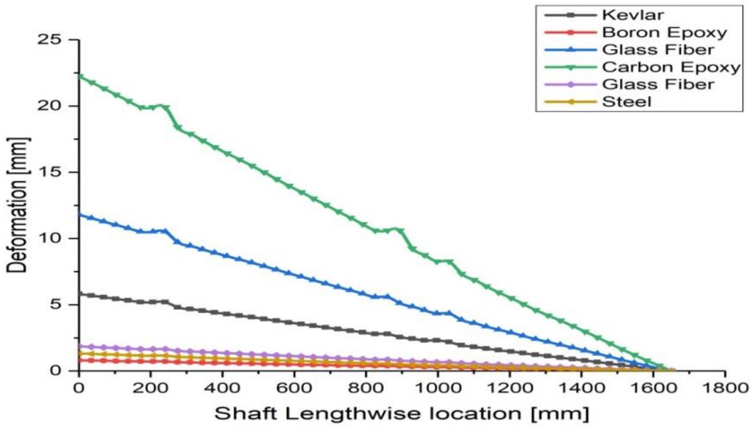

Figure 10: Deformation of various drive shaft materials.

The aim of the above consequences are to find an operative design of rotating shafts through examining the shaft features according to the factors influence the static strength features of rotating shafts, in other words variations in the material of the shaft. As can be seen the internal resistance can be advanced in the shaft material due to the static deformation (figure 8), thus a work is completed through the internal resistance build up in the shaft body which is stored as a state of energy. The calculated energy along lengthwise of shafts (figure 8) was higher for the shaft of material carbon epoxy, whereas, it was lower for the shaft of material steel and the shaft of the material of Boron Epoxy. The minimum static deformation was taken place for the shaft of Boron Epoxy material, this indication is refer to the better design among the other shaft materials (figure 10).

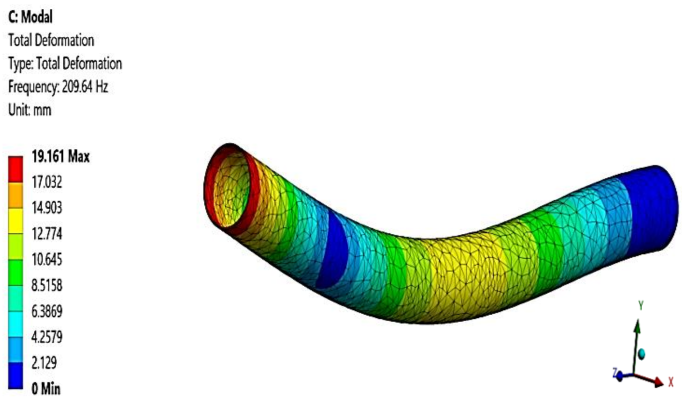

Figure 11: 1st bending modal shape of the Steel shaft.

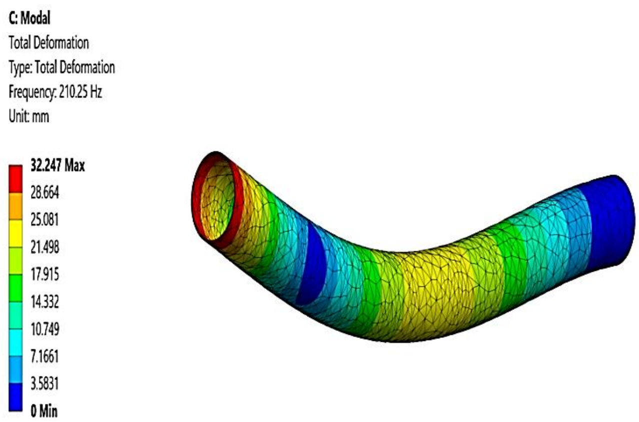

Figure 12: 1st bending modal shape of the Aluminum

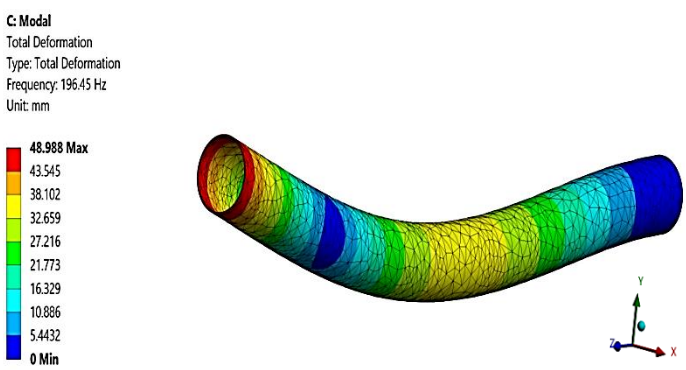

Figure 13: 1st bending modal shape of the Kevlar Epoxy

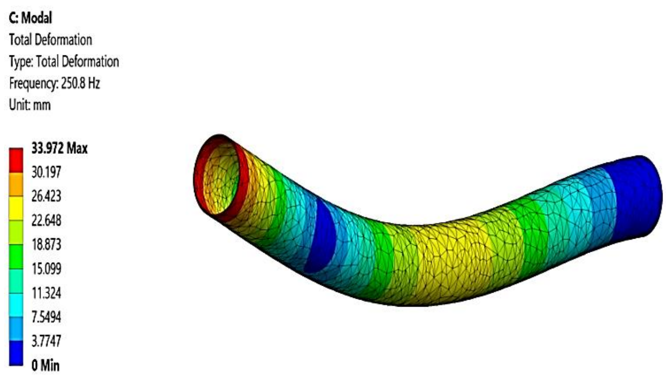

Figure 14: 1st bending modal shape of the Glass Fiber

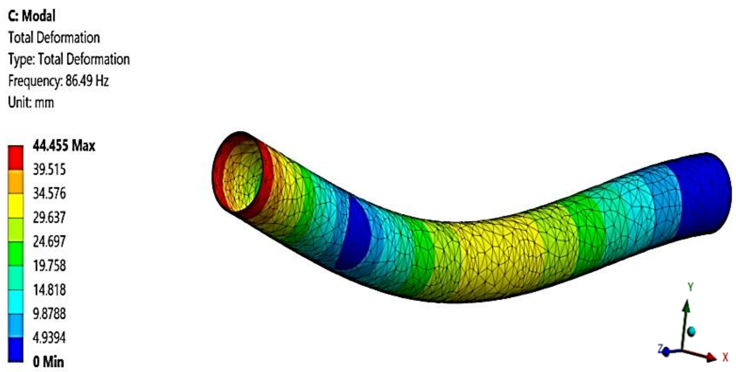

Figure 15: 1st bending modal shape of the Carbon Epoxy shaft.

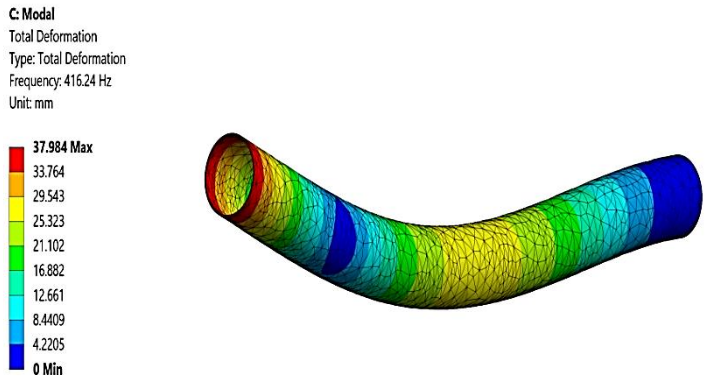

Figure 16: 1st bending modal shape of the Boron Epoxy shaft.

The above outcomes (figure 11 to figure 16) demonstrate that the kind of martials can influence on the natural bending frequency. The natural bending frequency of the shaft of Boron epoxy material can be increased by about 45 % to 50 % in comparison to the classical steel martial shaft, this can leads to the great shaft material in comparison to other shaft material. The strength and the dynamic vibration characteristics of the rotating shaft, in addition to the boundary conditions can produce a sophisticated strength and bending natural frequency varied to other classical shafts design [21].

5- Conclusion

It can be detected from the aforementioned investigation that some of the composite material shafts are greater to the one prepared from classical structural steel as composite shaft permits for sophisticated critical speeds, thus growing its effectiveness and competence. In addition, in composite shafts distortions are lesser than those in classical structural steel shaft for equivalent modes. The outcomes gained illustrate the benefits of composite shaft over classical steel shaft. More essential, it can be concluded that through utilizing a rotor shaft made of composite materials indicate improved dynamic performance than classical Steel shaft.

According to the simulation results using the finite element program ANSYS, one can notice that there are two optimal materials for design shafts, Boron-Epoxy and Aluminum Alloy, which denote the best choice that can be utilized to design the driving shaft. As a result of its high strength as well as its low weight, which leads to optimize the automobile design and also will be reduced the vehicle fuel consumption.

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