DESIGN AND ANALYSIS OF COMPOSITE DRIVE-SHAFT USING LM6 ALLOY AND ALUMINA

[1] A.Sai sree harsha , [2] T. Lakshmana kishore
[1] M.Tech Machine Design, Department of Mechanical Engineering, JNTUK-UCEV, Vizianagaram, India
[2] Assistant professor, Department of Mechanical Engineering, JNTUK-UCEV, Vizianagaram, India

***Abstract*:** The weight of the drive shaft will play a certain role in the general weight reduction of the vehicle and is a highly desirable goal. The advanced composite materials are widely used because of their high specific strength and high specific modulus. Advanced composite materials seem ideally suited for long, power driver shaft applications. The automotive industries are developing the composite material technology for structural components so that components weight is reduced without losing the component quality and reliability. It is known the energy is directly proportion to the fuel consumption and fuel consumption is directly proportion to the weight so the composite will posses less weight than metals. In this project different analysis is done on the drive-shaft with different percentage of compositions of a reinforcement in the composite material and concludes that using composite material will induce less stresses and reduces the weight of the drive-shaft. CATIA is used as modeling package for model the drive shaft arrangement and ANSYS is used as analysis package for analyse the drive-shaft.

***Keywords*: ANSYS, composite material, CATIA, drive-shaft.**

1. Introduction

In automobile engine is the source to give the power to the whole automobile. To transfer that engine power to the other parts we use the drive-shaft. In rear wheel drive-shaft the engine is at at front to transfer that power to the rear wheel we use the drive-shaft which is made of steel. To reduce the fuel efficiency the weight of the drive-shaft is the main factor and also to reduce the stress the young's modulus is the main factor. Stress is directly proportional to the young's modulus. The fundamental bending natural frequency of the drive-shaft is inversely proportion of the young's modulus. So by above sentences we can say that by decreasing the young's modulus we can achieve the above results. So improve the above properties without losing the strength of the material we go for composites.[1]

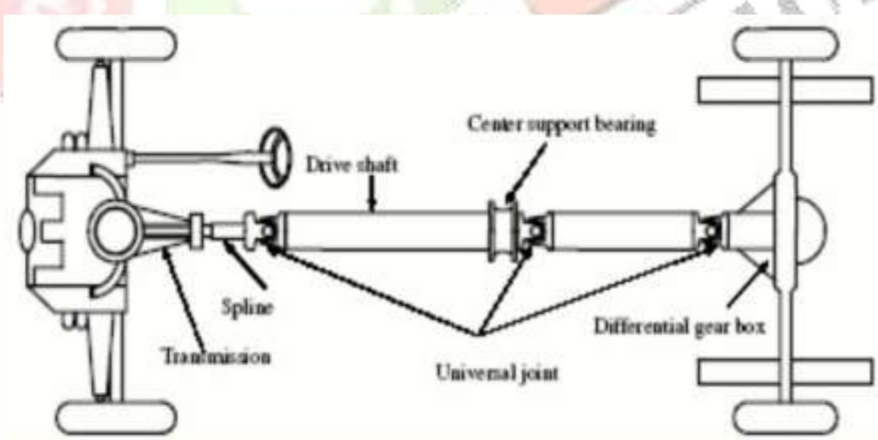


Figure 1: Schematic arrangement of Under-body of an Automobile(courtesy: Reference [1])

In the present work we use the composite as the substitute material for the steel and composite is aluminium metal matrix composite. That means aluminium alloy LM6 is used as the base material and alumina which is one of the hardest ceramic is used as the reinforcement in this project. By knowing the composite material properties and analysis the drive-shaft in ANSYS 15.

2. Literature survey

- Design and Analysis of Composite Drive Shaft using ANSYS and Genetic Algorithm by Sagar R Dharmadhikari in ijmer 2013. from this journal we take the dimensions of the drive-shaft and the formulae for the drive-shaft.

- Design and Comparison of the Strength and Efficiency of Drive Shaft made of Steel and Composite Materials in elsevier in 2016. from this journal how the fuel efficiency is increased by replacing the steel drive-shaft to composite drive-shaft is suggesting and also what are analysis had to done on the drive-shaft.
- Synthesis and Characterization of Aluminium Alloy AA6061-Alumina Metal Matrix Composite by Srinivasan Ekambaram and N. Murugan in 2015. from this journal how the composite is prepared using stir casting and how the strength of the composite is increasing is studied.
- Material Review: Alumina(Al_2O_3) by Karen Davis in 2010. this journal tell the how the applications of alumina and properties of alumina

3. Composite Material And It Properties

Composite material consists of two or more material constituents with very significant properties of physical or chemical properties and form a single material with rich properties than the base material. The composites materials can be classified is based on the matrix material and material structure[2].

1) Polymer Matrix Composites
2) Metal Matrix Composites
3) Ceramic Composites

Here we use metal matrix composite the metal is aluminium alloy LM6 and the reinforcement is alumina(Al_2O_3). Aluminium alloy LM6 is light metal and to improve it properties alumina reinforcement is add to the alloy. Alumina is one of strongest ceramic in the materials.

By using the stir casting [3] the composite is prepared in three composites like 5,10 and 15 percentage of reinforcement. To find the young's modulus of the composite material the tensile test is performed.

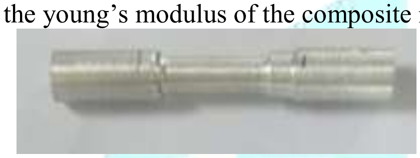


Figure 2: 5% reinforcement+LM6 alloy


Figure 3: 10% reinforcement+LM6 alloy


Figure 4: 15% reinforcement+LM6 alloy

By using the tensile test the properties of the composite is as in the following table 1

Table 1: Properties Of The Composite

Mechanical properties	Symbols	Units	Composite LM6+alumina		
			5% alumina	10% alumina	15% alumina
Young's modulus	E	Gpa	72.6	73.6	74
Poission's ratio	μ	--	0.314	0.309	0.303
Density	ρ	Kg/m^3	2715	2780	2845

3.1 *Advantages of composite materials over conventional materials:-*

1) High strength to weight ratio
2) Less density and weight
3) Corrosion resistant
4) High damping capacity
5) High impact strength
6) High stiffness to weight ratio

4. Specification Of The Drive-Shaft

The outer diameter of the drive-shaft should not be more than the 100mm due the space limit in the automobile. The fundamental bending natural frequency of the drive-shaft should not be higher than the 6,500rpm for the passenger cars, small trucks and vans due to the whirling vibration of the shaft. Torque transmission capacity of the drive-shaft should be higher than the 3,500Nm.

5. Design Requirements Of Steel Drive-Shaft

Table 2: Design Parameters(courtesy: Reference [4])

Parameters of shaft	Symbols	Value(mm)
Outer diameter	d_o	90
Inner diameter	d_i	83.36
Length	L	1250
Thickness	t	3.32

5.1 *design of the steel drive-shaft*

Table 3: Properties Of The Steel

Mechanical properties	Symbols	Units	Steel
Young's modulus	E	Gpa	207
Shear modulus	G	Gpa	80
Poisson's ratio	μ		0.3
Density	ρ	Kg/m^3	7600

Mass of the steel drive-shaft

$$m = \rho AL$$
$$= 7600*\pi/4*(d_o-d_i)*L \qquad \text{------} \quad (5.1)$$
$$= 8.58Kg$$

Total deformation of the drive-shaft $= \frac{TL^2}{2EI}$ ------ (5.2)

Where as T-- torque applied on the shaft i.e., 151N-m

I -- moment of inertia of the shaft

$$\text{Shear stress}(\tau) = \frac{Td_o}{2J} \qquad \text{------} \quad (5.3)$$

Where as J -- polar moment of inertia of the shaft

$$\text{Vonmisess stress}(\sigma) = 3\sqrt{\tau} \qquad \text{------} \quad (5.4)$$

Fundamental natural frequency

The natural frequency is found by two theories:

1) Timoshenko Beam theory
2) Bernoulli Euler Theory

From Timoshenko Beam Theory-Ncrt

$$fnt = Ks\frac{30\pi p^2}{L^2}\sqrt{\frac{Er^2}{2\rho}} \qquad \text{------} \quad (5.5)$$

Where as fnt= natural frequency base on Timoshenko beam theory, HZ

r = mean radius of shaft

Fs = Shape factor, 2 for hollow circular cross section

n = no of ply thickness, 1 for steel shafts

$$Ncrt = 60fnt$$

$$\frac{1}{K_s} = 1 + \frac{n^2\pi^2r^2}{2L^2}[1+\frac{f_sE}{G}] \qquad \text{------} \quad (5.6)$$

From Bernoulli-Euler Beam Theory-N_{crbe}

$$f_{nbe} = \frac{\pi p^2}{2L^2}\sqrt{\frac{EI_x}{m}} \qquad \text{------} \quad (5.7)$$

$$N_{crbe} = 60f_{nbe} \qquad \text{------} \quad (5.8)$$

5.2 *design of the composite drive-shaft*

Mass of the composite drive-shaft

$$m = \rho AL$$
$$= 2845*\pi/4*(d_o-d_i)*L \qquad \text{------} \quad (5.6)$$
$$= 3.1Kg$$

Other analysis is done using ANSYS 15 software

6. Design and Analysis

For theoretically the analysis of the drive-shaft is done by using above formulae. For analytical analysis we use finite element analysis(FEA) which is computer based analysis for computing the strength and behaviour of the structure. The whole structure is represent as the small finite elements and each element is joined at a point called nodes. FEA is used to calculate the deflections, stress, vibrations etc.

In our project FEA analysis is done by the software called ANSYS 15.0. model of the drive-shaft is prepared by using the CATIA V5 software is used[6].

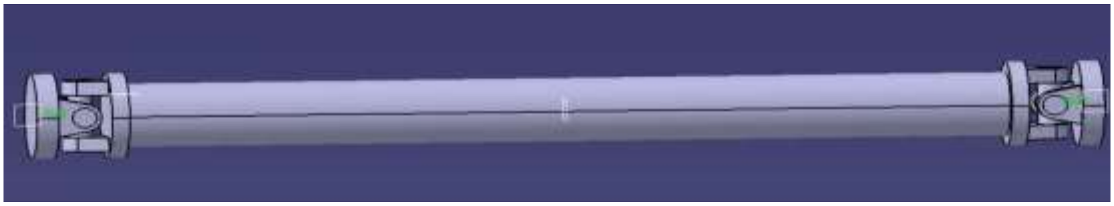


Figure 5: Drive-Shaft Assembly In CATIA

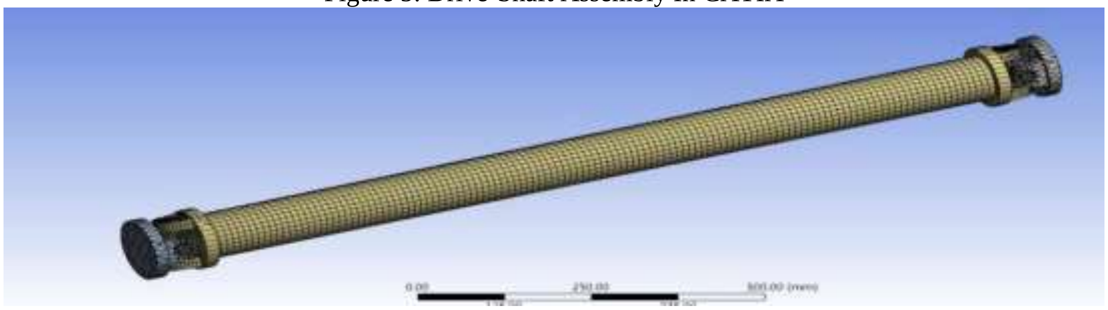


Figure 6: Drive-Shaft Assembly Meshing Into Finite Element Model

6.1 Boundary condition:

In finite element model the boundary conditions for the drive-shaft is one end of the drive-shaft is fixed due to the engine is attached to that fixed end and the other end of the drive-shaft torque 151N-m is applied due to that end is fixed to the differential.

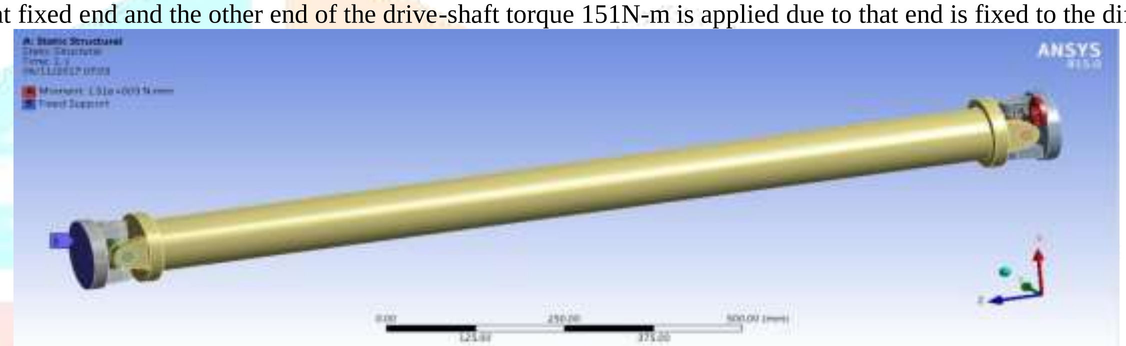


Figure 7: Application of the boundary condition

6.2 Assumptions[5]:

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 non-linear 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.

6.3 Static analysis:

Static analysis is done to determine the total deformation, stress, strains and forces in structures caused by loads without any damping effects. In static analysis steady inertia load are applied like gravity, spinning and time varying loads. If the stress in static analysis is crossed the allowable stress then the structure is failed in static conditions. To avoid these circumstances static analysis is necessary.

6.4 Modal analysis:

Modal analysis is used to determine the vibrations of the material and also the mode shapes of the structure. The natural frequency of the shaft is depends on the diameter of the shaft, thickness of the hollow shaft and length of the shaft.

7. Results and discussion

The weight of the steel and composite drive-shaft is found and also stress of the both drive-shaft is found and is tabulated in the table 3. Also at different dimensions like changing the length of the shaft and changing the yoke thickness of the drive-shaft assembly the static and modal analysis on the drive-shaft is done on those dimensions also.

1. total deformation:

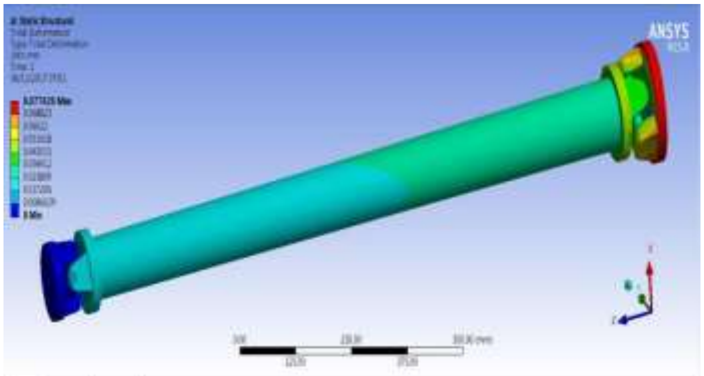


Figure 8: Total deformation of steel

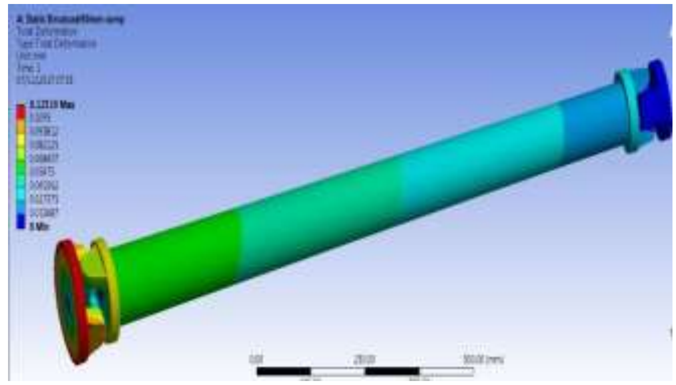


Figure 9: Total deformation of composite LM6+Alumina

2. vonmises stress:

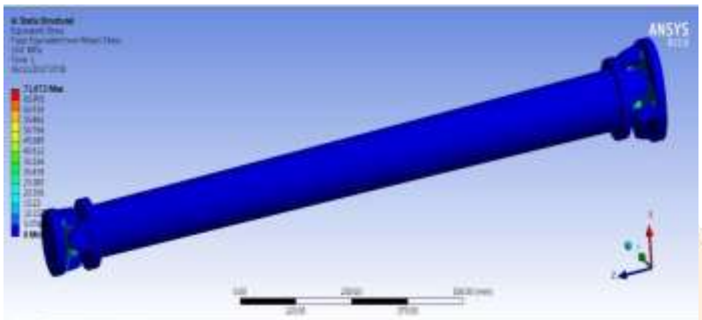


Figure 10: von-misess stress of steel

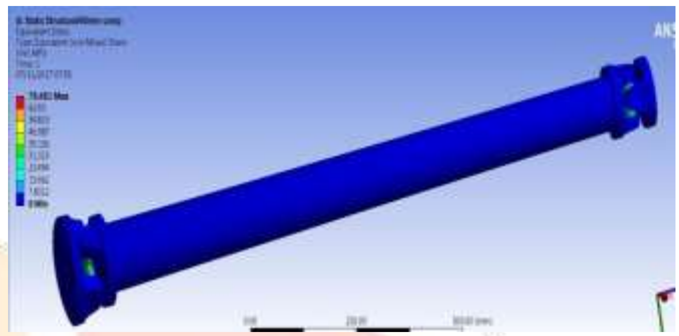


Figure 11: von-misess stress of composite LM6+Alumina

3. shear stress:

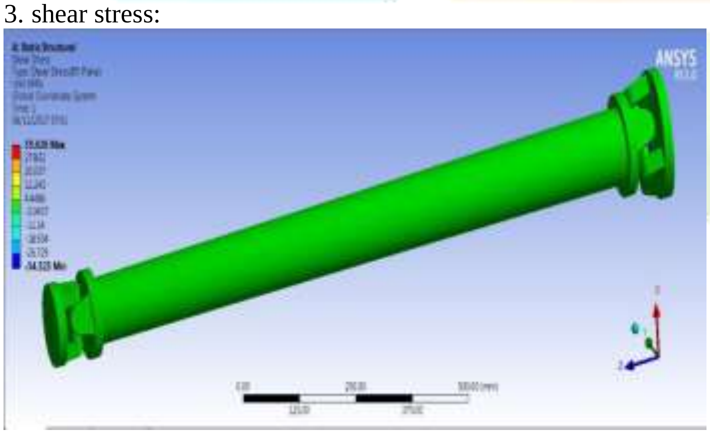


Figure 12: shear stress of the steel

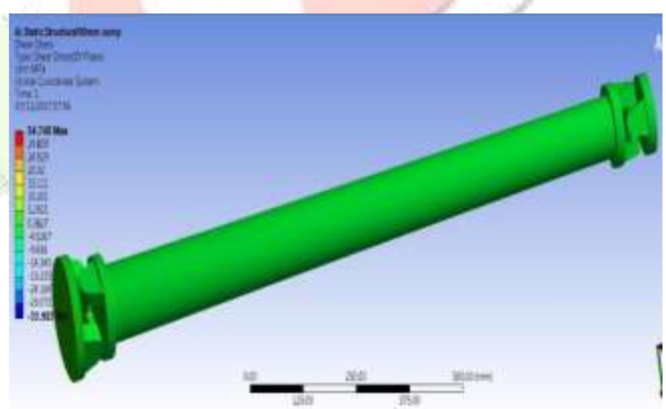
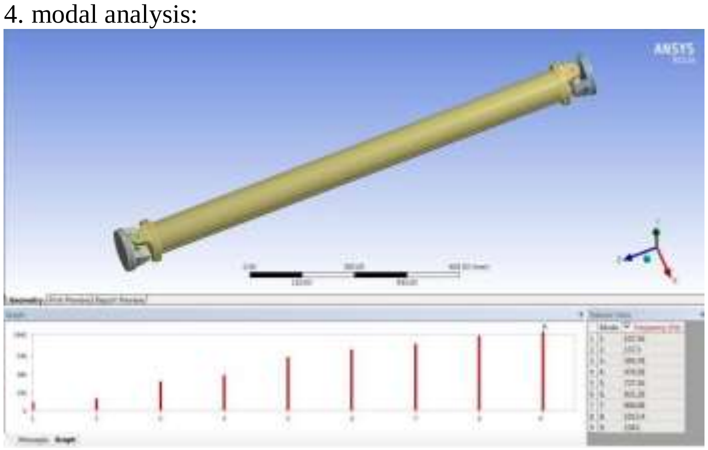


Figure 13: shear stress of the the composite LM6+Alumina

4. modal analysis:



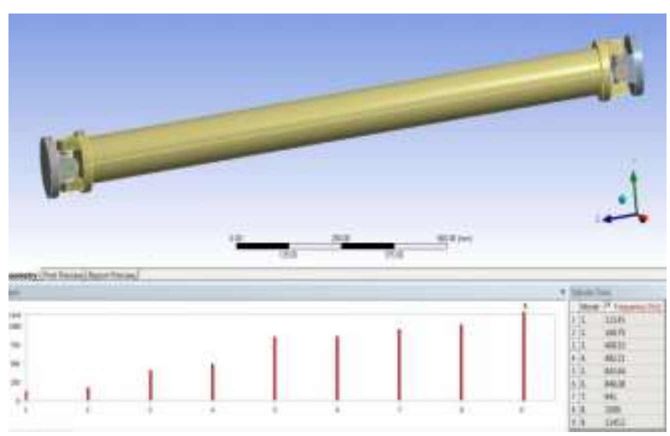


Figure 14: modal analysis of the steel Figure 15: modal analysis of the composite LM6+Alumina

Table 3: Results For Steel And Composite Drive-Shaft

Analysis	Structural steel		Al alloy LM6+5% Alumina	Al alloy LM6+10% Alumina	Al alloy LM6+15% Alumina
	Theoretical	ANSYS			
Total deformation (mm)	0.07	0.0774	0.1308	0.1299	0.12886
Von-mises stress (Mpa)	70.9	71.07	70.61	70.597	70.481
Shear stress (Mpa)	39.07	36.92	34.757	34.755	34.743
First mode natural frequency (Hz)	105	107	114	113	113
Density (Kg/m3)	--	7600	2715	2780	2845
Poission's ratio		0.3	0.3145	0.309	0.3035
Mass	8.59	8.59	2.96	3.03	3.10

Results for the drive shaft length of 1250mm, by varying the thickness of yoke are shown in Table 4.

Table 4: For Length 1250mm

Thickness of yoke (mm)	Total deformation (mm)	Von-mises stress (Mpa)	Shear stress (Mpa)	First mode frequency (Hz)
25	0.1105	50.951	24.828	120
30	0.1108	50.462	24.61	120
40	0.1090	49.722	24.828	120

Results for the drive shaft length of 1000mm, by varying the thickness of yoke are shown in Table 5.

Table 5: For Length 1000mm

Thickness of yoke (mm)	Total deformation (mm)	Von-mises stress (Mpa)	Shear stress (Mpa)	First mode frequency (Hz)
25	0.09854	53.759	25.802	175
30	0.0975	53.455	25.826	175
40	0.09639	49.708	24.482	176

Results for the drive shaft length of 600mm, by varying the thickness of yoke are shown in Table 6.

Table 6: For Length 600mm

Thickness of yoke(mm)	Total deformation (mm)	Von-mises stress (Mpa)	Shear stress (Mpa)	First mode frequency (Hz)
25	0.07762	49.68	22.128	405
30	0.077015	49.131	23.891	405
40	0.07625	48.589	21.72	406

From the above results by changing the length of the driveshaft and changing the thickness of the yoke the following graphs will be obtained. Figure 13 shows the total deformation graph. Similarly Fig 14 and Fig 15 shows the graph for von-misess stress and shear stress respectively.

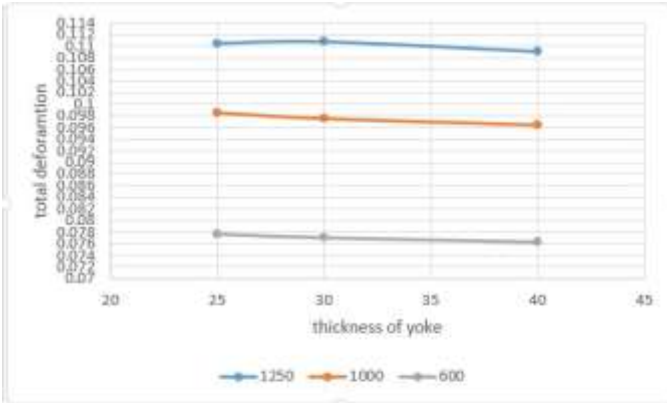


Figure 13: total deformation

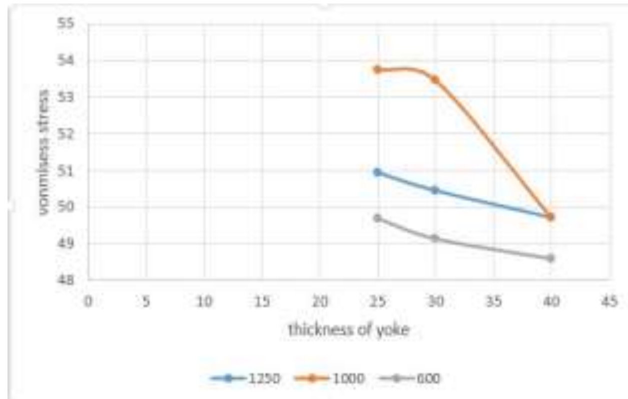


Figure 14: vonmises stress

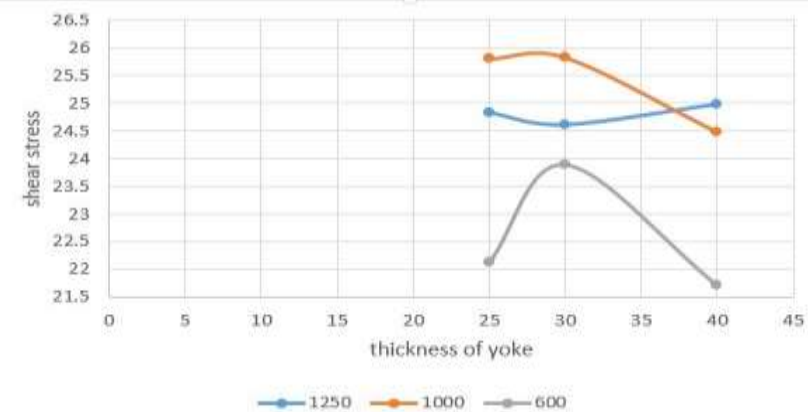


Figure 15: Shear stress

From the above results we can see that the first mode frequency of the shaft doesn't depend on the thickness of the yoke so it is same for all even-though thickness of the yoke is changing. Here the thickness of the yoke is changed because to decrease the total deformation of the drive-shaft that total deformation is falling on the yoke so thickness of the yoke is changed to improve it.

8. Conclusion

The model of drive shaft assembly is done by using CATIA and analysis is done using ANSYS(FEA) . By conducting analysis on composite material which is aluminium and alumina as reinforcement with different reinforcement composition. We got the results as following:

- For 5% reinforcement composite has 0.64% reduction in von-mises stress, 65% reduction in mass and 5.85% in reduction in shear stress than structural steel. But it has 40.82% in creases in deformation than structural steel. It also has 13.76% increase in frequency of shaft than the structural steel.
- For 10% reinforcement composition has 0.66% reduction in von-mises stress, 64.72% reduction in mass and 5.86% reduction in shear stress than the structural steel. But it has 40.41% increase in total deformation than structural steel. It also has 13.12% increase in frequency of shaft than the structural steel.
- For 15% reinforcement composition has 0.68% reduction in von-mises stress, 5.87% reduction in shear stress and 63.91% decrease in mass than the structural steel. But it has 39.9% increase in total deformation than structural steel. It also has 13.76% increase in frequency of shaft than the structural steel.

From the above result it is observed that the material which develop less von-mises stress exhibit a little more deformation. Though aluminium alloy LM6 and 15% alumina composite induce 5.87% less stress compared to the structural steel, considering the changes in both deformation, stress, weight and frequency. It can be said that using this composite material is better than the structural steel.

9. References

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