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Static and Modal Analysis of Metal Matrix Composite Based Propeller Shaft

PG Scholar Senavaraiyan S, Prof. Dr. S. Ayyappan
Dept. of Engineering Design,
Government College of Technology,
Coimbatore, Tamilnadu
senakadungon007@gmail.com, ayyappan.s.mech@gct.ac.in

Abstract- The main goal of this project is to analyze metal matrix composites' based a propeller shaft. In this project, it was attempted to determine the appropriateness of a hollow propeller shaft by altering the interior diameter. The CAD software was used to produce a model of the propeller shaft. The design optimization also showed significant potential improvement in the performance of the propeller shaft. ANSYS software was used to perform the static and modal analyses. The obtained results were compared among the selected materials. The achievement of weight reduction with an adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel without an increase in cost or decrease in vehicle quality and reliability.

Keywords- Propeller shaft, SM45C Steel, Metal Matrix Composite, CREO, ANSYS, Weight and Cost reduction.

I. INTRODUCTION

A driveshaft, also known as a driving shaft, tail shaft, propeller shaft, or cardon shaft, is a longitudinal shaft that transmits power from the engine to the wheels. Depending on the length of the vehicle, a front engine rear-drive vehicle's shaft will limit power. When long shafts are employed, natural bending will occur; to avoid this, universal joints will be needed. The power transferring capability of universal joints diminishes as the number of joints grows. The overall goal of this project is to use composite materials to decrease power loss. Composite materials offer a great degree of strength and stiffness, as well as the ability to tolerate extreme temperatures.

Property such as Shear Stress, Shear Strain, Equivalent elastic strain, Total deformation, and Von-misses stress are analysed when the analysis is done using ANSYS and modelling is done with CREO software. The composite materials, such as Metal Matrix Composite, as well as the traditional SM45C STEEL shaft, are investigated.

As a propeller shaft, a hollow shaft was employed. Variations in the hollow shaft's inner diameter were used to conduct the analysis. The shaft was found to have improved dependability and compatibility. This method reduces weight and increases power transfer while lowering costs.

II. LITERATURE REVIEW

Sakthi S et al [2020], optimized the design parameters were the objective of minimizing the weight of composite drive shaft. The composite drive shaft made up of high modulus material is designed by using CAD software and tested in ANSYSfor optimization of design or material check and providing a best material. The replacement of composite materials can result in considerable amount of weight reduction if compared to conventional steel shaft.

K. Krishnaveni et al [2019], The aim of this work is to replace the conventional steel driveshaft of automobiles with an appropriate composite driveshaft. The design optimization also showed significant potential improvement in the performance of drive shaft. In this present work an attempt has been to estimate the deflection, shear stresses by using

ANSYS 14.5. Ramchandra D Patil et al [2019], The design parameters were optimized with the objective of minimizing the weight of hybrid aluminum/composite drive shaft &increase in torque capability compared with a conventional two-piece steel drive shaft.

Nizam S Sakeer et al [2019], Composite materials have high strength and high stiffness. ''CHEVROLET TAVERA'' vehicle propeller shaft is analysed by using composite material. In this work, Al2O3 and AlSiC composite materials are used and analysing software's are SOLIDWORK & ANSYS.

Aniket Bhilare et al [2018], In this project, we can use Steel (AISI1053), Titanium Alloy (ti-6al-7Nb) and Aluminum Alloy(al-6061). We can check the three different materials for the drive shaft. Also check the different types of loads, stress. Also check by two types of analysis, A static analysis is used to study the effects of steady loading condition on a structure. By getting best result we can choose that material for the Drive shaft.

More S.D et al. [2018], This work deals with the design of propeller shaft for "MAHINDRA LOAD KING" considering the torque capacity, shear stress & critical rpm requirement. In this work Glass/Epoxy is used as composite material for replacement of conventional two-piece steel propeller shafts. The design parameters were optimized with the objective of minimizing the weight of composite propeller shaft.

Mrs. Vishwal Kawale et al [2018], In this paper we are try to explain and analyze the of propeller shaft design with input parameters like type of vehicle, engine, gear box Specifications, tyresize, application of vehicle, desired life expectancy, vehicle aggregate layout etc.

III. PROBLEM STATEMENT

To eliminate whirling vibration, the propeller shaft's basic natural bending frequency should be higher than 6,500 rpm for passenger vehicles, small trucks, and vans, and the torque transmission capability of the drive shaft should be greater than 3,500 Nm. Due to space constraints, the drive shafts outside diameter should not exceed 100 mm.

The shaft's outside diameter is 85 mm in this case. The drive shaft should be optimised to meet the design criteria listed in Table 1.

Table 1. Design requirement and Specifications.

Sr. No	Name	Notation	Unit
1	Ultimate Torque	T_{max}	Nm
2	Maximum Speed of Shaft	N_{max}	Rpm
3	Length of Shaft	L	mm
4	Outer Diameter	D_o	mm
5	Thickness	T	mm

IV. METHODOLOGY

The process of modelling and analysis to be described in the below flow chart.

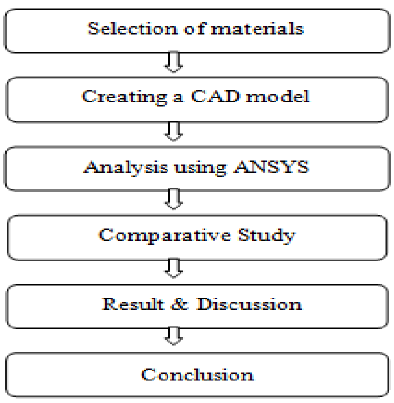

Fig 1. Process flow chart

1. Selection of materials:

1.1 SM45C Steel

1.2 Metal Matrix Composites

- Aluminium alloy + Fly ash + B4C
- Aluminium alloy + Al2O3 + SiC

2. Mechanical Properties of SM45C Steel:

The below table shows the Mechanical Properties of SM45C Steel.

Table 2. Mechanical Properties of SM45C Steel.

Mechanical properties	SM45C STEEL
Young's Modulus (GPa)	207
Shear Modulus (GPa)	80
Poisson's Ratio	0.3
Density (Kg/m³)	7600
Yield Strength (MPa)	370
Shear Strength (MPa)	275

3. Mechanical Properties of Aluminium Alloy + Fly Ash + B4C:

The below table shows the mechanical properties of material.

Table 3. Mechanical Properties of Aluminium Alloy + Fly Ash + B4C.

Mechanical properties	Aluminium Alloy + Fly Ash + B_4C
Density (Kg/m³)	2676.3
Young's modulus (GPa)	68
Poisson ratio	0.32
Shear modulus (GPa)	25.758
Tensile ultimate strength (N/mm^2)	184.72
Compressive ultimate strength (N/mm^2)	216.79

4. Mechanical Properties of Aluminium Alloy + Al2O3 + SiC

The below table shows the mechanical properties of material.

Table 4. Mechanical Properties of Aluminium Alloy + Al2O3 + SiC.

Mechanical properties	Aluminium Alloy + Al_2O_3 + SiC
Density (Kg/m³)	3300
Young's modulus (GPa)	71.7
Poisson ratio	0.31
Shear modulus (GPa)	27.366
Tensile yield strength (N/mm^2)	70
Tensile ultimate strength (N/mm^2)	92

V. MODELLING AND ANALYSIS

1. Design Specifications:

Length of the shaft, $L = 1150$ mm
Outer diameter, $d_o = 85$ mm
Inner diameter, $d_i = 78$mm
= 75mm
= 72mm
Load on the shaft, $M_t = 1260$ Nm
Ultimate torque, $T_{max} = 3500$ Nm
Maximum speed of shaft, $N_{max} = 6500$ rpm

2. Design Calculations:

Power transmitted by shaft,

$$P = \frac{2\pi NT}{60}$$

Torsional Strength

$$T = \frac{\left[Ss\frac{\pi}{4}(do^4 - di^4) \right]}{16do}$$

Torque

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

Torsional Buckling

A shaft is considered as a long shaft,

$$\frac{1}{\sqrt{1-\vartheta^2}} \times \frac{L^2 t}{(2r)^3} > 5.5$$

$$\text{where}, t = r_o - r_i$$

$$r = \frac{r_o - r_i}{2}$$

For a long shaft, the torsional buckling capacity:

$$T_b = \tau_{cr}(2\pi r^2 t) Nmm$$

Where,

Critical stress (τ_{cr}) is given by,

$$\tau_{cr} = \left[\frac{E}{3\sqrt{2}(1-\vartheta^2)^{3/4}} \right] \left[\frac{t}{r} \right]^{3/2}$$

Therefore, $\mathbf{T_b > T}$

Bending Natural Frequency: According to Bernoulli-Euler beam theory, by neglecting shear deformation and rotational inertia effects, the bending natural frequency of a rotating shaft is given by

$$\mathbf{f_{nb} = \frac{\pi}{2L^2}\sqrt{\frac{EI_x}{m'}}}$$

Where,

m' is mass per unit length in kg/m
I_x is area moment of inertia in x-direction (longitudinal) in m^4

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

$$m' = \rho(\pi/4)(do^2 - di^2)$$

The critical speed of the shaft

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

The total mass of the shaft is,

$$m = m'L$$

3. CAD modelling of propeller shaft:

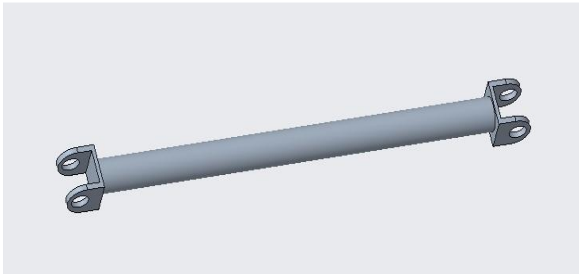

Fig 2. Cad Model of Propeller Shaft.

4. Meshing:

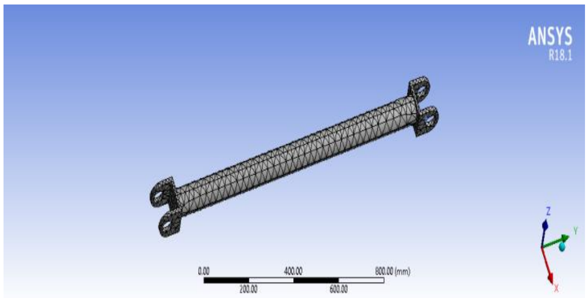

Fig 3. Meshed View of Propeller Shaft

5. Static Analysis:

Equivalent Stress Analysis

SM45C Steel

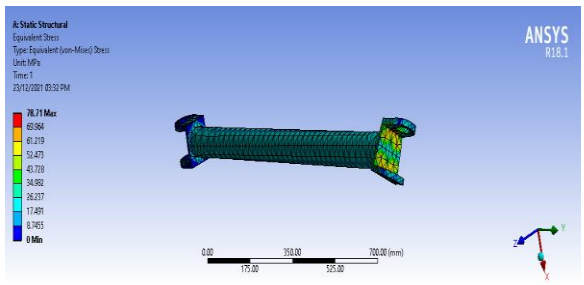

Fig 4. SM45C Steel Shaft1.

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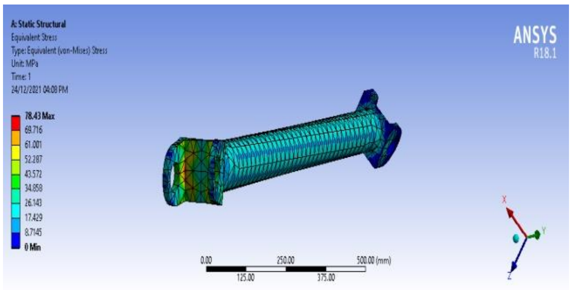


Fig 5. SM45C Steel Shaft2

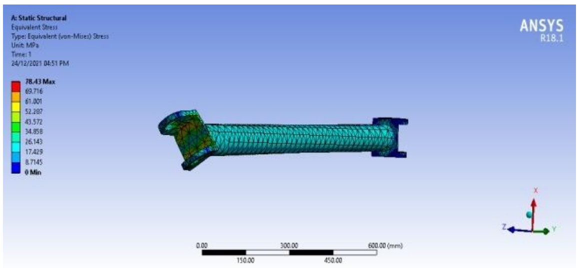


Fig 6. SM45C Steel Shaft3

Aluminium Alloy + Fly Ash + B_4C

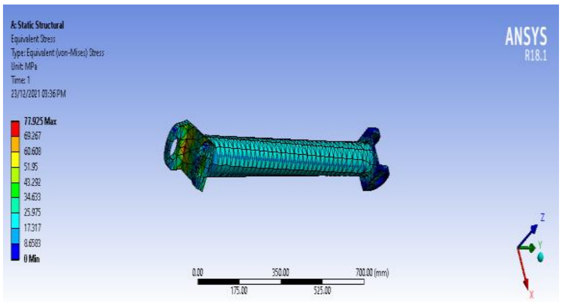


Fig 7. Aluminium Alloy + Fly Ash + B_4C shaft1

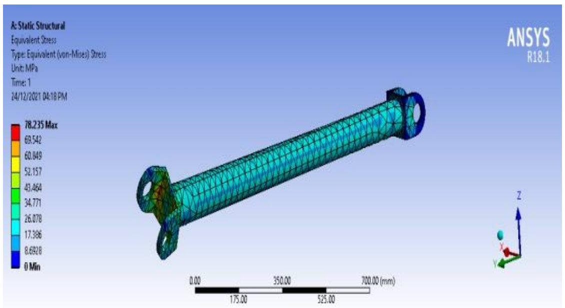


Fig 8. Aluminium Alloy + Fly Ash + B_4C shaft2

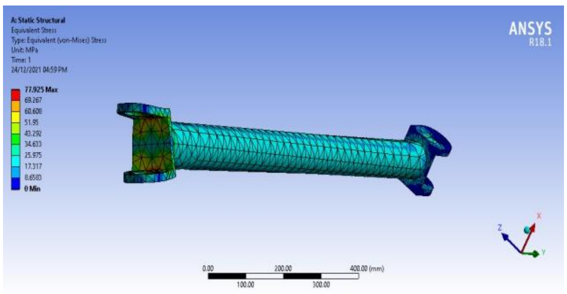


Fig 9. Aluminium Alloy + Fly Ash + B_4C shaft3

Aluminium Alloy + Al_2O_3 + SiC

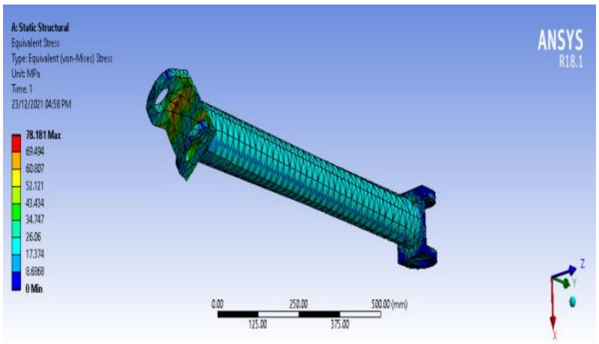


Fig 10. Aluminium Alloy + Al_2O_3 + SiC shaft1.

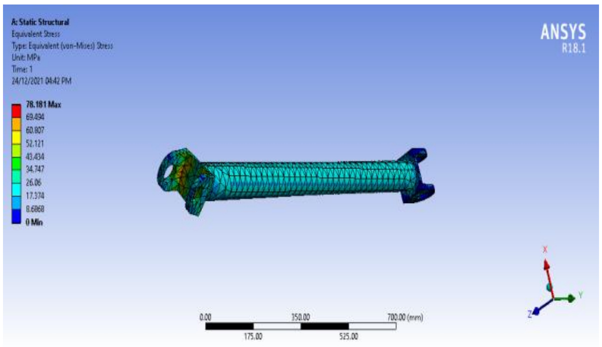


Fig 11. Aluminium Alloy + Al_2O_3 + SiC shaft2.

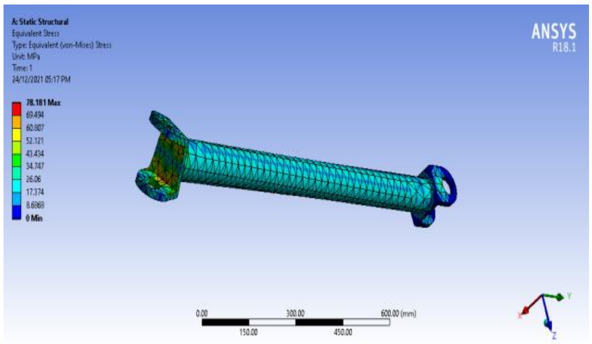


Fig 12. Aluminium Alloy + Al_2O_3 + SiC shaft3.

Equivalent Strain Analysis

SM45C Steel

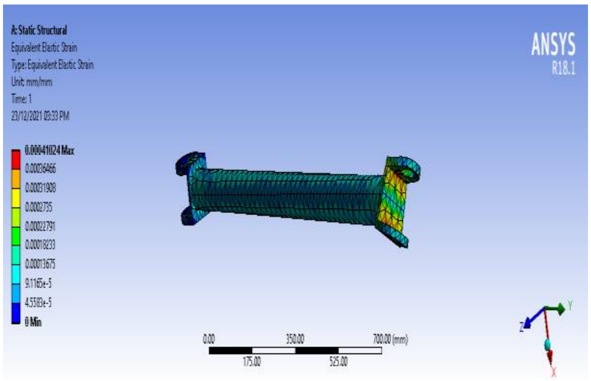


Fig 13. SM45C Steel Shaft1

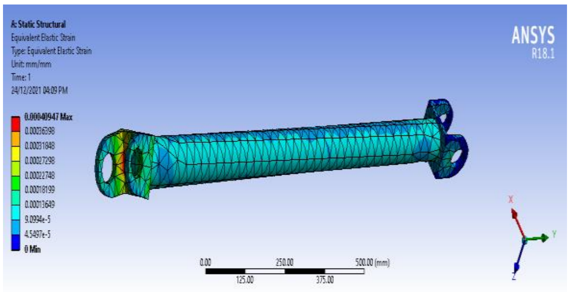


Fig 14. SM45C Steel Shaft2.

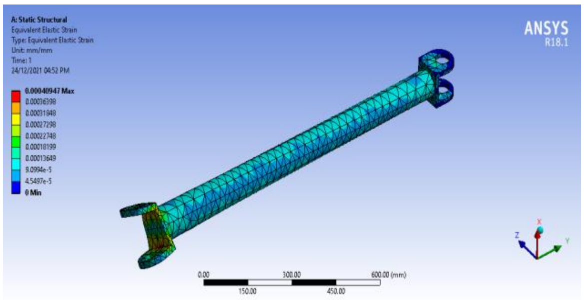


Fig 15 SM45C Steel Shaft3

Aluminium Alloy + Fly Ash + B_4C

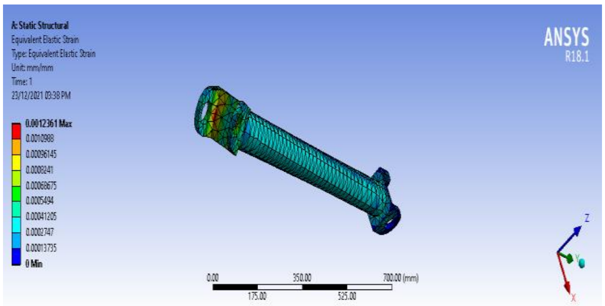


Fig 16. Aluminium Alloy + Fly Ash + B_4C shaft1

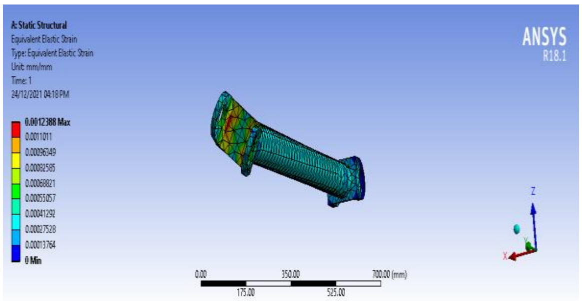


Fig 17. Aluminium Alloy + Fly Ash + B_4C shaft2

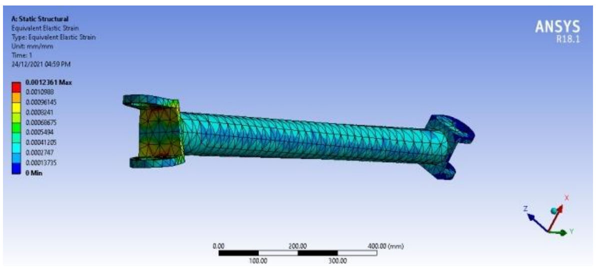


Fig 18. Aluminium Alloy + Fly Ash + B_4C shaft3

Aluminium Alloy + Al_2O_3 + SiC

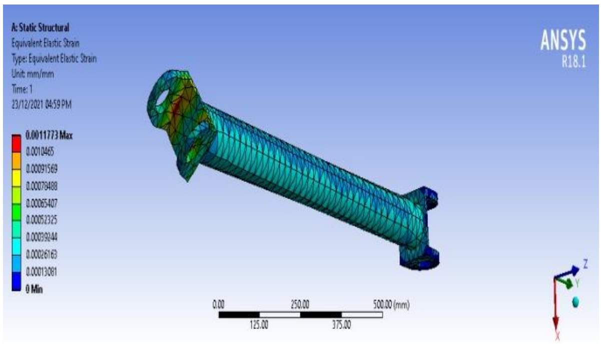


Fig 19. Aluminium Alloy + Al_2O_3 + SiC shaft1

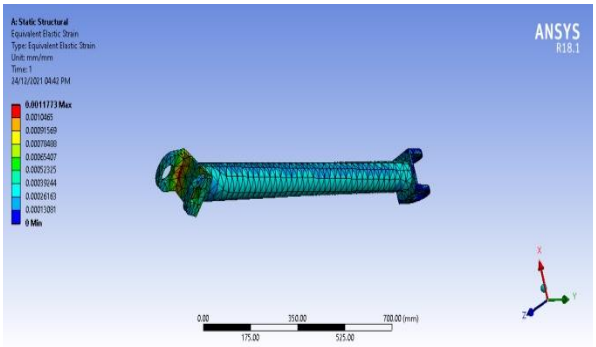


Fig 20. Aluminium Alloy + Al_2O_3 + SiC shaft2

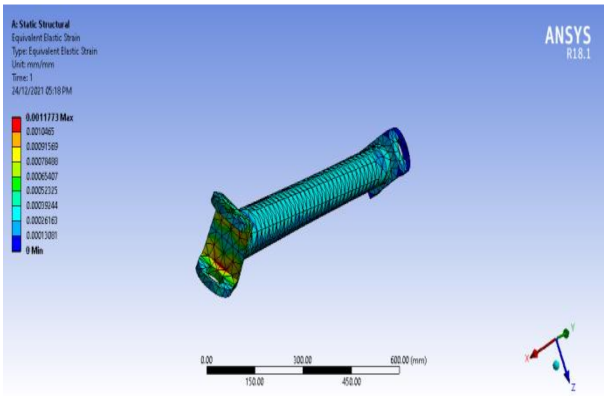


Fig 21. Aluminium Alloy + Al_2O_3 + SiC shaft3

Total Deformation

SM45C Steel

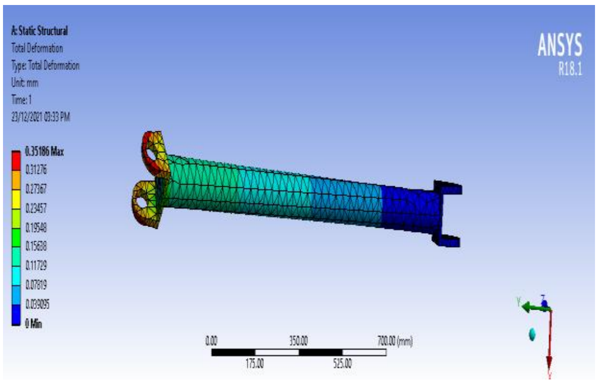


Fig 22. SM45C Steel Shaft1.

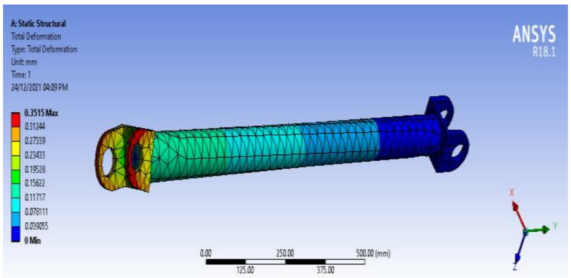


Fig 23. SM45C Steel Shaft2.

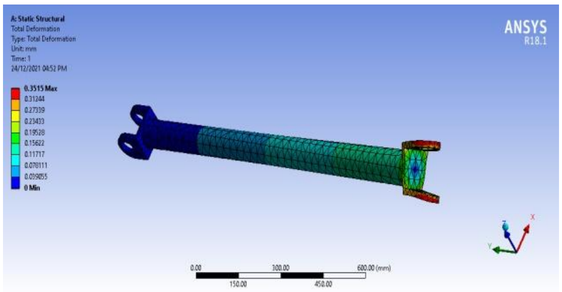


Fig 24. SM45C Steel Shaft3

Aluminium Alloy + Fly Ash + B_4C

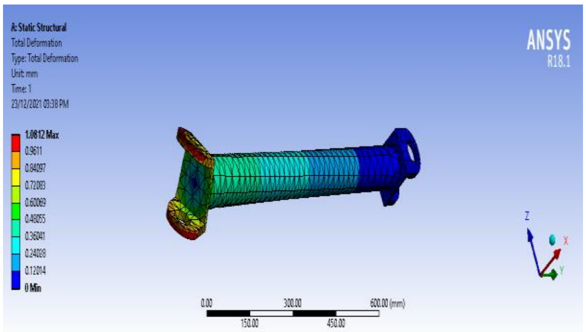


Fig 25. Aluminium Alloy + Fly Ash + B_4C shaft1

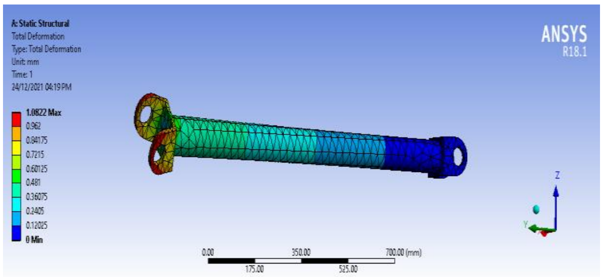


Fig 26. Aluminium Alloy + Fly Ash + B_4C shaft2

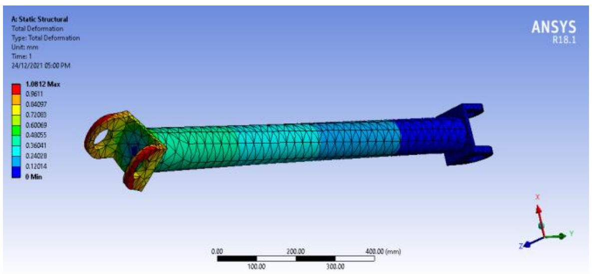


Fig 27. Aluminium Alloy + Fly Ash + B_4C shaft3

Aluminium Alloy + Al_2O_3 + SiC

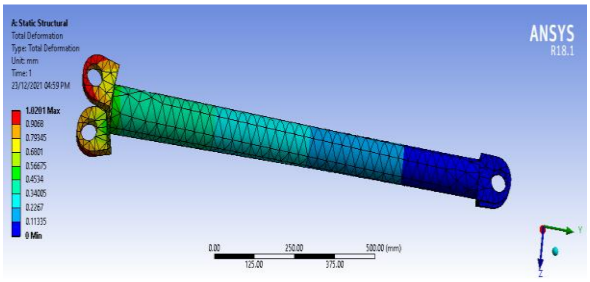


Fig 28. Aluminium Alloy + Al_2O_3 + SiC shaft1

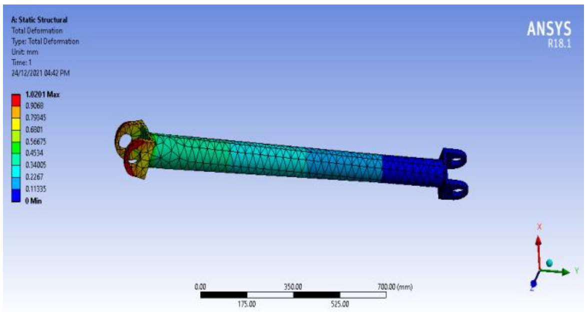


Fig 29. Aluminium Alloy + Al_2O_3 + SiC shaft2

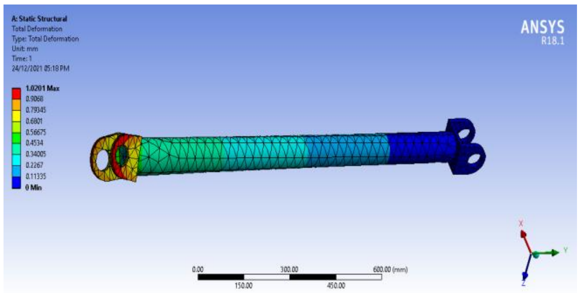


Fig 30. Aluminium Alloy + Al_2O_3 + SiC shaft3

6. Modal Analysis:

Modal analysis shows the movement of different parts of the structure under dynamic loading conditions, such as those caused by the lateral force generated by the electrostatic actuators, and helps to determine the vibration characteristics (natural frequencies and mode shapes) of a mechanical structure or component.

Total Deformation

SM45C Steel

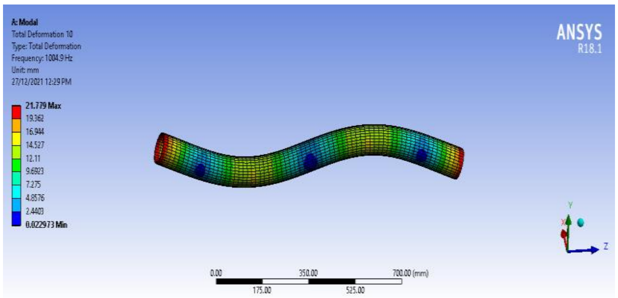


Fig 31. SM45C Steel Shaft1.

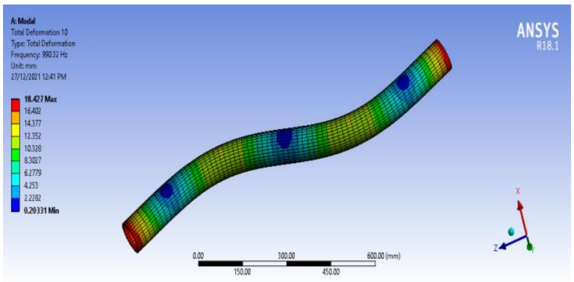


Fig 32. SM45C Steel Shaft2

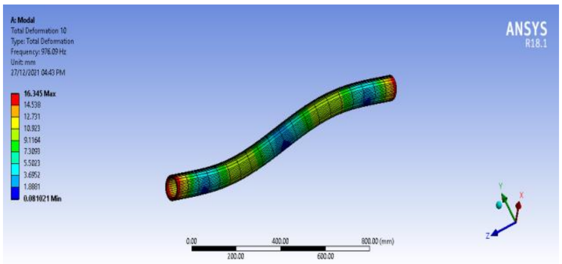


Fig 33. SM45C Steel Shaft3

Aluminium Alloy + Fly Ash + B_4C

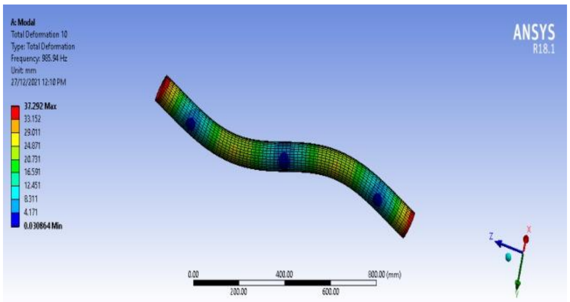


Fig 34. Aluminium Alloy + Fly Ash + B_4C shaft1

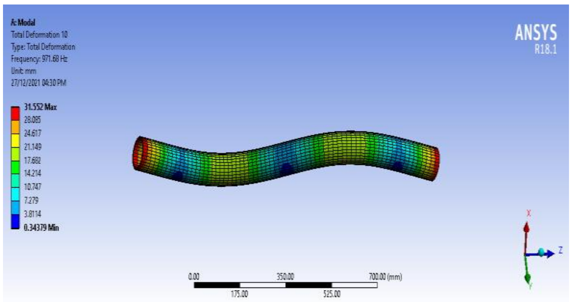


Fig 35. Aluminium Alloy + Fly Ash + B4C shaft2

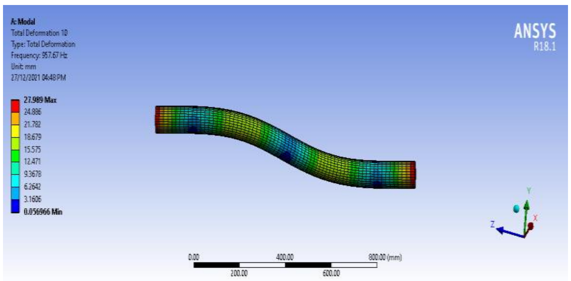


Fig 36. Aluminium Alloy + Fly Ash + B4C shaft3

Aluminium Alloy + Al2O3 + SiC

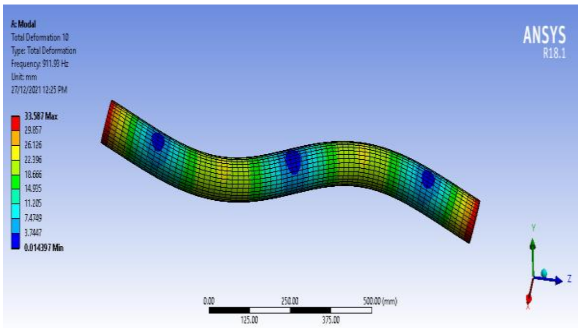


Fig 37. Aluminium Alloy + Al2O3 + SiC shaft1

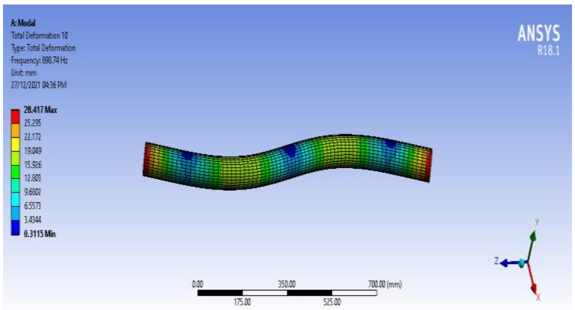


Fig 38. Aluminium Alloy + Al2O3 + SiC shaft2

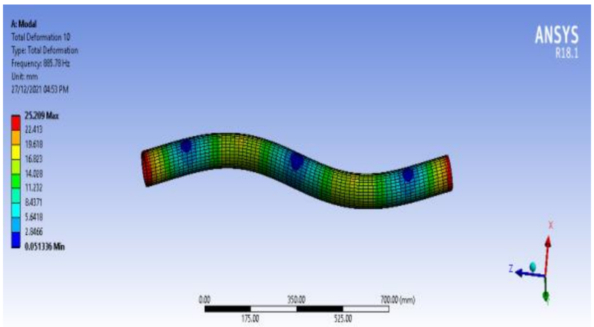


Fig 39. Aluminium Alloy + Al2O3 + SiC shaft3

VI. RESULT AND DISSCUSION

1. Equivalent Stress Results:

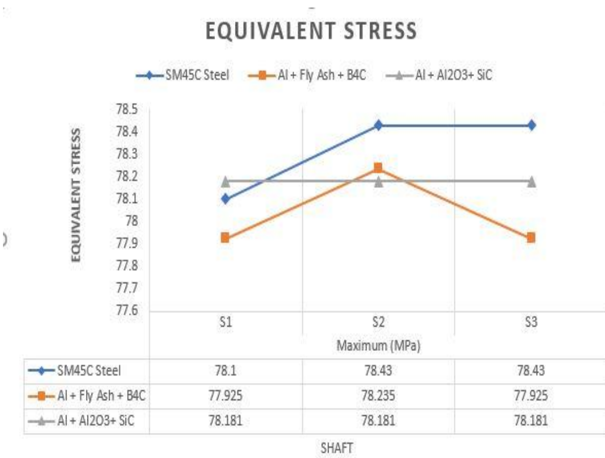


Fig 40. Graph .1. Equivalent Stress Results.

The stress values of metal matrix composite shafts are closer to those of a sm45c steel shaft, as shown in graph 1. Among the various composites, Aluminium Alloy + Fly Ash + B4C shows the best stress values.

2. Equivalent Strain Results:

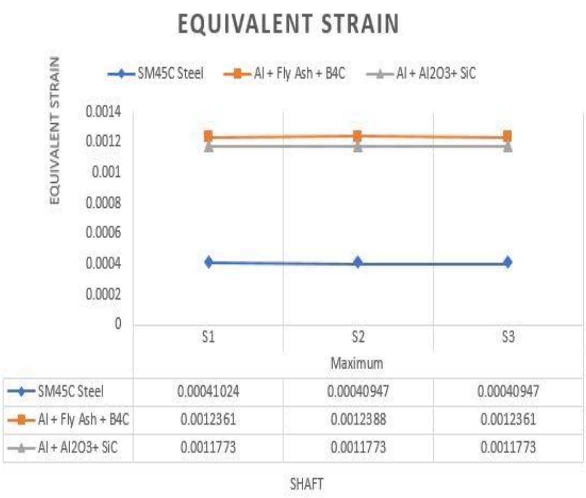


Fig 41. Graph .2. Equivalent Strain Results.

From the above graph 2, Composites provide considerably superior strain results than steel. However, when compared to the composite shaft, the strain values are closer together. The maximum strain value is found in Aluminium Alloy + Fly Ash + B4C.

3. Total Deformation Results:

Fig 42. Graph .3. Total Deformation Results.

From the above graph 3, shows that the Metal matrix composites with a high total deformation yield superior outcomes. Both composites were evaluated to determine which one was superior. The combination of Aluminium Alloy + Fly Ash + B4C yields a positive outcome.

4. Shear Stress Results:

From the above graph 4, The shafts' shear stress is closer together. Aluminium Alloy + Fly Ash + B4C, on the other hand, is somewhat greater than the rest.

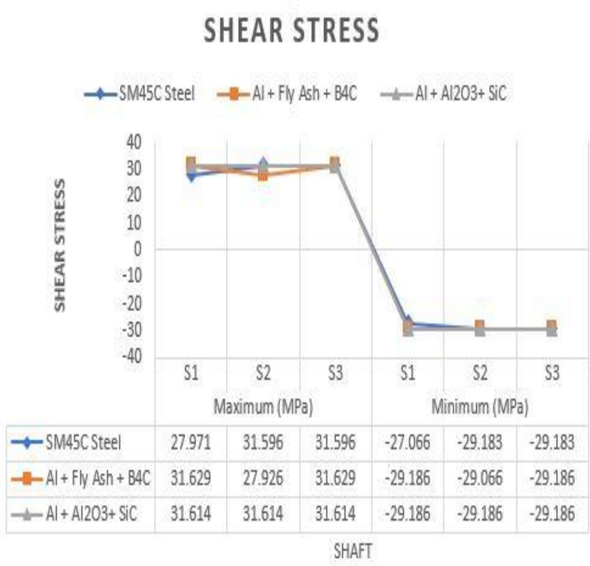


Fig 43. Graph .4. Shear Stress Results.

5. Shear Strain Results:

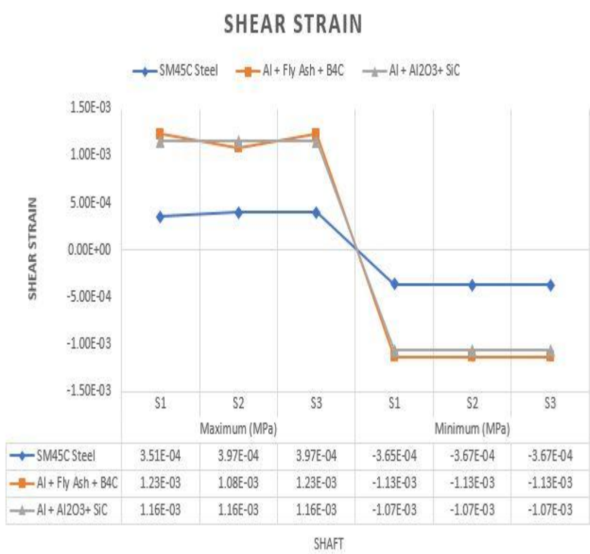
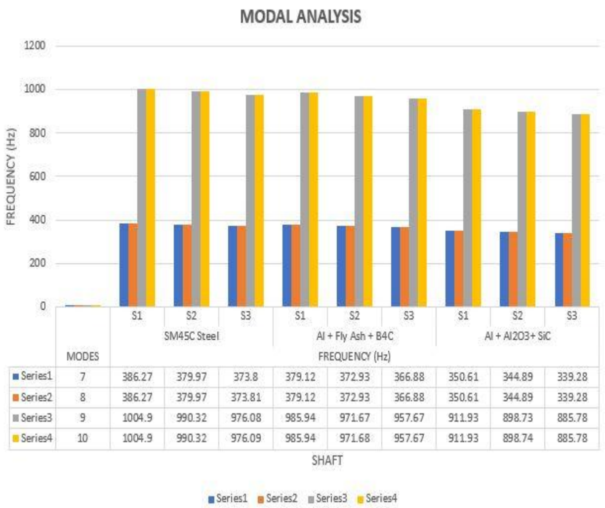


Fig 44. Graph .5. Shear Strain Results.

From the above graph 5, Shear strain is closer together in composite shafts than it is in steel shafts. On the other hand, Aluminium Alloy + Fly Ash + B4C has a higher value than the others.

6. Modal Analysis Results:

From the above graph 6, shows the Steel shafts have a greater frequency than metal matrix composites in terms of frequency. The frequency is closer to steel in Aluminium Alloy + Fly Ash + B4C.



	MODES	SM45C Steel S1	SM45C Steel S2	SM45C Steel S3	Al + Fly Ash + B4C S1	Al + Fly Ash + B4C S2	Al + Fly Ash + B4C S3	Al + Al2O3+ SiC S1	Al + Al2O3+ SiC S2	Al + Al2O3+ SiC S3
		FREQUENCY (Hz)								
Series1	7	386.27	379.97	373.8	379.12	372.93	366.88	350.61	344.89	339.28
Series2	8	386.27	379.97	373.81	379.12	372.93	366.88	350.61	344.89	339.28
Series3	9	1004.9	990.32	976.08	985.94	971.67	957.67	911.93	898.73	885.78
Series4	10	1004.9	990.32	976.09	985.94	971.68	957.67	911.93	898.74	885.78

Fig 45. Graph .6. Modal Analysis Results.

7. Modal Total Deformation Results:

	Maximum (mm) S1	Maximum (mm) S2	Maximum (mm) S3	Minimum (mm) S1	Minimum (mm) S2	Minimum (mm) S3
SM45C Steel	21.779	18.427	16.345	0.022973	0.20332	0.081021
Al + Fly Ash + B4C	37.292	31.552	27.989	0.030806	0.34379	0.056966
Al + Al2O3+ SiC	33.587	28.417	25.209	0.014397	0.3115	0.051336

Fig 46. Graph .7. Modal Total Deformation Results.

From the above graph 7, shows the deformation of the shafts caused by frequency. When Aluminium Alloy + Fly Ash + B4C is combined, the maximum deformation is achieved. As a result, it is preferable to utilise among the others.

VII. CONCLUSION

Thus, it can be concluded that metal matrix composite material can be the best alternative to use for application of propeller shaft compared to sm45c steel shaft as the weight of metal matrix composite material is less than sm45c steel shaft. Even the deformation, von-misses stress and stress induce due to the condition are much less in composite material compared to steel, out of all the selected metal matrix composite material, it can also be concluded that, Aluminium Alloy + Fly Ash + B4C is the best material for the application of propeller shaft. The present work was aimed at reducing the fuel consumption of the automobile in particular or any machine, which employs drive shaft. This was achieved by reducing the weight of the drive shaft with the use of metal matrix composite material. This also allows the use of a single drive shaft (instead of a two-piece drive shaft) for transmission of power to the differential part of the assembly.

Thus, the part complexity is reduced apart from being lightweight; the use of composite also ensures less noise and has excellent vibration damping. Composites require less assembly time, inventory cost and maintenance compared to steel. The composites are recyclable so they can be reuse. So, in comparison of mass, cost, safety and recycling steel shaft can be replaced by composite drive shaft.

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