International Journal of Ignited Minds (IJIMIINDS)

Static and Modal Analysis of Automotive Propeller Shaft for Performance Optimization

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ABSTRACT

Latest research on material with vast material combination gives option for replacing the conventional material with that of composite which helps in reducing the material cost, high strength and higher specific stiffness of composite materials. This work deals with replacement of conventional material with that of multi-layer composite material like e-glass/epoxy, high strength and high modulus carbon/epoxy composite drive shaft for automobile shaft for an automotive application. The design parameters (composite material) were optimized with the objective on minimizing the weight of composite propeller drive shaft. For this study, conventional FEA Software like ANSYS is used.

Keywords - *Conventional material, e-glass/epoxy, FEA, Composite, drive shaft, design parameters.*

1. INTRODUCTION

The main aim of this project is to conduct finite element analysis and to optimize the design with composite material. The common material for construction is high quality steel (Steel SM45). Due to high specific strength (strength/density) and high specific modulus (modulus/density) the advanced composite materials like Graphite, Carbon, Kevlar and Glass with suitable resins are widely used. The purpose of static analysis is to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not promote significant inertia and damping effects. However a static analysis can include steady inertia loads such as gravity, spinning and time varying loads. The modal analysis is necessary because1st mode frequency of vibration should be less than shaft operating frequency to avoid the failure of propeller shaft. Mujahid Khan, M. A. Mateen, D. V. Ravi Shankar [1] investigated the Design and Development of composite/ Hybrid Propeller Shaft. Arun Ravi [2] investigated Design, Comparison and Analysis of a Composite Propeller Shaft for an automobile. Parshuram D, Sunil Mangsetty [3] investigated Design and Analysis of Composite/Hybrid Propeller Shaft for Automotive.

2. RESULTS AND DISCUSSIONS

2.1 Geometry

Model of the propeller shaft is created in Solidworks and the cross section of the shaft is considered to be hollow circular section, in our analysis we have considered hollow circular cross-section was chosen because of the fallowing reasons. The hollow circular shafts are stronger in weight than that of solid circular per kg and the stress distribution in hollow shaft variation is smaller case compared to solid shaft which will have zero at the center and maximum at the outer surface, this is due to the fact that material close to the center are not fully utilized.

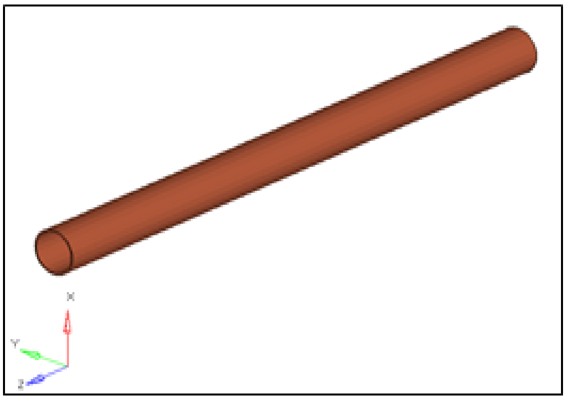


Fig 2.1: Geometry of body.

Geometric Parameters

Parameters	Values	Unit
Length	1250	mm
Outer Diameter	90	mm
Thickness	3.3	mm

Fig 2.2: Geometry Parameters.

2.3 Boundary Conditions

The shaft geometry is imported in Ansys and 2D shell meshing is carried out on the mid surface. The propeller shaft is modeled with good quality of shell elements with global element size of 10 mm. Maximum working torque is applied at one end of the shaft & other end is held fixed at all DOF (Degrees of Freedom).

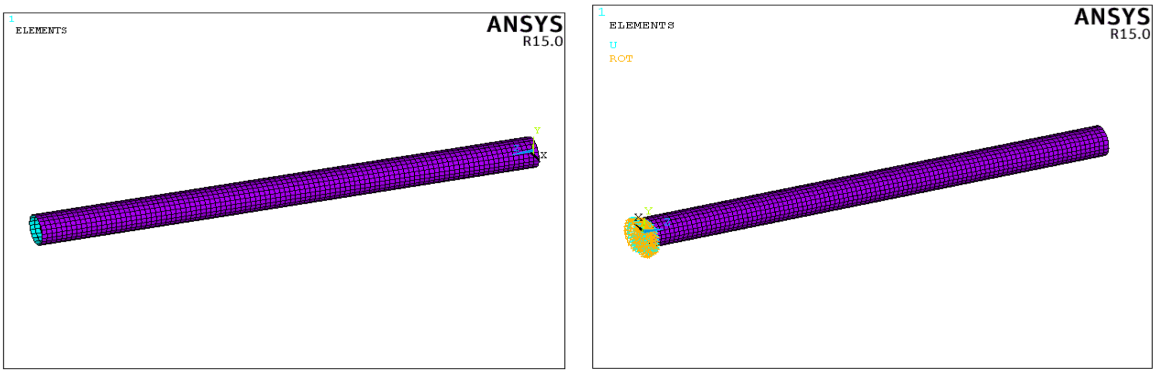


Fig 2.3: FE Model and Constrained at one end in all 6 DOF.

2.4 Loading Conditions

The designed twisting torque of 3500 N-m is applied at the other end of the shaft about Z axis as shown below.

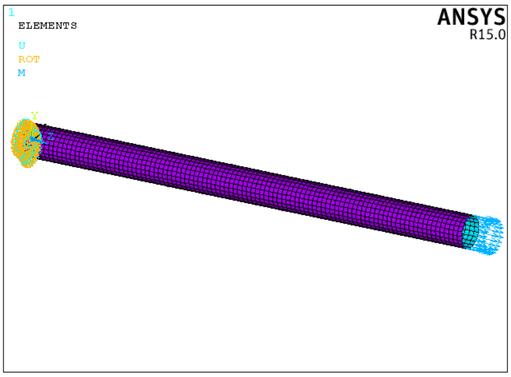


Fig 2.4: Loading Condition

Parameter	Values	Units
Young's Modulus (E)	210	GPa
Poisson's ratio	0.3	
Density	7850	Kg/m^3

Table 2.4: Material Properties (steel).

2.5 Displacement, von-Mises Stress and Mode Shape plot for Steel

The maximum displacement at the free end is found to be 1.524 mm and Max von-Mises stress is 154.79 Mpa and is shown in the figure below.

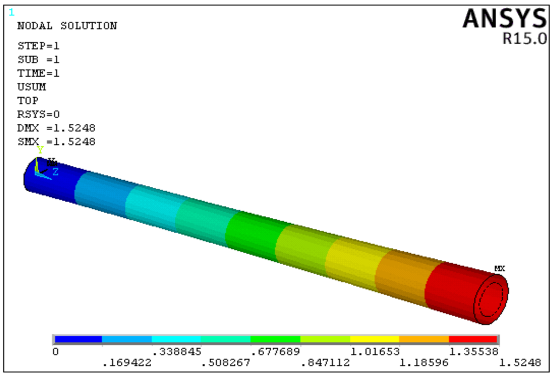


Fig 2.5.1: Displacement plot

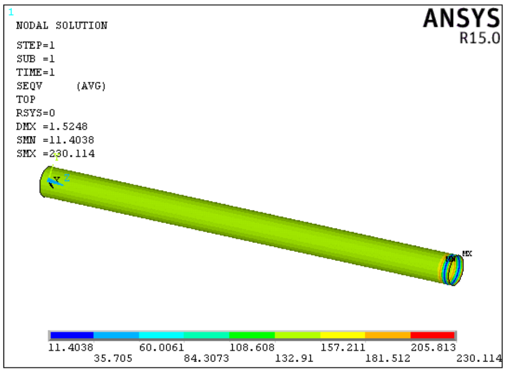


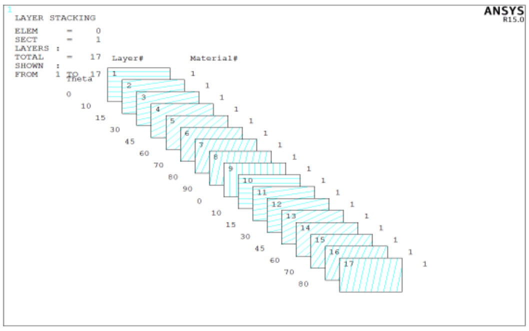
Fig 2.5.2: Von-Mises plot

2.6 Propeller shaft with Carbon Epoxy Resin

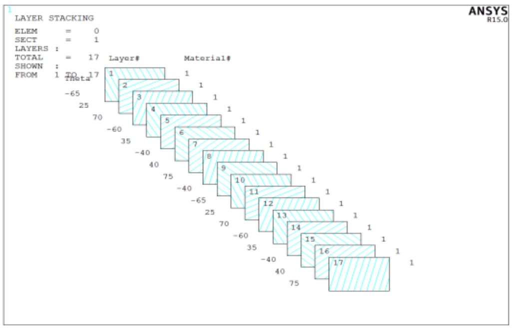
Parameter	Values	Units
Young's Modulus (E11)	134	GPa
Young's Modulus (E22)	7.0	GPa
Rigidity Modulus (G12)	5.8	GPa
Poisson's ratio	0.3	
Density	1600	Kg/m^3

Table 2.6: Material Properties Carbon-Epoxy Resin.

Various possible combinations of the stacking sequence of the carbon lamina were made like [0/10/15/30/45/60/70/80/90]$_s$, [10/-30/45/-20/-45//55/-60/75/-80]$_s$, [-55/-50/75/-80/65/70/15/-45/-75]$_s$, [45/-65/-15/-10/40/-85/-30/20/30]$_s$, and the best result was found for [-65/25/70/-60/35/-40/40/75/-40]$_s$. Where the displacement at the free end is 1.24 mm and von-Mises stress is 46Mpa which is shown in figure below.



(a) [0/10/15/30/45/60/70/80/90]$_s$



(b) [-65/25/70/-60/35/-40/40/75/-40]$_s$.

Fig 2.6.1: Stacking Sequence of Carbon-Epoxy Resin.

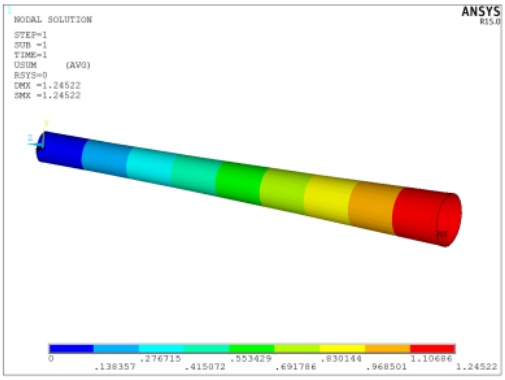


Fig 2.6.2: Displacement plot.

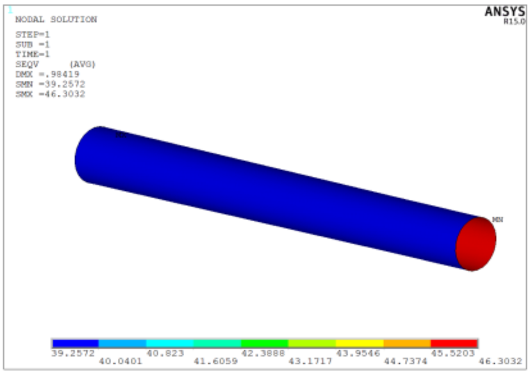


Fig 2.6.3: Von-Mises plot.

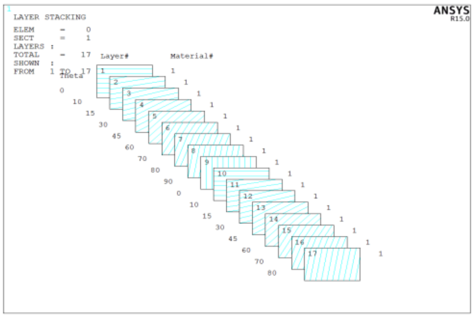
2.7 Propeller shaft with Glass-epoxy resin

The glass fiber with epoxy material properties used for the analysis purpose is listed below.

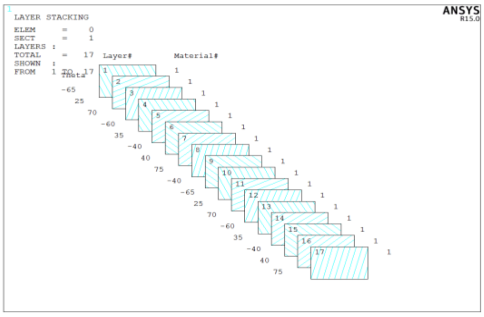
Parameter	Value	Units
Young's Modulus	50	GPa
Young's Modulus	12	GPa
Rigidity Modulus	5.6	GPa
Poisson's ratio	0.3	
Density	2000	Kg/m^3

Table 2.7: Material Properties Glass-Epoxy Resin.

Similarly like the previous case here also a different combination of stacking sequence of glass-epoxy resins have been used to get suitable results .The different combinations are $[0/10/15/30/45/60/70/80/90]_s$, $[10\text{-}30/45/\text{-}20/\text{-}45/55/\text{-}60/75/\text{-}80]_s$, $[\text{-}55/\text{-}50/75/\text{-}80/65/70\text{-}15/\text{-}45/\text{-}75]_s$, $[45/\text{-}65/\text{-}15/\text{-}10/40/\text{-}85/\text{-}30/20/30]_s$, $[\text{-}65/25/70/\text{-}60/35/\text{-}40/40/75/\text{-}40]_s$. The maximum displacement at the free end is found to be 2.81mm and Von-Mises stress is 62Mpa.



(a) $[0/10/15/30/45/60/70/80/90]_s$



(b) $[-65/25/70/-60/35/-40/40/75/-40]_s$

Fig 2.7.1: Stacking Sequence of the Properties Glass-Epoxy Resin.

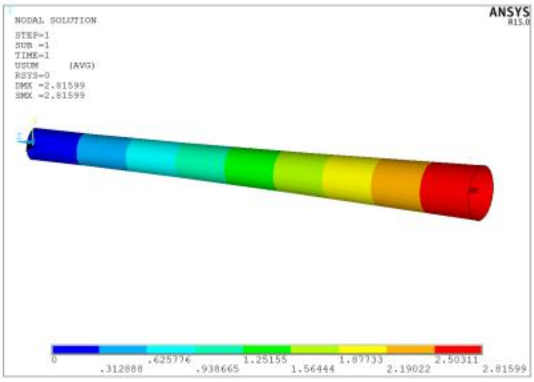


Fig 2.7.2: Displacement plot

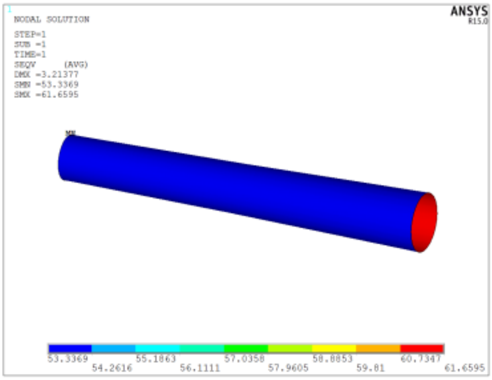


Fig 2.7.3: Von-Mises plot

Material	Weight (Kg)
Steel	8.82
Carbon-Epoxy	2.25
E Glass Epoxy	1.8

Table 3.1: Mass of the propeller shaft.

Material	**Lamina Orientation**	**Displacement (mm)**	**von-Mises stress (MPa)**
Steel	-	1.5	155
Caron - Epoxy	[0/10/15/30/45/60/70/80/90]$_s$	12.9	292
	[10/-30/45/-20/-45/55/-60/75/-80]$_s$	5.1	153
	[-55/-50/75/-80/65/70/15/-45/-75]$_s$	5.5	268
	[45/-65/-15/-10/40/-85/-30/20/30]$_s$	1.6	78
	[-65/25/70/-60/35/-40/40/75/-40]$_s$	1.2	46
E Glass - Epoxy	[0/10/15/30/45/60/70/80/90]$_s$	15.3	136
	[10/-30/45/-20/-45/55/-60/75/-80]$_s$	10.6	133
	[-55/-50/75/-80/65/70/15/-45/-75]$_s$	11.3	234
	[45/-65/-15/-10/40/-85/-30/20/30]$_s$	3.2	93
	[-65/25/70/-60/35/-40/40/75/-40]$_s$	2.8	62

Table 3.2: Stress and Displacement Induced in the Propeller Shaft.

Frequency (Hz)											
Mode No	**Steel**	**Carbon-Epoxy Composite**					**E Glass-Epoxy Composite**				
		Itr-1	**Itr-2**	**Itr-3**	**Itr-4**	**Itr-5**	**Itr-1**	**Itr-2**	**Itr-3**	**Itr-4**	**Itr-5**
1	327	332	348	274	377	301	500	557	423	616	460
2	837	816	904	723	964	796	1211	1454	1122	1574	1226
3	1180	934	1175	1346	1415	1402	1252	1861	2098	2277	2255
4	1221	1111	1205	1401	1515	1433	1669	1897	2234	2357	2296
5	1250	1182	1303	1467	1571	1485	1777	2039	2349	2443	2306
6	1327	1301	1303	1501	1698	1485	1961	2039	2397	2651	2306

Table 3.3: Natural frequencies of the Propeller Shaft.

3. CONCLUSION

The stacking sequence of the lamia is playing vital role in stress distribution and the maximum deformation in the shaft. The optimum stacking of the lamina helps to reduce weight and stress acting on the Propeller shaft. From the results of Finite Element Analysis, it is concluded that the optimum stacking sequence will be $[-65/25/70/-60/35/-40/40/75/-40]_s$ .The weight savings of the High strength carbon/epoxy is equal to 75 % approximately of the steel shaft. The weight savings of the E Glass/Epoxy is equal to 80 % approximately of the steel shaft .The stresses and displacement induced in the composite shaft with optimum sequence is less than the steel shaft .From the FE results it is clear that the steel material can be replaced with composite material for the propeller shaft.

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