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Modelling And Analysis of a High-Speed Hybrid Automotive Composite Propeller Shaft Using Ansys 18.1

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Abstract - *Due to their superior strength to weight ratio, composite constructions have many advantages over traditional metallic ones. Due to their benefit of having a greater specific stiffness, laminated composites have become widely used in the field of torque carrying constructions. Composite drive shafts have the potential to be the lighter, more durable, and higher critical speed drive train. This research investigates various composite material combinations and different stacking sequences that are the opposite of the torque direction to provide an alternative to the conventional steel drive shaft for an automotive application. ANSYS 18.1 is also used to calculate the natural frequency of the composite drive shaft.*

Keywords1: Composite drive shaft, ANSYS 18.1, finite element method, torsional rigidity.

1. INTRODUCTION

Another way to define composite materials is as a significant amalgamation of two or more materials with a distinguishable interface. The fiber or particle phase of composite materials is often stiffer and stronger than the continuous phase. Nowadays, individuals use composite materials in a variety of industries, including aerospace, automotive, construction, and others.

2. LITERATURE REVIEW

Kim et al. 2001, [20] examined composite propeller shafts bonded joints aluminium yoke and composite single layer joint has been carried out and found the combination of length, diameter, and thickness for 3500 Nm static torsion capacity.

According to Lee et al. (2004) [18], their proposed aluminium composite shaft had a mass reduction of 75% and a torque capacity improvement of 160%. The impact of fiber orientation angles and stacking order on the torsional stiffness, natural frequency, buckling strength, fatigue life, and failure modes of composite tubes was examined by Badie et al. in 2006 [29]. The maximal torsion capability of the hybrid aluminium/composite shaft was investigated by Mutasher in 2009 [17] for various winding angles, layer counts, and stacking orders. According to research by Talib et al. from 2010 [30], the drive shaft loses 46.07% of its buckling strength as the stacking sequence goes from the best to the poor.

3. PROBLEM FORMULATION

A comparative study will be done with the base paper B James Prasad Rao to find out better combination of materials for composite shaft to withstand torsion and have a longer life. Therefore, a drive shaft made of composite material with different materials like carbon fibre, aramid fibre and boron with different stacking sequence will be analysed for torsional rigidity and natural vibration. By applying clockwise torque and counterclockwise torque the influence will be discovered in such a loading condition.

Validation

As per base paper the composite propeller shaft technical data are.

Propeller shaft length = 1730 mm

The Mean radius of the shaft = 40 mm

The thickness of composite shaft = 4.578mm (Carbon/epoxy shaft)

Torque applied (Maximum) = 2030 N-m

Stacking sequence 45°/-45°/45°/-45°

Ansys 18.1 software is used for the analysis. Shear stress between layers have been plotted in Table 1 and the values are in line with the base paper a few of them have been shown from Figure 1 to 8. Figure 1 shows the validation of shear stress of carbon epoxy for layer 1 top side, all the contour figures have not been shown they are represented with their following values in Table 1. Figure 2 shows shear stress for carbon epoxy for layer 4 top side, as composite is made in sandwich system therefore while application of torsion stresses will be induced between the two successive layers that is represented in these contours. Figure 3 shows shear stress for carbon epoxy for layer 4 bottom side, Figure 4 shows shear stress for carbon epoxy for layer 6 topside, the maximum value of shear stress has been considered. Figure 5 shows shear stress for carbon epoxy for layer 6 bottom side, the drive shaft is considered as fixed from one end as one end is towards the wheel and it takes a lot of effort to overcome inertia and bring the wheels in motion the other side is connected towards the engine side which delivers the torque therefore, torque is applied as mentioned in the base paper. Figure 6 shows shear stress for carbon epoxy for layer 8 bottom side, Figure 7 shows shear stress for carbon epoxy for layer 10 top side, Figure 8 shows shear stress for carbon epoxy for layer 10 bottom side.

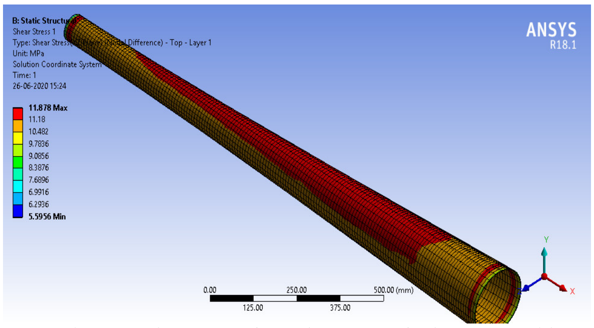

Figure 1: Shear stress for carbon epoxy for layer 1 top side

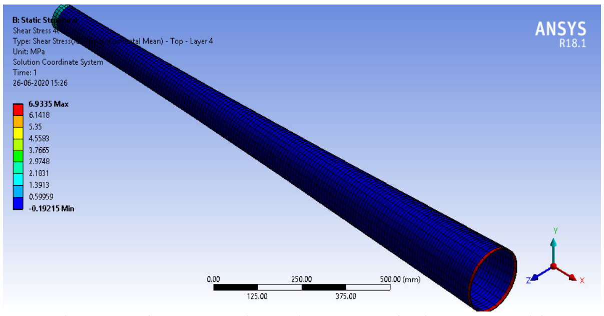

Figure 2: Shear stress for carbon epoxy for layer 4 top side

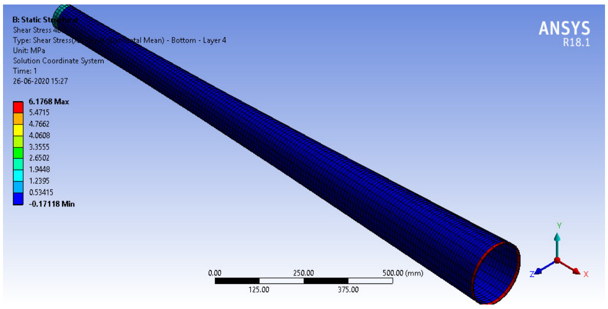

Figure 3: Shear stress for carbon epoxy for layer 4 bottom side

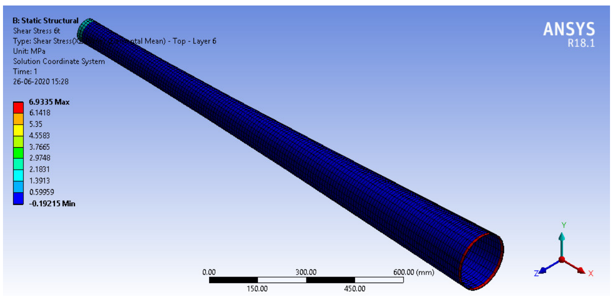

Figure 4: Shear stress for carbon epoxy for layer 6 topside

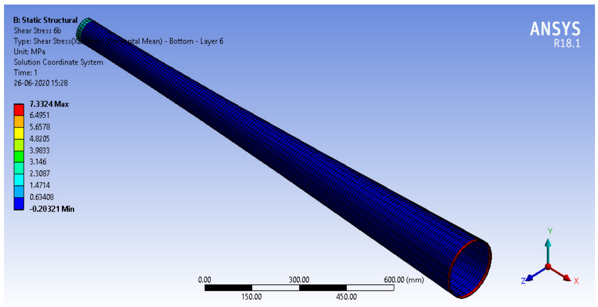

Figure 5: Shear stress for carbon epoxy for layer 6 bottom side

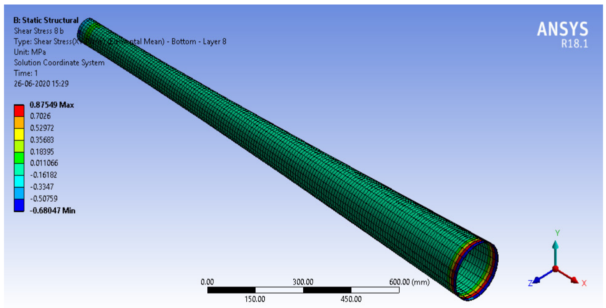

Figure 6: Shear stress for carbon epoxy for layer 8 bottom side

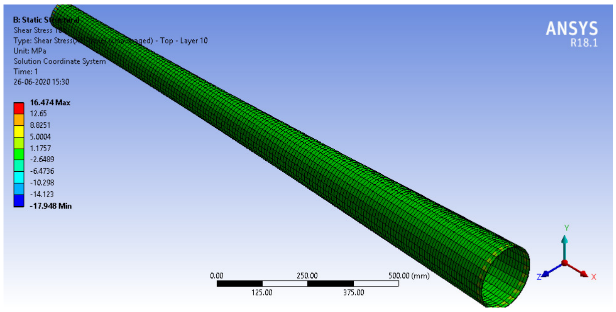

Figure 7: Shear stress for carbon epoxy for layer 10 top side

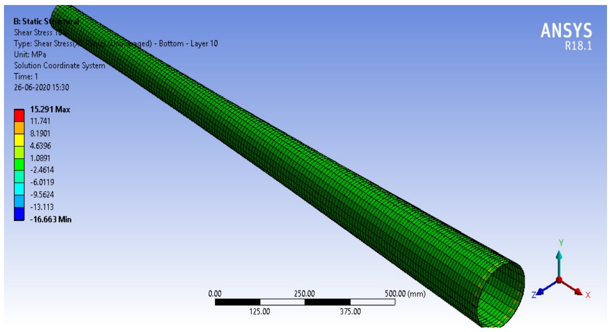

Figure 8: Shear stress for carbon epoxy for layer 10 bottom side

Table 1: Validation of Shear Stress Carbon/Epoxy

4. RESULTS

4.1. Comparative study based on different materials.

In this section carbon/epoxy is altered with boron/epoxy and aramid/epoxy and their comparative study will determine the better material amongst the three. Table 2 shows the different material properties which have been obtained from [13], [31] respectively.

Material's Name	E1(GPa)	E2(GPa)	Poisson's ratio	G12 (GPa)	G23(GPa)	G31(GPa)	Density (g/cm^3)
Boron/ Epoxy	204	18.5	0.23	5.59	——	——	2.00
Aramid/Epoxy	20.4	8.90	0.31	1.64	3.03	1.64	1.23

Table 2: Material Properties

Table 3: Comparison of Different Material Composite Shaft

Material Name	Shear stress Layer 1 Top (MPa)	Shear stress Layer 6 bot (MPa)	Shear stress Layer 10 bot (MPa)	Max Shear stress (MPa)	Von Mises stress (MPa)
Boron/ Epoxy	0.0033	.0018	9.8391	191.99	368.08
Aramid /Epoxy	19.848	3.372	21.541	87.75	151.99

From table 3 it can be clearly stated that shear stress between two layers is varying and not giving a clear consensus but maximum shear stress and Von-mises stress clearly states that aramid/epoxy is a better material for automotive propeller shaft.

4.2. Comparative study based on stacking sequence.

Table 4: Stacking Schemes

S.No.	Stacking definition
Case 1	0°/90°/45°/-45°/45°/-45°/45°/-45°/45°/-45°
Case 2	45°/-45°/45°/-45°/0°/90°/45°/-45°/45°/-45°
Case 3	0°/45°/-45°/45°/-45°/45°/-45°/45°/-45°/90°

Layer No.	Shear stress Carbon/Epoxy		
	ANSYS Base paper (Ref)	**CADEC Base paper (Ref)**	**ANSYS 18.1.**
1 - Top	11.2	13.03	11.878
1 - Bot	10.2	12.6	11.034
2 - Top	0.172	0.131	0.184
2 - Bot	0.181	000.127	0.193
3 - Top	-0.16	-0.139	-0.156
3 - Bot	-0.172	-0.132	-0.168
4 - Top	6.52	6.91	6.933
4 - Bot	6.21	6.78	6.176
5 - Top	6.87	6.832	6.942
5 - Bot	6.26	6.64	6.523
6 - Top	7.47	7.01	6.933
6 - Bot	6.87	6.882	7.332
7 - Top	7.84	7.39	7.721
7 - Bot	7.64	7.317	8.015
8 - Top	0.018	-0.186	.0271
8 - Bot	0.09	-0.181	0.875
9 - Top	0.072	0.191	0.210
9 - Bot	0.081	0.186	0.095
10-Top	18	15.3	16.474
10 - Bot	16.4	14.75	15.291

In this section aramid/epoxy is considered and stacking sequence as shown in table 4 is taken and comparative study will be done.

Table 5: Comparison of Different Stacking Sequence

Material Name	Shear Stress layer 1 Top (MPa)	Shear Stress layer 6 bot (MPa)	Shear Stress layer 10 bot (MPa)	Max Shear stress (MPa)	Von-Mises Stress (MPa)
Case 1	28.029	14.099	21.51	87.75	151.99
Case 2	19.848	4.5914	21.51	87.57	151.99
Case 3	28.029	3.2671	-26.97	87.57	151.99

Based on different stacking sequence the resultant stress between two layers where the stacking sequence have changed the shear stress between the two layers have also changed while between the successive layers for two different cases where there is no change the shear stress between layers is same. But the maximum shear stress and von-mises stress have no change in values for all the three cases as shown in table 5. Layer 1 top, layer 6 bottom and layer 10 bottom have been chosen randomly and have been used for comparison of all the cases. This helps to conclude that stacking sequence plays a vital role in fabrication of composites.

4.3. Comparative study based on the direction of application of torque.

A stacking sequence showing good results may not be able to exhibit the same strength in opposite torque direction of rotation. Thus, clockwise, and counterclockwise rotation is also needed to be examined. In the above case clockwise direction aramid/epoxy is already taken care of therefore, only counterclockwise direction analysis contours are needed which is shown in table 6.

Table 6: Comparison of Clockwise and Counter Clockwise Torque Direction

Material name	Shear stress layer 1 Top (MPa)	Shear stress layer 6 bot (MPa)	Shear stress layer 10 bot (MPa)	Max. Shear Stress (MPa)
Clockwise	19.848	3.372	21.541	87.75
Counter-Clockwise	19.848	14.099	21.51	87.57

Many at times it is seen that while changing the direction of the rotation of shaft the same stacking sequence do not play the same role as in automotive propeller shaft forward direction as well as reverse direction both are supposed to be used therefore, clockwise and counter clockwise both cases are investigated and found that in between some layers shear stress is varying.

4.4. Free vibration analysis

The composite propeller shaft underwent free vibration analysis to determine the fundamental and derived natural frequencies; figure 7 displays the corresponding mode failure shapes. Boundary conditions No load is imparted to the shaft other than by presuming that it is a pinned-pinned shaft.

Table 7: Comparison of Natural Frequency

Mode number	Frequency (Hz)-Boron	Frequency (Hz)-Aramid
1	43.446	24.496
2	43.447	24.517
3	216.47	151.28
4	216.48	151.31
5	233.09	412.13
6	233.09	412.22

Limitations

1. The fabrication of composite shafts has been significantly hampered by the cost constraints present in a mass production industry.

2. Aramid/ epoxy is an expensive material.

3. Impact analysis is also needed to be taken care of as drive shaft may be subjected different kinds of shocks which can be another case of failure.

4. In case of failure of drive shaft plastic welding type option is needed.

5. CONCLUSION

Two different materials namely boron/epoxy, aramid/epoxy, three different stacking sequences and two different directions of torque rotation clockwise and counter clockwise and finding their natural frequencies are considered and finite element modelling is done, and numerical problem is analyzed by the help of ANSYS 18.1 workbench. The results obtained may be concluded as:

I. In all the three materials aramid/epoxy is found to be the best compared with boron and carbon/epoxy composite.

II. In all the three stacking sequences the layers where angle of fiber direction is changed exhibiting change in shear stress values between those two layers therefore it can be concluded that stacking sequence plays a vital role and stacking sequence should be chosen as per the application perspective.

III. Clockwise and counter clockwise direction of application of torque shows that with the change in torque direction the shear stress varies among few layers. Thus, it also plays an important role in fabrication of composites.

IV. Fundamental and derived natural frequencies are known this helps to know the mode I, mode II, etc. failure.

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