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Investigation of Effect of Stacking Sequence and Fibre Orientation on Maximum Torque Transmission Capacity of an Composite Automobile Driveshaft by Analytical & FEA Methods

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ABSTRACT

In this thesis an investigation is carried out on Composite Drive Shaft for different Stacking Sequence and for different fiber angle orientation. A one-piece drive shaft for rear wheel drive automobile was designed optimally using E-Glass/Epoxy and High modulus (HM) Carbon/Epoxy composites. In this thesis an Analytical and ANSYS Software has been successfully applied to minimize the weight of shaft which is subjected to the constraints such as torque transmission, Static Structural capacities, Torsional Buckling Torque. The results of Analytical Analysis are used to perform static analysis using ANSYS software. The results show the stacking sequence and fiber angle orientation of shaft strongly affects static strength as well as the Buckling Capacity of shaft. It is possible to optimize the 83% weight than the Steel Shaft and 43% weight than the Aluminum Shaft in case of Composite Shaft.
Keywords: - E-Glass/Epoxy, ANSYS

1.INTRODUCTION

A composite material or a compound is a mixture of two or more distinct constituents all of which are present in reasonable proportions and have different properties so that the composite properties exhibited are the combination of the best qualities of their constituents and also some qualities that neither of their constituents possesses. Plastic is not a composite because it is compound. An alloy is not composite because it is a homogeneous mixture. Following are some of the properties that can be improved by forming a composite material Strength, Stiffness, Corrosion resistance, Wear resistance, Weight, Fatigue failure. In the present work an attempt is made to evaluate the suitability of composite material such as E-Glass/Epoxy and Carbon/Epoxy etc. for the purpose of automotive transmission applications. A one-piece composite drive shaft for automobile is designed and analyzed using suitable FEM package respectively for E-Glass/Epoxy and Carbon/Epoxy etc. composites with the objective of minimization of weight of the shaft which is subjected to the constraints such as torque transmission, torsional buckling strength capabilities.
Objective of the work:

- Static Structural Analysis for Effect of fibers angle and stacking sequence.
- Buckling Analysis for different fiber orientations and stacking sequence.
- Comparison conventional shaft (Metal and Alloys) with composite shaft.

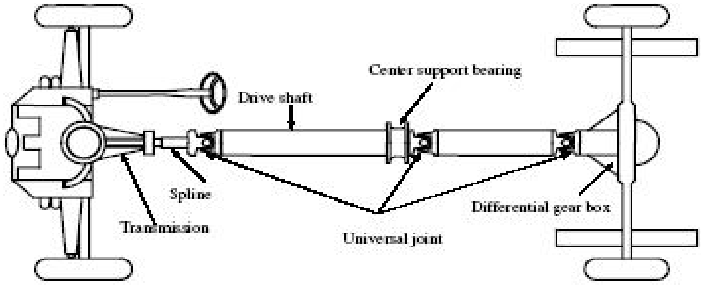


Figure 1 conventional two-piece drive shaft arrangement for rear wheel vehicle driving system

2.LITERATURE REVIEW

M.A. Badie et al. [1] examines the effect of fiber orientation angles and stacking sequence on the torsional stiffness, natural frequency, buckling strength, fatigue life and failure modes of composite tubes. Mahmood M. Shokrieh et al. [2] has done Shear buckling of composite drive shaft under torsion was performed using FEM. S.A. Mutasher [3] investigates the maximum torsion capacity of the composite shaft for different winding angle, number of layers and stacking sequences. This study makes a case for further investigation on the torsional strength of composite shaft. R. Sino et al [4] is investigated the dynamic instability of an internally damped rotating composite shaft. A homogenized finite element beam model, which takes into account internal damping, is introduced and then used to evaluate natural frequencies and instability thresholds. The influence of laminate parameters: stacking sequences, fiber orientation, transversal shear effect on natural frequencies and instability thresholds of the shaft are studied.

3.ANALYTICAL VALIDATION

3.1 Static Structural Analysis for Composite Shaft:-

$$\frac{1}{E_{11}} = \frac{\cos^4\theta}{Exx} + \frac{\sin^4\theta}{Eyy} + \left(\frac{1}{G_{12}} - \frac{2\mu_{12}}{E_{xx}}\right)\sin^2\theta\, cos^2\theta$$

$$= \frac{1}{40.3\times10^3}\cos^4\theta + \frac{1}{6.21\times10^3}\sin^4\theta + \left(\frac{1}{3.07\times10^3} - \frac{2\times0.2}{40.3\times10^3}\right)\sin^2 10 cos^2 10$$

$$E_{11} = 30.57\times10^3\ N/mm^2$$
$$E_{22} = 6.222\times10^3\ N/mm^2$$

$$\mu_{12} = E_{11}\left(\frac{\mu_{xy}}{E_{xx}}(\sin^4\theta + \cos^4\theta) - \left[\frac{1}{E_{11}} + \frac{1}{E_{22}} - \frac{1}{G_{12}}\right]\sin^2\theta\, cos^2\theta\right)$$

$=30.57$

$$\times 10^3\left(\frac{0.2}{40.3\times10^3}(\sin^4(10) + \cos^4(10)) - \left[\frac{1}{40.3\times10^3} + \frac{1}{6.21\times10^3} - \frac{1}{3.07\times10^3}\right]\sin^2(10)\, cos^2(10)\right)$$

$\mu_{12} = 0.2678$

$\mu_{21} = 0.0545$

$$\frac{1}{G_{12}} = 2\left(\frac{2}{E_{xx}} + \frac{2}{E_{yy}} + \frac{4\mu_{xy}}{E_{xx}} - \frac{1}{G_{xy}}\right)\sin^2\theta\cos^2\theta + \frac{1}{G_{xy}}(\sin^4\theta\cos^4\theta)$$

$$= 2\left(\frac{2}{40.3\times10^3} + \frac{2}{6.21\times10^3} + \frac{4\times0.2}{40.3\times10^3} - \frac{1}{3.07\times10^3}\right)\sin^2(10)\cos^2(10) + \frac{1}{3.07\times10^3}(\sin^4 10\cos^4 10)$$

For 0° of glass:

$$\boxed{G_{12} = 3.22\times10^3\ N/mm^2}$$

$$\mu_{21} = \frac{E_{22}}{E_{11}}\times\mu_{12}$$

$$= \frac{6.21\times10^3}{40.3\times10^3}\times 0.2$$

$$= 0.031$$

$$Q_{11} = \frac{E_{11}}{1-\mu_{12}\mu_{21}}$$

$$= \frac{40.3\times10^3}{1-(0.2\times0.031)}$$

$$\boxed{Q_{11} = 40.55\times10^3\ N/mm^2}$$

$$Q_{22} = \frac{E_{22}}{1-\mu_{12}\mu_{21}}$$

$$= \frac{6.21\times10^3}{1-(0.2\times0.031)}$$

$$\boxed{Q_{22} = 6.25\times10^3\ N/mm^2}$$

3.2 Buckling Analysis for Composite Shaft:-

Buckling Analysis for Inner Layers:-

$$E_x = \frac{1}{t}\left[A_{11} - \frac{{A_{12}}^2}{A_{22}}\right]$$

$$= \frac{1}{2.032}\left[96.857\times 10^3 - \frac{(2.924\times 10^3)^2}{13.649\times 10^3}\right]$$

$$E_x = 47.358\times 10^3\ \text{N}/mm^2 = 47.358\times 10^9\ \text{N}/m^2$$

$$T_{cr} = \frac{2.289}{\sqrt{L}} \times (E_x)^{0.375} \times (E_y)^{0.625} \times (t)^{2.25} \times (D)^{1.25}$$

$$\frac{1.854}{\sqrt{1}} \times (47.358\times 10^9)^{0.375} \times (6.673\times 10^9)^{0.625} \times (2.032\times 10^{-3})^{2.25} \times (102.032\times 10^{-3})^{1.25}$$

$$T_{cr} = 1.610\times 10^6 \text{N-mm}$$

3.3 Static Structural Analysis for Aluminium Shaft

3.3.1 Shear Stress and Shear Strain Analysis:-

$$\text{T} = \frac{\pi}{16} \times \tau \times \left[\frac{{D_o}^4 - {D_i}^4}{D_o}\right]$$

$$\tau = \frac{16T\times D_o}{\pi[{D_o}^4 - {D_i}^4]}$$

$$\text{Shear stress} = \tau = \tau_{xy} = 10.7384 N/mm^2$$

$$= \frac{16\times 350\times 10^3\times 104.064}{\pi[104.064^4 - 100^4]}$$

$$\text{Shear strain} = \gamma_{xy} = \frac{shear\ stress}{modulus\ of\ rigidity} = \frac{\tau_{xy}}{G}$$

$$\gamma_{xy} = \frac{10.7384}{2.65\times 10^4}$$

$$\therefore \gamma_{xy} = 0.405\times 10^{-3}$$

3.3.2 Torsional Buckling Analysis of Aluminium Shaft

$$\text{If} \quad \frac{1}{\sqrt{1-\mu^2}} \times \frac{L^2 t}{(2r^2)} > 5.5$$

$$\text{Then we can use the formula, } \tau_{cr} = \frac{E}{3\sqrt{2}(1-\mu^2)^{3/4}} \times \left(\frac{t}{r}\right)^{3/2}$$

$$\therefore \frac{1}{\sqrt{1-0.3^2}} \times \frac{(10^3)^2\times 2.032}{(2\times 50^2)} > 5.5$$

$$= 8.132 > 5.5$$

Now we have $\mu = 0.3$, E = 69 $\times 10^3 N/mm^2$ for Aluminum

$$\tau_{cr} = \frac{69\times 10^3}{3\sqrt{2}(1-0.3^2)^{3/4}} \times \left(\frac{2.032}{50}\right)^{3/2}$$

$$\tau_{cr} = 143.009 N/mm^2$$

$$T_{cr} = \tau_{cr} \times 2\pi r^2 \text{t}$$

$$= 143.009 \times 2\pi \times (51.016)^2 \times 2.032$$

$$T_{cr} = 4.752\times 10^6\ N - mm$$

3.4Weight Calculation of Steel, Aluminum and Composite Shaft

3.4.1Weight of Steel Shaft:-

Weight= Density X Volume

$$W = \rho \times V$$

$$W = 7810 \times \pi r^2 \times L$$

$$= 7810 \times 10^{-9} \times \pi \times (ro^2 - ri^2) \times L$$

$$= 7810 \times 10^{-9} \times \pi \times (52.032^2 - 50.00^2) \times 1000$$

$$= 5.08699 \text{ Kg}$$

3.4.2Weight of Aluminum Shaft:-

Weight= Density X Volume

$$W = \rho \times V$$

$$W = 2700 \times \pi r^2 \times L$$

$$= 2700 \times 10^{-9} \times \pi \times (ro^2 - ri^2) \times L$$

$$= 2700 \times 10^{-9} \times \pi \times (52.032^2 - 50.00^2) \times 1000$$

$$= 1.7586 \text{ Kg}$$

3.4.3Weight of Composite Shaft:-

Weight= Density X Volume

$$W = \rho \times V$$

For Stacking Sequence Carbon Epoxy/ Glass Epoxy/ Glass Epoxy/ Glass Epoxy & Glass Epoxy/ Carbon Epoxy/ Glass Epoxy/ Glass Epoxy

$$W = (\rho \times V)_1 + (\rho \times V)_2 + (\rho \times V)_3 + (\rho \times V)_4$$

$$= (1910 \times 10^{-9} \times \pi \times (50.1905^2 - 50^2) \times 1000) + (1610 \times 10^{-9} \times \pi \times (50.381^2 - 50.1905^2) \times 1000) + (1910 \times 10^{-9} \times \pi \times (51.016^2 - 50.381^2) \times 1000) + (1910 \times 10^{-9} \times \pi \times (52.032^2 - 51.381^2) \times 1000$$

W= 1.226 Kg

For Stacking Sequence Glass Epoxy/ Glass Epoxy/ Carbon Epoxy/ Glass Epoxy

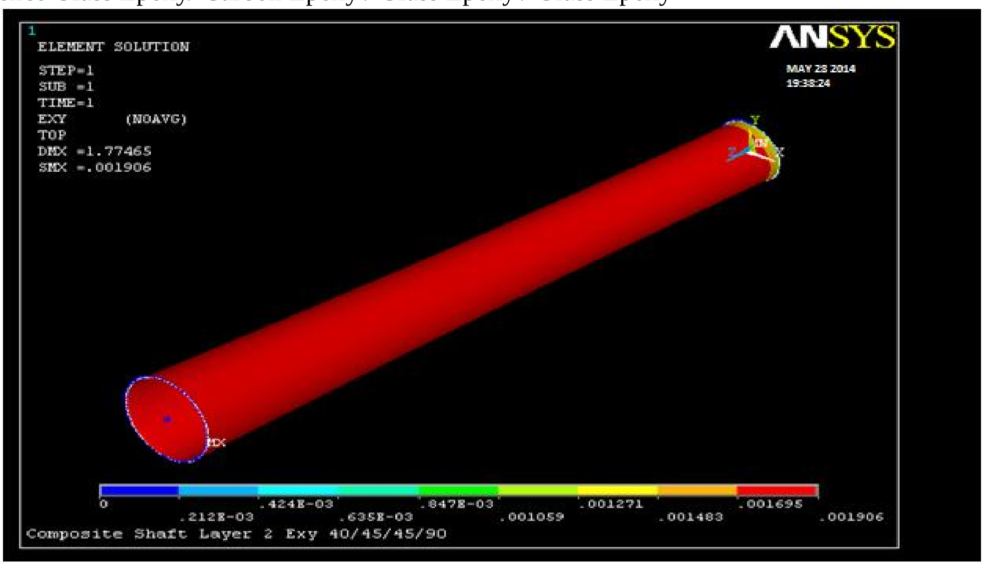
W = 0.9591 Kg

For Stacking Sequence Glass Epoxy/ Glass Epoxy/ Glass Epoxy/ Carbon Epoxy

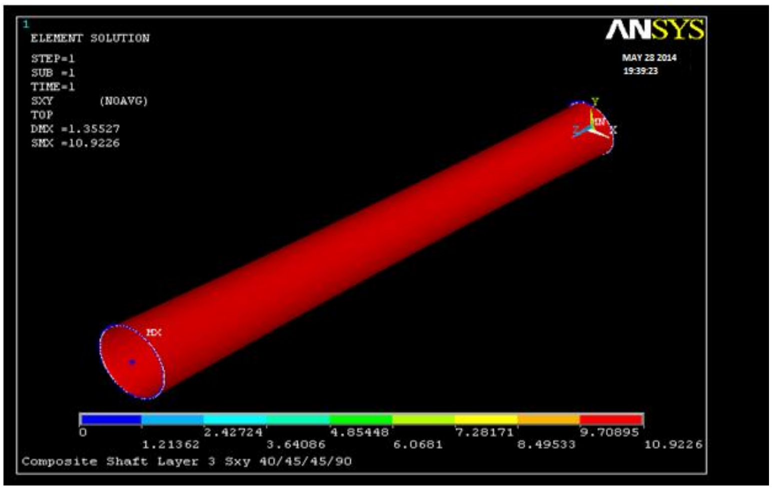
W= 0.9563 Kg

4 FINITE ELEMENT ANALYSIS

Stacking Sequence Glass Epoxy/ Carbon Epoxy / Glass Epoxy / Glass Epoxy

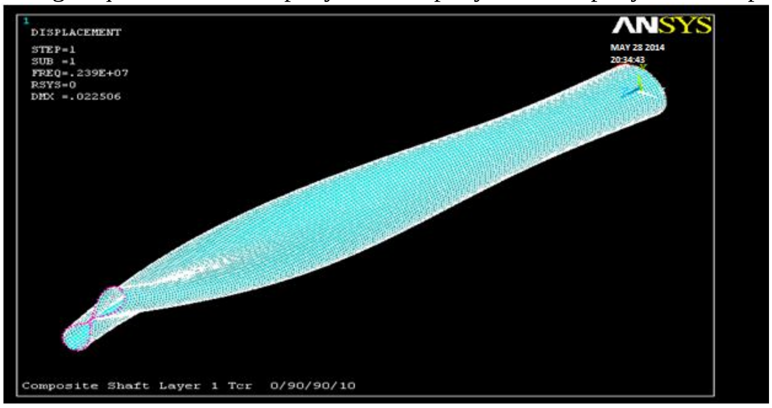


Stacking Sequence Glass Epoxy/ Glass Epoxy / Carbon Epoxy / Glass Epoxy

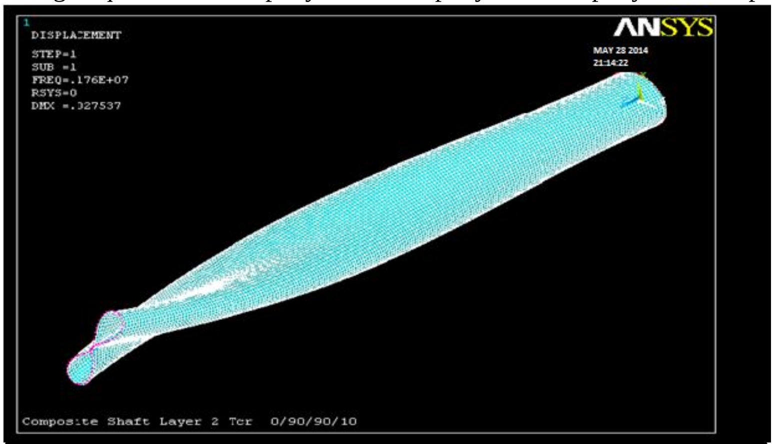


Torsional Buckling Analysis of Composite Shaft with Ansys

Stacking Sequence Carbon Epoxy/ Glass Epoxy / Glass Epoxy / Glass Epoxy



Stacking Sequence Glass Epoxy/ Carbon Epoxy / Glass Epoxy / Glass Epoxy



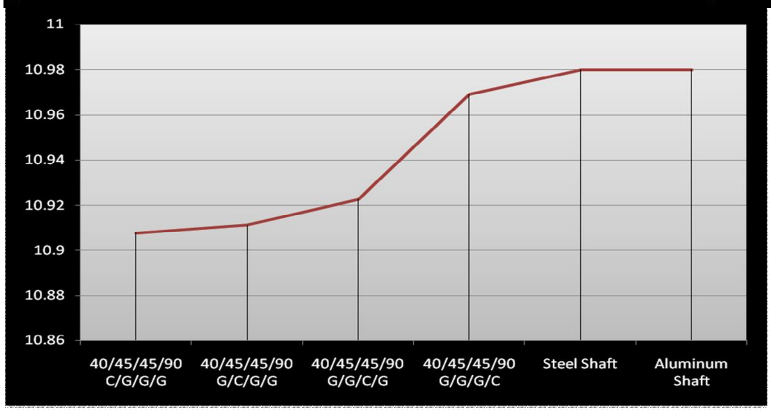


Fig. Comparison of Composite Shaft with Metal Shafts for Torsional Shear Stress

1 Conclusions ANSYS Result for Torsional Shear Stress and Shear Strain for Composite and Metal Shafts

Type of Shaft	Stacking Sequence	Fiber Angle Orientation	Torsional Shear Stress (N/mm^2)	Torsional Shear Strain	Weight of Shaft (Kg)
Composite Shaft	Carbon Epoxy /Glass Epoxy/ Glass Epoxy/ Glass Epoxy	$40^0/45^0/45^0/90^0$	10.9076	0.001952	1.226
Composite Shaft	Glass Epoxy /Carbon Epoxy/ Glass Epoxy/ Glass Epoxy	$40^0/45^0/45^0/90^0$	10.9112	0.001906	1.226
Composite Shaft	Glass Epoxy /Glass Epoxy/ Carbon Epoxy/ Glass Epoxy	$40^0/45^0/45^0/90^0$	10.9226	0.001436	0.9591
Composite Shaft	Glass Epoxy /Glass Epoxy/ Glass Epoxy/ Carbon Epoxy	$40^0/45^0/45^0/90^0$	10.9691	0.001529	0.9563
Steel Shaft	--	--	10.9799	0.000136	5.087
Aluminum Shaft	--	--	10.9799	0.000414	1.759

ANSYS Result for Torsional Buckling Torque for Composite and Metal Shafts

Type of Shaft	Stacking Sequence	Fiber Angle Orientation	Torsional Buckling Torque (N-mm)	Weight of Shaft (Kg)
Composite Shaft	Carbon Epoxy /Glass Epoxy/ Glass Epoxy/ Glass Epoxy	$0^0/90^0/90^0/10^0$	2.39×10^6	1.226
Composite Shaft	Glass Epoxy /Carbon Epoxy/ Glass Epoxy/ Glass Epoxy	$0^0/90^0/90^0/10^0$	1.76×10^6	1.226
Composite Shaft	Glass Epoxy /Glass Epoxy/ Carbon Epoxy/ Glass Epoxy	$0^0/90^0/90^0/10^0$	2.01×10^6	0.9591
Composite Shaft	Glass Epoxy /Glass Epoxy/ Glass Epoxy/ Carbon Epoxy	$10^0/0^0/90^0/10^0$	3.23×10^6	0.9563
Steel Shaft	--	--	14.00×10^6	5.087
Aluminum Shaft	--	--	4.59×10^6	1.759

From above comparison it is found out that there is very minor error occurs in Analytical and in ANSYS Method. To obtain optimum Torsional Shear Stress, Torsional Shear Strain and Torsional Buckling Torque we combine the fiber angle orientation and compare the Composite Shafts with Metal Shafts. For Torsional Buckling Torque of Drive Shaft the maximum permissible limit is 2.5×10^6 N-mm. Hence the Stacking Sequence Glass Epoxy/Glass Epoxy/ Glass Epoxy/ Carbon Epoxy with Fiber Angle Orientation $10^0/0^0/90^0/10^0$ give the Torsional Buckling Torque 3.23×10^6 N-mm which is beyond the permissible limit. For Optimum Torsional Shear Stress the Stacking Sequence Carbon Epoxy/Glass Epoxy/ Glass Epoxy/ Glass Epoxy with Fiber Angle Orientation $40^0/45^0/45^0/90^0$ gives the Torsional Shear Stress 10.9076 N/mm^2 which is less than 10.9799 N/mm^2 as compare to Steel Shaft and Aluminum Shaft.

The weight is almost reducing 80% than the steel shaft and 43% than Aluminum shaft in composite shaft.

REFERENCES

[1] M.A. Badie, E. Mahdi , A.M.S. Hamouda, “An investigation into hybrid carbon /glass fiber reinforced epoxy composite automotive drive shaft”, Materials and Design 32 (2011), pp 1485–1500.
[2] Mahmood M. Shokrieh, Akbar Hasani, Larry B. Lessard, “Shear buckling of a composite drive shaft under torsion”, Composite Structures 64 (2004), pp 63–69.
[3] S.A. Mutasher , “Prediction of the torsional strength of the hybrid aluminum/composite drive shaft”, Materials and Design 30 (2009), pp 215–220.
[4] R. Sino, T.N. Baranger, E. Chatelet, G. Jacquet, “Dynamic analysis of a rotating composite shaft”, Composites Science and Technology 68 (2008), pp 337–345.
[5] Y.A. Khalid, S.A. Mutasher, B.B. Sahari, A.M.S. Hamouda, “Bending fatigue behavior of hybrid aluminum/composite drive shafts”, Materials and Design 28 (2007), pp 329–334.
[6] Hak Sung Kim, Dai Gil Lee, “Optimal design of the press fit joint for a hybrid aluminum/composite drive shaft”, Composite Structures 70 (2005), pp 33–47.
[7] A.R. Abu Talib, Aidy Ali, Mohamed A. Badie, Nur Azida Che Lah, A.F. Golestaneh, “Developing a hybrid, carbon/glass fiber-reinforced, epoxy composite automotive drive shaft”, Materials and Design 31 (2010), pp 514–521.
[8] M. A. Badie, A. Mahdi, A. R. Abutalib, E. J. Abdullah and R. Yonus, “ Automotive Composite Drive Shafts Investigation of the Design Variable Effects”, IJET Vol. 3, No.2, 2006, pp. 227-237 .
[9] Nitin Gokhale, Sanjay Deshpande, Anand Thite, Practical Finite Element Analysis, Finite to Infinite, India.
[10] Y. Nakasone, S. YoshimotoT., A. Stolarski, Engineering Analysis With ANSYS Software, First edition 2006, Elsevier Butterworth-Heinemann Publication