Design and Optimization of Drive Shaft with Composite Materials

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Abstract: *Automotive drive Shaft is a very important components of vehicle. The overall objective of this paper is to design and analyze a composite drive shaft for power transmission. Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of composite materials. This work deals with the replacement of conventional two-piece steel drive shafts with a Composite material's. In this work Kevlar /Epoxy is used as composite material The design parameters were optimized with the objective of minimizing the weight of composite drive shaft. 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, stresses, natural frequencies under subjected loads using FEA. Further comparison carried out for both steel and composite materials and weight of the shaft is optimized and stress intensity factor found for both Steel and composite drive shafts.*

Keywords: *Stress intensity Factor, Defromation, Torsional stress, Drive Shaft, Modelanlysis*

I. INTRODUCTION

A driveshaft is a rotating shaft that transmits power from the engine to the differential gear of a rear wheel drive vehicles Driveshaft must operate through constantly changing angles between the transmission and axle. High quality steel (Steel SM45) is a common material for construction. Steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely proportional to the square of beam length and proportional to the square root of specific modulus. The two piece steel drive shaft consists of three universal joints, a center supporting bearing and a bracket, which increase the total weight of a vehicle. Power transmission can be improved through the reduction of inertial mass and light weight. Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials. Composite materials can be tailored to efficiently meet the design requirements of strength, stiffness and composite drive shafts weight less than steel or aluminum of similar strength. It is possible to manufacture one piece of composite. Drive shaft to eliminate all of the assembly connecting two piece steel drive shaft. Also, composite materials typically have a lower modulus of elasticity. As a result, when torque peaks occur in the driveline, the driveshaft can act as a shock absorber and decrease stress on part of the drive train extending life. Many researchers have been investigated about hybrid drive shafts and joining methods of the hybrid shafts to the yokes of universal joints. But this study provides the analysis of the design in many aspects.

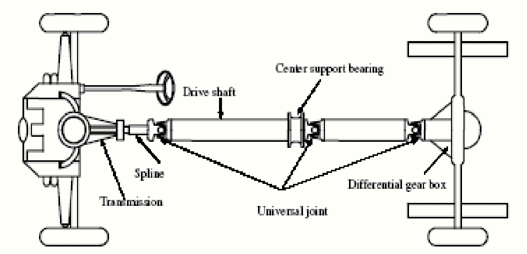

Fig 1: Schematic arrangement of Underbody of an Automobile

II. Design of composite drive shaft

2.1. Specification of the problem

The fundamental natural bending frequency for passenger's cars, small trucks and vans of the propeller shaft should be higher than 2,400 rpm to avoid whirling vibration and the torque transmission capability of the drive shaft should be larger than 154 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations.

The torque transmission capability of the drive shaft is taken as 151 N.m the length and the outer diameter here are considered as 1.5 meters and outer diameter of the shaft is 0.072, respectively. The drive shaft of transmission system was designed optimally to meet the specified design requirements.

2.2. Assumptions

The shaft rotates at a constant speed about its longitudinal axis. The shaft has a uniform, circular cross section. The shaft is perfectly balanced, all damping and nonlinear effects are excluded. The stress-strain relationship for composite material is linear and elastic; hence, Hook's law is applicable for composite materials. Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress.

2.3. Merits of Composite Drive Shaft

1. They have high specific modulus and strength.
2. Reduced weight.
3. Due to the weight reduction, fuel consumption will be reduced.
4. They have high damping capacity hence they produce less vibration and noice.
5. They have good corrosion resistance.
6. Greater torque capacity than steel or aluminum shaft.
7. Longer fatigue life than steel or aluminum shaft.

2.4. Theoretical and ansys results simulation

The drive shaft for simplicity has been first idealized as a hollow cylindrical shaft which is fixed at one end and on other end which a torque of 151Nm is applied as represented below

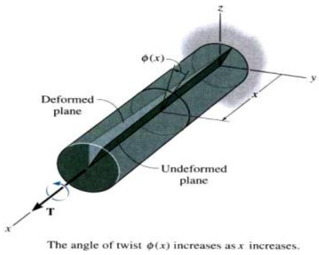

Fig 2: Shaft with torsional load

For the the hallow shaft, let
Ro = 0.036m ; Ri = 0.011m ; l = 1.5 m ; E= 207e9 ; Torque = 151Nm

Where Ro-Outer Radius of shaft
Ri- Inner Radius of shaft
L= Length of the shaft
E= Young's modulus of steel (SM45C)
T=Applied torque
Then:

$$\text{Deflection} = Y_{max} = \frac{ML^2}{2EI} = \frac{151 \times (1.5^{2})}{2 \times (207e9) \times (1.178e^{6})}$$

$$= 0.00069 \text{ m}$$
$$= 0.69\text{mm};$$

Maximum deflection = (T X (do/2))/ I

$$= \frac{151 \times (0.036)}{(\Pi/2)*[(0.036^{\wedge}4-0.011^{\wedge}4)]}$$

$$= 66.50 \text{ Mpa}$$

Maximum shear stress = (T X RO) /J
=20.78 Mpa

III. 3.Simulated results for Hollow shaft in an sys

3.1. Deformation results

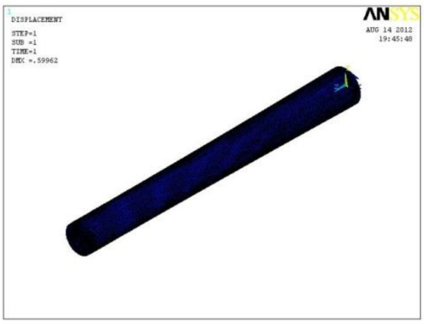

Fig 3: deformation result of steel shaft

It observed from above analysis results deformation value for steel shaft is 0.59mm**.**

3.2.Shear stress values

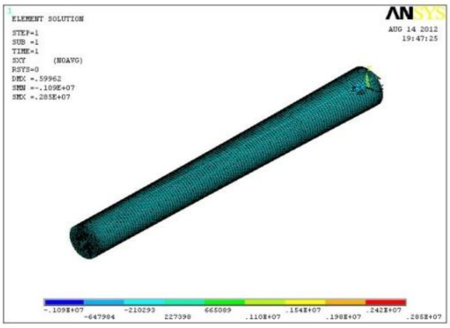

Fig 4: Shear stress value of steel shaft

It observed from above analysis results Shear stress value for steel shaft is 28Mpa

3.3. Von-Mises stress

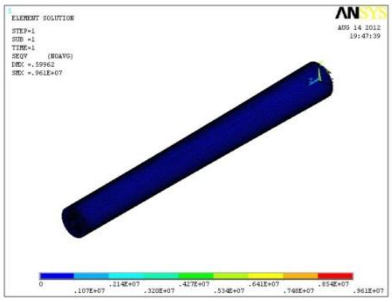

Fig 5: von-mises results

It observed from above analysis results von-Misses value for steel shaft is 96Mpa

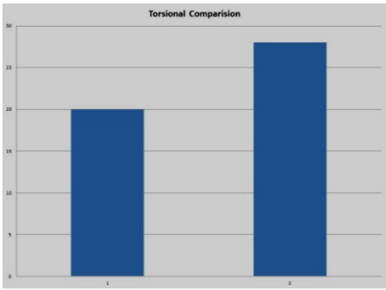

Fig 6: Torsional load comparison

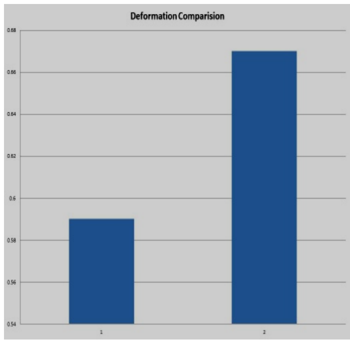

Fig 7: Deformation comparison

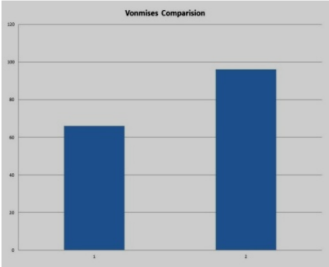

Fig 8: Von-mises Stress comparison

By comparing the theoretical values and hollow shaft analysis values it is observed that the calculated deformation value is 0.69 mm and the simulated value for deformation is .599 mm, Shear stress value calculated is 20.78Mpa for simulated it was 28Mpa, And for von-misses those values are 66Mpa and 96Mpa these results shows variation between theoretical and simulated up to 5.4 % only

IV. 4. Modeling and simulation

In this section the 3D CAD models and 3D FE Models along with the loads and boundary conditions will be presented.

Step1: 3D CATIA Model Creation was done based on considered Specifications and design consideration from Toyota Qualis specifications.

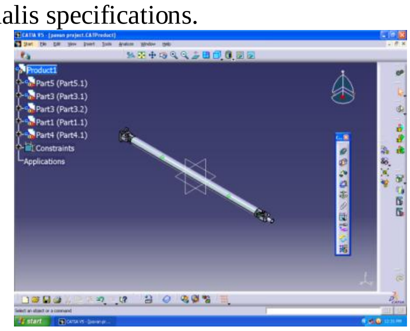

Fig 9: Catia Model

Step2: 3D FE Model Creation The 3D FE model for drive shaft was created by using FE modeling software HYPERMESH v10.0. The mesh has been generated using 2nd order Hexa elements (SOLID 95 and Solid 186) in Hypermesh.

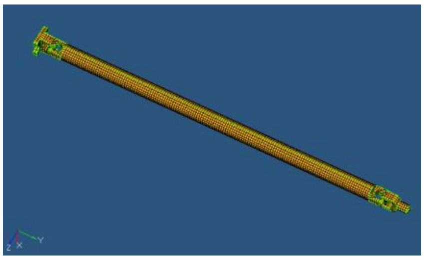

Fig 10: Hypermesh model with brick (solid 95 with contact elements)

Step-3: using above hypermesh model with boundary conditions in ansys12.0 required results are predicted.

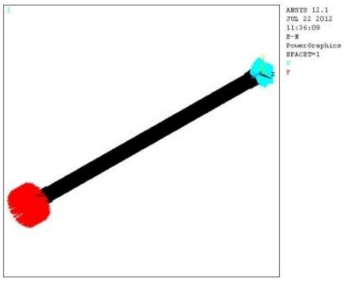

Fig 11 Ansys Model with boundary conditions

Step-4;By applying boundary conditions and loading conditions obtained results will compared and suitable material suggested which gives less torsional value and frequency nearer to steel.

4.1. Finding stress intensity value

Being able to determine the rate of crack growth, an engineer can schedule inspection accordingly and repair or replace the part before failure happens. Being able to predict the path of a crack helps a designer to incorporate adequate geometric tolerance in structural design to increase the part life. The methodology used to investigate the mechanics of crack propagation consists of the following steps:

Step 1: Introducing crack with 1mm width and 3mm depth in Catia geometric model

Step 2: Creating 3D FE model by using Hpermesh and creating fine mesh at crack located area. Using contact elements at universal joint locations

Step3: Applying Boundary conditions and to solve to get shear stress value at different locations nearer to cracktip

Step 4: Using above predicted values to plot graphs for finding stress intensity values for both Steel and Composite shafts

Step 5: Interpretation of results for both Steel and composite Intensity values

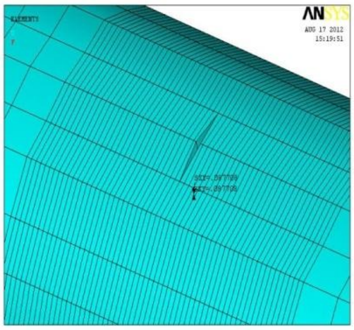

Fig 12: Shaft with crack

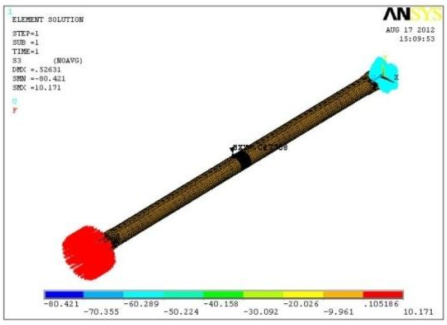

Fig13: Torsional Analysis with crack

4.2. Elements used for Analysis and its characteristics

S. No	Generic element type name	Ansys Name	Description
1	20 Node Quadratic Hexahedron	Solid 95	20 Node structural solid
2	20 Node Quadratic Hexahedron	Solid 186	20 Node structural solid
3	Quadratic Quadrilateral Contact	Conta 174	3D 8 Node surface to surface contact

4.3. Material properties used for analysis are listed below

SL no	**Property**	**Steel (SM 45C)**	**Kevlar/ Epoxy**	**units**
1	Young's Modulus X direction (E_{11})	**2.07e11**	**95.71e9**	**pa**
2	Young's Modulus Y direction (E_{23})	**-**	**10.45e9**	**pa**
3	Young's Modulus Z direction (E_{31})	**-**	**10.45e9**	**pa**
4	Major Poisson's Ratio XY (υ)	**0.3**	**0.34**	
5	Major Poisson's Ratio YZ (υ)	**-**	**0.37**	
6	Major Poisson's Ratio XZ (υ)	**-**	**0.34**	
7	Shear Modulus XY ($\square_{12}$)	**-**	**25.08e9**	**pa**
8	Shear Modulus YZ ($\square_{23}$)	**-**	**25.08e9**	**pa**
9	Shear Modulus XZ ($\square_{31}$)	**-**	**25.08e9**	**pa**
10	Density	**7600**	**1402**	**Kg/m3**

V. Analysis Results

Steel and Kevlar/Epoxy shaft deformation comparison.

5.1.Steel drive shaft defromation result

Fig 14: Steel shaft deformation results

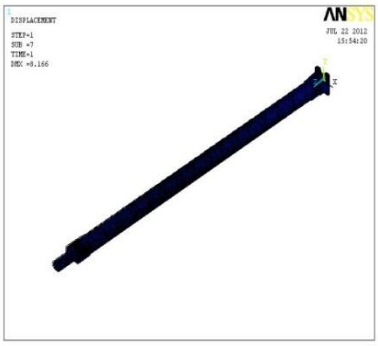

Fig 15: Kevlar/Epoxy drive shaft deformation results

By considering above results it is obseved that steel shaft having deformation value of 0.589 mm and Kevlar/Epoxy drive shaft having deformation value of 8.1 mm

5.2. Torsional stress comparison

It is observed from below anlysis results steel shaft having maximum stress value in of 53.80Mpa XY direction and Kevelar /Epoxy shaft having maximum shear stress value in XY direction is 49.82Mpa only.The ansys simulated values are as shown below

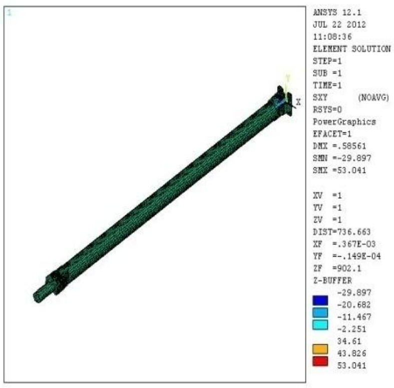

Fig 16: Steel shaft torsional analysis

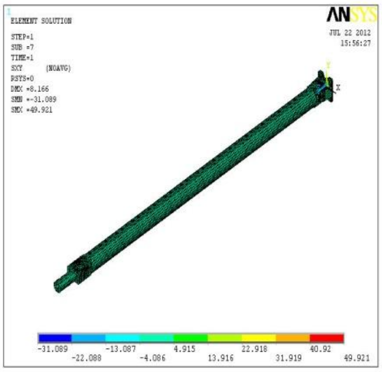

Fig 17: Kevlar/Epoxy torsional anlysis value

5.3. Model anlysis results

Fig18: Steel shaft Model analysis

Fig19: Model anlysis of Kevelar/Epoxy

It is obseved from avoe model anlysis results the natural frequency of steel shaft is 3.7Hzs and 2.78Hzs for Kevlar /Epoxy so it is from predicted values it is obseved natural frequency values are very nearer to each steel and Kevlar/epoxy shafts.

5.4. Eigen buckling Result's (inz direction)

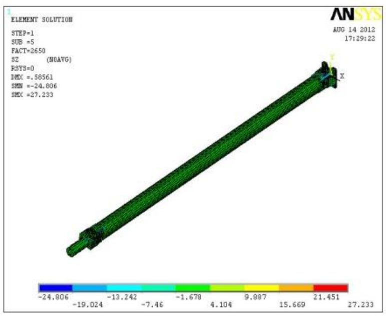

Fig 20: Steel shaft buckling

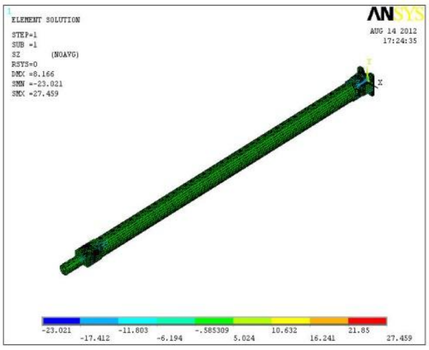

Fig 21: Kevlar/Epoxy buckling stress values

It is observed from above anlysis of bucklig results both shafts having buckling values of 27Mpa

5.5. Finding stress intensity values for cracked shaft

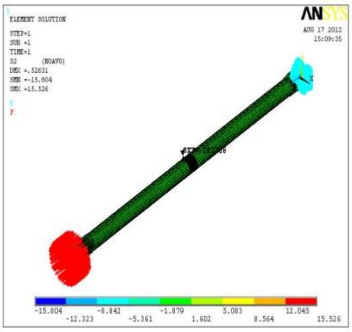

Fig 22: Torsional analysis of shaft with crack

5.6. Steel shaft with cut section with stresses at crack tip

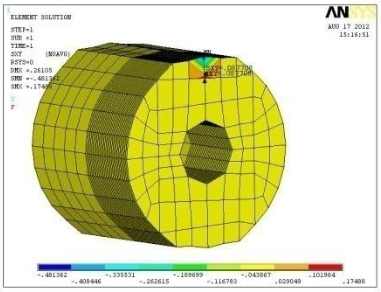

Fig 23: Steel shaft with crack tip cross-section

5.7.Steel shaft predicted intensity Values

S.NO	Distence (r)	Shear stress value in XY direction(σ)	K_I value (σ√(r))
1	29.51	0.08770	0.472
2	28.93	0.00904	0.09
3	30.59	-0.000055	-0.0003

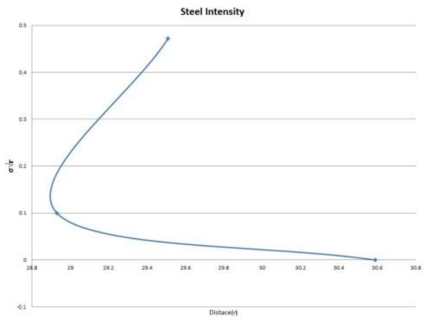

Fig 24 : Steel Shaft intensity Graph

By considering graph plotted between Distance (r) and stress σ√r from crack tip the stress intensity factor K_{III} value for steel shaft is observed as 0.13Mpa√mm.

5.8. Kevelar/Epoxy shaft with cut section with stresses at crack tip

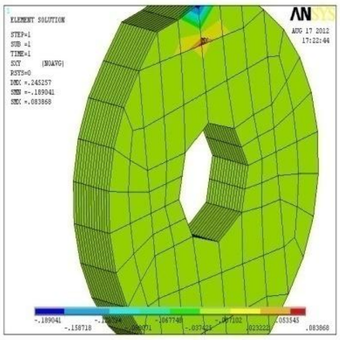

Fig 25: Composite shaft with crack tip cross-section

5.9. Composite shaft predicted intensity values

S.NO	Distance (r)	Shear stress value in XY direction(σ)	K_I value (σ√(r))
1	29.51	0.000741	0.003993
2	28.93	0.0001126	0.0007
3	30.59	-0.000056	-0.0003

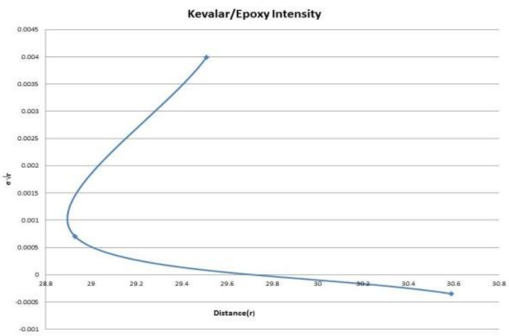

Fig 26: Composite Shaft intensity Graph

By considering graph plotted between Distance (r) and stress σ√r from crack tip the stress intensity factor K_{III} value for composite shaft is observed as 0.012 Mpa√mm

VI. Results summary

S.No	1	2
Material	Steel	Kevlar/Epoxy
Defromation in mm	0.5816	8.16
Number of layers	-	2
Angle of ply	-	±45
Natural Frequey in HZ	3.76	2.04
Trosional Stress value in N/mm2	53.80	49.82
Buckl-ing Stress Value inN/mm2	27.45	27.23
Weight reduction in %	-	23

6.1. Stress intensity values

S.No	**Material**	**Stress Intensity value in** Mpa√mm.
1	Steel	0.13
2	Kevlar/Epoxy	0.012

VII. Conclusion

1) The usage of composite material has resulted to inconsiderable amount of weight saving in the range of 28 % when compared to conventional steel shaft
2) Taking into considerations the weight saving, deformation, shear stress induced and resonant frequencies it is evident that Kevalar/Epoxy composite has the most encouraging properties to act as replacement for steel out of the considered two materials .
3) The presented work was aimed to reduce the fuel consumption of the automobile in the particular or any machine, which employs drive shafts ,in general it is achieved by using light weight composites like Kevelar/Epoxy
4) The presented work also deals with design optimization i.e converting two piece drive shaft (conventional steel shaft) in to single piece light weighted composite drive shaft.
5) The drive shaft of Toyota Qualis was chosen for determining the dimensions, which were used then used for the material properties of composites were used the stability of drive shaft is ensured by limiting the include values with in the permissible range in Ansy 12.0
6) The stress intensity value (K_{III}) at crack tip is observed for composite driveshaft is low.

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