

Computational Analysis of Fatigue Life of S-Glass/Epoxy Composite Drive Shaft

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ABSTRACT: Composites offer significant improvements over current available materials for automobile due to their excellent mechanical characteristics and relatively low density. Fatigue life of composite drive shaft with viscous interface under variable torsional loads is analyzed. The s-n curve is obtained explicitly by using the micromechanical model of composites. The study indicates that the life of the composite depends on several factors, including fiber volume fraction, the relative shear rigidity of fiber to matrix, and a dimensionless parameter composed of interface viscosity, fiber radius, vibration frequency and shear modulus of matrix. Computational approach is adopted for analyzing the fatigue life of composite drive shaft. S-N curve will be developed using a finite element analysis depends on the material directions of the layers. S-Glass fiber and epoxy composite material is considered for designing the drive shaft.

KEYWORDS: Automobile Drive Shaft, Stress Intensity Factor , Fatigue Life, ANSYS and UNIGRAPHICS.

I. INTRODUCTION

Drive shafts for power transmission are used in many applications, including pumping sets, aerospace, cooling towers, and automobiles. In metallic shaft design, the size of the shaft's cross-section can be determined by knowing the torque and the allowable service shear stress for the material. In order to satisfy the design parameter of torque divided by the allowable shear stress, there is unique value for the shaft's inner radius because the outer radius is constrained by the space under the car cabin. Metallic drive shafts have limitations of low critical speed, weight and vibration characteristics. Composite drive shafts have proven that they can solve many automotive and industrial problems that occur by the usage of the conventional metal ones. In the past many researchers have investigated the use of hybrid drive shafts. For automotive applications, the first composite drive shaft was developed by the Spicer U-Joint division of Dana Corporation for Ford econoline van models in 1985. The General Motors pick-up trucks which adopted the Spicer product enjoyed a demand three times that of projected sales in its first year, i.e. in 1988.

II. PROBLEM DEFINITION

The drive can be carried out to subject torsional moment and the composite drive shaft made up of Glass fiber and epoxy matrix these mixtures are divided by using volume fraction. The drive shaft analysis is doing on volume fraction and when brittle material glass fiber increases the fatigue life of drive shaft is decreases. The conventional steel drive shaft have more weight and less specific modulus and strength. The steel drive shaft is usually manufacturing in two pieces to increase fundamental bending natural frequency therefore the steel of drive shaft made in two sections connected by support structure, bearing and U-joints and hence over all weight of assembly will be more. Corrosion resistance is less compare to composite material.

III. MATERIAL PROPERTIES

Tensile properties are important for a material that is going to be stretched or under tension. the superior toughness of the thermoplastic material which results in an increase in flexural strength of the modified epoxy-glass fiber composites than the neat epoxy resin toughened glass fiber reinforced composites (GFRP) tensile strength of the multifunctional

epoxy resin increases significantly with the incorporation of thermoplastic. This is due to the effect of blending of thermoplastic material (PEI) which has superior toughness in comparison to the unmodified epoxy resin. the phase separates out which results in the increase in the mechanical properties. the interlaminar shear strength that depends primarily on the matrix properties and fiber-matrix interface shear strength.

Table 3.1: properties of S-Glass fibre /Epoxy

Mechanical Properties	S-Glass fibre	Epoxy
Density	2.60 (g/cm3)	1.8 (g/cm3)
Young's modulus	72.4 GPa	3.85 GPa
Poisson's ratio	0.20	0.30
Ultimate tensile strength	3620 MPa	50 MPa

With the data of mechanical properties of S-Glass Fiber-Epoxy as shown in the above table 3.1, the nine elastic constants are found out for three volume fractions using equation (1) to (7) as

$$E_{11} = E_f V_f + E_m V_m \dots \dots \dots (3.1) \quad E_{22} = E_{33} = \frac{E_f E_m}{V_m E_f + V_f E_m} \dots \dots \dots (3.2) \quad \nu_{12} = \nu_f V_f + \nu_m V_m \dots \dots \dots (3.3)$$

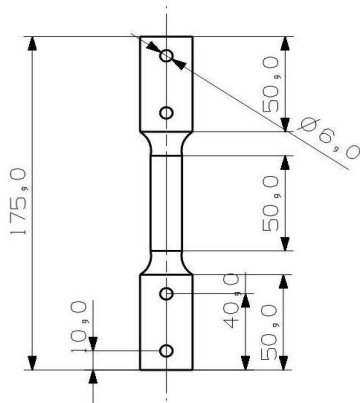
$$G_m = \frac{E_m}{2(1 + \nu_m)} \dots \dots \dots (3.4) \quad G_f = \frac{E_f}{2(1 + \nu_f)} \dots \dots \dots (3.5)$$

$$G_{12} = G_{13} = \frac{G_m G_f}{V_m G_f + V_f G_m} \dots \dots \dots (3.6) \quad \nu_{12} = \frac{E_{12}}{2G_{23}} - 1 \dots \dots \dots (3.7)$$

Table 3.2: Nine Elastic Constants of Glass fiber /Epoxy

Elastic Constant	S-Glass/Epoxy of Vol. 0.55	S-Glass/Epoxy of Vol. 0.60	S-Glass/Epoxy of Vol. 0.65
E1	41.55 GPa	44.98 GPa	48.41 GPa
E2	8.033 GPa	8.914 GPa	10.01 GPa
E3	8.033 GPa	8.914 GPa	10.01 GPa
G12	3.10 GPa	3.45 GPa	3.88 GPa
G13	3.10 GPa	3.45 GPa	3.88 GPa
G23	3.10 GPa	3.45 GPa	3.88 GPa
V12	0.245	0.24	0.235
V23	0.296	0.292	0.289
V13	0.245	0.24	0.235

4. Finite Element Modeling



The part was modeled in the UNIGRAPHICS tool. Drive shaft its geometry and elements used were carefully considered. Three dimensional geometry of the drive shaft is modeled using UNIGRAPHICS tool. CAD model of the drive shaft and the geometry details is shown in figure 4.1. The composite drive shaft consists single parts .

Table 4.1: shows number of nodes and elements

Details	values
Total number of nodes	2910
Total number of elements	594

V. RESULTS AND DISCUSSIONS

Static stress analysis was done to identify the stresses in the critical region of the drive shaft. Analysis is done to find the stress intensity factors and their modes along the crack front. Static Stress analysis was carried out to ascertain the critical region of drive shaft with a rotational velocity of 1000 RPM. The critical region or the crack zone is region in which maximum Equivalent (von-mises) stress occurs. This maximum stress is 2.374 MPa as shown in the figure.4.1.

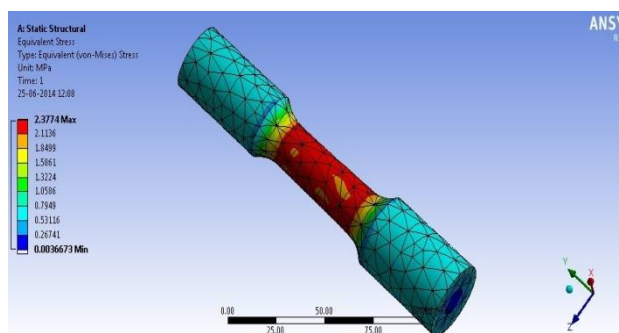


Figure 5.1 Static stress distributions without crack

5.1 STRESS INTENSITY FACTOR SOLUTION

Meshing of the drive shaft was performed by ANSYS mesh tool. The meshing of the drive shaft is done using tetrahedral elements. Fracture module method for crack generation required that elements be of higher order. Therefore out of choice of tetrahedral and hexahedral elements, tetrahedral elements of type SOLID 186 were chosen for accurate results. Also fracture module used for crack generation requires that all of the elements be either hexahedral or tetrahedral. SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain

capabilities. Therefore it was ensured that all of the elements are of the type tetrahedral or SOLID 186 type. The dimensions of the semi elliptical crack are calculated based on the crack aspect ratio (a/b). Figure 4.2 clearly specifies the aspect ratio and crack depth based on the crack length.

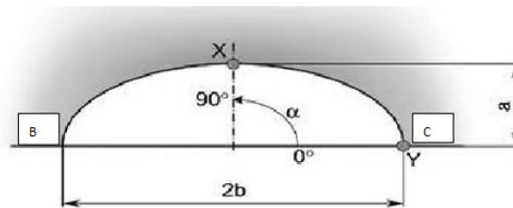


Fig 5.2. Nomenclature of the crack

The mid-side nodes near the crack tip are placed at the quarter point. Thus, in order to model a stress singularity without altering the finite element code, the mid-side nodes adjacent to the crack tip must be shifted to their quarter-point position. Since then this element became known as the quarter-point element. Figure 4.4 shows the crack near the maximum stress region.

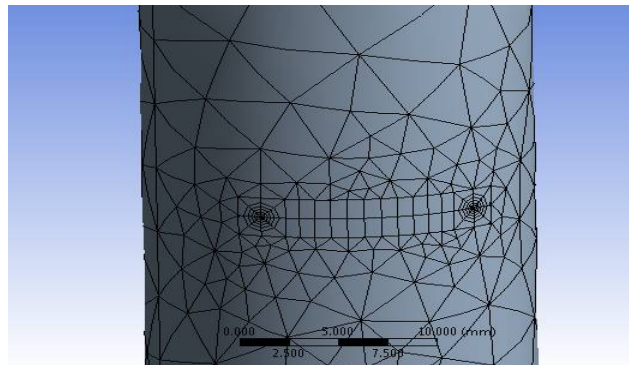


Fig 5.3 Crack generated at the fillet region

Crack propagation analysis was done for lengths of 3mm, 4mm, 6mm and 7 mm. Crack orientations was considered perpendicular to the plane of maximum stress direction. Stress intensity factor solutions along the crack front is presented in figure 4.5.

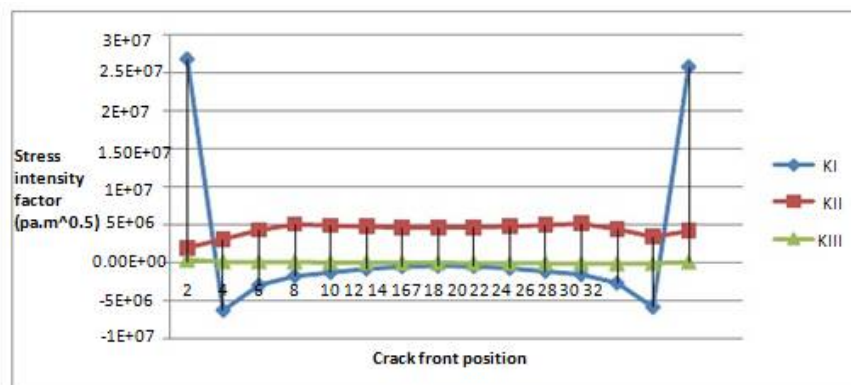


Fig 5. 4 Variation of K_I , K_{II} , K_{III} along the crack front for $a = 6\text{mm}$.

Since linear elastic fracture mechanics principles are not applicable to surface interception points, stress intensity factor at those points is to be neglected and the preceding points can be considered. From figure 4.6 it is seen that surface interception points are subjected to mode I, i.e. K_I is maximum at the surface interception. At the crack depth is subjected to mixed Mode I and Mode II i.e. K_I and K_{II} are maximum at point A. Value of K_{II} and K_{III} depends upon the direction of the torque applied. The change in value of K_{II} is because of change in the direction in plane sliding for an applied load.

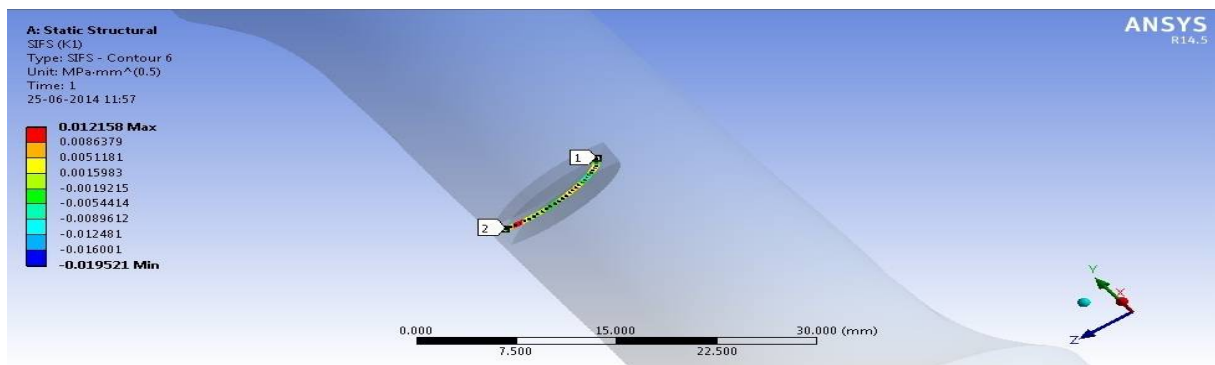


Fig 5.6 Stress intensity factor K_I for $a = 6$ mm

It is observed that mode I stress intensity at the surface crack interception points has increased to $-0.0019521 \text{ Mpa}\sqrt{\text{mm}}$ and $0.012158 \text{ Mpa}\sqrt{\text{mm}}$ for the crack depth of 6 mm.

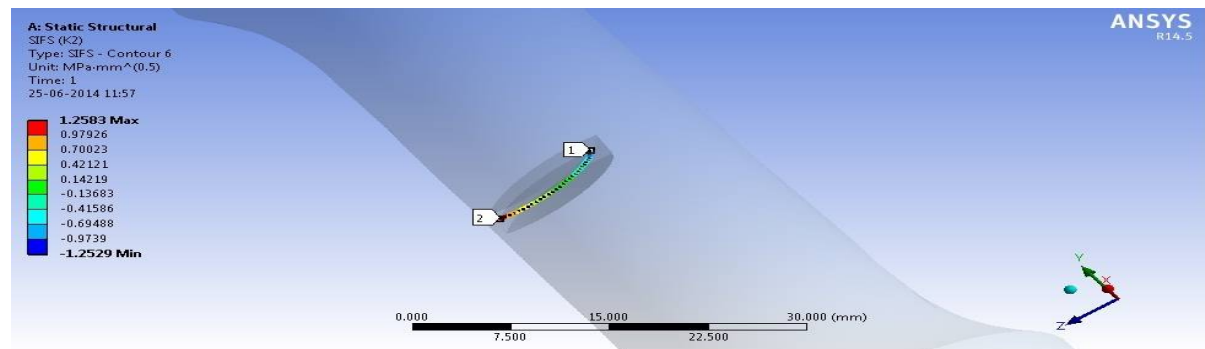


Fig 5.7 Stress intensity factor K_{II} for $a = 6$ mm

Mode II stress intensity at the surface crack interception points has increased from $-1.2529 \text{ Mpa}\sqrt{\text{mm}}$ to $1.2583 \text{ Mpa}\sqrt{\text{mm}}$ for the crack depth of 6 mm.

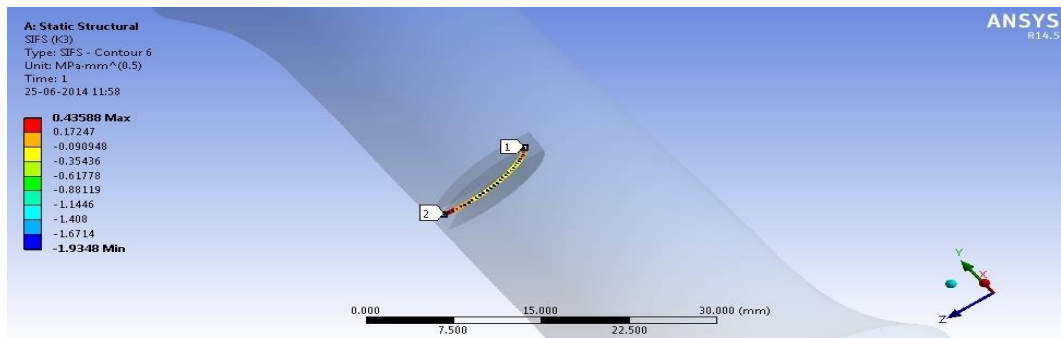


Fig 5.8 Stress intensity factor K_{III} for $a = 6\text{mm}$

Mode III stress intensity at the surface crack interception points has increased from $-1.9348 \text{ Mpa}\sqrt{\text{mm}}$ to $0.43588 \text{ Mpa}\sqrt{\text{mm}}$ for the crack depth of 6 mm.

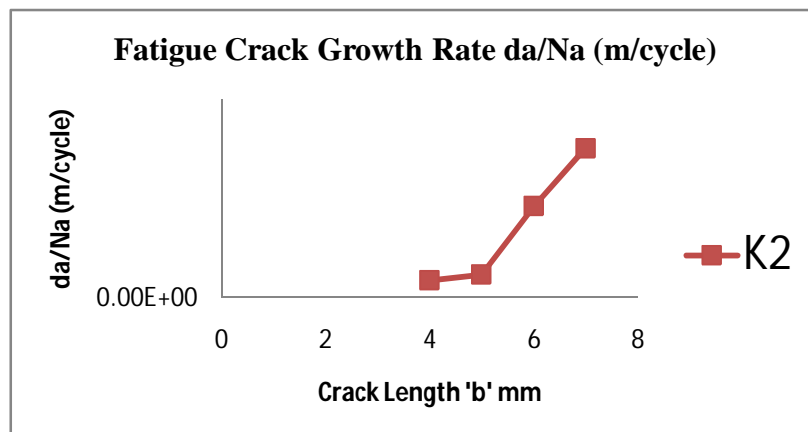


Fig:5.9 Mixed mode stress intensity factor solutions for different crack lengths is represented

VI. CONCLUSION AND FUTURE WORK

Based on the finite element analysis and the analysis done with the help of fracture module, the following conclusions were drawn. Static stress analysis for the operating conditions of drive shaft was performed. Crack zone in the drive shaft was identified on the main smaller diameter shaft having Von – Mises stress of 12.31MPa.

Fatigue crack growth rate at the crack depth increased with the increase in crack length. For more accurate solution, a method which takes care of crack closure effect and propagation of crack along an arbitrary, solution dependent path under fatigue loading conditions must be considered.

- The results clearly shows volume fraction 0.55 GSRP shows more fatigue line compare to other volume fraction and clearly because of glass fiber content less fatigue line is high.
- Brittleness is increases the fatigue life of fiber and ductility of epoxy of life is decreases.
- The replacement of convention drive shaft results in reduction in weight of automobile.
- The finite element analysis is used in this work to predict the deformation of weight.
- Hence the single piece High strength Glass/epoxy composite drive shaft has been proposed to design to replace the two piece conventional steel drive shaft of an automobile.
- The results reveal that the orientation of fibers has great influence on the dynamic characteristics of the composite shafts.
- Material in future development by change in volume fractions or matrix and fiber materials
- We can use variable amplitude loading condition

- We extend to stain life stress in elastic condition and then also extended to strain plastic condition.
- Thermal fatigue analysis can be carrying on the drive shaft.
- For Different thickness i.e. for Symmetric condition the Composite Shaft can be analyzed for further investigation. For further investigation, the composite shaft can be analyzed with negative fiber angle orientation.

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