FINITE ELEMENT EVALUATION OF MIXED MODE STRESS INTENSITY FACTORS IN EPOXY RESIN

Niranjan H R[1], H K Srinivas[2], Shashidhara L C[3], Madhusudhan T[4]

[1]*M-Tech student, dept. of Mechanical engineering, SJBIT, Bengaluru, India-560060*
[2]*Professor, dept. of Mechanical engineering, SJBIT, Bengaluru, India-560060*
[3]*Professor, dept. of Mechanical engineering, Dayanand sagar university, Bengaluru, India-560038*
[4]*Head: dept. of Mechanical engineering, SJBIT, bengaluru, India-560060*

Abstract

An edge cracked semi-circular specimen subjected to symmetric and asymmetric three-point bend loading was suggested for investigating mixed mode fracture in brittle material. Finite element modeling using commercial FEA software (ANSYS) is presented to compute accurate stress intensity factors K_I and K_{II} as a function of crack length(a/R) and support locations (S2=αR). It was shown that by selecting appropriate positions for the loading points, full mode mixities from mode I to pure mode II could be achieved. Choosing the strain energy density theory of fracture and material properties of epoxy resin, predicted crack growth direction and fracture load are graphically presented. These are co-related with available mixed mode fracture test results.

***Keywords:** Mixed mode fracture, Strain Energy Density theory, Stress Intensity Factor*

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1. INTRODUCTION

Cracked components made of many engineering materials such as ceramics, rocks, polymers often fail by brittle fracture. Linear elastic fracture mechanics can provide an appropriate description for mechanical behavior of crack as long as the amount of plastic deformation around the crack tip is negligible. fracture is defined as a mode of failure due to unstable propagation of a crack with applied stress. Fracture mechanics provides a methodology to study fracture in materials, components and structures. Fracture mechanics analysis is the basis for damage tolerant design methodology.

The main objectives of fracture mechanics analysis are;
1) Derivation of crack tip stress field equations and definition of fracture mechanics parameters (Stress Intensity Factor K, Energy Release Rate G, Non Linear Energy Release Rate J, Crack Tip Opening Displacement CTOD);
2) Determination of K, G, J and CTOD for cracked body problems;
3) Prediction of residual strength as a function of crack size and ;
4) Fatigue crack growth life Prediction under constant amplitude, variable amplitude and spectrum loads.

The objective of this paper is to present a novel mixed mode fracture test specimen- a semi-circular disc with an edge crack under three point bending. Stress intensity factor solutions use of strain energy density theory of fracture and co-relation of predictions with fracture test results on epoxy resin material are presented in the following sections. Epoxy resin has been recognised as a favourite material for fracture tests. Epoxy resin is a relatively homogeneous and isotropic material which often fractures in brittle manner at room temperature.

Several Analytical, numerical and experimental methods have been suggested by researchers for determination of mixed mode stress intensity factors. Finite element modeling for computational fracture mechanics using ANSYS software is used to provide accurate stress intensity factors *(KI, KII)* for the problem on hand.

2. FINITE ELEMENT MODELING

Fig 1 shows a semicircular disc with an edge crack subjected to three point bending. The dimensions of the specimen are R = 60 mm, S1 = 40 mm, S2 (variable from 6.07 mm to 40 mm), crack length a = 20 mm and thickness t = 6 mm.

The typical finite element model is presented in fig 2 and fig 3. A refined mesh of singular isoperimetric triangular element with 6 nodes (STRIA 6) with NS = 36, Δa = a/100.

Nodes at the support points are constrained in the Y direction and a point load of 1000 N is applied at the top.

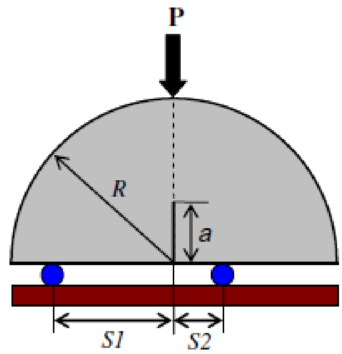

Fig 1: A test specimen to study mixed mode fracture

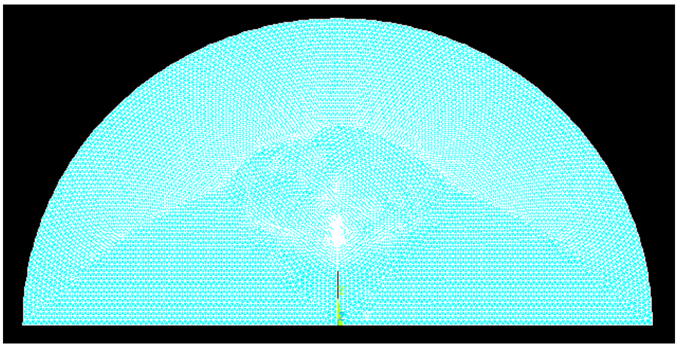

Fig 2: Mesh of SCB Specimen

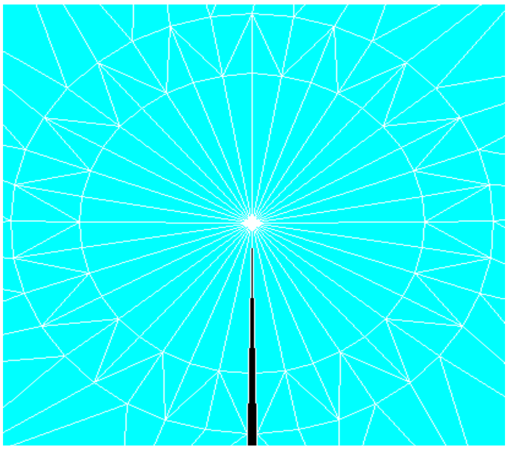

Fig 3: Crack tip singularity elements

3. STRESS INTENSITY FACTOR SOLUTIONS

The post processing command KCALC is used to calculate the stress intensity factors for different values of S2.

The geometric factors Y_I and Y_{II} are calculated from the stress intensity factors K_I and K_{II} using the formulas.

$$K_I = \frac{P}{2Rt}\sqrt{\pi a}\ Y_I(a/R, S1/R, S2/R) \quad (1)$$

$$K_{II} = \frac{P}{2Rt}\sqrt{\pi a}\ Y_{II}(a/R, S1/R, S2/R) \quad (2)$$

The variation of geometric factors with S2 is presented in the fig 4 and fig 5.

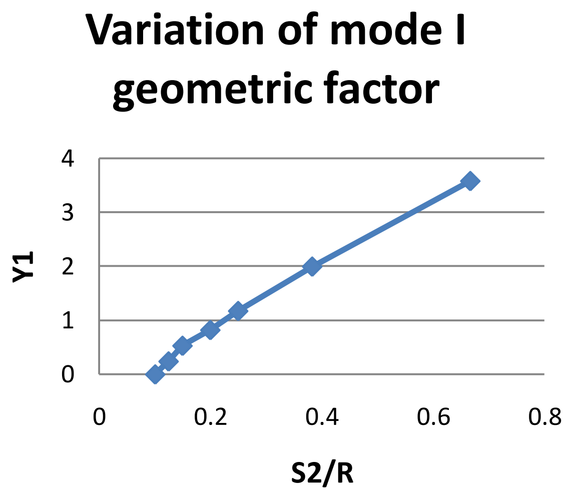

Fig 4: Variation of mode I geometry factor

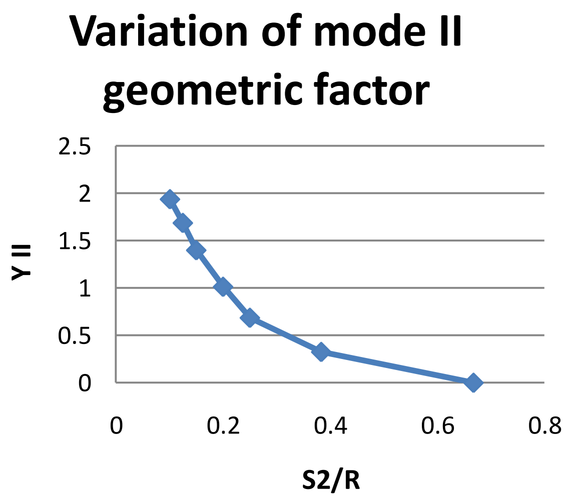

Fig 5: Variation of mode II geometry factor

The graphical post processing capabilities in ANSYS is demonstrated by capturing the von Mises equivalent stress contours at the crack tip as shown in fig 6 to fig 9.

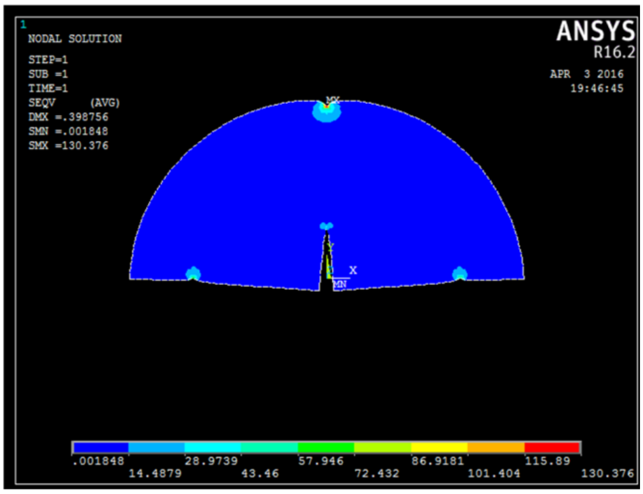

Fig 6: Von Mises stress plot for mode I loading condition

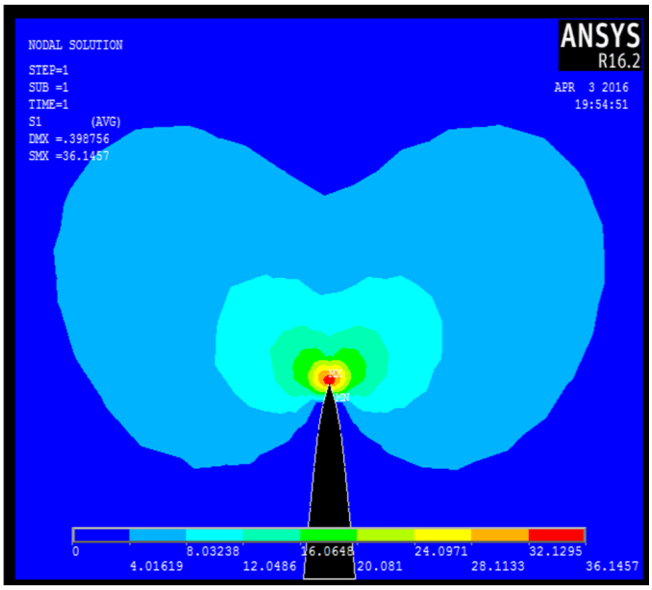

Fig 7: Von Mises stress plot at crack tip for mode I

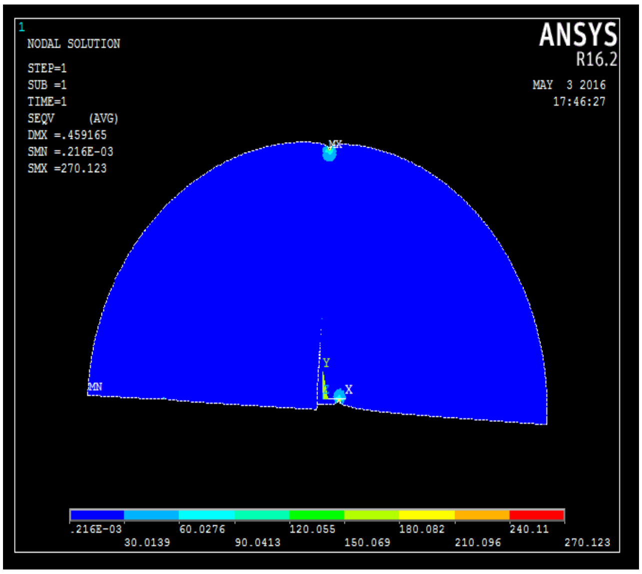

Fig 8: Von Mises stress plot for mode II loading condition

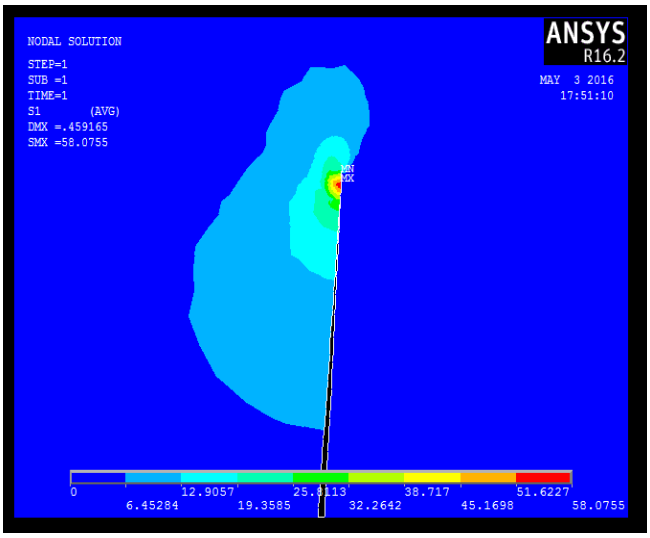

Fig 9: Von Mises stress plot at crack tip for mode II

4. STRAIN ENERGY DENSITY THEORY OF FRACTURE

According to SED criterion, crack extension will occur in the direction of minimum strain energy density factor (S), and the extension will occur when the minimum value of S reaches a critical value Sc which is a material dependent parameter where

$$S(\theta) = [g11\ KI^2 + 2g12KIKII + g22KII^2]/\pi \ (3)$$

$$g11 = \frac{1}{16\mu}[\ (1 + \cos\theta)(\kappa - \cos\theta)]$$

$$g12 = \frac{1}{16\mu}\sin\theta[\ (2\cos\theta - (\kappa - 1)]$$

$$g22 = \frac{1}{16\mu}[(\kappa + 1)(1-\cos\theta) + (1 + \cos\theta)(3\cos\theta - 1)]$$

$$\mu = \frac{E}{2(1+v)}$$

The conditions for predicting the direction of crack growth are

$$\frac{\partial s}{\partial \theta} = 0\ \frac{\partial^2 s}{\partial \theta^2} > 0 \ (4)$$

The equation to calculate the crack growth direction □ □ is given as

$$[2cos\theta - (k-1)sin\theta]K_I^2\ 2[2cos2\theta - k-1cos\theta KIKII+k-1-6cos\theta sin\theta KII2=0 \ (5)$$

under the inequality condition

$$[2cos2\theta - (k-1)cos\theta]K_I^2 + 2[2(k-1)sin\theta - 4sin2\theta KIKII+ k-1cos\theta - 6cos2\theta KII2>0 \ (6)$$

Crack extension will occur when the minimum value of strain energy density factor (Smin) reaches a critical value of strain energy density factor Sc thus the condition is given as $(S_{min}) \geq S_C$ (7)

The material dependent critical value Sc is obtained for pure mode I condition with □ c = 0 and KI = KIC as

$$S_C = \frac{K_{IC}^2}{4\pi E}(1+\vartheta)(k-1) \ (8)$$

Thus, Inequality (2) is expressed as

$S_{min} \geq \frac{K_{IC}^2}{4\pi E}(1+\vartheta)(k-1)$ (9) for crack to become critical.

The predicted fracture surface for possible combinations of stress intensity factors KI and KII in the edge cracked semi circular disc in three point bending is presented in the fig 10.

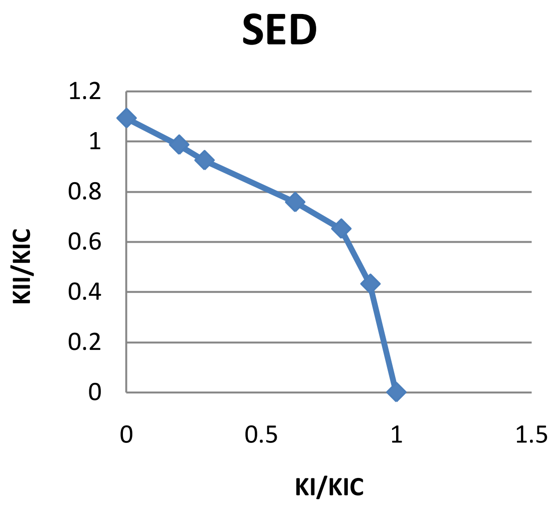

Fig 10: Predicted fracture surface curve using SED criterion

The predicted crack growth direction for possible combinations of stress intensity factors KI and KII in the edge cracked semi circular disc in three point bending is presented in the fig 11.

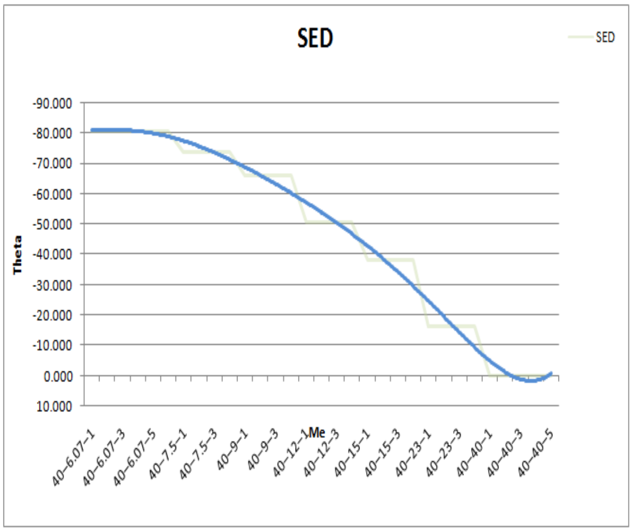

Fig 11: Predicted crack growth direction using SED Criterion

5. CONCLUSION

1. The FEM in general and ANSYS software in particular is demonstrated in this study to provide accurate mixed mode stress intensity factors for an edge cracked semi circular disc in three point bending.

2. The Strain Energy Density theory of fracture is successfully used to predict fracture surface and crack growth directions for an edge cracked semi circular disc in three point bending.

3. The fracture test results for an edge cracked semi circular disc in three point bending made of epoxy resin material are used to verify the above predictions.

4. It is fair to conclude that a good agreement exists between the prediction and test results.

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