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COMPARATIVE STUDY OF CRACK INITIATION ANGLE USING *K* BASED APPROACH UNDER MIXED MODE (I/II) FRACTURE

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ABSTRACT

The research on the mixed fracture criterion and crack growth is significant in fracture mechanics and engineering. Present study deals with the prediction of crack initiation angle under mixed mode (I/II) fracture using finite element using K based approach. The FE code "ANSYS" is used to estimate the stress intensity factor (K) numerically. Single edge crack specimens were used for the present analysis. Constant load was applied to all the specimens containing crack at angles of inclination to 0°, 15°, 30°, 45° and 50°. The crack initiation angle obtained using based approaches are close to analytical determination and also found to be in good agreement with the available experimental results in literature. It is also investigated thast as crack inclination angle increases, material was found to behave in a brittle manner.

Keywords: Finite element method, mixed mode fracture, stress intensity factor, crack initiation angle, fracture criteria

INTRODUCTION

The triaxiality of the state of stress is known to greatly influence the amount of plastic strain which a material may undergo before ductile failure. It is defined as the ratio of hydrostatic pressure or mean stress to the von Mises equivalent stress. In order to evaluate these failure criteria and to verify their application for industry, it is essential to know the effect of stress triaxiality on fracture and failure of materials. The accurate and meaningful modeling of elastic and plastic behavior of ductile materials is essential for the solution of numerous problems in various engineering fields. Present study deals with the prediction of crack initiation angle for mixed mode (I/II) fracture using finite element and K based approach. The FE code "ANSYS" is used to estimate the stress intensity factor (K) numerically. The estimated values of SIF were incorporated into six different crack initiation angle criteria to predict the crack initiation angle. Single edge crack specimens with mechanical properties similar to that of Araldite-Hardener, given as an input for the present FE analysis. This is done in order to compare the results obtained in present work with the available literature related to experimental work. Constant load was applied to all the specimens containing crack at different angles of inclination. The crack initiation angle obtained using K based approaches are close to the results in available experimental literature. It is also investigated that as crack inclination angle increases, material was found to behave in a brittle manner.

MATERIAL & METHODS

Why FEM only and not Experimental and Analytical Method?

Every criterion is based on the ratio of K_I and K_{II}. If this ratio is known then it is possible to determine the initiation angle. Here, SIF for all the cases were determined by using FE analysis because it is extremely difficult to determine the value experimentally or analytically. There are certain analytical methods such as Boundary Collocation method, Dugdale model, Modified Dugdale model, etc. can be employed to determine SIF of complex geometries, but such methods requires extensive knowledge of mathematics, Mechanics and solid mechanics. For e.g. suggests a geometry correction factor which is one of the parameter used for the determination of SIF for mode I condition. Such factors are geometry dependent and can be generated by using Boundary Collocation Method (BCM). But such factors are not available for every angle of crack inclination. Again, determination of SIF using experimental techniques is again highly cumbersome. Some techniques involves Photoelastic investigation, optical microscope and X-ray diffraction method, computerized UTM along with necessary accessories such as clip gage, strain gage, etc. can be used to determine SIF of mixed mode conditions. But application and implementation of such techniques for practical investigation needs skilled manual, sophisticated machines and advanced laboratory which is a costly approach. Using of such rigorous methods can be by-passed by employing FE techniques because it is simple and easy to determine the approximate value of SIF for mode I and mixed mode condition.

MODELING

1. Geometry

In the case of an inclined crack, the model was not symmetric thus full model of the edge cracked plate was analyzed using ANSYS 11 environment. The problem was idealized as 2D plane stress and the geometry was modeled using 8 keypoints with keypoint 7 being the crack tip. Keypoints 6 and 8 are coincident such that each one belonging to opposite crack face as shown in Fig. 1.1. Edge crack specimen was modeled with same crack length but different angle of inclination. The inclination angles considered in this study are 0°, 15°, 30°, 45° and 50°.

2. Material Model and Element Type

Material was modeled as a linear isotropic material with elastic modulus 1.99 GPa and Poisson's ratio 0.36 obtained from the available literature. But since the problem is idealized as two dimensional, therefore PLANE183 triangular 6 noded structural element having two degrees of freedom in *x* and *y* directions have been used for FE modeling. It is a higher order element and possesses quadratic displacement behavior and is well suited to modeling irregular meshes shown in Fig.1.5 and Fig 1.6. This element is defined by 8 nodes or 6-nodes having two degrees of freedom at each node: translations in the nodal x and y directions. In addition to this, element behavior was chosen to plane stress (as the problem is 2D) along with thickness to 6.5 mm as a real constant.

3. Finite Element Mesh

A typical finite element mesh for the 2-D analysis is depicted in Fig. 1.5 and 1.6 which has number of elements and nodes. Due to asymmetry, full model of the edge crack panel is modeled. To avoid problems of incompressibility, 6 noded quadratic triangular elements whose mid side nodes have been shifted to the quarter-points of the element sides (element type PLANE183 for plane stress condition with ANSYS library) are used for 2-D shown in Fig.1.5. Convergence of mesh is carried out shown in Fig.4.6 to get more accurate results. The radius of the concentration point is chosen to 0.8 *mm* and its location is at keypoint. On the other hand, the ratio of the second row elements radius to the first row was selected to be 0.5 and the element size was taken to 0.003. The number of elements in circumferential direction is selected to 6 which have created 12 singular elements around the crack tip. The specifications of the crack tip mesh and a close up view for crack inclination angles β = 45º are shown in Fig. 1.5.

4. Loading and Boundary Conditions

Pressure boundary condition is prescribed on the top surface of the model while the bottom surface is restricted in the *y*-direction and one node, at $x = 0$ and $y = 0$, is restricted in *x* and *y* direction as shown in Fig. 1.1. Uniformly distributed pressure of 444.8 *pa* was applied on top and bottom edges to all the panels containing crack at different inclination.

5. Crack Path Modeling

Since a full model is considered, five nodes need to be selected along the two crack faces to get the value of mixed mode stress intensity factors K_I and K_{II}. The first node should be the crack tip and the second and third nodes are the first and second nodes next to the crack tip on the crack's top face. The forth and fifth nodes have to be the first and second nodes next to the crack tip but on the crack's bottom face depicted in Fig 1.3.

RESULTS

In the presented work different criteria are used to determine the crack initiation angle and it is found that values obtained by each criteria are very close to each other with minute difference among them.

Effects on mode I and mode II SIF

Fig. 1.8 gives the comparison of K_I and K_{II}, computed numerically. It was observed that trend of the curve are similar to the experimentally obtained mixed mode SIF (Ayhan, 2004). Significant fall of curves was noticed between β = 30° to β = 48° which indicated that beyond β = 30° material tends to show slight brittle behavior. Fig. 1.2 shows that as β increases, higher stresses were required to fracture the specimens (loads up to critical limit are not the part of this research; this was done only to study the effect of β on behavior of material). Fig.1.8 gives the clear picture of yielding at the crack tip. It was observed that increasing crack inclination angle implies to decreasing the equivalent von Mises stresses for all *a/w* ratio from 0.1 to 0.7, which indicated that the yielding, at crack tip, decreases as β increases or in other words the stiffness of the material increases followed by shoot-up in stress triaxiality thus trigger the chance of brittle fracture. This phenomenon can also be observed in Fig.1.7 (*a to e*). It indicated that shrinkage of yield envelope was observed near the crack tip thus decreasing the amount of plastic zone at the crack tip thus give rise to brittle fracture.

CONCLUSIONS

For pure mode, the FE model compared very well with analytical solution. After estimating K_I and K_{II}, the SIF values are incorporated into crack initiation criteria for crack initiation prediction. All criteria give the same initiation angle between β equals to (0º to 15º). However, as the crack angle of inclination increases with an increment of 15º the difference in crack initiation angle prediction increases reaching more than 13º. For all inclination angles the S criterion was found to predict the minimum initiation angle and can also gives the relationship of ductile and brittle behavior of material while both M and T criteria were found to predict the maximum initiation angle. The crack initiation angle obtained using stress intensity factor and *J*-integral based approach are close to each other and also found to be in good agreement with the available experimental results in literature. It was also observed that as crack inclination angle increases material is found to behave as brittle fracture.

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FIGURES

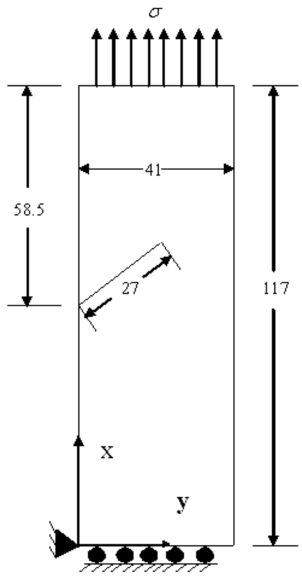

Fig. 1.1: Inclined cracked panel with boundary condition

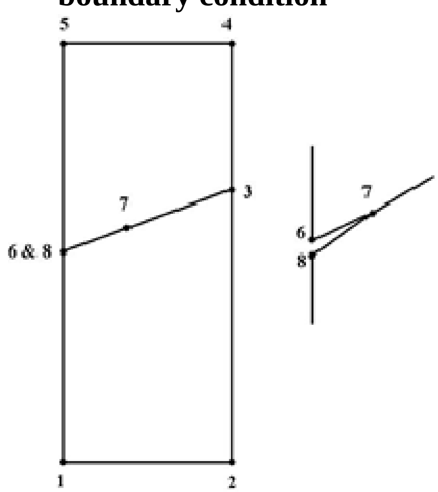

Fig. 1.2: Position of keypoints and lines at crack

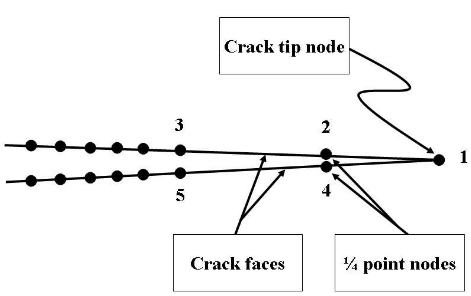

Fig. 1.3: Crack path definition of opening crack

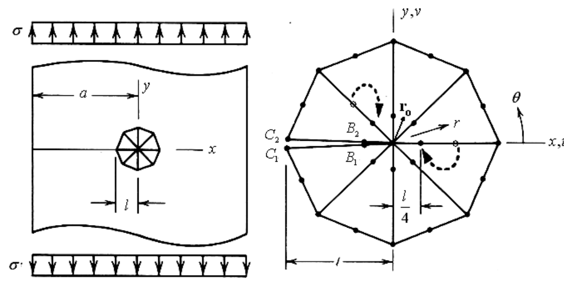

Fig. 1.4: Quarter node element at crack tip

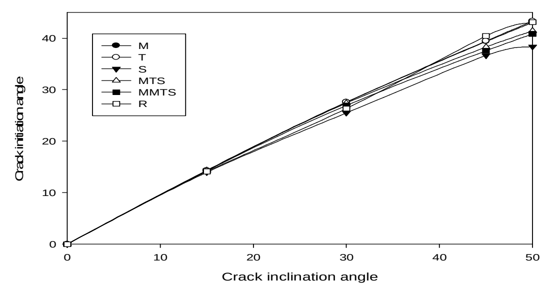

Fig. 1.5: crack initiation criteria at different β

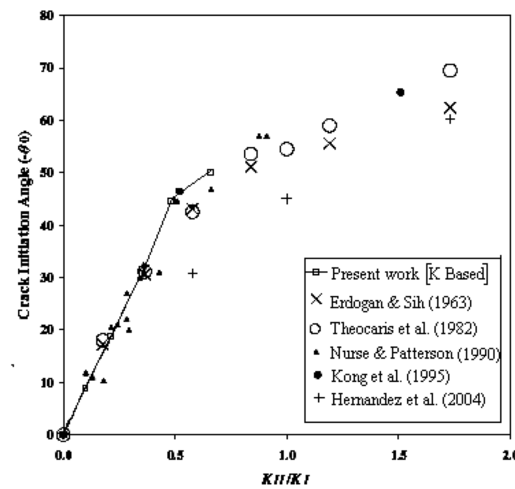

Fig. 1.6: Comparison between crack initiation angle crack initiation of this study and available Ewing *et al.* (1976)

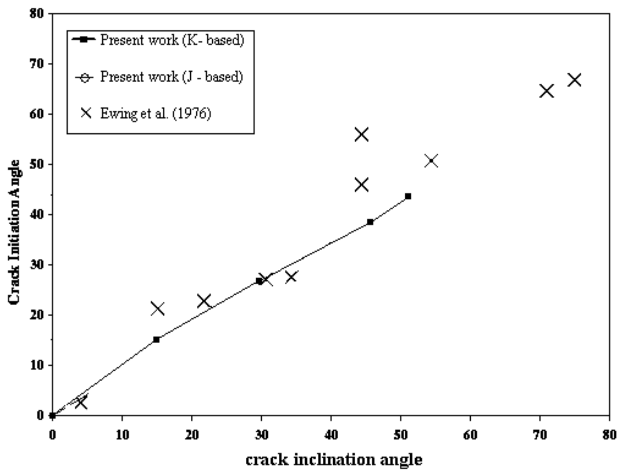

Fig. 1.7: Comparison between angle of this study and results in the literature

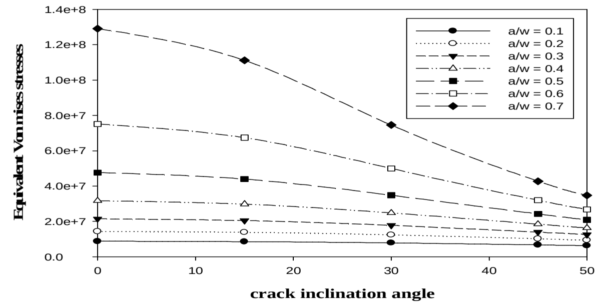

Fig. 1.8: Von Mises stress at the crack tip