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EFFECT OF THE CRACK GEOMETRY AND NOTCH ON STRESS INTENSITY FACTORS IN BONDING OF MATERIALS

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ABSTRACT

The failure of cracked components is governed by the stresses in the vicinity of the crack tip. The singular stress contributions characterized by stress intensity factors. The stress intensity factors depend on the geometry of the component and on loading condition. This paper addresses the evaluation of stress intensity factors (SIFs) of opening, shearing and tearing modes for compact tension specimens for bonding homogeneous materials. The aim of this work is to find the optimal pre-cracked length, crack notch radius and crack notching lei order to eliminate the effect of the menthe SIF and none the Fracture toughness. To achieve this goal ,a three-dimension finite element analysis(FEA) model using ANSYS program is constructed for specimens made of homogeneous materials such as stainless steel bonding with epoxy as a filler material. The effects of notch angle, notch tip radius and pre-crack length on the stress intensity factors are studied for different fracture modes. There salts for the stress intensity factors KI, KII and KIII are obtained using linear elastic fracture mechanics (LEFM) approach.

Keywords: (SIFs) of opening, shearing and tearing modes, FE, Crack notch angle, Pre-crack length, Crack notch radius

INTRODUCTION

Bimaterials systems may be found innumerous engineering devices structures and applications. Some of the more common applications include eliminated beam scooted systems for mechanical devices, and layered composites for main structural applications or microelectronic chips. Most Bimaterials systems are constructed by bonding together two similar or dissimilar material swith an adhesive. Other systems may be formed when a material is deposited onto a substrate by means of special deposition techniques. In these Bimaterials systems, the fracture behavior at the interface between these dissimilar materials is a critical phenomenon and frequently the weak link in the safe and confident use of these modern materials. Determining the stress intensity factors of interface cracks in bi-materials is the first step in predicting the subsequent crack propagation and damage tolerance. One important point is that the construction with these composite and sandwich systems typically involves the configuration of more or less thin ‘‘strip’’ geometry, therefore the formulations and results on infinite plane or half-plane configurations commonly encountered in the literature would not normally be applicable [1]. The fracture behavior of cracked structure is dominated by the near-tip stress field. In fracture mechanics most interest is focused on the stress intensity factors, which describe the singular stress field ahead of a crack tip and govern fracture of a specimen when a critical stress intensity factor is reached. The determination of stress intensity factors for specimens with pre-cracks is important in fracture analysis.

THE THREE DIMENSIONAL FINITE ELEMENT MODELING

The finite element method has been used extensively in solving problems involving homogeneous materials. The finite element method has been largely used to analyze various mechanical problems. It has been widely employed for the solution of problems in linear elastic fracture problems. Figure 1 shows the standard compact tension specimen [9], CT, geometry and defines some of the variables used in the analysis. The specimen size in the finite element analysis was W, with an initial pre-crack length, a. Note that the total crack length, L, is measured from the center of the loading holes rather than from the specimen edge. The modification of compact tension specimen showing the bond line is shown in Figure 2. The generation of a pre-crack in this specimen is outlined in ASTM 399 [14].

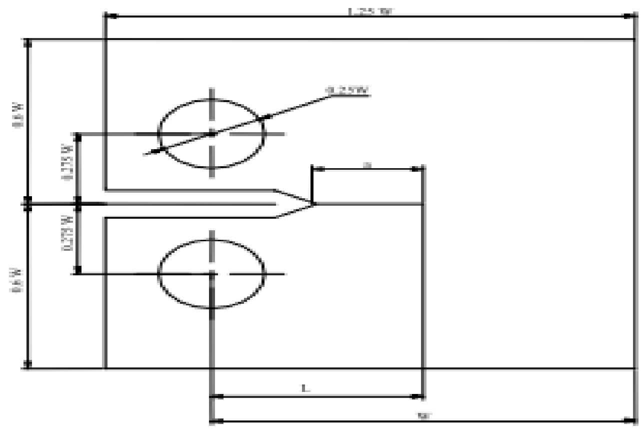

Figure 1.Configurationof compact tension specimen for fatigue and fracture mechanics-based testing

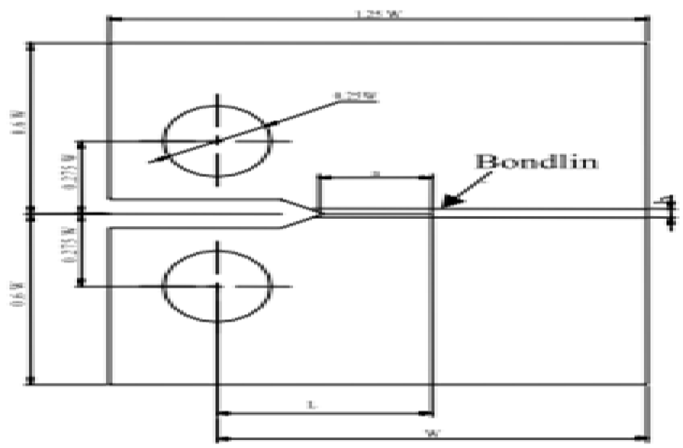

Figure 2.Configurationofthecompact tension specimen with centered bonded line and pre-crack

The finite element method is used to solve the problem of cracked plates with applied loads and appropriate displacement boundary conditions as in a uniaxial tension test, shear test and tear test device. The finite element program for three-dimensional problems has been used to perform the computations. The recommended element type for the three-dimensional model is SOLID 95. A full specimen is modeled. The first row of elements around the crack front should be singular elements [15].

The specimen has been modeled with two layers through its thickness of twenty node iso parametric hexahedron (brick) elements as shown in Figure 3. In the finite element formulation, the pre-crack of the specimen has been modeled by placing identical

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independent nodes. The x- and y- axes are in the plane of the plate and the z-axis is perpendicular to the plane of the specimen. The ANSYS code is developed to predict the propagation of fracture. Full geometry models with a pre-crack are used to measure the stress intensity factors for opening, shear and tear modes. The difference between the models is in the applied loading direction and the boundary conditions. For the opening mode, the applied loads are made to act on the upper and lower surfaces of the specimen as shown in Figure 4. In the shear mode, the applied loads are made to act oppositely at the side of the notch as shown in Figure 5. For the tear mode, the applied loads are made to act oppositely at the surface of the notched specimen as shown in Figure 6.

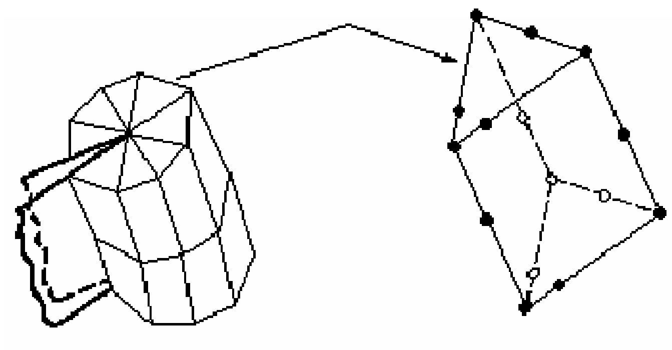

Figure 3.Twenty node isoparametric hexahedron (brick) elements and the first raw elements around the crack tip

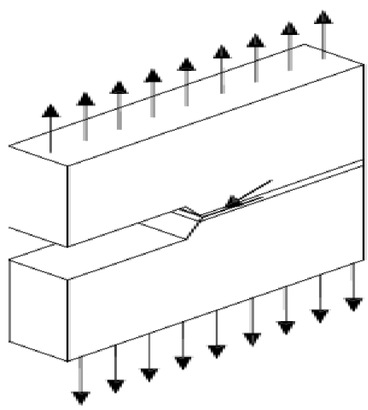

Figure 4. Thedirectionof axial pressure applied to simulate the opening mode

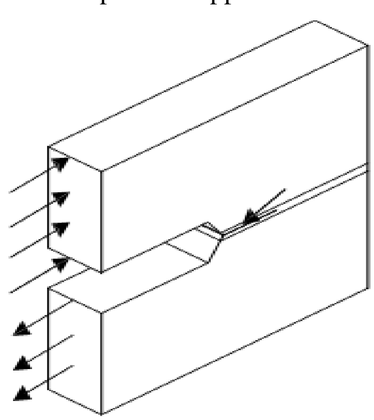

Figure 5. A lateral pressure loading condition on the specimen to simulate the shear loading mode

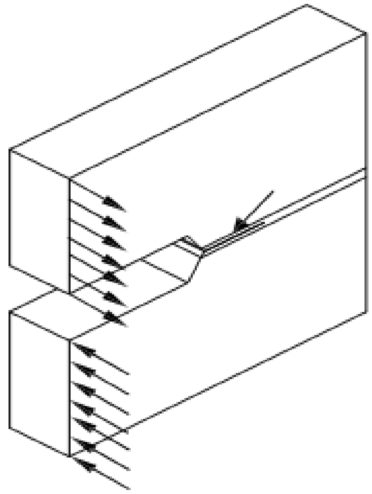

Figure 6. The out of plane pressure applied to simulate the tear mode

For all models, the notch angle varied from 8o to 120^{o}. The notch radius, r, varied from 0 (sharp edge) to 0.03333W, where W is the width of the specimen. Also the pre-crack length, a, varied from 0.00667 L to 3.33 L, where L is the total crack length.

The ANSYS input code is written in terms of notch angle, notch radius and pre-crack length in order to change the variables easily. All materials considered were homogenous and linearly elastic. Mesh refinement issues become complicated for three-dimensional models. Fine mesh of size less than

0.0025W are used in modeling the crack tip region. The mesh size is then gradually changed to coarser mesh as the edge is approached.

A total of 11892 elements with a total of 27490 nodes were generated in the discretization procedure that for two layer elements through the specimen thickness as shown in Fig.7. The mesh of the model used to measure the stress intensity factor for the opening, shear and tear modes is shown in Figure 7. This mesh includes two layer- elements through the crack tip. The mechanical properties of Epoxy are shown in Table 1.

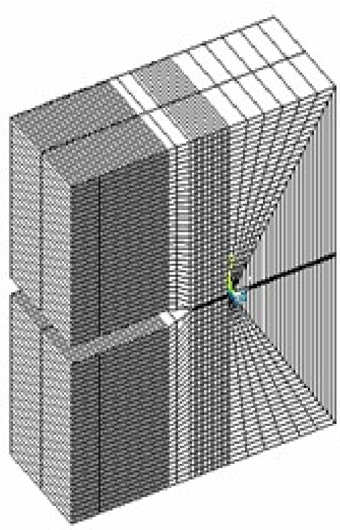

Figure 7. Three dimension mesh of the first mode includes two layer elements through the crack tip

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Table1. The mechanical properties of Epoxy [16].

Poisson's ratio	*Fracture toughness MPm1l2*	*Tensile Strength MPa*	*Young's Modulus GPa*	*Materials*
0.3	1.2	35	2.5	Epoxy

RESULTS AND DISCUSSION

Finite element analysis is briefly explained for stress intensity factors. Mode I, mode II and mode III stress intensity factors (KI, KII and KIII) are obtained using finite element analysis with the aid of Ansys Parametric Design Language (APDL). The finite element code ANSYS was used to perform three- dimensional linear-elastic stress analyses on compact tension specimen configurations.

The results from the running ANSYS codes, a full three-dimensional model, for bonded homogeneous stainless steel by epoxy as a filler material are shown in Fig. 8 - 16. The results consist of three groups; the first group is concerned with stress intensity factor for a specimen under opening mode loading conditions. The second group is concerned with stress intensity factor for a specimen under shear mode loading conditions. The third group is concerned with stress intensity factor for a specimen under tear mode loading conditions.

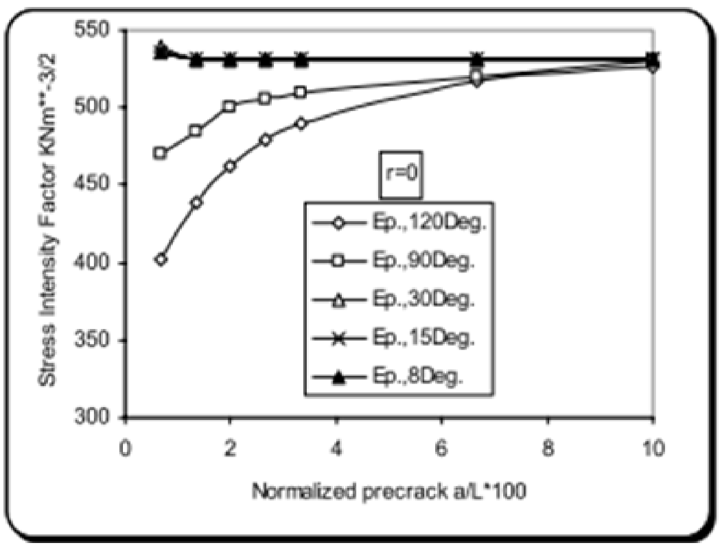

Figure 8. Effect of the pre-crack length on the stress intensity factor, KI, for a filler material (Epoxy) for different crack notch angles and r/w≈0.

Opening Mode Stress Intensity Factor, KI

Figure 8 shows the effect of the pre-crack length on the stress intensity factor, KI, for a filler material (Epoxy) for different notch angles and sharp notch, i.e., notch radius, r, approximately equal to zero. It is observed that the stress intensity factor, KI, increases as the crack notch angle decreases until it reaches a maximum value at an angle equal to 30°. Also, the stress intensity factors remain constant regardless of the value of the pre-crack length, a, greater than or equal to 10% of the total crack length, L. Therefore, the stress intensity factor becomes independent of the pre-crack length beyond a value of a pre- crack of 10% of total crack length.The stress intensity factor, KI, increases as the pre-crack length increases for all crack notch angles greater than 30° until reaching a maximum value at a pre-crack length, a, greater than or equal to 10% of the total crack length, L.

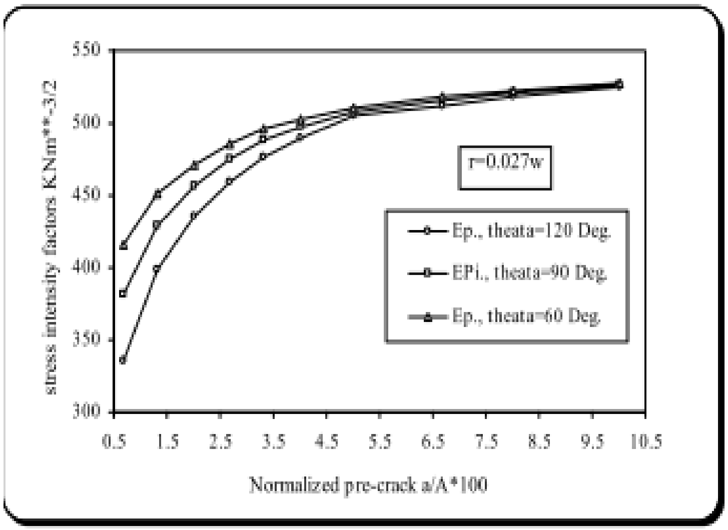

Figure 9. Effect of the pre-crack length on the stress intensity factor, KI, for a filler material (Epoxy) for different crack notch angles and r/w =0.027.

Figure 9 shows the effect of the pre-crack length on the stress intensity factor, KI, for a filler material (Epoxy)for different crack notch angles and for a given value of the notch radius, r = 0.027W. The stress intensity factor increases gradually reaching a maximum value at a pre-crack length, a= 0.1L. Also, it is observed that the stress intensity factor becomes not affected by the crack notch radius and is little affected by the crack notch angle for this case.

Figure 10 shows the effect of the crack notch radius on the stress intensity factor, KI, for a filler material (Epoxy) for different pre-crack lengths and crack notch angle equal to 30°. The stress intensity factor, KI, decreases as the crack notch radius increases for a pre-crack shorter than 0.1L. Also, It is observed that the stress intensity factor remain constant for a pre-crack length greater than or equal to 10% L, regardless of the notch radius and notch angle.

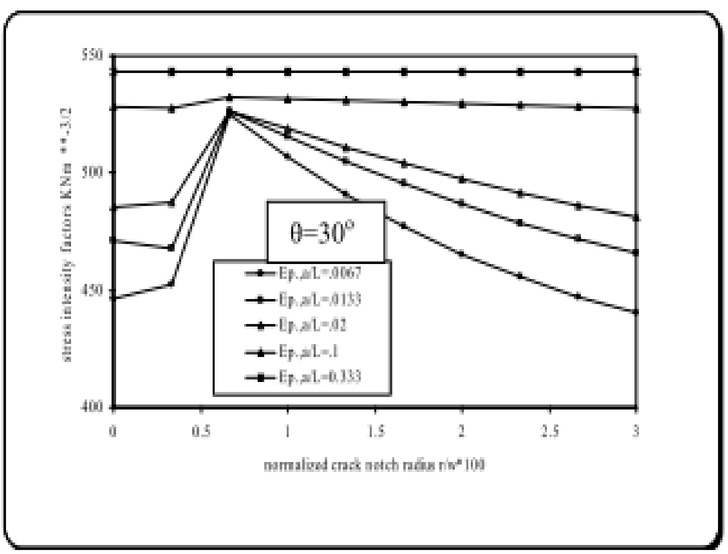

Figure 10. Effectof the crack notch radius on the stress intensity factor, KI, for a filler material (Epoxy) for different pre-crack lengths and crack notch angle equal to 30°.

Shear Mode Stress Intensity Factor, Kii

Figure 11 shows the effect of pre-crack length on the stress intensity factor, KII, for a filler

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material (Epoxy) for different crack notch angles and sharp notch, i.e., notch radius, r, approximately equal to zero. It is observed that the stress intensity factor increases as the crack notch angle deceases. Also, the shear mode stress intensity factor increases as the pre-crack length increases reaching a maximum value at a pre-crack length greater than or equal to 33% of the total crack length, L, then the stress intensity factor remains constant, i.e., independent on the notch angle.

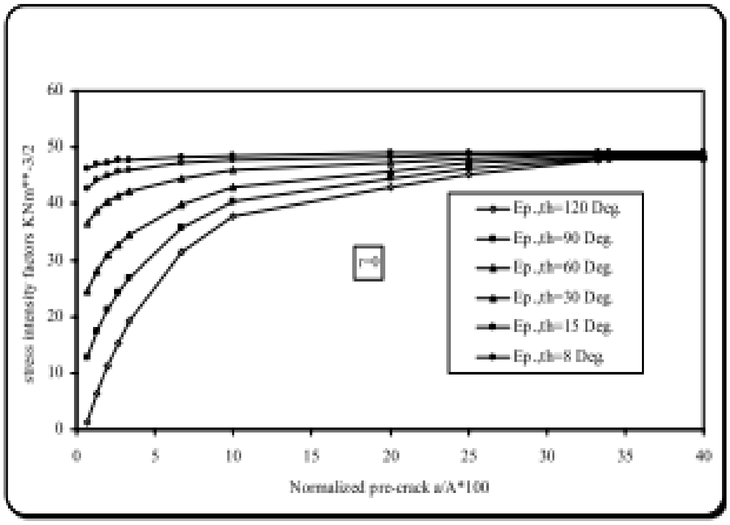

Figure 11. The effect of pre-crack length on the stress intensity factor, KII, for a filler material (Epoxy) for different crack notch angles and r/w ≈0.

Figure 12 shows the effect of pre-crack length on the shear mode stress intensity factor for a filler material (Epoxy) for different crack notch angles with a blunt notch, r, equal to 0.02 of specimen width, W. The shear loading mode stress intensity factor increases as the pre-crack length increases reaching a maximum value at a pre-crack length, a, greater than or equal to 33% of the total crack length, L. However, for the blunt notch, the shear loading mode stress intensity factor is not affected by the crack notch angle.

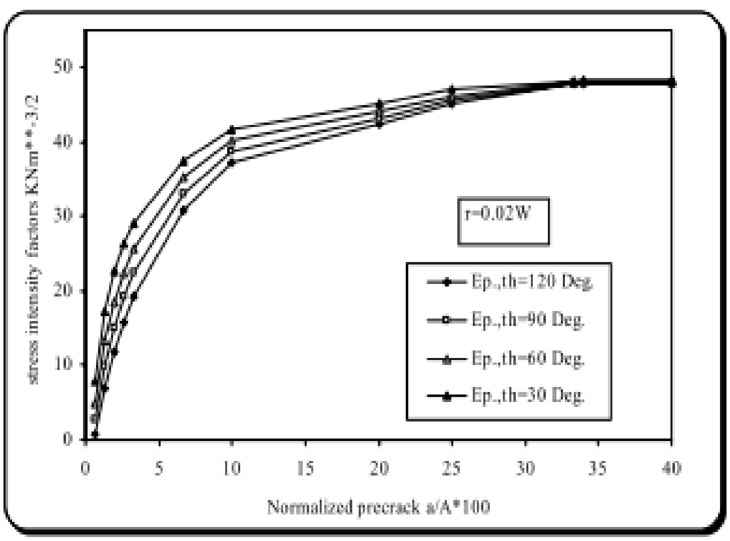

Figure 12. Effect of pre-crack length on the stress intensity factor, KII, for a filler material (Epoxy) for different crack notch angles with blunt notch r=0.02w of specimen width w.

Figure 13 shows the effect of crack notch radius on the shear mode stress intensity factor for a filler material (Epoxy) for different pre-crack lengths and crack notch angles equal to 30°. It is observed that the shear loading mode stress intensity factor is not affected by the crack notch radius for a pre-crack length greater than or equal to 33% of the total crack length, L. Also, the stress intensity factor is decreased as the notch radius increased for a pre-crack length less than 0.33L.This indicates that the value of shear loading mode stress intensity factor becomes independent whatever the value of crack notch angle and crack notch radius for a pre-crack length greater than or equal to 33% of the total crack length.

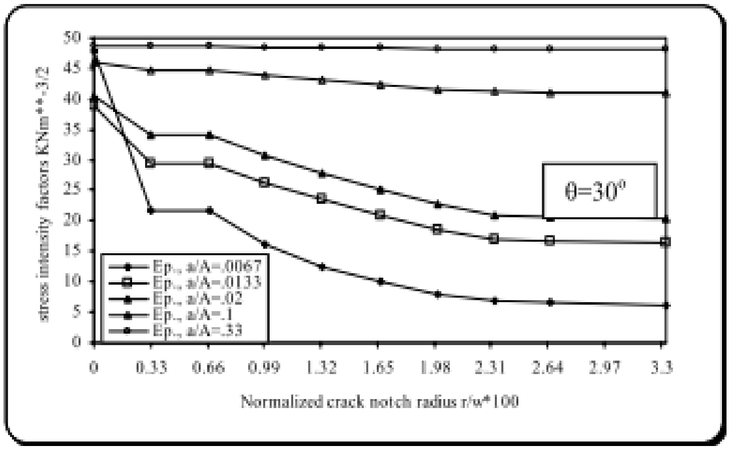

Figure 13. Effect of crack notch radius on the stress intensity factor, KII, for a filler material (Epoxy) for different pre-crack lengths and crack notch angles equal to 30°.

Tear Mode Stress Intensity Factor, KIII

Figure 14 shows the effect of the pre-crack length on the tear loading mode stress intensity factor for a filler material (Epoxy) for different crack notch angles and sharp notch, i.e., notch radius, r, approximately equal to zero. It is observed that the stress intensity factor, KIII, increases as the crack notch angle increases. For notch angle less than or equal to 30o the stress intensity factor, KIII, decreases as the pre-crack length increases, and for notch angle greater than 30o the tear mode stress intensity factor, KIII, increases as the pre- crack length increases reaching a maximum value at a pre-crack length equal to10% of the total crack length, L, then the stress intensity factor, KIII, decreases as the pre-crack length increases and remains constant for a pre-crack length greater than or equal to 33% of the total crack length.

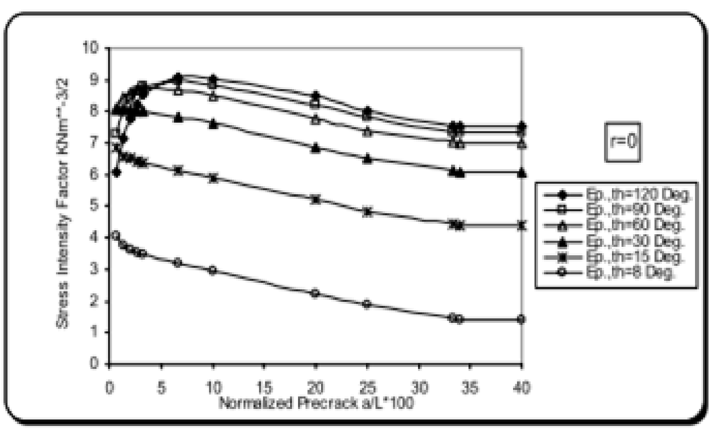

Figure 14. Effect of the pre-crack length on the stress intensity factor, KIII, for a filler material (Epoxy) for different crack notch angles and r/w ≈ 0.

Figure 15 shows the effect of the pre-crack length on the tear loading mode stress intensity

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factor, KIII, for a filler material (Epoxy) for different crack notch angles with a blunt notch, r, equal to 0.027 of specimen width, W. The tear mode stress intensity factor is not affected by the crack notch angle. Also, the tear loading mode stress intensity factor increases as the pre-crack length increases reaching a maximum at a pre-crack length less than or equal to 10% of the total crack length. After this value of pre-crack length the stress intensity factor, KIII, decreases and it remains constant for the pre-crack length greater than or equal to 33% of the total crack length.

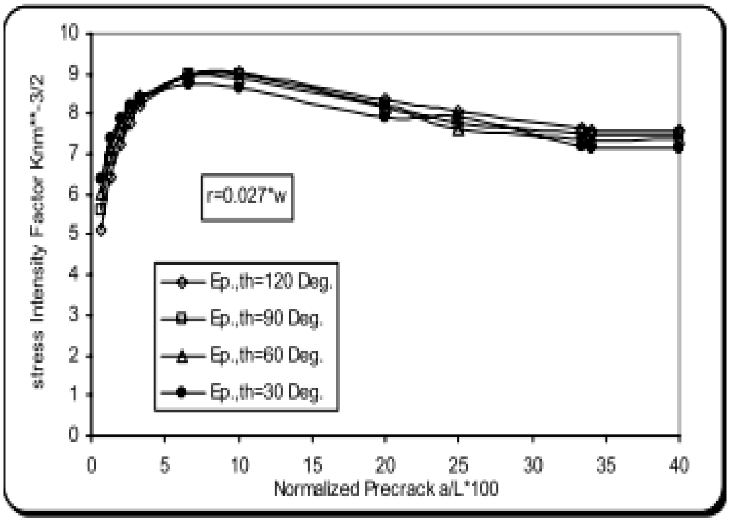

Figure 15. Effect of the pre-crack length on the stress intensity factor, KIII, for a filler material (Epoxy) for different crack notch angles and r/w =0.027.

Figure 16 shows the effect of the crack notch radius on the tear loading mode stress intensity factor, KIII, for a filler material (Epoxy) for different pre- crack lengths and crack notch angle equal to 30°.It is observed that for a small pre-crack length, the tear mode stress intensity factor decreases as the notch radius increases. However, in case of a pre-crack greater than or equal to 10% of total crack length, L, the stress intensity factor is not significant by the notch radius.

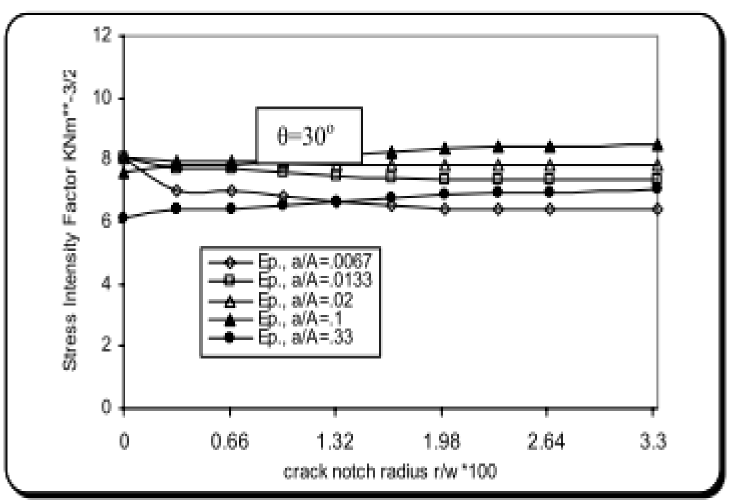

Figure 16. Effect of the crack notch radius on the stress intensity factor, KIII, for a filler material(Epoxy)for different pre-crack lengths and crack notch angle equal to 30°.

CONCLUSION

In the present work, the effect of notch radius, notch angle and pre-crack length on the stress intensity factors for mode I, mode II and mode III have been studied using finite element analysis method for bonded homogeneous materials. The conclusion consists of three groups; the first group is concerned with stress intensity factor for a specimen under opening mode loading conditions. The second group is concerned with stress intensity factor for a specimen under shear mode loading conditions. The third group is concerned with stress intensity factor for a specimen under tear mode loading conditions.

For Opening Mode Stress Intensity Factor, KI

1. For sharp notch, the opening loading mode stress intensity factor, KI, becomes independent on the crack notch angle beyond a value of 30° or below whatever the value of pre-crack length.
2. For blunt notch, the stress intensity factor, KI, is little affected by the crack notch angle.
3. The stress intensity factor, KI, remains constant for a pre-crack length greater than or equal to 10% L, regardless of the notch radius and notch angle.

For Shear Mode Stress Intensity Factor, KII

1. For sharp notch, the shear loading mode stress intensity factor, KII, increase as the crack notch angle decreases reaching constant value at an angle less than or equal 15° whatever the value of pre-crack length.
2. For a blunt notch, the shear loading mode stress intensity factor increases as the pre-crack length increases reaching a maximum value at a pre- crack length, a, greater than or equal to 33.33 % of the total crack length, L. However, for the blunt notch, the shear loading mode stress intensity factor is not affected by the crack notch angle.
3. The value of shear loading mode stress intensity factor becomes independent whatever the value of crack notch angle and crack notch radius for a pre-crack length greater than or equal to 33.33 % of the total crack length.

ForTearModeStressIntensityFactor, KIII

1. For sharp notch, the tear loading mode stress intensity factor, KIII, for bonded homogeneous materials is highly significant by the value of notch angle.
2. For blunt notch, the stress intensity factor, KIII, is not affected by the crack notch angle. However, in case of a pre-crack greater than or equal to 33.33 % of total crack length, L and notch angle equal to 30o the stress intensity factor is not affected by the notch radius.

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