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FRACTURE CRITERIA OF SHARP V-NOTCHED SPECIMENS

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ABSTRACT
In the present work fracture criteria for a sharp v-notched specimens for different notch geometries are investigated experimentally as well as using a finite element software. The stress fields near the tip of sharp v-notches can be characterized by generalized stress intensity factor, K^V which is a function of V-notch angle. By analogy with cracked specimens, a crack will propagate from the tip of a notch when the actual value of generalized stress intensity factor reaches a critical value. The critical value of generalized stress intensity factor, K_I^V of each V-notch angle needs to be obtained through experimental measurement on very sharp notched samples. In this present work, experiments were conducted for loading mode - I with different notch angles and different notch geometries for steel and aluminum alloy, keeping length and thickness constant. Based on critical load critical generalized stress intensity factors are measured. The result was presented with the variation of notch geometries against generalized stress intensity factor. The finite element software was used to study the localized stress at the notch tip. The results obtained from the finite element analysis showed that fracture criteria for sharp v-notched specimen strongly depends on stress singularity which is function of notch angle.

Keywords: Notches, Generalized stress Intensity factor, Mode-I, Mode – II and Mode –III loading.

1. INTRODUCTION
Stress Intensity factor, K implies is a parameter that amplifies the magnitude of the applied stress and depends on the geometry and also loading condition. These load types are categorized as Mode-I, Mode –II and mode – III loading. Generally there are three modes to describe different crack surface displacements as in Fig- 1. Mode – I is opening or tensile mode where the crack surfaces move directly apart. Mode – II is sliding or in plane shear mode where the crack surfaces slide over one another in a direction perpendicular to load edge of crack. Mode – III is tearing and anti plane shear mode where the crack surfaces move relative to one another and parallel to loading edge of the crack. Magnitude of elastic stress field for a cracked specimen at tip of the crack is defined by stress intensity factor and denoted as K. Similarly magnitude of elastic stress field for V-notched samples at notch tip is defined as notch stress intensity factor and denoted as K^V

Sharp notches are often met in engineering structures. Near the tip of a sharp notch there are always high local stresses and strains which may cause a crack and consequently a failure of the structure. Thus a fracture criterion for elements with v-notches is a critical matter. The damage around the V-notch tip is very difficult to study and strongly dependent on the microstructural aspects of each materials.

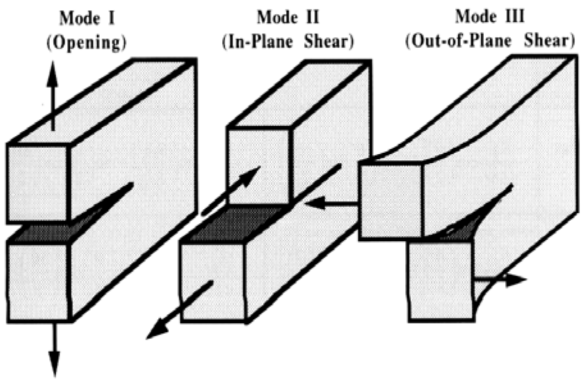

Fig 1: the three modes of loading that can creat crack propagation

The stress and displacement fields near the tip of sharp V-notches can be characterized by generalized stress intensity factor, K^V, which is a function of V-notch angle. By analogy with cracked specimens a fracture criterion based on critical values of the generalized stress intensity factors can be stated i.e. a crack will propagate from the tip pf a notch when the actual value of the generalized stress intensity factor reaches a critical value. The critical value of generalized stress intensity factor of each V-notch angle has to be obtained through experimental measurements on very sharp notched samples. The variation of generalized stress intensity factor with notch geometries has to be obtained through experimental and using finite element software.

Broek[1] first suggested a simple engineering solution for estimating the stress intensity factors for cracks estimating the stress intensity factors for cracks emanating from notches. His idea was to consider the crack length as including from notches. Smith and Miller [2] proposed a simple formula for the stress intensity factor of small crack at the root of a circular hole. Another approximation was suggested by Lukas[3] In. He suggested the method for calculating the stress intensity factor for small cracks emanating from notches. But only V-notch problems for linear elastic materials are first analyzed by C. Atkinson et al.[4] in 1988 by means of eigenfunction series expansion using auxiliary fields. Later in 1999 the problem is analyzed by Numerically by Strandberg[5].

For the crack problem, values of stress intensity factor have been studies for a large variety of geometries. This is however not the case for general V-notch problem. Thus in this present work the

2. GOVERNING EQUATION

For mode I loading, the stress distribution at the notch tip can be described as

$$\sigma_{ij}(r, \theta) = \frac{K_I^V}{\sqrt{2\pi}\, r^{1-\lambda}} f_{ij}(\theta, \alpha)$$

Where r and θ are the polar coordinates (as shown in fig 2), K_I^V is the generalized stress intensity factor, α is the notch angle, defined below and f_{ij} is a function of the polar and, implicitly of the notch angle and as known as shape factor.

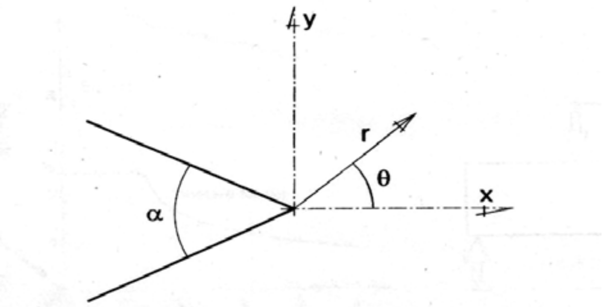

Fig 2: Coordinate system and symbols used for v-notch

The parameter λ characterizes, the strength of the singularity and is the root of the equation,

$$\sin(\lambda\beta) + \lambda\sin(\beta) = 0$$

The relationship between λ and β is –

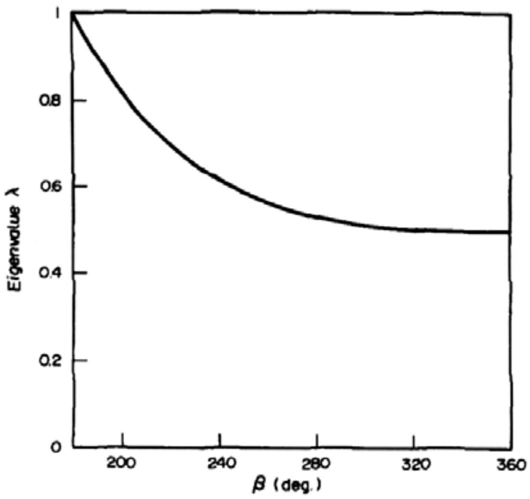

Fig 3: Dependence of λ on Notch Geometry

Here, β (in radian) = 2π – α ,where α is notch angle

For experimental procedure the following equation was used –

$$K_I^V = \sigma_a D^{1-\lambda} f(\alpha, a/D)$$

3. EXPERIMENTAL PROCEDURE

3.1 Materials Used:

For experimental procedures two types of materials were used. The materials were (with composition)-
Mild Steel (0.13% carbon) and Aluminum alloy (Cu 1.5% and Si 10%)

3.2 Geometry of Specimen

The width and thickness of the specimens were 23 mm and 3 mm respectively and these were kept constant. The length of the specimens were Notch depth were such that a/D ratio was kept 0.1 to 0.4.

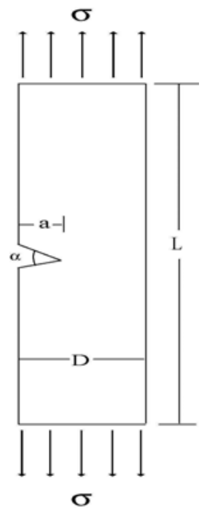

Fig 4: Geometry of the specimen

3.3 Procedures

The load was applied by Universal Testing Machine. The critical load was observed with a microscopic glass. The critical load was taken after the formation of plastic zone at notch tip. The same procedure was continued for

40 specimens of steel and aluminum.

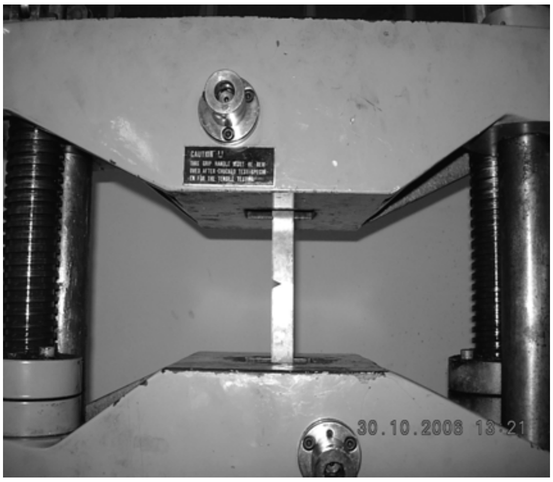

Fig 5: Specimen is loaded in Universal Testing Machine

4 FE MODELS

The FE models were generated using the solid 45 triangular elements available in Ansys 5.6 software [6] having the following material properties:

Young's modulus for steel and aluminum alloy was 200 GPa and 70 GPa respectively. Poisson's ratio for steel and aluminum alloy was 0.30 and 0.26 respectively.

All the analysis was done in free mesh condition. Particular care was taken to fine meshes where the stress singularity was expected to occur. The typical finite element meshes are shown in figure –

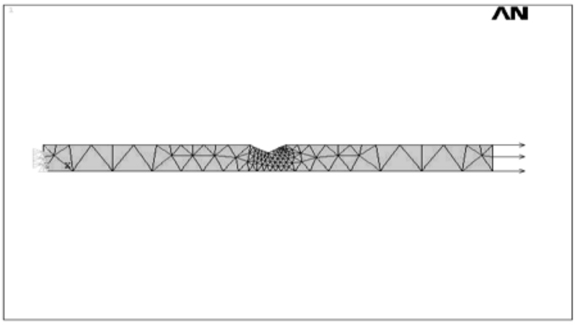

Fig 6: Loading Conditions and meshes

5 RESULTS AND DISCUSSIONS

The experiment was conducted for 40 specimens with different notch geometries. The experiment was done to study the variation of generalized stress intensity factor with notch geometries. As notch geometries were including a/D ratio as well as notch angle, so graphs were plotted for these two parameters. These graphs are discussed in the following articles.

5.1 Generalized Stress Intensity Factor vs. a/D

The variation of generalized stress intensity factor vs. a/D were shown from figure 7(a) to 7 (d) for steel and 7(e) to 7 (h) for aluminum alloy. The variation was found that, for increasing of a/D ratio is also increased. So with increasing of a/D ratio, possibility of crack growth is also increasing. The variation are almost similar for both steel and aluminum alloy.

5.3.1 For Mild Steel with 0.13% Carbon

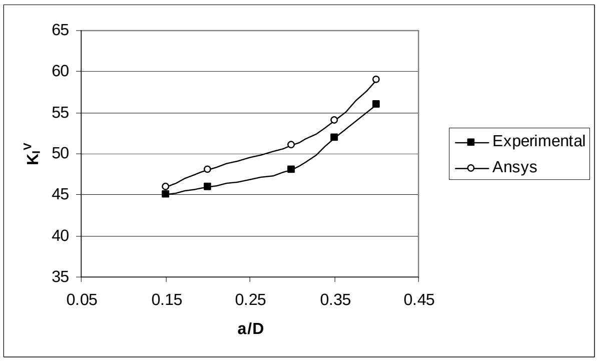

Fig 7(a): Variation of a/D vs. K_I^V for 45^o notch angle

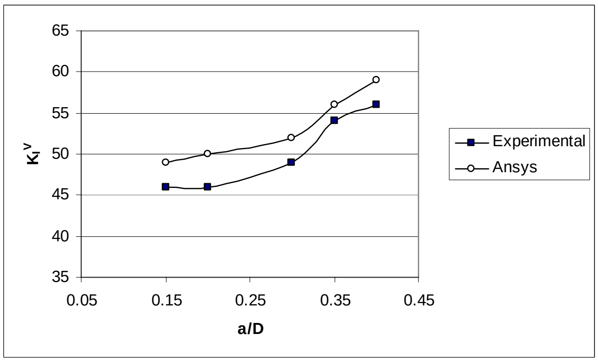

Fig 7(b): Variation of a/D vs. K_I^V for 60^o notch angle

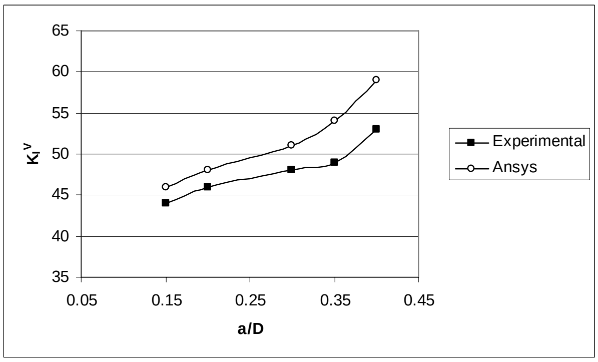

Fig 7(c): Variation of a/D vs. K_I^V for 90^o notch angle

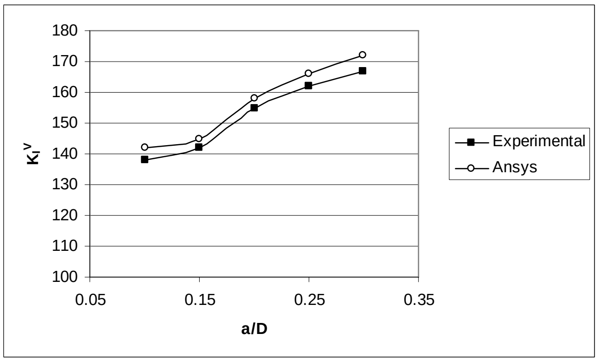

Fig 7(d): Variation of a/D vs. K_I^V for 120^o notch angle

5.1.2 Aluminum

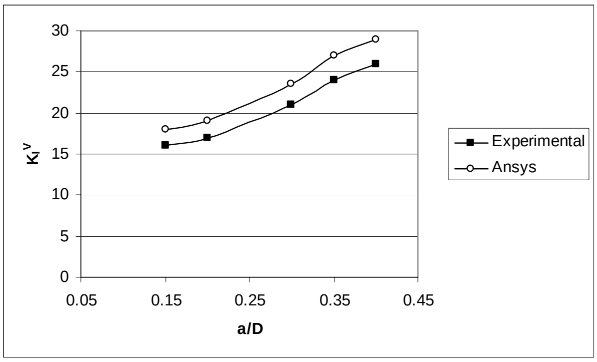

Fig 7(e): Variation of a/D vs. K_I^V for 45^o notch angle

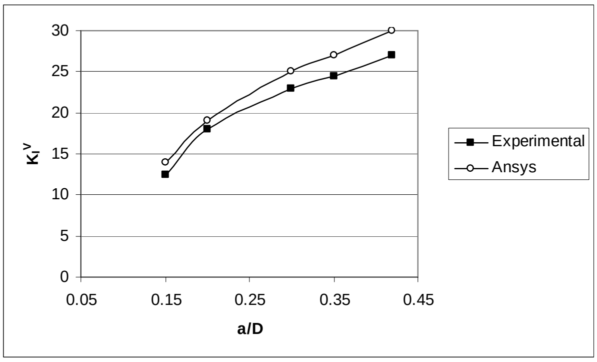

Fig 7(f): Variation of a/D vs. K_I^V for 60^o notch angle

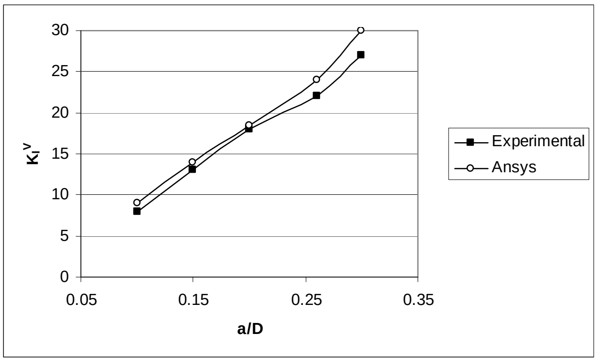

Fig 7(g): Variation of a/D vs. K_I^V for 90^o notch angle

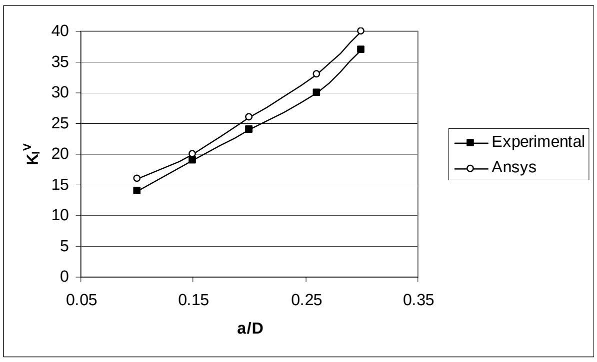

Fig 7(h): Variation of a/D vs. K_I^V for 120^o notch angle

5.2 Generalized Stress Intensity Factor vs. Notch angle

Generalized stress intensity factor was also observed with different notch angles. The variation curves for different a/D were almost symmetric. It has been noted that with increasing of the notch angle generalized stress intensity factor also increased. The increment was not linear nor was not uniform, rather it was likely greatly depends on stress singularity. As for higher notch angle stress singularity is greater than ½, so generalized stress intensity factors also greater for greater notch angle. The value of generalized stress intensity factor was not varied rapidly up to 90^o notch angle, but after that it increased rapidly which is cause for higher singularity. The variation curves of generalized stress intensity factors with different notch angles are shown in figure 8(a) to figure 8(c) for steel and figure 8(d) to figure 8(f) for aluminum alloy.

5.2.1 Mild Steel with 0.13% Carbon

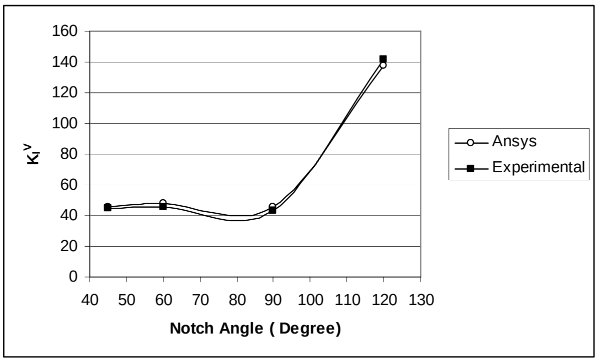

Fig 8(a): K_I^V vs. Notch Angle (a/D = 0.15)

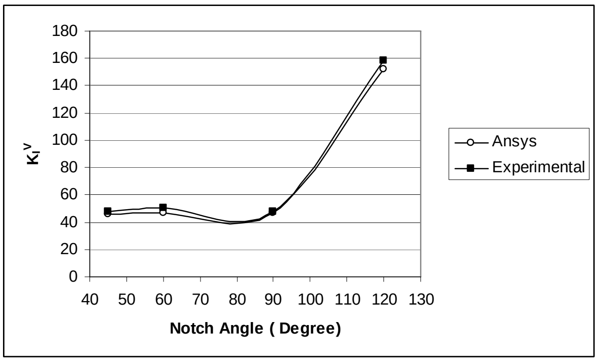

Fig 8(b): K_I^V vs. Notch Angle (a/D = 0.2)

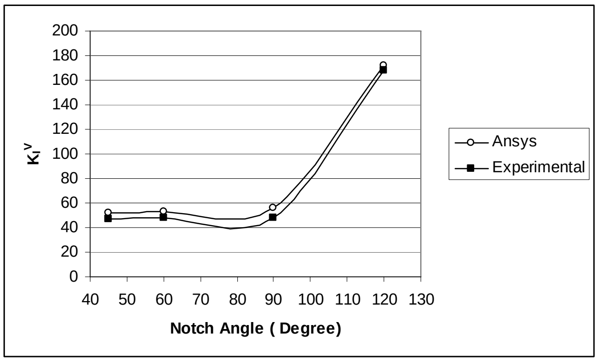

Fig 8(c): K_I^V vs. Notch Angle (a/D = 0.3)

5.2.2 For Aluminum Alloy

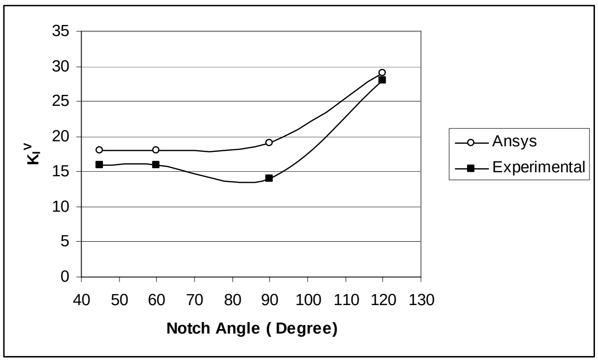

Fig 8(d): K_I^V vs. Notch Angle (a/D = 0.15)

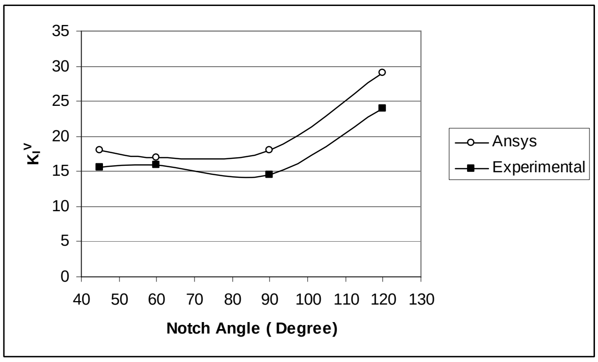

Fig 8(e): K_I^V vs. Notch Angle (a/D = 0.2)

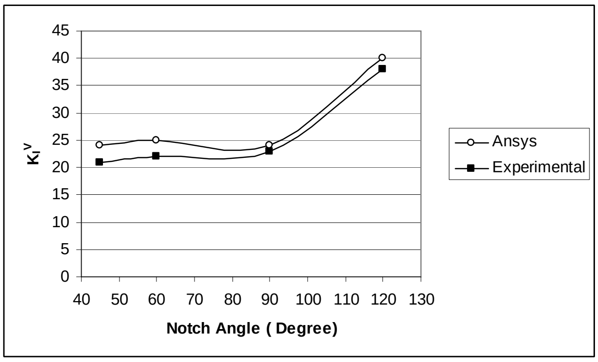

Fig 8(f): K_I^V vs. Notch Angle (a/D = 0.3)

6 CONCLUSIONS

The variation of generalized stress intensity factor against notch geometries was observed. It was found that, for increasing a/D ratio generalized stress intensity factor also increased. From this it can be concluded that with the increase of a/D ratio, possibility of crack growth is also increasing. The variations were almost similar for both steel and aluminum alloy.

Generalized stress intensity factor was also observed with different notch angles. The variation curves for different a/D were almost symmetric. It can be mentioned that the increase of the notch angle generalized stress intensity factor also increased. The increment was not uniform, rather it depends greatly on stress singularity. On the other hand stress singularity depends on notch angle as stated earlier. As for higher notch angle stress singularity is greater than ½, so generalized stress intensity factors are also greater for greater notch angle. The value of generalized stress intensity factor did not vary rapidly up to 90° notch angle, but after that it increased rapidly which was caused for higher singularity. Facture of v-notched specimen did not only depend on local stress developed, but also it is greatly dependent on the value of λ, which was a function of notch angle as well as of shape factor.

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8 NOMENCLATURE

Symbol	Meanings	Unit
a	Notch Depth	mm
D	Specimen Width	mm
α	Notch Angle	Radian
K_I^V	Generalized Stress Intensity Factor	MPa $m^{1/2}$
σ_a	Applied Stress	MPa
L	Length	mm
f	Shape Factor	Dimensionless