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Effect of Crack Length to Plate Width Ratio on Stress Intensity Distribution at the Crack Tip

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Abstract
To start the comprehending of the materials fracture, first must understand the stress fields and deformation distribution at the crack tips. Analysis the behavior of crack for a solid plate may be extensive importance of the plate design to evade the failure. The crack is small when rivalled to the dimension of solid plate and the smallest crack ligament to the exterior plate region is greatly than the crack can be estimated for an infinite plate with finite crack. The variant of the stress field and stress intensity distribution is not great in profile compared with the variation in values. The result evaluated using finite element method to analysis by using Ansys Parametric Design Language (APDL) code in Ansys v.11 with static analysis at two different cases for carbon steel material alloy. In the first case, tension load applied at the upper edge of the plate model and in the second case, shear load applied at the upper edge. The results extracted from the current study show increasing the crack length to width ratio (a/b) from 0.1 to 0.9, increases the Von Misses stress and stress intensity values especially at the crack tip. The Von Misses stress increasing to 369 MPa while the increasing to 1650 MPa in the first case which represent the maximum values from two cases. The extracted results appear that the elastic stress intensity under static load is above the yield strength of the two cases load take into account in the current study.
Keywords: Crack length, Crack tip, Stress Intensity, Tension Load, Shear Load.

Nomenclature
a/b: crack length to plate width ratio.
σ_{xx}: Normal stress in x-direction.
σ_{yy}: Normal stress in y-direction.
σ_{zz}: Normal stress in z-direction.
σ_{Von}: Von Misses stress..
σ_{xy}: Shear stress in xy-plane.
K_I: Stress intensity factor for mode I (opening mode).
K_{II}: Stress intensity factor for mode II (Sliding mode)

Introduction

The study of stress distribution and concentration is an important reflected in strategy of engineering working and throughout of their service life. Many of engineering components and constructions subjected to different load include some configuration of stress increasing that may be results from geometrical or metallurgical breaks or gaps. Throughout the past rare years, extensive energies, which dedicated to develop methodologies, which allow the estimation of stress distribution and concentration. As the experience related to stress expanded, it becomes perfect that in guaranteed cases stress might be treated from some point of object [Muhmmad Ajmal, 2009]. Usual, a fracture defined as the separation of material into two or more parts due to the stress action. Usually, in the plate, the development of continuous displacement of the plate surface cause the fracture [Najah, 2015]. Fracture mechanics techniques was widely used and became important part in prediction of crack. The finite element method commonly used for estimation the stress concentration and stress distribution for different crack types. Some methods depending on the nodal displacement to determine the stress values. The stress distribution can be determined from the nodal displacement solution, which represent the first output when using the finite element methods program. Analytical solution of stress distribution and concentration of crack type which is circular and square in rectangular or square plate can be performed using Matlab program [Miloud Souiyah, 2009].

By considering a 2D linear elastic body having a straight crack in plane strain or plane stress conditions. The symmetrical around the crack line include Both the body and the load applied [James, 1972]. Some metals, including alloys with high strength, carried a plastic deformation in zones of high stress concentration, and the fracture caused by a small extend of plastic deformation at tip of the crack. This deformation effect on stress distribution, which specify the failure, occurs [Zehnder, 2012]. [Rousseau and Tippur, 2002] are early works refer to a crack parallel to the elastic modulus, which suggested the stress distribution at the crack tip have proportional with the crack length. Also studied a measurement the crack tip deformation and fracture in compositionally ranked FGMs (Functionally Graded Materials). The crack tip deformations which effected by elastic gradients was studied with parallel crack oriented to the elastic gradient. [C.M. Davies et al., 2005] offers a good evaluation of the equivalent Von Mises stresses in the complete range levels of the load Using the Neuber approach. However, a non-conventional prediction occurs when use of the Neuber approach clearly to estimate the maximum principal stress in the crack plane. Also proposed a modified Neuber method to establish the maximum principal stress in the crack plane depending on the equivalent von Mises stress was evaluated by the Neuber approach.

[Priscilla L. Chin , 2011] used the finite element method in ANSYS program to simulate and compute the stresses distribution and concentration at the crack tip of the bracket. The yield strength of the bracket material compared with the Von Misses stress for the region near the crack tip. Also demonstrated 2D problems using plane elasticity solutions to quantify limited of effects the stress concentration about their tips. The finite element techniques are employed to evaluate thickness effects in the stress fields around the tips, and evaluate their importance at the structural design point. [Ali et al., 2014] achieved three theoretical models and identify effect of the of the plate width, length of crack and stress distribution ,while failed to identify the effect of the plate length. Also tries to evaluate the stress distribution in edge of the cracks alongside the length of a plate under a uniform tension using FEM for analysis. The stress intensity and the location of edge crack alongside the finite plate was calculated using Neural Network Method (NNM).

The current study investigate the Von misses and stress intensity distribution at the crack tip region under the applied tension and shear loads at the edges of the plate by using Ansys Parametric design language.

Materials and Finite Element Method Methods

For considerations in the practical, the types of stress, strains and deformations of single and assembly parts may be better approached using finite element method. Which is a numerical method to signify the governing equations in form of matrix solved by computer software. Solution of the model was evaluated by finite element method. The element type of the building unit specify the number of degrees of freedom (d.o.f) in the translation and rotation direction under effect the applied load plate, shell and solid type elements. The problem type and geometry depends on the best selection of element type.

Some of the parameters such as crack length to the plate width ratio can main purpose of this paper is to detect the plate behavior under the applied stress for various materials by evaluating stress distribution and concentration on the crack tip which affected on the stress intensity factors and Von-Mises. The model is chosen to signify the metal plate with crack in the center of model using finite element method (FEM) software (Ansys v. 11) when the geometry for specimen is symmetry and the load applied load on the plate from one side or edge, while in the other case was symmetry.

APDL (Ansys Parameter Design Language) in which the program written was used to evaluate the required results because it is faster and more accuracy than the GUI (graphical user interface). At the first step of solution, the structure was discretize to the finite element using software program and represented by element connected at the node. The number of element specify the accuracy of the required result. In the present work, PLANE183 was used as element type. This selected element was defined by 6-nodes or 8 nodes having two degrees of freedom for each node (translations in the nodal x and y directions) as shown in the figure (1). Plane element (plane stress, plane strain) used PLANE183 or can be used as an axisymmetric element. Also has plasticity, hyperelasticity, creep, large deflection, large strain capabilities, and support the Initial stress [Ansys v. 11, 2011].

Meshing of the model was performed by meshing tool using free mesh in which the lines of the area was divided into number of element. The lines of the crack was divided to the number of element more than the other lines in the model to give accurate results in the zones of the crack at which the stress concentration occurs as shown in the figure (2). The plate width (W=60 mm), height (H=70 mm), crack length (a=6 mm) with (h=2 mm) as shown in the figure (3).

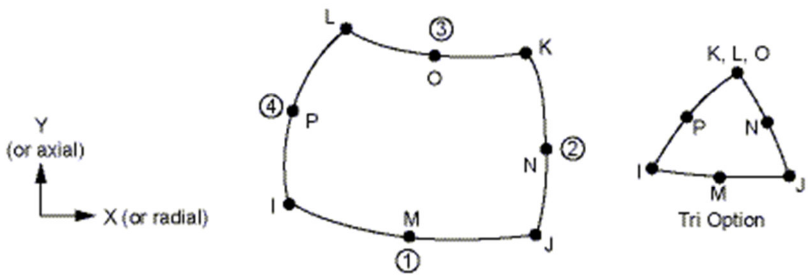

Figure (1):PLANE183 element type [10].

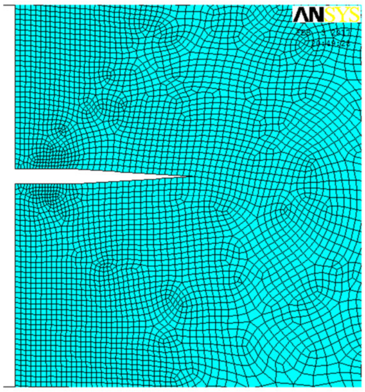

Figure (2): free mesh element.

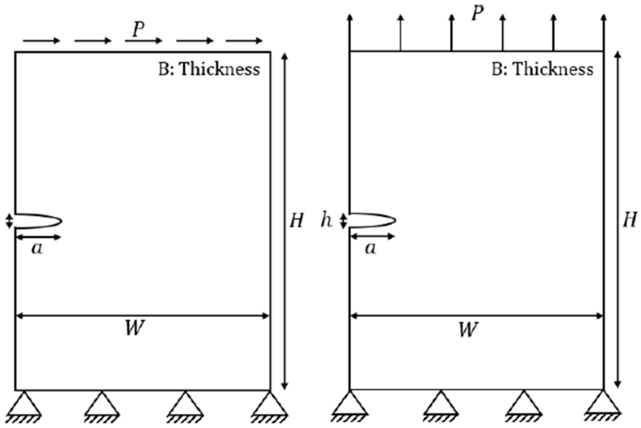

Figure (3): Mode I and II of single crack edge.

Carbon steel material was used in the plate of current study to calculate the stress concentration and distribution at the crack tip and the properties of this material was given in the table (1) [Najah, 2015].

Table (1): Mechanical properties of selected material [2].

Material	Modulus of elasticity, E (GPa)	Poisson's ratio, υ	Density, ρ (kg/m^3)
Carbon steel	210	0.3	7820

Ansys Parametric Design Language (APDL) Method.

APDL is a method used in Ansys v.11 program in which the program code was written in a text file then inter this code in command line to execute the solution. In APDL there is three important procedures in main menu:

1. Preprocessor (/PREP7): from which the build of model and defining of element type with real constant and material properties of the model. Also the meshing process of the model and crack tip region can be performed using preprocessor list.
2. Solution (/SOLU): permits to apply boundary condition to the model geometry including load such as (force, moment and pressure) and displacement constraint at the fixed edge. Also solution process contains the analysis type (static analysis) was used in the current study in which apply the static load to determine the stress concentration and distribution in the crack tip.
3. Postprocessor command (/Post1):used to presentation the result of nodal and element such as the displacement distribution under the applied load and stress concentration and distribution at the crack tip region including direct and shear stresses. Also Von Misses stress can be determined and plotted in graph. Figure (4) shows flow chart of APDL method.

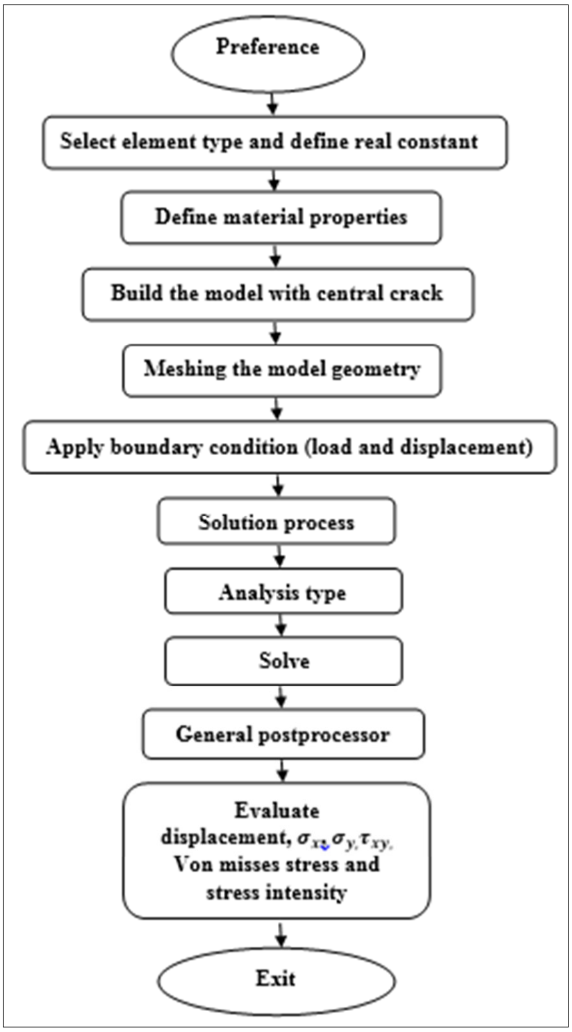

Figure (4): APDL Flow chart

The Von Misses yield criteria are given by:

$$\sigma_{Von\ Misses} = \frac{1}{2}\left[\left(\sigma_{xx}-\sigma_{yy}\right)^2 + \left(\sigma_{xx}-\sigma_{ZZ}\right)^2 + \left(\sigma_{yy}-\sigma_{ZZ}\right)^2\right]^{\frac{1}{2}} \qquad \ldots\ldots(1)$$

Results and Discussions

Stress intensity distribution was numerically evaluated using finite element method to analysis by using ANSYS V. 11 with static analysis at two different cases for carbon steel material alloy.

In the first case, the plate model analyzed under tension static load applied at the upper edge and the lower edge fixed degree of freedom (translation and rotation) in all direction. The analysis performed with different crack length to width ratio (a/b) and calculated the displacement, Von Misses stresses and stress intensity distribution at the crack tip zones.

The second case included applied the shear force at the upper edge of plate and the lower edge fixed degree of freedom (translation and rotation) in all direction. The displacement, stress intensity and Von Misses stress ($\sigma_{Von\ Misses}$) distribution was calculated with variation of (a/b) ratio.

Figures (5-14) show stress field and stress intensity distribution at the crack tip zone for crack length to width ratio a/b varies from (0.1-0.9) under the applied tension load at the upper edge. In the solid plate, the upper and lower faces of the crack will separated. Before deformation due to the applied load, the crack faces supposed to lie in the same surface. When the external loads applied at the cracked body at the edge of plate, faces of the crack will started to move with regard to each other and the movements defined the displacements field difference between the surfaces of the crack, at the local Cartesian coordinate system. From these results it seem clear when increasing the crack length to width ratio (a/b) from 0.1 to 0.9, the Von Misses stress and stress intensity values increases especially at the crack tip. The Von Misses stress increasing from (6 MPa-369 MPa), while the stress intensity increasing from (30.2 MPa to 1650 MPa). The variant of stress intensity about the tip of crack similar for the normal stresses, while in the Von Misses stress the variation of stress around the crack tip is not fully symmetric due to small amount of sliding mode touch the analysis. Stress intensity may be consider a new conception plays basic role to evaluate the strength of fracture in the cracked solids.

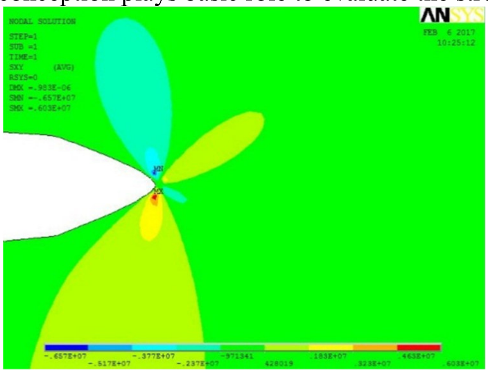

Figure (5):σ_{Von} distribution at a/b=0.1.

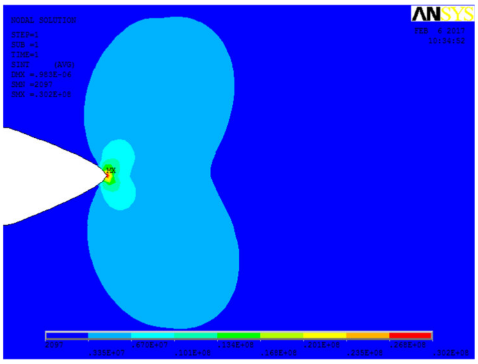

Figure (6): stress intensity distribution at a/b=0.1.

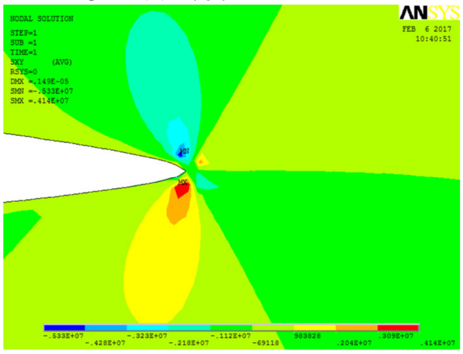

Figure (7):σ_{Von} distribution at a/b=0.3.

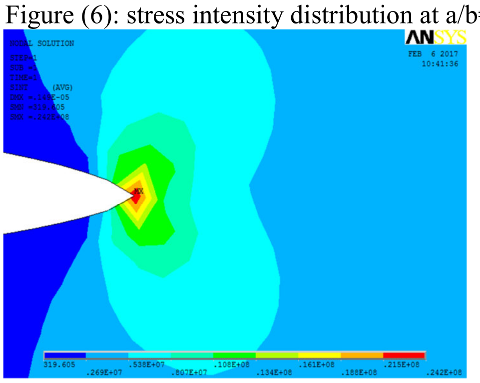

Figure (8): stress intensity distribution at a/b=0.3.

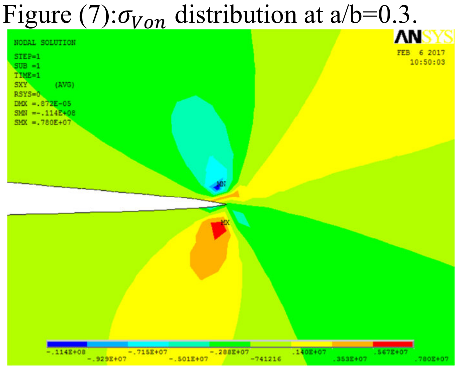

Figure (11):σ_{Von} distribution at a/b=0.5.

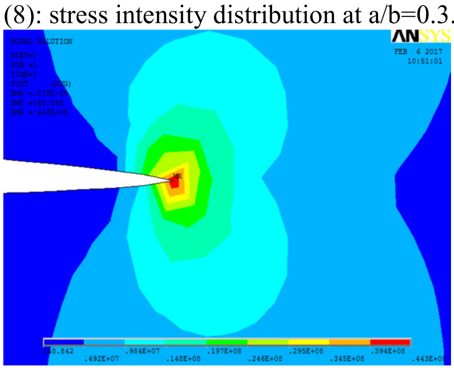

Figure (12): stress intensity distribution at a/b=0.5.

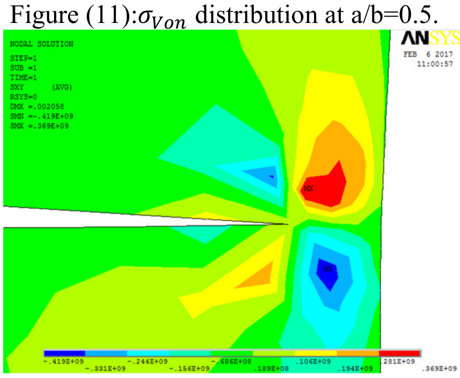

Figure (13):σ_{Von} distribution at a/b=0.9.

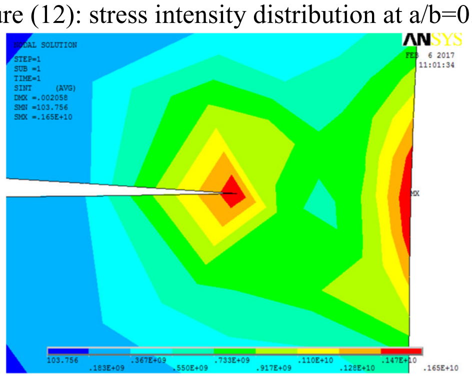

Figure (14): stress intensity distribution at a/b=0.9.

Figures (15-22) show stress field and stress intensity distribution at the crack tip zone for crack length to width ratio a/b varies from (0.1-0.9) under the applied shear load at the upper edge. The results extracted from these figures showed the increasing in crack length to width ratio (a/b), the Von Misses stresses increasing from (88.2 MPa to 200 MPa) and the stress intensity increasing from (221 MPa to 1000 MPa) at the crack tip when increasing a/b ratio from 0.1 to 0.9. The sliding between the upper and lower surface increasing under the applied shear load than tension load because the tendency to separate under the applied shear load. Finally, the results extracted of three cases by using APDL method was compatible with results [Najah, 2015].

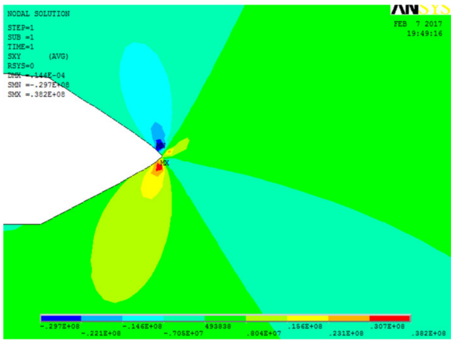

Figure (15):σ_{Von} distribution at a/b=0.1.

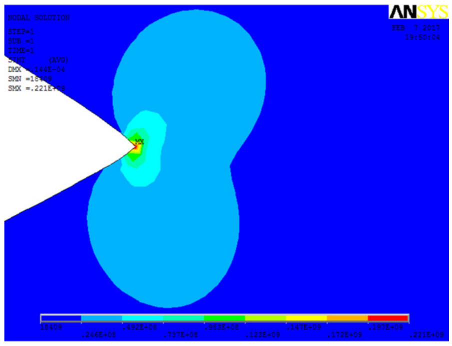

Figure (16): stress intensity distribution at a/b=0.1.

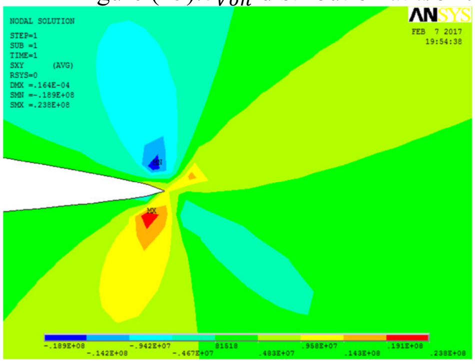

Figure (17):σ_{Von} distribution at a/b=0.3.

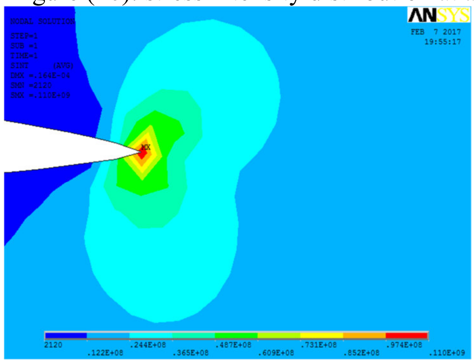

Figure (18): stress intensity distribution at a/b=0.3.

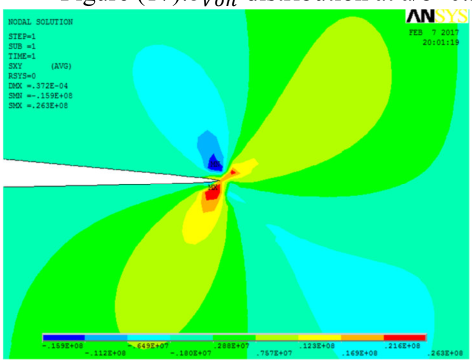

Figure (19):σ_{Von} distribution at a/b=0.5.

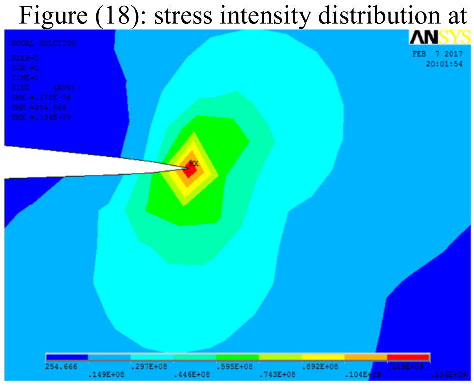

Figure (20): stress intensity distribution at a/b=0.5.

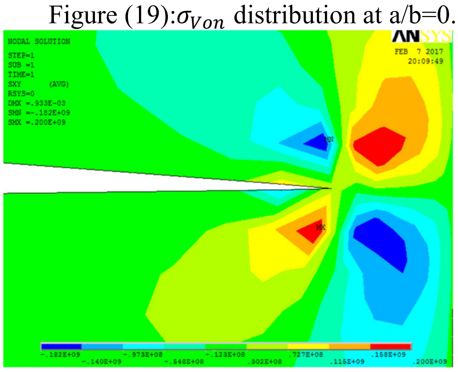

Figure (21):σ_{Von} distribution at a/b=0.9.

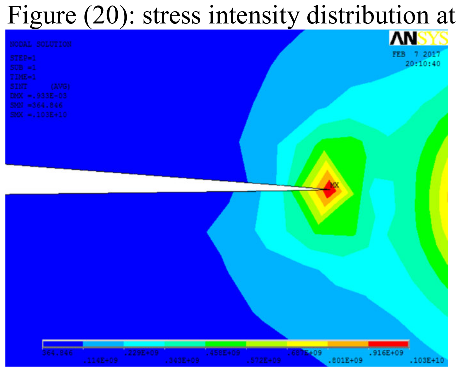

Figure (22): stress intensity distribution at a/b=0.9.

Conclusions

The purpose of current paper is to study the stress field distribution around the crack tip and effect the increasing of crack length to width ratio on these stress field and stress intensity using the finite element method with Ansys v.11 program using APDL method.

1. The Von Misses stress and stress intensity increases with increasing in crack length to width ratio a/b especially at the crack tip where stress concentrated.
2. The distribution of stress in uniaxial load applied at the upper and lower edge is more symmetric about the crack tip line and more opening or separate in crack faces than the first case when the load applied at the upper edge only.

3. Ansys Parametric Design Language (APDL) code is more effective and accurate tool used to obtain the stress behavior and distribution in finite element method.
4. The crack tip stress field and stress intensity is more affected to the applied load value in direction (tension and shear load).

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Ansys v.11 Help.