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Analysis on Crack Propagation in Ti-6al-4vskin under Tensile Loading

S.Seerat
Department of Mech,
Intell Engineering College,
Anantapur, India.

S.Khaleel Basha
Assistant Professor,
Intell Engineering College,
Anantapur, India.

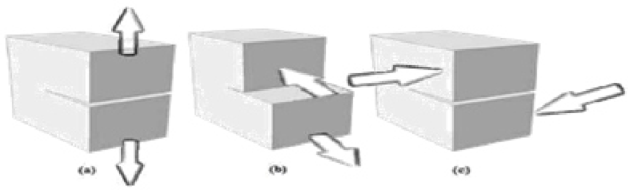
ABSTRACT:

The main objective of current work is to investigate the how a crack propagates and grows in a typical Ti-6Al-4V material plate. By using the finite element method software (ANSYS13) were used to simulate crack growth and to compute the stresses and the stress-intensity factor. A specific plate design was selected and a corner crack was investigated, since engineers often detect this type of crack in plates. The VonMises stress near the crack tip is compared against the yield strength of the material. Under the tensile loading i.e. in Mode-I the stress-intensity factor is compared against the material's fracture toughness. The results show that the plate can tolerate minute cracks in the structure. The fatigue strength of the structure is recommended to be assessed in the future.

INTRODUCTION:

Fracture is the local split-up of bonds at atomic scale in a structure resulting in the formation of new surfaces under severe mechanical and/or thermal loading.Dependingon the type of material, the separation is termed as 'fracture', used forbones of living creatures, 'tearing', in case of so ft tissues and 'breakage' for metals and composites. In general, failure in a structure, in most cases is instigated either due to (a) slackness in the course of design, manufacturing and operation of the structure or (b) employment of a new material or design .While the type-(a) fracture is usually caused by human error which can be avoided, improvement of a design or material can cause unexpected problems which are difficult to avoid.Ineither case, the strength of the material diminishes with increase in the extent of fracture.Even though, the problem of fracture has been there ever since the invention of man-made structures, it has come to light only after the world war-II. Lately, because of the increase in modern technologies, innovation of complex materials and compromise in design for cost effectiveness, the convolution of fracture is in turn escalating.

A few examples which have proven the devastating effects of fracture are airline crashes (Figure 1.1) due to initial flaws, collapse of skyscrapers, bridges in the event of natural calamities, bone fracture as well as tissue tearing because of implanted medical devices etc. Moreover, the rise in risk of such events will have a major impact on the economy.They further stated that, the cost could be reduced by $ 35 billion if an improved technology of studying cracks is used. Despite the fact that fracture can cause catastrophiceffects,



$$\varepsilon_{xx} = \frac{\partial u_x}{\partial x} \qquad \varepsilon_{yy} = \frac{\partial u_y}{\partial y} \qquad \varepsilon_{xy} = \frac{1}{2}\left[\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right] \qquad \text{Eq 1-1}$$

The stress-strain relationships:

i. For plane strain, where $\varepsilon_{zz} = \varepsilon_{xz} = \varepsilon_{yz} = \tau_{xz} = \tau_{yz} = 0$ Eq 1-2

$$\sigma_{xx} = \frac{E}{(1+\nu)(1-2\nu)}\left[(1-\nu)\varepsilon_{xx} + \nu\varepsilon_{yy}\right] \qquad \text{Eq 1-3}$$

$$\sigma_{yy} = \frac{E}{(1+\nu)(1-2\nu)}\left[(1-\nu)\varepsilon_{yy} + \nu\varepsilon_{xx}\right] \qquad \text{Eq 1-4}$$

$$\tau_{xy} = 2G\varepsilon_{xy} = \frac{E}{1+\nu}\varepsilon_{xy} \qquad \text{Eq 1-5}$$

$$\sigma_{zz} = \nu(\sigma_{xx} + \sigma_{yy}) \qquad \text{Eq 1-6}$$

there are a few advantages involved. One such instance is hydraulic fracture drilling, wherein; mineral ores are extracted from the earth mantle by creating new cracks. Study of the effects of fracture, was not so significant until early 1920's,when a well-defined fracture mechanics theory was established based on engineering principles. Fracture mechanics is a field of mechanics which deals with the study of crack propagation in materials. It utilizes the theories of elasticity and plasticity to estimate the force required for the crack to propagate in three different modes (mode-I, mode-II and mode-III) as described in Figure 1.2 resulting in complete failure of the structure. Thus, it plays a vital role in improving the mechanical response of a material.

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Depending on the type of material, the behaviour of the fracture mechanics theory varies, altering the onset of crack growth. Linear Elastic (LEFM), Elastic-Plastic (EPFM) and Dynamic or Time dependent Fracture Mechanics are the three available theories currently being used for linear elastic, elastic plastic and viscoelastic materials respectively. Due to this diversified nature of the theory, the application of fracture mechanics is not restricted just to metals, whereas; it can be applied to composites, polymers and most importantly in the field of life sciences, to predict the crack propagation in arteries.

and the compatibility equation:

$$\left[\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right](\sigma_{xx}+\sigma_{yy})=0 \qquad \text{Eq. 1-14}$$

The Airy stress function, Φ, can satisfy all the governing equations and is used to derive the stress field near the crack tip.

$$\phi=\frac{K_I}{3\sqrt{2\pi}}r^{3/2}\left(\cos\frac{3\theta}{2}+3\cos\frac{\theta}{2}\right) \qquad \text{Eq. 1-15}$$

$$\frac{\partial^4\phi}{\partial x^4}+2\frac{\partial^4\phi}{\partial x^2\partial y^2}+\frac{\partial^4\phi}{\partial y^4}=0 \qquad \text{Eq. 1-16}$$

The coordinates (r,θ) for the stress components are shown in Figure 1-3

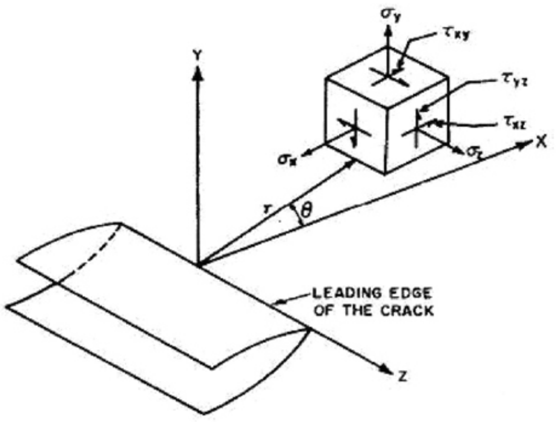


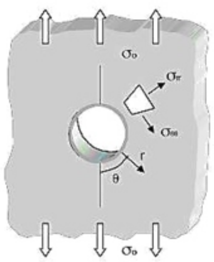
Figure 1-3 Co-ordinate system for the stress components

The parameter, K, is related to the nominal stress level (σ) in the structural member and the size of the crack (a), and has units of √ In general, the relation is represented by:
= √ Eqn-------- ------------ (1.17)
where P is a geometrical parameter depends on the structural memberand crack. According to Barsoum, "all structural members or test specimens that have flaws can in general; stress-intensity factor depends on the stress induced on a structure, the crack size and the geometry of the crack. The stress-intensity factor equation for an embedded circular crack is given by

STRESS CONCENTRATION AT FEATURES:

In some simple situations the equations governing elastic deformation can be solved analytically:
i.Expressing the stresses in terms of complex potentials
ii.Specifying the boundary conditions
iii.Finding functions to satisfy the above

More generally, solving the problem using finite element analysis. One problem for which there is a solution is that of a circular hole in an infinite thin plate subject to a stress σo.



In polar co-ordinates the stresses are given by:

$$\sigma_{rr}=\frac{\sigma_o}{2}\left\{1+\frac{r_o^2}{r^2}+\left(1+3\frac{r_o^4}{r^4}-4\frac{r_o^2}{r^2}\right)\cos 2\theta\right\}$$

$$\sigma_{\theta\theta}=\frac{\sigma_o}{2}\left\{1+\frac{r_o^2}{r^2}-\left(1+3\frac{r_o^4}{r^4}\right)\cos 2\theta\right\}$$

$$\sigma_{r\theta}=-\frac{\sigma_o}{2}\left\{\left(1-3\frac{r_o^4}{r^4}+2\frac{r_o^2}{r^2}\right)\sin 2\theta\right\} \qquad \text{Eq 3.10}$$

$$\sigma_{max}=\sigma_o\left(1+\frac{2a}{b}\right) \text{ or } \sigma_{max}=\sigma_o\left(1+2\sqrt{\frac{a}{\rho}}\right) \qquad \text{Eq 3.11}$$

where $\rho=\frac{b^2}{a}$ the radius tangential at the tip.

Hence for a long thin crack where a >>b, $\sigma_{max}=\sigma_o\left(2\sqrt{\frac{a}{\rho}}\right)$ Eq 3.12

Substituting r = ro and θ = 90 °and 0° : gives the maximum and minimum hoop stresses σθ, at the edge of the notch as 3 σ o and - σ o. Thus the presence of a round hole in the plate increases the tensile stress by a factor of three in one direction and introduces a compressive stress at the top of the hole equal to the distant tensile stress.Because all the stresses are elastic and therefore small, the imposed stress fields, and the solutions for those stress fields, can be added: this is known as the principle of superposition. Hence, adding two stresses σ o at right angles to each other to produce a 2D hydrostatic tension and the stresses around the hole in the plate are now: 3 σ o- σ o = 2σ o

3.6 J INTEGRALS:

The J integral is the equivalent of the G for the elastic-plastic case. It is the rate of energy absorbed per unit area as the crack grows; it is not however the energy release rate because the plastic energy is not recoverable as it would be in the elastic case.

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The definition is: $J = -\dfrac{dU}{dA}$

Where U is the potential energy of the system and A the area of the crack.

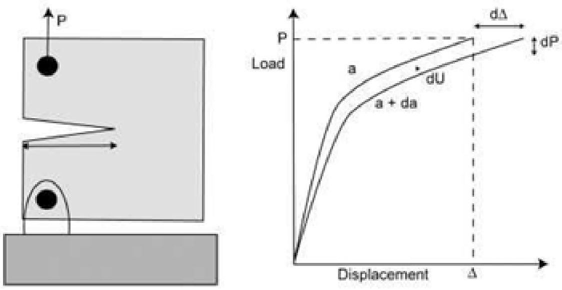

Figure 3-10energy release rate for non-linear deformation

An analogy with the Linear elastic case can be made; compare the Figure above with those on. The stress strain curve is no longer linear, but the area under the curve represents the work done in extending the cracked body (without extending the crack).Plotting two curves for specimens differing only in the length of the crack, a and a+Δa, the energy required to grow the crack is the difference in the areas under the two graphs shaded. Since the area decreases as the crack grows dU/da is negative and J = - dU/da at unit thickness. Although this is the same as the definition of the energy release rate we used earlier, the J integral for the plastic case does not represent the energy released as the crack grows because much of the energy used performs plastic deformation. This is fine so long as you are just loading the specimen but becomes tricky if you try and reverse the stress.The term ‘J integral’ comes from the property of J which can be expressed and evaluatedas a closed line integral around the crack tip. J is the strain energy density within the line minus the surface integral of the normal traction stress forces normal to the surface defined and is independent of the path the integral takes.

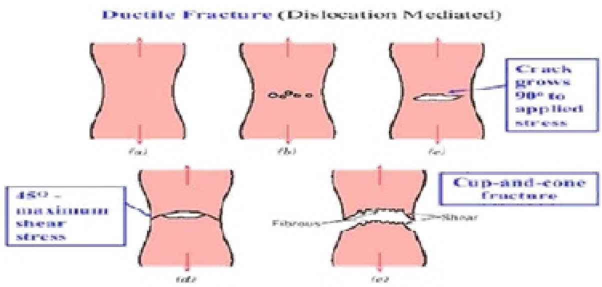

Figure 3-11crack tips variable loads and displacements

For Load control, the specimen extends at fixed load and the energy released is the area of the triangle OAB. Thus the only difference between the two cases is the area of the triangle ABC which is of the order 1/2δ P δ u and approaches zero in the limit. Thus the value of G depends only on the geometry of the sample: shape, crack length etc, and the loading, P.It can be evaluated experimentally by measuring the stress strain curves for a number of identical specimens containing cracks of different lengths and plotting the area under the graph U for each specimen as a function of the crack length and thus evaluating dU/dA and hence J.

There are also specific specimen geometries (deeply double notched and notched three point bending specimens) that allow J to be measured from a single specimen. These experiments allow J to be plotted as a function of the crack extension. Thus although J is defined in similar terms to the energy release rate G, and indeed reduces to G for linear elastic behaviour, J for elastic - plastic materials is closer to R, the resistance to crack growth, in both interpretation and form.

The curve plotted against the crack growth from the original crack length Δa, shows three distinct regions; an initial zone where the original crack blunts but does not grow and the curve rises steeply, a secondary region initiating atJIc, where a new crack nucleates and grows developing the elastic- plastic zone at the crack tip, until finally steady state crack tip conditions are achieved and the crack propagates at a constant value of the J resistance JR

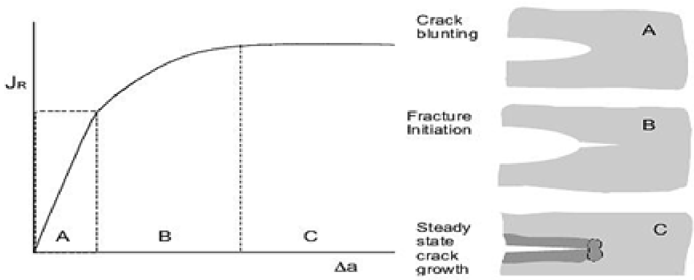

Figure 3-12 diagram indicating the j-curve during crack growth

The validity of this approach has limits, just as the LEFM has. These are reached, in general terms, when the extent of plastic yielding becomes a large proportion of the remaining ligament length. At this point a single parameter for crack growth is not sufficient and even more complicated analysis is necessary.

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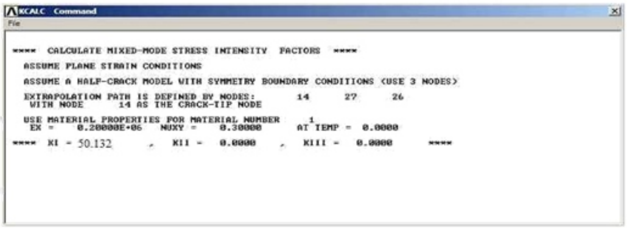


Figure 3-14 steps in crack

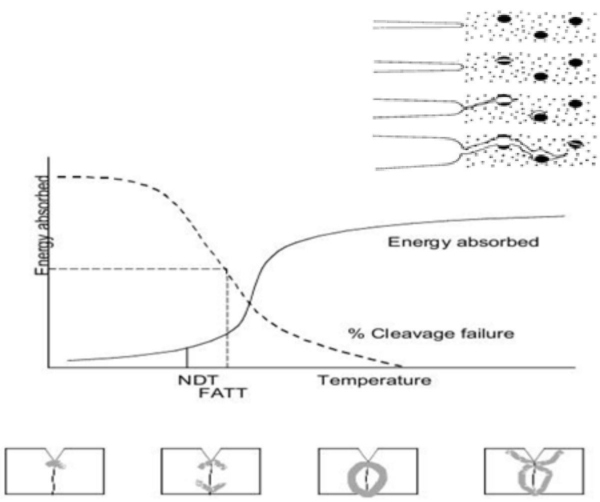
BRITTLE DUCTILE TRANSITION:

The brittle ductile transition represents the change from general plastic yielding to the propagation of a distinct crack – this so - called brittle failure can be very ductile and the fracture surface show evidence of extensive plasticity. The brittle ductile transition is governed by the macroscopic yield in the specimen, not what is going on at the crack tip. Hence values depend, within limits, on the particular geometry of the specimens. Tests such as the impact test of which there are several standards (Charpy, Izode) provide relative rather than quantitative data. They are nevertheless extremely useful as they are quick and simple to perform can be compared with reference data to provide excellent quality control.

3.coarse carbides – can crack

4.deep notches - constraint

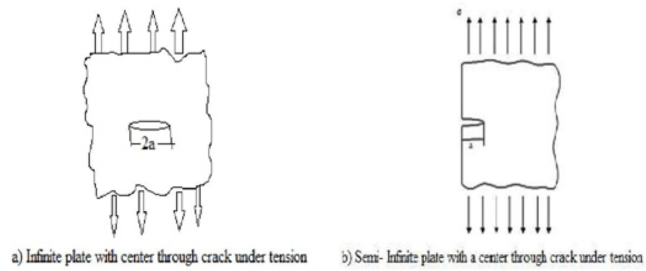
thick specimens (plane strain).



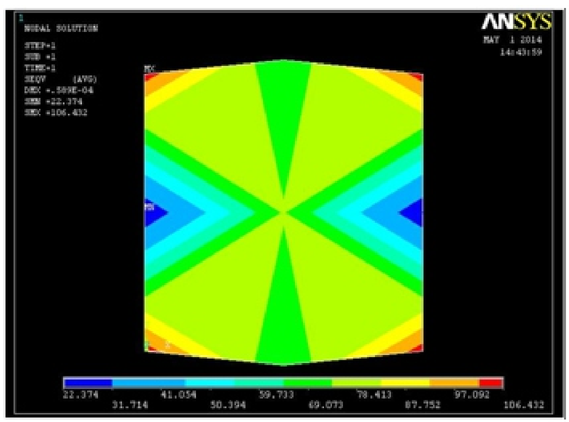
energy absorbed vs. temperature

DIFFERENT TYPES OF CRACKS IN DIFFERENT PLATESUNDER TENSION:

The concept of stress intensity factor plays a central role in fracture mechanics. We now refer to Tada [19] to present some classical examples of cracked geometries - represented in Figure 3 - for which the stress intensity factor has been computed or approximated explicitly. It is assumed that crack propagation may not occur, i.e., the problem is static.



1 Main Menu>Solution>Analysis Type>New Analysis Make sure that `Static' is selected. Click OK.
Main Menu>Solution>Solve>Current LS
Check your solution options listed in the`/STATUS Command window. Click the OK button in the Solve Current Load Step window.
Click the Yes button in the Verify window.
You should see the message solution is done!' in the `Note' window that comes up. Close
The Note and`/STATUS Command windows. 11. General Post Processing:
Main menu>result viewer>stress>VonMises stress>ok.
The following result window display



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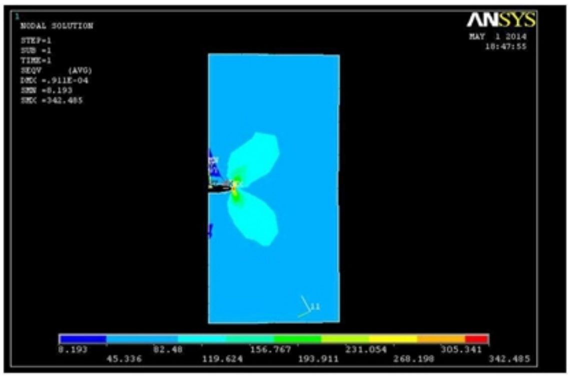


Result window:

Using the numerical package ANSYS, we also determined the value of the stress intensity factor KI for the same geometry. This was computed using finite elements on a mesh with quadratic triangular elements on the vicinity of the crack tip, and quadratic rectangular elements everywhere else. Quarter point elements, formed by placing the mid-side node near the crack tip at the quarter point, were used to account for the crack singularity. In Table 2 we display some values of KI/K0, whereK0=σ√πa, up to two significant digits. It can be seen that our results, identified by theoretical values by using of empirical formulas, are in line with those predicted by ANSYS, and even more so for smaller values of a/b. We further illustrate this analysis in Figure 5.3, for which more data points were taken.

Stress intensity factors

	a/b=0.1	a/b=0.2	a/b=0.4	a/b=0.6	a/b=0.8
ANSYS	1.01	1.1	1.28	1.50	2.03
Theoretical	1.01	1.07	1.23	1.48	1.98

As we had a lready mentioned, the stress intensity factor depends on thegeometry of the plate we are considering. In particular, it depends on the ratio h/b. On Table 3 we display th e values of KI/K0, determined again using ANSYS, for different geometries.

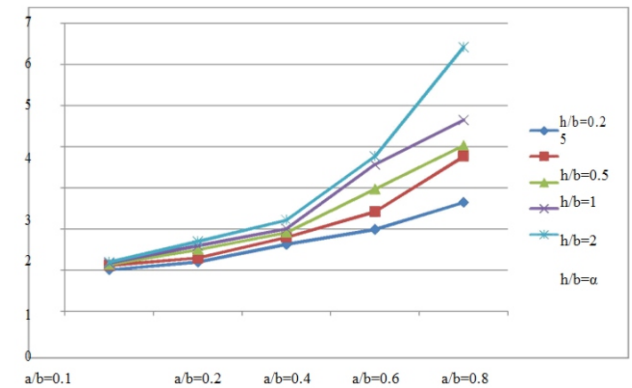
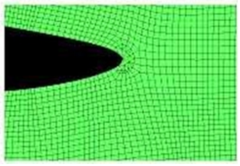


Figure 5-5 Variation of KI/Ko for different crack lengths and plate thickness x and y co-ordinates

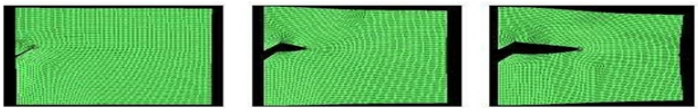
	X tip	Y tip
0	0.10	0.1 0
1	0.13	0.0 95
2	0.15	0.0 90
3	0.18	0.0 88
4	0.20	0.0 86

	X tip	Y tip
5	0.23	0.085
6	0.25	0.084
7	0.25	0.084
8	0.30	0.084
9	0.33	0.084

	X tip	Y tip
10	0.35	0.085
11	0.38	0.085
12	0.40	0.086
13	0.43	0.088
14	0.45	0.086



Finally Figure 6.5 represents the deformed state of the plate for the initialcrack, and again after 7 and 15 steps.



a)Initial crack b) crack pa th n=6 c) Crack path n=14.

CONCLUSIONS:

This project investigated the process of crack propagation and the resulting stress distribution in a typical Ti-6Al-4V aerospace skin using ANSYS . The behaviour of corner cracks was studied since this type of flaw is most frequently encountered in practice. The first step of the analysis consisted of using ANSYS to perform elastic stress analysis on an existing un notched skin to identify the high stress regions. In step two, the un-notched model was plotted in ANSYS, an initial crack of simple geometry was introduced and several ANSYS files were created with a re meshed finite element structure around the crack. Step three of the analysis consisted of using ANSYS to perform elastic stress analysis of the notched skin. In step four, ANSYS was used again to compute the stress-intensity factor and to further extend the crack. Steps three and four were then repeated twice to obtain the results reported in the thesis. For the model of corner cracks, the results show that the Von Misses elastic static stress is above the yield strength for the two load cycles considered in this study. Under tensile loading condition the stress-intensity factors for the cracked model are below the material's fracture toughness. Therefore, it appears that the skin can tolerate small corner cracks in the structure.