Analysis and Evaluation of Fractur Behaviour of Alluminium Alloy in Various Applications

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Abstract: In modern materials science, fracture mechanics is an important tool in improving the mechanical performance of mechanical components. It applies the physics of stress and strain, in particular the theories of elasticity and plasticity, to the microscopic crystallographic defects found in real materials in order to predict the macroscopic mechanical failure of bodies. Fractography is widely used with fracture mechanics to understand the causes of failures and also verify the theoretical failure predictions with real life failures. The prediction of crack growth is at the heart of the damage tolerance discipline. Fracture mechanics is the field of mechanics concerned with the study of the propagation of cracks in materials. It uses methods of analytical solid mechanics to calculate the driving force on a crack and those of experimental solid mechanics to characterize the material's resistance to fracture. The central difficulty in designing against fracture in high-strength materials is that the presence of cracks can modify the local stresses to such an extent that the elastic stress analyses done so carefully by the designers are insufficient. When a crack reaches a certain critical length, it can propagate catastrophically through the structure, even though the gross stress is much less than would normally cause yield or failure in a tensile specimen. The term "fracture mechanics" refers to a vital specialization within solid mechanics in which the presence of a crack is assumed, and we wish to find quantitative relations between the crack length, the material's inherent resistance to crack growth, and the stress at which the crack propagates at high speed to cause structural failure.

Key words: Fracture mechanics, Fractography, structural failure, KIc.

I. INTRODUCTION

In today's world aluminum and its alloys are the most used metal due to their excellent properties such as recyclability, high strength to weight ratios, high thermal conductivity and good corrosion resistance. As a result aluminum have found a widespread applications in automobile and aerospace industries. High strength aluminum alloys are widely used in aircraft structures due to their high strength-to-weight ratio, machinability and low cost. These are widely used for high strength structural applications such as aircraft wing skins and internal supporting members as well as missile components and automobile industries.

II. OBJECTIVES

The intend of the paper is to achieve the following

1. It is to gain a basic understanding of the relationship that exist between surface cracks and material toughness.
2. Improved levels of safety in transportation and construction.
3. Anticipating material failure.
4 Designing for material fracture at specific loading conditions.

III. TYPICAL PROPERTIES OF ALLOY

A. Lightness - With a specific mass of 2700 kg/m3, aluminium is the lightest of all ordinary metals, nearly three times as light as steel.
B.Electrical and thermal conductivity - Unalloyed aluminium has a thermal and electric conductivity about 60% of copper, which accounts for its development as a conductor, in the form of bars and tubes
C.Corrosion resistance - Aluminium and its alloys provide excellent resistance to atmospheric corrosion in marine, urban and industrial settings. This high resistance extends the life of equipment, significantly reduces

maintenance costs and preserves outward appearances. These properties are especially desired in industrial vehicles, street furniture and traffic signals.

D.Suitability for surface treatments - Aluminium and its alloys lend themselves to a huge variety of surface treatments, which enhances its intrinsic qualities.

E.The diversity of the alloys and intermediates - No less than eight families of aluminium alloys offer properties perfectly suited to their contemplated use, whether it is weldability, corrosion resistance, superior mechanical performance or something else.

F.Ease of use - Aluminium alloys are used in all the customary processes of forming, bending, vessel-making, stamping and machining where other metals are used.

G. Recycling - Aluminium can be recycled indefinitely without losing any of its intrinsic qualities. This is a considerable advantage in modern metallurgical industry.

IV. METHODOLOGY

4.1 Griffith Approach:

A Griffith (1893–1963) began his pioneering studies of fracture in glass in the years just prior to 1920, he was aware of Inglis'' work in calculating the stress concentrations around elliptical holes2, and naturally considered how it might be used in developing a fundamental approach to predicting fracture strengths. Griffith employed an energy-balance approach that has become one of the most famous developments in materials science.

The strain energy per unit volume of stressed material is

$$U^*=1/V \text{ ---1}$$

If the material is linear (σ = E), then the strain energy per unit volume is

$$U^*= Ee^2/2 = \sigma^2/2E\text{--- -2}$$

A simple way of visualizing this energy release, illustrated in Fig. 1, is to regard two triangular regions near the crack flanks, of width a and height βa, as being completely unloaded, while the remaining material continues to feel the full stress σ. The parameter β can be selected so as to agree with the Inglis solution, and it turns out that for plane stress loading β = π. The total strain energy U released is then the strain energy per unit volume times the volume in both triangular regions:

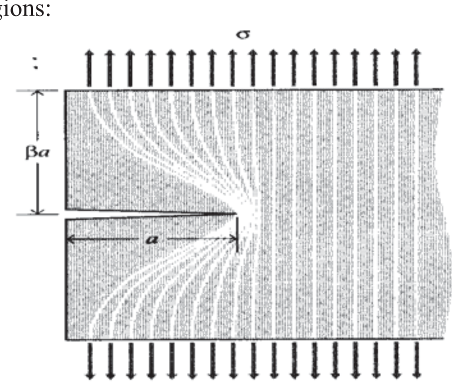


Fig.1: Idealization of unloaded region near crack flanks

$$U = - \sigma^2/2E \cdot \pi a2\text{----3}$$

The surface energy S associated with a crack of length a (and unit depth) is:

$$S = 2\gamma a\text{-----4}$$

Where γ is the surface energy (e.g., Joules/meter2) and the factor 2 is needed since two free surfaces have been formed. As shown in Fig. 2, the total energy associated with the crack is then the sumo f the (positive) energy absorbed to create the new surfaces, plus the (negative) strain energy liberated by allowing the regions near the crack flanks to become unloaded.

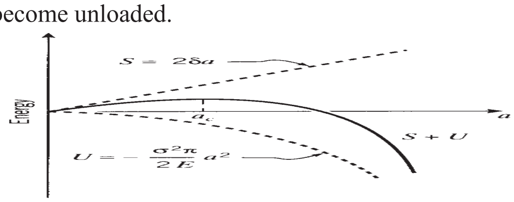


Figure.2: The fracture energy balance

The value of the critical crack length can be found by setting the derivative of the total Energy S + U to zero:

$$\partial(S + U)/\partial a= 2\gamma\text{-}\sigma 2E\pi a = 0\text{----5}$$

Since fast fracture is imminent when this condition is satisfied, we write the stress as σf. Solving, $\sigma f =2E\gamma/\pi a$

4.2 Irwin's modification (Approach):

Griffith's work was largely ignored by the engineering community until the early 1950s. The reasons for this appear to be (a) in the actual structural materials the level of energy needed to cause fracture is orders of magnitude higher than the corresponding surface energy, and (b) in structural materials there are always some inelastic deformations around the crack.

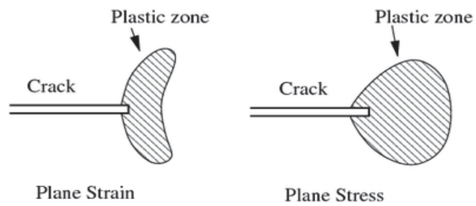


Figure. 3: The plastic zone around a crack tip in a ductile material

- The stored elastic strain energy which is released as a crack grows. This is the thermodynamic driving force for fracture.
- The dissipated energy which includes plastic dissipation and the surface energy (and any other dissipative forces that may be at work). The dissipated energy provides the thermodynamic resistance to fracture. Then the total energy dissipated is

4.3 Specimen size and Configurations: The fatigue pre-cracking shall be conducted with the specimen fully heat treated to the condition in which it is to be tested. The combination of starter notch and fatigue pre-crack must conform to the requirements. The nominal crack length is equal to 0.50*W* and is the total length of the starter notch slot plus fatigue crack. To facilitate fatigue pre-cracking at a low level of stress intensity, the notch root radius of a straight-across notch should be no more than 0.003in. (0.08 mm). If a chevron notch is used, the notch root radius can be as much as 0.01 in. (0.25 mm) because of the compound stress intensification at the point of the chevron. Early crack initiation can also be promoted by pre-compression of the notch tip region, as stated in it is advisable to mark two pencil lines on each side of the specimen normal to the anticipated paths of the surface traces of the fatigue crack.

The line most distant from the notch tip should indicate the minimum required length of fatigue crack, and the other the terminal part of that length equal to not less than 2.5 % of the overall length of notch plus fatiguecrack, that is 0.0125*W*.

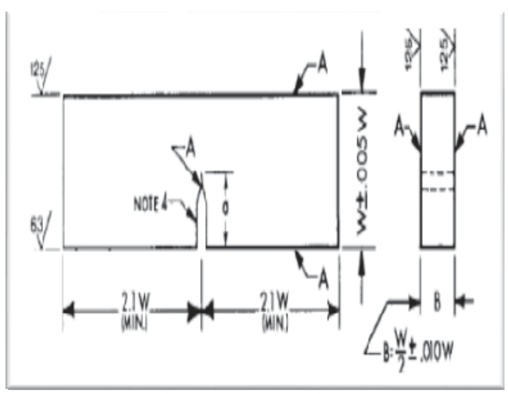


Figure.4: Speciman

During the final stage of fatigue crack extension, for at least this distance, the ratio of maximum stress intensity of the fatigue cycle to the Young’s modulus of the material, K_{max}/E shall not exceed 0.002in.1/2 (0.00032 m1/2).Furthermore, K_{max} must not exceed 60 % of the *KQ* value determined in the subsequent test if *KQ* is to qualify as a valid K_{IC}result

4.4 DIFFERENT TYPES OF FRACTURE TOUGHNESS:

There are actually four different types of fracture toughness, K_C, K_{IC}, K_{IIC}, and K_{IIIC}. K_C is used to measure a material's fracture toughness in a sample that has a thickness that is less than some critical value, B. When the material's thickness is less than B, and stress is applied, the material is in a state called plane stress. The value of B is given in equation. A material's thickness is related to its fracture toughness graphically in figure. Equation shows a material's K_C value in relation to the material's width.

$$B \geq 2.5 \left(\frac{K_{Ic}}{\sigma_y} \right)^2 \quad \text{----6}$$

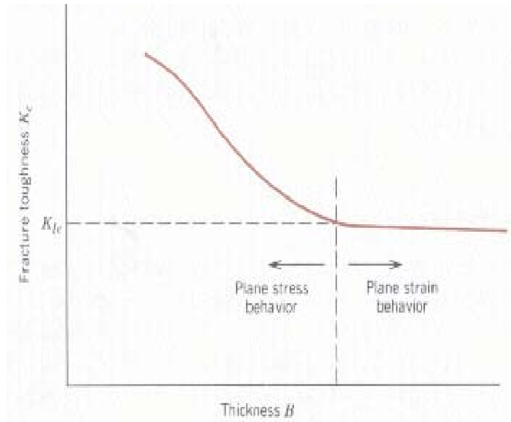


Fig.5 . Fracture Toughness as a function of material thickness

$$K_c = Y\sigma\sqrt{\pi a} \quad \text{----7}$$

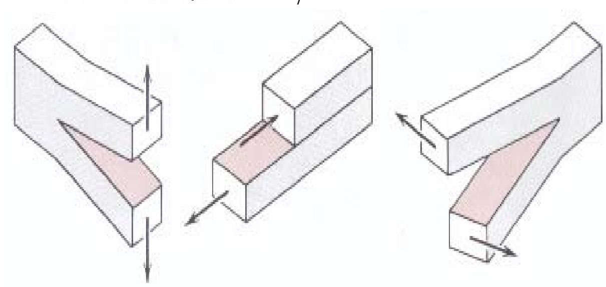


Fig.6: Mode I Fracture Fig: Mode II Fracture Fig: Mode III Fracture

$$K_{Ic} = Y\sigma\sqrt{\pi a}$$

Eq. The fracture toughness of a material with a thickness equal to or greater than B; when it fractures in mode I. K_{IC} values can be used to help determine critical lengths given an applied stress; or a critical stress values can be calculated given a crack length already in the material with equations and.

$$\sigma_c \leq \frac{K_{Ic}}{Y\sqrt{\pi a}}$$

Eq. Critical applied stress required to cause failure in a material.

$$a_c = \frac{1}{\pi}\left(\frac{K_{Ic}}{\sigma Y}\right)^2 \quad \text{------8}$$

Eq. Critical crack length required to cause failure in a material.

Table:1 KIC values for Engineering Materials:

Material	K_{IC} MPa (m)1/2
Metals	
Aluminum alloy	36
Steel alloy	50
Titanium alloy	44-66
Aluminum oxide	14-28
Ceramic	
Aluminum oxide	3-5.3
Soda-lime-glass	0.7-0.8
Concrete	0.2-1.4

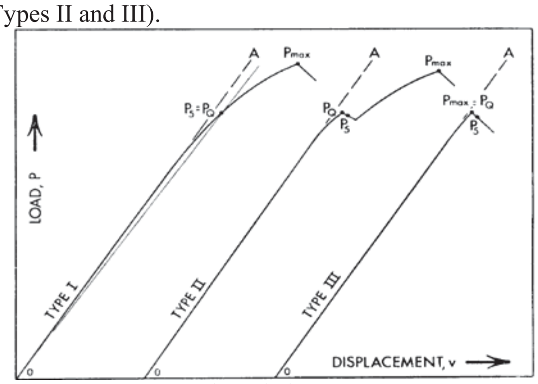
Polymers	
Polymethyl methacrylate	1
Polystyene	0.8-1.1

May notice that the ceramic materials have a much lower K_{IC} value than the metals. The low K_{IC} value reflects the fact that ceramic materials are very susceptible to cracks and undergo brittle fracture, whereas the metals undergo ductile fracture.K_{IC} values are determined experimentally.

V. RESULTS, ANALYSIS OF FRACTURE AND CONCLUSIONS:

Interpretation of Test Record and Calculation of K_{IC}—In order to establish that a valid K_{IC} has been determined, it is necessary first to calculate a conditional result, K_Q, which involves a construction on the test record, and then to determine whether this result is consistent with the size and yield strength of the specimen accordingly.

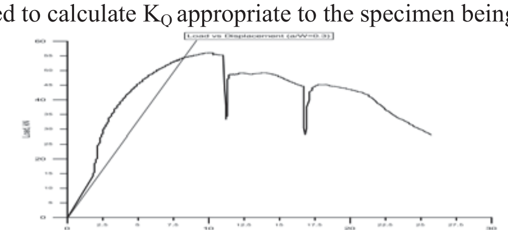
The procedure is as follows: Draw the secant line OP_5, shown in figure through the origin of the test record with slope $(P/v)_5 = 0.95\ (P/v)_o$, where $(P/v)_o$ is the slope of the tangent OA to the initial linear part of the record. The load P_Q is then defined as follows: if the load at every point on the record which precedes P_5 is lower than P_5, then P_5 is P_Q (Type I); if, however, there is a maximum load preceding P_5 which exceeds it, then this maximum load is P_Q (Types II and III).



Load vs. Displacement types

Slight nonlinearity often occurs at the very beginning of a record and should be ignored. However, it is important to establish the initial slope of the record with high precision and therefore it is advisable to minimize this nonlinearity by a preliminary loading and unloading with the maximum load not producing a stress intensity level exceeding that used in the final stage of fatigue cracking.

Calculate the ratio P_{max}/P_Q, where P_{max} is the maximum load the specimen was able to sustain. If this ratio does not exceed 1.10, proceed to calculate K_Q appropriate to the specimen being tested.



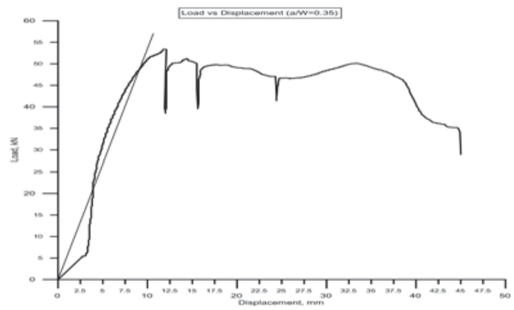
Tangent touches the curve at 52kN load. The secant is drawn at .95% slope of that of the tangent.

The secant intersects the curve at 54.2kN, this is taken as P_5. The load at every point preceding P_5 is lower than it, hence $P_5 = P_Q$.

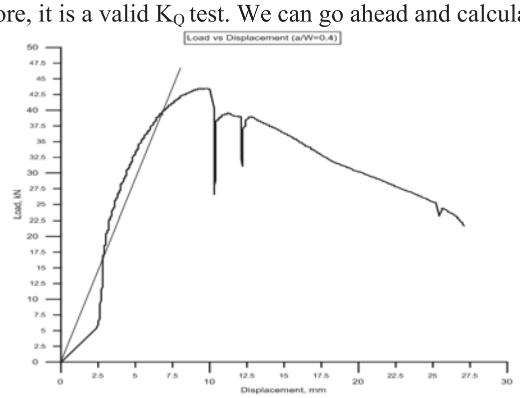
Therefore, P_Q = 54.2kN and P_{max} was found out to be

The ratio P_{max}/P_Q is: 56.04/54.2 = 1.033

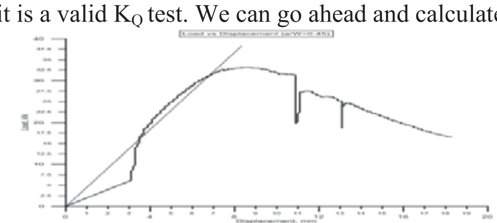
1.033 < 1.1 therefore, it is a valid K_Q test. We can go ahead and calculate the K_Q value.



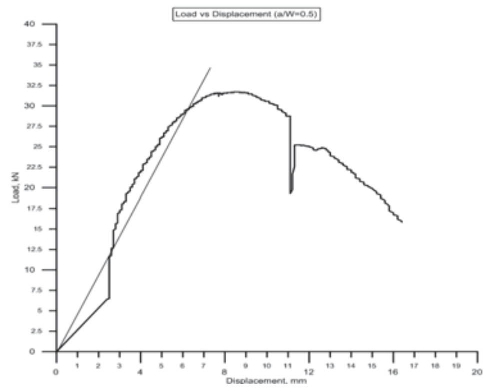
Tangent touches the curve at 51kN load. The secant is drawn at .95% slope of that of the tangent.
The secant intersects the curve at 47.5kN, this is taken as P_5. The load at every point preceding P_5 is lower than it, hence $P_5 = P_Q$.
Therefore, P_Q = 47.7kN and P_{max} was found out to be 53.34kN
The ratio P_{max}/P_Q is: 53.34/47.5 = 1.022
1.022 < 1.1 therefore, it is a valid K_Q test. We can go ahead and calculate the K_Q value.



Tangent touches the curve at 41kN load. The secant is drawn at .95% slope of that of the tangent.
The secant intersects the curve at 40kN, this is taken as P_5. The load at every point preceding P_5 is lower than it, hence $P_5 = P_Q$.
Therefore, P_Q = 40kN and P_{max} was found out to be 43.44
The ratio P_{max}/P_Q is: 43.44/40 = 1.086
1.086 < 1.1 therefore, it is a valid K_Q test. We can go ahead and calculate the K_Q value.



Tangent touches the curve at 31kN load. The secant is drawn at .95% slope of that of the tangent.
The secant intersects the curve at 32kN, this is taken as P_5. The load at every point preceding P_5 is lower than it, hence $P_5 = P_Q$.
Therefore, P_Q = 32kN and P_{max} was found out to be 33.12kN
The ratio P_{max}/P_Q is: 33.12/32 = 1.035
1.035 < 1.1 therefore, it is a valid K_Q test. We can go ahead and calculate the K_Q value.



Tangent touches the curve at 28kN load. The secant is drawn at .95% slope of that of the tangent.
The secant intersects the curve at 29kN, this is taken as P_5. The load at every point preceding P_5 is lower than it, hence $P_5 = P_Q$.
Therefore, P_Q = 29kN and P_{max} was found out to be 31.68kN
The ratio P_{max}/P_Q is: 31.68/29 = 1.092
1.092 < 1.1 therefore, it is a valid K_Q test. We can go ahead and calculate the K_Q value.

If P_{max}/P_Q does exceed 1.10, then the test is not a valid K_{IC} test because it is then possible that K_Q bears no relation to K_{IC}. In this case proceed to calculate the specimen strength ratio. Calculate 2.5 $(K_Q/s_{YS})2$ where s_{YS} is the 0.2 % offset yield strength in tension (see Test Methods E 8). If this quantity is less than both the specimen thickness and the crack length, then KQ is equal to K_{IC}. Otherwise, the test is not a valid K_{IC} test. If the test result fails to meet the requirements in one or other, or both, it will be necessary to use a larger specimen to determine K_{IC}. The dimensions of the larger specimen can be estimated on the basis of K_Q but generally will be at least 1.5 times those of the specimen that failed to yield a valid K_{IC} value.

Calculation of K_Q—for the bend specimen calculate K_Q

$$K_Q = (P_Q S/BW^{3/2}) \cdot f(a/W)$$

Here, f(a/W) value can be determined by using the given standard formula:

$$f(a/W) = \frac{3(a/W)^{1/2}[1.99 - (a/W)(1 - a/W) \times (2.15 - 3.93a/W + 2.7a^2/W^2)]}{2(1 + 2a/W)(1 - a/W)^{3/2}}$$

Where,
PQ =5 load as determined in using graphs, (kN),
B = specimen thickness as determined in measurements (cm),
S = span as determined in measurements, (cm),
W = specimen depth (width) as determined in measurements of specimen, (cm),
a = crack length as determined using a/W standards given by ASTM E-399 (cm).

Yield Stress:

The yield stress of a material is the point at which the material starts to deform physically. Prior to this point, the material is under elastic stress. The material can recover back to its original shape if the load is removed before it crosses the yield stress. Once the yield point is crossed, the material will not regain its original shape, it will be deformed permanently, plastic deformation occurs.
The yield stress is represented by σ_Y.
The formula for yield stress is: $\sigma_Y = \frac{K_{IC}}{\sqrt{\pi a}}$

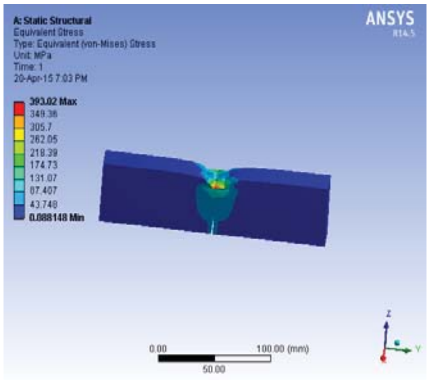
Calculations for KQ f(a/W)
Specimen 1(Crack length a = 1.5cm):

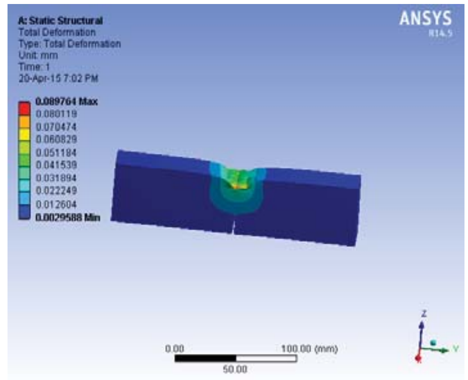
$$f\left(\frac{a}{W}\right) = \frac{3(.3)^{1/2}[1.99 - (0.3)(1 - 0.3) \times (2.15 - 3.93(0.3) + 2.7(\frac{1.5^2}{5^2}))]}{(2(1 + 2(.3))(1 - 0.3)^{3/2})}$$

$$f\left(\frac{a}{W}\right) = 1.53$$

The K_Q value is calculated : $K_Q = \frac{\frac{51.5\times10.4}{5}}{5.5(5)^{2}}(1.59)$, $K_Q = 20.835\ kN/cm^2$

Yield Stress $\sigma_Y = \frac{20.835}{\sqrt{\pi(1.5)}}$, Yield Stress $\sigma_Y = 14.21$





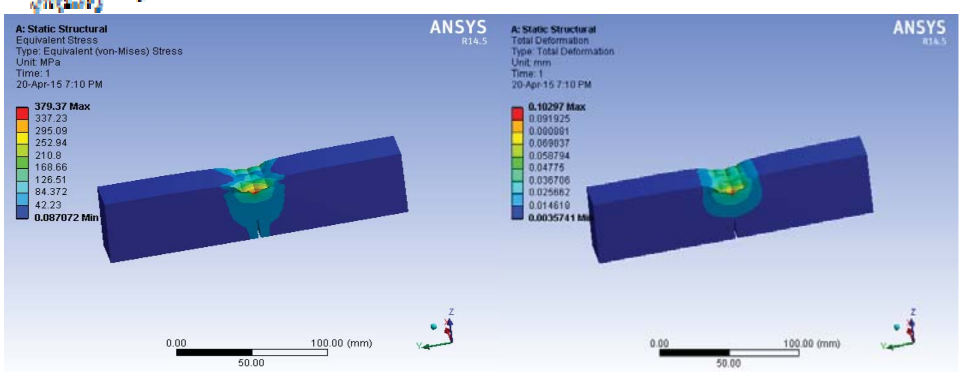
Specimen 2(Crack length a = 1.75cm):

$$f\left(\frac{a}{W}\right) = \frac{3(.35)^{1/2}[1.99 - (0.35)(1-0.35)(2.15 - 3.93(0.35) + 2.7(0.35)^2)]}{(2(1+2(.35))(1-0.35)^{3/2})}$$

$$f\left(\frac{a}{W}\right) = 1.73$$

The K_Q value is calculated: $K_Q = \frac{\frac{47.3\times10.4}{5}}{5.5(5)^{2}}(1.73)$, $K_Q = 30.59\ kN/cm^2$

Yield Stress: $\sigma_Y = \frac{30.59}{\sqrt{\pi(1.75)}}$, $\sigma_Y = 13.05$



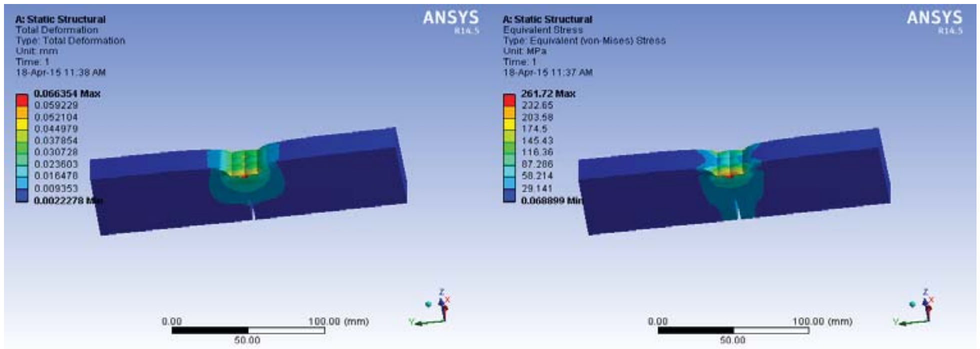
Specimen 3(Crack length a = 2cm):

$$f\left(\frac{a}{W}\right) = \frac{3(.4)^{1/2}[1.99 - (0.4)(1-0.4)(2.15 - 3.93(0.4) + 2.7(0.4)^2)]}{(2(1+2(.4))(1-0.4)^{3/2})},\quad f\left(\frac{a}{W}\right) = 1.98$$

The K_Q value is calculated:

$K_Q = \frac{\frac{40\times10.4}{5}}{5.5(5)^{2}}(1.98)$, $K_Q = 29.48\ kN/cm^2$

Yield Stress: $\sigma_Y = \frac{29.48}{\sqrt{\pi(2.0)}}$, $\sigma_Y = 11.76$



Specimen 4(Crack length a = 2.25cm):

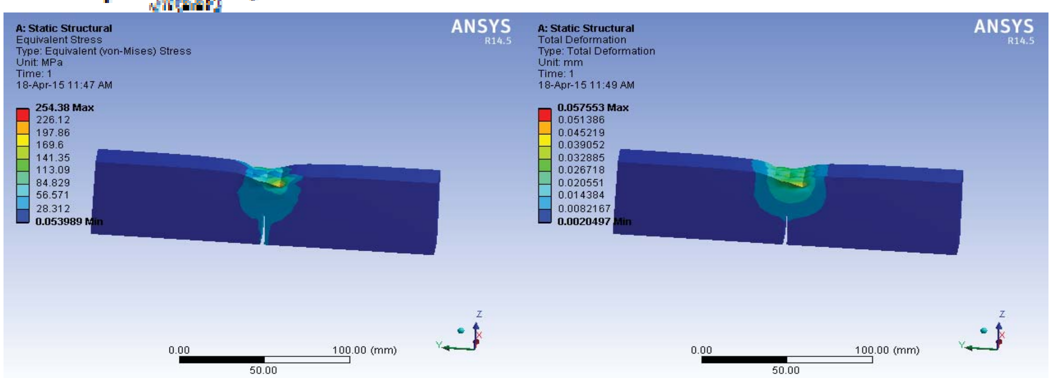
$$f\left(\frac{a}{W}\right) = \frac{3(.45)^{1/2}[1.99 - (0.45)(1-0.45)\times(2.15 - 3.93(0.45) + 2.7(\ldots))]}{(2(1+2(.45))(1-0.45)^{3/2})}$$

$$f\left(\frac{a}{W}\right) = 2.29$$

The K_Q value is calculated:

$$K_Q = \frac{[illegible]}{[illegible]}(2.29) \quad ,K_Q = 27.27\ kN/cm^2$$

Yield Stress: $\sigma_Y = \frac{27.27}{\sqrt{\pi([illegible])}}$ $,\sigma_Y = 10.26$



Specimen 5(Crack length a = 2.5cm):

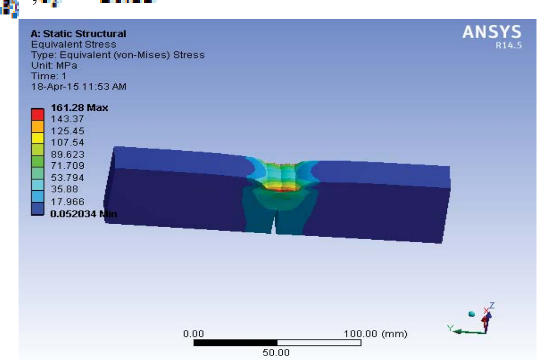
$$f\left(\frac{a}{W}\right) = \frac{3(.5)^{1/2}[1.99 - (0.5)(1-0.5)\times(2.15 - 3.93(0.5) + 2.7(\ldots))]}{(2(1+2(.5))(1-0.5)^{3/2})}$$

$$f\left(\frac{a}{W}\right) = 2.66$$

The K_Q value is calculated:

$$K_Q = \frac{[illegible]}{[illegible]}(2.66) \quad ,K_Q = 28.73\ kN/cm^2$$

Yield Stress: $\sigma_Y = \frac{28.73}{\sqrt{\pi([illegible])}}$ $,\sigma_Y = 10.23$



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