Simulation Of The Crack Propagation Using Fracture Mechanics Techniques In Aero Structures

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ABSTRACT

The focus of this project is to investigate how a crack propagates and grows in a high grade Steel C45 material plate. By using the finite element method software (ANSYS13) were used to simulate failure criteria and to compute the stresses and the stress-intensity factor. A specific object design was selected and a central crack was investigated. This configuration was used since the engineers often detect this type of crack in object. The Von Misses stress near the crack tip is compared against the yield strength of the material. The Mode I stress-intensity factor is compared against the material's fracture toughness. The results show that the bracket can tolerate small cracks in the structure. The fatigue strength of the structure is recommended to be assessed in the future.

Key words: Fracture Mechanics, ANSYS, Central Crack, Crack Propagation, Linear Elastic Fracture Mechanics (LEFM), Finite Element Method, Stress Intensity Factor, High Grade Steel C45.

I. INTRODUCTION:

Failure of the engineering structures is caused by cracks, which is depending on the design and operating conditions that extend beyond a safe size. Cracks present to some extent in all structures, either as a result of manufacturing defects or localized damage in service. The crack growth leads to a decrease in the structural strength. Thus, when the service loading to the failure of the structure. Fracture, the final catastrophic event takes place very rapidly and is preceded by crack growth, which develops slowly during normal service conditions.

Damage Tolerance (DT) assessment is a procedure that defines whether a crack can be sustained safely during the projected service life of the structure. DT assessment is therefore required as a basis for any fracture control plan, generating the following information upon which fracture control decision can be made: the effect of cracks on the structural residual strength, leading to the evaluation of their maximum permissible size, and the crack growth as a function of time, leading to the evaluation of the life of the crack to reach their maximum permissible size from safe operational life of the structure is defined.

Fracture mechanics has developed into a useful discipline for predicting strength and life of cracked structures. Linear elastic fracture mechanics can be used in damage tolerance analysis to describe the behaviour of crack. The fundamental assumption of linear elastic fracture mechanics is that the crack behaviour is determined solely by the values of the stress intensity factors which area function of the applied load and the geometry of the cracked structure. The stress intensity factors thus play a fundamental role in linear elastic fracture mechanics applications. Fracture mechanics deals with the study of how a crack in a structure propagates under applied loads. It involves correlating analytical predictions of crack propagation and failure with experimental results. Calculating fracture parameters such as stress intensity factor in the crack region, which is used to estimate the crack growth, makes the analytical predictions. Some typical parameters are: Stress intensity factors (Open mode (a) KI, Shear mode (b) KII, Tear mode (c) KIII

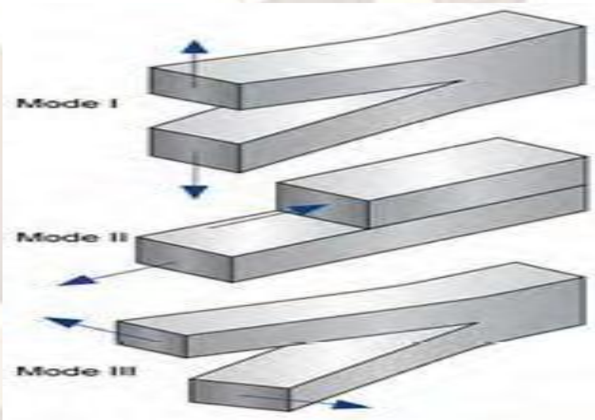


Figure 1: Three Types Of Loading On A Cracked Body;
(A) Mode I; (B) Mode Ii And (C) Mode Iii

Energy release rate is the amount of work associated with a crack opening or closure. The evaluation of the stress field around the crack tip to show that, for pure opening mode and in the limit of linear elastic fracture mechanics, the vanishing small fields fracture zone is surrounded by a linear elastic material with stress and strain fields uniquely determined, for any type of loading, geometry or structure size, by the stress intensity factor KI,.

It flows that a critical value KIC must exist so that when the actual KI, is lower, no crack growth can take place. This reasoning may be extended to other fracture mode to obtain fracture criteria. Hence, for pure shear mode and tear mode, critical stress intensity factors KIIC, KIIIC may be defined such that the crack growth may occur when the critical value are reached. But these parameters give only information for pure mode loadings, and do not allow following the cracking process, which in general involve change from pure to mixed modes. For mixed modes, the straight approaches consist that fracture may initiate the value of KI, KII, KIII a critical condition.

II PROBLEM STATEMENT

Cracks often develop in the corners of a structural member due to high stress concentration factor in those areas. If one can calculate the rate of crack growth, an engineer can schedule inspection accordingly and repair or replace the part before failure happens. Moreover, being able to predict the path of a crack helps a designer to incorporate adequate geometric tolerance in structural design to increase the part life. While producing durable, reliable and safe structures are the goals of every aerospace component manufacturer, there are technical challenges that are not easy to be solved. Given limited engine design space, engineers strive to optimize using material geometry to produce high efficient and high performance engines that will operate at minimum weight and cost. Engineers often look to shave materials from component and design the thinnest possible components. Benefits from this approach include reduced weight, and smaller probability of encountering brittleness inducing micro structural defects. The focus of this paper is to investigate the corner crack growth in a steel alloy plate. This paper will examine the stresses near the crack tip, compute the stress intensity factors and compare it against material toughness to determine the influence of the crack on the plate.

III METHODOLOGY

Engineers strive to optimize part geometry by designing the thinnest possible components because this approach not only reduce engine weight but also reduce the risk of brittle structure often found in bulk materials. Being able to determine the rate of crack growth, an engineer can schedule inspection accordingly and repair or replace the part before failure happens. Being able to predict the path of a crack helps a designer to incorporate adequate geometric tolerance in structural design to increase the part life. The methodology used to investigate the mechanics of crack propagation consists of the following steps:

- Model creation
- Elastic stress analysis of the uncracked body
- Flaw implementation
- Crack propagation
- Elastic stress analysis of the cracked body
- Calculation of stress intensity factor
- Interpretation of results

IV MODEL & MATERIAL PROPERTIES

Model is having with the dimensions of 0.4m in height, 0.4m in width, and crack length is 0.02m. In addition, the symmetry boundary conditions of steel plate as shown in bellow fig 2.

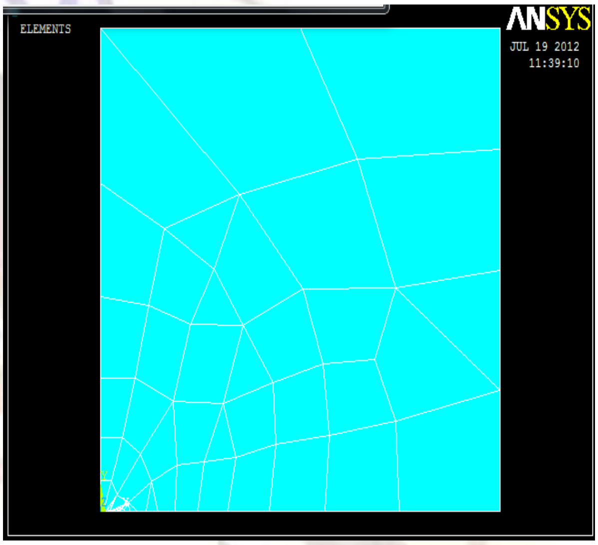


FIGURE 2: BASIC MODEL

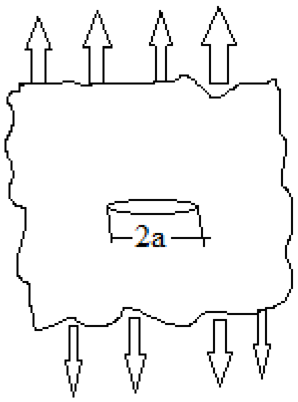
Among all the steel based alloys, according to Immarigeon et al [3], high grade steel c45 is by far the most widely used, accounting for almost half of all steel used in aircraft because the material can increase the strength+to+weight ratio in structures and provide heat resistance with weight savings. However, the significant weight savings permitted by these steel application developments generate specific drawbacks that need particular technological developments. Among the most important concerns are brittle inclusions, which are difficult to detect by non-destructive testing, can initiate cracks and produce early failure of the structures [2]. Materials imperfections due to manufacturing process, for example, voids and impurities can develop flaws that may cause the material to become weak. For those reasons, the material chosen in this study is high grade steel C45 and the properties are summarized in Table 1

TABLE 1
Properties of High Grade Steel C45

Quantity	Values		Units
	Minimum	Maximum	
Density	7850	7850	Kg/m^3
Young's modulus	210000	210000	Mpa
Tensile Strength	600	800	Mpa
Yield Strength	340	400	Mpa
Poisson's ratio	o.27	o.3	
Elongation	16	16	%
Hardening	820	860	°C/water, oil
Thermal expansion	11.7	11.7	e-6/K
Thermal Conductivity	46	46	W/m.K
Specific Heat	500	500	J/kg.K
Melting Temp	1540	1540	°C
Resistivity	-0.45	-0.45	Ohm.mm^2/m

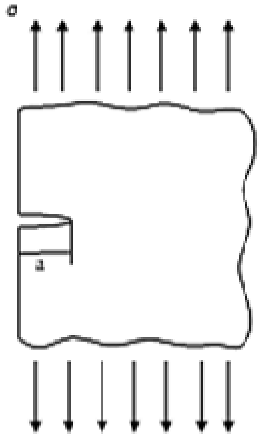
TABLE 2
Chemical Composition of C45 Steel

Grade	C(%)min-max	Si(%)min-max	Mn(%) min-max	P(%) max	S(%) max	Cr(%)min-max
C45 steel	0.42-0.50	0.15-0.35	0.50-0.80	0.025	0.025	0.20-0.40

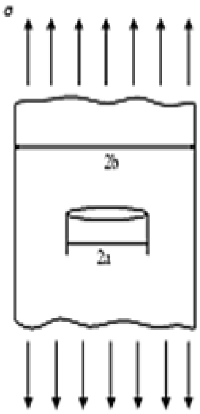


A) **Infinite Plate With Centre Through Crack Under Tension**

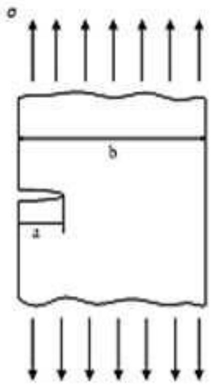
The concept of stress intensity factor plays a central role in fracture mechanics. We now refer to Tada [19] to present some classical examples of cracked geometries - represented in Figure 3 - for which the stress intensity factor has been computed or approximated explicitly. It is assumed that crack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



b) Semi-Infinite plate with a center through crack under tension



c) Infinite stripe with a centre through crack under tension



d) Infinite stripe with an edge through crack under tension

FIGURE 3 A,B,C,D.

The stress intensity values for these geometries are as follows, where the letters a) - d) used to identify the formulas are in correspondence with those of the pictures in figure 3

a) KI=σ C√ (Πa) ----------- (1)
b) KI=1.1215σ√(Πa) -----------(2)
c) KI=σ√ (Πa) (1-0.025(a/b) 2+0.06(a/b) 4) √ (sec (Πa/2b)) ------------ (3)
d) KI=σ√(Πa)√((2b/Πa) tan (Πa/2b)) 0.75+2.02(a/b) 0.37(1-sin (Πa/2b) 3)/cos (Πa/2b)) - (4)

The previous examples involved geometries of infinite dimensions. Ansys [1] computed the stress intensity factor for the finite geometry represented in Figure 4.

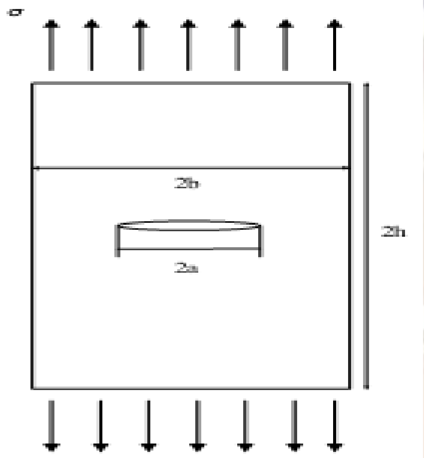


FIGURE. 4: Finite Plates With A Centre Through Crack Under Tension

He considered a rectangular plate, of height 2h, width 2b, with a central through crack of length 2a, which was loaded from its upper and lower edges by a uniform tensile stress (σ). For this particular geometry, he estimated

KI=σ√(Πa)(1+0.043(a/b)+0.491(a/b)2+7.125(a/b)3 -28.403(a/b)4+59.583(a/b)5- 65.278(a/b)6+29.762(a/b)7 ------------- (5)

Using the numerical package Ansys 13, 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. More details can be seen in [4].

In table 3 we display basically taken typical Steel aerospace object results. We further illustrate this analysis in Figure 5, for which more data points were taken.

TABLE 3:
Stress Intensity Factors

Stress Intensity Factor	**ansys**	**Theoretical**
	39.94	**35.44**

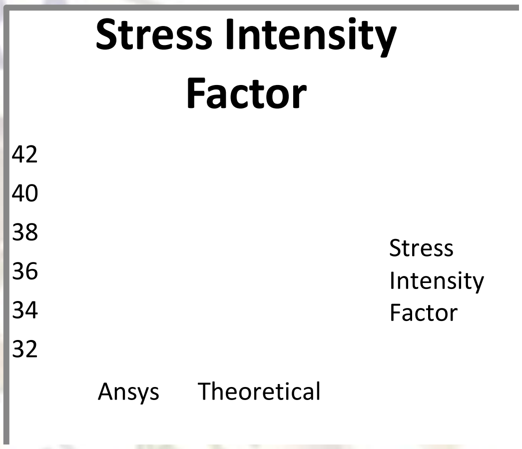


FIGURE 5 STRESS INTENSITY FACTOR

In Table 4 we display some values of KI/K0, whereK0 =σ c√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 6, for which more data points were taken.

TABLE 4:
STRESS INTENSITY FACTORS

	a/b =0.025	**a/b =0.05**	**a/b =0.075**	**a/b =0.1**	**a/b =0.125**	**a/b =0.15**	**a/b=0.175**
Ansys	**39.94**	**50.69**	**61.73**	**71.93**	**81.09**	**89.73**	**98.43**
Theoretical	**35.44**	**50.11**	**62.21**	**72.60**	**82.29**	**91.71**	**101.82**

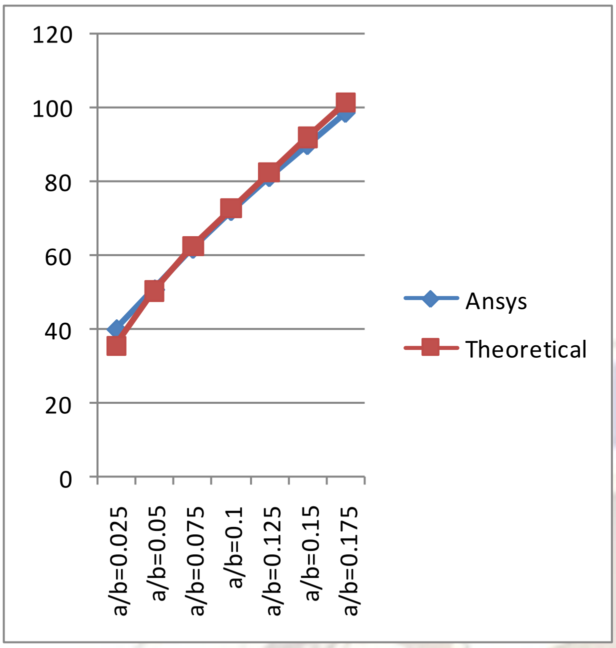


FIGURE 6

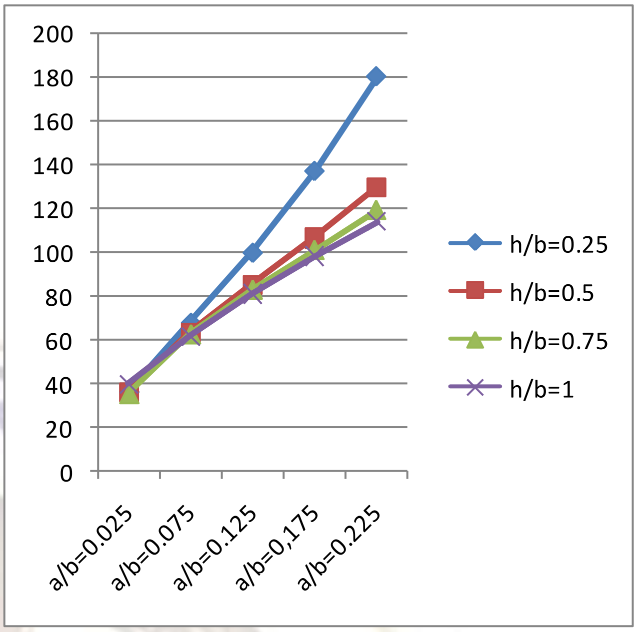


FIGURE 7

As we had already mentioned, the stress intensity factor depends on the geometry of the plate we are considering. In particular, it depends on the ratio h/b. On Table 5 we display the values of KI/K0, determined again using Ansys, for different geometries.

TABLE 5:
Values Of Ki/Ko For Different Geometries

	a/b=0 .025	a/b=0 .175	a/b=0 .125	a/b=0 .175	a/b=0 .225
h/b=0.25	35.97	67.59	99.63	137.0 5	180.3 6
h/b=0.5	35.83	63.09	85.06	106.7 6	129.8 7
h/b=0.75	35.10	62.33	82.70 9	100.7 7	119.0 3
h/b=1	39.94	61.73	81.09	98.34	114.0 3

We note that as the value of h/b increases, the values of KI/K0 tend to the values of the last line (h/b=0.4/0.4=1), which refers to values that we would expect for an Infinite plate with centre through crack under tension, as in Figure 3-a. We have computed these using the values of KI (from the formula 1). To better illustrate this idea, we conclude with the graphical representations of the values of Table 4 on Figure 7.

V ANALYSIS OF FAILURE CRITERIA

A static fracture analysis was performed, where the goal was merely to compute the stress intensity factors.

V.1.Steps in Analysis Procedure:

1. Pre-Processing

1. Give the job Name
2. Define Element Type
3. Define Material Properties
4. Define Key Points
5. Define Line Segments
6. Discretize Lines L3, L4&L5
7. Create the Concentration Key point (Crack Tip)
8. Create the Area
9. Apply Boundary Conditions
10. Apply Loads
11. Mesh the Model

2. Processing (Solving the Solution)

3. Post Processing

- Zoom the Crack-Tip Region
- Define Crack-Face Path
- Define Local Crack-Tip Coordinate System
- Activate the Local Crack-Tip Coordinate System
- Define the Model-1 crack deformation Define the Model-1 Stress Intensity Factor using KCALC
- Define the model-1 failure criteria From these figures it seems that there stress intensity factor & failure criteria of crack propagation to occur mainly in mode 1, during continued fracture.

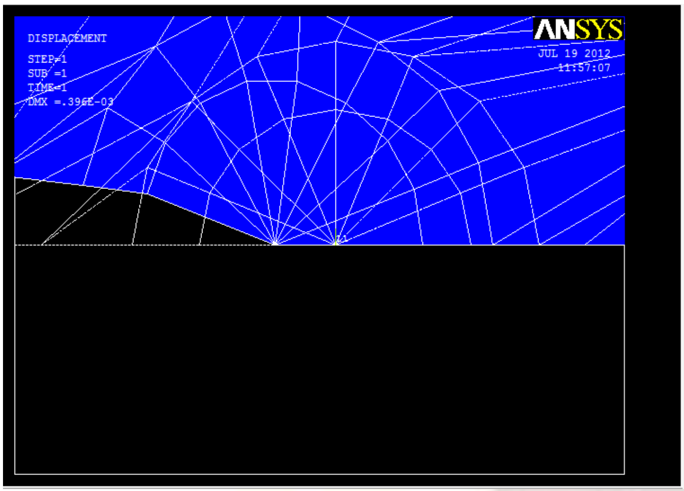


Figure 8

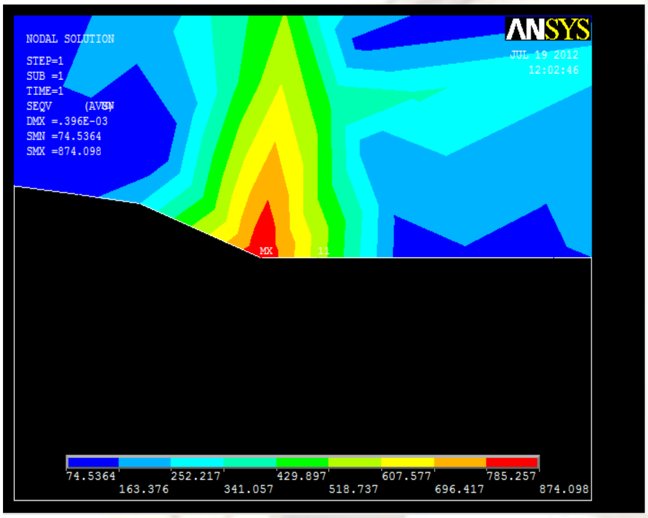


Figure 9

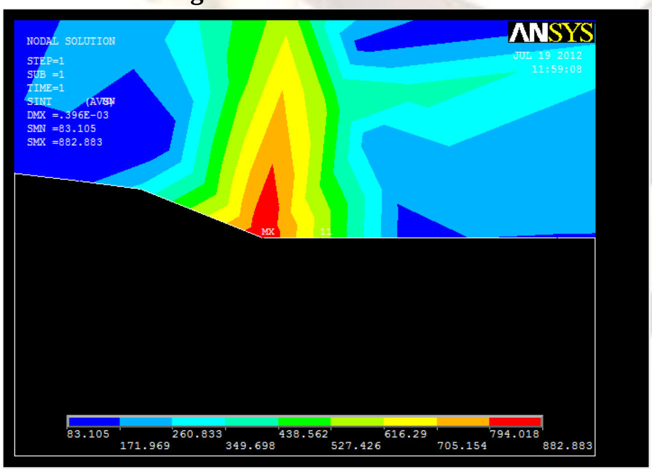


Figure 10

- From these figures it seems that there stress intensity factor & failure criteria of crack propagation to occur mainly in mode 1, during continued fracture.

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