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Simulation of Critical Crack Length Propagation Using Fracture Mechanics

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ABSTRACT

The focus of this paper is to investigate and analyze the study on the plate of steel, Aluminum and Epoxy with a center crack. Linear elastic fracture mechanics principles have been used for calculating Stress Intensity Factor, Critical crack length, Increment in crack, Mean stress and strain Amplitude at critical fatigue load cycles.
Above calculations will be done on the plate with centre crack of various materials (steel, aluminum and epoxy) to predict crack length to evaluate and to compare the results with theoretical calculations.
.Conclusions/results obtained on the basis of analysis.
Keywords: *FRACTURE MECHANICS,FEM,ANSYS*

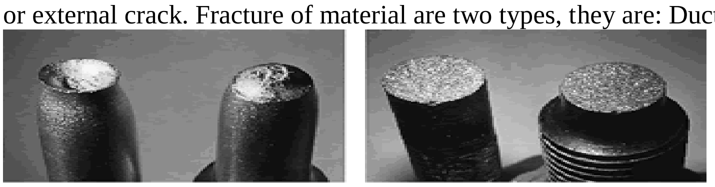
I. INTRODUCTION

Basically metal plates cause to fatigue cracks when it crosses its yield strength limit casually ,all the materials withstands up to 10^{+7} (cycles) this is called as **safe zone** limit 10^{+8} to 10^{+10}(cycles) is called **critical zone.** Most failures occur in materials are selection of proper material, processing, manufacturing procedures, incorrect usage. When the material is imposed of stresses, stress fracture of material can be two or more pieces.

Types of failure:
Failures of material are of two types, they are:
Buckling and Fracture.

Buckling:
When the material is subjected to a compressive load, buckling causes a lateral bend in the material. Buckling results failure of material within the catastrophic failure.

Types of fracture: In fracture failures Physical separation, or tearing of the material, through either an internal or external crack. Fracture of material are two types, they are: Ductile and Brittle fracture.



Ductile and brittle fracture

Fracture occurs due to stress concentrations at flaws like Surfaces scratches(stamp marks, inspection marks, surface irregularities), Variation in material properties(blow holes, cavities, weld strikes, and foreign inclusions)Discontinuities in the component(holes, grooves, keyways, screw threads and Abrupt changes in cross section (gears, sprockets, pulleys, ball bearings, splines on shafts)

Ductile fracture:
Ductile fracture materials are calculated by depending on momentum of the material. In Ductile fracture large amount of plastic deformation takes place before the fracture. Slow propagation and absorption of large amount energy is observed before the fracture. In ductile materials, particularly in high purity materials can with stand up to 50-100% large deformation or more strain before fracture under loading condition. Ductile fracture mostly influenced by: Transition temperature, inclusions, and strain hardening.

Brittle fracture:
Brittle fracture materials are calculated by depending on strength of the materials. In Brittle fracture small amount of plastic deformation takes place before the fracture. In brittle materials, particularly in brittle crystalline materials fracture can occur due to the result of tensile stress acting normal to crystallographic. Brittle fracture mostly results in catastrophic failure of a structure. Brittle fracture mostly influenced by: Defects, fatigue, and stress-corrosion.

Fatigue failures:

Fatigue means weakening of materials by applying repeated loading and unloading. When the material is subjected to cyclic loading, progressive and localized structural damage occurs in material. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit.

If the loads are above a certain threshold, microscopic cracks began to form at the stress concentrators such as surface, persistent slip bands (PSBs), and grain interfaces. Eventually crack will reach a critical size, the crack will propagate suddenly, and structure will fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure.

Low Cycle Fatigue:

Low cycle fatigue involves less numbers of cycles (N1000),

Failure of Set screws, short lived devices like missiles.

High cycle fatigue:

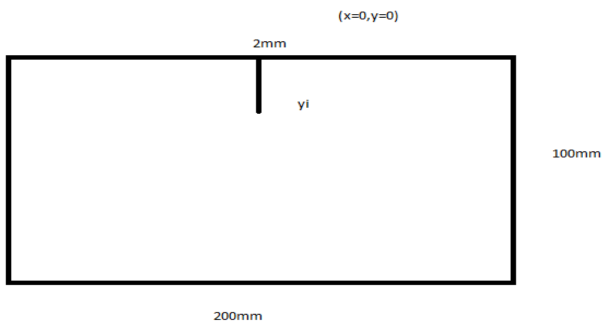
High cycle fatigue involves a large number of cycles (N4105 cycles) and an elastically applied stress. High cycle fatigue tests are usually carried out for 10^{+7} cycles sometimes 10^{+8} cycles for nonferrous metals. Although the applied stress is low enough to be elastic, plastic deformation can take place at the crack tip. Failure of Springs, ball bearings, gears subjected to fluctuating stresses. High cycle fatigue data are usually presented as a plot of stress, S, Vs the number of cycles to failure N. along scale is used for the number of cycles. The value of stress, s, can be the maximum stress, S max, the minimum stress, S min, or value of mean stress, S m, or one of the two ratios, R or A. The fatigue life is the number of cycles to failure at a specified stress level, while the fatigue strength (also referred to as the endurance limit) is the stress below which failure does not occur. As the applied stress level is decreased, the number of cycles to failure increases.

Normally, the fatigue strength increases as the elastic tensile strength increases.

II. EXPERIMENTAL ANALYSIS

Nomenclature

$A_{fracture}$	= cross-section of the specimen at fracture.
A_0	= initial cross-section of the specimen.
C	= fatigue ductility exponent.
E	= young's modulus.
N	= describe the relative position of the crack tip to the grain boundary.
N_f	= number of load cycles to failure.
$\delta^{I}f$	= fatigue strength coefficient.
$\epsilon_{fracture}$	= specific deformation of the specimen at fracture.
$\delta\epsilon$	= specific deformation increment.
δ^{I}_{f}	= fatigue ductility coefficient.
δ uts	= ultimate tensile strength



INPUTS FOR STEEL AISI:

$A_{fracture}$	=	5.89
A	=	6
C	=	3
E	=	180Gpa
N	=	2

N f	=	10^{8}
δ^{l} f	=	2.8
Є fracture	=	2.03735
δ'_{f}	=	10^{6}
δ uts	=	400mpa

Critical crack length calculation:
Fatigue crack initiation:

$$\frac{\Delta\epsilon}{2} = \frac{\delta a}{E} + \frac{\Delta\epsilon\, p}{2}$$

$$= \quad \frac{\delta^{l} f}{E}(2Nf)^{\;b} + \epsilon^{l} f(2.$$

$$\frac{10^{6}}{180000}(2*10^{8})^{.002} + 2.8(2*10^{8})^{.003}$$

=55.55*1.04+2.8*1.066

=56.59+3.866

=60.456

$$\Delta\epsilon = \frac{60.456}{2} = 30.228$$

Strain amplitude:

Marrows (- N) method

$$\in a = \frac{(\delta^{l} f - \delta m)}{E}$$

$$= (2Nf)^{b} + \epsilon^{l} f(2Nf2)^{c}$$

According to coffin-Manson

$$\in a = 1.75\frac{\delta uts}{E}N_f^{-0.2} + 0.5D^{0.6}N_f^{-0.6}$$

$$D = 1n\frac{A_0}{A_{Fracture}} \cong \in Fracture$$

$$D = \frac{6}{5.8}$$

=2*1.0186 =2.03735

$$\in a = 1.75\frac{400}{180000}10^{8^{-.02}} + 0.5*2.03735^{0.6}*10^{8^{-.06}}$$

$1.75*2.2^{-3}*0.083176+0.5*1.53263*3.98^{-6}$

$=0.01367+2.177^{-4}$

Strain =0.0138

Mean stress

Smith Watson Topper Method

$$= \quad \delta_f^{l}\epsilon_f^{l}(2Nf)^{b+c}\frac{\delta_f^{l2}}{E}$$

$$= 10^{6}*2.8(2*10^{8})^{0.05} + \frac{10^{6^{2}}}{180000}(2*10^{8})^{0.04}$$

8169643.74+235877379.9

=317575023.4 Pascal's

=317.5Mpa

INPUTS FOR ALUMINUM

$A_{fracture}$	=	5.89
A_0	=	6
c	=	3
E	=	74.5Gpa
N	=	2
N_f	=	10^{8}
δ^{l} f	=	10^{4}
Є fracture	=	2.03735
δ^{l}_{f}	=	3.2
δ uts	=	168mpa

Critical crack length calculations:
Fatigue crack initiation[1] :

$$\frac{\Delta\in}{2}=\frac{\delta a}{E}+\frac{\Delta\in p}{2}$$

$= \quad \frac{\delta^l f}{E}(2Nf)^{\ b} + \in^l f(2.$

$$\frac{10^4}{74500}(2*10^8)^{.002}+3.2(2*10^8)^{.003}$$

=0.1394+3.3888

=3.528

$$\Delta\in = 3.528*2 = 7.0565$$

Strain amplitude:
Marrows method

$$\in a=\frac{(\delta^l f-\delta m)}{E}$$

$$=(2Nf)^b+\in^l f(2Nf)^c$$

According to coffin-Manson

$$\in a=1.75\frac{\delta uts}{E}N_f^{-0.2}+0.5D^{0.6}N_f^{-0.6}$$

$$D=1n\frac{A_0}{A_{Fracture}}\cong\in Fracture$$

$$D=\frac{6}{5.8}$$

=2*1.0186 =2.03735

$$\in a=1.75\frac{168}{74500}10^{8^{-.02}}+0.5*2.03735^{0.6}*10^{8^{-.06}}$$

$=4.3270\times10^{-4}+1.2145\times10^{-5}$

=0.004448

Strain = 0.004448

Mean stress:
Smith Watson Topper Method

$= \quad \delta_f^l\epsilon_f^l(2Nf)^{b+c}\frac{\delta_f^{l^2}}{E}$

$$=10^6*2.8(2*10^8)^{0.05}+\frac{10^{4^2}}{74500}(2*10^8)^{0.04}$$

=7281310.163+2883.267

=7284193.43 Pascal's

=72.84Mpa

INPUTS FOR EPOXY

$A_{fracture}$	=	5.89
A_o	=	6
c	=	3
E	=	30Gpa
N	=	2
N_f	=	10^8
$\delta^l f$	=	10^7
$\epsilon_{fracture}$	=	2.03735
δ^l_f	=	2.1
δuts	=	550mpa

Critical crack length calculations:
Fatigue crack initiation:

$$\frac{\Delta\in}{2}=\frac{\delta a}{E}+\frac{\Delta\in p}{2}$$

$= \quad \frac{\delta^l f}{E}(2Nf)^{\ b} + \in^l f(2.$

$$\frac{10^7}{30000}(2*10^8)^{.002}+2.1(2*10^8)^{.003}$$

=346.3225+2.2239 =348.54

$\Delta\epsilon = 348.54 * 2 = 697.09$

Strain amplitude:
Marrows method

$$\epsilon\, a = \frac{(\delta^l f - \delta m)}{E}$$

$$= (2Nf)^b + \epsilon^l f (2Nf)^c$$

According to coffin-Manson

$$\epsilon\, a = 1.75 \frac{\delta uts}{E} N_f^{-0.2} + 0.5 D^{0.6} N_f^{-0.6}$$

$$D = 1n \frac{A_0}{A_{Fracture}} \cong \epsilon\, Fracture$$

$$D = \frac{6}{5.8}$$

=2*1.0186
=2.03735

$$\epsilon\, a = 1.75 \frac{550}{30000} 10^{8^{-.012}} + 0.5 * 2.03735^{0.6} * 10^{8^{-.06}}$$

$=3.5300\times10^{-3}$ Strain = 0.0035
Mean stress:
Smith Watson Topper Method

$$= \delta_f^l \epsilon_f^l (2Nf)^{b+c} \frac{\delta_f^{l^2}}{E}$$

$$= 10^7 * 2.1(2 * 10^8)^{0.05} + \frac{10^{7^2}}{30000}(2 * 10^8)^{0.04}$$

=7214723960 Pascal's=721.84Mpa

RESULTS TABLE
Theoretical

	STEEL AIST 1504	**ALUMINUM**	**E-GLASS EPOXY**
specific deformation increment	30.228	7.0565	697.09
Strain amplitude	2.03735	2.03735	2.03735
Strain	0.0138	0.004448	0.0035
Mean stress	317.5Mpa	72.84Mpa	721.84Mpa

Analysis results with 10x cycles

	STEEL AIST 1504	**ALUMINUM**	**E-GLASS EPOXY**
DISPLACEMENT	0.32605	0.92594	0.87737
STRAIN	0.0086302	0.0240	0.02459
STRESS	1726	1710.2	1781
LIFE	62.39 to $1e^6$	0 to$1e^8$	57.949-$1e^6$
DAMAGE	1000 to$1.602e^7$	10 to$1e^{32}$	1000 to $1.7257e^7$
FACTOR OF SAFTY	2.845	2.832	2.58
BI-INDICATION	0.99891to0.966	0.993 to 0.97666	0.99 to0.867
ALL-STRESS	1726	1710.2	1781
MODE 1	341.51	1631.8	1725.5
MODE 2	632.86	2939.1	3086.6
MODE 3	1540.8	3033.4	3122.7
MODE 4	2853.6	3663.6	3731.6
MODE 5	3132.4	4577	4772.7
MODE 6	3537	5615.1	5779.6

STEEL AIST 1504	
	Analysis
DISPLACEMENT	0.32605
STRAIN	0.0086302
STRESS	1726
LIFE	62.39 to $1e^{6}$
DAMAGE	1000 to$1.602e^{7}$
FACTOR OF SAFTY	0.049to2.845
BI-INDICATION	0.99891to0.966
ALL-STRESS	1726
MODE 1	341.51
MODE 2	632.86
MODE 3	1540.8
MODE 4	2853.6
MODE 5	3132.4
MODE 6	3537
Mean stress	

ALUMINUM	
	Analysis 10x
DISPLACEMENT	0.92594
STRAIN	0.0240
STRESS	1710.2
LIFE	0 to$1e^{8}$
DAMAGE	10 to$1e^{32}$
FACTOR OF SAFTY	0.04838 to2.832
BI-INDICATION	0.993 to 0.97666
ALL-STRESS	1710.2
MODE 1	1631.8
MODE 2	2939.1
MODE 3	3033.4
MODE 4	3663.6
MODE 5	4577
MODE 6	5615.1

E-GLASS EPOXY	
	Analysis 10x
DISPLACEMENT	0.87737
STRAIN	0.02459
STRESS	1781
LIFE	57.949-$1e^{6}$
DAMAGE	1000 to $1.7257e^{7}$
FACTOR OF SAFTY	0.048 to2.58
BI-INDICATION	0.99 to0.867
ALL-STRESS	1781
MODE 1	1725.5
MODE 2	3086.6
MODE 3	3122.7
MODE 4	3731.6
MODE 5	4772.7
MODE 6	5779.6
Mean stress	

III. CONCLUSION

Initially data collection and literature survey was done on critical length on various materials.

By analysis in three materials aluminum has high strength and life cycle and damage will be less compared to E-glass epoxy material.

In aerospace design epoxy's are widely used to make outer body's, these outer bodies caused to damage with small hit or crack initiation so better to use mixture of aluminum and carbon mixture in good qualities.

IV. FUTURE SCOPE

Epoxy materials are not able to withstand after crossing safe zone (initiation of crack). When we mix the aluminum materials and E-glass epoxy material the material can with stand and life cycle of material can be increased.

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