FINITE ELEMENT BASED FATIGUE CRACK GROWTH OF CRACKED PLATES UNDER AXIAL LOADING

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BACHELOR OF MECHANICAL ENGINEERING
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This report is submitted as partial fulfilment of the requirements for the award of the degree of Bachelor of Mechanical Engineering

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SUPERVISOR'S DECLARATION

I certify that the project entitled "*Finite Element Based Fatigue Crack Growth of Crack Plates under Axial Loading*" is written by *Mohamad Abiddullah bin Mohd Lasim.* I have examined the final copy of this report and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering.

Signature:
Name of Supervisor: Dr. Md. Mustafizur Rahman
Position: Associate Professor
Date:

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature ....

Name: Mohamad Abiddullah bin Mohd Lasim

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Date: 6 December 2010

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ABSTRACT

This project deals with the finite element based crack growth of the plate under axial loading. The structural model of cracked plate is developed using solidworks software. The finite element modelling and analysis of crack plate were performed utilizing the MSC.PATRAN and MSC.NASTRAN software respectively. The linear elastics method is used for crack growth analysis, it can be seen that Tetrahedral 10 chosen to be use for the overall analysis because it the TET10 are able to capture the higher stresses compared to TET4 for the same mesh global length and maximum principal stress with meshing sizes 0.2 mm. For the crack growth analysis, surface crack is the suitable orientation compared to other orientation with given the longer life (cycles).

ABSTRAK

Projek ini berkaitan dengan pertumbuhan retak elemen hingga berdasarkan dari plat di bawah beban axial. Model struktur plat retak dibangunkan menggunakan software SolidWorks. Pemodelan elemen hingga dan analisis plat retak dilakukan memanfaatkan MSC.PATRAN dan software MSC.NASTRAN masing-masing. Kaedah elastik linier digunakan untuk analisis retak pertumbuhan, dapat dilihat bahawa Tetrahedral 10 dipilih untuk digunakan untuk analisis keseluruhan kerana TET10 tersebut mampu menangkap voltan tinggi berbanding dengan TET4 untuk mesh yang sama panjang global dan voltan utama maksimum meshing dengan ukuran 0,2 mm. Untuk analisis pertumbuhan retak, retak permukaan adalah orientasi berpadanan dibandingkan dengan orientasi lain dengan diberi hidup lebih lama (kitaran).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CAD	Computer Aided Design
FEA	Finite Element Analysis
FEM	Finite Element Modeling
LEFM	Linear Elastic Fracture Mechanics
TET	Tetrahedral

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Surface cracks, which are most likely to be found in many structures in service, such as Pressure vessels, pipeline systems, recognized as a major origin of potential failure for such components. The study of fatigue crack propagation from such defects has been an important subject during recent decades. The surface crack in a finite thickness plate subjected to remote tension, bending or combined loading. (Lin and Smith, 1999).A fatigue limit can be interpreted from the physical damage phenomenon under constant amplitude loading because operating stresses, a micro crack will nucleate within a grain of material and grow to the size of about the order of grain until a grain boundary barrier impedes its growth. If the grain barrier is not strong enough, the micro crack will eventually propagate to a macro crack and may lead to final failure. If the grain barrier is very strong, the micro crack will be arrested and become a non propagating crack. The minimum stress amplitude to overcome the crack growth barrier for further crack propagation is referred to as the fatigue limit (Murakami and Nagata, 2002).

Stress is a parameter need to be measured in this project. Stress allows us to get a fair comparison of the effect of a force on different samples of a material. In this case, we use steel for this project. A tensile force will stretch and break the sample. However, the force needed to break a sample will depend the cross sectional area of the sample. If the cross sectional area is bigger, the breaking force will be bigger. However, the breaking stress will always be the same because the stress is the force per unit area. For fatigue analysis, a different load is applied to the specimen that will give different result of life cycles before the specimen fails. Meanwhile, we are required to investigate the crack growth of varies element.

The analysis of failures often reveals various weaknesses contributing to an insufficient fatigue resistance of a structure. This will be illustrated by a case history. A structure should be designed and produced in such a way that undesirable fatigue failures do not occur. Apparently there is a challenge which will be referred to as designing against failure. Various design options can be adopted to ensure satisfactory fatigue properties with respect to sufficient life, safety and economy, which are related to different structural concepts, more careful detail design, less fatigue sensitive material, improved material surface treatments, alternative types of joints, lower design stress level.

Fatigue is failure under a repeated or varying load, never reaching a high enough level to cause failure in a single application. The fatigue process embraces two basic domains of cyclic stressing or straining, differing distinctly in character. In each domain, failure occurs by different physical mechanisms:

a) Low-cycle fatigue—where significant plastic straining occurs. Low-cycle fatigue involves large cycles with significant amounts of plastic deformation and relatively short life. The analytical procedure used to address strain-controlled fatigue is commonly referred to as the Strain-Life, Crack-Initiation, or Critical Location approach.

(a) High-cycle fatigue—where stresses and strains are largely confined to the elastic region. High-cycle fatigue is associated with low loads and long life. The Stress-Life (S-N) or Total Life method is widely used for high-cycle fatigue applications. While low-cycle fatigue is typically associated with fatigue life between 10 to 100,000 cycles, high-cycle fatigue is associated with life greater than 100,000 cycles.

Fatigue analysis refers to one of three methodologies: local strain or strain life, commonly referred to as the crack initiation method, which is concerned only with crack initiation (E-N, or sigma nominal); stress life, commonly referred to as total life (S-N, or nominal stress); and crack growth or damage tolerance analysis, which is concerned with the number of cycles until fracture.

The three methods used to predict life include total life (S-N), crack initiation (E-N), and crack growth. S-N analysis is relatively straightforward, being based on the nominal stress-life method using rain flow cycle counting and Palmgren-Miner linear damage summation. A range of analysis parameters may be selected, including Goodman or Gerber mean stress corrections, confidence parameters, manufacturing details (surface finish), and material heat treatments.

1.2 PROBLEM STATEMENT

Many different mechanical failure modes exist in all fields of engineering. These failures can occur in simple, complex, inexpensive, or expensive component or structure. Failure due to fatigue is the most common cause of mechanical failure. Even though the number of mechanical failure compared to successes is minimal, the cost in lives, injuries, and money is too large. Proper fatigue design can reduce these undesirable losses. Proper fatigue design includes synthesis, analysis, and testing. The closure the simulated analysis and testing are to the real product and its usage, the greater confidence in the engineering result. It is important to predict the fatigue crack growth of cracked plate to reduce these undesirable losses.

For example, fatigue analysis early in the design phase can locate areas that are likely to succumb to fatigue quickly, minimizing expensive and unnecessary prototypes and tests. Due to this problem, common products manufactured are using non-suitable material. Aluminium alloys have a good characteristic in order to prevent or minimize the crack such as what happened to steel. So, analysis will be conduct on aluminium alloy to approve that aluminium alloy is better. The analysis will using Finite Elements Analysis (FEA) and stress strain analysis. The final result will display in stress elements, strain elements, displacement element and also force elements.

1.3 OBJECTIVES

The objectives of this project are as follows:

- To develop and analysis the finite element modeling of crack plates.
- To investigate crack growth a size of crack under axial loading.

1.4 SCOPE OF THE PROJECT

This focus area based on the following aspect:

- To build structure modeling of flat plate.
- Finite element modeling and to perform linear static analysis of cracked plate.
- To analysis the fatigue cracked growth under axial loading.

1.5 OVERVIEW OF REPORT

This report consists of five chapters. Chapter 1 is the introduction. Chapter 2 presents the literature review of the report. Chapters 3 discuss method and strategy. Result, analysis and discussion of this study are present in Chapter 4. While in Chapter 5, there will be present conclusions and recommendations on this project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will discuss on some literatures that give information about finite element analysis and how the analysis of fatigue crack growth will be done. This chapter is discussing on some literature review that give information about finite element analysis and show how the analysis of fatigue crack growth. Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values are less than the ultimate tensile stress limit, and may be below the yield stress limit of the material.

Fatigue occurs when a material is subjected to repeat loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the surface. Eventually a crack will reach a critical size, and the structure will suddenly 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 are therefore important to increase the fatigue strength of the structure.

2.2 MODEL GEOMETRY

The specimen used in the test was a 20% side-grooved standard CT specimen (Janssen, 2004; Zuidema, 2004; Wanhill, 2004). Crack lengths, a, in the test ranged from a = 0.54W to 0.67W, where W is the width of the specimen. Because of the high crack tip constraint due to the side grooves, the specimen may be modeled in 2-D plane strain in FE analysis with a thickness, B, equal to the net thickness of the 3-D specimen, other dimensions being the same as those for the 3-D specimen. The specimen simulated using the FE method and its dimensions are shown in Figure 2.1.

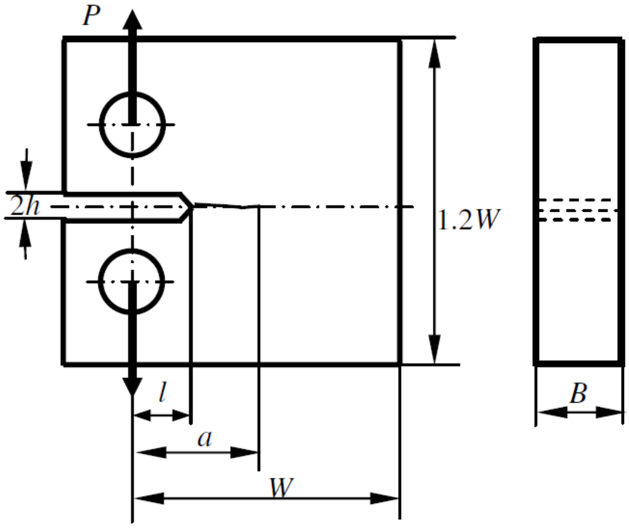

Figure 2.1: The geometry of CT specimen.

Source: Srawley (1976)

In this project, the value of width, W is set to calculate the other values. For the CT specimen, the stress intensity factor solution (Paris, 1963; Erdogan, 1963) can be evaluated in Equation (2.2) where P is the applied load.

$$K_I = \frac{P}{BW^{\frac{1}{2}}} \times f\left(\frac{a}{W}\right) \tag{2.1}$$

The non-dimensional function $f\left(\frac{a}{W}\right)$ in Eq. (2.2) is defined as

$$f\left(\frac{a}{W}\right) = \frac{\left(2+\frac{a}{W}\right)\left\{0.886+4.64\left(\frac{a}{W}\right)-13.32\left(\frac{a}{W}\right)^{2}+14.72\left(\frac{a}{W}\right)^{3}-5.6\left(\frac{a}{W}\right)^{4}\right\}}{\left(1-\frac{a}{W}\right)^{\frac{3}{2}}} \quad (2.2)$$

The drawing of the CT specimen will be done using SOLIDWORK software before it was imported to MSC PATRAN to go through the stress analysis.

2.3 FINITE ELEMENT METHOD

Finite element analysis (FEA) has become commonplace in recent years, and is now the basis of a multibillion dollar per year industry (Brebbia, 1982). Numerical solutions to even very complicated stress problems can now be obtained routinely using FEA, and the method is so important that even introductory treatments of Mechanics of Materials. In spite of the great power of FEA, the disadvantages of computer solutions must be kept in mind when using this and similar methods. There is a lot of software available for Finite Element Analysis, such as Algor (FEMPRO), ANSYS, ABAQUS, and MSC Patran. All this software widely used nowadays, in order to analyze the part. In solving partial differential equations, the primary challenge is to create an equation that approximates the equation to be studied, but is numerically stable, meaning that errors in the input and intermediate calculations do not accumulate and cause the resulting output to be meaningless. There are many ways of doing this, all with advantages and disadvantages. The Finite Element Method is a good choice for solving partial differential equations over complicated domains.

Finite element method, FEM is a numerical technique for finding approximate solutions of partial differential equation as well as of integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problem),or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, and Runge-Kutta.

In solving partial differential equation that approximates the equation to be studied, but is numerically stable, meaning that errors in thi input data and the intermediate calculations do not accumulate and cause the resulting output to be meaningless. There are many ways of doing this, all with advantages and disadvantage. The finite element is a good choice for solving partial differential equations over complicated domains, when the domain changes, when the desired precision varies over the entire domain, or when the solution lacks smoothness. For instance, in a frontal crash simulation it is possible to increase prediction accuracy in important areas like the front of the car and reduced it in its rear.

2.4 CRACK GROWTH

Fatigue is a localized damage process of component produced by cyclic loading. It is the result of the cumulative process consisting of crack initiation, propagation, and final fracture of a component. During cyclic loading, localized plastic deformation may occur at the highest stress site. This plastic deformation induces permanent damage to the component and a crack develops. As the increasing number of loading, the length of crack (damage) will increase. After a certain number of loads, the crack will cause the component to fail.

In general, it has been observed that the fatigue process involves the following stages:

1. Crack nucleation (stage I)
2. Short crack growth (stage II)
3. Long crack growth (stage III)
4. Final fracture

Cracks start on the localized shear plane at or near high stress concentrations, such as persistent slip bands, inclusions, porosity, or discontinuities. The localized shear plane usually occurs at the surface or within grain boundaries. This step, crack nucleation, is the first step in the fatigue process. Once nucleation occurs and cyclic loading continues, the crack tends to grow along the plane of maximum shear stress and through the grain boundary.

A graphical representation of the fatigue damage process shows where crack nucleation starts at the highest stress concentration site in the persistent slip bands like in the figure 2.2.The next step in the fatigue process is the crack growth stage. This stage divided between the growth of stage I and stages II cracks. Stage I crack nucleation and growth are usually considered to be the initial short crack propagation across a finite length of the order of a couple of grains on the local maximum shear stress plane. In this stage, crack tip plasticity is greatly affected by the slip characteristics, grain sizes, orientation, and stress level, because the crack size is comparable to the material micro-structure. Stage II crack growth refers to long propagation normal to the principle tensile stress plane globally and in the maximum shear stress direction locally. In this stage, the characteristics' of the long crack are less affected by the properties of the micro-structure than stage I crack. This is because the crack tip plastic zone for stage II crack is much larger than the material micro-structure.

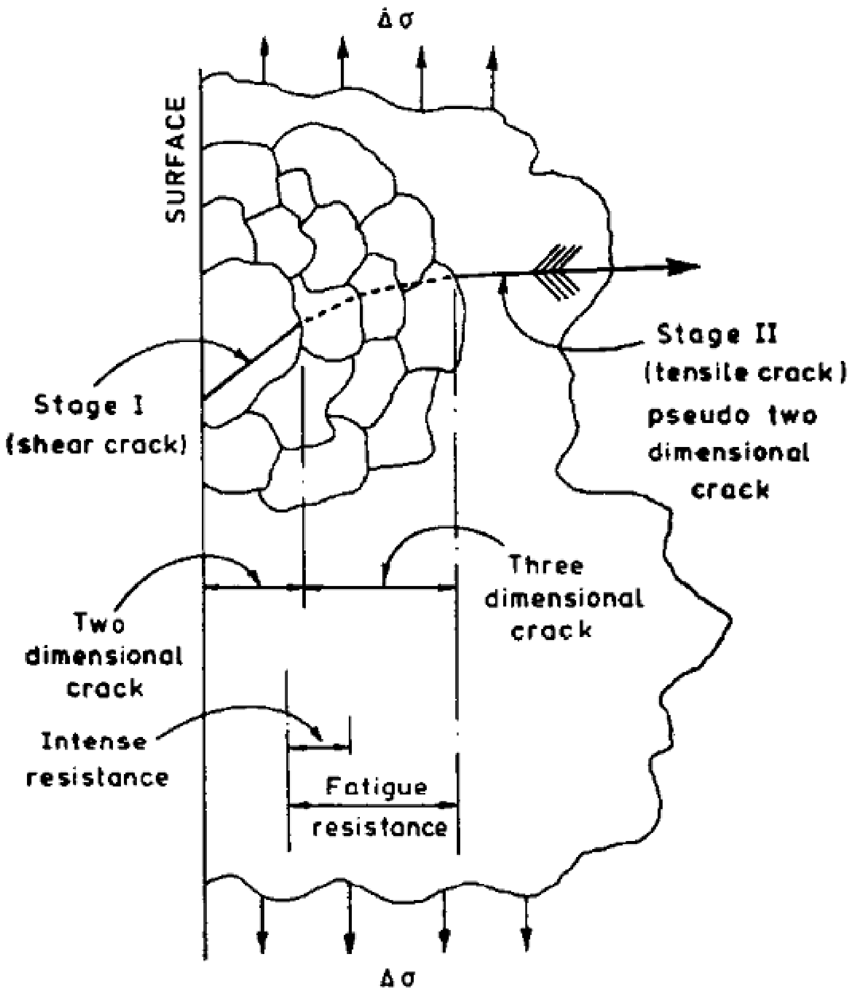

Figure 2.2: The transition from stage I to stage II crack growth

2.5 FATIGUE CRACK PREDICTION METHOD

In general, fatigue life refers to the ability of component to function in the presence of defect for given loading. In practice, the predominant failure mode is fatigue and hence the term fatigue life analysis of fatigue performance.

Skorupa and Skorupa (2005) were studied crack growth predictions for structural steel using constraint factors. At positive stress ratios, structural steel shows significant crack growth retardation under variable amplitude. It also studied load interaction effects in crack growth are negligible. The crack growth response of structural steel in some of the experiments is very different from Al-alloys used in the aircraft industry.

Fathi (2009) have been carried out to determine expressions for critical loads of crack propagation in flat plates under elementary load cases of shear, compression, bending and combination of theme. The effect of combined buckling shear and bending stresses on the crack propagation has been considered in this research. Different boundary conditions must be included in the flat plates, and new stress intensity factors for combined modes I and II have been developed for the crack growth. Also the results show the effect of crack length on the stress distribution and the direction of crack propagation.

Miloud et al. (2009) were studied two different geometries were used on this finite element model in order, to analyze the reliability of this program on the crack propagation in linear and nonlinear elastic fracture mechanics. These geometries were namely; a rectangular plate with crack emanating from square-hole and Double Edge Notched Plate (DENT). Where, both geometries are in tensile loading and under mode I conditions. Predict the crack propagations directions and calculate the Stress Intensity Factors. And the results are the application of the source code program of 2-D finite element model showed a significant result on linear elastic fracture mechanics.

Lu et al. (2009) proposed in their paper for fatigue-life prediction using crack growth analysis. This is the part II of the paper and focuses on the fatigue-life prediction under proportional and non proportional multi axial loading. The proposed model can automatically adapt for different materials experiencing different local failure modes. Reasonable agreements are observed between the model predictions and the experimental observations under proportional and non proportional loading.

Newman (1977) has pointed out that fatigue-crack closure has been experimentally measured under constant- amplitude loading on aluminum-alloy sheet materials. This was used to study crack extension and crack closure behavior in a center-cracked panel under constant-amplitude and two-level block loading. Under constant-amplitude loading, the effects of stress ratio (minimum to maximum applied stress), R, on calculated crack-opening stresses were investigated.

Richardo (2009) The present work shows the numerical determination of fatigue crack opening and closure stress intensity factors of a C(T) specimen under variable amplitude loading using a finite element method. A half compact tension C(T) specimen, assuming plane stress constraint was used by finite element method covering the effects in two-dimensional (2D) small scale yielding models of fatigue crack growth under modified wind turbine standard spectrum loading WISPER. The crack propagation of the finite element model was based on release nodes in the minimum loads to minimize convergence problems.

2.6 CONCLUSION

This chapter is about the summary of journal or works those others people have done that related project. There were discussed about crack growth and fatigue life prediction method. The next chapter is about the methodology of the project.