EFFECT OF CYCLIC STRESS RANGE ON CRACK GROWTH OF ALUMINUIM ALLOY UNDER AXIAL LOADING

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AWARD FOR DEGREE

Bachelor Final Year Project Report

Report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Mechanical Engineering.

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature
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Position: LECTURER OF MECHANICAL ENGINEERING
Date: 6th DECEMBER 2010

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.

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ABSTRACT

This thesis presented about the fatigue life of the material, which is focus on aluminium alloy. There are some important analysis needs to be done including stress analysis, and also fatigue analysis. People might prefer predict the fatigue life of aluminium alloy using experimental approach. But in this thesis, it comes out with different ways, by using software. The software used is MSC PATRAN with MSC NASTRAN as a solver and MSC Fatigue. The model is developed using the SOLIDWORKS. The results from initial analysis will be proceeding with second analysis which is fatigue simulation. Finally, the crack growth graph will be constructed. The effect of stress ranges of aluminium alloys on fatigue crack growth rate was simulated using the Compact Tension specimen as a model. The Fatigue Crack Growth curve, *da/dn* as a function of stress intensity factor, ΔK was plotted in order to analyze the crack growth properties of aluminium alloys. It has been done using MSC FATIGUE software. 4 different stress ranges were selected in range (4-10) kN in order to investigate the effect of stress range on crack growth rates. The model were simulated by means of Mode I loading in constant temperature and frequency. The constant value of **C** and gradient, **m** according to Modified Paris Law equation, are 1.2E-10 and 4.06 respectively. The life cycle graph (S-N curve) of aluminium alloy under this simulation will be compared to the established life cycle graph. It was show that the aluminium alloys have endurance limit of 95MPa.

ABSTRAK

Tesis ini membincangkan mengenai jangka hayat sesuatu bahan terhadap fenomena kelesuan bahan, yang memberi fokus kepada aloi aluminium. Terdapat beberapa analisis penting yang akan dilaksanakan termasuk analisis tegasan dan juga simulasi kelesuan bahan. Kebanyakan individu lebih suka untuk melakukan analisis jangka hayat kelesuan aloi aluminium dengan melakukan eksperimen, tetapi untuk tesis ini, simulasi perisian akan dilakukan untuk mendapatkan graf kadar pertumbuhan retak bagi aloi aluminium. Perisian yang digunakan ialah MSC PATRAN sebagai medium simulasi awal dan MSC NASTRAN and MSC Fatigue sebagai medium simulasi akhir. Hasil daripada setiap analisis akan dikumpul untuk menghasilkan graf pertumbuhan retak. Kesan julat tegasan terhadap kadar pertumbuhan retak kelesuan bagi aloi aluminium telah disimulasi menggunakan spesimen Tegasan Padat (Compact Tension Specimen) sebagai model. Graf kadar pertumbuhan retak melawan keamatan teganan telah dihasilkan bertujuan untuk mengenalpasti sifat – sifat aloi aluminium. Ia telah dihasilkan melalui Perisian MSC Fatigue. 4 julat tegasan yang berbeza telah dipilih untuk simulasi ini, iaitu di dalam julat (4-10) kN dalam mengenalpasti kesan julat tekanan terhadap kadar pertumbuhan retak. Model ini disimulasi menggunakan Mod 1 dan pada suhu dan frekuensi yang tetap. Berdasarkan persamaan Paris yang diubah (Modified Paris Law), nilai pintasan paksi Y ialah 1.2E-10 dan nilai kecerunan ialah4.06 Graf jangka hayat telah dihasilkan dan ia menunjukkan nilai batas ketahanan aloi aluminium ialah 47MPa.

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LIST OF SYMBOLS

Δ	Differential
σ	Stress
N	Number of Cycles
Al_2O_3	Aluminium Oxide
Al-Si	Aluminium Silicon

LIST OF ABBREVIATIONS

AA	Aluminium Alloy
ANSI	American National Standard Institute
CT	Compact Tension
DIN	Deutsch Institute for Normung (German Standardization Institute)
FCC	Face centred cubic
FEA	Finite Element Analysis
FEM	Finite Element Method
IACS	International Annealed Copper Standard
IADS	International Alloy Designation System
IR	Infra Red
ISO	International Standard Organization
UV	Ultra Violet

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

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.

(b) 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 PROJECT BACKGROUND

The analysis of crack growth is very important and its need to widely known by engineer and designer. This analysis comes to the priority because there are so many accidents occur nowadays. The accident such as aircraft accidents, building collapse, and bridge collapse is mostly caused by material failure. This failure includes two types, which is overloading and fatigue failure. This analysis will focus on fatigue failure or cyclic loading. The fatigue life is usually split into crack initiation period and a crack growth period.

The initiation period is supposed to include some micro crack growth, but the fatigue cracks are still too small to be visible by the unaided eye. In the second period, the crack is growing until complete failure. It is technically significant to consider the crack initiation and crack growth periods separately because several practical conditions have a large influence in the crack initiation period, but a limited influence or no influence at all on the crack growth period. In the analysis, the stress range values, ΔK threshold and ΔK critical will be determined in fatigue crack growth rate curve. The analysis will using Finite Elements Analysis (FEA) and stress strain analysis. It will also using a mode 1 under axial loading, and for the stress analysis, it will use a MSC PATRAN and MSC NASTRAN as pre-processor, solver, and post-processor. The final result will display in stress elements, strain elements, displacement element and also force elements. For the model in software stimulation, compact tension (CT) model is the best model to use since we apply the axial loading. There are parameters include in this analysis to determine the ΔK from fatigue crack growth rate curve, like cyclic loading, temperature, weight, and environment conditions. All this parameters need be constant.

1.3 PROBLEM STATEMENT

Predicting fatigue life is a critical aspect of the design cycle because virtually every product manufactured will wear out or break down. The critical issues are whether the product/component/assembly will reach its expected life, and if damaged, whether the product/component/assembly will remain safely in service until the damage can be discovered and repaired. And as with most simulation analysis, the earlier fatigue analysis is deployed in the product development process, the more benefits will be realized, including safety and economic.

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.

1.4 PROJECT OBJECTIVES

(i) To construct a curve of fatigue crack growth rate (differential crack length respect to number of load cycles to the range of stress intensity factor).

(ii) To determine the of stress intensity factor at threshold point and critical point.

(iii) To analyze and determine the S-N curve by numerical method using modified Paris Law equation.

1.5 SCOPES OF PROJECT

Scope of this project is limited to:

1. Investigate the effects of stress range on fatigue crack growth.
2. Identify the behavior of aluminum alloy under cyclic stress range under axial loading
3. Predict the total life of aluminum alloy based on fracture mechanics equation, from fatigue crack growth rate curve.
4. Analyze the model of Compact Tension (CT) in simulation using Finite Elements Analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This final year project basically analyze on the fatigue behaviour of aluminium alloy under Mode 1 or axial loading. The topic needs to be discussed and conclude because each material has their limitations. This research also important as reference to anyone especially manufacturers while produce a part using metal. 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 FINITE ELEMENT ANALYSIS

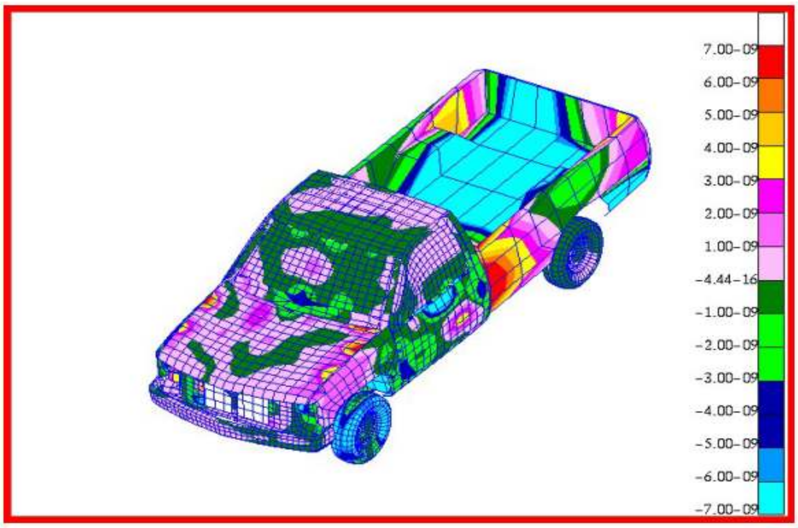

Figure 2.1: The example of finite element analysis on part.

Source: Christophe Pierre 2003

The boundary conditions applied to the mesh included a cyclically varying uniform traction with a minimum value and a maximum value applied on the surface for the axial loading analysis. To prevent rigid body movement, all nodes on the bottom surface of the mesh were fixed in the vertical (two-axis) direction. The nodes at the lower right hand corner were additionally fixed in the one-axis direction. This simulation model is actually a half part of the actual model. Smaller the component simulated, the result will be clearer and easy to analyze. The mesh was created with nodal pairs along the crack propagation path. The contact elements can also be used to prevent elements overlapping along the crack surface. During loading, the applied traction increased from minimum shear to maximum shear. Crack advance was executed with the loading held constant at maximum shear. The crack was grown by releasing all of the connector elements currently at the crack tip. The newly released connector elements were then replaced by contact elements. During the unloading cycle, the applied traction was returned to minimum shear. (Elwood 1992)

The finite element method (FEM) (its practical application often known as finite element analysis (FEA) is a numerical technique for finding approximate solutions of partial differential equations. The opening stress for each cycle was defined as the applied tensile stress on the uppermost elements of the aluminium alloy specimen when the crack first completely opened. The contact pressure for each crack surface node was monitored during the loading stage of each cycle. When all of the crack surface nodes in a particular calculation region (specimen surface or specimen interior) first experienced zero contact pressure, the applied tensile stress was the opening stress in the region. Although this is just a small angle disorientations, particles are more significant than bicrystal boundaries for fatigue crack growth as will be shown later in this paper when larger disorientations angles were employed. (Horstemeyer 2009)

2.3 SOFTWARE USED FOR MODEL SIMULATION

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.

The most suitable software used in this Finite Element Analysis is MSC PATRAN, because the Linear Static results will be proceed with Fatigue Analysis. The final analysis will determine the objective of this Final Year Project, which is generated Crack Growth from simulation under axial loading. From this graph, Life Cycle graph of metal also can be calculated, using a modified Paris Law or fracture mechanic equation. This simulation also will produce a data analysis of Safety Factor in order to prove that load applied is acceptable.

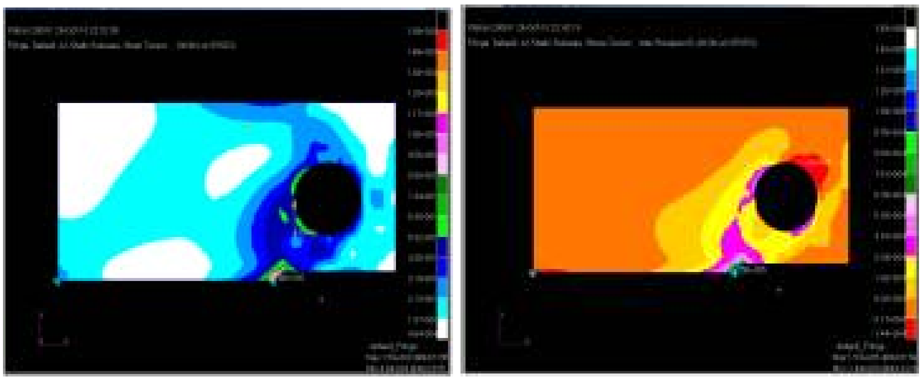

Figure 2.2: Example of MSC PATRAN analysis.

Source: www.mscsoftware.com/Solutions/Applications/Default.aspx

2.3.1 Crack Growth Graph from Database

Using MSC PATRAN as software in simulation is beneficial because it already provide user with database results. There are so many database graph that we can produced, include the Crack Growth graph. Even though we can use the database graph for results, it is not accurate according to the simulation. The final data must be different from analysis, especially ***C*** Value (Y-axis intercept) and ***m*** Value (Gradient of the straight line). In conclusion, the database results only act as references, and the Crack Growth Graph must be generated from the simulation and fatigue analysis.

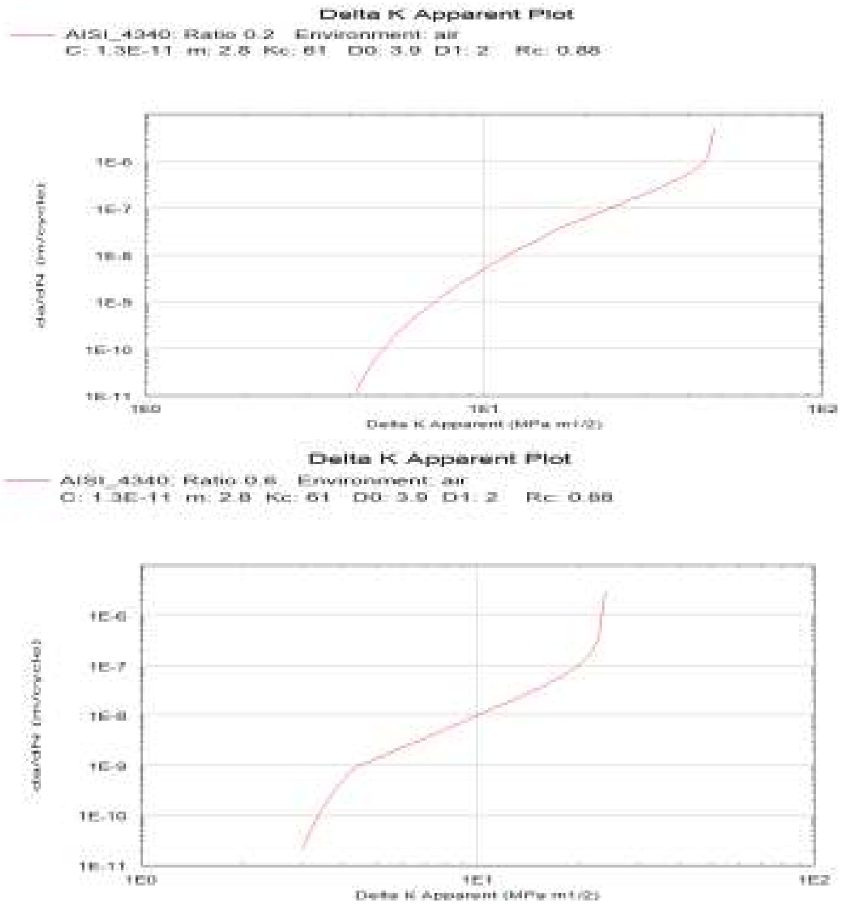

Figure 2.3: The crack growth graph get from the database for different stress ratio values.

Source: www.mscsoftware.com/Products/CAE-Tools/MSC-Fatigue.aspx

The Stress Ratio, R that inserted manually is different which is 0.2 and 0.6. Although the Stress Ratio is different but ***C*** Value (Y-axis intercept) and ***m*** Value (gradient of straight line) is constant. The data can't be used to create S-N Curve manually from Paris Law Equation.