UNIVERSITI PUTRA MALAYSIA

FATIGUE CRACK PROPAGATION IN ALUMINIUM 6063 TUBES

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FK 2009 9

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By

AZIM ATAOLLAHI OSHKOUR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

January 2009

To

My Beloved Parents, Sisters and Brother

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

FATIGUE CRACK PROPAGATION IN ALUMINIUM 6063 TUBES

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AZIM ATAOLLAHI OSHKOUR

January 2009

Chairman: Prof. Ir. Barkawi b. Sahari, PhD

Faculty: Engineering

Tubular structures have extensive usage from domestic to aviation. Therefore estimate of life and safety are essential for design and use. Fatigue is one the most frequent cause for failure in components. Beside fatigue, external surfaces of structures are always in contact with environment and due to imperfection during product fabrication, surface crack may exist. Therefore surface crack is the most common form of crack in engineering structures. To overcome the fatigue problem the design approaches should be considered. The fatigue design approaches are divided in two categories which are safe life approach and damage tolerant design. Due to the importance of tubular structure and possible effect of fatigue in structural damage, the present work has focused on fatigue and fatigue crack propagation behavior in cylindrical structures.

The fatigue design approaches utilized stress based safe life and damage tolerant design approach. The finite element software, ABAQUS used to analyze fatigue and determine fracture parameters. At the beginning fatigue test in finite life was carried out based on Japanese standard. The fatigue tests were done at room temperature and

about 350°C under stress ratio equal to -1 and 0.1. Following experimental part, a 3-D fatigue analysis was carried out by ABAQUS. In fatigue analysis by ABAQUS, the linear material is considered and the results of finite element analysis are plotted in maximum stress versus number of cycles to failure graph. Fatigue analysis was carried out in same condition as experimental part at room temperature and 350°C under stress ratio equal to -1 and 0.1. Subsequent to fatigue analysis, the fatigue crack propagation tests were also carried out. The fatigue crack propagation test was carried out under increasing stress intensity factor or constant amplitude stress. In fatigue crack propagation test, a cracked tubular specimen was used. The crack is located in specimen by wire cut. The crack was an external and circumferential with straight front with depth of 0.37mm. The results of fatigue crack propagation were plotted in two types of graphs; first is crack length ,a, versus the number of cycles, N at each crack length and second is the crack growth rate which plotted as function of rate of crack length upon the number of cycles, *da/dN* versus the stress intensity factor as fracture parameter. Moreover ABAQUS was used to derive the fracture parameters. Two types 3-D tubes with crack were modeled. In first model assumed as sharp and thin crack, but in the second type the blunt crack considered. Material of tube in ABAQUS assumed to be a linear elastic and elastic prefect plastic. The results of crack modeling include fracture parameters as stress intensity factor, and J-integral which were plotted as a function of crack front.

The experimental results of fatigue showed a good agreement with finite element fatigue results. Based on fatigue results the fully reversed fatigue is more severe than fatigue with stress ratio equal to 0.1. Temperature does affect fatigue life which is shown by a decrease in yield strength and ultimate strength of material which resulted in reduction in the fatigue life of specimens with increasing temperature. The fatigue crack propagation results indicated crack growth rate in loading with stress ratio equal to 0.1 is more than stress ratio equal to -1. Crack first grew through the thickness followed by the surface of specimen. This was verified by the results from finite element that show maximum fracture parameters in the deepest point of the crack.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PERTAMBAHAN KERETAKAN LSUE DALAM TIUB ALUMINIUM

Oleh

AZIM ATAOLLAHI OSHKOUR

Januari 2009

Pengerusi: **Prof. Ir. Barkawi b. Sahari, PhD**

Fakulti: **Kejuruteraan**

Kegunaan sturktur berbentuk tiub begitu luas, dari kegunaan rumah hingga bidang penerbangan. Oleh hal yang demikian, anggaran/kiraan jangka hayat dan keselamatan adalah penting dalam merekabentuk dan kegunaannya. Factor kelesuan adalah salah satu penymbang kepada kegagalan sesuatu komponen. Di samping itu permukaan luar yang sentiasa terdedah kepada persekitaran dan kesan dari fakbrikasi yang kurang memuaskan, keretakaan permukan boleh wujud. Dalam struktur kejuruteraan, retakan permukaan merupakan bentuk keretakan yang biasa wujud. Untuk mengatasi masalah kelesuan ini, pendekatan kelesuan rekabentuk perlu diambil kira. Pendekatan kelesuan rekabentuk terbahagi kepada dua kategori, iaitu pendekatan jangkahayat selamat dan ketahanan rekabentuk retak. Oleh yang demikian, kerja penyelidikan ini tertumpu kepada ujian kelesuan dan kelakuan lesu dengan penambahan retakan dalam struktur silinder.

Pendekatan kelesuan rekabentuk menggunakan tegasan jangkahayat selamat dan pendekatan ketahanan rekebentuk di lakukan. ABAQUS merupakan satu perisian unsur terhingga untuk menganalisis kelesuan struktur dan penghasilan parameter

retakan. Pada permulaan kagian, kaedah terhingga ini berdasarkan Japanese Standard. Ujian kelesuan telah dijalankan dalam suhu bilik dan pada 350°C di bawah nisbah tegasan bersamaan dengan -1 dan 1.0.

Untuk ujian yang seterusnya, analisis lesu 3-D dilaksanakan dengan ABAQUS. Analisis kelesuan dengan perisian unsur terhingga ini, bahan linar diambil kira dan keputusan tersebut diplotkan dalam graf tegasan maksimum hingga gagal terhadap bilangan kitaran. Ujian kelesuan dijalankan dengan keadaan yang sama dalam suhu bilik dan 350°C di bawah nisbah tegasan bersamaan dengan -1 dan 1.0. Setelah ujian kelesuan dijalankan, ujian kelakuan lesu dengan penambahan retakan dijalankan. Ujian ini dijalankan di bawah faktor tumpuan tegasan atau amplitud tegasan berterusan. Dalam ujian kelakuan lesu dengan penambahan retakan, spesimen tiub bertakuk di buat dengan mesin Wire Cut. Tiub tersebut dilekuk sedalam 0.37mm di permukaan luar tiub. Ujian kelakuan lesu dengan penambahan retakan ini diplotkan kepada 2 jenis graf; panjang retakan terhadap jumlah kitaran di setiap panjang retakan dan berikutnya adalah kadar penambahan keretakan diplotkan sebagai fungsi kadar panjang retakan keatas bilangan kitaran melawan faktor tegasan sebagai parameter keretakan. Disamping itu ABAQUS digunakan untuk memperolehi parameter retakan. Dua jenis tiub 3-D dengan retakan dimodelkan. Model pertama menganggapkan retakan tajam dan nipis. Model kedua menganggapkan retakan tumpul. Bahan tiub dalam ABAQUS memperkenalkan kengal linar dan kengal linar platci unggul. Keputusan model retakan mengandungi parameter retakan sebagai faktor kekuatan tegasan dan J-intergral yang diplotkan sebagai suatu fungsi kepelbaaian retakan hadapan.

Keputusan ujian kelesuan dan kelesuan unsur terhingga menunjukkan hwdungan yang baik. Berdasarkan ujian kelesuan, ujian berbalikan penuh lebih menyumbangkan tegasan berbanding nisbah tegasan bersamaan dengan 0.1. Kesan peningkatan suhu jangkahayat menunjiukkan peningkatan suhu mengurangkan kekuatan dan takat alah bahan tersebut. Keputusan penambahan retakan lesu menunjukkan penambahan kadar retakan dalam bebanan beserta nisbah tegasan bersamaan dengan 0.1 adalah lebih berbanding nisbah tegasan bersamaan dengan -1. Pembesaran retakan bermula dari ketebalan seterusnya ke atas permukaan spesimen. Ini dibuktikan melalui keputusan unsur terhingga yang menunjunkkan parameter retakan maksimum berlaku dalam kedalaman yang paling dalam daripada retakan tersebut.

ACKNOWLEDGEMENTS

First and foremost I would like to express my deep gratefulness to my supervisor Professor Dr. Ir. Barkawi b. Sahari providing me the wonderful opportunity to continue my master's program. I am also very thankful for his tireless, kind assistance, support, critical advice, encouragement and suggestions during the study and preparation of this thesis.

I would also like to express my gratitude towards my members of my supervisory committee Dr. Aidy Ali and Associate Professor Dr. Wong Shaw Voon, whom I am grateful for their practical experience and knowledge that made an invaluable contribution to this thesis. I truly appreciate the time they devoted in advising me and showing me the proper directions to continue this research and for their openness, honesty and sincerity.

I owe thank to Mr. Wildan Ilyas Mohd Ghazali, technician in Strength of Material Laboratory, Department of Mechanical and Manufacturing Universiti Putra Malaysia who has always been willing to provide assistance, give advice, and be a friend.

Last but not least the deepest appreciation goes to my very close friends, Hossin, Mehdi, Ali and Hamid and for their contentious support and encouragement.

I certify that an Examination Committee has met on **date of viva** to conduct the final examination of **Azim Ataollahi Oshkour** on his Master of Science entitled "Fatigue and Crack Propagation in Aluminium 6063 Tubes" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution

Azim Ataollahi Oshkour

Date: 1 April 2009

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LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional

CHAPTER 1

INTRODUCTION

1.1 Introduction

Many critical mechanical components experience cyclic loadings during their service life. Fundamental understanding of fatigue problem is important for the reliability assessment under realistic service condition and is valuable for the design and maintenance versus fatigue failure. Fatigue life prediction is one of the oldest problems which concern scientists and engineers. Due to the complicated nature of fatigue mechanisms and the large number of factors that influence fatigue life, there is so far no unified approach that can treat all fatigue problems (Weixing, 1993). It has been estimated that as large as ninety percent of all engineering structural and component failures may be attributed to fatigue failure (Dieter, 1986).

The well known approaches which concern fatigue and fatigue crack propagation analysis can be categorized in two groups. These include damage tolerant design and safe life approaches. Based on damage tolerant design, structures are designed to allow limited crack propagation so that growing cracks can be located and remedied. The safe life approaches are such as stress base or strain based approach. Damage tolerance is based on the likelihood of finding cracks and their estimated propagation rates (Lawson, Chen, and Meshii, 1999).

The accuracy of estimated life and safety of engineering components which in oil, gas, aviation and nuclear industries requires good understanding of fatigue property such as fatigue crack propagation rate (da/dN) and fatigue strength curve (S-N) is essential. In the case of existing crack in structure, damage tolerant design can be used to obtain accurate crack growth data. It mainly estimates the residual fatigue life of cracked structures on the basis of known crack propagation rates. To carry out this assessment, it is necessary to have reliable fracture parameters such as stress intensity factor and J-integral. There are two ways for calculating fracture parameters, namely analytical and finite element methods. By using finite element methods, it provides time and commercial benefit. Hence fracture parameters can be derived by carrying out crack simulation on two dimensional or three dimensional numerical modeling. Following which the finite element model was developed for calculating fracture parameters for cracks. Based on crack growth rate (da/dN) data obtained from fatigue tests and the results of finite element analysis, fatigue crack growth behavior can be predicted.

1.2 Problem Statement

Cylindrical components such as pressure vessels, pipes, borers, and driving shafts are commonly used parts of engineering structure. Due to a wide range of usage of this type of structures such as transmission or storage of fluid as in pipes and high pressure vessels, it is necessary that these structures be assessed with different conditions such as materials, temperature and loading. Fatigue caused a structure to fail and it is known to be one of the major reasons of failure in engineering structures. Some of the failures by fatigue happened suddenly and unexpectedly at stresses lower than their design strength, resulting in extensive property damage and loss of life. A lot of efforts have been done to understand why and how materials fail by fatigue and what are the main parameters and factors in fatigue. In the present days these economic and life cost of failure and fracture become greater due to structures become more complexes. Therefore it required special consideration on safety and life prediction. Based on the importance of fatigue and tubular structures, the present work focused on analysis and investigating fatigue and fatigue crack propagation this structures.

1.3 Research Objectives

The objectives of this study are:

1. To determine the fatigue behavior of Aluminum 6063 tube at room and 350°C by using of experimental and finite element methods.

2. To determine the parameters of fracture in aluminum tubes by using of finite element methods.

3. To determine the mechanisms of fracture associated with fatigue and develop a model to predict crack propagation length versus number of cycles.

1.4 Thesis Layout

This thesis is divided into six chapters. Following this introductory chapter, chapter two gives a critical review of relevant literature, from overview of fatigue, creep and fracture mechanics. Chapter three outlines the underlying theory as well as