UNIVERSITI TEKNIKAL MALAYSIA MELAKA

INVESTIGATION OF FATIGUE CRACK GROWTH ON HEAT TREATED ALUMINUM 7075 WITH THE EFFECT OF CORROSION

This report submitted in accordance with partial requirements of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Engineering Material) with Honours.

By

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APPROVAL

This report submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Material). The members of the supervisory committee are as follow:

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ABSTRACT

The objective of this research is to investigate effect the heat treatment on fatigue crack growth of aluminum 7075 in corrosive environment. In this research, the aluminum alloy 7075 is used because it has the highest attainable strength levels of all forged alloys and has a good stress corrosion resistance. However, they are very susceptible to stress corrosion cracking when aged into maximum strength heat treatment. The goal of this research is to be able to better predict fatigue crack growth (FCG) behavior in 7075 Aluminum Alloy. In this study, the aluminum alloy 7075 sample will be heat treated using two methods, the T6 and RRA heat treatment. The samples will then be exposed to exfoliation corrosion. Several non-heat treated samples will also be exposed to exfoliation corrosion to study the difference behavior between heat treated and non-heat treated samples under corrosion behavior. Those samples will be studied in terms of fatigue crack growth, hardness and fractography. Microstructure observation of the samples will also be done. Data obtained in the study will then be compared to non-heat treated samples. It is predicted that RRA heat treatment samples yield the best strength and corrosion resistance sample compared to the others.

ABSTRAK

Objektif daripada kajian ini adalah untuk menyiasat kesan proses rawatan haba pada pertumbuhan retak lesu aluminium aloi 7075 dalam persekitaran mengkakis (karat). Dalam kajian ini juga, aluminium aloi 7075 digunakan kerana ia mempunyai sifat kekuatan yang tinggi boleh dicapai berbanding semua aloi yang lain dan memiliki sifat ketahanan kakisan yang baik. Namun, Ia sangat mudah dikenakan tekanan retak karat apabila kekuatan maksimum rawatan haba bertambah. Objektif daripada kajian ini adalah untuk dapat menjangka dengan lebih baik perilaku pertumbuhan retak lesu (FCG) dalam Aluminium Alloi 7075. Dalam kajian ini, sampel aluminium aloi 7075 akan dikenakan dua kaedah proses rawatan haba iaitu, menggunakan rawatan haba T6 dan RRA. Sampel kemudiannya akan dikena proses pengaratan (pengakisan). Sampel yang tidak dikenakan rawatan haba juga akan dikenakan proses pengaratan (pengakisan) untuk mengetahui perbezaan kelakuan antara sampel yang dikenakan rawatan haba dan sampel yang tidak dikenakan rawatan haba. di bawah sifat pengatratan. Kajian akan dilakukan pada sampel tersebut dalam ujian perambatan retak lesu, ujian kekerasan dan fractography. Pemerhatian imej mikrostruktur sampel juga akan dilakukan. Data yang diperolehi dalam kajian ini kemudian akan dibandingkan dengan sampel yang tidak dikenakan rawatan haba.. Dalam hal ini, dapat dijangka bahawa sampel rawatan haba RRA adalah yang terbaik menghasilkan sample yang mempunyai kekuatan dan ketahanan kakisan berbanding sampel yang lain.

DEDICATION

This thesis is gratefully dedicated to my family and all my friends.

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

%	-	Percent
σ_y	-	Yield Strength,
σ	-	Tensile stress
^{0}	-	Degrees
^{0}C	-	Degrees Celsius
^{0}F	-	Degrees Fahrenheit
±	-	Plus and minus
µm	-	micrometer
Al	-	Aluminum
Al_2O_3	-	Aluminum Oxide
ASTM	-	American Society for Testing and Materials
Cu	-	Copper
E	-	Modulus of Elasticity
e.g.	-	For example
Pa	-	Pascal
mm	-	Millimeter
SEM	-	Scanning Electron Microscope
Zn	-	Zink
NaCl	-	Natrium Chloride
O_2	-	Oxygen
H	-	Hydrogen
H_2O	-	Water

CHAPTER 1

INTRODUCTION

1.1. Background

Aluminum alloys are widely used in aerospace engineering. The major problems faced by aluminum alloys in the application are the failure risk attributed by fatigue and corrosion. Corrosion such as pitting often induces crack initiation of corrosion fatigue that shortens the service life of the structural aluminium alloy, and even result in catastrophic accidents (Liu et. al., 2002). Corrosion is defined as the destruction or deterioration of a material because of reaction with its environment. The serious consequences of the corrosion process have become a problem of worldwide significance, where due this problem, more cost had been used in research and development of corrosion engineering as to control corrosion on the material.

Heat treatable aluminum alloys can be strengthened considerably by appropriate heat treatments. Not only does heat treatment increases the strength of the material, heat treatments also give better corrosion resistance to the heat treated material. This attribute is due to the alloying elements of the aluminum alloy that promotes corrosion resistance.

Alloy 7075 has a major shortcoming among other 7xxx series alloys. Its good heat-treated mechanical properties depend on high quench rates to maximize the artificial aging (precipitation hardening) response. High quench rates, however, cause thermal stresses to develop that can exceed the instantaneous local yield strength. Normally, compressive surface stress is desirable in terms of resistance to fatigue and stress corrosion. Unfortunately, the likely subsequent machining operation not only removes the surface condition, but can result in dimensional stability problems. The effect fatigue properties of heat treatment structures such as crack growth data (da/dN) and fatigue strength curves (S-N data) should be determined accurately so that the fatigue life of the heat treatment structure can be correctly evaluated.

T6 and RRA are heat treatment process done to a material to improve the mechanical properties to the material. The peak aged T6 temper provides maximum mechanical strength but the Cu-containing AA7xxx alloys in the T6 temper are susceptible to various forms of localized corrosion. RRA on the other hand improves the stress corrosion behavior of the material while maintaining the mechanical resistance of the T6 temper.

1.2. Problem Statement

Aluminum alloy 7075 becoming a very important engineering material widely employed in the aircraft and aerospace industry for the manufacturing of different parts and components due to its high strength-to-density ratio (DeBartolo and Hillberry, 2001). However, it has been pointed out that corrosion is one of the primary problems for aircraft around the world and there are major worldwide initiatives to study the issue of corrosion (DuQuesnay et. al., 2003). Corrosion often induces crack initiation of fatigue that shortens the service life of the structural aluminium alloy, and even result in catastrophic accidents (Liu et. al., 2002). Fatigue first initiates crack within the material which then propagates and leads to structural failure. Structural fatigue has become a major design issue in aviation, which is a matter of serious concern from a safety and economic standpoint. Crack growth depends heavily on material properties. Heat treatment can change the material properties in terms of its strength and resistance properties. The change in microstructure of the material when heat treated can impede crack propagation and dislocation motion. The problem with aluminum alloy 7075 is that they are very susceptible to stress corrosion cracking when aged into maximum strength heat treatment. This project is to investigate the effect of corrosion on fatigue crack growth with T6 and RRA heat treatment processes. A study conducted in order to measure the fatigue crack growth rates of a 7075 aluminum alloy in an exfoliation corrosion solution. The behavior of the crack growth will be compared to each heat treatment and non-heat treated samples.

1.3 Objectives

a. To study the effect of T6 and RRA heat treatments on fatigue crack growth of aluminum alloy 7075 in corrosion environment.
b. To correlate morphology and fatigue crack growth in corrosive environment.

1.4 Scope

The scope of this project is to study the role of Aluminum alloy 7075 with various heat treatments which is T6, and RRA. The corrosion of the material is done by using exfoliation corrosion technique. Structural and microstructure observation of the sample will be conducted using optical microscope and Scanning Electron Microscope (SEM) respectively. Mechanical properties will be conducted in terms of fatigue crack growth, fractography, tensile and hardness properties of the aluminium alloy 7075.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The widely used of Aluminum alloy in severe environments requires that the materials have good mechanical properties in these environments. The aim of this study is to investigate of fatigue crack growth on heat treated Aluminum 7075 with effect of corrosion. The relationship between the heat treatment and the effect of corrosion will be studied. Fatigue is one of the principle damage mechanisms for materials operating at cycling loading in long time. Finally the material or structure may fail in different modes, fatigue, rupture, loss and large deformation. For the material under elevated fatigue there is serious influence on the properties and fatigue life of the material.

Aluminum alloy are identified by a four-digit number, the first digit of which generally identifies the major alloying element as shown in the table below. For aluminum alloys, the fourth digit is separated from digit by a decimal point and indicates the form.

Table 2.1: Wrought Alloy Designation System (ASM Handbook)

Number Element	Major Alloying Element
1XXX	Aluminum (99.00% minimum)
2XXX	Copper
3XXX	Manganese
4XXX	Silicon

5XXX	Magnesium
6XXX	Magnesium and Silicon
7XXX	Zinc
8XXX	Other element
9XXX	Unused Series

2.2 Aluminum Alloy

Pure aluminum is soft and ductile. Most commercial uses require greater strength than pure aluminum affords. Aluminum is a lightweight structural material that can be strengthened through alloying and, depending upon composition, further strengthened by heat treatment and cold working. This is achieved in aluminum by addition of other elements to produce various strength level alloys. Aluminum and its alloys appear to have increasing applications and to be competitive to ferrous alloys due to their important advantages such as, low density, high specific strength, high corrosion resistance, good formability and weldability. (Hatch, J.E, 1983) The high strength heat treatable aluminum alloys of 7XXX series are highly used in automotive industry, aeronautics and architecture. (S. Pantelakis, 2005).

Table 2.2: Typical chemical composition of 7075 Aluminum Alloy

Element	Zn	Mg	Cu	Fe	Si	Mn	Cr	Ti	Other	Aluminum
Wt%	6.10	2.90	2.00	0.50	0.40	0.30	0.28	0.20	0.15	Balance

2.2.1 The Aluminum Alloy 7075

The materials studied here are Aluminum alloys 7075. These alloys are based on aluminum with zinc, copper, magnesium, and chromium as the principal alloying elements. The strength of aluminum 7075 depends primarily on precipitation hardening of the aluminum by zinc and magnesium, which in turn depends on heat treatment. 7075 is an aluminum alloy; it is strong, with high strength and good machinability, weldability and has moderate resistance to corrosion, stress corrosion, and fatigue, plus high fracture toughness. (Hatch, J.E, 1983).

2.3 Purpose of Heat Treatment

The process of heat treating is the method by which metals are heated and cooled in a series of specific operations that never allow the metal to reach the molten state. The purpose of heat treating is to make a metal more useful by changing or restoring its mechanical properties. Through heat treating, we can make a metal harder, stronger, and more resistant to impact. Also, heat treating can make a metal softer and more ductile.

The purpose of the heat treatment is to cause desire changes in the metallurgical structure and thus in the properties of metal parts. Differences in type, volume fraction, size, and distribution of the precipitated particles govern properties as well as the changes observed with time and temperature, and these are all affected by the initial state of the structure. The initial structure may vary in wrought products from unrecrystallized to recrystallized and may exhibit only modest strain from quenching or additional strain from cold working after solution heat treatment. These conditions, as well as the time and temperature of precipitation heat treatment, affect the final structure and the resulting mechanical properties. (Totten, G.E 1997). In this project, the combination of aluminum alloy 7075 is referred to use heat treatment solution.

2.3.1 Heat Treatment on Aluminum Alloy

Heat treating is a critical step in the aluminum manufacturing process to achieve required end-use properties. The heat treatment of aluminum alloys requires precise control of the time-temperature profile, tight temperature uniformity and compliance with industry-wide specifications so as to achieve repeatable results and produce a high-quality, functional product. The most widely used specifications are AMS2770 (Heat

Treatment of Wrought Aluminum Alloy Parts) and AMS2771 (Heat Treatment of Aluminum Alloy Castings) (ASM Handbook), which detail heat-treatment processes such as aging, annealing and solution heat treating in addition to parameters such as times, temperatures and quenching. These specifications also provide information on necessary documentation for lot traceability and the quality-assurance provisions needed to ensure that a dependable product is produced.

Wrought aluminum alloys can be divided into two categories: non-heat treatable and heat treatable. Non-heat-treatable alloys, which include the 1xxx, 3xxx, 4xxx and 5xxx series alloys derive their strength from solid solution and are further strengthened by strain hardening or, in limited cases, aging. Heat-treatable alloys include the 2xxx, 6xxx and 7xxx series alloys and are strengthened by solution heat treatment followed by precipitation hardening (aging). (Peeler, D, 2002)

2.3.2 Heat Treatment Processes

In general, the principles and procedures for heat treating wrought and cast alloys are similar. For cast alloys, however, soak times tend to be longer if the casting is allowed to cool below a process-critical temperature for the particular alloy. Solution soak times for castings can be significantly reduced to durations similar to that for wrought alloys if the castings are placed into the solution furnace while still hot (above the process-critical temperature) immediately following mold filling and solidification. The reduction of stress in complex cast shapes is achieved in large part by the control of quenching parameters such as agitation rate, quenching temperature, rate of entry and part orientation in the quench. (ASM Hanbook)

2.3.2.1 Aging

The goal of aging is to cause precipitation dispersion of the alloy solute to occur. The degree of stable equilibrium achieved for a given grade is a function of both time and temperature. In order to achieve this, the microstructure must recover from an unstable or "metastable" condition produced by solution treating and quenching or by cold working. (Peeler D, 2002)

The effects of age hardening or precipitation hardening on mechanical properties are greatly accelerated, and usually accentuated, by reheating the quenched material to about 212˚F-424˚F (100˚C-200˚C). A characteristic feature of elevated-temperature aging effects on tensile properties is that the increase in yield strength is more pronounced than the increase in tensile strength. Also ductility – as measured by percentage elongation – may decrease. Thus an alloy in the T6 temper has higher strength but lower ductility than the same alloy in the T4 temper. (Andreatta, F et al 2002)

In certain alloys, precipitation heat treating can occur without prior solution heat treatment since some alloys are relatively insensitive to cooling rate during quenching. Thus they can be either air cooled or water quenched. In either condition, these alloys will respond strongly to precipitation heat treatment (Andreatta, F et al 2002).

In most precipitation-hardenable systems, a complex sequence of time-dependent and temperature-dependent changes is involved. The relative rates at which solution and precipitation reactions occur with different solutes depend upon the respective diffusion rates, in addition to solubility and alloy contents. (Peeler D, 2002)

2.3.2.2 Annealing

Annealing is used for both heat-treatable and non-heat-treatable alloys to increase part ductility with a slight reduction in strength. There are several types of annealing treatments dependent to a large extent on the alloy type, initial and final microstructure and temper condition. In annealing it is important to ensure that the proper temperature is reached in all portions of the load. The maximum annealing temperature needs to be carefully controlled. (Totten G E, 1997)

During annealing, the rate of softening is strongly temperature dependent – the time required can vary from a few hours at low temperature to a few seconds at high temperature. Full annealing (temper designation “O”) produces the softest, most ductile and most versatile condition. Other forms of annealing include: stress-relief annealing, used to remove the effects of strain hardening in cold-worked alloys; partial annealing (or recovery annealing) done on non-heat-treatable wrought alloys to obtain intermediate mechanical properties; and recrystallization characterized by the gradual formation and appearance of a microscopically resolvable grain structure. (Totten G E, 1997)

2.3.2.3 Solution Heat Treatment

The purpose of solution heat treatment is the dissolution of the maximum amount of soluble elements from the alloy into solid solution. The process consists of heating and holding the alloy at a temperature sufficiently high and for a long enough period of time to achieve a nearly homogenous solid solution in which all phases have dissolved.

Care must be taken to avoid overheating or under heating. In the case of overheating, eutectic melting can occur with a corresponding degradation of properties such as tensile strength, ductility and fracture toughness. If under heated, solution treatment is incomplete and strength values lower than normal can be expected. In certain cases extreme property loss can occur. The solution soak times for castings can be reduced significantly by placing the casting directly into the solution furnace immediately following solidification. The casting is maintained at a temperature above a process-critical temperature (PCT), and the alloy solute is still in solution. (Andreatta, F et al 2002)

In general, a temperature variation of ±10˚F (±5.5˚C) from control set point is allowable, but certain alloys require even tighter tolerances. Tighter thermal variation (±5˚F) allows the set point to be controlled closer to the eutectic, thus improving proportion and reducing required soak time. The time at temperature is a function of the solubility of the alloy solute and the temperature at which the aluminum casting or wrought alloy is