UNIVERSITI TEKNIKAL MALAYSIA MELAKA

AN INVESTIGATION OF THE EFFECT OF RETROGRESSION AND REAGING (RRA) TREATMENT ON STRESS CORROSION CRACKING (SCC) OF ALUMINUM ALLOY 7075

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

By

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FACULTY OF MANUFACTURING ENGINEERING
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JUDUL: AN INVESTIGATION OF THE EFFECT OF RETROGRESSION AND REAGING (RRA) TREATMENT ON STRESS CORROSION CRACKING (SCC) OF ALUMINUM ALLOY 7075

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(Signature of Supervisor)

....................................

(Official Stamp of Supervisor)
DEDICATION

I dedicated all this work to my beloved mother, Salmah Said and my father Mohd Azizuddin Mohd Yusof.
ABSTRACT

The focus of this report is on the mechanical and corrosion properties of high-strength aluminum alloys. Aluminum alloy 7075, a common material in the aerospace industry, is susceptible to stress-corrosion cracking (SCC) in the T6, or peak-aged temper. The susceptibility of this temper to SCC is alleviated through the use of the T73, or overaged temper. This temper exhibits significantly better SCC resistance, but at a 10-15% strength loss compared to the T6 temper. Cina and Ranish patented a new heat treatment known as retrogression and reaging (RRA) in 1974. Experimental test results indicate that the RRA heat treatment reduces the traditional trade-off between T6 strength and T73 SCC resistance. However, the short time heat treatment limits the applicability of REA to thin sections of material.

Retrogression and Reaging (RRA) is a new thermal process introduced for the purpose of enhancing corrosion resistance of 7075-T651 aluminum alloy while maintaining its T6 strength. In this study a 7075 material so treated was investigated for its mechanical and corrosion resistant properties. Results indicated that the RRA treated 7075 was significantly better than the T6 temper in resistance to stress corrosion cracking and exfoliation corrosion. The loss in strength from RRA treatment was minimal. Electron microscopy of the fractured surface showed a distinct difference in the fracture mode when compared to the T6 temper condition. Tests results indicated that the RRA heat treatment resulted in fatigue and fracture toughness properties superior to the 7075-T651.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Aluminum alloy 7075 is one of the strongest alloys, with zinc as the alloying element. It has good fatigue strength and average machinability, but is not weld able and has less resistance to corrosion than many other alloys. One of the corrosion that might be happen to aluminum alloy 7075 is stress corrosion cracking (SCC).

Stress corrosion cracking (SCC) is the unexpected sudden failure of normally ductile metals or tough thermoplastics subjected to a tensile stress in a corrosive environment, especially at elevated temperature in the case of metals. SCC is highly chemically specific in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments. The chemical environment that causes SCC for a given alloy is often one which is only mildly corrosive to the metal otherwise. Hence, metal parts with severe SCC can appear bright and shiny, while being filled with microscopic cracks. This factor makes it common for SCC to go undetected prior to failure. SCC often progresses rapidly, and is more common among alloys than pure metals. The specific environment is of crucial importance, and only very small concentrations of certain highly active chemicals are needed to produce catastrophic cracking, often leading to devastating and unexpected failure.
Certain austenitic stainless steels and aluminum alloys crack in the presence of chlorides, mild steel cracks in the presence of alkali (boiler cracking) and nitrates, copper alloys crack in ammoniacal solutions (season cracking). This limits the usefulness of austenitic stainless steel for containing water with higher than few ppm content of chlorides at temperatures above 50 °C. Revie, R.W and Uhlig, H.H., (2008) Worse still, high-tensile structural steels crack in an unexpectedly brittle manner in a whole variety of aqueous environments, especially containing chlorides. With the possible exception of the latter, which is a special example of hydrogen cracking, all the others display the phenomenon of sub critical crack growth, i.e. small surface flaws propagate (usually smoothly) under conditions where fracture mechanics predicts that failure should not occur.

In order to overcome this problem, a new heat treatment called Retrogression and Reaging (RRA) has been suggested. RRA was claimed to increase dramatically the SCC resistance of the material without reducing strength. This method consists of retrogression the T6 structure at a high temperature within the two-phase field, then reaging at the original T6 condition. Retrogression and reaging result in an optimum combination of corrosion resistance and mechanical properties.
1.2 Problems Statement

Aluminum Alloy 7075 is a strong material, with good fatigue strength and average machinability with zinc as it alloying element. It is widely used for aircraft structural. However, its corrosions resistance is less than many other alloys, especially when aged to the maximum strength (T6 temper). The conventional method of solving the corrosion resistance problems is by heat treatment (T73). This method are successfully overcomes the corrosion problems, but at the same time it affecting the properties by decreasing the strength. Therefore retrogression and reaging treatment is suggested in order to overcome these problems.

Retrogression and reaging (RRA) was devised some time ago by Cina and Ranish and Cina, Park J.K (1988), and it was claimed to increase dramatically the SCC resistance of the material without sacrificing its maximum strength. This method consists of retrogression the T6 structure at a high temperature within the two-phase field for a short time and reaging the retrogressed materials at the original T6 condition.

1.3 Research Objective

These are the objectives of the project:

- Study the result of retrogression and re-aging treatment on strength characteristic of aluminum alloy 7075.
- Investigate the behavior of stress corrosion cracking and the factors involved.
- To obtain the best method of retrogression and re-aging treatment in order to overcome stress corrosion cracking on aluminum alloy 7075.
1.4 Scope of Research

This research are more focusing on effect of aluminum alloy 7075 on occurrence of Stress Corrosion Cracking before and after Retrogression and Reaging treatment. The aluminum alloy 7075 has to be heat treated to T6 and T73 at first to show that these heat treatment result SCC and reducing strength. Retrogression and Reaging treatment temperature have selected for two in accepted range to see and compare the difference result. The influence of Retrogression and Reaging treatment on high strength of aluminum alloy 7075 is study using tensile strength by measuring the stress corrosion crack growth using C-ring stress corrosion specimens.
2.1 Aluminum Alloy

Aluminum alloys are mixtures of aluminum with other metals (called an alloy), often with copper, zinc, manganese, silicon, or magnesium. They are much lighter and more corrosion resistant than plain carbon steel, but not as corrosion resistant as pure aluminum. Bare aluminum alloy surfaces will keep their apparent shine in a dry environment due to the formation of a clear, protective oxide layer. Galvanic corrosion can be rapid when aluminum alloy is placed in electrical contact with stainless steel, or other metals with a more negative corrosion potential than the aluminum alloy, in a wet environment. Table 2.0 shows the effect of allying elements to aluminum.
Table 2.0: Effect of alloying element to Aluminum, *Sheet metal material* (2009).

<table>
<thead>
<tr>
<th>Series</th>
<th>Main Alloy</th>
<th>Effect of Alloying Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>none (99% alu)</td>
<td>Unalloyed aluminum is highly corrosion resistant, low strength, workable, conductive. Non-heat-treatable.</td>
</tr>
<tr>
<td>3000</td>
<td>Manganese</td>
<td>Adds moderate strength, good workability. Non-heat-treatable.</td>
</tr>
<tr>
<td>5000</td>
<td>Magnesium</td>
<td>Moderate to high strength. Corrosion resistant. Non-heat-treatable.</td>
</tr>
<tr>
<td>6000</td>
<td>Magnesium &amp; Silicon</td>
<td>Increases strength, formability, corrosion resistance. Heat-treatable.</td>
</tr>
<tr>
<td>7000</td>
<td>Zinc</td>
<td>For greatest strength. Heat treatable.</td>
</tr>
</tbody>
</table>

Aluminum alloys with a wide range of properties are used in engineering structures. Alloy systems are classified by a number system (ANSI) or by names indicating their main alloying constituents (DIN and ISO). The strength and durability of aluminum alloys vary widely, not only as a result of the components of the specific alloy, but also as a result of heat treatments and manufacturing processes. Figure 2.0 shows the raw material of aluminum alloy.

**Figure 2.0:** Aluminum Alloy raw material.
One important structural limitation of aluminum alloys is their fatigue strength. Unlike steels, aluminum alloys have no well-defined fatigue limit, meaning that fatigue failure will eventually occur under even very small cyclic loadings. This implies that engineers must assess these loads and design for a fixed life rather than an infinite life.

Another important property of aluminum alloys is their sensitivity to heat. Workshop procedures involving heating are complicated by the fact that aluminum, unlike steel, will melt without first glowing red. Forming operations where a blow torch is used therefore requires some expertise, since no visual signs reveal how close the material is to melting. Aluminum alloys, like all structural alloys, also are subject to internal stresses following heating operations such as welding and casting. The problem with aluminum alloys in this regard is their low melting point, which make them more susceptible to distortions from thermally induced stress relief. Controlled stress relief can be done during manufacturing by heat-treating the parts in an oven, followed by gradual cooling in effect annealing the stresses.

The low melting point of aluminum alloys has not precluded their use in rocketry, even for use in constructing combustion chambers where gases can reach 3500 K. The Agena upper stage engine used a regenerative cooled aluminum design for some parts of the nozzle, including the thermally critical throat region.

Aluminum is specified with a 4 digit alloy followed by a temper designation. For example, 5052-H32 indicates an aluminum/magnesium alloy that has been strain hardened and stabilized by low temperature heating and is 1/4 hard. Table 2.1 shows the temper grade and its temper treatment for aluminum alloy.
### Table 2.1: Table of heat temper grade for Aluminum Alloy

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-H</td>
<td>Strain hardened (cold worked) with or without thermal treatment.</td>
</tr>
<tr>
<td>-H1</td>
<td>Strain hardened without thermal treatment.</td>
</tr>
<tr>
<td>-H2</td>
<td>Strain hardened and partially annealed.</td>
</tr>
<tr>
<td>-H3</td>
<td>Strain hardened and stabilized by low temperature heating.</td>
</tr>
<tr>
<td></td>
<td>A second digit denotes the degree of hardness.</td>
</tr>
<tr>
<td></td>
<td>-Hx2 = 1/4 hard.</td>
</tr>
<tr>
<td>2nd Digit</td>
<td>-Hx4 = 1/2 hard.</td>
</tr>
<tr>
<td></td>
<td>-Hx6 = 3/4 hard.</td>
</tr>
<tr>
<td></td>
<td>-Hx8 = full hard.</td>
</tr>
<tr>
<td>-O</td>
<td>Full Soft (annealed).</td>
</tr>
<tr>
<td>-T</td>
<td>Heat treated to produce stable tempers.</td>
</tr>
<tr>
<td>-T1</td>
<td>Partially solution heat treated and naturally aged.</td>
</tr>
<tr>
<td>-T3</td>
<td>Solution heat treated and cold worked.</td>
</tr>
<tr>
<td>-T4</td>
<td>Solution heat treated and naturally aged.</td>
</tr>
<tr>
<td></td>
<td>Partially solution heat treated and artificially aged.</td>
</tr>
<tr>
<td></td>
<td>-T51 Stress relieved by stretching.</td>
</tr>
<tr>
<td>-T5</td>
<td>-T510 No further straightening after stretching.</td>
</tr>
<tr>
<td></td>
<td>-T511 Minor straightening after stretching.</td>
</tr>
<tr>
<td></td>
<td>-T52 Stress relieved by thermal treatment.</td>
</tr>
<tr>
<td>-T6</td>
<td>Solution heat treated and artificially aged.</td>
</tr>
<tr>
<td>-T7</td>
<td>Solution heat treated and stabilized.</td>
</tr>
<tr>
<td>-T8</td>
<td>Solution heat treated, cold worked, and artificially aged.</td>
</tr>
<tr>
<td>-T9</td>
<td>Solution heat treated, artificially aged, and cold worked.</td>
</tr>
</tbody>
</table>
2.1.1 Aluminum Alloy 7075

7075 is an aluminum alloy, with zinc as the alloying element. It is strong, with good fatigue strength and average machinability, but is not weldable and has less resistance to corrosion than many other alloys. Its relatively high cost limits its use to applications where cheaper alloys are not suitable. It is commonly produced in several heat temper grades which are 7075-O, 7075-T6, and 7075-T651. Table 2.2 shows the minimum limit of chemical composition in aluminum alloy 7075.

Table 2.2: Chemical composition minimum limit in Aluminum Alloy 7075

| No. | Alloying elements | Chemical composition minimum limit (WT.%)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Si</td>
<td>0.40</td>
</tr>
<tr>
<td>2.</td>
<td>Fe</td>
<td>0.50</td>
</tr>
<tr>
<td>3.</td>
<td>Cu</td>
<td>1.2-2.0</td>
</tr>
<tr>
<td>4.</td>
<td>Mn</td>
<td>0.30</td>
</tr>
<tr>
<td>5.</td>
<td>Mg</td>
<td>2.1-2.9</td>
</tr>
<tr>
<td>6.</td>
<td>Cr</td>
<td>0.18-0.28</td>
</tr>
<tr>
<td>7.</td>
<td>Zn</td>
<td>5.1-6.1</td>
</tr>
<tr>
<td>8.</td>
<td>Ti</td>
<td>0.20</td>
</tr>
<tr>
<td>9.</td>
<td>Others</td>
<td>0.15</td>
</tr>
<tr>
<td>10.</td>
<td>Aluminum</td>
<td>Balance</td>
</tr>
</tbody>
</table>

The first aluminum alloy 7075 was developed by Japanese company Sumitomo Metal in 1936. Aluminum alloy 7075 was used for the Zero fighter's air frame of the Imperial Japanese Navy in pre-war times. Aluminum 7075 has a specific gravity of 2.73 (0.098 lb/cubic inch).
Table 2.3: Mechanical properties of different heat temper grade of Aluminum Alloy 7075.

<table>
<thead>
<tr>
<th>No.</th>
<th>Heat Temper Grade</th>
<th>Tensile Strength (MPa)</th>
<th>Yield Strength (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>7075-0 (un-heat-treated)</td>
<td>276</td>
<td>145</td>
<td>9-10</td>
</tr>
<tr>
<td>2.</td>
<td>7075-T6 (T6 temper)</td>
<td>510 - 538</td>
<td>434-476</td>
<td>5-8</td>
</tr>
<tr>
<td>3.</td>
<td>7075-T651 (T651 temper)</td>
<td>462 - 538</td>
<td>372-462</td>
<td>3-9</td>
</tr>
</tbody>
</table>

For the applications, 7075 is widely used for construction of aircraft structures, such as wings and fuselages. Its strength and light weight are also desirable in other fields. Table 2.3 shows the strength of aluminum alloy 7075 due to its heat temper grade. Rock climbing equipment, bicycle components, and hang glider airframes are commonly made from 7075 aluminium alloy. The bicycle industry is also using 7005 and 6061 aluminium alloys. Hobby grade R/C's commonly use 7075-T6 and 6061 for chassis plates. One interesting use for 7075 is in the manufacture of M16 rifles for the American military. It is also commonly used in shafts for lacrosse sticks.

Due to its strength, low density, thermal properties and its polishability of aluminum alloy 7075 is widely used in mould tool manufacture. This alloy has been further refined into other 7000 series alloys for this application namely 7050 and 7020.
2.2 Corrosion

Corrosion is the disintegration of a material into its constituent atoms due to chemical reactions with its surroundings. In the most common use of the word, this means a loss of electrons of metals reacting with water and oxygen. Figure 2.1 shows the example of corrosion in metal. Weakening of iron due to oxidation of the iron atoms is a well-known example of electrochemical corrosion. This is commonly known as rusting. This type of damage typically produces oxide or salt of the original metal. Corrosion can also refer to other materials than metals, such as ceramics or polymers.

![Figure 2.1: Example of corrosion in metal](image)

Most structural alloys corrode merely from exposure to moisture in the air, but the process can be strongly affected by exposure to certain substances. Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area to produce general deterioration. While some efforts to reduce corrosion merely redirect the damage into less visible, less predictable forms, controlled corrosion treatments such as passivation and chromate-conversion will increase a material's corrosion resistance.
2.2.1 Stress Corrosion Cracking

Stress corrosion cracking (SCC) is the unexpected sudden failure of normally ductile metals subjected to a tensile stress in a corrosive environment, especially at elevated temperature in the case of metals. SCC is highly chemically specific in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments. The chemical environment that causes SCC for a given alloy is often one which is only mildly corrosive to the metal otherwise. Hence, metal parts with severe SCC can appear bright and shiny, while being filled with microscopic cracks. This factor makes it common for SCC to go undetected prior to failure. SCC often progresses rapidly, and is more common among alloys than pure metals. The specific environment is of crucial importance, and only very small concentrations of certain highly active chemicals are needed to produce catastrophic cracking, often leading to devastating and unexpected failure.

On microscopic level, stress corrosion cracking failure appear to be brittle, that is the usual ductility of the material (e.g., when stresses in air) is considerably reduced. The tensile stress can be applied or residual, or both. Residual stresses result from fabrication processes, such as deformation (e.g., forming of a pipe) and welding. Stress corrosion cracks can be intergranular or transgranular, or a combination of the two. In general, there are three stages in the stress corrosion cracking process:

i. Generation of the environment that causes stress corrosion cracking.

ii. Initiation of stress corrosion cracking.

iii. Propagation of stress corrosion cracking until failure occurs.

Depending on the metal-environment combination and the stressing condition, the time to failure can vary from minutes to many years. Table 2.4 shows metal and it environment of stress cracking system. For this reason, inspection of stressed metals that are exposed to a corrosive environment during service is essential to establish whether cracks have initiated and develop mitigation procedures before failure occurs.