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جامعة ديالى – كلية الهندسة
قسم الهندسة الميكانيكية

# تحليل عمر الكلال لسبائك الالمنيوم AA2014 وAA7075-T651 مع الاخذ بنظر الاعتبار نمو التشققات

رسالة مقدمة الى

كلية الهندسة جامعة ديالى

وهي جزء من متطلبات نيل درجة الماجستير علوم في الهندسة الميكانيكية

من قبل

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**College of Engineering**

# ANALYSIS OF FATIGUE LIFE OF AA2014 AND AA7075-T651 ALUMINUM ALLOYS CONSIDERING CRACK GROWTH

**A Thesis Submitted to the Council of College of Engineering,**
**University of Diyala in Partial Fulfillment of the Requirements for**
**the Degree of Master of Science in Mechanical Engineering**

**by**

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# Chapter One

# Introduction

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## 1.1 Introduction

Aluminum alloys are a common high-performance material and have a long and successful history of use in many industries, especially in aircraft, marine, railway and automotive applications, due to their light weight nature, strength, durability, ductility and good resistance to corrosion [1][2]. The mechanical parts of these applications are often exposed to complicated loadings during their service life. These loads can be applied in many directions and have varying stress amplitudes, which expose these components to final failure under repeated loads that are lower than their static strength [3].

One of the most important types of metal damage is caused by fatigue failure. Often, the parts that are damaged by fatigue appear to be working at safe loads. However, a cumulative damage build-up caused by periodic loads results in internal alterations to the material structure and after that, microcrack initiation, formation, macroscopic crack propagation, and finally an unexpected fracture take place and may go undetected if not discussed during design. In order to prevent such events, fatigue damage has been thoroughly explored, resulting in detailed modeling and computational methodologies for predicting fatigue lifetimes [4][5].

## 1.2 Aluminum and Aluminum Alloys

In the Earth's crust, aluminum is the third most prevalent element. The appearance, light weight, fabricability (formability), specific strength, and corrosion resistance of aluminum are unique characteristics. But pure aluminum has relatively low strength and hardness, so most of the industrial applications in which aluminum is used are in an alloyed form by adding alloying elements to aluminum, and the basic alloying elements that are added to it are□Cu (copper), □ g (magnesium), □ n (manganese), □i (silicon), □n (□inc), and □i (lithium) [□]. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. □ rought alloys which are classified as [□]□

- 1□□□ □ure Aluminum (□□□ or larger).
- 2□□□ Al- Cu Alloy.
- 3□□□ Al- □ n Alloy.
- 4□□□ Al- □i Alloy.
- 5□□□ Al- □ g Alloy.
- □□□□ Al- □ g- □i Alloy.
- □□□□ Al- □n Alloy.
- □□□□ Al-□i Alloy.

Each of these series is distinguished by a particular characteristic, such as the series 1□□□'s higher electrical conductivity, which makes it primarily used in electrical applications□the series 2□□□ and □□□□'s high strength, which make them suitable for use in the production of aircraft parts[7]□the series 3□□□'s good formability and thermal conductivity, which makes it suitable for use in the production of heat exchangers□the series 4□□□ has a low melting point and excellent ductility, so it's beneficial for welding in the engineering industry□the series 5□□□ has excellent corrosion resistance, making it best for marine use□the series □□□□ has high ductility and excellent extrusion formability, making it suitable to produce a variety of extruded products and the □□□□ series has a medium strength, making it ideal for making wire and soft alloys for bearings[□].

## 1.3 Fatigue Failure

The failure of machine parts is commonly attributed to the application of repetitive or fluctuating loads, despite the fact that the most thorough investigation indicates that the actual maximum stresses were frequently much lower than the material's yield strength and were in fact considerably below the ultimate strength. The stresses have been repeated a very high number of times, which is the feature that sets these failures apart the most. The breakdown is hence referred to as a fatigue failure.

When the machine features fail statically, due to the load exceeding the yield strength, and the component is changed before actual fracture takes place, they typically acquire a very significant deflection. Because of this, many static failures provide clear advance notice. A fatigue failure, however, is unpredictable. It is harmful because it is sudden and complete. Finally, fatigue is a complex phenomenon that occurs in members of machines when exposed to alternating, fluctuating, or cyclic stresses and has only been experimentally understood [9][10].

## 1.4 Atomic Force Microscope (AFM)

Atomic Force Microscopy (AFM) is a powerful imaging technique used in nanotechnology and materials research to observe and manipulate the surfaces of materials at the atomic and molecular level. By employing a small probe to scan a specimen's surface, AFM delivers high-resolution topographical data where its resolution is greater than 1000 times that of optical microscopy [11].

A sharp probe, usually a tiny cantilever with a sharp tip at the end, is used in AFM. The probe is incredibly sensitive and can detect forces at the atomic level. It is then brought near the sample's surface and raster-scanned over it. The cantilever bends as a result of forces generated by the contact between the tip and the surface. A laser beam is used to detect the cantilever's deflection, and the laser beam reflects off the cantilever's back onto a position-sensitive detector. Any deflection indicates the topography or other characteristics of the surface. When the probe scans the surface, the deflection of the cantilever is recorded, generating a topographical map of the surface. This data can be used to create three-dimensional images of the specimen's surface features [12][13]. AFM was used to detect and determine the grain size of the alloy

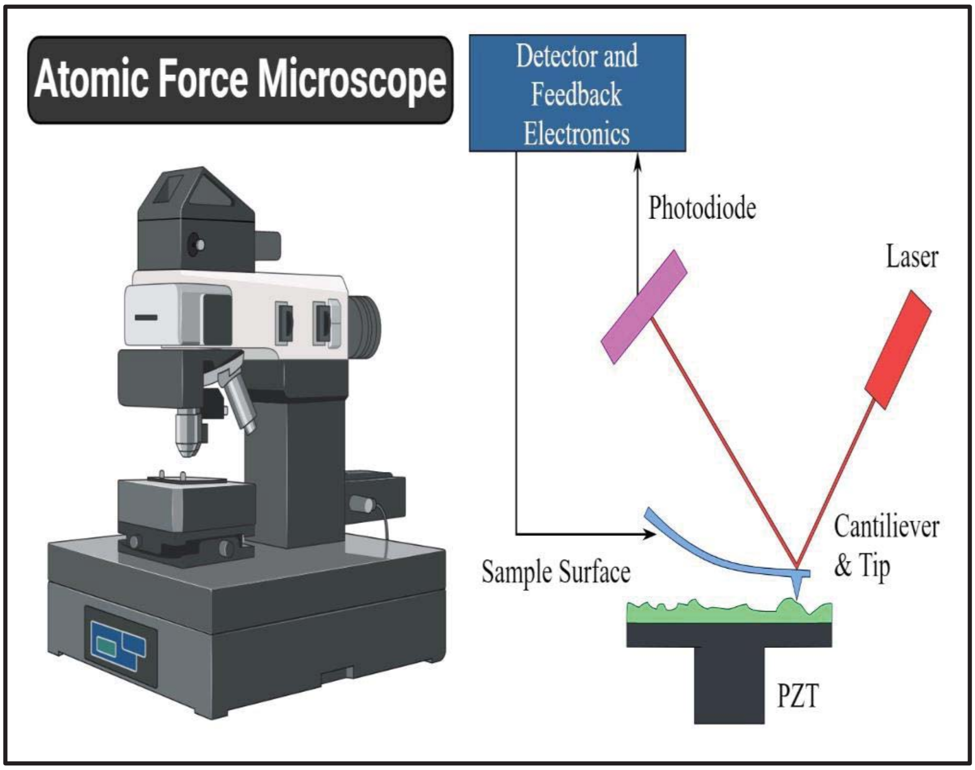

Fig. (1.1) The Principal Work of AFM

## 1.5 Application of Aluminum Alloys (AA2014 & AA7075-T651)

Due to their excellent mechanical qualities, AA2014 and AA7075-T651 aluminum alloys are utilized in a variety of applications, the most crucial of which are the following:

1- Industries of Aerospace: The high strength-to-weight ratio of AA2014 and AA7075-T651 makes them popular choices for aircraft structural components such as fuselage skins, wings, frames, and other important parts where strength and low weight are essential. Due to their good durability and machinability, the alloys are ideal for use in a variety of aerospace applications, such as satellite structures, rocket fittings, and missile components [14][15].

2- Industries of Automotive□As a result of their significant strength and exceptional formability, AA2□14 and AA□□5-T□51 are utilized in the automobile sector for the production of parts such as wheels, suspension parts, and drive shafts [1□].

3- Marine Applications□ Considering their resistance to corrosion, strength, and low density, AA2□14 and □□5-T□51 are used in the building of maritime structures and equipment [1□].

## 1.6 Problem Statement

Aluminum alloys are widely used in the aircraft industry in structures, engines, and wings. These parts are usually subjected to variable loads under different conditions of flight. In order to estimate the fatigue life of these aluminum alloys (AA□□5-T□51 and AA2□14). The best method for accurate life prediction is the crack growth model or crack replication method. This method is based on crack length measured experimentally, corresponding to recorded cycles until specimen failure. Two processes of crack growth can be established□fatigue life of short cracks ($□_{□}$) less than microstructure grain size ($□_{ave}$) and fatigue life of long cracks ($□_{□}$) longer than ($□_{ave}$). The final estimation of fatigue life can be obtained by adding these two lives, ($□_{□}$) and ($□_{□}$).

$$□_{Tmodel} □ □_{□} □ □_{□} \tag{1-1}$$

## 1.7 Objective of the Research

In order to get more explanation for the crack growth method to predict the total fatigue life under variable loading for the two aluminum alloys (AA□□5-T□51 and AA2□14). This work aims to□

1- Studying the mechanical properties at room temperature (□T).

2- Studying the fatigue S-N curves at room temperature (RT).
3- Measuring fatigue cracks by using the replication technique.
4- Testing these aluminum alloys under variable loading by Miner's rule.
5- Using the Miner rule to obtain the fatigue life.
6- Application of the present proposed fatigue crack model to the experimental results.
7- Comparison between these methods Experimentally, Miner and the present crack growth model.

## 1.8 Thesis Outline

The offered thesis is divided into the following six chapters:

1. **Chapter One: Introduction**
   This chapter clarified the main ideas of the overall project and the study's goal.
2. **Chapter Two: Literature Survey**
   This chapter begins the literature review on fatigue, provides an overview of the literature, and discusses how the current study compares to prior studies.
3. **Chapter Three: Theoretical Considerations**
   This chapter provided the theoretical theory, a few theories and models related to fatigue, the planned damage model for the current study, and a list of theories and models.
4. **Chapter Four: Experimental Work**
   This chapter illustrated the work's strategy, the specimen geometry's specification, and the mechanical characteristics of the materials utilized.
5. **Chapter Five: Results and Discussion**
   This chapter discussed the theoretical as well as experimental results and their outcomes.

6. **Chapter Six: Conclusions and Recommendations**

   This chapter outlines the project's key findings and proposals for further development.

# Abstract

Aluminum alloys are used in the manufacture of aircraft, cars, marine, and aerospace products due to their light weight and resistance to corrosion and fatigue. The main objective of this study is to experimentally determine the fatigue life of aluminum alloys AA2□14 and AA□□5-T□51 by measuring the lengths of short and long cracks practically under bending stress with constant amplitude loading and stress ratio ($\square_{s}$ □-1) at room temperature, and by applying Basquin's equation, the fatigue life curve was determined for the both alloys under five different levels of constant amplitude stresses by recording the average failure cycles of three specimens at each stress level, and the values of these stresses were □4, □43, □4□, □5 and □.□of the value of the ultimate tensile stress . Replication technique was used to measure the lengths of the cracks after copying the surface of the specimen with a piece of cellulose paper and liquid acetone and examining this piece by using an optical microscope to record the length of the crack and the number of cycles corresponding to it at a constant stress level of □2 of the ultimate tensile stress value. The copying process was repeated at regular intervals until the specimen was broken. The crack lengths were determined based on measuring the average grain size diameter ($\square_{ave}$) of the two alloys. In this study, short cracks were considered whose length does not exceed ($\square_{ave}$) and long cracks are those whose length exceeds ($\square_{ave}$). A new mathematical model was formulated to describe the relationship between the crack speed (da□d□) and the length of crack ($\square_{ave}$- $a_{ave}$) for short cracks, and (da□d□) and the length of crack ($a_{ave}$) for long cracks, and from these two equations, the number of cycles for short cracks ($\square_{\square}$) and the number of cycles for long cracks ($\square_{\square}$) were calculated, and the sum of these two values represents the total fatigue life ($\square_{Tmodel}$). The results obtained using the model were compared with the practical results, and they were safe and successful. Also, fatigue was tested under variable loads for both alloys at low-high stresses and vice versa. The practical results, the Miner rule, and the proposed model for

calculating the cumulative damage were compared. The results were satisfactory for the proposed damage model, but they are high and unsafe for the □ iner rule.