

**Republic of Iraq
Ministry of Higher Education
and Scientific Research
University of Babylon
College of Materials Engineering
Department of Metallurgical Engineering**



***Improving the Corrosion Resistance of A319
Aluminum Alloy by Cr Addition***

A Dissertation

**Submitted to the Department of Metallurgical Engineering /
College of Materials Engineering / University of Babylon in
Partial Fulfillment of the Requirements for the Degree of Higher
Diploma of Science in Materials Engineering / Metallurgical
Engineering**

By

Raflaa Ali Shalan Abd Zaid

(B.Sc. In Materials Engineering)

(2016)

Supervised by

Prof. Dr. Nawal Mohammed Dawood

(2021) A.D

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

❖ وَمَا جَعَلَهُ اللَّهُ إِلَّا بُشْرَىٰ وَلِتَطْمَئِنَّ

بِهِ قُلُوبُكُمْ وَمَا النَّصْرُ إِلَّا مِنْ عِنْدِ اللَّهِ

إِنَّ اللَّهَ عَزِيزٌ حَكِيمٌ ❖

صَدَقَ اللَّهُ الْعَلِيُّ الْعَظِيمُ

Supervisors Certificate

We certify that this thesis entitled “**Improving the Corrosion Resistance of A319 Aluminum Alloy by Cr Addition**“ is prepared by (Raflaa Ali Shalan Abd Zaid) under our supervision at the Department of Metallurgical Engineering/ College of Materials Engineering/ Babylon University in partial fulfillment of the requirements for the degree of higher diploma of Science in Materials Engineering/ Metallurgical Engineering.

Signature:

Name: Prof. Dr. Nawal Mohammed Dawood

(supervisor)

Date: / /

Dedication

To the heart pure white my soul My dear father

To The most beautiful flower in my life ... My dear mother

To the soul that dwelled my spirit ... my dear husband

To the pulse of my heart and the light of my eyes ... my children (Janna & Leen)

To the winds of my life..... My Brothers and sisters.

Raflaa Ali

(2021)

Acknowledgments

First of all, profusely all thanks be for (**ALLAH the most gracious**) of all creations who enable me to achieve this work.

I would like to express my gratitude and appreciation to my supervisor (**Prof.Dr. Nawal Mohammed Dawood**) for guidance, advice and enthusiastic encouragement throughout my study.

I am very grateful to my husband for his encouragement and support during the period of preparing my study, thank you for being in my life.

Finally, I greatly thankful to my department, Metallurgical Engineering and my College of Materials Engineering for their assistance.

Raflaa Ali
(2021)

Abstract

the development of new Al-Si alloys like (A319) with the required combination of good casting, machining and wear resistance properties to use in cylinder blocks-engine innovation that would simplify the manufacturing process and save costs. So the hypoeutectic Al-Si alloys can potentially provide the required combination to use in linerless automotive engine blocks, so studying their corrosion and tribological performance is of great importance in the effort to optimize the properties of automotive engine block materials.

In this study aluminum alloys (A319) have been prepared by casting technique, then the alloying element (chromium) has been added in different amounts (0.5, 1, and 1.5wt%), in order to study the effect of this element on the microstructure, electrochemical and mechanical properties of this alloy.

Corrosion tests were carried out by potentiodynamic polarization test and simple immersion was conducted as well in salt solution of (3.5 wt.% NaCl).

Several metallurgical aspect of the tested alloys were investigated by the optical microscope , x-ray diffraction , scanning electron microscope and energy dispersive spectrometer analysis equipped with SEM.

Hardness results showed that a significant increment was observed for (A319) after additions of Cr with different additions it reaches to 120 HV for 1.5 wt.% Cr while 87.08 HV for (A319).

Substantial improvement in corrosion resistance was observed. For instance, in salt solution 3.5 wt.% NaCl the corrosion current of

(A319).was 1.09×10^{-4} in comparison the corrosion current of alloy with 1wt% Cr in value which reach to 3.30×10^{-8} .

In wear test, the wear rate of A319 in the steady state was 12×10^{-8} g/mm with respect to the steady state for alloy with 1.5wt% Cr in value was 2.30×10^{-8} g/mm.

A319 alloy with different addition of Cr. showed a lower value of weight loss in erosion –corrosion test . This is expected according to Archard relationship. Since its hardness is almost more of that of A319.

List of Contents

| Sequence | Subject | Page No. |
|--|--|-------------|
| | <i>Abstract</i> | <i>I</i> |
| | <i>List of Contents</i> | <i>III</i> |
| | <i>List of Figure</i> | <i>VI</i> |
| | <i>List of Table</i> | <i>VIII</i> |
| | <i>List of Abbreviations</i> | <i>IX</i> |
| Chapter one | | |
| Introduction | | |
| <i>1.1</i> | <i>General View</i> | <i>1</i> |
| <i>1.2</i> | <i>A319 Alloy</i> | <i>3</i> |
| <i>1.3</i> | <i>Aims of the Present Study</i> | <i>3</i> |
| <i>1.4</i> | <i>Dissertation outline</i> | <i>4</i> |
| Chapter Two: | | |
| <i>Theoretical Part & Literature Review</i> | | |
| <i>2.1</i> | <i>Introduction</i> | <i>5</i> |
| <i>2.2</i> | <i>General View</i> | <i>5</i> |
| <i>2.3</i> | <i>Aluminum and Aluminum Alloy</i> | <i>6</i> |
| <i>2.4</i> | <i>Classification of Aluminum Alloys</i> | <i>6</i> |
| <i>2.4.1</i> | <i>Cast Aluminum Alloys</i> | <i>6</i> |
| <i>2.4.2</i> | <i>Wrought Aluminum Alloy</i> | <i>7</i> |
| <i>2.5</i> | <i>Al-Si System and Properties</i> | <i>8</i> |
| <i>2.6</i> | <i>Aluminum Silicon Cast Alloys</i> | <i>9</i> |
| <i>2.7</i> | <i>Effect of alloying elements on Al-Si alloys</i> | <i>11</i> |
| <i>2.7.1</i> | <i>Silicon</i> | <i>11</i> |
| <i>2.7.2</i> | <i>Copper</i> | <i>12</i> |
| <i>2.7.3</i> | <i>Nickel</i> | <i>13</i> |
| <i>2.7.4</i> | <i>Magnesium</i> | <i>13</i> |

| | | |
|---|--|----|
| 2.7.5 | <i>Iron</i> | 14 |
| 2.7.6 | <i>Titanium</i> | 14 |
| 2.7.7 | <i>Manganese</i> | 15 |
| 2.7.8 | <i>Chromium</i> | 15 |
| 2.7.9 | <i>Zinc</i> | 15 |
| 2.8 | <i>A319 Cast Alloy</i> | 15 |
| 2.9 | <i>Corrosion</i> | 17 |
| 2.9.1 | <i>Uniform Corrosion</i> | 17 |
| 2.9.2 | <i>Galvanic Corrosion</i> | 18 |
| 2.9.3 | <i>Pitting Corrosion</i> | 19 |
| 2.9.4 | <i>Crevice Corrosion</i> | 20 |
| 2.9.5 | <i>Erosion or Abrasion Corrosion</i> | 21 |
| 2.10 | <i>Wear Mechanisms</i> | 22 |
| 2.10.1 | <i>Adhesive Wear</i> | 22 |
| 2.10.2 | <i>Delamination Wear</i> | 23 |
| 2.10.3 | <i>Fatigue Wear</i> | 23 |
| 2.10.4 | <i>Erosion Wear</i> | 23 |
| 2.10.5 | <i>Tribochemical Wear</i> | 23 |
| 2.10.6 | <i>Abrasive Wear</i> | 23 |
| 2.11 | <i>Literature Review</i> | 24 |
| Chapter three: Experimental Part | | |
| 3.1 | <i>Introduction</i> | 31 |
| 3.2 | <i>Materials and Equipment</i> | 31 |
| 3.2.1 | <i>Materials used</i> | 31 |
| 3.2.2.1 | <i>The Chemical Composition for Aluminum Wire</i> | 32 |
| 3.2.2 | <i>Equipment's</i> | 32 |
| 3.3 | <i>program of the present study</i> | 34 |
| 3.4 | <i>The Manufacturing Technique (Melting & Casting)</i> | 35 |
| 3.4.1 | <i>Preparation of A319 Aluminium-Silicon alloy</i> | 35 |

| | | |
|---|--|----|
| | <i>Specimens by Casting</i> | |
| 3.4.2 | <i>Preparation of A319 Aluminium-Silicon alloys with (0.5 , 1 , 1.5)wt.% Cr Specimens by Casting</i> | 37 |
| 3.4.3 | <i>Heat Treatments</i> | 38 |
| 3.5 | <i>primary preparation process</i> | 39 |
| 3.6 | <i>Testing step</i> | 40 |
| 3.6.1 | <i>Chemical Composition Analysis and microstructure examination</i> | 40 |
| 3.6.2 | <i>X-ray Diffraction test</i> | 41 |
| 3.6.3 | <i>Optical microscope</i> | 41 |
| 3.6.4 | <i>scanning electron microscope</i> | 42 |
| 3.7 | <i>Electrochemical tests</i> | 43 |
| 3.7.1 | <i>Potentiodynamic Polarization</i> | 43 |
| 3.7.2 | <i>Immersion testing</i> | 45 |
| 3.7.3 | <i>Erosion/Corrosion Test</i> | 45 |
| 3.8 | <i>Mechanical test</i> | 46 |
| 3.8.1 | <i>Hardness Test</i> | 46 |
| 3.8.2 | <i>Sliding wear test.</i> | 47 |
| Chapter Four: Results and Discussion | | |
| 4.1 | <i>Introduction</i> | 49 |
| 4.2 | <i>Chemical Composition:</i> | 49 |
| 4.3 | <i>Characterization of Specimens</i> | 50 |
| 4.3.1 | <i>X-ray Diffraction (XRD) Test</i> | 50 |
| 4.3.2 | <i>Optical Microscopic Observations:</i> | 52 |
| 4.3.3 | <i>Scanning electron microscopy (SEM)</i> | 54 |
| 4.3.4 | <i>Energy dispersive spectrometer (EDS) analysis</i> | 55 |
| 4.4 | <i>Mechanical test</i> | 58 |
| 4.4.1 | <i>Hardness test</i> | 58 |
| 4.4.2 | <i>wear resistance test</i> | 59 |
| 4.5 | <i>Electrochemical Test</i> | 61 |
| 4.5.1 | <i>Potentiodynamic Polarization Test</i> | 61 |

| | | |
|--|--|----|
| 4.5.2 | <i>Erosion-Corrosion Test</i> | 64 |
| 4.5.3 | <i>Simple Immersion Test</i> | 65 |
| Chapter Five: Conclusions & Recommendations | | |
| 5.1 | <i>Conclusions</i> | 67 |
| 5.2 | <i>Recommendations For future works, the following recommended</i> | 67 |
| Reference | | |

List of Figure

| <i>Sequence</i> | <i>Figure</i> | <i>Page No.</i> |
|----------------------|--|-----------------|
| Chapter Two | | |
| 2-1 | <i>Thermal Equilibrium Diagram of Aluminum-Silicon Alloys</i> | 10 |
| 2.2 | <i>Uniform or general corrosion</i> | 18 |
| 2.3 | <i>Galvanic corrosion of coated carbon steel tube sheet</i> | 19 |
| 2.4 | <i>Pits on the carbon steel tube-sheet of a heat exchanger</i> | 20 |
| 2.5 | <i>Mechanism of crevice corrosion</i> | 21 |
| 2.6 | <i>Erosion-corrosion inside a liquefied petroleum gas (LPG) carbon steel tube. "Grooves" are formed as a result of erosion</i> | 22 |
| Chapter Three | | |
| 3-1 | <i>Shows the Block Diagram of the Experimental.</i> | 34 |
| 3-2 | <i>The apparatus used for casting</i> | 36 |
| 3-3 | <i>Electric furnace with stirrer</i> | 36 |
| 3-4 | <i>Rod samples of, (A319) after casting process</i> | 36 |
| 3-5 | <i>Rod samples of, (A319) – Cr additions after casting process</i> | 37 |
| 3-6 | <i>Electric Furnace Used for Heat Treatment.</i> | 38 |
| 3-7 | <i>Microstructure, hardness and XRD Specimens</i> | 39 |
| 3-8 | <i>Figure (3.8): Wear Specimens</i> | 39 |
| 3-9 | <i>XRF- Spectrometer</i> | 40 |
| 3-10 | <i>X-ray machine used (SHIMADZU Lab XRD-6000).</i> | 41 |
| 3-11 | <i>Light optical microscope (LOM).</i> | 42 |
| 3-12 | <i>Scanning Electron Microscopy (SEM)</i> | 43 |

| | | |
|---------------------|---|----|
| 3-13 | <i>DY2300 Potentiodynamic polarization</i> | 44 |
| 3-14 | <i>Erosion-Corrosion Device According to (G 73) ASTM.</i> | 46 |
| 3-15 | <i>Vickers (HV1000) Micro-hardness Device.</i> | 47 |
| 3-16 | <i>Pin on disc setup (a) Front view (b) Top view</i> | 48 |
| Chapter Four | | |
| 4-1 | <i>Chemical Analysis for (A319) Cast Alloy</i> | 50 |
| 4-2 | <i>shows the XRD patterns for B alloy</i> | 51 |
| 4-3 | <i>shows the XRD patterns for B3 alloy</i> | 51 |
| 4-4 | <i>Microstructure of base sample (A319) with different magnifications</i> | 52 |
| 4-5 | <i>Microstructure for (A319+0.5%Cr) samples with different magnifications</i> | 52 |
| 4-6 | <i>Microstructure for (A319+1%Cr) samples with different magnifications</i> | 53 |
| 4-7 | <i>Microstructure of (A319+1.5%Cr) samples with different magnifications</i> | 53 |
| 4-8 | <i>SEM images for etched B alloy with different magnification</i> | 54 |
| 4-9 | <i>SEM images for etched B1 alloy with different magnification</i> | 54 |
| 4-10 | <i>SEM images for etched B2 alloy with different magnification</i> | 55 |
| 4-11 | <i>SEM images for etched B3 alloy with different magnification</i> | 55 |
| 4-12 | <i>SEM-EDS image for etched A319 (B) alloy</i> | 56 |
| 4-13 | <i>SEM-EDS image for etched A319 alloy with (B1)0.5%Cr</i> | 57 |
| 4-14 | <i>SEM-EDS image for etched A319 alloy with 1%Cr (B2)</i> | 57 |
| 4-15 | <i>SEM-EDS image for etched A319 alloy with (1.5%Cr (B3</i> | 58 |
| 4-16 | <i>Effect of Cr addition on the hardness of A319 alloy</i> | 59 |
| 4-17 | <i>wear rate vs Time for A319 and with additions under (5N) load</i> | 60 |
| 4-18 | <i>wear rate vs Time for A319 and with additions under (10N) load</i> | 60 |
| 4-19 | <i>Current density (A/cm²) vs. potential (V) in 3.5 wt% NaCl at 25°C for B Alloy</i> | 61 |
| 4-20 | <i>Current density (A/cm²) vs. potential (V) in 3.5 wt% NaCl at 25°C for B1Alloy</i> | 62 |

| | | |
|------|--|----|
| 4-21 | <i>Current density (A/cm²) vs. potential (V) in 3.5 wt% NaCl at 25°C for B2 Alloy</i> | 62 |
| 4-22 | <i>Current density (A/cm²) vs. potential (V) in 3.5 wt% NaCl at 25°C for B3 Alloy</i> | 63 |
| 4-23 | <i>Effect of exposure time on Erosion– Corrosion rate of B ,B1,B2,B3 in saline solution (3.5wt% NaCl)</i> | 65 |
| 4-24 | <i>Fitting curves of simple immersion test for all specimens in salt solution for immersion period (20 days)</i> | 66 |

List of Table

| <i>Sequence</i> | <i>Table</i> | <i>Page No.</i> |
|----------------------|---|-----------------|
| Chapter Two | | |
| 2-1 | <i>Cast Aluminum Alloy Groups</i> | 7 |
| 2-2 | <i>Wrought Aluminum Alloy Groups</i> | 8 |
| 2-3 | <i>Effect of alloying element on Aluminum alloys</i> | 16 |
| Chapter Three | | |
| 3-1 | <i>clarify the materials of element used to prepare A319 aluminum alloy respectively</i> | 31 |
| 3-2 | <i>Amount of Element Used to Prepare A319 Aluminum Alloy</i> | 32 |
| 3-3 | <i>Chemical Composition of Aluminum Wire</i> | 32 |
| 3-4 | <i>Show code number of specimen</i> | 38 |
| Chapter Four | | |
| 4-1 | <i>Chemical Composition of the alloy Specimens Prepared in this Study</i> | 49 |
| 4-2 | <i>The corrosion potential (E_{corr}) , corrosion current (I_{corr}), Corrosion Rate , Current Density and Improvement percentage of samples in tap water at 25°C</i> | 63 |
| 4-3 | <i>Corrosion Rate (mpy) for specimens in salt solution at 25°C</i> | 66 |

List of Abbreviations

| <i>Symbol</i> | <i>meaning</i> |
|---------------|---------------------------------------|
| <i>OM</i> | <i>Optical microscopy</i> |
| <i>SEM</i> | <i>Scanning electron microscopy</i> |
| <i>EDS</i> | <i>energy dispersive spectrometer</i> |
| <i>HV</i> | <i>Vickers Hardness</i> |

Chapter

One

Chapter One

Introduction

1.1. General View

Aluminum is important in industrial applications such as the production of automobiles, aerospace equipments, packaging of food and beverages, in construction, the transmission of electric power, the transportation industry, the manufacturing of machinery and tools, and in numerous other domains. The fact that aluminum is non-ferromagnetic adds to its importance in the electrical and electronic industries. It is no secret that this element is also observably nontoxic and is routinely used in the manufacture of containers for food and beverages. The use of aluminum and its alloys has increased significantly over the last number of years, successfully replacing iron and steel in a number of different applications. Furthermore, aluminum becomes highly resistant after undergoing heat treatment and is noticeably simple to mold as a result of its high ductility [1]. The principal industries in which aluminum showed an increase in importance include the automotive and aerospace domains; this was effectuated through the smelting of the metal and the carrying out of suitable heat treatments for manufacturing cylinder heads ,engine blocks, and others crucial parts. The benefits derived from using aluminum for these parts include [2]:

- * Reduction in car weight;
- * Reduction in engine noise;
- * Reduction in vibrations; and
- * Absence of oxidation, unlike steel.

Al-Si alloys have potential in the inject plastic forming molds, such alloys exhibit heat conductivity, anti-corrosion properties, wear resistivity and

have a low heat expansion coefficient [1,3]. Al-Si alloys contain many acicular eutectic silicon particles in the α -Al matrix within hypoeutectic composition range. As the silicon contents rises to the hypoeutectic level, primary silicon particles, except those in the acicular hypereutectic silicon phase, form rod-like and massive structures [4]

The use of silicon as the major alloying elements in the aluminum alloys offers excellent properties such as [5,6]:

- * Castability ,
- * Good weldability ,
- * Good thermal conductivity ,
- * Excellent corrosion resistance, and
- * Satisfactory retention of physical and mechanical properties at elevated temperatures.

Alloys with silicon as the major alloying addition are the most important of the aluminum casting alloys mainly due to the high fluidity imparted by the presence of relatively large volumes of Al-Si eutectic. Commercial alloys are available with hypoeutectic, eutectic, and hypereutectic composition.

-The eutectic is formed between an aluminum solid solution containing just over 1% silicon and virtually pure silicon as the second phase. The eutectic composition has a matter of debate but it is now generally accepted as being close to Al-12.6%Si. As the silicon contents becomes less than the eutectic point hypoeutectic is formed. When the silicon contents becomes higher than the eutectic, the hypereutectic is formed. Hypereutectic consist of eutectic and primary silicon particles. Some of the major driving force for the development of Al-Si cast alloys are the superior wear resistance [7,8], low coefficient of thermal expansion (CTE), high corrosion resistance [9,10] high strength to weight ratio

[11,12] , excellent castability. This makes Al-Si cast alloys potential candidate materials for a tribological applications in automobiles and other engineering sectors [13,14].

1.2 A319 Alloy

The aluminum alloy to be used in this study is an alloy with the target chemical composition approaching alloy 319, from mechanical properties this alloy has considerable tensile strength which is equal to 27 ksi or 186.158 N/mm² for as cast and 36 ksi or 248.211 N/mm² for T6 . Besides good mechanical properties, the alloy are more environmentally friendly are also needed. The alternative material that is more environmentally friendly is obtained from scrap aluminum alloy[14].

1.3 Aims of the Present Study

Aluminum-silicon alloys continuously substitute the cast iron for engine blocks even for diesel vehicles. The engine blocks, cylinder heads, and wheels are produced from hypoeutectic alloys. A319 alloy is widely used in producing automotive components such as chassis and engine parts that are usually fabricated through various casting processes.

The aims of this study are:Improving the corrosion and mechanical behavior of A319 alloy by Chromium additions and determine the optimal ratio of this elements. This will done by the following steps :

- 1.Preparation of an alloy by die casting processes.
- 2.Investigate the influence of Chromium addition with different percentages (0.5, 1, 1.5) wt% on properties of the casting alloys.
- 3.Many tests were done to evaluate the performance of A319 alloy before and after Chromium addition, these tests include: Microstructure characterization (OM, XRD,SEM and EDS), Also Mechanical tests such

as hardness, erosion –corrosion test and wear test were achieved. Electrochemical test such as potentiodynamic polarization test and immersion test were conductive in 3.5 wt% NaCl solution.

1.4 Dissertation outline

The dissertation consists of five chapters, which can be briefly described as follows:

1. Chapter one: deals with the general introduction related to A319 alloy and aims of the present study.
2. Chapter two: gives an explanation about aluminum and the alloying elements and stir casting technique. In addition to some articles that are related to the main objective of this dissertation with a brief abstract that define the major idea.
3. Chapter three: describes the experimental setup, which includes A319 and addition element preparation and the examination of corrosion and mechanical characterization of the composite material.
4. Chapter four: all the results of the work have been obtained and discussed in details.
5. Chapter five: gives the main conclusions obtained from this investigation with recommendations for possible future works.

Chapter

Two

Chapter Two

Theoretical Part and Literature Review

2.1 Introduction

This chapter a brief about aluminum and its alloys, their classifications, Al-Si system and it's properties, the aluminum silicon cast alloys, the solidification of the aluminum silicon alloy, the influence of silicon and other element on the aluminum alloy in addition to a literature review for studies close to the present work.

2.2 General View

Aluminum is a light weight metal that has good corrosion resistance. This material is used in a broad field not only for household appliances but also used for industrial purposes, for example for the aircraft industry, ship industry, automobile components, regulator components and other constructions. Apart from these properties aluminum is also cheap and easy to obtain, so the use of aluminum as a base material from time to time is increasing. As a result of the increase in the use of aluminum as a base material so that the amount of aluminum that is not used anymore has increased so that a new problem arises, namely the accumulation of waste. Therefore, an effort is needed to recycle the aluminum waste so that it can be utilized again into a new product. Most small metal casting companies do not use pure aluminum, but use scrap or reject material from previous casting materials. So that this affects the results and quality of the goods produced. Therefore, the strength and composition of aluminum alloy must be tested properly

2.3 Aluminum and Aluminum Alloys

Aluminum is one of the most widely used metals owing to its characteristics of lightweight, good thermal and electrical conductivities. Despite these characteristics, pure aluminum is rarely used because it lacks strength. Thus, in industrial applications, most aluminum is used in the form of alloys. Aluminum in alloy the typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. The most important cast aluminum alloy system is Al–Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics. Aluminum alloys are widely used in engineering structures and components where light weight or corrosion resistance is required [15].

2.4 Classification of Aluminum Alloys

Aluminum alloys are usually classified into two main groups: casting compositions and formed compositions, each one of these groups are divided into two groups: heat treatable and non-heat treatable alloys [16].

2.4.1. Cast Aluminum Alloys

Cast aluminum alloys have relatively low melting temperatures when compared to steel and cast iron. They have a negligible solubility of gases except hydrogen, good fluidity and good surface finish. However, these alloys suffer from higher shrinkage (up to 7%) which occurs during cooling or solidification [17]. A system of four-digit numerical designation is used to identify aluminum and aluminum alloys in the form of castings and foundry ingots. The first digit indicates the alloy group according to the major alloying element as shown in table (2-

1). The second two digits identify aluminum alloy or indicate the alloy purity the last digit indicates the product form, casting (designated by “0”) or ingot (designated by “1” or “2” depending on chemical composition limits [17].

Table (2-1): Cast Aluminum Alloy Groups [17].

| Alloy Series | Principal Alloying Element |
|---------------------|---|
| 1XXX | 99.000% minimum Aluminum |
| 2XXX | Copper (4%...4.6%) |
| 3XXX | Silicon (5%...17%) with added copper and/or magnesium |
| 4XXX | Silicon (5%...12%) |
| 5XXX | Magnesium (4%...10%) |
| 6XXX | Unused Series |
| 7XXX | Zinc (6.2%...7.5%) |
| 8XXX | Tin |
| 9XXX | Others |

2.4.2. Wrought Aluminum Alloy

Wrought alloys have been produced by thermos-mechanically processing cast ingot into mill products such as billet, bar, plate, sheet extrusions, rods and wire [17]. Table (2.2) shows the main classes of wrought aluminum alloys. Like cast alloys, wrought alloys are also designated by a four-digit system. Both wrought and cast aluminum alloys are divided according to the specification of the alloying elements involved, into alloys which can be heat treated (in order to improve the

mechanical properties) and alloys which cannot be heat treated. Heat-treatable alloys are those strengthened primarily by solution [18,19].

Table (2-2): Wrought Aluminum Alloy Groups [18].

| Alloy Series | Principal Alloying Element |
|---------------------|---|
| 1XXX | 99.000% Minimum Aluminum |
| 2XXX | Copper (1.9%... 6.8%) |
| 3XXX | Manganese (0.3%... 1.5%) |
| 4XXX | Silicon (3.6%... 13.5%) |
| 5XXX | Magnesium (0.5%... 5.5%) |
| 6XXX | Magnesium and Silicon (Mg 0.4%... 1.5%, Si 0.2%... 1.7%) |
| 7XXX | Zinc (1%... 8.2%) |

2.5 Al-Si System and Properties

The additions of silicon to pure aluminum are improving casting characteristics. The great effect of silicon in aluminum alloys is the dramatically improve feeding characteristics, fluidity and hot tear resistance [19].

In addition to silicon which is a eutectic-forming element, other elements are present in commercial Al-Si alloys. They are either added as minor alloying elements to strengthen the material or are present as impurities. Formation of second-phase precipitates, grain refinement, influence on porosity and phase modification are the major mechanisms responsible for the effects of alloying elements on the properties of Al-Si alloys. The most known alloying elements used in the Al-Si alloys

include Mg, Fe, Cu, Mn, Zn, Ni and P and eutectic modifying elements such as Sb, Ca, Na, and Sr [20].

2.6 Aluminum Silicon Cast Alloys

The selection of a hypereutectic Al-Si alloy depends on its castability, the casting process, the required mechanical and physical properties and the use of the casting. Therefore, parameters such as the percentage of Si, its shape and distribution play an important role on the mechanical properties. The higher the silicon content, the harder and stronger material, but at the expense of ductility [21]. Silicon is the main alloying element in the major Al-Si alloy groups used commercially. Silicon imparts high fluidity and low shrinkage on the alloy, which results in good castability and weld ability. The maximum amount of silicon in cast alloys is of the order of 22-24% Si, but alloys made by powder metallurgy may go as high as 40-50% Si. Increasing silicon increases strength at the expense of ductility [22]. Figure (2-1) shows the equilibrium diagram of Al-Si alloys [22].

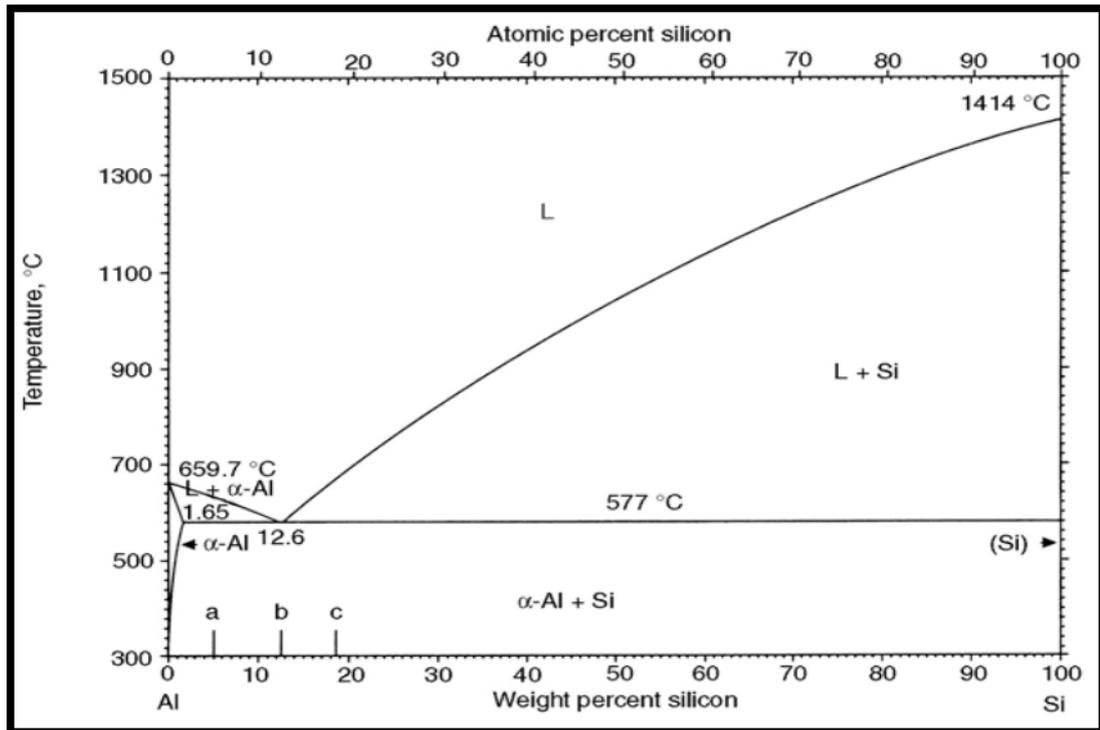


Figure (2-1): Thermal Equilibrium Diagram of Aluminum-Silicon Alloys [22]

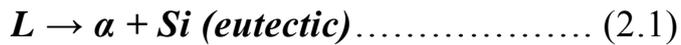
Thermal equilibrium diagram of Aluminum-Silicon Alloys divided in to three groups

- **Hypoeutectic Al-Si Alloys**

Hypoeutectic Al-Si alloys (<12.6%Si) alloys with silicon as a major alloying ingredient are by far the most important commercial casting alloys, primarily because of their superior casting characteristics in comparison to other alloys. May be used with all casting processes for parts in which good ductility, good corrosion resistance ; and pressure tightness is more important than strength [23,24].

- **Eutectic Al-Si Alloys**

Eutectic Al-Si casting alloys contain (12.6 %Si). Now widely accepted that the eutectic reaction takes place at 577°C. In equation (2.1), L is the liquid phase, α is predominantly aluminum [24,25].



Wide range of physical and mechanical properties are afforded by these alloys. Ratings of the casting alloys with respect to casting characteristics, corrosion resistance, machinability and weldability the usage of hypoeutectic and eutectic alloys is very widespread in the industries, because they are: [26]

- A. More efficient to be produced by casting.
- B. Simpler to control the casting parameters.
- C. Easier to be machined than hypereutectic.

• **Hypereutectic Al-Si Alloys**

Hypereutectic Al-Si casting alloys (> 12.6 %Si) are generally utilized as a part of the car business. Parts, for example, motor pieces, cylinders, chambers, and pump segments are produced using this class of combinations [27].

2.7 Effect of alloying elements on Aluminum alloys

There are many ways of changing properties of aluminum cast alloys. One of them is of course change in composition of the alloy. Although the influence of elements that are noticeable in the alloy is mainly considered, elements which are known as impurities cannot be omitted, and its effect are not always negative. Influence of all alloying as well as impurities which can be found in aluminum alloys are as following [28].

2.7.1 Silicon (Si)

Addition of Si to the aluminum alloys has a great number of benefits. It is one of the elements which do not increase the weight of the alloys and at the same time improves its properties. The casting ability of Al-Si alloys are on extremely high level which lowers costs of producing

Al-Si castings. Mechanical properties of aluminum alloys depend more on the distribution of added silicon than on the amounts of it. In these alloys where the Si particles are uniformly distributed represent increase in ductility, while alloys in which these particles are acicular, show small increase in strength. While adding silicon to the Al alloy corrosion resistance is only slightly affected. Generally, it stays on the same level or is slightly better than in case of pure aluminum. With increase content of Si decrease of the fluidity and the freezing range is observed. Moreover, silicon expands during solidification, so it compensates the shrinkage of the aluminum. When the content of Si in the Al-Si alloys is as high as 25% volume shrinkage of these alloys reaches zero level [29].

2.7.2 Copper (Cu)

Changes in mechanical properties of alloy while adding copper can be observed in its strength and ductility. Copper has the biggest influence on high temperature strength. These changes, like in Al-Si alloys, do not depend on the amount of added copper but rather on the way how it is distributed in solid solution. Copper can be found in the form of evenly distributed spheroidised particles show biggest increase in strength without negative effects on ductility, while alloys with Copper present as continuous network at grain boundaries appear to be less ductile without noticeable increase in strength. Addition of copper will also reduce corrosion resistance of the alloy. It happens because Copper disperses the oxide film which appears on the metal surface and this way prevents alloy to be electrically neutral. It leads to the fact that Al-Cu alloys can corrode not only by contacting another material but also another Al-Cu alloy [30].

2.7.3 Nickel (Ni)

Cast Al-Si alloys usually contain alloying components such as magnesium, copper, nickel, etc. which are widely used in the automotive industry in piston applications. These additions form intermetallic phases with complex morphologies and complex compositions. Nickel is added to Al-Cu and Al-Si alloys to improve hardness and strength, there is an increasing demand for Al-Si cast alloys with better performance concerning yield and tensile strength at elevated temperatures up to 250 °C. In fact, the addition of alloying elements such as Cu and Ni is an effective and practical way to improve the mechanical properties, especially in relation to the performance of piston alloys which are subjected to high temperature service conditions. The advantages of adding Ni and Zr to Al-Si alloys are that their precipitates (Al_3Ni) and (Al_3Zr) possess the following important characteristics:

- They are coherent.
- Possess low solubility.
- Directly affect the strength of the material because they act as hard pinning points which inhibit the movement of dislocations in the matrix [31].

2.7.4 Magnesium (Mg)

Magnesium is material which is lighter than aluminum and shows the same strength properties. It is the main alloying element in some Al alloys, but in the majority of them it is rather considered as impurity. The role of magnesium in aluminum-silicon alloys is to precipitate phase (Mg_2Si) [32] Al-Mg alloys show high strength with good ductility. Moreover, magnesium can, as one of the few elements, increase modulus of elasticity of Al alloys. Proper amount of magnesium in alloy will also

give extremely high response to heat treatment. Another property which is very good in Al-Mg alloys is corrosion resistance. It is better in salt water and in mild alkalis than in pure aluminum. when the content of magnesium is small (2-4%). It appears to be better with higher amounts of magnesium (up to 12%) [31].

2.7.5 Iron (Fe)

Iron added to aluminum alloys negatively influence its corrosion resistance. As far as mechanical properties are concerned, Fe improves strength of the alloy and in the same time reduce its ductility. Iron improves also resistance to hot tearing during solidification. Formation of beta iron needles have detrimental effect on mechanical properties of aluminum alloy. It happens because needle-shape like iron phases act as stress risers and cracks propagation can start in these points [32].

2.7.6 Titanium (Ti)

It is common practice to add Ti to Al-Si foundry alloys because of its potential to grain refining effect [32]. Sigworth and Kuhn have reported that the grain refining effect of titanium is enhanced if boron is present in the melt or if the Ti is added in the form of an Al-Ti-B master alloy containing boron and titanium, largely combined as TiB_2 which act as excellent nuclei for the α -Al phase. Titanium diboride has almost no solubility in liquid aluminum, thus, TiB_2 particles produce good refinement at small addition levels. The refinement is also long lasting, when the particles are not allowed to sediment from the melt [33].

2.7.7 Manganese (Mn)

Manganese is very soluble in aluminum, when the cast is chilled, most of the added manganese is substantially retained in solution. It increases the strength of the alloy either in solid solution or as a finely precipitated intermetallic phase by modifying the morphology of the intermetallic phases which are formed after heat treatment of the given alloy. As reported by Seifeddine et al. [34], it has no adverse effect on corrosion resistance. Manganese combines with Fe in the alloy forming the script-like α -iron phase which is more compact and less detrimental to the mechanical properties [35]. have reported that as the Mn content is increased up to 0.65 wt.% corresponding to an Fe/Mn ratio of 1.2 in the Al-7wt.% Si-3.8 wt.% Cu-0.5 wt.% Fe alloy, the plate-like β - Al₅FeSi iron intermetallic phase is completely converted to the Chinese script α - Al(Fe,Mn)Si iron phase, resulting in improved tensile properties. Excess amounts of Mn, however, deteriorate the mechanical properties by increasing the total amount of iron containing intermetallic phases formed [31].

2.7.8 Chromium (Cr)

Additions of chromium to the Al-Si alloys have a little increase in strength of these alloys. It is also caused slight decrease in tensile properties [31].

2.7.9 Zinc (Zn)

Zinc in Al-Si alloys improves its machinability but decrease high temperatures strength. It also increases tendency to hot tearing [32].

And table (2.3) show the effect of alloying element on properties of material

Table (2.3) show the effect of alloying element on Aluminum alloys.[31,32,33]

| <i>Element</i> | <i>Effect</i> |
|-----------------------|---|
| Si | With increase content of Si decrease of the fluidity and the freezing range is observed. And it compensates the shrinkage of the aluminum |
| Cu | Changes in mechanical properties of alloy while adding copper can be observed in its strength and ductility. Copper has the biggest influence on high temperature strength. |
| Ni | improve hardness and strength, there is an increasing demand for Al-Si cast alloys with better performance concerning yield and tensile strength at elevated temperatures up to 250 °C. |
| Mg | The role of magnesium in aluminum-silicon alloys is to precipitate phase (Mg ₂ Si)[32]. Al-Mg alloys show high strength with good ductility. Moreover, magnesium can, as one of the few elements, increase modulus of elasticity of Al alloys. Proper amount of magnesium in alloy will also give extremely high response to heat treatment. Another property which is very good in Al-Mg alloys is corrosion resistance. It is better in salt water and in mild alkalis than in pure aluminum |
| Fe | improves strength of the alloy and in the same time reduce its ductility. Iron improves also resistance to hot tearing during solidification |
| Ti | add Ti to Al-Si foundry alloys because of its potential to grain refining effect [32]. |
| Mn | It increases the strength of the alloy either in solid solution or as a finely precipitated intermetallic phase by modifying the morphology of the intermetallic phases which are formed after heat treatment of the given alloy |
| Cr | have a little increase in strength of these alloys. It is also caused slight decrease in tensile properties [31]. |
| Zn | improves its machinability but decrease high temperatures strength. It also increases tendency to hot tearing [32]. |

2.8 A319 Cast Alloy

Alloys with silicon as the main alloying element are the most important of the aluminum casting alloys mainly because of the high fluidity imparted by the presence of relatively large volume of the Al–Si eutectic. These age-hardenable alloys have attracted increasing attention in recent years, particularly due to the demand for lighter vehicles as part of the overall goal to improve fuel efficiencies and reduce vehicle emissions. Among these aluminums cast alloys, 319 alloy have been the object of extensive investigation considering their practical importance in the transport industry [36].

2.9 Corrosion

Corrosion is defined as the destruction or deterioration of a material because of reaction with its environment. Some insist that the definition should be restricted to metals, but often the corrosion engineers must consider both metals and nonmetals for solution given problem Corrosion can be fast or slow .There are many types of corrosion that have been presented as follows: [37,38]

2.9.1 Uniform Corrosion

Uniform corrosion occurs when corrosion is quite evenly distributed over the surface, leading to a relatively uniform thickness reduction. Metals without significant passivation tendencies in the actual environment, such as iron, are liable to this form. Uniform corrosion is assumed to be the most common form of corrosion and responsible for most of the material loss [39]. However, it is not a dangerous form of corrosion because prediction of thickness reduction rate can be done by

means of simple tests [40]. Figure (2-2) shows the Uniform or general corrosion.

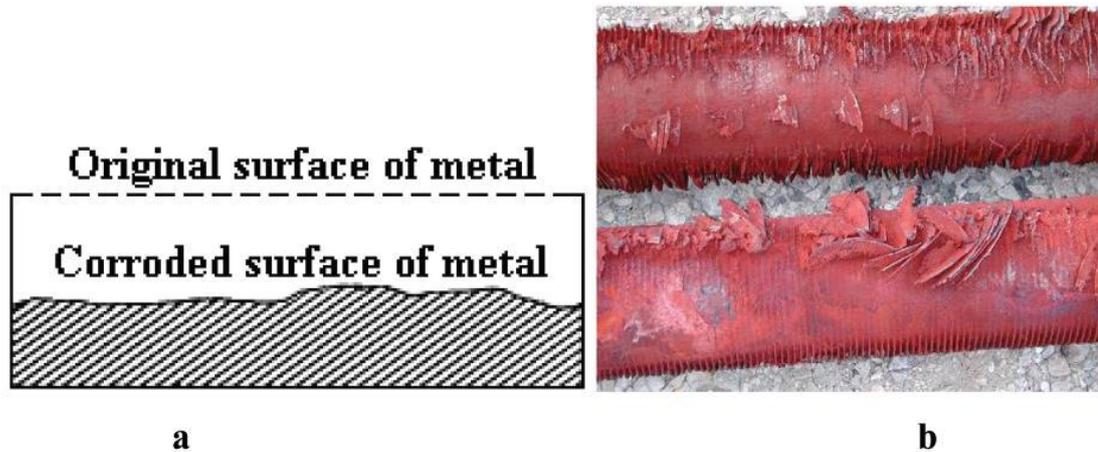


Figure (2.2): Uniform or general corrosion[39]

2.9.2 Galvanic Corrosion

Galvanic corrosion occurs when a metallic contact is made between a more noble metal and a less noble one. A necessary condition is that there is also an electrolytic condition between the metals, so that a closed circuit is established. The area ratio between cathode and anode is very important. For instance, if the more noble cathodic metal has a large surface area and the less noble metal has a relatively small area, a large cathodic reaction must be balanced by a correspondingly large anodic reaction concentrated in a small area, resulting in a higher anodic reaction rate [41]. This leads to a higher metal dissolution rate or corrosion rate. Therefore, the ratio of cathodic to anodic area should be kept as low as possible. Galvanic corrosion is one of the major practical corrosion problems of aluminum and aluminum alloys[42]. Since aluminum is thermodynamically more active than most of the other common structural materials and the passive oxide, which protects aluminum, may easily be broken down locally when the potential is raised due to contact with a

more noble material. This is particularly the case when aluminum and its alloys are exposed to water containing chlorides or other aggressive species [43].

According to these galvanic series, Aluminum 6061-T6 alloy is more active than 7075-T6 alloy, which is more active than 2024-T4 alloy. In this scheme, mild steel ranks lower than the aluminum alloys. This order may be opposite to the order of corrosion affinity in different circumstances, such as in the case of aircrafts [44].

The series of standard reduction potentials of various metals can be used to explain the risk of galvanic corrosion, the potential difference between two metals in a galvanic couple is too large, the more noble metal does not take part in the corrosion process with its own ions [45]. Figure (2.3) shows Galvanic corrosion of coated carbon steel tube sheet.



Figure (2.3): Galvanic corrosion of coated carbon steel tube sheet[41]

2.9.3 Pitting Corrosion

Pitting corrosion is one of the most observed corrosion types for aluminum and steel, and it is the most troublesome one in near neutral pH

conditions with corrosive anions, such as Cl^{-1} or SO_4^{-2} present in the media [46].

Pitting is initiated by adsorption of aggressive anions, such as halides and sulfates, which penetrate through the passive film at irregularities in the oxide structure to the metal-oxide interface, Corrosion products covering the pits facilitate faster corrosion because they prevent exchange of the interior and the exterior electrolytes, leading to very acidic and aggressive conditions in the pit [47].

Stainless steels have high resistance to initiation of pitting. Therefore, rather few pits are formed, but when a pit has been formed, it may grow very fast due to large cathodic areas and a thin oxide film that has considerable electrical conductance [48]. Conversely for several aluminum alloys, pit initiation can be accepted under many circumstances. This is because numerous pits are formed, and the oxide is insulating and has, therefore, low cathodic activity. Thus, corrosion rate is under cathodic control. [49]. Figure(2.4) shows Pitting corrosion.



Figure(2.4):Pits on the carbon steel tube-sheet of a heat exchanger[46]

2.9.4 Crevice Corrosion

Crevice corrosion occurs underneath deposits and in narrow crevices that obstruct oxygen supply, Crevice corrosion is a localized corrosion

concentrated in crevices in which the gap is wide enough for liquid to penetrate into the crevice but too narrow for the liquid to flow. A special form of crevice corrosion that occurs on steel and aluminum beneath a protecting film of metal or phosphate, such as in cans exposed to atmosphere, is called filiform corrosion[50].Figure (2.5) shows Mechanism of crevice corrosion

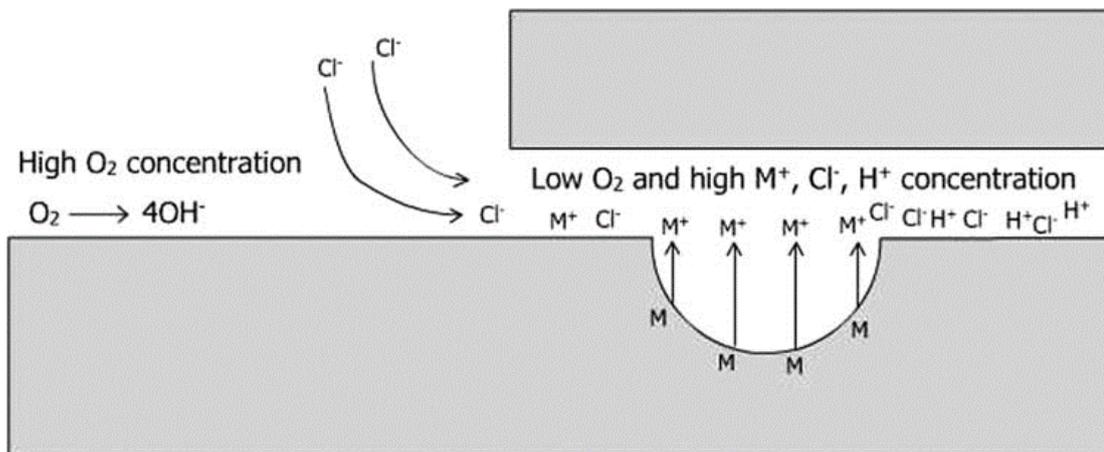


Figure (2.5): Mechanism of crevice corrosion[50]

2.9.5 Erosion or Abrasion Corrosion

Erosion or abrasion corrosion occurs when there is a relative movement between a corrosive fluid and a metallic material immersed in it. In such cases, the material surface is exposed to mechanical wear, leading to metallurgically clean surfaces, which results in a more active metal. Most sensitive materials are those normally protected by passive oxide layers with inferior strength and adhesion to the substrate, such as lead, copper, steel and some aluminum alloys. When wearing particles move parallel to the material surface, the corrosion is called abrasion corrosion. On the other hand, erosion corrosion occurs when the wearing particles move

with an angle to the substrate surface [51]. Figure (2.6) shows Erosion-corrosion.



Figure(2.6):Erosion-corrosion inside a liquefied petroleum gas (LPG) carbon steel tube. “Grooves” are formed as a result of erosion[51]

2.10 Wear Mechanisms

Understanding of wear mechanisms is very important in order to design materials which are suitable for wear reduction, wear mechanisms generally can be grouped into six generic types [52].

2.10.1 Adhesive Wear

Adhesive wear is caused by surface interaction and welding of the asperities junctions at the sliding contact. This wear mechanism is affected by the bonding type (ionic, covalent, metallic and van der Waals)

in the contact junction. The weaker part of the materials in contact is removed and transferred to the counter surface, if the bond in the junction is stronger than the bond in the bulk. Surface removal results in a rough appearance and a large volume of worn materials, hence severe wear [52].

2.10.2 Delamination Wear

The debris is plates, the length to the thickness is ten times caused by forming and fracture such as cylinder in internal combustion machining may occur in abrasive wear. It is seen that the ductility increases strength of material against desalination [53].

2.10.3 Fatigue Wear

wear debris is generated by cyclic loading of the contact. fatigue wear can be characterized by crack formation and flaking of surface material [54].

2.10.4 Erosion Wear

Caused by impact of solid or liquid or gaseous particles form losses in weight or removal of particles in which the fluid carries the particles. [54].

2.10.5 Tribochemical Wear

Tribochemical wear results from the removal of reaction products/layers formed in situ from the contacting surface [52].

2.10.6 Abrasive Wear

The removal of material by hard particles sliding between two surfaces in relative motion. The surface deforms plastically and grooves are produced in the surface. More than one type of mechanism can be involved in a wear situation. Moreover, these individual mechanisms can interact sequentially to form a more complex wear process. However, one mechanism generally is the controlling and primary mechanism. The

relative importance or occurrence of individual mechanisms can change with changes in tribo system parameters. Therefore, materials can exhibit transitions in wear behavior as a result of changes in other operational parameters, such as load, velocity, and friction [54].

2.11 Literature Review

S. Tahamtan and A. Fadavi Boostani (2009), evaluated the pitting behavior of thixoformed A356 alloy, with different reheating temperatures, and compared with the pitting behavior of rheocast and gravity A356 Al alloy with the same composition. The presence of silicon particles leads to the development of pitting at the silicon–matrix interface. The results showed that the resistance to pitting corrosion of thixoformed samples formed at 590°C was higher than the samples formed at 600°C and rheocast as well as gravity cast samples [55].

Guijun Xue (2009), studied the microstructures and wear performances of liner less engine cylinder blocks made of two eutectic Al-Si alloys with different Si morphologies, both the Al (11) wt. % Si alloy and the Al (12.6) wt. % Si alloy provided similar wear performance. Block-on-ring wear tests were applied to the Al (11) % Si alloy. The argon atmosphere produced a fold reduction in wear rates and the formation of LMW regime at loads less than 10 N. The metallic tribolayers formed in the MW under argon atmosphere were uniform and stable, resulting lower wear rates than those in air. The mechanism of material removal under argon atmosphere was delamination. The SW occurring in argon was observed at a relatively low load, compared to an air atmosphere. Wear was also more sensitive to applied load in the argon atmosphere [56].

G. Madhusudhan Reddy and K. Srinivasa (2010), investigate the feasibility of modifying the surface properties of A356 aluminum alloy by using friction stir processing (FSP). The result show that A356 aluminum alloy exhibited excellent wear resistance, also friction stir processed zone appeared to have adequate corrosion resistance. This work demonstrates that the friction stir processing is an effective strategy for enhancement of wear and pitting corrosion resistance of as cast aluminum alloys [57].

Ahmed S. Hassan et.al. (2010), investigate the corrosion behavior of dissimilar A319 and A356 Al alloys plates joined by friction stir welding (FSW). They studied the effects of tool rotational and welding speeds as well as post-weld heat treatment (PWHT) on corrosion behavior. Plates of A319 and A356 were friction stir welded using three different tool rotational speeds and two welding speeds. The PWHT was carried out using a solution heat treatment temperature of 540 °C for 12 hours followed by ageing at 155 °C for 6 hours. Corrosion behavior of welds was investigated by immersion in sodium chloride (NaCl) and hydrogen peroxide (H₂O₂) solution for 6 hours. The results showed that both as-welded (AW) and Photted welds showed better corrosion resistance than both A319 and A356 base alloys. The corrosion resistance of the welded zones was found to be reduced by increasing the tool rotational speed and/or reduction of the welding speed [58].

M. Babić a et.al. (2013), studied the basic tribological properties of A356/10SiC/1Gr hybrid composites in conditions with lubrication. They used A356 aluminum alloy as a base matrix alloy, reinforced with 10wt% of Sic and 1wt.% of graphite tribological tests were done on advanced and computer supported tribo meter with block-on disc contact pair. By the experimental plan, test is conducted under three different

values of sliding speed, three different values of normal load, different sliding distances, and also different lubricants. SEM and EDS are used for wear analysis. The analysis has shown the presence of MML, which means that there was transfer of material from steel disc to composite block [59].

R. Arrabal et.al. (2013), examined the microstructure and corrosion behavior of rheocast and gravity-cast A356 aluminum alloys. Scanning Kelvin Probe Force Microscopy (SKPFM) results proved that large potential differences between iron-containing intermetallic and the α -Al matrix were responsible for the initiation of the attack at the intermetallic/Al interfaces. For longer immersion times, corrosion attack proceeded through the eutectic areas. Semisolid processing refined the eutectic silicon and iron-intermetallic and reduced the potential difference between secondary phases and the matrix. This resulted in improved pitting corrosion resistance of the rheocasts A356 aluminum alloy [60].

M. S. Kaiser, Swagata Dutta (2014), studied the corrosion behavior of aluminum alloy engine block in 3.5% NaCl solution. The work was carried out using conventional gravimetric measurements and complemented by scanning electron microscopy (SEM) and X-ray analyzer (EDX) investigations. The results obtained indicate that the main process the alloy undergoes, under the medium of exposure studied, is related to localized corrosion that takes place as a consequence of the process of alkalization around the cathodes precipitates existing in the alloy. The alloy suffers a process of corrosion localized to the area surrounding the precipitates of the Al (Si, Mg) and Al-Mg, which resulted in hemispherical pits. This identification was confirmed by SEM

and EDX analysis. No evidence was found of the formation of crystallographic pitting for exposure times up to 54 days [61].

K. ŽABA et.al (2015), studied the abrasive wear resistance 2024 aluminum alloy strips under friction conditions involving various lubricants. Test were focused on the selection of the best lubricant for use in industrial environment, especially for sheet metal forming. Three lubricants of the Orlen Oil Company and one used in the sheet metal forming industry, were selected for tests. Tests without the use of lubricant were performed for a comparison. The results are presented in the form of the force friction, abrasion depth, weight loss and coefficient of friction depending on the lubricant used and the type of counter samples. The results allowed for predicting set lubricant-material for tools which can be applied to sheet metal made of aluminum alloy 2024 [62].

A.N. Farhanah and M.Z. Bahak (2015), used the commercial mineral lubrication oil (SAE 10W-30) from three manufacturers in order to compare the lubrication performance at three different temperatures (40°C, 70°C and 100°C) in 60 minutes' time duration by using four ball wear tester. The speed will be varied from 1000 rpm to 2500 rpm. Results show that all three lubricants have different lubricity performance, the smaller the wear scar, the better the lubricant since the lubricant can protect the moving surfaces from direct metal-to-metal contact occur [63].

H. Ghandvara, et.al. (2015), characterized the dry sliding wear and friction behavior of cast A356 aluminum alloy and composite containing 5wt. % ZrO₂ particles by means of a pins-on-disk apparatus over a loads of 5N and 20N and the sliding speed is 0.628m/s. The

experimental results showed that the composites exhibited a higher wear resistance in comparison to that of the unreinforced A356 alloy. The friction coefficient of tested materials increased with increasing applied load from 5 to 20 N [64].

Prosenjit Dasac et.al. (2015), studied the dry sliding wear behavior of A356 Aluminum alloy, by using cooling slope, as well as gravity cast A356 Al alloy have been investigated at low sliding speed of 1 ms^{-1} , against a hardened disk at different loads. The wear mechanism involves micro cutting-abrasion and adhesion at lower load for all the alloys, also at higher load, mainly adhesive wear along with oxide formation is observed for gravity A356 Al alloy, cast using 45° slope angle. The result showed that A356 Al alloy is found to undergo mainly abrasive wear at higher load [65].

N. Beigi Khosroshahi et.al. (2015), studied Three kinds of A356 based composites reinforced with 3 wt.% Al_2O_3 , 3 wt.% SiC, and 3 wt.% of mixed Al_2O_3 –SiC powders the novel composite with equal weights of reinforcement were fabricated in via a two-step approach. The result showed that The rolling process caused fracture of silicon particles, improved the distribution of fine SiC particles, and eliminate porosity remaining after the first casting process step. Examination of the mechanical properties of the obtained composites revealed that samples which contained a bimodal ceramic reinforcement of fine SiC and coarse Al_2O_3 particles had the highest strength and hardness [66].

H.K. Trivedia and D.V. Bhatt. (2017), developed a new method to evaluate the friction and wear behavior of cylinder liner and piston ring materials for four stroke engine system. Realistic engine oils are

used to describe the behavior of this test method. The friction and wear experiments were performed using pin-on-disc tester. The effect of lubricants and load conditions are important aspects of this test method and are focus of this work. The test uses actual piston ring segments sliding on the disc of grey cast iron used in cylinder liners. A wide range of commercial lubricants including SAE10W30, SAE20W40 and SAE20W50 were used to analyze frictional and wear behavior. Tests were conducted for constant load at 140 N for 105 min and increment load with the range from 20 N to 140 N for 105 min to evaluate the behavior of frictional force and wear for cylinder liner and piston ring. Relative amount of wear is directly correlate with the effectiveness of the lubricant due to this wear was measured by weight loss before and after testing. Result shows that viscosity and variation of load plays a vital role to characterize the behavior of frictional force and wear [67].

K. Sekar et.al. (2017), investigated the effects of addition of micro and Nano Sic particles on double shear strength, hardness and tribological properties of A356 alloy reinforced with Sic micro particles of size 37 μm and Al_2O_3 Nano particles of size 30 nm the results showed that. The addition of 0.5 wt. % of Al_2O_3 and 4 wt. % of SiC the double shear strength was increased by 9.5% and hardness is increased by 6.6%. also The addition of both SiC (4 wt.%) and Al_2O_3 (1.5 wt.%) decreased the hardness. Wet sliding test was carried on the composites using coconut oil and SAE20W40 lubricant ad coconut oil has shown better tribological performances [68].

S. meinathan and VR. Nitin (2017), investigated the combined effect of Mg and Cu element at different content on the microstructure, strength and wear resistance of A319 aluminum-silicon alloy. The results indicated that the hardness increased with increase copper content with

Chapter Two Theoretical Part and Literature Review

keeping ageing parameter constant. The tensile strength of the alloy with combined effect of Cu and Mg have a higher strength, because of increase Cu content in the alloy increased the hardness value which mean wear resistance is increased also [69].

Chapter

Three

Chapter Three

Experimental Part

3.1 Introduction

This chapter focuses on materials and equipments that are used in this study. It also describes the equipment and the experimental procedure which include (melting, casting for the specimens). In order to characterize the sample after casting, number of techniques are employed. X-ray diffraction (XRD) is used to investigate the phases of casting. Scanning electron microscope (SEM) and optical microscope are used to analyze the microstructure of the samples. Also chemical composition of the samples is identified by SEM equipped with EDS technique. This chapter describes also the mechanical test including hardness and wear test. Finally, the corrosion resistance of the specimens is studied by electrochemical test and immersion test.

3.2 Materials and Equipments

3.2.1 Materials Used

Table (3-1) clarify the materials of element used to prepare A319 aluminum alloy respectively

| Material | Condition | Purity% | Origin |
|--------------------------------|--------------|---------|------------------|
| Al | AL-wire | 99.97 | Local market |
| Si | Bulk | 99.95 | Fluke-swiss made |
| Cr | Small pieces | 99.95 | Fluke-swiss made |
| Cu , Ni , Fe , Mn , Ti , Zn | powder | | Local market |

Table(3-2):Amount of Element Used to PrepareA319 Aluminum Alloy[22]

| Si% | Cu% | Ni% | Fe% | Mn% | Ti% | Zn% | Al% |
|-----------|------|------|-----|-----|------|-----|-----|
| 5.5 - 6.5 | 3- 4 | 0.35 | 1 | 0.5 | 0.25 | 1 | Bal |

3.2.1.1 The Chemical Composition for Aluminum Wire

The Chemical composition analysis for aluminum wire was carried out using metal analysis by SPECTR at Ministry of Science and Technologies - Baghdad. The results are listed in Table (3-3).

Table (3-3): Chemical Composition of Aluminum Wire.

| V% | Si% | Cr% | Ni% | Ti% | Mn% | Fe% | Mg% | Al% |
|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| 0.007 | 0.035 | 0.003 | 0.001 | 0.002 | 0.003 | 0.129 | 0.001 | Bal |

3.2.2 Equipment's

The apparatus used in this study were:

1. Furnaces for heat treatment (Electric France, SRJX515, Germany). has been performed at the heat treatment laboratory in the College of Materials Engineering / Babylon University.
2. A melting put in a metallic mold with a circular aperture section of the dimensions (diameter 15.5mm, height 10 cm)
3. Furnaces for heat treatment (Electric France, SRJX515, Germany).
4. Vickers micro hardness device type (digital micro Vickers hardness tester TH 717, China).
5. Optical microscope type (Electron Eyepiece, model YJEYE01, resolution of 1280 (H)* 1024(V), Japan).

6. Turning machine type (+Harrison, with a spindle of (31-1600 r.p.m) and rate of (0.04- 0.7) mm/rev, China).
7. Grinding and polishing device type (metallographic lapping / polishing machine, MTI Corporation, model UN POL- 820, China).
8. Wear tester type (Control and data acquisition software for friction and wear testing, MT4003, version 10.0, Aspasia). has been performed at the heat treatment laboratory in the College of Materials Engineering / Babylon University.
9. Sensitive balance (0.0001 GM, Germany).
- 10.X-Ray Machine used (SHIMADZU Lab XRD-6000, Japan).
- 11.Scanning Electron Microscopy(SEM) and (EDS) model FEI Quanta 450, Czech.

3.3 Program of the Present Study

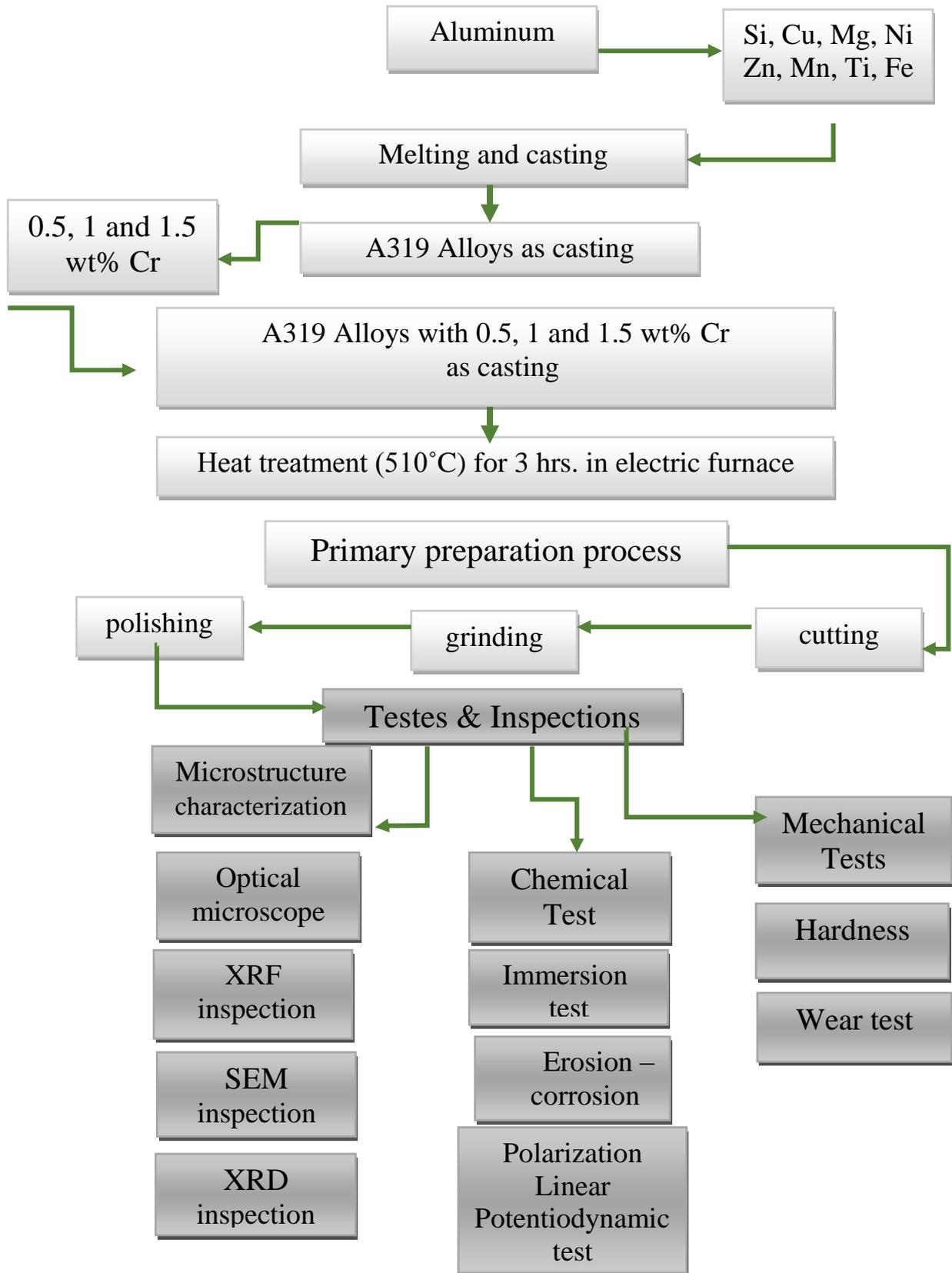


Figure (3-1): Shows the Block Diagram of the Experimental.

3.4 The Manufacturing Technique (Melting & Casting)

The technique of manufacturing is very important in this research because it determines many of the characteristic of the final product such as mechanical strength, hardness and final shape, it has been adopted casting technology in molds preparation for the characteristic distinguished it from the test of other techniques, including low cost and high flexibility in the manufacture of molds in different shapes and size.

3.4.1 Preparation of A319 Aluminium–Silicon alloys Specimens by Casting

High-purity aluminum wires used in the electrical connections were cut into small pieces to facilitate melting them in the alumina crucible in an electric furnace at (850°C).

After melting aluminum, a small amount of NaCl pieces was added with a percentage of 2wt.%. It was added to the aluminum molten to remove the impurities, after the removing of slug, the silicon and other alloying elements powders were encapsulated with aluminum foil and added sequentially according to the desired percentage. In order to ensure the uniformly of the distribution of the added alloying elements in the melted aluminum, an electric mixer with a stainless steel fan was used the electric mixer was dropped into the alumina crucible inside the oven and at 850°C, silicon and the other alloying were pulled into the molten aluminum and distributed through it. Stirring was continued for about 1.5 minute until molten homogenization was completed. The molted was then poured in a stainless steel mold that was coated with graphite and preheated to a temperature of 300°C to prevent the sudden cooling of the molten metal, then left it for freezing to get the required alloy.



Figure (3.2):The apparatus used for casting



Figure (3.3): Electric furnace with stirrer.



Figure (3.4): Rod samples of, (A319) after casting process.

3.4.2 Preparation of A 319 Aluminium – Silicon alloys with (0.5,1, 1.5) wt.% Cr Specimens by Casting

The stir casting technique was used to prepare A319 aluminium – silicon alloys with different additions of Cr. In this experiment, a prepared alloy (A 319) was first cut to small pieces in order to facilitate its melting in the furnace. It was then superheated above the liquids temperature to create a vortex in the melt using an electrical stirrer. The magnesium ribbon were rolled and covered by thick aluminum foil, and then immersed inside the melt to reduce its combustion .An electrical stirrer was used to mix Cr chips at (0.5, 1, 1.5 wt%) with the molten A319 Al-Si alloy . The Cr additions were added to the molten Al-Si alloy and ring the mixture was stirred for five minutes at a speed of 500 rpm. Then, the molten was poured into a pre-heated steel mold to 200°C by gravity casting. The specimens of the prepared alloys had dimensions of 14 mm in diameter and 15 cm height



Figure (3.5): Rod samples of, (A319) – Cr additions after casting process

Table (3.4) : Show code number of specimen

| Alloy | Sample coding | Addition element(Cr)% |
|---------------|---------------|-----------------------|
| A319 | B | 0 |
| A319+0.5wt%Cr | B1 | 0.5 |
| A319+1wt%Cr | B2 | 1 |
| A319+1.5wt%Cr | B3 | 1.5 |

3.4.3 Heat Treatment

The heat treatment was conducted at a temperature of (510°C) for (3) hr. In order to homogenize the composition, to eliminate the semi-soluble phases and to ensure that the alloying elements were homogeneously distributed in the alloy, which giving the alloy hardness and homogeneous mechanical properties, Figure (3-6) shows furnace used in heat treatment.

*Figure (3.6): Electric Furnace Used for Heat Treatment.*

3.5 Primary Preparation Process

All specimens after casting process were grinded by using (180, 220, 320, 600, 800, 1000, 1200, 1500, 2000 and 2500) grade silicon carbide papers, then polished with a diamond past of 15 μm to get a bright mirror finish for the final step. Specimen with a diameter of (14) mm and (5) mm were used for hardness, XRD, microstructure observation and corrosion test as shown in Figure (3-7). While specimens with a diameter of (14) mm and (5) mm were used for wear test as shown in Figure (3-8).



Figure (3.7): Microstructure, hardness and XRD Specimens.



Figure (3.8): Wear Specimens.

3.6 Testing Steps

3.6.1 Chemical Composition Analysis and Microstructure Examination

The chemical composition for specimen was done in order to ensure of both aluminum and other alloying element are present. This test had been done in the Ministry of science and technology /Baghdad, by spectrometer Figure (3-9).



Figure(3.9): XRF- Spectrometer.

3.6.2 X-ray Diffraction Test

X-ray diffraction analysis is a vital tool in which constituent phase can be monitored. A319 specimens was examined by XRD test in order to identify and analyze phases, this test was achieved in (Babylon university/ college of material engineering). The XRD generator with cu target at 40kV and 30 MA, scanning speed 5° per min was used with (30°-80°) scanning rate. Figure (3-10) showed the device used for this test.



Figure (3.10): X-ray machine used (SHIMADZU Lab XRD-6000)

3.6.3 Optical microscope

Microstructure of specimens was inspected using the light optical microscope (LOM) shown in Figure (3-11) with 100X magnification. After grinding and polishing, the specimens were etched using solution of ((HNO₃(1.25 gm) + HCL (0.75 gm) + HF (0.5) + Water Remaining) for (10-30 sec)[59]. Then washed in water, rinsed in ethanol, finally dried in stream of warm air .

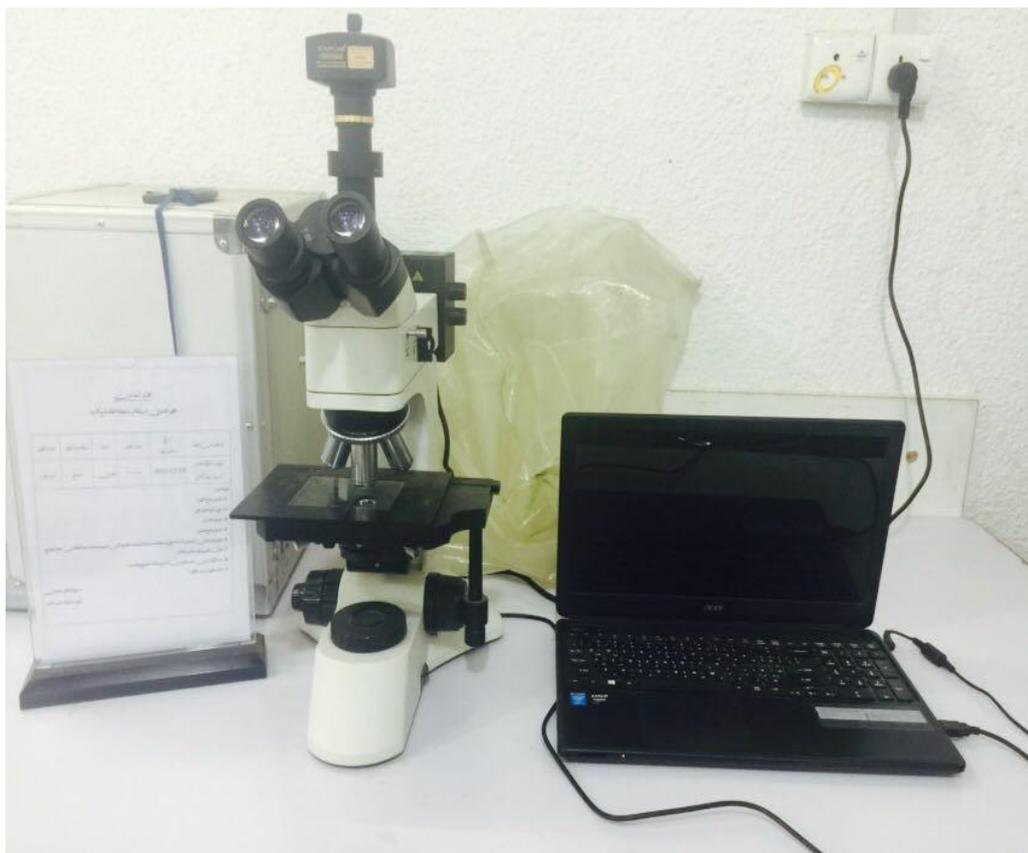


Figure (3-11): Light optical microscope(LOM).

3.6.4 Scanning Electron Microscope

SEM is one of the most commonly used surface analysis techniques in which a wide range of scales and feature can be observed. The scanning electron microscope examination has been used to apartness the microstructure of specimens after etching. The test has been done in college of Pharmacy /Babylon University and another sample in the Ministry of science and technology /Baghdad, as shown in Figure (3-12) model FEI.

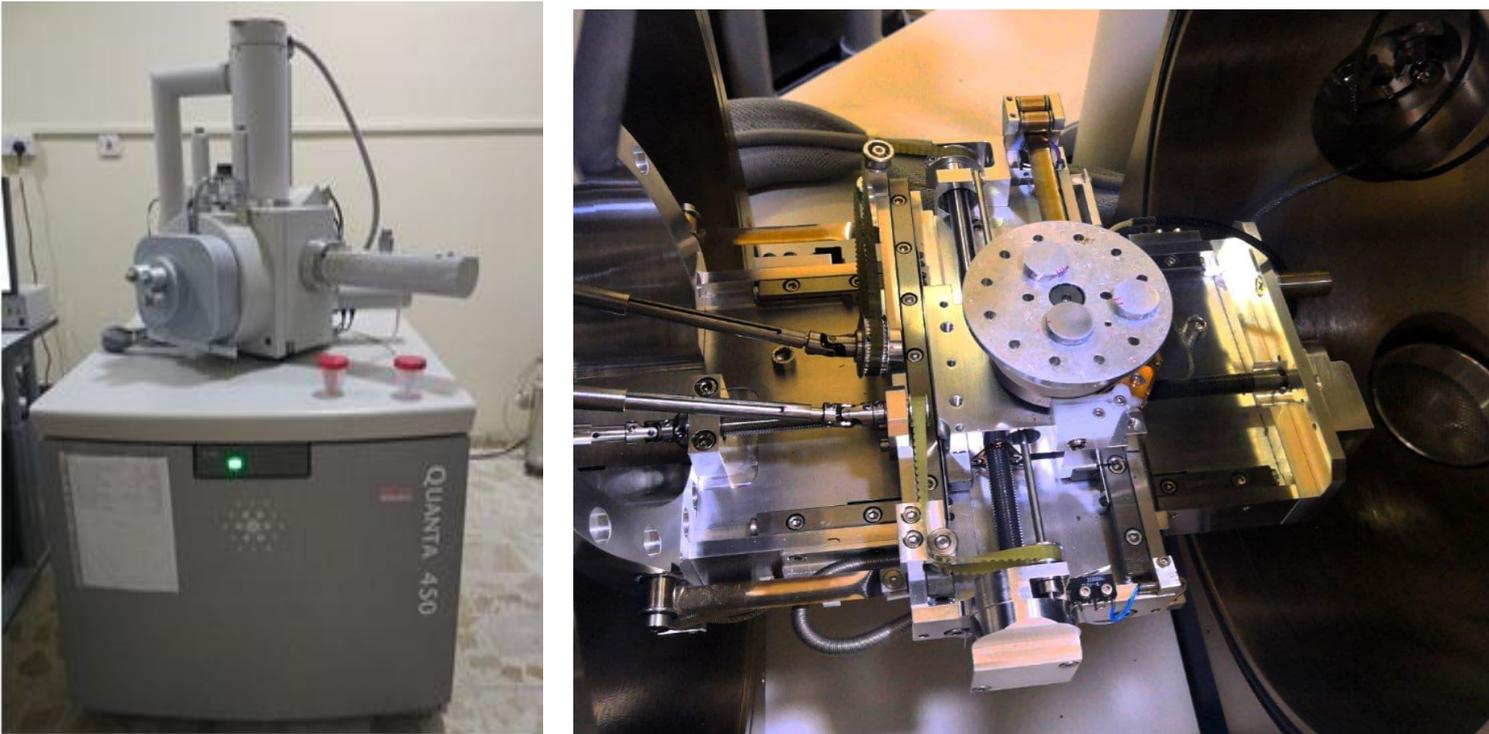


Figure (3.12): Scanning Electron Microscopy (SEM)

3.7 Electrochemical Tests

3.7.1 Linear Potentiodynamic Polarization test

The corrosive behaviour of the specimens studied in 3.5 wt.% NaCl solution. Electrochemical experiments were performed in a cell containing three electrodes. The counter electrode was Pt electrode and the reference electrode was SCE and working electrode (specimen) according to the American society for testing and materials (ASTM). Figure (3-13) shows schematic diagram of potential polarization.

The potentiodynamic polarization curves were plotted and both corrosion current (I_{corr}) and corrosion potential were estimated by Tafel plots by using anodic and cathodic branches. The electrochemical system used is shown in Figure (3-13). The test was conducted by stepping the potential using a scanning rate 0.4 mV/s from initial potential of 250 mV

below the open circuit potential and the scan continued up to 250 mV above the open circuit potential. Corrosion rate measurement is obtained by using the following equation.

$$\text{Corrosion rate} = \frac{0.13 I_{\text{corr}}(E_w)}{\rho} \quad \dots (3 - 1)$$

Where:

E.W= equivalent weight (g/eq.)

ρ = density (g/cm³)

0.13 = metric and time conversion factor

I_{corr} = current density ($\mu\text{A}/\text{cm}^2$).

mpy = Corrosion rate (mils per year).

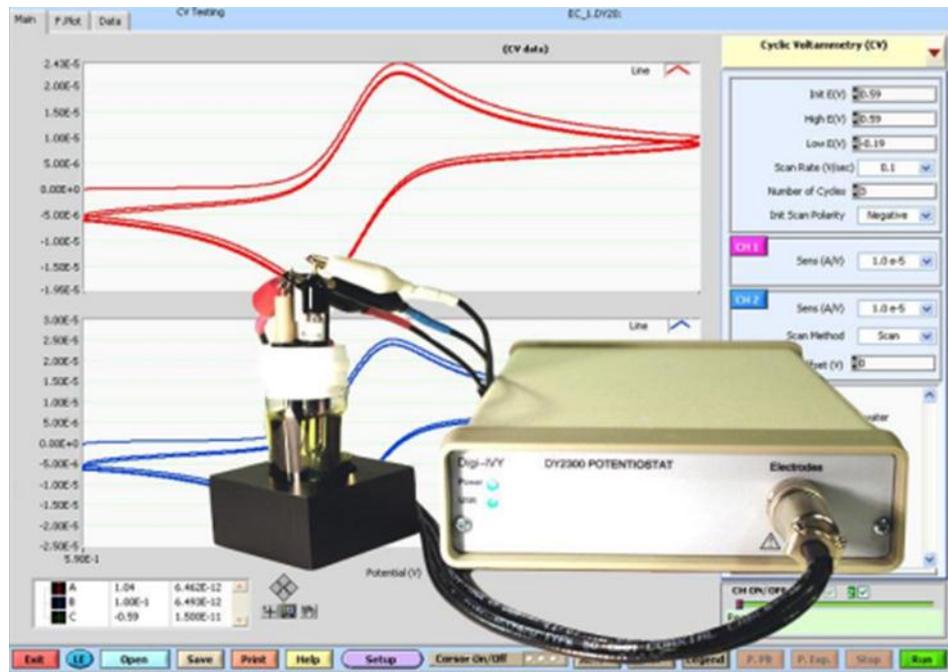


Figure (3-13):DY2300 Potentiodynamic polarization

3.7.2 Immersion Testing

Immersion test were performed for 20 days in 3.5 wt.% NaCl naturally - aerated solution the specimens weighed before and after the test using sensitive balance (0.0001), weight-loss measurements were made in triplicate and weighted was calculated by taking an average of these values [65].

$$\text{Weight loss, } \Delta W = \frac{(W_{\text{int}} - W_{\text{fin}})}{A}$$

$$\text{Corrosion Rate, } K_{\text{corr}} = \frac{(K \times \Delta W)}{(A \times T \times D)}$$

Where:

W_{int} = initial weight before immersion,

W_{fin} = final weight after exposure,

K = unit conversion constant ($K = 8.76 \times 10^4$ for the mpy unit),

T = time of exposure (hrs.),

A = area in (cm²),

ΔW = Weight loss (g) and D = density of metal (g/cm³)

3.7.3 Erosion/Corrosion Test

The erosion is a mechanical process such as remove part of the material from the surfaces because of the collision or gases and liquid effects. The erosion-corrosion apparatus was designed during this study depends on (ASTM G 73-98), The erosion-corrosion apparatus consists of motor (Q max 53 l/min, H max =38m, HP=1hp, 2850 rpm, Size 1in×1in), granite tank, tubes to fall the water by nozzle on the specimen.

All alloys examined were examined at temperature (25-30°C). The salt solution (sea water) will caused erosion-corrosion effect by falling from the nozzle at angle=90° at (1.21 m/s) .The nozzle is (2mm) in diameter and positioned at a fixed distance of (10 mm) from the specimen as shown in Figure (3.14). It is possible to calculate the change in weight and then get the erosion rate according to equation (3.3) as follow.

Change in weight(Δw) = original weight (W_o) - weight after a fixed time ($w_{1,2\dots}$)

$$\text{Erosion corrosion rate } \left(\frac{gm}{hr} \right) = \frac{\Delta w}{\text{time of exposure}} \dots \dots \dots (3 - 3)$$



Figure (3.14): Erosion-Corrosion Device According to (G 73) ASTM.

3.8 Mechanical Test

3.8.1 Hardness Test

Vickers micro-hardness tester is shown in Figure (3-15). It was used to measure the hardness of specimens at loading of 200 grams and time of 10 seconds. Five reading for each specimen had been taken and the average value was used. The Vickers hardness was determined by the following equation:

$$HV = 1.854 (F/D^2)$$

Where:

HV: Vickers micro hardness (kg/mm²).

F: Applied load (kg).

D: The average diameter of the indentation (mm²).



Figure (3.15): Vickers (HV1000) Micro-hardness Device.

3.8.2 Sliding Wear Test

The dry sliding wear studied by pin-on-disc concept, with (150 rpm) constant radius (6mm) and load 5N and load 10N. The ball of the pin was 4mm in radius made from carbide steel. The specimens are weighted before the test using an electric balance with accuracy of 0.0001. After a period of time (5 ,10 ,15 , 20, 25, 30 min) the specimens are reweighted. The wear instrument was showed in Figure (3-16).

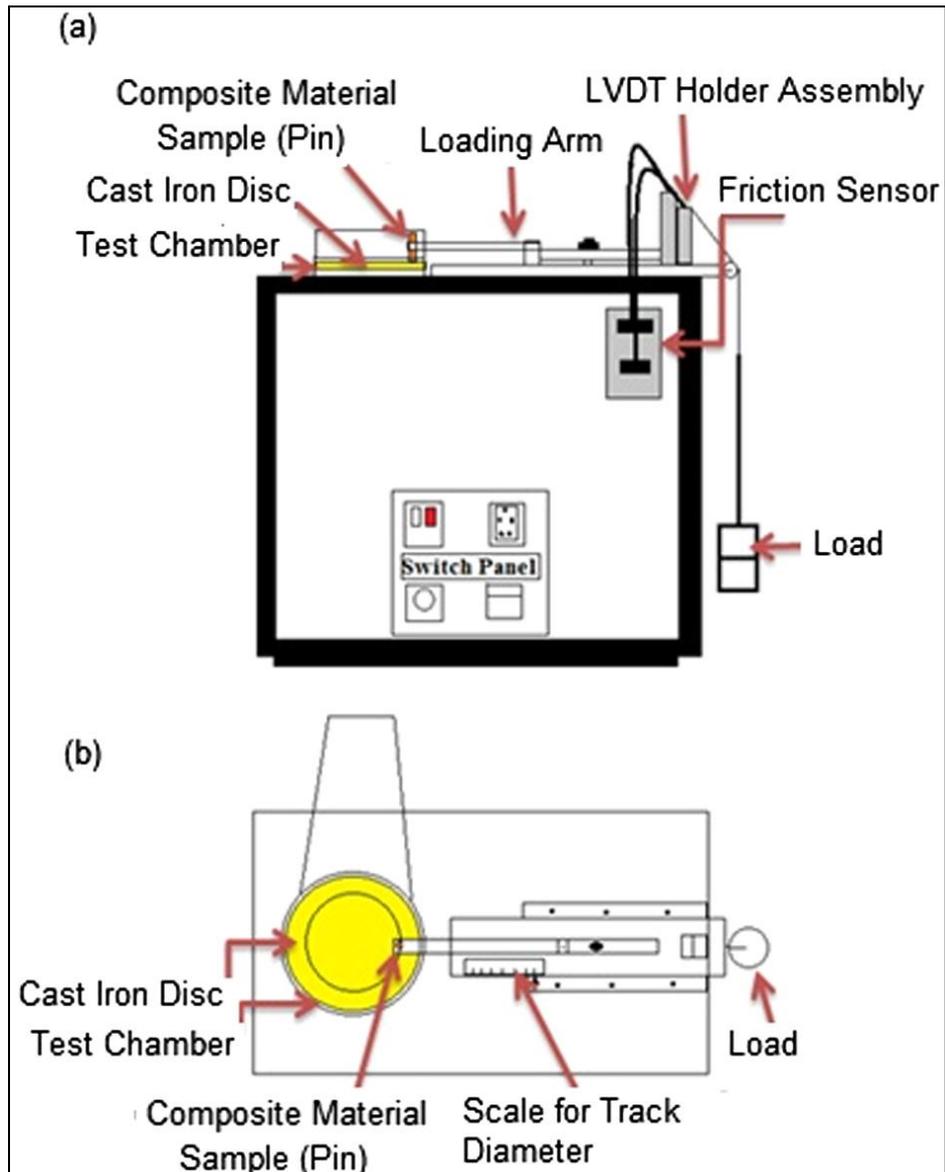


Figure (3.16): Pin on disc setup (a) Front view (b) Top view.

Chapter
Four

Chapter Four

Results and Discussion

4.1 Introduction

This chapter presents the obtained results from this work and their discussion, which includes (Chemical composition, X-ray diffraction, microstructure characterization, OM, SEM & EDS, hardness,), electrochemical tests (potentiodynamic polarization and weight loss tests) and mechanical tests (wear and hardness tests).

4.2 Chemical Composition

The chemical composition for the casting alloy, were analyzed by using (X-ray florescent test). The composition analysis confirm that the main alloying elements are presented within the specified limits. As litter in Table (4-1) for (A319) cast alloys, with their chemical composition analysis is shown in Figures (4-1)

Table (4-1): Chemical Composition of the alloy Specimens Prepared in this Study.

| Specimens | Si% | Cu% | Mg% | Zn% | Mn% | Ti% | Fe% | Ni% | Al |
|-----------|-----|------|------|------|------|-----|------|------|-------|
| A319 | 6.4 | 2.68 | 0.03 | 0.16 | 0.00 | 0.3 | 0.67 | 0.28 | 88.41 |

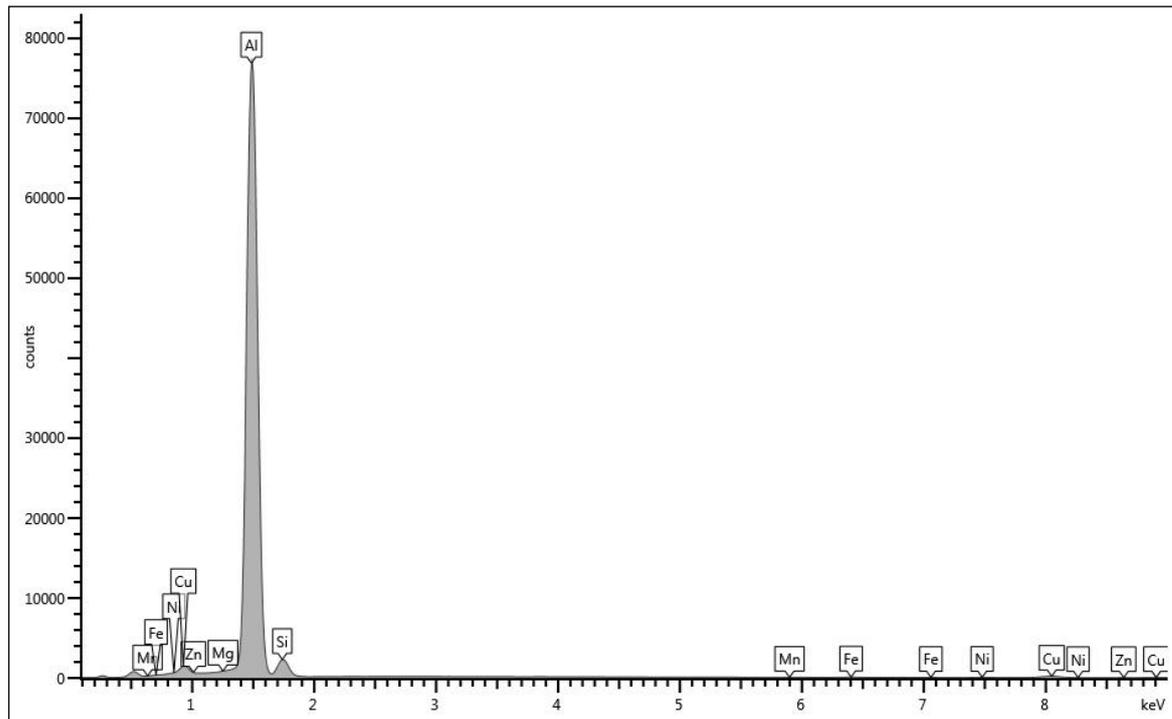


Figure (4-1): Chemical Analysis for (A319) Cast Alloy

4.3 Characterization of Specimens

In this study a variety of tests were conducted in order to get various properties of specimens.

4.3.1 X-ray Diffraction (XRD) Test

The technique of XRD is important to identify the phases of crystalline structure. Figure (4.2), (4.3) shows the XRD patterns for B and B3 only it can be observed that the presence of α – Al phase and Si. These results are similar to [71]

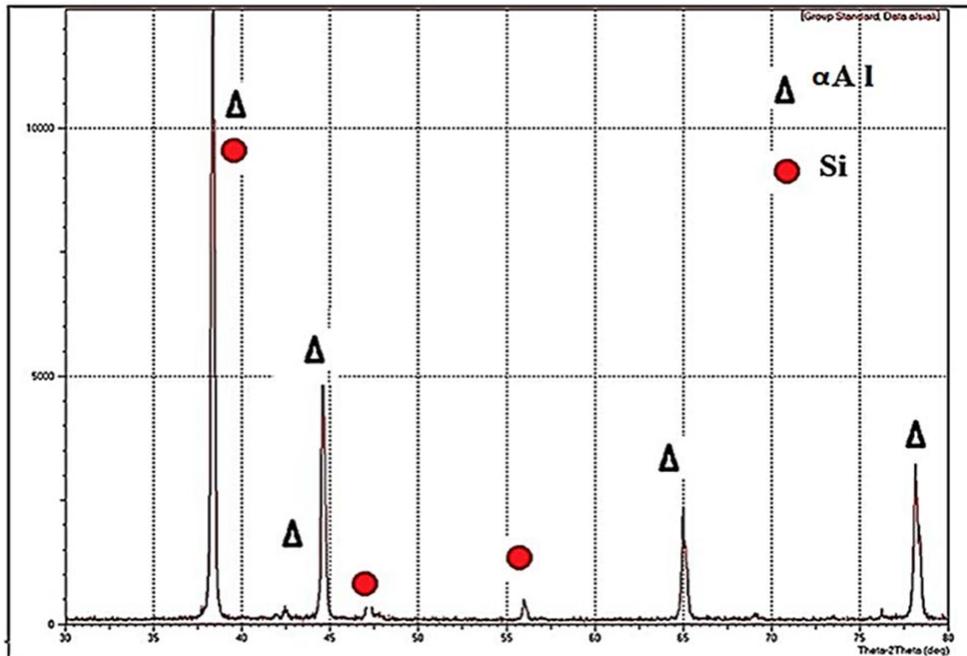


Figure (4.2): shows the XRD patterns for B alloy

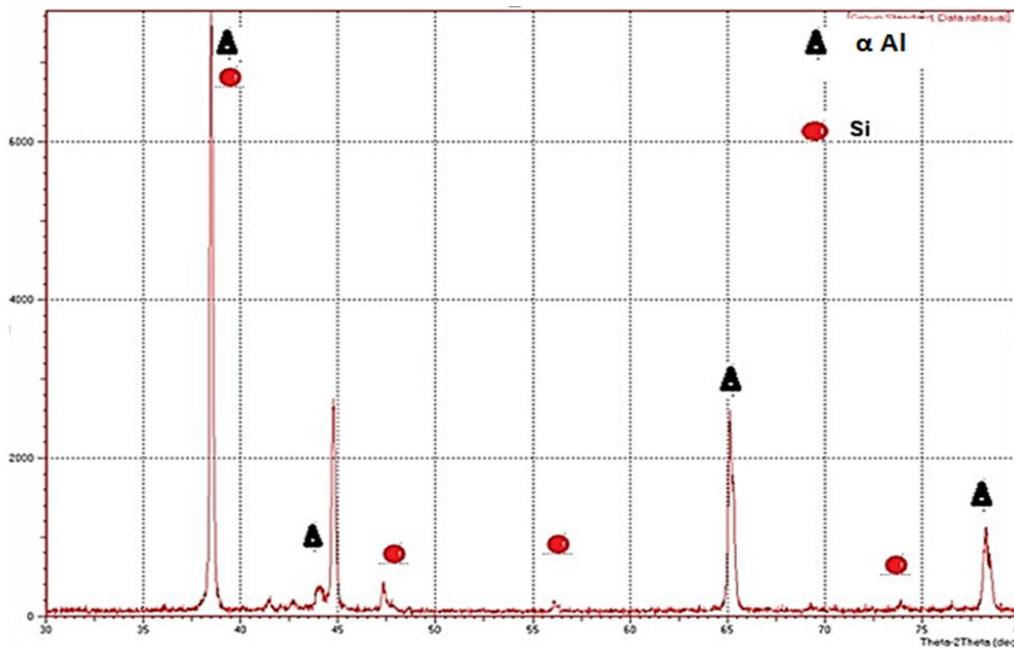


Figure (4.3): shows the XRD patterns for B3 alloy

4.3.2 Optical Microscopic Observations

Light optical microscope was used to examine the microstructure of specimens, Figure (4.4) shows the microstructure of specimens B, with different magnification.

While Figures (4.5 to 4.7) shows the optical microscopic observations of A319 with different additions of Cr. It illustrates the microstructures of etched B1, B2 and B3 alloys with different magnifications. The microstructures for mentioned alloys showed the grain boundaries, and the present phases.

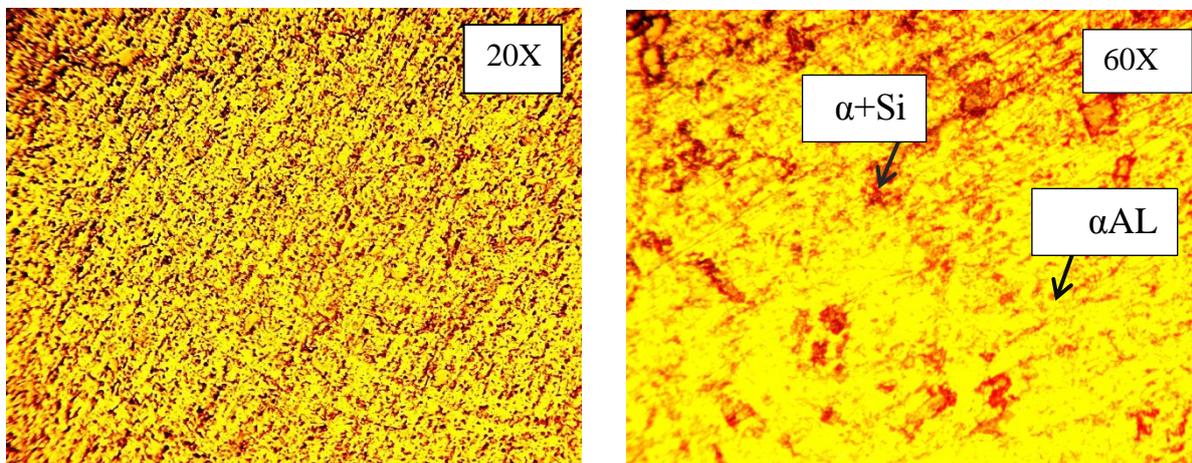


Figure (4.4): *Microstructure of base sample (A319) with different magnifications*

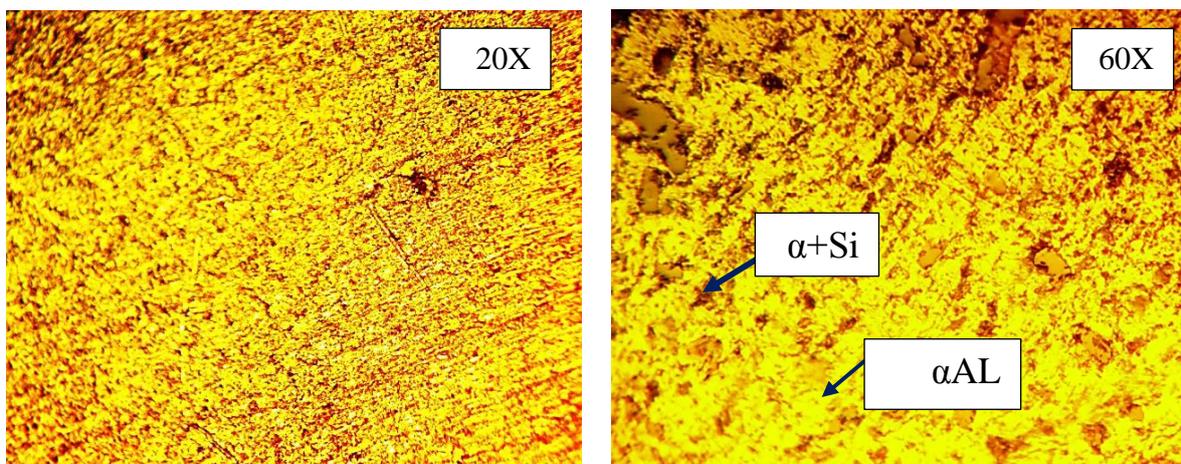


Figure (4.5): *Microstructure for (A319+0.5%Cr) samples with different magnifications*

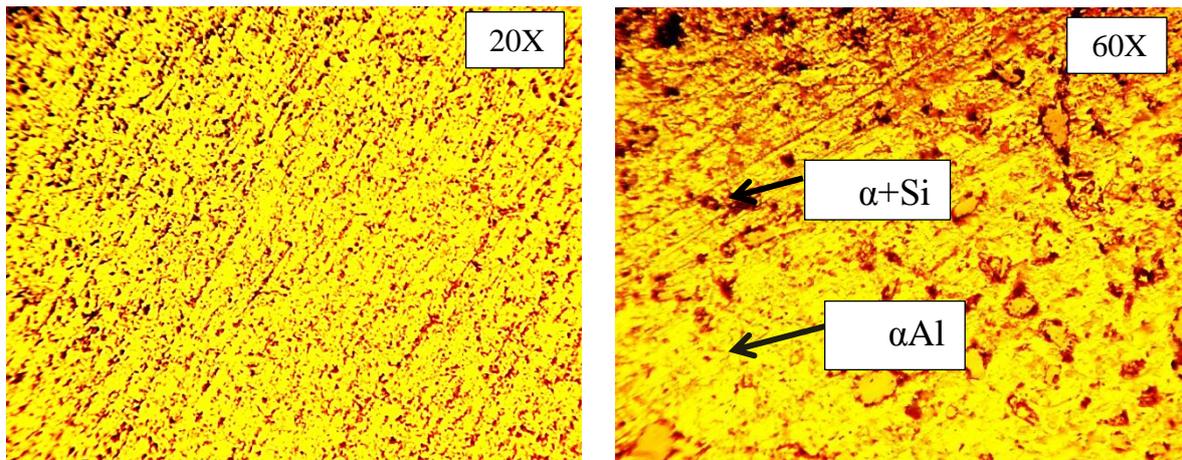


Figure (4.6): Microstructure for (A319+1%Cr) samples with different magnifications

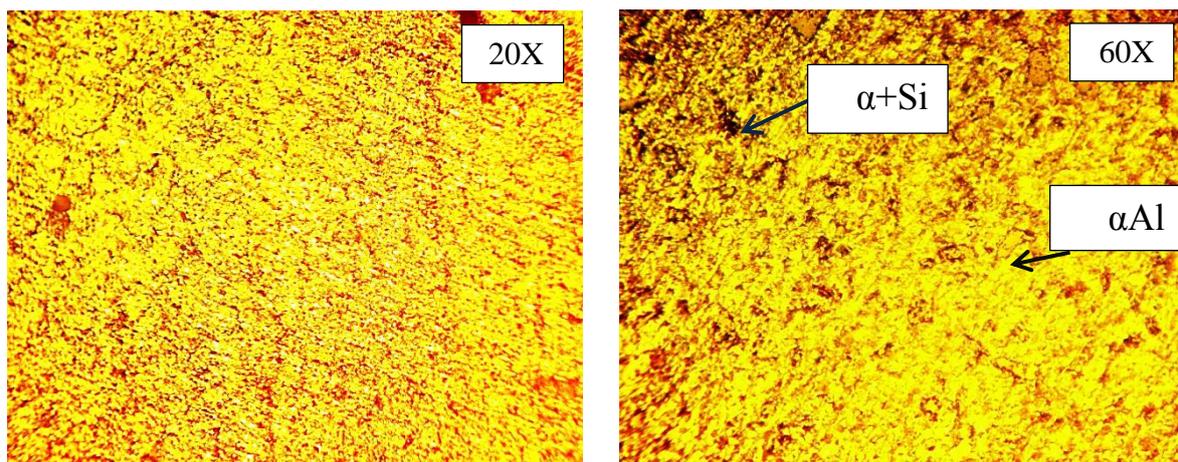


Figure (4.7): Microstructure of (A319+1.5%Cr) samples with different magnifications

Figure (4.4 to 4.7) showed the optical microscopic observations of base A319 with different additions of Cr. It is clear that the structure of the base alloys consists α Al (white region) and Eutectic (α +Si) (black regions). These results similar to previously reported by other research [57].

4.3.2 Scanning Electron Microscopy (SEM)

The micrograph gained from B , B1, B2 and B3 alloys after being etched with the above mentioned etching solution are shown in Figure (4.8) to Figure (4.11) respectively

The primary α -Al phase is depicted as the gray phases in the images and the bright grey region illustrate the aluminum-silicon eutectic E(α Al+Si). This result was expected compared with earlier researches that gave similar results [58,59,].

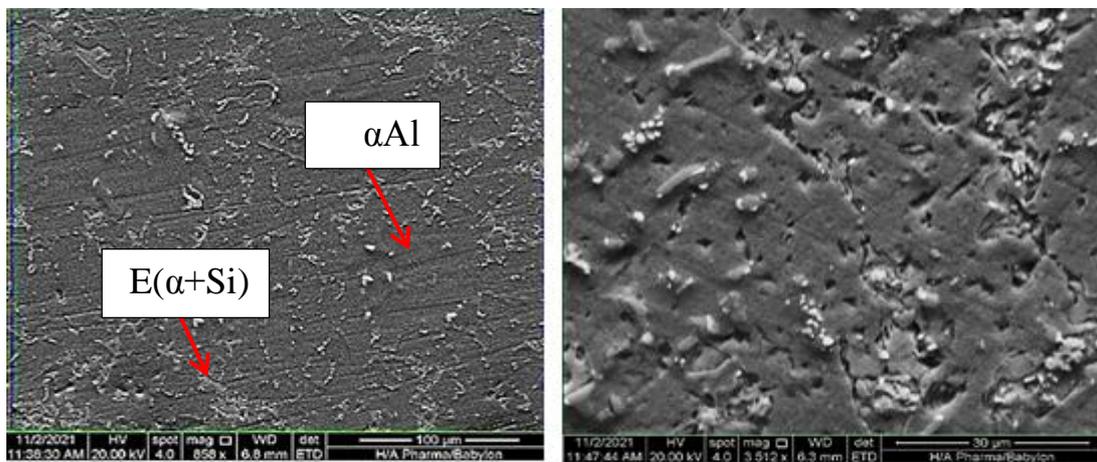


Figure (4.8): SEM images for etched B alloy with different magnification

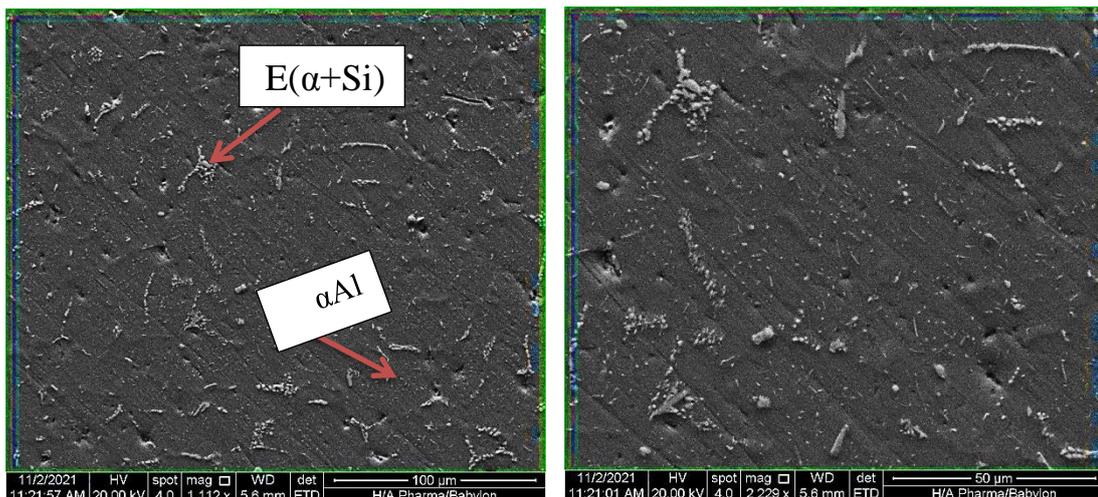


Figure (4.9): SEM images for etched B1 alloy with different magnification

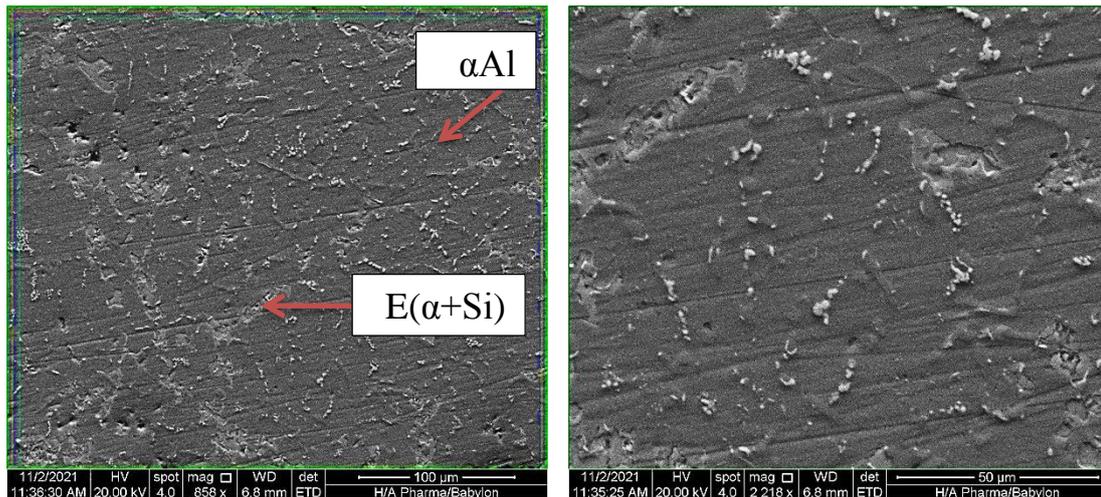


Figure (4.10): SEM images for etched B2 alloy with different magnification

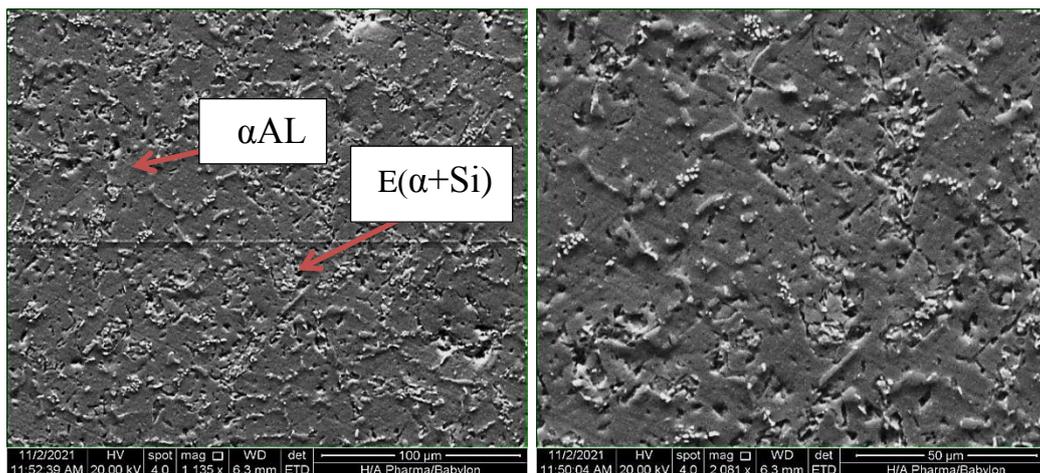


Figure (4.11): SEM images for etched B3 alloy with different magnification

4.3.3 Energy Dispersive Spectrometer (EDS) Analysis

SEM is attached with energy dispersive spectrometer (EDS) analysis to analyze the chemical composition of the casting specimens. A preliminary scan for element was conducted on the casting specimens (A319 and addition alloys) by using an energy dispersive analysis. The results are shown in Figure (4-12) to (4-15) for B , B1 , B2 and B3 specimens respectively.

The result of EDS analysis for A319 specimen is shown in Figure (4-12 to 4.15) showed the presence of Al as base alloy with Si and Cu as primary element and Ni and other element as an additional element. As it can be seen, the results of EDS analysis were relatively close to the percentage of addition, because the values gained from EDS analysis do not cover the total area only the spot where the electron stroke. Furthermore, the EDS results aide in verifying the purity of the initial elemental powders as well as the prevention of contamination during casting and the production of alloys [70,71].

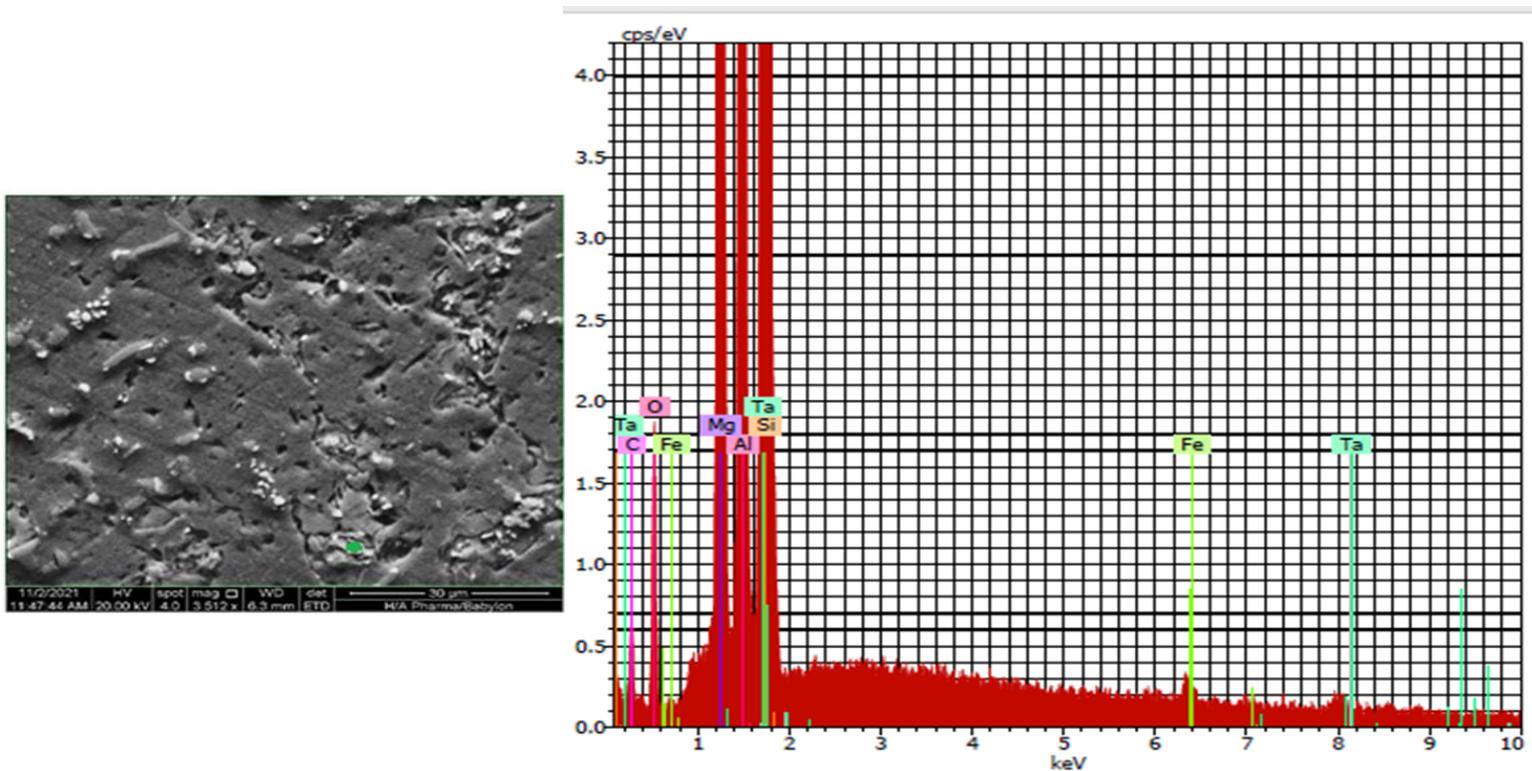


Figure (4.12) SEM-EDS image for etched A319 (B) alloy

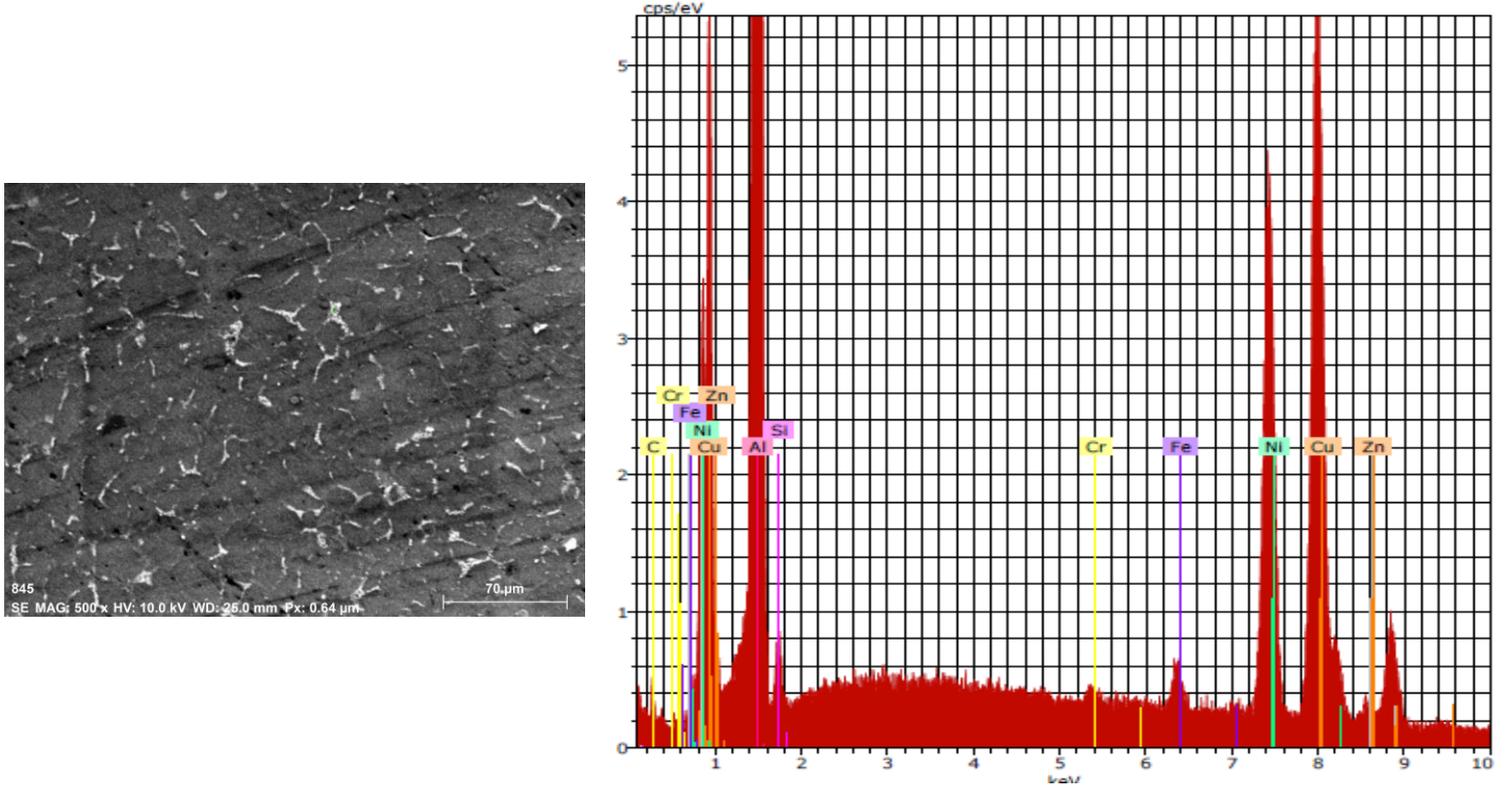


Figure (4.13): SEM-EDS image for etched A319 alloy with 0.5%Cr (B1)

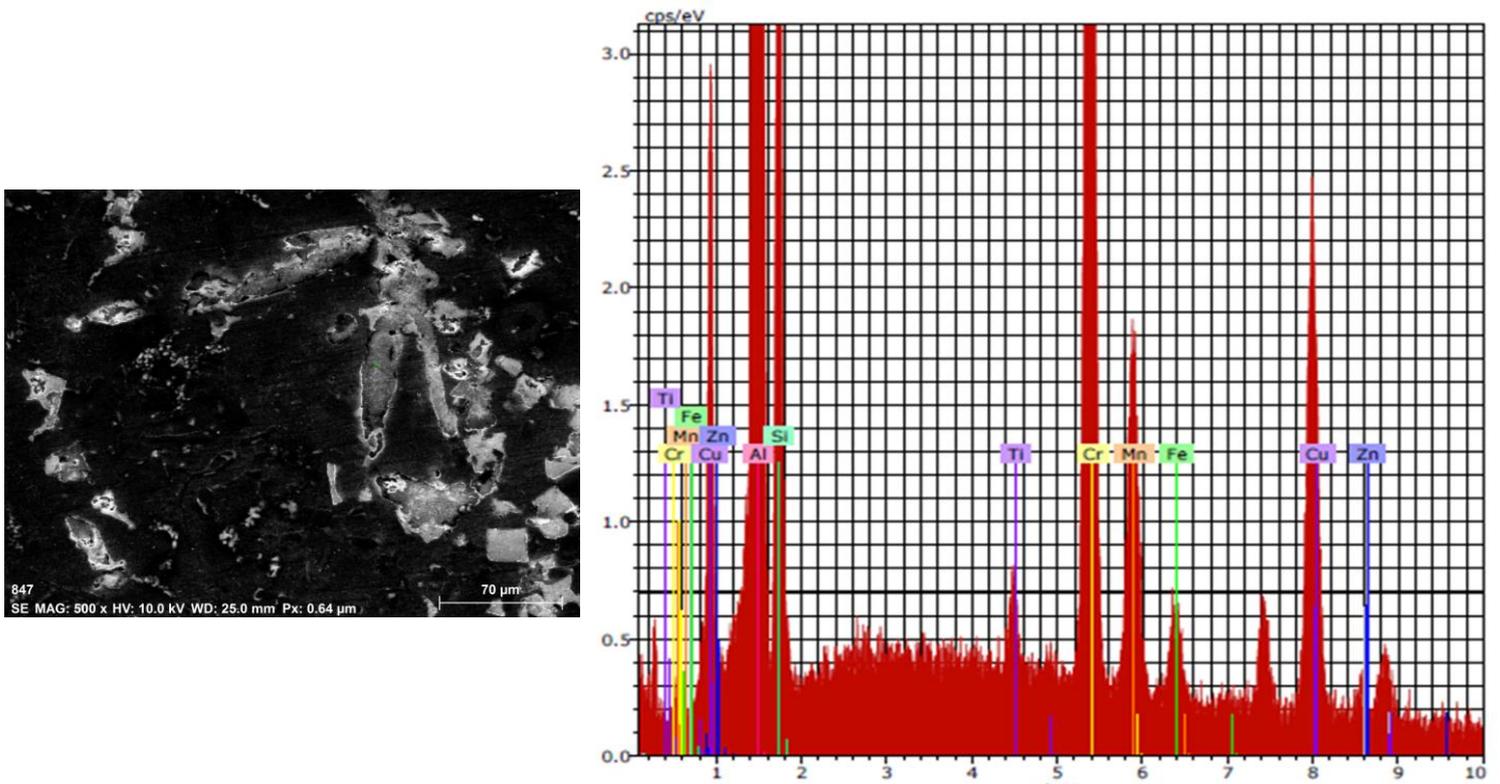


Figure (4.14): SEM-EDS image for etched A319 alloy with 1%Cr (B2)

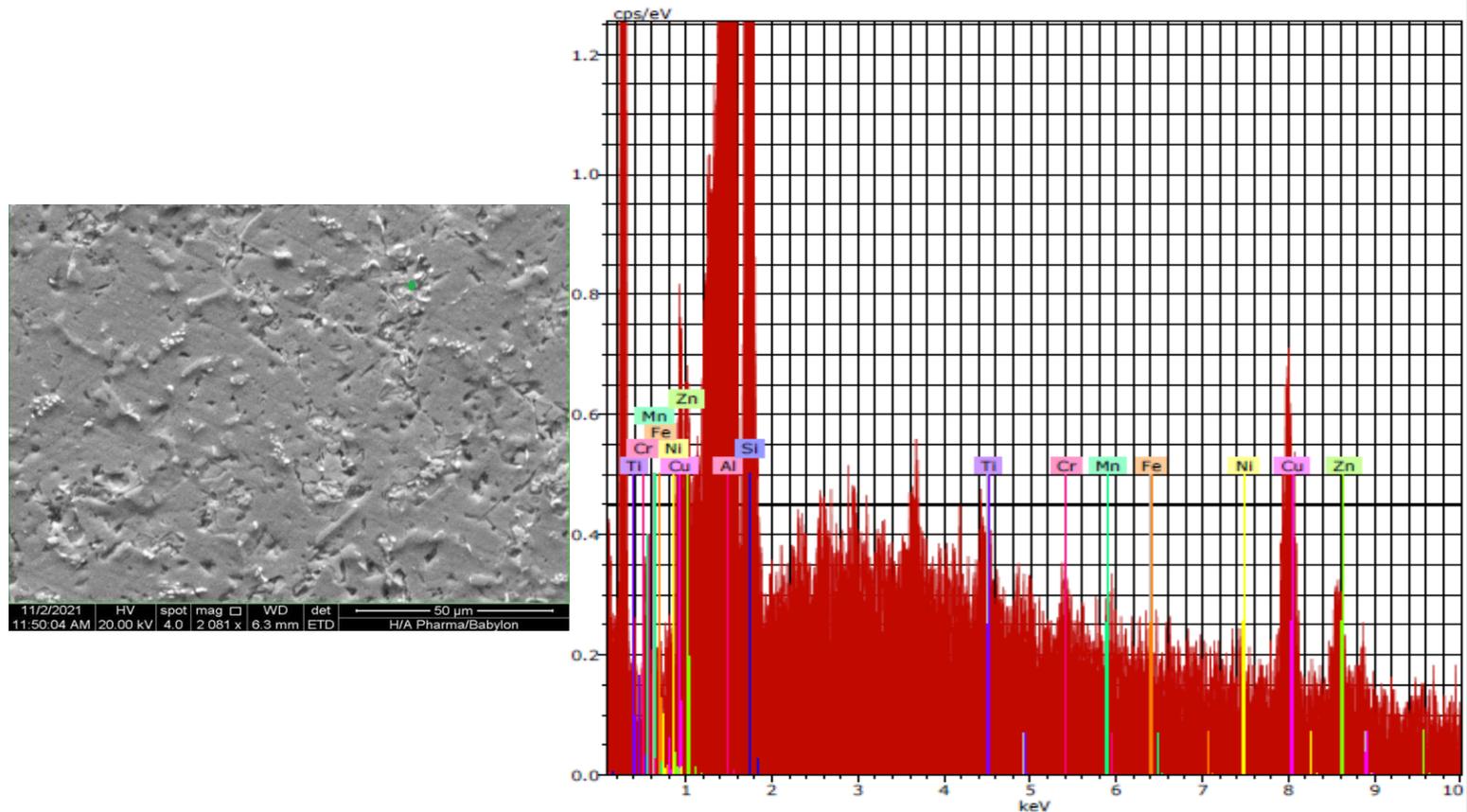


Figure (4.15): SEM-EDS image for etched A319 alloy with 1.5%Cr (B3)

4.4 Mechanical Test

4.4.1 Hardness Test

In the current study the hardness of the samples of all alloys are measured by Vickers hardness test and the results illustrated by Figure (4-16). The greatest value was recorded for B3 sample with Cr percentage of (1.5%). It is well known that Cr can be Al-Si alloys to enhance the strength of the materials by formation intermetallic compounds with high stability such as α -AlCrSi, α -Al(Cr,Fe,Si) these results are similar to [73].

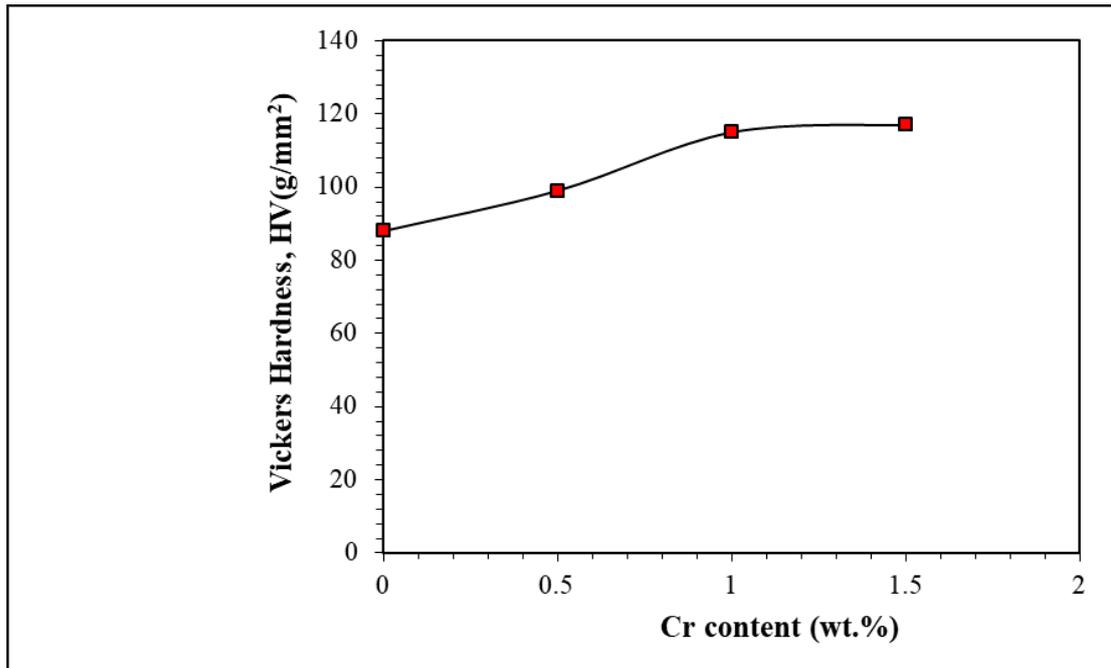


Figure (4.16): Effect of Cr addition on the hardness of A319 alloy

4.4.2 Wear Resistance Test

From figures (4-17,4-18) , it is clear that wear rate is increased with increasing the applied load, where the highest wear rate was recorded under (10 N). This is behavior is expected, where the increment in load leads to increase the friction between sample surface and the rotating disk. Also, the volume loss was increased with increasing time due to the increment of sample's particles loss with increasing friction time[74]. Figures (4.17) and (4.18.) show the effect of Cr addition on wear rates at different conditions.

From these figures, it can be noticed that the wear rate was decreased drastically with increasing Cr percentage, even it reaches the minimum value at the alloy that contained maximum Cr percentage (1.5%) This may duo to the role of Cr element blocking dislocation motion. hardness was increased and thereby wear resistance was also increased[73].

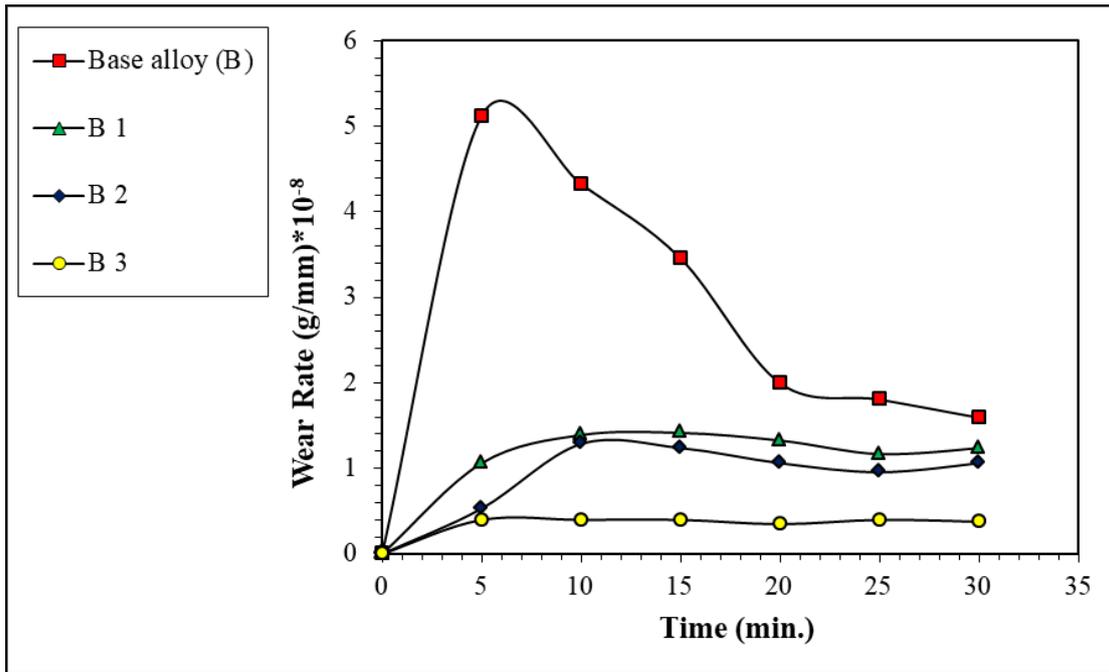


Figure (4-17): wear rate vs Time for A319 and with additions under (5N) load.

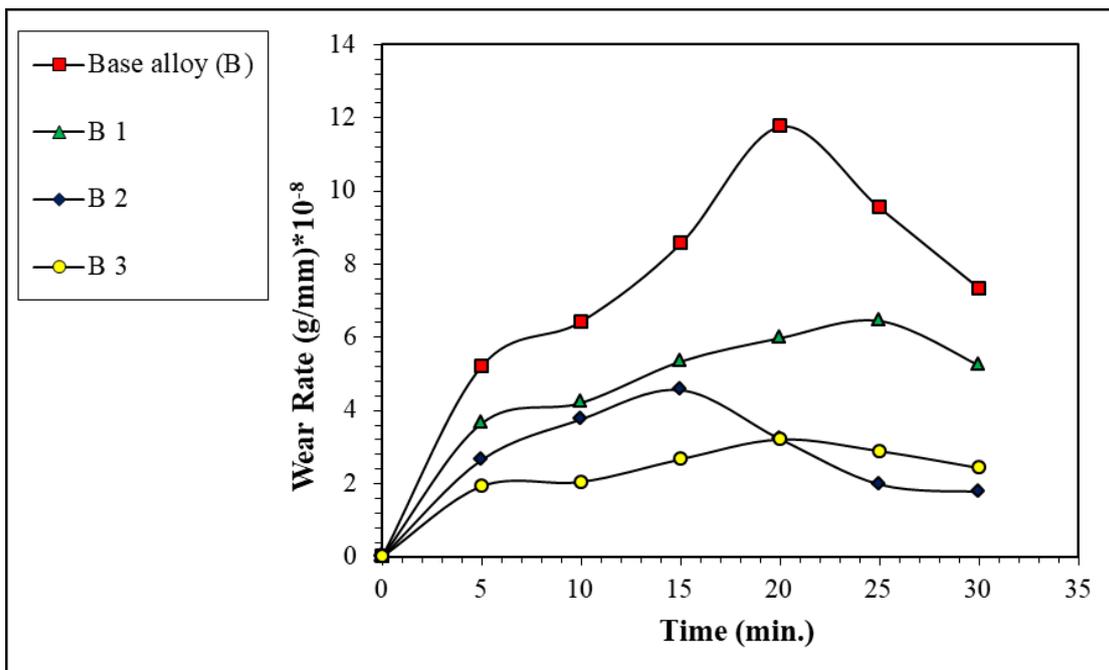


Figure (4-18): wear rate vs Time for A319 and with additions under (10N) load.

4.5 Electrochemical Tests

4.5.1 Linear Potentiodynamic Polarization Test

Potentiodynamic polarization test has been used in 3.5wt.% NaCl solution. The corrosion characteristics of cast B , B1, B2 and B3 alloys are depicted by the polarization curves in 3.5wt.% NaCl solution shown in Figures. (4.19) to (4.22) respectively.

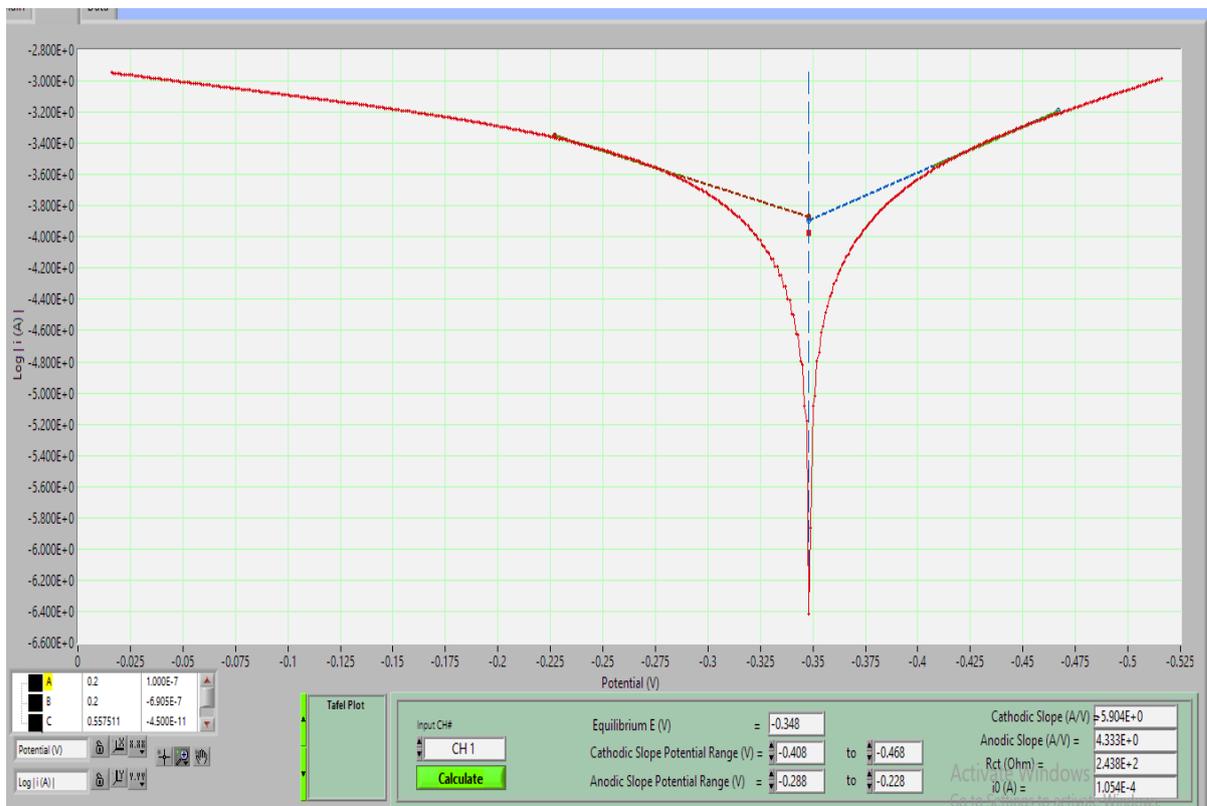


Figure (4.19): Current density (A/cm^2) vs. potential (V) in 3.5 wt% NaCl at 25°C for B Alloy

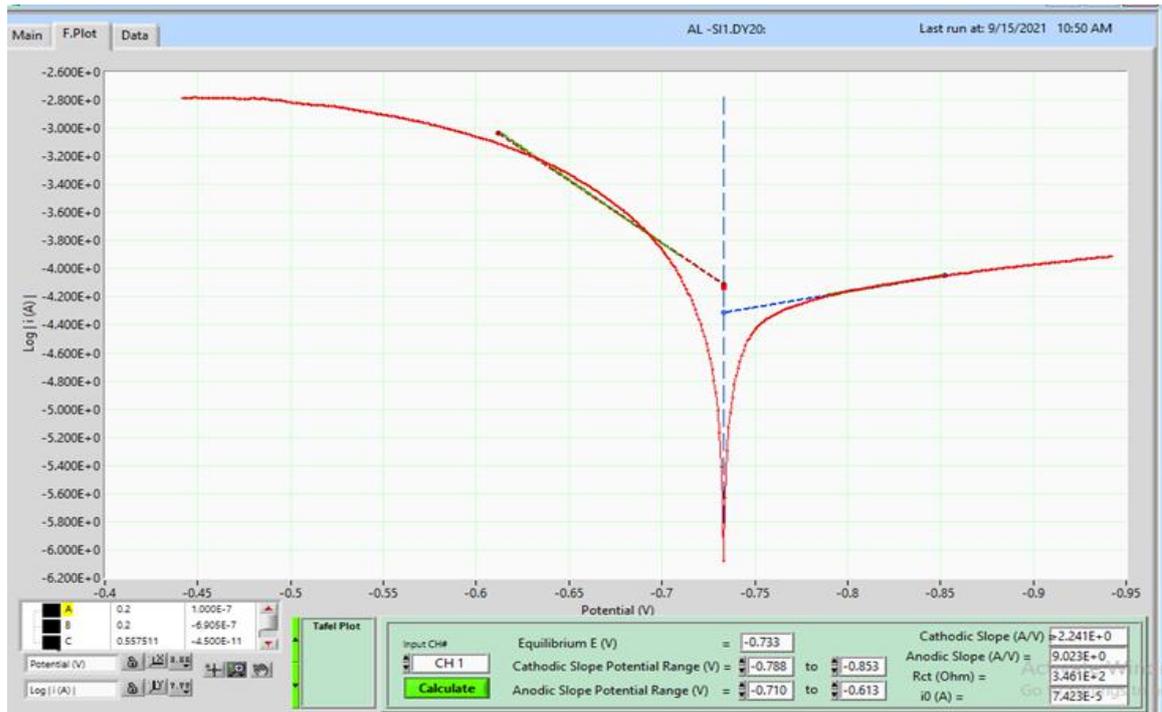


Figure (4.20): Current density (A/cm^2) vs. potential (V) in 3.5 wt% NaCl at 25°C for B1 Alloy

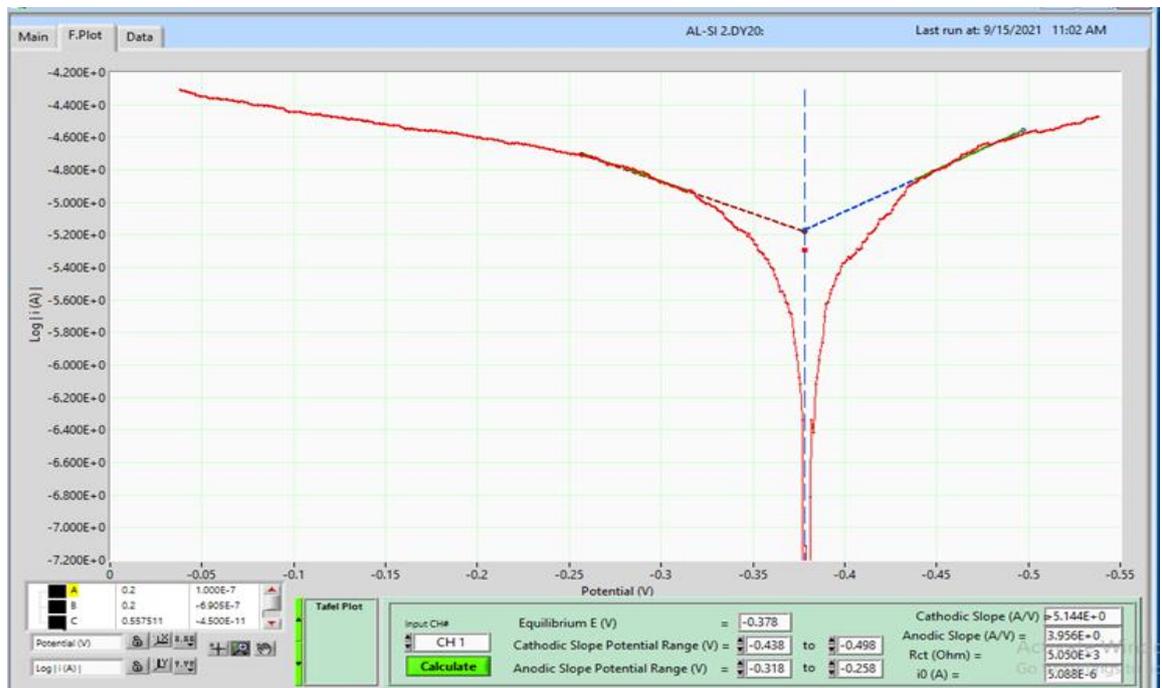


Figure (4.21): Current density (A/cm^2) vs. potential (V) in 3.5 wt% NaCl at 25°C for B2 Alloy

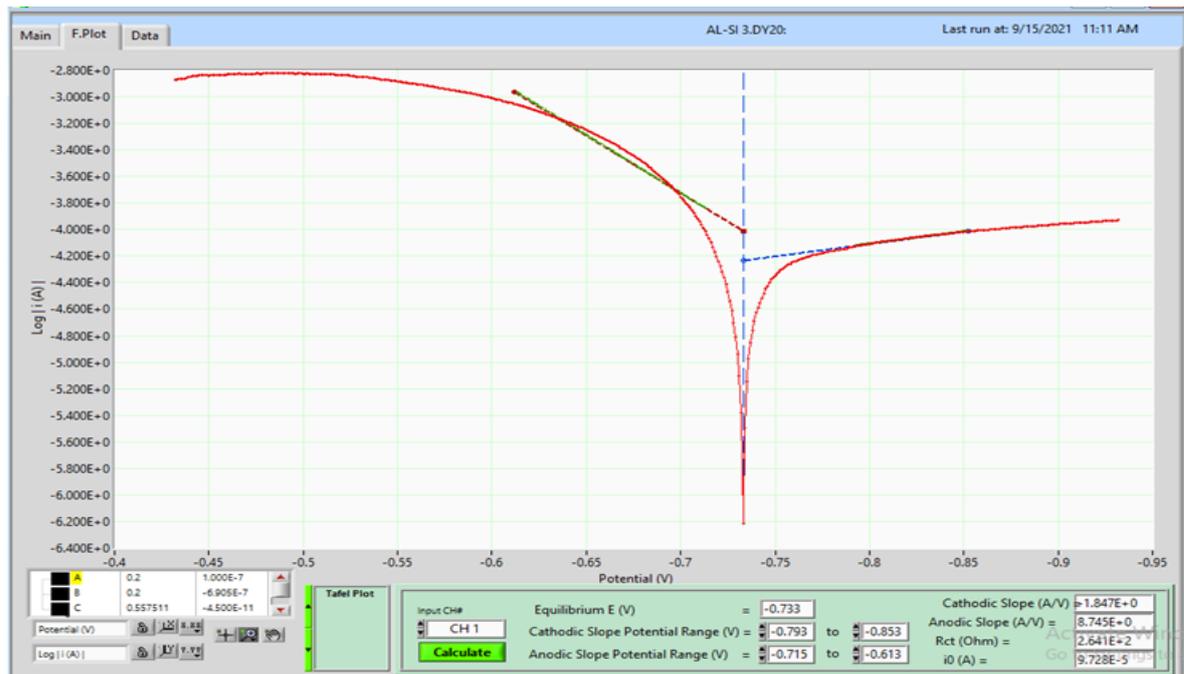


Figure (4.22): Current density (A/cm^2) vs. potential (V) in 3.5 wt% NaCl at $25^\circ C$ for B3 Alloy

According to electrochemical measurements, the B3, B2 and B1 cast alloys are more resistant to corrosion than the B cast alloy. This improvement was mainly attributed to the formation of a more homogeneous passive film and the rapid repassivation of the bare metal. These findings are in agreement with other studies [61,72]. Corrosion parameters (corrosion potential, corrosion current), extracted from these curves are listed in Table (4-2).

Table (4-2): The corrosion potential (E_{corr}), corrosion current (I_{Corr}), Corrosion Rate, Current Density and Improvement percentage of samples in tap water at $25^\circ C$

| ALLOY | SAMPLE CODE | I_{corr} (A) | E_{corr} (V) | Corrosion Rate (mpy) | Current Density (A/m^2) | Improvement Percentage % |
|-------------|-------------|------------------------|----------------|----------------------|-----------------------------|--------------------------|
| A319 | B | 1.954×10^{-4} | -0.348 | 30.876 | 1.641×10^{-6} | 0 |
| A319+0.5%Cr | B1 | 7.423×10^{-5} | -0.733 | 11.401 | 4.824×10^{-7} | 64% |
| A319+1%Cr | B2 | 5.088×10^{-6} | -0.378 | 3.124 | 3.306×10^{-8} | 91% |
| A319+1.5%Cr | B3 | 9.728×10^{-5} | -0.733 | 5.911 | 6.322×10^{-7} | 82% |

4.5.2 Erosion- Corrosion Test

Figure (4.23) shows the results of erosion-corrosion in 3.5 wt% NaCl solution with time of alloys (B,B1,B2,B3) after exposure times for (2 hours) at (15 min) cycle using impact angle 90 °.At the begning of expose to corrosive solution, the corrosion rate is expected to be higher because of easy removal of corrosion products and occurrence of fresh metal surface to contact of corrosive media [63]. In the first stage (incubation period) the surface of the sample was subjected to (deformation) due to impingements of water jet .The second period represents the acceleration part due to cracking and spalling of the hardened surface by fatigue mechanism, because of strain hardening these two stages were followed by slowing region. The cause of reducing of weight loss is due to the formation of grooves on the surface of the sample which then filled with water. Hence, water in these grooves absorbs the impact energy of the water jet. As can be seen in the Figure (4.23) the weight loss decreased when the Cr added to base alloy . This addition decreased the erosion-corrosion rate. The macroscopic oposervation showed that there is alarge pits at surface of base alloy exposed to 3.5wt% NaCl solution is higher than that of alloys (B1,B2,B3) .This is attributed to high chloride ion contents and low pH inside the pits which leads to growing pits and increasing the corrosion rate of alloy. This is consistent with results of researcher [75].

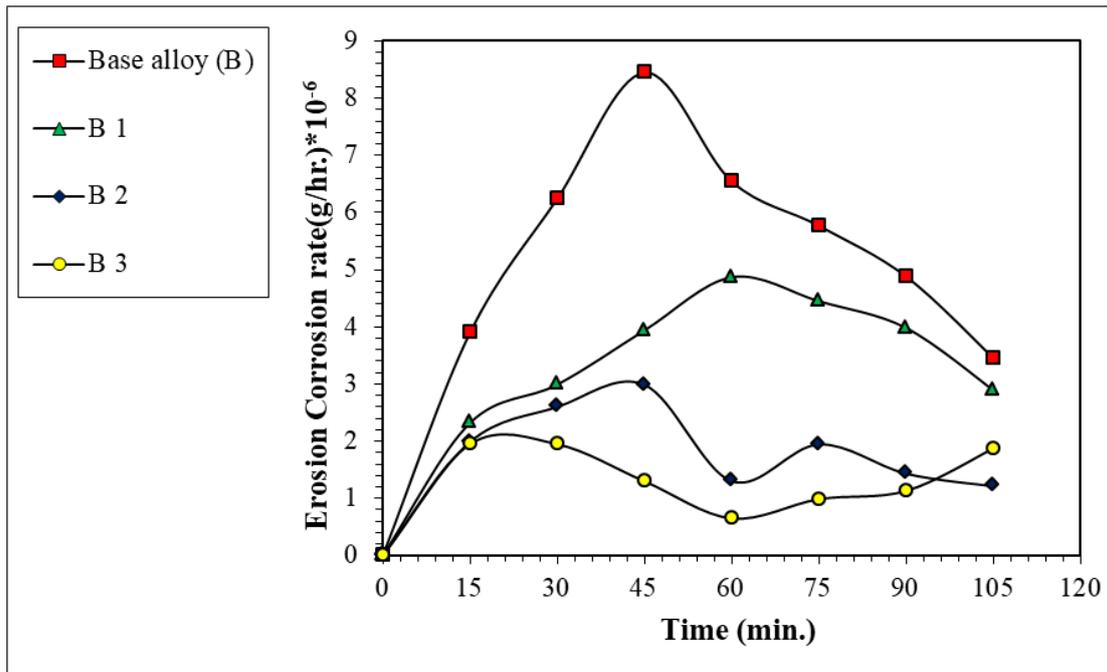


Figure (4.23): Effect of exposure time on Erosion– Corrosion rate of B ,B1,B2,B3 in saline solution (3.5wt% NaCl).

4.5.3 Simple Immersion Test

According to ASTM G3, to study the corrosion rate of specimens. The specimens were completely immersed in salt solution (3.5 wt% NaCl), and they have been taken out for examining the loss in mass, after every two days of immersion at room temperature. The corrosion rate calculated from measurement of the weight loss over a period of 20 days of immersion in 3.5 wt.% NaCl solution, indicating a higher corrosion resistant of the A319 alloy with different percentage of Cr as shown in Figure (4.24) .Cr in Al-Si alloys incorporated in the Al₂O₃ passive film. This incorporation resulted in a significant passivation of the oxide film which resulted in decreased the corrosion rate of A319 alloy after Cr addition these results similar to[75].

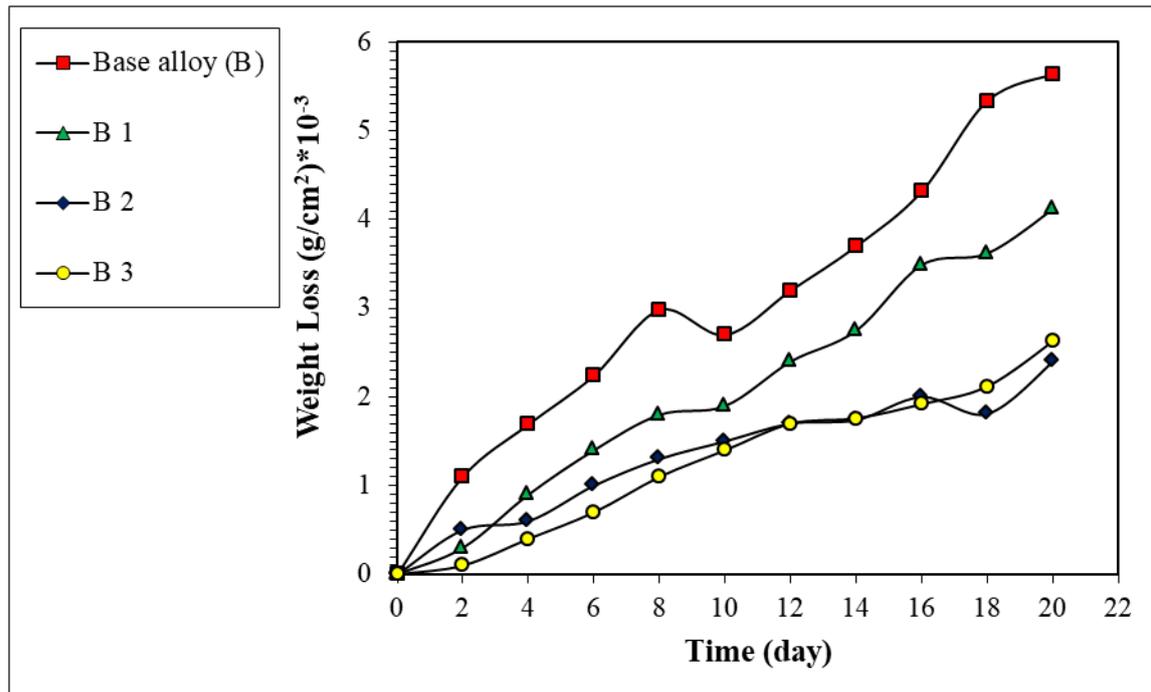


Figure (4.24): Fitting curves of simple immersion test for all specimens in salt solution for immersion period (20 days).

Table (4-3) Corrosion Rate (mmpy) for specimens in salt solution at 25°C

| <i>Sample code</i> | <i>Corrosion Rate(mmpy)</i> |
|--------------------|-----------------------------|
| <i>B</i> | <i>0.621</i> |
| <i>B1</i> | <i>0.304</i> |
| <i>B2</i> | <i>0.181</i> |
| <i>B3</i> | <i>0.201</i> |

Chapter

Five

Chapter Five

Conclusion

5.1 Conclusions

1. Corrosion resistance significantly enhanced with addition of Cr element to A319 alloy, the variation percentages comparing with base alloys are increased with addition of Cr.

2. Vickers hardness significantly enhanced with addition of Cr to A319 alloy, the variation percentages comparing with base alloys are increased with addition of Cr by (13%), (32%) and (41%) for samples of (0.5wt%Cr), (1wt%Cr) and (1.5wt%Cr) respectively.

3. Erosion corrosion rate decreased with the additions of Cr element to A319 alloy by (12%), (33%) and (40%) for samples of (0.5wt%Cr), (1wt%Cr) and (1.5wt%Cr) respectively.

4. Wear resistance significantly enhanced with addition of Cr element to A319 alloy, the variation percentages comparing with base alloys are increased with addition of Cr.

5.2. Recommendations For future works, the following is recommended

1. Studying the effect of other elements such as Zr, Ta and Y on other properties such as fatigue strength, creep strength and corrosion resistance.

2. Preparation of A319 alloy by another technique like Mold Vibration.

References

- [1] D Raymond, F Philip, 2000, "Manufacturing Feasibility of All-Aluminum Automotive Engines Via Application of High Silicon Aluminum Alloy" SAE International, Vol 61, No 1.
- [2] M. Tadashi, Oct 2000, "Advanced Near Dry Machining System, "Chief Engineer, Machine Tool R&D Division, Horkos Corp, " Effect of Silicon Particles on 43, No. 2, pp. 199 –205.
- [3] Metals Handbook, Alloy Phase Diagrams, 1990, American Society for Metals, 10th ed (Metals Park, Ohio, Vol. 3, pp 52–55.
- [4] D.C. Tsai, T.S L Lui and L.H Chen , February 2002 "Effect of silicon particles on the EDM characteristics of Al-Si .
- [5] J.L. Jorstad, 1980, "Influence of Aluminum Casting Alloy Metallurgical Factors on Machinability, "Society of Automotive Engineers, warrendale ,PA. 15096.
- [6] Y.H. Cho , Y.-R. Im, S. -W, Kwon, H.C, Lee. The effect of alloying elements on the microstructure and mechanical properties of Al-12Si cast alloys, Materials Science Forum ,426-432(2003) 339-344
- [7] L. Lasa, J. M. Rodriguez, Ibabe ,2003, wear behavior of eutectic and hypereutectic Al-Si-Cu-Mg casting alloys tested against a composite brake pad Materials science and engineering A363.193-202.
- [8] V.C.Srivastava ,R.K.Mandal ,S.N. Ojha ,2004,Evaluation of microstructure in spray formed Al-18Si alloy; Materials science and engineering A 383. 14-20.

- [9] L.L Ge,R.P.Liu, G. Li,M.Z.Ma,W.K.Wang, 2004,solidification of Al-50at.%Si alloy in drop tube ,materials science and engineering A385. 128-132.
- [10] Aibin Ma, Kazutaka SuzukNaobumi Saitoi, Yoshinori Nishida, Mokoto Takage, Ichinori Shigematsu, Hiroyuki Iwata, 2005, impact toughness of an ingot hypereutectic Al-23%Si alloy improved by Rotary Die equal-channel angular pressing: Materials science and engineering A399. 181-189.
- [11] Lina Yu Xiangfa Liu, Haimin Ding, Xiufang Bian , 2007, new nucleation mechanism of primary Si by peritectic-like coupling of AlP and TiB₂ in near eutectic Al-Si alloy;Journal of alloys and compound 432.156-162.
- [12] N. Saheby, T.Laouiz, A.R.Daudy,R.Yahayay ,and S Radiman, 2002, microstructure and hardness behavior of Ti-containing Al-Si alloys philosophical Magazine, ,VOL. 82,NO.4,803-814.
- [13] C.L.Xu ,H.Y Wang ,Y,F.Yang ,Q.C .Jiang ,2007, Effect of Al-P-Ti-TiC –Nd₂O₃ modifier on the microstructure and mechanical properties of hypereutectic Al-20%Si alloy :Material science and engineering ,A 452 -453.341-346.
- [14] Dheerendra Kumar Dwivedi ,2006, wear behavior of cast hypereutectic Al-Si alloy materials and design 27.610-616.
- [15]Jorstad, J., Apelian, D. Hypereutectic Al-Si Alloys: Practical Casting Considerations. Int. J. Met. cast. (2009).
- [16]L, Lasa, J, Rodrigucz-Jbabe, Evolution of the main intermetallic phases in Al-Si-Cu-Mg casting alloys during solution treatment,J ,Matcr, Sci , 39(2004) 1343-1355.

- [17] Shi, W., Gao, B., Tu, G., Li, S., Hao, Y. and Yu, F. 'Effect of Neodymium on Primary Silicon and Mechanical Properties of Hypereutectic Al-15%Si Alloy ', Journal of Rare Earths, Vol.28, No.1, (2010).
- [18] Hong, S.J., Suryanarayana, C., 'Mechanical Properties and Fracture Behavior of an Ultrafine-Grained Al-20 Wt % Si Alloy ', Metallurgical And Materials A, Vol. 36 ,No.13, (2005).
- [19] Mondolfo, L. M. Aluminum alloys structure and properties 338, London, Boston, Butterworth's (1976).
- [20] Z., Asghar, G. Requena, Three dimensional post-mortem study of damage after compression of cast Al-Si alloys, Mater ,Sci, Eng. A, 591 (2014) 136-143
- [21] Eskin, Dmitry G., ' physical metallurgy of direct chill casting of Aluminum alloys ' Series advances in Metallic Alloys, (2008).
- [22] Kaufman, J.G. and Roy, E.L, Aluminum alloy castings: properties, processes, and applications. ASM International, (2004).
- [23] George S. Brady, Materials handbook fifteenth edition, Vol. 15, McGraw- Hill. (1992).
- [24] Osorio, W. R., Cheung, N., Peixoto, L. C., & Garcia, A. corrosion resistance and mechanical properties of an Al 9wt% Si alloy treated by laser surface remelting', International Journal of Electrochemical Science, Vol. 4, No.6, (2009).

[25] A wham Jumea Salman, "Experimental Analysis of In- situ Composite Al-Si Eutectic Alloy", Unpublished MSc thesis, University of Babylon (2009).

[26] Deshpande, J. U. "The effect of mechanical mold vibration on the characteristics of Aluminum alloys", Unpublished PhD thesis dissertation, Worcester Polytechnic Institute (2006).

[27] R. S. Rana, Rajesh Purohit, and S Das Review on the influences of the alloying elements on microstructure and mechanical properties of aluminum alloys and aluminum composite(2012).

[28] G.T. Abdel-Jaber et al "Solidification and Mechanical Properties behavior of Al-Si Casting Alloys" International Journal of Mechanical & Mecha1tronics Engineering IJMME-IJENS Vol: 10 No: 04(2010)

[29] S.G. Shabestari, H. Moemeni Effect of copper and solidification conditions on the microstructure and mechanical properties of Al-Si-Mg alloys Journal of Materials Processing Technology (2004).

[30] F. Hernández-Méndez, A. Altamira no-Torres et "Effect of Nickel Addition on Microstructure and Mechanical Properties of Aluminum-Based Alloys".2015

[31] Davis, J. R., Corrosion of Aluminum and Aluminum alloys, Ohio,ASM International(1999).

[32] Mondolfo, L. F., Aluminum alloys: Structure and Properties, London, Butterworth's (1976).

- [33] Zhengang Liuy, Guoyin Zu, Hongjie Luo, Yihan Liu and Guangchun Yao J. Influence of Mg addition on graphite particle distribution in the Aluminum alloy matrix composites Mater. Sci. Technol, (2010).
- [34] Shubin Ren , Xinbo He, Xuanhui Qu, Islam S. Humail, Yan Li “ Effect of Mg and Si in the aluminum on the thermo-mechanical properties of pressure less infiltrated Sic/Al composites Composites” Science and Technology 67 (2007).
- [35] J. L. Murray and A.J. McAllister, Bulletin of Alloy Phase Diagrams, 5(1984).
- [36] L. Gergely V. Sandu "investigation of friction coefficient of additive engine lubricant in flaxes tester 2 "(2014).
- [37]W. D. Callister, Jr."Materials Science and Engineering An Introduction" seventh edition, Copyright © 2007 John Wiley & Sons, Inc.
- [38] Fontana, M. G.; Greene, N. D.; Corrosion Engineering, New York- Singapore, McGraw-Hill, 1967,1978,1986.
- [39] Bardal, Einar. Corrosion and protection. Springer Science & Business Media, 2007..
- [40]Groysman, Alec. Corrosion for everybody. Springer Science & Business Media, 2009.
- [41]Wallen, B.; Anderson, T.; "Galvanic Corrosion of Copper Alloys in Contact with a Highly Alloyed Stainless Steel in Sea water," 10th Scandinavian Corrosion Congress, 1986.

[42]Dexter, S. C; "Galvanic Corrosion," University of Delaware Sea Grant College Program, November, 1999

[43]Bardal, E.; Drugli, J. M.; Gartland, P. O.; "A Review: The Behavior of Corrosion Resistant Steels in Seawater," Corrosion Science, 1974,30,343- 353. 69

[44] "Practical Galvanic Series," Army Missile Command Report RSTR-67-11,1997

[45]J Kruger, GG Long, M Kuriyama, AI Goldman . "Passivity of Metals and Semiconductors." Elsevier Science Publishers: Amsterdam 163 (1983).

[46]Strehblow, H. H.; Mechanisms of Pitting Corrosion in Corrosion Mechanisms in Theory and Practice, 2nd ed., New York, Basel, Marcel Dekker, 2002.

[47]Smith, E.; Dislocations in Solids, Nabarro, F. R. N. (Ed.); New York, North Holland Publishing Co., 1979,4, 365.

[48] Kaesche, H.; The Corrosion of Metals; Physico-Chemical Principles and Actual Problems, Berlin, Springer-Verlag, 1966, 374.

[49]Combrade, P.; Crevice Corrosion of Metallic Materials in Corrosion Mechanisms in Theory and Practice, 2nd ed., New York, Basel, Marcel Dekker, 2002.

[50]Ahmad, Zaki. Principles of corrosion engineering and corrosion control. Elsevier, 2006.

[51]Hutchings, I. M.; The Erosion of Materials by Liquid Flow, Columbus, Materials Technological Institute of the Chemical Processing Industry, 1986,25.

[52]A.S. Hemza."Study of Microstructure, Corrosion and Dry Sliding Wear of Copper – Aluminum –Nickel Shape Memory Alloys ", MS.C thesis, materials engineering college, university of Babylon / Iraq (2013).

[53]L. Tan, C. Crone. Wilson and K.Sridhnan "Experimental Investigation of the Wear Behavior in Surface Modified NiTi", university of Wisconsin , Madison , USA. (2008)

[54]R. G.Bayer,Tribology Consultant " Fundamentals of Wear Failures ", J.Bijwe. Indian Institute of Technology, Delhi. (2009)

[55]S.Tahamtan and, A. Fadavi Boostani "Quantitative analysis of pitting corrosion behavior of thixoformed A356 alloy in chloride medium using electrochemical techniques" (2009).

[56]GUIJUN XUE Tribological studies of eutectic AL-SI alloys used for automotive engine blocks subjected to sliding wear damage, (2009).

[57]G. Madhusudhan Reddy and K. Srinivasa Rao "Enhancement of wear and corrosion resistance of cast A356 aluminum alloy using friction stir processing "(2010).

[58]Ahmed S. Hassan, Tamer S. Mahmoud, Fouad H. Mahmoud and Tarek A. Khalifa "Corrosion Behavior of Dissimilar A319 and A356 Cast Aluminum Alloys Joined by Friction Stir Welding (FSW)" (2010).

- [59]M. Babić, B. Stojanović, S. Mitrović, I. Bobić, N. Miloradović, M. Pantić, D.Džunić "a Wear Properties of A356/10SiC/1Gr Hybrid Composites in Lubricated Sliding Conditions" (2013).
- [60]R. Arrabal, B. Mingo, A. Pardo, M. Mohedano, E. Matykina, I. Rodríguez "Pitting corrosion of rheocast A356 aluminium alloy in 3.5 wt.% NaCl solution" (2013).
- [61]M. S. Kaiser, Swagata Dutta "Corrosion Behavior of Aluminum Engine Block in 3.5% NaCl Solution "(2014).
- [62]K. ŻABA. P. KITA, M. NOWOSIELSKI, M. KWIATKOWSKI, M. MADEJ "Influence of lubricant on wear resistance of aluminum alloy strips series 2xxx" (2015).
- [63]A.N. Farhanah*, M.Z. Bahak "Engine oil wear resistance" (2015).
- [64]H. Ghandvara, S.Farahanyb, H. Idris and M.Daroonparvard "Dry Sliding Wear Behavior of A356-ZrO₂ Metal Matrix Composite" (2014).
- [65]Prosenjit Das, Sudip K. Samanta, Himadri Chattopadhyay, Pradip Dutta, Nilkanta Barman Rheological "Characterization of Semi-Solid A356 Aluminum Alloy" (2015).
- [66]N. Beigi Khosroshahi, R. Taherzadeh Mousavian, R. Azari Khosroshahi, D. Brabazon "Mechanical properties of rolled A356 based composites reinforced by Cu-coated bimodal ceramic particles" (2015).

[67]H.K. Trivedi and D.V. Bhatt “Effect of Lubricating Oil on Tribological behaviour in Pin on Disc Test Rig”(2017).

[68] K. Sekar, M. Ravi², K. Jayakumar "Investigation of Wear and Mechanical Properties of A356-SiCp-Al₂O₃ Hybrid Composite by Stir and Squeeze casting" (2017).

[69] S. Meinathan¹ and Nitin.VR² "Effect of Cu on microstructure and mechanical properties of Mg added Al-Si-Cu (A319) alloy" (2017).

[70]E. Rincón , H.F. López b, M.M. Cisneros, H. Manchac, M.A. Cisneros” Effect of temperature on the tensile properties of an as-cast aluminum alloy A319 (2006).

[71]Requirements and the Properties for Lubricants "from Wikipedia, the free encyclopedia, <http://en.wikipedia.org>

[72] R. Arrabal , B , Mingo and I . Rodriguez ,, Pitting corrosion of rheocast A356 aluminium alloy in 3.5wt%NaCl solution ,, Corrosion Science Vol 2 , 2013 .

[73] R. Ahmed ,, The Effect of Chromium Addition on Fluidity , Microstructure and Mechanical Properties of Aluminium LM6 Cast Alloy ,, international Journal of Material Science and Research , Vol. 1, ,I.1 , ISSN : 2638-1559 , 2018 .

[74] Kutz, M. (Ed.). "Mechanical Engineers' Handbook, Volume 1: Materials and Engineering Mechanics" (2015).

[75] S. Tahamtan , A . Fadavi ,, Quantitative analysis of pitting corrosion behavior of thixoformed A356 alloy in chloride medium using electrochemical techniques " , Materials and Design , Vol.30 ,2483-2489,2009.

أخلاصه

في الاونه الاخيريه تم تطوير سبائك جديده من سبائك Al-Si وهي سبيكة A319 مع تركيب مجهري مميز للحصول على خواص افضل . مثل قابلية السباكه الجيده والتشغيل الجيد ومقاومه جيده للتآكل لاستخدامها في محركات السيارات الحديثه . وهو ابتكار من شأنه ان يعزز الية التصنيع ويوفر الكثير من الكلفه .

ان دراسة التآكل والبلى لهذه السبائك المطوره لها اهميه كبيره لتحسين خصائص هذه السبائك الحديثه المستخدمه في محركات السيارات .

في هذا البحث تم تحضير سبائك A319 بتقنية السباكه التقليديه ، ثم اضافه عنصر الكروم (Cr) الى السبيكه وبنسب مختلفه (0.5%wt , 1%wt , 1.5%wt) وذلك لدراسة تأثير هذا العنصر على البنيه المجهرية والخواص الكهروكيميائيه والميكانيكيه لهذه السبيكه.

العديد من الاختبارات اجريت لتقييم اداء هذه السبيكه بعد اضافه عنصر الكروم . اختبار المجهر الضوئي ، والمجهر الماسح واختبار فحص حيود الاشعه السينيه وفحص التركيب الكيميائي اجريت لتوصيف السبيكه.

اختبارات الصلاده اكدت ان الكروم له دور في زياده الصلاده حيث ارتفعت قيم الصلاده الى 120Hv مع نسبة الكروم 1.5%wt بينما للاساس هي 87.08Hv .

هناك زياده ملحوظه في مقاومه التآكل قد لوحظت مع اضافه عنصر الكروم الى السبيكه ، حيث في محلول (3.5wt%NaCl) انخفض تيار التآكل للسبيكه الاساس من 1.09×10^{-4} الى 3.30×10^{-8} بعد اضافه الكروم بنسبة 1wt% .

في اختبار البلى معدل البلى للاساس A319 في حالة الاستقرار هو 12×10^{-8} مقارنة مع نسبته في السبيكه المحتويه على 1.5wt%Cr حيث وصلت الى 2.30×10^{-8} في حالة الاستقرار .

سباكه A319 مع نسب مختلفه من الكروم اضهرت انخفاض واضح في قيمة الوزن المفقود في اختبار تآكل-تعريه وكما هو متوقع بسبب زياده صلاده السبيكه بعد اضافه الكروم .



وزارة التعليم العالي والبحث العلمي
جامعة بابل
كلية هندسة المواد
قسم هندسة المعادن

تحسين مقاومة التآكل لسبيكة المنيوم A319 بواسطة إضافة الكروم

رسالة

مقدمة إلى قسم هندسة المعادن في كلية هندسة المواد/ جامعة
بابل وهي جزء من متطلبات نيل درجة الدبلوم العالي في

هندسة المواد/ المعادن

من قبل

رفلاء علي شعلان عبد زيد

(بكالوريوس هندسة معادن)

(2016)

بإشراف

أ. د. نوال محمد داوود

2021م