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من قبل
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Study the Effects of Mold Type and Nano (Al_2O_3) on Some Properties of 2024 Al Alloys.

A Dissertation

Submitted to the council of the Faculty of Materials Engineering / University of Babylon in Partial Fulfillment of the Requirements for the Degree of Higher Diploma in Materials Engineering/Metallurgical.

By

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Supervised by

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2022A.M **1443 A.H**

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿يَرفَعِ اللهُ الذين آمَنُوا مِنكُمْ والذين أُوتوا

العِلْمَ دَرَجاتٍ و اللهُ بما تَعْمَلُونَ خَبِير﴾

صَدَقَ اللَّهُ الْعَلِيّ الْعَظِيم

سورة المجادلة الآية ﴿١١﴾

Dedication

To

The One whose throne is in the sky…To the One whom we praise and thank… Allah .

To

The Messenger of Allah…Mohammed (peace and blessings of Allah be upon him and his progeny) **.**

To

My Family

Acknowledgments

First of all, profusely all thanks be for *ALLAH* who enabled me to achieve this work.

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Prof.Dr.Jassim M.Salman Al-Murshdy

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Zahraa

2022

Examining Committee Approval Sheet

We certify that we have read this dissertation entitled **(Study the Effects of Mold Type and Nano (Al_2O_3) on Some Properties of 2024 Al Alloys.**) and as an examining committee, we have examined the student **(Zahraa Isam Hakeem Hatif)** in contents and that is related to it, and that in our opinion it meets the standard of a dissertation for the Higher Diploma Degree in Material's Engineering/Metallurgical Engineering.

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تعتبر سبيكة (الألومنيوم –النحاس-المغنيسيوم) إحدى سبائك الألمنيوم المهمة التي تمثل سلسلة (2xxx) ، حيث يمثل النحاس عنصر السبك الرئيسي. اعتمدت الدراسة الحالية عدة تقنيات لتحسين أداء السبيكة حيث تم تحضير اربعة انواع من السبائك بتقنية السباكة الرملية والسباكة المعدنية باضافة اوكسيد الالمنيوم النانوي (AL_2O_3)

تم إجراء الاختبارات لتقييم أداء السبائك الأربعة (A,B,C,D) والتي شملت اختبار الصلادة والبلى والبنية المجهرية باستخدام المجهر الالكتروني الماسح (SEM) والمجهر الضوئي (LOM) بينت النتائج المستحصلة في هذا البحث بان اضافة اوكسيد الالمنيوم النانوي للسبائك المسبوكه بطريقتي الرملية والمعدنية اظهرت ارتفاعا في قيم الصلادة بمقدار (157.155) للسباكة المعدنية و(135.475)للسباكة الرملية ،كما بينت النتائج ارتفاعا في تحسين قيم البلى للسبائك المسبوكة بطريقة السباكة المعدنية عن السباكة الرملية حيث كان مقدار التحسن في البلى للسبكة المعدنية افضل من البلى في السباكة الرملية من خلال الفقدان بالوزن .كما بينت النتائج من خلال صور البنية المجهرية للمجهر الالكتروني الماسح تجانس في الحبيبات من خلال الترسبات الموجودة في السبائك المستخدمة في البحث كما بينت صور البنية المجهرية للمجهر الضوئي توزيع منتظم للحبيبات بتاثيرات الاضافات النانوية لكل السبائك المستخدمة .

Abstract

The (Aluminum-Cu-Magnesium) alloy is one of the important aluminum alloys representing the (2xxx) series, with copper being the main alloying element. The current study adopted several techniques to improve the performance of the alloy. Four types of alloys were prepared with the technique of sand casting and metal casting by adding nano-aluminum oxide (Al_2O_3).

The tests were conducted to evaluate the performance of the four alloys (A, B, C, D), which included the test of hardness, wear and microstructure using scanning electron microscopy (SEM) and optical microscopy (LOM). The results obtained in this research showed that the addition of nano-aluminium oxide to the alloys cast by the sand and metal methods showed an increase in the hardness values by (157Hv) for the metal casting and (135Hv) for the sand casting. The improvement in the wear of the metal alloy was better than the wear in the sand casting through weight loss. The results also showed through the microstructure images of the scanning electron microscope homogeneity in the grains through the sediments in the alloys used in the research as the microstructure images of the light microscope showed Uniform distribution of granules with the effects of nano-additives for all alloys used.

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List of Abbreviations

OM	Optical Microscope
XRD	X-Ray diffraction
XRF	X-Ray fluorescent
SEM	Scan electron microscope
α	Alpha phase
Hv	Vickers hardness

Chapter One

Introduction

1.1 General View

Aluminum and its alloys occupy a wide position in the aerospace industries due to their good engineering properties and a high value of (strength / weight) ratio, as these ratios make these materials suitable for the aerospace industries.

The properties of aluminum change negatively or positively when certain alloying elements are added. Therefore about three-fifths of the aluminum produced in the world is consumed to manufacture aluminum alloys, to meet the need for certain properties, Most aluminum alloys contain at least 87% of aluminum. The main alloying elements added to aluminum are copper, zinc, magnesium, silicon, lithium, manganese and others [1].

The aerospace industries always required materials with light weight, high strength, thermal stability and corrosion resistance [2].

Aluminum alloys of the (2XXX) Duralumin, including the base alloy (Al - Cu - Mg) have good mechanical properties, in addition to their low density (2.70 g / cm^3). However, the development in the aerospace industry has created a continuous need for lighter alloys. Higher weight and thermal stability qualifies it for service at temperatures higher than (150 ºC). This means increasing the operating range of aircraft and spacecraft, improving flight characteristics and reducing fuel consumption [3].

In general, the alloying elements added to aluminum improve the properties of strength, hardness and cast ability, but other properties are affected by these additions such as ductility, formability, workability, and weld ability [4].

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1.2 Aluminum

Aluminum ores ranks first among all minerals in terms of abundance in nature, and it constitutes approximately (8%) of the weight of the earth's crust. So far, more than (250) metallic materials containing aluminum have been known in nature. And as soon as it was discovered practically, and economically reached to extract it from its raw materials, it actively participated in various aspects of civil and military life and, became one of the most important engineering materials [5].

Aluminum is distinguished by its light weight, where its density almost one-third of the density of steel, which makes it suitable for good thermal and electrical conductivity in many industrial applications, it has a good strength to weight ratio, good ductility and excellent corrosion resistance. It is extruded in any way, and has a strong ability to combine with oxygen and form a thin layer that protects the outer surface of the metal [6].

Table (1-1) some properties of the aluminum metal [7].

Symbol of Element	**Al**
Atomic Number of Aluminum	**13**
Atomic Mass	**26.98amu**
Melting point	**660.37 °C (933.37 K)**
Boiling point	**2467.0 °C (2740.0 K)**
Crystal Structure	**F.C.C**
Density at 293K	**2.70 $g.cm^{-3}$**
Color of Aluminum	**Silver**

1.3 History of Aluminum-Copper-Magnesium Alloys

The heat treatable aluminum-copper-magnesium alloy with composition Al-4% Cu-0.6% Mg which reported by Wilms A., (1911) and designated as AA 2017 is now limited in use. Some of heat treatable alloys AA2014 and AA 2024 were available in 1920's to 1930's remains in use today [1]. The AA 2014 was developed by adding alloy characteristics with silicon to make it more responsive to artificial aging than AA 2017. This response to artificial aging provides a desirable high level of strength unattainable in naturally aged AA 2017 or AA 2014. Although, alloy AA 2014 was used initially as a high-strength forging alloy to replace AA 2025, it is now available in a range of wrought products and widely used in structural applications. Alloy AA 2024 was introduced in the 1930's as a higher strength, naturally aged alloy to replace AA 2017 in the aircraft field. It is one of the outstanding structural alloys in the industry. The hardening phase in AA 2024 is a complex phase of aluminum, copper and magnesium, rather than the copper-aluminum phase of AA 2017. Mozely (1943) has response to artificial aging of several 2XXX series alloys in excess of levels normally required for flattening, straightening, and stress relieving [9] Dix, et al. (1945) reported that strength of such material after artificial aging markedly improved.. 2.0 Aluminum 6 series alloys Aluminum 6 series alloys are the most important alloy in Aluminum alloy family due to its heat

1.4. The aim of the research

The current research has the following aims:

1. Improving the mechanical properties of this plumbing by adding ceramic materials and a composite material of alumina as well as studying the effect of cooling rates on the properties using sand and metal molds.

2. Preparation of the base alloy (Al-Cu-Mg) Duralumin with the addition of 0.5wt% of Al_2O_3.

3. Examination of (Al-Cu-Mg) Duralumin ingots in sand mold and metal mold.

4. Examination of (Al-Cu-Mg) Duralumin ingots in sand mould and metal mold with addition of Al_2O_3.

5. Study the mechanical properties such as micro-hardness and wear,

6. Study the microstructure of alloys using optical microscopy.

7. characterization of material using Scanning electron microscopy (SEM).

8. Comparison between sand Mould and metal Die casting on microstructure and properties of Al-alloys.

Chapter Two

Theoretical and Literature Review

2.1. Introduction

This chapter presents a brief review on aluminum and its alloys, their classifications. it study the sand casting and die casting of Al-alloys.

2.2. Classification of Aluminum Alloys

Aluminum alloys are normally classified into two major categories: cast alloys and wrought alloys, each of these categories are divided into two groups: heat treatable and non-heat treatable alloys [8].

2.2.1 The Wrought Non-Heat Treatable Alloys

Wrought aluminum alloys are shown in Table (2.1) represent the alloys that have undergone certain working processes. Wrought alloys produced by thermo mechanically processing cast ingot into mill products such as billet, bar, plate, sheet extrusions, rods and wire [9]. Wrought non-heat-treatable alloys cannot be strengthened by precipitation hardening, but they can hardened primarily by cold working. They include the commercially pure aluminum series (1xxx), the aluminum-manganese series (3xxx), the aluminum-silicon series (4xxx), and the aluminum-magnesium series (5xxx). While some of the 4xxx alloys can be hardened by heat treatment, others can only be hardened by cold working [10]

2.2.2 Wrought heat treatable alloy

Can be precipitation hardened to develop quite high strength levels. These alloys include the 2xxx series (Al-Cu and Al-Cu-Mg), the 6xxx series (Al-Mg-Si), the 7xxx series (Al-Zn-Mg and Al-Zn-Mg-Cu) and the aluminum-lithium alloys of the 8xxx alloy series. The 2xxx and 7xxx alloys, which develop the highest strength levels, are the main alloys used for metallic aircraft structure [11].

2.2.3. Cast Alloys

Cast aluminum alloys have relatively low melting temperatures when compared to steel and cast iron. They have negligible solubility for gases except hydrogen, good fluidity and good surface finishing. However, these alloys suffer from higher shrinkage (up to 7%) which occurs during cooling or solidification. Cast aluminum alloy are shown in Table (2.1), This group includes both non-heat-treatable and heat treatable alloys. The major categories include the 2xx.x series (Al-Cu), the 3xx.x series (Al-Si +Cu or Mg), the 4xx.x series (Al-Si), the 5xx.x series (Al-Mg), the 7xx.x series (Al-Zn), and the 8xx.x series (Al-Sn). The 2xx.x, 3xx.x, 7xx.x, and 8xx.x alloys can be strengthened by precipitation hardening, but the properties obtained are not as high as for the wrought heat treatable alloys [12]

Table (2-1) cast aluminum alloy [12]

Alloy Series	Principal Alloying Element
1xxx	99.000% minimum Aluminum
2xxx	Copper
3xxx	Silicon Plus Copper and/or Magnesium
4xxx	Silicon
5xxx	Magnesium
6xxx	Unused Series
7xxx	Zinc
8xxx	Tin
9xxx	Other Elements

2.3. Effects of Cu as Alloying Element in Al-Alloys

The aluminum-copper alloys typically contain (2~5.65wt %) copper, with smaller additions of other elements. The copper provides substantial increases in strength and facilitates precipitation hardening. The introduction of copper to aluminum can also reduce ductility and corrosion resistance. The susceptibility to solidification cracking of aluminum-copper alloys are increased consequently, some of these alloys can be the most challenging aluminum alloys to weld. These alloys include some of the highest strength heat treatable aluminum alloys. The most common applications for the 2xxx series alloys(Al-

Cu alloys) are aerospace, military vehicles and rocket fins [13]. Both cast and wrought aluminum-copper alloys respond to solution heat treatment and subsequent aging with an increase in strength, hardness, and a decrease in elongation. The strengthening effect is maximum between (4 - 6% Cu), depending upon the influence of other constituent's present. The aging characteristics of binary Aluminum- Copper alloys have been studied in greater detail than any other system, but there are actually very few commercial binary aluminum-copper alloys. Most commercial alloys contain other alloying elements 2xxx wrought alloys and 2xxx casting alloys, in which copper is the major alloying element, are less resistant to corrosion than alloys of other series, which contain much lower amounts of copper. Copper is one of alloying additions that significantly increase solid solution strength [14].

The presence of copper strengthens the aluminum at elevated temperature, but it has less effect than the higher solid solubility elements, alloys AA 2014 (Al-3.9~5wt%Cu), 2024 (Al- 4.3~4.5wt%Cu -0.5~0.6wt%Mn- 1.3~1.5wt%Mg) and AA 2017 (Al-4wt%Cu) result in increasing the hardness [15, 16].

2.3.1. Solidification of Al-Cu Alloys

The solidification path of a dilute Al–Cu alloy was studied using controlled solidification conditions and thermal analysis. Under equilibrium considerations, below the limit of maximum solubility, a unique α phase is expected, rounded by rich non eutectic composition as show in Figure (2.1)

The precipitation of the second phase θ is present even for dilute compositions, fundamentally favored by segregation in the liquid and instabilities in front of solidification.

The maximum solubility of copper in the α solid solution is 5.65 percent at the eutectic temperature of 548°C, and the solubility decrease to 0.45 percent at 300°C. Although the solvas line shows lower solubility at lower temperatures, these alloys are generally not heat treatable [17].

The solidification of Al-Cu alloys is very important as it controls final microstructure which in turn controls the mechanical properties.

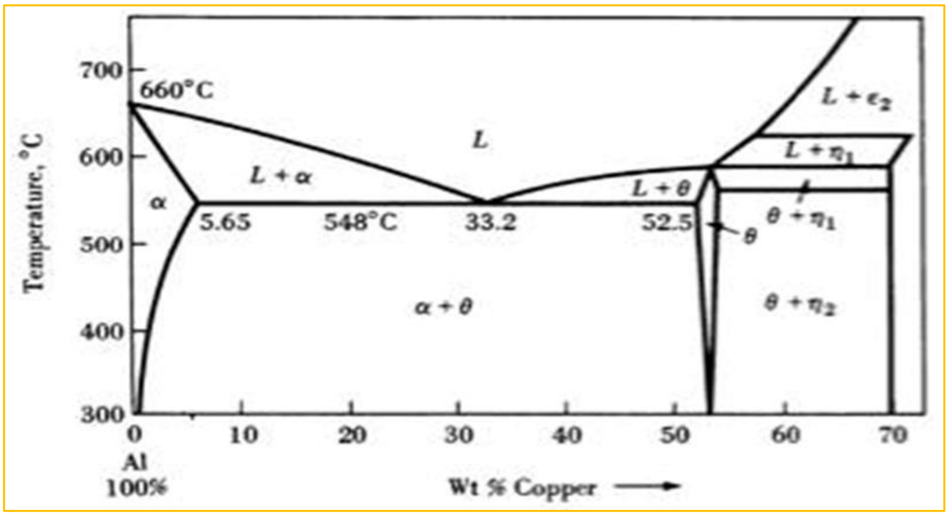


Fig (2-1) Thermal equilibrium diagram of Al- Cu alloys [15].

In general, solidification of an alloy occurs in two stages: nucleation and growth. In the nucleation stage, stable nuclei are formed into the liquid metal and the subsequent growth of these nuclei into crystals and the formation of the final grain structure.

Two types of grain structures may be formed upon solidification: columnar and equiaxed grains as shown in Figure (2.2) equiaxed grains form as a result of equal growth in all directions of the crystal , while columnar grains are present as thin, long structures which grow under a temperature gradient during slow solidification in a direction opposite the heat flow.

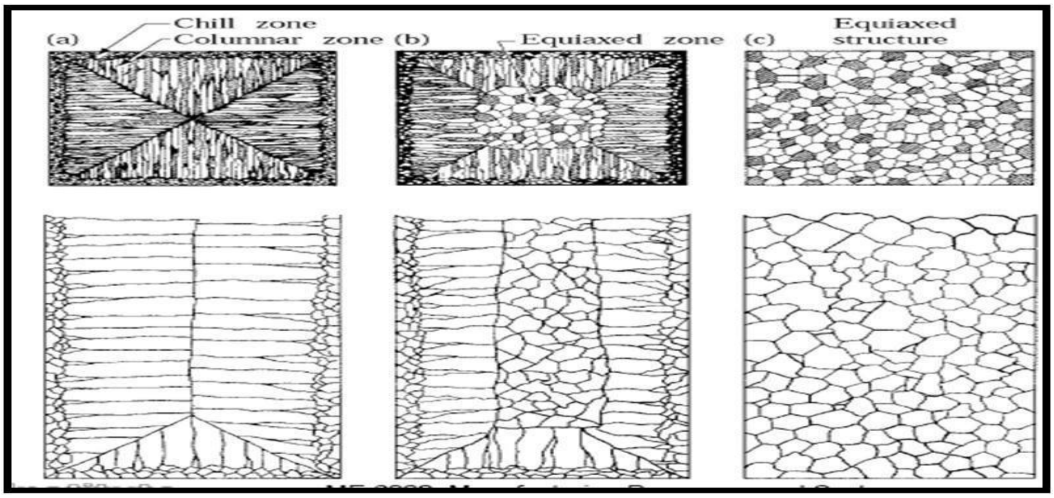


Figure (2-2): Types of microstructures that may form

The preferred structure of a casting is one that has small equiaxed grains, since this type of structure improves feeding, resistance to hot tearing and enhances the mechanical properties. Producing such grains can be achieved through control of the solidification conditions or by the use of grain refiners [18, 19]

2.4 Aluminium oxide

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Nano(Al_2O_3). It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium(III) oxide. It is commonly called alumina and may also be called aloxide, aloxite, or alundum depending on particular forms or applications. It occurs naturally in its crystalline polymorphic phase α-Al_2O_3 as the mineral corundum, varieties of which form the precious gemstones ruby and sapphire. Nano(Al_2O_3) is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point [20].

2.5 (Aluminum - Copper - Magnesium) Alloys

This group includes aluminum alloys that contain copper with a small percentage of magnesium and are distinguished by their ability to harden by aging. With this treatment, a tensile strength of not less than (400 N/mm^2) can be achieved and the resistance against forming increases with addition of manganese and silicon. The ability of these alloys to solidify depends on alloying elements such as copper, magnesium, silicon and zinc. These elements accept solubility, singly or in combination, better in aluminum at higher temperatures than at room temperature [21].

The main thanks to the properties of these alloys is due to the treatment of the originals by precipitation, and the resulting properties are characterized by their high stability. Due to the containment of these alloys on copper, they are not resistant to corrosion except under certain conditions, especially against water, sea air and basic solutions. When there is an urgent need to resist corrosion, the products of these alloys are encapsulated with a layer of pure or high purity aluminum or other corrosion-resistant aluminum alloy [22].

The most important areas of using these alloys are summarized as follows:

1 - For constructions when high mechanical properties are required.

2 - In the manufacture of cars, machinery and ships.

2.6 Effects of Alloying Elements

2.6.1 Magnesium

Small additions(0.25-0.5 %) of Mg allow Al-Si or Al-Cu alloys to be hardened by heat treatment, improving mechanical properties through the precipitation of Mg_2Si in a finely dispersed form. Their proof stress can be almost doubled **[23]**. In general terms. It has been reported that a higher Mg content increases the yield stress while decreasing the ductility, the fracture toughness, its major effect on the age-hardening potential **[24]**. As well as, magnesium dissolved in aluminum renders it more anodic although dilute Al-Mg alloys retain a relatively high resistance to corrosion; particularly to sea water and alkaline solutions **[25]**, give a bright surface finish for decorative components. Besides, the presence of Mg increases the oxidation losses of liquid aluminum **[26]**.

2.6.2 Copper

Copper improves strength, hardness, machinability and thermal conductivity. Heat treatment is the most effective respectively with 4-6% Cu alloys. It decreases cast ability and hot tear resistance together with corrosion resistance **[27]**. Copper reduce the corrosion resistance of aluminum more than any other alloying element and this arises mainly because of its presence in micro-constituents. However, it should be noted that when added in small amounts (0.05-0.2%), corrosion of aluminum and its alloys tends to become more general and pitting attack is reduced **[28].** An addition of Cu to Al-Mg-Si alloys decreases the width of precipitate free zones and increases the total elongation of the alloys **[29].**

2.7 Applications of Al-Cu-Mg alloys

Aluminum is a silvery gray metal that possesses many desirable characteristics. It is light, nonmagnetic and non-sparking. It stands second among metals in the scale of malleability, and sixth in ductility. It is extensively used in many industrial applications where a strong, light, easily constructed material is needed. Elemental Aluminum although has only 60% of the electrical conductivity of copper, it is used in electrical transmission lines because of its light weight. Pure aluminum is soft and lacks strength, but alloyed with small amounts of copper, magnesium, silicon, manganese, or other elements it imparts a variety of useful properties [30]

High strength, low weight alloy; in the solution heat-treated and aged condition, mechanical properties are as good as, or better than, low-carbon steel, Limited weld ability. Used in aircraft and aerospace applications, Poor corrosion resistance [31].

2.8 Sand Casting

Sand casting is widely used because this process is simple, and almost any material can be cast, no limit to size, shape or weight, low tooling cost. The basic steps of sand casting process are:

1- Selection suitable sand to create sand mould and to control on quality of casting.

2- Put pattern from wood or metal in sand to create mould cavity.

3- Do small hammering on the sand to make stability of the pattern.

4- Remove the pattern.

5- Fill the mould cavity with molten metal.

6- Allow the molten metal to solidify

7- Break the sand mould and remove the casting product. The sand casting process is usually economical for small batch size production, but with small limitations, some finishing required, small coarse finish, wide tolerances.

The quality of the sand casting depends on the quality and uniformity of green sand material that is used for making the mold. Figure (2-4)show schematically the two of parts of sand mold, also referred to as a cope and drag sand mold. The molten metal is poured through the pouring cup and it fills the mold cavity after passing through down spruce, runner and gate. The core refers to loose piece which are placed inside the mold cavity to create internal holes or open section. The riser is used as a container or reservoir to excess molten metal that facilities additional filling of mold cavity to compensate for volumetric shrinkage during solidification. Sand castings process provides several advantages. It can be employed for all types of metal. The tooling cost is low and can be used to cast very complex shapes. However sand castings offer poor dimensional accuracy and surface finish. The main components of any molding sand are:

(a) Silica sand (SiO_2) 80.8%

(b) Alumina (Al_2O_3) 14.9%

(c) Iron oxide (Fe_2O_3) 1.3%

(d) Combined water 2.5%

(e) Other inert materials 1.5%

The molding sand should possess the following properties:

1. Porosity or permeability: It is that property of sand which permits the steam and other gases to pass through the sand mold. When hot molten metal is poured into the sand mold, it evolves a great amount of other gases while coming in contact with the moist sand. If these gases do not escape completely through the mold, the casting will contain gas holes and pores. Thus, the sand from which the mold is made must be porous or permeable. The porosity of sand depends upon its grain size, grain shape, and moisture and clay contents in the molding

sand. The quality of sand has directly affects to the porosity of the mold. If the sand is too fine, its porosity will be low.

2. Plasticity: It is very important to made a mold, that property of sand due to which it flows to all portions of the molding box and taken a predetermined shape under hammering pressure and keep this shape when the pressure is removed. The sand must have sufficient plasticity to produce a good mold. The plasticity is increased by adding water and clay to sand.

3. Adhesiveness: It is the property of sand due to which it adheres to the sides of the molding box. Good sand must have sufficient adhesiveness so that heavy sand masses can be successfully held in molding box without any danger of its falling out when the box is removed.

4. Cohesiveness: It is that property of sand due to which the sand grains stick together during ramming. It may be defined as the strength of the molding sand. It is of the following three types,

(a) Green strength: The green sand, after water has mixed to it, must have suitable

strength and plasticity for making of mold. The green strength depends upon the grain shape and size, amount and type of clay and the moisture content.

(b) Dry strength: When the molten metal is poured, the sand adjacent to the hot metal quickly loses water content as steam. The dry sand must have the strength to resist of erosion and also the pressure of the molten metal, otherwise the mould may increase.

(c) Hot strength: After the moisture has evaporated, the sand may be required to possess strength at high temperature, above 100°c. If the sand does not possess hot strength, the pressure of the liquid metal bearing against the mold walls may cause mould enlargement or if metal is still flowing, it may cause erosion, cracks or breakage.

5. Refractoriness: It is that property of the sand which enables it to resist high temperature of the molten metal without breaking or fusing. The higher pouring

temperature, such as those for ferrous alloys, requires great refractoriness of the sand. The degree of refractoriness depends upon the quartz contents, and the shape and grain size of the particles.

6. Flowability: It is the property of sand due to which it behaves like a fluid so that, when rammed, it flows to all portions of a mould and distributes the ramming pressure equally. Generally, sand particles resist moving around corners. In general, flowability increases with decrease in green strength and decrease in grain size. It also varies with moisture content [32].

2.9 Die Casting

Die casting is a permanent-mold casting process in which the molten metal is injected into the mold cavity under high pressure. Used for low melting point (non-ferrous) metals.

Die casting is a manufacturing process that can produce geometrically complex metal parts through the use of reusable molds, called dies, hence the name die casting. This process is a further development of Permanent – mold casting.

1. A permanent mold casting process in which molten metal is injected into mold cavity under high pressure, typical pressures are (7 to 350 MPa).
2. Pressure is maintained during solidification, then mold is opened and part is removed.
3. Use of high pressure to force metal into die cavity is what distinguishes this from other permanent mold processes. It differs from sand casting. Sand casting uses a mold made of sand which is a poor conductor of heat, so the cooling process is very slow, molten metal is simply poured into the mold and the mold is expendable. In permanent mold casting, by contrast, the mold is made from steel or other metal which is a good conductor, so the cooling is fast, it can be reused and the molten metal is being injected [33].

2.9.1 Die Casting Machines

Die casting operations are carried out in special die casting machines which is designed to hold and accurately close two mold halves and keep them closed while liquid metal is forced into cavity Figure(2-3).

There are four key steps in the process of die casting, the die casting machine should be at the required temperature, to ensure the molten metal not to solidify too quickly. According to the size of the casting, heating can take from several hours to several minutes. The four steps are:

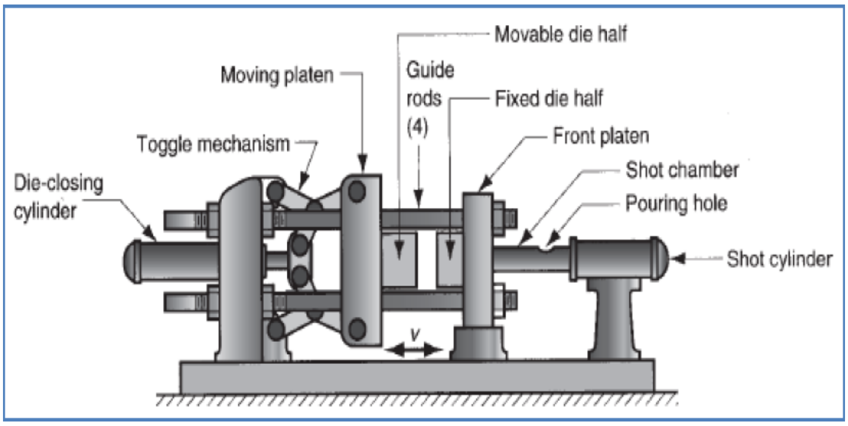


Figure (2.3) General configuration of a Die Casting machine

1) Spray the mold with lubricant and close it, allowing for an easier removal of the cast object later on.

2) Inject the molten metal into the die. The metal is inserted at an extremely high pressure, which allows the metal to conform to the precise shape of the die. Air escapes into overflow wells, and out vents, and metal fills the molds

3) Cool the mold, and wait for the metal to solidify. In some cases, the mold may be immersed or sprayed with cold water to help the casting become solid faster. A high pressure is maintained inside the mold, which ensures the metal doesn't change properties while inside the die.

4) Open the two molds halves and remove the solid cast by knockout pins eject the part. The parts are cut off the runners and sprues.

There are two main types of Die – Casting machines:

1. Hot-chamber machine.
2. Cold-chamber machine.

2.9.2 Hot-Chamber Die Casting

Metal is melted in a container, and a piston injects liquid metal under high pressure into the die see Figure (2-4)

High production rates - 500 parts per hour not uncommon [33].

- ✓ Applications limited to low melting-point metals (approximately 400^{o}C) that do not chemically attack plunger and other components due to the hot metal that is poured in to them.
- ✓ Casting metals: zinc, tin, lead, and magnesium.
- ✓ With die closed and plunger withdrawn, molten metal flows into the chamber.
- ✓ Plunger forces metal in chamber to flow into die, maintaining pressure during cooling and solidification.

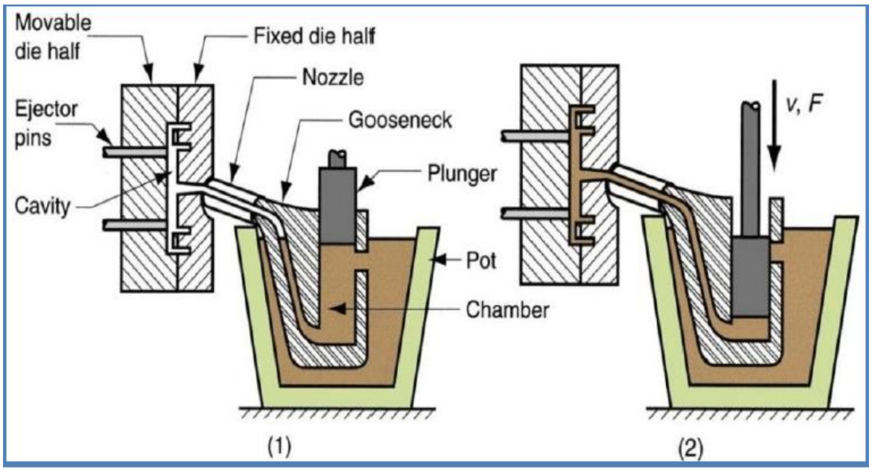


Figure (2.4) Cycle in hot - chamber casting.

2.9.3 Cold Chamber Die Casting Machine

Molten metal is poured into unheated chamber from external melting container (ladle), and a piston injects metal under high pressure into die cavity at pressure as much as (10 times) than that in the Hot – Chamber process, see Figure (2-7)

- High production but not usually as fast as hot-chamber machines because of pouring step
- Casting metals: aluminum, brass, and magnesium alloys.
- Advantages, its use on low melting-point alloys (zinc, tin, lead) can also be cast on cold-chamber machines, but the advantages of the hot-chamber process usually favor its use on these metals.

Figure (2-5) shows the steps of this process:

(1) With die closed and ram withdrawn, molten metal is poured into the chamber.

(2) Ram forces metal to flow into die, maintaining pressure during cooling and solidification.

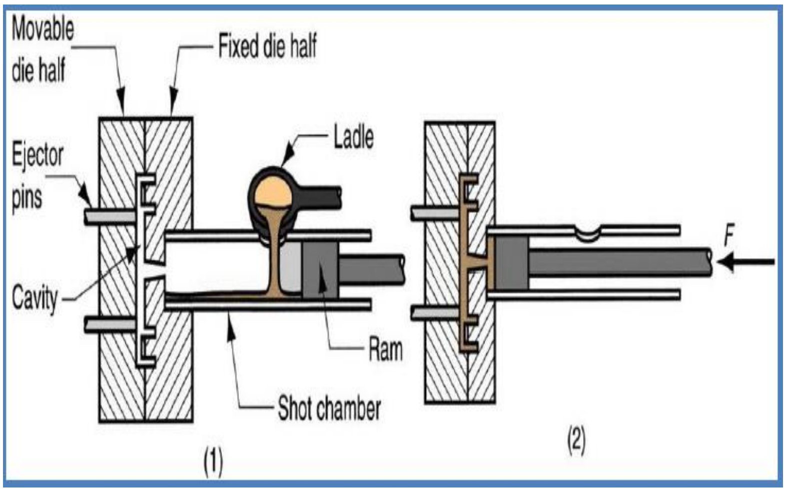


Figure (2-5) Cycle in cold-chamber casting.

2.9.4 Molds for Die Casting

- Usually made of tool steel, mold steel, or managing steel (a strong tough low-carbon martensitic steel which contains up to 25 percent nickel and in which hardening precipitates are formed by aging)
- Tungsten and molybdenum (good refractory qualities) used to die cast steel and cast iron.
- Ejector pins required to remove part from die when it opens.
- Lubricants must be sprayed into cavities to prevent sticking.

Die casting, Economical for large production quantities, good accuracy and surface finish, Thin sections are possible, Rapid cooling provides small grain size and good strength to casting.

Disadvantages of die casting are generally limited to metals with low metal points, Part geometry must allow removal from die, Metal dies must withstand high pressures, and Die life is shortened by extreme temperature fluctuations.

2.10 Literatures Survey

Aluminum can be casted with many metallic elements for the purpose of improving some properties. Copper and magnesium are considered among the basic alloying elements in aluminum [1]. Many researches have been conducted in the field of improving aluminum-based alloys (Al – Cu – Mg), and the following are some studies in this aspect:

Macchi et al. (2012) [34].studied Three of the aging processes in an aluminum-copper-magnesium alloy with different ratios of copper / magnesium, using Vickers hardness as a function of artificial aging time at (175 ^{o}C), and they found that the complementary information on the decomposition series by means of a differential thermal scanning calorimeter (DSC), as well. They found that the Vickers hardness increased with increasing the aging time to a certain extent and that the greatest hardness was for the alloys that had a higher copper content than the magnesium percentage.

Cooke et al. (2012) [35] improved the properties of (Al-Cu-Mg) alloy with different proportions of (Cu / Mg) using powder metallurgy technology. and The largest percentage that discovered for the purpose of developing the alloy was (Al -2.3Cu - 1.6Mg). The results showed that the response of the alloys was a natural response to pressure in a uniaxial direction with the performance that was in line with the commercial alloys. The density of the prepared alloys was also calculated and found to be almost equal to the theoretical values. The alloys also showed response to the heat treatment (T6) at aging temperature of (200 ºC) for (20 hrs.).

Zhou (2012) [36] studied the solidification behavior in the multi-element (binary and trinary) systems of (Al-Cu-Ag) and (Al-Cu-Mg) alloys, where a quadruple model system was proposed and the energy dispersive spectrum was used EDS)(Energy Dispersive Spectrometry) and Differential Scanning Calorimetry (DSC). The microstructure of the alloys was also studied using the Scanning Electron Microscope (SEM). Eutectic dendrites, the growth of dendritic stages was also depicted in the microstructure of the alloy

Al- Maamori et al. (2013) [37] studied the most important characteristics of aluminum is light weight, durability, and portability recycle ability , rust resistance, ease of handling, susceptibility to the formation and electrical conductivity. As a result of this topic characteristics of aluminum became its use is necessary in our lives so that we cannot aviation, or ride a valuable trains and fast cars as he cannot get heat and electricity in our homes without it. results Showed that have been reached in this study the possibility of measuring mechanical properties using ultrasound technology.

Musa et al. **(2014) [38]** used several techniques to improve properties of the alloy (Al – Cu – Mg) using alloying elements such as (B) and (Ti). Four different types of alloys were prepared and heat treated using homogenizing treatment and artificial ageing with various temperatures (150ºC,175ºC,200ºC) and with different periods. Results showed that the addition of (1.0% Ti) to base alloy and using artificial ageing at (200 ºC) improves Vickers hardness by (82.12%) compared to the base alloy. The optical microscope examination for alloys after casting after homogenization and after all the operations of artificial ageing showed change in microstructure during the early stages mentioned and the emergence of new phases in the structure of alloys .

Avendaño et al. (2014) [39] evaluated the effect of the silver content on Al-Cu based alloys on the microstructure, the tensile strength, the electrical resistance , For that purpose, Al-4% Cu-0, 5% Mg alloys were tested with silver content in percentages of 1.5%, 2.5% and 3.5%. Precipitation hardening was carried out after homogenization heat treatment of solid solutions. The microstructure analysis was carried out using optical microscope and SEM . Vickers hardness tests were also performed and tests of tensile strength and electrical conductivity, which were compared with the alloy A356-T6. The results showed that the increase of silver in the alloy increased tensile strength and decreases the resistivity. By SEM and EDS analysis the phase Ө ($CuAl_2$), Al_6 (Cu, Fe) and Al_7Cu_2Fe were observed.

Alkubasy et al. (2015) [40] studied the effect of addition (0.3,0.6,0.9%) of pure (Ca) on the microstructure and mechanical properties of Al-Cu-Mg alloy. The Alloys were produced using sand casting and heat treated using (T6) treatment at 220º C for different periods. The results of hardness and tensile tests for (0.6% Ca) and 4 hrs. aging time showed the best response as compared with the other alloys. The hardness and strength values have been changed from (78.29HV), (110.57MPa) after aging for (30min) at 220ºC for (Ca -free) alloy to (125.9HV),(164.2Mpa) for (0.6%C) alloy. X-Ray diffraction, results show that the basic phase that forms is Al_2CuMg (S``, S` phase) and it was found that (Ca) addition leads to form (Al_4Ca) and (Al_2Ca) which delay the alloy response to precipitation hardening by delaying the formation of (S)phase. Also (Ca) addition in the range of (0.3- 0.6%) gives the refining effect. While increasing Ca content up to 0.9%wt has resulted in a reduction in the grains refining which leads to a decrease in hardness and tensile strength.

Singh et al. (2016) [41] studied the microstructure and mechanical properties of LM 25 Alloy produced by liquid metallurgical route under as-cast and T6 heat treatment conditions. Results showed that, eutectic silicon, α-Al primary and Mg_2Si were the main phases in the microstructure of LM 25 alloy produced by liquid metallurgical route. The hardness, ultimate tensile strength, yield strength and Elongation of LM 25 alloy under T6 heat treatment improved by 14.8%, 49%, 73% and 18% respectively as compared to as-cast conditions.

Guannan Guo (2017) [42] Applied typical T6 heat treatment process to improve the properties of aluminum alloy in order to facilitate the formation of prime strengthening precipitate phases. Critical steps in T6 heat treatment process include solution treatment, quenching and aging. Due to the high thermal gradients in quenching process and aging process, large thermal stress will remain in the matrix and may bring unexpected deformation or distortion in further machining. Therefore, in order to predict the thermal stress effects, constitutive model and precipitate hardening model are needed to simulate the mechanical properties of alloy. Quench factor analysis method was applied to describe the microstructure evolution and volume fraction of primary precipitate phases during quenching process. Classical precipitate hardening models were reviewed and two models were selected for Al-Cu-Mn alloy aging treatment. Thermal growth model and Euler algorithm were used to improve the accuracy and the selected precipitate hardening models were validated by yield stress and microstructure observations of Al-Cu-Mn aging response experiments.

Miyake et al (2017) [43] examined microstructures and formability of scandium and zirconium added to Al-Mg-Mn alloy sheets with various heating conditions to improve their mechanical properties. Formability of these samples were judged by the Lankford value, r-value. It was possible to fabricate mechanically balanced Al-Mg-Mn-Sc-Zr alloy with high hardness76.2 HV and with high formability, with r = 1.2, by not only adding scandium and zirconium but also optimizing the heat treatment conditions.

Zhang et al (2017) [44] Selective laser melting (SLM) was used to fabricate Al-Cu-Mg alloy and Zirconium-modified Al-Cu-Mg alloy components. The hot-cracking phenomena during the SLM process was significantly reduced by the grain refining effect caused by the addition of Zr. Compared to the Al-Cu-Mg part, the Zr-modified Al-Cu-Mg part with the ultrafine grain exhibits increased yield strength (446 ± 4.3 MPa) and ultimate tensile strength (451 ± 3.6 MPa). These findings provide a basis for innovative alloy design for SLM.

Canyooket al.(2018) [45] studied the effects of heat treatment on microstructure and mechanical properties of rheocasting ADC12 aluminum alloy produced by gas induced semi-solid (GISS) technique. The solution heat treatment performed at a temperature of 520°C under various solution treatment times (2, 4, 6, 8, 10, and 12 h) and followed by water quenching at room temperature. The results showed that the optimum solution heat treatment condition for the non-dendritic structure of ADC12 aluminum alloy was 520°C for 8 h. The age hardening was also carried out at 170°C for different aging times of (6, 8, and 10 h) . It was found that the artificial aging at 170°C for 6 h was sufficient to achieve the highest hardness of 73.2 HRB. This was due to the appropriate refinement of acicular eutectic structure.

Zamani et al (2019) [46] used Thermo-Calc software to design optimal alloy compositions and heat treatment parameters for Al–Cu–(Mg–Ag) cast alloys (2xxx) having different microstructural scales. Differential scanning calorimetry (DSC), scanning electron microscopy and wavelength-dispersive spectroscopy technique were employed to determine proper solution heat treatment temperature and homogenization time as well as incidence of incipient melting. Proper artificial ageing temperature for each alloy was identified using DSC analysis and hardness measurement. Microstructural scale had a pronounced influence on time and temperature required for complete dissolution of Al_2Cu and homogenization of Cu solute atoms in the α-Al matrix. Addition of Mg to Al–Cu alloys promoted the formation of phases. Presence of Ag decreases the melting temperature of intermetallic (beside Al_2Cu) and improvement in age-hardening response.

HwaLee et.al. (2021) [47] studied the effects of addition of 0.1 wt% Ti on the microstructure and mechanical properties of Al–7.6Zn–2.6Mg–2.0Cu–0.1Zr alloy during solidification, extrusion, solution treatment, and aging. The addition of Ti reduces the grain size and degree of phase agglomeration during solidification, thereby improving the strength and ductility of the as-cast alloy. The extrusion forms a bimodal structure consisting of fine dynamically recrystallized (DRXed) grains and coarse elongated unDRXed grains. Ti induces the refinement of the η-phases. The dissolution of the η-phase occurs in the initial stages of the solution treatment, followed by coarsening of the η-phase. The solution treatment causes static recrystallization and grain growth, increasing the grain size. The addition of Ti also enhances heterogeneous nucleation of η-$Mg(Zn,Cu,Al)_2$ at the $Al_{18}Mg_3Ti_2$ interface and grain boundary.

Chapter Three

Experimental Work

3.1. Introduction

This chapter provides a view of the experimental work and shows all the conditions and tests that used. It contains preparation of specimens, equipment, mechanical tests of (Al-4.5%Cu-0.5%Mg) alloy. Casting techniques were adopted to facilitate the addition of AL_2O_3.also study tessting SEM, EDX analysis, optical microscopy analysis, hardness test and wear test.

3.2. Materials

Table (3-1) shows the chemical composition of the raw materials. High-purity aluminum wire after being cut into small pieces was used. All the raw materials used were received from the Iraqi local markets.

Table (3-1): Materials Used in this Study

Materials	Conditions	Description
Aluminum (Al)	Al-wire	99.8%
Copper (Cu)	wire	99.9%
Magnesium(Mg)	ribbon	99.3%
Al_2O_3	powder	99.98%,20-25nm

3.3. Preparation of Alloy

This section deals with the melting, casting and preparation of test specimens for the alloys used, which include:

1. Alloy (A) (Al -4.5% Cu -0.5% Mg in metal mold).

2. The alloy (B) (Al – 4.5% Cu – 0.5%Mg -0.5% Al_2O_3 [in metal mold]).

3. The alloy (C) (Al – 4.5%Cu – 0.5%Mg [in sand mold]).

4. Alloy (D) (Al – 4.5% Cu -0.5% Mg – 0.5% Al_2O_3[in sand mold]).

This work involved performing the testing of the hardness by Vickers method, and imaging the microstructure of the samples.

3.4. Casting Process

Pieces of aluminum were weighed and the corresponding quantities of alloying elements were calculated to obtain the required weight percentages, taking into account the oxidation that occurs to the elements during casting. Therefor an additional quantity of the elements with greater burning potential (magnesium) was added.

For the purpose of melting alloy components, gas furnace was used and weight percentages of the alloys used in the current research.

Table (3-2) Weight percentages of the alloys prepared in the current research

Composition Alloy Code	Al (660 C^0) wt % g	Cu(1083C^0) wt % g	Mg(650C^0) wt % g	Al2O3(2072C^0) wt % g (nano)
A	95	4.5	0.5	-
B	94.5	4.5	0.5	0.5
C	95	4.5	0.5	
D	94.5	4.5	0.5	0.5

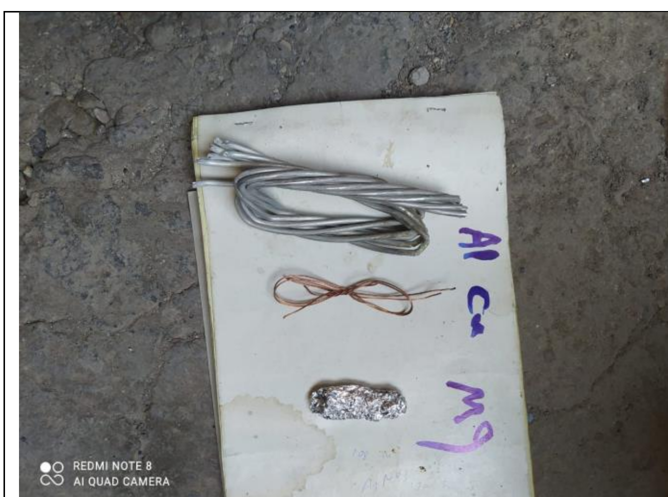
The smelting and casting process took place according to the following:

1. After the weighing process is completed, the aluminum is taken in the form of wires and placed in a flask of silicon carbide and then placed in the furnace and melted, then copper is added and it is in the form of wires also.

2. Magnesium was in the form of strips and wrapped well with aluminum foil, and is added to the molten after the heating of it initially to about(200-300), and submerges inside the molten metal.

3. The mixture is mixed and then the flux was added within 1 g (aqueous aluminum chloride). After mixing well the slag remove .then the molten is poured into a metal mold and the other part into a sand mold and after it cools it comes out of the mold.

4. Alumina was wrapped in aluminum foil. It is discharged into the air and then heated to about 300. Before adding to get rid of moisture, Then it are added to the molten vortex while mixing with an electric mixer at a rotation speed of 630 cycle/min. the smelting and casting process shows in Figure (3-1).




SMART SENSOR
INFRARED THERMOMETER
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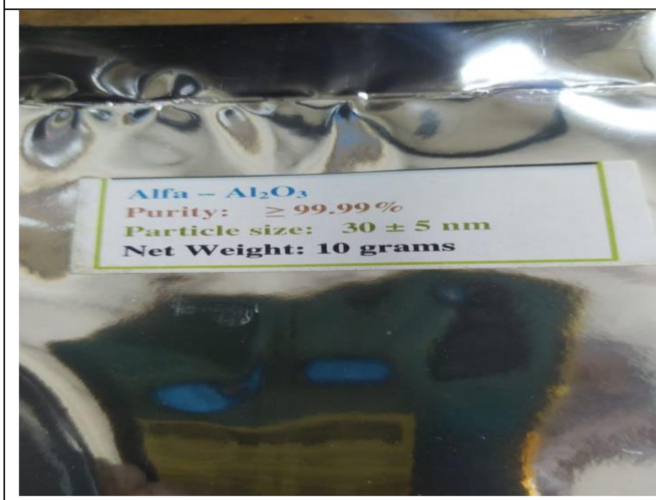
Alfa – Al_2O_3
Purity: ≥ 99.99 %
Particle size: 30 ± 5 nm
Net Weight: 10 grams


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Figure (3-1) shows the smelting and casting process

3.5. Weight Calculation

Casting weight = Density * Volume, where diameter equal to (14 mm) and height equal to (22 mm)

d= 104 cm

$$w = 3 * \frac{\pi d^2}{4} * 22 = 100 \text{ g}$$

Weight of copper= (4.5/100) * 100= 4.5 g

Weight of magnesium= (0.5/100)*100= 0.5 g

Weight of aluminum for casting without Al_2O_3 = 100-1-4.5= 94.5

3.6. Specimens Preparation

After cast, the castings were cut into specimens of (14mm) in diameter and height equal to (22 mm) to test the hardness and microstructure. Samples after cutting are shown in Figure (3-2).

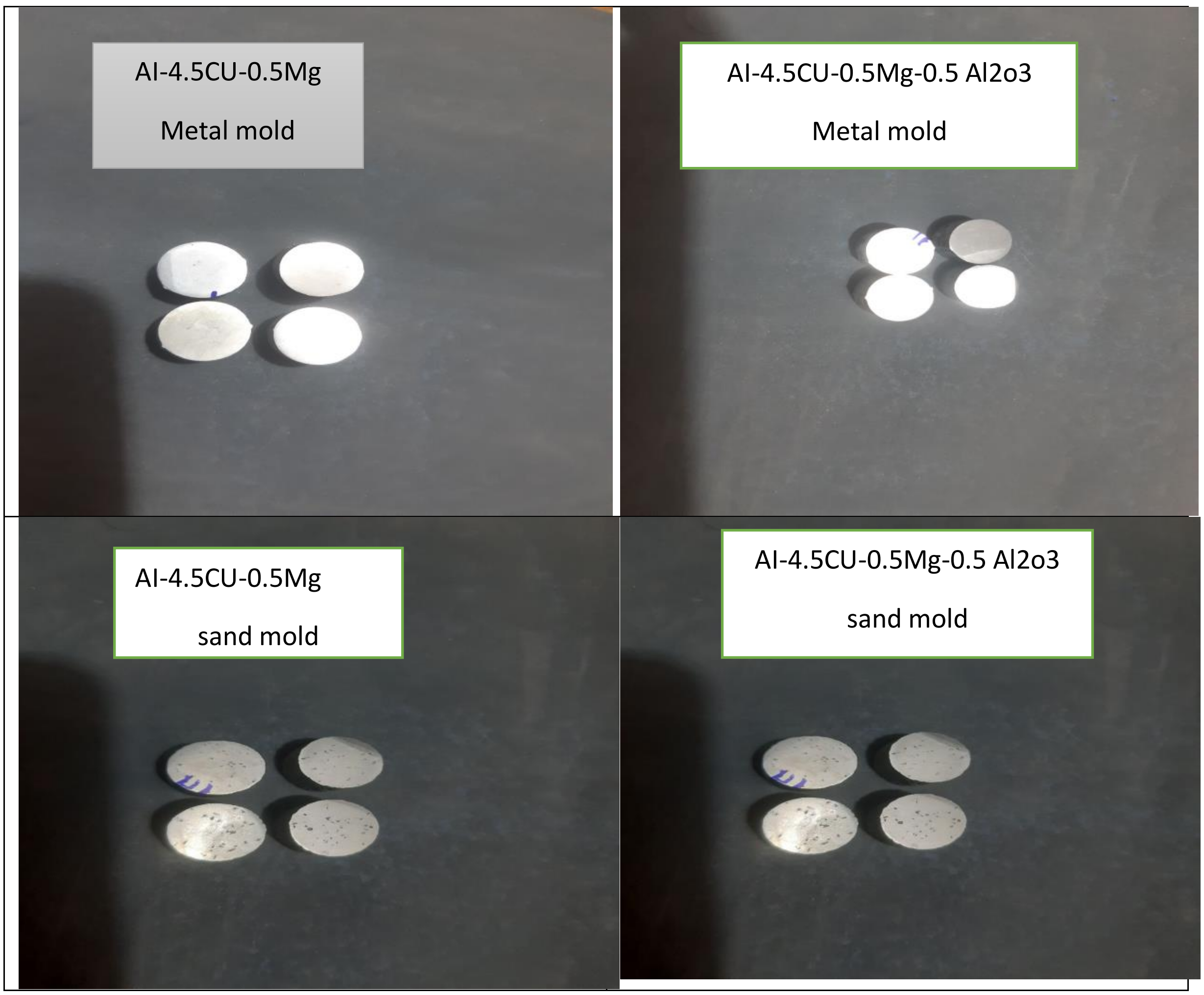


Figure (3-2) Some samples after cuttin

For the purpose of conducting the hardness measurements and microscopic examination, the process of preparing the samples was performed. The grinding process began with a grinding paper made of silicon carbide with grit of (180, 400, 600, 800, 1000, 1200, 1500, 2000), after which the polishing process was carried out using the (HERGON) mechanical grinding machine as shown in the Figure (3-3)

Figure (3-3) the mechanical grinding machine

3.7. Microhardness Measurements

The hardness of a material is the property that enables it to keep the shape of its surface intact under the influence of loads. Hardness may be also defined as the ability of the material to resist wear as a result of friction or resistance to scratching or cutting or the occurrence of a mark in it.However this definition cannot be more general since some minerals have little resistance Because the mark occurs with it while it has a high ability to resist abrasion. Therefore there is no general basic definition that defines the hardness characteristic and applies to all metals until now. Hardness is measured in units (Kg / mm^2) and there are four main methods of measuring hardness (Brinell, Knoop, Vickers and Rockwell). All of these methods are based on creating a dent or a very small impact on the surface of the material for which the hardness is to be measured. The various hardness tests differ in terms of the material used to create the engineering effect and the impacted load. The material penetrated to cause the dent or impact is made of steel or tungsten carbide or diamonds. They have either spherical, conical, pyramidal, or needle shaped. The choice of hardness test depends on the material to be tested and the expected hardness range.

Where the dimensions of the effect (area, depth) are measured under a microscope and from knowing the impacted load and the resulting effect, the hardness can be known [21].

The following is a prife review of the Vickers hardness method

The method of making test by shedding a load with a material that leaves a dent or a pyramidal effect at an angle of (136^0) .Figure (2-3) shows the shape of the trace on the surface of the material for which the hardness is to be measured. The average impedance loads of (10 - 1200g), used to measure the hardness of materials with a small area and very hard materials. In this research this method was used, where the hardness of Vickers hardness is calculated from the equation [30, 31].

$$HV = \frac{1.8544 \times P}{d^2} \quad \text{.................................} \quad (3\text{-}1)$$

HV: Vickers hardness (Kg / mm^2).

P: Impressive load (Kg).

d: average diameter (mm).

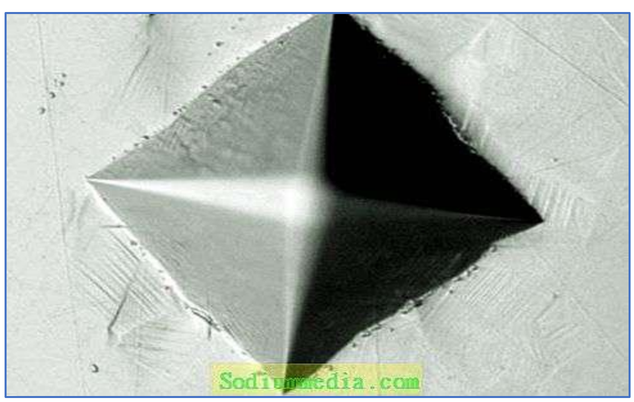


Figure (3-4) the dent or trace of a Vickers hardness test. [31]

The samples grinding and polishing were done before its subjected to hardness tests. Vickers Micro hardness tester type (Micro hardness Tester HV-1000) has test loads are between 1 and 1000g with 136° square-base Vickers diamond pyramid. In this research the test parameters were (200g) load and holding time of (10 seconds). Tester also equipped with an optical microscopy to measure the diagonal of Vickers's impression. As shown in Figure (3-5) that presence in the Metallurgical laboratory in Material Engineering College. The Vickers's micro hardness (HV) test a very small diamond indenter having pyramidal geometry is forced into the surface of the specimen, (HV) defined by formula as follows:

$Hv. = 1.854\, P/d^2$ …………………………………….. (3-2)

Where:-, P = applied load.(kg), **d=** average length of diagonal. (mm^2)

Three readings were recorded for each sample.

Figure (3-5) Micro hardness testing machine

3.8. Optical Microscopic Examination

A union ME-3154 optical microscope with a magnification power of 1000X was used to study the alloy microstructure.

The samples were prepared by grinding and polishing processes and by using the mechanical polishing device shown in Figure (3-6).

Keller's Reagent solution with the following chemical composition was used: (1cm^3 HF, 1.5 cm^3 HCl, 2.5cm^3 HNO3, 95cm^3 H2O) and the time ranged between(10-20 s), and the Figure (3-6) shows a photograph of the microscope used in this study.

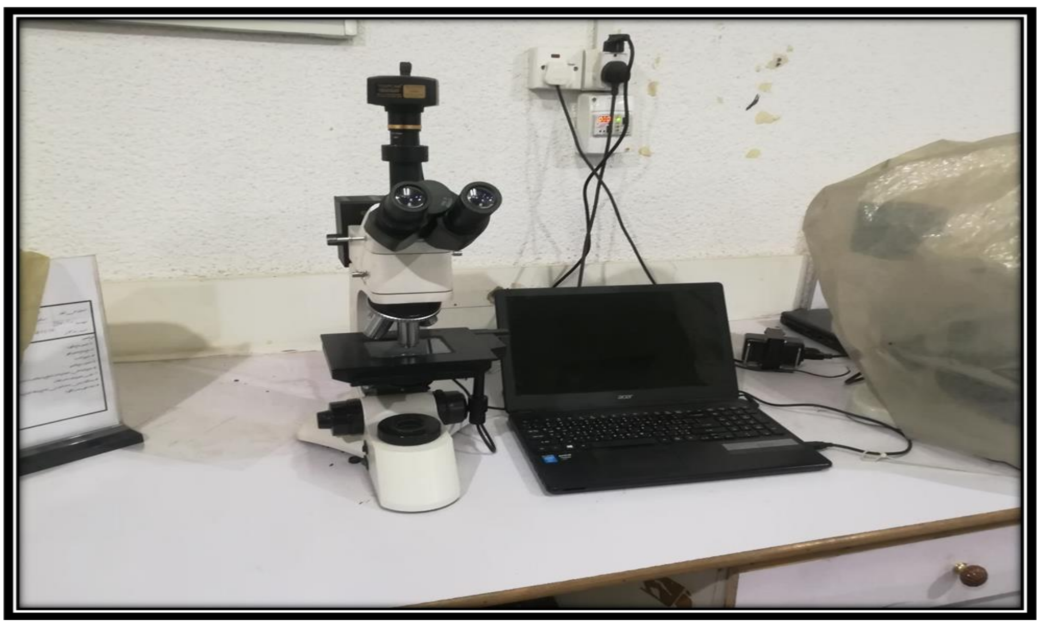


Figure (3-6) The optical microscopy

3.9. Scanning Electron Microscopy

Scanning Electron Microscopy, or SEM analysis, provides high-resolution imaging useful for evaluating various materials for surface fractures, flaws, contaminants or corrosion. Through SEM and EDX analysis, the metallurgical experts provide a thorough examination of material properties and give valuable insights to manufacturers.

SEM analysis is a powerful investigative tool which uses a focused beam of electrons to produce complex, high magnification images of a sample's surface topography. Once an area of interest has been identified on the sample and evaluated using SEM, our experts can dive deeper into the detail of the material using energy-dispersive x-ray spectroscopy, or EDX analysis.

Performing a visual analysis of a surface using scanning electron microscopy contributes to the identification of contaminates or unknown particles, the cause of failure and interactions between materials.

In addition to surface evaluation, SEM analysis is utilized for particle characterization, such as wear debris generated during mechanical wear testing. The high magnification, high-resolution imaging of our SEM analysis supports the determination of the number, size, and morphology of small particles, allowing clients to understand the wear properties of their material, Figure (3-7) shows SEM device.

Figure (3-7) SEM device.

3.10. Energy-dispersive X-ray spectroscopy

Energy-dispersive X-ray spectroscopy (EDS, also abbreviated EDX or XEDS) is an analytical technique that enables the chemical characterization elemental analysis of materials. A sample excited by an energy source (such as the electron beam of an electron microscope) dissipates some of the absorbed energy by ejecting a core-shell electron. A higher energy outer-shell electron then proceeds to fill its place, releasing the difference in energy as an X-ray that has a characteristic spectrum based on its atom of origin. This allows for the compositional analysis of a given sample volume that has been excited by the energy source. The position of the peaks in the spectrum identifies the element, whereas the intensity of the signal corresponds to the concentration of the element. Energy-dispersive X-ray spectroscopy detector is shown in Figure (3-8).

Figure (3-8) Energy-dispersive X-ray spectroscopy device

3.11. Wear testing

Wear testing is a method for assessing erosion or sideways displacement of material from its "derivative" and original position on a solid surface performed by the action of another surface. This test is commonly used as a simple measure of workability of material in service. Materials behave differently in friction state so it may be important to perform mechanical tests which simulate the condition the material will experience in actual use. Wear testing is typically carried out on the alloy. Wear tests of the selected alloy is a critical parameter for determining the quality of these materials. The loads and forces acting on these materials while in service are compressive in nature and their ability to withstand such loads. The availability of a wear testing machine for materials is the first step to effective quality control and good manufacturing practice, where weight used in wear testing equal to 10 N, Time=30 s and rotational speed= 350 km/h, wear testing device shows in figure (3-9).

Figure (3-9) wear testing device **Figure (3-10) precision balance**

Chapter Five

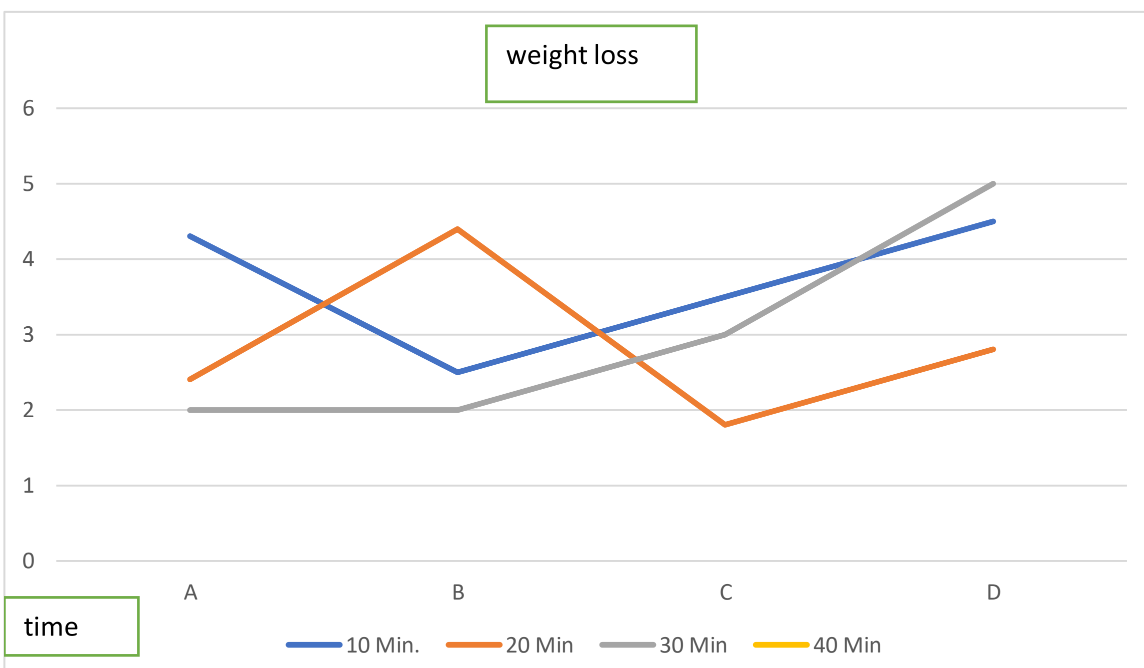
Conclusions and Recommendations

This chapter, present the most important conclusions, recommendations and proposals for future work.

5.1. Conclusions:

The conclusions were:

1. Grain size in samples cast in meta mold was smaller than in sand mold.
2. Grain size in samples with addition of 0.5% NanoAl_2O_3 was smaller than samples without Nanoalumina additive.
3. Hardness of sample cast in metal mold was higher than in sand mold.
4. Hardness of samples with Nanoalumina additive were higher than without additive.
5. Wear resistance of sample



1. The addition of (0.5%) Al_2O_3 (metal mould) has a significant effect in the micro hardness values. Where the Vickers micro hardness was improved by (91.77%) compared to the base alloy.

2. The addition of (0.5%) Al_2O_3 (sand mould) has a significant effect in the micro hardness values. Where Vickers micro hardness was improved by (90.35%) compared to the base alloy

3. The Metal mould with and without Al_2O_3 in samples (C and D) had a lower weight loss in the sliding wear test than that of sample (B), sand mould with Al_2O_3 and sample (A), sand mould without Al_2O_3 alloys.

4. The reduction in weight loss of metal mould with and without Al_2O_3 compared with other alloys, (A and B) , could be attributed to higher hardness results.

5.2. Recommendations

Through the results that were obtained the fourth chapter and what is in our hands from previous studies, some recommendations and proposals for future

work that go in this direction and are necessary to complete the following research directions are addressed

1. Expanding tests on alloys such as corrosion test, surface roughness test, thermal conductivity tests and grain size measurements.

2. Using other percentages of the added elements and other elements and study their effects on the properties.

3. Using the powder metallurgy technique to manufacture the alloys used in the current research and compare it to the casting process.

4. Carrying out the treatment of artificial aging by choosing different temperatures and studying their effect on hardness, microstructure and corrosion resistance.

Chapter Four

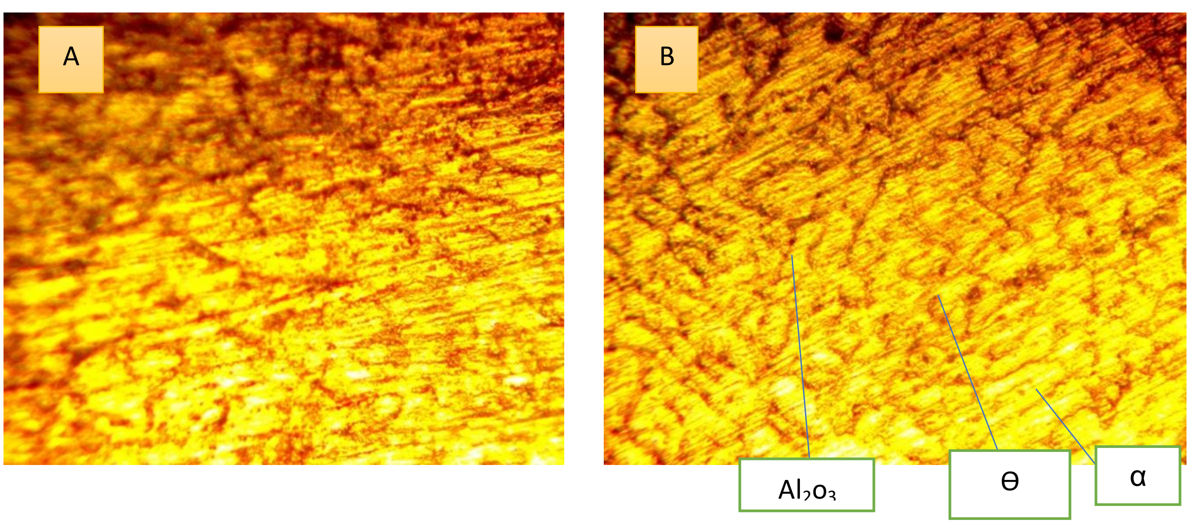
Results and Discussion

4.1 Introduction

In this chapter, the results obtained in each parts of work will present and follow by the discussion of results. Experimental results of microstructure and Property characterization was presented. The results of composition, and materials characterization, light optical microscopy (LOM), and Scanning electron microscopy (SEM) and Energy dispersive X-ray spectroscopy (EDS) also mechanical testing such as micro-hardness and wear were also carried out

4.2. Microscopy Investigations

` The output of the optical microscopy is shown in figure (4-1) for sand and metal mold. As shown in metal mold without addition of NanoAl_2O_3, the size of grains clearly appear as small grains. The size of grains in in metal mold are smaller. The reason for this result was as the presence of Nano particles which act as nucleation centers and the grains be smaller compared with image without Nanoparticles.



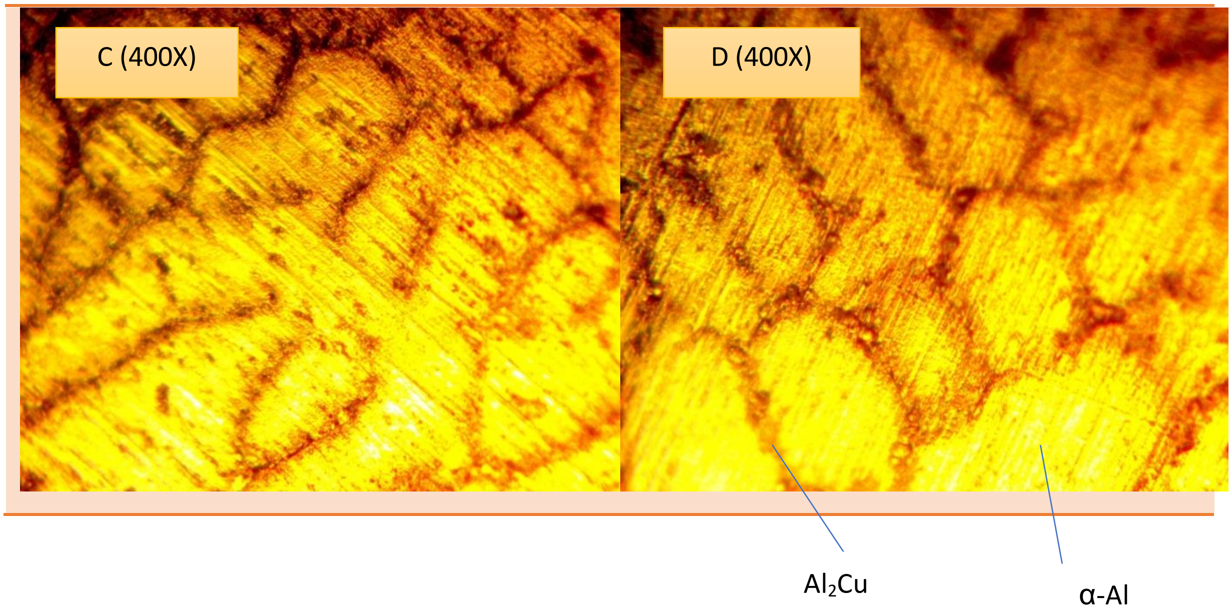


Figure 4-1 Light optical microscope image 400X. A) in metal mold without Al_2O_3. B) In metal with AL_2O_3, C) in sand mold without Al_2O_3, D) in sand mold with Al_2O_3

Images in C and D show microstructure of samples cast in sand mold. This microstructure appear with larger grains compared with microstructure of samples in metal mold. This result because the low cooling rate of sand mold compared with metal mold as a result of low thermal conductivity of sand mold.

4.3 Hardness of Alloys

The hardness values were measured in a metal and sand mold, where it was found that the hardness measure in a metal mold with the addition of Nanoalumina is higher than the value of the hardness without adding alumina. This as result of the smaller grain size and the presence of Nanoparticles which act as barriers to moving of dislocations. Also it can be distinguish from table (4-1) that the hardness of metal mold samples is higher than in sand mold as a results of the small grains in metal mold.

Table (4-1) the hardness values of metal and sand mold samples with and without Nanoparticles

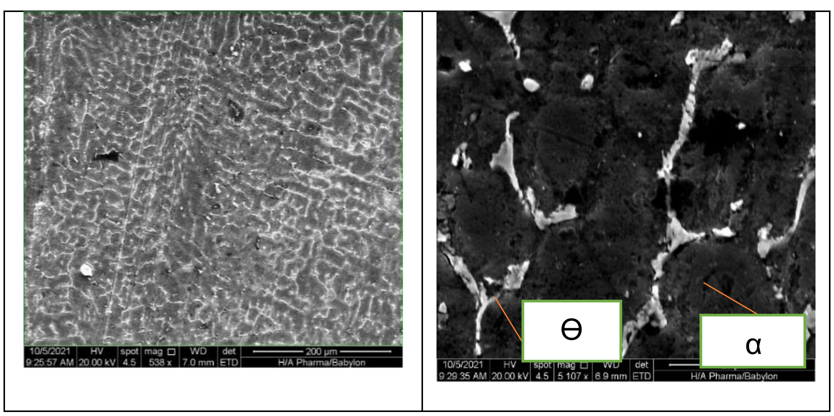
Alloy Code		HV (Kg/mm^2)
A	In metal, without Al_2O_3	**144.235**
B	In metal, with Al2O3	**157.155**
C	In sand mold, without Al2O3	**122.405**
D	In sand mold with Al2O3	**135.475**

4.4 Scanning electron microscopy results

The SEM images, show microstructure and composition of aluminum alloys used in this work. are shown in figure (4.2 - 4.5). Figures (4.7 - 4.9), show the EDX results for the four samples (A ,B ,C and D) respectively.

Scanning electron microscopy (Fig. 4-2) shows the initial grains for aa2024 without Nanoalumina sample cast in metal mold. Average grain sizes were almost near to 70µm.

Sample (A),



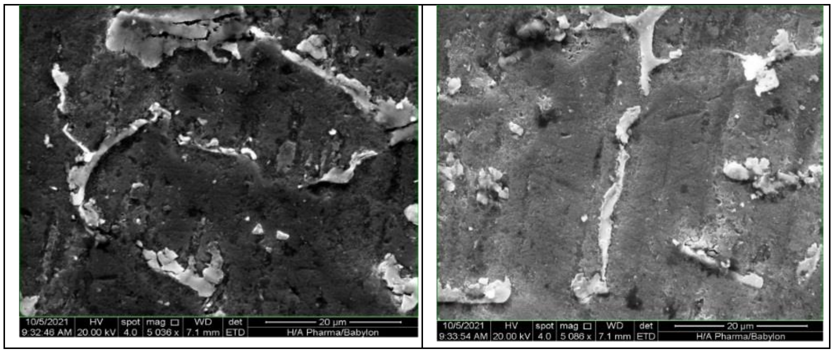


Figure 4.2 SEM micrographs of (Al-Cu-Mg) alloy in metal without Al_2O_3

Scanning electron microscopy shows that during formation of alloy, Al-Cu-Mg phased particles were elongated in {001} plane while Al2Cu is distributed across {111} planes. From EDS phases were identified although exact chemical composition couldn't be identified due to presence of oxide layers in each phase [51].

As shown in figure4-3 that the size of grains is smaller compared with microstructure of alloy without NanoAl_2O_3. This decrease as a result of presence of NanoAl_2O_3 which act as nucleus that decreases the grain size.

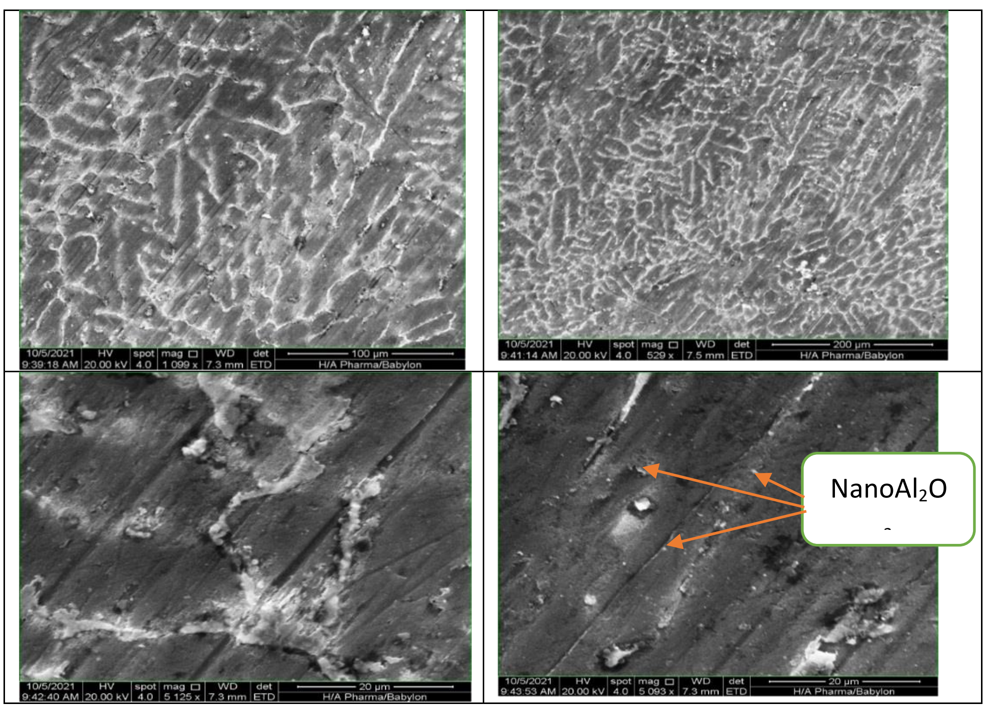


Figure 4.3 SEM micrographs of (Al-Cu-Mg) alloy with Al_2O_3 cast in metal mold with Al_2O_3

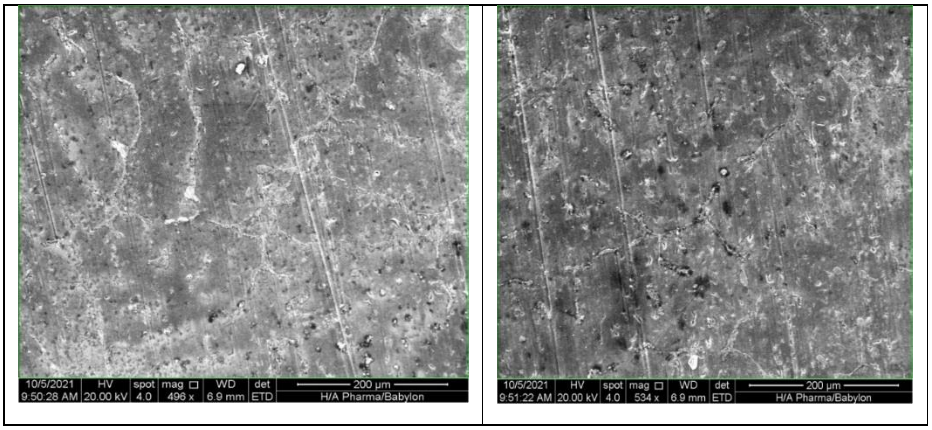


Figure 4.4 SEM micrographs of (Al-Cu-Mg) alloy with Al_2O_3 (sand mold without Al_2O_3)

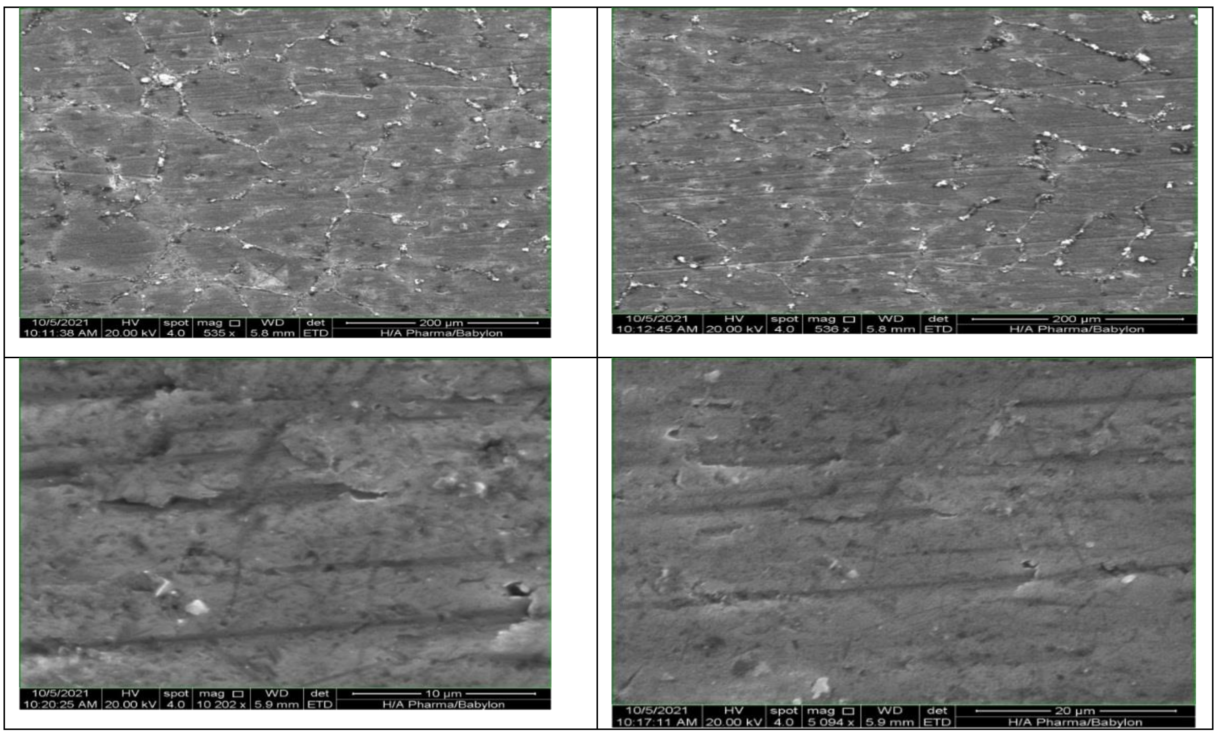


Figure 4.5 SEM micrographs of (Al-Cu-Mg) alloy without Al_2O_3

SEM images in figure 4-4 and 4-5 represents the microstructure of samples with and without additive of NanoAl_2O_3 in sand mold respectively. As shown in these microstructure, the grain size larger compared with figures 4-2, 3-4 respectively. This was as a result of low cooling rate of sand mold.

4.5 Energy-dispersive X-ray spectroscopy results.

The graphs of EDS results appear in figure 4-6. The graph shows the main content of elements in aa2024.

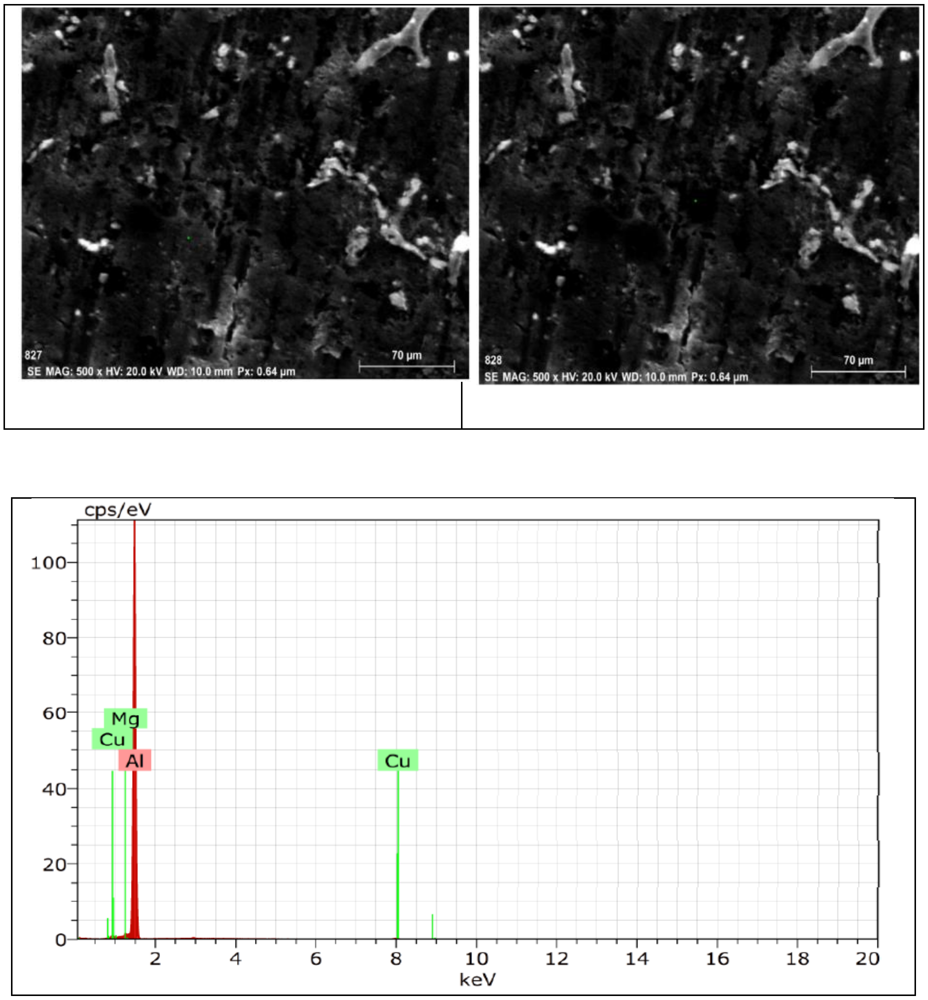


Figure 4.6 Energy Dispersive X-ray (EDX) (A) alloy

4.6. Wear Testing Results

The weight loss (g) during wet sliding wear with time (30s), and rotational speed= 350 rad/s at load of 10 N is shown in Figures (4.7). In general on the surface of all alloys at normal load of 10 N. The metal mold with and without nano(Al_2O_3) in samples (A and B) had a lower weight loss than that of Sample C, and Sample (D), sand mold without and with NanoAl_2O_3 alloys respectively. The reduction in weight loss of metal mold with and without nanoAl_2O_3 compared with other alloys, (A and B) , was because finer grain size and the presence of Nano sand mold with NanoAl_2O_3 respectively.

Moreover was reported in the literature [50], that hardness is usually regarded to be important mechanical property for assessing the wear resistance.

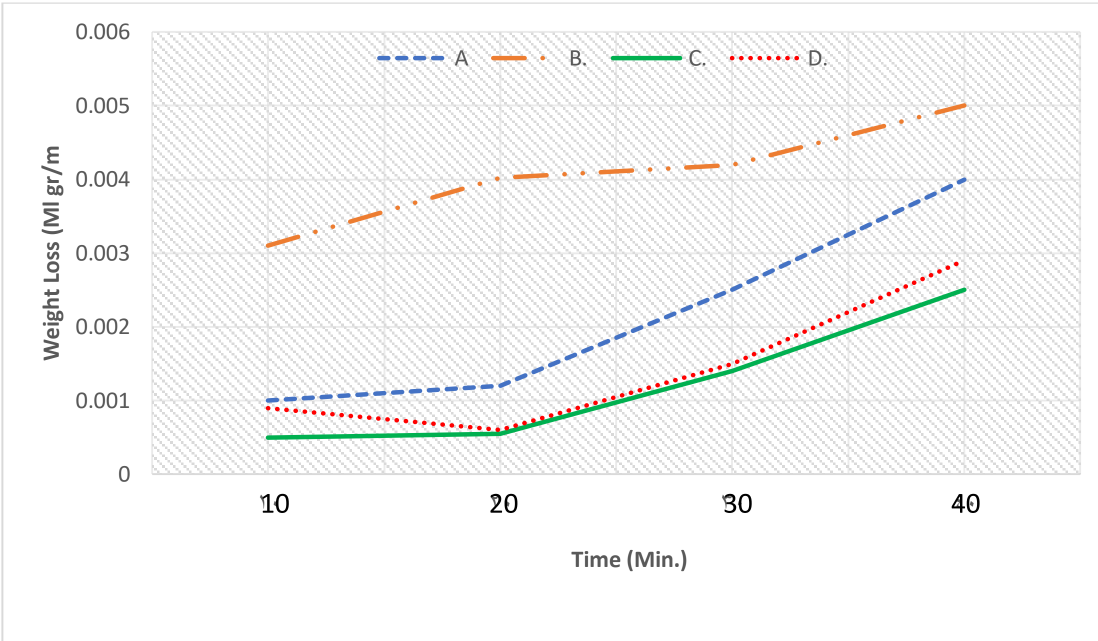


Figure.4.10 The relation between weight loss during wet sliding wear with Time for aluminum alloys used in this work at load of 10N

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