Study the Effect of Magnesium Addition on Microstructure , Electrical Conductivity and some Mechanical Properties of Pure Aluminum

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Abstract

In this research study the effect of addition of magnesium on the mechanical properties (Hardness , yield strength , Ultimate stress) for pure aluminum and also microstructure , density , in addition to the electrical conductivity . three alloys were prepared by change ratios add magnesium (5% , 10%,15%).

The results showed that the increase proportion of the magnesium added to pure aluminum caused an increase in the yield stress and improving ratio reach to 78.46% ,an increase in ultimate stress and improving ratio reach to76.92% at ratio(15%), and an increase in the hardness to value (91.9 Hv) and improving ratio reach to 90.78% at ratio (15 %) while the decrease in electrical conductivity to the value of (0.596 $*10^6\ \Omega^{-1}\ .m^{-1}$) while there is a decrease in the density to (2.371 g/cm^3) when the ratio of magnesium added to the pure aluminum increases. A change in microstructure and regular distribution of magnesium on the boundary of crystalline for alloys , has also been noticed.

Keywords: Aluminum alloy Magnesium , Mechanical properties , Electrical conductivity.

الخلاصة :

تم في هذا البحث دراسة تأثير إضافة المغنيسيوم على الخواص الميكانيكية (الصلادة ،إجهاد الخضوع ،أقصى إجهاد) للألمنيوم النقي وكذلك البنية المجهرية والكثافة بالإضافة إلى الموصلية الكهربائية .
تم تحضير ثلاث سبائك يتغير نسب إضافة المغنيسيوم (5%, 10%, 15%).
حيث بينت النتائج انه بزيادة نسب إضافة المغنيسيوم إلى الألمنيوم النقي يسبب زيادة إجهاد الخضوع وبنسبة تحسن تصل إلى 78.46% وكذلك زيادة أقصى إجهاد وبنسبة تحسن تصل الى 76.92% عند النسبة (15%) وزيادة في الصلادة تصل الى (91.9 Hv) وبنسبة تحسن تصل الى 90.78% عند النسبة (15%)بينما يحدث انخفاض في الموصلية الكهربائية إلى قيمة ($0.596 *10^6\ \Omega^{-1}\ m^{-1}$) وانخفاض في الكثافة إلى قيمة ($2.371\ g/cm^3$) عند زيادة نسبة المغنيسيوم المضافة. كما تم مشاهدة التغير بالبنية المجهرية والتوزيع المنتظم للمغنيسيوم على الحدود البلورية للسبائك.

كلمات مفتاحيه :سبائك الألمنيوم ، المغنيسيوم ، الخواص الميكانيكية ، الموصلية الكهربائية.

1. Introduction

Nowadays aluminum and aluminum alloys are widely used in automotive industries. These are light weights (density of about 2.7g/cc), having good malleability and formability, high corrosion resistance and high electrical and thermal conductivity. High machinability and workability of aluminum alloys are prone to porosity due to gases dissolved during melting processes. However, in the engineering application pure aluminum and its alloys still have some problems such as relatively low strength, unstable mechanical properties. The microstructure can be modified and mechanical properties can be improved by alloying, cold working and heat treatment . [Jambukar & Kharde , 2013]

Aluminum and aluminum alloy are gaining huge industrial significance because of their outstanding combination of mechanical, physical and tribological properties over the base alloys. These properties include high specific strength, high wear and, high stiffness, better high temperature strength, controlled thermal expansion coefficient and improved damping capacity. These properties are obtained through addition of alloy elements. Alloying elements are selected based on their effects and suitability.

[Rana , *et.al* .,2012].

There are many research studies that deal with the addition of alloying elements for a pure aluminum , they include:

[Isadare , *et.al.*, 2013] have studied the effects of annealing and age hardening heat treatments on the microstructural morphology and mechanical properties of 7075

Al alloy. The material was cast in the form of round cylindrical rods inside green sand mould from which some samples were rapidly cooled by early knockout and others gradually cooled to room temperature. One of the results was the formation of microsegregations of MgZn2 during gradual solidification which was not present during rapid cooling. It was also found out that age hardening and annealing heat treatment operation eliminated these microsegregations and improve mechanical properties of 7075 Al alloy.

[Nafsin & Rashed , 2013] Studied the most important cast aluminum alloy system is Al-Cu. The addition of copper as main alloying element (mostly range 3–6 wt. %, but can be much higher), with or without magnesium as alloying constituent (range 0–2 %), allows material strengthening by precipitation hardening, resulting in very strong alloys. Also the fatigue properties are very good for this series. With increasing the amount of deformation, hardness continues to increase for different magnesium addition. Also, the higher the magnesium content is, the greater the hardness will become.

[Ahmed, 2012] studied the effect of adding Magnesium to the pure Aluminum they obtained results showed that increasing the percentages of adding Magnesium to the pure Aluminum causes a decrease in the thermal diffusion coefficient by (1.9%) During this study, it was found that the best addition is (30% Mg) to the pure Aluminum, which gave the highest thermal properties ($C_{v,}$ k,α).

[Ali , 2010] studied some mechanical properties for metal matrix composite material (based Aluminum) with ceramic material (boron carbide) as a reinforced material .powder technology process was used for manufacturing the specimen. Good improvement in results of those properties appeared.

In this research , the magnesium element is used to show its effects in an improving the pure aluminum .

The research aims to study the effect of adding different ratios of magnesium on the mechanical properties (yield stress , ultimate stress , hardness), microstructure , density and electrical conductivity for pure aluminum , because the importance of aluminum alloys in industrial fields.

2. Experimental Part

Experimental part includes preparation of materials used in the chemical composition of the alloy , process of melting , casting , operation , preparation of samples and tests.

2.1. Preparation of Alloys

The alloy was prepared by the weight of a piece of pure aluminum (wires length is (1-2) cm) and calculating the corresponding quantities of magnesium element to get the required weight ratio (5%, 10%, 15%) Mg.

The use of ceramic pot is for the purpose of setting the components of the alloys during the process of melting in electric furnace.

The melting process and casting are as follows:-

1. pure aluminum wires are used and cut into pieces (wires length (1-2) cm).
2. Aluminum pieces are put in the melting pot and put in the melting furnace(Italian origin type MILAN-20122) for the melting process after being heated to temperature (700 ^{o} C) to ensure the total melting for the purpose of obtaining fusible empty from defects.
3. magnesium powder surrounded by foil of aluminum is added to molten aluminum and its moved well by tool made of graphite for the purpose of obtaining complete homogeneity and then it is casted in a mold that has been heated to a temperature

(300 º C), before the casting process in order to avoid a sudden solidification and the non-homogenized molten in the mold.

4. Casting process was conducted three times to aluminum – magnesium alloy and different ratios of magnesium.
5. sample cast of diameter (22.6 mm) and length (80 mm) were obtained.

Figure (1) show melting furnace.

2.2. Samples preparation

The samples were run by turning machine and cut into new samples of different sizes for the purpose of making the necessary tests which began the process of grinding using paper of silicon carbide with grades (400, 600, 800, 1200, 1500, 2000) after the conducting the polishing process , a polishing machine (Model (MP-2B), Chinese origin) were also conducted , alumina powder , and water were used. washing and drying process with hot air between each operation of polishing and other.

2.3. X-Ray Diffraction Test

X-ray diffraction was used to study the phases of the Aluminum – Magnesium alloys with measuring condition as below.

Target: Cu, wave length = 1.5406 $\mathring{A}$, speed (6.000 deg / min).

2.4. Microstructure Test

An optical microscope type (union – 3154 ,Model (optical- 1101579), Chinese origin) magnification (200X). for the purpose of examining the microstructure of the alloys.

After grinding and polishing using mechanical polishing device type (HERGON),imaging microstructure after casting process, use of etching solution, (Keller' s Reagent) chemical composition is used as the following:

(25% HF+ 10% HCL+ 15% HNO_3 + 50% H_2O) .It was the time of showing ranges between (10-20)s. [Yasir , 2014]

2.5. Compression Test

Compressive strength is the value of stress compression which the sample reaches when the total collapse (usually cylindrical sample will shorten and spread sideshow diagonally) occurs.

Since the atoms in solid bodies are always trying to find for itself a balanced position between atoms , the forces inside the material inversion process appear , these forces are shown in the form of strain.

In this test the values are calculated for each sample (ultimate stress, yield stress), these values have been gotten through the use of schemes resulting from.(Universal

Testing ,Model (WAW- 200) Chinese origin) where it gives the values of forces applied on the sample and the amount of elongation.

Forces are turned to the corresponding values of stress by using the following law:

$$\sigma = \frac{F}{A_\circ} \qquad \text{.................................... (1)}$$

Where as

σ........... Stress

F .... Force

$A_\circ$ .... Original area

Elongation values turned to the corresponding for values of strain by using the following law:

$$\varepsilon = \frac{\Delta L}{L_\circ} \qquad \text{.......................................(2)}$$

ε ....strain.

ΔL ....elongation.

$L_\circ$ ....original length.

After that draw a relationship between stress and strain values.

Test sample cylindrical where length (1.5) amount of diameter and it was sample strain rate (1mm/s).

2.6. Hardness Test

A hardness test is an indicator of changes in the mechanical properties for samples, where measuring the hardness of the samples after the process of casting.

The method used to measure the hardness is a Vickers method (Model (HVS- 1000), Chinese origin) and the amount of load is (15.63) kg according to the following formula: [Nayak & Karthik ,2011]

$$VHN = \frac{1.854\,P}{D^2} \qquad \text{..................................(3)}$$

Where as

HVN ......Vickers hardness

P ......applying load (kgf)

D ....average length of diagonals,(mm)

2.7. Electrical Conductivity Test

Electrical conductivity of aluminum calculate after the addition of magnesium. It used samples of (22.6) mm diameter and (5.5) mm length, where the user device measuring the electrical resistance is (ATS 12 Precision Ohmmeter, Chinese origin) through which we can calculate resistivity through the following law [Miller , *etal*, 1988]:

$$\rho_{Ele} = \frac{R.A}{L} \qquad \text{... (4)}$$

Where as

ρ_{Ele} ....resistivity.

R ....resistance.

L ....sample length.

Electrical conductivity (σ_{Ele}) is measured by reversed resistivity.

$$\sigma_{Ele} = \frac{1}{\rho_{Ele}} \quad \text{………………………………………... (5)}$$

2.8. Density Test

Density described the physical properties of objects to express the relationships of unit size and unit mass for material or objects. The increased density increased mass per unit sizes.

To calculate the density after the addition of magnesium element for pure aluminum,

the samples of alloy were of (22.6) mm diameter and (5.5) mm length. we weight samples and measure the size then calculate the density by the following law:

$$\rho = \frac{m}{V} \quad \text{……………………………....…….. (6)}$$

Where as

ρ ……..density.

m ………mass.

V ………volume.

If ($V = A \times L$)

$$V = \frac{\pi}{4} d^2 \times L$$

3. <u>Results and Discussion</u>

3.1. X- Ray Diffraction Test

Figure (2) represent the diffraction of x-ray of pure aluminum , shows the peaks of pure aluminum and figure (3) illustrated x-ray diffraction for samples of aluminum – magnesium alloys and shows the peak of aluminum and magnesium in alloy .

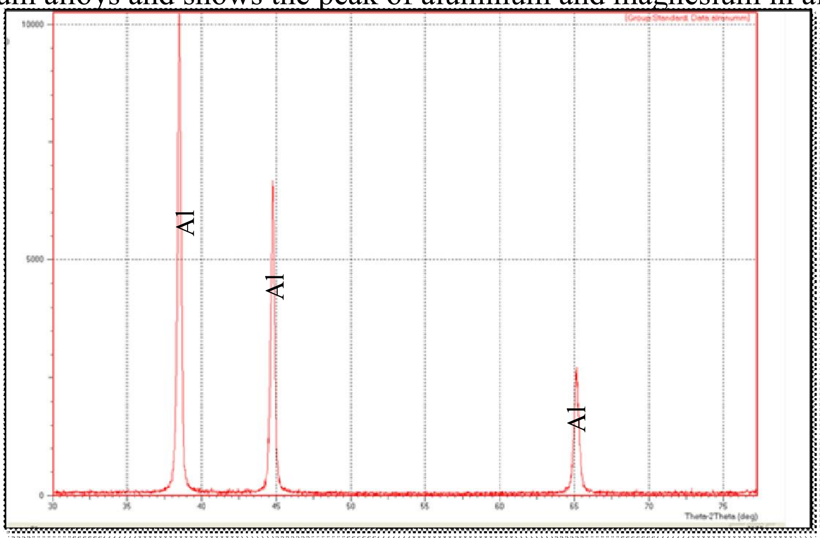

Figure (2) represent X- ray diffraction of pure aluminum.

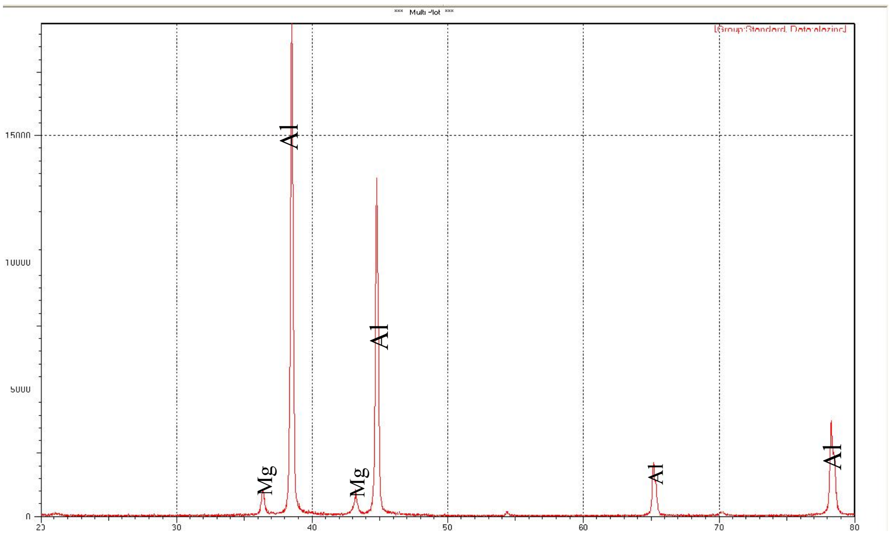

Figure (3) represent the diffraction of x-ray of Al- 5 % Mg alloy

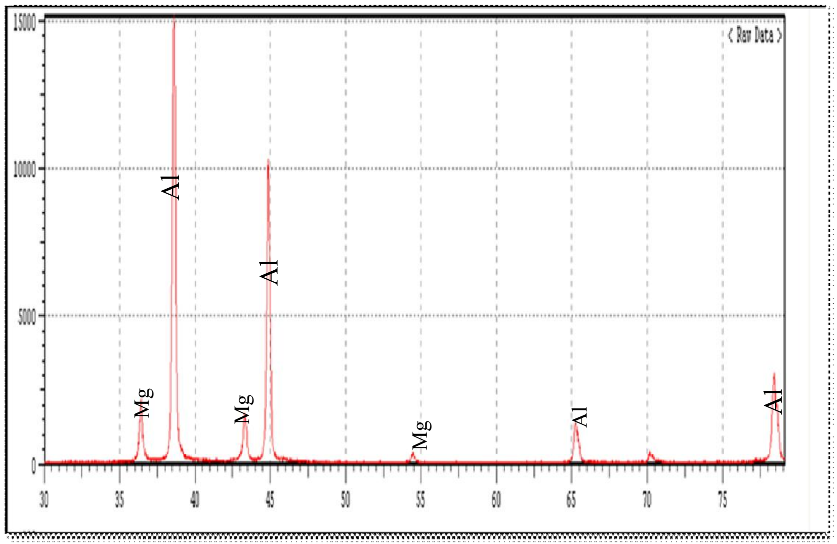

Figure (4) represent the diffraction of x-ray of Al- 10% Mg alloy.

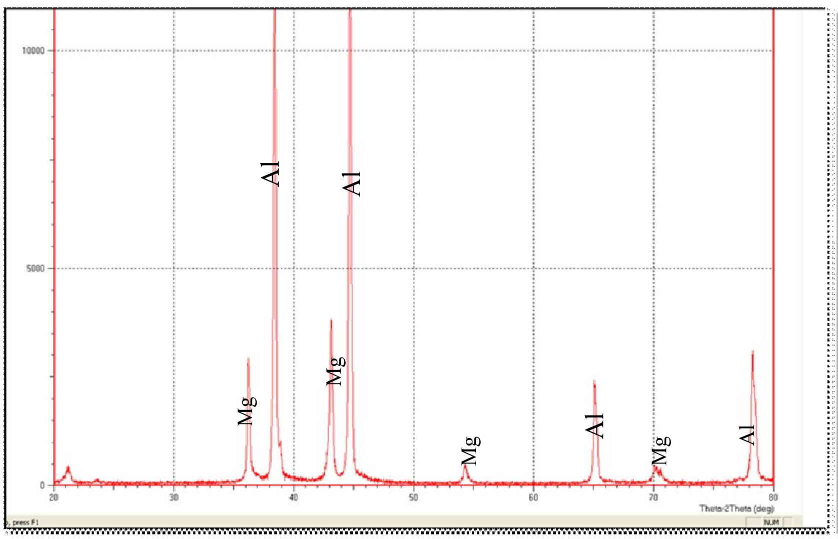

Figure (5) represent the diffraction of x-ray of Al- 15% Mg alloy.

3.2. Microstructure Testing

The results obtained from the green area indicate the aluminum element while the black areas indicates the magnesium element where we note that this area increases with the proportion of magnesium element and the increased deposition of magnesium in the crystalline boundaries of alloy.

Figures (6), (7), (8)&(9) show microstructure for pure aluminum, alloys and percentages of magnesium additive.

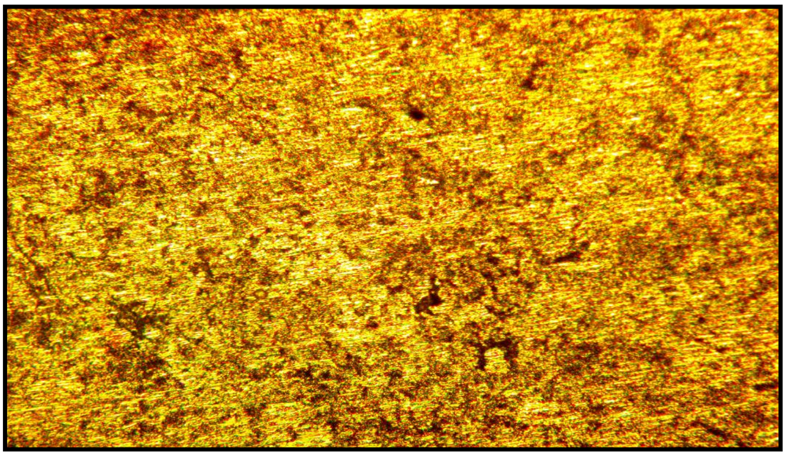

Figure (6) show microstructure for pure aluminum (200X).

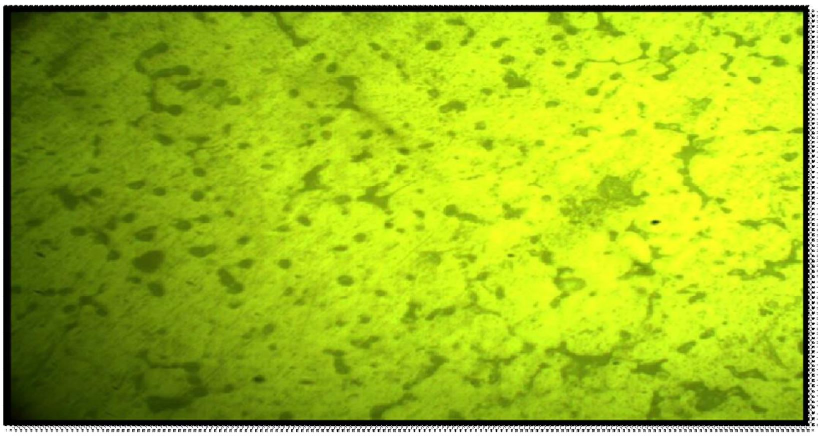

Figure (7) show microstructure for (Al- 5%Mg) alloy(200X).

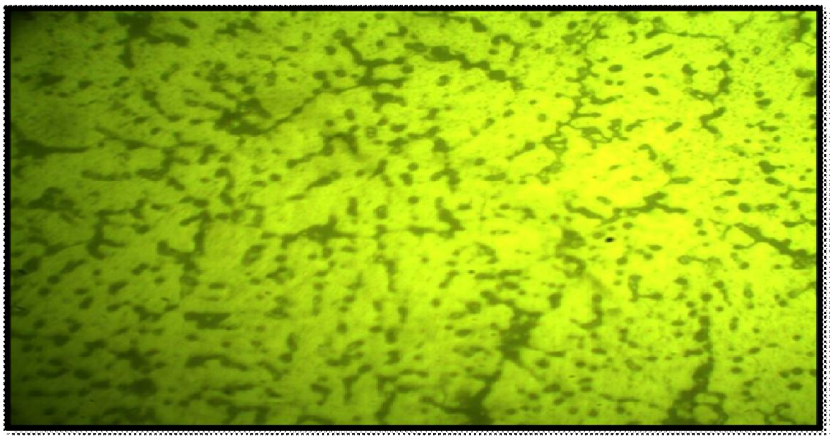

Figure (8) show microstructure for (Al-10%Mg) alloy (200X).

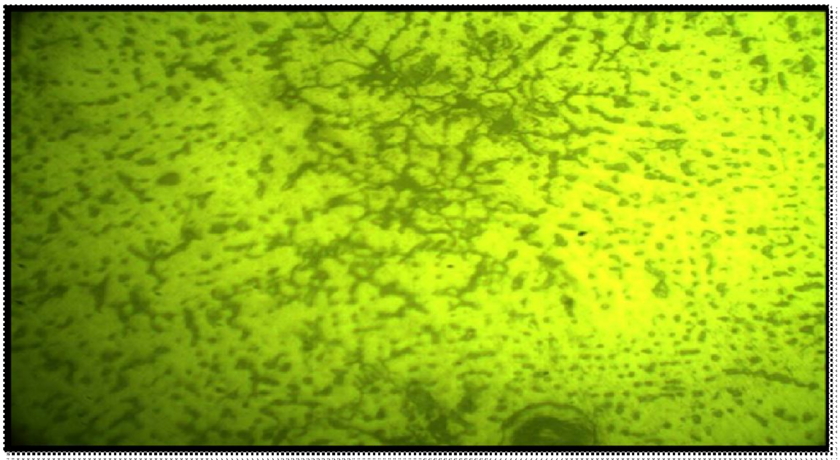

Figure (9) show microstructure for (Al-15%Mg) alloy (200X).

3.3. Compression Test

The relationship between stress and strain that has been observed through the schema ,the value of the yield stress increases with the increase of the proportion of magnesium and improving ratio reach to 78.46% and so the improving ratio of ultimate stress is 76.92% at ratio 15% compared with other ratios and the reason is crystals of magnesium work as a barrier movement of dislocations and thus will increase both(σy) and (σu), since the magnesium will be on the crystalline boundaries.. Table **(1)** shows yield stress and ultimate stress values for pure aluminum , percentages of additive and improving ratio.

Table (1) shows yield stress and ultimate stress values for pure aluminum , percentages of additive and improving ratio.

Mg wt.%	σy(Mpa)	improving ratio %	σu(Mpa)	improving ratio %
0	89.126	0	190.985	0
5	238.731	62.66	509.29	62.499
10	241.91	63.16	611.15	68.74
15	413.8	78.46	827.62	76.92

3.4. Hardness Testing

Vickers hardness was measured for Aluminum-Magnesium alloy after the addition of different ratios of Magnesium to pure Aluminum , it has been observed that the Aluminum – Magnesium alloy possessed a higher hardness (91.9)Hv and improving ratio reach to 90.78% when adding 15% Magnesium compared with other ratios whose improving ratio reach to 36.8% when the ratio 10% and 12.93% when the ratio is 5% .This means that increasing magnesium element increases the value of hardness of the alloy and the reason for this is to phase hardening of the element magnesium , which is deposited on a crystalline boundaries .Table (2) shows the hardness values for pure aluminum , percentages of magnesium additive and improving ratio. [Nayak & Karthik ,2011]

Table (2) shows the hardness values for pure aluminum , percentages of zinc additive and improving ratio.

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Mg wt. %	Hardness values(HV)	Improving ratio %
0	48.17	0
5	54.4	12.933
10	65.9	36.8
15	91.9	90.78

3.5. Electrical Conductivity Test

Note that the addition of magnesium element to pure aluminum will reduce electrical conductivity , the reason for this is to enter the magnesium element as a distortion and an impurity element of each of the free electrons and crystalline network .[Alean & Banbury , 1994]

Table **(3)** shows the resistance, resistivity and electrical conductivity values and percentages of additive.

Table (3) shows the resistance, resistivity and electrical conductivity values and percentages of additive.

Mg wt.%	R(Ω)	ρ(Ω.m)	$\sigma(\Omega^{-1}.m^{-1})$
5	$1.35*10^{-5}$	$0.984*10^{-6}$	$1.015*10^{6}$
10	$1.70*10^{-5}$	$1.239*10^{-6}$	$0.807*10^{6}$
15	$2.30*10^{-5}$	$1.677*10^{-6}$	$0.596*10^{6}$

3.6. Density Test

Note that the addition of magnesium element to pure aluminum, leads to decrease density of the alloy because magnesium has less density than aluminum, this decreases with the increase of the proportion of the added magnesium as the density of aluminum is (2.7)g/cm^3 while the density of magnesium is(1.738) g/cm^3 .Table **(4)** shows the density values and ratios of the added magnesium.

Table (4) shows the density values and ratio of magnesium additive.

Mg wt.%	ρ(g/ cm^3)
5	2.566
10	2.475
15	2.371

4. Conclusions:

1. Properties of aluminum drastically changed when certain elements of casting are added. The hardness of aluminum increases when magnesium element is added and improving ratio reach to 90.78%.
2. Density described the physical objects, when magnesium is added to pure aluminum; it leads to the decrease of density to become less then it is in the pure aluminum.
3. The pure aluminum has high electrical conductivity and the electrical conductivity of aluminum depends on the degree of purity while; the addition of any element to pure metal reduce electrical conductivity.
4. Microstructure of the alloy was observed regular distribution for the deposition of magnesium element on the crystalline boundary for alloy (Al – Mg).
5. The addition of magnesium element to pure aluminum leads to increased yield stress and improving ratio reach to 78.46 % also increased ultimate stress reaches improving ratio to 76.92%.

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