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# HARDNESS, CORROSION BEHAVIOR, AND MICROSTRUCTURE OF AL-CU-MG ALLOY AS A FUNCTION OF 0.3 WT.% ZR ADDITION

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Abstract

The effect of adding zirconium (Zr) as an alloying element to Al-Cu-Mg alloy on the hardness and corrosion of this alloy was investigated. The hardness and polarization test results of samples treated for various periods by aging at 423.15 K for 3hr showed a significant increment in the Brinell hardness (HBW) improvement ratio of 115.6% (from 45HBW to 97HBW) and an extreme reduction the corrosion rate of the alloy after Zr adding decrease in the current density by 79.42% (from 56.50 µA cm-2 to 11.63 µA cm-2) with aging for 3 hr compared to the base alloy. The impact of this addition is also reflected in the strengthening, recrystallization, and modification of the grain microstructure. These changes were clearly demonstrated by microscopic testing and proves that the addition of Zr has a considerable synergistic effect causing inhibition of recrystallization and refinement of grain size.

Keywords: Al- alloy, effect of alloying element addition, Brinell hardness, current density, recrystallization.

**List of Symbols/Acronyms**
Al - Aluminium metal;
Cu - Copper metal;
IGC - inter-granular corrosion;
Mg -Magnesium metal;
wt.% - weight percentage;
Zr -Zirconium metal;
%- The percent sign;
µA cm-2- current density unit,

## 1. INTRODUCTION

(*Aluminum, copper, and magnesium*) Alloys are distinguished by their capacity to harden with age, such as aluminum alloys with trace amounts of copper and magnesium. With this method, tensile strengths of at least 400 N mm$^{-2}$ can be achieved, and silicon and manganese increase the resistance to forming. The ability of these alloys to solidify something depends on the alloying elements used, such as copper, magnesium, silica, and zinc. These elements accept solubility in aluminum more readily at higher temperatures than at room temperature, either individually or in combination. The aerospace and shipbuilding industries frequently use aluminum alloys because of their excellent mechanical and physical characteristics. Due to their high specific strength, exceptional heat resistance, and simplicity of processing, Al-Cu-Mg alloys are significant structural materials that have been used extensively in the aerospace industry[1-2]. However, due to the potential difference between the heterogeneous distributions of S ($Al_2CuMg$) or ($Al_2Cu$) precipitates along the grain boundaries and in the matrix, the tendency for inter-granular corrosion (IGC) of Al-Cu-Mg alloys is relatively significant. As a result, one of the main research objectives for potential applications in the aerospace, aviation, and other high-tech industries is the development of Al-Cu-Mg alloys with high specific strengths and superior corrosion resistance[3]. Micro-alloying with transition metals (such as Sc, Zr, Cr, Nb, Sr, and Ti) or rare earth elements has been found to be the most effective way to alter the microstructures and improve the performance of the aluminum alloy [4-9]. Studies on the corrosion behavior of Zr-containing Al alloys, particularly Zr-containing Al-Cu-Mg alloys, are rare and have received little attention in the literature [4, 10, 11-15], which has mainly concentrated on microstructure and mechanical properties. This study's primary objective is to determine how adding 0.3 % Zr to Al-Cu-Mg alloys affects how they behave toward corrosion and how tough they are.

## 2. METHODOLOGY

### 2.1. Materials

The elements used for casting aluminium alloy and their percentages are illustrated in Table.1, which are: Aluminium as wire, Copper as chips, Magnesium as flakes, and finally, Zirconium powder.

### 2.2. Alloy preparation

The procedure of alloy preparation is shown in Fig.1. After each component has been weighed with the weight

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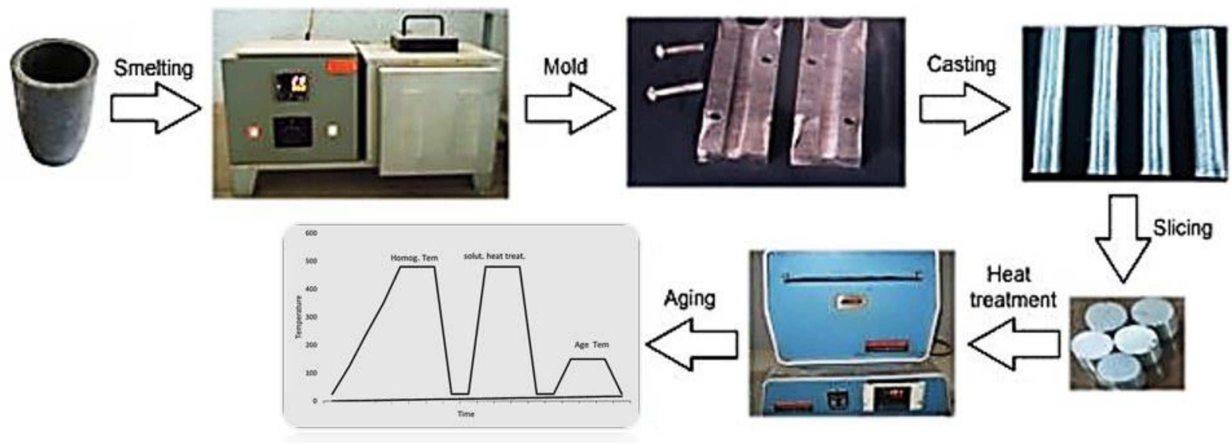

Fig. 1. Procedure for alloy preparation and heat treatment

Table.1. Elements used for casting aluminium alloy

| Component type | Element | Quantity, wt.% | Purity, % |
|---|---|---|---|
| Basic alloy | Al | Bal | 99.97 |
| | Cu | 2.5 | 99.95 |
| | Mg | 1.5 | 99 |
| Additive | Zr | 0.3 | 99 |

mentioned in Table.1, it is melted in an electric furnace. First, the aluminium is melted at 1023.15 K, then the rest of the casting elements are added. Stirring the molten takes 4-5 minutes to obtain the optimum homogeneity. Next, the molten alloy is poured into a cylindrical mould of diameter 15 mm and length 20 cm. The mould was heated to 573.15 K to avoid molten freezing before entering the mould and casting defects. After the casting is taken out of the mould, it has been processed by turning to of 10 mm and 14 mm in diameter and 8mm in thickness.

### 2.3. Heat treatments

To ensure the homogeneity of the castings' microstructure and prepare them for the tests, sequential heat treatments were carried out by using an electric furnace type LINDBERG. Before the heat treatment, the casting samples were ground and polished to remove scratches that might have resulted from the slicing process. These heat treatments are:

1. homogenizing heat treatment: was completed at 753.15 K for 3 hr., and slowly cooled down in the furnace to room temperature.
2. Solution heat treatment: this treatment was carried out 753.15 K for 3 hr. Also, then the castings are quenched in cold water.
3. Aging heat treatment: only artificial age hardening applied in this study at 423.15 K for different times (1-6 hr.), to get the best mechanical performance of these castings.

### 2.4. The tests

All tests were done in the metallurgical laboratory in material engineering college, university of Babylon.

1. Brinell hardness (HBW): this test was done according to ISO 18265:2013 standard by using Brinell machine [16].
2. Corrosion test: The corrosion test was achieved according to ISO 17475:2005 standard [17] .The Tafel tester type MLab 100, power 35 W, shown in Fig.2, has been used to measure the current density. This tester consists of an electrolyte, a calomel reference electrode, a platinum counter electrode, and the specimen as the working electrode was used for this purpose. The sample has a circular surface area with a 10 mm diameter as opposed to an attack electrolyte. A software program (Bank-Elechtionies) was used to plot the polarization curves anodic and cathodic. Electrolytes were prepared from 3.5 wt. % sodium chloride salt and distilled water. The selection of salt was based on the most abundant anions in seawater.

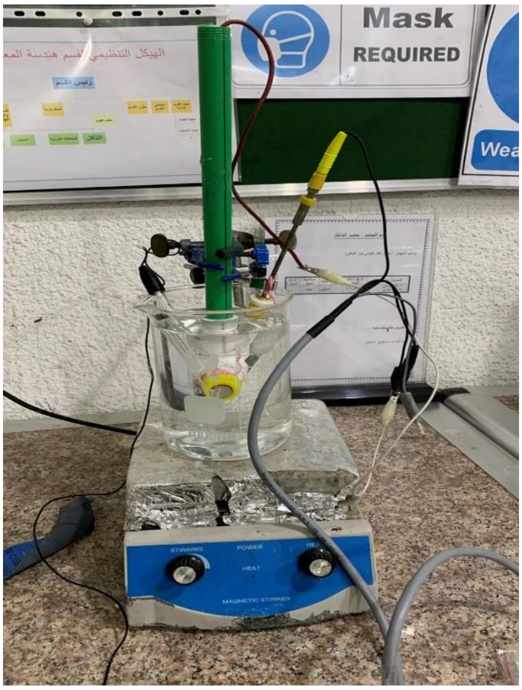

Fig. 2. The cell of electrochemical corrosion test

### 2.5. Chemical Composition Analysis

The chemical composition of the samples was also taken after the casting process at the General Company for Engineering Examination and Rehabilitation / Baghdad, where the results were as shown in the table (2).

Table. 2, Chemical composition and its weightages

| Code of alloy | Al Wt.% | Cu Wt.% | Mg Wt.% | Zr Wt.% | Si Wt.% | Fe Wt.% |
|---|---|---|---|---|---|---|
| base alloy | Bal | 2.8l | 1.3 | --- | 0.1 | 0.5 |
| 0.3% Zr | Bal | 2.4 | 1.8 | 0.26 | 0.1 | 0.5 |

## 3.RESULTS AND DISSCUSION

### 3.1. Hardness Tests at Aging Behaviour

The variation in hardness at different temperatures with time indicate precipitation sequences behaviour at these temperatures.

The relationship between Brinell hardness (HBW) and exposure time at aging temperature 423.15 K appears in Fig. 3.

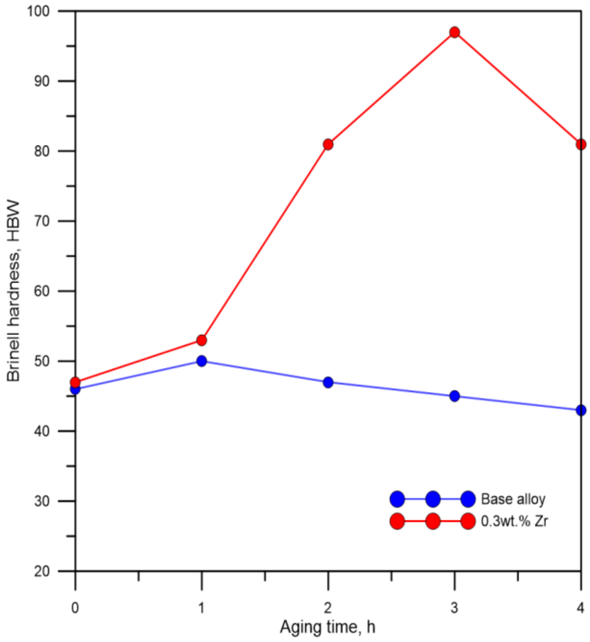

Fig. 3. Variation of Brinell hardness of (base alloy and 0.3% Zr) Alloy Sample with Aging Time at 423.15 K Aging Temperature.

Fig. 3 shows the hardness of alloys (base alloy and 0.3% Zr) Hardness increased the alloy (0.3% Zr). The results of hardness obtained through experiments. After the Age procedure and for different periods of time, we find that the hardness increases by increasing the Age hours at a temperature of 423.15 K. The highest hardness value was obtained after 3 hours of the operation. It is (97 HBW). There was an increase in hardness values due to the formation and spread of compounds ($Al_2CuMg$ and $Al_2Cu$ and production a new precipitate such as ($Al_3Zr$). That spread inside the crystalline lattice of the alloy in the (α-Al) phase, generating an increase in hardness values. After continuing the Age operation after 3 hours, found a decrease in the hardness curve. The reason is because intermetallic compounds are spread within the crystalline lattice to a point above saturation, generating reverse stresses that lead to low hardness values.

### 3.2 Corrosion Test after Age

Show the results obtained through the TAFL test, shown in the following the figures 4-8.

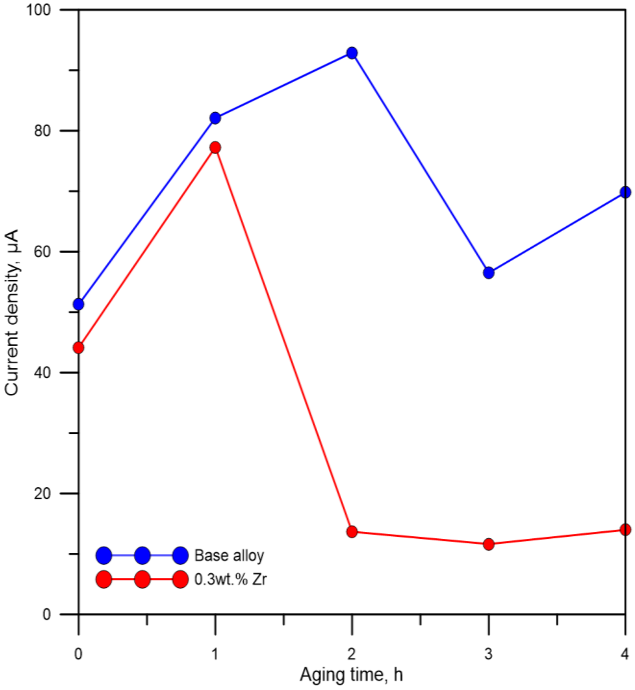

Fig. 4. Current density for base alloy and 0.3 % Zr

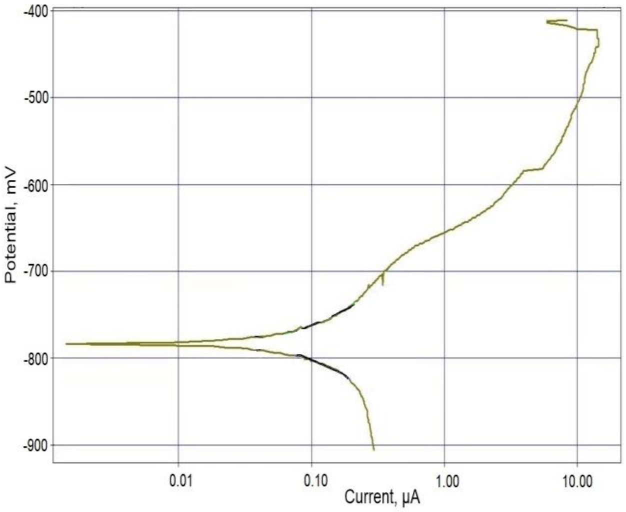

Fig. 5. The current density plot for Al-Cu-Mg base alloy before aging heat treatment

The corrosion resistance of the alloy (Zr) increased by 79.42% compared to the base alloy. The reason for this is the role of (Zr) in reducing the internal cracks in the crystalline lattice because of the formation of ($Al_3Zr$) In summary, the addition of the element (Zr) can increase the resistance to recrystallisation and stabilize the microstructure as a result of the formation of ($Al_3Zr$) The

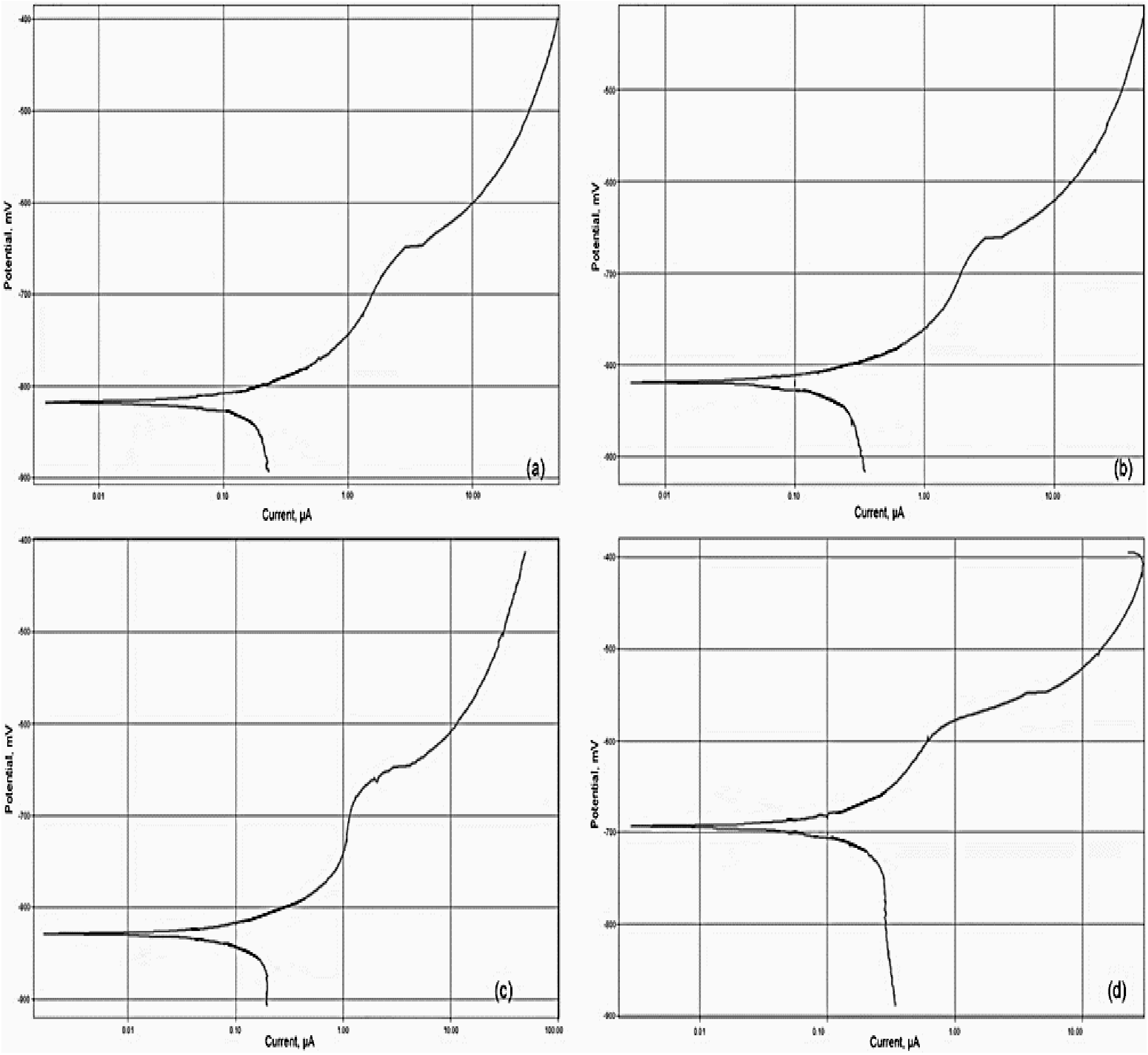

Fig. 6. The current density plot for Al-Cu-Mg base alloy after aging heat treatment for (a) 1h, (b) 2hs., (c) 3 hr., and (d) 4 hr

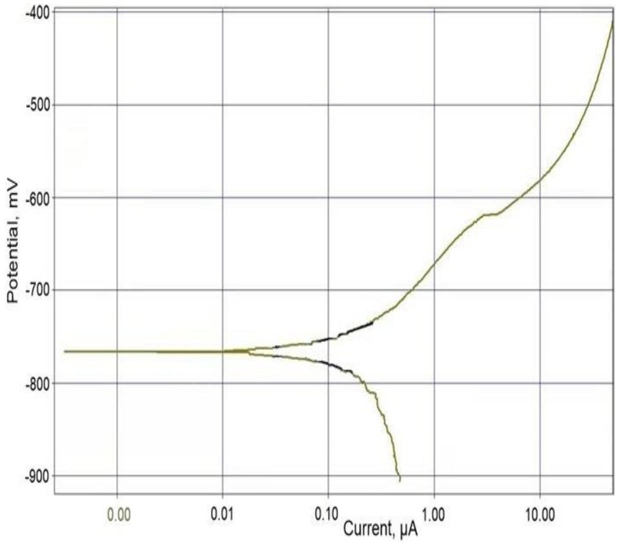

Fig. 7. The current density plot for Al-Cu-Mg-Zr alloy before aging heat treatment

distorted microstructure with the intermittent distribution of sediment at the Grean boundary improved corrosion resistance. The decrease in granular corrosion is also due to the Zr effect, which reduced the copper content at the Grean boundary and reduced the dissolving of magnesium and thus hindered the corrosion process [18].

### 3.3 Microphotographs analysis

Microphotographs show in the following the figures 9-10.

That show the microstructure of the base alloy and the alloy that has been added to Zr, which the age process was performed at a temperature of 423.15 K and for 3 hours, showing the difference in granular size and the method of distributing molecules for both the base alloy and the alloy inlaid with Zr. It was found that the granular size is smaller in the presence of Zr compared to the base alloy.

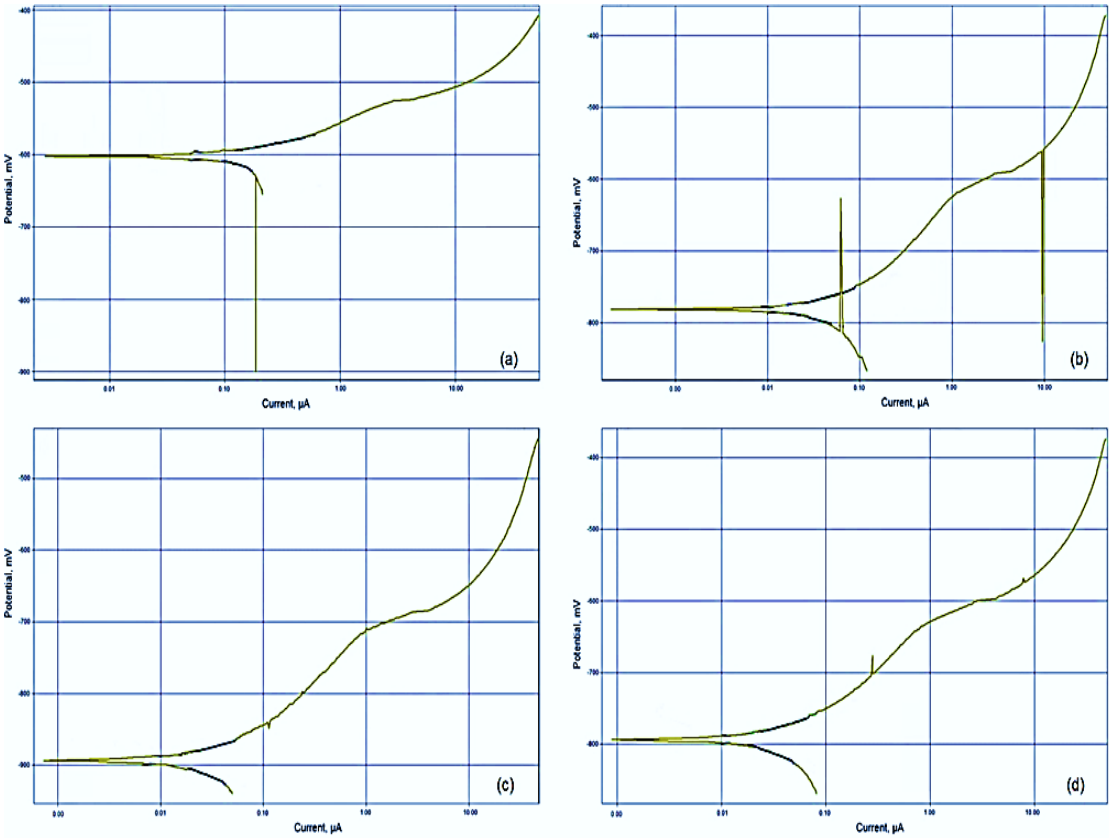

Fig. 8. The current density plot for Al-Cu-Mg-Zr alloy after aging heat treatment for (a) 1h, (b) 2hs., (c) 3 hr., and (d) 4 hr.

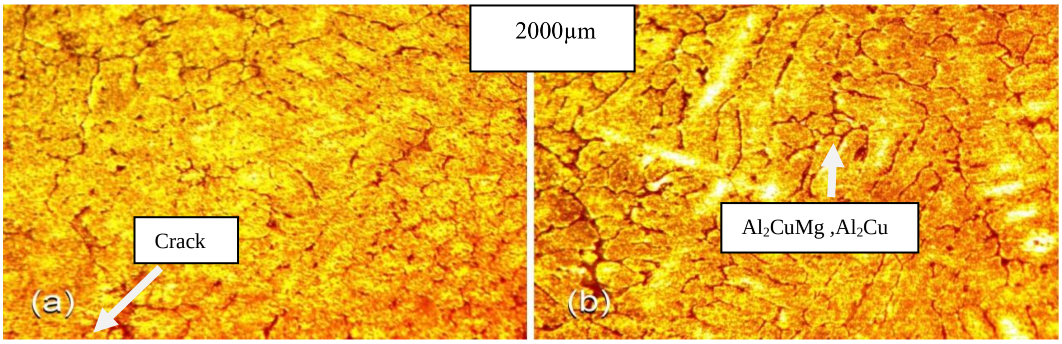

Fig. 9. Microstructure of base Alloys (a) before and (b) after ageing treatment in 423.15 K

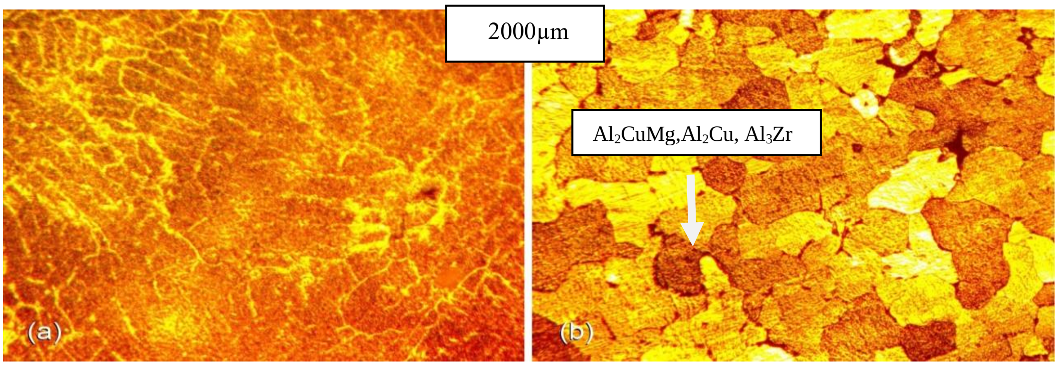

Fig. 10. Microstructure of Al-Cu-Mg-Zr alloys (a) before and (b) after ageing treatment in 423.15 K

## CONCLUSION

The formation of intermittent $Al_3Zr$ conjugated to Zr additions increases the hardness significantly, where the rate of improvement in the hardness of the alloy modified with Zr reached to 115.65% compared to the base alloy after adding 3wt.% of Zr. Moreover, Zr additions refine the grains in the modified alloy compared to the basic alloy. As a result of this microstructure change, the corrosion resistance increased considerably after adding 3wt.% of Zr, where the increment percentage in the resistance of the modified alloy reached to 79.42% compared to what it is in the case of the base alloy.

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**Declaration of competing interest:** *The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.*

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