ARTICLE

JOURNAL OF UNIVERSITY OF BABYLON For ENGINEERING SCIENCES (JUBES)

Vol.31, No.5. | 2023

ISSN: 2616 - 9916 | www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com

Hardness, Corrosion Behavior, and Microstructure of Al-Cu-Mg Alloy as a Fuction of 0.3 wt.% Ti Addition and Treatment of Alloy by Polymer Solution PAG

Karrar Saad [1],*, Jassim Mohammed [2]

[1,2] *College of Materials Engineering, University of Babylon, Iraq*
* Corresponding author: karrarsaad1994@gmail.com

Received:	23/5/2023	Accepted:	22/6/2023	Published:	10/8/2023

Abstract

The effect of adding titanium (Ti) 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 5hr showed a significant increment in the Brinell hardness (HBW) improvement ratio of 113.95% (from 43HBW to 92HBW) and an extreme reduction the corrosion rate of the alloy after Ti adding decrease in the current density by 77.54% (from 58.14 μA cm^{-2} to 13.06 μA cm^{-2}) with aging for 5 hr compared to the base alloy. The impact of addition (Ti) and solution heat treatment (in PAG) 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 Ti has a considerable synergistic effect causing inhibition of recrystallization and refinement of grain size.

Keywords: Al-Cu-Mg alloy, Ti addition, Brinell hardness, Current density of corrosion, Recrystallization.

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

ISSN: 2616 - 9916 | www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com
مجلة جامعة بابل للعلوم الهندسية

improve the performance of the aluminum alloy [4]-[9]. Studies on Ti-containing Al alloys, particularly Ti-containing Al-Cu-Mg alloys, are rare and have received little attention in the literature [10,14,15], which has mainly concentrated on microstructure and mechanical properties. This study's primary objective is to determine how adding 0.3 % Ti to Al-Cu-Mg alloys affects how they behave toward corrosion and how tough they are.

2. Methodology

2.1. Materials

Table 1 presents the composition of elements utilized in the casting of aluminum alloy, including Aluminum in wire form, Copper in chip form, Magnesium in flake form, and Titanium powder.

Table.1: Elements used for Casting Aluminiun Alloy

Component type	Element	Quantity, wt.%	Purity, %
Basic alloy	Al	Bal	99.97
	Cu	2.5	99.95
	Mg	1.5	99
Additive	Ti	0.35	99

2.2. Alloy Preparation

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

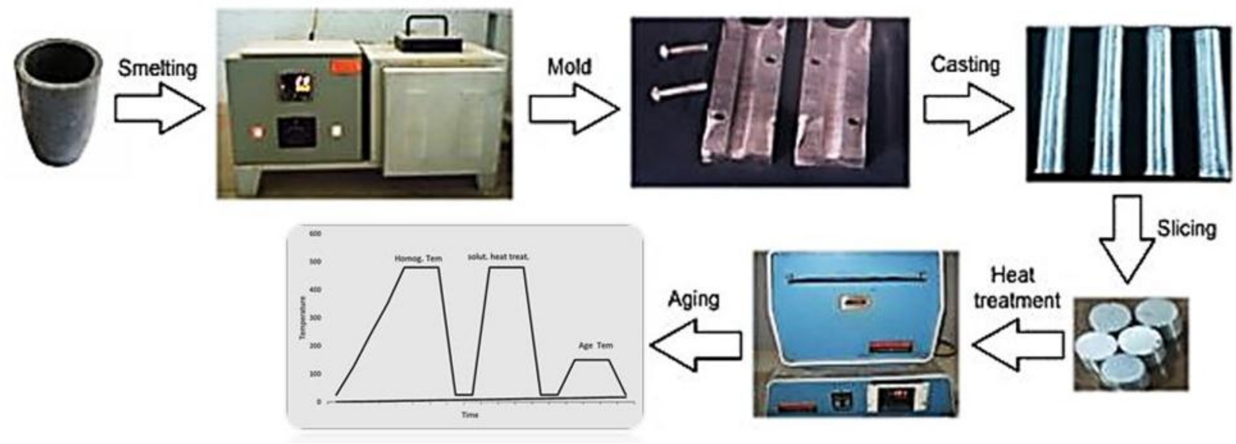

Fig.1: The Methodology for the Fabrication of Alloys and Subsequent Thermal Processing.

مـجلــة جـــامعة بـــابل للعلـــوم الهندسية مـجلــة جـــامعة بـــابل للعلـــوم الهندسية مـجلــة جـــامعة بـــابل للعلـــوم الهندسية

ISSN: 2616 - 9916 | www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com

2.3. Heat Treatments

A sequence of successive heat treatments was carried out using a LINDBERG electric furnace to attain homogeneity in the microstructure of the castings and simplify their preparation for testing. The casting specimens were subjected to grinding and polishing procedures to eliminate any surface imperfections that may have arisen from the slicing process, in preparation for heat treatment. The thermal energy application procedures for altering the properties of materials including the homogenization process entailed exposing the material to a temperature of 480 ˚C for a period of 3 hours, succeeded by a gradual cooling process to attain room temperature within the furnace:

1. The process of heat treatment solution involved subjecting the material to a temperature of 480 ºC for a duration of 3 hours. Subsequently, the castings undergo quenching in a polymer solution known as PAG.
2. The present study solely employed an artificial aging heat treatment technique, whereby the castings were subjected to a temperature of 150°C for varying durations ranging from 1 to 10 hours, with the aim of achieving optimal mechanical properties.

2.4. The Tests

The experiments were conducted at the metallurgical laboratory located in the College of Material Engineering at the University of Babylon.

1. The Brinell hardness (Hardness Brinell Wolfram carbide HBW) was assessed in accordance with the ISO 18265:2013 standard, utilizing a Brinell machine. [11]
2. The ISO 17475:2005 standard was employed to conduct the corrosion assessment. The current density was measured using the Tafel tester type MLab 100, as shown in Figure 2. The power capacity of this device is 35 watts. The experimental setup comprised of an electrolytic solution, a calomel reference electrode, a platinum counter electrode, and the specimen, which served as the working electrode. The sample under observation exhibits a circular morphology with a diameter of 10 mm, which is distinct from that of a highly reactive electrolytic solution. The Bank-Elechtionies software was employed to produce polarization curves for the anodic and cathodic reactions. The electrolyte solution was formulated through the amalgamation of distilled water and sodium chloride salt with a weight percentage of 3.5%. The choice of the salt was determined by the prevalence of the most abundant anions present in seawater.

ISSN: 2616 - 9916 www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com

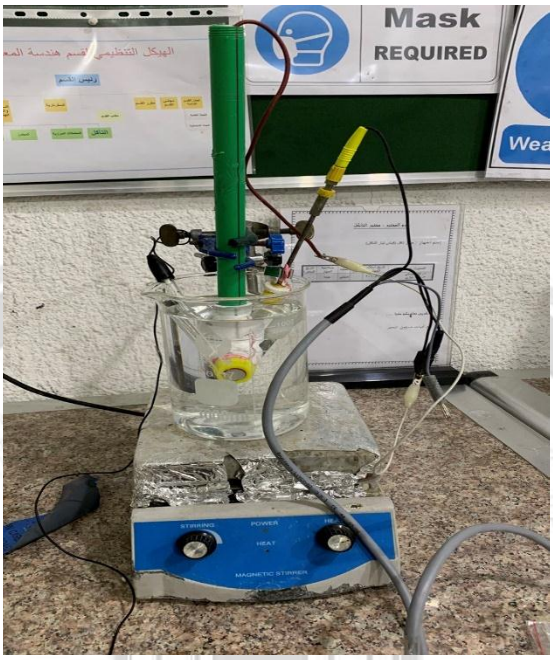

Fig.2: The Electrochemical Corrosion Test Cell.

2.5. Analysis of Chemical Composition

The chemical composition of the specimens was analyzed subsequent to casting, at the General Company for Engineering Examination and Rehabilitation located in Baghdad. The findings of the analysis are presented in Table 2.

Table 2: Chemical Composition and its Weightages

Code of alloy	Al Wt.%	Cu Wt.%	Mg Wt.%	Ti Wt.%	Si Wt.%	Fe Wt.%
A	Bal	3.00	1.23	----	0.1	0.5
B	Bal	2.99	1.24	0.34	0.07	0.1

3.Results and Discussion

3.1 Hardness Result

The fluctuations in hardness that have been observed in relation to temperature and time are suggestive of the precipitation behavior that is taking place at those particular temperatures.

Figure (3) depict the graphical representation of the correlation between Brinell hardness (HBW) and the duration of exposure at an aging temperature of 150℃.

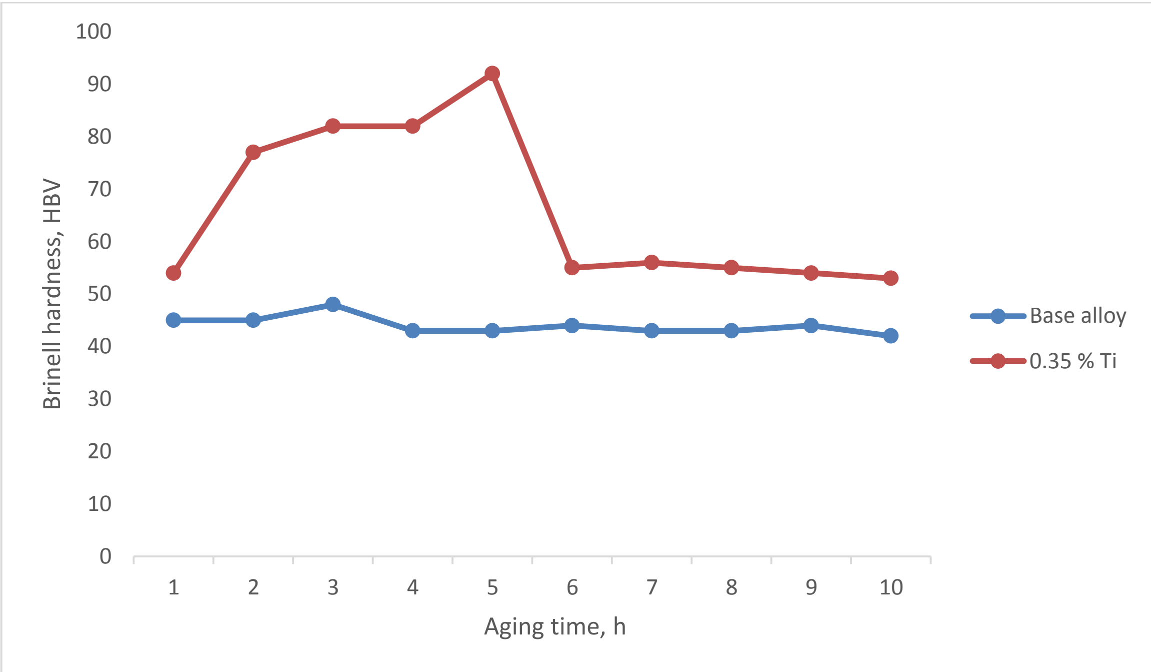

Fig. 3: The present study investigates the variation in Brinell hardness of Alloy Sample A and B as a function of aging time at a constant temperature of 150°C..

The third figure depicts the comparative hardness of two alloys, A and B. The alloy (B) exhibits an increase in hardness. The experimental findings pertaining to hardness. Following the age procedure, it has been observed that the hardness of the material exhibits an increasing trend with an increase in the Age hours at a temperature of 150˚C over varying time intervals. The maximum hardness value was achieved subsequent to a 5-hour duration of the operation. The hardness value of the material is 92 HBW. The observed rise in hardness values can be attributed to the formation and dissemination of compounds, namely Al_2CuMg and Al_2Cu, as well as the generation of a novel precipitate, Al_3Ti. The propagation of the aforementioned phenomenon within the crystalline lattice of the alloy in the (α-Al) phase resulted in a notable augmentation of the measured hardness parameters. After conducting the Age operation for a duration of 5 hours, a reduction in the hardness curve was observed. Intermetallic compounds are distributed throughout the crystalline network beyond the point of saturation, resulting in reverse stresses that contribute to reduced hardness values. This phenomenon can be attributed to the underlying cause.

3.2 Corrosion Test after Age

Show the results obtained through the Tafel test (polarization behaviour Tests), shown in the following the figures 4 and 8.

ISSN: 2616 - 9916 | www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com
مجلة جامعة بابل للعلوم الهندسية

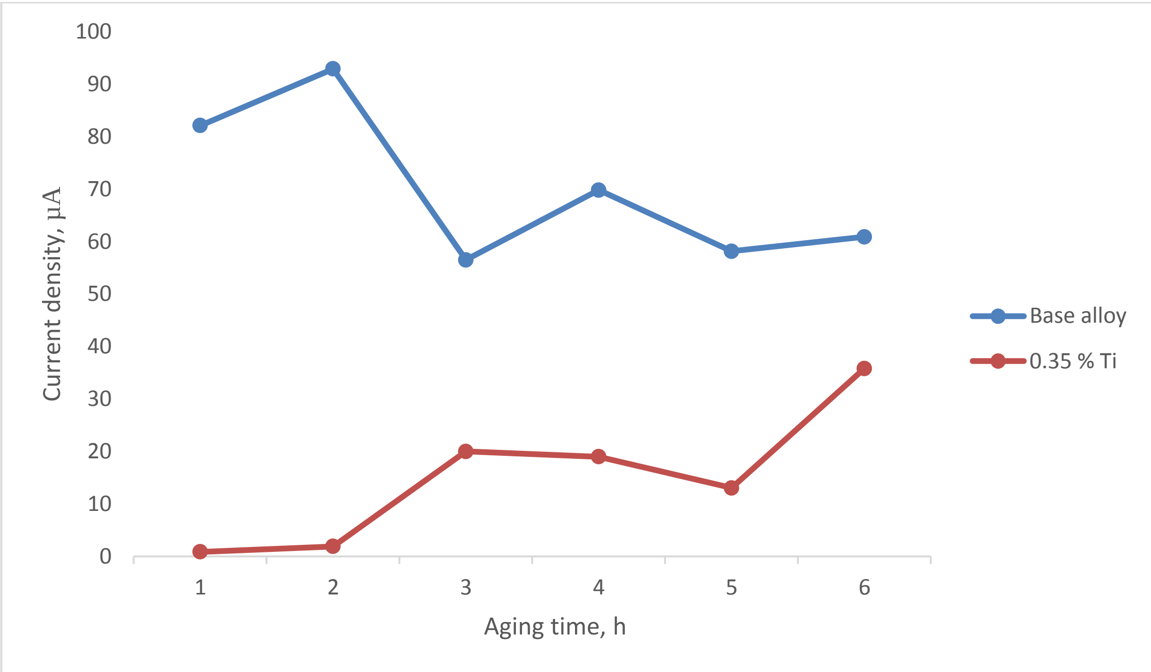

Fig. 4: The present study investigates the current density of the base alloy and an alloy containing 0.35% Ti.

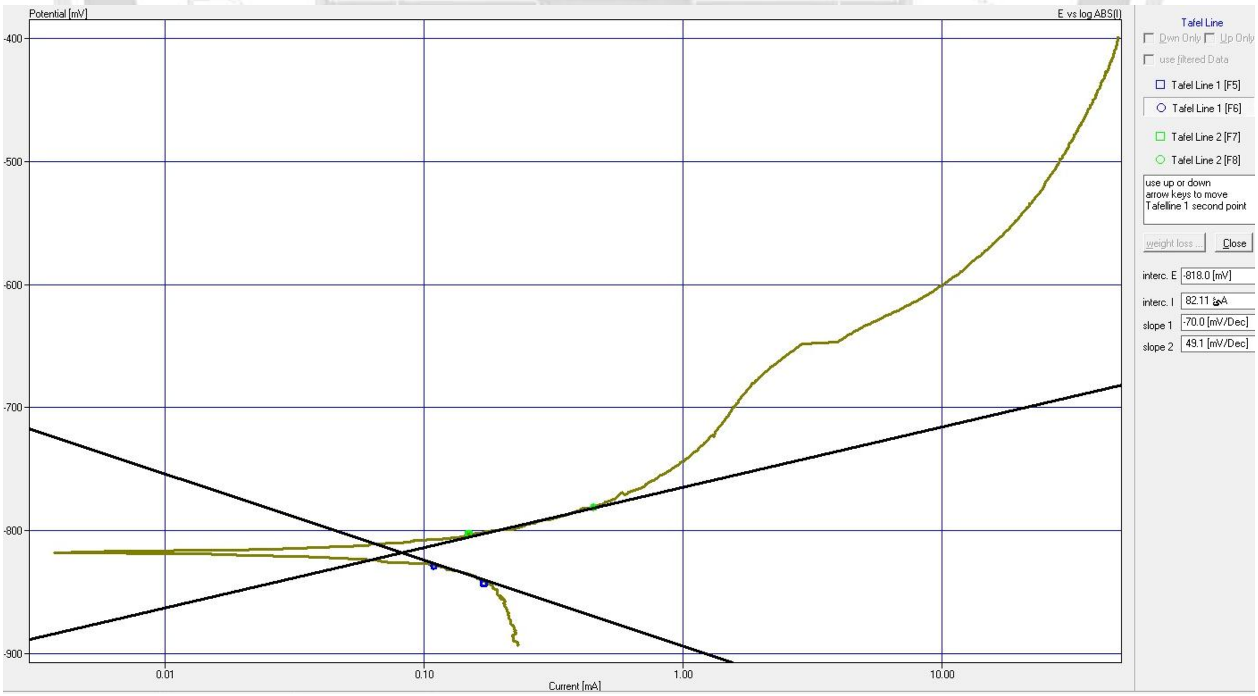

Fig. 5: The present study depicts the current density plot of an Al-Cu-Mg base alloy subsequent to a 1-hour aging heat treatment.

مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية
ISSN: 2616 - 9916
www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com

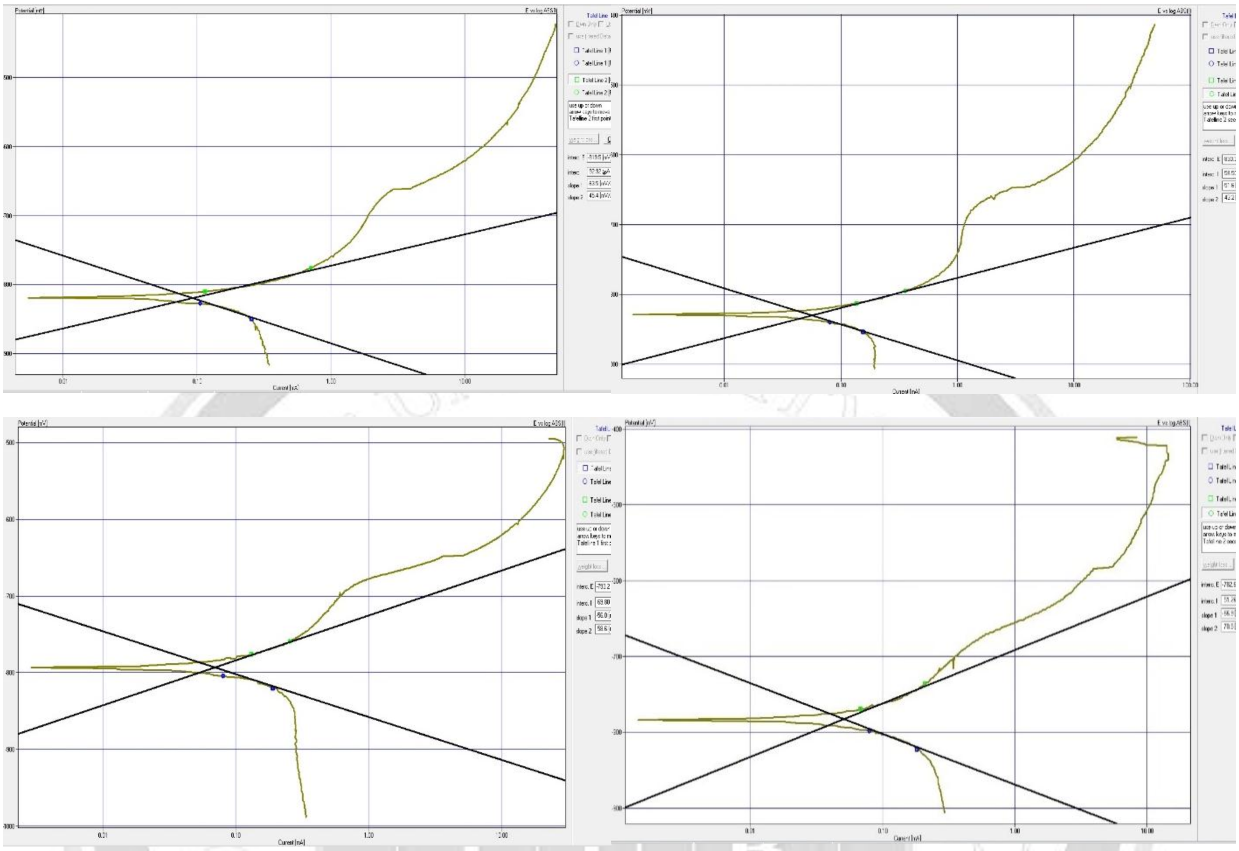

Fig. 6: The present study depicts the current density plot of an Al-Cu-Mg base alloy subsequent to an aging heat treatment for varying durations, namely (a) 2 hours, (b) 3 hours, (c) 4 hours, and (d) 5 hours..

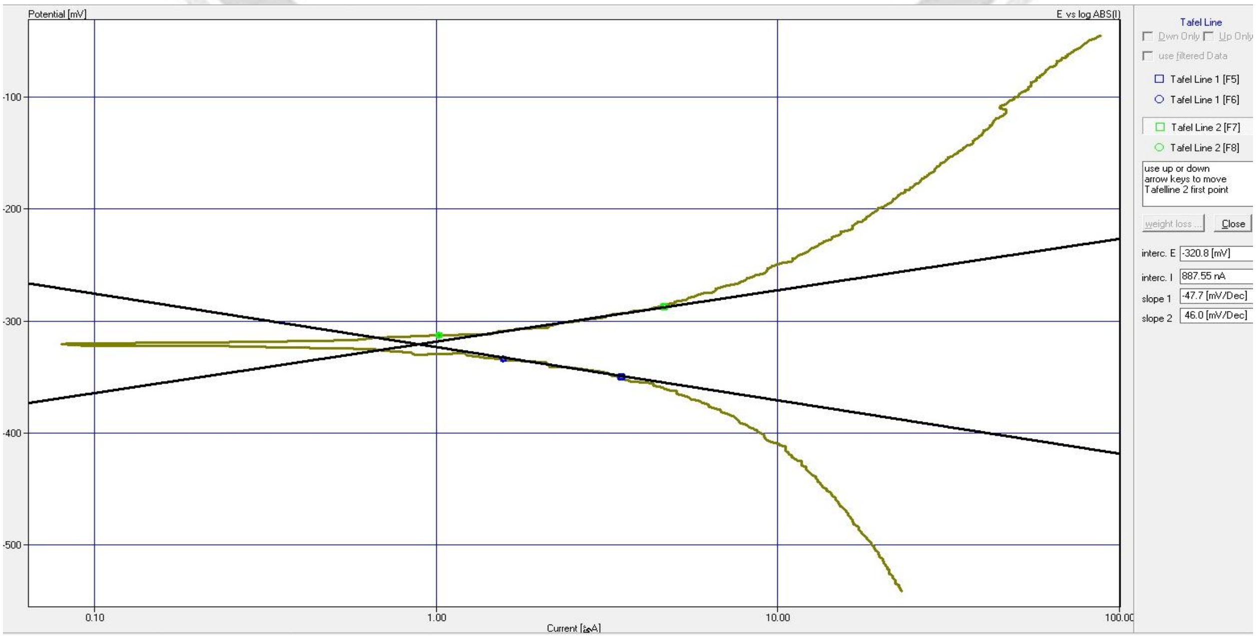

Fig. 7: The present study showcases the current density plot of Al-Cu-Mg-Ti alloy subsequent to a 60-minute aging heat treatment.

ISSN: 2616 - 9916 | www.journalofbabylon.com | info@journalofbabylon.com | Journal.eng@uobabylon.edu.iq | www.journalofbabylon.com | info@journalofbabylon.com

مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية

ISSN: 2616 - 9916
info@journalofbabylon.com | Journal.eng@uobabylon.edu.iq | www.journalofbabylon.com
مجلة جامعة بابل للعلوم الهندسية

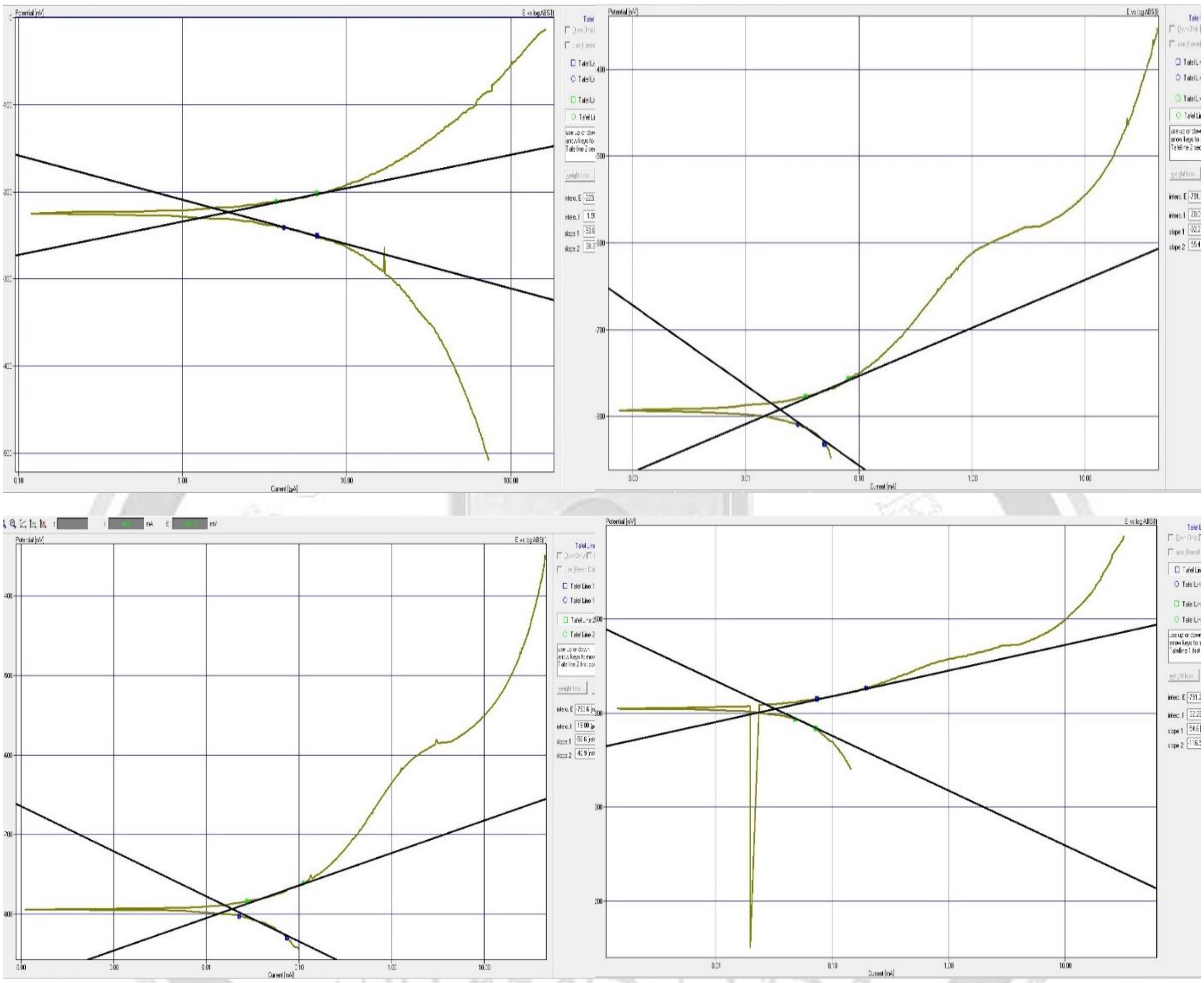

Fig. 8: This study presents the current density plot of an Al-Cu-Mg-Ti alloy subjected to aging heat treatment for varying durations of 2, 3, 4, and 5 hours.

The titanium (Ti) alloy exhibited a significant improvement in its corrosion resistance. Following an hour of aging, the alloy demonstrated a notable enhancement of 98.9%, while after five hours of aging, it exhibited a substantial improvement of 77.54% when compared to the base alloy. The fundamental rationale behind this phenomenon is based on the function of (Ti) in diminishing the probability of internal fissures within the crystal lattice, which is attributed to the creation of (Al3Ti). To summarize, the incorporation of titanium (Ti) has the potential to improve the resistance to recrystallization and promote a uniform microstructure, as a result of the emergence of aluminum titanium intermetallics (Al3Ti). The enhanced corrosion resistance can be attributed to the distorted microstructure, which displayed an intermittent distribution of sediment at the Grean boundary. The reduction in granular corrosion that was observed can be attributed to the influence of titanium, which resulted in a decrease in the concentration of copper at the Grean boundary. As a consequence, the dissolution of magnesium was hindered, leading to a hindrance of the corrosion process [13].And, This is because low deformation in lattice is due to precipitates and relatively slow cooling rate when used polymer as solution heat treatment .

مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية
ISSN: 2616 - 9916 | www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com

3.3 Optical Microscope Testing

See the following figures (9,10).

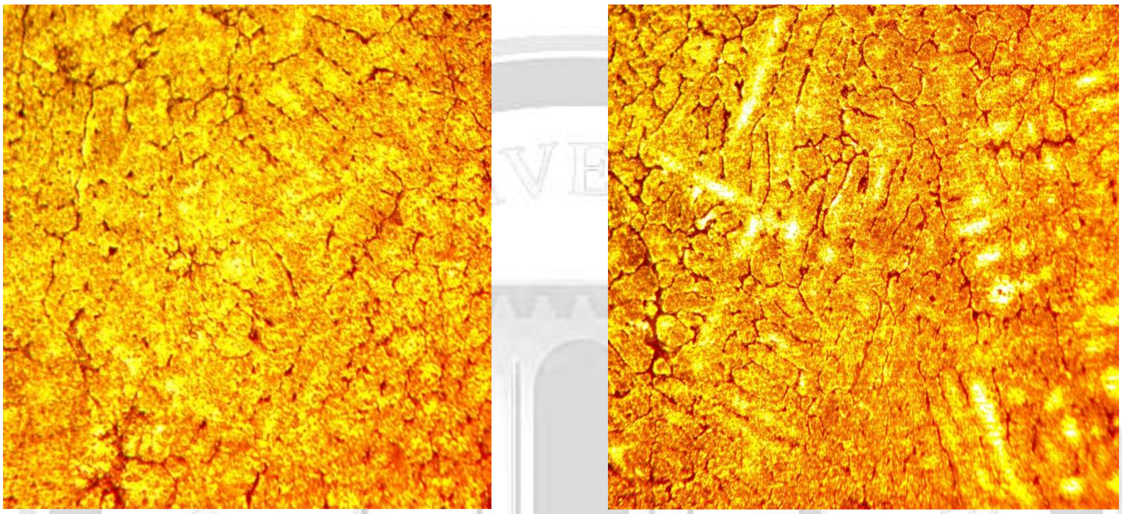

Fig. 9: The microstructure of the base material. The alloys were examined both prior to and subsequent to undergoing an ageing treatment at a temperature of 150℃.

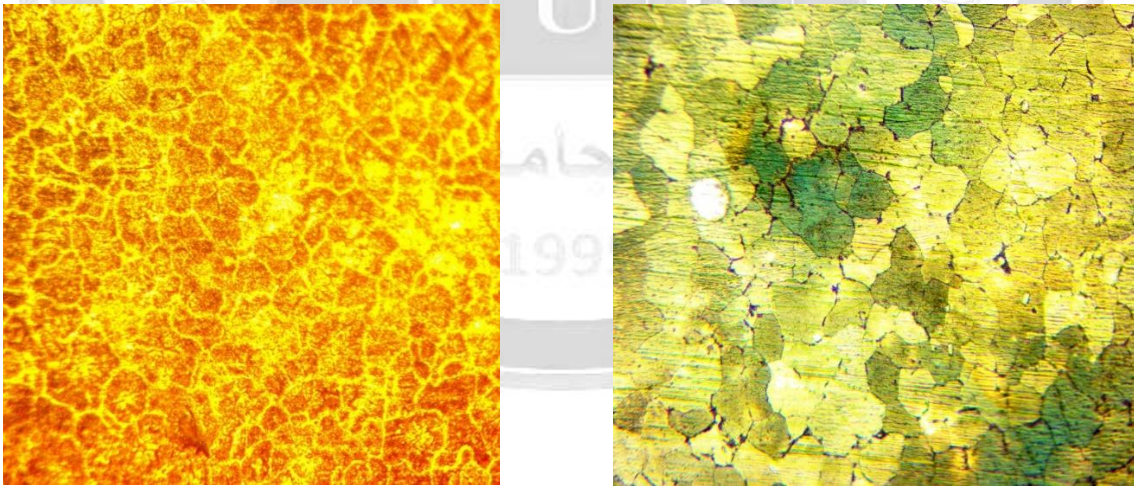

Fig. 10: The microstructural characteristics of Al-Cu-Mg-Ti alloys were examined in two distinct states: (a) prior to ageing treatment and (b) subsequent to ageing treatment at a temperature of 150℃.

This study presents a comparative analysis of the microstructure of the base alloy and the Ti-inlaid alloy subjected to an aging process at 150 ˚C for 5 hours. The results demonstrate notable differences in granular size and molecular distribution between the two alloys. The study revealed that the addition of Ti to the base alloy resulted in a reduction in granular size. And, Generally when comparing the figures, it is obtained that the microstructure of alloys consists of shape, size and uniform distributing for precipitates in microstructure of alloys which quenching in polymer.

ISSN: 2616 - 9916 | www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com

CONCLUSIONS

Based on the results of the alloy sample testing, the following conclusions can be drawn:

1-The incorporation of titanium into the base alloy resulted in a significant increase in hardness, specifically by 113.95%, after a 5-hour aging process.

2-It was discovered that the (Ti) alloy exhibited a 98.9% increase in corrosion resistance after 1 hour of aging and a 77.54% increase after 5 hours of aging in comparison to the base alloy.

3- The grain size of the Al-Cu-Mg alloy without Ti is large, and the size decreases by the addition of Ti [15].

The aforementioned phenomenon can be attributed to the emergence of sporadic (Al_3Ti) compounds dispersed throughout the crystalline matrix, as evidenced by the aforementioned findings. The microstructural analysis reveals that the addition of Ti has a discernible impact on the granular size, resulting in a reduction when compared to the base alloy.

Reference

[1] J. C. Williams, E. A. Starke Jr., "Progress in structural materials for aerospace systems", *Acta Materialia*, vol. 51,pp. 5775-5799 , 2003.
https://doi.org/10.1016/j.actamat.2003.08.023 .

[2] A. Heinz, A. Haszler, C. Keidel, "Recent development in aluminium alloys for aerospace applications", *Recent development in aluminium alloys for aerospace applications*,vol. 280,pp. 102-107, 2000.
https://doi.org/10.1016/S0921-5093(99)00674-7 .

[3] Y. Deng, Z. Yin, K. Zhao, "Effects of Sc and Zr microalloying additions and aging time at 120 °C on the corrosion behaviour of an Al–Zn–Mg alloy", *Corrosion Science* ,vol.65, pp.288-298, 2012. https://doi.org/10.1016/j.corsci.2012.08.024

[4] J. Liu, P. Yao," Effect of minor Sc and Zr on recrystallization behavior and mechanical properties of novel Al–Zn–Mg–Cu alloys", *Journal of Alloys and Compounds*,vol. 657, pp.717-725, 2016.
https://doi.org/10.1016/j.jallcom.2015.10.122

[5] Y. Shi, Q. Pan, "Effect of Sc and Zr additions on corrosion behaviour of Al–Zn–Mg–Cu alloys", *Journal of Alloys and Compounds*, vol. 612, pp.42-50, 2014.
https://doi.org/10.1016/j.jallcom.2014.05.128

[6] T. Wang, T. Gao, "Influence of a new kind of Al–Ti–C master alloy on the microstructure and mechanical properties of Al–5Cu alloy", *Journal of Alloys and Compounds*, vol. 589, pp.19-24, 2014. https://doi.org/10.1016/j.jallcom.2013.11.187

[7] R.K. Gupta, R. Zhang, "Theoretical Study of the Influence of Microalloying on Sensitization of AA5083 and Moderation of Sensitization of a Model Al-Mg-Mn Alloy via Sr Additions", *corrosion* , vol.70, pp.402–413, 2014.
https://doi.org/10.5006/1117

[8] R.K. Gupta, D. Fabijanic, "Simultaneous improvement in the strength and corrosion resistance of Al via high-energy ball milling and Cr alloying", *Materials & Design*, vol. 84, pp.270-276, 2015. https://doi.org/10.1016/j.matdes.2015.06.120

[9] Y. Wang, H. Yang, "An updated meta-analysis on the association of TGF-β1 gene promoter -509C/T polymorphism with colorectal cancer risk", *Cytokine*, vol.61, pp.181-187, 2013. https://doi.org/10.1016/j.cyto.2012.09.014

[10] M. Jaradeh, T. Carlberg, "Effect of titanium additions on the microstructure of DC-cast aluminium alloys", *Materials Science and Engineering*: A, vol. 413–414, pp. 277–282, 2005.
DOI:10.1016/j.msea.2005.09.006

[11] ISO 18265, Metallic materials — Conversion of hardness values, International Organization for Standardization (ISO), 2013.

[12] ISO 17475, Corrosion of metals and alloys-Electrochemical test methods -Guidelines for conducting potentiostatic and potentiodynamic polarization measurements, International Organization for Standardization (ISO), 2005.

[13] F. Sun, G. L. Nash, "Effect of Sc and Zr additions on microstructures and corrosion behaviour of Al-Cu-Mg-Sc-Zr alloys", *Journal of Materials Science & Technology*, vol.33, pp.1015-1022, 2017. https://doi.org/10.1016/j.jmst.2016.12.003

[14] D.H. Xiao, J.N. Wang, "Effect of titanium additions on mechanical properties of Al–Cu–Mg–Ag alloy", *Materials Science and Technology,* pp. 1199-1204, 2013. https://www.tandfonline.com/doi/abs/10.1179/026708304225022106

[15] S. Min, C. Kanghua, "Effects of Ce and Ti on the microstructures and mechanical properties of an Al-Cu-Mg-Ag alloy", *Rare Metals*, vol. 26, pp.28-32, 2007. https://doi.org/10.1016/S1001-0521(07)60023-0

ISSN: 2616 - 9916 | www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com

ARTICLE
JOURNAL OF UNIVERSITY OF BABYLON
For ENGINEERING SCIENCES (JUBES)
Vol.31, No.5.| 2023

ISSN: 2616 - 9916
www.journalofbabylon.com | Journal.eng@uobabylon.edu.iq | info@journalofbabylon.com

مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية

الصلادة, سلوك التاكل والبنية المجهرية لسبائك (Al-Cu-Mg) بعد إضافة (٠.٣%) من عنصر التيتانيوم ومعاملة السبيكة بمحلول بوليمر (PAG)

كرار سعد [١*] جاسم محمد [٢]
[١,٢] كلية هندسة المواد-جامعة بابل -العراق
karrarsaad1994@gmail.com*

الخلاصة:

تم دراسة تأثير إضافة التيتانيوم (Ti) كعنصر سبك إلى سبيكة Al-Cu-Mg على صلادة وتآكل هذه السبيكة. أظهرت نتائج اختبار الصلادة والاستقطاب للعينات المعالجة لفترات مختلفة عن طريق التعتيق عند ٤٢٣.١٥ كلفن لمدة ٥ ساعات زيادة كبيرة في نسبة تحسين صلابة برينل (HBW) بنسبة ١١٣.٩٥٪ (من HBW٤٣ إلى HBW٩٢) وانخفاض شديد في معدل التآكل في السبيكة بعد إضافة Ti تنخفض كثافة التيار بنسبة ٧٧.٥٤٪ (من ٥٨.١٤ $\mu A\ cm^{-2}$ إلى ١٣.٠٦ $\mu A\ cm^{-2}$) مع التعتيق لمدة ٥ ساعات مقارنة بالسبيكة الأساسية, ينعكس تأثير إضافة (Ti) والمعالجة الحرارية للمحلول (في PAG) أيضًا في تقوية وإعادة بلورة وتعديل البنية المجهرية للحبوب. تم إثبات هذه التغييرات بوضوح من خلال الاختبار المجهري وتثبت أن إضافة Ti لها تأثير تآزري كبير مما يتسبب في تثبيط إعادة التبلور وصقل حجم الحبيبات.

الكلمات الدالة:سبيكة المنيوم-نحاس-مغنيسيوم, إضافة عنصر التيتانيوم, صلادة برنل, كثافة تيار التاكل, إعادة التبلور.