

EFFECT OF SN ADDITION ON MECHANICAL PROPERTIES AND CORROSION RESISTANCE OF Al-Cu IN THE PRESENCE OF H₂O₂

Sabah Mahdi Salah¹, Mohammed S. Ahmed¹

¹College of Engineering, Mechanical Engineering Department, Tikrit University, Iraq

E-mails: Sabahmsalih69@gmail.com, Mohammed.sa1972@gmail.com

Abstract - Corrosion of AlCu-xSn alloys was investigated at 0, 0.1, 0.2 and 0.5 % H₂O₂ concentration in deionized water at neutral pH. The aim of this work was to study the effect of Sn concentration in alloy on its dynamic corrosion in the presence of H₂O₂ oxidizer. The concentration of Sn in the alloy was 0%, 1%, 2% and 3%. Potentiodynamic polarization of the alloys in different concentration of H₂O₂ was obtained to understand their electrochemical behavior. The dynamic corrosion tests were conducted by immersing the samples in beakers on a magnetic stirrer. The corrosion rates were calculated via weight loss measurements. The corrosion rates obtained show an increase with 1% Sn in the alloy as compared to Sn free AlCu. However, beyond 1% till 3% an almost linear decrease in corrosion rates have been observed. The samples had the surface roughness before corrosion tests however after the tests the roughness values show the same trend as corrosion behavior which can be attributed to their wettability behavior.

Keywords: Corrosion, AlCu-xSn Alloys, Potentiodynamic Polarization, Surface Roughness, Mechanical Properties.

1. Introduction

Aluminium and its alloys offer a wide range of mechanical and electrical properties that upon precise engineering can meet the demands of both general and specific applications. Owing to its various industrial applications, aluminium and its alloys and their nontoxic nature, good weld-ability, ability to retain strength at lower temperatures and high strength to weight ratio have attracted the attention of many researchers [1-3]. Another important property of Aluminium alloys is their resistance to degradation and corrosion [4-6]. This property is due to the formation of a natural protective oxide layer of around 5nm on its surface which offers good corrosion resistance towards natural atmospheres and other environments [7]. Although, due to corrosive attack of aggressive ions like chloride this protective layer can be locally destroyed which with time propagates and can result in failure [8]. However, if appropriately protected, aluminium alloys may have longer service life and be more reliable.

Corrosion by pitting in aluminium alloys can be affected by several factors such as the temperature, the pH and the type of ion present in the environment [9-12]. Another factor is that the electrochemical nature of the intermetallic phases can also results in localized corrosion in alloys. Several researchers have investigated the corrosion behaviour of aluminium alloys as a function of concentration of active element addition [4, 12-15],

time and surface roughness [16], concentration of salt i.e. NaCl [4, 16], acidic/basic nature of environment [4,7,14-17]. However, these investigations have been conducted in static conditions and acidic or basic environments in the absence of an oxidizer. Aluminum is generally anodic in nature [4] in mostly used media as compared to other metals in its alloys and therefore tend to suffer from localized type of corrosion may lead to formation of different cathodic precipitates. Although it is well understood that some inhibitors can protect aluminum and its oxide film from corrosion attacks.

In the present work, the main objective of is to observed the effect of Sn addition on the corrosion behaviour of AlCu-xSn alloy in the presence of varying H₂O₂ concentration in DIW under dynamic conditions. The work provides a relation between the wettability, electrochemical behaviour of the alloy and dynamic corrosion rates. The work also relates the corrosion rates to surface roughness of alloy before and after dynamic corrosion.

2. Materials and Methods

2.1 Materials

A proper appearance of the paper will help the reader go through it more easily. To obtain it, is imperative that authors use this template.

The aluminum alloy (Al-Cu-xSn) with chemical composition (weight %) is listed in Table 1 has been investigated for its corrosion behavior. The alloys were prepared by adding pure tin (99.92%) to pure aluminum (99.96) in the presence and absence of pure copper (99.96%) through the casting process in a metal mold intended for this purpose.

Table 1. Chemical composition of the AlCu-xSn alloy

Element	Al	Cu	Sn
%	Balance	4	0
%	Balance	4	1
%	Balance	4	2
%	Balance	4	3

2.2 Methods

2.1.1 Sample Preparation

The samples were prepared by cutting the alloy into 10*10*2 mm coupons and then mechanically polished using 1200 silicon carbide papers while lubricated with tap water. The prepared samples were cleaned with ethanol, washed with distilled water, dried with pressurized air and stored in desiccators prior to use.

2.1.2 Hardness Measurement

The hardness of aluminum copper alloys with tin addition after mechanical polishing treatments were evaluated using Vickers hardness test protocol with ARS9000 Full Automatic Micro hardness testing system (Future Teach, FM-300e, Kanagawa, Japan) with applied load of 500g. Three values were taken on each sample to calculate the average hardness value.

2.1.3 Contact angle measurement

The samples were characterized for wettability after CMP treatments through contact angle measurements with DIW. The contact angles were measured via sessile drop method using KSV ATTENSION Theta Lite Optical Goniometer.

The size of the drop was maintained at ~150 μm.

Three tests were performed for each sample at room temperature and the results were averaged.

2.1.4 Potentiodynamic polarization

Potentiodynamic polarization technique was utilized in order to understand the electrochemical behavior of the alloys' corrosion.

All tests were performed with Gamry 1000 Interface potentiostat utilizing a three electrodes cell.

A spiral platinum wire was used as a counter electrode, the reference electrode used was Ag/AgCl while the alloy's coupons prepared were used as working electrode in the tests.

The tests were conducted in 250mL glass container with a glass top designed for this purpose.

The polarization curves were recorded for scanning the electrode potential from -0.5 to 1.5 V (vs. SCE) with 1mV/s scanning rate.

2.1.5 Dynamic corrosion

For dynamic corrosion the samples were immersed in 250mL DIW having different concentrations of H₂O₂ in beakers on magnetic stirrer.

The revolutions per minute were adjusted to provide linear velocities of 1, 2 and 5 m/s. All the testes were repeated three times and average values of corrosion rate is reported.

The corrosion rate was determined via weight loss measurements using the following equation

$$V_a = C \times \frac{W_o - W}{\rho A t}$$

where, V_a is the corrosion rate or the annual speed, mm/y, C is the conversion factor, which is equal to 8.76×10⁴, W_o is sample's weight (g) before test, W is sample's weight (g) after test, ρ is the density of the sample, which is equal (2.7g.cm⁻³), A is working or exposed to environment area of the sample (cm²) and t is the testing time in hours.

2.1.6 Surface roughness measurement

The samples prepared were ultra-sonicated in DI water for 10 min, degreased with acetone and dried with pressurized air.

The surface roughness was determined using DEKTAK 6M stylus profile which measure the roughness values in X-Y dimensions.

The roughness measurements were repeated three times with a scan area of 3*3mm² and the average values were taken.

3. Results and Discussion

3.1. Hardness measurement

Figure 1 demonstrates the hardness measurements evaluation of the Al-Cu-x Sn samples.

The results show that the hardness of the alloy with 1% tin (Sn) has the highest value however after further increase of Sn alloy the hardness decreases.

This change in the hardness affects the corrosion rate of the alloy i.e. higher corrosion rates have been obtained for samples with lower hardness and vice versa as shown sections 3.3 and 3.4.

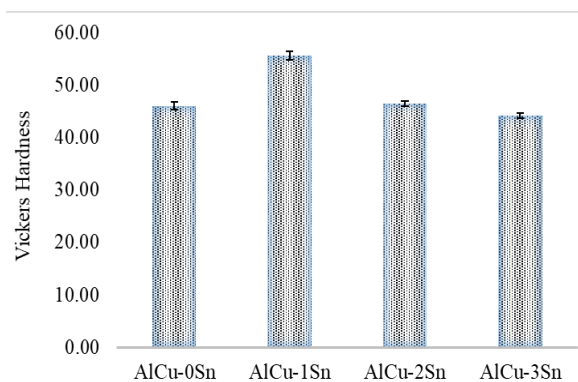


Figure 1: Vicker's Hardness of the alloys

3.2 Contact angle measurement

Figure 2 shows the wettability analyses of AlCu-xSn alloy. It can be seen that the addition of 1% Sn to the AlCu-xSn alloy decreases its wettability as compared to the baseline (AlCu-0Sn). However, upon further increase in Sn concentration in the alloy results in decrease in contact angle of DIW on the alloy's surface i.e. the wettability increases with increasing concentration of Sn in the alloy which is expected to affect its corrosion resistance.

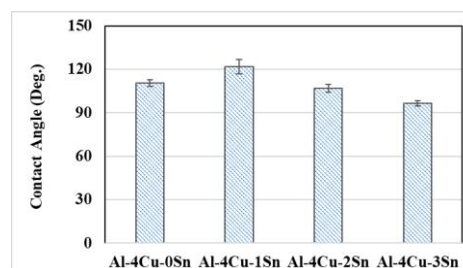


Figure 2. Contact angles (deg) of DIW on Al4Cu-xSn alloy's surface

3.3 Potentiodynamic polarization

Table 2. list the electrochemical parameters of AlCu-xSn alloy in the presence of different concentration of H₂O₂. It can be seen that the alloy offers greater resistance to corrosion in DIW in the absence of H₂O₂.

The corrosion rate has been observed to increase with increasing concentration of H₂O₂ in the electrolyte. Moreover, as we increase the Sn concentration from 0 to 1 in the alloy the corrosion rate increases however with further increase in Sn concentration in the alloy the corrosion rate decreases. The decrease in corrosion rate can be attributed to the fact that the alloy becomes more wettable with increasing Sn concentration beyond 1.

 Table 2. Electrochemical parameters of AlCu-xSn alloy in the presence of different concentration of H₂O₂

Solution	Tafel variables	AlCu-0Sn	AlCu-1Sn	AlCu-2Sn	AlCu-3Sn
DIW	$I_{corr}(\mu A) \cdot 10^{-6}$	15.4	44	19.7	12.1
	$E_{corr}(mV)$	291	379	406	-420
	CR (mm/year)	0.25	0.68	0.3	0.19
0.1 %wt. H ₂ O ₂	$I_{corr}(\mu A) \cdot 10^{-6}$	42.5	113	36.1	29.1
	$E_{corr}(mV)$	39.9	111	-113	-152
	CR (mm/year)	0.66	1.75	0.56	0.45
0.2 %wt. H ₂ O ₂	$I_{corr}(\mu A) \cdot 10^{-6}$	59.3	73.5	58.2	51.8
	$E_{corr}(mV)$	8.75	101	-48.8	-66.9
	CR (mm/year)	0.96	1.19	0.903	0.802
0.5 %wt. H ₂ O ₂	$I_{corr}(\mu A) \cdot 10^{-6}$	68.7	64.9	93.9	54.7
	$E_{corr}(mV)$	86.5	120	31.1	151
	CR (mm/year)	1.12	1.05	1.47	0.89

3.4 Dynamic corrosion

The dynamic corrosion rates (mm/yr) of the alloy AlCu-xSn as a function of Velocity (m/s) and H₂O₂ concentration in DIW is shown in Figure 3a, b and c. The corrosion rate observed over a period of four hours for AlCu-0Sn is 0 mm/yr in DIW at neutral pH

which can be attributed to ability of aluminum forming a protective oxide layer on its surface.

The results obtained clearly show that the corrosion rate of the alloy rate is significantly high for AlCu-1Sn as compared to AlCu-0Sn. However, when Sn concentration in the alloy increases more than 1, a nearly linear decrease in corrosion rate has

been observed. The observed dynamic corrosion rate is well in agreement with the corrosion rate obtained via Tafel fit for potentiodynamic polarization. Increasing velocity means increasing wall shear stress which in turn increases the corrosion rate i.e. the corrosion rates observed at 5m/s velocity are higher than at 2m/s velocity which in turn is higher than corrosion rates at a velocity of 1m/s.

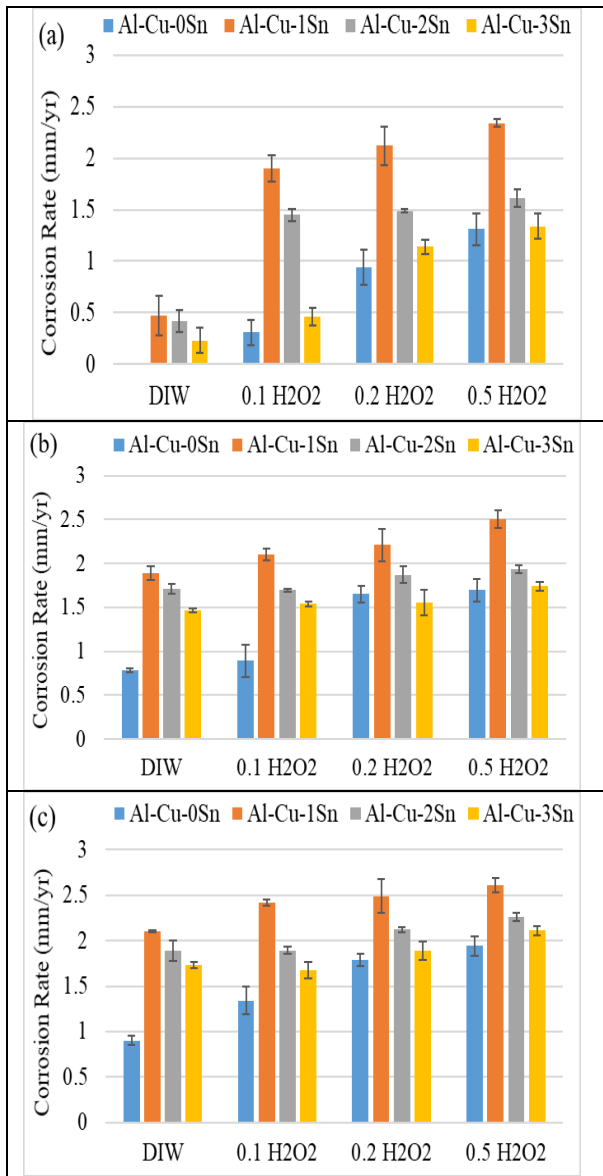


Figure 3. Corrosion rate as a function of H₂O₂ concentration in the environment and Sn in AlCu-xSn at (a) 1m/s, (b) 2m/s and (c) 5m/s velocity.

3.5 Surface roughness measurement

Surface roughness of the alloy AlCu-xSn, after dynamic corrosion tests, as a function of Velocity (m/s) and H₂O₂ concentration in DIW is reported in Figure a, b and c. The alloy AlCu-1Sn has been found have highest corrosion rate for every concentration of H₂O₂ in DIW among the alloys tested.

Upon further addition of Sn (i.e. AlCu-2Sn AlCu-3Sn) the surface roughness decreases. The alloy corrodes faster as the velocity and/or concentration of H₂O₂ increases and results in higher surface roughness as shown in Figure 4a, b and c.

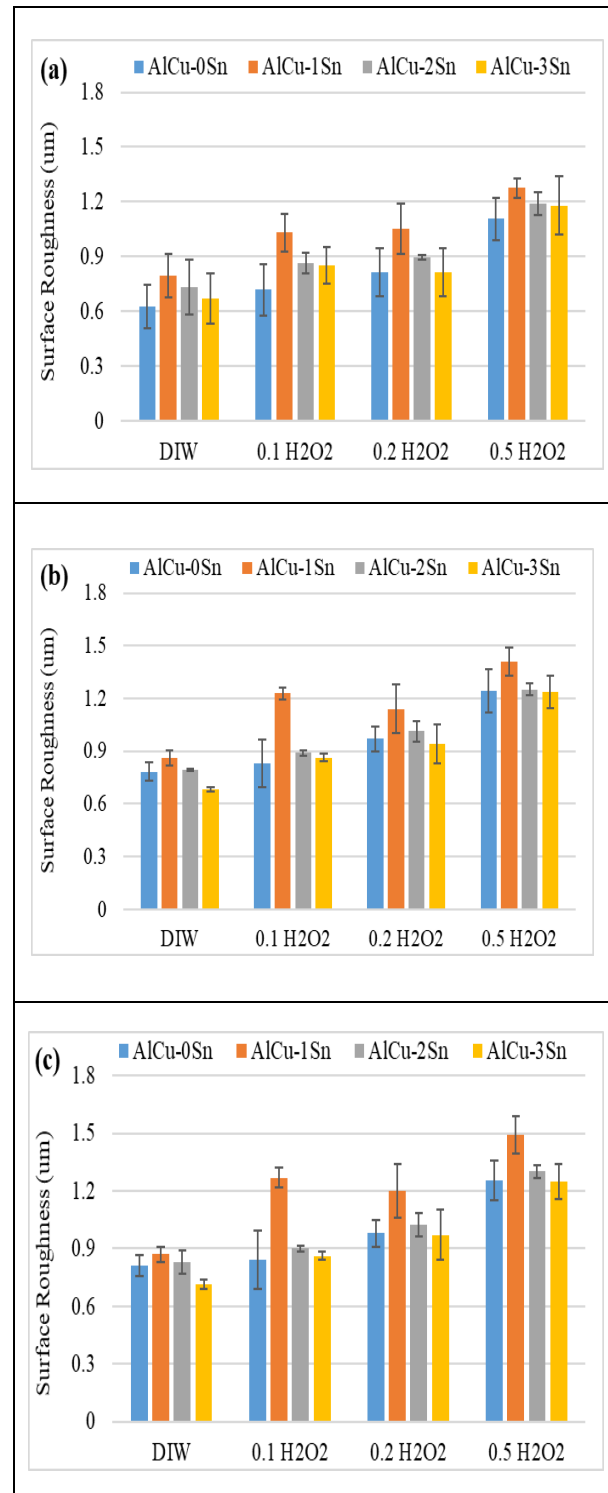


Figure 4. Surface roughness after dynamic corrosion as a function of H₂O₂ concentration in the environment and Sn in AlCu-xSn at (a) 1m/s, (b) 2m/s and (c) 5m/s velocity.

4. Conclusion

Understanding corrosion behavior of has attracted the attention of many researchers because of their excellent properties and applications in several industries. In this study the corrosion behavior of AlCu-xSn alloys as a function of Sn concentration in the alloy and H₂O₂ concentration in DIW under dynamic conditions. The alloys had the same surface roughness before dynamic corrosion experiments. However, after the experiments a significant difference in the surface roughness has been observed. The corrosion rates obtained for 1% Sn in the alloy as compared to Sn free AlCu-xSn. However, from 1% to 3% Sn in the alloy an almost linear decrease in corrosion rates have been observed. A similar trend has been seen in surface roughness of the alloys after dynamic corrosion experiments. This decreasing trend in the corrosion rates and surface roughness can be attributed to the wettability and hardness of the alloys.

Acknowledgements (not mandatory)

The authors would like to be obliged to Tikrit University for providing laboratory facilities and financial support.

References

- [1] Aballe, A., Bethencourt, M., Botana, F. J., Cano, M. J., & Marcos, M. 2001. Localized alkaline corrosion of alloy AA5083 in neutral 3.5% NaCl solution. *Corrosion science*, 43(9), 1657-1674.
- [2] Cheng, Y. L., Zhang, Z., Cao, F. H., Li, J. F., Zhang, J. Q., Wang, J. M., & Cao, C. N. 2004. A study of the corrosion of aluminum alloy 2024-T3 under thin electrolyte layers. *Corrosion Science*, 46(7), 1649-1667.
- [3] Hintze, P. E., & Calle, L. M. 2006. Electrochemical properties and corrosion protection of organosilane self-assembled monolayers on aluminum 2024-T3. *Electrochimica Acta*, 51(8-9), 1761-1766.
- [4] Khireche, S., Boughrara, D., Kadri, A., Hamadou, L., & Benbrahim, N. 2014. Corrosion mechanism of Al, Al-Zn and Al-Zn-Sn alloys in 3 wt.% NaCl solution. *Corrosion Science*, 87, 504-516.
- [5] Gudić, S., Smoljko, I., & Kliškić, M. 2010. The effect of small addition of tin and indium on the corrosion behavior of aluminium in chloride solution. *Journal of alloys and compounds*, 505(1), 54-63.
- [6] Bessone, J. B., Salinas, D. R., Mayer, C. E., Ebert, M., & Lorenz, W. J. 1992. An EIS study of aluminium barrier-type oxide films formed in different media. *Electrochimica Acta*, 37(12), 2283-2290.
- [7] Adebayo, I. O., Bodude, M. A., & Onovo, H. O. 2018. Study on Corrosion Inhibition Efficiency of Solanum Erianthum Extract on 6063 Aluminium Alloy in Different Sea Water.
- [8] Rosliza, R. 2012. Improvement of corrosion resistance of aluminium alloy by natural products. *Corrosion Resistance*, 377-395.
- [9] Szklarska-Smialowska, Z. 1992. Insight into the pitting corrosion behavior of aluminum alloys. *Corrosion science*, 33(8), 1193-1202.
- [10] El Shayeb, H. A., El Wahab, F. A., & El Abedin, S. Z. 1999. Electrochemical behaviour of Al, Al-Sn, Al-Zn and Al-Zn-Sn alloys in chloride solutions containing indium ions. *Journal of applied electrochemistry*, 29(4), 473-480.
- [11] El Shayeb, H. A., El Wahab, F. A., & El Abedin, S. Z. 1999. Electrochemical behaviour of Al, Al-Sn, Al-Zn and Al-Zn-Sn alloys in chloride solutions containing indium ions. *Journal of applied electrochemistry*, 29(4), 473-480.
- [12] Munoz, A. G., & Bessone, J. B. 1999. Pitting of aluminium in non-aqueous chloride media. *Corrosion science*, 41(7), 1447-1463.
- [13] Flamini, D. O., Saidman, S. B., & Bessone, J. B. 2006. Aluminium activation produced by gallium. *Corrosion Science*, 48(6), 1413-1425.
- [14] Bessone, J. B., Flamini, D. O., & Saidman, S. B. 2005. Comprehensive model for the activation mechanism of Al-Zn alloys produced by indium. *Corrosion science*, 47(1), 95-105.
- [15] Almansour, A., Azizi, M., Jesri, A. M., & Entakly, S. 2015. Effect of Surface Roughness on Corrosion behavior of Aluminum Alloy 6061 in Salt Solution (3.5% NaCl). *Int. J. Acad. Sci. Res*, 3, 37-45.
- [16] Alvarez, R. B., Martin, H. J., Horstemeyer, M. F., Chandler, M. Q., Williams, N., Wang, P. T., & Ruiz, A. 2010. Corrosion relationships as a function of time and surface roughness on a structural AE44 magnesium alloy. *Corrosion Science*, 52(5), 1635-1648.
- [17] Flamini, D. O., & Saidman, S. B. 2012. Electrochemical behaviour of Al-Zn-Ga and Al-In-Ga alloys in chloride media. *Materials Chemistry and Physics*, 136(1), 103-111.