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Effect of Nanoparticles Coating on Properties of Al-12Si Alloy

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ABSTRACT

This work involves study the effect of Al_2O_3/SiC/ZrO_2 nanoparticles coating on behavior of Al-12Si alloy. Electrical, thermal and electrochemical properties have been investigated before and after coating with Al_2O_3/SiC/ZrO_2 by atomization process. Coated layer was identified by AFM and optical microscopy. Nanoparticles coating greatly decrease the electrical conductivity by acting a barrier to transport of electrons through the coated layer. While thermal conductivity was increased by nanoparticles coating due to filling the voids and then easily transport the phonon can occur. Electrochemical properties was estimated by corrosion test in seawater at room temperature and the data indicated that the corrosion resistance increased for coated alloy and get a protection efficiency equal to 85.17% with porosity percentage 8.685%.

Keywords: Al-12Si Alloy, Nanocoating, Atomization, electrical and thermal conductivity, electrochemical behavior.

I. INTRODUCTION

Commercially pure aluminium (99.0% pure) is soft, ductile and of little structural value, but as extracted it normally contains up to 1.5% impurities; mainly iron and silicon. These have a marked effect on the properties of the metal, so that, with the further hardness acquired during rolling, commercial purity aluminium has a useful degree of strength and is widely produced in sheet form. It is very ductile in the annealed condition, has excellent corrosion resistance and is ideal for use in the food and chemical industries. Because the importance of Al-Si alloy, many authors investigated on properties of this alloy. Many researchers studied the mechanical properties of Al-Si alloys [1-5]. While the corrosion and inhibition properties of Al-Si alloys were investigated in different media by many authors [6-8].

Adam L. studied the recommended values for the thermal conductivity of aluminium for different purities in the cryogenic to room temperature range, and a comparison with copper [9], and in another study he predicted the thermal conductivity of aluminium alloys in the cryogenic to room temperature range [10]. In this work, coating with nanomaterials was achieved by atomization technique to study the effect of this coating on electrical and thermal conductivity, in addition to investigate the electrochemical properties of Al-12Si alloy in simulated seawater at room temperature.

II. METHODS AND MATERIAL

Al-12Si alloy was used in this work with chemical composition is shown in Table (1) obtained by spectromax. Nano powders were used in this work to prepare the emulsion in absolute ethanol. These powders are Al2O3, SiC and ZrO2 which added with the same wt% of each powder. Ultrasonic and magnetic stirring have been used to get homogeneity of coating solution. Airbrush was used with nitrogen gas to apply cold spray coating on Al-12Si alloy surface. The distance between the tip of nozzle and alloy surface was about 7cm and the surface was heated to 100+5 oC using hotplate.

Thermal conductivity was measured by Hot disk, TPS 500 obtained from Sweden. Electrical conductivity was tested by ammeter. electrochemical measurements were achieved by WINKINK M lab 200 Potentiostate/Galvanostat at scan rate 5 mV/sec. in seawater (3.5wt% NaCl) at room temperature using standard cell with three electrodes, Pt as counter electrode, saturated calomel as reference electrode and Al-12Si alloy as working electrode. The results of corrosion were calculated using Tafel extrapolation method.

III. RESULTS AND DISCUSSION

Characterization of Nanocoating Layer

The coated layer was characterized by AFM and optical microscopy as shown in Figs. (1) and (2) respectively. The AFM images show 2D and 3D of nanoparticles Al_2O_3/SiC/ZrO_2 coating.

The particle size distribution is tabulated in Figure (1), it showed that the average particles size around 129.42 nm. While the optical microscopy shows the deposited particles of coating by atomization on alloy surface compared with uncoated surface (Figure (2)).

The thickness of coated layer is 5.4555 μm which calculated from the following equations:

$$\text{Volume}_{\text{coating}} = \frac{\text{weight}_{\text{coating}}}{\text{density}_{\text{coating}}} \quad \text{and}$$

$$\text{Thickness}_{\text{coating}} = \frac{\text{volume}_{\text{coating}}}{\text{area of sample}} \quad \text{....(1)}$$

Electrical Conductivity

The electrical resistance of a conductor depends on the material of the conductor and the conduction path, thus:

$$R = \frac{\rho\, l}{A} \quad \text{........(2)}$$

where ρ is the electrical resistivity of the conduction path, l is the path length, and A is its cross sectional area, and then:

$$\text{Electrical conductivity} = \frac{1}{\rho} \quad \text{........(3)}$$

The electrical conductivity of studied Al-12Si alloy with l=0.3 cm was $222\times10^{-4}\ \Omega^{-1}.cm^{-1}$.

The electrical conductivity of studied alloy is between the electrical conductivity of pure aluminum and silicon (Al=$3.77\times10^{5}\ \Omega^{-1}.cm^{-1}$ and Si=$5\times10^{-4}\ \Omega^{-1}.cm^{-1}$). After apply nanocoating, the electrical conductivity of coated alloy was greatly dropped. This result indicates that the coated layer acts as barrier to reduce the transition of electrons through the metallic material and then may be reduce the corrosion. Since, from Ohm's law, then, it becomes obvious that to reduce corrosion you could:

a-Reduce the voltage gradient. For example, do not electrically connect two metals that have very different corrosion potentials (voltages) if they could possibly form an electrochemical cell, **b-** Increase the resistance of the conduction path. A coat of paint on metal increases the electrical resistance of the path between the corrosive environment and the metal, and even though the resistance is not infinite, the paint provides some protection by reducing the current.

Thermal Conductivity

The thermal conductivity, κ, of a metal is related to the electrical resistivity, ρ, by the Wiedemann-Franz law [11]:

$$\kappa = \frac{L\, T}{\rho} \quad \text{......(4)}$$

where L is the Lorenz number, and T is temperature.

Figure (3) shows the rise of temperature with time for uncoated and coated Al-12Si alloy. The result of thermal conductivity was different compared with the result of electrical conductivity, where the coated layer increased the thermal conductivity compared with uncoated alloy as shown in Table (2). The thermal conductivity of Al-12Si alloy less than for pure Al (237 W/mK) and pure Si (149 W/mK). The increasing in thermal conductivity after coating may be due to the heating during coating process up to 100 ± 5^{o}C in air at atmospheric pressure which allows nanoparticle to diffuse into the bulk material. The higher thermal conductivity of coated alloy attributed to mechanism of phonon transport in coated alloy without voids.

Electrochemical behavior

Aluminium has a higher resistance to corrosion than many other metals owing to the protection conferred by the thin but tenacious film of oxide. This oxide layer is always present on the surface of aluminium in oxygen atmospheres.

The formation of the oxide is so rapid in the presence of oxygen that special measures have to be taken in thermal joining processes to prevent the oxide instantly forming while the process is being carried out.

Aluminium is, however, a very reactive chemical element and its successful resistance to corrosion depends on the completeness with which the protective film of aluminium oxide prevents this underlying activity coming into play.

Figure (4) shows the polarization curves of uncoated and coated Al-12Si alloy in seawater at room temperature. This figure indicates the cathodic and anodic behavior of Al-12Si alloy as follow:

$O_2 + 4e + 2H_2O \rightarrow 4OH^-$ At cathode
$Al \rightarrow Al^{3+} + 3e$ At anode

The corrosion data are listed in Table (3) indicate that corrosion potential became more negative after coating and get a lower corrosion current density. Nanoparticles coating led to decreasing cathodic Tafel slop and increasing anodic Tafel slop. From corrosion current densities (i_{corr}) for uncoated and coated alloy, protection efficiency PE can be calculated according to the following formula:

$$PE\% = \left[1 - \frac{i_{corr_{uncoated}}}{i_{corr_{coated}}}\right] * 100 \quad \ldots\ldots(5)$$

Nanoparticles coating led to get good protection efficiency 85.17%. Surface porosity percentage fraction was estimated by potentiostatic polarization. In this case, the porosity percentage (PP%) can be calculated using the following equation [12]:

$$PP\% = \frac{R_{p_{uncoated}}}{R_{p_{coated}}} 10^{\frac{-\Delta E_{corr}}{b_a}} * 100 \quad \ldots\ldots(6)$$

where $R_{p,uncoated}$ and $R_{p,coated}$ are the polarization resistances of the uncoated Al-12Si alloy and the coating sample by nanoparticles, respectively, ΔE_{corr} is the corrosion potential difference between them, and b_a is the anodic Tafel slop of the uncoated sample. After coating, we get porosity percentage equal to 8.685%. This low porosity of coat layer confirms the lowering in electrical conductivity by electron and increasing in thermal conductivity by phonon and then the decreasing in corrosion rate.

IV. CONCLUSION

Appling nanoparticles coating of alumina/silicon carbide/zirconia led to decreasing in electrical conductivity due to form a barrier reduce the moving of charged particles to produce a current, and increasing of thermal conductivity due to filling the voids and allow to transport of phonon rather than reflect it. Also, nanoparticles coating affect electrochemical properties by decreasing corrosion current density in seawater and get protection efficiency 85.17% with low porosity of coat layer.

V. REFERENCES

[1] Janez Sušnik, Roman Šturm and Janez Grum, "Influence of Laser Surface Remelting on Al-Si Alloy Properties", Strojniški vestnik - Journal of Mechanical Engineering 58(2012)10, 614-620, DOI:10.5545/sv-jme.2012.696.

[2] Yong-Jin Kim and Jin-Chun Kim, "Tensile property of Al-20 MASS.% Si alloys production by a gas atomization process", Rev.Adv.Mater. Sci. 28 (2011) 207-211.

[3] S.P. Nikanorov, M.P. Volkov, V.N. Gurin, Yu.A. Burenkov, L.I. Derkachenko, B.K. Kardashev, L.L. Regel, and W.R. Wilcox, "Structural and mechanical properties of Al–Si alloys obtained by fast cooling of a levitated melt", Materials Science and Engineering A 390 (2005) 63–69.

[4] Tim Jaglinski and Roderic Lakes, "Creep behavior of Al-Si die-cast alloys", Journal of Engineering Materials and Technology, 126 (2004) 378-383.

[5] Haitham Razouqi Saleh, "Mechanical properties of the modified Al-12%Si alloy reinforced by ceramic particles", Eng. & Techn., 28(2) 2010, 289-300.

[6] Rana Afif Majed, "Corrosion inhibition of Al-Si-Cu alloy in the basic media by using six inhibitors at four temperatures", Um-Salama Science Journal, 5(2)2008.

[7] Wislei R. Osório, Noé Cheung, Leandro C. Peixoto and Amauri Garcia, "Corrosion resistance and mechanical properties of an Al 9wt%Si alloy treated by laser surface remelting", Int. J. Electrochem. Sci., 4 (2009) 820 – 831.

[8] Rana A. Majed, Majid Abdulmajeed, Slafa I. Ibrahem and Hawraa Deaa Al-Deen, "Effect of oxygenated additives on the corrosion behavior of Al-Si-Cu alloy in synthetic condensed automotive solution", JKAU: Eng. Sci., 23(2), (2012 A.D. /1433 A.H.) 3-18 DOI: 10.4197 / Eng. 23-2.1

[9] Adam L. Woodcraft, "Recommended values for the thermal conductivity of aluminium of different purities in the cryogenic to room temperature range, and a comparison with copper", http://www.sciencedirect.com/science/journal/00112275

[10] Adam L. Woodcraft, "Predicting the thermal conductivity of aluminium alloys in the cryogenic to room temperature range", http://www.sciencedirect.com/science/journal/00112275

[11] Hust JG, Clark AF., "The Lorenz ratio as a tool for predicting the thermal conductivity of metals and alloys", Materials Research and Standards 1971;11:22.

[12] Khulood A. S and Haider A.Y., "Corrosion protection study for carbon steel in seawater by coating with Sic and ZrO2 nanoparticles", American Journal of Chemistry, 5(1): 28-39, 2015, doi:10.5923/j.chemistry.20150501.05.

Table (1): Chemical composition of Al-Si alloy

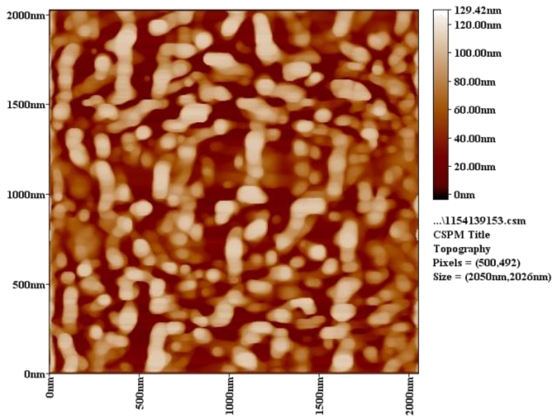
M	Si	Fe	Cu	Zn	Mg	Mn	Pb	Cr	Ni	Ti	Sn	V	B	Al
wt%	12.74	1.050	1.010	0.490	0.344	0.195	0.100	0.043	0.040	0.030	0.009	0.006	0.002	83.90

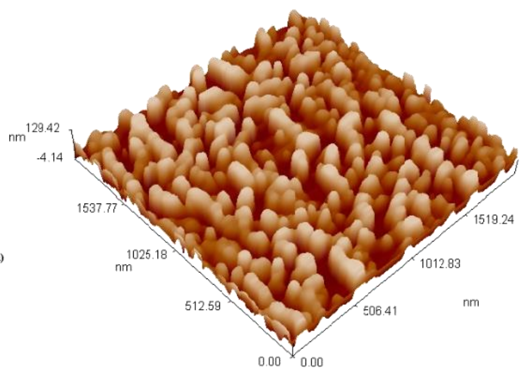
Table (2): Thermal properties of uncoated and coated Al-12Si alloy by nanoparticles

Thermal properties	***Uncoated alloy***	***Coated alloy***
Thermal conductivity W/mK	6.839	7.758
Thermal diffusivity mm^2/s	0.008867	0.008595
Specific heat MJ/m^3	771.2	902.6

Table (3): Electrochemical properties of uncoated and coated Al-12Si alloy by nanocoating in seawater at room tempature

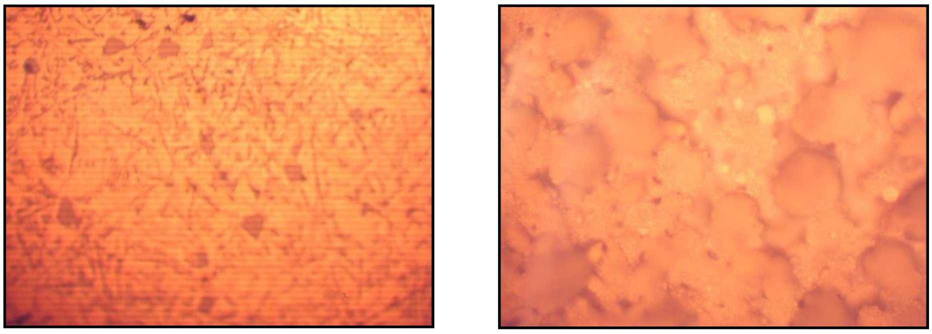
Sample	E_{corr}/ mV	i_{corr}/ $\mu A.cm^{-2}$	-bc $mV.dec^{-1}$	+ba $mV.dec^{-1}$	$Rp*10^3$ $\Omega.cm$	***Protection efficiency%***	***Porosity percentage%***
Uncoated alloy	-664.6	1.41	135.7	38.9	9.31	---	---
Coated alloy	-688.9	0.2091	94.1	101.2	101.26	85.17	8.685





2D **3D**

Fig. (1): AFM images of coated Al-Si alloy by nanoperticles.



(a) (b)

Fig. (2): Optical microscopy of uncoated (a) and nanocoated Al-Si alloy (b).

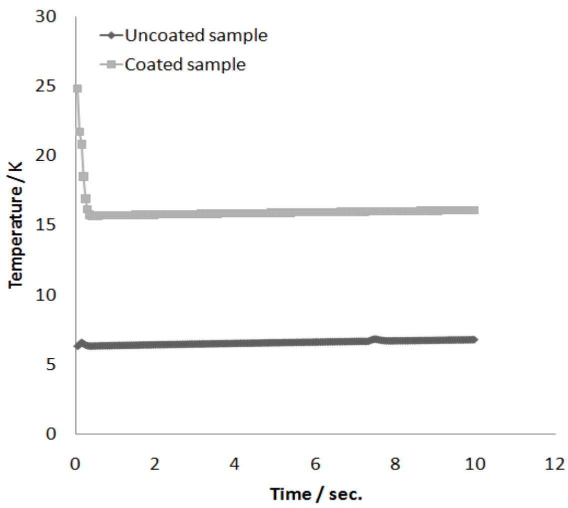


Fig. (3): Temp. – time relationship for uncoated and coated Al-12Si alloy

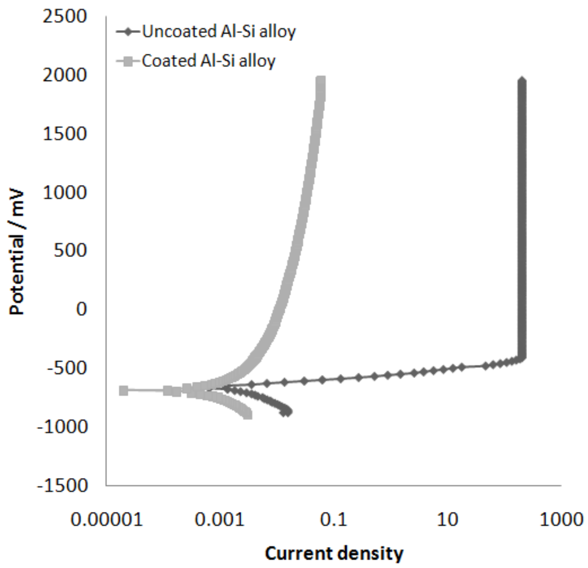


Fig. (4): Polarization curves of uncoated and coated Al-Si alloy by Al_2O_3/SiC/ZrO_2 nanoparticles in 3.5% NaCl solution.