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Study of Corrosion Resistance of Aluminum Alloy 6061/SiC Composites in 3.5% NaCl Solution

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Abstract—**This paper aims to study the corrosion resistance of metal matrix composite of an aluminum alloy (Al 6061) reinforced by SiC particles with 10wt% and 20wt%. Composite materials were prepared by stir casting using vortex technique. Corrosion behavior of aluminum matrix composite in sea water (3.5% NaCl solution) was examined using potentiostatically polarization measurements. The corrosion rate was calculated by Tafel equation and from the achieved polarization results. It was found that adding of SiC particles to the aluminum alloy matrix increases the corrosion rate. It was shown that the corrosion resistance decreases with increasing of SiC particles as compared of base alloy.**

Index Terms—**Aluminum matrix composite, stir casting, electrochemical corrosion.**

I. INTRODUCTION

Aluminum is the most popular matrix for the MMCs Aluminum alloys which are quite attractive due to their low density, good corrosion resistance, high thermal and electrical conductivity and high damping capacity [1]. Aluminium alloy composites (AACs) are becoming potential engineering materials offering excellent combination of properties such as high specific strength, high specific stiffness, electrical and thermal conductivities, low coefficient of thermal expansion and wear resistance. Because of their excellent combination of properties, AACs are being used in varieties of applications in automobile, mining and mineral, aerospace, defense and other related sectors [2]–[5]. In the automobile sector, Al composites are used for making various components such as brake drum, cylinder liners, cylinder blocks, drive shaft etc. In aerospace industries, Al composites are used essentially. in structural applications such as helicopter parts (parts of the body, support for rotor plates, drive shafts), rotor vanes in compressors and in aero-engines .

Ehsani and Seyed Reihani [6] [2004] produced Al 6061 /SiC composites using squeeze casting method. SiC preforms were manufactured by mixing SiC powder having a 16 and 22 μm particles size, with colloidal silica as a binder. 6061 Al melt was squeeze cast into the pores of the SiC perform to manufacture a composite containing 30 vol. % reinforcement. The results showed that the hardness, yield point and tensile strength increase with addition of SiC particles to 6061 Al alloy.

L. A. Dabrzanski, A. Wladarczyk and M. Adamiak [7] studied the corrosion resistance of PM composite material based on ENAW-2124 aluminum alloys reinforced with Al_2O_3 ceramic particles. They concluded that Al_2O_3 particles causes decrease in the corrosion resistance of the AMCs composite. This is due the possibility of occurring the selective corrosion on the boundary of the ceramic particles and the matrix materials phases.

Ali Faris [8] studied the corrosion behavior of metal matrix composite of an aluminum alloy 7020 reinforced by Al_2O_3 particles with weight percentages of 5%, 7%, and 10% and its size of (53-75) μm. The alloys were prepared using molten metal atomization technique. Corrosion behavior of aluminum matrix composite (AMC's) in 3.5% NaCl solution was examined using potentiodynamic polarization measurements. He concluded that the corrosion rate increases with increasing percentages of Al_2O_3 particles for the given atomized samples in 3.5% NaCl solution at a temperature of 30 ℃. This is due to galvanic corrosion between the matrix and reinforcement and the presence of second phases around Al_2O_3 particles in microstructure of AMCS. In recent years, aluminum 6061 has been used as matrix material owing to its excellent mechanical properties coupled with good formability and good corrosion resistance and its wide applications in industrial sector [9].

The aim of the present work is to study the corrosion resistance of Al 6061 (Al-Mg-Si) alloy matrix composite reinforced with 10% and 20wt% SiC particles in 3.5% NaCl solution.

II. EXPERIMENTAL WORK

A. The Used Materials

The base alloy (Al-Mg-Si) (Al 6061 alloy) was used as the matrix material. The chemical composition analysis is carried out using ARL spectrometer instrument as indicated in the Table I. The silicon carbide particles (α-SiC) of size less than 20 μm were used as reinforcement for preparation the Al-6061/ SiC composite.

TABLE I: CHEMICAL COMPOSITION OF AL 6061ALLOY

Element wt%	Mg	Si	Fe	Mn	Cu	Cr	Zn	Al
Measured value	1.03	0.978	0.6	0.44	0.082	0.09	0.03	Rem

B. Composite Materials Preparation

The base alloy of Al 6061 (Al-Mg-Si) was melted in a

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graphite crucible using an electric furnace at temperature of 700 °C and pouring the melt and cast in the preheated cylindrical steel mold with dimensions of 25mm diameter and 100mm height. The composite materials were prepared by dispersing the hard particles (SiC particles) in aluminum alloy matrix (Al 6061 alloy) using stir-casting technique. The steps involved in preparing the composite were melting the base alloy, stirring the melt using a mechanical stirrer, dispersing the preheated silicon carbide particles of size less than 20 μm and with 10wt% SiC in the vortex of the melt with stirring speed of 600 rpm for 5min and pouring the melt in the steel mold. The same procedures were carried out for preparation the composite material containing 20wt% SiC in Al-Mg-Si matrix alloy.

C. Specimens Preparation for Microstructure

The specimens were ground, polished and etched and observed under optical microscope in sequences steps. Wet grinding operation with water was done by using emery paper of SiC with the different grits of (220,320,500, and 1000). Polishing process was done to the samples by using diamond paste of size (1 μm) with special polishing cloth and lubricant. Etching process was done to the samples by using etching solution which is composed of (99% H_2O+1%HF). Then the samples were washed with water and alcohol and dried. Optical examination of samples was performed using optical microscope equipped with camera and connected to a computer.

The Vickers hardness test was made by using Vickers hardness tester type (Einsingenbei U/M, Mode Z323). A 300gf load for (10-15) sec was used for hardness of the sample. Five readings for hardness values were taken for each sample and the average hardness (VHN) were found.

D. Corrosion Test

Specimens for corrosion tests were fabricated with dimensions (1.5×1.5×0.2 cm) according to ASTM specifications for all metals used. After completing the fabrication of specimens, these specimens were categorized and sorted into groups and hardness values as shown in Table II.

TABLE II: CATEGORIZATION OF SPECIMENS AND HARDNESS VALUES

Specimen symbol	**State of specimens**	**HV Hardness (Kg/mm^2)**
A	Base alloy of Al 6061	55
B	Composite with addition 10%SiC	75
C	Composite with addition 20%SiC	102

The prepared specimen of area 1.5 × 1.5 cm was fixed in the holder. The reference electrode was fixed about (1 mm) apart from the surface of the specimen to be tested. The reference electrode used in this study was saturated calomel electrode (SCE). The auxiliary electrode used in the electrochemical cell was platinum type. The specimen holder (working electrode), together with the reference and auxiliary electrode were inserted in their respective positions in the electrochemical cell used for this purpose that can fit all these electrodes as shown in Fig. 1.

Fig. 1. Potentiostat apparatus for polarization test.

The cell used was made of glass. Constant potentials (anodic or cathodic) can be imposed on the specimen, by using the potentiostat (Mlab200 of Bank Eleck .Germany). This potentiostat is able to induce a constant potentials ranging from (–1 to + 1V) the potentials of the standard reference electrode used in this study (SCE). The potential difference between the working and the reference electrode (WE - RE) and any current passing in the circuit of working electrode were the auxiliary electrode can be measured by using the SCI Computer Software. Any potential difference between the working and reference electrodes and also any current in the working electrode circuit can be automatically recorded. The results and plots were recorded using window XP. The scan rate can be selected also.

Polarization technique tests were used to obtain the micro cell corrosion rates. In the tests, cell current reading was taken during a short, slow sweep of the potential. The sweep was taken from (–100 to +100) mV relative to (OCP) [10], [11]. Scan rate defines the speed of potential sweep in mV/sec. In this range the current density versus voltage curve is almost nearly linear. A linear data fitting of the standard model gives an estimate of the polarization resistance, which used to calculate the corrosion current density (I_{corr}) and corrosion rate. The tests were performed by using a WENKING MLab multi channels and SCI-Mlab corrosion measuring system from Bank Electronics-Intelligent controls GmbH, Germany 2007.

III. RESULTS AND DISCUSSION

A. Microstructure of Composites

The optical micrograph of the cast base alloy of Al 6061 (Al-Mg-Si) is indicated in Fig. 2. The microstructure consists of α-Al grains and fine particles of phase Mg_2Si distributed uniformly in the matrix alloy of (Al-Mg-Si). Fig. 3 and Fig. 4 indicate the microstructures of Al6061-10 wt% SiC and 20 wt% SiC composites respectively. The distribution of SiC particles in a matrix alloy is uniform. Further the micrographs reveal good bond between the matrix alloy and SiC particles. This is due to the presence of Mg in chemical composition of Al-alloy which improves the wettability of ceramics particles with matrix alloy and also increases the retention percentage of SiC particles in matrix. X-ray diffraction analysis (XRD) results are confirmed the appearance of the SiC particles in the alloy matrix as small peaks in XRD pattern as shown in Fig. 5 and Fig. 6 for the base alloy of Al 6061 and composite material with 10wt%SiC respectively. These results are in agreement with those of other researchers [12], [13].

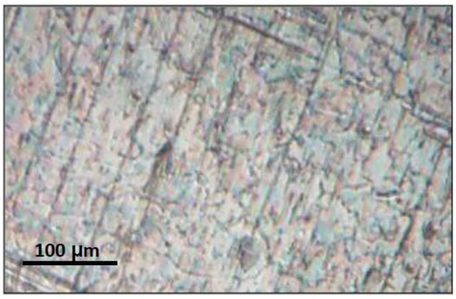


Fig. 2. Microstruture of base alloy of Al 6061 in 3.5% NaCl solution.

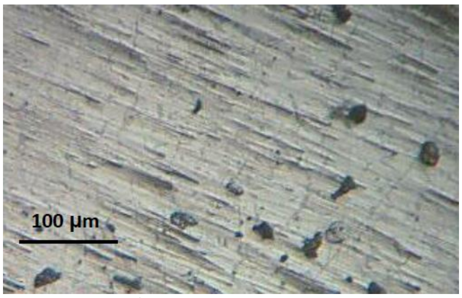


Fig. 3. Microstruture of composite material (Al 6061- 10% SiC).

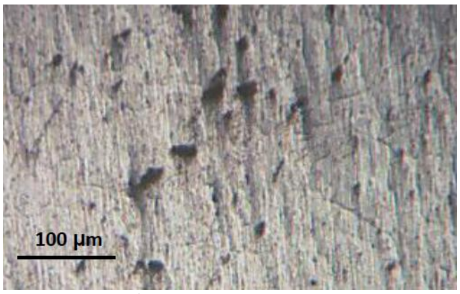


Fig. 4. Microstruture of composite material (Al 6061- 20% SiC).

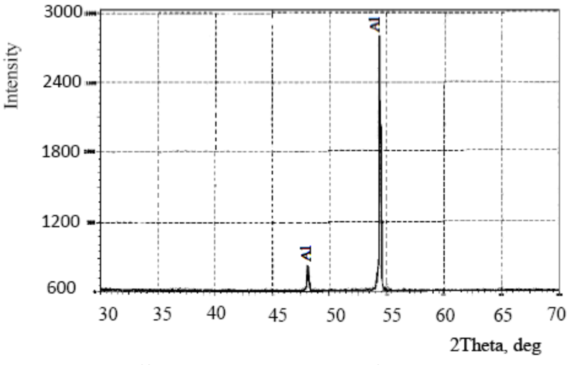


Fig. 5. X-Ray diffraction analysis patterns of the base alloy Al 6061.

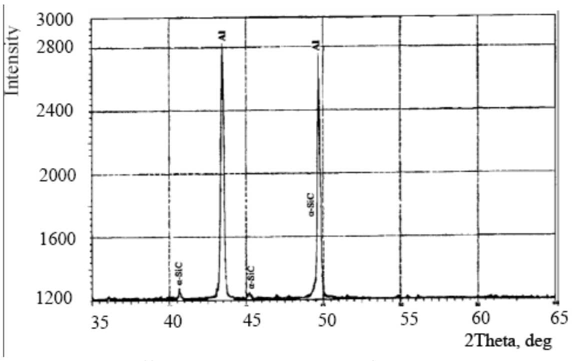


Fig. 6. X-Ray diffraction analysis pattern of the composite material (Al 6061-10% SiC).

B. Electrochemical Corrosion Results

The electrochemical tests consist of open circuit potential monitoring, cyclic anodic polarization and potentiostatic holds. Fig. 7-Fig. 9 show the cyclic polarization curves for base alloy of Al 6061 and composites with 10% SiC and 20% SiC respectively in 3.5% NaCl solution. These figures indicate that the cathodic and anodic polarization curves are similar in the corrosion behavior for both composites with 10% and 20% SiC in 3.5% NaCl solution but the corrosion current density and corrosion potential of the both composites are different . This is due to increasing to SiC particles distributed in the matrix alloy. The anodic polarization curves for base alloy of Al 6061 and for both composites showed continuous increase in corrosion current density indicating susceptibility to pitting corrosion. Similar behavior observed for the base alloy of Al 6061 but the corrosion rate is lower than that of both composites. This is attributed to the clean surface of Al 6061 alloy reaches to the passivity rapidly when exposed to oxygen containing environment forming protective oxide film (Al_2O_3) which is good adherence to metal surface and poor conductor for charge transfer. But this film contains flaws and increased pitting in chloride solution [14].

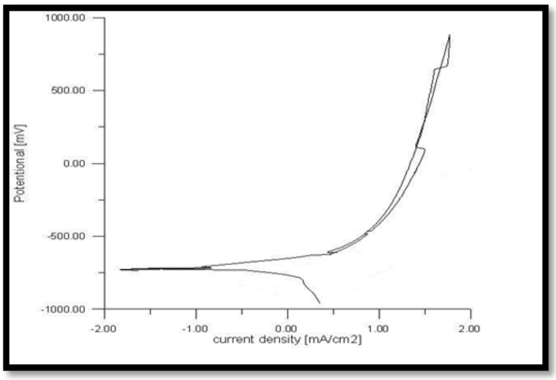


Fig. 7. Polarization curve of base alloy Al 6061 in 3.5% NaCl solution.

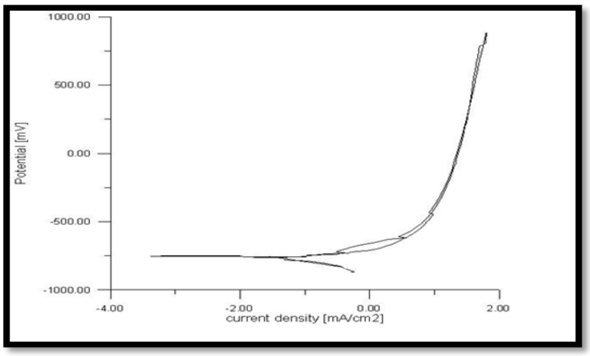


Fig. 8. Polarization curve of composite material (Al 6061-10% SiC) in 3.5% NaCl solution.

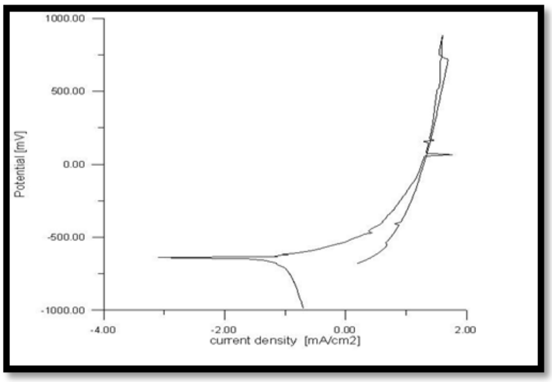


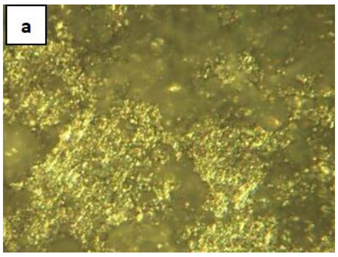
Fig. 9. Polarization curve of composite material (Al 6061-20% SiC) in 3.5% NaCl solution.

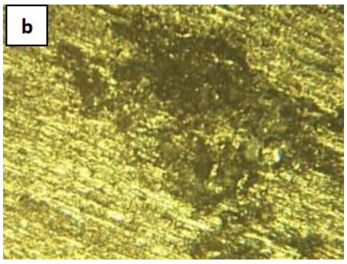
Uhlig and Revie [15] observed that the corrosion behavior of aluminum is sensitive to small amounts of impurities (or alloying elements) in the metal, all these impurities, with the exception of magnesium, tend to be cathodic to aluminum.

From Table III, it was seen that composite with 10 wt% SiC has lower corrosion current density and less negative potential (more noble) than that composite with 20 wt% SiC. This is due to the lower reinforcement content in same alloy matrix which reduces the cathodic areas to localized regions such as impurities, porosities and reinforcements in the alloy matrix. Also the residual stresses in the matrix which are arising due to the difference in thermal and mechanical properties between the matrix and reinforcement are considered preferred sites for dissolution and pitting [16]. These results are in coincidence with other researchers [6], [8]. Fig. 10 shows the optical micrographs showing surface topography after electrochemical corrosion in 3.5% NaCl solution. It can be seen that the base alloy of Al 6061 has shallow pits and the pits density is lower and smaller pits than that of composites with 10% SiC and 20% SiC as shown in a Fig. 10(a). This is due to presence of aluminum oxide protective layer on surface which reduces the corrosion rate or cathodically protect smaller pits or forming non- propagating pits. While from Fig. 10(b) and (c) it was noticed an excessive pitting of the matrix in both composites. This is due to presences of large content of reinforcements (SiC particles) at the surface of composite which accelerates the pits growing into the metal. In addition, that the pits initiation sites tend to possibility of occurring galvanic corrosion on the interface between the hard ceramic particles and soft matrix alloy [7].

TABLE III: ELECTROCHEMICAL CORROSION AND POLARIZATION RESULTS OF SPECIMENS IMMERSED IN 3.5% NACL SOLUTION

Specimen symbol	I corr. µA/ cm^2	E corr. (mV vs SEC)	Corrosion rate mpy
Base alloy Al 6061	59.3	-639.9	25.45
Composite with 10% SiC	83.4	-723.8	35.86
Composite with 20% SiC	168.1	-761.3	72.24





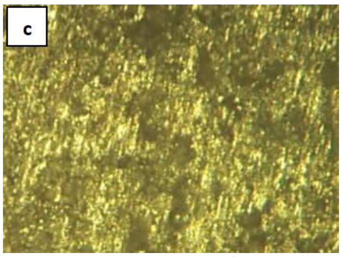


Fig. 10. Optical micrographs showing surface topography after electrochemical corrosion in 3.5% NaCl solution at 125X: (a) Al 6061 alloy, (b) composite with 10 wt% SiC, (c) composite with 20 wt% SiC.

IV. CONCLUSIONS

1) Microstructures reveal a uniform distribution of SiC particles in the matrix alloy of Al 6061 with good wettability and bond between the matrix and reinforecment which causes high retention percent of SiC particles in the matrix alloy and increases the hardness of alloy.
2) Composite with 10 wt% SiC and 20 wt% SiC shows lower corrosion resitance than that of base alloy Al 6061 in 3.5% NaCl solution.
3) The base alloy and both composites samples have similar anodic polarization curves and show repassivation potentials, but the base alloy exhibits less suscepability to pitting corrosion in 3.5% NaCl solution.

REFERENCE

[1] S. Wenlai and D. D. L. Chung, “Fabrication of particulate aluminum matrix composites by liquid metal infiltration,” *J. Mat. Sci*., vol. 29, pp. 3128-3150, 1994.

[2] S. Das, “Development of aluminum alloy composite for engineering applications,” *Trans. Indian Inst. Met.*, vol. 57, no. 4, pp. 325-334., August 2004.

[3] S. T. Peters, *Handbook of Composites*, 2nd edition, Chapman & Hall, California, USA, 1998.

[4] K. U. Kainer, *Metal Matrix Composites, Custom-Made Materials for Automotive and Aerospace Engineering*, Wiley, 2006.

[5] N. Chawla and K. K. Chawla, *Metal Matrix Composites*, Springer Science, Business Media, Inc., 2006.

[6] R. Ehsani and S. M. S. Reihani, “Aging behavior and tensile properties of squeeze cast Al 6061/SiC metal matrix composites,” *Scientia Iranica*, vol. 11, no. 4, pp. 392-397, Sharif University of Technology, October, 2004.

[7] L. A. Dabrzanski, A. Wladarczyk , and M. Adamiak, “Structure properties and corrosion resistance of PM composite material based on ENAW-2124 aluminum alloys reinforced with Al_2O_3 ceramic particles,” *J. of Mater. Proc. Techn*., vol 162/163, pp. 27-31, 2005.

[8] A. S. Faris, “Development of 7020 Al-Al_2O_3 composite by atomization and stir casting processes,” PhD Thesis, School of Applied Sciences, University of Technology, Baghdad, 2009.

[9] N. R. P. Swamy, C. S. Ramesh, and T. Chandrashekar, “Effect of heat treatment on strength and abrasive wear behavior of Al 6061-SiCp composites,” *Bull. Mater. Sci*., vol. 33, no. 1, pp. 49-54, 2010.

[10] G. D. Enos, “The Potentiodynamic polarization scan,” Technical Report 33, University of Virgin.

[11] N. B. Z. and R. G. Buchheit, “Electrochemical characteristics of intermetallics phases in aluminum alloys an experimental survey and discussion,” *J. Electrochem. Soc.*, Fontana corrosion center, Department of Materials Science and Engineering, 2005.

[12] A. Shamkhy, "Preparation and characterization of cast aluminum matrix-SiC particulate composite,” PhD Thesis, Dept. of Production Engineering and Metallurgy, University of Technology, Baghdad, 2000.

[13] M. K. Abbass, E. K. I Brahim, and E. S. Noeem, “Effect of heat treatments on the mechanical properties and wear resistance of Al-alloy matrix composite,” *J. of Engineering and Technology*, University of Technology, Baghdad, vol. 29, no. 12, pp. 518-533, 2011.

[14] G. E. Thompson and G. C. Wood, *Corrosion Science*, vol. 18, 1978, pp. 721-728.

[15] H. H. Uhlig and R. W. Revie, *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering*, 4th edition, Copyright © 2008 by John Wiley & Sons, Inc.
[16] R. C. R. Nunes and L. V. Ramanathan, *Corrosion*, vol. 51, no. 8, pp. 610-617, 1995.

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