Study of Erosion- Corrosion Behavior of Aluminum Metal Matrix Composite

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ABSTRACT

The aim of present work is to study the erosion –corrosion behavior of aluminum metal composite which consists of the (Al – 12wt % Si) alloy as matrix phase and 10wt% SiC particles as reinforcing phase. Composite material was prepared by stir casting using vortex technique. A general corrosion and erosion-corrosion for the base alloy and the prepared composite were carried out in 3.5wt% NaCl solution as corrosive medium for general corrosion while in erosion-corrosion ,with varying impact angles (0° ,30° ,45° and 90°) in slurry solution (1wt%SiO$_2$ sand in 3.5wt% NaCl solution as the erodent).

It was found that the general corrosion rate for composite specimen is lower than that of the base alloy (Al-12%Si). In case of erosion-corrosion results, it was found that the weight loss rate or corrosion rate in (gmd) unit at impact angle (0°) is lower than that of other impact angles for the base alloy and composite material.

Keywords: Erosion-Corrosion, Composite Material, Seawater, Corrosion Rate.

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دراسة سلوك تأكل التعرية لمادة مركبة ذات أساس من سبيكة ألألمنيوم

الخلاصة

يهدف البحث الحالي الى دراسة سلوك تأكل التعرية لمادة مركبة ذات أساس من سبيكة (الألمنيوم-12 % سليكون) مقواة بدقائق كاربيد السليكون بنسبة وزنية 10%. وقد تم تحضير المادة المركبة بطريقة السباكة باستعمال تقنية الدوامة . وقد أجري أختبار التأكل العام والتأكل بالتعرية للسبيكة الأساس والمادة المركبة في محلول ملح الطعام بنسبة وزنية 3.5 % وفي محلول عالق يتكون (من رمل السليكا بنسبة 1 % في محلول ملحي من NaCl % 3.5)على التعاقب عند زوايا صدمة مختلفة هي: (°90 °45, °30, °0 .) في المحلول العالق. وقد جد ان معدل التأكل العام للمادة المركبة اقل من السبيكة الأساس. أما نتائج تأكل التعرية فقد وجد أن معدل التأكل بوحدة (gmd) عند زاوية صدمة صفركان أقل مما هو عليه عند الزوايا الاخرى لكل من السبيكة الأساس المادة المركبة.

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INTRODUCTION

Metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound [1].

Aluminum 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[1-4]. 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 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, and rotor vanes in compressors and in aero-engines [5].

Aluminum-silicon castings are excellent candidates for replacing wrought structural components in the aerospace and automobile industries due to increasing requirements to reduce weight, improve energy efficiency, and minimize environmental impact at a low cost.

The corrosion behavior of this class of materials during exposure to chloride containing environments has been studied by a variety of researchers**. Aylor and Moran** [6] found SiC/AA6061 immersed in seawater exhibited pitting, concentrated around the SiC. Metallographic analysis revealed that formation of crevices at the SiC/Al matrix interface, **Durai et al.** [7] analyzed the corrosion behavior of Al-Zn/Al_2O_3 AMC's with minor alloying additions of Cu and Mn. The results of the corrosion tests evaluated using the potentiodynamic method indicates that the corrosion of the investigated composites materials depends on the weight fraction of the reinforcing particles.

Abbass et al. [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 were prepared using molten metal atomization technique. Corrosion behavior of aluminum matrix composite (AMC's) in 3.5wt% 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 samplesin 3.5wt% NaCl solution at a temperature of 30°C. 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.

S. Daset et al. [9] investigated in details the slurry erosive wear behavior of cast and hot extruded Al6061 and Al 6061-SiC composites in sand slurry. Al6061-SiC composites have been prepared by vortex method and hot extrusion of these composites and the matrix has been carried out at 550ºC using a 500T hydraulic press. The hot extruded composites exhibit higher hardness and slurry erosive wear resistance when compared with as cast alloy and its composites.

The aim of the present work is to study the erosion- corrosion behavior of Aluminum -12wt% Silicon alloy matrix composite reinforced with 10wt% SiC particles in the seawater (3.5% NaCl solution) and slurry solution with 1wt% SiO_2 sand in seawater.

EXPERIMENTAL WORK

a. **Materials**

The Al-12wt%Si alloy was used as the metal matrix and SiC particles with size of +75µm as the reinforcement. Table (1) shows the chemical composition of the 1725 (Al-Si) alloy.

b. Gravity Die Casting

The standard alloy Al-12%Si is melted and poured into a steel die or mold by gravity casting. For each experiment about 200gm of prealloyed (Al-12%Si) was melted in a graphite crucible in an electric resistance furnace at temperature of 750ºC. The melt was poured into the steel die which was dried before casting process at 200ºC using drier type (Heracus). The casting was left to cool down in the air. The samples of prepared alloy had dimensions of 15mm in diameter and 100 mm in height.

Table (1) The chemical composition of the (Al-Si) alloy DIN 1725.

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
Wt%	12.2	1.2	0.81	0.18	0.08	0.34	0.17	Rem

c. Preparation of Composites by Stir Casting

The stir casting technique was used to prepare the composite samples. In this experiment, a standard alloy (Al-12%Si) was first superheated above the liquidus temperature of 750ºC to create a vortex in the melt with using a stainless steel stirrer. An electrical stirrer was used to mix the SiC particles with the molten Al-12%Si alloy, and in the production of SiC particles reinforced Al-Si matrix composites. A SiC particles (10 wt%) was wrapped in a high purity aluminum foils and heated to 300°C for 60 minutes in the heating furnace. The heated SiC particles were added to the molten Al-Si alloy and ring the mixture was stirred for 5 minutes at speed of 500rpm. Then the molten Al-Si alloy with SiC particles was put again in the melting furnace. Then the molten was poured into a pre-heated steel mold .to 200°C by gravity casting. The samples of prepared alloy had dimensions of 15 mm in diameter and 100mm height.

d. Specimens preparation for Microstructure

The specimens made from a prepared composite of Al -12% Si / 10%SiC and base alloy 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 specimens by using diamond paste of size (1µm) with special polishing cloth and lubricant. They were cleaned with water and alcohol and dried with hot air. Etching process was done to the specimens by using etching solution which is composed of (99% H_2O+1%HF).Then the specimens were washed with water and alcohol and dried. Optical examination of specimens was performed using optical microscope equipped with camera and connected to a computer.

e. Corrosion Tests
Experimental Media
 The pure corrosion and erosion-corrosion tests conditions are shown in the Tables (2 and 3) under the effect of some parameters such as flow rate and pH at constant temperature (25°C) and media pressure at 1 bar**.**

Table (2) General pure corrosion test conditions.

Medium Type	Single – Phase :(Corrosive Medium)
Temperature (º C)	25
Medium Pressure (bar)	Zero (Static Medium).
Flow Rate (Q) (l/min)	Zero (Static Medium).
pH	8.2

Table (3) Erosion – corrosion test conditions.

Medium Type	Two-Phase :Sea water (Corrosive Medium)and 1wt% silica sand as slurry(Erosive Medium)
Temperature (º C)	25
Medium Pressure (bar)	1
Flow Rate (Q) (l/min)	36
pH	8.2

Corrosive media
 Two media were used in this work, first was seawater of 3.5wt% NaCl solution for general pure corrosion test at room temperature, 25°C, second slurry media was mixture of 1wt%SiO_2 sand in 3.5wt%NaCl solution for erosion-corrosion test at 25C°.The chemical composition of the sand type AL-Ardhemah (Iraqi sand) are 98.37%SiO_2 and other oxides (CaO, Al_2O_3, Fe_2O_3 and MgO….etc) as the reminder, particle size ranges are 53µm-350µm.

Erosion- Corrosion Test Apparatus
 A test apparatus used in this study was similar to that proposed by Mksim Antonov[10]. The principal scheme is shown in Figure (1).
Figure (2) shows schematic diagram of corrosion, erosion and erosion-corrosion device.The erosion -corrosion apparatus was designed and manufactured in accordance with the test apparatus explained in American Standard (ASTM G73) and has many modifications were carried out by the researcher Ahmed[11] .

Figure (1) Illustrates erosion-corrosion device [11].

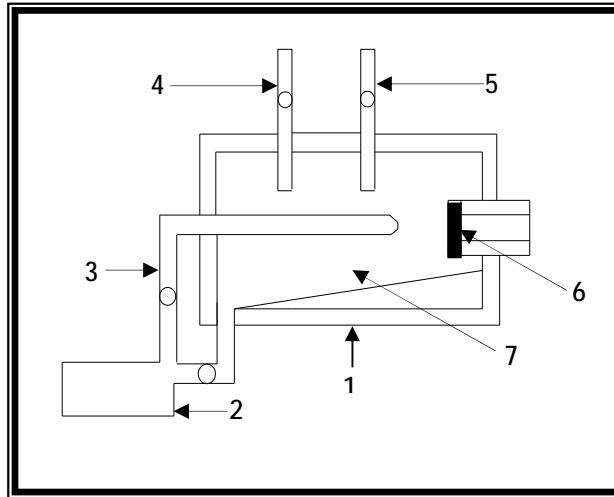|	
1	Tank Perspex (plastic) Tank
2	1 H.P Motor
3	P.V.C PIPE
4	Outlet gas pipe
5	Inlet gas pipe
6	Metal specimen
7	Effective Media

Figure (2) Schematic diagram of erosion-corrosion device [11].

Specimens Preparation for Corrosion Test

The specimens were machined and formed to pieces have squire cross section $(1x1\ cm^2)$ and 55mm length for immersion test or weight loss method. The specimens were ground or abraded in sequence on 180, 220, 320, 500, and 1000 grades with emery paper of SiC and water for cooling the specimens. Then the specimens were polished using special cloth with alumina (Al_2O_3) suspension of particles size of 0.5µm in solution. The specimens were washed with water and acetone, then dried with hot air and kept in a desecrater for 1 hr.

RESULTS AND DISCUSSION
Microstructure of Prepared Specimens

The microstructures evaluation was investigated by means of optical microscope (MEIJI TECHO ML8000SERIES JAPAN 2003) connected to the computer. Figure(3) shows the microstructure of gravity cast sample (base alloy Al- 12%Si) which consists of primary phase (α-Al) which represents the matrix of the

microstructure and black color of silicon phase(As flakes). A part of silicon phase is shown as massive silicon (Grey color) in some regions of matrix microstructure. Figure (4) shows the microstructure of composite sample (10%SiC) which was prepared by stir casting with using vortex technique It was seen that the composite has a relatively uniform distribution of SiC particles, primary α-Al grains, eutectic phase and massive primary Si phase in the interdentritic regions.. The α-Al grains and eutectic phase are greatly refined with adding of SiC particles to the matrix of Al-Si alloy, in addition to the high cooling rate associated with the rapid solidification processes during the gravity die casting as the molten metal is pouring in the die cavity. These results have been pointed out by several researchers [12, 13].

General Pure Corrosion Results

Figure (5) indicates the results of weight loss rate in the general pure corrosion of base alloy (Al-12%Si) and composite samples in 3.5wt% NaCl after immersion time for five weeks It was seen that weight loss rate or corrosion rate in unit (gmd) [or gram/m^2.day] increases continuously with the immersion time, because of removed of surface layer and oxide and formation of new surface exposed to corrosion. The composite specimen has the lower weight loss rate than that of base alloy after different immersion times. This is due to presences of hard phase of SiC particles which are uniformly distributed in the microstructure of aluminum alloy .These particles improve the microstructure and increase the hardness of Al-alloy. Figure (6) shows the micrograph of base alloy (Al-12%Si) which is the metal surface exposed to pure corrosion in 3.5 % NaCl solution, pits are seen on the surface resulting from pitting corrosion with chloride ions . This is due to breaking of oxide film and the oxide film is porous,and non-adherent as indicated by Shreir[14]. Figure (7) showsthe micrograph of composite sample (Al-12%Si/ 10%SiC)which the parts of metal surface are removed leaving dark, deep and large cavities with no definite form. Furthermore, it removes the surface layer and produces new and naked surface exposed to corrosive medium which contains chloride ions and break carbonic acid.

Erosion – Corrosion Results
Weight Loss Results

Figure (8) indicates the results of erosion- corrosion of base alloy (Al-12%Si) and composite samples in slurry solution (3.5wt% NaCl with 1% SiO$_2$) after exposure times for (0.5-2.5 hr) at impact angle 45º. It was seen that weight loss increases continuously with the exposure time to slurry for both samples. At first time of immersion in corrosive solution, the corrosion rate is expected to be higher because of easy removal of corrosion product and occurrence of fresh metal surface to contact of corrosive media. Additionally ,the extent of deformed zone (created due to the impact of erodent) at the site of impact on the specimen surface increases with increasing exposure time at a constant speed of slurry[12].The composite sample containing 10% SiC has the lowest weight loss as comparing with base sample**.** Figure (9 and 10) show the micrographs of base alloy and 10%SiC composite samples respectively after erosion-corrosion test in slurry solution (1wt%SiO$_2$ in 3.5%NaCl) at impact angle 45º and exposure time 2.5hr.It was observed that the pits in the composite sample (Al- 12%Si – 10% SiC) were smaller and more shallow than that in base alloy when exposed to quiescent 3.5%NaClsolution.

It is seen that the presence of sites of large pits at the surface of base alloy exposed to 3.5%NaCl solution is higher than that of composite sample .This is

attributed to high chloride ion contents and low pH inside the pit tend to accelerate the anodic dissolution reaction within the pits which leads to growing pits and increasing the corrosion rate of alloy. This is consistent with results of researcher Zahair et al. [15], they noticed that the number of pit initiation sites increases with the volume fraction of the reinforcement in composite material (Al 6061 –Al_2O_3).

Effect of Impact Angle on Erosion –corrosion Rate

From Figure (11)it is noticed the erosion – corrosion rate in unit(gmd) increases with increasing impact angle ,until reach to maximum value at impact angle 45º and then decrease sat impact angle of 90º.However , the erosion-corrosion rate is reported to be minimum at an impact angle(0º). This is due to that the specimen is subjected to maximum impact energy at 45º impact angle, whereas at 0º impact angle the specimen surface is subjected to only shear force because of sliding of erodent over the specimen surface when the specimen is exposed to a dynamic slurry media.

This behavior is similar for both base metal and composite samples but the erosion-corrosion rate for composite sample was lower than that of base metal at all impact angles. This is due to presences of hard SiC particles in matrix of Al-Si alloy which have moreresistance to erosion–corrosion than the soft matrix. In addition to,when the silica particles bombardment of the surface increase the hardness of metal surface due to deformation and hardening the surface. From above mention figure it is seen that weight loss rate or corrosion rate in unit (gmd) increases continuously with exposed time as result of mechanical effect of pure erosion and electrochemical effect of corrosive medium. The combined effect of sand in the slurry will lead to pitting corrosion [16].

Das et al [9] noted that the wear rate is significantly higher at normal incidence angle (impact angle 90◦) and at higher speed in sand slurry media   as compared to that occurred at lower speed and smaller incidence angle. They observed that interface between aluminum alloy and hard particles (SiC particle) in composite material plays an important role in the process of material removal under synergistic effect of corrosion and erosion.

Figure (12 and 13) show the micrographs of base alloy and 10%SiC composite samples respectively after erosion-corrosion test in slurry solution(1wt%SiO2 in 3.5%NaCl) at impact angle 30º and exposure time 2.5hr.

It produces horse-shoe-like traces which are a distinctive characteristic of erosion-corrosion with slurry. This type of corrosion produces great weight loss as a result of removing large and clear-cut metal portions due to impingement, cavitations, erosion and corrosion. The horse-shoe-like areas are dark, distinctive and oriented toward flow direction of the erosive-corrosive medium. The horse-shoe-like areas are distinctively deep because the metal is soft and easily eroded and spelled by sand grains which are considered erosive matter in the corrosive medium. This is in good agreement with that shown by Stephen M. McIntyre al [17], who studied common features typically observed with erosion-corrosion of horse shoe-shaped and comet tail pitting damage.
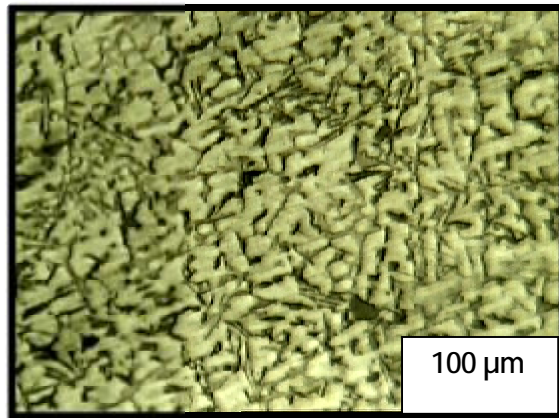
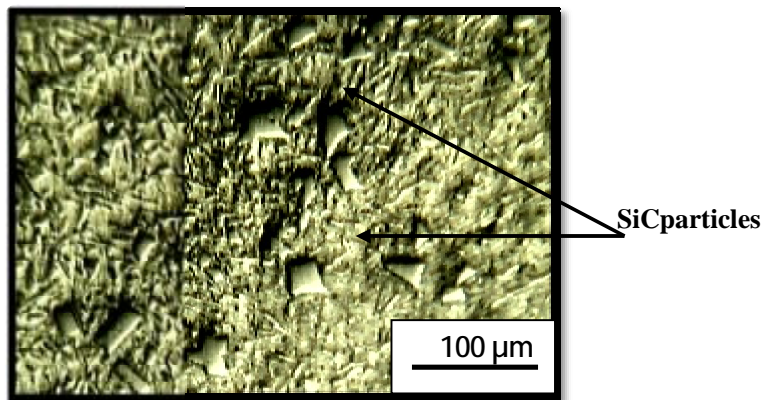**Figure (3) Microstructure of base alloy (Al-12%Si), as cast.**

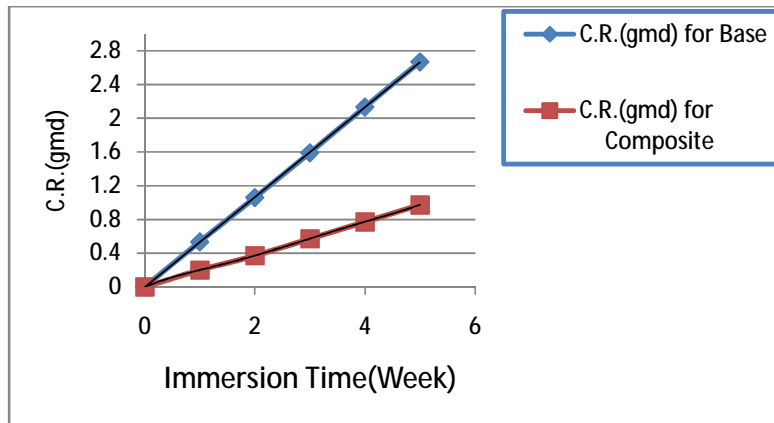**Figure (4) Microstructure of 10% SiC composite, as cast.**

**Figure (5) Effect of immersion time on the general pure corrosion
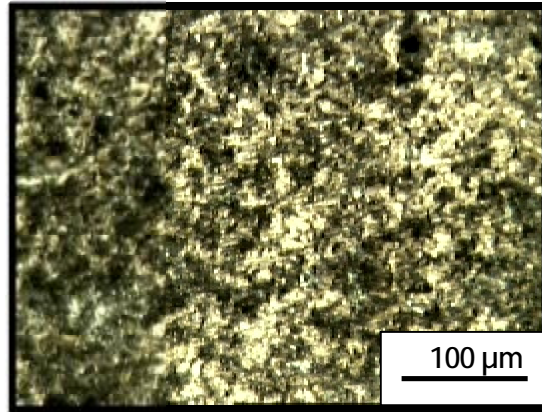in 3.5%NaCl solution for base alloy and composite samples.**

Figure (6)   Micrograph of base alloy after general corrosion
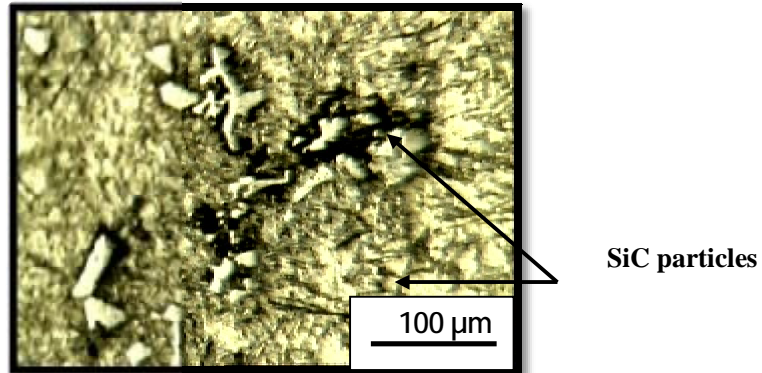**Test in 3.5% NaCl after immersion time (5 week).**

Figure (7) Micrograph of 10%siC composite after general
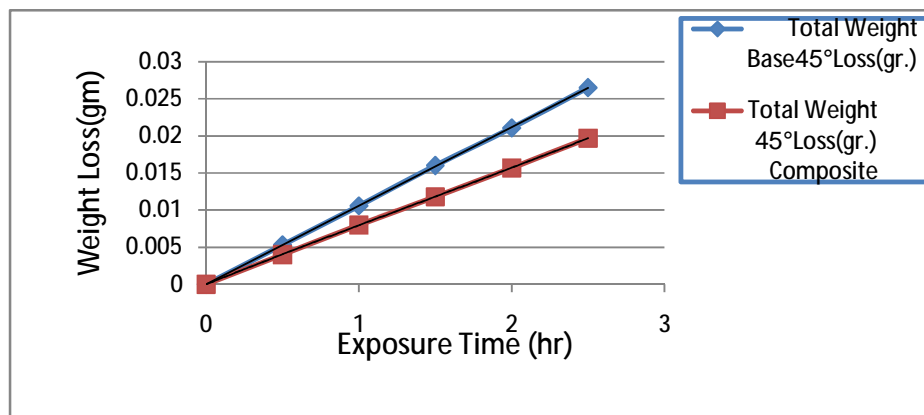**Corrosion Test in 3.5% NaCl after immersion time (5 week).**

Figure (8)   Weight loss of erosion-corrosion test in the slurry solution
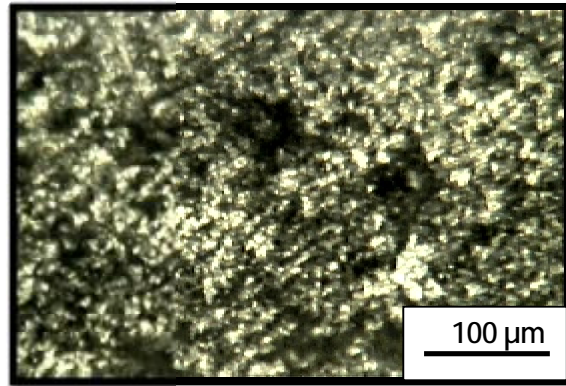**(1wt% SiO$_2$ in 3.5%NaCl solution) of base alloy and composite Samples at**
impact angle 45º

**Figure (9)   Micrograph of base alloy after Erosion-corrosion test in slurry
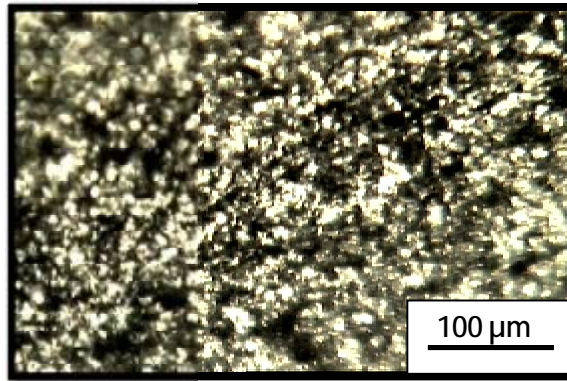solution(1wt%SiO2in 3.5%NaCl) at impact angle
45º and exposure time 2.5hr.**

**Figure (10)   Micrograph of 10%siC composite after Erosion-corrosion test in
slurry solution(1wt%SiO2 in 3.3%NaCl) at impact angle
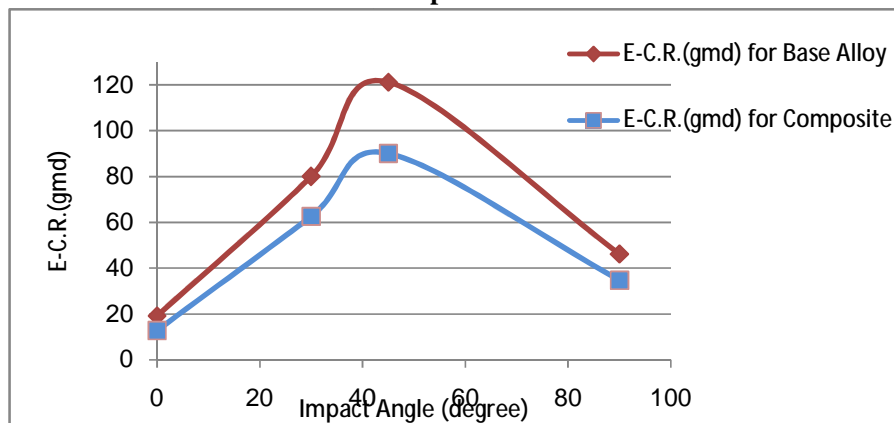45º and exposure time 2.5hr.**

**Figure (11) Effect of impact angle on erosion-corrosion rate in the slurry
solution (1wt% SiO2 in 3.5%NaCl solution) for base alloy and composite
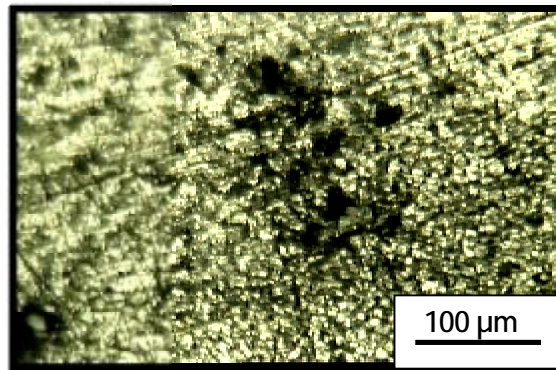samples at exposure time 2.5hr.**

Figure (12) Micrograph of base alloy after erosion-corrosion Test in slurry solution (1wt%SiO2in 3.5%NaCl) at Impact angle 30º and exposure time 2.5hr.
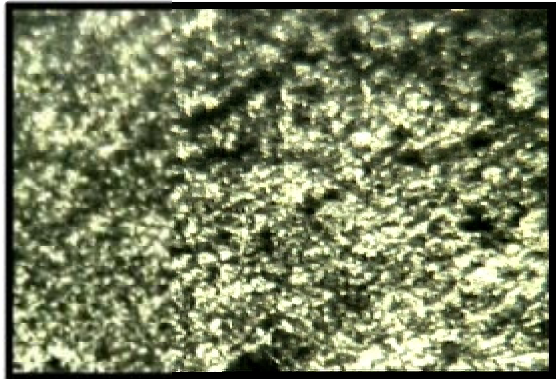

Figure (13)Micrograph of 10%siC composite after Erosion-corrosion Test in slurry solution (1wt%SiO2in3.5%NaCl) at Impact angle 30º and exposure time 2.5hr.

CONCLUSIONS

1- A stir casting with using vortex technique gives uniform distribution of SiC particles in the matrix of base alloy (Al-12%Si)

2- The general corrosion rate or weight loss rate of composite sample (10%SiC) is lower than that of the base alloy (Al-12%Si) at all immersion times (0- 5 week) in 3.5wt%NaCl.solution.

3- The corrosion rate or weight loss rate increases continuously with immersion times for base alloy and composite samples.

4- The erosion-corrosion rate in slurry solution (1wt%SiO$_2$)in 3.5%NaCl)for composite sample is lower than that of alloy base at all impact angles (0º, 30º, 45º, 90º).for exposure times (0- 2.5 hr).

5- The erosion- corrosion rate at impact angle 45º in slurry solution is higher than other impact angles for both base alloy and composite samples.

6- In erosive-corrosive media the removal of material is due to the combined effect of erosion and corrosion and hence the weight loss rate is significantly higher.

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