Fabrication of Metal Matrix Composites Reinforced with Nano SiC and Studying their Corrosion Behavior in 3.5%NaCl

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***Abstract*—In the present investigation, the static electrochemical corrosion behavior of nano $(SiC)_P$ based (AA6061) aluminum alloy in 3.5% NaCl was evaluated. The nanocomposites were fabricated using powder metallurgy technique. The effect of nanoparticulates weight percentage (0,3%, 6%, 9% & 12%) on the corrosion was studied. The corrosion rates of composites were calculated using electrochemical method. The results showed that Al/SiC composites have higher corrosion resistance than (AA6061) Al matrix. The corrosion resistance exhibited the highest corrosion resistance by increasing of the weight percentage of the nano $(SiC)_P$. The corrosion rate was found to be increased by increasing of weight percentage of the SiC particles. SEM of the microstructures obtained in both matrix and reinforced composites were performed in order to know the effect of silicon carbide on the corrosion resistance of composites.**

Keywords- (AA6061) Aluminium alloy, nano silicon carbide, Powder metallurgy, Corrosion rate, potentiostatic measurements, 3.5% NaCl.

I. INTRODUCTION

Aluminum-based metal matrix composites (MMCs) become attractive for the automotive and aerospace industries when a light weight and near-net-shape component is desired. Aluminum-based MMCs are well known for their high wear resistance, improved elevated temperatures tensile and fatigue strengths[1]. The mechanical and tribological characteristics of MMCs have been extensively studied [2], while corrosion characteristics are of increasing importance as MMCs become candidates for use in specific components subjected to corrosive media. Generally, the corrosion resistance of aluminum-based MMCs is less than the monolithic alloys, due to several reasons such as the crevices at the matrix/ reinforcement interface ,manufacturing defects, internal stress, microstructural differences and galvanic effects due to coupling of the matrix and reinforcement [3,4]. The composites were produced by stir casting are easier to produce and are compatible with further processing such as machining, welding and deformation [5,6]. Aluminium matrix composites, an epitome of metal matrix composites have been given much attention by researchers due to the light weight, high strenrgth, ductility, low melting point and corrosion resistance offered by aluminium alloys [7,8]. As a result, they have been used extensively in aerospace, automotive, recreational and marine industries. The application of these materials in the marine industries exposes the materials to chloride ions which could attack and deplete the materials [9].

Metal matrix composites (MMCs) reinforced with nano-particles, also called Metal Matrix nano-Composites (MMnCs), are being investigated world wide in recent years, owing to their promising properties suitable for a large number of functional and structural applications. The reduced size of the reinforcement phase down to the nano-scale is such that interaction of particles with dislocations becomes of significant importance and, when added to other strengthening effects typically found in conventional MMCs, results in a remarkable improvement of mechanical properties [10].

The resistance of particle reinforced MMCs to environmental attack is a critical design criterion. Several studies [11,12] have indicated that the corrosion resistance of particle-reinforced composites depends on the composition of the base alloy, reinforcing particles, and corrosive environment. Other factors include the fabrication routes for the composites, volume fraction of the reinforcing particles, and the temperature of the corrosive medium [13]. The aim of this present work is an effort has been made to fabricate of (AA6061) Al/ nano SiC metal matrix composites containing various weight percentages (3%, 6%, 9% and 12%) of nano particles and to study their corrosion behavior in 3.5 % NaCl by potentiostat and at scan rate (3) $mV.sec^{-1}$. SEM were carried out to identify the corroded surface.

II. EXPERIMENTAL WORK

A) Materials

Aluminium powder (AA6061) used with an average particle size of <25 μm was used as the matrix material. Table (I) illustrates the composition of aluminum (AA 6061). Metal matrix composites containing various weight percentages of (0,3,6,9&12) nano SiC particles were produced by liquid metallurgy route. For the production of MMCs, aluminum alloy (AA 6061) was used as the matrix material while SiC particles with an average size of (30) nm were used as reinforcement materials. The characterization of nano (SiC) reinforcing materials is shown in Table(II).

B) Composite preparation

The composites examined in this study were fabricated by using powder metallurgy technique. particles were added to β-silicon carbide powder in different weight percent (0, 3, 6, 9 &12) using Satorius electronic balance with an accuracy of ± 0.1 mg. The powder were mixed ball milling.

Mixed powders according to the above weight percentages were pressed at (300 MPa) using hydraulic press. Die wall lubrication was applied by brushing a thin layer of graphite powder over die cavity and the top punch press, sintering was carried out at 600ºC for 3 hrs. In the furnace and slow cooling until reached room temperature in an argon atmosphere.

C) Polarization measurements

All experiments were carried out in (500) ml of test solution by using a three electrodes cell with saturated calomel electrode (SCE) as a reference, platinum electrode as counter electrode and the cylindrical specimens of the alloy with active flat disc of (0.78) cm^2 as the working electrode. All the values of potential are therefore referred to the SCE. Finely polished composite and base alloy specimens were exposed to corrosion medium and allowed to establish a steady stat open circuit potentially, followed by polarization measurements at a scan rate of (3) mV/s for Tafel plots. Fig. 1. Shows the experimental set up for electrochemical measurement.

The values of corrosion current density (i_{corr}) were obtained from the point of intersection of both linear parts of the anodic and cathodic polarization curves with the stationary corrosion potential (E_{corr}).

Corrosion rate can be calculate by using the following equation [14]:

$$\text{Corrosion rate (mm/y)} = \frac{3.27 \times 10^{-3} \times i_{corr} \times EW}{\rho} \qquad (1)$$

Where , i_{corr} (in $\mu A/cm^2$) is the corrosion current density, EW in (gm) is the equivalent weight of the corroding species, and ρ in (g/cm^3) is the density of the corroding species.

III. RESULTS AND DISCUSSION

A) Corrosion behavior in 3.5% NaCl solution

The evaluated electrochemical corrosion parameters for the matrix alloy and the composites are given in TableIII. From polarisation curves for Al 6061 matrix alloy and the composites containing 3, 6, 9 and 12% by weight of SiC nanoparticulates are shown in Figs.2. to 6. It can be observed from the Tafel plots and the associated data that the corrosion current (i_{corr}) values and the corrosion rates decrease with increase in SiC content in the composites in 3.5% NaCl solution. The corrosion parameters, corrosion current density and corrosion rate were obtained from the Tafel polarization measurements. These observations show that both the (i_{corr}) values and the corrosion rate decrease with increase in the content of SiC and increases with an increase in 3.5% NaCl solution. These results point to the fact that SiC reinforced composites have higher corrosion resistance as compared to Al matrix alloy. The observed increase in corrosion resistance for composites is assigned to possible electrochemical decoupling between SiC particles and Al 6061 matrix alloy.

For all the investigated nanocomposites, there is a trend of increasing of the corrosion resistance with the increase of the SiC nanoparticulates weight percentage and SiC nanoparticulates are ceramic materials and they remain inert. The corrosion behavior of nanocomposites depends on weight percentage of the reinforcements.

B) Morphological investigations using SEM

Scanning electron microscopy images of the Al 6061 matrix powder and reinforcement SiC particles are shown in Fig. 7**.** The SEM images of Al 6061 matrix alloy and its SiC (3%, 6%, 9% &12%) composites taken after the polarization studies in chloride solution, are presented in Fig. 8.

The SEM images of the samples after the polarization studies clearly indicate the severe surface deterioration due to pitting corrosion. The decrease in driving force required for localized corrosion of the SiC reinforced composite is attributable to the introduction of reinforcement/ matrix interfacial products such as oxides of alloying elements (Mg & Si) and the possible refinement of microstructure. The combination of reinforcement inclusions and structural flaws/ defects formed at the time of MMC fabrication decrease the susceptibility of Al-SiC composites to pitting by reducing the required driving force.

IV. Conclusions

According to the results obtained from the current investigation, the following conclusions can be pointed out:

- The Al/ nano SiC composites exhibited lower corrosion rates in 3.5 % NaCl solution than the (AA6061) Al alloy.
- Corrosion current density values (i_{corr}) decrease with increase in nano SiC content in the composites for (3.5 % NaCl) solution..
- The Al composite reinforced with nano SiC exhibited higher corrosion resistance and SiC nanoparticulates are ceramic materials and they remain inert. The corrosion behavior of nanocomposites is attributed to excellent bond integrity of SiC particulates with Al 6061 matrix alloy.
- The morphology of (AA6061) aluminum alloy reinforced with nano silicon carbide particles seem to be distributed uniformly except some clusters, after corrosion.

TABLE I. The composition of aluminium powder (AA 6061)

Element	Cu%	Si %	Mg%	Cr%	Fe%	Mn%	Al %
Composition (wt.%)	0.25	0.62	0.92	0.22	0.23	0.03	Balance

TABLE II. Silicon carbide ceramic nanopowder properties
(Anhui Elite International Tradeco.Ltd China)

properties	**Silicon Carbide**
Purity	99+%
Particle size	30 nm
Color	Green powder
Density	3.22 g/cm^3
Morphology	nearly spherical
Crystal Phase	SiC nanopowder (β)

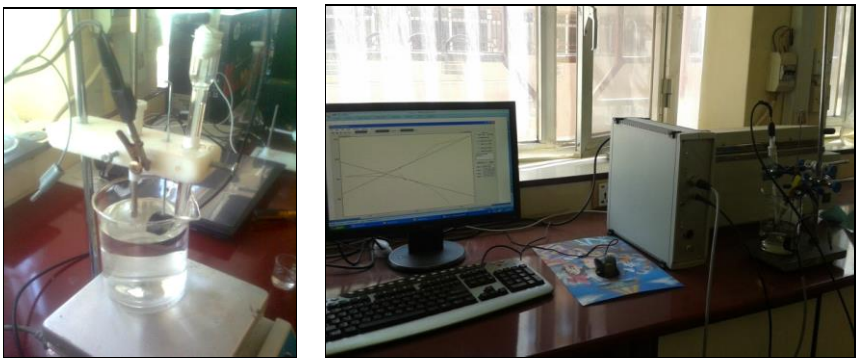


Figure1. Experimental set up for electrochemical measurement.

TABLE III. Corrosion parameters of (AA6061) aluminum alloy and its composites in (3.5% NaCl) solution

Composite (AA6061)Al/nano SiC	In (3.5% NaCl) solution		
	i_{corr} (μA/cm^2)	E_{corr} (mV)	Corrosion Rate (mm/y)
0%	16.44	-717.9	0.1644
3%	10.46	-595.4	0.1046
6%	9.33	-664.7	0.0933
9%	5.23	-627.0	0.0523
12%	2.82	-824.0	0.0282

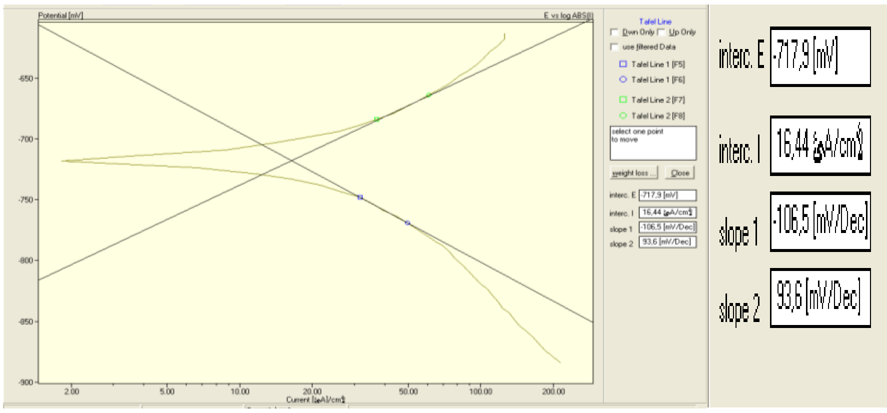


Figure 2. Polarization curves for (AA6061) aluminum alloy in 3..5% NaCl.

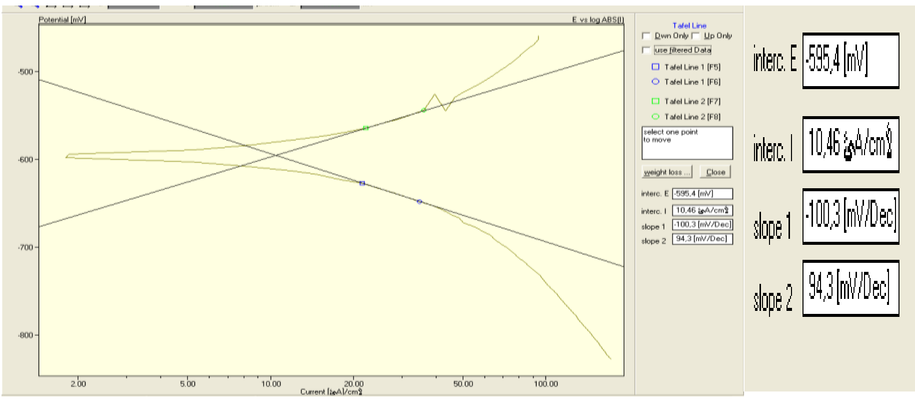


Figure 3. Polarization curves for (AA6061) Al /3% nano SiC composite in 3..5% NaCl.

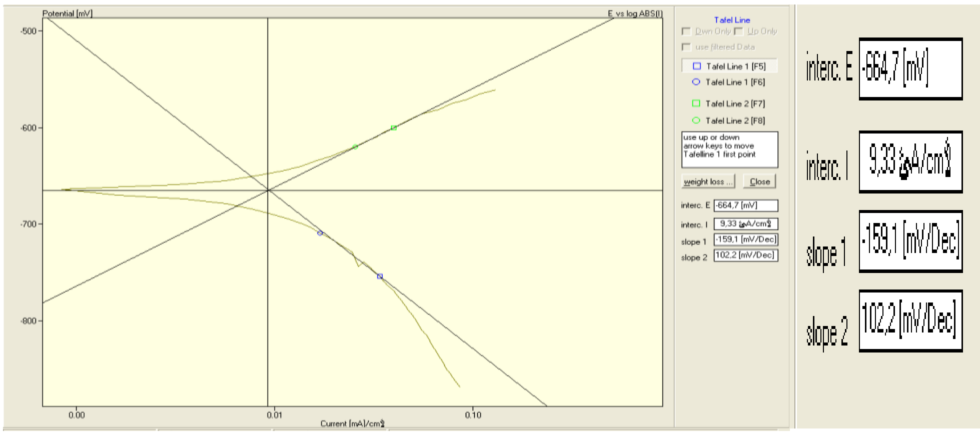


Figure 4. Polarization curves for (AA6061) Al /6% nano SiC composite in 3..5% NaCl.

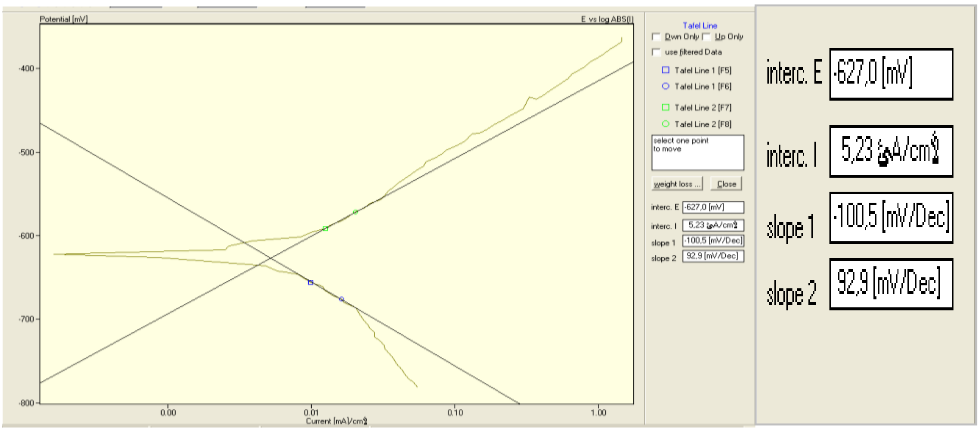


Figure 5. Polarization curves for (AA6061) Al /9% nano SiC composite in 3..5% NaCl.

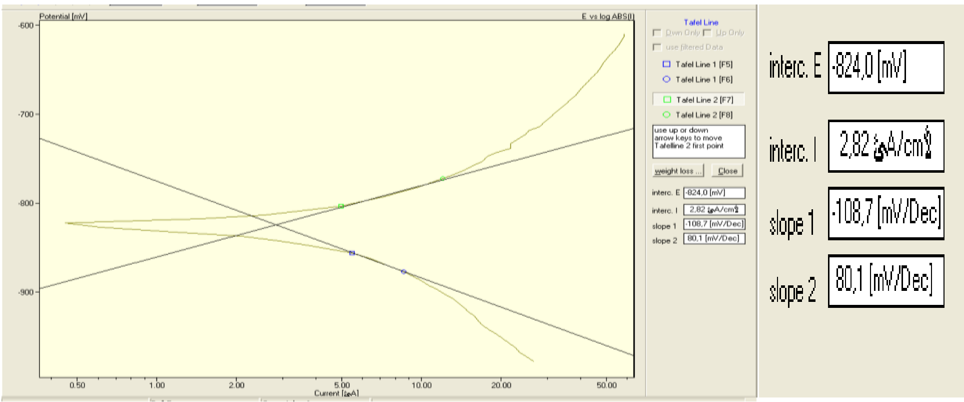
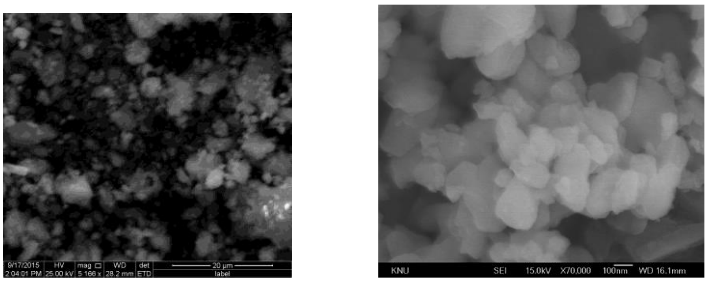
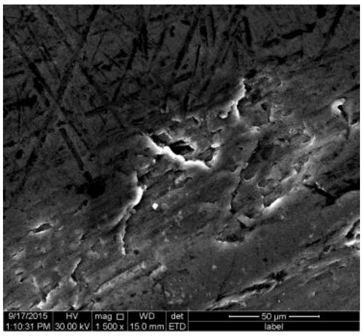


Figure 6. Polarization curves for (AA6061) Al /12% nano SiC composite in 3..5% NaCl.

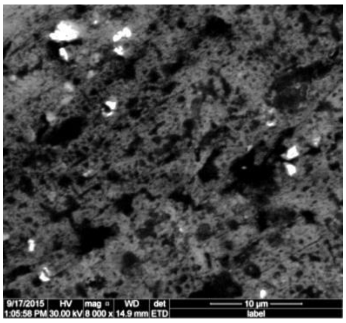


(a) (b)

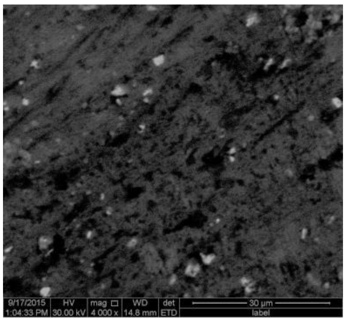
Figure 7 . SEM micrographs of (a) Al 6061 matrix powder and (b) SiC particles.



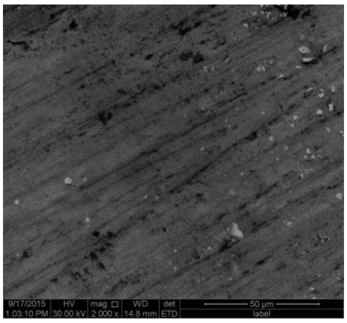
(a)



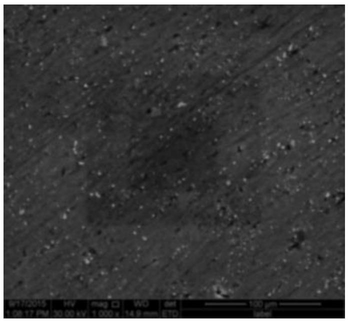
(b)



(c)



(d)



(e)

Figure 8.SEM micrographs of corroded samples of (a) Al 6061 matrix alloy, (b) Al 6061-SiC (3 wt %) composite, (c) Al 6061-SiC (6 wt %) composite, (d) Al 6061-SiC (9 wt %) composite and (e) Al 6061-SiC (12 wt %).

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