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Electrochemical analysis of Corrosion Behavior of Al6061- SiC / Graphite Composite in Various medium

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Abstract

Abstract

Silicon carbide particulate – reinforced Al6061 matrix alloy possess a unique combination of high specific strength, high elastic modulus, good wear resistance and good thermal stability than the corresponding non-reinforced matrix alloy system. They are used in aerospace, automobile and marine industries because of their increased corrosion resistance. In the present investigation, the corrosive behavior of Al6061-SiC particulate composites prepared by liquid metallurgy has been studied in acid chloride, acid sulphate and neutral chloride medium. Samples were prepared by taking different percentage of SiC and casted by liquid metallurgy and samples were prepared as per ASTM standard. In this paper the corrosion characteristics of as casted Al 6061/ SiC composites were experimentally assessed using Tafel extrapolation technique and A.C. Impedance or electrochemical impedance spectroscopy (EIS) technique. The study was also complimented by scanning electron microscopy (SEM) and energy dispersive X – ray investigation. Polarization studies indicates an increase in corrosion resistance in composites compared to the metal matrix alloy. Tafel extrapolation technique and electrochemical impedance spectroscopy were in good agreement. It is observed that corrosion rate is more in acid chloride and acid sulphate media than in neutral chloride media. Further polarization curves indicates that corrosion rate decreases with the increase in the reinforcement content of the composite in as casted Al6061 composite. EIS study reveals that the polarization resistance (R_p) increase with increase in SiC content in composites, thus improved corrosion resistance in composites.

Key words: Al6061. Composite. SiC. Tafel. AC impedance. SEM. EIS.

1. Introduction

Aluminium metal matrix Composites (AMCs) have received considerable attention for military, automobile, aerospace and marine environment fields because of their low density, high strength and stiffness [1-4]. Further addition of ceramic reinforcement such as SiC, graphite, alluminium oxide and boron etc increases the better corrosion resistance than their base alloy. (U.Achutha kini,Prakash Shetty, s. Divakar Shetty.) Metzger and Fishmann reviewed and discuss the corrosion of boron composite suffered from interfacial attack due to crevice and galvanic corrosion [5]. Pitting was the primary type of attack on the silicon carbide composite and was associated with the silicon carbide particles. A.J .Trowsdale et al studied on the influence of SiC reinforcement on the pitting behavior of Al1050 and found that a significant contribution to the increased pitting susceptibility arises from presence of voids and crevice at the reinforcement/ matrix interface [6]. A Comparative study of silicon carbide composite and corresponding matrices of alloys 2024, 5456 and 6061 were carried out and it was found that pitting susceptibility was same for the composite and the matrix alloy except for the 2024 alloy (Trzaskoma et al) [7]. Polarization behavior and pitting morphology differed between the composite and matrix of Al6061/ SiC alloy composite were studied and deduced that the formation of aluminium carbide during processing and not galvanic coupling lead to the marked corrosion susceptibility of this composite.(Aylor and Moran) [8]. A. C. Impedance or electrochemical impedance spectroscopy (EIS) used to examine the chemical passivation of Al6061 alloy and composite with SiC-graphite and found that cerium pretreatment of all deoxidized materials increased the time to pit initiation relative to that for untreated composite and alloy (Mansfeld et al)[9].

The present investigation was initiated to ascertain the analysis of corrosion behavior of Al6061 base alloy and composite with different percentage of reinforcement SiC and hybrid composite with graphite in various medium such as acid chloride, acid sulphate and neutral chloride medium by using Tafel extrapolation technique and A.C. Impedance or electrochemical impedance spectroscopy (EIS) [10-13].

2. Experimental procedure

2.1. Material selection

Material utilized for present study is Aluminium alloy 6061. Al6061 which exhibit excellent Casting properties and reasonable strength used as the base alloy with good strength, being suitable for mass production of light metal casting and its composition is given in the table 1.

Table1: Percentage Composition of Al6061base alloy

Element	Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	other	Al
Percentage	0.8-1.2	0.4 – 0.8	Max. 0.7	0.15 – 0.40	Max. 0.15	0.04 -0.35	*Max. 0.25*	*Max. 0.15*	0.05	95.85

2.2. Reinforcement

SiC of AR Grade used as reinforcement in the form of particulate of mean diameter 25 micron of 99.8 percent of purity.

2.3. Composite preparation

Liquid metallurgy route using vertex technique was employed to prepare the composite. The Al 6061 alloy ingots were charged into a gas –fired crucible furnace and heated to a temperature of 750^0C above the liquid temperature of the alloy and the liquid alloy was then allowed to cool in the furnace to a semi solid state at a temperature of 600^0C. The preheated Silicon carbide reinforcement of 2%, 4% and hybrid Composite with graphite was added. The composite slurry was then stirred using a mechanical stirrer at a speed of 300 rpm with graphite coated helical shaped arranged blades using hexachloro ethane or hexafluro ethane as a degassing tablet to improve the distribution of SiC particles in the molten Al6061 alloy. After degassing, Scum and other impurities were removed. The molten composite was then cast in the steel moulds [14-16].

2.4. Specimen Preparation

Cast material was cut into 15X15mm cylindrical pieces using an abrasive cutting wheel for the test coupons samples. The matrix was also cast under identical condition as composites for comparison, for corrosion study by weight loss method and For Polarization studies, composites and pure alloy matrix were cut into rectangular species of length 83mm, 21mm length width and 4mm thickness. The exposed flat surface of the mounted part was polished with 240, 320, 400, 600,800and1000 grade emery papers and polished according to standard metallographic techniques and degreased in acetone and dried.

3. Experimental procedure

Potentiodynamic polarization studies of an Al6061 base alloy and its composite have been carried out. A solution of 3.5 % of sodium chloride, 0.1M acid chloride solution and 0.1M acid sulphate solutions were prepared. An electrochemical cell with a three-electrode Pyrex glass configuration was used for electrochemical measurements. Al6061 matrix alloy and its SiC composites [2%SiC, 4%SiC & hybrid (SiC and graphite)] were used as a working electrode. A platinum electrode and a Ag/Agcl electrode used as counter and reference electrode respectively. Polarization scan was performed in the electropositive direction at a rate of 0.01V / sec .The open circuit potentials were recorded for Al6061 matrix alloy and its SiC composites in neutral chloride media, acid chloride media and acid sulphate media.

4. *Result and Discussion*

The plots for the matrix alloy and the composites in 3.5 % of NaCl, 0.1M HCl and 0.1M H_2SO_4 medium are shown in the figure1,2 & 3. The evaluated OCP are given in the table 2. It is observed that the OCP values increases in positive direction with increase in SiC content, from -0.7440 V for Al6061 matrix to -0.6810 V for reinforced hybrid composites (SiC+graphite) in Neutral chloride medium. Similar increase in OCP values in positive direction with increase in SiC content, from -0.7030 V for Al6061 matrix to -0.6640 V for reinforced hybrid composites (SiC+graphite) in acid chloride medium and increase in OCP values in positive direction with increase in SiC content, from -0.6930 V for Al6061 matrix to -0.6670 V for reinforced hybrid composites (SiC+graphite) in acid sulphate medium.

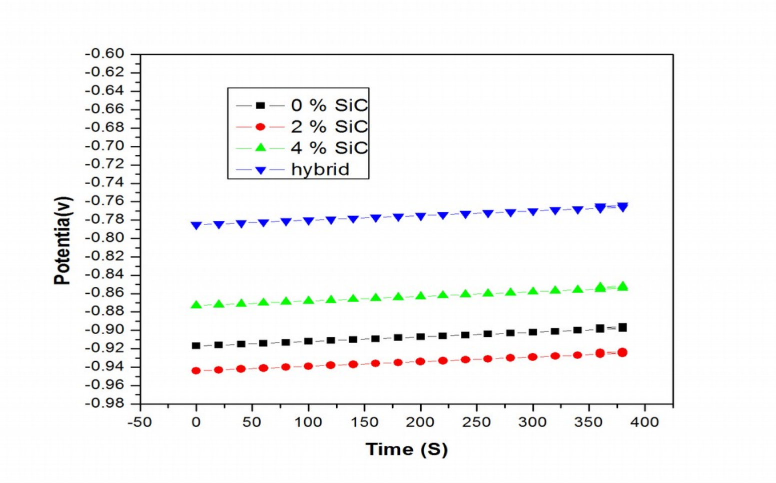

Figure 1: Open circuit potential for Al6061 matrix alloy and its SiC composite in neutral chloride medium

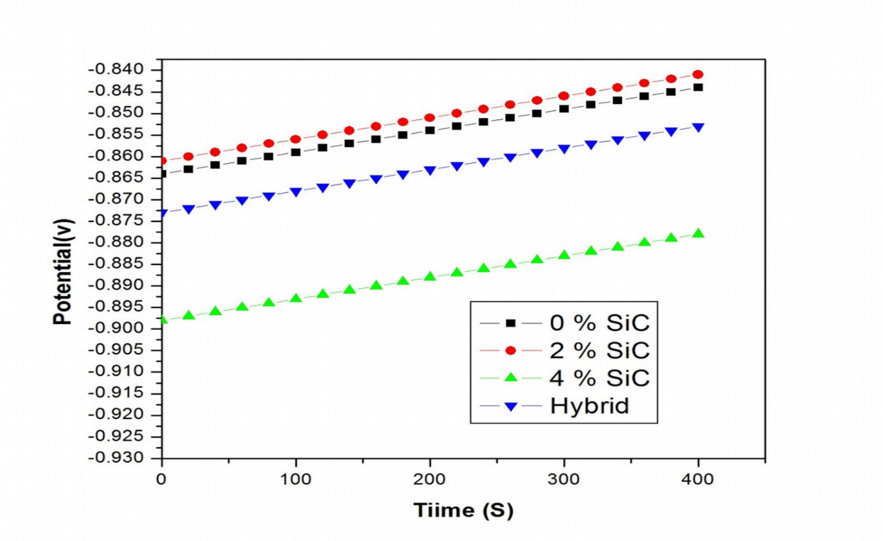

Figure 2: Open circuit potential for Al6061 matrix alloy and its SiC composite in acid chloride medium

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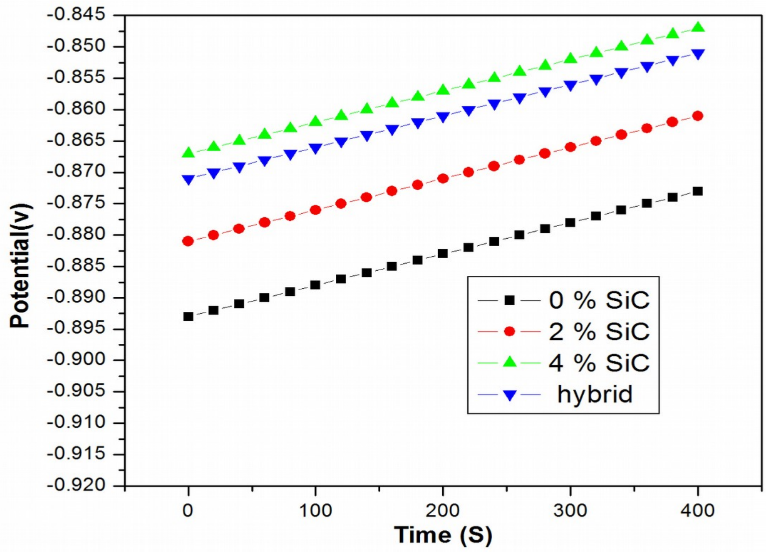

Figure 3: Open circuit potential for Al6061 matrix alloy and its SiC composite in acid sulphate medium

Table 2. Open circuit potentials of Al 6061 matrix alloys and Sic composites in different medium

SiC content in composites	Open circuit potentials (E_{corr}) values in volts in different medium		
	0.1 M HCl	0.1M H_2SO_4	3.5 % Nacl
0 %	-0.7030	-0.6930	-0.7440
2 %	-0.6810	-0.6810	-0.7030
4 %	-0.6610	-0.6710	-0.7170
hybrid	-0.6640	-0.6670	-0.6810

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Analysis of Tafel extrapolation and A.C. Impedance spectroscopy (EIS) studies were carried out using electrochemical workstation Instrument (Model: CHI608E). Tafel polarization curves for Al6061 matrix alloy and its composites containing 2, 4 and (hybrid SiC+graphite) % by weight of SiC particulates in different medium such as acid chloride, acid sulphate and neutral chloride medium are shown in figure 4-6. The evaluated electrochemical parameters (i_{corr}) , linear polarization resistance (R_p), anodic tafel slope (b_a), cathodic tafel slope (bc) and Corrosion rate in miles per year that is associated with the polarization measurement for the Al6061 matrix alloy and its composites are given in the table 3. The corrosion parameters, corrosion current density (I_{corr}) and corrosion rate were obtained from the tafel polarization measurements. The values of the corrosion potential and corrosion current were obtained from the extrapolation of anodic and cathodic tafel lines located next to the linearized current regions. The pitting potential was determined from the forward anodic polarization curves where a stable increase in the current density occur. it can be observed from the tafel plot that corrosion current values and corrosion rate decreases with increase in SiC content in the composites. The conducting SiC particulate possibly forms microgalvanic couple with Al6061 matrix alloy and causes pitting corrosion. The decrease in corrosion rate observed in case of composites is due to decoupling between SiC particles and Al6061 due to decoupling of conducting SiC particles after the interfacial corrosion product, thus eliminating the galvanic effect between them [17-20].

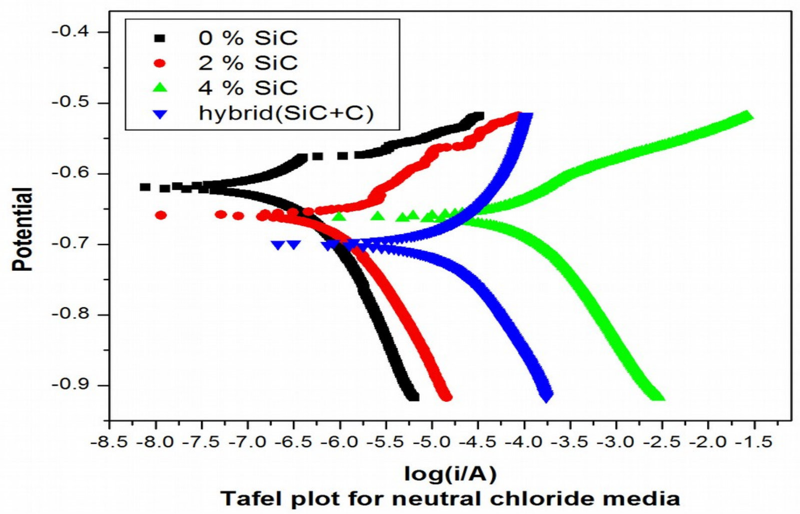

Figure 4: Tafel polarization plots for Al6061 matrix alloy and its SiC (2 , 4 & hybrid) composite in neutral chloride medium

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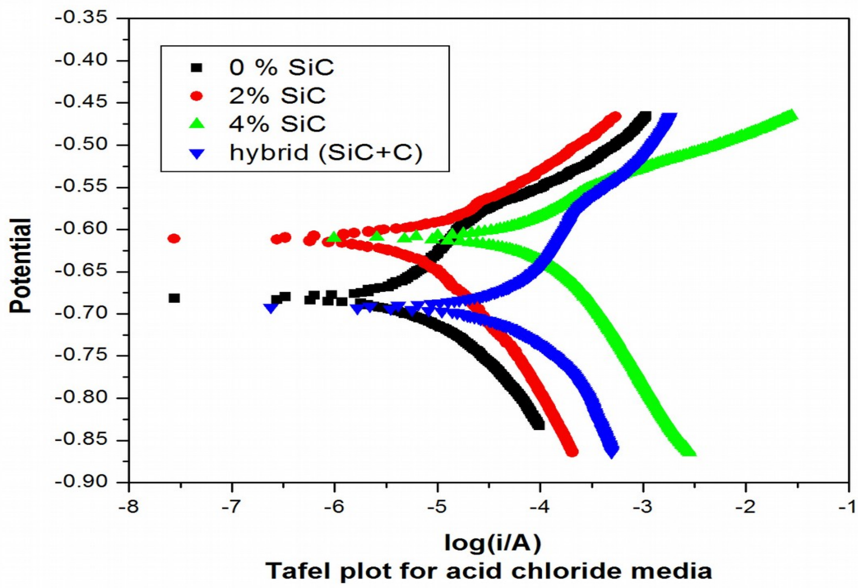

Figure 5: Tafel polarization plots for Al6061 matrix alloy and its SiC (2, 4 & hybrid) composite in acid chloride medium.

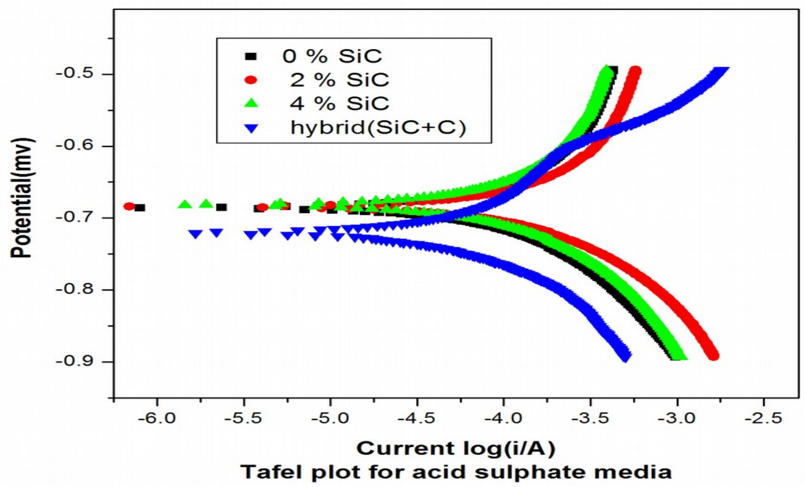

Figure 6: Tafel polarization plots for Al6061 matrix alloy and its SiC (2, 4 & hybrid) composite in acid chloride medium.

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Table 3. Results of Tafel polarization studies, for the Al6061 base alloy and its composite in different medium

Medium	Percentage of SiC	R_P (ohm)	I_{Corr} (A)	b_a	b_c	Corrosion Rate(mpy)
0.1M acid chloride medium	0 %	3910	5.923	11.042	7.729	2.539
	2 %	4241	5.195	12.557	7.179	2.210
	4 %	211	1.995	6.110	4.214	8.431
	Hybrid(2%SiC + 2% Graphite)	207	1.511	6.431	6.828	6.408
0.1M acid sulphate medium	0 %	323	1.337	4.156	5.920	5.732
	2 %	212	1.974	3.864	6.537	6.141
	4 %	305	1.453	3.697	6.115	8.370
	Hybrid(2%SiC + 2% Graphite)	582	6.865	3.944	6.938	2.920
3.5 wt % of neutral chloride medium	0 %	99748	1.567	22.011	5.808	6.716
	2 %	12566	1.659	15.231	5.620	7.036
	4 %	211	1.995	6.110	4.214	8.431
	Hybrid(2%SiC + 2% Graphite)	217	1.511	6.828	6.431	6.382

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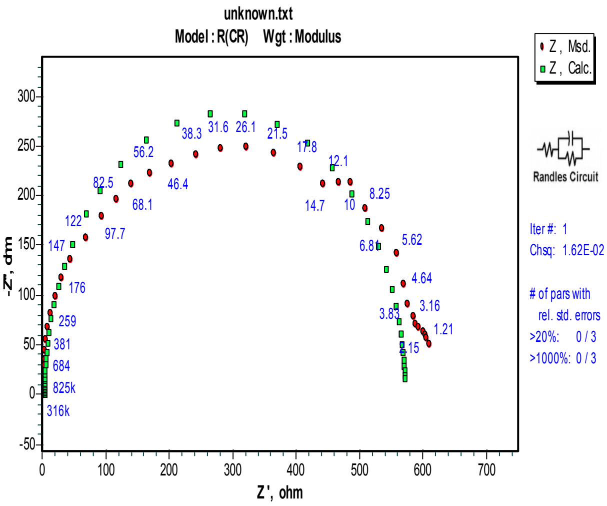
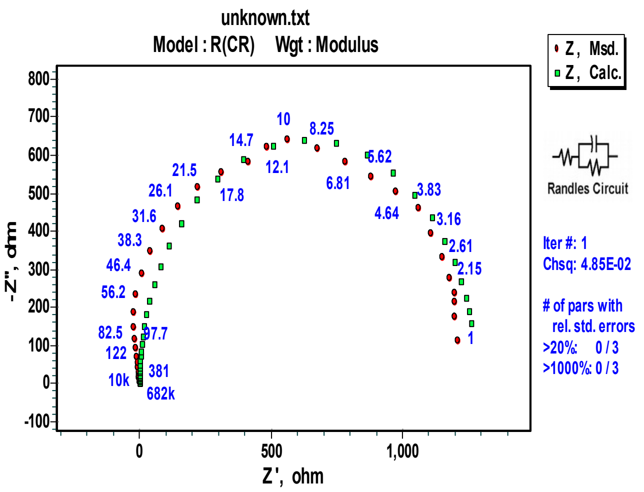
5. EIS studies:

EIS study of the matrix alloy and its composite is carried out at OCP in order to assess the contribution of the composites. Nyquist plots and its equivalent circuit used to fit the experimental data of Al6061 matrix alloy and its composites are shown in the figure.7.It can be observed from the Nyquist plots that radius of the capacitive loops above the real axis increased with increase in SiC content for the composites.

a



b



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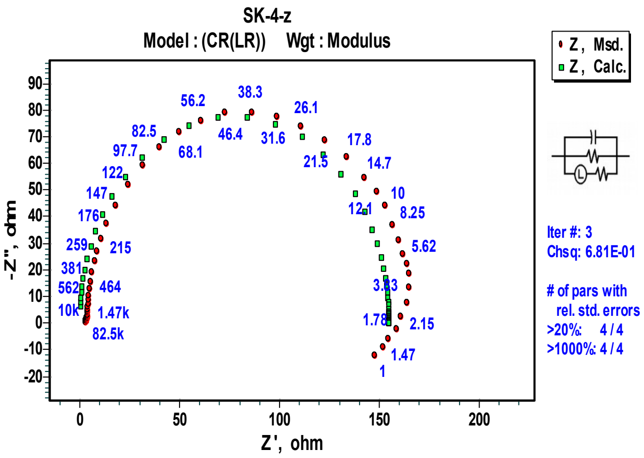

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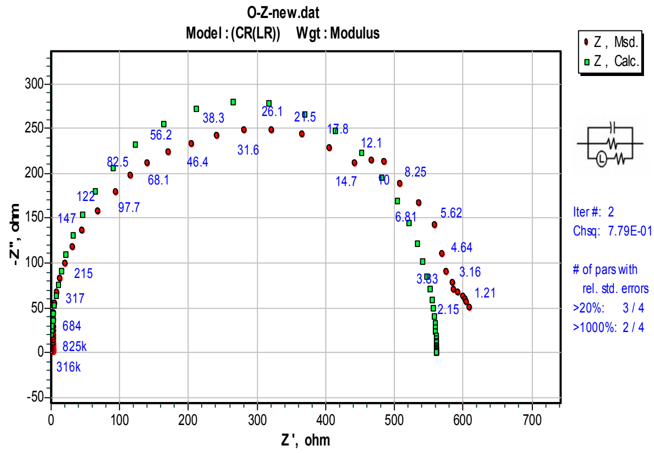

ISSN 1466-8858 Volume 21, Preprint 14 first submitted 5 January 2018

Figure 7 a, b, c & d: Nyquist plot with Equivalent circuit model used to fit experimental data of Al6061 matrix alloy and its composite (2%, 4% and hybrid)

6. Scanning electron microscopy

Scanning electron microscopy (SEM) images of the Al6061 matrix alloy and its composites (2 %, 4% and hybrid) was carried out using Scanning electron microscope (model: IS:150-2002,RA2007) . The SEM images of Al6061 matrix alloy and its composites (2 %, 4% and hybrid) before corrosion are shown in the figure 8. The particle size of reinforcement SiC particulate is about 20µm as observed in the SEM images. The SEM images of Al6061 matrix alloy and its composites (2 %, 4% and hybrid) in 0.1M acid chloride medium, acid sulphate medium and neutral chloride medium are show in the figure 9-11. The corrosion of Al601 alloy and its composites is presumably due to the anodic dissolution either at the grain boundaries or at the metal-media interface. A comparison of the SEM images of the samples before and after the polarization studies clearly indicates severe surface deterioration in acid chloride and acid sulphate medium than neutral chloride medium due to pitting corrosion in all the samples. Pitting susceptibility for aluminium alloy is mainly affected by the microstructural heterogeneity of these commercial alloys. The decrease in corrosion deterioration of composites can be attributed to matrix – reinforcement interface and formation of micro and sub micro load cells at the metal surface.

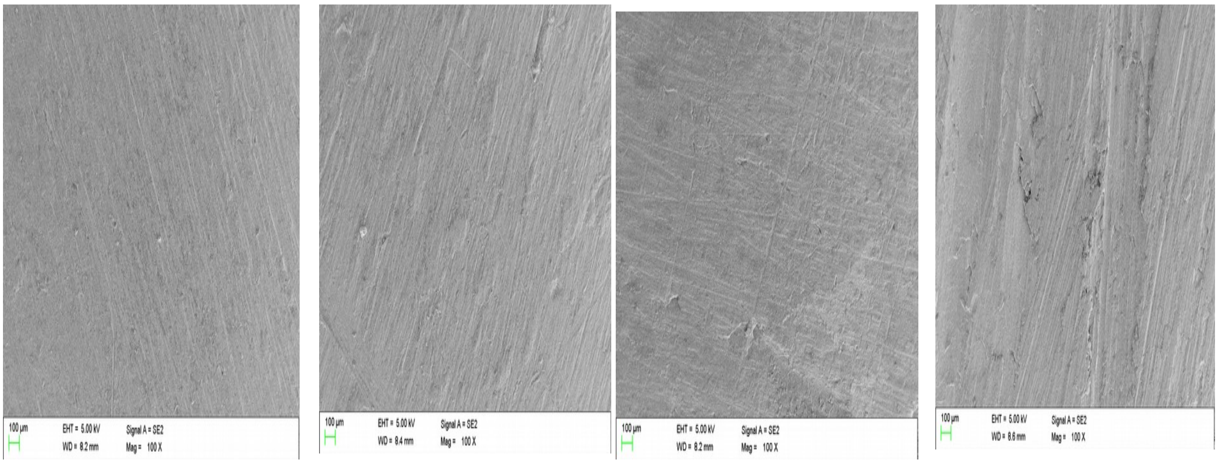

figure 9: SEM micrograph of corroded Al6061 matrix alloy and its composites (2, 4 & hybrid) in acid chloride medium

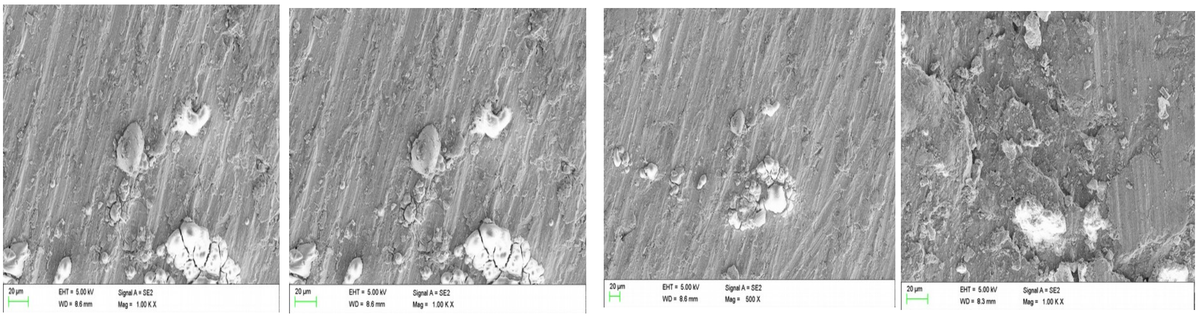

Figure 10: SEM micrograph of corroded Al6061 matrix alloy and its composites (2, 4 & hybrid) in acid sulphate medium

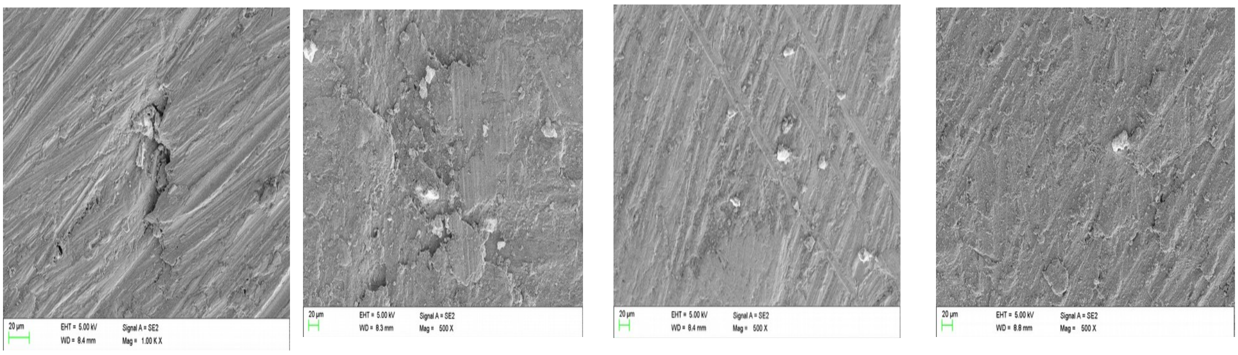

Figure 11: SEM micrograph of corroded Al6061 matrix alloy and its composites (2, 4 & hybrid) in neutral chloride medium

7. Conclusion:

In this paper the corrosion characteristics of as casted Al 6061 matrix alloy and its composite with SiC (2% 4% and hybrid) were experimentally assessed using Tafel extrapolation technique and A.C. Impedance or electrochemical impedance spectroscopy (EIS) technique. The study was also complimented by scanning electron microscopy (SEM)

From the result it is observed that Al6061 composite exhibited excellent Corrosion resistance in neutral chloride medium than in acid chloride and acid sulphate medium. The Corrosion rate of the composites was lower than that of the corresponding matrix alloy.

The Corrosion rate of composites decreases with increase in percentage of reinforcement which may be due to increase in bonding strength.

Increased corrosion resistance in composites is believed to be due to reinforcement particulate modifying the microstructure of matrix and also acting as physical barrier to the initiation and development of pitting corrosion.

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