

# EFFECT OF SiC-GRAPHITE PARTICULATE ON THE CORROSIVE BEHAVIOR OF Al 6061 COMPOSITES IN VARIOUS MEDIUM

Saifulla khan<sup>1</sup>, Dr.K.G.Manjunatha<sup>2</sup>  
<sup>1</sup>Assistant Professor, <sup>2</sup> Professor and Head,

Department of Chemistry,  
Ghousia college of Engineering, B-M Road Ramanagaram – 562159, Karnataka, India.

**Abstract :** In the present investigation, the corrosive behavior of Al6061-SiC / graphite particulate composites prepared by liquid metallurgy has been experimentally assessed in neutral chloride medium, acid chloride medium and acid sulphate medium using Tafel extrapolation technique and electrochemical impedance spectroscopy (EIS). Surface morphology of the sample was examined using scanning electron micrographic and energy dispersive X-ray method. The results obtained from Tafel extrapolation technique and EIS were in good agreement. Polarization studies indicates an increase in the corrosion resistance in composites compared to the matrix alloy. Presence of graphite in the hybride composite activates the corrosion of Al6061 matrix alloy due to the occurrence of galvanic corrosion EIS study reveals that the polarization resistance increase with increase in SiC content in composites, thus confirming improved corrosion resistance in composites.

**Keywords:** Corrosion, Al6061, SiC, Tafel, EIS, SEM.

## 1. INTRODUCTION

Corrosion a part of our everyday life, Corrosion is an environmental degradation and rusting are terms commonly used to describe the processes that bring about a loss of performance of engineering materials. Corrosion is the term generally used to describe the chemical “wasting” which occur when a metal and alloy reacts with the environment within which it is in contact.[1-6]. There are many different types of corrosion but most common type in Aluminum alloy and its composite is pitting corrosion. This Localized form of corrosion is characterized by the formation of irregularly shaped cavities on the surface of metal their diameter and depth depends on several parameter related to metal and the medium. Pit can be either hemispherical or cup shaped. Aluminium is prone to pitting corrosion. The pitting attack is highly localized corrosion and is usually in the form of holes that can penetrate inwards extremely and ultimately damage the structure by either perforating the material or developing crack due to stress. It often difficult to detect pits because of their small size and often covered with corrosive products.in addition it is difficult to measure quantitatively and compare the extent of pitting because of varying depth and number of pits that occur under identical conditions[7-11]

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 [12-15]. 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 kuni,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 [16]. 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 an

d found that a significant contribution to the increased pitting susceptibility arises from presence of voids and crevice at the reinforcement/ matrix interface [17]. 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 ) [18]. 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) [19]. 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 )[20].

Recent studies on the Corrosion resistance of SiC particulate- reinforced Aluminium alloy reinforcement with TiN 2, 4 and 6 Wt % in NaCl media ( H C Anandamurthy , V Bheema Raju and C Shivakumara 2012). Corrosion Characterization of Al6061/red mud metal matrix composites (P.V. Krupskaya 2013), SiC Despersoid on the Corrosion behaviour of Squeeze Cast

Aluminium alloy – SiC composite (O.P. Modi, M. Sexena , B.K. Praad and A.H . Yegnewaran 1991) Show a marked decrease in the Corrosion rates of the matrix alloy and Composites with increase in the Content of TiN and SiC reinforcement. The reinforcement of SiC alloy increase the susceptibility to pitting Corrosion.

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) [21-22].

## 2. EXPERIMENTAL PART

### 2.1. Material Selection

Material utilized for present study is Aluminium 6061 alloy in the form of ingots shown Aluminium alloy was cut from its ingot size into smaller pieces by an electric power saw in order to feed the crucible properly. Al6061 alloy is a precipitation-hardened aluminum alloy containing magnesium and silicon as its major alloying elements. 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. Silicon carbide, also known as carborundum, is a semiconductor containing silicon and carbon with chemical formula SiC. It occurs in nature as the extremely rare mineral moissanite. It has Low density, high strength, low thermal expansion, high thermal conductivity, high hardness, high elastic modulus, excellent thermal shock resistance, superior chemical inertness. For hybrid composite preparation graphite has been used which is historically, known as black lead or plumbago. The acoustic and thermal properties of graphite are highly anisotropic.

### 2.3. Composite Preparation

Liquid metallurgy route using vertex technique was employed to prepare the composite. Al 6061 alloy is best applicable for mass production of light metal casting which shows better casting residences and affordable strength has been used as base alloy with good strength. The Al 6061 alloy ingots were charged into a gas –fired crucible furnace and heated to a temperature of 750°C 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°C. The preheated Silicon carbide reinforcement of 2%, 4% hybrid Composite with equal quantity of silicon carbide particulate and graphite was added. Addition of Silicon carbide and graphite into the molten aluminium alloy melt above its liquidus temperature of 500 °C was carried out by creating a vortex in the melt using a mechanical stainless steel stirrer coated with aluminite (to prevent migration of ferrous ions from the stirrer material into the aluminium alloy melt). The melt was rotated at a speed of 500 rpm in order to create the necessary vortex. The molten Al 6061 alloy and SiC particles are thoroughly stirred manually. After sufficient manual stirring, the semi-solid liquid melt was reheated to a fully liquid state in the resistance furnace followed by automatic mechanical stirring using a mixer to make the melt homogenous for about 15 minutes at 300 rpm with graphite coated helical shaped arranged blades using hexachloro ethane or hexafluoro ethane (C<sub>2</sub>Cl<sub>6</sub> or C<sub>2</sub>F<sub>6</sub>) solid degasser 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. Al6061 base alloy without reinforcement is also casted in the identical way for comparisons. The casting composition is shown in the Table .2 [23-26].

**Table.2: Casting composition of Samples**

Percentage of Composites	Al6061 alloy in kg	SiC in grams	Graphite in grams
0 %	4 kg	----	----
2 %	4 kg	80 g	----
4 %	4 kg	160 g	----

hybrid	4 kg	80 g	80 g
--------	------	------	------

## 2.4. Specimen Preparation

For Polarization studies, composites and pure alloy matrix were cut into rectangular species of length 83mm, 21mm length width and 4mm thickness as shown in the figure. 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 with SiC composites [2%SiC, 4%SiC & hybrid (SiC and graphite)] have been carried out in 3.5 % of sodium chloride solution, 0.1M acid chloride solution and 0.1M acid sulphate solutions.. 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. only 1 cm<sup>3</sup> of the sample was exposed to the electrolyte solution. All experiments were performed at room temperature. The open circuit potentials(OCP) is recorded . The Tafel plots of potential versus log I were drawn and the corrosion current density ( $I_{corr}$ ) and the corrosion potential ( $E_{corr}$ ) were determined for Al6061 matrix alloy and its SiC composites containing 2% SiC, 4%SiC & hybrid (2% SiC and 2% graphite) in neutral chloride media, acid chloride media and acid sulphate media using Electrochemical analyzer model (Model: CHI608E). Using corrosion current  $I_{corr}$ , the corrosion rate were calculated using the following relation and recorded in the Table 3.

$$\text{Corrosion rate (mpy)} = \frac{0.1288 \times \text{Eq.wt.} \times I_{corr}}{D}$$

where

mpy = Milli-inches per year

$I_{corr}$  = Corrosion current density ( $\mu\text{Acm}^2$ )

Eq.Wt = Equivalent weight of the corroding species, (g).

d = Density of the corroding species, (g/cm<sup>3</sup>) calculated using rule of mixture

**Table 3: Corrosion rate calculated during pitting corrosion for Al 6061 matrix alloy and its composites in different medium**

Medium	Percentage of SiC	$I_{Corr}$ ( $\mu\text{A}$ )	Equivalent weight	Density (g / cc)	Corrosion Rate (mpy) $\times 10^{-4}$
0.1M acid chloride medium	0	$1.995 \times 10^{-4}$	8.99383g	2.7	0.855932
	2	$1.511 \times 10^{-4}$	8.99383g	2.7296	0.641247
	4	$4.932 \times 10^{-6}$	8.99383g	2.7388	0.0208604
	hybrid	$5.993 \times 10^{-6}$	8.99383g	2.7206	.02551761
0.1M acid sulphate medium	0	$1.974 \times 10^{-4}$	8.99383g	2.7	0.8469229
	2	$1.453 \times 10^{-4}$	8.99383g	2.7296	0.6166335
	4	$6.865 \times 10^{-5}$	8.99383g	2.7388	0.2903626
	hybrid	$1.337 \times 10^{-4}$	8.99383g	2.7206	0.5692817
3.5 wt % of neutral chloride medium	0	$1.995 \times 10^{-4}$	8.99383g	2.7	0.8559328
	2	$1.659 \times 10^{-4}$	8.99383g	2.7296	0.70405715
	4	$1.511 \times 10^{-4}$	8.99383g	2.7388	0.6390939

	hybrid	1.567 X 10 <sup>-4</sup>	8.99383g	2.7206	0.6672135
--	--------	--------------------------	----------	--------	-----------

4. RESULT AND DISCUSSION

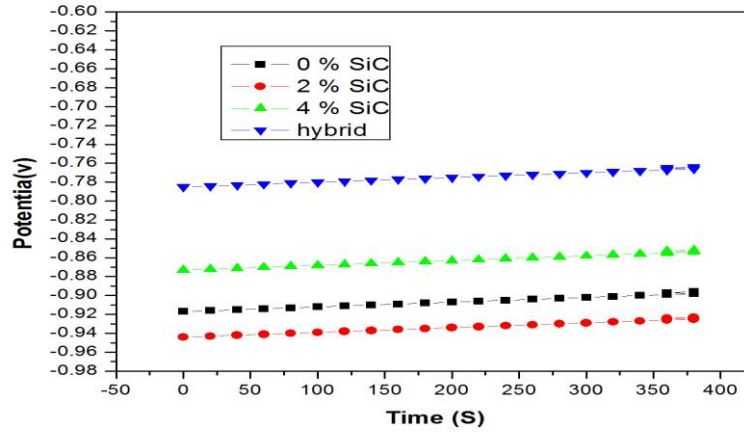


Figure 1: Open circuit potential for Al6061 matrix alloy and its SiC composite in neutral chloride medium

The OCP plots for the matrix alloy and the composites in 3.5 % of NaCl, 0.1M HCl and 0.1M H<sub>2</sub>SO<sub>4</sub> medium are shown in the figure 1, 2 & 3. The evaluated OCP are given in the table 4. It is observed that the OCP values increase 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.

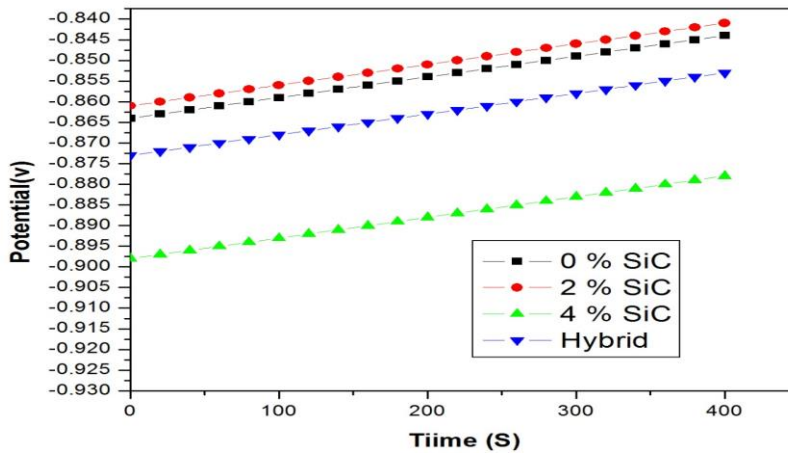


Figure 2: Open circuit potential for Al6061 matrix alloy and its SiC composite in acid chloride medium

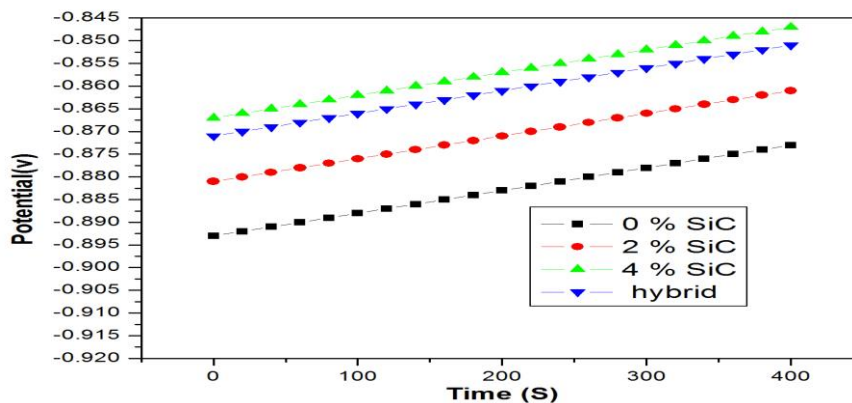


Figure 3: Open circuit potential for Al6061 matrix alloy and its SiC composite in acid sulphate medium

**Table 4. 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 <sub>2</sub> SO <sub>4</sub>	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

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 ( $b_c$ ) 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 5. 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 [27-30].

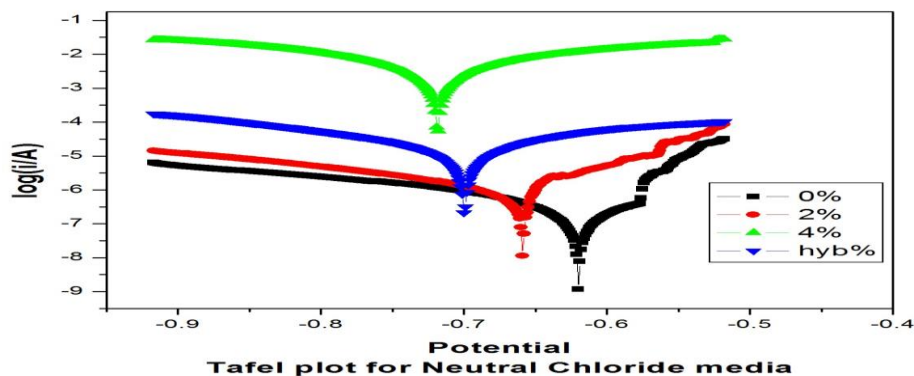


Figure 4: Tafel polarization plots for Al6061 matrix alloy and its Composites in neutral chloride medium

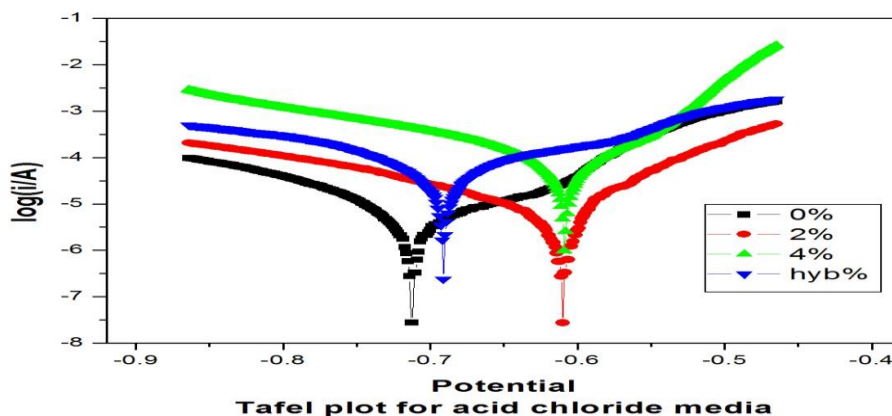


Figure 5: Tafel polarization plots for Al6061 matrix alloy and its composite in acid chloride medium.

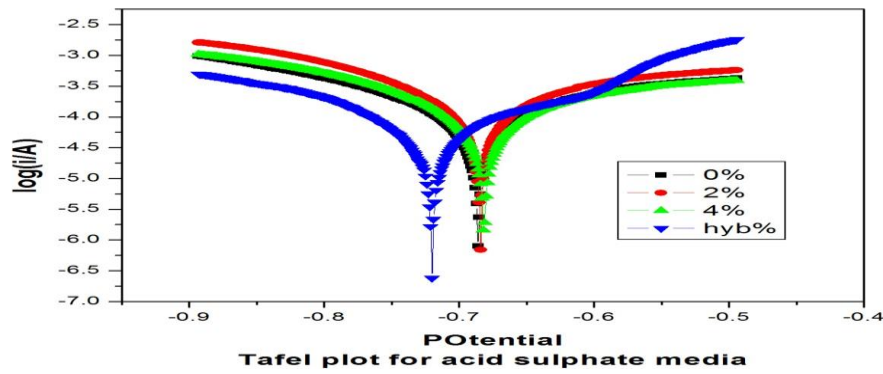


Figure 5: Tafel polarization plots for Al6061 matrix alloy and its composite in acid chloride medium.

**Table 5. 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

## 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 obtained from the experimental data of Al6061 matrix alloy and its composites are shown in the figure:6-8. It can be observed from the Nyquist plots that the radius of the capacitive loops above the real axis increased with increase in SiC content for the composites.

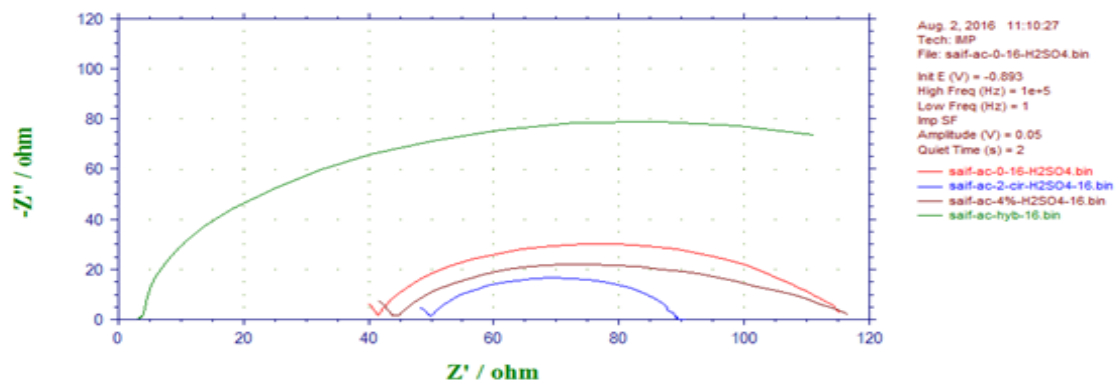


Figure 6: Nyquist plots of Al6061 base alloy and its Composites in acid sulphate medium.

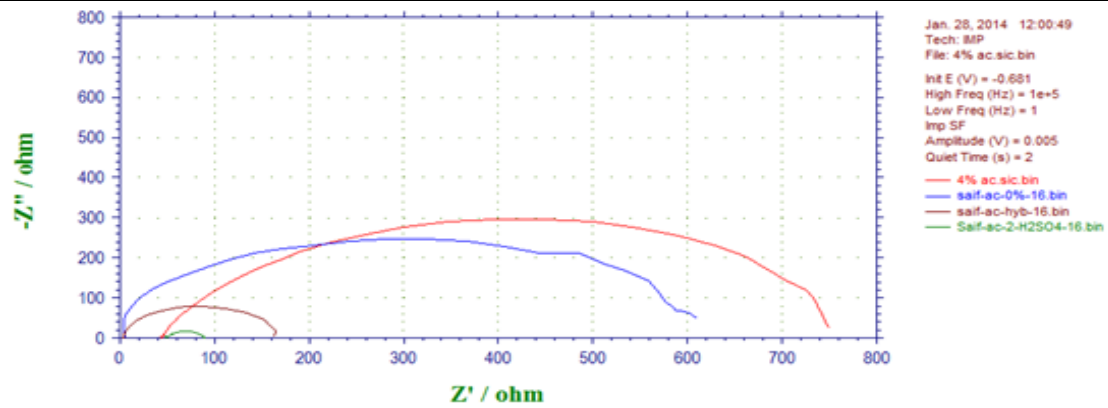


Figure 7: Nyquist plots of Al6061 base alloy and its Composites in acid chloride medium

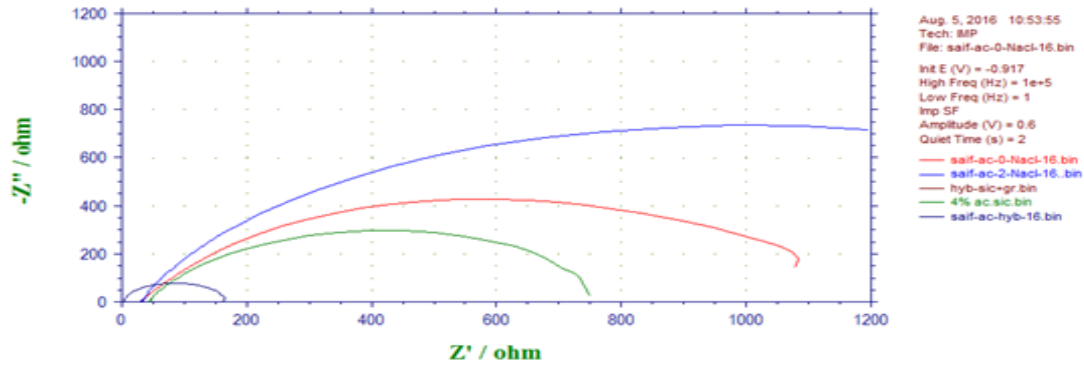


Figure 8: Nyquist plots of Al6061 base alloy and its Composites in neutral chloride medium

## 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 20 $\mu$ m 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.

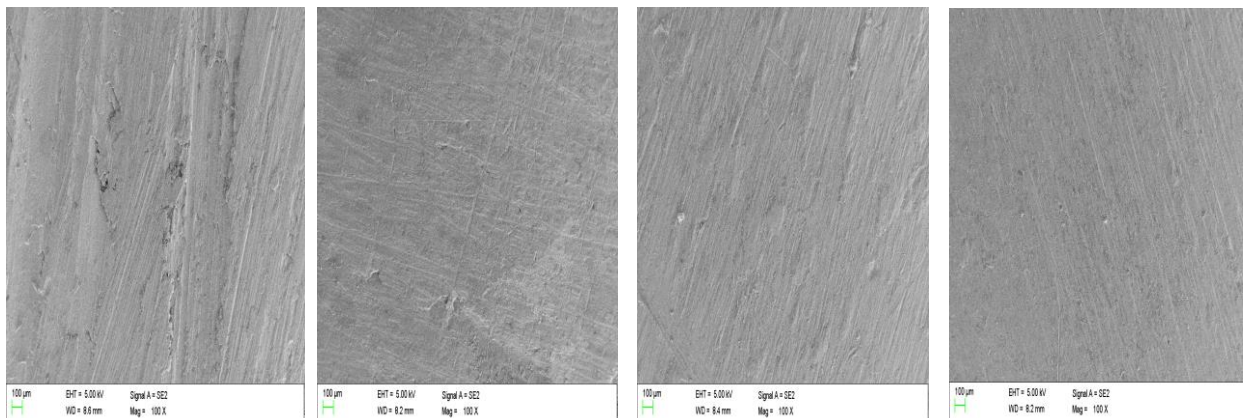


Figure 9: SEM micrograph of Al6061 matrix alloy and its composites (2, 4 &amp; hybrid) before corrosion

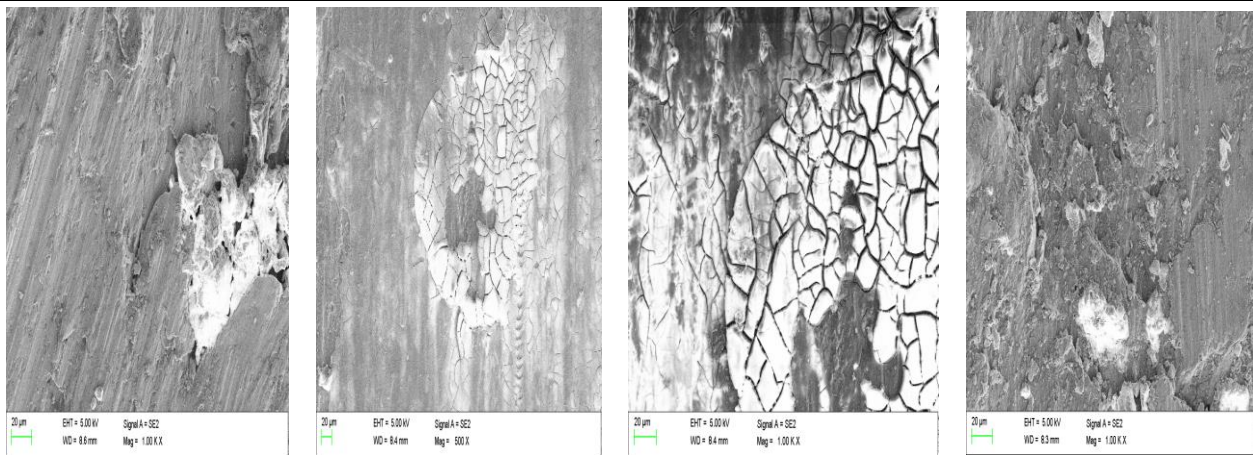


Figure 9: SEM micrograph of corroded Al6061 matrix alloy and its composites in acid chloride medium

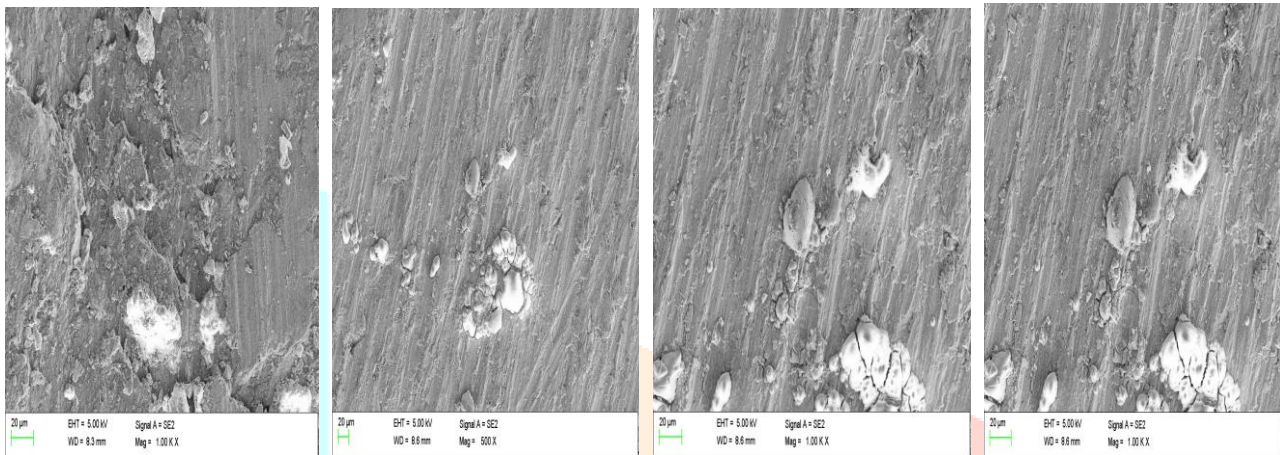


Figure 10: SEM micrograph of corroded Al6061 matrix alloy and its composites in acid sulphate medium

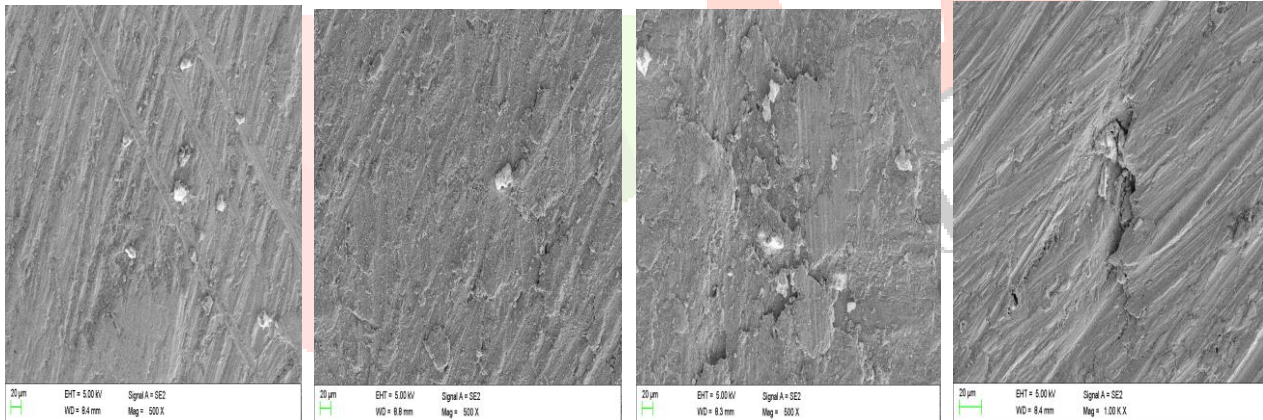


Figure 11: SEM micrograph of corroded Al6061 matrix alloy and its composites in neutral chloride medium

## 7. CONCLUSIONS

In this paper the Effect of SiC-graphite particulate on the corrosive behavior of Al6061 composites in various medium were experimentally assessed using Tafel extrapolation technique and 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. Presence of graphite in the hybride composite activates the corrosion of Al6061 matrix alloy due to the occurrence of galvanic corrosion

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.

## 8. ACKNOWLEDGEMENT

I sincerely thanks Vision Group on Science and Technology (VGST), Government of Karnataka for funding this research work and also R& D Centre, Department of Chemistry, Ghousia college of Engineering, Ramanagaram.



## References

- [1]. J. W. Oldfield 'Electrochemical theory of galvanic corrosion "ASTM, STP, 978, 1988, P 5-22
- [2]. James K Wessel Hand book of advanced materials ISBN0-471-45475-3 copyright@2004
- [3]. Hatch, J, E. Aluminium: Properties and physical metallurgy, American society for metals 1984, 242-315
- [4]. Vujicic, V, Lovecek, B, Properties of boehmitized aluminium surface, surface technology (1982)17, 29-35
- [5]. M.G. Fontana, N.D. Greene ' Corrosion Engineering", Mc Graw-Hill, New York 1998
- [6]. J. E. Breakell, M. Siegwart, K. Foster "Management of Accelerated low water corrosion In steel Maritime Structures", ISBN 0-86017-634-7
- [7]. R. Takebeya "Aluminium corrosion products formed in atmospheric environment corrosion engineering, vol 36 1987, P 279-286
- [8]. A.J. Trowsdale, B. Noble, S.J. Harris . Corrosion science, vol.38.No.2 PP.177-191.1996
- [9]. J. R Galvele "Transport process and the Mechanism of pitting of metal", J. electrochem.Soc., 123,464,1976.
- [10]. Hongel Li, Margaret R, Jiaming Li , Javier EchauZ, JE Research, annual conference of Prognostics and health management society 2014
- [11]. Rao, K.S Rao K.P. 2004 pitting corrosion of heat treatable aluminium alloy and welds , vol.57, No 6, pp. 593-610
- [12]. T.S. Srivastava, T. S . Sudarshan and G.e. Bobeck, Brit. Corr. J., 25(1990)39
- [13]. D.M. Aylor "HandBook" 9<sup>th</sup> edition . Vol 13( American Society for metals. 1987 p-859
- [14]. Sahin Y & Acilar M Composite Part A, 24(2005)709
- [15]. W. Neil C. Garrard corrosion science, vol.36.No 5, pp837-851, 1994. Elsevier Ltd
- [16]. M. Metzger and S. G. Fishmann, Ind. Engg. Chem. Prod. Res. Dev. 22, 296-1983
- [17]. A.J. Trowsdale, B. Noble, S.J. Harris . corrosion science, vol.38.No.2 PP.177-191.1996
- [18]. P. P. Trzaskoma , E. Mc Cafferty and C.R. Crowe, j. electrochemical soc .130,(1983)
- [19]. D.M. Aylor and P.J. Moran j. electrochemical soc .132, 1277 (1989)
- [20]. F. Mansfeld, S. Lin. S. Kim and H. Shih Corrosion 45, 615 (1989)
- [21]. U. Achutha et al Indian journal of Chemical technology vol.18. November 2011, pp, 439-445
- [22]. M.S.N. Bhat, M.K. Surappa and H.V. Sudhaker nayak journal of material science 2(1991) 4991-4996
- [23]. Min K S, Ardell, Ek sj et al . j mater Sci. 1995:30:5479-5483
- [24]. K.K. Alaneme and M.O. Bodunrin journal of Minerals & Material Characterization & Engineering, 12, PP, 1153-1165, 2011
- [25]. Krupakara, P. V, Corrosion Characterization of Al6061/RedMud Metal Matrix Composites, Portugaliae Electrochimica Acta 31(3), (2013), 157-164
- [26]. H.C. Ananda murthy, V Bheema raju and C Shivkumara Bull. Mater Sci, vol,36, No,6, November 2013, pp1057-1066
- [27]. H.C. Ananda murthy, V Bheema raju and C Shivkumara Bull. Mater Sci, vol,36, No,6, November
- [28]. G. Velayudham, INCAL, 31 july-2 aug. 1991, 879-882
- [29]. Z. Karm july-December 2014 vol.8 No.2 ISSN: 1985-3157
- [30]. El-Sayed M. Sherif, A. Almajid, Fahamsyah Hamdan Latif, Harri Junaedi. Int j. Electrochem. Sci, 6(2011)1085-1099