Corrosion Analysis of Al-6061 MMCs Reinforced With Fly Ash & Rice Husk Ash

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Abstract

Tests with various reinforcements were delivered to comprehend their mechanical and corrosion behavior of the material, by utilizing fly ash and rice husk ash as reinforcement and aluminum 6061 alloy as metal matrix material. The composite were created by stir casting method. The primary target of this study is to study the mechanical and corrosion properties of material utilizing different arrangement. So we are shone on creating light weight material with high rigidity and hardness with high corrosive resistance which can be benefit for vehicle enterprises or avionic business. The microstructure determines the material's properties, and the production technique determines the microstructure. Composite materials are created to modify the qualities of a material to our specific requirements. It was found that corrosion resistance in case FA reinforced composites shows better than RHA reinforced composites.

Keywords: Aluminum alloy, stir casting, metal matrix composites, SEM, EDS

1 Introduction

The arrangement of a material's interior components is known as its structure. The subatomic structure is the arrangement of electrons within individual atoms and their interactions with their nuclei. On an atomic scale, the arrangement of atoms or molecules in relation to one another is referred to as structure. The way a material is handled will determine its structure. The microstructure of a substance determines its qualities. The qualities of the material will determine its performance; these are the important aspects in a material.

The ability to achieve a desirable combination of strength, stiffness, toughness, and density and corrosion resistance with traditional monolithic materials is limited. Composites are the most promising materials of recent interest for overcoming these drawbacks and meeting the ever-increasing demand of modern technologies. Metal matrix composites (MMCs) are sophisticated materials that are created by combining two or more components to achieve specific features. When compared to unreinforced alloys, MMCs have dramatically improved features such as high specific strength, more resistance to corrosion, damping capacity, wear and high ultimate tensile strength. AMCs will be less expensive and perform better if low-cost reinforcements and natural materials are used.

2 Materials and methods

Al 6061 alloy from GLEMCO Inc. as 20 kg plates was purchased. The fly ash powder which was used as reinforcement material was procured from NALCO ODISSA, INDIA, & rice husk was purchased from local market which was later turned into rice husk ash.

Stir casting method with graphite crucible was used for the fabrication of aluminum alloy. The chemical composition of AL-6061 alloy, RHA & FA is presented below (Table 1-3).

Table 1: Chemical Composition of Al 6061 alloy

Component	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Other, total
Weight %	95.8 - 98.6	0.04 - 0.35	0.15 - 0.4	Max 0.7	0.8 – 1.2	Max 0.15	0.4 – 0.8	Max 1.5	Max 0.25	Max 0.15

Table 2: Chemical composition of Fly Ash

Component	Silica (SiO_2)	Carbon (C)	Calcium Oxide (CaO)	Magnesium oxide (MgO)	Potassium oxide (K_2O)	Hematite (Fe_2O_3)	Alumina	Others
Weight %	91.56	4.0	4.0	0.35	1.4	0.06	4.6	0.93

Table 3: Chemical Composition of Rice Husk Ash

Component	Silica (SiO_2)	Carbon (C)	Calcium Oxide (CaO)	Magnesium oxide (MgO)	Potassium oxide (K_2O)	Hematite (Fe_2O_3)	Alumina	Others
Weight %	88.56	4.8	1.58	0.53	0.39	0.21	4.93	0.93

The process parameters employed for casting the samples are given below (Table 4):

Table 4: Optimized Parameters for Stir Casting Al6061/FA / RHA Composites

STIR CASTING PARAMETERS	**VALUE**
Temp. to melt raw aluminum (in ^oC)	725
Preheated temp of RHA particles (in ^oC)	600
Preheated temp of FA particles (in ^oC)	600
Time taken to preheat reinforcement (in minutes)	60
Temp. of crucible used for pouring composite slurry	760
Stirring speed of melt (in RPM)	600
Stirring time of melt (in minutes)	10

2.1 X-ray diffraction analysis of Al6061/ FA/ RHA MMC

This experiment procedure was done at IMMT, Bhubaneswar. Scans were performed between 2θ range of 4 and 90 with 10mm divergence slit and 1° diffracted beam slit. X-ray diffraction patterns were acquired to find the constituents exist in the Al6061/RHA/FA composite containing different weight percentage of RHA and FA particles. The intensity of SiO_2 peaks increases as RHA & FA content in the AMC increases.

2.2 Microstructural analysis by SEM

The result of this test was gathered from CUTM, Parlakhemundi. All the specimens were polished using standard metallographic technique. Mechanical grinding is performed using SiC abrasive papers of different grit sizes, from 220, 600, 800 to 1000 grit.

The density gradient between the aluminum matrix, FA and the RHA particles is a key factor during solidification. It has been observed that the distribution of RHA and FA particles is intragranular.
The intragranular distribution of RHA and FA particles reveals that the particles were engulfed by the solidification. The SEM micrographs of RHA and FA are shown below:

2.3 Microstructural analysis of MMC by EDS

Electron Discharge Spectrum (EDS) images confirm a clear formation of grain boundaries in the composites. It can be ascertained that RHA and FA particles played a role in refining the grains. It was observed that the average grain size reduced with an increase in RHA and FA particles. The reduction in grain size suggests that RHA and FA particles acted as grain nucleating agents. Below image shows the EDS of Al 6061/FA/RHA:

2.4 Density of Al6061/ RHA/ FA MMC

The density test was done at GIET University, Gunupur. Density is measured by Archimedes principle and inverse rule of mixture. Inverse rule of mixture is given as follows;

$$\rho_C = 1/(W_{Al} / \rho_{Al} + W_{RHA} / \rho_{RHA}) \quad (1)$$

$$\rho_C = 1/(W_{Al} / \rho_{Al} + W_{FA} / \rho_{FA}) \quad (2)$$

Where ρ_C, ρ_{Al}, ρ_{FA} and ρ_{RHA} are densities of composite, Al6061 alloy, fly ash and rice husk ash respectively. The W_{Al}, W_{FA} and W_{RHA} are weight fractions of Al6061, fly ash and rice husk ash. The density of Base Al6061 alloy, fly ash MMC and rice husk ash MMC are 2.7gm/cm^3, 2.64 gm/cm^3 and 2.59 gm/ cm^3 respectively as shown in Table below:

2.5 Hardness of Al 6061/ FA/ RHA MMC

The hardness was measured using a Brinell cum Rockwell hardness tester (ME/MT/04) at 187.5kg load applied for 15 seconds at twenty different locations in order to contradict the possible effect of ball indentor resting on the harder particles and the average value of hardness was calculated.

It is evident that reinforcement of FA and RHA particles significantly improves the hardness of the AMCs. The 15%weight fraction addition of fly ash and rice husk ash to Al 6061 alloy exhibits 71.12 HV and 69.52 HV higher hardness compared to unreinforced AL6061 alloy which is 62.51 HV.

2.6 Tensile behavior of Al 6061/ FA/ RHA MMC

The effect of weight fraction of FA and RHA Ultimate Tensile Strength (UTS) of the Al6061/FA/RHA AMCs is done using electronic tensometer. Al6061/ 15% FA/ 15% RHA (weight fraction) AMC exhibits 128.57 N/mm^2 FA and 123.3 N/mm^{2}RHA higher UTS compared to unreinforced Al6061 alloy which is 112.5 N/mm^2. The results clearly indicate that FA and RHA particle strengthens the AMCs. But UTS of FA is more than that of RHA. The grain refinement and size reduction of the ductile aluminum alloy matrix content and increase in weight percentage of fly ash and rice husk ash particles reduces the ductility of the AMCs.

2.7 Compressive behavior of AL6061 FA/ RHA MMC

The effect of compression on Al6061/ FA/ RHA MMC was conducted using ultimate tensile machine which is available at GIETU. It has been shown that as the weight fraction of FA and RHA particles increases compressive strength of the MMCs also increases. Below Table shows compressive strength of MMCs:

2.8 Impact strength behavior

Charpy Impact test was conducted at GIET University, Gunupur. Impact strength of base Al 6061 alloy was 1.58 J which was much lesser than that of MMCs reinforced with RHA and FA at 15 wt. % that is 1.765 J and 2.05 J.

When compared RHA and FA, FA reinforced MMC showed higher resistance to Impact strength.

2.9 Corrosion test OF Al 6061/ FA/ RHA MMC

Potentiodynamic polarization test was performed to get the desired result of the given Al 6061 alloy with FA and RHA at 15 wt. % (Figure 1). Results indicated that Al 6061 FA composite has higher resistance than that of Al 6061 RHA and base Al 6061 alloy. This MMC was made using stir casting method. The table below shows Evaluation and Comparison of Corrosion Behavior of Al-6061 Alloy Based Metal Matrix Composites Reinforced with Fly Ash and Rice Husk Ash is shown below:

Fig 1: Potentiodynamic polarization tester

3 Results and discussion

3.1 Metallurgical characterization

Stir casting of Al 6061 alloy reinforced with 15% weight percentage rice husk ash and fly ash metal matrix composites was effective. The following findings are drawn from the analysis of composites utilizing XRD patterns, SEM micrographs, and EDS images:

1. The diffraction peaks of SiO_2, which is the primary ingredient of FA and RHA particles, are clearly visible in the XRD patterns of the generated composites (Figure 1-3). The strength of SiO_2 peaks increases as the AMC's FA and RHA concentration rises. Other than Al and SiO_2, no other elements had noticeable peaks. This suggests that the integrity of the FA and RHA particles is conserved throughout composite production. Under the stir casting conditions used in this study, FA and RHA particles are thermodynamically stable. FA and RHA particles do not degrade or interact with aluminum in any way to generate intermetallic complexes.

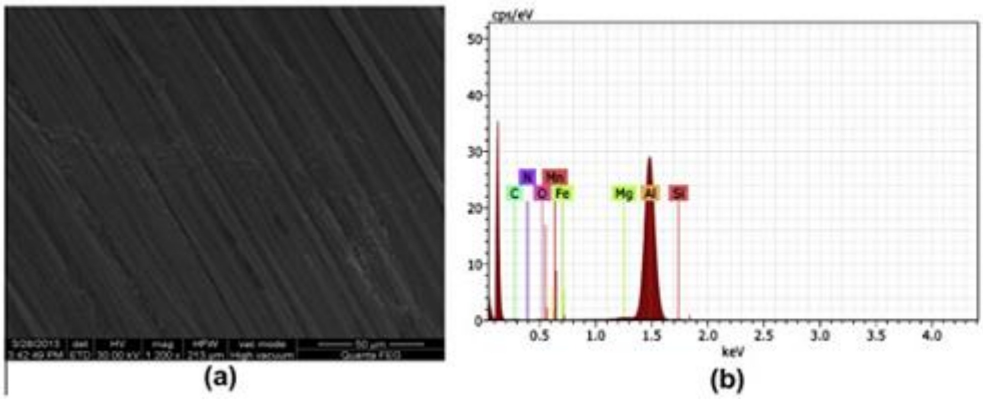

Fig 2: EDS of Al 6061

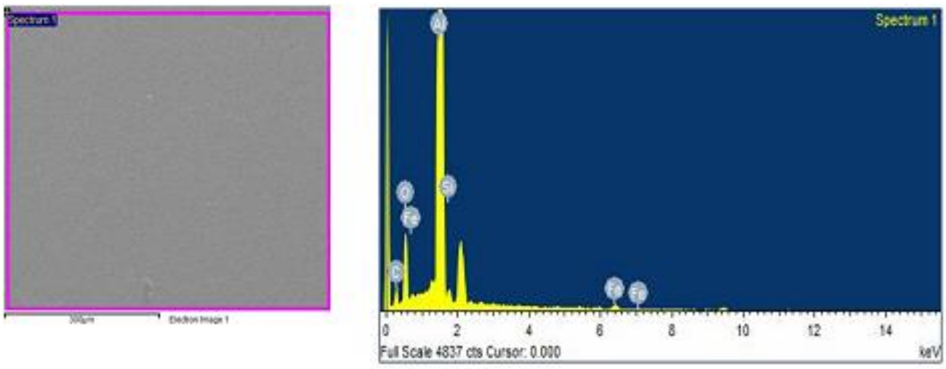

Fig 3: EDS of Al6061 RHA

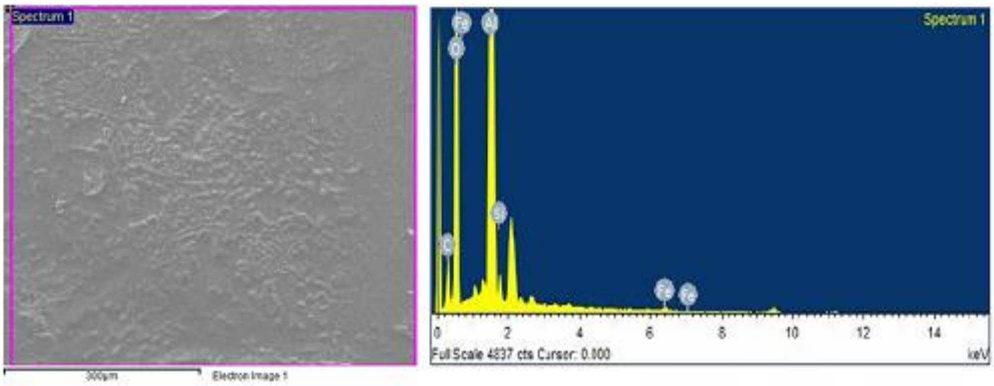

Fig 4: EDS of FA

2. SEM micrographs were used to examine the microstructure. The microstructure of composites determines its properties. Dendrite arms and intermetallic phase may be seen in SEM micrographs of cast Al 6061 alloy. Rapid solidification created a characteristic dendritic pattern in the microstructure. Mg and Si, which are alloying elements in Al 6061, are present at a quantity that exceeds their solubility limit. As a result, during casting, the intermetallic phase Mg_2Si forms around the dendrites, reducing the characteristics of aluminum alloy.

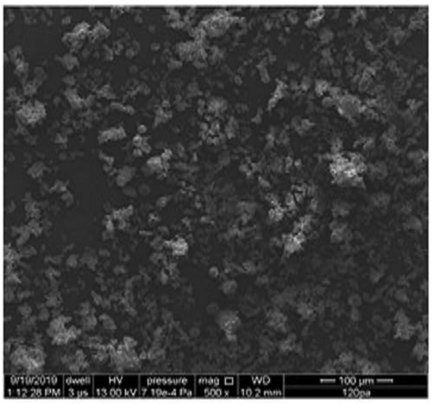

Fig 5: Photomicrograph of Fly ash

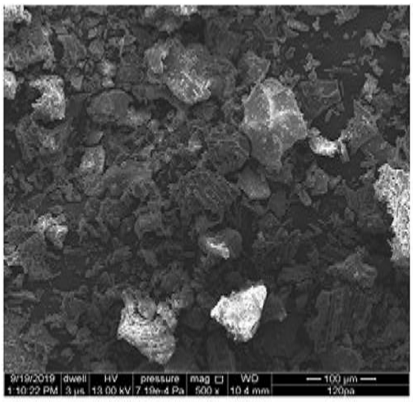

Fig 6: Photomicrograph of RHA

3. In the SEM micrographs of the AMCs (Figure 5-6), the dendritic form is absent. The dendritic structure of the aluminum matrix is altered by the addition of FA and RHA particles. The FA & RHA particles operate as efficient grain refiners, as shown in the micrographs. The average grain size shrinks as the FA and RHA concentration rises. FA &RHA particles act as grain nucleation sites and the aluminum grains solidify on it. Therefore, uniform and intragranular distribution of fly ash and rice husk ash particles are achieved. The constitution under cooling zone in front of the FA & RHA particles may cause it to act as a grain nucleation site. The higher the content of FA &RHA particle, the more the grain nucleation sites are created. This offers more resistance to the freely growing α (Al) grains. Therefore, it eliminates the dendritic structure.

4. EDS scans show that grain boundaries in the composites are clearly formed. The average grain size decreased as the number of FA and RHA particles increased. FA & RHA particle locations serve as nucleating sites for grains, and aluminum grains tend to develop on them. With more nucleation sites, the resistance to aluminum grain development rises. The end

outcome is grain refinement in composites. The grain size reduces as the number of FA and RHA particles increases.

3.2 Mechanical characterization

Mechanical characterization is used to determine the link between a material's microstructure and its mechanical characteristics. The mechanical characteristics of fly ash and rice husk ash reinforced composites were evaluated using the Archimedes principle of density measurement, Brinell cum Rockwell hardness test, tensile test, compressive test, and impact test. On the basis of mechanical characterization investigations, the following observations were represented in the figures below.

1. The density of both the alloy and the composite was estimated using the Archimedes principle. With increasing weight % additions of fly ash and rice husk ash, the density of rice husk ash reinforced aluminum composites decreases. Fly ash and rice husk ash have a lower density than aluminum alloy. The density of the composites is reduced by including low-density fly ash and rice husk ash into the mix. Fly ash and rice husk ash particle reinforced Al 6061 alloy composites have a lower density than unreinforced alloy composites (Figure 7).

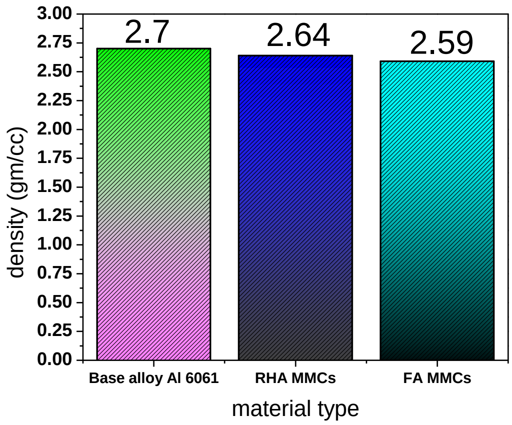

Fig 7: Density comparison

2. The hardness of the composites increased when the proportion of fly ash and rice husk ash in the matrix alloy was increased. The good interface between FA & RHA particles and matrix aluminum alloy act as hard obstacles to the motion of the dislocation. This in turn increases the hardness of the composite. During indentation (deformation) the grain boundaries act as barriers to dislocation motion and thus hardness increases. The 15% weight fraction addition of fly ash and rice husk ash to Al 6061 alloy exhibits higher hardness compared to unreinforced Al 6061 alloy (Figure 8).

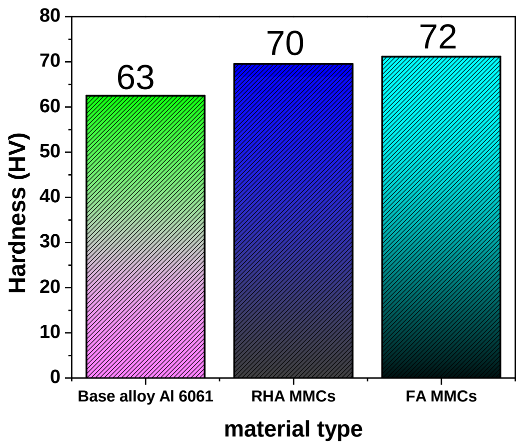

Fig 8: Hardness comparison

3. The reinforcement of FA & RHA particle significantly increases the ultimate tensile strength of the composite. The value of coefficient of thermal expansion of aluminum alloy, FA and RHA particles is different. The variation in coefficient of thermal expansion sets up strain fields around RHA particles during solidification. These strain fields hinder the motion of dislocations during tensile loading. Higher applied load is required to pass the dislocations around the strain fields. The good bonding and clear interface delay the detachment of FA &RHA particles from the aluminum matrix during tensile loading. Therefore, ultimate tensile strength is increasing with increase in weight percentage of fly ash &rice husk ash particles. The 15-weight percentage of FA & RHA (weight fraction) reinforced Al 6061 AMC exhibits higher UTS compared to unreinforced Al 6061 alloy (Figure 9).

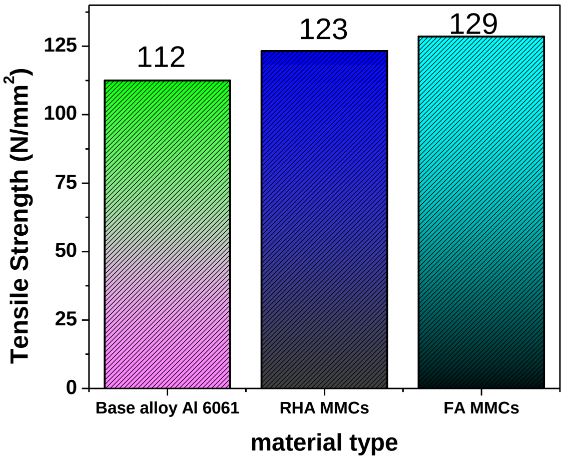

Fig 9: Tensile strength comparison

4. Additional studies showed that FA & RHA reinforced Al 6061 AMC can bear greater compressive loads than basic Al 6061 alloy, and that this material was made using the stir casting process. When FA & RHA were added to Al 6061 alloy, the compressive strength increased as the weight % of FA & RHA increased. FA & RHA with 15% FA & RHA yielded better results than Al 6061 alloy (Figure 10).

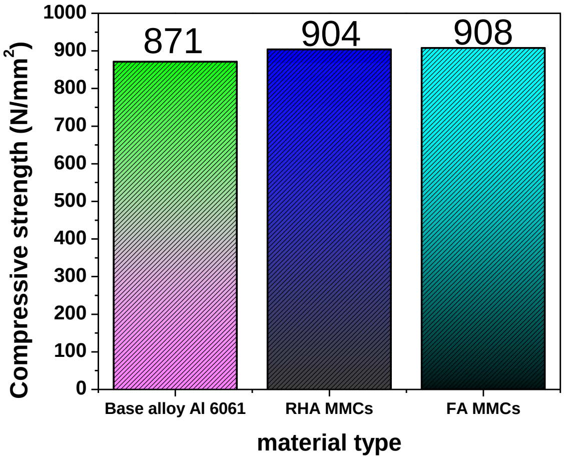

Fig 10: Compressive strength comparison

5. The impact tests on the FA & RHA reinforced Al 6061 alloy revealed excellent impact resistance. It was clear that as the weight percent of FA and RHA was raised, the specimen's impact strength rose as well. The impact strength of the given specimen found to be 11% & 29% greater in FA and RHA MMCs compared with the basic Al 6061 alloy (Figure 11).

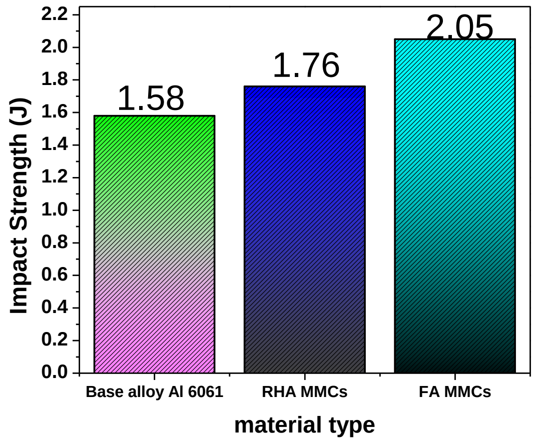

Fig 11: Impact test comparison

3.3 Corrosion characterization

Electrochemical procedures are a rapid and very affordable way to determine a material's electrochemical characteristics. These methods are primarily dependent on the capacity to identify metal corrosion by examining the charge-transfer process' reaction to a controlled electrochemical perturbation. The polarization scan obtained by a potentiostat can be used to predict the corrosion properties of a test specimen.

Immersion testing was used to investigate the corrosion behavior of Aluminum 6061 alloy. The samples were suspended in a NaCl aqueous solution for various periods of time. After the time was up, the samples were mechanically cleaned with a brush to remove the severe corrosion deposits on the surface, and then rinsed with distilled water and acetone. Then it was air dried. Changes in weights and corrosion rates were recorded as a result. The corrosion rate of FA & RHA reinforced AMC lowers when the weight percent of FA & RHA in Al 6061 rises, according to the findings. The corrosion resistance of 15 wt. % FA & RHA is higher than that of the standard Al 6061 alloy, but FA MMC is more resistive to corrosion as compared to RHA MMC.

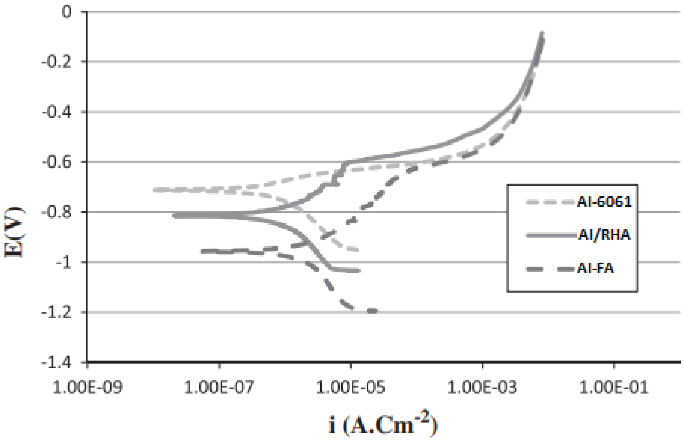

Fig 12: Polarization diagram for Al-6061 alloy, Al/RHA MMCs and Al/FA MMCs

According to Figure 12 and Table 5, corrosion potential of the MMCs increases by the addition of FA and RHA as compared base alloy.

Table 5: Effect of addition of reinforcement on corrosion and current density of Al-6061 alloy

Material Type	E (mV)	$I_{corrosion}$ (μA cm^{-2})
Al 6061 alloy	-725	0.5
Al/RHA MMCs	-800	0.9
Al/FA MMCs	-950	1.6

4. Conclusion:

1. Al6061/FA/RHA AMCs were successfully produced using the stir casting method. The FA and RHA particles were homogeneously distributed in the aluminum matrix. The distribution was predominantly intragranular.
2. The FA and RHA particles refined the grains of the aluminum matrix.
3. The FA and RHA particles were thermodynamically stable at the stir casting temperature. There was no interfacial reaction between the FA and RHA particle and the aluminum matrix. The interface between the aluminum matrix, FA and the RHA particle was clear and were bonded well with the aluminum matrix.
4. The reinforcement of FA and RHA particles enhanced the mechanical properties of the AMCs. Al 6061/15% FA/15% RHA AMC exhibited 71.12 HV& 69.52 HV higher hardness and 128.57 N/mm^2&123.3 N/mm^2 higher UTS strength as compared to the unreinforced A6061 alloy.
5. FA and RHA MMC showed 907.05 N/mm^2& 904.44 N/mm^2 higher compressive strength as compared to the unreinforced A6061 alloy.
6. Addition of FA and RHA resulted in higher impact strength as compared to base Al 6061. But by comparing FA and RHA MMCs, FA MMC showed more resistance to impact strength test.
7. Tensile and compressive strength is increased due to decrease in grain size and increase in grain boundary area due to reinforced fly ash and rice husk ash particles in the aluminum alloy.
8. The fracture mode of the produced AMCs was observed to be ductile fracture. The fracture is macroscopically brittle and microscopically ductile.
9. FA reinforced alloy consist higher resistance to corrosion which is relatively higher than that of RHA. This result was verified using potentiodynamic polarization.

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