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EFFECT OF PARTICLE SIZE AND WEIGHT FRACTION OF SIC ON CORROSION BEHAVIOUR OF AL/SIC/MOS_2 METAL MATRIX COMPOSITES USING ELECTROCHEMICAL STUDIES

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Abstract-The work aims to study the effect of Silicon carbide (SiC) particles on corrosion resistance of Al5059/SiC/MoS_2 hybrid metal matrix composites (MMC). Aluminium metal matrix composites are (AMCs) reinforced with different particle sizes of SiC (10,20, 40µm) and weight fraction of SiC (5% ,10% 15%) at constant 2%.volume of MOS_2. The composite were fabricated through stir casting method. To relate the corrosion resistance of aluminium MMCs is investigated by polarization study and AC impedance spectra. The above materials are immersed in an aquaise 3.5% sodium chloride (NaCl) solution. The effect of corrosion parameters such as corrosion current (I_{corr}), corrosion potential (E_{corr}), Linear polarization resistance (LPR), charge transfer resistance (R_t), will be evaluated from these control parameters to analyze the optimum corrosion resistance composites. The electrochemical studies reveal that weight fraction of SiC at 15% with particle size of 10µm shows the higher corrosion resistant composites.

Keywords: Aluminium Metal Matrix Composites; Silicon Carbide; Potentiodynamic ,Polarization; AC impedance spectra

I. Introduction

In recent development in industrial sector, results in need of advancements in material which poses low density with high strength to weight ratio, this leads to the increase in weight reduction in transport industries which support green environment[1]. This made the researches to focus on the Aluminium (Al) based alloys which support weight reduction by replacing components made up of steel. But still Al based materials have some certain drawback like inferior wear resistance and poor corrosion behaviour[2]. Basic and functional properties of the material can be enhance by using different available technique like laser cladding, surface treatment, surface coating and composite fabrication. amid these methods composite fabrication is moistly prefer in which desired properties of the material can be obtained with affecting the bulk properties of base materials by adding hard reinforcements particles like SiC, TiC, B_4C etc[3].

In current scenario hybrid reinforcement are come into existence in which two are more reinforcement are added in order to improve the bulk properties of the composites[4]. Selection of reinforcement particle play a key role in the enhancing the properties of metal matrix composite (MMC) the hard ceramic particles are added to increase the hardness of the material and Also corrosion resistance of composites containing hard reinforcement increases with increasing particle additions; likewise solid lubricant like graphite,MoS_2, BN are used to improve the tribological behaviour of the material these lubricating material have tendency to form a tribo layer which reduce contact between the material surface[5]. Al MMC are fabricated through liquid state processing like stir casting, squeeze casting, reheocasting, compo casting and also with solid based material processing like powder metallurgy, ECAP, hot pressing. Among these methods Stir casting method is mostly adopted due to it cheaper cost with high production rate[6].Numerous variations of ceramic particles are used as reinforcements to improve the corrosion behaviour of the Al MMC[7].Investigation over the corrosion behaviour by addition of Si_3N_4, AlN and ZrB_2 particles as a reinforcement improvise both mechanical and corrosion resistance of the MMC[8].The corrosion behaviour of AMMC by addition of SiC particle at 25 µm size in acidic environment at various temperature differences. They notified that addition of SiC perk up corrosion resistance of the matrix even at increasing the concentration level of acidic medium[9]. Fabricated AMMC using powder by varying wt. % of graphite as reinforcement, the corrosion studies are conducted in 3.5 wt. % of NaCl solution in which they observed that occurrence of galvanic corrosion with respect to increase in wt. % graphite thus initiate high corrosion rate[10]. The effect of SiC addition in Al matrix material the corrosion behaviour investigation affirm that SiC increase the hardness of the developed AMMC which initiate the reduction of corrosion behaviour of AMMC with 3% NaCl solution in which improved corrosion resistance is achieved[11].Developed AMMC through stir casting and studies it corrosion behaviour at 3.5 wt.% NaCl solution in which SiC and Zr is used as reinforcement. They found that absence of galvanic coupling in between the matrix and reinforcement particles during the corrosion test[12].Through vacuum hot pressing the corrosion behaviour is investigated through weight loss method and revels that addition SiC inhibits the corrosion rate[13].

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Studies about the corrosion behaviour Al MMC in which increase in the corrosion resistance is noted in addition of TiC with and various percentage of SiC (20%, 40%)[14].The corrosion rate of both composites of $AlSiC_p$ is increased with the increase in the concentration of NaCl [15].

The particle size and weight percentage of reinforcement plays a key role to improve the corrosion rate. But through literature assessment researches mainly focuses on addition of weight percentage of ceramic reinforcement by limiting its particle sizes. Hence in this research the corrosion characteristics Al MMC by varying weight percentage SiC (5%, 10%,15%) with different particle sizes (10, 20, 40 µm) are used as reinforcement with constant MoS_2 (2 wt. %) for improving the mechanical and corrosion behaviour of the developed MMCs.

II. Experimental Details

A. Specimen preparation

Al 5059 armor aluminium is used as base material and its chemical composition is shown in Table 1.

Table1 Chemical composition of Al 5059 (wt.%).

Al	Mg	Mn	Zn	Fe	Si	Zr	Cr	Cu	Ti
91.5	5.32	0.8	0.68	0.45	0.42	0.19	0.21	0.23	0.2

Silicon carbide ceramic particles and Molybdenum disulphide solid lubricant were selected as the reinforcements. The reinforcements were preheated in a crucible by heating it in a muffle furnace at 400°C. The aluminium alloy is heated in a stir casting furnace up to temperature of 700°C to melt the base alloy completely and was then cooled down to(620°C) keep the slurry in semi-solid state. At this stage, the preheated SiC particles and Molybdenum disulphide particles were added to the vortex in different combination. SiC particles of three different sizes (10, 20, 40µm) were reinforced at three different mass % (5, 10 & 15) and mass fraction of MoS_2 is kept constant as 2%. The compositions of developed aluminium composites and hardness value are shown in Table 2.

Table 2 Composition of Aluminium MMC with hardness

Sample.No	1	2	3	4	5	6	7	8	9	Pure Al Alloy
SiC (%)	5	10	15	5	10	15	5	10	15	
SiC (µm)	10	10	10	20	20	20	40	40	40	
Hardness	83	84.52	86.66	78.33	82.33	83.6	75.16	76	78.3	75.1

Each specimen is cut down into strips at30x3x1 mm, and Semi Micro Glass tubes are used to produce Electrode. The specimens are inserted in the glass tube and that is set with the araldite. Then the setup has to be held with the time of 3 Hrs. 3.5 NaCl (Sodium chloride) is used as the corrosion medium.

B. Study of potentiodynamic polarization and AC impedance spectra measurement

The poteniostat/galvonostat experiment was carried out with strips made up of material aluminium 5059 composites with various amount of reinforcement. The apparatus has three electrodes[16]. The working electrode, second Platinum as counter electrode and third saturated calomel electrode (SCE) as reference electrode made of aluminium MMCs with various ratio of reinforcement is added to the base. When aluminium composite were immersed in 3.5% of NaCl solution it was allowed to even out for about 30min in this medium. In addition to 3.5% of NaCl solution, the corrosion inhibitor is added to reduce the corrosion rate of the alloy or reinforcement[17]. It is also applied with the current of 1.5 mA cm^2. The cathode and anode polarization composite of AMMCs in the NaCl solution is tested in presence and absence of inhibitors which is recorded at a scan rate of 1mV s^{-1}. The electrochemical parameters such as linear polarization resistance (LPR), corrosion potential (Ecorr), corrosion current (Icorr), and Tafel slopes (ba and bc) are measured by using potentiodynamic polarization study. The same one is used here to record the AC impedance spectra. The same type of electrode assembly is used. The input parameters such as real part (Z’) and imaginary (Z”) of the cell impedance were recorded in ohms for various frequency. The charge transfer resistance (R_t) is calculated.

III. Results And Discussion

A. Analysis of polarization curves

Polarization study is adopted to confirm the formation of a thin passive layer over the developed composite surface. The potentiodynamic curve is obtained for fabricated composite materials which are reinforced with various percentages of hard ceramics reinforcements. The developed samples are immersed in 3.5% NaCl aqueous electrolyte which are considered to saline condition. Tafel plot is obtained for developed MMC is demonstrated in fig.2. Different corrosion parameters like corrosion potential (E_{corr}) ,corrosion current(i_{corr}) ,Tafel constant(β_A and β_C), linear polarization resistance are curve fitted and it can be notified in the Table 3. Polarization resistance used to measure amount of metal dissolve during corrosion. Anodic and cathodic Tafel is related to amount of metal dissolution and hydrogen evaluation if anodic tafel constant value is high it denotes iron formation which is termed as anodic reaction likewise if the cathodic Tafel constant value is high it clear cut the hydrogen evaluation during corrosion reaction it is termed as cathodic reaction.

Aluminium based material exposed to atmosphere it retorts with the oxygen molecules present in air and form thin film over the material surface which is also known as alumina. The formation of Alumina layer formation can be exemplified by means of chemical reaction as showcased below

When pure Al5059 is immersed in 3.5% NaCl, the corrosion potential (Ecorr) is -798.56 mvVs SCE (Saturated Calomel Electrode). LPR (Linear Polarization Resistance) is 259.830 ohm, Anodic Tafel constant (β_A) value is 14.7390 mV/dec and cathodic Tafel constant (β_C) value is 14.2060 mV/dec. The corrosion current value is 12.0910 x 10^{-6} A/cm^2. At 5%, 10µm of SiC the corrosion potential is shifted from -798.56 mV to -843.79 mV which denote that cathodic reaction were occurred. The LPR value increases from 249.830 ohm to 2.8831 k ohm. This suggests that the corrosion resistant of pure alloy decreases. Anodic Tafel constant (β_A) value decrease from 14.7390 mV/dec to 9.97050 mV/dec which implies formation of passivation layer is decreased and Cathodic Tafel constant(β_C) value increases from 14.2060 mV/dec to 20.299 mV/dec which implies hydroxide formation.The corrosion current decreases from 12.0910 x 10^{-6} A/cm^2 to 1.00720 x 10^{-6} A/cm^2. It is concluded that first sample increases the corrosion resistance when compared to pure alloy.

At 10%,10µm the corrosion potential is shifted from -798.56 mV to -771.92 mV which implies the occurrence of anodic reaction. The LPR value increases from 259.830 ohm to 523.7 ohm, This suggests that the corrosion resistance increases at second sample. Anodic Tafel constant (β_A) value decreases from 14.7390 mV/dec to 12.2840 mV/dec which implies formation of passivation layer is decreased and Cathodic Tafel constant (β_C) value increases from 14.2060 mV/dec to 21.8800 mV/dec which implies hydroxyl formation was occurred. Then the corrosion current decreases from 12.0910 x 10^{-6} A/cm^2 to 6.52400 x 10^{-6} A/cm^2.

At 15%, 10µm the corrosion potential is shifted from-798.56 mV to -726.720 mV which results the formation of alumina oxide formation. The LPR value increases from 259.830 ohm to 282.790ohm, this suggests that the corrosion resistance of third sample due to increase in hardness of the composites. Anodic Tafel constant (β_A) value increases from 14.7390 mV/dec to 35.6840 mV/dec which denote that formation of passivation layer is increased and Cathodic Tafel constant(β_C) value increases from 14.2060 mV/dec to 25.885 mV/dec which implies hydroxyl formation was occurred. Then the corrosion current increases from 12.0910 A/cm^2 to 23.0400x10^{-6} A/cm^2. The reason behind the decrement in corrosion rate is due to the particle size of SiC. This micro sized particle uniformly distrusted over the matrix material and act as hinder material to avoid the ion dissolution during the corrosion process[20]. At 5%, 20µm the corrosion potential is moved from -798.56 mV to -807.910 mV which confirm the hydrogen evolution in cathodic reaction. The LPR value decreases from 259.830 ohm to 120.280 ohm. Anodic Tafel constant(β_A) value increases from 14.7390 mV/dec to 46.4960 mV/dec from this we can confirm that passive layer remains for long time which avoid the metal dissolution by the corrosive environment and cathodic Tafel constant(β_C) value increases from 14.2060 mV/dec to 49.6330 mV/dec which implies OH groups. Then the corrosion current increases from 12.091x10^{-6} A/cm^2 to 86.6830 A/cm^2. It is concluded that the composite four decreases the corrosion resistance.

At 10%, 20µm the corrosion potential is shifted from -798.56 mV to -787.66 mV. This denotes anodic reaction. The LPR value decreases from 259.830 ohm to 220.130 ohm, this suggests that the corrosion resistance of S0increases when compared to thatS5.Anodic Tafel constant (β_A) value decrease from 14.7390 mV/dec to 7.2746 mV/dec which denote that formation of passivation layer is decreased and cathodic Tafel constant (β_C) value decreases from 14.2060 mV/dec to 11.8510 mV/dec which implies hydroxyl formation was decreased. Then the corrosion current decreases from 12.0910 A/cm^2 to 8.89300 A/cm^2. When sample 6 is immersed in 3.5% NaCl solution the corrosion potential is shifted from -798.56 mV to -750.360 mV. The LPR value increases from 259.830 ohm to 966.680 k ohm, this suggests that the corrosion resistance of sixth composites increases. Anodic Tafel constant(β_A) value decreases from 14.7390 mV/dec to 6.4767 mV/dec which denote that formation of passivation layer is decreased and cathodic Tafel constant(β_C) value decreases from 14.2060 mV/dec to 6.0881 mV/dec which implies formation aluminium hydroxide is decreased. During corrosion process the chloride ions reacts over surface of the developed MMC thus results in nucleation and growth of the pits[21].Then the corrosion current decreases from 12.0910x10^{-6}A/cm^2 to 1.40990 nA/cm^2.

At 5%, 40µm the corrosion potential is shifted from -798.56 mV to -784.830 mV. This denotes anodic reaction. The LPR value increases from 259.830 ohm to 198.05 kohm. Anodic Tafel constant(β_A) value increases from 14.7390 mV/dec to 425.89 mV/dec which denote that formation of passivation layer is increased and cathodic Tafel constant(β_C) value increases from 14.2060 mV/dec to 88.4250 mV/dec which implies cathodic reaction which initiates hydrogen formation[22]. Then the corrosion current decreases from 12.0910x10^{-6}A/cm^2 to 160.560 nA/cm^2.

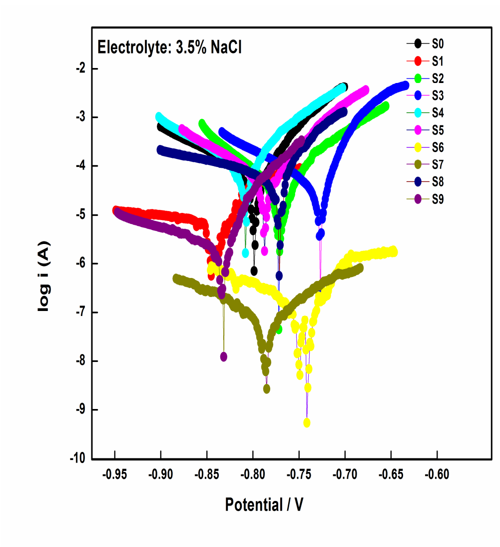

Fig. 2 Potentio dynamic polarization curves for Al5059 alloy with various amount of Wt%.

At 10%, 40µm the corrosion potential is shifted from -798.56 mV to -771.280 mV. Which denote that anodic reaction occurrence which forms a strong passive alumina layer over the substrate materials. The LPR value increases from 259.830 ohm to 279.430 ohm. Anodic Tafel constant(β_A) value decreases from 14.7390 mV/dec to 5.0304 mV/dec which denote that formation of passivation layer is decreased and cathodic Tafel constant(β_C) value decreases from 14.2060 mV/dec to 6.3912 mV/dec which implies hydroxyl formation was decreased. Then the corrosion current decreases from 12.0910×10^{-6}nA/cm^2 to4.3749×10^{-6}A/cm^2. It is concluded that decreases the corrosion resistance of the composites. Finally at 15%, 40µm the corrosion potential is shifted from -798.56 mV to -831.650 mV. This denotes cathodic reaction. The LPR value increases from 259.830 ohm to 4.7351 k ohm , this suggested that the corrosion resistance of pure alloy decreases when compared to sample 9. Anodic Tafel constant (β_A) value increased from 14.7390 mV/dec to 24.880 mV/dec which denote that formation of passivation layer is increased and cathodic Tafel constant(β_C) value decreases from 14.2060 mV/dec to 11.3120 mV/dec which implies hydroxyl formation decreased. Then the corrosion current decreases from 12.0910×10^{-6}A/cm^2 to713.230 nA/cm^2. It is concluded through electrochemical studies, the corrosion resistance of the composites increases at maximum hardness.

Table 3 Corrosion potentials obtained from polarization curves for Al5059 composite with various amount of wt%

Composite	Corrosion potential (Ecorr) mv	Anodic Tafel (b_a) mV/dec	Cathodic Tafel (b_c) mV/dec
0	-798.56	14.739	14.206
1	-843.79	9.9705	20.299
2	-771.92	12.284	21.88
3	-726.720	35.684	25.885
4	-807.910	46.496	49.633
5	-787.660	7.2746	11.8510
6	-750.360	6.4767	6.0081
7	-784.830	425.89	88.4250
8	-831.650	24.880	11.3120
9	-771.280	5.0304	6.3912

IV. Conclusion

1. The hardness is increased in addition of 15% weight fraction of SiC at 10 µm of particle size.
2. The potentiodynamic study through Tafel plot shows that the corrosion resistance is increased at anodic Tafel constant by adding 15% weight fraction of SiC at 10 µm of particle size.
3. AC impedance spectra reveal that a protective film formed on the metal surface of Al5059 composite material and charge transfer resistance is increased with harder composites.

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