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Mechanical and Corrosion Behavior of Al7075 (Hybrid) Metal Matrix Composites by Two Step Stir Casting Process

Abstract

This paper investigates the mechanical properties and corrosion behavior of Metal Matrix Composites prepared using Al7075 alloy as a matrix, Silicon Carbide and Titanium Carbide as reinforcement particles. Two step stir casting process was used to fabricate the composites by varying volume fractions of Silicon Carbide and Titanium Carbide (0 to 15 vol. %). Microstructural analysis, mechanical and corrosion behavior were used to evaluate the performance of the composites. Uniform distribution of reinforcement particle was observed through optical photomicrographs. Vickers micro hardness tests were performed and the hardness values were increased with an increase in reinforcement from 0 to 15 vol. %. The tensile strength of the 10 vol. % of aluminum hybrid matrix composite was better than that of the base alloy. In 3.5% NaCl solution, it was observed that the 15 vol. % of the aluminum hybrid matrix composite have higher corrosion resistance in comparison the base alloy.

Keywords

Al7075; Two step stir casting; Mechanical properties; Corrosion

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1 INTRODUCTION

During the last few decades aluminium matrix composite materials are replacing the conventional engineering materials. There is a continuous interest among researchers to develop aluminium matrix composites with high strength to light weight, stiffness, good wear and corrosion resistance material for the structural applications, especially for aerospace and automobile engineering (Takahashi et al., 2002; Jiejun et al., 2003; Previtali et al., 2008; Sreenivasan et al., 2011). Al7075 alloys are used for such application and it has some significant disadvantages like strength and stiffness. The required properties are increased by adding hard ceramic particles into the aluminium alloy (Vintila et al., 2011; Wu et al., 2014). Among the numerous ceramic particles, Silicon carbide (SiC) is chemically suitable with aluminium. Because it produces a bond between the matrix and reinforcement without inter-metallic phases. It has some other advantages such as excellent thermal conductivity, good workability, high machinability and low cost (Nair et al., 1985; Umanath et al., 2013). Titanium carbide (TiC) particle possess a sufficient lattice matching for the direct nucleation of the aluminium and it has low friction coefficient, high electrical conductivity and good wettability(McCartney, 1989). Because of high wettability of TiC, it can easily match with aluminium alloy matrix. A large number of manufacturing methods are used to place reinforcement into matrix alloy. Stir casting technique is one of the promising routes for producing large size components and high volume production(Poddar et al., 2007). In the present study, two step stir casting method was used to develop hybrid composite with uniform particle distribution.

Baradeswaran and Elaya Perumal (2013) developed the Al7075 composites reinforced with B_4C by stir casting route and found that the wear increased by increasing the volume fraction of reinforcement. Zhang et al. (2008) studied the tensile deformation and fracture behavior of Al7075/SiCp composites prepared by spray deposition method. Doel and Bowen (1996) fabricated Al7075/SiC (5, 13 and 60 μm) composites and concluded that tensile strength was improved for 5 and 13 μm SiC particles than that of base alloy. Kalkanli and Yilmaz (2008) prepared Al7075/SiC composites by squeeze casting method and concluded 10 wt.% SiC reinforced composites showed the best hardness, tensile strength and flexural strength in both as cast and heat treated conditions. Flores-Campos et al. (2010) fabricated the Al7075 composites with carbon-coated silver nanoparticles and concluded that Vickers micro hardness (HVN) values were higher at higher Ag-CNP contents. Baradeswaran and Elaya Perumal (2014) developed the Al7075 hybrid metal matrix composite through stir casting method. The results exhibited improvement in hardness, ultimate tensile strength, flextural strength, wear resistance while increasing the weight fraction of Al_2O_3 reinforcement. Kumar and Dhiman (2013) studied the specific wear rate of the unreinforced Al 7075 and hybrid aluminum metal matrix composite reinforced with the 7 wt. % of silicon carbide (SiC) and 3 wt. % of graphite and concluded that the specific wear rate showed an increasing trend with a change of load. Sherafat et al. (2010) presented the mechanical and physical properties of the Al/Al7075 two-phase material and concluded that the tensile and compression strength increased and ductility decreased when decreasing base powder. Su et al. (2004) developed the Al7075 composite reinforced with SiC and studied the relationship between true stress and true strain. Yang et al. (2011) prepared Al7075 composite reinforced with TiC and studied the wear rates under different load conditions. Karunanithi et al. (2014) studied the electrochemical behavior of Al7075/TiO_2 composites in 3.5 wt. % NaCl solution showed the better corrosion potential with the addition of TiO_2. Nagaswarupa et al. (2012) developed the Al7075 composites reinforced with zircon inert particles and studied the stress corrosion by using sea water. They reported as an addition of zircon particles in the matrix, reduce the corrosion and pit formation.

Based on the above discussion, there is no enough data available on the mechanical properties and corrosion behavior of particulate (SiC and TiC) reinforced Al7075 composites. The main aim of the the present study is to fabricate of Al7075 hybrid (SiC and TiC) composites containing a various volume fraction of particles and to analyze their mechanical properties and corrosion behavior.

2 EXPERIMENTAL DETAILS

The base matrix and the reinforcement particles for the present studies are Al 7075 (Perfect metal works, Bangalore) and particles of SiC and TiC (Coimbatore metal mart, Coimbatore). The chemical composition of matrix and properties of matrix and reinforcing material are tabulated in Table 1 and Table 2.

Chemical Composition	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al7075	0.4	0.5	1.6	0.3	2.5	0.15	5.5	0.2	rest

Table 1: Chemical Composition of Al7075 by weight percentage.

Properties	Al 7075	SiC	TiC
Elastic Modulus (Gpa)	70-80	410	493
Density (g cc-1)	2.81	3.1	4.9
Poisson's Ratio	0.33	0.14	0.187
Hardness (HB500)	60	2800	3400
Tensile Strength (T) / Compressive Strength (C) (Mpa)	220(T)	3900(C)	118(T)

Table 2: Properties of matrix and reinforcement material.

Samples of the hybrid composites were prepared by two step stir casting route . The amounts of the matrix material and the reinforcements were determined by calculating the volume percentages. 5, 10 and 15 vol. % of reinforcements (SiC and TiC) were added to prepare hybrid composite material. The melting was carried out in a furnace and the stirring process completed with the help of fire resistant stirring motor arrangement and speed regulator. The set up used is shown in Figure 1(a). The SiC and TiC particles were preheated before adding into Aluminium melt. The aluminum material was first heated above the liquidus temperature to melt completely. It was then slightly cooled below the liquidus temperature to maintain the slurry in the semi-solid state. The preheated reinforcements were added into the molten metal and mixed manually. Then the composite slurry was reheated to a liquid state and mechanical mixing was carried out for about 10 to 15 min at an average mixing speed of 150 to 200 rpm. The final temperature was controlled to be within 750°C ± 10 °C. Finally, the melted material was transferred to a mild steel die with a dimension of 150 x 60 x 50 mm^3.

In this paper, AST0 contains pure Al7075, AST5 contains 95 % Al7075 + (2.5 % SiC + 2.5 % TiC), AST10 contains 90 % Al7075 + (5 % SiC + 5 % TiC), and AST15 contains 85 % Al7075 + (7.5 % SiC + 7.5 % TiC)

By Archimedes principle, the density was calculated. Phase analysis of the fabricated composites was analyzed by an X-ray diffraction (XRD) method using Rigaku Ultima IV. Wilson microhardness tester served the purpose of measurement of Vickers microhardness (S.R.Technologies, Chennai, Model: 402MVD). The Vickers microhardness of cast Al7075 base matrix and their composites were evaluated as per the standard of ASTM E384 - 11 using diamond indenter at an applied load of 500g with dwell period of 10s. The polished and mirror finished specimens were examined under inverted metallurgical microscope to obtain optical photomicrographs (S.R.Technologies, Chennai, Model: Inverto Plan - I). The tensile specimens were prepared as per the ASTM E8M - 13a sub size. The test was performed with samples in the Universal tensile testing machine (Instron) with a strain rate of 1 mm/min. Four tensile specimens (each in AST0, 5, 10, 15) were tested and the average value of the tensile strength was plotted. Figure 1(b-c) shows the cast composite, tensile test specimen respectively. Corrosion test specimens (3 cm * 3 cm * 3 mm) were prepared, the potentiodynamic polarization test were performed in 3.5% NaCl solution at room temperature and conducted with three-electrode cell configuration (PSG College of Technology, Coimbatore). Working electrode was the composite sample, the auxiliary electrode was graphite rod and the reference electrode was saturated calomel electrode. The measurement started from -1.5 V vs. reference and ended when the anode current density was close to 0.1 A/cm^2. The Fractography and the severity of corrosion were studied by SEM (Annamalai University, Chidambaram).

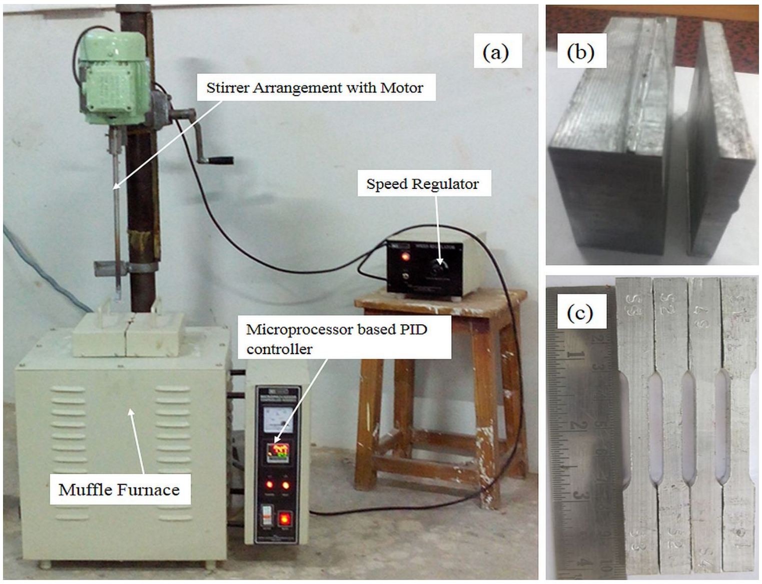

Figure 1: (a) Stir casting setup, (b) Al7075 hybrid cast composite, (c) Tensile test specimen.

3 RESULT AND DISCUSSION

3.1 Density and Porosity

The theoretical density was calculated by the rule of mixture, actual density was measured by Archimedes principle and porosity of the composites were obtained by theoretical and actual densities. Theoretical, actual densities and porosity values are tabulated in Table 3. The theoretical and actual density values are increasing while adding reinforcement into the matrix. From the table 3, it can be observed that the densities of composites are higher than that of their base matrix. Further, the density increases with the percentage of reinforcement content increased in the composites. The increase in the amount of reinforcement during stir casting, the porosity of the composites were also increased because of pore nucleation at the reinforcement particulate surfaces. This increases the generation more gas bubbles and decreases the liquid metal flow in the composites (Ponappa et al., 2013). Porosity levels within 4% have been reported to be acceptable in cast Aluminium matrix composites.

Composition	Theoretical Density (g cm-3)	Actual Density (g cm-3)	Porosity (%)
AST0	2.81	2.78	1.067
AST5	2.82	2.75	2.482
AST10	2.91	2.82	3.092
AST15	3.06	2.94	3.758

Table 3: Comparison of theoretical density, measured density and porosity of the composites.

3.2 XRD Analysis

The XRD technique is one of the important phase analysis method performed in the MMC to determine the reaction between the alloy and ceramic components. The XRD results corresponding to Al7075 matrix composite results and some intermetallic peaks like Al12Mg17, Al3Ti1 are shown in Figure 2. The XRD pattern confirmed the presence of Al7075, SiC and TiC particulate in the composite. Al, SiC and TiC peaks were indexed using JCPDS.

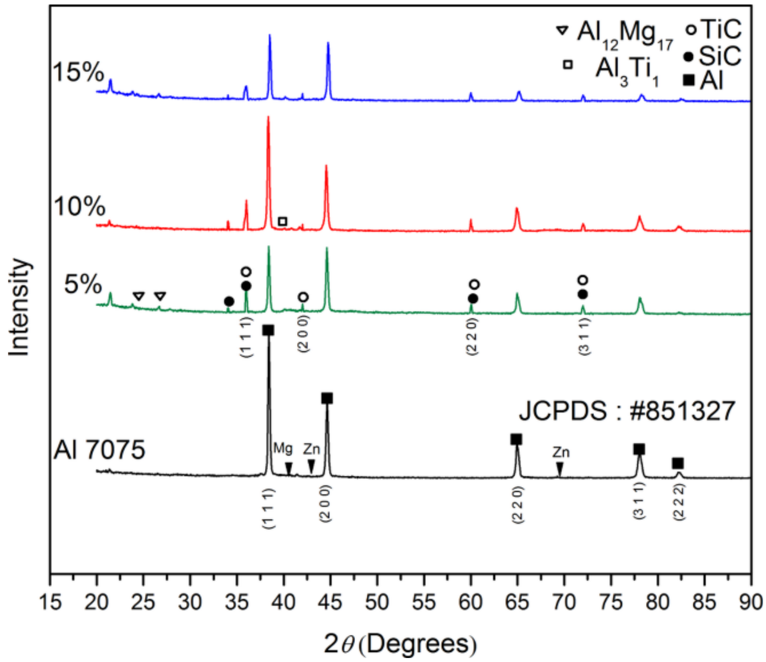

Figure 2: XRD image of SiC and TiC reinforced aluminium 7075 composite.

3.3 Microstructure and Micro Hardness

The optical microstructure of the composites can be used as an indicator of the quality of the composites and a measure of the effectiveness of the technique adopted for the production of the composites. Figure 3 (i) represent optical photomicrographs and corresponding micro hardness of the composites. From the optical photomicrographs, it can be seen that reinforcements were uniformly distributed in the matrix material and also clearly show the increased reinforcement content in the composite. The Vickers microhardness values are represented in Figure 3 (ii). The microhardness of the composites is always higher than the base alloy. The Vickers microhardness of the composite containing higher reinforcement material revealed higher hardness. The presence of hard reinforcement particles (SiC and TiC) increases load bearing capacity of the composite material and also limit the matrix deformation by confining movement of dislocation (Poddar et al., 2007).

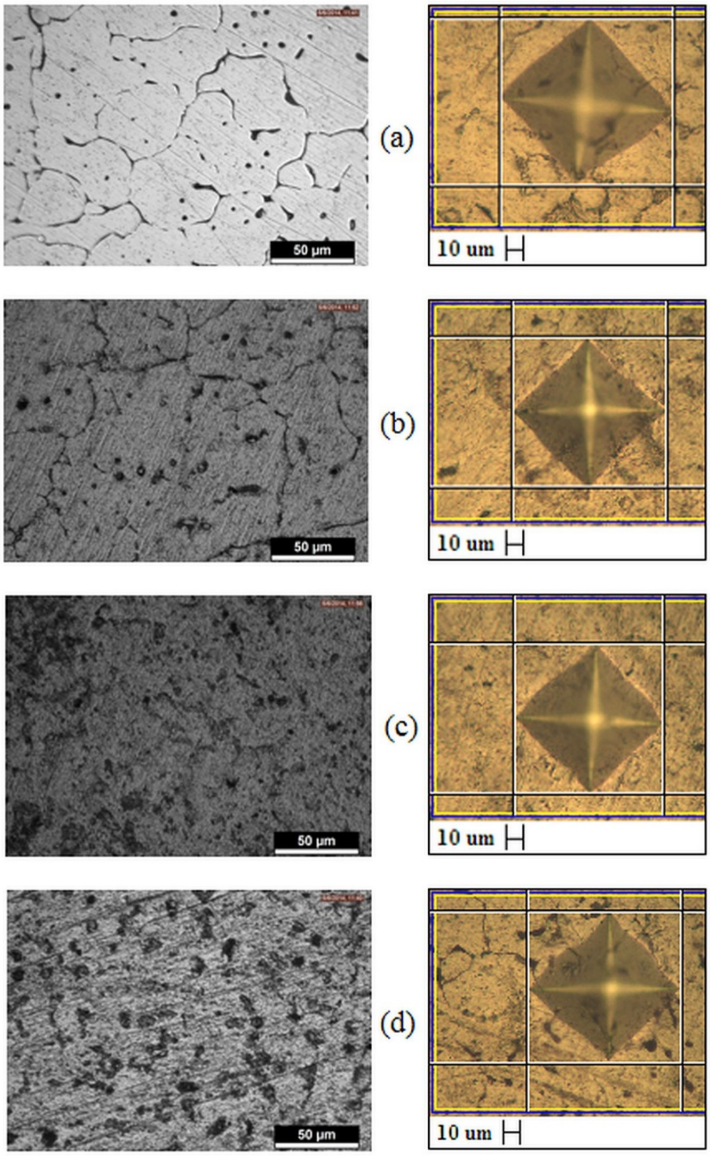

Figure 3: (i) The optical photomicrographs and Vickers microhardness of (a) AST0 (b) AST5 (c) AST10 (d) AST15.

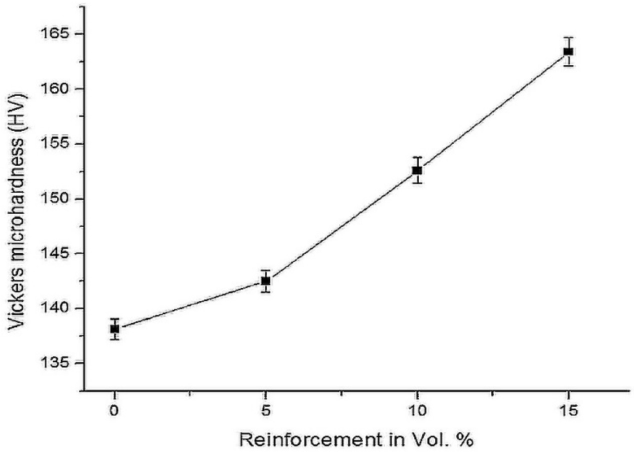

Figure 3: (ii) Vickers microhardness values of SiC and TiC reinforced aluminium 7075 composites.

3.4 Tensile Strength

The lower density of aluminium makes the material suitable for aerospace and automobile applications. Lower strength and stiffness of aluminium alloy limits their applications. Figure 4(a) shows the tensile strength values of the Al7075 hybrid metal matrix composites reinforced with SiC and TiC. Al7075 hybrid composites show improved tensile strength as compared to base alloy. The strengthening effect of the composites is based on the presence of hard reinforcement particles. In aluminium alloy composite, the ceramic particles (SiC and TiC) are distributed homogeneously, resulting in the act as a block off for dislocation motion of matrix alloy, thereby reducing the fracture. The addition of ceramic particles mainly improves the affecting fracture and tensile strength of composite by stress transfer from the aluminium matrix (ductile) to the reinforced (brittle) particles. This is because of orowan mechanism by which a dislocation bypasses heavy obstacles where a dislocation restricted around a particle (Murali et al., 2014). This leads to improve the tensile strength. Sample 3 showed the maximum strength of 240 MPa increased by about 60 MPa (33%) compared to the base alloy. The reason for the decrease in the strength in sample 4 is that the sharp edges of the hard ceramic particles act as a nucleation site. The concentration of stress in the nucleation site will lead to fracture (Bhushan and Kumar, 2011).

The relationship between stress and strain for an Al7075 hybrid metal matrix composites is shown in the figure 4(b). The increase in the volume fraction of reinforcement from 5% to 10% increased the tensile strength and yield strength respectively. The fracture strain decreased while increasing the volume percentage of reinforcement particles. As shown in figure 4(b), the ductility of the composite materials was also decreased gradually because the reinforcement particle resist the plastic flow of matrix material.

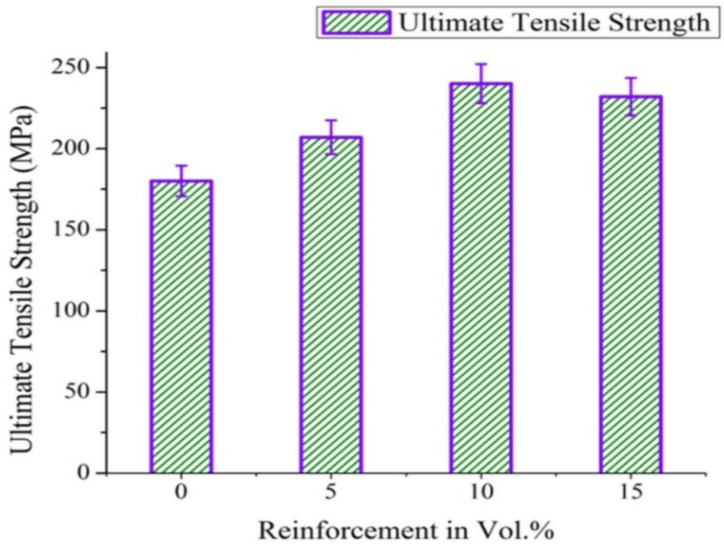

Figure 4 (a): Tensile strength of SiC and TiC reinforced aluminium 7075 composites.

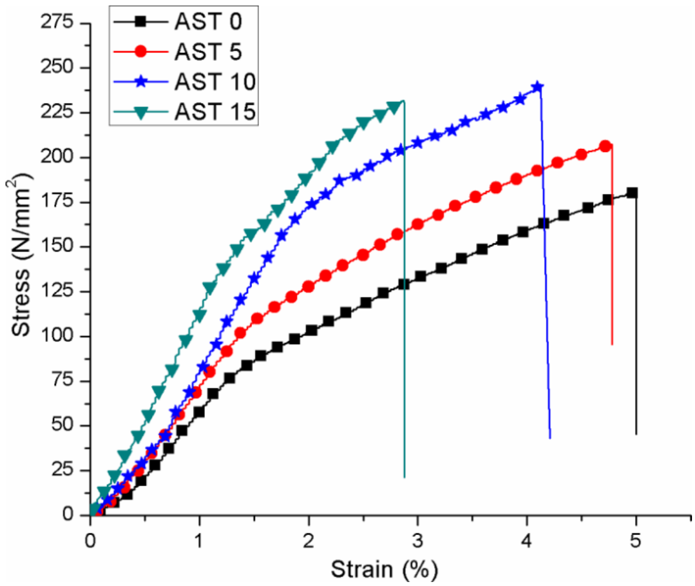

Figure 4 (b): Stress-Strain curve for SiC and TiC reinforced aluminium 7075 composites.

3.5 Fractography

Figure 5(a-c) presents the fracture surfaces of Al7075 hybrid metal matrix composites. In the case of aluminium alloy composites, with a higher percentage of reinforcement, matrix cracks adjacent to the TiC & SiC particles and a limited amount of material displacement are observed in the fractograph.

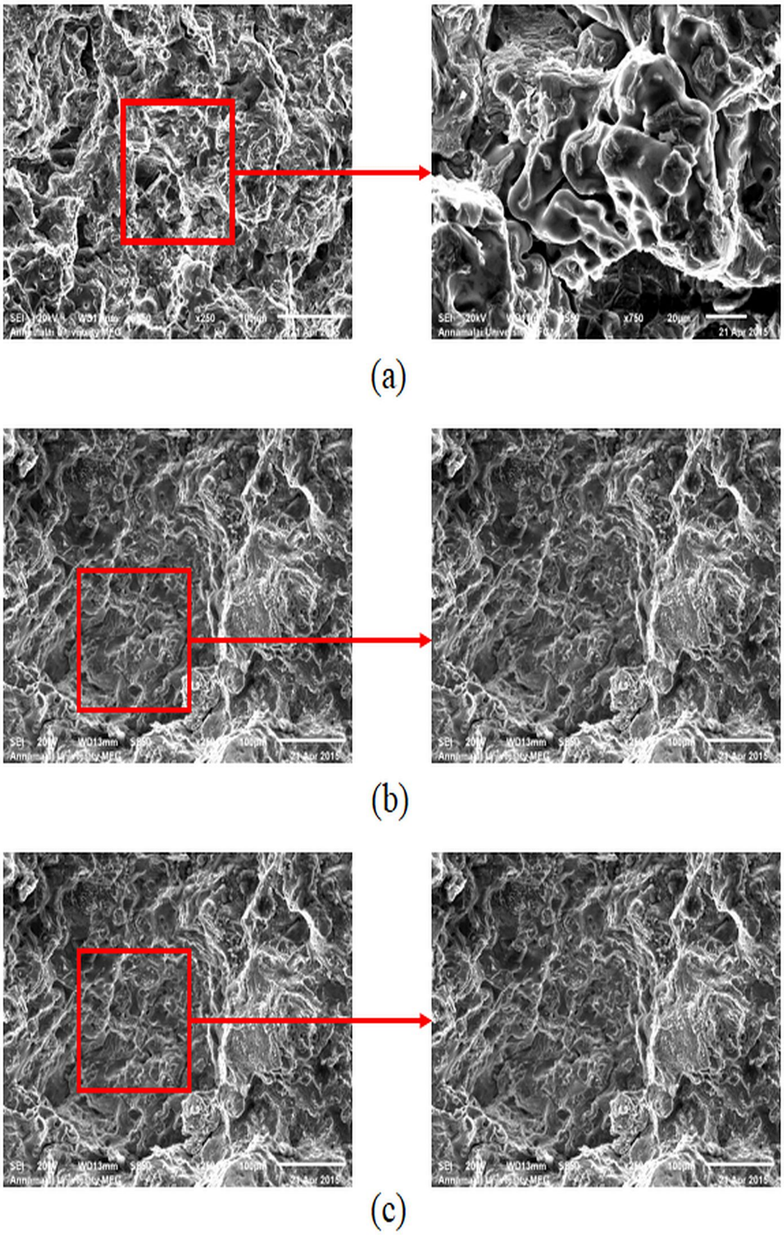

Figure 5: SEM micrographs of the tensile fracture surface (a) AST5 (b) AST10 (c) AST15.

3.6 Potentiodynamic Polarization Test

Figure 6 gives the electrochemical behavior of Al7075 hybrid metal matrix composite in 3.5% NaCl solution at room temperature. Corrosion current density and potential (Icorr & Ecorr), cathodic (βc), anodic (βa) slopes, corrosion rate are obtained from cathodic and anodic region of the TAFEL scan and the results are tabulated in Table 4. During the potentiodynamic polarization testing, the potential started from −1.5 V and for all MMC the Ecorr values were in the range of – (0.920 to 1.0)V which is higher than that of base alloy. The corrosion current density (Icorr) values were decreased by increasing the reinforcement (SiC and TiC) particles. The addition of hard particles into the alloy can increase the corrosion resistance by the physical properties of reinforcement. Uniform dispersion of reinforcement particles in an aluminium alloy which shows the better corrosion resistance. Increasing the volume fraction of the reinforcement particles (SiC and TiC) increasing the corrosion resistance of the Al7075composite. From table 4, it has been found that the Al7075 composites show better corrosion resistance when compared with the Al7075. Candan (2009) studied the polarization behavior of Al-Mg matrix reinforced with SiC obtained a beneficial effect on corrosion resistance. Furthermore, the author reported addition magnesium exhibits higher corrosion resistance. Shimizu et al. (1995) developed Al7075/SiC metal matrix composite (MMC) by squeeze casting method and studied the heat treated MMC increase the pitting potential and resist the stress corrosion cracking in 3.5% NaCl solution.

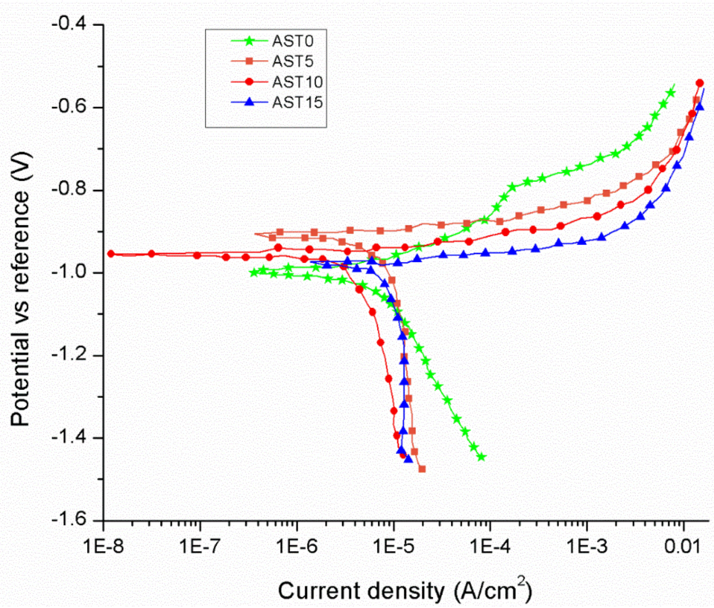

Figure 6: Polarization curves of the Al7075 alloy and its composites in 3.5%NaCl Solution.

Composition	bA e-3 V/decade	bC e-3 V/decade	Icorr µA	Ecorr mV	Corrosion Rate mpy
AST0	148.5	596.9	8.590	-996.0	3.925
AST5	42.20	607.0	5.480	-709.0	2.505
AST10	44.10	500.8	2.700	-747.0	1.235
AST15	91.50	267.9	0.878	-778.0	0.401

Table 4: Icorr, Ecorr, corrosion rate for Al7075 composites.

3.7 Scanning Electron Microscopic (SEM) Study

Figure 7(a-c) indicates severe corrosion of Al7075 hybrid metal matrix composite with different volume percentage. In potentiodynamic polarization testing, NaCl solution being a highly corrosive medium for aluminum attacked both the base and the composite materials. However, the AST5 composition undergone higher corrosion as compare to the AST15 composition materials. This may be attributed to the corrosion due to the TiC and SiC particles acting as cathodic sites, with the galvanic action.

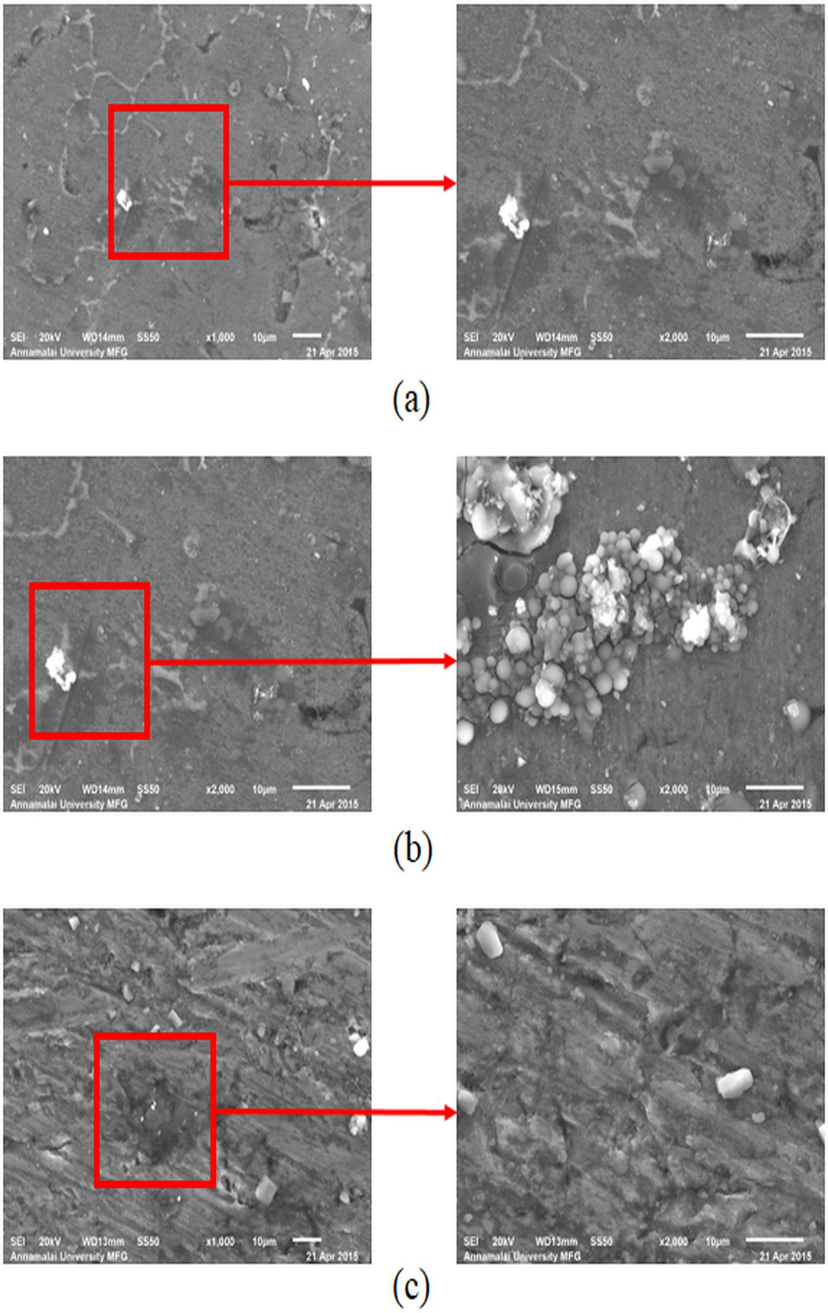

Figure 7: Micrographs obtained by SEM of Al7075 composites corroded in 3.5%NaCl Solution (a) AST5 (b) AST10 (c) AST15.

4 CONCLUSION

Testing results have provided the following conclusions and salient observations:

- The manufactured composite exhibited higher values of hardness and Tensile Strength than the base alloy by two step stir casting.
- Optical photomicrographs of the composite material revealed the uniform distribution of reinforcement in the matrix material.
- By Archimedes principle, the measured densities of composites are higher than that of their base matrix.
- Micro hardness of the composite material was increased with an increase in reinforcement from 0 to 15 vol.%
- In the tensile test, the composite containing 10 vol.% SiC and TiC showed the maximum strength of 240 MPa increased by about 60 MPa (33 %) compared to the base alloy.
- Al7075 hybrid metal matrix composites exhibited better corrosion resistance than the pure Al matrix in 3.5 wt. % NaCl solution. Increasing the volume fraction of the reinforcement (SiC and TiC) particulates increased the corrosion resistance of the composites.

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