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Investigation of mechanical and corrosion properties of Al 7075/Redmud metal matrix composite

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ABSTRACT: Investigation in this paper is mechanical properties and corrosion properties of Al 7075 metal matrix composites. Al 7075 metal matrix composite is prepared from Al 7075 as a matrix and redmud as a reinforcement by using two step stir casting process. Volume percentage of reinforcement is varied from 0% to 15%. The experimental density of the composite material produced was calculated according to the Archimedes principle, greater than the basic matrix. Uniform distribution of the reinforcement and matrix in the composite is studied by using optical micrographs and microhardness of the composite is measured by using Vickers hardness testing machine. The microhardness of the composite was increased while the reinforcement went from 0% to 15%. The tensile strength of the composite material is raised at 5% of the reinforcement tolerance (326 MPa), which is higher than the base matrix. The Al 7075 metal matrix composites have a lower corrosion rate in a 3.5% NaCl solution than the base matrix. As the volume percentage increase in red mud, was reduced the corrosion rate of the composites.

KEYWORDS: Al 7075; Corrosion properties; Mechanical Properties; Redmud; Stir casting; Two-step

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RESUMEN: *Investigación sobre las propiedades mecánicas y de corrosión del compuesto de matriz metálica Al 7075/Redmud*. En el presente trabajo se realiza una investigación sobre las propiedades mecánicas y el comportamiento frente a corrosión del compuesto de matriz metálica Al 7075. El cual se preparó a partir de Al 7075 como matriz y lodo rojo como refuerzo, mediante el uso de un proceso de fundición por agitación en dos pasos. El porcentaje en volumen de refuerzo varía de 0% a 15%. La densidad del material compuesto se calculó mediante el principio de Arquímedes, mayor que la matriz básica. La distribución uniforme del refuerzo y la matriz en el material compuesto se estudió utilizando micrografías ópticas, y la microdureza del material se determinó utilizando una máquina de ensayo de dureza Vickers. La microdureza del compuesto aumentó, mientras que el refuerzo pasó del 0% al 15%. La resistencia a la tracción del material compuesto se elevó al 5% de la tolerancia de refuerzo (326 MPa), que es más alta que la matriz base. Los compuestos de matriz metálica Al 7075 presentan una velocidad de corrosión más baja en una solución de NaCl al 3,5% que la matriz base. A medida que aumenta el porcentaje en volumen en el lodo rojo, se reduce la velocidad de corrosión de los compuestos.

PALABRAS CLAVE: Al 7075; Lodo rojo; Fundición por agitación en dos pasos; Propiedades frente a la corrosión; Propiedades mecánicas

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1. INTRODUCTION

In recent times aluminium alloys play a major role in composite preparation. There are N no. of combination available in aluminium alloys, they are Al7075, Al6061, Al2024, Al8081, Al6063, A413, A380, A356, A535, etc. This is the reason why researchers move to aluminium composites. Due to its high strength to density ratio, high tensile strength, high yield strength and its high elongation during downtime is the reason for Al7075 has a large number of applications in the automotive, aerospace, machine and ship industries (Baradeswaran and Perumal, 2014a; Baradeswaran and Perumal, 2014b; Imran *et al.*, 2016; Devaganesh *et al.*, 2020; Alaneme *et al.,* 2020; Çavdar *et al.*, 2020) There are various methods for producing the particles reinforced MMC, including stir casting is one of the best method for production of MMC. Casting is very popular because of its simplicity and flexibility and is the most economical method for the production of large components (Sambathkumar *et al.*, 2017; Sharma *et al.*, 2018). Composites consist of one or more discontinuous phases that are integrated in a continuous phase. The discontinuous phase is generally harder and stronger than the continuous phase and is called a reinforcing material, the continuous phase is called a matrix. The main function is to transfer and distribute the load to the fiber reinforcement. The matrix can be selected based on its resistance to oxidation and corrosion. Metallic matrix Composite materials (MMC) offer designers advantages, they are particularly suitable for applications good resistance to high temperatures, good structural rigidity, dimensional stability, and light (Prasad *et al.*, 2013). Red mud is one of the main wastes in the production of aluminium oxide from bauxite using the Bayer process. It is an insoluble product that is produced after the digestion of bauxite with sodium hydroxide at high temperature and pressure and is known as red mud or "bauxite residue". It contains oxides of iron, titanium, aluminium and silica as well as other secondary components. Due to economic and ecological issues, enormous efforts have been made worldwide to solve problems of red mud management, i.e., the use, storage and disposal (Pradeep *et al.*, 2014).

Corrosion can affect the metal matrix composite in several ways, depending on its nature and the prevailing environmental conditions. Examination of the corrosion resistance of Al-based materials is important, especially for automotive and aerospace applications where the parts are exposed to corrosive media such as salt water solutions, acidic and alkaline media. The main advantages of AMMC compared to unreinforced materials are as follows: higher strength, improved rigidity, reduced density, good corrosion resistance, improved properties at high temperature, coefficient of controlled thermal expansion, thermal/thermal management, resistance to improved wear and improved damping capacities. Aluminium 6061-MMC with a volume percentage of 0 to 6 percent reinforced with red mud particles has been successfully manufactured using liquid molten metallurgy technology. The corrosion rate of the alloy and the composite material decreased with increasing time in seawater. The corrosion rate of the composite materials was lower than that of the corresponding matrix alloy in seawater Composite materials are better suited to marine environments than matrix alloys (Krupakara and Ravikumar, 2015). It has also been observed that the addition of red mud under the current test conditions results are increase in hardness and a decrease in the yield strength and electrical conductivity. Here it is observed that as the size of the red mud particles decreases, the density, hardness, yield strength and electrical conductivity of the sintered compacts gradually increases (Sai, 2014). Red mud, the waste from the Production of alumina, has been used successfully as reinforcement material based on an aluminium alloy Composites with better wear resistance. These composite materials can be used instead of the classic ones Aluminium-based alloys. Composites can replace expensive reinforcement materials like, SiC and Al_2O_3 with red mud, which leads to Reduce costs and use industrial waste (Singla *et al.*, 2015). The results show that the specific wear rate of the composite increases with increasing temperature. The reason for an increase in the wear rate at high temperature may be a loss of wear resistance at high temperature by softening the matrix (Dabral *et al.*, 2017). Heat treated Al 6061/red mud composites improved the surface property like reduction of the cracks on surfaces (Panwar *et al.,* 2020). Addition of cermet (WC-Co) in to the Al 7075 matrix improves the hardness around 10.52%. The cermet particles also improve yield strength (49%) and tensile strength (58%) of the Al 7075 composite (Guruchannabasavaiah *et al.*, 2021). Samples of the Al 7075 hybrid metal matrix composites are fabricated by two step stir casting process. Theoretical densities are calculated by using rule of mixture concept and experimental densities are calculated by using Archimedes principle. Phases of the composite was analyzed by using the method X-Ray diffraction (XRD) in Rigaku Ultima IV. Hardness of the composite is measured by using Vickers hardness tester in the standard of ASTM E384-11 (2011) by using diamond indenter. Microstructure of the composites are studied by using the optical photomicrographs. Tensile test of the specimen is carried out by using universal tensile testing machine in the standard of ASTM E8/E8M-13a (2013). Corrosion test for the composite is done with 3.5% NaCl solution by using potentiodynamic polarization method. Finally studied the fractography and severity of corrosion by using SEM (Sambathkumar *et al.*, 2017). Addition of 15wt.% of SiC particles into the matrix improved the composite hardness and also showed better wear resistance compared to base alloy. Percentage of SiC and load play a significant role in the wear loss and coefficient of friction (Surya and Prasanthi, 2021).

The samples were subjected to wear and mechanical properties tests according to ASTM standards. It has been found that the microhardness, tensile strength, compressive strength and impact resistance of smaller composites have been increased Red mud particles were added to the composite (Geetha and Ganesan, 2019). The addition of graphite to an aluminium alloy is known to reduce hardness, tensile strength, compressive strength and flexural strength, and has been overcome by the addition of Al_2O_3 in hybrid composites. The presence of graphite in the hybrid composites has shown a tendency to maintain wear, less due to the formation of a thin layer of graphite on the surface of the tribo (Baradeswaran and Perumal, 2014b). Corrosion tests were carried out according to ASTM standards. A salt spray test using NaCl was carried out according to ASTM B117-19 (2019) and immersion tests using NaCl and NaOH as corrodents were carried out according to ASTM G31-12a (2012) standards (Ravi Kumar *et al.*, 2018). In a two-step stir casting method, the structural defects such as wettability, interfacial reactions, particle cluster, porosity and oxide inclusions were overcome compared to the conventional casting technique (Zhou and Xu, 1997; Aravindan *et al.*, 2015).

Based on the literature survey, studies on mechanical and corrosion behaviour of Al 7075 composite reinforced with (5, 10, 15 Vol. %) red mud particle is not available. The main objective of the present study is to fabricate of Al7075/red mud composites and to investigate their mechanical and corrosion behaviour.

2. MATERIALS AND METHODS

The base matrix is Al 7075 and the reinforcement material is Redmud for this present study of different composition of metal matrix composite. The chemical composition of the matrix and the properties of the matrix and the reinforcements are given in Table 1 and Table 2. Samples of the metal matrix composites are made using the two-stage stir casting technique. The amounts of matrix material and reinforcements were determined by calculating the volume percentages.

Table 1. Chemical Composition of Al7075 by volume percentage

Chemical Composition	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al 7075	0.4	0.5	1.6	0.3	2.5	0.15	5.5	0.2	Rest

Table 2. Properties of matrix and reinforcement material

Properties	Density $g{\cdot}cm^{-3}$	Specific gravity $g{\cdot}cm^{-3}$	Hardness	Tensile strength MPa	Poisson's ratio	PH value	Particle size
AL 7075	2.81	2.73	60 (HB500)	220	0.33	-	-
REDMUD	3.26	2.77	-	-	-	10-13	6 µm

The configuration of the stirring of moulding process consists of the furnace, the fire resistance stirring motor and the speed controller. The melting was carried out in the oven at 700 °C and the stirring was completed using a stirring motor and a speed controller. This setup is shown in Fig. 1a. The Redmud was preheated before being added to the aluminium matrix. The aluminium material was first heated to complete melting above the temperature of the liquid and converted to liquid form. It was then cooled below the liquid temperature to keep the molten metal in a semi-solid state. The preheated reinforcement (Redmud) was placed in the molten metal and stirred manually. The oven was then turned on to return the molten mixture to the liquid state. This was stirred mechanically for about 10 to 15 min at an average stirring speed of 150 to 200 rpm. The final temperature was maintained at 750 °C ± 100 °C.

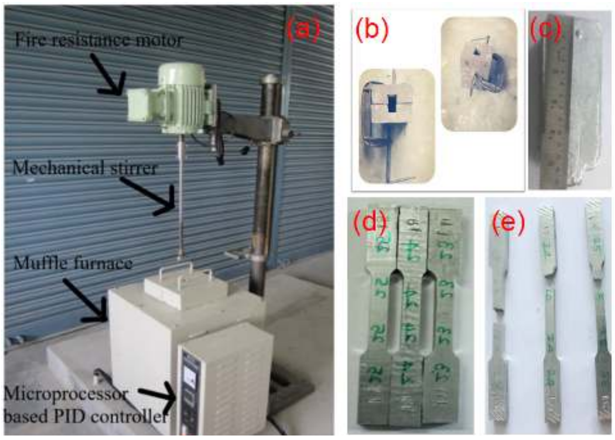

Figure 1. (a) Stir casting setup, (b) Die, (c) Fabricated metal matrix composite, (d) Tensile specimens before testing and (e) Tensile specimens after testing

Finally, the molten metal matrix composite was transferred to a metal of die. The die is made of mild steel with dimensions 150 x 60 x 50 mm^3. Volume % of the matrix and the reinforcement in the metal matrix composite are shown in Table 3. The die used for preparing composite and produced composites are illustrated in Fig. 1 (b and c).

Table 3. Volume % of matrix and reinforcement material

S.No.	1	2	3	4
NAME	ALR0	ALR5	ALR10	ALR15
Vol. % of AL 7075	100	95	90	85
Vol. % of Redmud	0	5	10	15

Archimedes' principle was used to calculate the experimental density and the mixing rule to calculate the theoretical density. The porosity of the composites produced is calculated using the theoretical and experimental densities calculated. The Vickers microhardness of the composites produced is measured using a Wilson microhardness tester. The Vickers microhardness of the cast base material Al 7075 and its composites (ALR0, ALR5, ALR10, ALR15) was determined according to ASTM standard E384-11 (2011) using a diamond penetrator with an applied load of 500 g with a time of 10 s nominal stay. The microstructure of the polished and mirror polished samples is examined using an inverted metallurgical microscope to obtain optical microphotographs.

The samples are prepared for tensile tests in accordance with ASTM E8/E8M-13a (2013) as shown in Fig. 1d. These samples are tested in the universal tensile testing machine (Instron) at an elongation speed of 1 mm/min. Seven tensile test pieces were tested and the mean value of the tensile strength of each pieces was shown graphically. Figure 1e each shows the tensile test pieces tested. Tensile test provides different kind of results they are, peak load, elongation and Ultimate tensile strength.

3. RESULTS AND DISCUSSION

3.1. Density and porosity

The theoretical density of the metal matrix composite produced was calculated using the concept called as rule of mixture. The experimental density of this composite was measured using the principle of Archimedes. The porosity of the composite was calculated using theoretical and experimental densities. Porosity or void proportion is a measure of voids in a material. These values obtained are presented in Table 4. During the analysis of Table 4, it can be observed that the theoretical and experimental density and porosity of the composites are higher than the base matrix Al 7075. The theoretical,

Table 4. Comparison of theoretical, experimental density and porosity of the composites

S.No.	Name	Density ($g·cm^{-3}$)		Porosity (%)
7.	ALR0	Theoretical	2.810	1.067
8.		Experimental	2.780	
9.	ALR5	Theoretical	2.8325	1.64
10.		Experimental	2.786	
11.	ALR10	Theoretical	2.855	2.10
12.		Experimental	2.795	
13.	ALR15	Theoretical	2.8775	2.73
		Experimental	2.799	

experimental values of density and porosity of the composites are increased while increasing the Vol. % of the reinforcement during the stirring casting process. The reason for the increased porosity is the formation of pores on the surfaces of the reinforcing particles. This increases the generation of gas bubbles and the flow of liquid metal in the composite materials. The maximum permissible degree of porosity for die-cast aluminium composite materials is within the limit of 4%.

3.2. Microhardness and microstructure

The microstructure optic of the composite is used taking into account the quality and an assessment of the efficiency of the technology used by the composite. Figure 2 and Fig. 3 show the photomicrographs and the corresponding microhardness of the composite. From the images of the light microscope, we can see that the reinforcements were evenly distributed in the matrix material and also clearly show the increased content of reinforcement in the composite material.

The effect of Redmud on the microhardness of the composite materials obtained from the hardness test. The hardness measurements are carried out on a Vickers microhardness testing machine. From the microhardness test, it has been observed that the hardness of the Al7075 + Redmud metal matrix composite increases with the addition of Redmud. It was higher than that of the base alloy Al 7075. The hardness of all the metal matrix composites was significantly higher than that of the base alloy.

Table 5 shows that the hardness measurement of metal matrix composites reinforced with Redmud in 5 times. From the measurement of the 5 times, the average is taken as a hardness of the metal matrix composite reinforced with red mud.

3.3. Tensile strength

Due to the low density of aluminium, the material is suitable for applications in the aerospace and automotive industries. The lower resistance of the aluminium alloy limits their applications. Table 6 shows that the values obtained tensile strength values of Al 7075

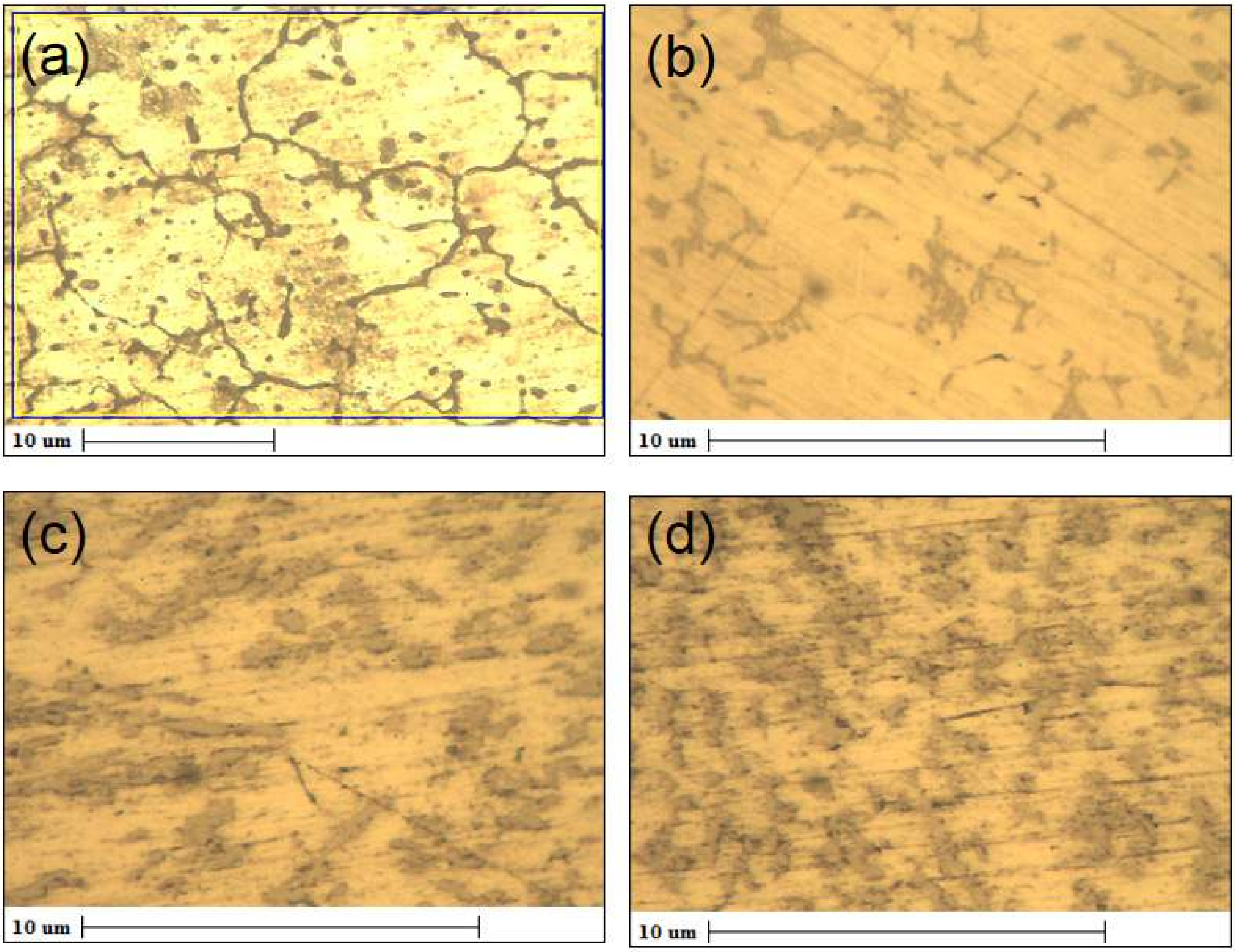

Figure 2. Microstructure images of (a) ALR0, (b) ALR5, (c) ALR10 and (d) ALR15.

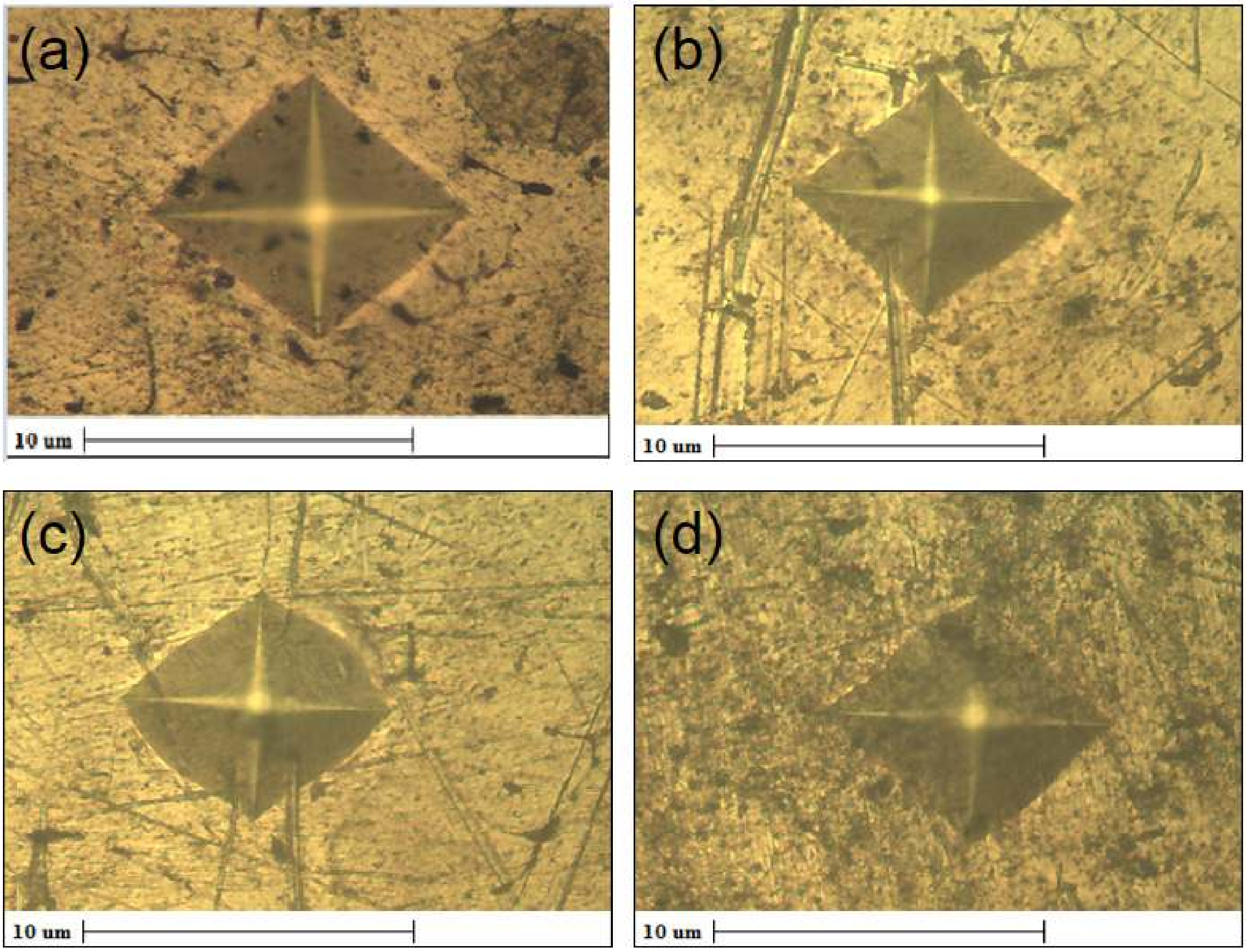

Figure 3. Microhardness images of (a) ALR0, (b) ALR5, (c) ALR10 and (d) ALR15.

metal matrix composites reinforced by redmud. The Al 7075 metal matrix composites reinforced with red mud show that the tensile strength increases compared to the base alloy. To increase the strength of the composite, the presence of hard reinforcing particles is used. The addition of Redmud particles mainly improves the impact on the rupture and the tensile strength of the composite material by transferring the stresses of the aluminium matrix (ductile) to the reinforced particles (brittle).

The elongation of the metal matrix composite was also measured in the tensile test. The elongation in tension is the elongation that a material undergoes when it is pulled under tension. The ductility of the material is measured from the percentage of elongation. Table 6 shows that the elongation values and peak load values of the metal matrix composites reinforced by Redmud. Here is the discussion on the peak load of the metal matrix composite, it is the maximum load that the test object can support during the test. The higher the tension required to create a certain stretch, the more rigid the material.

Table 5. Hardness measurement of Redmud reinforced metal matrix composite in VHN

Trails	ALR0	ALR5	ALR10	ALR15
1st trail	142.5	175.0	179.3	183.6
2nd trail	134.1	176.5	181.0	179.8
3rd trail	140.7	173.2	176.3	180.1
4th trail	138.4	176.0	175.2	177.4
5th trail	136.1	177.1	181.6	185.0
Average	138.36	175.56	178.68	181.18

Table 6. Tensile result for the Al7075/Redmud metal matrix composite

Name	UTS in MPa	Peak Load in kN	Elongation in %
ALR0	87	3.115	6.40
ALR5	326	11.720	12.0
ALR10	272	9.800	10.20
ALR15	223	8.040	10.0

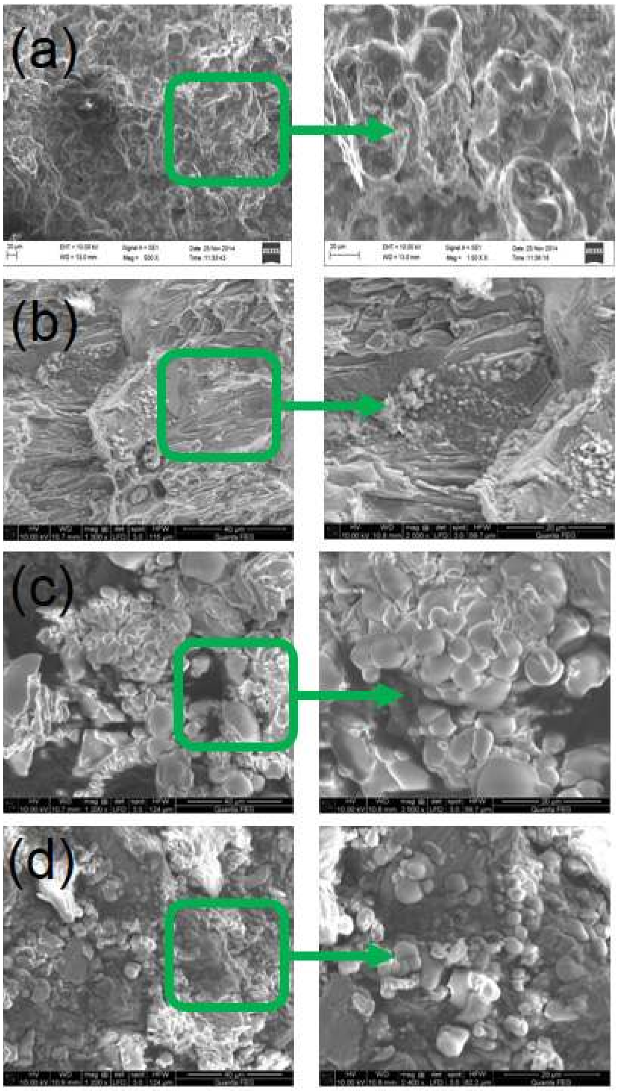

Figure 4. SEM micrographs of the tensile fracture surface of (a) ALR0, (b) ALR5, (c) ALR10 and (d) ALR15.

3.4. Fractography

Figure 4 shows that the fracture surface of base Al 7075 and Al 7075 metal matrix composites. In this study of fractography from the aluminium composites, with the higher percentage of reinforcement used matrix cracks are adjacent to the Redmud particles and the limited amount of material flow is observed in the fractography. The following SEM images are in 1200x and 2500x magnifications and scale of 40 µm and 20 µm.

4. POTENTIODYNAMIC POLARIZATION TEST

Electrochemical behaviour of Al 7075 metal matrix composites in 3.5% NaCl solution at room temprature is shown in Fig. 5. Corrosion current density and potential (Icorr & Ecorr), betta cathodic (ßc), betta anodic (ßa) slopes and the corrosion rate are obtained from the cathodic and anodic region of the TAFEL scan and the results are tabulated in Table 7. In potentiodynamic polarization testing, values of potential started from -1.3 V and for all the metal matrix composites result for Ecorr values are in between the range of -700 mV to -800 mV, which is higher than base alloy Al 7075.

The corrosion current density (Icorr) values were decreased, while increasing the volume percentage of reinforcement (Redmud) particles. Naturally sand particles are corrodable, but here the addition of redmud into the Al 7075 alloy can increase the corrosion resistance by the physical properties of reinforcement.

Increasing the volume percentage of reinforcement particle (redmud) increases the corrosion resistance of the Al 7075. Possibilities of corrosion is reducing due to the bonding between the reinforcement and matrix, while increasing the vol percentage of reinforcement. Uniform flow of reinforcement is the reason behind increasing the corrosion resistance. From Table 7, it has been found that the Al7075 composites show better corrosion resistance when compared with the base alloy Al7075.

Shimizu *et al.* (1995) developed an Al7075/SiC metal matrix composite (MMC) using a squeeze casting process and investigated heat-treated MMC to increase the potential for pitting and resist stress corrosion cracking in NaCl solution at 3.5%.

4.1. SEM Analysis

Figure 6 shows that the corrosion of Al 7075 base alloy and Al 7075 metal matrix composites in different volume percentages. 3.5% of NaCl solution is used

Table 7. Icorr, Ecorr and corrosion rate for Al 7075 metal matrix composites

Composition	ßa e-3V/decade	ßc e-3V/decade	Icorr µA	Ecorr mV	Corrosion Rate mpy
ALR0	148.5	596.9	8.590	-996.0	3.925
ALR5	42.00	763.9	5.910	-771.0	2.701
ALR10	41.10	405.0	4.970	-708.0	2.273
ALR15	40.20	540.9	3.270	-756.0	1.496

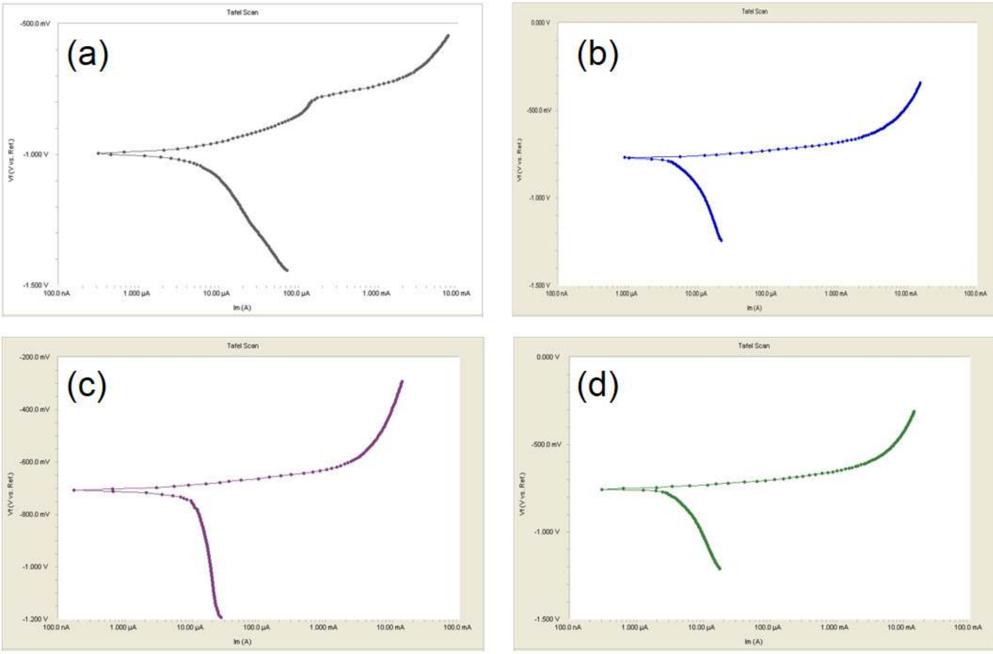

FIGURE 5. Polarization curve for: (a) ALR0, (b) ALR5, (c) ALR10 and (d) ALR15.

for the potentiodynamic polarization testing process. NaCl is a highly corrosive medium for the both Al 7075 base alloy and Al 7075 metal matrix composites. Here, ALR5 composition is highly corroded when compare to the ALR15 composition. The reason behind the corrosion rate reduction is, Redmud was acting as a cathodic sites with the galvanic action.

5. CONCLUSIONS

Testing results provided the following conclusions:

- Experimental density of the fabricated composite was calculated by using Archimedes principle, which is higher than base matrix.
- Highest level of porosity for the fabricated composite is not exceeded 3%.
- The fabricated composite provide high hardness and tensile strength while compare to the base matrix.
- Microhardness of the composite was increased while increasing the reinforcement from 0% to 15%.
- Ultimate tensile strength of the composite is high at 5% of reinforcement addition, which is 326 MPa. It is higher than the base matrix.
- Elongation and Peak load both are more over same, increases up to 5% addition of reinforcement. Afterwards, slightly decreases.
- Al 7075 metal matrix composites provided lower corrosion rate than the base matrix in 3.5% NaCl solution. Increasing the volume percentage of redmud reduces the corrosion rate of the composites.

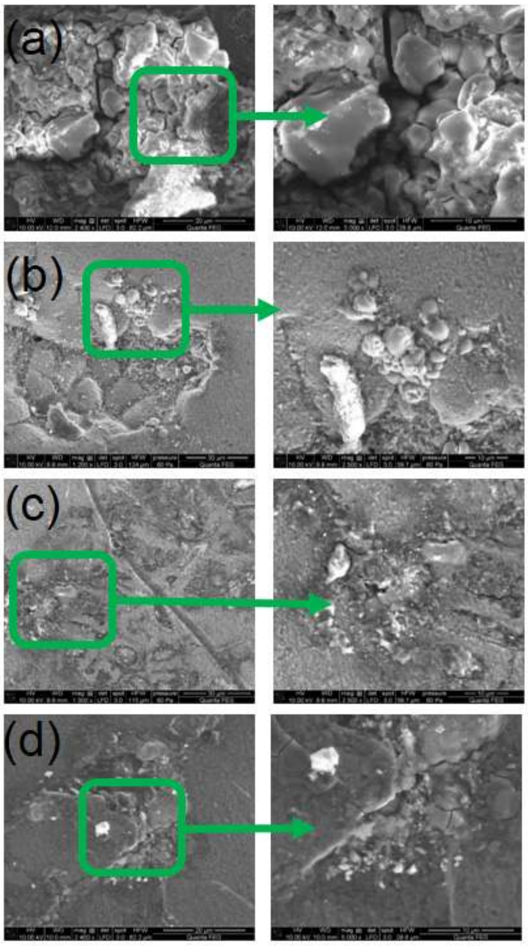

FIGURE 6. SEM micrographs of the corroded: (a) ALR0, (b) ALR5, (c) ALR10 and (d) ALR15.

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