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INVESTIGATION OF MECHANICAL AND CORROSION PROPERTIES OF Al 7075/GARNET METAL MATRIX COMPOSITES BY TWO-STAGE STIR CASTING PROCESS

The impact of Garnet addition into the AL7075 Aluminium matrix on the physical, mechanical and corrosion properties are studied in this research paper. Al 7075/garnet composites are fabricated by using two-stage stir casting method in different (0, 5, 10, 15) volume percentages. Photomicrograph of prepared samples revealed the uniform distribution of garnet reinforcement into the base matrix. The corrosion rate is calculated by potentiodynamic polarization method. The actual density is increased by around 1.2% for Al 7075 / garnet (15%) composite as compared to base alloy. Micro hardness of Al 7075 / garnet (15%) composite is raised by around 47 (34%) compare to as cast base matrix. Al7075 / garnet (15%) composite tensile strength stood at 252 Mpa, which is 40% greater than the base alloy. Al 7075 / 15% garnet composites reduce around 97% of corrosion rate than the base matrix. Alloy elements influenced the corrosion than Garnet reinforcement.

Keywords: Al 7075, Garnet, Two-Stage Stir Casting, Mechanical Properties, Corrosion Properties

1. Introduction

The tendency for safe use of Metal Matrix Composites (MMC) components in the aerospace industry is particularly structural and corrosive environments increased. Nowadays researchers will focus primarily on aluminium, Due to the unique mixture of low density, good mechanical properties, better wear and corrosion resistance. Aluminium Matrix Composites (AMC) have become advanced materials for various possible aviation applications. The automobile, defense and engineering sectors are in the need of aluminium composites due to their high strength and hardness [1-3]. MMC with non-ferrous material like aluminium, magnesium matrix and so on and ceramic reinforcements are popular material in the aircraft, automotive and aviation industries due to their strength to weight ratio, stiffness, corrosion and wear resistance, etc. [4,5]. The increasing demand for light, hard and solid materials that can cause mineral growth ceramic reinforced composite fabric dispersion. MMC are having excellent mechanical characteristics and are considered as possible technical materials for various tribal applications. Several researchers were involved in the study of mechanism of wear and corrosion of MMC reinforced with ceramic particles such as SiC, Al_2O_3, etc., and proved that particles inclusion improved wear and corrosion resistance [6]. Composite materials have been developed by various techniques such as stir casting, squeeze casting, powder metallurgy, and infiltration process. Among these techniques, stir casting route is the most promising one to fabricate the composite because of its cost-effectiveness, simplicity, absence of size limitation and large quantity [7,8]

Garnet is essentially a silicate, abundant and with hardness values of 981-1161 HV. It softens at temperatures of 1413-1553 K. Since the SiC, Al_2O_3 and TiB_2 ceramic reinforcement are more expensive, garnet particles obtained from naturally available rocks and inexpensive. Garnet is basically composed of alumina-silicates of calcium and it is chemically inert. LM24 /15 wt.% garnet composite shows higher hardness (98.14BHN) compare to base alloy which is 81.38 BHN. Tensile strength also improved around 18% compare to LM24 alloy. 15 wt.% composite wear rate also drastically reduced around 74% under 80N applied load, 3 m/s sliding velocity [9]. The AA 7075/TiC (40μm) composite materials are developed as liquid metallurgy method. TiC particles varying between 3 and 7%. The tensile strength of the AA 7075/TiC composite material and the hardness are studied. The results showed an increase in hardness (around 17%) and tensile strength (around 43%) of the composite materials compared to the AA7075 due to the presence of the TiC particles [5]. In both

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the unreinforced alloy and the reinforced composite materials, wear rates increase with increasing force and speed of the experiments. The increase in the force, wear mechanism is changed from abrasion to cracking of the particles. The wear resistance has been found to increase monotonically around 66% with increasing garnet content. The Scanning Electron Microscope (SEM) analysis is used, explain the observations of the worn surfaces [10]. Mechanical and corrosion behaviour were used to assess this composite performance. The optical micrograph is used to identify the distribution of reinforcement particles in to matrix. When increasing the SiC/TiC reinforcement particles improves the microhardness of the composite around 18%. The tensile strength of 10 vol. % hybrid matrix composite was better than that of the as cast base alloy and increased around 33%. In a 3.5% NaCl solution was observed as 15 vol. % of hybrid matrix composites have lower corrosion rate in comparison with the as cast base alloy [11]. The characterization of the microstructure and mechanical properties such as hardness and tensile strength of the reinforced hybrid composites were examined. The test pieces are prepared and tested in accordance with the ASTM (American Society for Testing and Materials) standard. A vickers hardness measurement was performed to examine the hardness of the composite. The effect of cooling and strengthening properties was presented and compared to the composite hybrid without cooling material. The results confirm the positive relationship between the mechanical behaviour and the dispersion content. It has been found that the cast composite cooled with copper with 9% by weight of garnet and 3% by weight of carbon increases the ultimate tensile strength around 43% [12]. Aluminium alloy with ceramic particles have been reduce wear resistance and the coefficient of friction. The hybrid composite Al 7075 / Al_2O_3 (2, 4, 6 and 8 wt.%) / graphite (5 wt.%) particles and developed by stir casting method. The hardness (increased around 18%), the tensile strength (increased around 12%), flexural strength (increased around 34%), and compressive strength (increased around 10%) of hybrid composite materials are improved by an increased wt. % of the ceramic phase [13].

The composites which contained different ranges of garnet sizes reinforced with an LM13 alloy were manufactured by technique of liquid metallurgy. The variation in the grain size of the garnet mineral and its variation of reinforcement wt.% amount (5, 10 15) significantly influenced the physical and tribological properties of composite materials. Compare to coarse size garnet composite (microhardness: 81, 83, 91), fine size garnet composite shows higher microhardness (123, 122, 133) at the matrix and reinforcement interface region. The wear rate of small garnet-mineral composites is low compared to composites which are reinforced by large garnet mineral particles under all loads. The wear rate of 15% by weight of the composite material reinforced with garnet and fine-grained minerals is minimal even under higher loads (49 N) compared to cast iron, which is used in vehicle brake drums [14]. Adding garnet particles to Al6061 has shown that this reduces wear rate around 0.55 mm^3/m and reduce coefficient of friction around 0.44 for 12 wt.% reinforcement under 50N applied load compared to base alloy. Al 6061 / 12 wt.% garnet composite have higher brinell hardness (65BHN) compare to Al 6061 alloy (30BHN). SEM with EDS analyses were carried out to clarify the worn out surfaces of the wear pin [15].

Based on the literature survey, studies on mechanical and corrosion behaviour of Al 7075 composite reinforced with (5, 10, 15 Vol. %) garnet particle is not available. Garnet particles with other aluminium matrix composites improve the properties. The main objective of the present study is to fabricate of Al7075/ garnet composites by using two-step stir casting method and to investigate their mechanical and corrosion behaviour.

2. Experimental Details

In this present study, Al 7075 is selected as the base matrix material (purchased from Perfect Metal Mart, Bangalore, India) and the garnet particles (purchased from VV Minerals, Chennai, India) are selected as the reinforcement material. The chemical composition garnet material is given in Table 1. Samples of the MMC are prepared by using two-stage stir casting process technique, which is similar to the one used by Uthayakumar et al. [16]. Al 7075 and garnet amounts are determined based on the volume percentages. 5%, 10%, 15% of garnet is used to fabricate the MMC and the pure Al 7075 is denoted as ALG0. The arrangement of stir casting process setup is muffle furnace (Model: MF12) with speed regulator. The melting was carried out by the furnace in 750°C. This setup is showed in Fig. 1(a).

TABLE 1

Chemical composition of garnet particles by wt.%

S. No.	Elements / Name Almandine ($Fe_2Al_2(SiO_4)_3$)	Wt.%
1.	Silica (SiO_2)	40
2.	Iron (Fe_2O_3)	37.3
3.	Alumina (Al_2O_3)	22.7

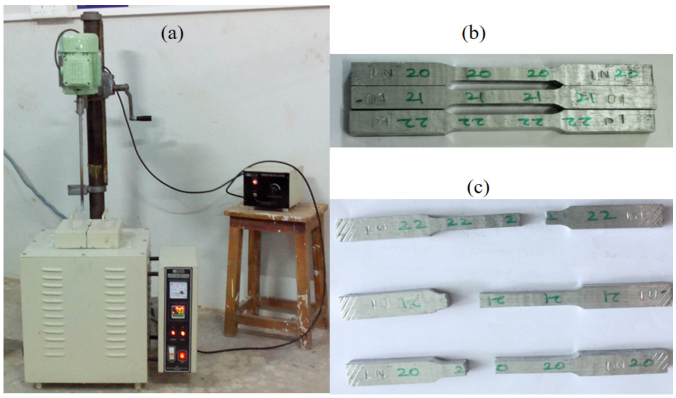

Fig. 1. (a) Experimental Setup, Tensile specimen: (b) before testing, (c) after testing

Initially, Al 7075 was heated over the liquid temperature for upto molten stage and then it was cooled up to under the liquid stage and to keep the molten metal in semi-solid state for adding reinforcement. Here, the 250°C preheated garnet particles were mixed in the Al 7075 molten metal and stirred by steel rod. Afterwards, the furnace was started up for reheating the molten mixture to the melted state. Here, stirring was carried out by stirring arrangement about 5 to 10 min. Finally, the molten metal matrix composite was transferred in to a die. Vol. % of the matrix and reinforcement in the metal matrix composite is shown in Table 2.

TABLE 2

Vol. % of matrix and reinforcement material

Composition	ALG0	ALG5	ALG10	ALG15
Vol. % of Al 7075	100	95	90	85
Vol. % of Garnet	0	5	10	15

By using, Archimedes principle to calculate the actual density and rule of mixture to calculate the theoretical density. Porosity of the fabricated composites are calculated by using the obtained theoretical and actual densities. Vickers microhardness of the ALG composites are measured by Wilson microhardness tester. The vickers microhardness of the as cast Al 7075 material (ALG0) and their composites (ALG5, ALG10 and ALG15) were evaluated by ASTM E384 – 11 standard under 500g load with dwell period of 10s. Inverted metallurgical microscope (Model: Inverto Plan-I) is used to study microstructure of prepared composites.

ASTM E8M – 13a sub size specimens are prepared for tensile test. The tensile specimens are tested in the Instron Universal Tensile Machine (UTM) with 1 mm/min strain rate.

Fig. 1(b-c) shows that the prepared and tested tensile specimens respectively. Potentiodynamic polarization method is used to calculate the corrosion rate of the prepared Al 7075/garnet composite.

3. Result and Discussion

3.1. Density and Porosity

Al 7075/Garnet (ALG) Composite theoretical density was assessed by using rule of mixture. Physical density of ALG composite was assessed by using Archimedes principle. Porosity of the composite was computed by using the theoretical and actual densities. Fig. 2 shows the obtained results of theoretical, actual densities and porosity of ALG composites. From Fig. 2, it can be observed both of the theoretical and actual densities and porosity of the ALG composites are higher than the as cast base matrix. Actual, theoretical densities and porosity values of the ALG composites are increases while step-up the vol. % of garnet reinforcement during stir casting process. Reason for density increment is density of garnet particles and porosity increment is pore nucleation at the garnet particulate surfaces. More gas bubbles were generated at the nucleation site of the garnet particles. ALG15 actual density is 1.2% higher than the as cast base matrix. The maximum porosity of the Al 7075/garnet composite material produced did not exceeds 4%.

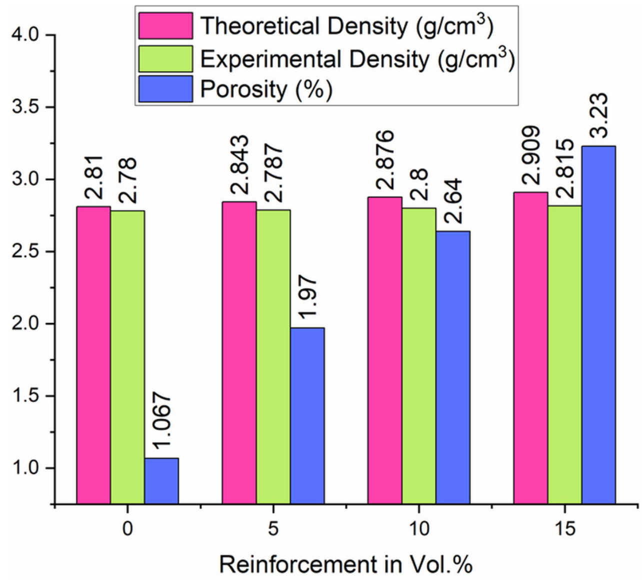

Fig. 2. Theoretical density, Actual density and Porosity

3.2. Microhardness and Microstructure

The optical microstructure of the composite material are used taking into account the quality and an assessment of the effectiveness of the technology that was adopted by the composite materials. Fig. 3(a-d) shows the microphotographs and Fig. 4(a-d) shows the microhardness of the ALG composite. We can see from the microscope images that the garnet particles were evenly strew in the ALG composite and also clearly show the increased garnet content in the Composite. The effect of garnet on the microhardness of the ALG composites obtained from hardness test is shown in Fig. 5.

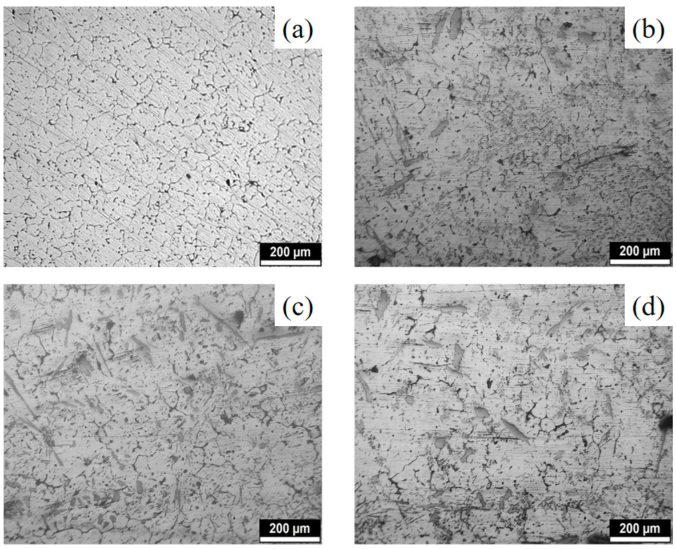

Fig. 3. Microstructure images of (a) ALG0, (b) ALG5, (c) ALG10 and (d) ALG15

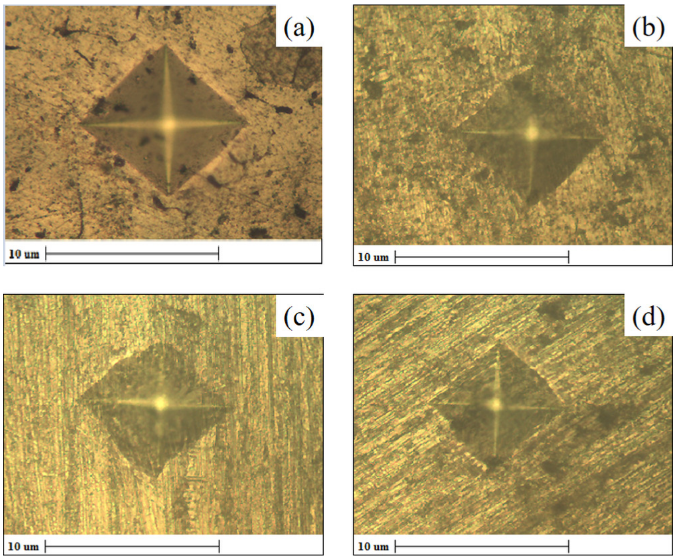

Fig. 4. Microhardness images of (a) ALG0, (b) ALG5, (c) ALG10 and (d) ALG15

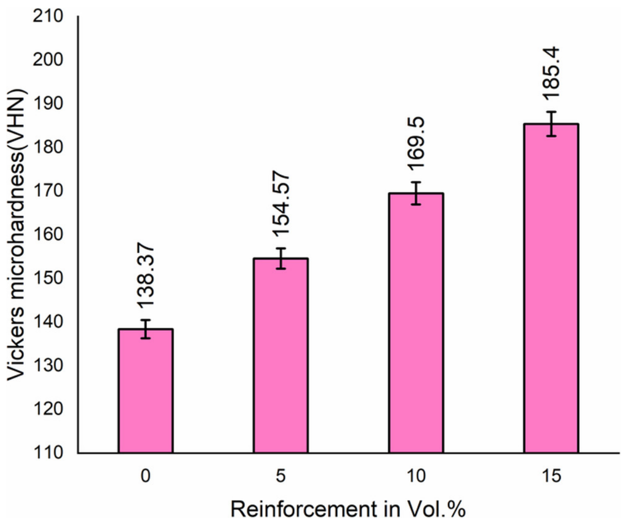

Fig. 5. Microhardness of Al 7075/Garnet MMC

From Fig. 5, the microhardness of the ALG composite increases with the step-up of garnet. Compared to the as cast base matrix, ALG15 microhardness is raised by around 47 (34%). The presence of hard garnet particles in the matrix, restrict the dislocation and increase the load carrying capacity of matrix [11].

Sharma et al. [17] have studied the wear behaviour of Al-Si alloy (LM13) / garnet (fine and coarse) composites by stir casting technique. Uniform distribution of garnet particles is identified by an optical microscope with dark phase. The micro-hardness increase when increasing the reinforcement particles in both fine (50-75 mm) and coarse (106-125 mm) composites. Microhardness of coarse size composite is 7-9% lower than the fine size reinforced composites, because the interface area between garnet particle and alloy is more in fine size composites. Addition garnet particles into matrix, result in restrict the plastic deformation and increase the hardness values of the composite [13,14].

3.3. Tensile Strength

Fig. 6(a) shows that the tensile strength values of the ALG composites. From the Fig. 6(a) the increment of garnet particles, Improve the tensile strength as compared with as cast base matrix. To increases the tensile strength of the ALG composite is based on the presence of garnet reinforcement particles. Garnet particles are evenly distributed in base alloy, which hold the dislocation movement of base material and improves the tensile strength of ALG composite by transfer the load from the Al 7075 to garnet particles. The lowest ultimate tensile strength is obtained for ALG0 is 181 MPa and highest ultimate tensile strength is obtained for ALG15 is 252 MPa raised by about 71 MPa (40%) compare as cast base alloy.

Elongation of the metal matrix composite also measured while in the tensile test. Elongation in tension is the elongation that a material experiences when it is pulled under tension. The percentage of elongation measures the ductility of the material.

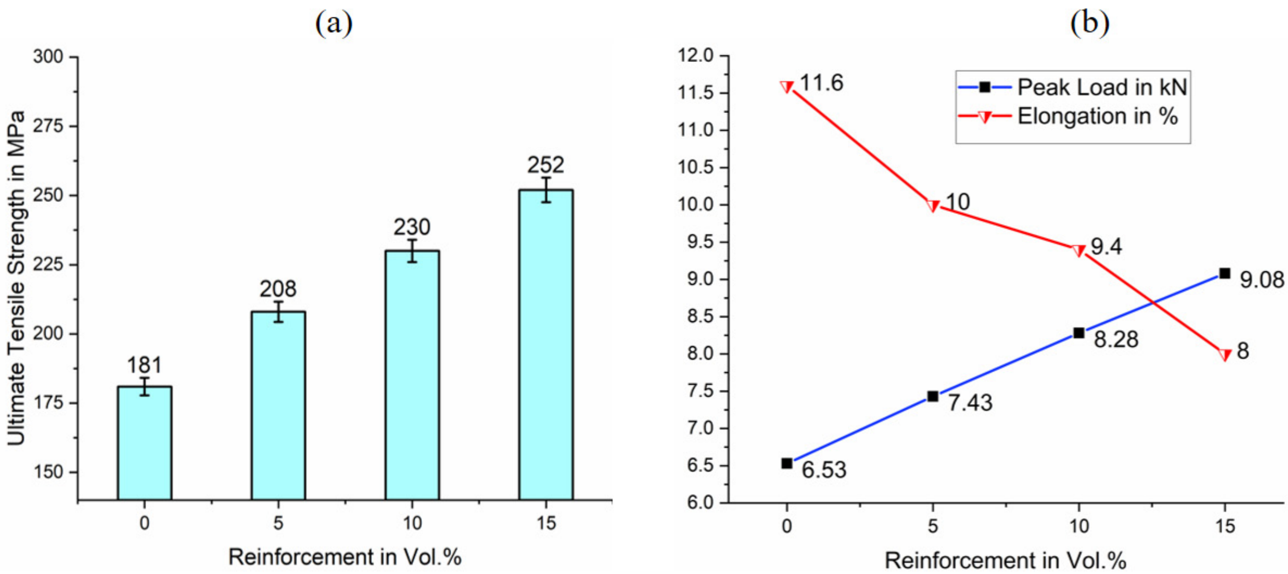

Fig. 6. (a) Ultimate tensile strength (b) Peak load and Elongation of Al 7075/Garnet MMC

Fig. 6(b) shows that the peak load and elongation values variations between base alloy and garnet reinforced metal matrix composites. Peak load is same as Ultimate tensile strength, low rate at ALG0 and significantly increases while adding volume percentage of garnet. The elongation is decreased from 11.6 to 8, when increasing garnet from 0 to 15%.

Sivakumar et al. [9] also have developed aluminium LM24 (A380) alloy / garnet composites by stir casting technique and studied the mechanical and sliding wear properties. The tensile strength and load carrying capacity of the composite is increased with the addition of garnet particles from 0% to 15 wt. % of due to better bonding behaviour between garnet and matrix alloy. The lowest tensile strength was obtained for as cast alloy as 180 MPa and highest tensile strength was obtained for 15 wt.% garnet composite as 212 Mpa raised by about 32 MPa (18%) compared to as cast base alloy. Naeem and Abdullah [18] developed Al-Si-Ni-Cu-Mg alloy/garnet composites by using copper, steel chill and without chill casting. Addition of 9 wt.% garnet particles significantly increasing the ultimate tensile strength of the steel and copper chill composite around 16% and 21% compare to without chill.

3.4. Fractography

Fracture surface of the ALG composites are shown in Fig. 7(a-d). From the investigation of this fractography of ALG composites, it is evident that the presence of garnet is clearly identified. The SEM depicts a ductile fracture mechanism with shear effects on the surface for all the cases considered. The increase in mechanical properties may be attributed to the arrest of movement of the matrix by the reinforcements. During fracture, the matrix tends to move laterally but the reinforcements hinders the movement this makes the composite material to be stronger than the base alloy which does not posses the reinforcements. Al 7075 base alloy cracks adjacent to the garnet particles and a restricted amount of matrix displacements in composites were observed from Fig. 7(b-d) compared to the Fig. 7a.

3.5. Potentiodynamic Polarization

Fig. 8 shows that the electrochemical behaviour of ALG composite at room temprature in 3.5% of NaCl solution. This NaCl solution is one of the salt solution, here which is used to corroding the Al 7075/garnet metal matrix composite. Table 3 shows the result of obtained values from Tafel scan graph with the cathodic and anodic region. Which is I_{corr} (corrosion current density), E_{corr} (potential), βc (betta cathodic), βa (betta anodic) slopes and the corrosion rate.

In the potentiodynamic polarization tests, the potential values for all metal matrix composites started at –1.4 V. However, the base matrix Al 7075 starts at –1.5 V. The result for the Ecorr values is between –750 mV and –800 mV, which is greater than that of the as cast base alloy. The values for the Icorr were reduced, while the volume percentage of the garnet particles was increased. Increasing the volume percentage of garnet particles reduces the corrosion rate. The reason behind the reduction of corrosion rate after the increment is bonding between the Al 7075 and garnet. The distribution and presence of garnet particles in the ALG composite can reduces the corrosion rate. From Table 3, it was found that the ALG composites have low corrosion rate than the Al 7075 base alloy. ALG15 shows around 97% lower corrosion rate than the base matrix.

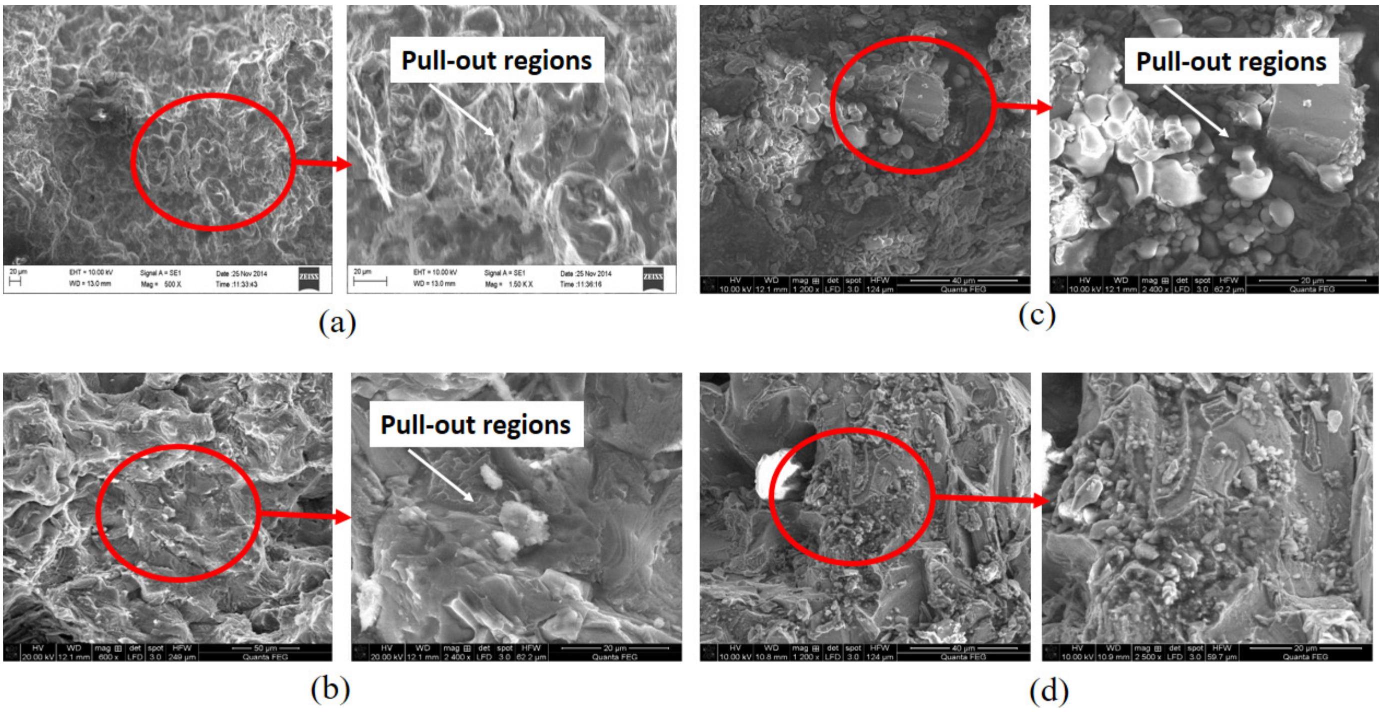

Fig. 7. SEM micrographs of the tensile fracture surface for (a) ALG0, (b) ALG5, (c) ALG10 and (d) ALG15

TABLE 3

Icorr, Ecorr and corrosion rate for Al 7075/Garnet metal matrix composites

Composition	βa e^{-3}V/decade	βc e^{-3}V/decade	I_{corr} µA	E_{corr} mV	Corrosion Rate mpy
ALG0	148.5	596.9	8.590	–996.0	3.925
ALG5	55.10	548.6	6.080	–778.0	2.777
ALG10	36.70	574.0	5.620	–768.0	2.566
ALG15	41.20	97.80	0.197	–754.0	0.0901

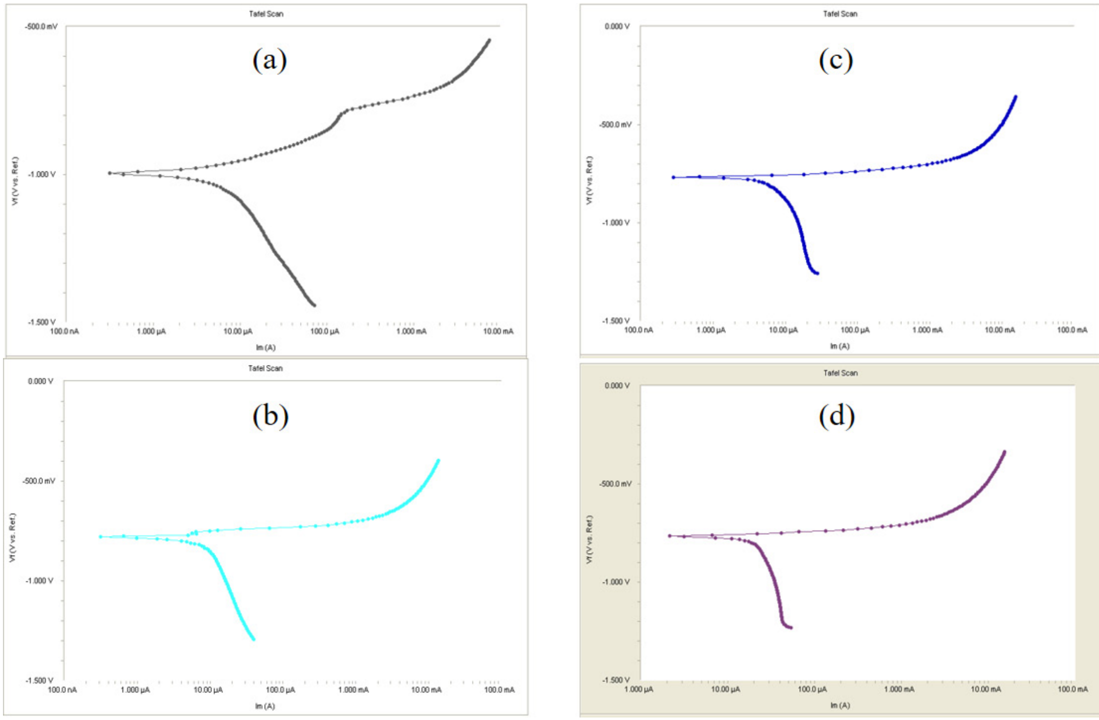

Fig. 8. Polarization curve for (a) ALG0, (b) ALG5, (c) ALG10 and (d) ALG15

The corrosion rate of as cast ALG0 is higher than those of the ALG composites, because there is no reinforcement particles presence in the alloy and also in the acidic medium ALG0 having less corrosion resistance. Seah et al. [19] have developed LM13 Aluminium alloy reinforced with garnet particles by casting technique and conducted static immersion test to study the corrosion properties of composites. In the acidic medium, formation of protective black film on the surface, increase the corrosion resistance. Corrosion rate is measured and it is found that the corrosion rate is decreased with the increase in garnet percentage

3.6. Scanning Electron Microscope

Corrosion rate of ALG composite is shown in Fig. 9(a-d). This SEM images are taken after the potentiodynamic polarization testing, which is done with 3.5% of NaCl solution. NaCl solution is one of the highly corrosive medium for ALG composite. From the investigation of following SEM images states that, corrosion appearance in ALG0 is high while compare with other Al 7075/garnet composites. Analyse of the corrosion reduction during the addition of garnet is states that, garnet is act as an anti-corrode material. Fig. 9 reveals the presence of pits and domes which are symbolic of localized corrosion.

4. Conclusions

The test results provide the following conclusions,

- The actual density of the Al 7075/Garnet composite was calculated according to the Archimedes principle, ALG15 actual density is 1.2% higher than the as cast base matrix. The maximum porosity of the Al 7075/Garnet composite material produced is not exceeds 4%.
- The microhardness of the composite was increased while the reinforcement went from 0% to 15%. Compared to the as cast base matrix, ALG15 microhardness is raised by around 47 (34%).
- The lowest ultimate tensile strength is obtained for ALG0 is 181 MPa and highest ultimate tensile strength is obtained for ALG15 is 252 Mpa raised by about 71 MPa (40%) compare as cast base alloy.

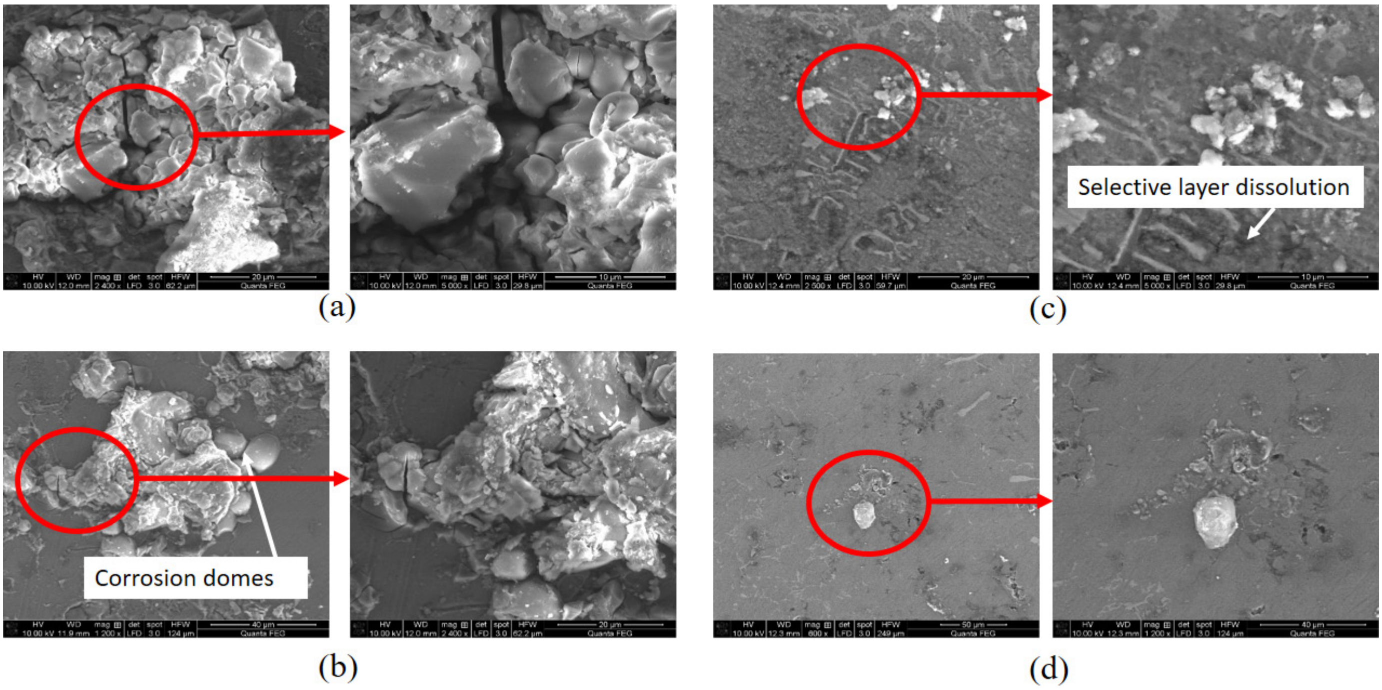

Fig. 9. SEM images of (a) ALG0, (b) ALG5, (c) ALG10 and (d) ALG15

- Peak Load is same as Ultimate tensile strength low rate at ALG0 and significantly increases while adding volume percentage of Garnet. The elongation is decreased from 11.6 to 8, when increasing garnet from 0 to 15%.
- Al7075/garnet composites shows better corrosion resistance compare as cast base matrix in 3.5wt.% NaCl solution. ALG15 shows around 97% lower corrosion rate than the base matrix.

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