VOL. 10, NO. 14, AUGUST 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EFFECT OF SQUEEZE PRESSURE ON MECHANICAL PROPERTIES OF LM6 ALUMINIUM ALLOY MATRIX HYBRID COMPOSITES

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ABSTRACT

Melt stirring and squeeze casting technique was successfully used to fabricate hybrid aluminium matrix (LM6) composites containing SiC and Al_2O_3 particles. The reinforcement particles were added into molten aluminium matrix by a mechanical stirrer and composite mixture was cast by applying pressure using a hydraulic press. The effect of squeeze pressure (30 - 120 MPa) on mechanical properties of LM6 aluminium alloy and composite were investigated. The specimens were prepared from the casting and are subjected to microstructural and mechanical characterization. The microstructural characterization revealed that grain size is decreased with increasing squeeze pressure. The density and hardness of composite increased with increasing squeeze pressure, but porosity decreased. The tensile properties such as yield strength, ultimate tensile strength of composite increased with increasing squeeze pressure and reached maximum value at a pressure of 90 MPa but elongation decreased. The tensile fracture surface of composite specimen indicates the modes of fracture mechanism.

Keywords: hybrid composites, LM6 Al alloy, mechanical properties, squeeze casting.

1. INTRODUCTION

Hybrid metal matrix composites are a unique class of engineering materials in which a metal is reinforced with two or more different types of reinforcements. The hybrid composites possess excellent properties such as low coefficient of thermal expansion, better wear resistance and high mechanical properties than single reinforcement reinforced composites. Aluminium reinforced with silicon carbide and alumina particles are the most generally available aluminium metal matrix composites. Therefore, they are extensively used in several industrial areas such as aerospace, automotive and electronic industries [1, 2]. Metal matrix composite components can be manufactured by several methods. The stir casting technique is especially attractive in terms of its ability to produce complex near net shapes. However, non-uniform distribution of reinforcements, poor wettability of reinforcements with matrix, interfacial reaction products and porosity in stir casting technique deteriorates the mechanical properties of composites [3, 4]. In order to overcome the above problems, melt stirring and squeeze casting technique utilized to develop the aluminiumhybrid composites. Higher cooling rates employed by squeeze casting leads to uniform distribution of second phase particles and refinement of microstructure [5, 6]. The wettability and the bonding force between reinforcement particles and melt were improved by the application of pressure after the casting and the porosity was also decreased because of this pressure [7, 8]. The possibility of interfacial reaction is decreased because of the contact time between the reinforcement and the melt is shortened. Therefore, squeeze casting method is known as a very promising route for manufacturing near net shape metal matrix composite components at relatively low cost [9, 10].

The mechanical and tribological properties of squeeze cast composite improved compared to corresponding gravity die cast composite [11, 12]. The properties of the composites were improved by adding reinforcements and increased with an increase in the content of reinforcements [13, 14]. A pressure level of 100 MPa was found to be sufficient to get the microstructural refinement and very low porosity level [5, 8]. The application of squeeze pressure decreases the dendrite cell size, increases the fraction of particles engulfed within the cell and reduces the porosity. The mechanical properties such as hardness, tensile strength and compressive strength are increased by increasing squeeze pressure but porosity is reduced [15, 16]. It is observed from the review of literature that no studies has been reported on manufacturing of LM6 aluminium alloy hybrid composites with SiC and Al_2O_3 particles by using melt stirring and squeeze casting technique. The objective of this study is to (i) produce particulate reinforced aluminium matrix composites using melt stirring and squeeze casting methods and (ii) investigate the effect of squeeze pressure on mechanical properties of composites.

2. EXPERIMENTAL PROCEDURE

2.1 Materials and equipment

Al-Si alloy (LM6) was chosen as a matrix material and its chemical composition is given in Table-1. The particles of silicon carbide (SiCp) and aluminium

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oxide (Al_2O_3p) were used as the reinforcements. The experimental setup for fabricating metal matrix composites is shown in Figure-1. It mainly consists of a bottom pouring furnace with crucible, mechanical stirrer assembly, cast iron mould and hydraulic press. An electrical resistance heating furnace with a capacity of 1000°C was used to melt the metal and to hold the molten metal at a desired temperature. The temperature in the furnace was measured and accurately controlled by a PID temperature controller. Stainless steel material has been selected for the crucible, stirrer rod and impeller because of its good corrosion resistance. The mechanical stirrer was connected to a variable speed (0 - 2000 rpm) motor which has been used to mix the ceramic particles with matrix alloy. A lifting mechanism was provided to extract the stirrer from the melt and to facilitate the stirrer positioning, cleaning and replacement.

Table-1. Chemical composition of LM6 Al alloy.

Element	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Al
%	0.1	0.1	10.0 - 13.0	0.6	0.5	0.1	0.1	0.1	0.05	0.2	Balance

A spilt type cast iron permanent mould was specially designed for fabricating composites of 50 mm diameter and 150 mm height. The molten metal has been poured into the mould through a path way which connects the melting furnace with mould. The path way was heated to maintain fluidity of the molten metal. A hydraulic press with 100 ton capacity was used to apply pressure on molten metal during the process of solidification. With the help of ejection mechanism the composite casting have been ejected from the mould.

Figure-1. Squeeze casting set up.

2.2 Processing of composites

The hybrid aluminium composites were produced by using melt stirring and squeeze casting method. The two most important stages in the processing of composites are (i) reinforcement incorporation into molten melt and (ii) casting under pressure. The matrix alloy in the form of ingots was charged into the crucible and the temperature of the furnace has been raised to 800°C. The inner side of the crucible and stirrer were coated to avoid any contaminations at high temperatures. The SiC and Al_2O_3 particulates were preheated at 800°C for 2 hr to improve their wettability with the matrix alloy. After the metal was melted, the melt has been degassed fully with hexachloroethane tablets. The preheated mechanical stirrer was introduced into the melt and positioned just below the surface of the melt. The molten metal was stirred at the approximate speed of 375 rpm and then preheated ceramic particles (10 wt %) with 1:1 ratio were added gradually in the vortex. After the particle addition the stirring was continued for another 5 min to prepare homogeneous slurry. The pouring temperature has been maintained at 720°C. The permanent cast iron mould was preheated to 250°C to obtain uniform solidification. The molten slurry was poured into the mould and then a pressure in the range 30-120 MPa has been maintained until completion of solidification using a hydraulic press. The squeeze pressure was increased in steps of 30 MPa keeping the holding time constant at 60 seconds. After solidification the castings were taken out from the mould. For the purpose of comparison unreinforced aluminium alloy was also fabricated by using the same procedure.

2.3 Characterization of composites

The specimens of required size were cut from the cast unreinforced aluminium alloy and composite to carry out the microstructural analysis. The specimens were carefully prepared following standard metallographic procedures of grinding and polishing followed by etching in Keller's reagent. The general structure and particulate distribution in the matrix alloy was observed by Optical microscopy. The experimental density of matrix alloy and composite were measured by the Archimedes principle, while the theoretical density was calculated according to the rule of mixture. The porosities of the composites were calculated using the theoretical and experimental densities, according to the equation

$$Porosity\ (\%) = \frac{dt-de}{dt} \quad (1)$$

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where *dt* and *de* represent the theoretical and experimental densities, respectively.

Brinell hardness tester was used to measure the macro hardness of aluminium alloy and composite. The test has been carried out using 10 mm steel ball indenter at a load of 500 kgf for 30 s at five different locations on all specimens. The average value of macro hardness was reported. Tensile specimens were prepared from the matrix alloy and composite as per ASTM E8M - 04 standards (Figure-2). The tensile test was carried out using universal testing machine and then the ultimate tensile strength has been estimated. Three trials have been carried out for the purpose of repeatability and the average of them presented here.

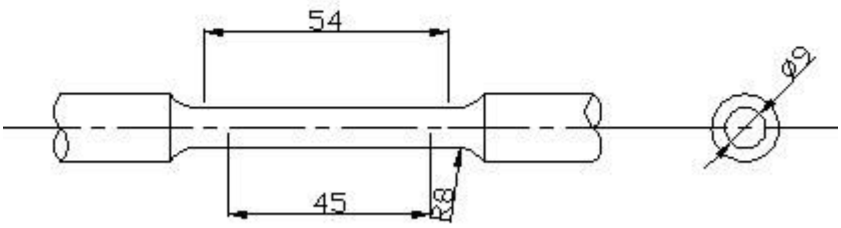

Figure-2. Schematic diagram of tensile specimen (dimensions in mm).

3. RESULTS AND DISCUSSIONS

3.1 Microstructure

The dispersion of second phase particles in the matrix alloy influences the properties of composites. The homogeneous dispersion of reinforcements is the most important factor to obtain the desired properties in the material. Figures 3 and 4 shows the microstructure of LM6 Al alloy and composites fabricated at different squeeze pressure. Figure-3 shows the microstructure of cast LM6 Al alloy and the phases present are α-Al in dendritic network structure and eutectic silicon with plate shape. The final microstructure of Al alloy is affected by the application of pressure during the process of solidification of melt. It is observed that the size of α-Al is decreased with an increase in squeeze pressure. The microstructures of the composite are shown clearly in Figure-4 that indicate the uniform distribution of SiC and Al_2O_3 particles in the matrix alloy and existence of particle clustering and agglomeration in some places [12, 14].

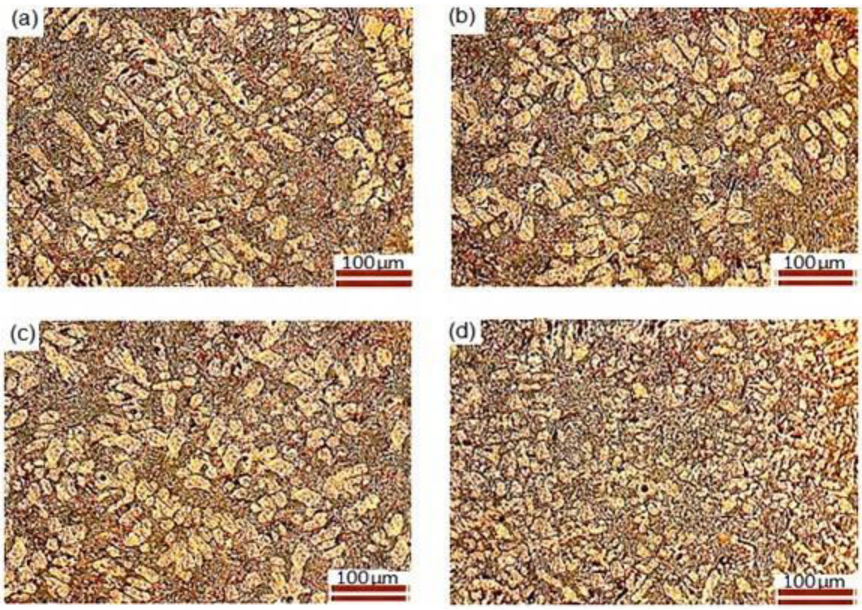

Figure-3. Microstructure of LM6 Al alloy at different squeeze pressure (a) 30 MPa, (b) 60 MPa, (c) 90 MPa and (d) 120 MPa.

The size of α-Al dendrites in composite is changed due to the addition of SiC and Al_2O_3 particles in the matrix alloy. A strong interface between matrix and reinforcements is revealed from the microstructure of composite [17]. Application of external pressure during the process of solidification increases liquidus temperature of the alloys, which brings undercooling in superheated alloy, resulted in a finer grain size. The heat transfer coefficient between the melt and mould increases by applying higher pressure, which is also resulting in grain refinement. With an increase of squeeze pressure, the heat transfer coefficient increased which leads to finer grain size [5].

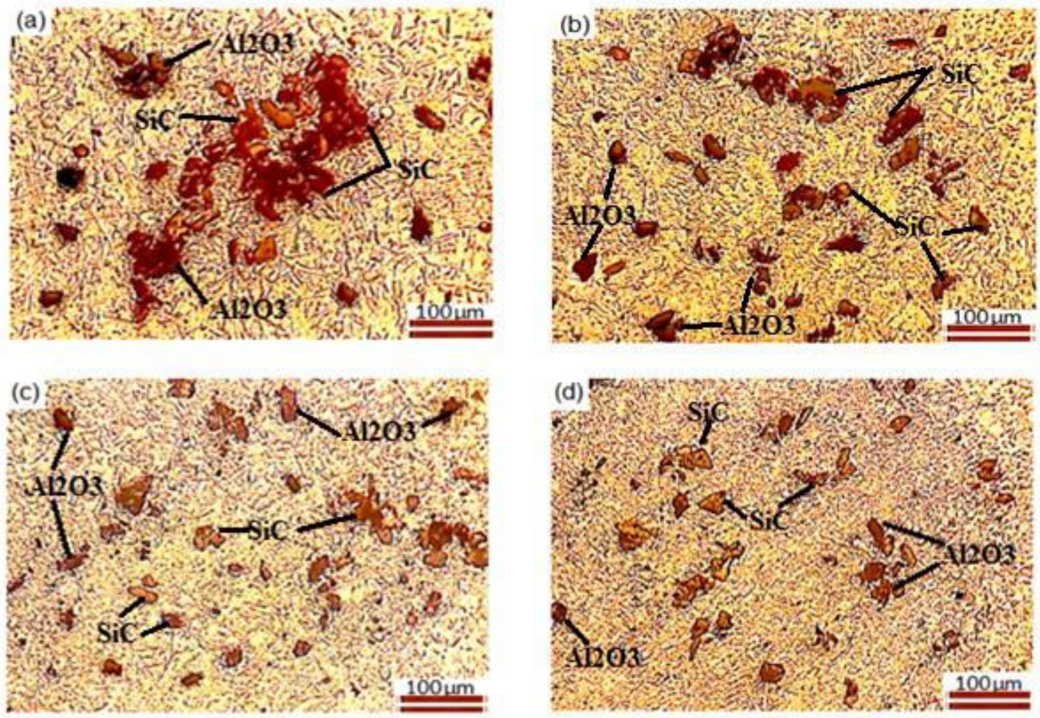

Figure-4. Microstructure of LM6/10 wt % (SiCp + Al_2O_{3P}) composite at different squeeze pressure (a) 30 MPa, (b) 60 MPa, (c) 90 MPa and (d) 120 MPa.

3.2 Mechanical properties

The relationship between the densities of composite and squeeze pressures is presented in Figure-5a. The matrix alloy, SiC and Al_2O_3 particles have the densities of 2.65, 3.2 and 3.9 g/cm^3 respectively. As the density of SiC and Al_2O_3 particles are higher than Al alloy, the density of composite is improved [17]. It is observed from Figure-5a that the density of composite increases with increasing the squeeze pressure. The variation in percentage of porosity of composite with squeeze pressures is shown in Figure-5b. The poor wettability of reinforcement particles with gas bubbles nucleating during solidification process leads to porosity in composites. Application of external pressure on melt increases the gas solubility in a liquid metal which resulting in low gas evolution. It indicates that the gas and shrinkage pores were reduced. There is a decreasing trend in porosity level with increasing squeeze pressure [5]. Figure-5c shows the variations in hardness of composite with squeeze pressures. The hard reinforcements in the soft matrix alloy increases the hardness of composite. This may be attributed to the presence of hard reinforcements, which improves the load bearing capacity of materials and restricts the deformation of matrix alloy [7]. It is evident from Figure-5c that the hardness of composite increases with increasing squeeze pressure and reaches a maximum value at a pressure of 120 MPa. This can be attributed to an increasing degree of grain refinement and low level of porosity with squeeze pressure [8].

The relationship between ultimate tensile strength (UTS) of composite and squeeze pressures is shown in Figure-5d. The uniform dispersion of SiC and Al_2O_3 particles and reduction in porosity level enhances the UTS of composite. The UTS of composite strongly depends on the weight fraction of reinforcements [14]. It is clear from Figure-5d that with an increase in the squeeze pressures the UTS of composite increases and reaches the maximum value at a squeeze pressure of 90 MPa. This improvement in tensile strength of composite can be attributed to strong bonding force at the matrix/reinforcement interface,

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reduction of porosity level and an increasing degree of grains refinement obtained upon squeezing [5]. Hence, UTS of composite decreased at a squeeze pressure of 120 MPa, the reason may be due to reinforcement particle fracture under excessive squeeze pressure and weak bonding force at the interface of matrix/reinforcement [8, 18]. Figure-5e shows the variations in yield strength of composite with squeeze pressures. The pattern of yield strength is similar to those of UTS, although with different values. The reasons for increase in yield strength are the same for those for increase in UTS.

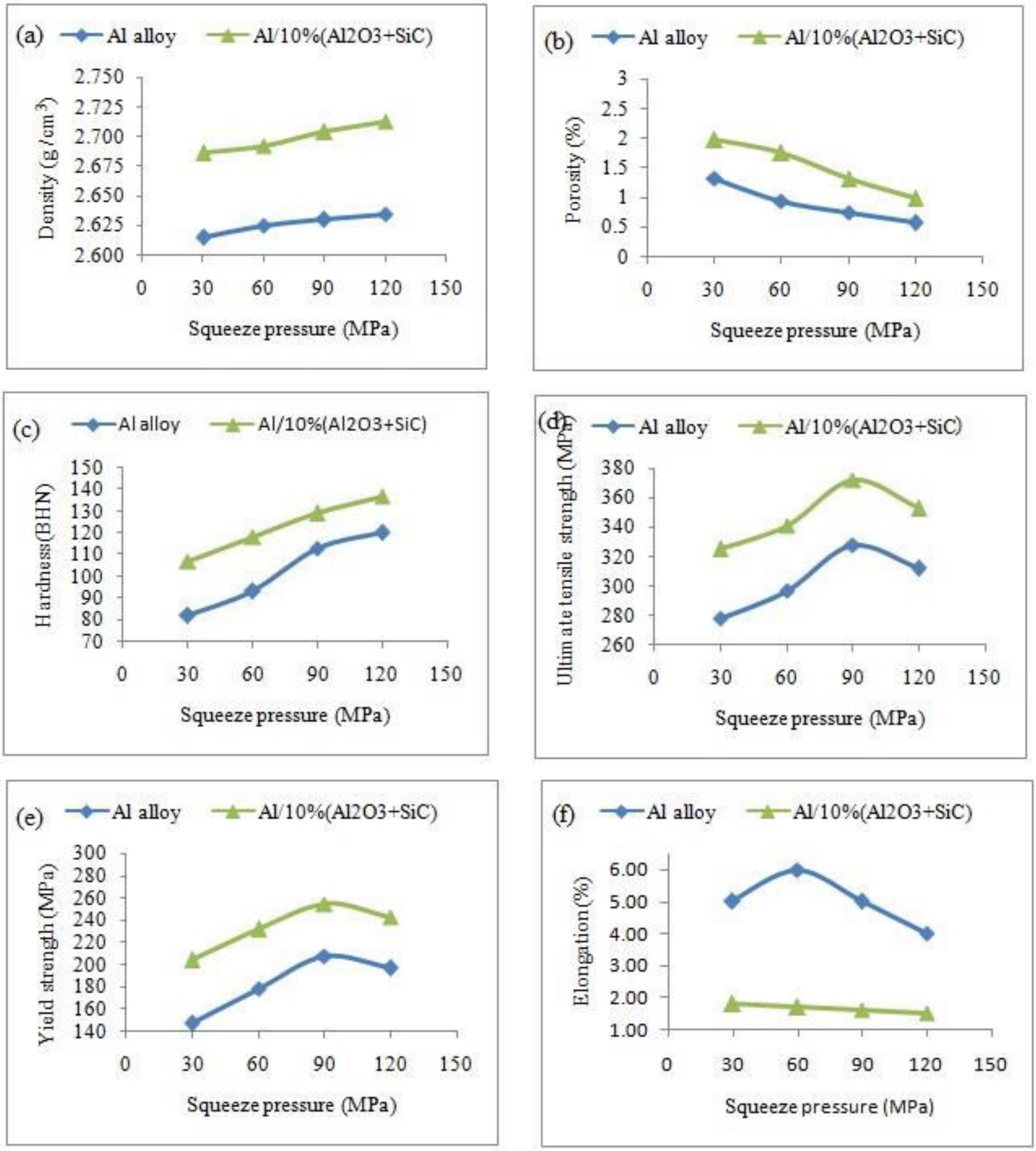

Figure-5. Relationship between the squeeze pressure and (a) density, (b) porosity, (c) hardness, (d) ultimate tensile strength, (e) yield strength and (f) elongation.

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The relationship between elongation of composite and squeeze pressures is shown in Figure-5f. The addition of SiC and Al_2O_3 particles deteriorates the ductility/elongation of LM6 aluminium alloy. The elongation of Al alloy is increased from squeeze pressure 30 MPa to 60 MPa and then decreased up to maximum pressure. The elongation of composite is decreased with increasing squeeze pressure [19].

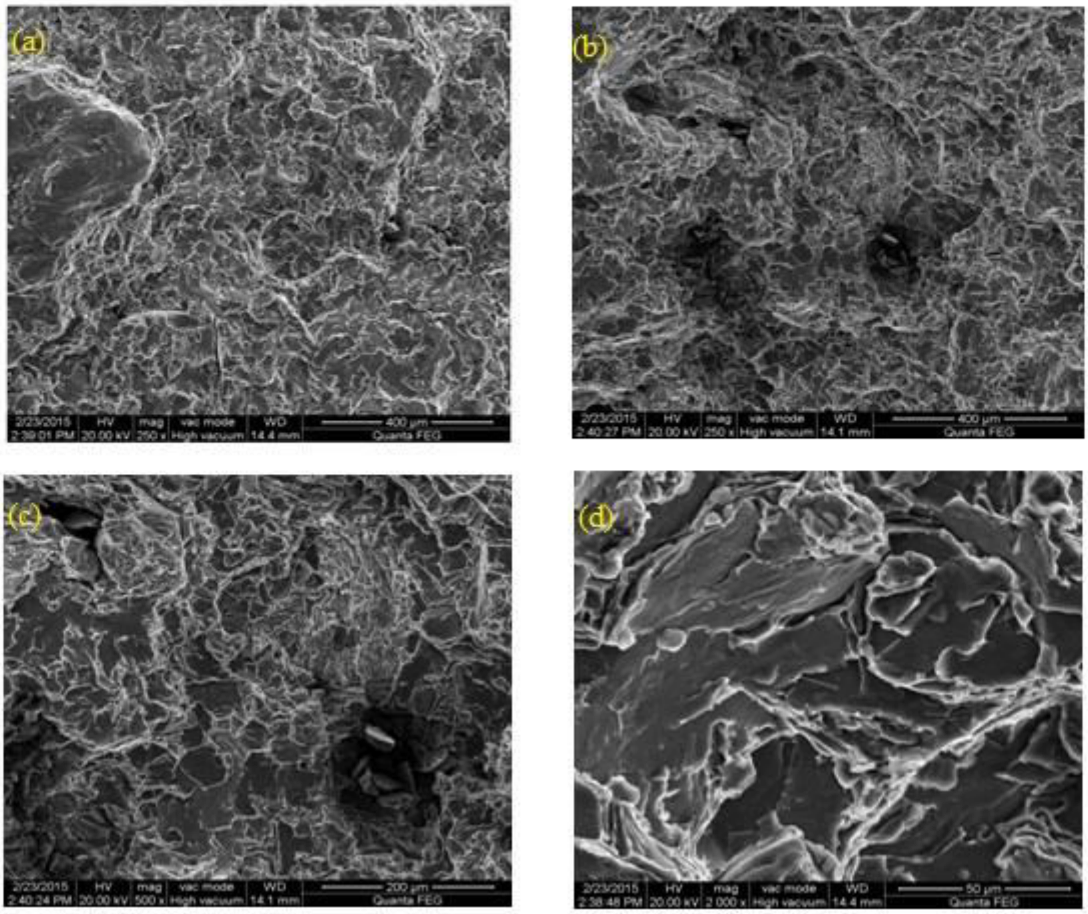

Figure-6.SEM microstructure of tensile fracture surface of (a) LM6 Al alloy and (b-d) Composites.

Fracture surface analysis of tensile specimen was observed by scanning electron microscopy (SEM). Figure-6 shows the typical SEM fractograph of tensile specimen of LM6 aluminium alloy and composite. Fracture surface of LM6 Al alloy specimen cast at 60 MPa squeeze pressure is shown in Figure-6a which revealed numerous fine size dimples indicative of ductile mode of fracture [6]. Figure-6b depicts the fracture surface of composite specimen prepared by 60 MPa squeeze pressure. In the case of composite the shape of the dimples were modified according to the shape of the second phase particles and a few pulled out particles are also observed. Two kinds of dimples were observed in composites; (i) dimples in the particle free matrix region and (ii) dimples associated with particles. The higher magnification of the fracture surface (Figure-6c) exhibits a mixed mode of brittle and ductile fracture for the composite [13]. Fracture surface of composite specimen produced at 120 MPa squeeze pressure is presented in Figure-6d. The excessive pressure applied during solidification causes particle cracking and interfaces debonding [8, 18] and it is evident from Figure-6d.

4. CONCLUSIONS

The hybrid composites of LM6 aluminium alloy reinforced with SiC and Al_2O_3 particles were fabricated by melt stirring and squeeze casting technique. The aluminium alloy and composite were subjected to microstructure, density, hardness and tensile tests. The following conclusions have been drawn from the test results.

a) The results obtained from microstructure analysis revealed that uniform distribution of SiC and Al_2O_3 particles in the matrix alloy and grain size decreased with increasing squeeze pressure.

b) The wettability and interfacial bonding between matrix alloy and reinforcements were improved by the application of squeeze pressure on the melt.
c) The density and hardness of composite enhanced due to grain refinement and low level of porosity in squeeze casting technique. The density and hardness of composite increased with increasing squeeze pressure but the porosity level of composite decreased.
d) The tensile properties such as yield strength, ultimate tensile strength of composite increased with increasing squeeze pressure but elongation decreased. The tensile fracture surface of composite specimen indicates the particle cracking and interface debonding.

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