International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 4 (2015) pp. 10671-10684

http://www.ripublication.com

Fabrication And Characterization Of Particulate Reinforced LM6 Aluminium Alloy Hybrid Composites Processed By Squeeze Casting

M.Kamaraj[1] and A.Ramesh[2]

[1]Department of Mechanical Engineering, SRM University,
Kattankulathur, Kanchipuram - 603203, India.
E-mail: kamarajmuthukumar@gmail.com
Phone: 91- 9962189209
[2]Department of Mechanical Engineering,
Sri Krishna College of Engineering & Technology, Coimbatore - 641008, India.
E-mail: ramesha@skcet.ac.in

Abstract

In the present study, LM6 aluminium alloy was reinforced with SiC and Al_2O_3 particles in three different weight fractions, using squeeze casting technique. The effects of weight fractions of reinforcements on the composite properties were investigated. The reinforcement particles were introduced into the LM6 aluminium alloy by vortex method. The molten slurry was poured into the mould and then a pressure of 90 MPa was being maintained until completion of solidification. The microstructural characterization studies revealed uniform distribution of SiC and Al_2O_3 particles in the aluminium matrix and refined grain size. The results of mechanical characterization revealed that the density, porosity, hardness and tensile strength of composites increased with an increase in weight fractions of reinforcements. Wear rate decreased linearly with an increase in the content of reinforcement particles and increased with sliding speed.

Keywords: Metal matrix composites; LM6 Al alloy; SiCp; Al_2O_3p; Squeeze casting

1. Introduction

Aluminium metal matrix composites (AMMCs) are advanced engineering materials which replace the conventional aluminium alloys in many applications due to their excellent physical and mechanical properties. In soft aluminium alloys, a hard ceramic phase in the form of fibres, whiskers, platelets and particles are incorporated to improve its properties. Particulate reinforced AMMCs are the most attractive one because of its low cost and isotropic properties compared to fibre-reinforced composite materials [1]. Based upon the processing temperature of matrix material, there are three types of fabrication techniques used to prepare particulate reinforced AMMCs. The fabrication techniques are named (i) solid phase processes, (ii) liquid phase processes and (iii) semi solid phase processes. Compared with solid phase processes, the other two processes have some advantages; simplicity, flexibility and economical to large scale production and near net shape fabrication. However, the liquid phase and semi solid phase processes deeply involves with stirring of molten metal to incorporate reinforcement particles [2,3]. The vortex created during melt stirring that sucks in air bubbles along with reinforcement particles into the molten metal which resulted in large amount of porosities in cast composites. Many investigations on stir cast AMMCs have been reported that they have high porosity content, which causes deterioration in the mechanical properties [4,5]. The liquid forging or squeeze casting of stirred molten slurry is the only possible way to eliminate the porosity in the composites. Squeeze casting is an economical, single step and near net shaping process in which the pressure is applied during solidification that results increase in solidification rate, refined microstructure, and reduction of gas and shrinkage porosities [6,7]. Herewith a brief literature survey on AMMCs prepared by melt stirred squeeze casting technique is discussed below.

Kok [8] studied the effects of reinforcement size and content on mechanical properties of metal matrix composites. The composites containing Al 2024 alloy and Al_2O_3 particles were fabricated by using a vortex method and the pressure is applied subsequently. There was an improvement in wettability and bonding force between aluminium and Al_2O_3 particles due to the application of pressure during solidification of melt and the porosity level was also minimized because of this pressure. The results indicate that the porosity, hardness, and tensile strength of composites increased by increasing the content of Al_2O_3 particles and decreasing size of particles whereas the density of composites increased with an increase in content of Al_2O_3 particles and particle size. Ali Mazahery and Mohsen Ostad Shabani [9] studied the mechanical properties of squeeze-cast A356 aluminium alloy composites reinforced with B_4C particulates fabricated by squeeze casting. They observed that the porosity, hardness, and ultimate tensile strength (UTS) of composites increased with increasing B_4C content. They reported that the great enhancement in the values of UTS in composites compared to unreinforced Al alloy that was due to refined microstructure by squeeze casting. Ali Kalkanli and Sencer Yilmaz [10] synthesised 7075 aluminium alloy composites reinforced with silicon carbide particulates using squeeze casting technique. They observed that a homogeneous distribution of SiC particulates in the composites due to rapid solidification of melt. Some agglomeration of particles have also been observed but there was no evidence of porosity. They reported that the hardness and tensile strength of composites increased with SiCp content and composites containing 10 wt% SiCp showed the maximum strength.

Sahin [11] successfully synthesized aluminium alloy composites containing various particle sizes of 10 and 20 wt. % SiC particles by using molten metal mixing and squeeze casting method. It was reported that the hardness of the aluminium alloy improved significantly by adding SiC particles into it, while density of the composite increased almost linearly with the weight fraction of particles. However, porosity level increased slightly with an increase in particulate content and decreased with increasing particle size. Huseyin Sevik and Can Kurnaz [12] investigated the effects of volume fractions and size of Al_2O_3 particles on mechanical and wear properties of Al-Si based alloy (LM6) composites produced by using vortex method and pressure die-casting technique. They reported that addition of Al_2O_3 particles enhanced the density of composites and the hardness of composites increased with increasing particle content and decreasing particle size. The tensile strength of the composites decreased with an increase in particle content and size. The wear rate of composites decreased with increasing particle volume fraction and decreasing particle size but increased proportionally to the applied load. 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 vortex and squeeze casting technique. The objective of this study is to (i) produce particulate reinforced aluminium matrix composites using vortex and squeeze casting methods, (ii) investigate the effects of weight fractions of reinforcements on mechanical and wear properties.

2. Experimental procedure

In the present study, Al-Si based alloy (LM6) was selected as a base material because it exhibits high strength at elevated temperature and excellent resistance to corrosion and wear. Table 1 gives the chemical composition of the LM6 aluminium alloy. Silicon carbide (SiCp) and alumina (Al_2O_{3P}) particles were chosen as second phase material to fabricate hybrid AMMCs. The average particle size of SiCp and Al_2O_{3P} were 45 µm and 35 µm respectively. The composites were processed by using vortex method and squeeze casting technique and the experimental setup is shown in Fig. 1. The particle incorporation, mixing and casting under pressure are the most important stages in the processing of composites.

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	85.95 - 87.95

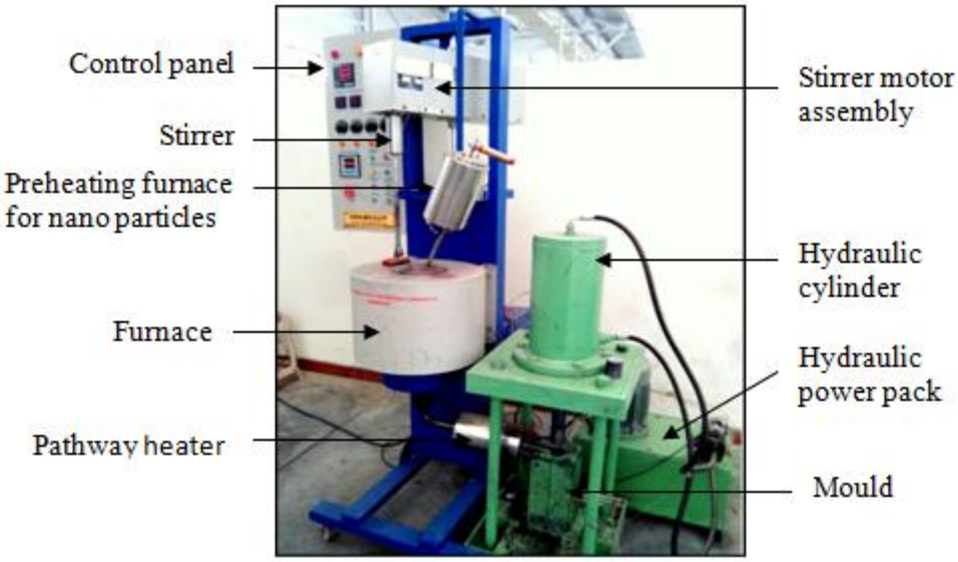


Fig. 1. Squeeze casting set up.

A measured amount of LM6 Al alloy is melted in an electrical resistance heating furnace and the temperature of Al alloy was maintained around 750°C. The SiC and Al_2O_3 particulates were preheated at 800°C for 2 hr to improve their wettability with the matrix alloy. The superheated Al alloy melt was degassed fully using hexachloroethane tablets and then the mechanical stirrer was positioned in the melt to add second phase particles. The molten metal was stirred at the approximate speed of 375 rpm and then three different weight percentages (5, 10 and 15) of ceramic particles in equal proportions were added gradually in the vortex. To obtain homogeneous mixing, the stirring was extended for another few minutes after adding the second phase particles. The pouring temperature has been maintained at 720°C and the cast iron mould was preheated to 250°C to obtain uniform solidification. A hydraulic press with a maximum capacity of 100 ton and 50 mm diameter punch was used to shape the castings. The molten slurry was poured into the mould and then a pressure of 90 MPa has been maintained until completion of solidification. After the fabrication of composite castings, specimens were prepared from these castings.

The dispersion of second phase particles in the matrix alloy was examined using an optical microscope. The specimens for microstructural study were carefully prepared by using standard metallographic procedures. Archimedes principle was used to measure the experimental density, while rule of mixture gives the theoretical density according to the content of second phase particles. The porosity was estimated by using the theoretical and experimental densities. The hardness measurements were carried out using Brinell hardness tester. The load of 500 kg is applied on the specimen for 30 s using 10 mm steel ball indenter. The impression of indenter on the specimen was measured and the value of hardness was estimated. According to ASTM E8M - 04 standards the tensile specimen was prepared (Fig. 2). The tensile test was performed using a universal tensile testing machine and then the ultimate tensile strength was estimated. Three trials have been carried out for the purpose of repeatability and the average of them presented here.

A pin on disc wear testing apparatus (Model: TR 20 LE – M108, Ducom Make, Bangalore, India) was used to study the wear behaviour of composites. The test was performed under dry sliding conditions at room temperature as per ASTM G99 – 03 standards. The pin specimen was made with a diameter of 10 mm and length of 30mm from the casting. The disc was made of EN32 steel with a hardness of 65 HRC. The test was carried out under the following conditions: applied load 19.62 N, sliding speeds 1.51, 2.26 and 3.02 m/s and sliding time 15 min. The pin specimen was weighed before and after testing and then the amount of wear loss was calculated from the weight differences. For each experimental condition, a set of three samples were tested and the average wear loss was reported. The worn surface of the pin specimens were analyzed by scanning electron microscopy.

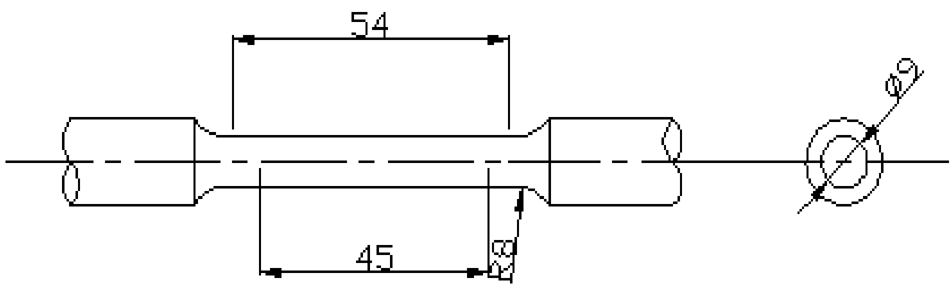


Fig. 2. Schematic diagram of tensile specimen (dimensions in mm).

3. Results and discussion

3.1 Microstructure

In the fabrication of AMMCs, the dispersion of reinforcements plays an important role to obtain the desired properties in the material. Fig. 3(a) shows the microstructure of LM6 Al alloy and the phases present are aluminium in dendritic network structure and eutectic silicon with plate shape. The composites microstructures are shown clearly in Fig. 3(b)-(d) that indicate the uniform distribution of SiC and Al_2O_3 particles in the matrix. The size of aluminium dendrites in composites is reduced 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 composites. Application of external pressure during solidification results in an increase in heat transfer coefficient and liquidus temperature of the alloys. Higher cooling rates employed by squeeze casting which leads to uniform distribution of second phase particles and refinement of microstructure.

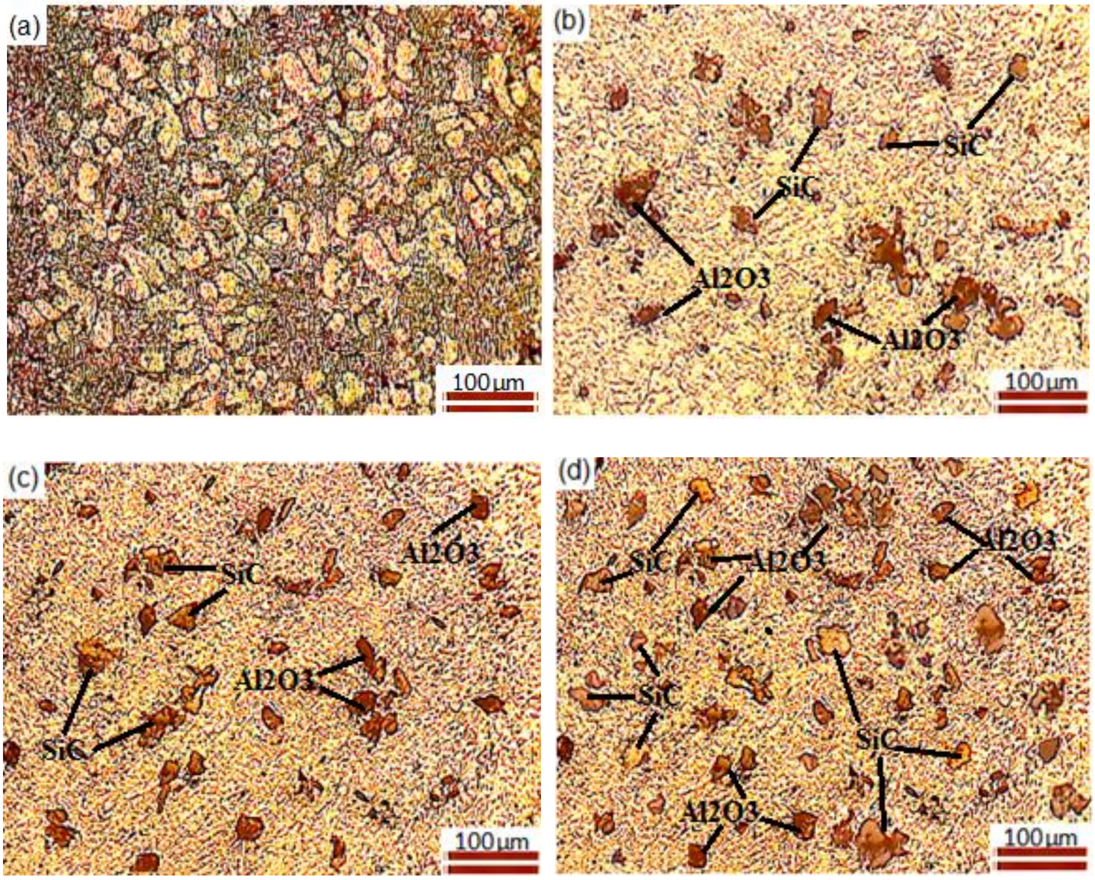


Fig. 3. Microstructure of LM6 Al alloy and composites (a) Al alloy, (b) 5wt % ($SiCp + Al_2O_{3P}$), (c) 10 wt % ($SiCp + Al_2O_{3P}$) and (d) 15wt % ($SiCp + Al_2O_{3P}$).

3.2 Density and porosity

The relationship between the density of the composites and weight fractions of reinforcements is presented in Fig. 4(a). As the density of SiC and Al_2O_3 particles are higher than Al alloy, the density of composites is improved. The theoretical density of composites increases linearly with increasing the content of SiC and Al_2O_3 particles based on rule of mixtures. The experimental densities of composites are lower than the theoretical densities. The casting defects are minimized in squeeze casting which resulted improvement in density. It is observed from Fig. 4(a) that the density of composites increases with increasing the weight fractions of reinforcements [8]. The variation in porosity of composites with weight fractions of reinforcements is shown in Fig. 4(b). It is evident from Fig. 4(b) that the porosity of composites increases with weight fractions of reinforcement. This could be long duration of reinforcement addition into Al alloy with increasing weight fractions of SiC and Al_2O_3 particles. The porosity of composites is significantly reduced in squeeze casting due to solubility of gas in liquid melt that increases under an applied pressure [11].

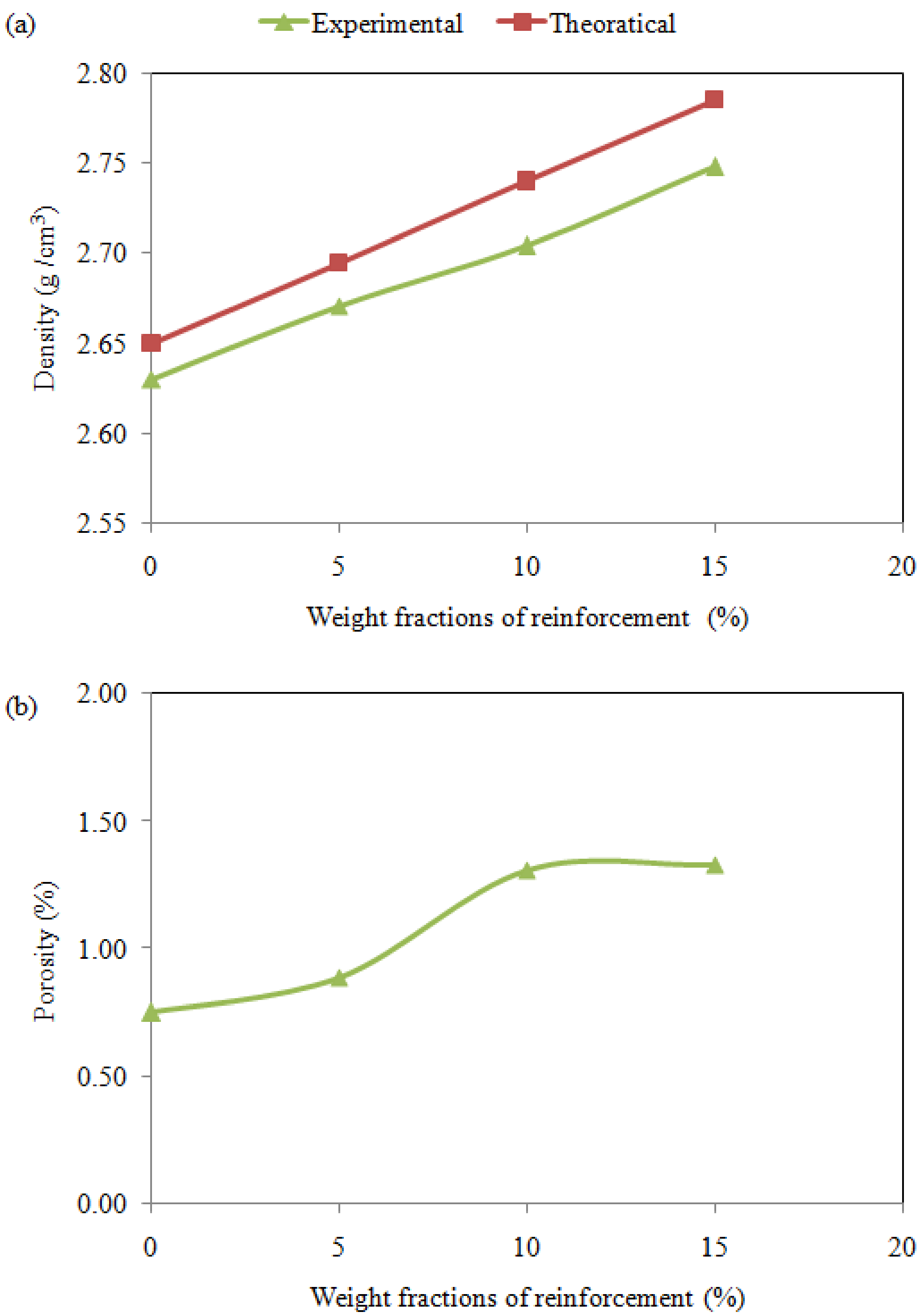
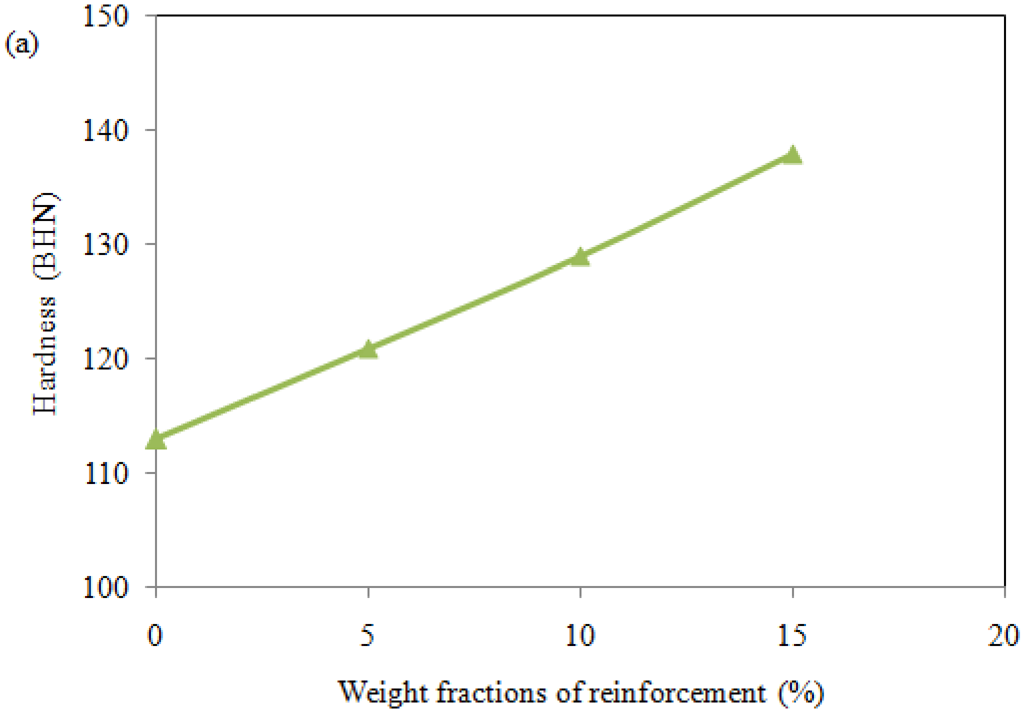


Fig. 4. Effects of weight fractions of reinforcement on (a) Density and (b) Porosity of composites.

3.3 Hardness and tensile strength

Fig. 5(a) shows the variations in hardness of composites with weight fractions of reinforcements. The hard reinforcements in the soft matrix alloy increases the hardness of composites. The hardness of squeeze cast composites is improved because of low porosity. It is noted from Fig. 5(a) that the hardness of composites increases with weight fractions of reinforcements. This can be attributed to the presence of hard reinforcements, which improves the load bearing capacity of materials and restricts the deformation of matrix alloy [8]. The effect of weight fractions of reinforcements on ultimate tensile strength (UTS) is shown in Fig. 5(b). The UTS of squeeze cast composites enhanced because of homogeneous dispersion of second phase particles, reduction in porosity level, strong bonding force at the matrix/reinforcement interface and refinement of microstructure. Thus the UTS of composites strongly depend on the weight fraction of reinforcements [9].



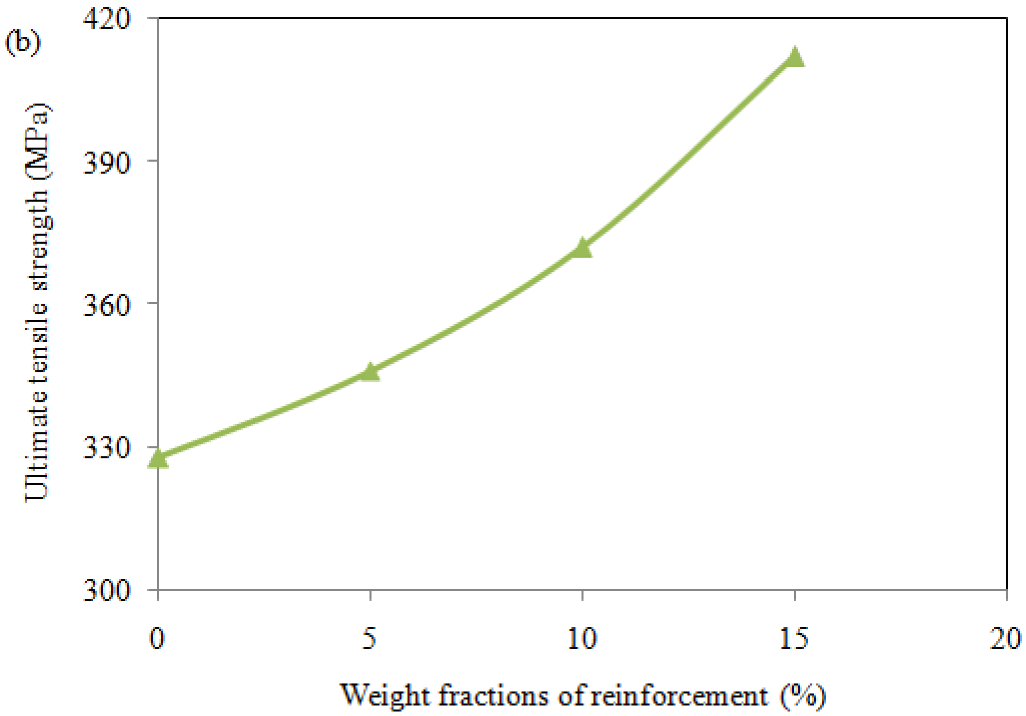


Fig. 5. Effects of weight fractions of reinforcement on (a) Hardness and (b) Tensile strength of composites.

3.4 Wear rate

The wear test was conducted for various weight fractions of composite and the average wear rates (mm^3/s) for the matrix alloy and composites was calculated. The wear resistance of composites depends upon the wear resistance and hardness of reinforcement particles. The wear rates are illustrated graphically in Fig. 6 as a function of weight fractions of composites and sliding speed. It is evident from the graphs that wear rate decreases linearly with an increase in the content of reinforcement particles. The wear rate of composites is reduced due to the incorporation of hard SiC and Al_2O_3 particles into matrix alloy. The hard ceramic particles in the matrix alloy limits the plastic deformation and resist the penetration of the counter surface asperities that results a low amount of material loss in composites [12,13]. Because of the lower degree of effective contact between the sliding surfaces, the wear rate of composites decreases with an increase in the content of SiC and Al_2O_3 particles. From the observation it is found that the wear rate increases linearly with increasing sliding speed. At lower sliding speed the composite surface is protected from severe wear by a mechanically mixed layer (MML) formed at pin/disc interface. In composite, the MML is stronger than in Al alloy and contains more amount of iron and aluminium oxide. At higher speeds, the MML is broken down by subsurface plastic deformation and worn out reinforcement particles from pin specimen. The direct metallic contact between the sliding surfaces resulted in higher wear rates [13,14].

The worn surfaces were examined using scanning electron microscope (SEM) equipped with Energy dispersive X-ray spectroscopy. Fig. 7 depicts the worn surface of Al alloy and the composites with 10 wt % (SiCp + Al_2O_3p) reinforcement. The worn surface of Al alloy at 1.51 m/s speed (Fig. 7(a)) shows the long continuous grooves parallel to sliding direction, tearing of surface and formation of MML. Fig. 7(b) the worn surface of Al alloy at 3.02 m/s sliding speed shows the breakdown of MML along with the sliding direction. As the Al alloy was much softer than the steel disc, the asperities of the steel disc could penetrate deeply into the surface of Al alloy that resulted extensive plastic deformation on the surface and so there was a greater amount of material loss [15]. The worn surface of composite at 1.51 m/s sliding speed shows (Fig. 7(c)) smooth wear grooves, some damaged region and the existence of worn out particles. The degree of contact between the sliding surfaces was low in composites because of second phase particles. The hard ceramic particles protect the wear surface which resulted a low amount of material loss in composites. The worn surface of composite at 3.02 m/s sliding speed is shown in Fig. 7(d). The MML was removed from the surface at higher speed due to the thermal softening of Al alloy [14]. Worn surface analysis demonstrated that a combination of abrasion and delamination wear mechanism have been occurred in matrix alloy and composites. The mechanically mixed layer (MML) at the interface of pin and disc was observed by Energy dispersive X-ray spectroscopy (EDS) analysis. The EDS analysis of worn surface of composite pin specimen (Fig. 8) shows the transfer of Fe, Cr, and O from steel disc which can be a part in the formation of MML.

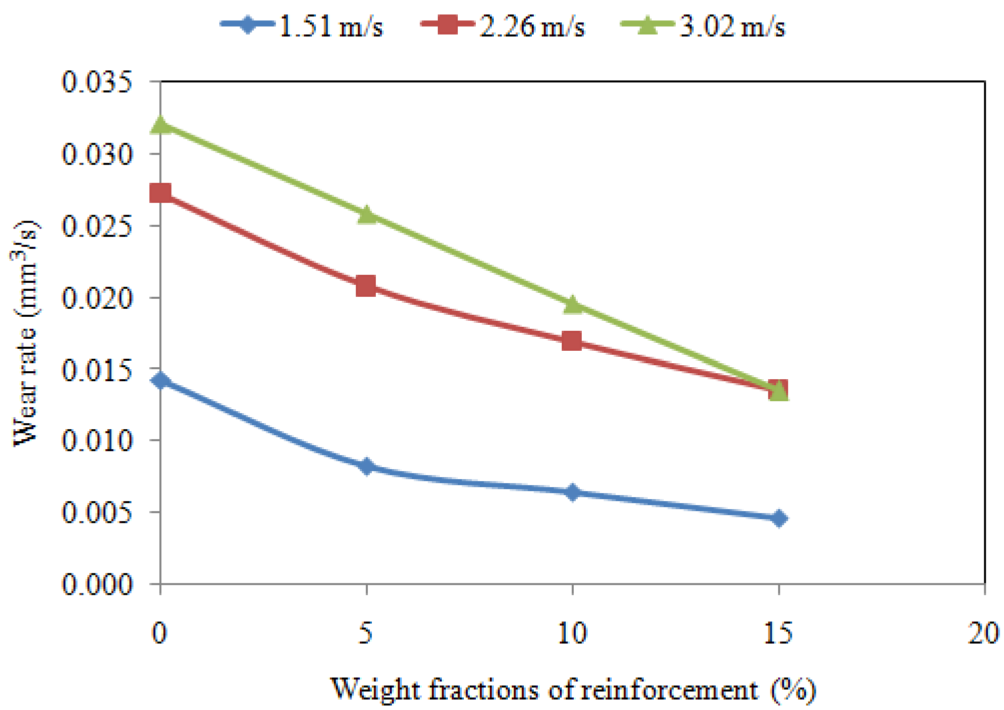
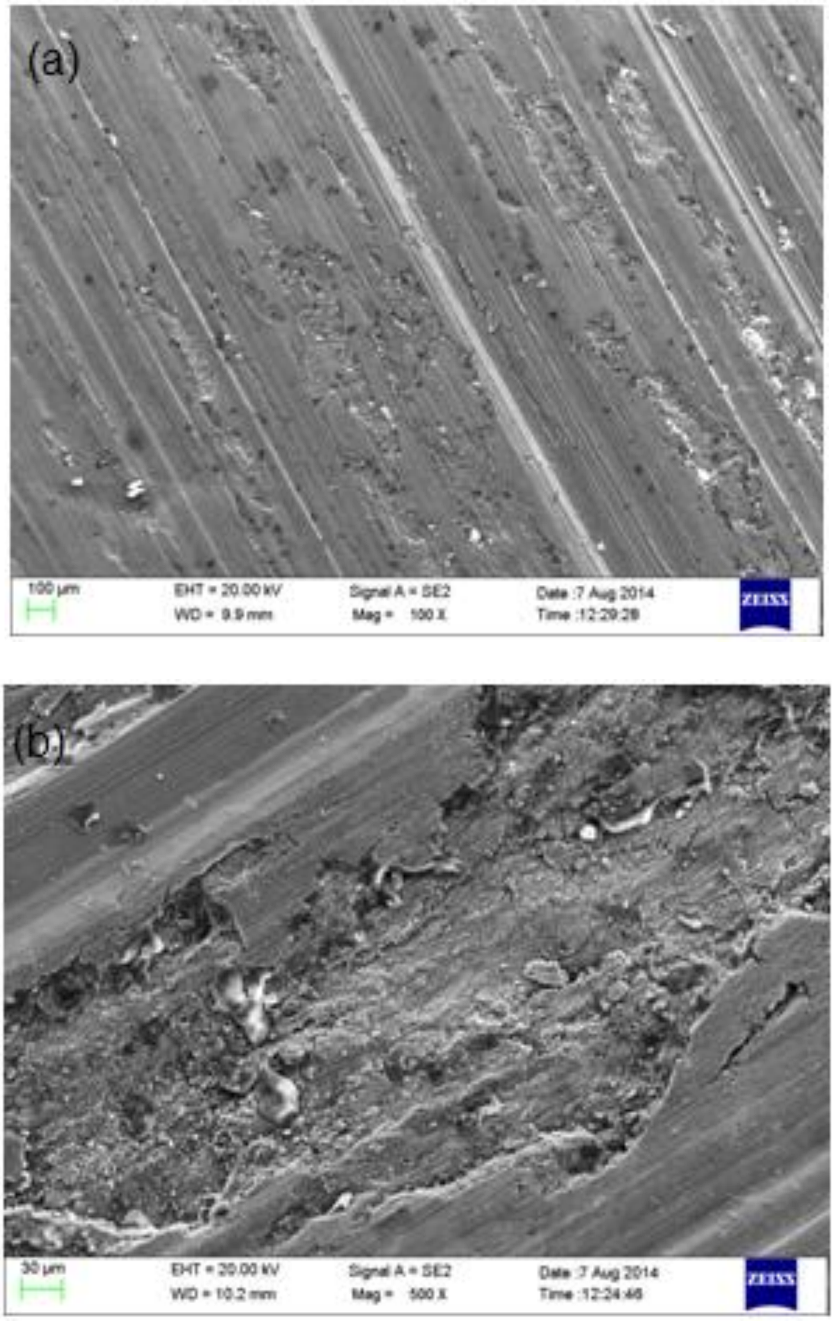


Fig. 6. Variations in wear rate with weight fractions of reinforcement for various sliding speeds.


(a)
100 µm
EHT = 20.00 kV
WD = 9.9 mm
Signal A = SE2
Mag = 100 X
Date :7 Aug 2014
Time :12:29:28
ZEISS
(b)
30 µm
EHT = 20.00 kV
WD = 10.2 mm
Signal A = SE2
Mag = 500 X
Date :7 Aug 2014
Time :12:24:46
ZEISS

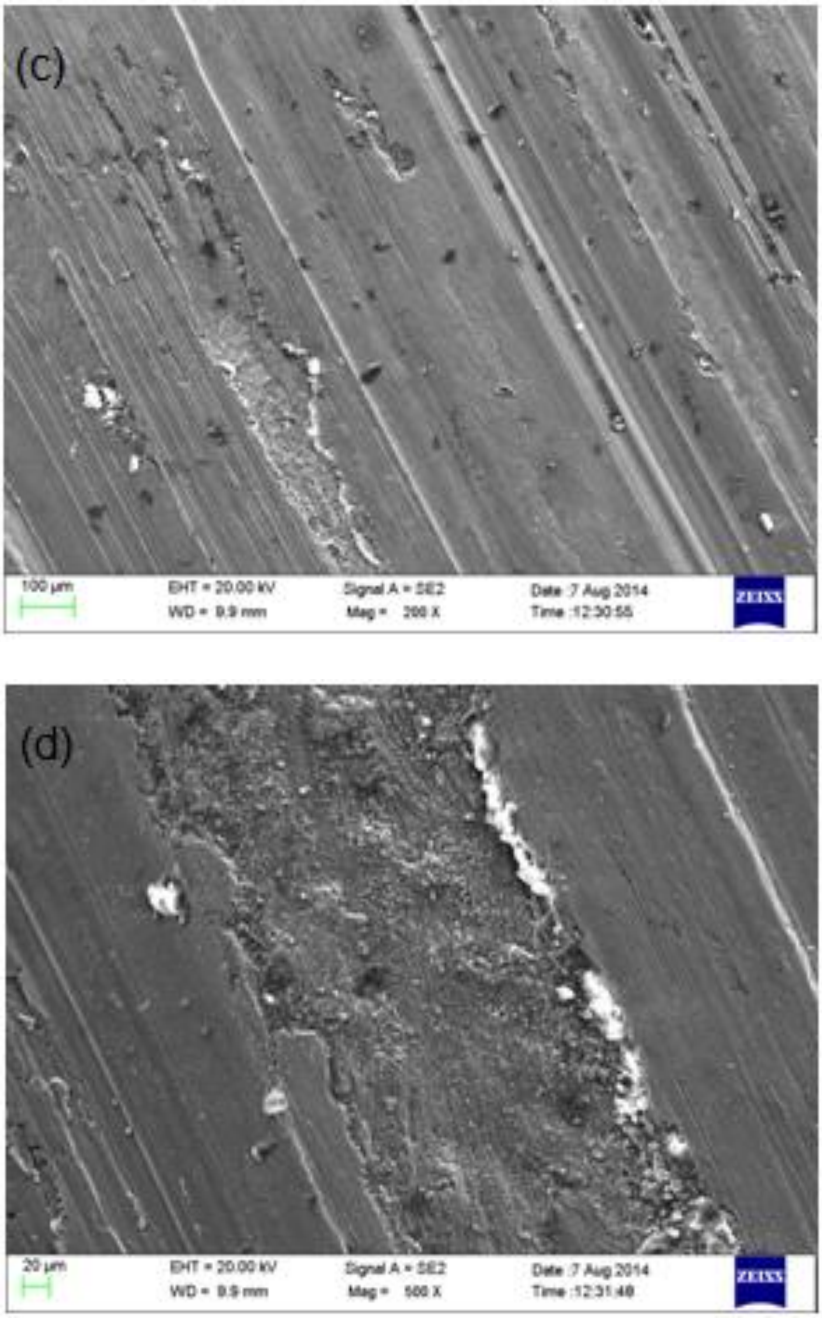


Fig. 7. Worn surface of Al alloy at (a) 1.51 m/s, (b) 3.02 m/s, and Al/10 wt% ($SiCp + Al_2O_3p$) composite at (c) 1.51 m/s, (d) 3.02 m/s.

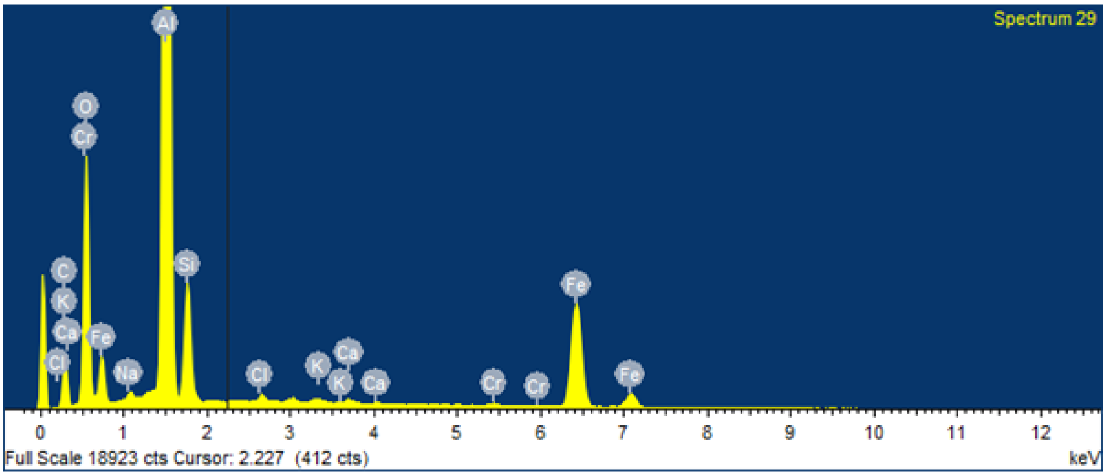


Fig. 8. EDS analysis of Al/10 wt% (SiCp + Al_2O_3p) composite.

4. Conclusion

The LM6 aluminium alloy matrix composites reinforced with SiC and Al_2O_3 particles were successfully fabricated by squeeze casting technique. The following conclusions have been arrived:

1. The results of microstructure investigation revealed that second phase particles are uniformly distributed and grain sizes refined because of the pressure applied during the solidification of melt.
2. Addition of SiC and Al_2O_3 particles increased the density of composites and the porosity of composites increased with increasing weight fraction of reinforcements. The porosity level of the composites was significantly reduced in squeeze casting.
3. The hardness and tensile strength of composites increased with increasing weight fractions of reinforcements. These improvements can be attributed to strong matrix/reinforcement interface, reduction of porosity level and grain refinement obtained upon squeezing.
4. Wear rate decreased linearly with an increase in the content of SiC and Al_2O_3 particles and increased with increasing sliding speed. Worn surface analysis demonstrated that a combination of abrasion and delamination wear mechanism occurred in matrix alloy and composites.

References

[1] Ibrahim, I.A., Mohamed, F.A., and Lavernia, E.J., 1991, “Particulate reinforced metal matrix composites – a review”, J. Mater. Sci., 26, pp. 1137–1156.

[2] Huda, D., El Baradie, M.A., and Hashim, M.S.J., 1993, "Metal matrix composites: Manufacturing aspects. Part I", J. Mater. Process. Technol., 37, pp. 513–538.

[3] Brain Ralph, Yuen, H.C., and Lee, W.B., 1997, "The processing of metal matrix composites – an overview", J. Mater. Process. Technol., 63, pp.339–353.

[4] Ghosh, P.K., and Ray, S., 1987, "Effect of porosity and alumina content on the high temperature mechanical properties of compocast aluminium alloy - alumina particle composites", J Mater Sci, 22, pp. 4077 – 4086.

[5] Hashim, J., Looney, L., and Hashmi, M.S.J., 1999, "Metal matrix composites: Production by the stir casting method", J. Mater. Process. Technol., 92 – 93, pp. 1–7.

[6] Ghomashchi, M.R., and Vikhrov, A., 2000, "Squeeze casting: an overview", J. Mater. Process. Technol., 101, pp. 1 – 9.

[7] Yue, T.M., and Chadwick, G.A., 1996, "Squeeze casting of light alloys and their composites", J. Mater. Process. Technol., 58, pp. 302 – 307.

[8] Kok, M., 2005, "Production and mechanical properties of Al_2O_3 particle reinforced 2024 aluminium ally composites", J. Mater. Process. Technol., 161, pp. 381–387.

[9] Ali Mazahery, and Mohsen Ostad Shabani, 2012, "Mechanical Properties of Squeeze-Cast A356 Composites Reinforced With B_4C Particulates", J. Mater. Engg. Performence, 21, pp. 247 –252.

[10] Ali Kalkanli, and Sencer Yilmaz, 2008, "Synthesis and characterization of aluminium alloy 7075 reinforced with silicon carbide particulates", Mater. Des, 29, pp. 775–780.

[11] Sahin, Y., 2003, "Preparation and some properties of SiC particle reinforced aluminium alloy composites", Mater. Des, 24, pp. 671–679.

[12] Huseyin Sevik, and Can Kurnaz, 2006, "Properties of alumina particulate reinforced aluminium alloy produced by pressure die casting", Mater. Des, 27, pp. 676–683.

[13] Rao, R.N., and Das, S., 2010, "Effect of SiC content and sliding speed on the wear behaviour of aluminium matrix composites", Mater Des xxx, pp. xx-xx.

[14] Adem Onat, 2010, "Mechanical and dry sliding wear properties of silicon carbide particulate reinforced aluminium–copper alloy matrix composites produced by direct squeeze casting method", Journal of Alloys and Compounds, 489, pp.119 –124.

[15] Ali Mazahery, and Mohsen Ostad Shabani, 2012, "Influence of the hard coated B4C particulates on wear resistance of Al–Cu alloys", Composites: Part B, 43, pp. 1302–1308.