Effect of SiC Reinforcement on Microstructure and Mechanical Properties of Aluminum Metal Matrix Composite

To cite this article: Pavitra Ajagol *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **376** 012057

Effect of SiC Reinforcement on Microstructure and Mechanical Properties of Aluminum Metal Matrix Composite

Pavitra Ajagol[1], Anjan B N[2*], Rajaneesh N Marigoudar[3], Preetham Kumar G V[2]

[1]Department of Mechanical Engineering, Sahyadri College of Engineering and Management, Mangalore, Karnataka, India.
[2]Department of Metallurgical and Materials Engineering, National Institute of Technology Karnataka, Surathkal, Mangalore, India.
[3]Department of Mechanical Engineering, Jain Institute of Technology, Davanagere, Karnataka, India.
[*]Corresponding author Email Id:anjanbn89@gmail.com,

Abstract: Aluminum reinforced with silicon carbide composites areextensively used in automobile industries and aerospaceowing to their favourable microstructure and improved mechanical behaviour with respect to pure aluminium but at a lower cost. Aluminium is remarkable for the low density and its ability to resist corrosion. The aim of present study istoevaluate the mechanical and microstructural properties of aluminum with silicon carbide (average particle size 30-45μm) reinforced in varying weight percentages (wt %) ranging from 0–15 wt% in a step of 5% each. Ultimate tensile strength, micro hardness and density of the fabricated composites were investigated as a function of varying SiC wt%. Microstructure analysis was carried out on casted composites using optical microscopy and scanning electron microscopy. From micrographs it is clear that fair distribution of reinforcing particles in the matrix and also observed some clustering and porosity in the cast material. Results revealed that, the addition of SiC reinforcement in the aluminum matrix increases the hardness and ultimate tensile strength gradually from 23 HV to 47 HV and 84 MPa to 130 MPa respectively.
Key words:MMCs, Silicon carbide, Mechanical properties, Hardness, Tensilestrength.

1. Introduction

Aluminum is most abundant and naturally occurring metal in the earth's crust, modern life needs the aluminum as an essential element. The conveniences of today's world would not be simple, without the proper utilization of aluminum by which it increases the sustainability of national economy. Aluminium and its alloys as a base metal in metal matrix composites (MMCs)[1] plays a prominent role in order to make present materials more commercially attractive.Metal matrix composites are materials with metals as the base matrixand typically ceramic or organic compounds added as reinforcements to enhance the properties. The reinforcements will be in the form of particulates, whiskers and fibers. Metal matrix composites can be tailored by varying the nature of the components and their volume fraction [2]. The MMChas superior properties as compared with the base metal likecreep resistance, improved strength, wear resistance, stiffness, conductivity, dimensional stabilityetc.Generally used reinforcements are graphite, boron carbide (B_4C), silicon carbide (SiC),aluminium oxide (Al_2O_3),Zirconium silicate ($ZrSiO_4$) andtitanium di-boride (TiB_2)[3-5].The tailorability is a key advantage of all types of composites, but it is particularly so in the case of MMCs. There are numerousconventional processing methodsof fabricating metal based composites such as co-spray deposition process, vacuum hot pressing, powder metallurgy,stir casting and squeeze casting methods. The stir casting method is commonly preferred for discontinuously reinforced metal matrix composites because of its simplicity, inexpensive and offers a wide selection of processing conditions and materials.In general, the solidification synthesis of MMCs includespreparing a melt of selected matrix material followed by the incorporation of a reinforcement material into the melt by constant stirring to achieve a suitable dispersion. To attain higher strength in composites, the basic requirement is strong interface bond between matrix and reinforcement.By preheating of the reinforcement and the addition of small amount of magnesium will help in good wetting of the reinforcements inmolten matrix during casting [6-7].A few researchers made an investigation on Al based composites reinforced with SiC particles + graphite fibres, Al_2O_3 particulates, carbon short fibres + Al_2O_3 short fibres, Al_2O_3 fibres + SiC particles and many are available in which studies on effect of volume fraction, particle size and type of reinforcement were reported [8-18]. The literature review reveals that the main problem was to get uniform dispersion of the reinforcement by using the cost conventional technique for commercial applications likeheat sinks, substrates for electronics, heat spreaders,lids for electronic chips and also in automobile industries.In the present study, Al-SiC composites containing 5%, 10% and 15% weight fractions of silicon carbide particles were prepared with the use of stir casting technique. The effects of volume fraction of SiC particles and its dispersion on the properties of Al/SiC composites were investigated. The properties such as density, tensile strength, micro Vickers hardness and microstructure of the composites were analyzed.

2. Experimental Work

2.1.Materials Used

The materials used in the fabricationareAl (1100) and SiC. Al (1100) procured from PMC Corporation Ltd., was used as the matrix material. The SiCof average particle size 30-45µm procured from KemphasolPvt. Ltd. was used as the reinforcement material for the fabrication process. The chemical composition analysis is carried out using optical emission spectrometer and the composition is as shown in the Table 1.

Table1 Chemical composition of the Aluminum (1100)

Elements	Aluminium	Beryllium	Copper	Iron	Manganese	Vanadium
Percentage(%)	99	0.0008	0.05	0.04	0.05	0.038

2.2. Fabrication

Liquid state fabrication of MMCs involves integration of dispersed ceramic phase into a molten metal, followed by its solidification process. Stir casting technique is the simplest and the most cost effective method in all liquid state fabrication processes. Figure 1 shows the schematic diagram of the stir casting setup for the fabrication of metal matrix composites.

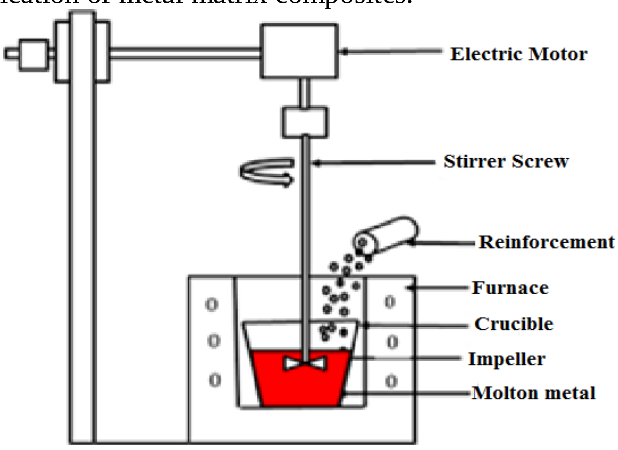


Figure1 Schematic diagram of stir casting Setup for the fabrication of MMC

A weighted quantity of aluminum in the form of ingots was taken in the graphite crucible and temperature is raised such that a uniform phase of molten aluminium is formed. Calculated amount of flux was added to minimize the oxidation of the molten aluminium. To minimize voids, porosity and blow holes formation in the fabricated specimen, degassing tablets are put in to the molten aluminium. Thus obtained melt was stirred using a stainless steel impeller at a speed 600 rpm tocreate the vortex [19]. The impeller blades were designed in such way that it creates a vortex to achieve the sound particle mixing[20]. The reinforcement is preheated to a temperature of 450 ^{o}C to remove the oxide layer around the SiC particle and to create a good bonding between matrix and particles[21]. Soon after the formation of vortex in the melt, the reinforcing particles were introduced with a separate pouring attachment at the rate of 15–20 g/min into the melt during stirring and also a small quantity of magnesium was added to increase the wettability of SiC Particles. The stirring was continued for another fewminutes, even after the completion of particle feeding to achieve homogeneous distribution of the reinforcing particles. The mixture was poured in to the preheated permanent metallic mould of dimension 45 x 60 x 100 mm (LxBxH). The temperature of 680^{o}C was maintained during pouring. The melt was allowed in the mold for complete solidification. The similar processing condition was used to cast the base material for comparison. Three sets of composites of Al/SiC were fabricated by varying SiC content in volume percentage and the composition is shown in table 2. During stir casting process, the stirring duration,the position of stirrer in the crucible and the quantity of matrix material usedwas kept constant to minimize the contribution of variables related to stirring on the distribution of reinforcing particles [22].

Table2 Composition of mixtures for each composite

Matrix	Reinforcement
Al - 100 %	SiC 0%
Al - 95%	SiC 5%
Al - 90%	SiC 10%
Al - 85%	SiC 15%

2.3 Microstructure Characterization

Microstructural characterizations were conducted on both unreinforced and reinforced as cast samples. The specimenpreparation is done in three steps, i.e., ground, polished and etched,after that the same samples were observed under optical microscope. The specimens were mounted and mechanically polished on a series of silicon carbide (SiC) abrasive papers of increasingly finer grit sizes and using diamond paste of size (1μm) with special polishing cloth. Specimens will be chemically etched using Keller's Reagent (190ml distilled water,5 ml Nitric acid, 3 ml Hydrochloric acid and 2 ml Hydrofluoric acid) for about 25-30 seconds. Then the samples were washed with running water and alcohol further it is completely dried. Optical examination of the samples was performed using optical microscope equipment connected to a computer. The morphology of the composites was studied by scanning electron microscope (JEOL JSM-6380LA).

2.4Mechanical Properties Evaluation

The tensile specimen was prepared by machining as per the ASTM E-8 standards [23]. The dimensions of the tensile specimens are as shown in figure 2 and the test was conducted using Shimadzu AG-X plus TM 100kN, universal testing machine with a fixed crosshead speed of 1mm/min and tensile properties like ultimate tensile strength, percentage elongation and fracture surfaces of the tensile tested samples were also analyzed.

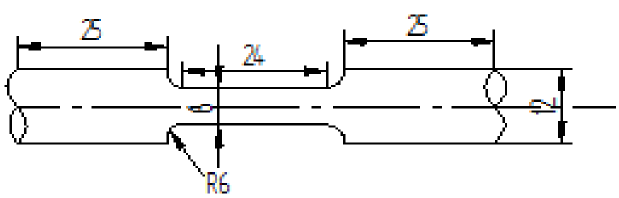


Figure 2ASTM E8 tensile specimens

The theoretical and experimental densities of each composition of the Al/SiC reinforced composites were compared. The experimental density was determined by dividing the measured weight of a test

IOP Conf. Series: Materials Science and Engineering **376** (2018) 012057 doi:10.1088/1757-899X/376/1/012057

specimen by its measured volume and theoretical density was evaluated by using the rule of mixtures [24]. The percent porosity of the composites was calculated using the equation (1).

$$\% \text{ porosity} = \{(\rho T - \rho Ex) \div \rho T\} \times 100\% \quad (1)$$

Where, ρT = Theoretical density (g/cm^3),
ρEx = Experimental density (g/cm^3).

Vickers hardness measurements were carried out in order to examine the influence of SiC particles on matrix hardness. The test samples were sectioned using an abrasive cutter, then ground and polished using conventional metallographic methods and hardness measurements were carried out using Zwick Vickers hardness tester at100 gf load applied for 15Seconds.Six readings for hardness values were taken for each sample and the average hardness (HV) were reported.

3. Results and Discussion

Microstructural analysis gives us an idea about the distribution of the reinforced particles in the matrix, which has a great influence on the properties of the composite. Figure 3 shows the optical micrograph of (a) Aluminium (1100) without Silicon carbide (b) Aluminium with SiC 5%, (c) Aluminium with SiC 10%, and (d) Aluminium with SiC 15%. It is clearly observed that the reinforcing particles are visible and the particles are fairly distributed in composites with some clusters.

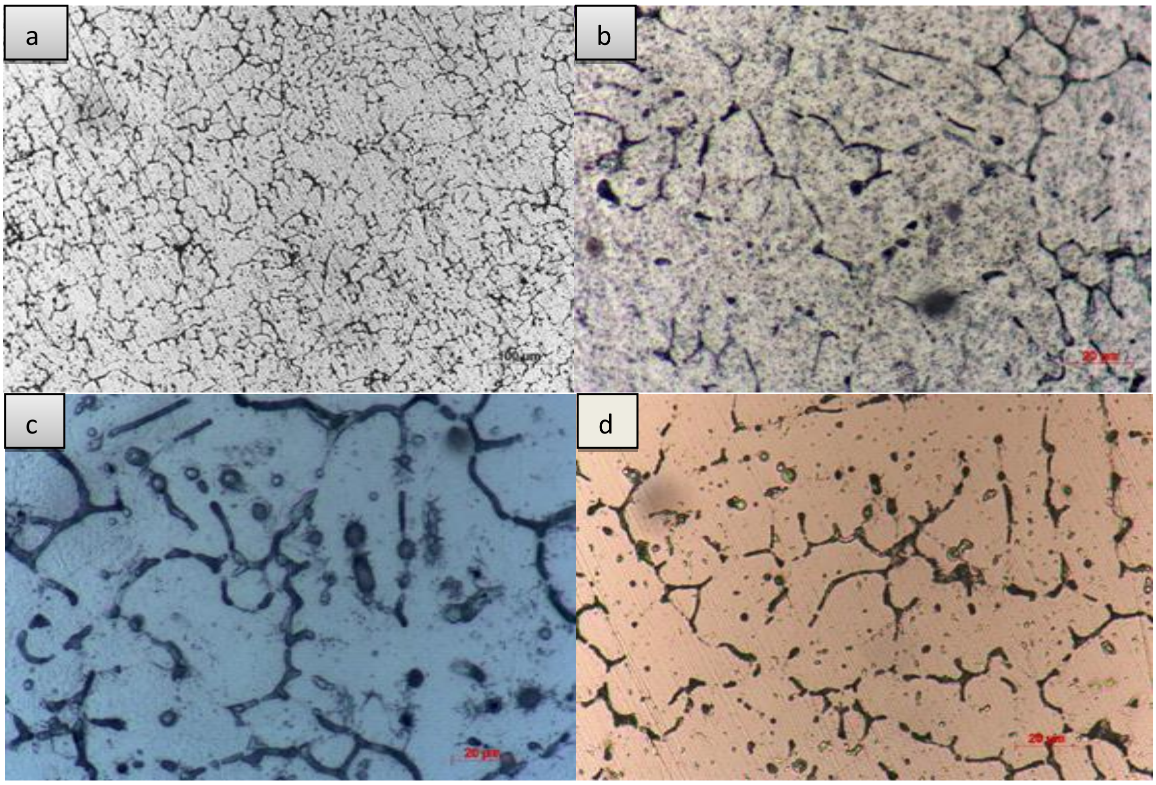


Figure 3 Optical microscopic images showing the silicon carbide particles distribution in as cast condition (a) Aluminium (1100) without Silicon carbide (b) Aluminium with SiC 5% (c) Aluminium with SiC 10% and (d) Aluminium with SiC 15%.

The SEM micrographs of cast Al (1100) and the composite are shown in Figure 4. The micrographs clearly reveal minimal micro porosities in the casting, and it is also observed that, the distributions of reinforcement in the respective matrix are fairly uniform. These micrographs also clearly reveal the increased filler contents in the composites. We can clearly distinguish between the unreinforced and reinforced composite due to the presence of SiC particles in the matrix in the latter, Al-10wt% and Al-15% SiC shows a higher amount of SiC particles.

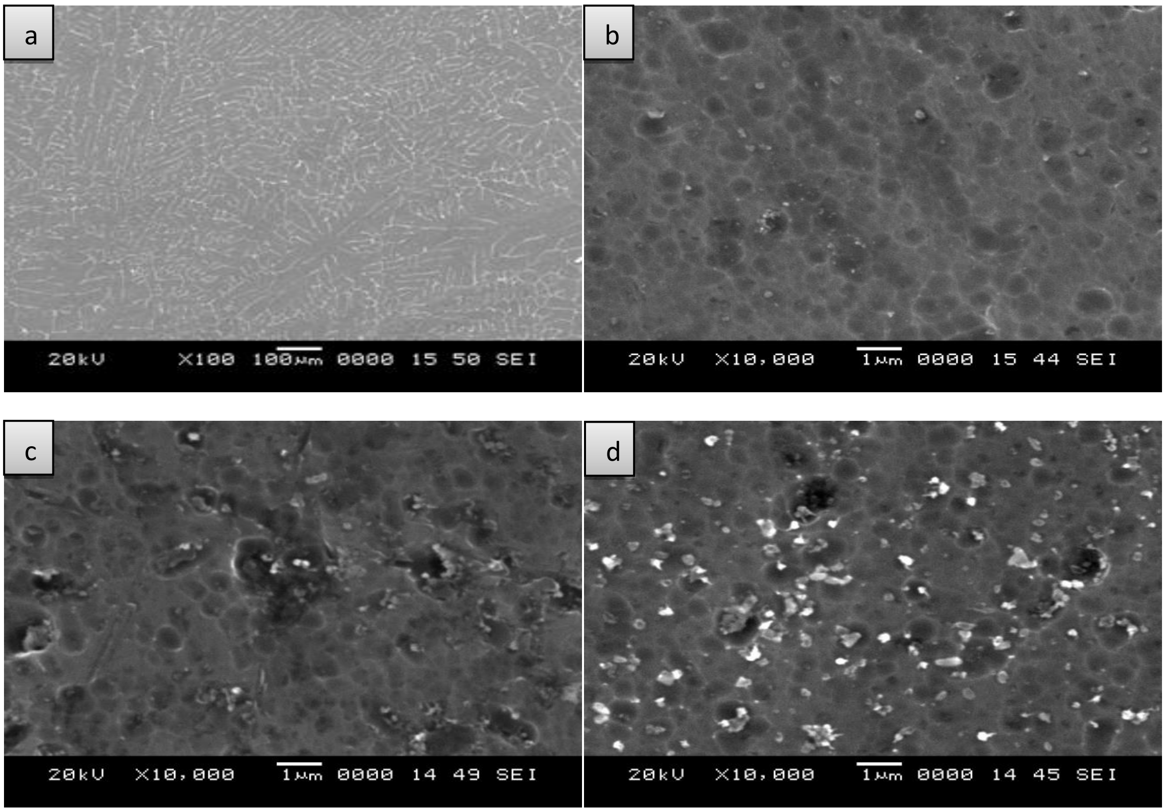


Figure 4SEMimages showing silicon carbide particlesdistribution (a) Aluminium (1100) without Silicon carbide (b) Aluminium with SiC 5%, (c) Aluminium with SiC 10%, and (d) Aluminium with SiC 15%.

The table 3 shows the results of a porosity percent of the composites with their theoretical and experimental values with respect to composition, results revealed that the composites are slightly porous in nature but it's less than 1%. Porosity percentage increases with increase in SiC particles addition.This is due to the fact that while casting, usually particles enter the melt as a group of particles trapping air in between them to form a void space [4][25].Therefore, as the volume fraction of SiC particles increases, the amount of trapped air also increases. Large pours observed in Al/SiC 15% contain a cluster of SiC particles which did not get properly dispersed within the Al matrix during processing.The Porosity level and variations in theoretical and experimental density values with composition are graphically represented infigure 5 (a) and (b).Acceptability of porosity level is maximumof 4 % have been reported [26] for cast aluminium matrix composites.

Table3 Composite density and estimated percent porosity

Sl. No	Material Composition	Theoretical Density	Experimental Density	`Porosity in %
1	Al(1100)	2.72	2.71	0.47
2	Al/SiC 5%	2.74	2.73	0.51
3	Al/SiC 10%	2.77	2.75	0.64
4	Al/SiC 15%	2.78	2.75	0.93

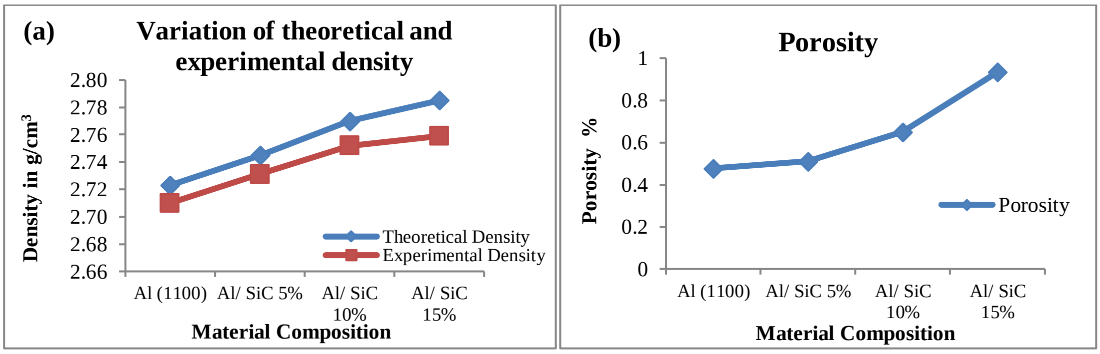
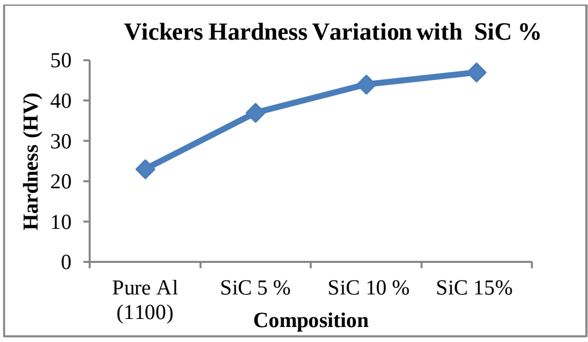


Figure5(a)Variation of theoretical and experimental density (b)Porosity versus materials composition

The hardness is termed as resistance of materials against surface indentation. The plot shown below (Figure 6) reveals that there is an increase in the hardness value with the increase inthe addition of reinforcement, similar type of results were observed by other researchers also[27]. Unreinforced Al has hardness value of 23 HV and maximum obtained hardness value is 47 HV for 15 wt. % SiC reinforced Al composite.



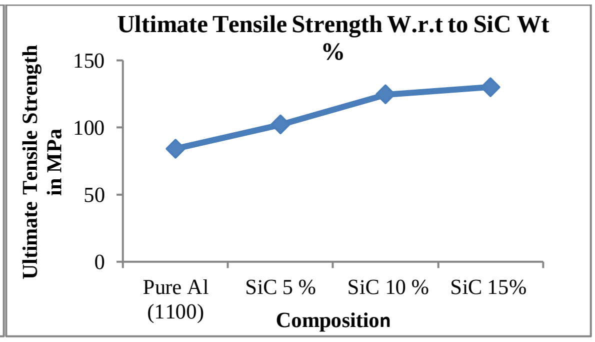


Figure6 Vickers Hardness versesSiC wt% **Figure 7** Ultimate Tensile Strength versus SiC wt%

The micro hardness of composites evaluates the interface bonding strength between matrix and reinforcing particles. The Vickers hardness for 5 wt% SiC and 10 wt% SiC reinforced composites are 37 HV and 44 HV respectively. The presence of harder and well bonded SiC particles in aluminum matrix that hinders the movement of dislocations, which increases the hardness of the Al-SiC composite. The ASTM standard E-8 specimen was prepared by machining the cast composites using conventional machining process. The figure 7 shows the variation of ultimate tensile strength with respect to wt % of SiC particles.The tensile strength of 15% SiC reinforced composite is higher as compared to 5% and 10% SiC reinforced composites and pure Aluminium. Similar kind of result was obtained by Shanmugaraja et al., [28]. Hence, we can conclude that tensile strength increases with increase in SiC content in Aluminium matrix. This is due to strong interfacial bonding between the matrix and reinforcement, which improves the tensile strength of MMCs. The aluminium matrix contains high amount of dislocations, responsible for the strengthening of the material [29][30].During cooling process the dislocations are introduced by the SiC particles, due to the difference in thermal expansion coefficient [31]. The dislocation to dislocation interaction, dislocation density and constraint of plastic flow due to the resistance offered by particles are the expected reasons for strengtheningof composites. By many researchers it is reported that, there is a possibility of increase in dislocation density within the matrix due to the thermal mismatch stress, which leads to local stress increasing strength of the matrix and the composite[32].

4. Conclusion

In this research, aluminum as base matrix and SiC as reinforcement in varying Wt % from 0 to 15 in a step of 5were fabricated using stir casting method. Microstructural aspects and mechanical properties of the prepared composites were studied. Based on experimental evaluation, following conclusions can be drawn

- Adoption of stir casting technique was successful in fabricating aluminum-silicon carbide composites.
- Clustering and fair dispersion of silicon carbide particles in aluminum matrix were observed in microstructure andporosity level increased with increase in SiC Content.
- It was found that tensile strength and hardness were significantly improved by the addition of SiC particles with respect to unreinforced composites.
- Increases in the mechanical properties were found to be directly proportional to the wt % of SiC particles added. The best results have been obtained for composites reinforced with 15% weight fraction of SiC particles, maximum hardness achieved was 47HV & maximum ultimate tensile strength was 130 MPa.
- Due to its improved mechanical properties achieved by one of the easiest ways of fabrication method, thus it can replace the aluminum and its alloys in various commercial applications.

References

[1] Sijo M. and Jayadevan K. R.(2016). Analysis of stir cast aluminium silicon carbide metalmatrix composite : A comprehensive review. *Procedia Technology,* 24, 379–385.

[2] K Karvanis, D Fasnakis, A Maropoulos and S Papanikolaou.(2016) Production and mechanical properties of Al-SiC metal matrix composites, *Materials Science and Engineering,* 161-012070.

[3] Alaneme K. K. (2013). Mechanical properties and corrosion behaviour of aluminium hybrid composites reinforced with silicon carbide and bamboo leaf ash.Tribology in Industry, Vol 35(1), 25–35.

[4] Bhatia R. S. (2017). An experimental analysis of aluminium metal matrix composite using Al2O3/B4C/Gr particles. International Journal of Advanced Research in Computer Science, Vol.8(4), ISSN No. 0976-5697.

[5] S.JohnyJames A. Raja Annamalai. (2017). Fabrication of aluminium metal matrixcomposite and testing of its property, Mechanics, Materials Science & Engineering,ISSN 2412-5954.

[6] Shorowordi K.M, Laoui T, Haseeb A.S.M. A, Celis J.Pand Froyen L. (2003). Microstructure and interface characteristics of B4C, SiC and Al2O3 reinforced Al matrix composites: A comparative study,Journal of Materials Processing Technology, 142,738-743.

[7] Leuven, K. U. (1987). Review-The wetting of solids by molten metals and its relation to the preparation of metal-matrix composites. Journal of materials science, 221-16 Review3-4.

[8] Feng Y. C, Geng L, Fan G.H, Li A.B and Zheng Z.Z. (2009). The properties and microstructure of hybrid composites reinforced with WO3 particles and Al18B4O33 whiskers by squeeze casting. Materials and Design, 30(9), 3632–3635.

[9] Naiqin Zhaoa, Philip Nashb and Xianjin Yang.(2005). The effect of mechanical alloying on SiC distribution and the properties of 6061 aluminum composite. Journal of Materials Processing Technology, 170, 586–592.

[10] Jit N, Tyagi A. K, Singh N, and Chand D. (2011). Properties of (A384.1)1-x [(sic)p] x composites by keeping particle size at 0.220 µm. Proceedings of the World Congress on Engineering , III, 0–4.

[11] Kumar D.R, Narayanasamy R, and Loganathan C. (2012). Effect of glass and SiC in Aluminum matrix on workability and strain hardening behavior of powder metallurgy hybrid composites. Materials and Design, 34, 120–136.

[12] Rajesh A.M, Mohammed Kaleemulla.(2016). Experimental investigations on mechanical behavior of aluminium metal matrix composites.Materials Science and Engineering, 149-012121.

[13] S. Das, R. Behera, A. Datta, G. Majumdar, B. Oraon, G. Sutradhar.(2010).Experimental investigation on the effect of reinforcement particles on the forgeability and the mechanical properties of aluminum metal matrix composites. Materials Sciences and Applications, 1, 310-316.

[14] Asif M, Chandra K, and Misra P. S. (2011). Development of aluminium based hybrid metal matrix composites for heavy duty applications.Journal of Minerals & Materials Characterization & Engineering, 10(14), 1337–1344.

[15] Oluwatosin M , Kanayo K and Heath L. (2015). Aluminium matrix hybrid composites : A review of reinforcement philosophies ; Mechanical, corrosion and tribological characteristics.Journal of materials research and technology, 4(4), 434–445.

[16] Roshan M. R, Mousavian R. T, Ebrahimkhani Hand Mosleh A. (2013). Fabrication of Al- based composites reinforced with Al2O3-TiB2 ceramic composite particulates using vortex- casting method. Journal of Mining and Metal section B, 49(3), 299–305.

[17] Michael Oluwatosin Bodunrina, Kenneth Kanayo Alaneme, Lesley Heath Chown.2015). Aluminium matrix hybrid composites: A review of reinforcement philosophies; mechanical, corrosion and tribological characteristics. Journal of Material Research a Technology,4(4):434–445.

[18] Ashraff Ali Kaveripakkam Suban, Marimuthu Perumal, Athijayamani Ayyanar and Arungalai Vendan Subbiah. (2017).Microstructural analysis of B4C and SiC reinforced Al alloy metal matrix composite joints. International Journal of Advance Manufacturing Technology, 93:515–525.

[19] Manoj Singla, D. Deepak Dwivedi, Lakhvir Singh, Vikas Chawla. (2009).Development of aluminium based silicon carbide particulate metal matrix composite.Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.6, pp 455-467.

[20] Li-na G, Lin G, Hong-wei Z, and Lu-jun H. (2011). Effects of stirringparameters on microstructure and tensile properties of (ABOw + SiCp)/ 6061Al composites fabricated by semi-solid stirring technique. Transactions of Nonferrous Metals Society of China, 21(May), s274–s279.

[21] Inegbenebor A. O, Bolu C. A, Babalola P. O, Inegbenebor A. I and Fayomi O. S. I. (2016). Aluminum silicon carbide particulate metal matrix composite development via Stir casting processing. Silicon,1-7.

[22] Gowri Shankar M.C, Jayashree P.K, Raviraj Shettya, Achutha Kinia and Sharma S.S. (2013) Individual and combined effect of reinforcements on stir cast aluminium metal matrix composites-A Review. International Journal of Current Engineering and Technology, Vol.3, No.3.ISSN 2277 - 4106.

[23] ASTM E 8M:(2001). Standard Test Method for Tension Testing of Metallic Materials (Metric). Annual Book of ASTM Standards, Philadelphia.

[24] M.D. Bermudeza, G. Martinez-Nicolas, F.J. Carrion, I. Martinez-Mateo, J.A. Rodriguez, E.J. Herrera. (2001). Dry and lubricated wear resistance of mechanically-alloyed aluminium base sintered composites.Wear, 248, 178–186.

[25] M.K. Surappa, R.K. Rohatgi. (1981). Preparation and properties of cast aluminium–ceramic particle composites.Journal of Material Science. 16,983–993.

[26] K.K. Alaneme, A.O. Aluko. (2012).Production and age hardening behaviour of borax premixed SiC reinforced Al-Mg-Si alloy composites developed by double stir casting technique. The West Indian Journal of Engineering, Vol. 34, No. 1-2, pp. 80 – 85.
[27] Anilkumar H.C, Hebbar H.S and K.S Ravishankar. (2011).Mechanical properties of fly ash reinforced aluminium alloy (Al6061) composites.International Journal of Mechanical and Materials Engineering (IJMME), Vol.6, No.1, 41-45.
[28] Sri Priya R, Yogeshwaran R, Syed Mohammed K, Bharathvaj S, M. Shanmugaraja. (2016). Investigation on mechanical properties of aluminium 6061 reinforced with SiC and Al2O3. International Conference on Explorations and Innovations in Engineering & Technology, ISSN: 2349 – 9362.
[29] Manoji, V. B, Biradar, V. R, Venkatesh, N, & Haragapure, L. I. (2016). Characterization of silicon carbide reinforced aluminum matrix composites by using stir casting.International Journal of Mechanical and Production Engineering, 85–89.
[30] Seetharaman, S. (2014). Mechanical properties and microstructure studies of aluminium (7075) alloy matrix composite reinforced with short basalt fibre. European Journal of Scientific Research,68(4).606-615.
[31] Vogelsang Mary, Arsenault R. J, Fisher R. M. (1986). An in situ HVEM study of dislocation generation at Al/SiC interfaces in metal matrix composites. Metallurgical Transactions A. 17 (3): 379.
[32] Rahman H, and Al H. M. Rashed. (2014). Characterization of silicon carbide reinforced aluminum matrix composites. Procedia Engineering, 90, 103–109.