Manufacturing Feasibility of Al6061and Boron Carbide Particulate Reinforcement to Cast a Metal Matrix Composite with Wettability Agent

Veeresh Kumar G B, Ulhas K Annigeri, T Srinivas Rao,

Abstract*: *Aluminium metal matrix composite with a combination of Al6061 as base matrix and B4C as particulate up to 0 to 3% by weight in the steps of 1 wt% is manufactured by liquid metallurgy method by stir casting process. The choice of the process has been concluded from the literature survey and is tabulated. The steps involved in the processing of composite have been reported in detail. A conventional stir casting technique and the steps followed are recorded. The different process parameters controlled during the process have been reported. With the processing of the composite, the chemical stability between the particulate and the alloy matrix as known from its properties has been ascertained. The addition of wettability agent and thus its effect has been discussed. The optical microscope images of the processed composite have been presented in the paper as an indication to successful fabrication of composite. Based on the images, distribution of particulates in matrix alloy and possible reasons for this to get exhibited have been discussed. The paper aims at bridging the gap of essentials of wetting of solid particulates and the practice of casting.

Keywords*: *Metal matrix composites, Particulate reinforcement, Wettability, Bonding

I. INTRODUCTION

The extraordinary performance of composite materials compared with monolithic materials has been widely studied by investigators [1-4]. The earthenware particulates filled composite materials display improved resistance for indentation and found applications like automobile segments as cylinder, pistons, calipers, cylinder rings, microwave channel, vibrator segment, contactors, impellers and space structures [5]. Amongst Metal Matrix Composites (MMCs) Aluminum (Al) composites have demonstrated excellent mechanical properties [6-8]. Sliding speed and distance, weight percentages of reinforcement and applied load has considerable impact on height loss due to friction and wear of Al6061 and Al6061-TiO_2 composites [9, 10]. The straightforward reason behind damage and following disaster of parts of machine are wear [11-13].

Revised Manuscript Received on December 30, 2019.
***** Correspondence Author

Veeresh Kumar G B*, Associate Dean (SA), National Institute of technology Andhra Pradesh, Tadepalligudem, Andhra Pradesh, India.

Ulhas K Annigeri, Department of Mechanical Engineering, Amrita School of Engineering, Bengaluru, Amrita Vishwa Vidyapeetham, India.

T Srinivas Rao, Department of Mechanical Engineering, Amrita School of Engineering, Bengaluru, Amrita Vishwa Vidyapeetham, India.

The goal is fabrication of Al-MMCs was compatibility of Al or its alloy with oxides, nitrides and carbides to achieve the properties that are attributed to both of them.

The properties that are usually attributed to Al-MMCs are better physical and mechanical properties compared to conventional metal and are usually in between that of matrix alloy (in this paper Aluminium) and that of oxides, nitrides and carbides which are added as reinforcement. Aluminium has good ductility, strength and light in weight whereas carbides are having good strength and stiff although they are brittle [14]. Al, boron carbide and alumina for example possess comparable mechanical characteristics: Young's moduli are 71, 380 & 362GPa respectively and tensile strength 190-250, 255.2 and 261MPa respectively. With compatibility of these three materials, a metal matrix composite is produced which gives a maximum tensile strength of 68.24MPa [15]. There are different fabrication methods available for particulate filled MMCs; stir casting is dominantly used route to fabricate since it is easy, pliable and applicable for high quantity production, another advantage that is unique to this process is the conventional method of its procedure of manufacturing. It is also one of the economical processes of fabrication and is useful in production of large sized components [16]. The cost incurred by this casting method is 33% - 50% of that compared to other methods and for a very large production; the cost can fall down to 10% of other methods [17]. Stir casting technique can be used to manufacture composites with a maximum quantity of reinforcement up to 30% by volume with good bonding of matrix and reinforcement [18]. It is found out from literature survey that stir casting produces a composite that enhances the properties as compared to a monolithic metal. In this study it was to ascertain the fabrication feasibility with a wettability agent and hence the distribution of the boron carbide in the Al6061 alloy after fabrication of the composite since it is reported that the other combinations such as Al-SiC are reactive systems [19]. There has been very little research with boron carbide as reinforcement due to high raw material cost. Boron carbide is a hard-ceramic particle with good strength and wear resistance. It has excellent chemical and thermal stability. It is useful in applications such as bullet proof vests, neutron absorber in nuclear plants and armor tanks [20]. It has higher hardness and lower density as compared to SiC and Al2O3. The other commonly used fabrication process for MMCs is the powder metallurgy where the powders of reinforcement and Aluminium alloy are blended, sintered and worked plastically.

Table 1 Differentiation for particulate reinforced MMCs [21]

Process	Attributes
Stir Casting	Near to net shape process, can use ingots rather than powders and is least expensive
Powder metallurgy	No near to net shape process, Higher amount of reinforcement can be added, costly
Squeeze Casting	Net shapes can be produced, molds and presses are costly to fabricate

Stir casting process for fabrication of Al-MMCs involves melting the aluminium or its alloy in a crucible and incorporating the reinforcement in the vortex produced by stirring of the melt. Stirring of the melt is for a small duration of time say 5-10 minutes. After mixing reinforcement properly, molten metal is poured into molds and solidified. In the present study a cast iron mold was used. The mold was also heated since it improves the casting soundness [22]. The mold was air cooled till it comes to room temperature. Air cooling is one way of quick cooling and hence gives a finer dendrite size as well limited settling of particles thus resulting in a better distribution of particles [23]. There are many other elements to be considered during the process such as

1. Chemical stability between reinforcement and matrix
2. Uniform distribution of particulates
3. Wettability between the reinforcement and matrix - The upper level to which there is effective contact amongst reinforcement, matrix alloy and the spreading of the liquid on the solid surface is defined as wettability.

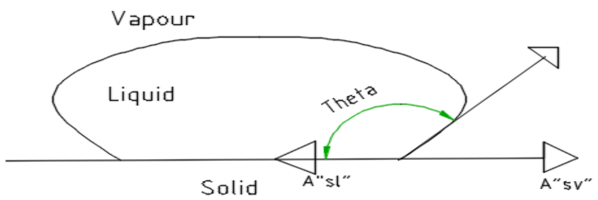

Fig. 1 Measurement technique of Sessile drop test angle.

The definition of wettability can be explained by the Figure 1 as shown above. The figure indicates drop of liquid on solid surface. The contacting angle θ is calculated by the Young-Dupre relation [24].

$$A''sv'' = A''sl'' + A''lv''\cos\theta \quad (1)$$

Where A"sv" is specific energy of solid-vapor interfaces, A"sl" is specific energy of liquid and solid interfaces, and A"lv" specific energy of liquid and vapor interface. Specific energy was energy per unit area, else surface tension forces. When a drop of liquid was dropped on the solid surface, a region of the solid-vapor interface is replaced by solid-liquid and liquid- vapor. Spreading of the liquid shall occur when there is free energy of system. The bonding force (or work of adhesion) between liquid and solid phase iwas given by

$$W_{adhesion} = A''lv'' + A''sv'' - A''sl \quad (2)$$

With equation (i) and (ii) we get

$$W_{adhesion} = A''lv''\,(1+\cos\theta) \quad (3)$$

Hence, the binding force can be expressed in terms of contact angle θ.

a. θ = 180, wetting is not possible
b. θ = 0, best wetting results
c. 0 < θ <180, partial wetting results

Thus, low contact angle results in good wetting. The properties of wettability are checked by sessile drop test where the material is allowed to freeze & then measurements are made [25]. Decent wetting is vital condition for generation of reasonable bonding between particulates and Al liquid matrix during composites casting, permits transfer and distribution of load from matrix to reinforcement without failure [26]. Particulates are not wet by the matrix material due to the occurrence of the oxide film since the film creates a hindrance to the penetration of the particulate especially when the reinforcement is added from above the cast. It is reported that a 50nm film of oxygen is formed on Al at about 400-degree celsius in about duration of four hours [27]. It was reported that ceramic particulates are usually covered with layer of gas [28]. It is also reported that this layer of gas enhances the resistance to contact of other particulates and when alarming quantity of particulate has been reached the layer of gas forms a barrier resulting in the rejection of particulates in the melt [29]. A modification by the production of a transient layer between the matrix and the particulate occurs with lower wetting angle which, reduces surface stiffness of liquid and surround particle with structure that was analogous to particle and matrix. Reactive elements like Ti, Zr, Ca or Mg are added to induce wettability. Porous composites being formed are reduced.

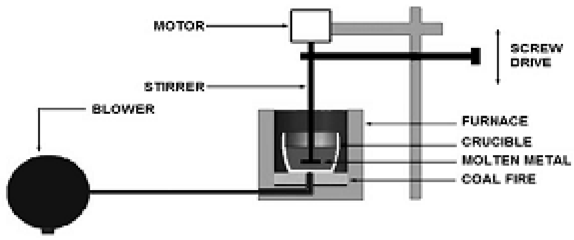

Fig. 2 Basic stir casting process [30]

As seen in the stir casting apparatus the screw drive helps in adjusting the stirrer depth in the crucible for stirring. The motor helps in rotation of stirrer at the speed that is adjustable. In the as figure in figure 2, the heating is done by coal fire which is conventional type. In our present study the heating was carried out by electric heating coils placed all around the crucible in the furnace. The voltage requirement for the motor and the furnace is as used for domestic purpose. The crucible is made out of graphite material. The maximum temperature that can be reached in the furnace is limited. The stirrer depth in the crucible also plays a vital role in the process of fabrication and also decides the distribution of the particulates in the matrix material. The stirrer depth has to be in such a way that 35% is below the liquid and 65% is above [31]. It is kept to 2/3 of height of the crucible in the preparation of the composite. The turbine blade type stirrer is used more frequently among all the designs available [32].

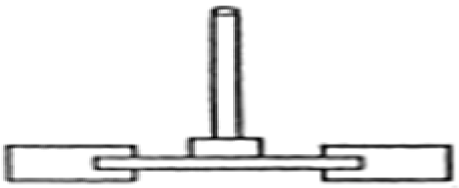

Fig. 3 A turbine type stirrer [30]

A turbine type stirrer has been used in the process. The method of vortex creation maintains a better distribution of the added material into the molten matrix when the metal solidifies. Stirring helps in better mixing and suspension of particulates. This is due to difference in pressure between the outside and inside surface of melt thereby sucking the particulate into liquid [17]. Further because of the significant differences in the densities of the dispersed and matrix phase, there may be gravity segregation. Dispersal of dispersed phase may enhance if matrix remains in semi liquid condition, method of by means of stirring molten composite, in semi-liquid condition was termed as Rheocasting. High viscosity of semi-liquid matrix enables improved mixing of dispersed segment.

II. SELECTION OF MATRIX ALLOY & REINFORCEMENT

The base and reinforcement materials used were Al6061 and Boron Carbide (B_4C) of 74µm size. The matrix alloy Al6061 in ingots form were supplied by Fenfee Metallurgicals; Bengaluru. The reinforcement B_4C were obtained by Quesst International distributor for Sigma Aldrich Bengaluru, India. The base alloy and filler material properties were presented in Table II.

Lightness stays outstanding and best-known property of Al. Metal has 26.98 atomic weight and 2.70 specific gravity, about one third weights of other usually used metals. By way of most metals' density diminutions with rise in temperature, adding of other metal in amount normally used in alloys of Al doesn't noticeably variation in density. Al6061 is a heat treatable alloy and uses combination of silicon and magnesium as alloying elements. Further the same alloying elements are adopted for aluminium alloy designation system. Alloys found medium strength, shared with corrosion resistance, formability facility and ability to anodized [33].

Table II. Matrix alloy and reinforcements charactristics.

Materials	Elastic Modulus in GPa	Hardness (HB500)	Density in g/cc	Tensile Strength in MPa
Al6061	75	31	2.71	116
B_4C	445	38*	2.53	262

* Vickers hardness in GPa

III. EXPERIMENTAL METHOD

This Initially, 2853 grams of Al6061 alloy was weighed and selected for fabrication of composites by casting method i.e., liquid metallurgy route via stir casting. The percentage of particulate to be added was arbitrarily selected to be 3% by weight for the present study. The calculation for amount of particulate is (2853grams / (100-3)) × 3 = 88.3 grams. In the calculation, "3" denotes the percentage by weight. A difficulty expected during the process was the density difference between the boron carbide particulate and the Al6061 alloy, since, there is settling of particulates during the process. This was eliminated by having a mechanical stirrer of stainless steel coated with zirconia and was held in stirring condition for 10 minutes. The stirring speed was kept at 400 rpm. Proper dispensation of particulate in matrix was also affected with pouring temperatures which was maintained at 720°C. The dispersion was by vortex method where the matrix material is stirred rapidly and reinforcement was introduced at side of vortex at approximately uniform rate manually. The stirring is continued for duration of 5 minutes totaling to 10 minutes before the mixture is cast. Dispensation of reinforcement particulates through air contact to the stirred melt will entrap impurities such as oxides and slag, which was taken care by adding an alkaline agent with trade name 'coverall'. The particulate heat treatment before dispensation into the melt assists in removal of adsorbed gases from the surface of particulate. Heating of particulates assists in removal of impurities, removal of gases and also altering the surface composition as indicated by many researchers [34-36]. A good clean surface of the particulate assists in better wetting and better interaction between reinforcement and matrix melt.

Fig. 4 Alkaline agent coverall in a container.

Fig. 5 Muffle Furnace for B_4C particulate preheating up to 300℃.

Air envelopes are formed between particulates and melt, degrading the interface properties which were stopped by adding magnesium, which was 1% of total Al6061 melt quantity. The addition of magnesium improves wettability since magnesium surface tension is 0.599 N/m and same of Al was 0.760 N/m and hence reducing Al surface tension, thereby promoting wettability as stated by K. Sukumaran [37]. However, caution has to be taken while adding since more quantity of magnesium will change the microstructure of base metal alloy degrading the properties of the composite. It has also been reported that casting fluidity was reduced with the addition of magnesium [38]. The viscosity of the slurry will change very rapidly if there is lot of temperature difference between particulate and melt while dispensation and this was taken care by preheating the particulate to 200°C. Hexachloroethane (C_2Cl_6) tablet was added as a degassing agent as is reported by various researchers [39-40].

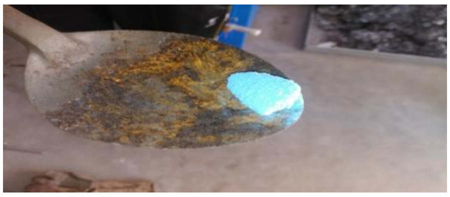

Fig. 6 Hexachloroethane (C2Cl6) degassing tablet bluish green in color

The mold for casting was preheated to 350°C and a pouring temperature of 720°C was achieved. The castings were cylindrical of dimensions Ø25 x 150mm. The cast was cooled to room temperature.

The summary of the parameters controlled during the process are tabulated in the table 2 below.

Table III Stir Casting Process Parameters

Process parameter	Values
Stirring time	10 minutes
Stirring speed	400 rpm
Preheat temperature of reinforcement particulates	300°C
Preheat temperature of permanent mold	350°C
Temperature of melt	900°C

In Table III, five parameters during the process have been considered for controlling the manufacturability of the Al MMC. Stirring speed was peripheral speed of stirrer blade used in the manufacturing process. The blade used has been detailed in the previous paragraphs. The stirring time includes the time of adding the particulate in to the heating furnace with crucible, containing the melt of base metal Al6061 and also the time period for which the mixing of both the materials was carried out. Preheat of particulate, implies the degree of hotness to which the particulate was subjected to preheating before pouring it into the vortex of melt during mixing. Preheat of permanent mold implies the degree of hotness to which the mold made of cast iron was subjected to before the melt with the particulate was poured. The temperature of melt is the degree of hotness to which the base material was subjected to before pouring into the mold. The pouring temperature is lesser compared to melt temperature. The powder feed rate is the velocity at which the particulate was fed into the melt.

TableIV Properties of Boron carbide (B_4C)

Reinforcement	Average particle size	Density
B_4C	74μm (200 mesh)	2.51g/cm^3

Mesh size is the number of openings in one-inch screen. 200 meshes imply there are 200 little squares across one linear inch of screen. A 200 mesh means all particulates are retained in the 200 screens. The size in this present research was 74 microns.

IV. RESULTS AND DISCUSSIONS

The sample for micro-structure inspection were machined from cast specimens. The specimens were ground to remove burrs and polished for a rough surface finish. Specimens are further polished carefully by emery papers of grade 1/0 & 2/0. Lastly, was polished using disc polishing to get improved surface finish. Metallographic etching is a chemical technique used to highlight features such as character, quantity and distribution of metals at microscopic levels. Etching is used to expose the shape and size of the grain boundaries, metallic phases and inclusions.

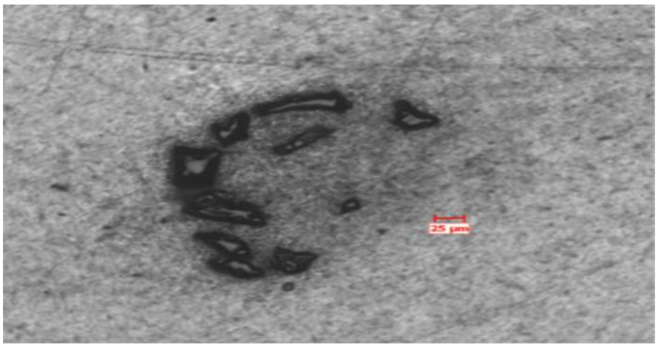

Fig. 7 Al6061 + 3%B_4C at 100X magnification

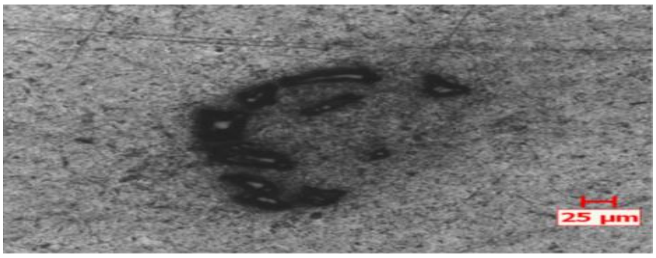

Fig. 8 Al6061 + 3%B_4C at 200X magnification

The manufactured castings were machined and Keller's reagent was applied at the surface to be examined under the optical microscope. Keller's etching reagent is mixture of nitric acid, hydrofluoric and hydrochloric acid were used normally to etch alloys of Al. The magnified images are 100, 200 times and clearly show that the particulate reinforcement boron carbide is more or less uniformly dispersed in the Al6061 matrix. The test reference is IS: 7739-part III 1975 RA 2007. The equipment used is Nikon microscope LV150 with clemex image analyser. The darker regions which are very minute are the alloying elements which were present in the Aluminium alloy. The dark regions which are clearly visible in the image indicate the boron carbide particulate in Al6061 matrix. This further confirms the suitability of the stir casting process as per other numerous researchers in the literature for manufacturing of the metal matrix composites.

It is very important to have small differences in coefficient of thermal expansion of matrix and reinforcement as reported for effective compatibility. The coefficient of thermal expansion of Al6061 and boron carbide is 23.5 x 10^{-6}m/m°C and 5 x 10^{-6}m/m°C respectively. The thermal mismatch strain is given by the relation $\varepsilon = \Delta\alpha \times \Delta t$, where $\Delta\alpha$ is the difference between the coefficient of thermal expansions of matrix and reinforcement and Δt is the temperature change [26]. In the present study during solidification from melting temperature of 750°C to room temperature of 25°C the difference would be 725°C. The value of difference in coefficient of thermal expansion would be 18.5 x 10^{-6}m/m°C, thus the value of strain is 0.0134 which is less and hence this could be one of the reasons for a good distribution of boron carbide in Al6061. The incorporation of B_4C particulate in Al6061 is assisted with flux. The flux reacts with the surface of the particulate which is exothermic and heat is evolved in the interface of B_4C and melt. This promotes the dispensation of particulate in melt and proper bonding will occur [28]. This could be one of the other reasons for proper bonding between the particulate and the matrix alloy as confirmed from the optical microscope images.

V. CONCLUSIONS

There are many comprehensive conclusions that can be reported from the study. There is chemical stability between reinforcement; matrix and is ascertained from the successful manufacturing of the composite. There is uniform distribution of particulates in the Al6061 matrix and it can also be reported that this is due to the continuous stirring of the melt with a motor driven agitator to prevent settling of particulates due to gravity segregation.

The problem of particulates getting attached to gas bubbles which is energetically conducive has been eliminated and particle agglomeration has not occurred. A particle concentration gradient has not developed although the particle size is 74µm. It can also be reported that the addition of magnesium as wettability agent has reacted with the oxygen present on the surfaces of the particulates, thinning the gas layer and has thus reduced the agglomeration tendency as is evident from the optical images showing proper distribution. The addition of magnesium has increased the surface energy of the particulates. The addition of quantity was based on experience of casting personnel and from literature survey as reported earlier. Porosity has not been observed as can be seen from the optical microscope images.

ACKNOWLEDGMENT

The authors acknowledge the support and encouragement of the management of Amrita school of engineering, Bengaluru campus.

REFERENCES

1. R Pramod, G. B. Veeresh Kumar, "Influence of WC Particulate Reinforcement on the Mechanical Properties and Sliding Wear of Al6061 Alloys" Applied Mechanics & Materials, pp. 67-73. 2015.
2. Ulhas K. Annigeri, Veeresh Kumar G.B., "Method of stir casting of Aluminum metal matrix Composites: A review" Elsevier's Materials Today: Proceedings, pp. 1140–1146.2017.
3. Jyothish J, Krishna D, Kumar A.A, Ravi Kumar V, Mohan Kumar S, "Electrochemical corrosion studies and mechanical characterization of Al7050 metal matrix composite reinforced with ZrO2 particulate by stir casting method", International Journal of Mech Engg and Technology, 8 (11), pp. 949-957, 2017.
4. C.S.P. Rao, G.B. Veeresh Kumar, N. Selvaraj, "Mechanical and dry sliding wear behavior of Al7075 alloy-reinforced with SiC particles", Journal of Composite Materials, 46 (10), pp. 1201–1209, 2012.
5. G.B. Veeresh Kumar, C.S.P. Rao, N Selvaraj, "Mechanical and Tribological Behaviour of Particulate Reinforced Aluminium Metal Matrix Composites – a review", Journal of Minerals and Materials Characterization & Engineering, pp. 59-91. 2010.
6. Mohan Kumar S, Pramod R, Shashi Kumar M.E., Govindaraju H.K., "Evaluation of fracture toughness and mechanical properties of aluminum alloy 7075, T6 with nickel coating", Procedia Engineering, pp. 178-185. 2014.
7. A. R. K. Swamy, G.B. Veeresh Kumar, A. Ramesha, J. N. Prakash, "Effect of Particulate Reinforcements on the Mechanical Properties of Al6061-WC and Al6061-Gr MMCs", Journal of Minerals & Materials Characterization & Engineering, pp.1141-1152. 2011.
8. C.S.P. Rao, G.B. Veeresh Kumar, Bhagyashekar M.S, Selvaraj N, "Studies on Al6061-SiC and Al7075-Al2O3 Metal Matrix Composites", Journal of Minerals & Materials Characterization & Engineering, pp.47-59. 2009.
9. G.B. Veeresh Kumar, R Pramod, P S Shivakumar Gouda, C S P Rao, "Synthesis and Characterization of TiO2 Reinforced Al6061 Composites", Advanced Composites Letters,pp.18 – 23. 2017.
10. Bhagyashekar M.S., Veeresh Kumar G.B, C.S.P. Rao, Selvaraj N, "Mechanical and Tribological Behavior of Al6061-SiCp Composites", proceedings of the International Conference on Recent Trends in Materials and Mechanical Engineering (ICMME2008), Pollachi, TN, India, 2008, pp.1-8.
11. Veeresh Kumar G. B, C.S.P. Rao, Selvaraj N, Bhagyashekar M.S., "Studies on Al6061-SiC and Al7075-Al2O3 Metal Matrix Composites", Journal of Minerals and Materials Characterization & Engineering, pp.47-59, 2009.
12. G. B. Veeresh Kumar, R Pramod, "Artificial Neural Networks for Predicting the Tribological Behavior of Al7075-SiC Metal Matrix Composites", Journal of Material Science & Engineering, [ISSN 2374 – 149X], pp. 06-11.2014
13. Ravi Kumar V, Mohan Kumar S, Shashi Kumar M.E., Govindaraju H.K., "Mechanical characterization and fracture toughness of electroplated cadmium coating of Al -Zn alloy, T6" AIP Conference Proceedings, 1859, 020085, 2017.
14. R. Taherzadeh Mousavian, R. Azari Khosroshahi, S. Yazdani, D. Brabazon, A.F. Boostani. "Fabrication of aluminium matrix composites reinforced with nano- to micrometer-sized SiC particles", Materials and Design 89, pp.58-70.2016.
15. B. Vijaya Ramnath, C. Elanchezhian, M. Jaivignesh, S. Rajesh, C. Parswajinan, A. Siddique Ahmed Ghias, "Evaluation of mechanical properties of aluminum alloy-alumina-boron carbide metal matrix composites", Materials and Design 58, pp.332-338.2014.
16. D.B. Miracle, "Metal matrix composites – From science to technological significance", Composites Science and Technology 65, pp.2526- 2540.2005.
17. J. Hashim, L. Looney, M.S.J. Hashmi, "Metal matrix composites: Production by the stir casting method", Journal of Materials Processing Technology 92-93, pp.1-7.1999.
18. Pardeep Sharma, Satpal Sharma, Dinesh Khanduja," A study on microstructure of aluminum matrix composites", Journal of Asian Ceramic Societies 3, pp. 240-244.2015.
19. K.M. Shorowordi, T. Laoui, A.S.M.A Haseeb, J.P. Celis, L.Froyen, Microstructure and interface characteristics of B4C, SiC and Al2O3 reinforced Al Matrix composites: a comparative study, Journal of Materials Processing Technology 142, pp. 738-743.2003.
20. K. Kalaiselvan, N Murugan, Siva Parameswaran, "Production and characterization of AA6061 – B4C cast composite", Materials and Design 32, pp. 4004 – 4009.2011.
21. U.S Congress, office of technology Assessment, Advanced materials by Design, OTA E-351, Washington D C: US Government printing office, June 1988, Library of congress catalogue card number 87-619860
22. A.M. Samuel and F.H. Samuel, "Foundry aspects of particulate reinforced aluminum MMCs". Factors controlling composites quality, Key Engineering Materials, pp. 65-98.1995.
23. A. M. Samuel, A. Gotmare, F.H. Samuel, "Effect of solidification rate and metal feedability on porosity and SiC/Al2O3 particle distribution in an Al-Si-Mg (359) alloy", Composites science and technology, 53, pp. 301-315. 1995.
24. Thomas Young: "An Essay on the Cohesion of Fluids", Philosophical Transactions of the Royal Society of London, 1805 volume 95, pp.65-87; DOI:10.1098/rstl.1805.0005.
25. F. Delannay, L. Froyen, A. Deruyttere, "Review: The wetting of solids by molten metals and its relation to the preparation of metal-matrix composites", Journal of Materials Science, pp. 1–16.1987.
26. K. Wefers, "Properties and characterization of surface oxides on aluminum alloys", Aluminum 57 (11), pp. 722–726.1981.
27. S Ray," Casting of Composite Components", Proceeding of the 1995 Conference On Inorganic Matrix Composites, Bangalore, India, TMS, pp. 69-89,1996.
28. R. Warren, C.H. Anderson, "Silicon carbide fibers and their potential for use in composite materials", Composites, Part II, pp. 69-89.1984.
29. S. Suresh, N ShenbagaVinayagaMoorthi, "Process development by stir casting and investigation on microstructures and wear behaviour of TiB2 on Al6061 MMC", Proceedia Engineering 64, pp.1183-1190.2013.
30. N.H. Parker, Mixing Chem. Engg. Journal (1964) 208.
31. N. Harnbby, M.F. Edward, A.W Nienow,"Mixing in process industries", Butterworths, London 1985.
32. Ron Cobden, Alcan, Banbury, "Aluminum: Physical Properties, Characteristics and Alloys", TALAT Lecture 1501, European Aluminum Association, 1994.
33. H. Ribes, R. dasilva, M. Suery, T. Breteau, "Effect of interfacial oxide layer in Al-SiC particle composites on bond strength and mechanical behavior", Material Science and Technology, pp. 621-629, 1990.
34. L.N. Thanh, M. Suery, "Influence of oxide coating on chemical stability of SiC particles in liquid aluminium", Scripta Metallurgica et Materialia, pp. 2781-2786.1991.
35. T.W. Clyne, Proceedings of ICCM-VI and ECCM-2, Elsevier, Amsterdam, pp.275-286.1987.
36. K. Sukumaran, S.G.K Pillai, R.M. Pillai, V.S. Kelukutty, B.C. Pai, K.G.Satyanarayana, K.K. Ravikumar, J. Mater. Sci. 30, pp. 1469-1472.1995.
37. A.M. Korolov, "casting Properties of Metals and Alloys", Consultant Bureau, New York, pp.26-27.1965.
38. G.B. Veeresh Kumar, C.S.P. Rao, N. Selvaraj," Studies on mechanical and dry sliding wear of Al6061-SiC composites", Composites Part B 43, p.1185 – 1191.2012.
39. G.B. Veeresh Kumar, ARK Swamy and A Ramesha, "Studies on properties of as cast Al6061-WC-Gr hybrid MMCs", Journal of Composite materials 46(17), pp. 2111-2122.2011
40. Toptan F, Kilicarslan A, Cigdem M, Kerti I," Processing and microstructural characterisation of AA1070 and AA 6063 matrix B4C reinforced composites", Mater Des, 31 pp.3585-9.2010.

AUTHORS PROFILE

Dr. Veeresh Kumar G B is Assistant Professor in the department of mechanical Engineering at National Institute of Technology, Andhra Pradesh. He has a teaching and research experience in the field of composite materials in metal matrix composites. He is author to several papers in journals and conference proceedings.

Ulhas K Annigeri is Assistant Professor in the department of Mechanical Engineering at Amrita School of Engineering, Bengaluru campus, with masters in Mechanical Engineering. He is teaching material science and metallurgy to undergraduates and is research scholar at Amrita Vishwa Vidyapeetham. He has a few publications in journals and conference proceedings.

Dr. T Srinivas Rao is Associate Professor in the department of mechanical Engineering at Amrita School of Engineering, Bengaluru campus, He has a teaching and industrial experience in the field of materials planning and supply chain management. He is author to several papers in journals and conference proceedings.