Crictical Review of Fabrication & Characterisation of Metal Matrix Composites

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Abstract— Metal Matrix Composites (MMC) have been broadly considered as an alternative for the engineering materials due to their tremendous mechanical properties like high strength to weight ratio, wear resistance, high specific modulus, stiffness, damping capacity etc. Metal matrix composites specially aluminium based metal matrix composites (AMC) are getting popular day by day due to their diverse applications such as aerospace, aircrafts, automobile parts, electronic parts, turbine blades, golf clubs etc. Over the years, AMC have several operational, non-operational and functional uses in numerous engineering fields due to their better performance, environmental and economic benefits. AMC have been widely used in transportation industries because of less noise, lower fuel consumption and lower aerial emissions. It is now accepted that in order to empower the AMC substitution for engineering materials and to make it wide spread, there is a fascinating need to redesign the whole engineering system to reduce weight and volume.

***Keywords** - Composite; AMC; stir casting; fabrication.*

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I. INTRODUCTION

1.1 *COMPOSITES*

Composites comprise of reinforcement distributed in a continuous phase called matrix. The matrix develops its various characteristics from the geometry of constituents and the properties of interfaces between different constituents. Composite materials are typically characterized on the basis of the chemical and physical nature of matrix material and types of reinforcement. A composite is designed to show the characteristics of constituent materials.

Composite materials are getting popular due to their diverse applications and advantages over traditional engineering materials. Composites may have polymer matrix, ceramic matrix, metal matrix or carbon & graphite matrix and may have reinforcements in the form of particulates, whiskers, short fibers or long fibers. Hybrid composites consist of more than one reinforcing materials which helps attain desired properties. Composite materials have been widely used in aerospace, aircrafts, automobile parts, diesel piston, electronic parts, brake-shoes, turbine blades, golf clubs, armors of tanks, transportation industries etc.

1.2 *PROPERTIES OF COMPOSITES*

The properties of the composite materials depends predominantly on arrangement and type of reinforcements. Composites have many advantages over traditional engineering materials such as:

- Higher strength-to-density ratios
- Better fatigue resistance
- Higher strength
- Higher stiffness-to-density ratios
- Better wear resistance
- Better elevated temperature tolerance properties
- Lower creep rate
- Lower coefficients of thermal expansion

1.3 TYPES OF COMPOSITES BASED ON MATRIX MATERIAL

1.3.1 Polymer Matrix Composites (PMC)

Polymers can be ideally used as matrix materials as they possess good mechanical properties, can be processed easily and have light weight. High temperature synthetic materials are extensively used in aeronautical applications. Thermosets and thermoplastics are two different kinds of polymers used mainly. Polymeric materials have a tendency to degrade when they are exposed to elevated temperatures above 300°C. Hence Most of the PMC operate at temperatures below 300°C.

1.3.2 Ceramic Matrix Composites (CMC)

Ceramic matrix composites (CMC) have been established to overcome the drawbacks of monolithic ceramics such as intrinsic brittleness and lack of reliability of ceramics. CMC are used in place of heavy super alloys in order to reduce the weight of components. CMC have been widely used in gas turbines for power plants, fusion reactor first wall, heat shields for space vehicles, heat treatment furnaces, aircraft brakes etc.; but still they have limited application due to high cost, lack of suitable reinforcements lesser lifetime and difficulties in processing.

1.3.3 Carbon and Graphite matrix composites (CGMC)

Carbon and graphite have high temperature friendly materials with their rigidity and strength that are not affected by temperature ranges up to 2300°C. They can be fabricated through chemical vapor deposition of pyrolytic carbon.

1.3.4 Metal Matrix Composites (MMC)

MMC are made by scattering of reinforcing material into a metal matrix. Matrix is characteristically a lighter metal such as magnesium, titanium or aluminium which provide yielding support for the reinforcement. Cobalt and cobalt-nickel alloy matrices are generally used for high temperature applications. The reinforcing particles increase physical properties such as wear resistance, thermal conductivity, friction coefficient etc. of the matrix material. The reinforcing particles may have continuous or discontinuous phase in the metal matrix composites.

MMC possess diverse characteristics over conventional polymer matrix composites such as:

- MMC are resistant to fire
- They are resistant to radiation
- They are Damp proof
- They can function in wider range of temperatures
- They have better electrical and thermal conductivity

1.4 ALUMINIUM BASED METAL MATRIX COMPOSITES

Among MMC, aluminium matrix composites (AMC) are getting popular day by day and finding numerous applications. In AMC one of the constituent is aluminium based alloy known as matrix phase and other constituent is reinforcement, which is generally a ceramic such as SiC, Si3N4, TiC, BN, B_4C and Al_2O_3 are most commonly used. AMC properties can be tailored by varying the constituents and their volume fraction. Over the years, AMC have several operational, non-operational and functional applications in numerous engineering fields due to their better performance, environmental and economic benefits. AMC are being widely used in transportation industries because of less noise, lower fuel consumption and lower aerial emissions. With increasing environmental rules & regulations to enhancing fuel economy and efficiency, use of AMC in transport industries will be appropriate option in upcoming years. It is now accepted that in order to empower the AMC substitution for engineering materials and to make it wide spread, there is a fascinating need to redesign the whole engineering system to increase further weight and volume savings. AMC can be categorized into four types based on the type of reinforcement.

1.4.1 Particle reinforced Aluminium Matrix Composites (PAMC)

PAMC contain equiaxed ceramic reinforcements having aspect ratio less than 5. Ceramic reinforcements are usually oxides, borides or carbides (Al_2O_3, TiB_2 or SiC) and are present in metal matrix by volume fraction of less than 30%, when used for wear resistance and structural application. In general, PAMC can be fabricated either by solid state or liquid state fabricated processes. PAMC are least expensive when compared with CFAMC. Mechanical properties of PAMC are lower as compared to whisker/continuous fiber/ short fiber reinforced AMC but there properties are far superior to unreinforced aluminium alloys. They are isotropic in nature and can have many applications in forming operations such as rolling, extrusion and forging.

1.4.2 Short fiber and whisker reinforced Aluminium Matrix Composites (SFAMC)

SFAMC contain reinforcements having an aspect ratio greater than 5, but they are not continuous fiber. Most popular AMC is Short alumina fiber reinforced in aluminium matrix composites which is used in pistons. Short fiber reinforced composites are fabricated by using squeeze infiltration process, while Whisker reinforced composites are fabricated either by powder metallurgy (PM) process or by infiltration process. Mechanical properties of whisker reinforced composites are superior than short fiber reinforced composites. However; usage of whiskers as reinforcements in AMC is restricted due to their apparent health hazards. Short fiber reinforced AMC have characteristics of continuous fiber and particle reinforced AMC.

1.4.3 Continuous Fiber-reinforced Aluminium Matrix Composites (CFAMC)

CFAMC are continuous fibers of SiC, alumina or carbon with a diameter less than 20µm. AMC having fiber volume fraction of about 40% are fabricated by squeeze infiltration process. Recently CFAMC with 60 vol% alumina fiber (continuous fiber) reinforced composites with an ultimate tensile strength and elastic modulus of 1500 MPa and 240 GPa respectively have been fabricated by 3M corporation. These composites were fabricated by using pressure infiltration process.

1.4.4 Mono Filament reinforced Aluminium Matrix Composites (MFAMC)

Monofilaments are generally fabricated by chemical vapor deposition (CVD) of either Boron carbide or SiC into a core of Tungsten wire or of carbon fiber. Bending flexibility of monofilaments is less as compared to multi filaments. Diffusion bonding technique is often used to fabricate mono filament reinforced composites and is restricted to super plastic forming aluminium alloy matrices.

1.5 MANUFACTURING OF AMC

Fabrication techniques help in governing microstructure behavior, interfacial bond etc. in the composites Metal matrix composites specially aluminium based MMC can be fabricated by various techniques such as:

1.5.1 Solid State Processing

1.5.1.1 Powder Metallurgy (PM)

Mixing powder of ceramic whisker particle/short fiber in aluminium alloy is a valuable technique for the fabrication of AMC. Blending can be processed in dry or in liquid suspension. Blending generally have cold compaction followed by degassing and high temperature consolidation step such as extrusion. PM processed AMC, contain oxide constituent ranging from 0.05 to 0.5 depending on powder and processing conditions. These fine oxide particles have a tendency to act as a dispersion-strengthening agent and has strong influence predominantly during heat treatment on the matrix properties.

1.5.1.2 DIFFUSION BONDING PROCESS

Diffusion bonding technique is often used to fabricate mono filament reinforced composites. The technique is cumbersome and distribution of homogeneous fiber is difficult. The process is also not appropriated to fabricate complex shapes and components.

1.5.2 Liquid State Processing

1.5.2.1 STIR CASTING

In this process hard ceramic particles are fused into the molten aluminium melt and allowing the mixture to solidify. A good wettability is created between reinforcement and the molten aluminium alloy melt. Stir-casting technique is most simplest and economical fabrication process used for fabrication of AMC. The technique includes the addition of pre-heated reinforcing particles into the vortex of molten aluminium alloy created by the mechanical stirrer. After proper mixing of matrix and reinforcement, composite melt is casted into a suitable mould to get the desired shape of the AMC.

1.5.2.2 INFILTRATION PROCESS

Liquid aluminium alloy is intruded into the interstices of continuous fiber/whisker or short particle to fabricate AMC. Depending on the nature of reinforcement infiltration can be done with or without pressure application. AMC having volume fraction ranging from 10 to 70% of reinforcement can be fabricated using different infiltration techniques. In order to maintain its shape and integrity, it is necessary to use alumina and silica based mixtures as binder. During fabrication of AMC by infiltration process may have porosity as casting defect in casted samples.

1.5.2.3 SPRAY DEPOSITION

Spray deposition process may have two different classes, depending on whether the droplet stream is fabricated from a molten bath or by continuous serving of cold metal into a region of rapid heat injection. The spray deposition has been extensively explored for the fabrication of AMC by injecting ceramic particle/short fiber/ whisker into the spray. There is inhomogeneous distribution of ceramic particles in fabricated AMC. The AMC produced by spray deposition process may possess porosity as casting defect in casted samples.

1.6 CHARACTERIZATION OF AMC

AMC are characterized in order to reveal microstructure, chemical composition etc. Distinct techniques may be used for observing microstructural constituents of fabricated metal matrix composites such as optical microscopy, Scanning electron microscopy (SEM), X-ray diffraction technique (XRD), Electron probe micro analyzer (EPMA), Energy dispersive X-ray spectroscopy (EDS), Energy dispersive analysis of X-ray (EDAX) etc.

1.6.1 Optical Microscopy

Optical microscopy technique is used to analyze the magnified image of microstructure of AMC. The optical microscopy is carried out using a metallurgical microscope. The microstructural specimens of AMC are prepared via standard polishing process and etching by a suitable etching agent. In this technique magnified images are detected and images are captured digitally.

1.6.2 Scanning Electron Microscopy–Energy Dispersive Analysis of X-Rays

SEM technique is used to generate variety of signal on the surface of fabricated composites. In this technique high resolution image of microstructure, chemical composition etc. is generated. EDAX technique is used for chemical characterization and elemental analysis of fabricated composites. This technique follows the fundamental principal that each element has a unique set of peaks on electromagnetic emission spectrum.

1.6.3 X-Ray Powder Diffraction Technique (XRD)

XRD technique is used for phase identification of crystalline material along with information about unit cell. This technique is used to detect constituent particles present in fabricated composites.

II. LITURATURE ANALYSIS

2.1 FABRICATION OF METAL MATRIX COMPOSITES

MMCs especially aluminium based MMCs have distinct techniques for fabrication of composites. Fabrication of MMCs is important in determining microstructure behavior, interfacial bond, defects such as misrun, porosity etc. in MMCs. Different fabrication techniques such as powder metallurgy, squeeze casting, diffusion bonding, spray & rheo casting, Stir casting etc. are used in fabrication of MMCs [21].

It is observed Al alloy reinforced with SiC using stir casting as fabrication process, porosity around SiC particles is observed [2, 3, 19] which can be reduce by preheated of mold [3]. It is researched Al alloy reinforced with groundnut shell ash & SiC using Stir casting, continuous phase of metal matrix along with dispersed reinforcement is observed [4]. It is investigated Mg MMCs reinforced with B_4C fabricated with powder metallurgy techniques using sintering cycle, clustering of B_4C particles in the MMCs is observed [6]

Al6082 reinforced with graphite [7], Al alloy reinforced with SiC [9], fabricated with stir casting techniques, clustering & non uniform distribution of reinforcement is observed [7, 9]. A356 reinforced with SiC, fabricated with Compo casting, porosity throughout the specimen is observed as a defect in MMCs [10]. Al alloy [A536, 6061] reinforced with SiC, fabricated with gravity casting, porosity & interdentritic micro shrinkage along with clustering of reinforcement is observed as defects in MMCs [12]. Al alloy reinforced with breadfruit seed hull ash fabricated with stir casting, density dislocation defect is observed in MMCs [13]. LM6 aluminium alloy reinforced with fly ash fabricated with stir–squeeze casting & gravity casting, no porosity & discontinuity is observed during stir–squeeze casting in metal matrix composites [16].

1) 2.2 STIR CASTING TECHNIQUE

Among distinct fabrication techniques stir casting is used for manufacturing MMCs because of its simplicity, low cost in fabrication and flexibility in production. In stir casting, reinforcing particles are mixed with molten metal matrix with the help of stirrer. After mixing molten metal matrix is pour into preheated mold. In order to fabricate MMCs distinct parameters are involved such as stirrer type, stirring time, pouring temperature, mold type, preheat of reinforcement, preheat of mold etc. Stirrer can be of stainless steel [10], coated with graphite [13] or BN coating [1], Mild steel [3, 9].

Stirring speed is important for enhancing wettability and controlling flow pattern of MMCs.

Stirring speed varying from 200-400 rpm [4, 7, 8, 10, 12, 15, 17], 500-800rpm [1, 2, 3, 9, 13, 16, 19, 20]. But optimum stirring speed ranging from 300-600rpm [24]. Stirring time helps in uniform distribution of reinforcement in MMCs along with proper bonding. Stirring time varying from 5 min. [4, 13, 16], 10 min. [2, 3, 5, 7, 9, 17, 19], 20 min [12, 15] etc. in order to maintain proper uniformity [24].

Reinforcement preheat temperature helps in enhancing wettability and removing moisture content from the reinforcement [1]. Preheat temperature of reinforcement varies from material to material used as reinforcement. Reinforcement such as fly ash 150-650^{o}C [1, 16], SiC 8001100^{o}C [2, 3, 9, 10], Graphite 500^{o}C [7] etc. have preheated temperature. Pouring temperature is used for determining grain orientation & structure of fabricated MMCs. Pouring temperature of distinct MMCs varies from 700-900^{o}C. Mold governs the shape & size of fabricated MMCs. Mold may be permanent mold [5, 7, 12, 15], metallic mold [1, 2, 4, 8], Die mold [3, 16], sand mold [4, 9] with shape of cylindrical [2, 3, 5, 15], rectangular [1], circular [8], cast bar [12] etc. Preheat temperature of mold reduces porosity, misrun etc. in MMCs. Preheat temperature of mold varies 250^{o}C [5, 7], 350^{o}C [12, 15], 500^{o}C [13] etc.

2) 2.3 CHARACTERIZATION OF FABRICATED METAL MATIX COMPOSITES

Fabricated metal matrix composites are characterized in order to reveal microstructure, chemical composition etc. of composites. Distinct techniques are used for observing microstructural constituents of fabricated metal matrix composites such as optical microscopy, Scanning electron microscopy (SEM), X-ray diffraction technique (XRD), Electron probe micro analyzer (EPMA), Energy dispersive X-ray spectroscopy (EDS), Energy dispersive analysis of X-ray (EDAX) etc.

It is observed from optical microscopy, SEM, EPMA, XRD techniques that fly ash particles reinforced with Al alloy shows shape of untreated fly ash particles are spherical with presence of Al, Si, O whereas treated fly ash particles have rod shaped with distinct aspect ratio, presence of Si, Al, O, C and conversion of SiO_2 into SiC is obtained in metal matrix composites [1]. It is investigated from optical micrograph that HE-30 Al alloy reinforced with SiC shows presence of porosity with uniform distribution of reinforcing particles is obtained in metal matrix composites [2]. It is researched from EDAX, EDX test sample that SiC reinforcement mixed with Al2024 shows chemical composition of fabricated metal matrix composites as shown in the table 2.3 [3].

Table 2.3 Chemical composition of 10 %wt. Al-SiC composites [3]

S.No	Element	Weight %
1	Caco3	24.19
2	SiO2	7.67
3	MgO	0.87
4	Al	64.79
5	Cu	2.47

It is investigated from SEM, EDS, XRD techniques that Mg MMCs reinforced with boron carbide (B_4C) shows uniform distribution of boron carbide (B_4C) with clustering particles, good interfacial bonding and presence of Al_2O_3, MgO, MgB_2 in the composites samples[6]. It is observed from SEM, XRD, and test that Al6082reinforced with graphite shows large impurities, non-uniform distribution and clustering of graphite particles at some places. The microstructures of MMCs shows inter-dendritic network of aluminium silicon eutectic. XRD results also reveal elements such as Al, C, Si peaks are present in fabricated MMCs [7]. It is investigated from metallurgical microscope that Al alloy reinforced with SiC shows at some location there are clustering of particles and without SiC particles inclusion when stirring process is not applied [9].

It is analyzed from optical microscopy that A356 alloy reinforced with SiC analysis perimeter (J. m), aspect ratio, sphericity, SiC area percentage and count. It also shows presence of porosity as isolated particles [10]. It is observed from optical microscopy that Al alloy reinforced with SiC shows plastic deformation is helpful in improving homogeneity of reinforcement [11]. It is investigated from Optical microscopy, SEM equipped with EDX & WDX that Al alloy (A536 & AA6061) reinforced with SiC shows presence of many phases such as primary, α-Al, SiC particles and eutectic structures. It is also observed that porosity & inter dendritic micro shrinkage are main defects in metal matrix composites [12].

It is analyzed from XRD, SEM/EDS, XRF (X-ray fluorescent) that Al-Si-Fe alloy reinforced with breadfruit seed hull ash particulates shows uniform distribution of reinforcement particles in Al alloy. XRF results shows chemical composition of breadfruit seed hull ash, while XRD shows count of various element present in the sample [13]. It is observed from optical microscopy and SEM that Al 6063, al 6061 and Al 7072 matrix alloy reinforced with SiC shows non uniform distribution, clustering and allomeration of SiC particles in metal matrix composites. There are many phases observed in microstructure such as Mg_2Si, Cu_2Si_6, Al_5Mg_8, Al_3Fe, Al_2Cu, and Al_3FeSi [14]. It is investigated from optical microscopy that Al6063 alloy reinforced with SiC shows uniform distribution of reinforcement and good homogeneous dispersion of SiC particles is observed in metal matrix composites [15]. It is analyzed from optical micrograph that LM6 Al alloy reinforced with fly ash shows uniform distribution, good retention of reinforcement, without any porosity, voids and discontinuities in MMCs. There are agglomeration of fly ash particles at some location in composites. It is also observed that there are good interfacial bonding between metal matrix and reinforcement particles in MMCs [16]. It is observed from metallurgical microscope that Al6061-SiC & Al7075-Al_2O_3 shows fairly uniform distribution of reinforcement and homogeneity of fabricated composites [17].

It is investigated from metallographic examination that Al356 alloy reinforced with SiC shows non uniform distribution of reinforcement with agglomerations of particles at some location is observed. It is reveal that some particles have polygonal shape with sub angular edges and other have granular shape with aspect ratio of 1 [18]. It is observed from SEM that Al alloy reinforced with SiC shows porosity and clustering of reinforced particles is observed in metal matrix composites [19]. It is investigated from optical microscope & SEM that Al6061 alloy reinforced with SiC shows due to crack initiation and growth in composite matrix, there is fracture of coarse particles reinforced metal matrix composites [20].

III. CONCLUSION

It is observed & researched that powder metallurgy cause fracture damage to reinforcement & are expensive as reinforced particles required in this process is in powder form. Squeeze casting cause severe damage to reinforcement & moderate expensive with less or little porosity is observed in MMCs [23]. Stir casting cause less damage to reinforcement, flexible, economical and not restricted to shape & size, but porosity with non-uniform distribution of reinforcement is observed in MMCs [2, 3, 5, 9, 18, and 23]. Stir–Squeeze casting cause less or no damage to reinforcement and no or little porosity with uniform distribution of reinforcement in MMCs [16]. The main of this review paper is to establish an understanding of fabrication and characterization of MMCs.

REFERENCES

[1] Ajit Kumar Senapati, R. I. Ganguly, R.R. Dash, P. C. Mishra and B. C. Routra, " production, characterization and analysis of mechanical properties of newly developed novel aluminium-silicon alloy based metal matrix composited", Procedia Materials Science 5 (2014) 472-481.

[2] Pradyumna Phutane, Vijay Kumar S. Jatti, Ravi Sekhar and T. P. Singh, "Synthesis and characterization of SiC reinforced HE-30 Al alloy particulate MMCs", International Journal of Engineering and Technology (IJET) Vol. 5 No. 3 jun-jul 2013 ISSN: 0975-4024.

[3] N. Subramani, M. Balamurugan and K. Vijayaraghavan, "Mechanical behavior of Al-SiC composites prepared by stir casting method", International Journal of Innovation Research in Science, Engineering and Technology, Vol. 3 Issue 3, March 2014.

[4] Kenneth kanayo Alanema, Michael Oluwatosin and Adebimpe A. Awe, "Microstructure, mechanical and fracture properties of groundnut shell ash and silicon carbide dispersion strengthened aluminium matrix composites", Journal of King Saud University- Engineering Sciences (2016).

[5] Pardeep Sharma, Dinesh Khanduja and Satpal Sharma, "Parametic study of dry sliding wear of aluminium metal

matrix composites by response surface methodology", Materials Today: Proceeding 2 (2015) 2687-2697.

[6] L. F. Guleryuz, S. Ozan, D. Uzunsoy and R. Ipek, "An investigation of the microstructure and mechanical properties of B_4C reinforced PM magnesium matrix composites", Powder Metallurgy and Metal Ceramic, Vol. 51, Nos. 7-8,November, 2012.

[7] Pardeep Sharma, Satpal Sharma and Dinesh Khanduja, "A study on microstructure of aluminium matrix composites", Journal of Asian Ceramic Societies 3 (2015) 240-244.

[8] Mohammed Imran, A.R. anwar Khan, Sadananda Megeri and Shoaib sadik, "Study of hardness and tensile strength of aluminium-7075 percentage varying reinforced with graphite and bagasse –ash composites"

[9] Manoj Singla, D Deepak Dwivedi, Lakhvir Singh, Vikas Chawla, "Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite", Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.6, 2009, pp. 455-467.

[10] S. Naher, D Brabazon and L Looney, "Development and Assessment of a New Quick Quench Stir Caster Design for the Production of Metal Matrix Composites", Journal of Material Processing Technology, Vol. 166, 2004, pp. 430-439.

[11] S. Das, R. Behera, A. Datta, G. Majumdar, B. Oraon, G. Sutradhar, "Experimental Investigation on the Effect of Reinforcement Particles on the Forgeability and the Mechanical Properties of Aluminum Metal Matrix Composites", Materials Sciences and Applications, 2010, pp. 310-316.

[12] W. Zhou, Z. M. Xu, "Casting of SiC Reinforced Metal Matrix Composites", Journal of Materials Processing Technology, Vol. 63, 1997, pp. 358-363.

[13] C. U. Atuanya, A. O. A. Ibhadode, I. M. Dagwa, "Effects of breadfruit seed hull ash on the microstructures and properties of Al–Si–Fe alloy/breadfruit seed hull ash particulate composites", Results in Physics 2, 2012, pp. 142–149.

[14] A. Chennakesava Reddy and Essa Zitoun, "Matrix Al-alloys for Silicon Carbide Particle Reinforced Metal Matrix Composites", Indian Journal of Science and Technology, Vol. 3, No. 12, 2010.

[15] K. L. Meena, Dr. A. Manna, Dr. S. S. Banwait, Dr. Jaswanti, "An Analysis of Mechanical Properties of the Developed Al-SiC-MMC's", American Journal of Mechanical Engineering, 2013, Vol. 1, No. 1, pp. 14-19.

[16] K. N. P. Prasad and M. Ramachandra, " Effect of squeeze pressure on hardness and wear resistance of aluminium flyash composite manufactures by stir-squeeze casting", International Journal of Engineering Inventions, e-ISSN:2278-7461, p-ISSN 2319-6491, Volume 3 Issue 4 (November 2013) PP: 01-08.

[17] G. B. Veeresh Kumar, C. S. P. Rao, N. Selvaraj, M. S. Bhagyashekar, " Studies on Al6061-SiC and Al7075 - Al2O3 Metal Matrix Composites", Journal of Minerals & Materials Characterization & Engineering, Vol. 9, 2010, pp. 43-55.

[18] Mohammad M. Ranjbaran, "Experimental Investigation of Fracture Toughness in Al 356- SiC Aluminium Matrix Composite" American Journal of Scientific and Industrial Research, 2010.

[19] Hai Su, Jian Lu, Zheng Lu, Wenli Gao, Hui Zhang and Hongbo Liu, "Optimization of Stirring Parameters Through Numerical Simulation for the Preparation of Aluminum Matrix Composite by Stir Casting Process", Journal of Manufacturing Science and Engineering. 132(6), 2010.

[20] Lihe Qian, Toshiro Kobayashi, Hiroyuki Toda, Takashi Goda and Zhong-Guang Wang, "Fracture Toughness of a 6061 Al Matrix Composite Reinforced with Fine SiC Particles", Transactions, Vol 43, No 11, 2002, pp. 2838 – 2842.

[21] Sijo MT and KR Jayadevan, "Analysis of stir cast aluminium silicon carbide metal matrix composite: A comprehensive review", Procedia Technology 24 (2016) 379-385.

[22] M. K. Surappa, "Aluminium Matrix Composites: Challenges and Opportunities", Sadhana Vol. 28, Parts 1 & 2, February/April 2003, pp. 319–334.

[23] Hashim, L Looney and M S J Hashmi, "Metal Matrix Composites: Production by the Stir Casting Method", Journal of Material Processing and Technology, Vol. 92, 1999, pp. 1-7.

[24] C. Saravanan, K. Subramainian, V. Ananda Krishnan and R. Sankara Narayanan, "Effect of particulate reinforced aluminium metal matrix composite- A review", Mechanics and Mechanical Engineering, Vol. 19, No. 1 (2015) 23-30.