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Fabrication methods used to prepare Al metal matrix composites- A review

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Abstract - *In the past few years the global need for low cost, high performance and good quality materials has caused a shift in research from monolithic to composite materials. Metal matrix composites (MMCs) as new and promising materials are under constant development and their application in different industries are increasing. Aluminium matrix composites (AMCs) are rapidly finding their way to be commercially used due to their high strength and light weight properties. Also a simple and cost effective method for manufacturing of the composites is very essential for expanding their application. The low cost processing method and uniform distribution of different reinforcements used to prepare AMCs is a demanding challenge in this area. A variety of processing ways have been established for the production of particle/whisker/short fibre reinforced composites. In this paper an attempt has been made to provide a literature review on the basic existing techniques used to fabricate the Aluminium based MMCs and suggest a least expensive method for the scientific and technical applications.*

Key Words: MMCs, AMCs, SiC, Reinforcement, Stir casting

1. INTRODUCTION

In the past few years, materials development has shifted from monolithic to composite materials for adjusting to the global need for reduced weight, low cost, quality, and high performance in structural materials. Driving force for the utilization of AMCs in areas of aerospace and automotive industries include performance, economic and environmental benefits. Parallel to this trend, metal-matrix composites (MMCs) have been attracting growing interest [1-4].MMCs consist of a non-metallic reinforcement incorporated into a metallic matrix which can provide advantageous properties over base metal alloys. These include improved thermal conductivity, abrasion and wear resistance, creep resistance, dimensional stability, exceptionally good stiffness-to-weight and strength-to-weight ratios. They also have better high temperature performance. Hard and strong particles in the form of particulates or fibers are added to improve the thermo mechanical properties and performance of the lightweight but comparatively soft host metal. Common reinforcement particles include ceramics such as silicon carbide and alumina, B4C, AlN, TiC, TiB2, TiO2 and hard metals such as titanium and tungsten [5-8].

2. PROCESSING ROUTES FOR ALUMINIUM MATRIX COMPOSITES

A vast literature is available on the processing of MMCs. The selection of the processing route depends on many factors including type and level of reinforcement loading and the degree of micro structural integrity desired [9]. Fabrication of the composite materials is focused on obtaining materials with improved properties compared to the matrix material. A key challenge in the processing of composites is to homogeneously distribute the reinforcement phases to achieve a defect-free microstructure. Primary processes for manufacturing of AMCs at industrial scale can be classified into two main groups. Various processes are used to manufacture MMCs which are described here. These processes are classified on the basis of temperature of the metallic matrix during processing [10] accordingly; the processes can be classified into two categories:

1. Liquid State Processes.
2. Solid State Processes

3. LIQUID STATE FABRICATION OF MMCs

In the liquid casting technique, the particulates are mechanically well distributed over the liquid metal before casting and solidification [11]. These methods are typically cost effective [12].

3.1 Stir Casting

Stir casting is currently the most popular commercial method of producing aluminium based composites Stir casting of MMCs was initiated in 1968, when S. Ray introduced alumina particles into aluminium melt by stirring molten aluminum alloys containing the ceramic powders [13]. Fabrication of aluminum and it's alloys based casting composite materials via stir casting is one of the prominent and economical technique for development and processing of MMCs and widely used for applications that require high production volumes and low cost. [14]. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement [15];allows for the use of conventional metal processing methods with the addition of an appropriate stirring system such as mechanical stirring; ultrasonic or electromagnetic stirring; or centrifugal force stirring [16], to achieve proper mixing of reinforcement into melt which depends on material properties and process parameters such as the wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification .The distribution of the particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added [17] and finally the liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies.

J. hashim et al [18] reported that there are limitations which reveals during the process are non-uniform distribution, poor wet ability between reinforcement particulate and matrix material, porosity in casted MMCs and chemical reaction between particulate and matrix. To overcome the limitations an interesting recent development in stir casting is a two-step mixing process [19] in which gas layer around the particle surface which impedes wetting between the particles and molten metals are effectively breached by mixing of the particles in the semi-solid state and effectively break the gas layer because the high melt viscosity produces a more abrasive action on the particle surface. Breaking of the gas layer improves the effectiveness of the subsequent mixing in a fully liquid state.

By giving heat treatment to the reinforcement particles before dispersion into melt can be improved the wettability of reinforcement particles within the molten matrix alloy and the adsorbed gases can be removed from the particle surface [20]. The resulting microstructure has been found to be more uniform than that processed with conventional stirring. Another problem is if the reinforcement particles are distributed uniformly in molten matrix, they tend to sink or float to the molten melt due to the density differences between the reinforcement particles and the matrix alloy melt. If the dispersion of reinforcement particles is not uniform then they have high tendency to agglomeration and clustering. By injecting the particles with an inert gas into the melt is useful in improving the distribution of the reinforcement particles [18].

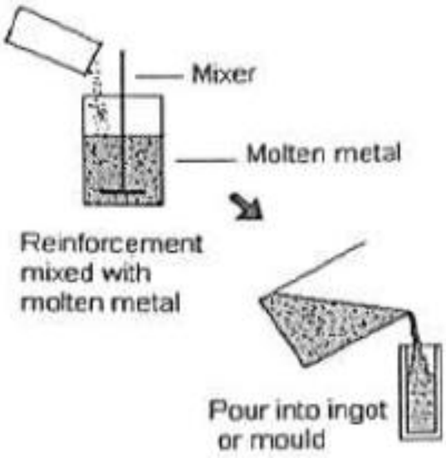


Fig. stir casting process [21]

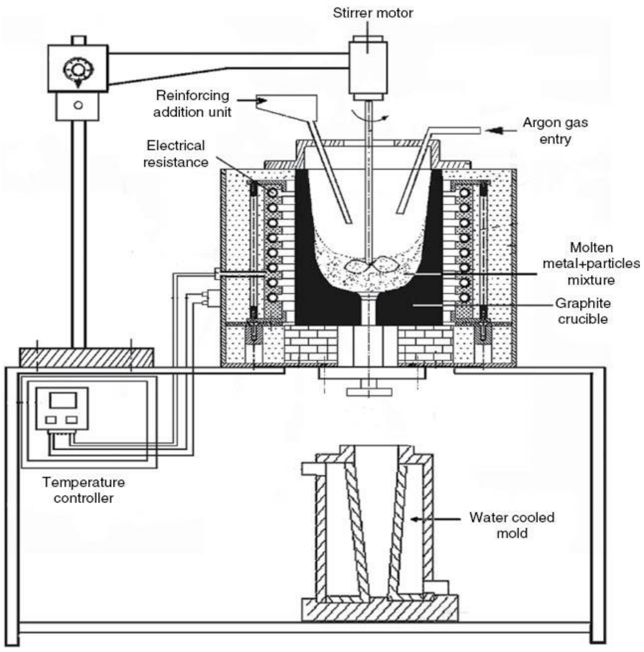


Fig. Stir casting machine equipped with inert gas source [22]

3.2 Compocasting

Wettability and distribution of nano size reinforcement are the key challenge in stir casting because very fine particles are having more surface energy and surface area resulting in agglomeration of reinforcement particles. To achieve uniform distribution, weak agglomeration and effective incorporation of the very fine reinforcement particles into the matrix alloy we move towards Compo casting [23]. Compocasting can mechanically entrap the semisolid slurry and reinforcing particles, prevent their gravity segregation and reduce their agglomeration [24]. Reduction in particle size to nano scale results in greater improvement in ductility of compo-cast product compare to stir casting. In Compo-casting the particles are incorporated at semi-solid temperature of the alloy [25].Because of lower operating temperatures of liquid metal matrices energy can be saved by compo casting and longer tool life achieved [26]. Chemical reaction between molten aluminum and silicon carbide will not occur, due to the low relative operating temperature, the formation of Al_4C_3 chemical compound can be avoided via compo-casting [27]. The melting process has two major problems, one is ceramic particles are not wetted by the liquid metal matrix and secondly, the particles tend to float according to their density relative to the liquid metal which results in nonuniform dispersion of ceramic particles. Reduced porosity in composite material is achieved by squeeze casting and die casting methods [28]

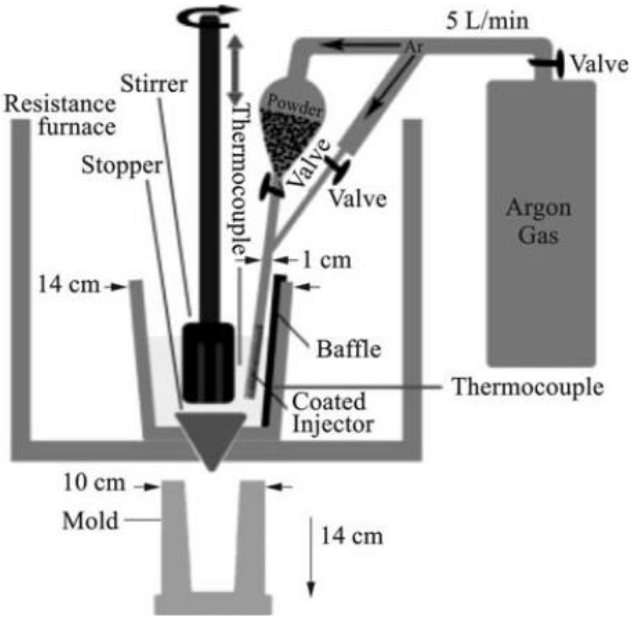


Fig. Experimental set-up used by Amirkhanlou *et al*. [29].

3.3 Squeeze Casting

The concept of squeeze casting dates back to the 1800s [30]. The idea was suggested by Chernov in 1878 [31] to apply steam pressure to molten metal while being solidified. Squeeze casting experiment was not conducted until 1931 [32]. Squeeze casting technique is a liquid phase fabrication method of AMCs in which metal solidifies under pressure within closed die halves, using a movable mould part for applying pressure on the molten metal and force it to penetrate into a preformed dispersed phase, placed in the lower fixed mould part [33]. Squeeze casting fabricated components have superior weldability, heat treatability, high degree of surface finish and dimensional accuracy [34].

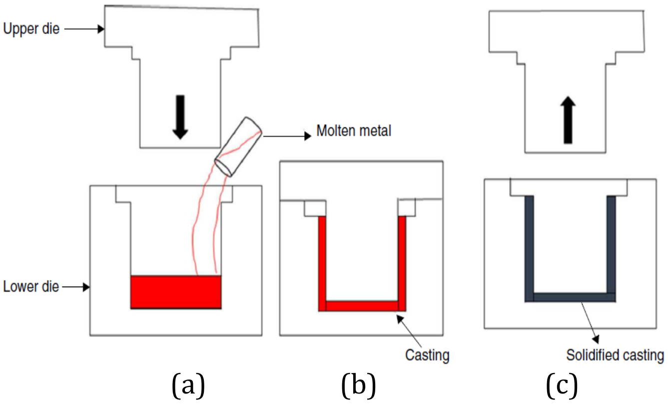


Fig. Schematic diagram illustrating the sequence of steps involved in squeeze casting (a) molten metal poured into the pre-heated die, (b) application of squeeze pressure and (c) solidified casting. [35]

3.4 Spray Forming

Fabrication of composite by spray forming process involves melting of an alloy in a furnace, forcing the melt through a small orifice, passing a stream of compressed inert gas, injecting reinforcement through the jet and breaking the liquid metal into fine semi solid droplets. These semi solid droplets are deposited over a stationary substrate to form solid preform. It is difficult to attain uniform distribution of reinforcements into the metal matrix by this method but the composites formed by spray deposition process are not very expensive [36].

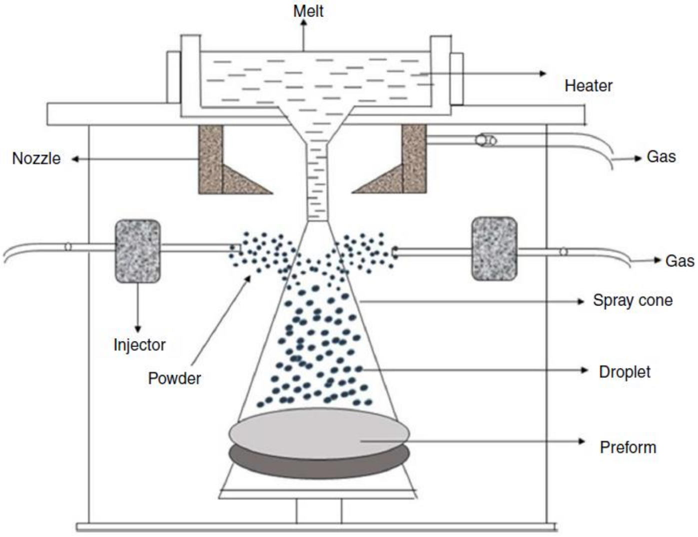


Fig. Schematic diagram of spray forming process. [35]

3.5 In-Situ Synthesis

In-situ synthesis is a process wherein the reinforcements are formed in the matrix by controlled metallurgical reactions with various reinforcement ceramic particles SiC [37], AlN [38] and TiC [39].During fabrication, one of the reacting elements is usually a constituent of the molten matrix alloy. The other reacting elements may be either externally-added fine powders or gaseous phases, final reaction products is the reinforcement dispersed in matrix alloy. It is difficult to disperse the reinforcing particles uniformly in metal melts due to the low wettability with the melt [40].Ahmad Changizi [41] examined that the main difficulty in the process is the reaction of particle size of less than 1mm and the problem of agglomeration and health hazards reveals. The interface bonding may be lowered due to the porosity and segregation at the interface between the matrix and reinforcement [42]. It requires the higher reaction time temperature and longer holding time, which is greatly, increases the cost of production and process requires that the reaction system be carefully screened.

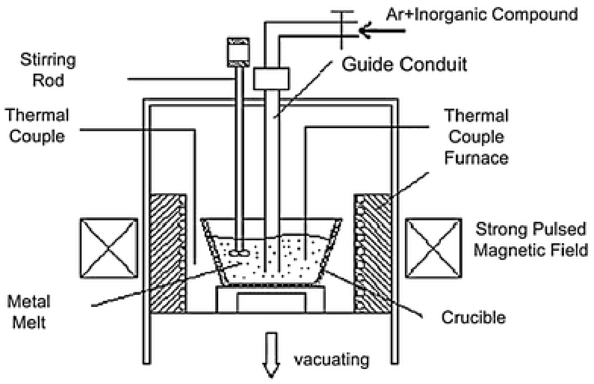


Fig. Schematic diagram of in situ direct reaction synthesis apparatus [43]

3.6 Liquid Metal Infiltration

It is a forced infiltration method of liquid phase fabrication of AMCs and begins with a ceramic preform of the desired shape and accomplished by the application of a pressure of inert gas. The pressure required for combining matrix and reinforcement is a function of the friction effects due to viscosity of the molten matrix as it fills the ceramic preform. Wetting of the ceramic preform depends on: alloy composition, ceramic preform material, ceramic surface, interfacial reactions, atmosphere, temperature and time [44]. Precise shape, high degree of surface finish and suitability for mass production are the advantages of this process [45]. Some of the drawbacks of this process include reinforcement damage, preform compression, non-uniform microstructure, coarse grain size, and undesirable interfacial reactions [46]

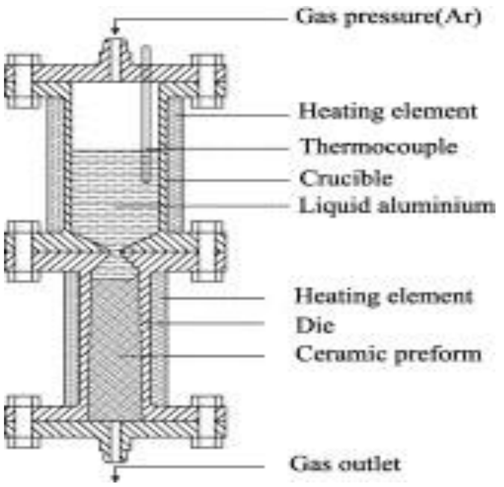


Fig. Schematic representative of the infiltration system [47]

4. SOLID STATE FABRICATION OF MMCs

4.1 Powder Metallurgy

Fabrication of AMCs via powder metallurgy includes uniform mixing of reinforcement with metal alloy and blending of powders; degassing the solidified product in vacuum and sintered under high temperature conditions [48]. Powder metallurgy route can exploit the nano particles and grain boundaries strengthening capability [49]. This method is cost effective for producing complex parts at very close dimensional tolerances, with minimum scrap and not suitable for mass production due to high cost of powder.

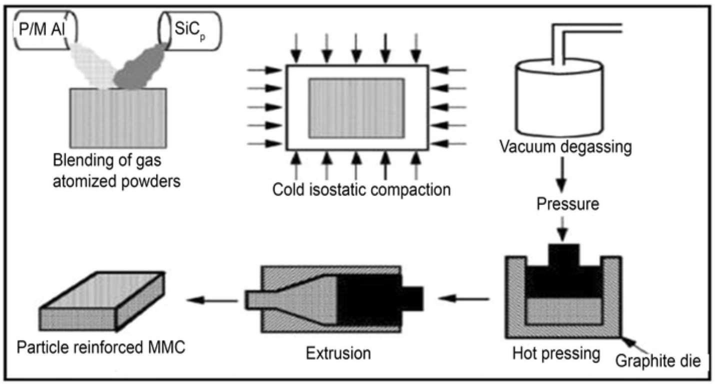
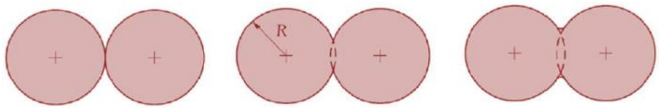
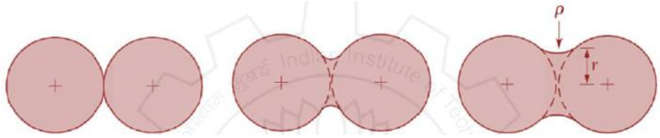


Fig. Schematic of typical powder metallurgy processing scheme [50]



(a) Initial powder Particle
(b) Neck formation by diffusion
(c) Reduction in inter particle distance

Fig. Sintering of compact preform using solid state diffusion between powder particles [51]

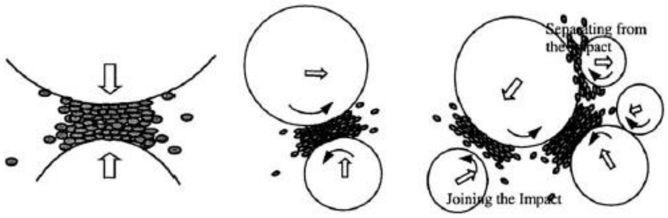


(a) Initial powder Particle
(b) Neck formation by liquid phase transport Of particle
(c) inter particle distance remains same

Fig. Sintering of compact preform using liquid phase transport between powder particles [51]

4.2 High Energy Ball Milling

High energy ball milling utilizes high energy impacts, high frequency from balls to repeatedly forge powder particles together and trapped between colliding balls and inner surface of the vial which causes repeated deformation, re-welding, fragmentation of premixed powders to form dispersed particles in grain refined matrix [52,53]. In mixtures of ductile components the particles are initially flattened but the brittle component undergoes size reduction by fragmentation [54].During milling process addition of ceramic hard particles to metal alloys improve the strength, wear resistance and micro hardness of synthesize composite [55] and extensively employed to obtain, amorphous structures [56], nanocrystalline solids [57], and immiscible components [52].The mechanical properties of particle reinforced composites are largely dependent on the particle microstructure, distribution and volume fraction [58]. This method consume time for achieving required properties of composites and milling of powder require inert atmosphere which is difficult to maintain therefore method is not suitable for mass.



(a)Head-on impact (b) oblique impact (c) Multi-ball impact

Fig. Schematic diagram showing the different forms of impact in which powder particles are trapped between balls which might occur during high-energy ball milling [59].

4.3 Ultrasonic Probe Assisted Method

Traditional fabrication methods cannot be used for mass production and net shape fabrication of complex structural components without post processing [60].In recent years, significant effort has been taken to develop metal matrix nano composites [61]. Ultrasonic probe assisted method is very effective in dispersing nano sized particles in the metal matrix. The process generally requires resistance heating furnace for melting metal, nano particle feeding mechanism, inert gas envelope for protection and an ultrasonic system. The ultrasonic processing system consists of an ultrasonic probe, a transducer and power source. The ultrasonic probe assisted method helps to achieve uniform distribution of particles in metal matrix. The ultrasonic energy is widely used in the manufacturing for welding, casting and non-destructive testing. Ultrasonic stirring is used for purifying, degassing and refinement of metallic melt and utilized to generate nuclei in casting. The ultrasonic cavitation based processing of MMNCs has been successfully utilized by researchers to fabricate bulk MMCs [62-63]. Experimental results show a nearly uniform distribution and good dispersion of the nano-particles within the Al matrix, although some of small agglomeration found. Both hardness and tensile strength are enhanced by incorporation of nano materials into matrix., which was confirmed by SEM pictures [64].It is difficult to distribute and disperse nano scale particles uniformly in metal melts due to their large surface to volume ratio and their low wettability in metal melts.

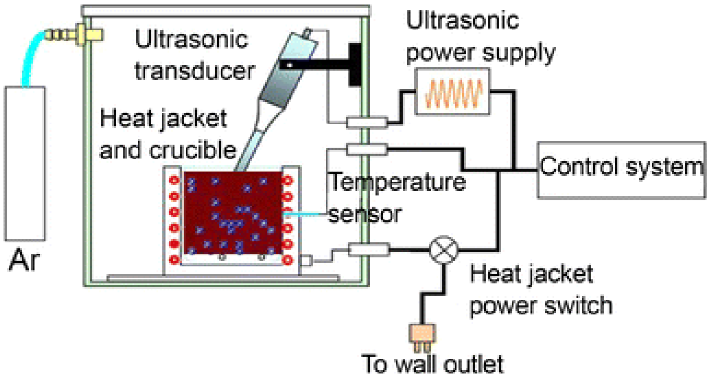


Fig. Schematic of ultrasonic solidification processing [65]

4.4 Diffusion Bonding

Diffusion bonding is a solid state processing technique which is commonly used to produce mono filament reinforced AMCs. Inter diffusion of atoms between clean metallic surfaces which is in contact at an elevated temperature leads to bonding due to the inter-diffusion of atoms across the surfaces of particulates and metal [66]. The principal advantages of this technique are the ability to process a wide variety of metal matrices and control of fiber orientation and volume fraction.

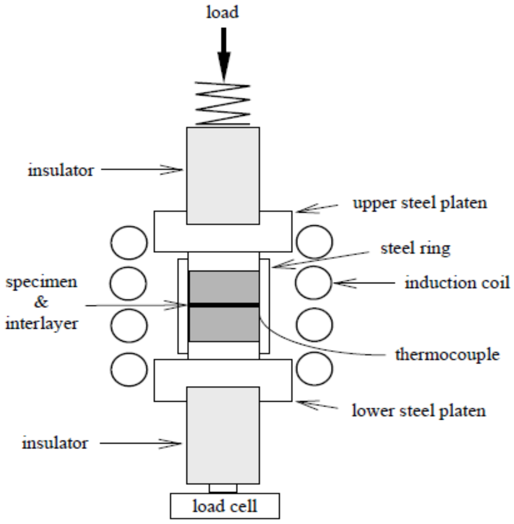


Fig. Diffusion bonding process [67]

4.5 Friction Stir Welding (FSW):

Friction stir welding was developed in 1991 [68] and is essentially a solid state joining process, widely used for the welding of light and difficult-to-weld metals and their alloys like aluminum, magnesium, copper etc. [69]. Recently, its applications have been extended to the welding of high melting point materials such as various types of steels [70], Ti alloys [71], Ni-based super alloys [72]. This method is used as a surface modification to produce composites with good mechanical properties and corrosive resistance by addition of nano, micro and macro size reinforcements [73]. The reinforcement particle size and as well as shift of rotational direction between passes affect the microstructure and mechanical properties of the material [74]. Friction stir processing has been carried out on Aluminum 7075 using nano sized SiC reinforcements, which were shown good metallurgical and mechanical properties such as strength, stress corrosion crack resistance and excellent fatigue resistance [75].

N.T. Kumbhar et al [76] discussed the process of FSW and concluded that it is mature and efficient solid state joining method for Al alloys in which a rotating cylindrical tool with a shoulder and a profiled pin is plunged into the abutting plates to be joined and traversed along the line of the joint. Friction between the tool and work pieces results in localized heating that softens and plasticizes the work piece. During process, the material undergoes intense plastic deformation and this result in significant grain refinement. Mishra et al. [77] fabricated the Al/SiC surface composites by FSP, and indicated that SiC particles were well distributed in the Al matrix, and good bonding with the Al matrix was generated.

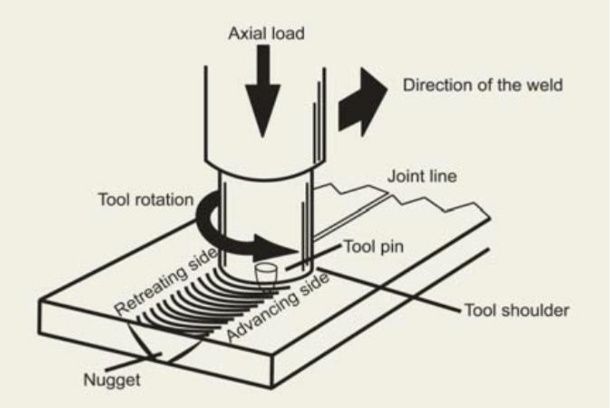


Fig.: Schematic of friction stir welding process [76]

5. ADDITIONAL RELEVANT REVIEW:

D.B. Miracle [78] suggests that the MMCs can be fabricated by both casting and powder metallurgy (P/M) methods but Casting is of interest due to economic reasons.

S A Sajjadi et al [25] reported that the cost of manufacturing Setup and reinforcement material selection is a considerable element for cost effective development of Al MMCs. which exhibits better strength to weight ratio, high strength and ductility, good tribological properties, heat resistance, wear resistance and atmospheric corrosion resistance.

Yoshida K et al [79] reports that The main challenge which has been encountered so far during the processing of AMCs by Stir and compo casting processing methods is the non-wetting characteristics, non-uniform distribution of reinforcement particulate and undesirable interfacial reaction which leads in difficulty to limit greatly the improvement of thermal properties of Carbon/Metal and diamond/metal composite.

David Raja et al [80] has reported that Among various reinforcement used, fly ash is one of the cheapest available reinforcement and its advantage includes low density which clears the way for the development of cost effective AMCs.

M Rodriguez Reyes et al and Sato Y S et al [81-82] reports that the Stir casting incorporate low setup cost, easy handling, quick to access and its suitability for mass production without damaging the reinforcement particles, so it is in demand in the current scenario.

Jayaseelan et al [83] compared the performance characteristics of Al/SiC composites produced through stir casting and powder metallurgy. Stir casting specimen was found to exhibit high hardness and have finer grains in the microstructure as compared to powder metallurgy specimen. After extrusion both the extruded specimen exhibited reduced porosity.

L. Salvo et al [84] found that the stir casting techniques have been among the simplest and the most economical processes of fabricating of the particulate metal matrix composites. However, due to poor wetting of the ceramic particles by molten alloy, the introduction anD uniform dispersion of the reinforcement into the liquid matrix is difficult.

A A Adebisi et al [85] reported that the stir casting is very unique processing method for the development of reinforced AMCs. This is widely acceptable due to its convenience, low set up cost and easy portability to overcome the problem of expensive processes. The development of this dominating fabrication process evolved as a result of recent technological advancement in material application and the demand for light weight material with improved mechanical and thermal properties at low cost.

P.O Babalola et al [86] concluded that the Stir casting, an example of liquid metal route was found to predominate because it is cost effective and processing parameters could be readily varied and monitored. Specimens from stir casting have high hardness and finer grains in the microstructure than the powder metallurgy one.

M. K. SURAPPA et al and D. M. SKIBO et al [87-88] reported the major merit of stir casting is its applicability to large quantity production. Among all the well-established MMCs fabrication methods, stir casting is the most economical Compared to other methods and having costs as little as one third to one tenth for mass production.

J. Hashim et al [18] reported that Liquid phase processing has attractive economic aspects and stir casting method is having an edge over other composite fabrication techniques due to possibility of bulk size, simplicity of operation and good mechanical properties of fabricated MMCs.

6. COMPARISION AMONG FABRICATION TECHNIQUES OF MMCs [83, 87, 89]

Table 1. COMPARISION AMONG LIQUID STATE FABRICATION OF MMCs:

Route	Cost	Application	Comments
Stir casting	Least expensive	Applicable to large quantity production. Commercial method of producing aluminum based composites.	Depends on material properties and process parameters. Suitable for particulate reinforcement in AMC.
Compocasting	Low	Widely used in automotive and aerospace Industries.	Suitable for discontinuous fibres, especially particulate reinforcement.
Squeeze casting	medium	Widely used in automotive industry for producing pistons, connecting rods, rocker arms, cylinder heads; suitable for manufacturing complex objects.	Generally applicable for any type of reinforcement and may be used for large scale manufacturing.
Spray casting	medium	Used to produce friction materials, electrical brushes and contacts, cutting and grinding tools.	Particulate reinforcement used; full density materials can be produced.
In-situ (reactive) processing	Expensive	Automotive applications.	Homogeneous distribution of the reinforcing particles.
Liquid-metal infiltration	Low/Medium	Used to produce structural shapes such as rods, tubes, beams with maximum properties in a uniaxial direction.	Filaments of reinforcement used.

Table 2. COMPARISION AMONG SOLID STATE FABRICATION OF MMCs:

Route	Cost	Application	Comment
Powder metallurgy	Medium	For producing small objects (especially round), bolts, pistons, valves, high-strength and heat-resistant materials.	Both matrix and reinforcements used in powder form; best for particulate reinforcement; since no melting is involved, no reaction zone develops, showing high strength composite.
Ultrasonic assisted casting	Expensive	Used for net shape fabrication of complex structural components, applicable for mass production.	Nearly uniform distribution and good dispersion Of reinforcement particles.
Diffusion bonding	High	Used to make sheets, blades, vane shafts, structural components.	Handles foils or sheets of matrix and filaments of reinforcing element
Friction Stir welding	Moderate/ Expensive	In automotive and aerospace application.	Used as surface modification process. Increase in micro hardness of the surface, significant improvement in wear resistance.

7. CONCLUSION

Various solid and liquid metal routes employed by myriad researchers to produce AMCs. The successful commercial production of AMCs will finally depend on their cost effectiveness for different applications. Stir casting, an example of liquid metal route is found to predominate because processing parameters could be readily varied and monitored. This review concludes the cost effective methods used to prepare the AMCs. Fabrication of aluminium alloy based composite via stir casting is one of the prominent and economical technique as compared to other method and applicable for large quantity production. Specimens from stir casting have high hardness and finer grains in the microstructure than the other method. . Stir casting method is widely acceptable due to its advantages like low setup cost, easy portability, incorporate mass production and uniform distribution of reinforcement to achieve better mechanical properties. Stir casting is one of the most universally used approach to manufacture particle reinforced composites and among all the fabrication techniques considered, stir casting stands out as the most economical method.

REFERENCES:

[1]J.E. Allison and G.S. Cole. *JOM* **45** (1993), pp. 19–24. View Record in Scopus | Cited By in Scopus (122)

[2]C.K. Narula and J.E. Allison. *CHEMTECH* **26** (1996), p. 48.

[3]N. Chawla, C. Andres, J.W. Jones and J.E. Allison. *Metall. Mater. Trans. A* **29** (1998), p. 2843. View Record in Scopus | Cited By in Scopus (85)

[4]Asthana R 1998 Solidification processing of reinforced metals (Trans. Tech. Publ.)

[5]Tjong SC. Recent Advances in Discontinuously Reinforced Aluminum Based Metal Matrix Nanocomposites, Composite Materials Research Progress (ISBN: 1-60021-994-2), Editor: Lucas P. Durand, Nova Science Publishers, Inc, 2008; pp 275 296.

[6]Law E, Pang SD, Quek ST. Discrete dislocation analysis of the mechanical response of silicon carbide reinforced aluminium nanocomposites. Composites, 2011; Part B 42: 92–98.

[7]Senthilkumar V, Omprakash BU. Effect of Titanium Carbide particle addition in the aluminium composite on EDM process parameters. J Manufact Processes, 2011; 13: 60–66.

[8]Kumar BA, Murugan N. Metallurgical and mechanical characterization of stir cast AA6061-T6–AlNp. Composite Materials Design, 2012; 40: 52–58.

[9]M. N. Wahab, A. R. Daud and M. J. Ghazali " PREPARATION AND CHARACTERIZATION OF STIR CAST-ALUMINUM NITRIDE REINFORCED ALUMINUM METAL MATRIX COMPOSITES" International Journal of Mechanical and Materials Engineering (IJMME), Vol. 4 (2009), No. 2, 115-117

[10]G. Ramu, Ranjit Bauri,"Effect of equal channel angular pressing (ECAP) on microstructure and properties of Al– SiCp composites", Materials & Design, 2009, Vol. 30, Issue 9, pp. 3554–3559.

[11]Estrada-Guel I, Carreno-Gallardo C, Mendoza-Ruiz DC. Graphite nanoparticle dispersion in 7075 aluminum alloy by means of mechanical alloying. J Alloys Compd 2009;483:173–7.

[12]Kerti I, Toptan F. Microstructural variations in cast B4C-reinforced aluminium matrix composites (AMCs). Mater Lett 2008;62:1215–8.

[13] S. RAY, ‚MTech Dissertation' (Indian Institute of Technology,Kanpur, 1969).

[14]Evans A, Marchi CS, Mortensen A. Metal matrix composites in industry: an introduction and a survey. Dordrecht, Netherlands: Kluwer Academic Publishers; 2003.

[15]A. LUO, Metall. Mater. Trans. A **26A** (1995) 2445.

[16]P . ROHATGI, Modern Casting **April** (1988) 47.

[17]N. HARNBY, M. F.EDWARD and A. W. NIENOW,‚Mixing in Process Industries' (Butterworths, London, 1985).

[18]J. Hashim, L. Looney, and M. S. J. Hashmi, "Metal matrix composites: production by the stir casting method," Journal of Materials Processing Technology, Vol.92–93, 1999, pp. 1–7.

[19]Wikipedia, powder metallurgy

[20]S. A. Sajjadi, H. R. Ezatpour, H. Beygi "Microstructure and mechanical properties of Al-Al2O3 micro and nano composites fabricated by stir casting" Materials Science and Engineering A 528 (2011) 8765–8771.

[21]J Hashmi, Dr L Looney, The Production of metal matrix composites Using the stir casting technique, School of Mechanical and Manufacturing Engineering Dublin City University Ireland, August, 1999

[22]V. Suong and Hoa, Handbook of science and engineering of composite materials, Vol. 21, Issue 4, Sep 2014.

[23]M. Rosso, J. Mater. Process. Technol. 175, 364-375 (2006).

[24]J.U. Ejiofor, R. G. Reddy, JOM 49 (1997) 31-37.

[25]S. A. Sajjadi, H. R. Ezatpour, M. Torabi Parizi, "Comparision of microstructure and mechanical properties of A356 aluminum alloy/ Al2O3 composites fabricated by stir and compo-casting processes" Materials and Design 34 (2012),pp 106-111

[26]Llija Bobie, Jovana Ruzic, Biljana Bobic, Miroslav Babic, Aleksandar Vencl, Slobodan Mitrovic, "Microstructural characterization and artificial aging of compo-casted hybrid A356/SiCp/Grp composites with graphite macroparticles" Materials Science & Engineering A 612 (2014) 7-15.

[27]J.C. Viala, P. Fortier, J. Bouix, J. Mater. Sci. 25, 1842-1850 (1990).

[28]Sevik H, Can Kurnaz S, "Properties of alumina partculate reinforced aluminum alloy produced by pressure die casting" Mater Des, 27, 676-83 (2006).

[29]Amirkhanlou S, Roohollah J, Behzad N, Mohammad RT. Using ARB process as a solution for dilemma of Si and SiCp distribution in cast Al–Si/SiCp composites. J Materials Process Technol, 2011; 211:1159–1165.

[30] J. Hollinggrak, Casting Metals, UK Patent 4371 (1819).

[31]D.K. Chernov, "Reports of the Imperial Russain Metallurgical Society" (1878).

[32]V. G. Welter, Z Metallkd, 23, 255 (1931).

[33]B.B .Gulyaev, "Crystallization of steel under mechanical pressure" Liteinoe Proizvodstvo, 12, 33 (1960).

[34]M.R. Ghomashchi, A. Vikhrov, "Squeeze casting: an overview" Journal of Materials Processing Technology 101, 1-9 (2000).

[35]Satish Kumar Thandalam Subramanian Ramanathan, Shalini Sundarrajan, Synthesis, microstructural and mechanical properties of ex situ zircon particles (ZrSiO4) reinforced Metal Matrix Composites (MMCs): a review, j mater res technol. 2015;**4(3)**:333–347

[36] J White, I Hughes, T Willis, R Jordan, Metal matrix Composites based upon Aluminium, lithium and Silicon carbide , HAL Journal de Physique Colloques, **1987**, 48, C3, C3-347- C3-353

[37]M.F. Zawrah, M.H. Aly, "In situ formation of Al2O3-SiC- mullite from Al-matrix composites" Ceramics International 32, 21-28 (2006).

[38]. W. Daoush, A. Francis, Y. Lin, R. German, " An exploratory investigation on the in –situ synthesis of SiC/ AlN/Al composites by spark plasma sintering" Journal of Alloys and Compounds 622, 458-462 (2015).

[39]Jinfeng Nie, Dakui Li, enzhao Wang, Xiangfa Liu, " In-situ synthesis of SiC particles by the structural evolution of TiCx in Al-Si melt" Journal of Alloys and Compounds 613, 407-412 (2014).

[40]R.Jamaati, M.R. Toroghinejad, Mater. Sci. Eng, A 527, 4146-4151 (2010).

[41] Ahmad Changizi (2005), A thesis to the graduate school of natural and applied sciences, Middle East Technical University.

[42]M. K. Aghajanian, M.A. Rocazella, J.T. Burke, " The fabrication of metal matrix composites by a pressureles infiltration technique" Journal of Materials Science, 26, 447-454 (1991).

[43]Y. T. Zhao, S. L. Zhang, G. Chen, X. N. Cheng, C. Q. Wang, Comp. Sci. Technol. 68, 1463(2008)

[44]T.W. CLYNE, M. G. BADER, G. R. CAPPLEMAN and P. A. HUBERT, *J. Mater. Sci.* 20 (1985) 85.

[45]Mattern A, Huchler B, Staudenccer D, Oberaccer R, Nagel A, Hofmann M J, (2004) Journal of European Ceramic society, 24, pp. 3399-3408

[46]A. MORTENSEN, J. A. CORNIE and M. J. C. FLEMINGS, *Met. Trans.* 19A (1988) 709

[47]]Necat Altinkok, , Adem Demir, , Ibrahim Ozsert, Processing of Al2O3/SiC ceramic cake preforms and their liquid Al metal infiltration, Volume 34, Issue 7, July 2003, Pages 577–582.

[48]QC Jiang, HY Wang, BX Ma, Y Wang and F Zhao, Magnesium Metal Matrix Composites- A Review, *Journal of* Alloys *and* Compounds, **2005,** 386, 177.

[49]R. Casati, F. Bonollo, D. Dellasega, A. Fabrizi, G. Timelli, A. Tuissi, M. Vedani, " Ex situ A-Al2O3 ultrafine grained nanocomposites produced via powder metallurgy" Journal of Alloys and Compounds 615, S386-S388 (2014).

[50]C. Borgonovo, D. Apelian, Mater. Sci. Forum 678, 1 (2011).

[51]Rajput R. K., A textbook of manufacturing technology, Laxmi Publications (P) Ltd., New Delhi, 2007.

[52] Ismail Ozdemir, Sascha Ahrens, Silke Miicklich, Bernhard Wielage, "Nanocrystalline Al-Al2O3p and SiCp composites produced by high energy ball milling" Journal of Materials Processing Technology, 205, 111-118 (2008).

[53] L.Lu, M.O. Lai, " Mechanical alloying" Kluwer Academic Publishers, Boston, 1998.

[54]C. Suryanarayana, "Mechanical alloying and milling" Progress in Materials Science, 46 (2001).

[55]G. M. Scamans, N. Birbilis, R. G. Buchheit, "Corrosion of aluminum and its alloys" In Shreir's Corrosion, 3,p.1974 (2010).

[56]W. L. Johnson, H. J. Fecht, "Mechanisms of instability in crystalline alloys with respect to vitrification" J. Less- Common Met. 145, 63-80 (1988).

[57]J. Eckert, J. C. Holzer, C. E. Krill III, W. L. Johnson, "Investigation of nanometer-sized F.C.C. metals prepared by ball milling" in: P. H. Shingu (Ed), Mechanical Alloying, Materials Science Forum, Vols.88-90, Trans Tech, Switzerland, 505-512 (1992).

[58]Y. Saberi , S.M. Zebarjad,, G.H. Akbari , On the role of nano-size SiC on lattice strain and grain size of Al/SiC nanocomposite ,Journal of Alloys and Compounds 484 (2009) 637–640.

[59] Wang W. Ph.D Thesis. University of Waikato,NZ; 2000.

[60] A.F. Zimmerman,G palumbo, K.T. Aust U. Erb, Materials science and engineering A vol. 328,(2002),137

[61] S.Hirsosawa,Y shingemoto,T Miyoshi H. Kanekiyo, Scripta materialia Vol.48 (2003),839

[62] Cao G., Kobiksha J., Konishi H., Li X., Tensile properties and microstructure of SiC nano particle reinforced Mg-4Zn alloy fabricated by ultrasonic cavitation based solidificationprocessing, Metallurgical and Materials Transections A , 39 A, (2008),880-886.

[63]Li X.,Yang Y, Cheng X., Ultrasonic assisted fabrication of metal matrix composites, Journal of material science, 39,(2004), 3211-3212.

[64]Donthamsetty S. Damera N. R. Jain P.K. ,Ultrasonic Cavitation Assisted Fabrication and Characterization of A356 Metal Matrix Nanocomposite Reiforced with Sic, B4C, CNTs' AIJSTPME (2009) 2(2): 27-34

[65] Y. Yang, J. Lan, X. C. Li, Mater. Sci. Eng. A380, 378 (2004)

[66]BC Kandpal, J Kumar and H Singh, Production Technologies of Metal Matrix Composite: A Review, International Journal of Research in Mechanical Engineering and Technology, **2014**, 2(2), 27-32.

[67]Amir A. Shirzadi, Diffusion Bonding Aluminium Alloys and Composites: New Approaches and Modelling, Ph.D thesis King's College Cambridge, December 1997

[68]W.M. Thomas ,E.D. Nicholas, J.C. Needham, M.G. Murch, P. Templesmith, C.J. Dawes, G. B. Patent Application No.9125978.8, December 1991.

[69]R. Mishra and Z. Ma, Mater Sci Eng R Rep, 50(1-2), 1-78 (2005).

[70]H. Bhadeshia and T. Debroy, Sci Technol Weld Joining, 14(3), 193-196 (2009).

[71]Y. Zhang, Y. Sato, H. Kokawa, et al. Sci Technol Weld Joining, 15(6), 500-505 (2010).

[72]G. Xie, Z. Ma and L. Geng, Mater Sci Eng A, 486(1-2), 49-55 (2008).

[73]SA Alidokht, A Abdollah zadeh, S Soleymani, H Assadi, "Microsturcture and tribological performance of an aluminum alloy based hybrid composite produced by friction stir processing" Mater Des, 32, 2727-2733 (2011).

[74]M Zohoor, MK GiVi Besharati, P Salami, "Effect of processing parameters on fabrication of Al-Mg/Cu composites via friction stir processing" Mater Des 39, 358-65 (2012).

[75]Hatamleh, J Lyons, R Forman, " Laser and shot peening effects on fatigue crack growth in friction stir welded 7075-T7351 aluminum alloy joints. Int J Fatigue , 29, 421-34 (2007).

[76]N.T. Kumbhar and G.K. Dey, K. Bhanumurthy, Friction Stir Welding of Aluminium Alloys, Research Article BARC Newsletter Issue no. 321I JULY - AUG. 2011 I 11

[77] R.S. Mishra, Z.Y. Ma, I. Charit, Mater. Sci. Eng. A 341 (2003) 307–310.

[78]D.B. Miracle, Metal matrix composites—from science to technological significance, Composites Science and Technology 65 (2005) 2526–2540.

[79] Yoshida K and Morigani H,(2004), Micrielectrons reliab, 34,pp. 303-308.

[80]David Raja Selvam J, Robinson Smart , Dinaharan D S I, (2013), Journals of Composite, 34, pp. 637-646.

[81]Rodriguez-Reyes M, Pech-Canul I, Rendon-Angeles J and Lopez-Cuevas J,(2006),Composite Science Technology,66, pp. 1056.

[82]Sato Y S, Kokawa H, Enomoto M and Jogan S,(1999), Metall Mater Trans A, 57, pp. 2429-2437.

[83]Jayaseelan V, Kalaichelvan K, Kannan M, Ananth SV. Extrusion Characterizes of Al/SiC by different Manufacturing Process. Int J Appl Engine Res, Dindigul, 2010; 1: 1.

[84]L. Salvo, G. L'Esperance, M. Suery, J.G. Legoux, Interfacial reactions and age hardening in Al–Mg–Si metal matrix composites reinforced with SiC particles, Mater. Sci. Eng. A 177 (1994) 173–183.

[85]Adebisi A A, Maleque M A, Rahman M M (2011), IJAME, 4, pp. 471-480.

[86]P.O Babalola, C.A Bolu, A.O Inegbenebor and K.M Odunfa, Development of Aluminium Matrix Composites: A review, ISSN 2346-7452; Volume 2: pp. 1-11; April, 2014

[87]M. K. SURAPPA, *J. Mater. Proc. Tech.* **63** (1997) 325

[88]D. M. SKIBO, D. M. SCHUSTER and L. JOLLA, USPatent No. 4786 467 (1988).

[89]M. M. Schwartz, Composite materials, volume II: processing, fabrication and applications, Prentice Hall PTR, 1997.