IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 6 Ver. IV (Nov. - Dec. 2015), PP 22-40
www.iosrjournals.org

Review of Effective Parameters of Stir Casting Process on Metallurgical Properties of Ceramics Particulate Al Composites

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Abstract: *The low density, environment resistance and adequate mechanical and physical properties of aluminium metal matrix composites (AMMC's) make them one of the most interesting material alternatives for the manufacture of lightweight parts for many types of modern engineering equipments. 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 metal matrix composites materials. The major challenges of this technique are to achieve sufficient wetting of particles by liquid metal, to get ahomogeneous dispersion of ceramic particles and to reduce porosity in the cast metal matrix composite.This article is just a review of stir casting for production of aluminum metal matrix composites, various process parameters of stir casting process, such as stirrer design, stirrer speed, stirring temperature, stirring time (holding time), preheat temperature of reinforcement, preheated temperature of mould, reinforcement feed rate, wettability-promoting agent and pouring of melt, and difficulties encountered in successful fabrication of AMMC's via stir casting technique. There were various articles accessed, however not all were completely relevant and as a result not included in this review.*

Keywords:*Aluminum metal matrix composites, Ceramic reinforcements, Stir casting process.*

I. Introduction

The importance of the use of aluminum metal matrix composites (AMMCs) reinforced with ceramic particles in modern engineering applications lies in the combined and unique characteristics that distinguish them from the rest of the engineering materials, such as light weight, environment resistance and adequate mechanical and physical properties [1]. Various techniques are used for manufacturing of MMC's, they can be classified into two main groups:

I. Liquid state processes, such as casting, melt stirring and in-situ and infiltration.
II. Solid state processes, such aspowder metallurgy, diffusion bonding and physical vapour deposition.

Melt stirring method has a good potential in all-purpose applications as it is a low cost MMCs production method [2-3]. Stir casting is a liquid state method of composite materials fabrication, in which a dispersedphase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies [4]. In preparing metal matrix composites by stir casting process, some of the factors that need considerable attention, which are [5]:

To achieve uniform distribution of the reinforcement material.
To obtain sufficient wettability between the two main substances.
To reduce porosity in the cast metal matrix composite.

Various process parameters of stir casting should be properly controlled to obtain good metallurgical properties of AMMC's [6-7]:

1. Stirrer design.
2. Stirrer speed.
3. Stirring temperature.
4. Stirring time (Holding time).
5. Preheat temperature of reinforcement.
6. Preheated Temperature of Mould.
7. Reinforcement Feed Rate.
8. Wettability-promoting agent.
9. Pouring of melt.

The simplest and economical technique to fabricate MMC's is simply mixing the solid reinforcement in the liquid metal and then allowing the mixture to solidify in a suitable mold. The mixture can be continuously agitated while the reinforcement is progressively added. In principle, this can be performed using conventional processing equipment on a continuous or semicontinuous basis. Though the technique seems simple, there are difficulties in this technique. Some of the problems are increased viscosity because of addition of reinforcement, inhomogeneous microstructure and adverse chemical reactions.Commonly particulate reinforcements are used in this technique due to the difficulty in casting with fibrous forms. A mixture of particles and molten matrix material is cast into ingots and a secondary mechanical process, such as extrusion or rolling is commonly applied to the composite to remove casting defects. Casting of MMCs needs some modifications to the existing casting technique, which are [8]:

- The viscosity should be kept within the allowed limit.
- Alloys with minimum reactivity to the reinforcement must be used.
- Covering the melt with an inert gas atmosphere to reduce the oxidation.
- Stirring of the melt to minimize the settling of particles due to density difference.

The stirring action should be slow to prevent the formation of vortex at the surface of the melt, and care must be taken not to break the surface too often, which could contaminate the bath with dross. Use of a slowly rotating, propeller like mechanical stirrer is preferred by some foundries. In fact, results of laboratory studies indicate that the mechanical property of the casting are maximized by continuous stirring versus intermittent (hand) stirring. When induction melting, the furnace's natural eddy current stirring action usually is sufficient to disperse the particles, although supplementary hand stirring (with the power off) also is recommended to ensure that no particles have congregated in potential "dead" zones [9].

II. Metal Matrix Composites

There are several perspectives used for classification of engineering materials, but the most common perspective stipulates that the engineering materialsare classified into the following broad groups: metals, ceramics, polymers and various types of composites of these.

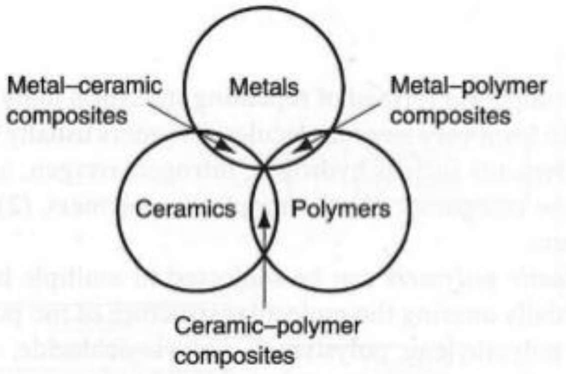


Fig. 2.1: Classification of engineering materials [10]

Composites are two or more chemically discrete materials (constituents) which when combined have enhanced properties over the individual constituents. One of the constituents is called the reinforcing phase, is in the form of fibers, sheets, or particles, and is embedded in the other constituent called the matrix (continuous phase). These type of materials could be natural or synthetic. Composite materials are classifiedby matrix into metal matrix composites (MMC's), ceramic matrix composites (CMC"s) and polymer matrix composites (PMC"s), They can also be classified by filler type into particle reinforced composites,fiber reinforced composites andstructural composites.

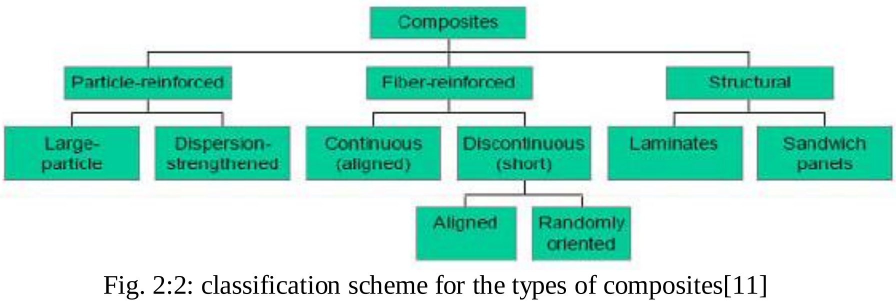


Fig. 2:2: classification scheme for the types of composites[11]

The fabricationtechnique used to synthesis a composite structure is dependent upon material performance requirements, structure configuration, and production rates [12].A metal matrix composite (MMC) is generally designated simply by at least twoconstituent parts, one being a metal necessarily and is called matrix, the other material may be a different metal or another material, such as a ceramic or organic compound and called reinforcement.MMC's differ from other composites in several ways. Some of these general distinctions are:

1. The matrix phase of MMC is either a pure or alloy metal.
2. MMCs exhibitlower ductility and toughness than their respective unreinforced metal matrix alloys, but they have higher ductility and toughness than CMCs.
3. The role of the reinforcement in MMCs is to increase strength and modulus.
4. MMCs are characterized by a temperature capability higher than polymers and polymer composites but less than ceramics and ceramic composites.
5. Low to moderately reinforced MMCs can be formed by processes normally associated with unreinforcedmetals.Generally, properties of produced metal matrix composites reinforced with ceramic particles depend on the properties of ceramic reinforcements such as type, size, geometry and distribution of reinforcements, also the reinforcement volume ratio (RVR) [13-14].

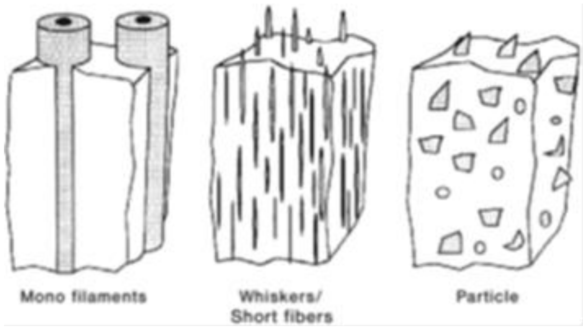


Fig. 2.3: Schematic presentation of three shapes of metal matrix composite materials [15]

2.1. Aluminium metal matrix composites (AMMC's)

Different kinds of composite materials can bemanufactured via different techniques. Metal matrix composite (MMC's) is one of these kinds. Aluminum and its alloys are the most commonly used matrix materials in the production of MMC's because of their preferred advantages. The major advantages of AMMCs compared to unreinforced materials include: high strength, good stiffness, low density (weight), controlled thermal expansion coefficient, thermal/heat management, enhanced and tailored electrical performance, improved abrasion and wear resistance, control of mass (especially in reciprocating applications), good environmental resistance and improved damping capabilities. The combination of these properties have made aluminum and its alloys to be the most commonly used matrix materials in the production of (AMMCs), thus to make them the more popular composites. Furthermore, aluminum is characterized by high melting point high enough to satisfy many application requirements [1-16].

2.1.1. AMMC's reinforced with ceramic particles

Different types of ceramics such as SiC, CuO, Fe_2O_3, Fe_3O_4 SiO_2, Al_2O_3, MgO, ZnO, BeO, MnO_2, TiO_2, TiC, etc. can be used as reinforcing phases and embedded in the metal matrix to fabricate MMC's. Ceramics are characterized by superior properties such as refractoriness, high compressive strength and hardness, excellent wear resistance, etc. These properties make them appropriate for use as reinforcement in MMCs [17-18-19].

III. Stir Casting Technique To Fabricate AMMC's

Stir Casting method is a liquid metallurgy technique in which the second phase materials (reinforcements) are introduced into the molten matrix and allowing the mixture to solidify. Here, the critical thing is to create good wetting between the reinforcements and the moltenaluminium or aluminium alloy, this is the simplest and most commercially used technique and known as vortex technique or stir-casting technique. The vortex technique involves. To reduce gravitational segregation in the crucible, the vortex technique is developed to involve the introduction of pre-treated ceramic particles into the vortex of molten aluminium alloy created by the rotating impeller [1-20].

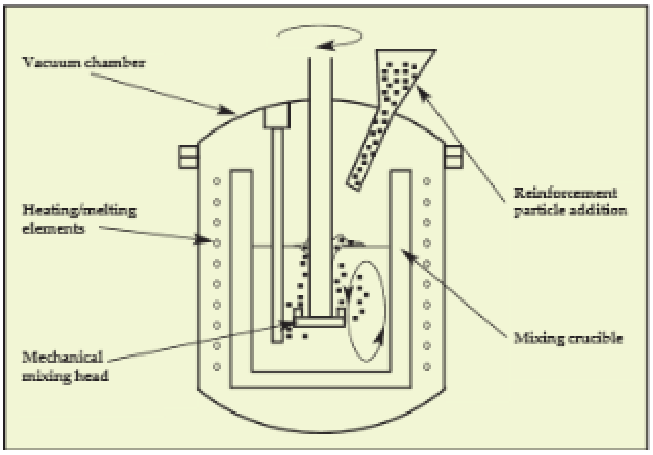


Fig. 3.1: Conventional stir-casting setup for the compositing of aluminum MMC material. This is the most common commercial method. [21]

In case of some molten metal like aluminum, inert gas such as nitrogen and argon can also be used to remove hydrogen, this method involvesintroducing bubbled inert gas into the liquid aluminum. The hydrogen is drawn to the inert gas bubbles, then carried up through the aluminum and released on the surface. In recent development, the composite is stirred while the molds are filled by pouring the melt through the bottom of the crucible [20].

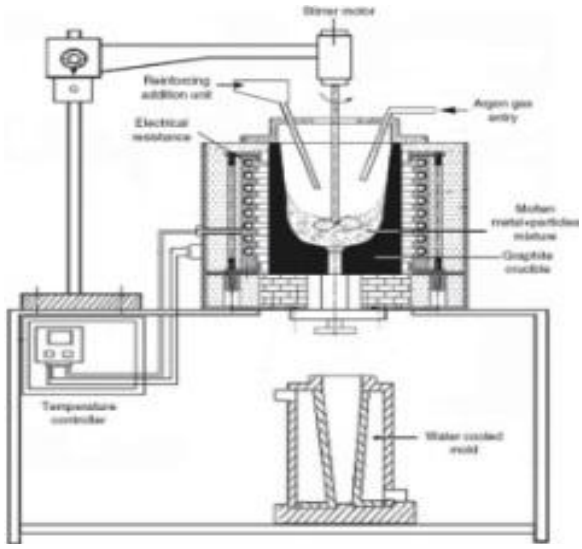


Fig. 3.2: Stir casting machine (equipped with inert gas source and pour molten system[22]

Choose theappropriatemethod and material are the most important and effective criterion toproduce MMCs. In case of MMC's manufacturing via melt stirring technique, increased reinforcement volume ratio (RVR) and decreased particle size resulted more difficult production process and increased porosity and particle agglomeration.This technique is attractivebecause of simplicity, flexibility and most economical for largesized components to be fabricated [23-24].

IV. Investigative Review On Ceramic Particulate Al Composites Fabricated Using Stir Casting

Aluminum LM25 as matrix material and silicon carbide (SiC) with various RVR as reinforcement material were selected to fabricate aluminum metal composites using stir casting method. SiC particles were preheated up to 800 ^{o}C and added to the Al matrix in semi-solid state.

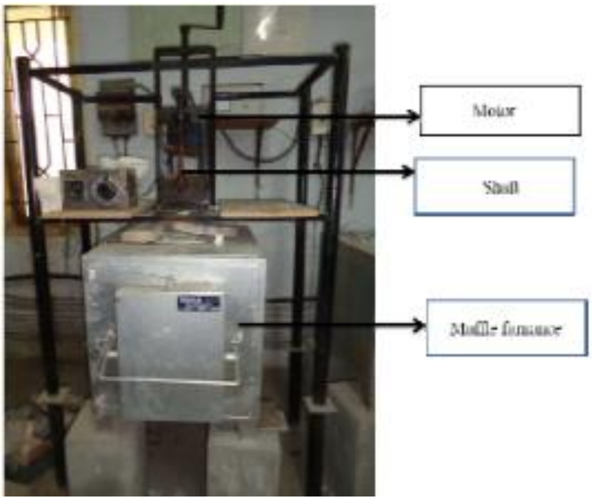
Stir Casting Apparatus

The results showed that the stir casting technique can be considered as an effective liquid based technique for making the aluminium metal matrix composites [25].

AMMCs using AA 356 alloy as matrix andmilled alpha alumina as reinforcement are manufactured via stir casting method. A combined route of stirring at semi-solid state followed by stirring at liquid state was proposed to conduct a quantitative analysis of the mechanical stir casting . The effect and interactions of factors, such as time, rotation, initial fraction and particle size on the incorporated fraction were investigated. Other factors, such as matrix and reinforcement composition, crucible and propeller blade geometry, reinforcement treatment and mould material, were kept constant. It was found that the best incorporations were obtained with all factors at high levels and the time factor does not show any significant influence on the incorporation process. The particle size and rotation are the factors of greater influence. Particle wetting occurs during stirring at semisolid state because of interactions among the particles themselves, between particles and solid aluminium and between particles and the remaining liquid phase. Addition of Mg as a wettability-promoting agent enhanced the wettability between the particles and aluminum [26].

A. Mazahery and M. Shabani studied the microstructure of nano composites based on the A356 aluminum alloy reinforced with nanoSiC particles fabricated via stir casting. The results showed that the nano-sized SiC particles are successfully incorporated into the aluminum matrix and the composites contain little porosity and the amount of porosity increases with increasing volume fraction of SiC which can be attributed to the increased surface area of the nanoSiC particles. It was also observed a reasonably uniform distribution of SiCnano particles in the Al matrix. [27].

M. Prakash and M.Jaswin used SiC and B_4Cparticles as reinforcements and Al6061 as matrix to produce a composites by stir casting process. The composites were producedby varying the particulate addition by weight fraction of Al (90%), SiC (5%, 6.5% and 8%) and B_4C(5%, 3.5% and 2%). Al rods were preheated at 850 ^oC for 3 to 4 hours before melting and mixing the SiC and B_4C particles were preheated at 840 ^oC for 1 to 3 hours to make their surfaces oxidized. The furnace temperature was first raised above the liquids to melt the Al alloy completely and was then cooled down just below the liquidus to keep the slurry ina semisolid state.Manual mixingwas used because it was very difficult to mix using automatic device when the alloy was in a semisolid state. Aftersufficient manual mixing was done, the composite slurry was reheated to a fully liquid state and then automaticmechanical mixing was carried out for about 10 minutes at a normal stirring rate of 600 rpm.

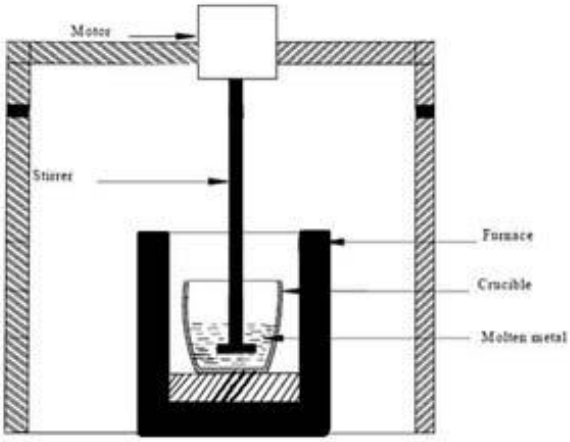


Experimental setup used for stir casting

Results showed that the dispersion of theSiC and B_4C particles are equal in all over the composites and also shown in the images. It was noted that an increase the particles cluster corresponding to an increase in the processing temperatures [28].

AMMCs were developed using AL6063 as matrix material and SiC particles with various RVR (between 10% and 50% at 10% intervals) as reinforcement. Composites were produced using stir casting technique and the homogeneous mixture obtained cast into cylindrical blanks. The results indicated that the produced composites possess superior metallurgical properties. It was also found that an increase in the quantity of SiC reinforcement positively effects on the metallurgical properties only up to a 40%wt SiC beyond this, increased clustering of the reinforcements [29].

A conventional low cost technique (Stir casting) was developed to produce aluminum based silicon carbide particulate Metal Matrix Composites (MMCs) type (Al+4%Cu+5%SiC) were fabricated with homogenous dispersion of ceramic material. The balanced aluminium with 4% Cu was meltedin a graphite crucible in an open hearth furnace. Al-4%Cu alloys where preheated at 450^{o}C for 3 hours and the SiC particleswere preheated at 1100°C for 2 hours.After stirring for 3 minutes at 600 rpm, composites were poured with pouring temperature 700 ^{o}C, 725 ^{o}C and 750 ^{o}C respectively.

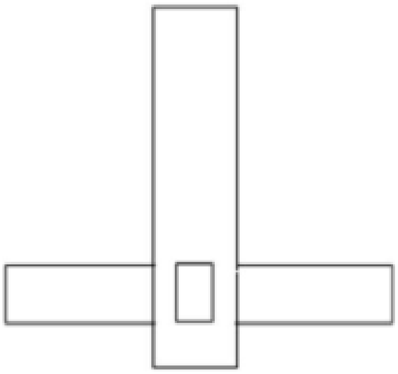


Schematic View of Experimental Set Up

Results indicated that Al-4%Cu alloy reinforced with 5% SiC composites were prepared successfully via liquid metallurgy technique (stir casting). It was found that the pouring temperature at 725°C which gave the bestoptimum value of hardness, impact strength and ultimatetensile strength. When the pouring rate kept constant at 2.5cm/s for all composites [30].

Aluminum alloy (Al-11Si-Mg) matrix composites reinforced with silicon carbide (SiC) particles with average size of 40 μm were fabricated by different processing temperatures with different holding time to evaluate the effect of process parameters on the distribution of particle in the matrix. The matrix was melted in a graphite crucible at different temperature level (700°C, 750°C, 800°C, 850°C and 900°C). The

SiCreinforcement was preheated at 1000°C for two hours before added in the matrix melt. The 10% by volume of preheated SiC powder was added in the liquid melt and the slurry was consciously stirred using a stirring. The four blade stirrer was designed in order to produce the adequate homogenous particle distribution throughout the matrix material.



Stirrer blade setup

Results showed that the particles were distributed uniformly in the processing temperature 750°C and 800°C. Particles agglomerations were found in the processing temperature of 700°C, 850°C and 900°C because of the changes of viscosity in liquid Al matrix.The viscosity of Al matrix decreases with increased processing temperatures. It is revealed that holding time influences the viscosity of liquid metal, particles distribution and also induces some chemical reaction between matrix and reinforcement.The hardness values increases more or less linearly with increasing of processing temperatures from 750°C to 800°C at 20 minutes holding time [31].

L.Saravanan and T. Senthilvelan fabricated aluminum composite with nano- Al_2O_3 using a three stepmixing stir casting process. Its dispersion was investigated andcompared with the characteristics of thenano-composite fabricated usingconventional method as well as the basematrix alloy. The three step mixing method includes the following:

1. Heat treatment of reinforcement particles at 1100 ^{o}C for 10 minutes in an inert atmosphere.
2. Injection of heat-treated particles within the melt by inert argon gas.
3. Stirring of the melt 10 minutes before and after incorporation of particles at the speed of 300 rpm.

Experimental setup used for thefabrication of nanocomposite

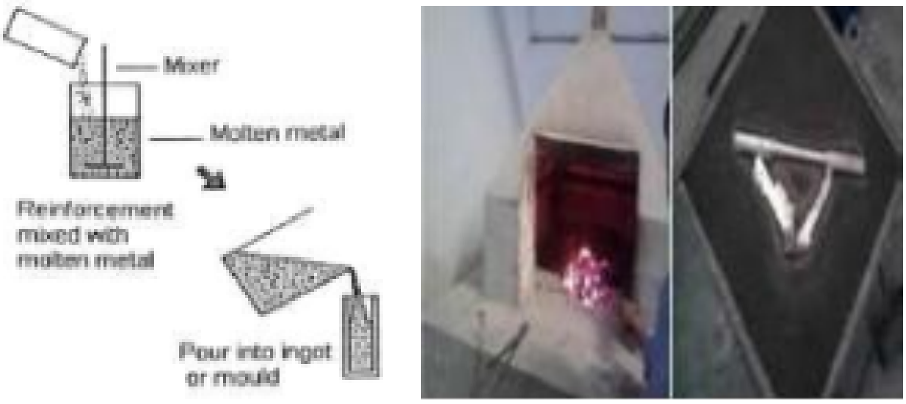
The results showed homogeneousdistribution of the nanoparticles inthe case of the three step mixingmethod, whereas poor incorporationof the particles and particle clusteringwere observed in the case of nanocomposite fabricated usingconventional stir casting method [32].

Aluminium siliconcarbide mica a hybrid metal matrix composite was manufactured by stir casting method. Three different compositions were taken with various percentage of mica as 1%, 2% and 3%. Al 6061 was used as matrix, it was melted at a temperature of 850°C. The required quantity of reinforcement materials were weighed and kept inside the furnace, in order toincrease the intermolecular bonding with Al.The dies were preheated to a temperature of 500°C. 1% Pure Mg powder was added to the molten metal to compensate for the loss during heating and also toincrease the wettability. Degasser powder was added to remove the impurities in the molten metal and coverall was sprinkled over the Al to prevent oxidization.The reinforcement materials were added with the molten Aland were manually stirred.It is then again kept inside the furnace to obtain a temperature of 850°C. Stirrer was introduced inside the furnace which rotates at 300 rpm. The stirring was done keeping the temperature constant and was carried out for approximately 10minutes.Then the molten metal matrix composite obtained was poured into preheated die and was set to cool off for threehours. This procedure was repeated for the 3 different compositionsand the specimens required for the vibration analysis are thus obtained.

stir casting equipment

It is observed that the AMMCs can be fabricated using stir casting technique. SEM photos revealed that the reinforcements were uniformly distributed in all the three compositions [33].

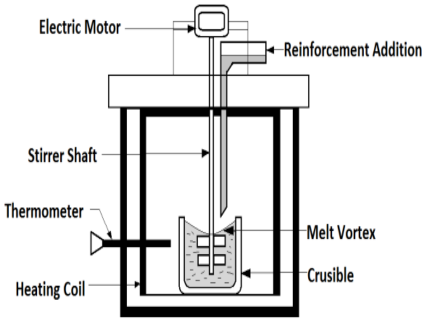
Aluminum cast Alloy (6063) as matrix and alumina (Al_2O_3) powder with various volume ratio as reinforcement were used to producemetal matrix composite by the stir casting technique.



Stir Casting

Aluminum Alloy 6061 was melted in acrucible by heating it in a muffle furnace at 800°Cfor three to four hours. Al_2O_3particles were preheated at 1000 ºC and 900 ^oC respectively for oneto three hours. The temperature was first raised about 750 ^oC, above the liquidus temperature of aluminum alloy, to melt it completely and was then cooleddown just below the liquidus to keep the slurry insemi solid state. Stirrer was carried out for about 10minutes at stirring rate of 290 RPM. At this stage,the preheated Alumina particles were addedmanually to the vortex. In the final mixing processesthe furnace temperature was controlled within 700 ±10ºC. After stirring process the mixture was pour inthe other mould to get desired shape of specimen. Results showed that aluminum matrix composites were successfully fabricated by stir casting process with fairly uniform distribution of alumina particles [34].

R. Adat, S. Kulkarni and S. Kulkarni manufactured a metal matrix composite by reinforcing alloy Al356 with Al_2O_3 and fly ash particles with difference RVR (2,4 and 6% each) using stir casting process. After cleaning A356 alloy ingots, they were cut to proper sizes, weighed in requisite quantities and charged into a cast iron crucible placed in the furnace at 400 ^oC.1% pure Mg was added into the charge at 600 ^oC after confirming the semisolid state to improve wettability. Then material was hold for about an hour until its temperature gain reached 800 ^{o}C. The scum powder (0.05% of Al356) was added into the melt which resulted into accumulation of impurities at the surface of liquid melt. Then the scum was removed. Degasification tables of Hexachloroethane (0.05% of Al356) were added for removal of gases from the molten alloy.The combination of reinforcement was preheated to 300 ^{o}C – 400 ^{o}C for 1 hour before pouring in to the melt of Al356. Al_2O_3 were poured centrally into the vortex at 0.5 g/s feed rate.




Stir Casting Setup (Schematic)Stirring processStirrer Blades

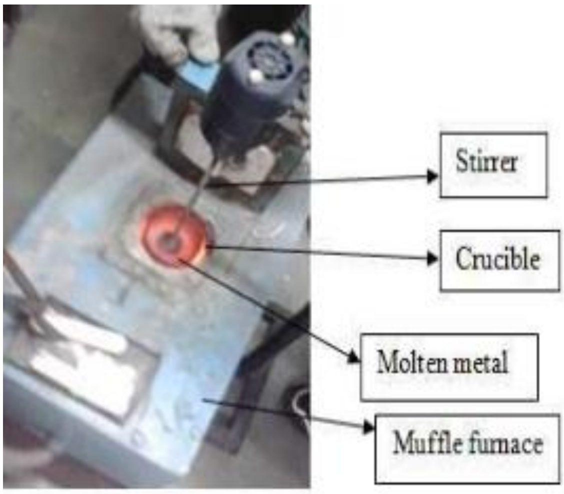
The stirrer was moved down slowly, from top to bottom by maintaining a sufficient clearance from the bottom. The stirrer was then pushed back slowly to its initial position. The pouring temperature of the liquid was kept around 800 ^{o}C. Liquid Composite was poured in the MS permanent mould with uniform pouring rate, keeping pouring distance constant, to maintain the fluidity of melt. Mould also was preheated at 300 ^{o}C – 400 ^{o}C for 1 hour. Results showed that AMMCs were successfully manufactured by stir casting technique with fairly uniform distribution of fly ash and Al_2O_3 particles.Stir casting is very efficient, simple and cost effective method of manufacturing of AMMCs and also it is most suitable for mass production. Processing parameters such as holding temperature, stirring speed and time, blade design of the stirrer and preheating process are among the important factors to be considered in the production of cast AMMCs as these have an impact on quality and properties of casting.It was observed that preheating the mould improves the soundness of the casting, shown by a decrease in the porosity level. The wettability between matrix and reinforcement was improved by addition of Mg in melt.The fabricated AMMC is isotropic in nature due to fairly uniform distribution of reinforcement [35].

LM 26 Al, rice husk ash and red mud (LM 26 Al/RHA/RM) hybrid composites were prepared via stir casting. Taguchi's L9 orthogonal array was used for experimental design. Overall performance of the stir casting method was improved significantly by combining the experimental and analytical concepts and the most important parameter was determined on the result response. Threedifferent parameters, stirring time, stirring speed, and weightfraction of the reinforcement particles were used for optimization of the tensile strength and hardness. Red mud was maintained constant at 5wt% and rice husk ash was varied at 5, 10 and 15 wt% for fabricated the composites. LM 26 aluminium alloy was taken into agraphite crucible and melted. RHA and RM powder was preheated at1500^{o}C for 20 minutes and then added to the melt. The melt was stirred inside the furnace at different speed andtimes to make a vortex in order to disperse the particles. The melt temperature was controlled around 7000^{o}C and poured into steel die.

Stir casting equipment

The results showed that the hybrid composites prepared with 15% weight fraction particles, 12 minutes stirring time and 100 rpm stirring speed have optimum good tensile strength, hybrid composites prepared with 15% weight fraction particles, 12 minutes stirring time and 200 rpm stirring speed have optimum level of hardness. It can be concluded that Taguchi method has proved its success in prediction the optimum casting parameters to reach the best properties [36].

Pure Al as matrix material and Al_2O_3as reinforcement were used for the preparation ofcomposite by stircasting route. Particle sizes of Al_2O_3 (75, 105 and 150 micron), wt. % of reinforcement (3%, 6% and 9%) and stirring time (15, 20 and 25 minute) were used to fabricate different sample of AMMCs. Each parameter has three different levels. L9 orthogonal array table used to made different specimen. The effect of these input process parameter on the output response were analyzed using analysis of variance (ANOVA). The contribution of each process parameters on the hardness, impact strength and tensile strength was analyzed by using ANOVA. Al was melted at 800 ^oC, Al_2O_3 was preheated at 300 ^oC for 1 hr. The temperature was cooled down just below the liquidustemperature near about 700ºC to form the slurry in the semisolid state. The stirrer also placed in the furnacefor preheating purpose. Now the molten Al was stirred for 10 minutes at stirring rateof 300 RPM. Preheated alumina particles were embedded inthe molten by three steps mixing of melt. At every stagebefore and after introduction of reinforcement, mechanicalstirring is carried out for a period of 5 min. Similarly remainedreinforcement particles were added. In the final mixingprocess the furnace temperature were controlled within700±10ºC. The stirrer position was such that 35% of materialshould be below the stirrer and 65% of material should be above the stirrer. After the complete addition of particles,the melt was stirred for a defined time. The melt was poured inthe preheated mould (300ºC) to get a desired shape ofcomposite. The mixture was allowed to solidify for a desiredtime.



Stir casting setup

Results indicated that all composites were successfullysynthesized by stir casting technique.It was revealed that the hardness of composite increased with increasing the weight percentageof Al_2O_3 particles, stirring time but decrease withincrease in particle size.The tensile strength of the manufactured compositewas higher in composite. Impact strength was higher in case of composites ascompared to the pure Al.The Signal-to-noise ratio showed the effect of eachparameter at each level on the hardness, impactstrength and tensile strength of composite.Analysis of variance determined the contribution ofeach parameter in the hardness, impact strength andtensile strength of the prepared composite.All these mechanical properties showed increasing trend with increase in wt.%, stirring time anddecrease in particle size of the reinforcement [37].

Manufacturing of composite material by reinforcing Al alloy as matrix and SiC, Al_2O_3 and graphite particles using stir casting process was studied. The fabricated composite was tested for its mechanical, metallurgical andtribological properties. At first heatertemperature is set to 500°C and then it is gradually

increased up to 900°C. Aluminium alloy was cleaned, weighed and then kept in the cruciblefor melting. Nitrogen gas was used as inert gas to avoidoxidation. 4 blades were welded to the shaft at 45°C.. Pure Mg powder was used 1% by weightas wetting agent. Required quantities of reinforcementpowder and magnesium powder were weighed thoroughlymixed for 24 hour.Reinforcements were preheated for 1/2 hour and attemperature of 500°C. When matrix was in the fullymolten condition, stirring is started after 2 minutes. Stirrerrpm was started at slow rate of 30 rpm and increasesslowly in between 300 to 600 rpm with speed controller. Temperature of the heater is set to640°C which is below the melting temperature of thematrix. A uniform semisolid stage of the molten matrixwas achieved by stirring it at 640°C. Preheatedreinforcements were poured at the semisolid stage. Reinforcement particles were fed in constant rate to avoid coagulation and segregation of the particles.The flow rate of reinforcements measured was 0.5 g/s. Dispersion time was taken as 5minutes. After stirring 5 minutes at semisolid stage slurrywas reheated and hold at a temperature 900°C to make sure slurry was fully liquid. Composite slurrywas poured in the metallic mould, which was preheated at temperature500°C.

Stir cast apparatus

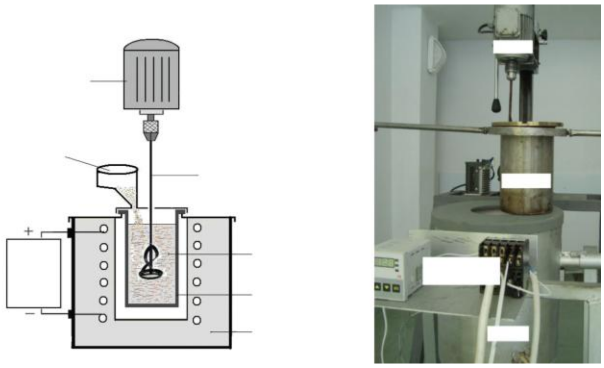
Results included that for uniform dispersion of material blade angle shouldbe 45° or 60 ° and number of blade should be 4.For good wettability, operatingtemperature should be kept at semisolid stage i.e. 630 for Al (6061). Atfull liquid condition it was difficult uniform distributionof the reinforcement in the molten metal. Porosity was reduced by preheating of mould [38].

LM25 aluminum alloy reinforced with micro and nano-sized 10 wt.% Al_2O_3 was successfully produced via stir casting method.LM25 Al alloy was charged into the crucible and heated to 750 ^oC. The mixer was lowered into the melt slowly to stir the molten metal. The micro and Nano Al_2O_3 particles were preheated before being mixed with the Al alloy melt. After the completion of particle feeding, the mixing was continued for a further 7 min. The molten mixture was poured in the preheated mold positioned below the furnace. The furnace had a provision for bottom tapping and this permitted heating as well as stirring to be continued even during tapping of the melt.

Stir casting furnace setup

The results revealed that stir casting could be an economical route for the production of nano composites. Scanning electron microscopic observations of the microstructures revealed that the dispersion of the micron size particles where more uniform while nanoparticles led to agglomeration of the particles.By proper optimization of the process parameters, stir casting can be a promising and economically viable route for the production of nano particle reinforced MMCs [23].

Al-MgO reinforced metal matrix composites (MMCs) of 5%, 10% and 15% RVR were produced by melt stirring. EN AW 1050A aluminum alloy as the matrix and MgO powders with particle size of –105 μm were used as the reinforcement were used to produce the composites. Matrix material Al was put in the crucible, melting process was started and continued until the temperature of liquid matrix increased to 750 °C. Stirring apparatus was immersed in liquid metal and stirring was started. Stirring speed was gradually increased until 500 rev/min and MgO powder determined on the basis of RVR was added in liquid metal by a funnel during stirring process. After the addition of reinforcement element MgO in liquid matrix Al, the mixture was stirred about 4 minutes at 500 rev/min in order to allow homogenous distribution of MgO particles in the mixture. Subsequent to the completion of stirring, the crucible was taken out of the furnace, the liquid melt was poured in steel containers.

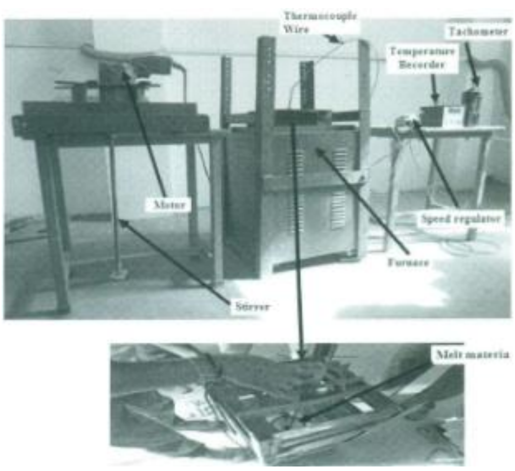


Melt stirring test apparatus (For the production of composite specimens

Results showed that in the MMCs production by the melt stirring technique, theMgO with the particle size of –105 μm was homogeneouslydistributed inside the liquid Al at all RVR. It was noted a little difficulty in wetting because of increasingthe amount of MgO reinforcement in liquid matrix.It can be stated that 750 °C liquid Al temperature,500 rev/min, the mixing speed and mixing time of 4 minutes were sufficient in experiments. However, to obtain morehomogeneous distribution of reinforcement within thematrix MgO and to improve the wetting these values canbe increased.Depending on the increasing MgO reinforcement ratio,the porosities increased in the composites [39].

Metal matrix composites containing analuminium alloy C355 as base material and 5 wt.%SiC as reinforcement material were produced by stir casting method.

Aluminum alloy C355 was heated to above its liquidtemperature in muffle furnace. The temperaturewas700°C to 790 °C. The 5 wt.% SiC particles withan average size of 50 micrometer were added on the surface of the molten liquid before preheating. The SiC particledisperses into the melt material. C355+5%SiC MMCstirred about 200 to 600 seconds and the stirring speed ofmelt material was 140 to 240 rpm.



Experimental setup of mechanical stir casting

Results revealed that the mechanical stir casting process was successfullyutilized for casting (C355+5%SiC) matrix composites. It was found that the SiC particles are properly distributed withmatrix C355 [40].

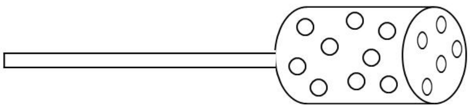
S. Nair and N. Joshi fabricated aluminium matrix composite (AMC) using stir casting technique, where Al 6061 was the base metal and 10 wt.% silicon carbide (SiC)in powder form with 320 mesh size was the reinforcement material. Al 6061 was melted in a graphite crucible at around 650º C.Into the molten matrix, 10 wt.%SiC powder of 100 mesh size was added. 1% Magnesium powder wasalso added in order to improve the wettability and decrease the porosity. Stirrer was made out of graphite rod of 100mm length and 25mm diameter for stirring. Externalthreading was done on the stirrer . An internally threaded 3 feet long stainless steel rod was fitted overthis stirrerThe mixture was mechanically stirred using a motor of around 250 RPM for 10 minutes before pouring into themould.The AMC mixture was poured into the mould and allowed to solidify for some time.

Graphite StirrerStirring of Al+ SiC mixture using motorPouring of molten Al into mould

Results indicated that the SEM micrographs show good distributionof SiC particles. The magnesium powder on adding reduced the porosity and improved wettability. Stir castingmethod is the simplest and most economical method to produce good quality aluminium metal matrix composites [41].

Aluminum-magnesium matrix composites reinforced with silicon carbide were produced using modified stir casting technique. The usual solid shaft stirrer was replaced by a hollow spindle stirring mechanism through the additions of particulate silicon carbide and magnesium turnings were introduced in small cylindrical capsules

Aluminum were cut from Al-ingot and was melted in a cast iron cylindrical crucible at 800 ^{o}C. Then the capsule / bullet charged with pieces of Mg-chips or Silicon carbide particulates. The mixer was turned on and set to the predetermined speed of 500 rpm. Then previously prepared silicon carbide particulate (10 wt %) bullet charges were introduced one after the other into the Al-Mg alloy melt. Then crucible was lifted and the melt waspoured into previously readied mould made of fire bricks joined by fire clay.

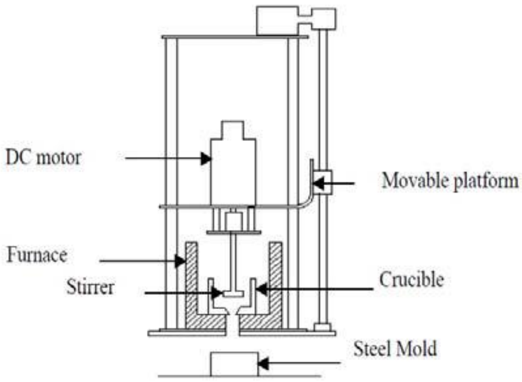


Perforated steel capsule welded to plunger rod

The results showed that the modified stir casting process can address some of the problems of producing cast metal matrix composites. The method is suitable for eliminating the fading effect of inoculation and simultaneous addition of alloying element and reinforcement. The process can be easily adopted for production in industrial scale [42].

Al-base 2024 alloycomposites reinforced with SiC nanoparticles were fabricated using stir casting method.

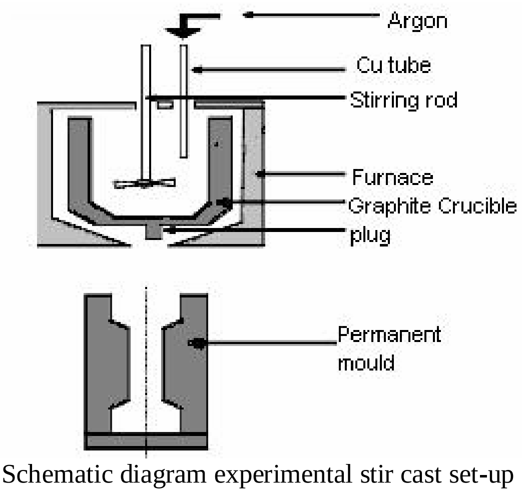
Two different master powders (pure Aland pure Cu powders with a mean size of 60µm, and each containing 1wt.% SiCnano-powder with 50 nmparticles size)were produced by mechanical milling and used as a reinforcement. Mechanical milling wasperformed for 1 h at the rotational speed of 900 RPM with steel balls with 10 mmdiameter.Each charge consisted of 450 g commercial Al-2024 alloy inwhich 18 g of master powders were added. These master powders were separatelyadded to the melt, and in two separate molds for each composite. The temperature of the melt was 750ºC and the stirring process began at 512 RPM for 6 minutes. All castingprocesses were held under inert atmosphere. Melt was poured to a cylindrical steel mold.



Schematic drawing of the utilized rheocaster device

Results revealed that Alcoated particles have higher wettability and better dispersion in the matrix because of their lower melting point and also this dispersion induces particles to act asgrain refiner of the melt. Hence, grains become finer. Furthermore, high nucleation rate inmelt which is result of great temperature difference between powder and melt which produces a spherical and rosette-shaped grains, so this phenomena can reduce theviscosity of melt during casting process [43].

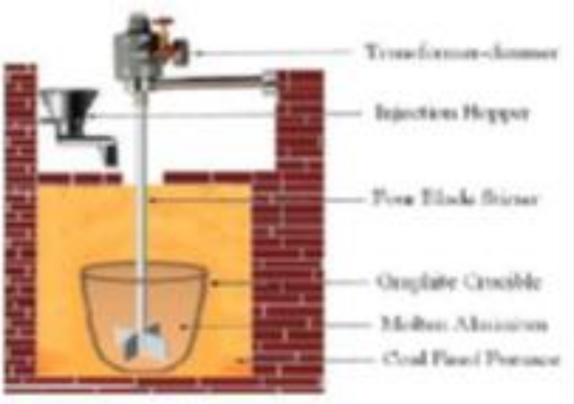
AMMCs reinforced with AlN were produced using stir casting technique. Al-Si alloy and AlN with purity of >98% and average size of <10 μmwere chosen as matrix and reinforcement material, respectively. The metal matrix composites prepared contained 2, 5 and 10 wt% of AlN. The Al alloy was cleaned with acetone in ultrasonic bath prior to melting, then heated in a graphite crucible under controlled argon environment. Less than 0.5% Mg was added into the crucible which acted as wetting agent. A furnace heating temperature was increased to 750ºC, hold for 30 minutes until Al alloy melted completely. Aluminum dross then removed from the surface of the molten metal. Small amounts particulate aluminum nitride preheated to 750º were added continuously to the molten metal through the side of vortex created by mechanical stirring by the stir impeller.The impeller and stirring rod was coated with liquid alumina so as to avoid any metals contamination to the molten metal. The optimum stirring speed was determined at 450 rpm. The composite melt was stirred for 5 minutes then immediately cast into a permanent mould by bottom pour technique.



Schematic diagram experimental stir cast set-up

Results showed that a stir casting process which was set at 750ºC was successfully utilized for casting Al-Si matrix composites reinforced with AlN particles. Lack of porosity exhibited in the microstructure of Al-Si matrix composite indicates there is a rather good particulate-matrix interface bonding [44].

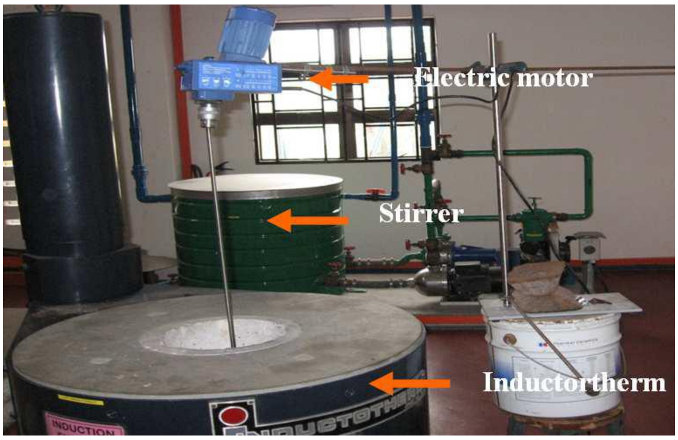
A. Anis, M. Nagarajan and N. Balaji developed the metal matrix composite Al-10%MoO_3 by stir casting method. They used MoO_3 is used as reinforcement and aluminium (98.41%) as matrix. Aluminium powder was heated at 900 ^oC.This metal-matrix composite is then pouredinto the graphite crucible winded with resistive heatingcoil at 760°C. 10% of reinforcement was added and stirred the composite byusing the stir casting machine. The stirrer is exactly plus sign blade having zigzag angle 90° of each side. Automatic stirring was carried out for 10 minutes with normal 400 rpm of stirring rate.



Experimental diagram

Results revealed that the prepared composite have the better properties than the purealuminium, this suggests that the composite characterizes by good metallurgical properties [45].

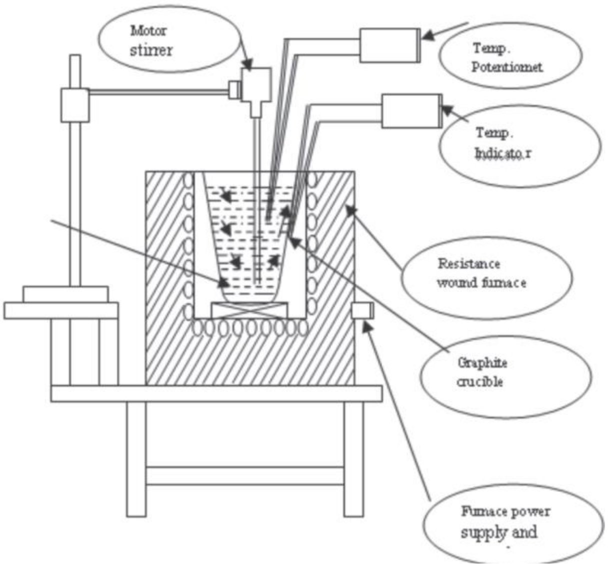
A. Jailania and S. Tajuddin selected SiC particlereinforced aluminum alloy to produce metal matrix composites (MMC) using different of parameters blade angle and stirring speed, also different composition of SiC reinforcement. After the experimental settling up the aluminium alloy was heated in the induction furnace until it melt, the impeller was set at the angle of 30° and the stirring speed was 50 rpm to mix the SiC reinforcement. The SiC reinforced aluminum alloys is stirred for 15 to 20 minutes. Then the mixture is poured into the mould to prepare some specimens.



Schematic diagram for stir casting technique used

The result of the experiment showed that the composite with 10 wt.% SiC at blade angle of 30^o andstirring speed of 100 rpm gave has metallurgical properties. Results revealed that during lower speed and lower stir time particle clustering occurred in some places, and some places were identified without SiC inclusion. It was found that by increasing the stirring speed and stirring time better homogeneous distribution of SiC in the Al matrix. Better distributions of SiC were found at blade angle of 30^o , stirring speed of 100 rpm and 10% SiC [46].

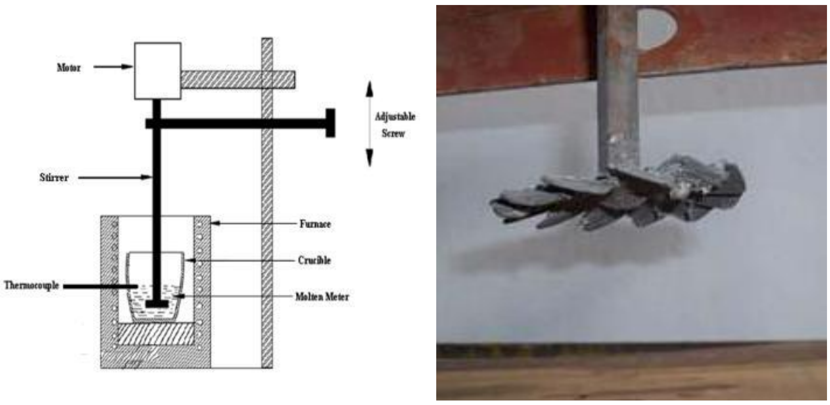
A2218 Aluminum alloy reinforced with alumina (Al_2O_3) particles in size range < 53 microns was selected to produce metal matrix composite. The composite was investigated to find out the effect of stirring speed on retention of ceramic dispersions. The process parameters varied are speed of stirrerin steps 180, 250, 400 and 1400 rpm. Particle wt% is also varied as 10 and 20% respectively. The effect of stirring speedand particle content on microstructure and mechanical properties of the composites. The alloy was placed in the graphite crucible at superheatedtemperature of 750°C to 850°C in the electrical resistancefurnace until it melted completely. When this molten alloy was achieved, the additive (Al_2O_3) was added in it after preheatingthem at the temperature about 700°C.



Schematic representation of stir casting set-up

Results indicated that with the increase in stirring speed, the distributionof the particles in the matrix became uniform andtheir segregation reduced. This may be due to the additional energy applied by the stirrer at higherrpm [47].

The effect of stirring speed and pouring temperature on mechanical, microstructure and machining properties of Al6061-Cu reinforced SiC MMC was investigated. The composite was fabricated using stir casting technique.Billet of aluminium and copper were preheated at 450 ^{o}C for 40 minutes before melting and the SiC particles were preheated at 1100 ^{o}C for 2 hours to make their surfaces oxidized. The furnace temperature was first raised above the liquidus to melt the feed stock completely and was then cooled down just below the liquidus to keep the slurry in a semi-solid state. At this stage the preheated SiC particles were added and mixed manually. After sufficient manual mixing, the composite slurry was reheated to a fully liquid state and then automatic mechanical mixing was carried out for about 10 minutes at five different stirring speed. In the final mixing process, the furnace temperature was within 800 ^{o}C and the composite slurry was poured in a sand mould designed to get standard specimens.



Schematic view of Experimental setup and stirrer

Results showed that an increase in stirring speed increases the impact strengthand hardness of material up to a certain limit after that theseproperties decrease drastically. It was observed from an SEM study that at stirring speed400 rpm better homogeneity can be obtained compared to200 and 600 rpm [48].

K. Paul and M.Sijo investigated the effect of stirrer parameter on aluminium alloy (LM6) reinforced SiC MMC produced by stir casting method. Aluminium was preheated for 3 to 4 hours at 450°C andsilicon carbide also with 900°C. At first heater temperature is set to 500^{o}C and then it was gradually increased up to 900^{o}C. Temperature of the heater was set to 620^{o}C which is below the melting temperature of the matrix. An electrical resistance furnace assembled with stainless steel impeller with 2 blade, 4 blade and 5 blade used as stirrer was used for stirring purpose. A uniform semisolid stage of the molten matrix was achieved by stirring it at 600 rpm. Pouring of preheated reinforcement at the semisolid stage of the matrix enhance the wettability of reinforcement, reduces the particle settling at the bottom of the crucible. After stirring for 10 minutes at semisolid stage slurry was reheated and hold at a temperature 900°C to make slurry in liquid state. Stirrer rpm was then gradually lowered to the zero. The molten composite slurry was then poured in to the metallic mould which is preheated at temperature 500°C this makes sure that the slurry is in molten condition throughout the pouring.

Stirrer Blade preparation

Results indicated that composite fabricated using four blade stirrer shows better properties than two blade and five blade [49].

V. Conclusion

After review of various literature on stir casting for production of aluminum metal matrix composites, various process parameters of stir casting processand difficulties encountered in successful fabrication of AMMC's via stir casting technique, the following conclusions were made:

1. Stir casting method is the simplest and most economical method to produce good quality aluminium metal matrix composites.
2. AMMC's with larger particle size exhibit more homogeneous and uniform distribution in the matrix than small particles.
3. Possibility of clustering of the reinforcements increases with increasing volume fraction of particles.
4. The nano-sized ceramic particles can be successfully incorporated into the aluminum matrix with a reasonably uniform distribution, but the amount of porosity increases with increasing volume fraction of nanoparticles, which can be attributed to the increased surface area of the nanoparticles.
5. In a combined route of stirring at semi-solid state followed by stirring at liquid state, the particle size and rotation are the factors of greater influence on the incorporation of particles into the matrix, whereas the time factor does not show any significant influence on the incorporation process.
6. Processing temperature, holding time influence on the viscosity of liquid metal and particles distribution, also induce some chemical reaction between matrix and reinforcements, this varies depending on the type of constituents. For good wettability, operating temperature should be kept at semisolid stage.
7. Wetting of ceramic particles occur during stirring at semisolid state because of interactions among the particles themselves, between particles and solid aluminium and between particles and the remaining liquid phase. Addition of a wettability-promoting agent,such as Mg, enhances the wettability between the particles and aluminium.
8. Aluminium coated particles have higher wettability and better dispersion in the matrix because of their lower melting point. This dispersion induces particles act as grain refiner of the melt. Furthermore, high nucleation rate in melt which is result of great temperature difference between powder and melt which produces a spherical and rosette-shaped grains, so this phenomena can reduce the viscosity of melt during casting process.
9. The impeller and stirring rod can be coated with liquid oxide such as alumina or zirconia so as to avoid any metals contamination to the molten metal. For an optimized stirrer position, about 1/3 of material should be below the stirrer and 2/3 of material should be above the stirrer.The stirring should be continued for few minutes before, during and after feeding the reinforcement, also during the filling of the molten through the bottom of the crucible. In case of using conventional stir casting, the stirring should be continued after the feeding the reinforcement till just before the pouring. Hollow spindle stirring mechanism can be replaced the usual solid shaft stirrer through the additions of ceramic particles turnings were introduced in small cylindrical capsules. The method is suitable for eliminating the fading effect of inoculation and simultaneous addition of reinforcements.
10. Blade design of the stirrer and preheating process are among the important factors to be considered in the production of cast AMMC's as these have an impact on quality and properties of casting. Toprevent or reduce the formation of vortex at the surface of the melt as much as possible for the purpose ofuniform dispersion of

material,results of laboratory studies indicated that the blade angle should be 30°, 45°, 60° or 90°, and number of blade should be 4.

11. Pouring temperature and pouring rate have significant impact on the metallurgical properties of composites prepared using stir casting rout, depending on the type of composites.

12. Degasification tables of Hexachloroethane can be added into the melt instead of use of inert gas for removal of gases from the molten alloy.The scum powder can be added into the melt which resulted into accumulation of impurities at the surface of liquid melt.

13. Preheating the mould improves the soundness of the casting, shown by a decrease in the porosity level

14. Three step mixing method revealed an effective impact on the distribution of the nanoparticles. It showed good incorporation of the particles and particles clustering, whereas poor incorporation of the particles and particles clustering were observed in the case of nanocomposite fabricated using conventional stir casting method.

15. Taguchi method has proved its success in prediction the optimum casting parameters to reach the best metallurgical properties.

References

[1] J. Wiley & Sons, "Technology & Engineering – Handbook of Composite Reinforcements ", P 344-355, 30-Nov-1992.
[2] R. Calin, M. Pul and Z. Pehlivanli, The Effect of Reinforcement Volume Ratio on Porosity and Thermal Conductivity in Al-Mgo Composites, Materials Research, 2012; 15(6): 1057-1063.
[3] N. Jit, A. Tyagi and N. Singh, Al-Cu-Si - (Al_2O_3)p composites using A 384.1 Al Alloys, Asian Journal of Chemistry Vol. 21, No. 10 (2009), S066-071.
[4] B. Kandpal, J. Kumar and H. Singh, Production Technologies of Metal Matrix Composite: A Review, IJRMET Vol. 4, Issue 2, Spl - 2 May - October 2014.
[5] S. Kulkarni, J. Meghnani and A. Lal, Effect of Fly Ash Hybrid Reinforcement on Mechanical Property and Porosity of Aluminium 356 alloy, Elsevier, Procedia Materials Science 5 (2014) 746-754.
[6] S. Shinde, Manufacturing of Aluminum Matrix Composite Using Stir Casting Method, IJIERT, Vol. 2, Issue 5, May-2015.
[7] P. Sharma, Production of AMC by stir casting – An Overview, International Journal of Contemporary Practices, ISSN: 2231-5608, Vol.2, Issue 1.
[8] M. Balasubramanian, Composite Materials and Processing - Technology & Engineering, Handbook,P 276, 2013.
[9] J. Davis, Aluminum and Aluminum Alloys, Technology & Engineering, Handbook, P 164, 1993.
[10] W. Callister and Wiley, Material Science and Engineering, 9th Addition, 2011.
[11] N. Singh, S. Rai and S. Agarwal, Polymer Nanocomposites and Cr(VI) Removal from Water, Symbiosis, NB Singh, Research and technology development centre, sharda university, Jan. 29, 2014.
[12] ASM International Handbook Committee: Composite, Engineered Materials Handbook, Volume 1, Third Printing, August 1989.
[13] Department of Defense USA, 2002, Composite Materials Handbook, Vol. 4, Metal Matrix Composites,
[14] Department of Defense USA, 2002, Composite Materials Handbook, Vol. 5, Ceramic Matrix Composites,
[15] K. Kainer, Metal Matrix Composites - Custom-made Materials for Automotive and Aerospace Engineering, 2006, ISBN: 3-527-31360-5.
[16] K. Surappa, Aluminium matrix composites: Challenges and opportunities, Sadhana Vol. 28, Parts 1&2, February/April 2003, pp. 319–334.
[17] A. Khedera, G. Marahleh and ,D. Al-Jamea, Strengthening of Aluminum by SiC, Al_2O_3 and MgO. Jordan Journal of Mechanical and Industrial Engineering, Volume 5, Number 6, Dec. 2011.
[18] D. Ramesh, R. Swamy and T. Chandrashekar, Effect of Weight Percentage on Mechanical Properties of Frit Particulate Reinforced Al6061 Composite., ARPN Journal of Engineering and Applied Sciences, Vol. 5, No. 1, January 2010.
[19] W. Callister and Jr, Materials Science and Engineering, Department of Metallurgical Engineering, The University of Utah, seventh edition, 2007.
[20] N. Cheremiisinoff, Handbook of ceramics and composites, synthesis and properties, Vol. 1, Marcel Dekker, New York-Basel 1990.
[21] D. Herling, G. Grant and others, Low-cost aluminum metal matrix composites, Advanced materials & processes, July 2001.
[22] V. Suong and Hoa, Handbook of science and engineering of composite materials, Vol. 21, Issue 4, Sep 2014.
[23] S. Suresh, D. Mishra and others, Production and characterization of micro and nano Al2O3 particle-reinforced LM25 Aluminum alloy composites, Journal of Engineering and Applied Sciences, Vol. 6, No. 6, June 2011.
[24] T. Hashmi,Liquid state methods of Producing metal matrix composites: A Review, International journal of research in mechanical engineering & technology, Vol. 5, Issue 1, Nov. 2014 – Apr. 2015.
[25] D. Roystan, Satyanarayen and others, A Study on mechanical properties of aluminum LM25- Sic composites fabricated using stir casting, IJARTET, Vol. II, Special issue XXII, February 2015.
[26] K. Ranieria, C. Kiyana and others, Analysis of semi-solid processing for metal matrix composite synthesis using factorial design, Materials research. 2012; 15(1): 144-150.
[27] A. Mazahery and M. Shabani, Characterization of cast A356 alloy reinforced with nanoSiC composites, Elsevier, Nonferrous met. soc. China 22(2012) 275−280.
[28] M. Prakash and M. Jaswin, Microstructural analysis of aluminum hybrid metal matrix composites developed using stir casting process, Int. J. Adv. Eng., 2015, 1(3), 333-339.
[29] M. Hassan, T. Ofor and others, Development of aluminum metal matrix composite using stir casting method, The international journal of engineering and science (IJES) ,Vol. 3, Issue 8, P.36-39, 2014.
[30] S. Mathur and A. Barnawal, Effect of process parameter of stir casting on metal matrix composites, International journal of science and research (IJSR), Vol. 2 Issue 12, Dec 2013.

[31] G. Sozhamannan, S. Prabu and others, Effect of processingparameters on metal matrix composites: Stir casting process, Journal of surface engineered materials and advanced technology, 2012, 2, 11-15.
[32] L. Saravanan and T. Senthilvelan, Fabrication and characterization of AL-AL_2O_3nano composite, IJCESR, Vol. 2, Issue 1,2015.
[33] R.Raghuram, Investigation of vibration properties of aluminum, silicon carbide, Mica a hybrid metal matrix composite, IJLTET, Vol. 5 Issue 2 March 2015.
[34] A. Singh, L. Kumar and others, Manufacturing of AMMC's using stir casting process and testing it's mechanical properties, International journal of advanced engineering technology, July-Sept.,2013/26-29.
[35] R. Adat, S. Kulkarni and S. Kulkarni, Manufacturing of particulate reinforced aluminum metal matrix composites using stir casting process, International journal of current engineering and technology, Vol.5, No.4, Aug 2015.
[36] A. Kumar, B. Naik and others, Optimization of casting parameters for casting of AL/RHA/RM hybrid composites using taugchi method, IJETT, Vol. 4, Issue 8, August 2013.
[37] L. Singh, B. Ram and A. Singh, Optimization process parameter for stir casted aluminum metal matrix composite using taugghi method, IJRET, Vol. 2, Issue 08, Aug-2013.
[38] R. Bhandare and P. Sonawane, Preparation of aluminum matrix composite by using stir casting method, International Journal of Engineering and Advanced Technology, IJEAT, Vol. 3, Issue 2, Dec 2013.
[39] R. Calin, M. Pul and Z. Pehlivanli, The effect of reinforcement volume ratio on porosity and thermal conductivity in Al-Mgo composites, Materials research, 2012, 15(6), 1057-1063.
[40] S. Dwivedi, B. Gupta and D. Chaudhary, The effect of process parameters on mechanical stir casting process, Journal of engineering & technology, Vol. 1, Issue 2, 2013.
[41] S. Nair and N. Joshi, Preparation of Al 6061/ SiC metal matrix composite (MMC) using stir casting technique, IJARIIE, ISSN(O), 2395-4396, Vol. 1, Issue 3, 2015.
[42] B. Samal, S. Panigrahi and B. Sarangi, Use of modified stir casting technique to produce metal matrixcomposites, IJETR, ISSN: 2321- 0869, Vol. 1, Issue 9, Nov 2013.
[43] P. Melali, A. Mashayekhi and M. Shahmiri, Fabrication of high strength OF AL-base alloy composites reinforced with SiC nanoparticles coated with Al and Cu, Association of Metallurgical Engineers of Serbia (AMES), Metall. mater. eng., Vol. 21 (2) 2015, p. 73-78.
[44] M. Wahab, A. Daud and M. Ghazali, Preparation and characterization of stir cast-aluminum metal matrix composites, International Journal of Mechanical and Materials Engineering, Vol. 4, (2009), No. 2, 115-117.
[45] A. Micheal, A. Visu and others, Mechanical and corrosion properties of Al5034-Moo_3 metal matrix composite, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Special Issue 3, Mar 2014.
[46] A. Jailania and S. Tajuddin, Mechanical properties of stirred SiC reinforced aluminum alloy: stir casting with different composition of SiC, blade angle and stirring speed. Advanced materials research, Vols. 622-623 (2013) pp 1335-1339.
[47] P. Kumar and V. Tirth, Effect of stirring speed on retention of particles in AA2218-Al_2O_3 MMC's processed by stir casting, MIT, International journal of mechanical engineering, Vol. 3, No. 2, Aug. 2013, pp. 123–128.
[48] S. Haque, A. Ansari and P. Bharti, Effect of pouring temperature and stirring speed on mechanical microstructure of AL6061- CU reinforced SiC_P metal matrix composites, IJRET, Vol. 03 Special Issue 10, Jun 2014.
[49] K. Paul and S. MT, Effect of stirrer parameter of stir casting on mechanical properties of aluminum silicon carbide composite, IJMER, ISSN: 2249–6645, Vol. 5, Iss. 8, Aug. 2015.