Some Optimization in Production of Alumunium Metal Matrix Composites (AMMC) by Stir Casting Process -Review-

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Abstract

Many processing were developed in production alumunium metal matrix composites. Stir casting is one of methods that used it, but still have problem in processing. Generally, the problems was found such as the distribution of reinforcement materials, wettability between reinforcement material and matrix alloy and porosity in cast alumunium metal matrix composites. The problems can be reduced by optimization of process in production alumunium metal matrix composites, such as stirrer and stirring optimization, pre-treatment of reinforcement, wetting agent and stirring in semisolid condition. The optimization will promoted wettability between reinforcement and matrix, particle distribution and decreasing of porosity. This paper attempts to review and analyze some of result of experiment in production aluminium metal matrix composites for optimization of processing in stir casting technique.

Keywords**:** Alumunium metal matrix composites, stir casting, wettability, stirrer, wetting agent, pre-heated of particle.

Introduction.

Alumunium Matrix Composite (MMC) is to combine the desirable attributes of alumunium and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produces a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcements. Aluminum metal matrix composites (AMMC) are being considered as a group of new advanced materials because of its light weight, high strength, high specific modulus, low co-efficient of thermal expansion, and good wear resistance properties. Combinations of these properties are not available in a conventional material (Sakthivel et al. 2008).

Processing techniques for MMC can be classified into melt processing (liquid-phase processing) and powder metallurgy (solid-phase processing). The powder metallurgy method has better matrix-particle bonding, easier control of matrix structure, and uniform dispersion of the reinforcement (Kok et al. 2005). Compared with powder metallurgy, melt processing has some advantages such as simplicity, low cost of processing, manufacturing of intricate components, and near-perfect shape components. Stir casting is generally accepted currently as a commercial practicable method. Its advantages lie in its simplicity, flexibility, and applicability to large volume production. This melt processing is the most economical of all the available routes for MMC production and allows very large-sized components to be fabricated. (Sahin et al. 2002; Taha, et al.1998) The melting process has two major problems: first, the ceramic particles are generally not wetted by the liquid metal matrix, second, the particles tend to sink or float depending on their density relative to the liquid metal and so the dispersion of the ceramic particles are not uniform, whereas powder metallurgy enables uniform distribution of the ceramic particles (Kok et al. 2005).
In recent years many processing techniques have been developed to process particulate reinforced metal matrix composites. According to the type of reinforcement, the fabrication techniques can vary considerably. These techniques are stir casting, liquid metal infiltration, squeeze casting, Among the variety of processing techniques available for particulate or discontinuous reinforced metal matrix composites, stir casting is one of the methods accepted for the production of large quantity commercially practised. It is attractive because of simplicity, flexibility and most economical for large sized components to be fabricated. (Ravi et al. 2007) Stir casting consists of vigorous stirring of a molten matrix by mechanical or magneto–hydrodynamic means, followed by incorporation of a reinforcement and creation of a homogeneous mixture. The process is relatively simple and readily adaptable in a conventional

foundry. Usually, the molten matrix is mechanically stirred to create a vortex, which draws the reinforcement together with the ambient gases into the fluid medium. As a result, the gas content of the slurry is also dependant on mixing parameters, such as the depth of immersion and the speed of the impeller. The creation of homogeneous mixture is a prerequisite. This is important as SiC particulates have poor wettability with aluminum melt. In order to allow appropriate incorporation and distribution of particulates in the melt, the design, dimension and placement of stirrer in crucible and its speed are of paramount importance besides the properties of the metallic melt and reinforcement particulates. The effect of stirrer diameter on the distribution of solid particulates in the melt, who indicated that an optimum stirrer diameter is necessary to ensure that the solid particles remain fluidized in both the central and peripheral parts of the crucible. The results of the present study showed that the stirrer diameter used, ensured gradient distribution of SiC particulates in the vertical direction and uniform distribution in the radial direction, for their given geometries, at a stirring speed of 294 rpm. (Nai et al. 2003).

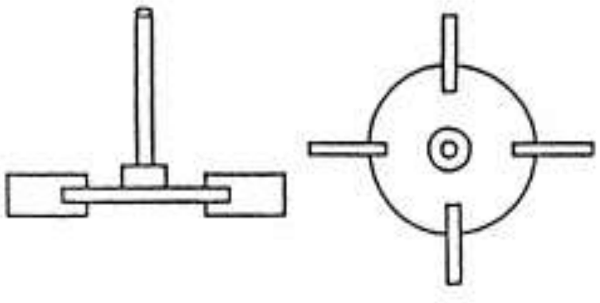
Stir casting method is a relatively low cost liquid processing present to produce MMC and hence, this processing technique had been utilized in this study. Besides being simple, flexible, and attractive, as compared with other techniques, it also allows very large size components to be fabricated and is also applicable to large quantity production. Stir casting route also ensures that undamaged reinforcement materials are attained. Moreover, this type of processing is now in commercial use for particulate Al-based composites and the material produced is suitable for further operations, such as pressure die-casting. There are several difficulties in stir casting that are of concern, which are: (i) porosity in the cast MMC, (ii) difficulty in achieving a uniform distribution of the reinforcement material, (iii) wettability between the two main substances, and (iv) chemical reactions between the reinforcement material and matrix alloy. (Aqida et al. 2004)
In a stir casting process, the reinforcing phases (usually in powder form) are distributed into molten magnesium by mechanical stirring. Stir casting of metal matrix composites was initiated in 1968, when S. Ray introduced alumina particles into aluminum melt by stirring molten aluminum alloys containing the ceramic powders. Mechanical stirring in the furnace is a key element of this process. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement. The cast composites are sometimes further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement. (Hai Zhi Ye, et al. 2004)
Processing variables such as holding temperature, stirring speed, size of impeller, and the position of the impeller in melt are among the important factors to be considered in the production of cast matrix composites as these have an impact on mechanical properties. Therefore, by controlling the processing condition as well as the relative amount of the reinforcement material, it is possible to obtain a composite with a broad range of mechanical properties. This paper covered investigation of result of some experiments to obtain optimum condition in production AMMC by stir casting.

Stirrer

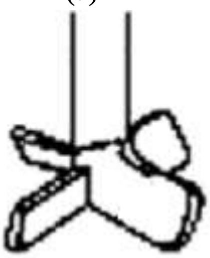
a. Geometry of Blades

In stir casting process, the mechanical stirrer used (usually during melt preparation or holding) during stirring, the geometry of impeller, impeller position in molten matrix and stirrer angle are some of the main factors to be considered in production alumunium metal matrix composites. During stir casting for synthesis of composites, stirring helps in two ways: (a) transferring particle into the liquid metal, and (b) maintaining the particle in a state of suspension. (J. Hashim et al. 1999**)**. Some of designs of mechanical stirrer (three bladed impeller, four-bladed turbine, simple paddle, anchor impeller, helical ribbon, and screw with draft tube) were done in production AMMC. Among them, the turbine stirrer is quite popular. (Sakthive et al. 2008) was used some stirrer ; zig zag, graft and turbine type in production SiC particle reinforced 2618 alumunium alloy composites. The turbine type (Figure 1) has provide good mixing because the development of the vortex during stirring is helpful for transferring the particle into the matrix melts as the pressure difference between the inner and the outer surface of the melt sucks the particle into the liquid with limited stirrer speed. Aniban et al. (2002) has done analysis of impeller parameter for alumunium metal matrix composites by used axial flow and radial flow impeller/stirrer. Axial flow impellers have more discharge than shear while radial flow impellers have more shear than flow for a particular power specified.
The stirrer diameter is also an important factor to be considered. When the stirrer diameter is too small, the solid particles remain suspended at the periphery of the vessel in spite of the lack of deposits at the centre. When the diameter is too large, solid particles are apt to remain un-dispersed in the centre of the vessel bottom. Therefore the optimum diameter of the stirrer is the size at which solid particles are fluidized

in both the central and peripheral part at the same speed. It has been found (J. Hashim et al. 2002) that for a flat bottom vessel, stirrer diameter d should be equal to 0.4*D*, where D is the diameter of the vessel, and the blade width *b*, should be equal to 0.1–0.2*D*. (Young et al.1995) The inside diameter of crucibles was either 45 and 63 mm and the diameter of the impeller was varied from 38 to 48 mm (d equal to 0.6*D*) and mounted on the lower portion of the shaft are four mixing blades. (Kok et al. 2005) The melting process is carried out in a graphite crucible with upper diameter of 102mm and lower diameter of 70mm while the mixing process is conducted with a 55mm diameter graphite mixer having four channels, which combines with a steel mandrel driven by a variable speed AC motor. (*d* equal to 0.5*D*)



(a)



(b)

Gambar 1, Schematic of mechanical stirrer (turbine type) (a) Proposed by J. Hashim et al. [1999] (b) Proposed by Sakhtivel et al. [2002]

The effect of impeller diameter (d) can be assessed only with respect to the crucible diameter (D) in which the liquid with secondary particles is being stirred. For solid suspension applications, the practical maximum *d/D* ratio is 0.6 while the minimum will vary according to process viscosity, increasing as the viscosity increases. A large number of impellers have a *d/D* of approximately 0.3 which is applicable to fluid viscosity of 10poise. (Aniban et al. 2002).

b. Stirrer Position in molten

Stirrer position in molten matrix has effect in flow in molten matrix surface. Based on past research was done research on stirrer position in matrix meltdown. (J. Hashim et al. 1999) Their experimental work showed that there is a decrease in the porosity level with an increase in the holding temperature. It has been recommended that a turbine stirrer should be placed so as to have 35% liquid below and 65% liquid above. (Young et al. 1995) The impeller was lowered into the melt and attached to the motor shaft. The clearance of the impeller from the bottom of the crucible was approximately 10 mm, the melt depth being about 50 mm**.** (Kok et al. 2005) The clearance of the impeller from the bottom of the crucible was approximately 10mm with the melt depth being about 90mm. (Sakthivel et al. 2008). The clearance of the stirrer from the bottom of the crucible was approximately 10 mm with the melt depth of 100 mm. Table 1 was shown some of positions of stirrer by investigators in production alumunium metal matrix composites. Table was shown stirrer position in molten matrix from that be done by investigator.

Table 1. Stirrer position in molten matrix

Investigators	Matrix & Particle	Stirrer position	% from bottom of furnace
J. Hashim et al. 1999	A359 & SiC	35-100 mm	35 %
Young et al. 1995	Al-15Si & SiC	10-50 mm	20 %
Kok et al. 2005	A2024 & Al_2O_3	10-90 mm	11 %
Sakthivel et al. 2008	A2618 & SiC	10-100 mm	10 %

c. Stirrer Angle

Generally, in stir casting processing, the stirrer fitted unidirectional with wick line crucible graphite (J. Hashim et al. 1999; Young et al. 1995; Kok et al. 2005 dan Sakthivel et al. 2008) and has successfully produced AMMC. Figure 2 showed unidirectional stirrer with wick line crucible graphite and pattern of fluidisation of solid particles. In the figure was showed that the particle founded in policy division crucible that does not stirred. This could cause reinforcement agglomeration. With use stirrer which owns angle on wick line crucible could cause better stirring and dispersion. With this method can be generated AMMC with properties better.

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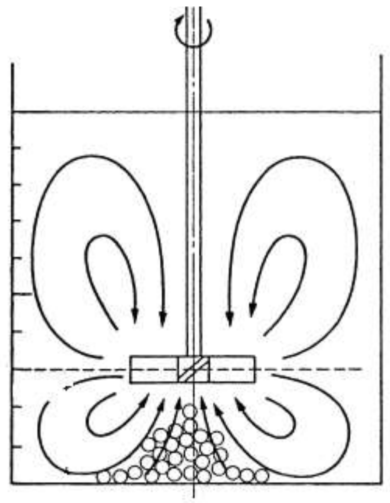

Figure 2, Pattern of fluidisation of solid particles. (J . Hasim, 2002)

The Alcan Coopertaion (Duralcan) developed new technique in production AMMC. The preheated 'motorized' stirrer should be placed in the melt, at an angle to maintain an upward flow of metal and low enough into the melt to keep the bottom layer moving, to provide good movement of metal underneath the melt skin without creating a vortex that would drag surface oxides into the melt and cause air entrapment. The stirrer should be placed at angle 15-30 to minimize vortex at melt surface (Figure 3).

(Ravi et al. 2008), investigated the influence of mixing parameters such as impeller blade angle, rotating speed, direction of impeller rotation, and optimized the same through a water model. The work revealed that to obtain uniform distribution an average speed of 250-270 rpm was required with clockwise rotation of the stirrer having 30° blade angle with respect to stirrer axis.

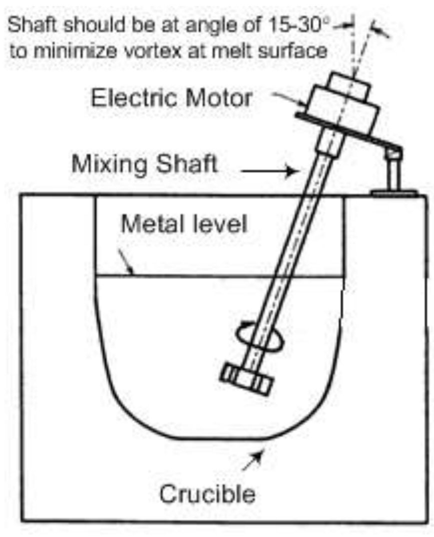

Figure 3, Stir casting that introduced by *DURALCAN* MMC Foundry

Speed, time, and temperature of stirring and degassing

Main reason of stir casting was continued stirring of molten matrix by using of special stirrer. The purpose of stirring was to draw and distribute reinforcement in molten matrix. The stirring also was done on high temperature for sufficient time to eliminate precipitation of reinforcement in bottom of crucible because generally reinforcement density higher than matrix. Particle distribution in molten matrix before solidification process was controlled by movement of particle in crucible graphite. (J. Hashim 1999).
A mechanical force can usually be used to overcome surface tension and improve wettability. However, in the experimental work of Zhou (1995), it was found that mechanical stirring cannot solve poor wettability when the matrix alloy is in a completely liquid state. Stirring ini a matrix alloy is in a completely liquid state. Stirring in a semi-solid state did help to promote wettability between SiC particles and Al-Si and Al-Mg alloys. In a semi-solid state, primary a-Al phase exists, so agitation can apply large forces on the SiC particles through abrasion and collision between the primary α-Al and particles. This process can help to break the gas layers and perhaps oxide layers as well and to spread the liquid metal onto surfaces of the particles, thus helping to achieve good wettability

Table 2: Condition of stir casting processing (temperature, speed and time of stirring and dagassing)

Investigators	**Matrix & Particle**	**Speed ; Time** (rpm ; min)	**Temperature**(°C)	**Degassing**
J. Hashim et al. (1999)	A359 & SiC	100 ; 50	Semisolid	Nitrogen
Young et al. (1995)	Al-15Si & SiC	750; 5	680-700	Argon
Kok et al. (2005)	A2024 & Al_2O_3	900;5	Superheat	Argon
Sakthivel et al. (2008)	A2618 & SiC	700;10	Super heat	Tablet
Zhou & Xu (1995)	A356-A6061 &SiC	150-200	Semisolid	Argon

Some experiments were done to produce alumunium metal matrix composites by using of stir casting.

Table 2 was shown the optimum condition of process parameter (stirring, temperature, and degassing) of stir casting technique from experiment was done by J Hashim et al. (1991), Young et al. (1995), Zhou (1995), M. Kok et a (2005) dan Sakthivel et al.(2008).

Pre-Treatment of reinforcement

Heat treatment of particles before dispersion in the melt aids their transfer by causing description of adsorbed gases from the particle surface. J. Hashim (1991) observed the importance of preheating in the incorporation of graphite particles in alumunium alloys. There was no retention when the graphite particles were not preheated. Heating silicon carbide particles to 900°C assists in removing surface impurities desorption of gases, and altering the surface composition to the formation of an oxide layer on the surface. The addition of preheated alumina (Al_2O_3) particles in an Al-Mg melt has also been found to improve the wetting alumina. The addition of pre-heated alumina particles in Al-Mg melt has been found to improve the wetting of alumina. A clean surface provides a better opportunity for melt-particles interaction, and thus, enhances wetting. Ultrasonic techniques, various etching techniques, and heating in a suitable atmosphere can be used to clean the particle surface. Ultrasonic vibration has been applied to molten aluminium in order to improve the wettability of alumina particles.

Therefore, other parameters have effect for production AMMC were technique and temperature of particle addition. Young et al. (1995) explained when the melt temperature reached 700°C, particles addition was started with full furnace power applied. The Particles were added uniformly over a time period of approximately 30 min. The particulates were added uniformly using a funnel-shaped pipe. (Sakthivel et al. 2008) After the molten metal was fully melted degassing tablet was added to reduce the porosity. The stirrer was lowered into the melt slowly to stir the molten metal at the speed of 700 rpm (W. Zhou, 1995). The furnace temperature was first raised above the liquidus to melt the alloy scraps 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. Manual mixing was used because it was very difficult to mix using automatic device when the alloy was in a semi-solid state. J Hashim (2001) said that mechanical stirring cannot solve poor wettability when the matrix alloy is in a completely liquid state. Stirring in a semisolid state did help to promote wettability between SiC particles and Al-Si and Al-Mg alloys. (Sahin, 2003) The packet was added into molten metal of crucible when the vortex was formed at every 15–25 s. Approximately, 5–8 g of silicon carbide particles were inserted on an aluminium foil by forming a packet. The packet of mixture melted and the particles started to distribute around the alloy sample. This method enabled a full and homogenous distribution of the particles in the matrix alloy. Table 3 was shown some of technique pre-treatment of reinforcement, addition temperature, and method in production AMMC by stir casting.

Table 3: Condition of stir casting processing (pre-heated of particle, temperature, and methode of addition)

Investigators	**Matrix & Particle**	**Pre-heated of particle** (Temp; Time)	**Addition Temperature**	**Addition Method**
J. Hashim et al. (1999)	A359 & SiC	900°C;2 hr	Semisolid	Packet
Young et al. (1995)	Al-15Si & SiC	-	700	Funnel-shaped pipe
Kok et al. (2005)	A2024 & Al_2O_3	400;10	700	Feeding systems
Sakthivel et al. (2008)	A2618 & SiC	900°C;1 hr	700	Packet
Zhou & Xu [(1995)	A356-A6061& SiC	1100;3h	Semisolid	-
Sahin (2003)	Al2014 & SiC	1100; 2hr	-	Packet

Wetting agent

In order to improve the wettability of SiC particles, the melt was alloyed with 1% Mg (Pai et al., 1995) and temperature was dropped below the liquidus, to the semi-solid state. SiC particles, preheated at 300 °C for 2h were added to the slurry and manually stirred until the particles were completely wetted. (Cetin, 2008) However, for the composites studied, the problem of poor wetting could not be solved by mechanical stirring. To overcome this problem, the particulates were chemically treated by solution rich in Na ions for several hours, dried and then preheated to 200°C before adding them into the melt. Also, Mg in small lumps was added into the melt just prior to

the addition of the particulates to decrease the surface tension of the matrix alloys. (Daoud et al. 2002)
Mg is one such reactive element and its addition to Al melt has been reported to improve wettability of fibers by reducing the surface tension of the molten Al. Addition of Mg to Al melt improves wettability by changing the interfacial energy possible through some interfacial reaction. (Mandal et al. 2006) The addition of Mg to molten aluminium to promote the wetting of alumina is particularly successful, and it has also been used widely as an addition agent to promote the wetting of different ceramic particles, such as silicon carbide. (J. Hashim et al. 1999).

Conclusion

From comparison of some of experiment of stir casting in production of alumunium metal matrix composites (AMMC) can be conclude;

1. The suitably stirrer geometry was turbine type; the stirrer position in molten metal was 20-35 % of molten metal from bottom furnace; the stirrer should be placed 15-30 from shaft of stirrer.
2. Stirring while the slurry (semisolid state) is solidifying improves incorporation of the particles into the matrix alloy. However, the slurry must then be re-melted to a fully liquid condition in order to enable pouring into a mould. Decreasing this solidifying time during increases the percentage wetting.
3. Low speed stirring (50-250 rpm) in semisolid temperature was resulted good distribution of the reinforcement particle without air entrapment. Degassing with argon often was used to reduce the porosity.
4. Addition of magnesium enhances wettability, however increasing the content above 1 wt % Mg increase the viscosity of the slurry to the detriment of particles distribution.
5. Pre-heated of reinforcement to make their surface oxidized, thus the ability of this particle oxide layer to improve the wettability of particle by matrix.

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