Liquid State Methods of Producing Metal Matrix Composites: A Review Article

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Abstract

The main objective of this paper is to review the works on two broadly used methods of producing metal matrix composites : stir casting method and squeeze casting method. The major issues regarding the use of liquid state method of producing metal matrix composites are; the wetting of the dispersed phase in the metal matrix, reaction between the dispersed phase and the matrix, reinforcement distribution and porosity. Such cases have been studied and improved over a period and the present paper is directed towards a comprehensive review of them.

Keywords

Metal Matrix Composites, Stir Casting, Squeeze Casting, Reinforcements

I. Introduction

Composites are one of the most advanced and adaptable engineering materials presently known [1]. Developments in the field of materials science and technology gave birth to these fascinating and wonderful materials .Composites are heterogeneous in nature, produced by the assembly of reinforced fibers and compactable matrix. The matrix mat be metallic ceramic or polymeric in origin. It gives the composites their shape, surface appearance, environmental tolerance and overall durability while the fibrous reinforcements carry most of the structure loads thus giving macroscopic stiffness and strength.

Metal Matrix Composites (MMCs) have gained a considerable interest in the last three decades. The driving force has been the fact that addition of ceramic reinforcement in the metal matrix can improve specific strength, stiffness, wear, fatigue and creep properties compared to conventional engineering materials[6]. MMCs are widely used in several industrial areas such as aerospace, automotive, and electronics. It has been observed that properties of the composites are greatly influenced by the methods they are prepared. Properties of the composites are also influenced by the type of reinforcements and their distribution, chemical nature of components, morphology of particles their distributions and their interface reactions. Recently 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, spray decomposition and powder metallurgy. In this paper we have reviewed the liquid state methods of producing MMCs viz; Stir casting and Squeeze casting.

Stir casting is one of the methods accepted for the production of large quantity commercially practiced [2]. It is attractive because of simplicity, flexibility and most economical for large sized components to be fabricated. It is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. This involves incorporation of ceramic particulate into liquid aluminum melt and allowing the mixture to solidify. Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix.

In squeeze casting method liquid metal is injected/infiltrated into the interstices of the porous pre-forms of continuous fibers or whisker or particle to produce MMCs [14]. Depending upon the nature of reinforcement and its volume fraction preform can be infiltrated, with or without the application of pressure or vacuum. Some level of porosity and local variations in the volume fractions of the reinforcement are often noticed in the MMCs by this technique.

II. Stir Casting Method

Brabazon et. Al [10] studied the effects of controlled stirring during solidification on the microstructure and mechanical properties of aluminum alloys, in comparison to conventionally gravity chill cast material. A stir casting device was specially designed to study of the alloys in the mushy state. Effect of the process variables shear rate , shear time, and volume fraction solid during shear on microstructure and both static and dynamic mechanical properties of the stir cast alloy was studied. In all cases, improved mechanical properties and reduced porosity were obtained in the stir cast condition in comparison with conventional casting and in comparison with previous work on stir casting. Comparison with alloy commercially rheocast via electromagnetic stirring, however, showed that the latter had superior mechanical properties.

The main factors that control the properties of MMCs fabricated using casting techniques include: reinforcement distribution, wetting of reinforcement by matrix alloy porosity in the cast metal matrix and chemical reaction between reinforcement material and the matrix alloy. Hashim [6] researched on solving the problem of poor wettability between particulate SiC and molten Al (A359 alloy). He found that increasing both, SiC content and T6 artificial treatment increased the mechanical properties such as hardness and tensile strength o f the matrix alloy.

This was characterized by microstructure, porosity content measurement, tensile strength, micro-hardness, and compression strength measurements. Hashim also observed that the use of clean Sic particles, Mg as a wetting agent, and continuous stirring while the MMC slurry is solidifying were found to promote the wettability of SiC and the matrix alloy. Decreasing solidification time was found to improve the wettability significantly. When stirring is stopped, the particles tend to return to the surface indicating that particles tend to return to the surface indicating that particles floated mainly because of the surface gas layer surrounding. He used a computer program in order to optimize the stirring condition and simulate the fluid flow in the process. Sozhamannan et. Al [7] produced the effects of processing parameters of stir casting method on the MMCs. He made specimen at 700°C, 750°C and 800°C, and found particles uniformly and dendritic structure was more profound with no large pores. Increasing temperature however, to 850°C and 900°C enhanced pores and particle clustering owing to decreased viscosity and shearing strength as a result of increased temperature. Also it was observed that higher holding time decreased the particle clustering.

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The ultimate tensile strength increased up to 800°C gradually and started decreasing gradually due to clustering with increased temperature. The ultimate tensile strength decreased with increase in holding time as it influences the viscosity of the liquid metal, particles distribution and also induces some chemical reaction between matrix and reinforcement. Hardness was also seen to increase more or less linearly with increasing the processing temperature from 750°C to 800°C at 20 minutes holding time.
Smeulders et. Al [5] explained the slurry thixotropy and spherical particle morphology during the stir casting of metal alloys by performing the real time microscopic observation during the stir casting process using a model substance the transparent organic alloy neopentyl alcohol with water and made the following observations:

1. Fraction of solid increased by formation of new nuclei rather than by outgrowth of existing nuclei
2. Not the fragmentation or clustering mechanism but coarsening of the (branches of) equiaxed dendrites leads to the typical spherical particles shapes after stir casting.
3. Rate of coarsening increases with stirring rate
4. Complex flow pattern at higher stirring rates can be attributed to the presence of Taylor vortices.

Prabhu et. Al [4] studied the effect of stirring speed and stirring time on microstructure. He found that at lower speeds and lower stirring time particle clustering occurred in some places while in some places no reinforcement (SiC) inclusion was found. Increasing the stirring speed and stirring time provided better homogeneous distribution of SiC in the Al matrix and better hardness. Best results were found for a stirring speed of 600 rpm and stirring time of 10 minutes. However at very high speeds (700 rpm) porosity observed is more in the microstructure as vigorous stirring enables oxide skins, gases and contaminants to be entrained in the melt.
Mohammadpour et.al [9]exposed the effects of interfacial active elements addition on the incorporation of micro sized SiC particles in molten pure Aluminum. The various alloying elements used were Mg, Ca, Zr, Ti, and Si of 1% by weight and it was found that Ca and Mg were the most effective alloying elements which would ease the dispersion of ceramic particles into the molten metal. Intermetallic phases of Al_3Ti and Al_3Zr were formed during stir casting when Ti and Zr were added to the matrix loading to a considerable increase in hardness. Also, a reaction layer at the interface was observed not for all the samples suggesting that even 1% wt. of interfacial active elements could affect the quality of matrix reinforcement interface.
Naher et. Al [8] did the computational and experimental analysis of particulate distribution during Al-SiC MMC fabrication and discovered that fully uniform suspension remained for just a couple of seconds in the lower viscosity systems compared to about an hour for the higher viscosity system. He concluded that higher viscosity was observed for a stirring time of 540-3920 sec and lower viscosity for a stirring time of 14-170 seconds. Similarly 200 rpm and 300 rpm of stirring speed were established as best for lower and higher viscosity fluids in order to produce uniform distribution of SiC.
Samal et.al [3] used a modification of stir casting method in which a solid shaft stirrer was replaced by a hollow spindle stirring mechanism through which the additions of particulate SiC and Mg turnings were introduced in small cylindrical capsules. The method was found stable for eliminating the fading effect of inoculation and simultaneous additions of alloying element and reinforcement.

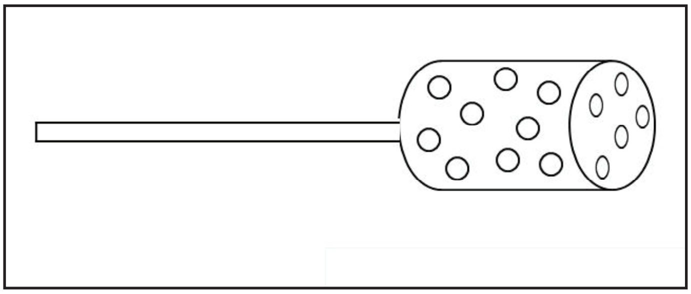


Fig. 1: Perforated Steel Capsule Welded to Plunger Rod

III. Squeeze Casting Method

Squeeze casting is a liquid phase method to produce reinforced MMCs. In squeeze casting technique molten metal is injected into a form with fibres pre-placed inside it.
Asthana [11] studied the two forces to overcome for achieving a good bonding and dispersion of the reinforcement as capillary forces and viscous. Chemical modifications like coating the 'perform' with Ni/Co checks the chemical reaction between the 'perform' and molten metal to keep the properties of the composite intact. External pressure is applied to the metal to force the contact and enhance the wettability. Borgonova [12] preferred mechanical forces over chemical modifications as it leads to unstable phases and limits the range of matrix alloy that can be used.

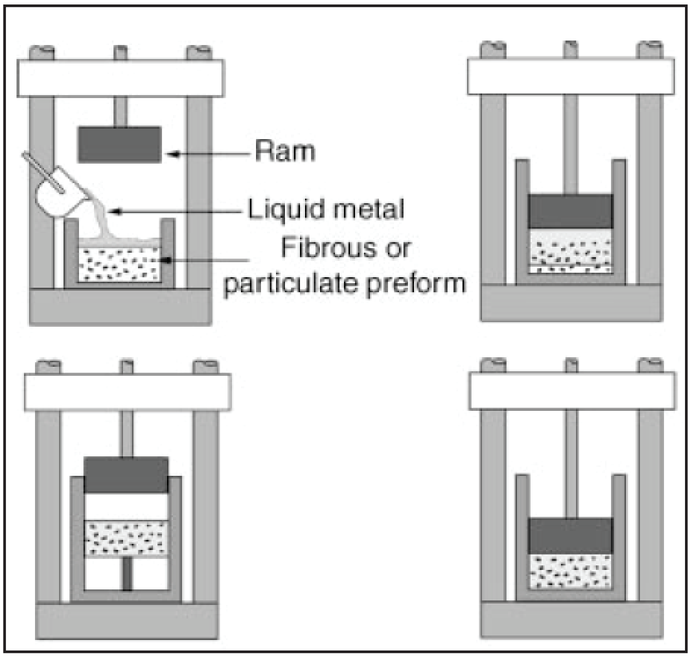


Fig. 2: Schematic Representation of Pressure Driven Infiltration

Moosa [13] found that the squeeze casting technique produced less porous parts due to high applied pressure during solidification and efficient liquid feeding obtained by moving the ram to compensate for the freezing contraction.

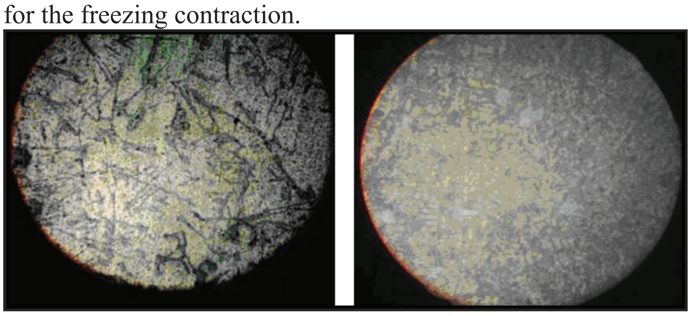
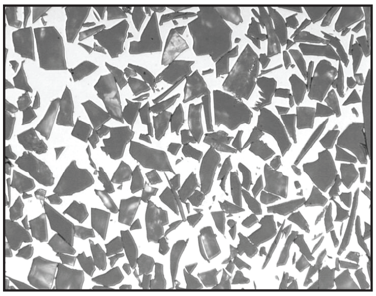


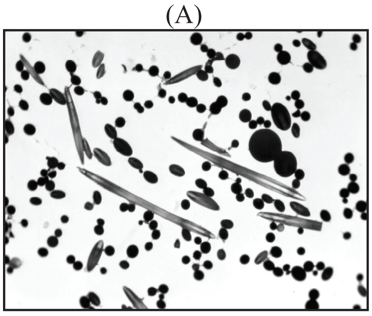
Fig. 3: Unreinforced Al-Si Alloy & Squeeze Cast Alloy

Lokesh et al. [14] also recorded the good bonding between the base and the alloy and lower casting defects for the same reasons. Belisario [15] et al worked to propose a squeezing system and related numerical model as well as prediction of Al-Si alloys mechanical properties as a function of the squeezing pressure. Shen et al. [16] found the optimal range of pressure in which macro-segregation in squeeze casting can be avoided (PSC<P<PMS) where PSC is that critical pressure under which shrinkage defects form and PMS is that critical applied pressure above which macro-segregation occurs. Zhang et al. [24] showed that optimum applied pressure followed by and optimum diffusion annealing process can substantially reduce micro-segregation and improve the mechanical properties. Long et al [18-23]studied the processing feasibility and processing optimization of Al based MMCs by indirect squeeze pressurized infiltration of ceramic perform on a shot-control die casting machine.

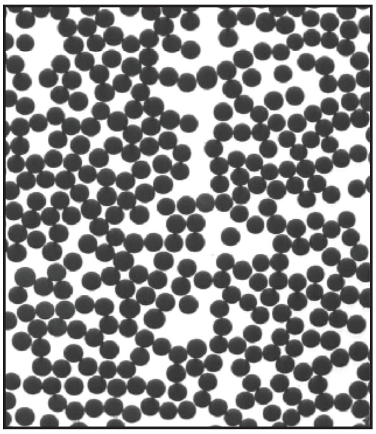
First the thermal parameters (melt superheat, perform preheat) were optimized and then the effect of hydrodynamic parameters (squeeze infiltration hydrodynamics, infiltration speed, maximum pressure, pressure-melt infiltration system) were examined on the infiltration kinetics. Further these optimizations were characterized microscopy and mechanical testing.



(A)



(B)



(C)

Fig. 4: Microstructures of the Peak-age Hardened F500S-SiCp/AlCu4MgAg Composite (A), 15% Saffil /AlCu4MgAg composite (B), and As-cast Altex /Al Composite (C) Produced on a Bühler SC die caster under optimal processing parameters.

IV. Conclusion

Stir casting method is a widely used process for mass production of MMCs as it is economical. However the product quality is higher when produced by squeeze casting method. Improvements in the squeeze casting methods by optimizing the parameters can lead to lowering the costs and improve the quality.

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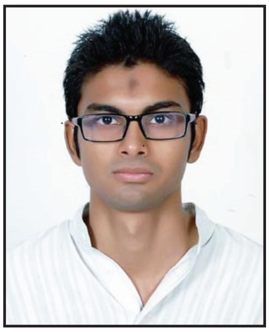

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