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RECENT DEVELOPMENTS IN THE FABRICATION OF METAL MATRIX COMPOSITES BY STIR CASTING ROUTE – A REVIEW

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ABSTRACT

Combining high specific strength with good corrosion resistance, metal matrix composites (MMCs) are materials that are attractive for a large range of engineering applications. There are several fabrication methods available in manufacturing the MMC materials. According to the type of reinforcement, the fabrication methods can vary considerably. In this review, the relatively low cost stir casting technique is evaluated for use in the production of silicon carbide/Aluminum alloy MMCs. This paper presents the effect of various factors effecting the stir casting process, challenges associated with it and techniques adopted to overcome these challenges.

Key words: Metal matrix composites, Reinforcement, Particle distribution, Al–SiC, Stir casting.

INTRODUCTION

Metal matrix composites (MMCs) are a range of advanced materials providing properties, which are not achieved by conventional materials. These properties include increased strength, higher elastic modulus, higher service temperature, improved wear resistance[1], decreased part weight, low thermal shock, high electrical and thermal conductivity, and low coefficient of thermal expansion compared to conventional metals and alloys[2]. The excellent mechanical properties of these materials and the relatively low production cost make them very attractive for a variety of applications in automotive and aerospace industries[3].

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There are several fabrication techniques available in manufacturing the MMC materials. Fabrication methods can be divided into three types. These are solid phase processes, liquid phase process and semi-solid fabrication process[4]. Solid state processes are generally used to obtain the best mechanical properties in MMCs, particularly in discontinuous MMCs. According to the type of reinforcement, the fabrication techniques can vary considerably. These techniques include stir casting, liquid metal infiltration, squeeze casting, and spray code position. Compocasting involves the addition of particulate reinforcement into semisolid metal (SSM) by means of agitation.

There are several technical challenges currently exist with this method. The following technical challenges need considerable attention[5].

1. The difficulty of achieving a uniform distribution of particles in the melt,
2. Wettability between the particles and matrix,
3. Porosity in the cast metal matrix composites,
4. Chemical reactions between the reinforcement material and the matrix alloy.

Unfortunately, in normal practice the effect of the stirring action on the flow patterns cannot be observed as they take place in a nontransparent molten metal within a furnace. As such, and because of the fact that direct measurements of metal flow characteristics can be expensive, time consuming and dangerous. By taking this into consideration, it is possible to approximate the flow characteristics at such high temperatures using simulation software. Now a day's Computational Fluid Dynamics (CFD) is used for simulation due to low research cost, short research period and detailed description to fluid dynamic behavior, computational fluid dynamics have received rapid development in recent decades[6].

Stir casting for fabrication of metal matrix composites

In stir casting method of composite materials fabrication, a dispersed phase (ceramic particles) is mixed with a molten matrix metal by means of mechanical stirring[3] as shown in Fig. 1. The composite material is cast by conventional casting methods and if required, may also be processed by conventional metal forming technologies. The stir casting methodology is relatively simple and low cost[9]. This can usually be prepared by fairly conventional processing equipment and can be carried out on a continuous and semi continuous basis by the use of stirring mechanism[10].

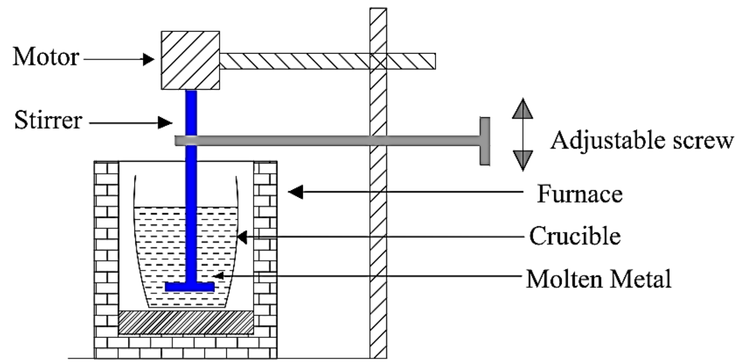

Fig. 1: Schematic diagram of stir casting process

Stir casting process parameters

There are several important process parameters, which effect the performance of the fabricated composite material. Stirring speed, stirring temperature, stirring time and pouring temperature, holding time are the prominent factors of the list[7]. The stirring speed effects the structure, increase in velocity upholds the refinement and low speed results in instability of the fluid mass. Stirring speed controls the flow pattern and promotes the wettability. Stirring speed promotes the uniform distribution of the particles and interface between matrix and reinforcement. The processing temperature effects the viscosity of the melt. The particle distribution is subjective to the viscosity change. So, the stirring speed is considered as a crucial factor in the fabrication of MMCs. The pouring temperature is another factor, which effects the metal flow the structure formation during solidification. This change of viscosity was calculated theoretically by using Arrhenius equation[8].

$$\eta = \eta_0 \exp\left(\frac{E}{RT}\right)$$

Where η_0 = viscosity of aluminum at the melting temperature. E = activation energy for viscous flow of aluminum, R = universal gas constant and T = processing temperature.

Challenges in stir casting process

Non- uniform distribution of reinforcement particles, wettability, porosity and chemical affinity between melt and reinforcement[7] are the important challenges faced in the stir casting practice. Non-uniform distribution of particles is due to the density differences between reinforcement particles and matrix alloy melt. Type and geometry of stirrer, melt temperature and nature of particles effects the distribution of the particles. It can be solved by proper design of the stirrer, control of stirring speed[12] and bottom pouring of the melt[13]. Proper dispersion of the particles in a matrix is also affected by pouring rate, pouring temperature and gating systems[3]. Wettability is the ability of liquid melt to spread on a solid surface. Some of the reasons, which contribute to low wettability are high ratio of surface area to average diameter of particles. Increase in tendency for agglomeration of particles, surface energy etc.

Porosity arises due to gas entrapment during mixing, hydrogen evolution and shrinkage. Porosity should be minimized as this kind of a composite defect can be detrimental to the corrosion resistance of the casting and it can control mechanical properties of the cast metal. To increase the mechanical properties and decrease the porosity the manufactures may go for secondary processing like extrusion, forging etc., Strategies to minimize porosity, like compocasting in vacuum, Extensive inert gas bubbling through the melt, casting under pressure, Compressing and extruding and rolling of materials after casting to close the pores may also be adopted. The chemical affinity is the tendency to react with each other. It contributes to the poor quality of cast AMC. Preheating of both matrix and reinforcement before mechanical stirring may solve this problem. The surface of both must be properly cleaned in order to minimize the reaction between the two elements.

Methods and techniques used to overcome the challenges in stir casting process

Hashim[14] evaluated a modified stir casting technique for use in the production of silicon carbide/Aluminum alloy MMCs. In this modified technique the investigators placed all substances in a graphite crucible and melted in the Nitrogen atmosphere. After the complete melting of matrix, a 2-step stirring action before pouring into a mold was carried out. The observations conform this modified technique promoted the wettability of SiC and the A359 matrix.

Uniform particle distribution

Singla, Dwivedi[15] made a modest attempt to develop aluminum based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. To achieve these objectives two step-mixing method of stir casting technique has been adopted and subsequent property analysis has been made. Aluminium (98.41% C.P) and SiC (320-grit) has been chosen as matrix and reinforcement material, respectively. The best results have been obtained at 25% weight fraction of SiC. According to Hashim et al.[16], accomplishing a uniform dissemination of reinforcement is one a challenge, which affects straightforwardly on the properties and nature of the composite material. To achieve a uniform distribution of particles, the accompanying variables should be comprehended i.e., density of particles, size, shape and volume fraction will impact the fortification settling rate.

Sahu and Padhi[17] studied the major difficulty is to get a uniform distribution of reinforcement especially in higher volume fractions. An innovative method of producing cast composites was tried in present study to overcome this problem we need homogeneity of matrix. The method involves multi axis rotation of liquid aluminum and silicon carbide particulates packed in a steel pipe inside a rotating drum. Up to 65% volume of the metal (aluminum) is incorporated by SIC by this technique. The particle distribution is a result of the combined influence of random mixing of particles and liquid aluminum and the solidification pattern obtained. Yu, Deng[18] reinforced aluminum with alumina by sintering an Al–10 wt.% ZnO sample at 1000^{o}C. During sintering, alumina particles are in situ formed by the displacement reaction between Al and ZnO. In comparison, the alumina particles are distributed more uniformly in the Al(Zn) solid solution matrix of the oil-quenched sample than that in the furnace-cooled sample.

Ourdjini et al.[19] contemplated the SiC/Al composite as a function of particle size, weight fraction and melt temperature amid isothermal holding and solidification tests. Authors observed pre-settling of nanoparticles at significantly slower rates, which are predicted by the theoretical models. It was also observed that the molten matrix temperature seems to have a slight effect on the settling behavior. Conducted tests on settling during mixing and solidification exposed that at low melt temperatures the volume fraction of particles does not affect the rate of settling. But as the melt temperature of mix increases the particles tend to settle when present in low volume fractions.

Effect of process parameters

Vykuntarao, Rao[7] appraised the influence of various reinforced particles and process parameters on the properties of aluminum based metal matrix composite through stir casting process. S Balasivanandha and V. S. K. Venkatagalapathy[20] conducted a study, in which aluminum metal matrix composites were fabricated by different processing temperatures with different holding time to understand the influence of process parameters on the distribution of particle in the matrix and the resultant mechanical properties. The distribution is examined by microstructure analysis, hardness distribution and density distribution. Prabu, Karunamoorthy[5] studied the microstructure of the produced composites by optical microscope and scanning electron microscope. Conformed that stirring speed and stirring time influenced the microstructure and the hardness of composite. Microstructure analysis revealed that at lower stirring speed with lower stirring time, the particle clustering was more. Increase in stirring speed and stirring time resulted in better distribution of particles.

Naher et al.[13] analyzed liquid and semi-solid casting techniques to produce Al-SiC composites. Authors designed, fabricated and validated a quick-quench compocaster for the high temperature handling. Trials were directed by changing stirring speed from 200 to 500 rpm and stirring time. It was seen in the microstructure that the uniform distribution of reinforcement in the aluminum matrix reliant on stirring speed, time, rate of cooling and volume fraction of reinforcement. Naher et al.[21] this literature work, which examines the effect of viscosity during Al–SiC MMC production. Processing periods (up to 65 min), stirring speeds (50-500 rpm), and re-inforcement sizes (13-100 lm) for two different viscosity levels (1 and 300 mPa s) were investigated. Computer simulations, room temperature analogue fluid simulations, and MMC castings were performed. The modelling approach chosen was found to be useful in predicting settling behavior in the semi-solid metal.

Simulational studies

Brucato, Ciofalo[22] performed a flow field-based three-dimensional simulation, which led to predictions that compared very well with the experimental data, though no adjustable parameters were used. Interestingly, those encouraging results were obtained by modelling only the `macromixing a phenomenon, while `micro mixing a phenomena were neglected, i.e. the system was always considered as being locally perfectly micro-mixed. Authors found good agreement between simulation predictions and experimental data retrospectively confirms the negligibility of micro mixing phenomena in the investigated. Yang, Boselli[23] simulated a series of finite-size particle distributions to investigate the effects of particle size, shape, orientation, and area fraction on the quantification of homogeneity in structural particulate metal matrix composites (MMCs). Authors found that, for nominally random distributions, the value of conventional center-to-center nearest-neighbor spacing parameters are influenced by particle morphology.

Naher et al.[6] optimized some of the parameters for uniform particle distribution for batch compocasting the present simulation studies were conducted. The simulation involves visualization experiments. SiC reinforcement particulate similar to that used in Aluminum MMCs was used in the simulation fluid mixtures. Authors found the dependence of the photography conditions (shutter speed, aperture control, lighting), particles dispersion and settling times and vortex height on stirrer geometry and speed. Pavan Kumar et al.[24] conducted simulation based studies to study the effect of speed of the stirrer on the particle distribution in matrix material. Copper was used as Semi Solid Metal (SSM) and Silicon-Carbide is used as nano reinforcement. The simulations were carried out by varying the stirrer speed 200 rpm and 400 rpm while keeping other parameters constant such as

Viscosity 4.4 mPa-s and Blade Angle 60 degrees. Authors observed uniform particle distribution at 400 rpm.

CONCLUSION

The emphasis has been given to MMCs fabricated by the stir casting technique. In order to design an effective process, which gives a homogeneous distribution of reinforcement the following factors need to be understood:

- Particle density, size, shape and volume fraction, which may influence the reinforcement settling rate.
- Mixing parameters must be such that to produce a uniform particle distribution in the radial and axial directions.
- The speed of rotation of the stirrer was possessing significant impact on fluid flow characteristics.
- During solidification settling time must be minimized.
- Process parameters plays a vital role on properties of Al based MMC. In case of Stir casting, process parameters like stirring rate, stirring temperature, pouring temperature etc., are to be maintained for achieving improved behavior and performance in the MMCs.

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