DESIGN AND DEVELOPMENT OF BOTTOM POURING CRUCIBLE FOR THE PRODUCTION OF AL6063 SIC REINFORCED METAL MATRIX COMPOSITES

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ABSTRACT

The MMCs will possess the desirable attributes of metal and ceramics if they are designed and developed correctly. The high strength, ductility and high temperature resistance are some of the major attributes of metals and on the other hand the ceramic reinforcements have high stiffness and hardness with highly brittle behavior. The properties of the ceramic reinforcement combined with the ductile metal matrix, produce a material which has mechanical properties in-between the metallic matrix and the ceramic reinforcement.The present study includes the development and fabrication of a stir casting set-up using melt-stir-squeeze-bottom pouring route to yield near net shape of metal matrix composites.

Keywords: Metal Matrix Composites, Bottom Pouring, Wettability

I INTRODUCTION

The main design consideration for the development of stir casting set-up is to obtain the objectives as follows [1]:

- Stirring mechanism design with variable speed
- Type of stirrer, blade angles and position of blade in the melt
- Temperature measurement and control
- Squeezing unit design and placement for bottom pouring
- Design of crucible for bottom pouring
- Inert mixing atmosphere to prevent oxidation of the melt
- Particle addition arrangement in the melt
- Pretreatment of reinforcement to enhance wettability
- Use of allowing elements to enhance wettability
- Self-alignment of all mating parts for better control on the process
- Design of mold for near net manufacturing
- Selection of material for stirrer, stirrer blade, crucible and squeezer
- Reduction of process time to reduce settlement of particles

The valuation of the developed setup for the production of MMC was judged by the characteristics of the product (MMC) produced. Trials and errors led to the overall development in the design and manufacturing of various components in the setup which enhanced the performance of the setup. The porosity and wettability [2-3] are the most challenging issues faced by the research fraternity. The optimal control of the process parameters and conditions such as, operating temperature, stirring speed, stirrer blade angles, pre-treatment of SiC particles, addition of alloying elements, reduction of time gap between phases of stirring and squeezing led to the successful stir casting procedure [4-5].

II DESIGN AND DEVELOPMENT OF BOTTOM POURING CRUCIBLE

A bottom pouring crucible was designed and developed for near-net-shape manufacturing of metal matrix composites. Numbers of brain storming sessions were organized with fellow researchers and supervisors to finalize the design of bottom pouring crucible. Numbers of experimental trials were performed for successful/unsuccessful manufacturing of MMCs by bottom pouring arrangement but they led to several manufacturing or material problems. The three partially/fully successful attempts have been discussed in the subsequent sections for the successful casting of Al-6063-SiC metal matrix composites using bottom pouring route.

ATTEMPT 1: A cylindrical valve of stainless steel as shown in **Figure 1 (a)** was designed and developed. The valve consist of cylindrical rod of diameter 70 mm, with a circular hole of 12 mm at the center of the surface of rod perpendicular to the central axis of rod. The cylindrical rod was placed on the sleeve and the sleeve was cut into two parts in proportion of 1/3. The smaller cut part of the sleeve was connected to the bottom (base) of the crucible and the larger part along with cylindrical rod was connected to the mold. The whole assembly was placed inside the furnace and the mold was placed below the furnace. The valve has only two positions (on and off) and is controlled with the help of a stainless steel lever as shown in **Figure 1(a).** The complete assembly, including valve assembly, and crucible were placed on the closed metallic mold of mild steel. When the valve was in off position, the upper portion of the sleeve makes contact with the solid surface of the cylindrical rod and a self-sealing is maintained due to gravity action provided the mating surfaces which are very smooth. When the valve is in on position, a passage of 12 mm was available for free flow of melt in the mold. A successful Al-6063 alloy casting was made with this attempt. But when the SiC reinforcement was added to the melt, chocking of the opening takes places because of semi-solid state of the melt.

ATTEMPT 2: The drawbacks of attempt 1 were improved in attempt 2, and a butterfly type valve of stainless steel was made and placed at the bottom of the crucible as shown in **Figure 1 (b).** Similar to the previous attempt, the valve consists of two positions and is controlled by a stainless steel lever as shown in **Figure 1(b)** inset. The valve has an elliptical hole of major and minor diameter of 30 and 15 mm, respectively for free flows of melt when the valve is in on position. This attempt yielded successful MMC casting. But after only three castings, the surface of the valve was eroded by the abrasive particle during rotation of melt which caused the leakage of the melt through the valve into the furnace as well as in the mold. This attempt was considered as successful but with a limited repeatability.

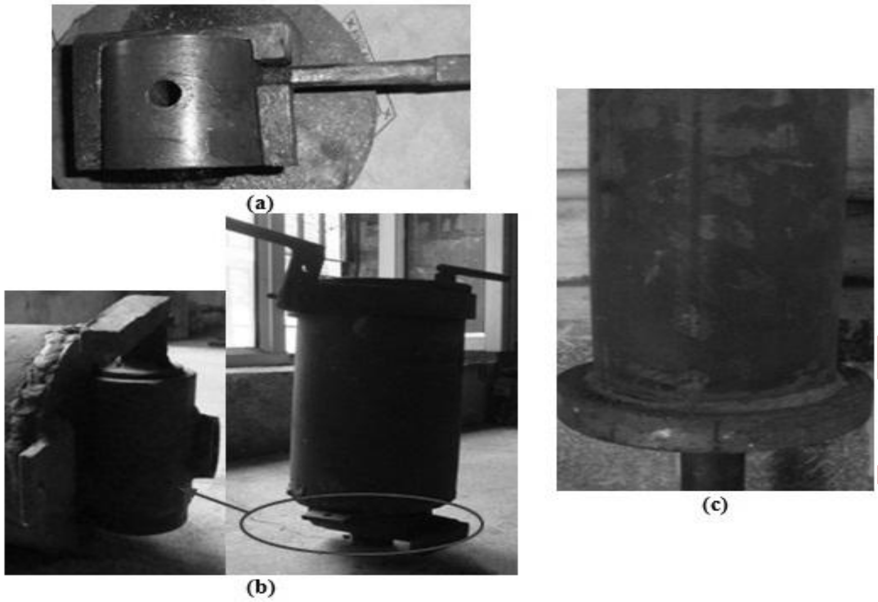

Figure 1 Bottom Pouring Techniques for the Production of MMCs

ATTEMPT 3 In the third attempt, elliptical shaped stainless steel plug was designed and placed inside the stainless steel crucible for bottom pouring as shown in **Figure 1 (c).** During pouring of melt into the mold, the plug was removed and free flow of melt occurred. This attempt was considered successful with high degree of repeatability.

III STIR CASTING OPERATION

The method for the production of metal matrix composites using stir casting route was finalized after several experimental trials. The detailed procedure to produce Al-6063-SiC MMCs is described as below:

A known quantity of aluminium matrix alloy (Al-6063) was charged into the specially designed and developed bottom pouring stainless steel crucible placed inside the primary furnace under inert atmosphere. The temperature inside the primary furnace was raised to 700^{0}C and maintained until the charge fully melted. After that, the temperature of the primary furnace was lowered down to 650^{0}C. At the same time, the squeezing unit was lowered down in the secondary furnace and squeezer was preheated to 600^{0}C to avoid thermal shock to the melt during pouring of melt into the mold with the help of squeezing action of the squeezer. The lumps of magnesium, 3% by weight of the melt were wrapped in the aluminium foils and were plunged into the melt before the addition of SiC particles [6]. After the addition of SiC particles, the stirring was continued for 6 minutes while maintaining the temperature of primary furnace at 650^{0}C. The temperature of the primary furnace was lowered down until the stirring turned out to be difficult (when the melt is in mushy zone).

The stirrer and the squeezer were withdrawn from primary and secondary furnace respectively and both the furnaces were moved on the rail track in order to bring the primary furnace along with bottom pouring crucible under the squeezing unit. At this movement, the valve of bottom pouring crucible was opened and the semisolid (mushy zone) melt was mechanically squeezed into the mold placed below the furnace using reciprocating action of the squeezer. After pouring action, both furnaces slide on the rails to come back to their previous positions. The mold with melt is immediately taken and water quenched. The quenching ensures better uniformity in the distribution of reinforcement particles throughout the casting. The MMC billet was removed from the mold by unscrewing its side plates.

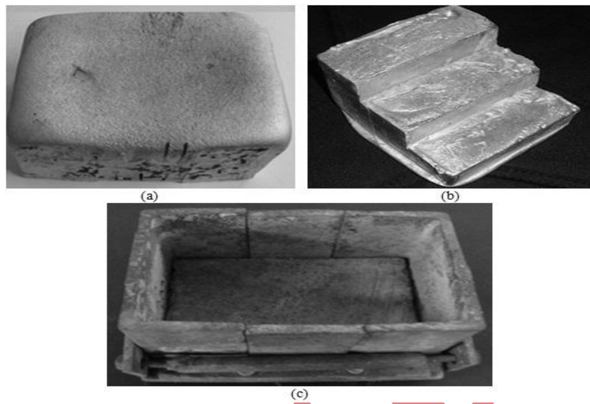

Figure 2 (a) Brick Casting (b) Step Casting (c) Mild Steel Split Mold

Al 6063 alloy SiC MMC of near-net-shape reinforced with 5μm, 10μm and 15μm SiC particles of weight fraction 5% and 10% were produced using melt-stir-squeeze-bottom pouring-quench method. A representative billet of near-net-shape manufacturing is shown in **Figure 2.** A smooth external appearance is evident from the side view of the resulting MMC.

IV MICROSTRUCTURAL CHARACTERIZATION

Microstructural characterization intended to find out the distribution of SiC particles in the aluminium matrix was carried out using optical microscopy. The resulting microstructure of the polished samples has been examined under optical microscope (Leitz MM6 large field metallographic microscope) at different magnifications.

The properties of MMCs depend comprehensively on the distribution of the reinforcing particles and the interfacial bonding between the particle and the matrix [7]. In practice, to attain uniform distribution of the reinforcing particles in the MMC is a challenging task. The optical micrographs, SEM and FE-SEM images of the Al 6063 alloy reinforced with SiC particles of 10 μm is shown in **Figure 3.** Micrographs are taken for the samples both in etched and un-etched condition in order to distinguish the matrix and reinforcement phase. Dark areas visible in the micrographs indicate the porosity present in the developed composites.

Figure 3shows the SEM image of Al6063/10%-SiC reinforced composites with SiC particles of size 10 μm. Reasonably uniform distribution is identified from the SEM image. Good interfacial bonding between the SiC particles and aluminium matrix was observed.

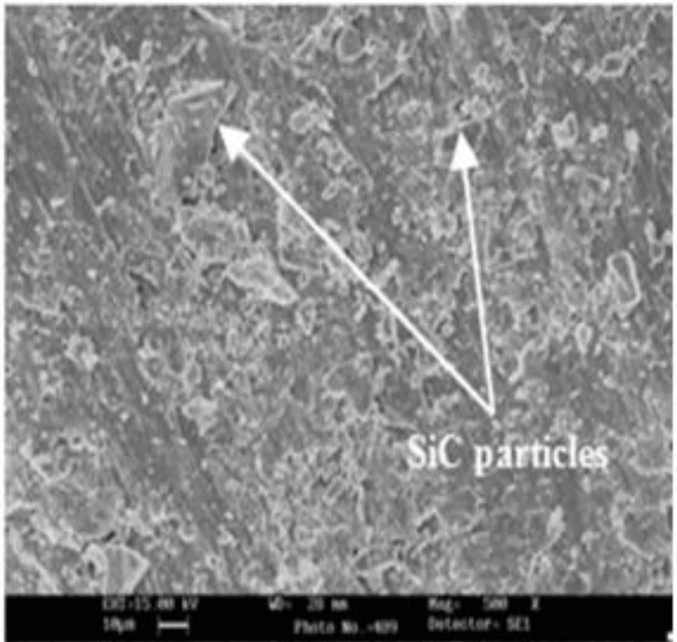

Figure 3 SEM Image of Al6063/10% SiC Composites Reinforced with SiC Particles of Size 10µm

IV HARDNESS MEASUREMENT OF THE DEVELOPED MMCS

Hardness is a material property and it is a defined as resistance offered by the material for indentation or permanent deformation. The hardness of the developed MMCs was measured with Brinell hardness tester (Make: Democratic Republic, Germany). The Brinell hardness testing is based upon a simple indentation test performed on polished specimen to find their hardness and it is extensively used for MMCs. It provides better average hardness value over a large area, which contains both matrix and reinforcing phase. In order to eliminate the agglomeration effect, the mean of four tests was taken for each specimen.

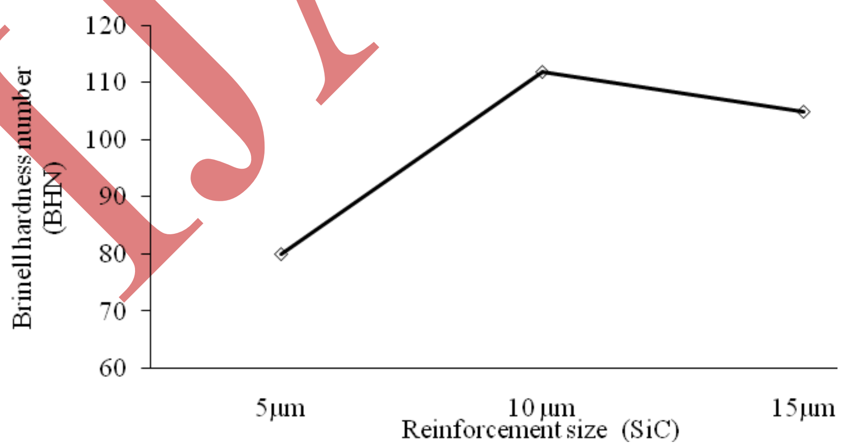

Figure 4 Variation of Hardness with the Variation in Reinforcement size

Figure 4 presents the variation of hardness for Al6063/10%SiC for 5µm, 10µm and 15 µm reinforcement sizes. From the figure it is observed that the 10 µm and 15 µm size reinforced composites exhibit higher hardness as compared to 5 µm size reinforced MMC. The percentage increase in hardness of 10 µm and 15 µm size reinforced MMC with respect to 5 µm reinforced MMC is 40% and 33% respectively. The increase in hardness with increase in reinforcement size indicates the better interfacial bonding with the matrix and reinforcement. However, a slight decrease in hardness for 15 µm reinforce MMCs is attributed to larger metal reinforcement interface area and increased gravitational effect on the SiC particles because of density difference. Porosity present in the developed MMCs also affects the hardness, because increase in hardness is attributed by less amount of porosity present in the composites [8].

V CONCLUSIONS

The following conclusions can be drawn for design and development of bottom pouring crucible for the production of metal matrix composites:-

1. The metal matrix composites were successfully developed using stir-squeeze-bottom pouring casting route.
2. A uniform distribution of SiC particles is evident from the SEM images
3. Wettability of the SiC particles with the aluminium matrix is a critical issue for proper interfacial bounding and it can be improved with the addition of magnesium particles during the stirring action.
4. The SiC particulate size has significant effect on hardness of the developed composites.

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