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Plunger Technique: A New Approach to Stir Casting AMMC Preparation

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Abstract

Metal matrix composites (MMCs) are materials that are highly attractive for large range of hi-tech engineering applications. Keeping this in mind, materials for the present investigation were prepared by a drastically modified stir-casting technique where the usual solid shaft stirrer was replaced by a hollow/tubular spindle-stirring mechanism through which silicon carbide particulates in small cylindrical capsule were introduced to the aluminum-magnesium alloy matrix with the help of a plunger rod to obtain uniform distribution and low porosity in the product that are extremely important to this class of material. This plunger technique is a clear alternative to the established vortex route which is known to be the low-cost method amongst the lot. Interestingly, aluminum-magnesium alloy matrix material in this modified technique was also prepared similarly by directly introducing magnesium turning contained in mild-steel capsule plunger rod into Al-melt, which gives high Mg recovery (95%) in the alloy. It was found that modified stir-casting technique is simple to operate, smooth, trouble free, highly efficient and above all an inexpensive process in comparison to other methods.

Keywords: *AMMC-Aluminum metal matrix composites, stir casting, hollow shaft, composite; plunger rod*

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INTRODUCTION

Particle reinforced metal matrix composites (MMCs) are now recognized as important structural materials. Therefore, in the present study, a new approach to aluminum metal matrix composites (AMMCs) production has been proposed which in principle has been adopted earlier in obtaining very high recovery of Mg in making Al-Mg alloy [1, 2]. The reinforcement of light-weight aluminum alloys with short fibers, platelets and particles of ceramics such as silicon carbide or alumina results in composite of high specific strength and stiffness suitable for engineering applications like aerospace and automotive parts [3–11]. There are several routes by which the reinforcement may be introduced in the matrix. The microstructure and property of resulting composite material depends on production method, type and amount of reinforcing particulates. In order to get desirable properties in composites, factors such as nature and choice of the metal matrix, the kind of dispersed particulates making the composite and the technique involved in the composite production, are important and must be standardized [4, 5, 15–17].

Most convenient metal matrices used are of light-weight metals like aluminum, magnesium and their alloys. Generally, ceramic materials with moderate to high strength and high modulus are used as reinforcement particles. Predominantly used particulate reinforcements are SiC, Al_2O_3, fly ash, TiB_2, B_4C_3, etc. [3, 4, 11]. Though variety of other materials have also been tried during the past years, SiC appears to be unique because of cost effectiveness and easy availability. The processing technique for preparation of MMC includes solid-state processing and liquid-metal processing. Of the two, liquid-metal processing involves various types of solid particulate incorporation methods such as pressure infiltration, centrifugal casting, ultrasonic infiltration, spray casting and stir casting processes [3–5]. Good wetting between solid ceramic particles and liquid matrix metal is essential to get uniform dispersion and satisfactory properties in MMC. Alloying elements such as magnesium, lithium, calcium or zirconium are added for inducing wettability [3, 12–14]. Magnesium is predominantly used as wetting agent for preparation of AMMC [3–6].

EXPERIMENTAL PROCEDURE

Equipment

The aim of this work is to present a novel modification in the existing stir-casting method of AMMC production [1–2]. A common laboratory model stir-casting apparatus was improved upon to suit the present work; where, the usual impeller solid shaft was substituted by a hollow mild-steel tube as the spindle. Figure 1 shows the basic arrangements of a laboratory scale stir-casting apparatus with assembly modifications which has been used to prepare the AMMC.

In Figure 1, a cast-iron cylindrical container 1 (coated with alumina cement) is used to hold the Al melt 2. The assembly consists of a hollow spindle 3 with impeller-type stirrer blades 4 attached at the bottom and a motor and V-belt arrangement 5 for rotating the spindle to affect agitation (stirring) in the aluminum melt so that homogeneous dispersion of ceramic (SiC) particulates can take place [8, 12, 16]. The plunger rod 6 attached with perforated mild-steel capsule 8 is used to hold SiC particulates. Mild-steel capsule containing ceramic particulate is pushed inside melt directly by a plunger rod 6. The plunger, Figure 2, containing ceramic (SiC) particles wrapped with Al foil is introduced from top to the bottom of the melt through the rotating hollow spindle 3. In less than 30 s, the foil melts in the super-heated Al-melt when the SiC particles are set free quickly and dispersed almost uniformly in the melt matrix due to vigorous stirring effect of the melt. Similar new approach to make Al- Mg alloy was adopted [2] utilizing plunger rod technique containing Mg turnings wrapped with Al foil, as shown in Figure 2.

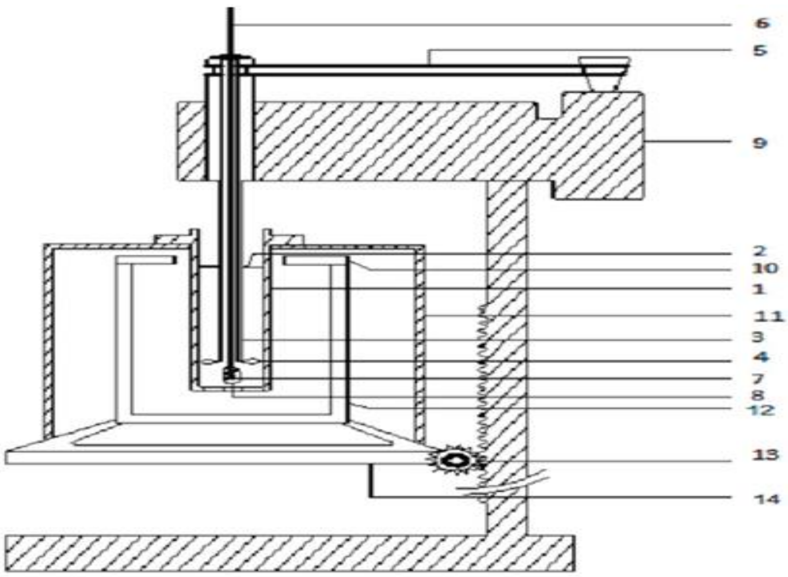

Fig. 1: Schematic Diagram of Modified Stir-Casting Apparatus for Preparation of Al-Mg Alloy and MMC. Crucible, (2) Melt Level, (3) Hollow Spindle, (4) Impeller Blade, (5)V-belt Drive, (6)Plunger Rod, (7) Capsule, (8) Mg turnings and SiC Particle, (9) a.c. Motor and Gear Assembly, (10) Split Cover, (11) Crucible Holder, (12) Electric Furnace, (13) Rack and Pinion Arrangement, (14) Base Plate.

Fig. 2: *Photograph of Perforated Mild Steel Capsule Welded to Plunger Rod (below), Mg or SiC Particles inside the Capsule Shown Wrapped with Al Foil (top).*

Materials

Both Al-Mg alloy and Al-Mg-SiC MMC were prepared from commercially pure Al supplied by NALCO India, in the form of 20 kg ingots. The chemical composition of aluminum is given in Table 1.

Table 1: *Chemical Composition of Aluminum Ingot Used.*

Al	Si	Fe	V	Mn	Cu
99.76	0.08	0.15	0.006	0.003	0.001

Composition of magnesium metal turning used for preparation of Al-Mg alloy is given in Table 2.

Table 2: *Chemical Composition of Magnesium Turning Used for Alloying.*

Mg	Al	Cu	Fe	Pb	Mn	Ni	Si	Zn
99.68	0.05	0.005	0.05	0.005	0.1	0.005	0.1	0.005

Silicon carbide particles of 600 mesh size were used for AMMC preparation. The chemical composition of silicon carbide is given in Table 3.

Table 3: *Chemical Composition of Silicon Carbide Particles Used for AMMC Preparation.*

SiC	SiO_2	Si	Fe	Al	C
98.8	0.41	0.3	0.09	O.1	0.3

Procedure

To start with, 700 g Al block was cut away from 20 kg Al-ingot and was melted in a cast-iron cylindrical container (coated with alumina cement) in a resistance furnace at 800 °C (well above melting temp 660 °C of Al). This was the starting matrix liquid-Al. Then the impeller assembly was lowered into the crucible until the clearance between the bottom of the submerged impeller and the bottom of crucible was 60 mm apart (this space helps to accommodate the capsule charged with pieces of Mg-chips or silicon carbide particulates as the case may be) [2, 8]. A thick split semi-circular f/c cover was then pushed to place to reduce heat loss from the hot metal. The mixer was turned on and set to the predetermined speed of 500 rpm [14–17]. Weighed Mg metal turnings in capsules were dropped one after the other (each one containing 7 g Mg which took about 10–15 s to completely get absorbed in the Al-melt) to make the alloy matrix as per requirement. In this method, there was no scope of atmospheric air (oxygen) coming in contact with hot Mg and thereby there was no loss of Mg as oxide or any flashes observed during the alloy formation [2].

After the addition of required wt% Mg, the alloy was stirred for 5 min for proper mixing and homogenization when previously prepared silicon carbide particulate capsule charges were introduced one after the other (each of the bullet containing about 12 g SiC took less than 40 s to be completely dispersed into the melt-matrix) until the required number of capsules were charged.
This operation was complete when 70 g of SiC (10 wt%) was introduced. Finally, allowing for about 10 min stirring, for maximum possible homogeneous dispersion of SiC particles, the motor was switched off and stirrer assembly was slowly withdrawn out of the AMMC melt. Then the crucible was lifted manually from the furnace and the melt was poured into a previously readied mold made of fire bricks joined by fire clay. The mold size was (18 × 8 × 5) cm^3. Samples for chemical analysis and hardness measurements were cut from this ingot of MMC (Al-3%, Mg-10%, SiC).

For comparison purpose (reference), Al-Mg an alloy-melt casting was made. In this case, only 700 g of Al block was melted in the crucible in the f/c and 21 g of Mg was added in similar method as explained earlier when the ensuing melt was taken out and poured into the mold for desired castings.

RESULTS AND DISCUSSION

Small samples of (20 × 10 × 5) mm size were cut from reference Al-Mg casting and Al-Mg-SiC MMC castings from three positions for further analysis of mechanical property and metallographic studies [7]. In handling the above casting, a naked eye observation revealed that there were no apparent visible blow holes or any macro-porosity present inside the cut samples.

To begin with, mechanical strength property indicator hardness parameter determination was made which is given in Table 4. The hardness of the samples was measured using Vickers micro-hardness testing machine with 10 kgf load applied for 10 s. Hardness data are tabulated in Table 4.

Table 4: *Hardness Parameter Determination.*

Casting position	**Hardness (VHN)**	
	Al-3 wt% Mg alloy	**Al-3 wt% Mg-10 wt% SiC MMC**
Top (5 mm from top)	43.5	56.8
Middle	43.5	72.1
Bottom (10mm from bottom)	43.5	59.2

The microstructures were observed with OLYMPUS BX51 optical microscope. From the micrographs as shown in Figures 3, 4, 5 and 6, it is evident that the reference Al-Mg cast ingot as well as Al-Mg SiC MMC ingot contains some micro-porosity. The process seems to have yielded reasonably sound castings.

From the given hardness values, a clear correlation with the observed micro-structures is evident. Figures 4 and 6 contain minimum of SiC particles whereas Figure 5 contains the maximum density of SiC particles with a greater uniform distribution resulting in higher (~25%) hardness.

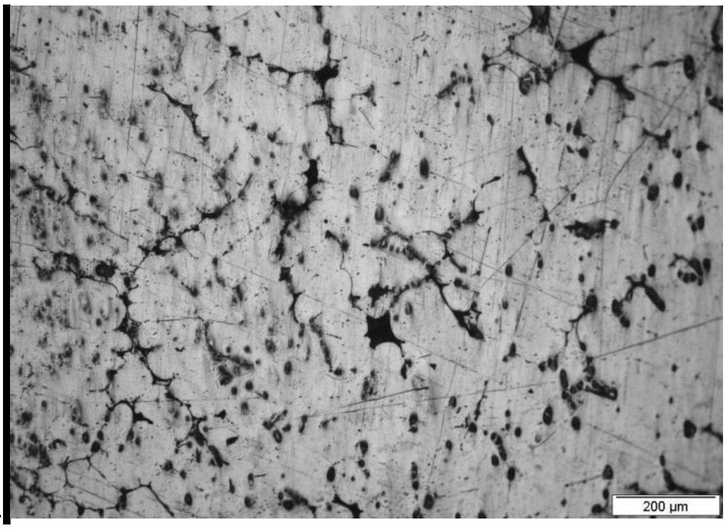

Fig. 3: *Microstructure of Al-3 wt% Mg Alloy Showing Some Micro-porosity and Few Scratches on the Sample.*

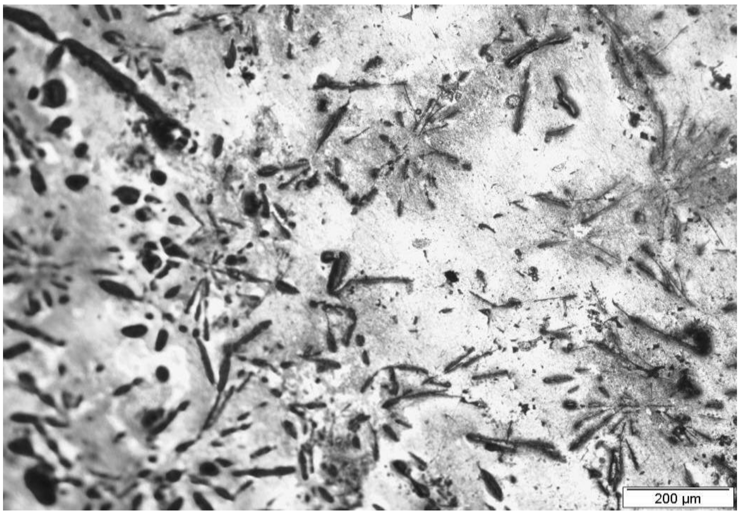

Fig. 4: *Microstructure of Al-3 wt% Mg-10 wt% SiC MMC about 5 mm from the Top of the Casting. Long Dark Spikes-like Structures are of SiC Particulates.*

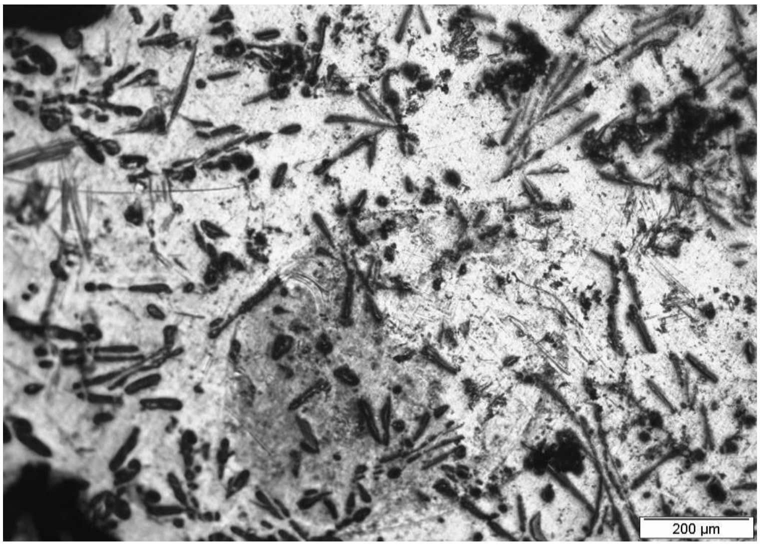

Fig. 5: *Microstructure of Al-3 wt% Mg-10 wt% SiC MMC from the Middle of the Casting Showing Much More Uniformly Dispersed SiC Particles and the Amount of SiC Observed Higher Too.*

***Fig. 6**: Microstructure of Al-3 wt% Mg-10 wt% SiC MMC from the Bottom 10 mm of the Casting. Micrograph Shows Relatively Larger Size SiC Particles due to Gravity Sedimentation during Solidification of the Ingot.*

Further aspects of mechanical strength evaluations are underway, which will be reported in future.

CONCLUSIONS

A major novel modification in the age-old stir-casting process since its invention has been successfully incorporated and tested to satisfaction.

The present technique adopted in this work to prepare Al-Mg MMC material appears to have solved most of the difficulties encountered in alloy making of high-vapor-pressure elements as well as in addition of non-dissolving ceramic particulates into the melt matrix. The hassle-free method with absolutely no loss of volatile metal additions and the extremely effective AMMC preparation technique is bound to prove to be uniquely cost saving approach in this class of material manufacturing. From this elaborate work experience and the ease with which the equipments functioned, it is expected that this process will face no challenging problem in successful upscale production of various kinds of AMMC materials to industrial requirements in the near future.

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