CHAPTER-4

DESIGN AND FABRICATION OF EXPERIMENTAL SET-UP

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This chapter attempts to introduce basic synthesis techniques related to magnesium alloy and its composites. The design and fabrication of two different stir casting facilities for experiments have been discussed extensively. The different way of incorporating reinforcement in metal matrix composites is also discussed.

4.1. Introduction

There are various synthesis techniques have been attempted to synthesized magnesium alloy and its composites. The selection of the right processing technique is a challenging task because it profoundly influences the microstructure of the product. The materials with the same constituent are different yield properties, depending on methods of processing. It is broadly classified into the following two categories [2], [18], [40], [86].

a) Liquid phase methods

b) Solid Phase method

These processing methods have their advantages and limitations. The liquid phase method is preferred over the solid phase in general. The stir casting is a most suitable and versatile technique for fabrication of particulate reinforced metal matrix composites. Stir casting method has been broadly adopted for the fabrication of MMCs due to its flexibility, simplicity, and applicability of the technique to huge scale fabrication of industrial components [177]. Stir-casting is also known as “SemiSolid Metal Casting” or “Rheocasting” or “Compocasting” and is used with the nonferrous metals [178]. The reinforcement is added in molten metal, and it is stirred appropriately for uniform distribution of particles. Most of the methods used for the manufacturing of metal matrix composites (MMCs) are costly and required sets of complicated operations. The liquid phase routes are more similar to the conventional casting process, and it is economical for the production of metal matrix composites. Hence liquid phase route (Stir casting) is chosen in this research work. Stir casting setup with motor and stirrer arrangement along with the crucible furnace is shown in Figure 4.1.

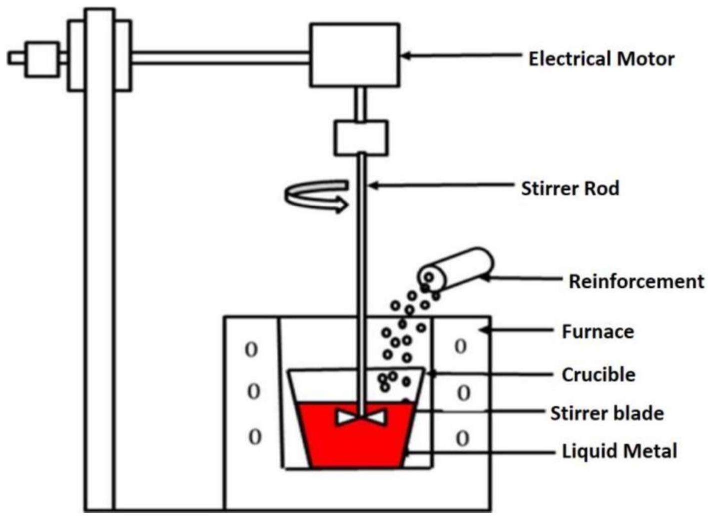

Figure 4. 1: General schematic view of stir casting set-up [179]

The casting of Al and Cu based composites can be performed well in any stir casting furnace since the protective oxide layer of metal oxide protects the molten metal from further oxidation. However, in the case of magnesium alloy based metal matrix composites, a particular type of furnace is required because magnesium alloy has a very high affinity toward oxygen present in the environment.

4.2. Fabrication of experimental set-up

Two different kinds of experimental set-ups have been developed for the casting of magnesium alloy and its composites. The magnesium casting can be performed with flux and without flux protection. Initially, flux has been used as protecting medium in magnesium casting in the first experimental set-up (general stir casting set-up) design and developed at the Production Engineering lab of the IIT BHU, Varanasi. The experimental set-up developed at IIT BHU was not able to protect molten magnesium from oxidation. Therefore, a second modified version of the experimental set-up was conceptualized for the casting of magnesium alloy and its composites. In the new set-up, the controlled atmosphere with a vacuum is proposed and developed at KNIT Sultanpur with technical support of VB ceramics and financial aid of WB/ TEQIP-II.

4.2.1. General Stir casting

A general stir casting set-up is developed to cater to the problem of magnesium casting issue. The schematic of the developed stir casting set-up has been presented in Figure 4.2. The parts and dimensions of the set-up are mentioned in Table 4.1. The experimental set-up furnace is designed as a close type furnace to avoid excess interaction of oxygen with molten magnesium alloy. The first experimental set-up is fabricated as per the schematic diagram presented in Figure 4.2 and parts and dimensions of materials presented in Table 4.1.

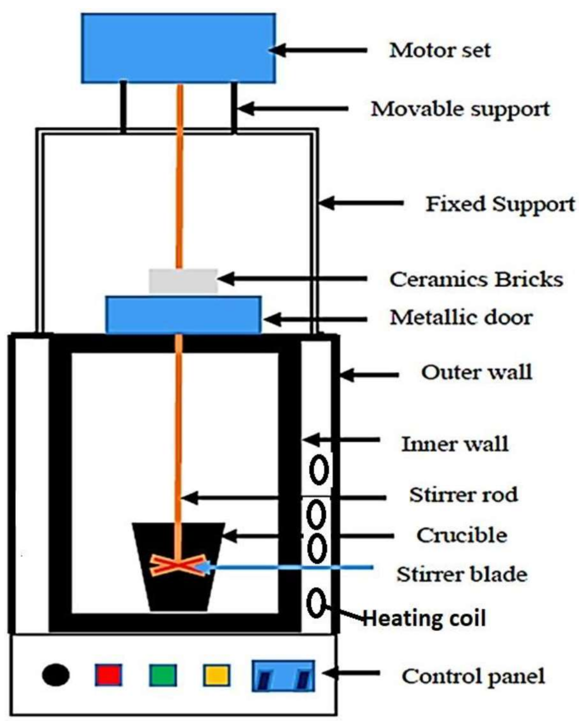

Figure 4. 2: Schematic of the general stir casting set-up

Table 4. 1: Different pats/ dimension and its specifications

S. N.	Parts/Dimension	Specification/Materials
1.	Outer dimension of the furnace(HxWXL)	70 cm x 50 cm x 50cm
2.	Outer dimension of the furnace(HxWXL)	35 cm x 25 cm x 25cm
3.	Furnace outer material with stand and stirrer motor casing	Mild steel
4.	Insulation	Ceramic wool insulation
5.	Power Supply	220 Volts and 5 AMP
6.	Heating Element	Kanthal
7.	Temperature Controller	Digital, LED display
8.	Temperature range	1000º C
9.	Crucible	Ceramic
10.	Stirrer motor	0.25 HP with a maximum speed of 80 RPM
11.	Stirrer rod	Zirconia ceramics coated , Stainless steel
12.	Stirrer Motor support	Mild steel

The first experimental set-up is developed with the materials locally available in Varanasi. The snaps of the set-up are shown in Figure 4.3.

Figure 4. 3: Photograph of first experimental stir casting set-up

Initially, the fixed type of stirrer motor (Figure 4.4) has been used for mixing the particle in molten metal. For incorporating vertical agitation during stirring, the stirrer design has been modified, and different types of stirrer motor (Figure 4.5) are used to provide vertical motion in a controlled manner so that the desired movement could be made during stirring.

Figure 4. 4: Initial stirrer motor

Figure 4. 5: Modified Stirrer motor

4.2.2. Melting and solidification of unprotected magnesium alloy

Since magnesium and its alloy form a loose permeable oxide on the molten metal, which allows oxygen from the air to pass through and support its burning. The burning of magnesium alloy during melting indicated the improper protection of molten metal. Due to the very high oxidative nature of magnesium alloy, around 30 % of magnesium alloy converted into magnesium oxide. The melted and solidified magnesium alloy developed through the first experimental set-up is presented in Figure 4.6. After this unsuccessful casting which is mentioned here, the authors have identified main issues related to magnesium alloy casting (i.e., melt protection).

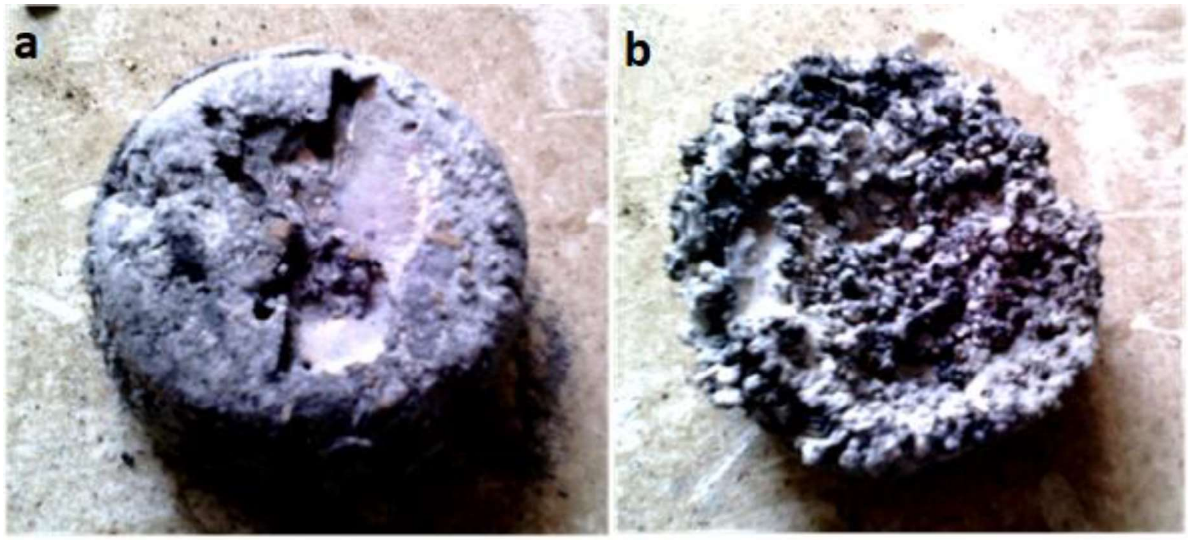

Figure 4. 6: First magnesium alloy casting a) Backside b) Front side

To get the possible casing solution for magnesium alloy, the author started a discussion with several experts of magnesium alloy around the world because only limited work has been reported by other researchers on the issue of melt protection. After experts' suggestion, the following possible solutions are received for development of magnesium alloy and its composites.

i) Using proper flux.

ii) Using reactive elements

iii) Using SF_6 as melt protection.

iv) Vacuum melting furnace.

v) Vacuum-assisted inert atmosphere furnace.

It has been observed that use of flux might decrease ductility of the alloy and composites, a method of reactive elements may develop some unwanted intermetallic compounds, and since the use of SF_6 has already banned because of adverse effect on the environments. Therefore, vacuum melting furnace and vacuum assisted inert atmosphere furnace seems to an appropriate method for magnesium based melting and casting. However, vacuum-assisted inert atmosphere furnace is more suitable because there is no chance of sucking reinforcement and molten magnesium alloy (due to the high vapor pressure) in the vacuum pump during melting. The above observation leads to the design and development of a vacuum assisted inert atmosphere stir casting set-up.

4.2.3. Vacuum-assisted inert atmosphere stir casting furnace

The schematic drawing of the vacuum-assisted inert atmosphere stir casting is presented in Figure 4.7. The design is motivated by disintegrated melt deposition (DMD) technique developed by Manoj Gupta et al. [180] at Nation University Singapore, but in the current set-up, gravity die casting is used instead of disintegrated melt deposits.

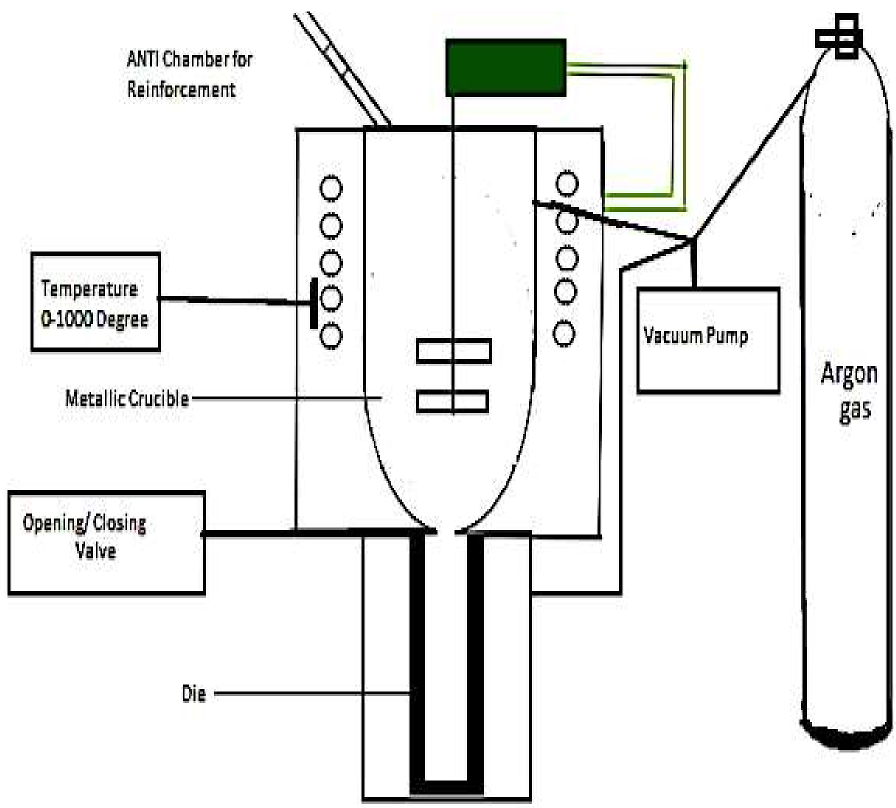

Figure 4. 7: Schematic of the vacuum-assisted inert atmosphere experimental set-up

The essential parts of the vacuum-assisted inert atmosphere experimental set-up are as mentioned below:

1) Heating furnace
2) Melting crucible

3) Stirrer and motor assembly

4) A pneumatic system with an air compressor

5) Vacuum pump

6) Argon gas cylinder

7) Die chamber

8) Anti-chamber

9) Temperature controller

Figure 4.8 shows the current stir casting furnace along with different other parts of the experimental set-up. The exact dimensions of the furnace along with other different parts are proprietary and reserved to disclose here. The furnace is designed to work up to a maximum temperature of 1200℃ by using four number of Kanthal resistance heating elements. The main structure is made with high-quality mild steel angles and sheets.

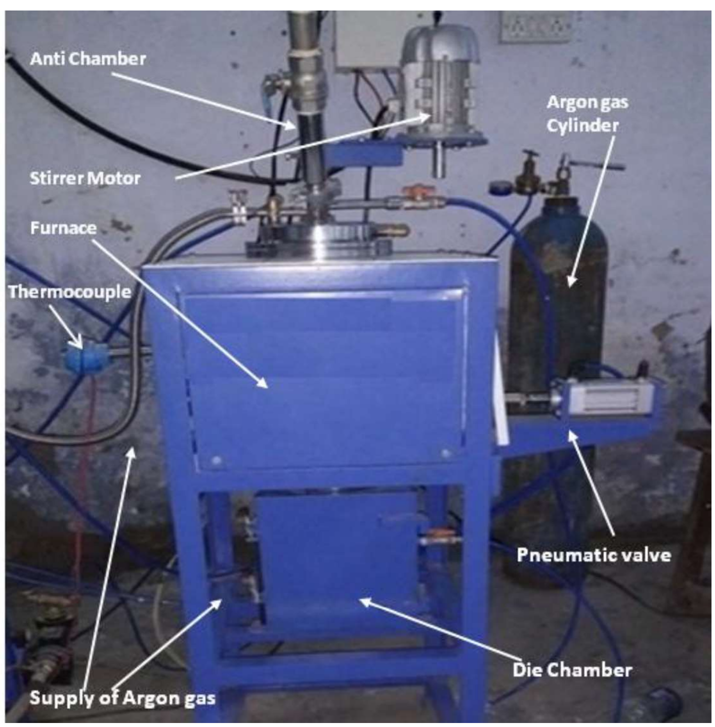

Figure 4. 8: Furnace with other attachments

Figure 4. 9: Metallic crucible with flange

The set-up has metallic crucible with flange (Figure 4.9) made of Inconel 718 (Ni: 50-55, Cr: 17-21 and balance Fe) to achieve a longer life. The metallic crucible may be hanged from the top with flanged to provide space below it for bottom pouring. The inner wall of the crucible is coated with boron nitride paste to prevent reaction between the molten metal and Inconel crucible. The specialized coating also helps to drain the molten metal entirely out. A DC motor with 0.25 HP and 1400 RPM speed is used to stir the molten metal as shown in Figure 4.10. The stirrer motor assembly can be pushed either left or right before its engagement to stirrer rod. It will facilitate manual plugging to support vertical agitation of molten metal and reinforcement for uniform mixing. It will also facilitate the complete removal and proper cleaning of Inconel crucible. Figure 4.10 shows the two different position of the stirrer motor. The speed of the stirrer may be varied with the knob available in the front control panel. Variable frequency drive is used and kept inside the control panel for changing the speed. The average operating speed is 250 rpm to 300 rpm. Figure 4.11 shows a special pneumatic arrangement is used for closing/opening the crucible orifice to fill the mold/die by molten metal discharge.

Figure 4. 10: Different position of stirrer motor assembly

Initially, the valve is in the closed position when molten metal is ready to release after proper mixing with reinforcements; then the pneumatic valve is opened with the help of compressed air. The required compressor and air tank are available inside the control panel.

Figure 4. 11: Pneumatic high-pressure cylinder arrangement for opening and closing of the pouring valve

Mold/die is made of cast iron in two parts, which is joined through nut bolt is shown in Figure 5.12. The diameter and length of the die cavity are 39 mm and 200 mm respectively. The mold/die is kept in die holder which is available at the furnace. The vacuum and the inert atmosphere are also created in the die chamber. A standard pressure gauge is used to measure the pressure inside the crucible and die/mold. The variation of pressure inside the crucible and die chamber at different time instances is shown in Figure 4.13. Initially, the pressure inside the crucible and die holder is similar to atmospheric pressure.

Figure 4. 12: a) Die holder with die b) two-part die of cast iron

At the time of vacuum, the pressure gauge indicator falls negative side up to 700 mm Hg, and at time of melting, the pressure was maintained more than atmospheric pressure by purging of inert gas. The pressure inside the crucible and die area remains higher than atmospheric pressure during melting and pouring.

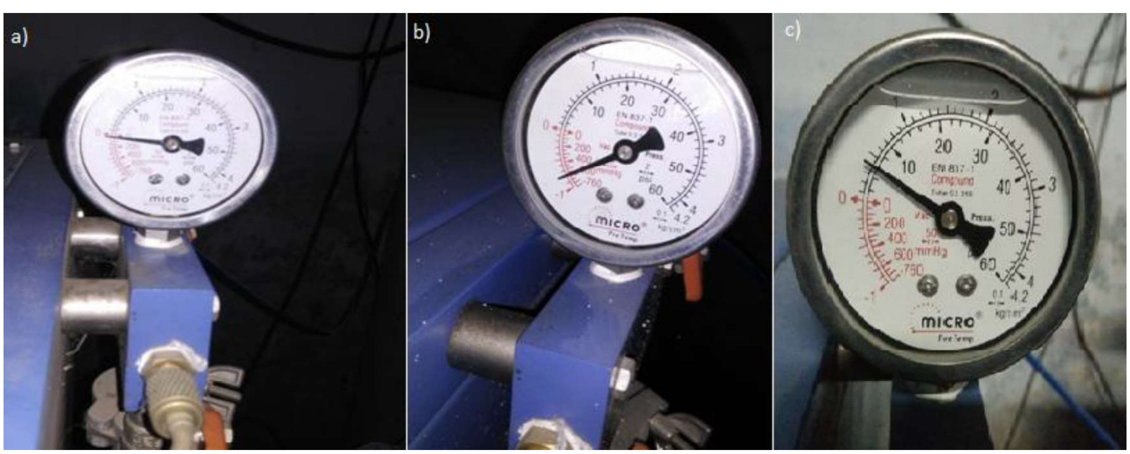

Figure 4. 13: Pressure variation at different time frame a) normal condition b) vacuum reaction c) melting and pouring

4.3. Mode of the addition of reinforcement

Several methods are used for incorporating particulates reinforcement in the molten metal. Some of which are discussed below:

1. The secondary phase materials like nano and microparticle reinforcement are used to feed through anti-chamber attached at the top of the furnace. The particle of known weight is taken in this chamber and particles are fed through the valve, after the successful melting of the alloy.
2. The reinforced particles of known weight are packed in aluminum foil in the form of a capsule, which is directly fed into the furnace through the opening provided for anti-chamber.
3. An array of the small drills is created in the block of base alloy, and then it is fed with a known weight of reinforcement.

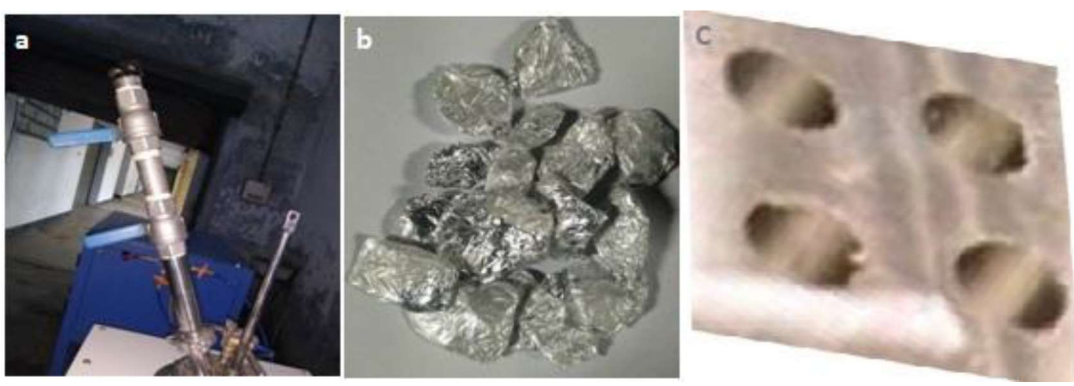

Figure 4. 14: Different modes of reinforcement addition in molten metal a) through anti-chamber b) aluminum foil capsule c) array of the hole

Rigorous manual plunging is performed after adding reinforcement into the molten metal for uniform distributing of it in the molten alloy. Further, stirrer rod is fixed in stirrer motor for uniform mixing of reinforcement into the molten alloy. The speed and time of stirring are depended on the size and amount of reinforcement added to the molten alloy. Figure 4.14 shows the different modes of reinforcement addition in the molten metal.

4.3. Cast product

Several successful castings are performed by the experimental set-up of vacuum-assisted inert atmosphere stir process. The effect of a different mode of addition of reinforcement, stirrer speed, stirrer time and pressure inside the furnace is observed, and some data for the acceptable variable are shown in Table 4.2. The addition of reinforcement through an array of the drill in the base materials is a more appropriate mode for uniform distribution of reinforced particles. The photograph of the successful casted product is shown in Figure 4.15.

Table 4. 2: Effect of a different mode of reinforcement addition with the decision

Sr. No	**Some important Casting variable**	**Observation**	**Decision on processing**
1.	Reinforcement addition through Anti –chamber	Some amount of reinforcement got stuck in anti-chamber and less amount of reinforcement	Not acceptable
2.	Reinforcement addition through capsule form (aluminum foil used for making capsule)	Large agglomeration of the reinforced particle inside the casting due to the interaction of capsule with the high temperature inside the crucible	Not acceptable
3.	Low inert pressure during melting and castings	The high porous structure is formed in castes product	Not acceptable
4.	Addition of reinforcement through an array of drill in magnesium alloy	Almost uniform distribution of reinforcement and sound casting is observed	Acceptable

Figure 4.15: Photograph of Cast product

The product obtained through casting is defect free, and approximately uniform distribution of reinforcement has been seen in the prepared sample. The argon gas pressure, manual plunging and motorized stirring are the important parameters for the current casting process. The cast product is sectioned into small pieces for further testing and investigations. The detail of further investigation has been discussed in chapter 5 and chapter 6.