© 2017 IJSRST | Volume 3 | Issue 8 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Use of Rheocasting Mould in SSM Processing

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ABSTRACT

The principal constituent of the present research work is a description of the experimental system and methods for rheocasting experiments by means of the stirrer for molten A356 aluminium alloy and proper dashboard to accomplish the same. It includes descriptions of the key physical process parameters involved, rheocasting procedures, methods and measurements along with the safety precautions followed during design/fabrication or performing the entire experiments. The experiments also include consideration of the right aluminium alloy for the semisolid material (SSM) processing (i.e. forming or casting), sprouting an experimental technique and handling of temperature data observed from the stated rheocasting experiments.

Keywords: Rheocasting, Mould, Semisolid, Processing.

I. INTRODUCTION

Amidst all the solidification modelling procedures, the rheocasting practice using electromagnetic stirring is incomparable one on account of the near net shape together with the productivity. It practices a variable viscosity model of slurry in the transport process to symbolise the fluid as semisolid material (SSM) slurry. In the solidification modelling process used in the present research work, a cylindrical mould is used for production of a rheocast billet of 100 mm diameter and 500 mm length. Figure 1 shows a schematic diagram of the mould. The mould consists of two parts. The upper part of the mould is surrounded by a linear electromagnetic stirrer of 350 mm length, which is the zone of active stirring. The lower part of the mould (150 mm length) is used to cool the liquid metal. In the upper portion of the mould, an electrically non-conducting clay graphite crucible and vacuum chamber surrounding the mould are constructed, as shown in figure 1, with the aim of minimizing the radial heat transfer. The top surface of the mould is open to atmosphere whereas the bottom surface is closed by an adiabatic ceramic plate. Based on the physical problem already described, a 2D axisymmetric geometry is taken into account for numerical simulation. In the present research, liquid A356 Al alloy having 7.32 % Si is selected for solidification processing using electromagnetic stirring, which is normally used for casting applications. The initial temperature of the alloy is 625°C. A water or air cooled stainless steel mould is kept at the bottom of the refractory tube for extracting heat (q) from the liquid A356 Al alloy.

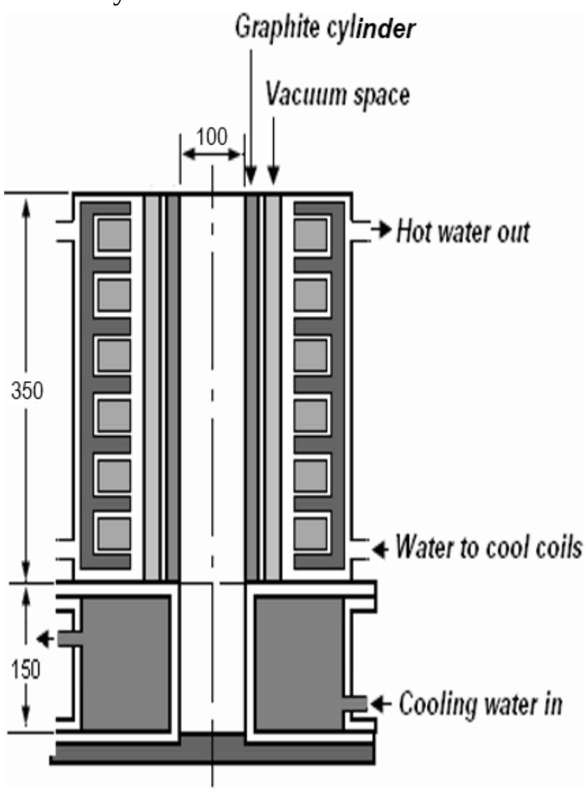


Figure 1. Schematic of rheocasting arrangement

II. KEY PHYSICAL PROCESS PARAMETERS

The establishment of a physical model pertaining to the already specified process is based on the rheological properties of the semisolid material (SSM) slurry which depends on solid fraction, stirring intensity and cooling rate during solidification processing. Hence, the key physical process parameters in the present solidification process are viscosity of the slurry, stirring intensity and cooling rate, as particularized beneath in details.

A. Viscosity of Semisolid Slurry

Semisolid material (SSM) slurry viscosity reveals a unique behaviour compared to that of s pure liquid, which intensifies the flow complication during processing. The effective viscosity of the slurry depends on several process parameters. In the present research work, the slurry viscosity is represented as a variable viscosity function which reflects the process parameters for better understanding of the semisolid material (SSM) processes.

B. Stirring Intensity

Stirring intensity is a key variable affecting the ultimate properties of the rheocast billets. The microstructures obtained in the billets may be rosetted or globular, depending on the stirring intensity. In electromagnetic stirring, a minimum stirring intensity is required to activate the shearing of dendrites at the solid/liquid interface which depends on the magnitude of the Lorentz force. The Lorentz force depends mainly on the current input to the coils. Accordingly, the selection of current can be made, which produces sufficient Lorentz force to shear the dendrites. Furthermore, the distributions of solid fraction and species also depend on stirring intensity. Thus, in the present research work, the influence of stirring intensity on transport phenomena is kept in mind.

C. Cooling Rate

It is observed that cooling rate throughout semisolid material (SSM) processing is also an indispensable parameter influencing the ultimate product. In the present research work, the bottom mould is cooled with different cooling heat fluxes (q/3.5, q and 2.5q) in order to explore the effect of cooling rate on transport phenomena for the present solidification process. The cooling heat flux ‘q’ corresponds to the extraction of heat from the molten liquid using water which passes through the cooling jacket (cooling rate ~ 6 °C/min). The cooling heat flux ‘q/3.5’ corresponds to the extraction of heat from the molten metal using air which passes through the cooling jacket (cooling rate ~ 1 °C/min). The cooling heat flux ‘2.5q’ indicates the extraction of heat at higher rate from the molten metal (cooling rate ~ 15°C/min).

III. DESCRIPTION OF RHEOCASTING PROCEDURE

Liquid A356 Al alloy at a predetermined superheat is poured into an electrically non-conducting clay graphite crucible kept within the annulus of the stirrer. The molten metal is cooled at the bottom from the top part of the metallic mould attached to the graphite tube. The liquid metal in the graphite tube is inside the domain of the electromagnetic field. The electromagnetic forces act on the solidifying melt and shear the dendrites formed at the phase change interface as shown schematically in figure 2. It is expected that most of the heat transferred during solidification occurs at the bottom of the mould. Since, the top surface is exposed to air, there will be cooling due to convection and radiation. Also, as the graphite tube has a finite thermal conductivity, some amount of heat loss in the radial direction will always be present. The stated mould cooling arrangement would give rise to upward advancement of the solidification front. The rate of advancement of the solidification interface would depend on other parameters like cooling rate at the bottom and the stirring intensity. This research work has already described these parameters.

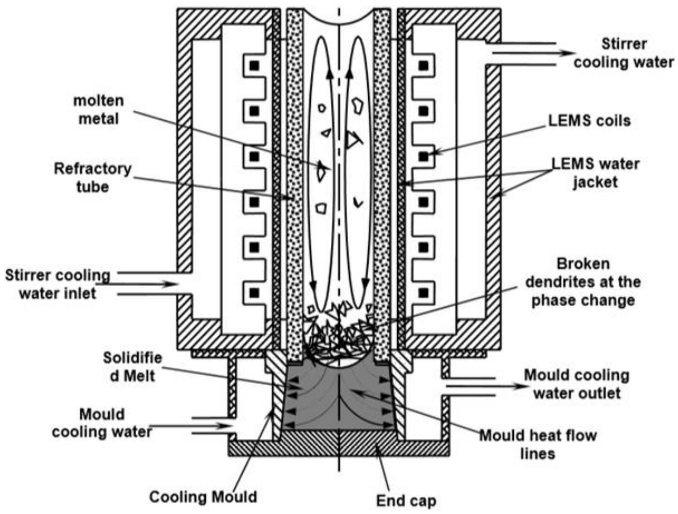


Figure 2. Schematic of rheocasting assembly

IV. METHODS AND MEASUREMENTS

The representative sketch of the experimental procedure for the rheocasting experiments is depicted in figure 3. An exploded photograph of the experimental facility is also illustrated in figure 4.

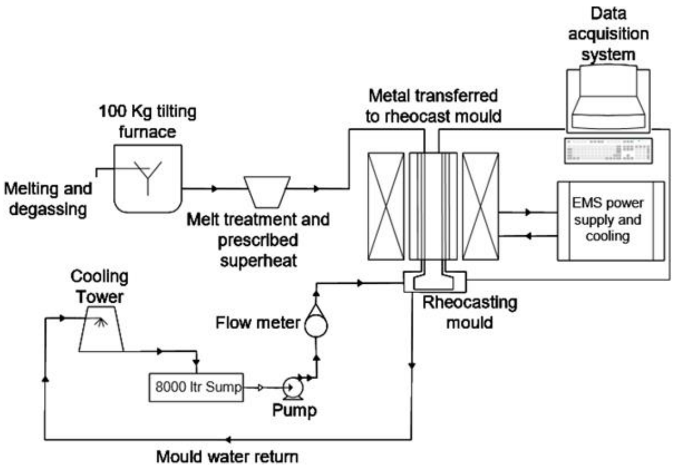


Figure 3. Particulars of experimental setup

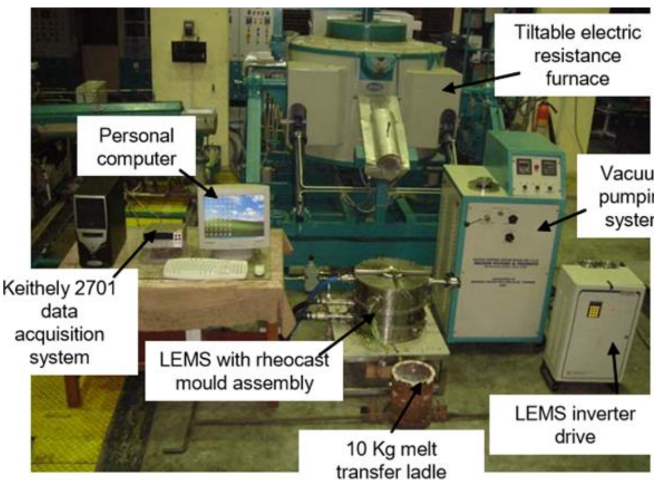


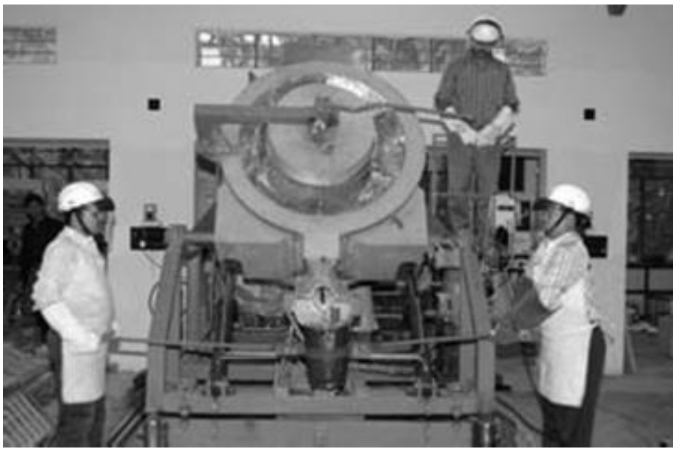
Figure 4. Photograph of experimental facility

A. Melt Preparation and Treatment

Prior to every experiment, around 40 kg of A356 Al alloy is melted in a mica glazed silicon carbide crucible placed in a tilting electric resistance furnace. After completion melting, the molten alloy is kept for about 50 min at 745°C ± 5°C, to permit for temperature uniformity and complete dissolution of alloying elements. After holding the melt for about 50 min, it is degassed. A provision is made in the furnace lid for inserting a degassing tube into the molten metal. The degassing process is carried out inside the furnace crucible by blowing dry nitrogen into the melt using a 10 mm ID silicon carbide tube. Typical degassing time is 35 min with a nitrogen flow rate of 42 litres per minute. The temperature of the alloy is maintained between 710-750°C during the degassing period. After degassing of the melt, the slag collected at the top of the melt is removed. This is followed by addition of predetermined quantities of grain refiners and modifiers. Al-Sr master alloy is used as a modifier in the experiments. Preliminary experiments are carried out with different quantities of modifier and the resulting microstructures are analyzed to ascertain the exact amount of Sr required for optimum modification of the Si-phase. Accordingly, in each melt, Al-Sr master alloy amounting to 0.25% of the total melt weight of the alloy is added before each pour. Melt spectroscopic analysis shows that this value corresponds to about 50 ppm required for optimum modification. Similarly, in each 30 kg melt, about 50 g of Ti-B tablets is added for grain refinement. Then, the melt is held for about 20 minutes (before pouring) to fully realise the effect of grain refiner and modifier. During the experiments, depending on the superheat and melt quantity, a 40-50°C drop in temperature is normally observed while the metal is transferred from the furnace to the mould. This explains the need to keep up such an elevated superheat in the furnace.

B. Melt Transfer into Rheocast Mould

The rheocast mould is kept in the annulus of the linear EMS. The linear EMS is switched on and fixed at a high frequency mode of usually 200 Hz though the inverter. In the high frequency mode, the linear EMS acts like an induction heater and rapidly heats up the rheocast mould. This preheating stage is necessary from operational safety point of view, in order to evaporate traces of moisture in the graphite refractory tube. In addition, preheating provides sufficient time for the metal to stir by ensuring that the metal does not solidify immediately upon entering the mould. Typical mould preheating temperature is 210°C± 10°C. For each pour, about 10 kg of melt is transferred from the furnace into a ladle. The temperature of the melt in the ladle is monitored using a K-type thermocouple. The melt is gently poured into the rheocast mould at the predetermined melt superheat temperature. Pouring is done gently and cautiously, to confirm laminar filling and steadiness. The series of trials during a usual experiment is demonstrated in figure 5.



(a) Melt transfer to ladle

(b) Pouring into rheocast mould

Figure 5. Series of trials in an actual experiment

C. Temperature Measurement

The temperatures are measured at different points within the molten metal (while it solidifies) as well as at several strategic points in the mould wall. The technique and procedure for each type of measurement are described below.

(a) Temperature measurement in molten metal

Pre-calibrated Class I, K-type MI twisted-pair thermocouples are utilized for the measurement of temperature of molten metal in the mould kept inside the linear EMS. The MI thermocouple assembly is introduced into another inconel shield, such that only the junction tip is exposed to the molten metal. The annular space between the thermocouple assembly and the outer inconel shield is filled with insulating ceramic cement. Such an arrangement is observed to minimize the instabilities owing to the electromagnetic field. Independent trials are performed in the molten metal with and without the external electromagnetic field for ensuring the effectiveness of the shielding techniques. A usual thermocouple-tube assembly used in the present experiments is illustrated in figure 6.

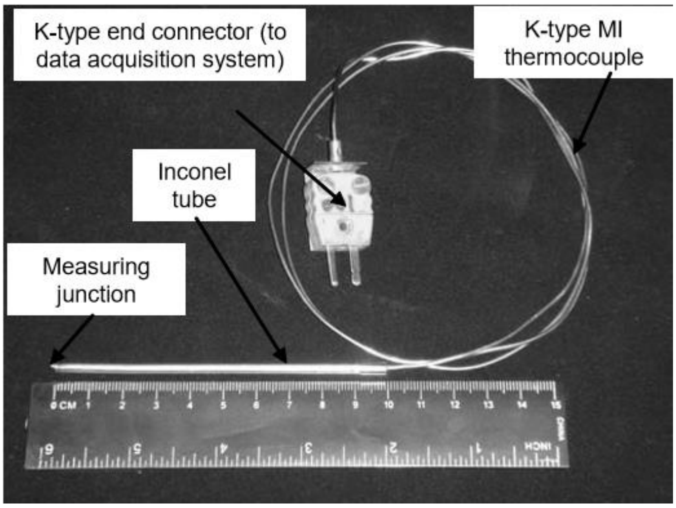


Figure 6. Typical K-type MI thermocouple assembly

Figure 7 demonstrates a photograph of the “T” frame thermocouple tube assembly. The “T” frame is fixed firmly to the top plate of the EMS but rests on the graphite mould. This design is observed to realize the following: (i) the positions of temperature measurement are not changed while pouring of metal into the mould, (ii) evenness in measurement positions between different trials and (iii) avoiding lateral drifts of thermocouples caused by convection in the melt pool.

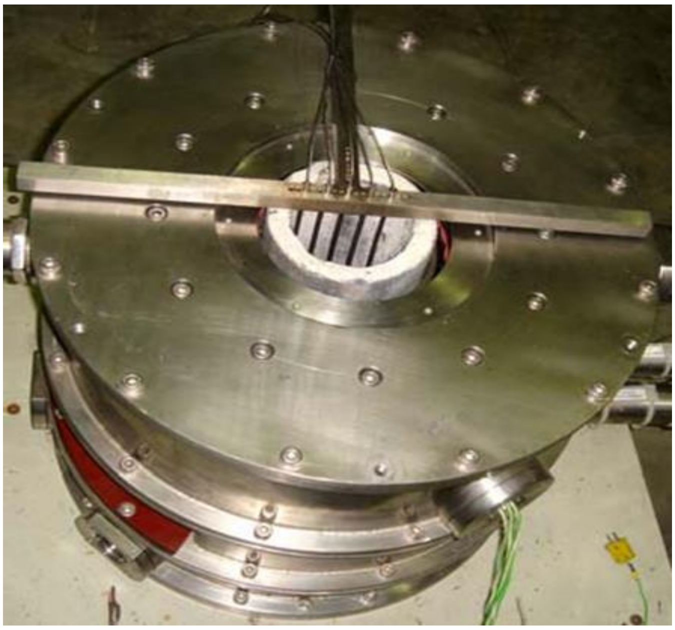
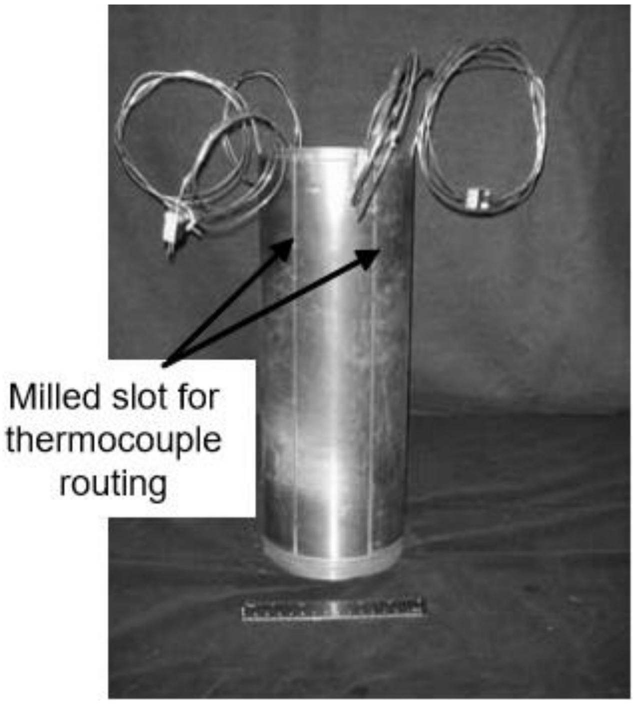
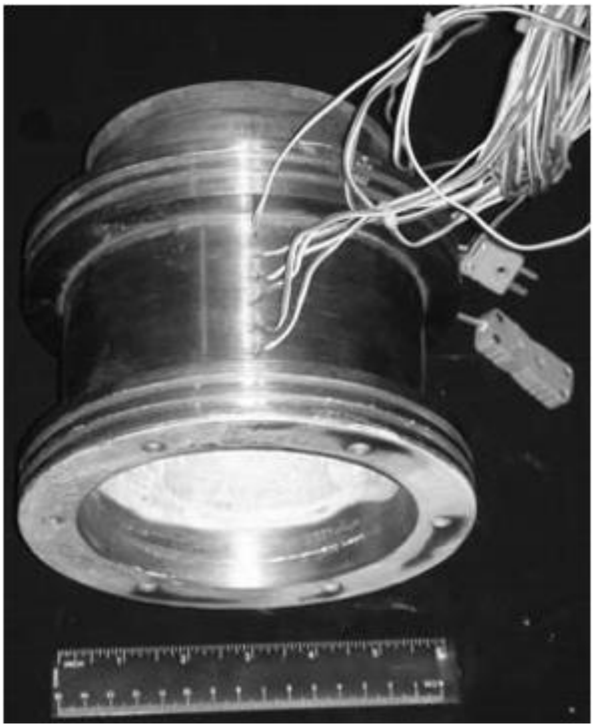


Figure 7. Melt temperature measurement with thermocouple "T" bar assembly



(a) Stainless steel tube



(b) Bottom mould

Figure 8. Temperature measuring points

b) Temperature measurement at mould wall

Besides the temperature measurements in the molten metal, the thermocouples are also mounted at different places on the mould wall to observe the surface heat losses. In the upper half the mould, six K-type thermocouple tube assemblies are routed through milled grooves provided on the outer surface of the stainless steel tube surrounding the graphite refractory. The milled grooves are evenly spaced 60° apart along the stainless steel tube circumference as illustrated in figure 8 (a). Holes are drilled at different heights in each milled slot to mount the thermocouple measuring junction. This arrangement enables the assessment of the vertical temperature gradient in the top part of the mould.

In the bottom portion (active cooling region) of the mould, K-type twisted pair teflon coated thermocouples are inserted in the holes drilled along a vertical line on the outer wall as shown in figure 8 (b). This arrangement enables the ultimate assessment of heat loss through the mould surface. Besides the above locations, temperature measurements are also done at the inlet and outlet of the coolant, and at the bottom stump, while conducting the experiments. The coolant temperatures are also measured using T-type copperconstantan thermocouples.

Besides the stated temperature measurements, the melt top surface temperature is measured by keeping a K-type MI thermocouple on the melt meniscus straightway after completion of melt transfer into the rheocasting mould. The signals from the thermocouples are collected by an

48 channel Keithely Integra 2701 series ethernet based data acquisition system interfaced with an Intel Pentium IV based desktop computer. The sampling interval is set at 1.2 s to confirm stability in the measurement data. The instrument and the thermocouples are calibrated prior to start of experiments.

V. SAFETY MEASURES

As exceedingly high temperature is associated with the rheocasting experiments, enough safety measures are followed at all steps, especially in the design of the setup. It is well known that contact of molten A356 Al alloy with water is very risky and can cause explosions. Hence, suitable care is taken to ensure that water inlet and outlet connections to the linear EMS and to the rheocasting mould are leak proof and the area surrounding the experimental setup is absolutely dry. The other vital safety precautions that are considered and included in the design are complete isolation of molten metal from water and thermal shielding to circumvent burn related injuries. The paramount aspect has been considered by the basic design of the mould, by ensuring that there is no static pressure build up because of accumulation of water. This is realized by draining of the water in direction of gravity to circumvent any accumulation of water. Thermal shielding is provided through a highly conservative design of the insulation system, like use of vacuum insulation of housing and enclosing the hot metal zone inside the coolant circulation system. Besides the stated safety procedures, the thermocouple tube assembly is preheated to around 200°C by a gas burner for evaporating any entrapped moisture before it is kept within the mould.

VI.CONCLUSION

In the present research work, the rheocasting experiments with use of the EM stirrer for molten A356 aluminium alloy and proper dashboard to accomplish the same are described very clearly. This involves a detailed description of the schematic of the experimental setup, melt preparation, temperature measurement techniques, experimental procedure and techniques for thorough investigations. Besides, it also describes about the key physical process parameters (influencing the ultimate SSF products), selection of the proper aluminium alloy for the semisolid material (SSM) forming or casting processes, developing an experimental method and treating of temperature data obtained from the said rheocasting experiments. The safety precautions followed starting from the experimental designs to performing rheocasting experiments through different techniques are also highlighted.

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