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GRAIN REFINEMENT OF LM25 ALUMINUM ALLOY CASTING USING SLOPING PLATE PROCESS

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ABSTRACT

Grain refinement during semi-solid processing is believed to augment the mechanical properties of metals. The introduction of nucleation in the die pool, generated as a result of localize solidification of molten metal, over a sloping plate can serve as an economical and efficient way for grain refinement. In this research, flow from the sloping plate was used for enhancement of material properties through grain refinement in gravity die casting using Aluminum alloy LM25. The castings were prepared with different slope angles of 800mm long, naturally cooled Stainless Steel plate, with varying angles of 15^0 increments with the horizontal. The specimens obtained were then tested for microstructure characterization, tensile strength and percentage elongation. Conclusions were drawn on the grain size and precipitate morphology as a function of angle of sloping plate. Microstructure examination, elongation measurements and tensile tests show that best properties were achieved with the sloping angle of 60°.

Keywords: grain refinement, grain morphology, sloping plate, nucleation.

INTRODUCTION

Semi-solid Processing refers to the manufacturing of the near-net shaped geometry using partially melted alloys [1]. Since 1990's Semi-Solid Metallurgy (SSM) is focused on aluminum and its alloys and today many of the tools made by this technique are replacing the conventionally process like Sand casting, Gravity casting etc. SSM processing has practiced extensive research, development and commercialization attempts after 2000's [2]. Rheocasting and Thixocasting are two chief techniques which are contained in the SSM. The former process commences using molten alloy and forms into the desired geometry whereas the later initiates with the solid alloys, heated to make it very slightly flow-able and subjected to forming [1, 3]. Grain refinement is achieved by controlling the size of grain of structure formed during solidification process by different techniques [4]. Grain refinement can be performed by using mechanical (introducing ultrasonic vibration during nuclei formation), chemical (inoculant addition) and thermal (time and Temperature and control) techniques.

Amount of heat extraction into a melt, rate of nucleation, temperature on which molten poured are the factors which influence properties of SSM products [5]. By avoiding the cast defects like micro and macro-shrinkage cold shuts, etc. design manufacturability can be achieved [6]. Cooling plate process is used to transform microstructure from dendritic to globular shape by detachment of nuclei through shearing effect. The sloping plate processing is a useful technique for preparing slurry due to its low cost and high efficiency. A low superheat melt is poured on slope to form slurry [7]. Micro structure refinement is controlled by high cooling rates (up to 1000 K/s) and Process temperature control. Flow velocities over cooling plate affect the cooling rate and result in meta-rapid solidification at low flow velocities and folding effect at high flow velocities. Stirring action produced globular grain instead of dendritic metal in a semi-solid state with low viscosity [8]. Sloping channel can be made by different materials such as mild steel aluminum and copper and many of other materials and different type of cooling media like water and oil can be used [9]. Introducing wave slope is good for producing finer spherical like grain with short globular structure and burst nucleation to produce more nucleation site which result in micro-structural improvement [10]. Microstructure properties are also dependent on the slurry processing technique [11]. Heterogeneous nucleation refers to the accumulation of grains proximal to the surface, whereas homogeneous nucleation occurs distal to the surface [12].
Yahia Ali *et al* [13] studied effects of addition of CaO in magnesium alloys in order to mitigate the average grain size, from 1042 to 470 µm and to facilitate heterogeneous nucleation. Y. Berol [14] characterized the thixoforming features of micro structure of A357 alloy using sloping plates of lengths 200 - 400 mm with pouring temperatures 620 - 640 ^{0}C. It was observed that the globular microstructure was visible for isothermal holding of only 5 min. beyond which, coarse hardening of Al appeared, followed by Ostwald ripening effect. Y. Berol [3] characterized hardness and porosity of A390 aluminum alloy thixocast from cooling slope plate and observed increase of hardness to 144 HB with initial pouring temperatures of 844 K rather than typical temperature of 973 - 1033 K used for die casting. Dae Cho *et al* [12] studied grain refinement of Mg-Zn-Ca alloy by adding Mn to facilitate super cooling aimed to refine the grain size. The study concluded that addition of Mn in Mg-4Zn-0.5Cae0.4Mn and Mg-4Zn-0.5Ca-0.8Mn resulted the grain size 42 and 63% refiner than Mg-4Zn-0.5Ca alloy. Li *et al* [15] deployed rotating magnetic field in order to refine the grains of magnesium alloy. The refined grains as a result of optimized frequency of 250 Hz were observed to have average diameter of 120 µm.

From the literature it was revealed that there exist a substantial research regarding the grain refinement of manganese, magnesium and aluminum alloys in semi-solid processing, yet the grain refinement without any inoculant and use of gravity die casting for high Silicon-aluminum alloy has seldom been found. Moreover, the aluminum alloy LM25 has neither been used for sloping plate casting, nor for the study of mechanical properties or micro-structure characterization. This paper focuses the use of sloping plate to pour LM25 alloy for gravity die casting. Comprehensive study of microstructure, hardness and the mechanical properties of specimens is presented.

EXPERIMENT

The purpose of using sloping plate was to facilitate heat extraction and generate localized undercooling. Molten alloy at 800 ^{0}C was poured through sloping plate as shown in Figure-1. Thermocouple was used to measure the temperature of alloy. Sloping channel of 800mm length was prepared with stainless steel and was inclined at 15^0, 30^0, 45^0, 60^0 and 75^0 sloping plate angle to perform gravity die casting. The dimensions of die were according to ASTM standard E8M [16] in order to proceeded for the testing and evaluation of mechanical properties. The casting was followed by studies of metallography and mechanical properties. Universal Hardness Testing Machine MTS 810 was used for mechanical testing and Olympus metallurgical microscope was used for microstructure characterization.

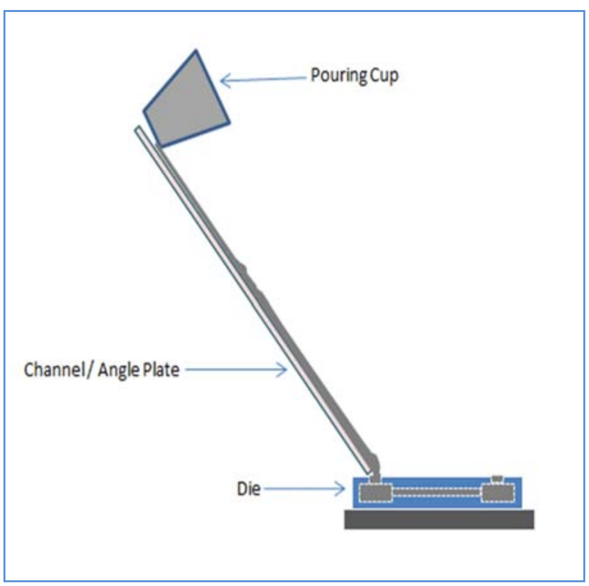

Figure-1. Experimental setup.

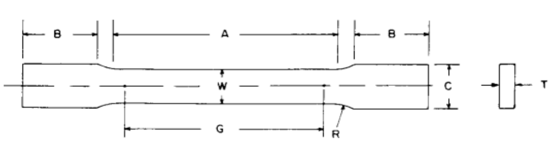

Figure-2. Cast specimen.

Figure-3. Unassembled view of the mild steel die.

RESULTS

Effect of sloping plate angle variation on ultimate tensile strength (UTS)

Low flow velocities caused segregation of melt which produced non-uniform properties whereas high flow velocities resulted folding effect, due to which, shrinkages and voids appeared causing inferior mechanical properties. Ultimate tensile strength (UTS) decreased up to 45^0 slope angle and increased from 60^0 onwards. Therefore, optimum pouring angle for LM25 Aluminum Alloy is 60^0. At 75^0 the value of ultimate tensile strength is at minimum due to dominating voids, caused by high flow velocities.

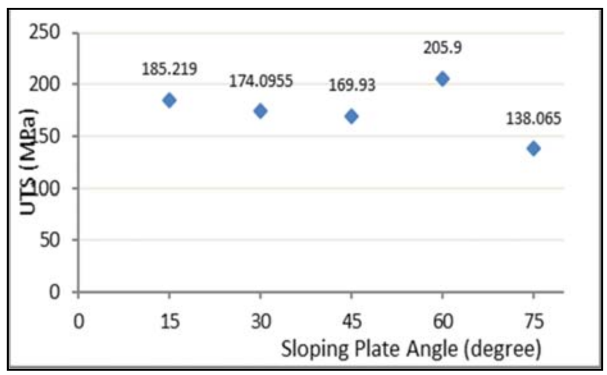

Figure-4. Sloping plate angle vs ultimate tensile strength.

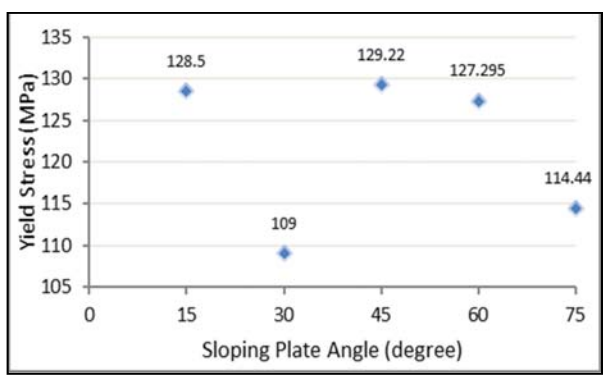

Figure-5. Yield stress vs slope angle.

Effect of sloping plate angle variation on yield stress

From figure 5 it can be learnt that at 15^0, 45^0 and 60^0 plate angles, the value of yield stress is almost same but at 30^0, anomalous behavior can be noticed. 75^0 cast

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samples showed minimum value of yield stress due to casting defects, caused by improper filling due to high filling speeds. At 30^0 pouring angle, the alloy turned plastic as the grains formed were too big in size i.e. 222 µm (see Figure-7). It was because the flow speed was neither too slow to let the grains arrange evenly, nor was it too fast to avoid super-cooling within the pouring channel.

Effect of sloping plate angle variation on grain structure

In Figure-6 (a) 15^0 cast specimen shows elongated denderatic growth. Tree shaped Grain boundries were seen. Casting defects like pores are also present and equally dispersed. Precipitate morphologies are connected at grain boundaries and some independent crystals are visible. In Figure-6 (b), dendritic structure, irregular shape and deposition of eutectic phase are visible in 30^0 cast sample. Thicker precipitate morphology at grain are observed at boundaries, yet they are continuous. In Figure-6 (c) at 45^0, porosity was reduced, dendretic structures were seen, grain structure was random and precipitate morphologies were thinner but contionus.

In Figure-6 (d) at 60^0, grain of gloublar morphologies can be seen. Pores and precipitate morphologies also exist succinctly. In Figure-6 (e) at 75^0, dendritic growth was still visible. Cracks are present and the grains are smallest in size i.e 201 µm, compared to other pouring angles (see Figure-7).

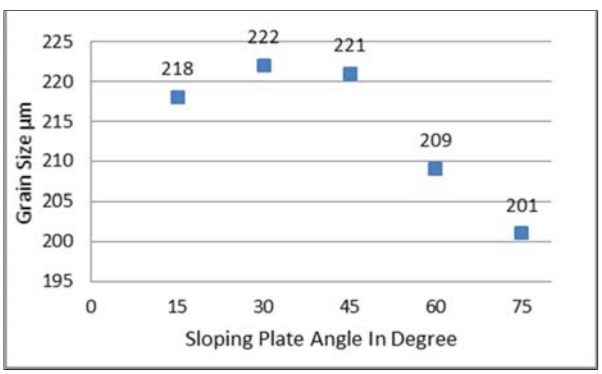

Figure-6. Different sloping angle cast specimen (Microstructure, Scale: 20µm 500x Magnification).

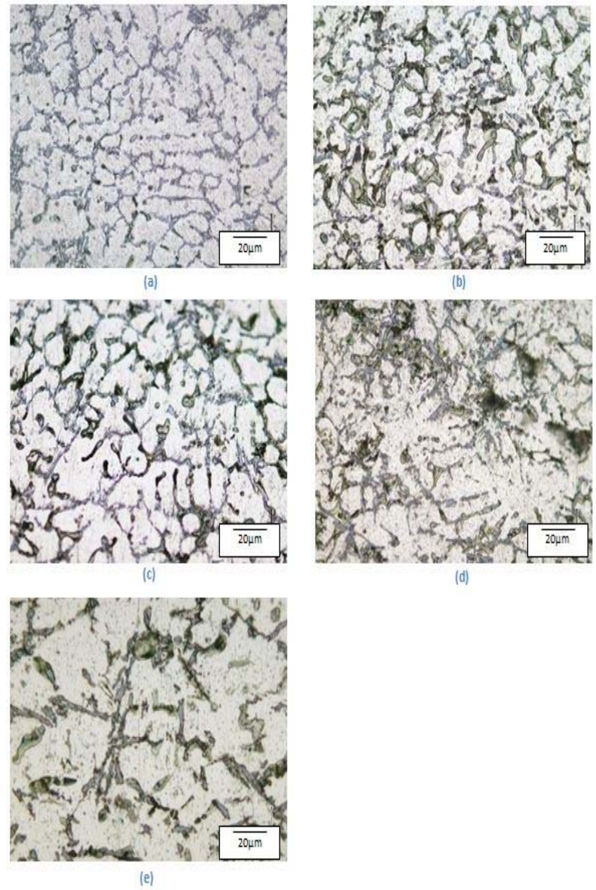

Figure-7. Grain size vs slope angle.
a) Slope angle 15^0 b) Slope angle 30^0 c) Slope angle 45^0 d) Slope angle 60^0 e) Slope angle 75^0

Effect of sloping plate angle variation on grain size

At an inclination angle of 15°, 30^0, 45^0 the grain size remains almost same (see Figure 7). The average grain size changed from 221 µm to 209 µm at sloping angle of 75° and corresponding to pouring temperature of 800 °C. The minimum grain size of 201 µm was obtained at sloping angle and temperatures of 75° and 800 °C respectively.

CONCLUSIONS

Following conclusions can be derived from the above research:

- 15^0 and 75^0 are non-recommended angles for LM25 casting due to associated segregation and folding effect respectively
- At sloping plate angles of 30^0 and 45^0, no substantial effect was recoded on grain size
- 60^0 channel angle is most suitable in terms of die filling and grain formation
- At 60^0 matrix is continuous around the precipitates, providing good ductility

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It can be concluded from boundary layer of molten deposited on the slope that at 60^0, that the fraction of solid metal is highest

RECOMMENDATIONS

It is recommended that research be continued on;

- Different plates with different nucleation capacities
- Using ultrasonic vibrator for induced grain refinement
- The effect of sloping plate on the porosity

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