International Journal of Mechanical and Materials Engineering (IJMME), Vol. 4 (2009), No. 2, 176-180

PRODUCTION OF FEEDSTOCK MATERIAL FOR SEMI-SOLID MATERIALPROCESSING BY COOLING SLOPE CASTING PROCESS

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ABSTRACT

Semi-solid processing routes for metallic alloys require feedstock materials with non-dendritic microstructure in the semi-solid state. Cooling slope casting process is one of the methods used to produce such structure whereby molten alloy is poured onto a *cooling slope* into a mould before semi-solid metal processing is carried out. This paper discusses the resulting microstructures of the ingot cast via the cooling slope. Al-Si alloy was melted in crucible graphite with dry argon degassing then poured on mild steel cooling slope which is coated with Boron Nitride. In this experiment, comparison between cooling slope with and without water circulation was investigated. From the experiment, it can be concluded that the water circulation influenced the fraction volume of α-Al particle, grain size and shape factor (SF).

Keywords: Semi-solid processing, Cooling slope casting, non-dendritic microstructure, water circulation

INTRODUCTION

Semi-solid metal (SSM) forming, i.e., forming a metallic alloy at a temperature between its equilibrium liquidus and equilibrium solidus temperatures, is a hybrid metalworking process combining elements of both casting and forging/extrusion. One of the key elements for the successful operation of a thixoforming process is the microstructure of the metallic alloy raw material.

Producing raw material for semi-solid processing requires specialized techniques. One of these is vigorous agitation such as by mechanical stirring or inductive electromagnetic stirring. Rheocasting was the first process developed for SSM technology (Spencer *et al*., 1932). Vigorous agitation using a mechanical stirrer either continuously during solidification or isothermally in the semisolid state eliminates at least some of the dendritic structure. The resulting slurry is composed of solid, relatively fine, non-dendritic particles in a liquid matrix (Fleming, 1991). The process of solidifying the original slurry as either a continuous casting or a shaped casting is termed rheocasting.

Haga and Suzuki (2001) analyzed the factors which affect the spheroidicity of α-Al particles in ingots obtained by casting Aluminum ingots via a cooling slope (mild steel) at a range of temperatures of 640 to 680^{o}C. They found that the cooling rate strongly affect the globularization of of primary α-Al particles and obtained a small particle size. (Motegi *et al.,* 2002), performed experiments using a water cooled slope made of pure copper, with tilt angles of 40, 60 and 80^{o}, and lengths of 80, 160, 200 and 240 mm. They poured an Al 1.63wt%Si0.54wt%Mg alloy at 656, 666, 676, 686 and 696^{o}C. They found that the cooling slope is useful in generating numerous crystal seeds. The best condition was at tilt angle 60^{o} and 656 ^{o}C pouring temperature. It was found that if the slope length is too long, the slurry could form solid shell on the slope. On the other hand, if it is too short, nucleation sites may be insufficient. They found evidence that increase in pouring temperature resulted in a bigger particle size.

Haga and Kapranos (2002) produced A356 and A390 aluminium alloy ingots via both cooling slope and low superheat casting. For the cooling slope process, they used two pouring distances 150 and 250 mm, with a tilt angle of 60^{o}, and superheats of 20 and 40 K. The low superheat casting was carried out with superheats of 10, 20 and 40 K. For both experiments, copper and insulating moulds were used. The resulting ingots were reheated at 570, 580 and 590^{o}C and then thixoformed. The results from this work are only qualitative. With copper die, if the ingot was heated up to 570 ^{o}C the primary particles did not spheroidise, but if the temperature is 580 or 590 ^{o}C the particles became spheroidal, with a larger particle size for the higher temperature. With the insulating die, when the ingot was heated up to 570^{o}C the primary particles spheroidised, for 580 or 590^{o}C, the particles also became spheroidal, with a larger particle size for the higher temperature.

The objective of this study was to examine the microstructure of cooling slope (CS) casting Al Si alloy, which is a popular Al-alloy for automotive components. Results from cooling slope casting with and without water circulation were compared.

EXPERIMENTAL PROCEDURE

In this study, commercial Al-Si aluminium alloy was used. The composition of the Al-Si alloy is given in Table 1.

Table 1. Composition of aluminium alloys used in this study (wt.%)

Si	6.60
Mg	0.24
Mn	0.03
Fe	0.36
Ni	0.01
Ti	0.04
Zn	0.02
Cu	0.08
Al	Bal.

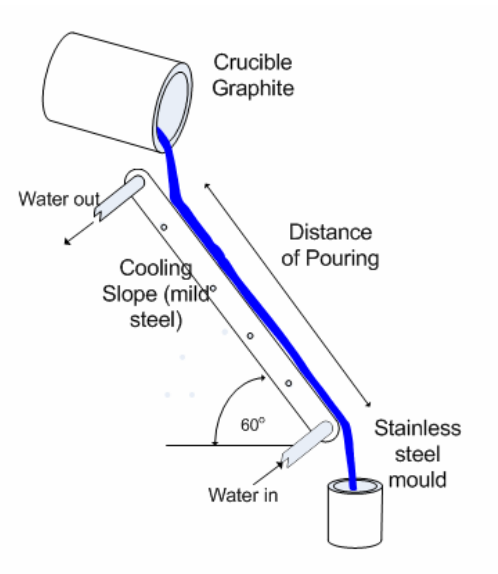


Figure 1: Equipment installation of CS casting used in the present work.

For the CS casting process, the melt was continuously poured on the slope and collected into a stainless steel mould. The equipment installation is shown in Figure 1. Temperature and distance of pouring was respectively fixed at 250 mm and 620^{o}C. Pouring was carried out in two conditions, i.e. CS casting with and without water circulation.

The ingots from the CS casting process were cut into two parts, top and bottom parts. Samples prepared from these parts, ground and polished. They were then etched with modified Keller's reagent (2 cm^3 HF, 3 cm^3 HCl, in 175 cm^3 H_2O) for microstructural examination. Analysis on grain size, fraction volume α-Al particle and shape factor (SF) were carried out. Schematic description of the sample location for metallography is shown in Figure 2.

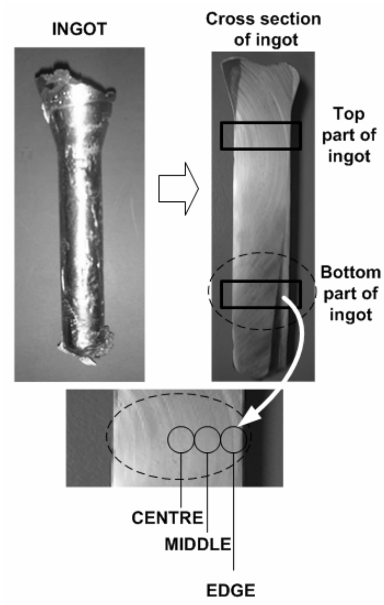


Figure 2: Schematic description of the sample location for metallography

The average grain size of α-Al particles were measured by the linear intercept method according to the ASTM standard, E112-96 (ASTM standards, 1996). A commercial software package (V-Test Image software analysis) was used to determine the area and perimeter of the α-Al particles, and hence, the shape factor can be calculated. Fraction volume of α-Al particles were also analyzed by using image analysis software. Furthermore, comparisons of this result were done for both with and without water circulation.

RESULTS AND DISCUSSION

The alloy used in this study was a commercial Al-Si alloy which The microstructure of this alloy is shown in Figure 3. The figure shows that microstructure is fully dendritic as compared to spheroid morphology for CS casting sample. The STA data was used to estimate the optimum range of pouring temperatures for the CS casting experiments (Figure 4). The solidus and the liquidus temperatures of the alloy were estimated by STA to be 556◦C and 617◦C. Pouring temperatures in the range of 610–630 ◦C, were employed in the CS casting experiments.

The figures (5 & 6) show that the microstructures obtained when CS casting was carried with water circulation has resulted in the formation of finer α-Al grain. It can also be seen that the α-Al particle are generally finer near the edge of ingot than the middle and centre.

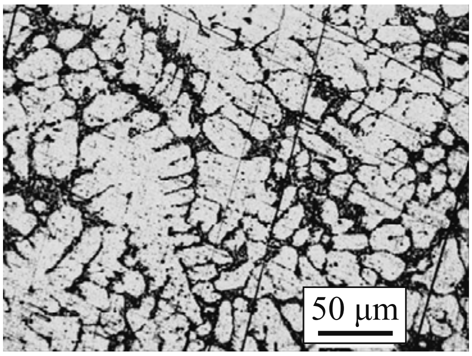


Figure 3: Microstructure of the conventionally cast Al-Si alloy

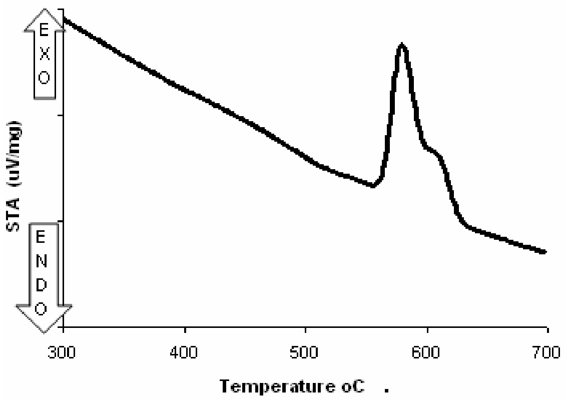


Figure 4: STA curve of the Al-Si alloy recorded during cooling from the molten state

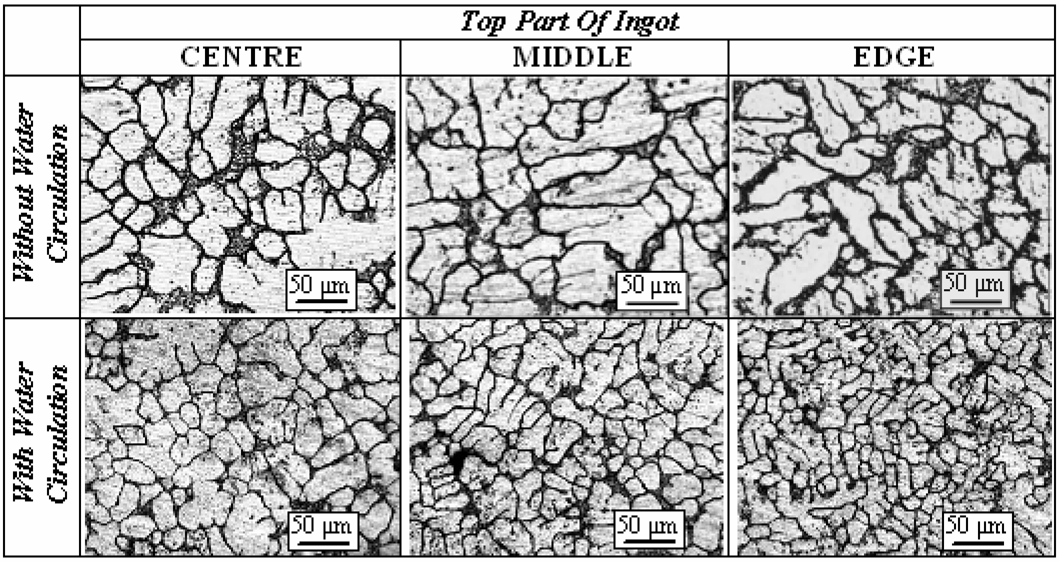


Figure 5: Microstructure of upper part of CS casting ingot for both with and without water circulation

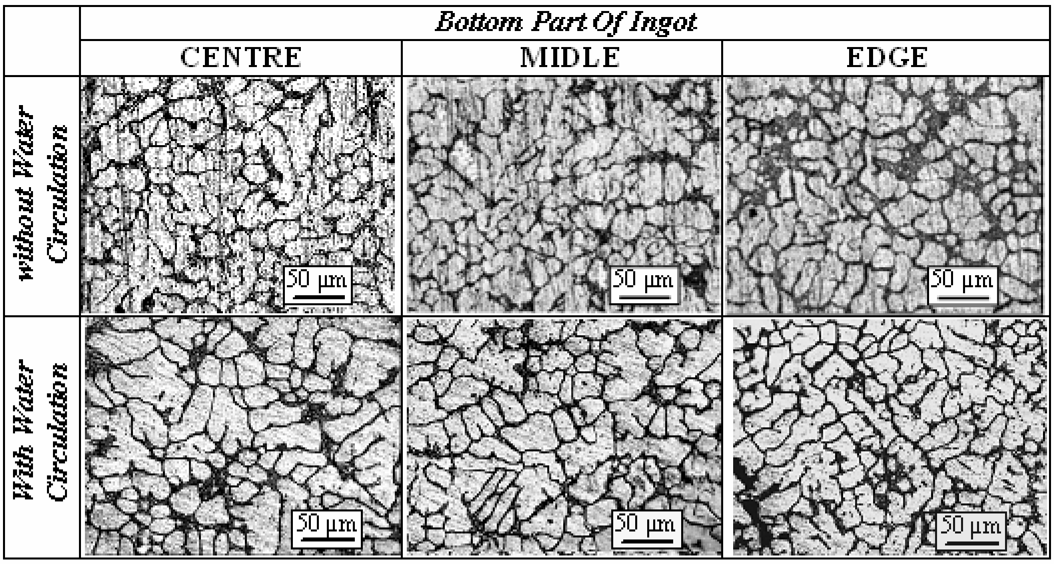


Figure 6: Microstructure of bottom part of CS casting ingot for both with and without water circulation

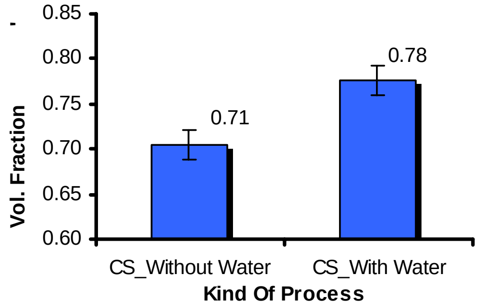


Figure 7: Volume faction of α-Al particle for CS casting process with and without water

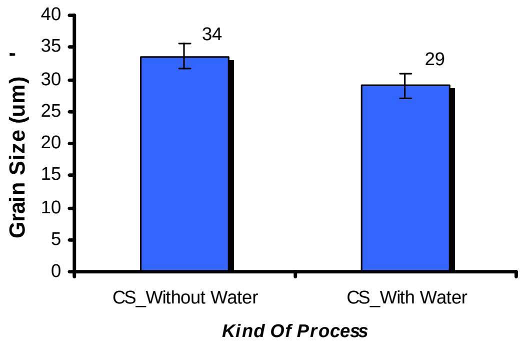


Figure 8: Grain Size of α-Al particle for CS casting process with and without water

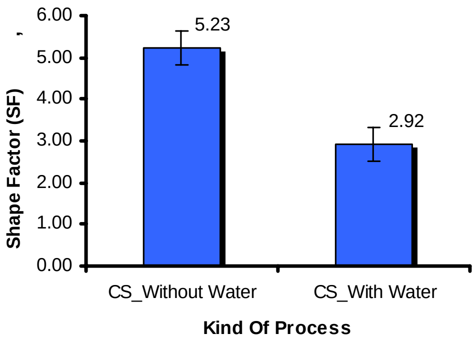
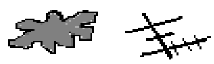


Figure 9: Shape factor of α-Al particle for CS casting process with and without water

Fraction volume of α-Al grain, grain size, and shape factor (SF) were shown in figure 7, 8 and 9. The addition of water circulation has resulted with an increased in fraction volume from 0.71 to 0.78 but a decreased in grain size from 34 to 29 μm and shape factor from 5.23 to 2.99, respectively. To represent quantitatively the shape of grains, shape factor was commonly used to characterize SSM microstructures. Shape factor is defined as $p^2/4\pi A$, where P is the perimeter and A is the area of the particle (Cardoso Legorreta, 2004). Table 2 shows schematic change of microstructure in terms of shape factor. For a perfect circle, the shape factor would be one (Xia and Tausing, 1998).

Table 2: Change of microstructure in terms of shape factor (Cardoso Legorreta, 2004).

Shape Factor F	Typical particle shape
F≥1	
3≥F≥2	
F>3	

CONCLUSIONS

The dendritic primary phase in the conventionally cast Al-Si alloy has successfully transformed into a non-dendritic after CS casting process. CS casting process with water circulation has resulted in a bigger volume fraction of α-Al particle but smaller grain size and shape factor (SF) of α-Al particle. Hence, it can be seen that water circulation influence on volume fraction liquid/solid, grain size and shape factor.

ACKNOWLEDGEMENTS

The author would like to thank the Universiti Kebangsaan Malaysia and Ministry Of Science, Technology and Innovation (MOSTI), Malaysia for financial assistance.

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