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Simple rheocasting processes

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Abstract

This work describes two recently invented simple rheocasting processes. One process used a cooling slope and the other low superheat casting in order to generate semisolid slurries with spheroidal microstructures that are amenable to thixoforming. In the former process, A356 aluminum alloy was poured into the lower part of a die and immediately an upper die, containing an internal cavity, was inserted in the lower die half. The A356 alloy was in a semisolid slurry form when it flowed into the lower die via a cooling slope. In the latter process, the A356 changed from fully liquid to semisolid slurry condition by cooling in the lower die half after being poured into it as low superheat casting. The primary crystals of the cast metal in the both processes became spheroidal. There was no major observable difference between conventional thixocasting microstructures and those of the two processes used in the present study. The mechanical properties obtained in the present study were: tensile strengths of 310 MPa and 18% elongation for the process using the cooling slope, and tensile strengths of 290 MPa and 12% elongation for the process using the low superheat casting.

Keywords: Rheocasting; Thixocasting; Semisolid; Spheroidal microstructure; Aluminum alloy

1. Introduction

The process of thixocasting offers a number of advantages, such as improved mechanical properties, good surface finish, near net shape and so on. However, the thixocasting process has also a number of disadvantages, such as the need for special feedstock with near spherical primary crystals. In order to cast such special billets for thixocasting one has to pay a more expensive premium than normal. Eliminating this additional specialized casting step leads to savings in both costs and time. A product can be cast into a near net shape part directly from the molten metal state as in rheocasting [1], where the need of special billet is removed. Therefore, rheocasting is advantageous from an energy and cost saving point of view when compared to thixocasting. In the early days of semisolid casting research, mechanical stirring was used in order to achieve the right microstructures. More recently, electric stirring has used. In the present study, two kinds of rheocasting process were devised and tested. A process using a cooling slope and a process using low superheat casting [2]. In the process using the cooling slope, the metal was in the semisolid condition when it flows into the die. In the low superheat casting process, the seed of the crystals are generated at the die surface. The casting was carried out before the crystal seeds could be re-melted. The crystal seeds could then grow to become spherical primary crystals. In the processes described in this present study, only pouring of the molten metal into the die was needed for the semisolid casting to take place.

In conventional semisolid casting, the solid metal fraction content is usually ~50% [1,3–5], however, in the present study, casting was tried at lower than 50% fraction solids. The primary crystal size becomes smaller as the solid rate becomes lower. In thixocasting, metal handling is difficult at fraction solids lower than 50%. However, in rheocasting, casting metal with lower fraction solids is easy because the product, which is thin, can be cast at low fraction solids.

2. Simple rheocasting processes

Fig. 1 shows the two rheocasting processes devised in the present study. The rheocasting process using the cooling slope is schematically shown in Fig. 1(a). The molten metal was poured into the lower die half via the cooling slope. The molten metal became semisolid slurry on the cooling slope. The cooling slope, which is very compact and simple, is made from mild steel, it is water-cooled and as a package offers both low equipment costs and low running costs. The

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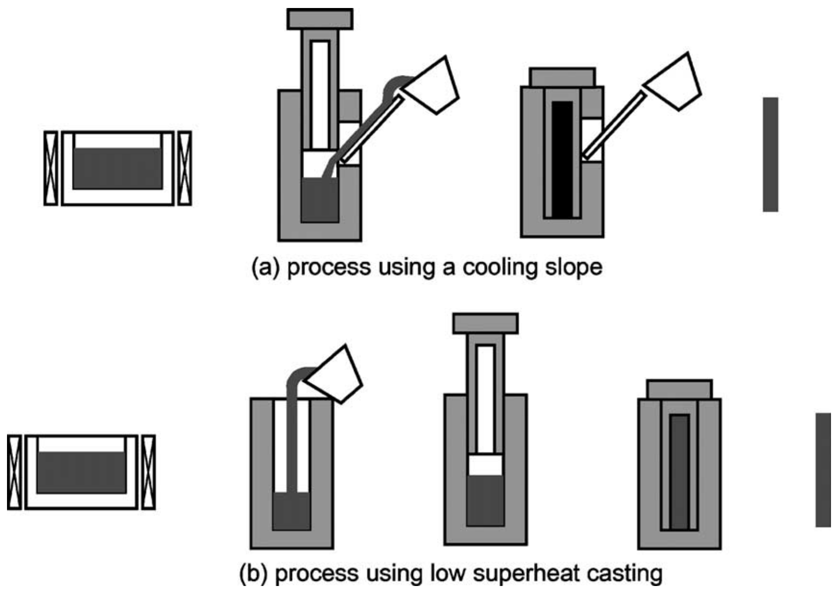

Fig. 1. Two kinds of simple rheocasting process.

cooling slope can be easily mounted as part of any conventional casting machine. In conventional semisolid casting process, a typical fraction solid of about 50% is required, however, the present study aimed at fraction solids lower than 50%. The primary crystal size in the product becomes smaller as the fraction solid is reduced. The solidification rate of the semisolid slurry after flowing through on the cooling slope was about 10%. Casting was done immediately after pouring without holding the slurry in order not to increase the solidification rate. Therefore, there was no need of a system that controls the rate of solidification; this simplified the processes investigated in the present study.

Fig. 1(b) shows the rheocasting process that used low superheat casting. The superheat of the molten metal was 10 °C. The crystal seeds are generated at the lower die surface, and the upper die is inserted into the lower die before the metal solidifies. When the superheat of the molten metal is low, the crystal seeds do not melt and if sufficient crystal seeds remain, they can grow into spheroidal primary crystals. The low superheat casting is simpler than the cooling slope process.

3. Experimental conditions

A356 aluminum alloy was used with both processes. In the process using the cooling slope, the effect of the lower die temperature on the upper die insert and the ingot microstructures were investigated. The lower die was preheated in an electric furnace before being set within the press prior to casting. The upper die, which was at room temperature, was inserted into the lower die immediately after pouring the metal. The load exerted by the small press was 2 kN and load dwell time was 1 min. In the low superheat casting process, the temperature of the lower die was decided from the results obtained from using the cooling slope process (Table 1).

Table 1
Experimental conditions

Material	A356
Temperature of molten metal	620, 650 °C
Upper die	Diameter: 20 mm, length: 90 mm (size of inside) copper
Lower die	Diameter: 50 mm, length: 70 mm (size of inside) SKD61
Temperature of lower die	350, 400, 450, 500 °C
Cooling slope	Size: width 50 mm, length 300 mm water cooling Material: mild steel, coating: BN
Angle of a cooling slope	60°
Cooling length of the slope	250 mm
Speed of a ram	50 mm/s
Load of a ram	20 kN

The surface of the lower die was coated with boron nitride (BN) but the upper die was not coated to encourage rapid solidification. The resulting microstructures and mechanical properties were investigated. The tensile specimens machined from the cast parts for testing had 25 mm gauge length and 4 mm diameter.

4. Results and discussion

The effect of the lower die temperature on the upper die insert and the primary crystal shape are shown in Table 2. When the temperature of the lower die was 350 °C and the melt temperature was 620 °C, the upper die could not be inserted into the lower die and the metal solidified before the upper die was fully inserted. However, when the temperature

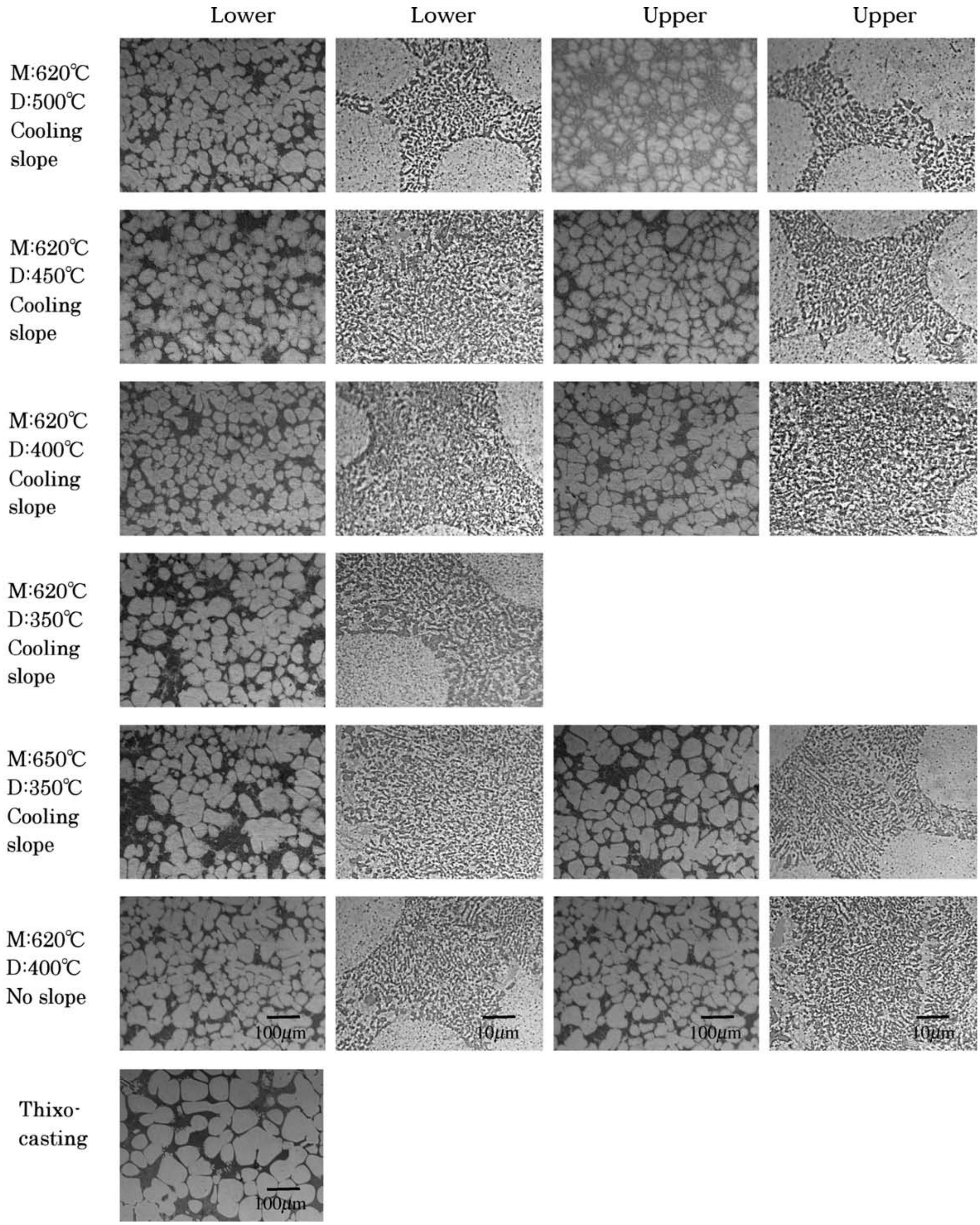

Fig. 2. Microstructure of as cast A356 ingot. M: melt temperature, D: under die temperature, no slope: low superheat casting.

of the lower die was higher than 400 °C and the melt temperature was 620 °C, the upper die could be fully inserted into the lower die. When the lower die temperature was 350 °C, the upper die could be inserted fully by setting the melt temperature 650 °C. When the upper die was inserted fully into the lower die, the cavity incorporated in the upper die was filled with metal. The lower die temperature was set at 400 °C in the low superheat casting. The upper die could be inserted fully during the low superheat casting. Fig. 2 shows microstructures of ingots in the as cast condition. The primary crystals became spheroidal at all conditions. In the processes described in the present study, the primary crystal size was smaller than that of thixoforming. This is a feature of the rheocasting process. Casting at low solid fractions affected the size of primary crystals. In the process using the cooling slope, the primary crystal size

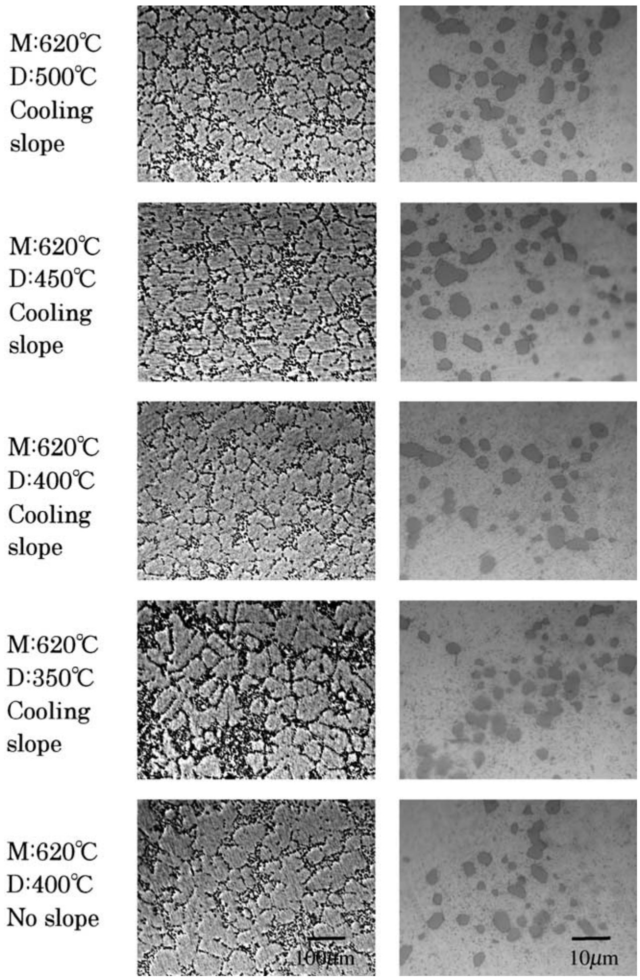

Fig. 3. Microstructure of A356 after T6 heat treatment. M: melt temperature, D: under die temperature, no slope: low superheat casting.

was very fine when the melt temperature was 620 °C and the lower die temperature was 400 °C. The primary crystal size of the ingots cast using the cooling slope was smaller than that of the ingots cast using the low superheat casting. The eutectic Si was very fine. The microstructure of the ingots after T6 heat treatment is shown in Fig. 3. The eutectic Si is fine and globular. There was no observable difference in the

Table 2
Effect of a lower die temperature on insert of a upper die and microstructure of an ingot

Cooling slope	Temperature of a lower die (°C)	Temperature of a molten metal (°C)	Insert of an upper die in a lower die	Spherical of primary crystal
Yes[a]	350	620	No	Yes
Yes[a]	350	650	Yes	Yes
Yes[a]	400	620	Yes	Yes
Yes[a]	450	620	Yes	Yes
Yes[a]	500	620	Yes	Yes
No[b]	350	620	Yes	Yes

[a] Process using a cooling slope.
[b] Process using a low super heat casting.

Table 3
Mechanical properties (heat treatment (T6))

Process	Tensile strength (MPa)	Yield stress (MPa)	Elongation (%)
Process using a cooling slope	310	241	18
Process using a low super heat casting	290	237	12

shape of the eutectic Si between the processes used in the present study and conventional thixoforming. The mechanical properties obtained are shown in Table 3. The mechanical properties of parts cast using the cooling slope were superior to those of conventional thixoforming, especially the elongation that was excellent. The low fraction solid casting gave excellent mechanical properties to the ingots. Ingots that were cast using the low superheat casting were the same as the mechanical properties of conventional thixocasting.

5. Conclusions

Two kinds of simple rheocasting process were devised in the course of the present study. One process employs a cooling slope, and the other process uses low superheat casting. The attractive features of these processes are simplicity and low fraction solids. Rheocasting can be simply carried out only by pouring the molten metal into a die (mould). Temperature control of the metal or stirring of the melt were not necessary in the processes investigated. The microstructures of the ingots cast by the processes described above had features that were similar to those in semisolid casting. The primary crystals were spheroidal as in conventional thixocasting. The primary crystals of the ingots cast by these two processes were smaller than those of conventionally thixocast ingots. This was the direct result of the casting at low fraction solids.

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