SEMISOLID COTINUOUS CASTING AND THIXOFORMING OF WROUGHT ALUMINUM ALLOYS

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Abstract: In order to produce AA6070 and 7075 aluminum alloy billets for thixoforming, a new semisolid continuous casting was introduced. An inclined cooling plate was used to generate numerous crystal seeds of α aluminum. Seeds grew granularly in the tundish and the semisolid slurry with a high solid fraction was continuously cast to make a billet. The continuous casting machine produced 60 mm-diameter, 1000mm- long billets at a speed of 3 mm/s. Thixoforming test was also performed to evaluate semisolid continuous casting billets.

Keywords: semisolid casting, continuous casting, wrought aluminum alloy, solidification, thixoforming

1. Introduction

Semisolid casting and forming have become the most important casting and forming technologies today. The advantages of semisolid casting are the ease of casting at low temperatures, high fluidity, and high-quality output. Thus, various continuous casting methods for semisolid alloys are used to produce granular, fine, and homogeneous crystal grains during solidification. For example, electromagnetic stirring and mechanical stirring are used for conventional methods, but, the equipment is huge and cost is high.

We developed a new, simple semisolid casting process using an inclined cooling plate and based on the Crystal Separation Theory proposed by Ohno and Motegi.[1] According to their theory, granular crystals nucleate and grow on a cooling site such as a mold wall, and then separate from the cooling site by fluid motion. The phenomena of crystal formation and separation repeat during solidification until the fluid flow stops. In this investigation, numerous crystal seeds of primary α aluminum were generated on the inclined cooling plate. They then separated from the cooling plate and flowed with molten alloy into the tundish. The primary aluminum crystals grew granular grains in the tundish, and then the granular semisolid slurry was continuously cast. A thixoforming test was also performed. Billets obtained with and without using the inclined cooling plate were compared with the thixoforming force.

2. Experimental procedures

2. 1 Semisolid continuous casting

Table 1 describes the chemical compositions of AA6070 and 7075 aluminum alloys. Liquidus temperatures of 646℃ (AA6070)and 632℃(AA7075) and solidus temperatures of 540℃ (AA6070)and 476℃(AA7075) were determined by thermal analysis.

Figure 1 schematically illustrates the horizontal continuous casting machine used in this investigation. It consisted of an electric furnace, an inclined cooling plate with cooling pipe, a tundish, and a horizontal direct-chill continuous casting machine. In the electric furnace, molten alloys weighed 7kg and were held at a constant temperature.

Table 1 Chemical composition of 6070 and 7075 aluminum alloy used.

AA6070	Si	Mg	Fe	Ti	Cu	Zn	Mn	Al
	1.63	0.54	0.15	0.00	0.16	0.01	0.41	balance
AA7075	Si	Mg	Fe	Cu	Zn	Mn	Cr	Al
	0.10	2.50	0.20	1.60	5.75	0.03	0.23	balance

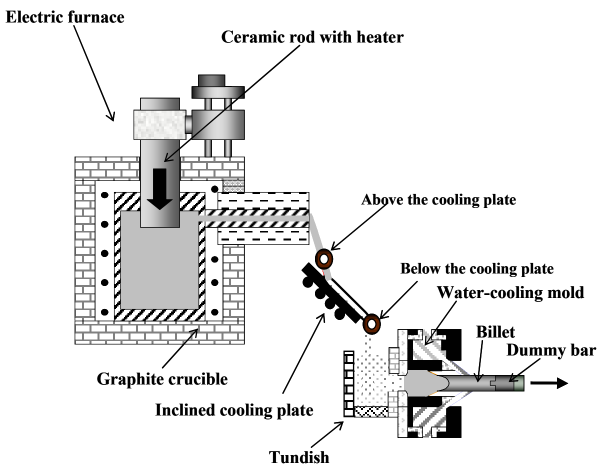

Figure 1. Schematic illustration of apparatus for the horizontal continuous casting of semisolid alloy.

A heated 100mm diameter ceramic rod was lowered at a constant speed into the molten alloy. The molten alloy was poured on the cooling plate through a pipe connected through a tap hole at the top of the crucible wall, and then cast into the horizontal continuous casting machine. The billet was 60 mm in diameter and 1000 mm in length, and the casting speed was 3 to 4 mm/second. Table 2 presents the continuous casting conditions. Each billet was examined metallographically.

Table 2 Conditions of continuous casting.

AA6070	Pouring temperature (℃)	656	666	676
	Length of cooling plate (mm)	160	200	240
	Angle of cooling plate (°)	40	60	80
AA7075	Pouring temperature (℃)	642	652	662
	Length of cooling plate (mm)	80	160	240
	Angle of cooling plate (°)	40	60	80

2.2 Thixoforming of continuous casting billet

The semisolid continuous casting billets of two kinds of alloys were reheated for thixoforming. The billet reheating temperature is the most important parameter for thixoforming. The test piece for thixoforming was heated to 640℃ and held for 0, 300, and 900 seconds. It was then taken from the furnace subjected to thixoforming by a press machine at a pressure of 50MPa. Figure 2 presents a flow-chart of thixoforming test.

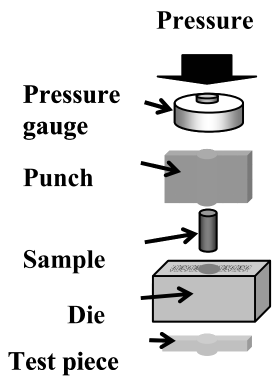

Figure 2. Flow-chart of thixoforming test.

3. Results and discussion

3.1 Continuous casting billets

3.1.1 Influence of inclined cooling plate on the formation of granular crystals

We first confirmed whether or not crystal seeds generate on the cooling plate. Quenched samples of AA6070 alloy were taken just above and below the cooling plate during pouring to observe microstructures. No crystals were found just above the cooling plate as shown in Fig. 3 (a), but many crystals were observed just below it as shown in Fig. 3 (b). Therefore the cooling plate is an important element in making the semisolid slurry.

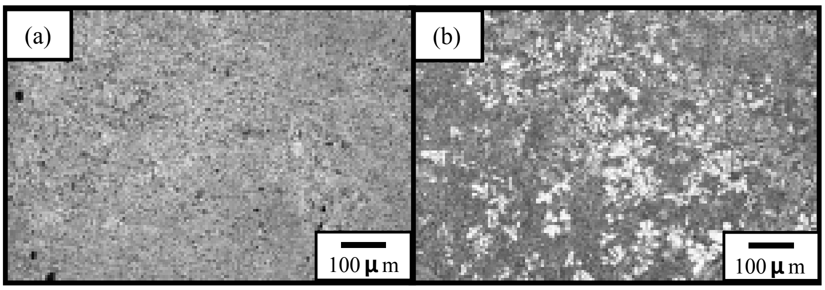

Figure 3. Microstructures of quenched sample during pouring. (a) above cooling plate (b) below cooling plate.

3.1.2 Microstructures of continuous casting billets

Figure 4 illustrates AA6070 aluminum alloy billet obtained by horizontal continuous casting.

Figure5 presents the microstructures of this billet. When the cooling plate was used, granular crystal structures appeared throughout the billets as shown in Fig. 5 (a). In contrast, when the cooling plate was not used, α aluminum dendrites appeared throughout the billet as depicted in Fig. 5 (b). Many crystal seeds of primary α aluminum are formed on the cooling plate and moved with molten alloy into the tundish. In the heat-insulating tundish, crystal seeds became granular grains and the semisolid slurry was cast in the continuous casting mold. However, when the cooling plate was not used, no crystal seeds generated in the tundish, and crystals nucleated only on the continuous casting mold wall and grew dendrite crystals.

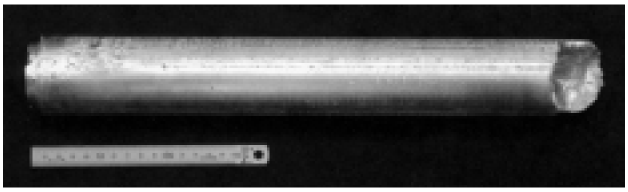

Figure 4. AA6070 aluminum alloy billet obtained by horizontal continuous casting.

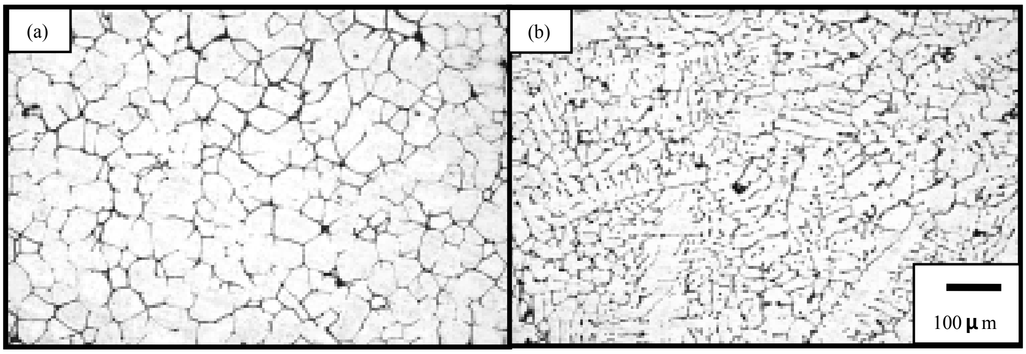

Figure 5. Microstructures of 6070 aluminum alloy obtained by horizontal continuous casting. (a) with cooling plate, (b)without cooling plate.

3.1.3 Influence of pouring temperature, and length and angle of the cooling plate on the grain size

We examined the influences of pouring temperature, and length and angle of the cooling plate to obtain the fine grains. Figure 6 presents the relationship between the pouring temperature onto the cooling plate and the grain size of AA6070 aluminum alloy billet. The lowest pouring temperature produced the smallest grains.

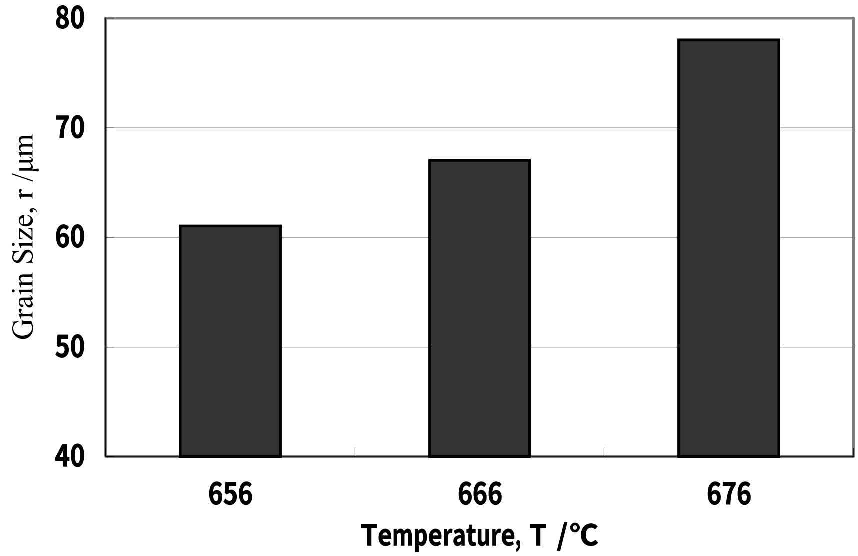

Figure 6. Relationship between grain size and poring temperature for semisolid AA6070 alloy using an inclined cooling plate.

It was noted that the lower the pouring temperature, the more the crystal seeds existed in the tundish. In this investigation, a 200 mm plate was optimum for obtaining the finest grains. If the cooling plate is too long, the molten alloy flowing onto it forms a solid shell because the temperatures of the molten alloy decreases. In contrast, a shorter plate generates smaller amounts of crystal seeds because there are fewer positions for the seeds to generate. Granular grains in the billet are also related to the inclined angles of the cooling plate. The best angle for AA6070 alloy is 60 degrees. Same results were obtained for the AA7075 alloy.

3.2 Thixotropy of continuous casting billet

3.2.1 Influence of microstructures on thixoformability

Figure 7 illustrates appearance of 6070 aluminum alloy test pieces after thixoforming. The test piece in Fig. 7 (a) consisted of granular grain structures ; that is (b) dendrite crystal structures. During thixoforming, the first test piece formed perfectly, but the second one did not. Figure 8 presents the relationship between the forces and times in the thixoforming test. The samples were heated at 640℃. Curve (b) of Fig. 8 consisted of dendrite crystals, indicating that the thixoformed force exceeded 30kN. In contrast, Curve (a) of Fig. 8 consisted of granular crystals and demonstrates that thixoformed forces were below 1 kN until 4 seconds. The suprising good flow behavior of this semisolid slurry can be observed when comparing the results in Figs. 8 (a) and (b). Same results were obtained for the AA7075 alloy.

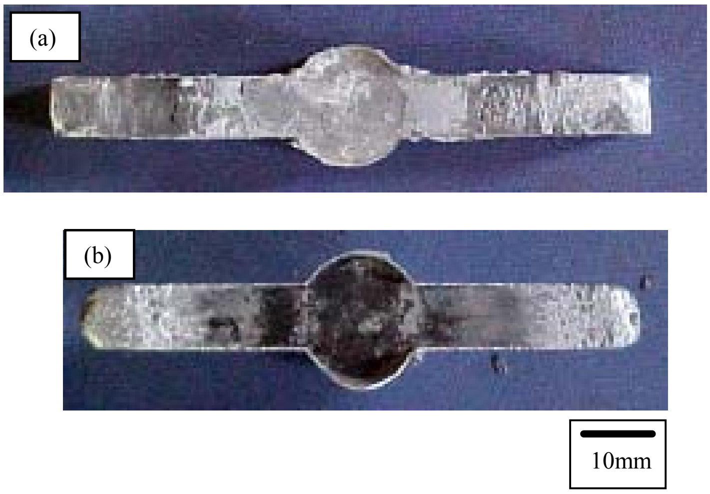

Figure 7. Appearance of 6070 aluminum alloy test pieces after thixoforming test. (a) granular grain structure, (b) dendrite structure.

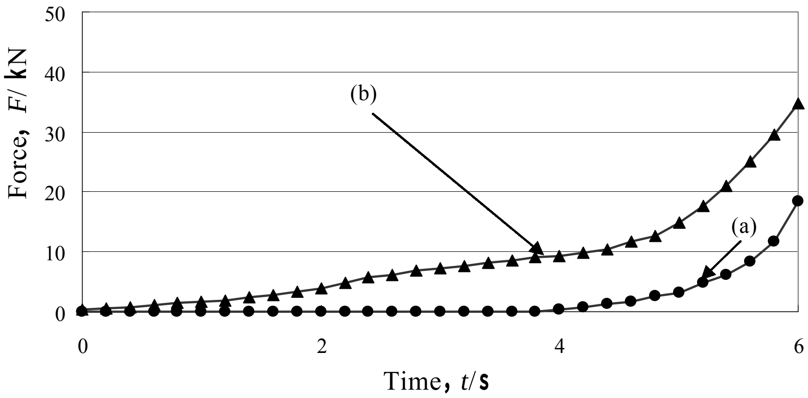

Figure 8. Relationship between force and time during thixoforming of 6070 aluminum alloy reheated to 640℃. (a) granular grain structure, (b) dendrite structure

3.2.2 Behavior of α aluminum crystals during thixoforming

Figures 9 and 10 present the microstructures of the test piece of 6070 aluminum alloy after thixoforming at 640°C. The microstructure of this test piece was originally consisted of granular grains and revealed the granular grains after thixoforming. Granular grains surrounded by liquid phase are easy to move by the small force for thixoforming. However, test pieces that originally consisted of dendrite crystals did not reveal the granular grains after thixoforming. It is difficult to move the semisolid alloy with dendrite crystals and liquid phase. Therefore, the latter test piece was not perfectly formed as shown in Fig. 7 (b). The same phenomenon was observed for the AA7075 aluminum alloy.

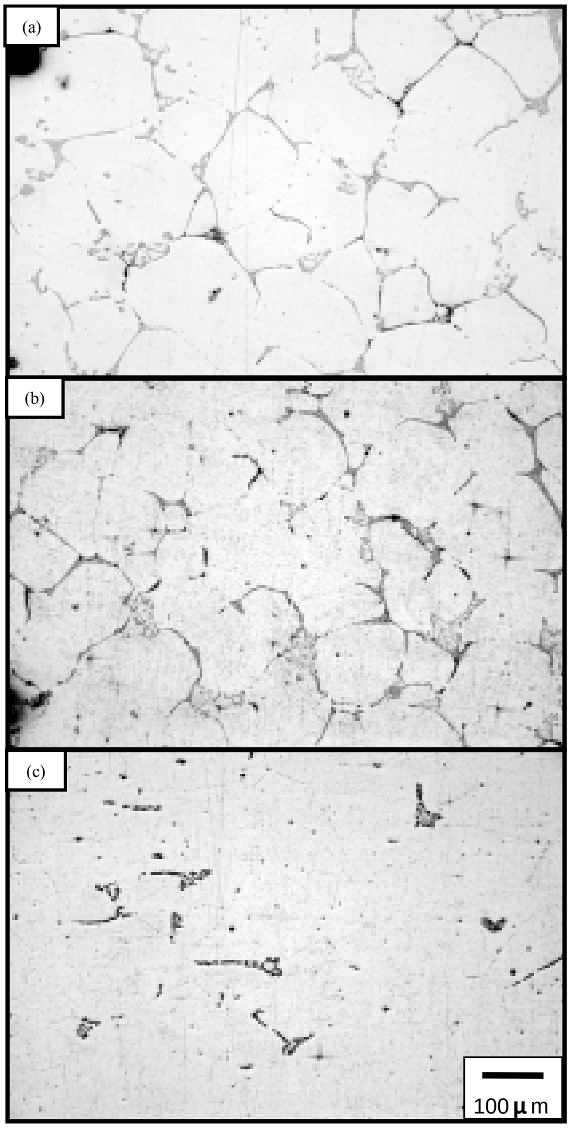

Figure 9. Microstructures of 6070 aluminum alloy obtained by thixoforming test of granular grain structure reheated to 640°C. (a) near edge, (b) 20mm from center, (c) center

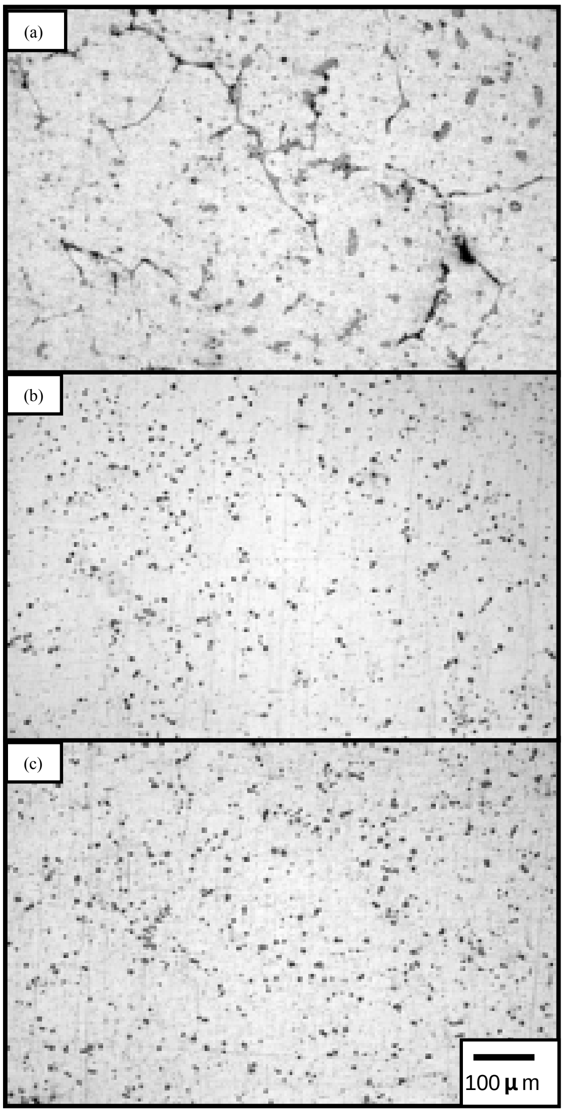

Figure 10. Microstructures of 6070 aluminum alloy obtained by thixoforming test of dendrite structure reheated to 640°C. (a) near edge (b) 20mm from center (c) center

4. Conclusions

In order to produce AA6070 and 7075 aluminum alloy billets for thixoforming, semisolid continuous casting was performed. An inclined cooling plate was used to generate the crystal seeds of primary crystals of α aluminum. The crystal seeds grew granularly in the tundish prior to entering the mold of the casting machine. A thixoformability test was also performed. The results obtained are as follows.

1) The cooling plate effectively generates crystal seeds in the molten AA6070 and 7075 aluminum alloys.
2) Lower pouring temperature onto the cooling plate yields more granular crystals of α aluminum in both wrought aluminum alloys.
3) The inclined cooling plate and molten pool in the tundish were useful for forming granular grains of the cast structures in the continuous casting billets.
4) The power of the thixoforging press depends on the billet structure.
5) Granular grains of the billet structures became rounder and larger during the forming process.

5. References

1) A. Ohno, T. Motegi and H. Soda, 1971, “Origin of the equiaxed crystals in castings”, Trans. Iron and Steel Institute of Japan, Vol.18, pp.11-14