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High Speed Twin-Roll Casting of Aluminum Alloys

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Abstract

A high-speed twin-roll caster was designed and used in order to increase casting speeds. Several Al-Mg-Si alloys were cast at a speed of 60 m/min. The Si content in these alloys is in the range of 0.5 - 7 mass%, and the Mg content is 0.3 mass%. Strips thinner than 4 mm can be cast continuously from the Al-Mg-Si alloys. The strips have an equiaxed, rather than columnar, grain microstructure. Rolled strips of 0.5 mm thickness with T4 heat treatments are not broken after 180-degree bending. The retained eutectic Si particles after T6 heat treatment are smaller than 5 um and spherical.

1. Introduction

The conventional twin-roll caster for aluminum alloys has a horizontal configuration. The disadvantages of the conventional twin-roll caster for aluminum alloy (CTRCA) are low casting speeds and limited choices of alloys that are castable by this processing. The vertical-type high-speed twin-roll caster (HSTRC) used in the present study was devised to overcome these disadvantages [1]. It is known that strip casting of aluminum alloys 5083 and 5182 is very difficult because of their wider freezing zones. HSTRC can, however, be used to cast strips of 5083 and 5182 alloys at a speed of 60 m/min. Strip casting of aluminum alloys that have wide freezing zones has been achieved in HSTRC due to its capability in obtaining high cooling rates. Some methods have been adopted in HSTRC to help achieve high cooling rates. These methods include the use of a copper roll, a cooling slope, and the elimination of the use of lubricants.

The 1000 and 3000 series aluminum alloys can be cast by CTRCA, and there have been many reports on strip casting of these alloys. However, there are few reports on strip casting of age hardenable aluminum alloys such as Al-Mg-Si alloys. The shape and size of the eutectic Si affect the ductility, and especially the bending of the strip. The strip would be bent to a small bend radius if the eutectic Si could be refined by rapid solidification. Therefore, strip casting of Al-Mg-Si alloys is useful to make the eutectic Si small and spherical. The castability, surface condition, microstructure and mechanical properties were investigated.

2. The Twin-Roll Caster Used in This Study

A schematic illustration of the high-speed twin-roll caster is shown in Figure 1 [1]. A vertical-type twin-roll caster equipped with a nozzle and a cooling slope was adopted [1,2]. The vertical type is not suitable from the standpoint of strip transfer. This is because the strip is bent at a right angle. However, the feed of the molten metal into the roll bite is easy in the vertical type. The nozzle was adopted to increase the hydrostatic pressure between the roll and the molten metal at the time when the molten metal starts to contact the roll [3,4]. Low superheat casting and semisolid casting were useful in increasing the cooling rate and roll speed. The separating force (rolling load) was very small. This small load means that hot rolling was not used. This load is necessary to improve the heat transfer between the strip and the roll [5]. However, an extra load was not needed. Copper rolls were used, but not lubricant. This was very useful for increasing the cooling capability of HSTRC. The thermal conductivity of copper is very large. Usually, lubricant is sprayed on the roll to prevent the strip from sticking to the roll. However, the lubricant becomes a source of heat resistance. Therefore, without lubricant, the cooling rate of the strip increases. In HSTRC, the strip did not stick to the roll due to the low rolling load and the use of the copper roll.

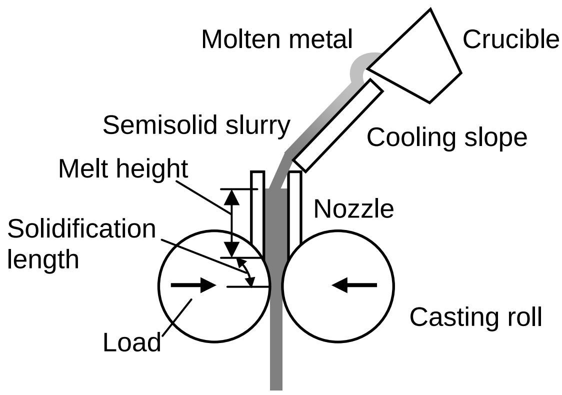


Figure1: Schematic illustration of the vertical-type high-speed twin-roll caster.

Table 1: Experimental conditions and specifications of the roll caster.

Roll material	copper, diameter 300 [mm], width 100 [mm], speed 60 [m/min]
Aluminum alloy	Al-0.3%Mg-XSi (X=1, 3,5,12,20 mass%), 6063, A356, super heat lower than 15°C
Cooling slope	mild steel, length 300 mm, width 100 mm, inclination angle 60°
Separating force	0.14 kN/mm
Solidification length	100 mm
Melt head	100 mm

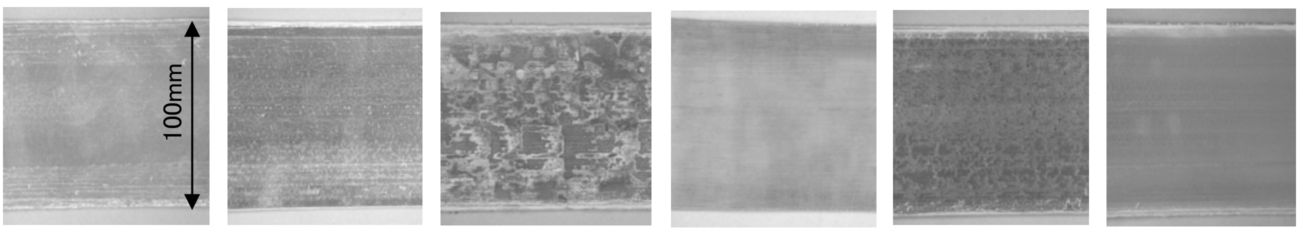
3. Experimental Conditions

Experimental conditions and specifications of the roll caster are shown in Table 1. The alloys tested were Al-0.3%Mg-Si of varying Si contents, 6063, and A356. Each alloy of 3 kg was melted in a carbon crucible using an electric furnace. The molten metal in the crucible was poured down the cooling slope, then flowed in the roll bite. The rotating speed of the rolls was 60 m/min. Specimens for tensile tests were prepared as follows. The cast strip was homogenized at 540°C for 2 hours, then cold rolled to 1 mm. The 1 mm thick strip was annealed at 540°C for 1 hour and cold rolled to 0.5 mm. The width and gage length of the test piece were 10 mm and 20 mm, respectively. The heat treatment condition of T4 and T6 was performed as follows. The test piece was kept at 540°C for 2 hours and water quenched, and after that the test piece was kept at 160° C for 6 hours.

4. Result and Discussions

4.1 Surface of the Strip

The surface of the as-cast strip is shown in Figure 2. The surface condition was affected by the Si content. When the Si content was lower than 1 mass% or higher than 5 mass%, the surface of the strip was sound. When the Si content was 3 mass%, ripple marks occurred on the surface. The ripple marks did not exist on the surface of 6063. In contrast to the cast strips of Al-0.3%Mg-1%Si, Al-0.3Mg-12Si and Al-0.3Mg-20Si, some marked ripple marks occurred on the surfaces of Al-0.3Mg-5Si and A356**.** The rippling on the strip surface of the Al-0.3%Mg-3%Si alloy could be improved by cold rolling, as shown in Figure 2 (d). These ripple marks corresponded to roll speeds and hydrostatic pressures of the molten metal at the start point of the roll-melt contact. The higher the speed was, the worse the surface condition. The higher the pressure was, the better the surface quality. The ripple marks occurred at the tip of the nozzle. The existence of the ripple marks was not affected by the shape of the nozzle tip. The ripple marks resulted from the vibration of the meniscus of the melt at the nozzle tip. These ripple marks may affect the flowability of the melt in the semi-solid condition. The ripple marks did not exist on the strip surface of non-mushy-type forming alloy such as 6063. Also, the semi-solid layer almost did not exist in the skin-formation-type alloys. A356 and Al-0.3%Mg-12%Si alloys are mushy-type casting alloys. The flowability of the semi-solid state is good. The solid faction of the semi-solid metal in the puddle is low and mushy. The semi-solid metal in the puddle acts like a liquid. Therefore, the vibration does not influence the meniscus on the surface. The flowability of the semi-solid layer of the Al-0.3%Mg-3%Si alloy is not good, and the semi-solid metal acts like a solid metal. The oscillation of the meniscus at the nozzle tip affects the starting position of the solid solidification layer, which moves with the roll. The oscillation of the starting point of the solidification layer with the roll became the ripple marks.



(a) (b) (c) (d) (e) (f)

Figure 2: Surface of as-cast Al-Mg-Si alloy strips. (a) 6063, (b) Al-0.3%Mg-1%Si, (c) Al-0.3%Mg-3%Si, (d) cold rolling of (c), (e) Al-0.3%Mg-5%Si, (f) A356.

4.2 Strip Thickness

The thickness variation of the cross section of the as-cast Al-0.3%Mg-3%Si alloy is shown in Figure 3. The variation in thickness was less than 0.4 mm, and the shape of the as-cast cross-section was convex. This shape was suitable for rolling. The variation of thickness after rolling is also shown in Figure 3. There was little variation in thickness after rolling. The thickness variation of other strip cast Al-Mg-Si alloys was almost the same as that of the Al-0.3%Mg-3%Si alloy.

The relationship between the strip thickness and Si content is shown in Figure 4. The Si content affected the thickness of the strip, and the shape of the relationship between the Si content and thickness is convex. When the Si content was 2 mass%, the strip was the thickest. The surface of the strip was the worst when the Si content was 3 mass%, as shown in Figure 2. There may be a relationship between the results of the thickness and the surface [6]. The flowability of melt in a semi-solid condition may affect the thickness of the strip. There is a semi-solid layer on the solid that has formed. The thickness of the semi-solid layer may be the largest when the Si content is 2 mass%. The flowability in the semi-solid condition of 2 mass% Si may be the worst. The semi-solid metal, with a low solid faction, moved with the solid layer. As a result, the strip of the metal with low flowability in the semi-solid condition was expected to become thick. When the flowability of the semi-solid metal is good and has a higher solid faction, the thickness of the semi-solid layer, which moves with the solid layer, becomes thin. The flowability of the semi-solid metal differs, depending on the composition of the alloy. Usually, the flowability in the semi-solid condition improves as the addition of the alloying element becomes larger. Therefore, the thickness of the strip becomes thinner as the Si content increases, particularly when the Si content is larger than 2 mass%, as shown in Figure 4. The semi-solid layer is very thin for non-mushy-type forming alloys. The thickness of the semi-solid layer of 6063 was very thin, and the thickness of 6063 became thinner than that of Al-0.3%Mg-2%Si.

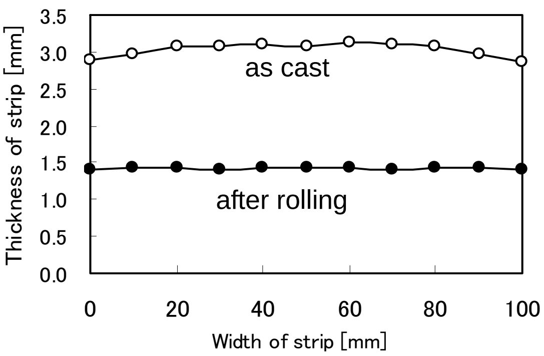


Figure 3: The thickness variation of Al-0.3%Mg-3%Si alloy in the width direction.

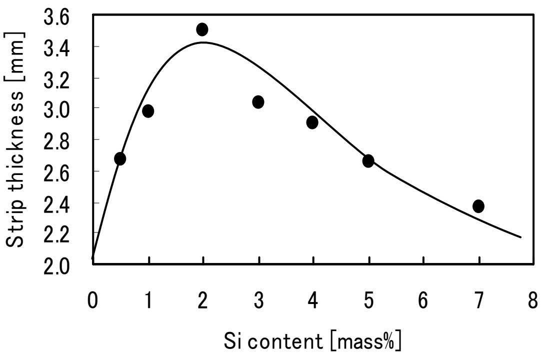
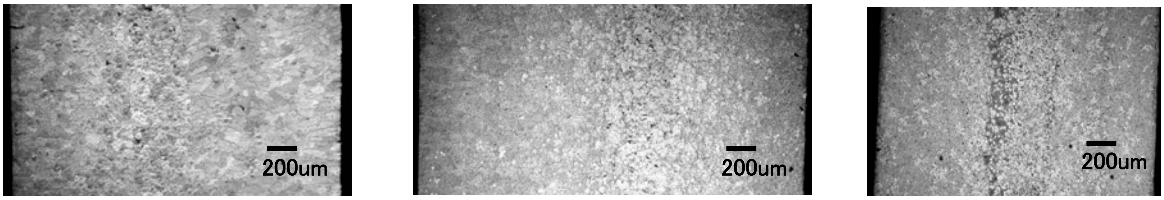


Figure 4: Relationship between Si content and strip thickness.

4.3 Microstructure

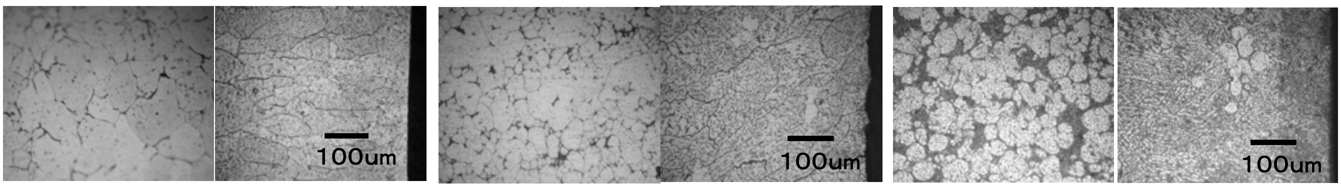
The microstructure of the as-cast strips is shown in Figures 5 and 6. These figures show the cental area and the area near the surface. The microstructure was very fine. It was clear that the strips were rapidly solidified due to low superheat casting (or semi-solid casting), the use of the copper roll and the elimination of lubricant. Rapid solidification was attained by high-speed roll casting using the HSTRC. While strips produced by CTRCA usually had a columnar microstructure, the strips produced in the present study did not contain any columnar structures. These strips had a duplex structure. At the center of the strip was a spherical structure, and both sides of the center region were almost equiaxed. The microstructure in the central region was almost the same as that observed in products produced by rheocasting and thixocasting. The eutectic Si of the as-cast strips was very fine and spherical. This was the effect of rapid solidification. The eutectic Si of the as-cast A356 strip was 3 um. This non-uniformity of the microstructure could be improved.

The microstructure of the cross-section and eutectic Si is shown in Figure 7 in samples after homogenization, cold rolling to 1 mm, annealing, cold rolling to 0.5 mm and T6 heat treatments. The microstructure became almost uniform in the thickness direction. The size and shape of the eutectic Si greatly affected the crack on the outer surface when the strip was bent. The eutectic Si after T6 was larger than that of the as-cast strip. However, the size of the eutectic Si was smaller than 5 um. The number of the eutectic Si became higher as the Si content increased. The size of the eutectic Si was not much affected by the Si content. The size of grains of the T6 strip became smaller as the Si content increased. The grain size of 6063 was about 60 um, and about 30 um for A356.



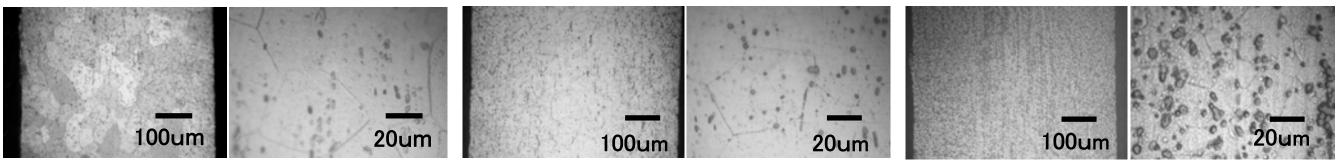
(a) 6063 (b) Al-0.3%Mg-3%Si (c) A356

Figure 5: Microstructure of the cross section of the as-cast strip.



(a)6063 (b)Al-0.3%Mg-3%Si (c)A356

Figure 6: Microstructure of the center area and the area near the surface of the cast strip. On the left side is the center area. On the right side is the area near the surface.



(a) 6063 (b) Al-0.3%Mg-3%Si (c) A356

Figure 7: Microstructure Al-Mg-Si alloy strips. The heat treatment was T6. The photos on the right are enlarged views of the photos on the left.

4.4 Mechanical Properties

The mechanical properties of the Al-Mg-Si alloys obtained through tensile testing are shown in Figure 8. The heat treatment was T6. The tensile strength and 0.2% proof stress became gradually larger as the Si content increased. When the Si content was larger than 3 mass%, the increment became small. On the other hand, the elongation became small as the Si content increased. The balance among tensile strength, proof stress and elongation was the best when the Si content was 3 mass%. The 180-degree bending was carried out. The test piece was cut from the same piece that was used for making tensile samples. The thickness of the test piece was 0.5 mm, and bending was carried out after T4 and T6 heat treatments. The result of the 180-degree bending test is shown in Table 2. “Yes” indicates that there was no crack after bending. “No” indicates that cracks formed on the surface after bending. The crack did not occur at the outer surface of the test piece after the T4 heat treatment. This result was due to the effect of the fine and spherical eutectic Si.

5. Conclusions

High-speed roll casting of Al-Mg-Si alloys was performed using a vertical-type high-speed twin-roll caster (HSTRC). The effect of the Si content was investigated. The Si content affected the thickness and surface condition of the strip. When Si was 2 mass%, the strip was the thickest. Ripple marks on the surface were noted when Si was 3 mass%. When the Si content was lower or higher than 3 mass%, the surface condition was sound. The microstructure of the as-cast strip had almost equiaxed grains, and the eutectic Si was very fine and globular. The balance between the tensile strength and elongation was good when the Si content was 3 mass%. A rolled 0.5-mm thickness of strip was used as the test piece for the 180-degree bending test. Cracks did not form at the outer surface of the bent test piece after the T4 heat treatment.

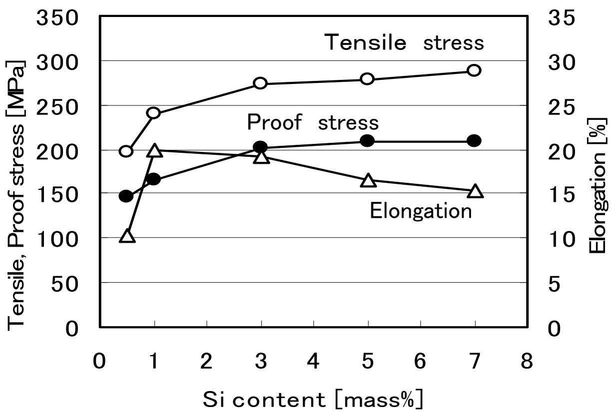


Figure 8: Tension testing of Al-Mg-Si alloys.

Table 2: Results of 180-degree bending test. Yes: without cracks, No: wit cracks.

Alloy	T4	T6
6063	Yes	Yes
Al-0.3%Mg-1%Si	Yes	Yes
Al-0.3%Mg-3%Si	Yes	Yes
Al-0.3%Mg-5%Si	Yes	No
A356	Yes	No

Acknowledgements

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