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A High-Speed Twin Roll Caster for Aluminum Alloy Thin Strip

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A high-speed twin roll caster intended for recycled aluminum alloy was designed and assembled. A vertical arrangement was adopted, in view of the ease of pouring molten metal into the roll bite. This caster attained increased cooling rate and increased casting speed. In order to investigate caster characteristics, the castings of 1000, 3000, 5000, and 6000 series aluminum alloys containing added impurities and of A356 were demonstrated to form into strips. The strips thinner than 4 mm were cast at the speeds of 60 m/min to 150 m/min. Use of copper rolls, non-use of parting materials, and reducing the thickness of the strip contributed to improve the cooling rate and casting speed of the strip. In the most cases, the strip cast by the high-speed twin roll caster was of duplex microstructure. Grains at the center in thickness were equiaxed or spherical, and grains at the surface sides were short columnar or equiaxed. Cold rolling and heat treatment improved nonuniformity of the microstructure in the thickness direction. The caster has an advantage to provide aluminum alloy having a wide freezing zones. A cast strip of A356 showed good ductility. An annealed A356 strip was not broken in a 180 degree bending test.

Key words: twin roll caster, strip casting, thin strip, rapid solidification, recycle

1. INTRODUCTION

A twin roll caster for aluminum alloy has several advantages, including rapid solidification, low equipment cost, and low running cost. In the present study, attention was paid to the ability to attain rapid solidification. In casting, precipitates of impurities can become fine, resulting in deterioration of mechanical properties. Also, the casting process for recycled aluminum alloy must incur low running cost. The twin roll caster satisfies this requirement, and requires little space for installation and operation. However, the twin roll caster for aluminum alloy also has disadvantages, including low casting speed and limitations on alloys that can be cast. Use of a twin roll caster for recycled aluminum requires an increase in cooling rate and improvement of other disadvantages. In the present study, attempts were made to increase cooling rate and roll speed, and these efforts were successful. In conventional roll casting, strip casting of aluminum alloy having a wide freezing zone is said to be difficult. The high-speed twin roll caster of the present study could cast aluminum alloys having wide freezing zones, such as 5083 and 5182 aluminum alloys.

In the recycling of aluminum alloy, deterioration of mechanical properties and limitations on the variety of alloys that can be cast are important problems that remain to be solved. Rapid solidification will contribute to solving these problems. Aluminum alloy for casting has good castability; therefore, roll casting of aluminum alloy for casting is easy. However, aluminum alloy for casting is said to have poor ductility, making aluminum alloy for casting unsuitable for forming. The poor ductility of aluminum alloy for casting can be improved by rapid solidification using the twin roll caster. If aluminum alloy for casting can be used for forming, the variety of the aluminum alloys available for recycling can be improved.

In the present study, a high-speed twin roll caster intended for recycling aluminum alloy was designed and assembled. The effects of the high-speed twin roll caster on alleviating the deterioration of mechanical properties by impurities were investigated, along with improvement of poor ductility of aluminum alloy for casting. Properties of the cast strip were investigated by metalography, a tension test, and a bending test.

2. HIGH-SPEEDTWIN ROLL CASTER

2.1 Rapid solidification

One of most important features of the twin-roll caster is rapid solidification. In the present study, some improvements were implemented in order to increase cooling rate. The conventional twin caster for aluminum alloys (CTRCA) uses steel rolls [1,2]. The material used for the rolls has marked influence on the cooling rate of the strip, which increases with the thermal conductivity of the roll material. Copper is higher in thermal conductivity than steel, making copper rolls suitable for the twin roll caster. In the CTRCA, the strip is hot-rolled at reductions greater than 20%. When the copper rolls are used, hot rolling under large load is difficult. The High-Speed twin roll caster (HSTRC) adopts copper rolls, and the hot rolling is not performed. Load affects the heat transfer coefficient between the roll and the strip; specifically, the hear transfer coefficient increases with load. When the load is too small, the strip cannot be cast continuously; the strip is not sufficiently solidified, and is broken. Therefore, a sufficient load for continuous casting of the strip must be applied. The load of the HPTC is 1/10 to 1/100 the load of the CTRCA.

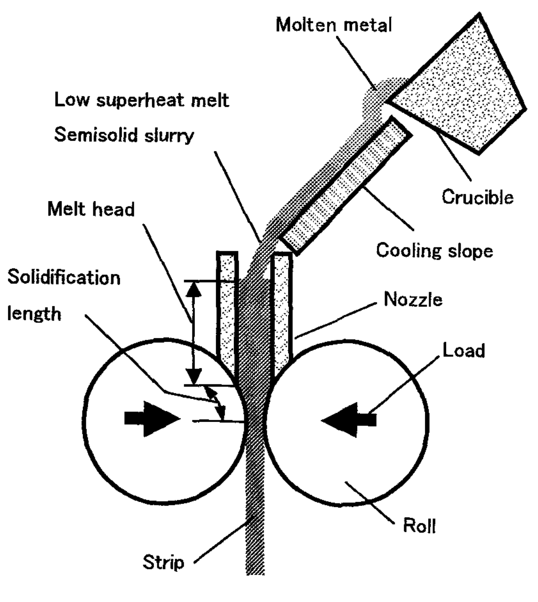


Fig.1 Schematic illustration of a vertical type high speed twin roll caster equipped with a cooling slope

Lubricant (parting material) is sprayed on the roll surface in order to prevent sticking of the strip to the roll in the CTRCA. The lubricant adds heat resistance, lowering the heat transfer coefficient between the roll and the strip. Therefore, use of a lubricant is not suitable for rapid solidification. Several factors influence sticking, including roll material (thermal conductivity), roll speed, and load. The roll material and the roll speed are related to the surface temperature of the roll. When roll has a high surface temperature, the strip tends to stick to the roll. The surface temperature of the roll increases with decreasing thermal conductivity of the roll material or increased roll speed. As shown in Table I, the use of copper prevents sticking of the strip to the rolls, especially in high-speed roll casting. The HSTRC does not require lubricant, because the strip does not stick to the roll. Even without lubricant, use of the copper roll increases cooling rate. Use of the copper roll promotes rapid solidification from two standpoints: the thermal conductivity of the copper is very large, and lubricant is not required.

A cooling slope was mounted on the HSTRC in order to perform low superheat casting and semisolid strip casting [3]. Low superheat casting and semisolid casting have several advantages, including an increase in the cooling rate of the strip and an increase in casting speed.

2.2 Roll speed (Casting speed)

In the CTRCA, roll speed is said to be slow, and productivity low. The upper limitation on roll speed is determined by continuity of the strip. When the roll speed is too high, the strength of the strip is insufficient, and the strip is broken as shown in Fig. 2. The continuity of the strip is dependent on the temperature of the strip, which increases with the roll speed. As the roll speed becomes faster, contact time between the strip and the roll becomes shorter, until the strip cannot be cooled enough to maintain sufficient strength. Cooling of the strip is influenced by the cooling ability of the roll, contact time between the strip and the roll, strip thickness, and melt temperature. The cooling ability of the roll can be increased by use of a material of high thermal conductivity and avoiding use of a lubricant. The temperature of the strip, especially around the strip surface, can be maintained lower as the contact time becomes longer. The temperature of the strip becomes lower as the strip becomes thinner, and the strip becomes thicker with increasing solidification time. Usually, when the copper roll is used, a strip of 4 mm thickness or less can be cast continuously. Therefore, the casting conditions are preferably set so that the thickness becomes 4 mm or less. The melt temperature affects the temperature of the strip; the temperature of the strip becomes high as the temperature of the melt temperature becomes high. Therefore, the upper limitation imposed on roll speed becomes higher with lower melt temperature.

In the CTRCA, the effect of the melt temperature has not been investigated over a wide range of melt temperature. Especially, few investigations have been conducted on low superheat casting. One of reasons is that the low superheat casting in the CTRCA is difficult, because the melt may solidify in the tip (nozzle) and a launder. Meanwhile, the low superheat casting can be carried out in the HSTRC. The mechanism of the nozzle of the HSTRC is different from that of the CTRCA. Experiments using the HSTRC demonstrated the effectiveness of low superheat casting in the field of the roll casting.

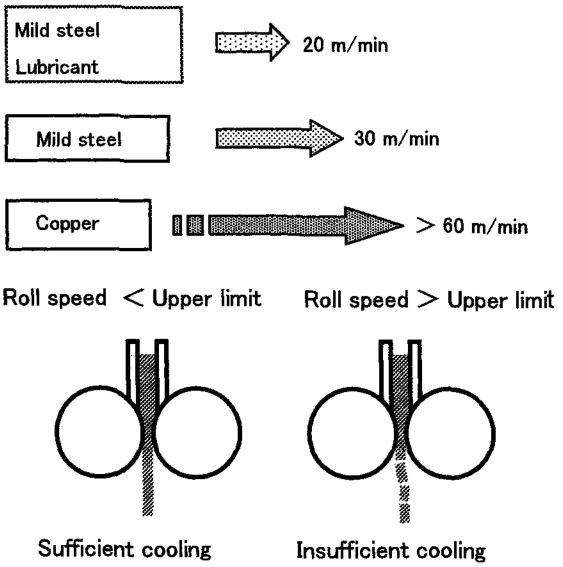


Fig.2 Effect of roll material and lubricant (parting material) on the upper limitation of the roll speed in order to continuously cast strip with sufficient cooling

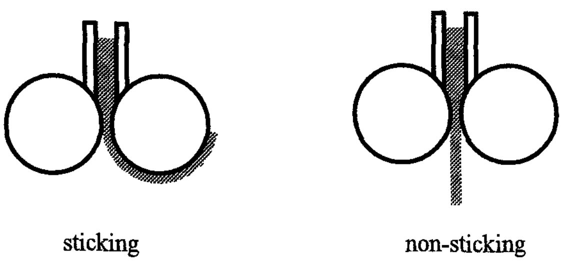


Fig.3 Schematic illustration showing sticking of the strip to the roll

Table 1 Relationship among sticking of strip, roll material and aluminum alloy.

Roll	1050	Al-4%Si	Al-12%Si	5182
Mild steel	●	●	●	O
Copper	O	O	O	O

● sticking O non-sticking

2.3 Hydrostatic pressure and a nozzle

A conventional twin caster for aluminum alloys (CTRCA) is a horizontal-type twin roll caster. The conventional twin roll caster for steel is of vertical type. The high-speed twin roll caster (HSTRC) of the present study is also a vertical-type twin roll caster. However, as shown in Fig. 1, a casting nozzle is mounted on the twin roll caster of the present study, whereas a casting nozzle is not mounted on the twin roll caster for steel. In the CTRCA, the nozzle is not in contact with the roll, but in the HSTRC, the nozzle is in contact with the roll. Therefore, the melt does not leak from the clearance between the nozzle and the roll. Consequently, the hydrostatic pressure due to the melt head is set higher.

When the molten metal is poured in the conventional vertical-type twin roll caster not equipped with the nozzle, the melt flow becomes turbulent near the rolls. When the nozzle is used, the melt flow exhibits lower turbulence, because the turbulence occurs only near the meniscus of the molten metal.

The solidification length can be controlled by the position of the nozzle. In the conventional vertical-type twin roll caster, bouncing of the meniscus of the melt leads to variation in the solidification length. In the HSTRC, the nozzle maintains the solidification length constant, and therefore strip thickness can be maintained constant.

Oscillation of meniscus of the molten metal occurs at the corner where the nozzle comes into contact with the roll, forming an oscillation mark on the strip surface. The contact condition between the melt and the roll is worse at the oscillation mark than at other areas. Oscillation marks become increasingly prominent with higher roll speed, and are a notable problem in high-speed roll casting. Hydrostatic pressure is useful for preventing oscillation.

In the CTRCA, strip thickness is controlled by roll speed and load. In the HSTRC, strip thickness is controlled by two factors; roll speed and solidification length. Operation of the CTRCA serves two functions; casting and hot rolling. In the HSTRC, only casting is considered. Thickness of the solidification layer is determined by the solidification time. In the CTRCA, the solidification time is controlled by roll speed. In the HSTRC, the solidification time is controlled by roll speed and solidification length, and changing the solidification length is easy. The mechanism of the nozzle (tip) of the HSTRC differs from that of the CTRCA. The nozzle of the HSTRC is assembled from four plates, including two side dam plates and two nozzle plates, the nozzle plates being moveable. A puddle is formed in the space between the four plates. The nozzle of the HSTRC is simple and adjustable. Roll speed affects the microstructure. The HSTRC can cast a strip of proper thickness and proper microstructure.

3. EXPERIMENTAL CONDITIONS

Roll casters have numerous advantages, including low energy consumption, low equipment and operating costs, and rapid solidification[1,2]. Although wrought aluminum alloys are often cast by a twin roll caster, such a caster can cast only certain wrought aluminum alloys. Aluminum alloy having a narrow freezing zone are suitable for a conventional twin roll caster; mechanical properties of a strip cast by a twin roll caster are inferior to those of a strip made from DC-cast ingot. Aluminum alloys may be more easily strip cast by the HSTRC of the present study. Generally, elongation of an aluminum alloy by semisolid casting is larger than that from molten metal. Sheet aluminum alloys cast from semisolid have no known applications; therefore, they have never been produced. However, recent studies have shown that semisolid casting of aluminum alloys for casting improves elongation; therefore, low superheat casting and semisolid strip casting may improve the elongation of a strip of aluminum alloy for casting.

Table 2 Experimental conditions

Roll material	copper
size	diameter 300 [mm], width 100 [mm]
speed	60, 90, 150,180 [m/min]
aluminum alloy	1050, 3004, 5083, 5182, 6063, 6111, A356,
superheat	15[C]
Cooling slope	
Material	Mild steel
Size	length 300 [mm], width 100[mm]
inclination angle	60 [degrees]
Separating force	0.14 [kN/mm]
Solidification length	100[mm]
Melt head	100 [mm]

In the present study, attempts were made to perform low superheat and semisolid strip casting of some aluminum alloys. A cooling slope was used for low superheat and semisolid casting [3]. The cooling slope is very simple, and is very easy to mount on the twin roll caster. The aluminum alloy strip cast by the conventional twin roll caster usually has a columnar microstructure. From the standpoint of mechanical properties, an equiaxed structure is more suitable than the columnar structure. Low superheat casting is useful for obtaining an equiaxed structure.

4. RESULTS AND DISCUSSION

4.1 Strip casting at high roll speed

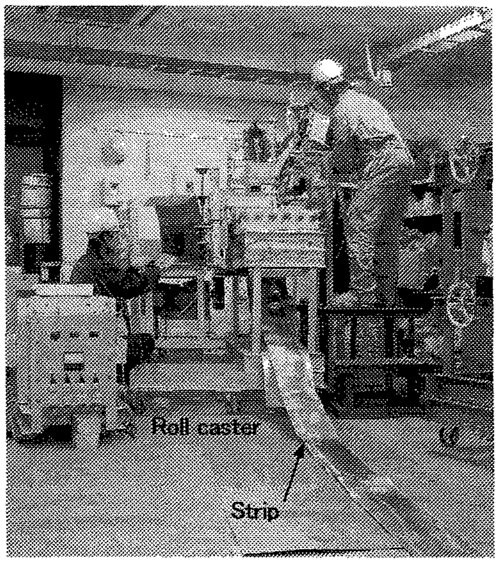
Seven kinds of aluminum alloys were cast by the HSTRC. These aluminum alloys could be strip cast continuously at speeds ranging from 60 m/min to 150 m/min. Strip thickness was 4.0 mm or lower. The HSTRC was able to cast at speeds 10 times those of the CTRCA. No lubricant was applied, and the strip did not stick to the roll. The strip cast by HSTRC had a thickness half that of the strip cast by the CTRCA. Moreover, the strip cast by the HSTRC without hot rolling was thinner than that cast by the CTRCA. The microstructure of the strip cast by the HSTRC differs from that of the strip cast by the CTRCA. Rolling improved the surface and thickness distribution. A reduction of 20% was sufficient for improving the surface and thickness distribution. Figure 5 shows the surfaces of as-cast strips. Periodic defects are observed on the surfaces of 5083 and 5182, and are caused by oscillation of the meniscus at the tip of the nozzle. This defect could be improved by cold rolling. Opposite surfaces of the strip cast by the CTRCA are identical.

4.2 Microstructure

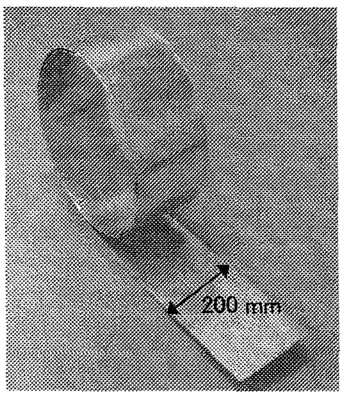
Figure 6 shows microstructure of as cast strip of 6111 cast at speed of 60 m/min. Most of the cross section exhibits an equiaxed or spherical microstructure, achieved by semisolid casting and rapid solidification. Figure 7 shows microstructures of cross section of A356 strip as cast and under T6 conditions. The microstructure of as cast strip was not uniform in the thickness direction, but the nonuniformity in microstructure was improved by cold rolling and annealing. The T6 strip exhibits a uniform microstructure. Eutectic Si of the T6 strip is spherical and very fine. The strip cast by the CTRCA exhibits some undesirable features, including columnar grains, gain inclination, and center segregation. The HSTRC improved these structures.

4.3 Adaptability to forming of alloy for casting

Figure 8 illustrates 180 degree bending of annealed A356 strip. The A356 strip could be bent 180 degrees without occurrence of crack at the outer surface or breaking, demonstrating that rapid solidification by high-speed roll casting can impart good ductility to the aluminum alloy for casting. This ductility is an effect of spherical and fine eutectic Si illustrated in Fig. 8.

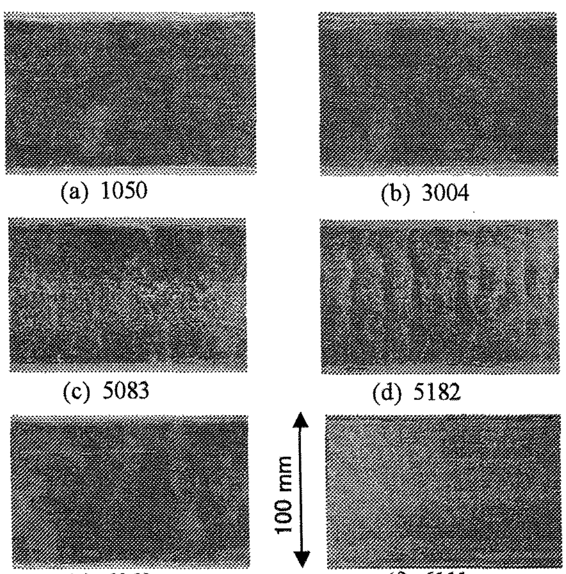


(a) Strip casting in operation



(b) coil of as cast A356 strip

Fig.4 Experiment of roll casting and as cast strip



(e) 6063 (f) 6111

Fig.5 surface of as cast strips by high speed twin roll caster at speed of 60 m/min

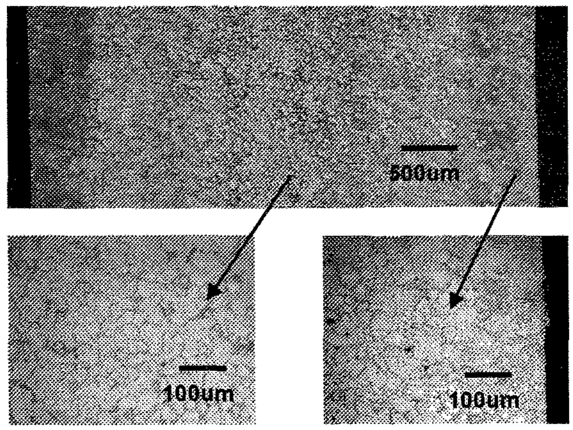


Fig. 6 Microstructure of cross section of as cast 6111 strip. Roll speed is 60 m/min

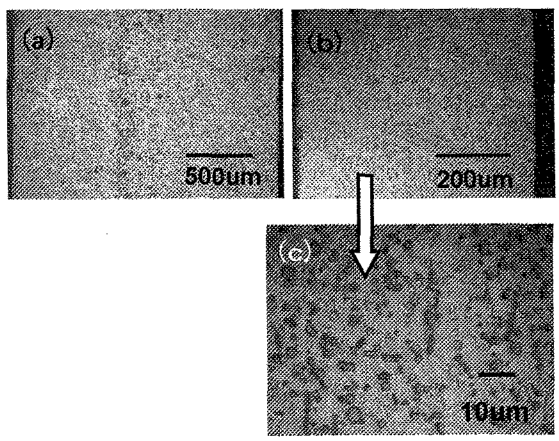


Fig.7 Microstructure of cross section of A356 strip. (a) as cast strip, (b) homogenized, cold rolled and T6 heat treated and (c)enlarged view of (b).

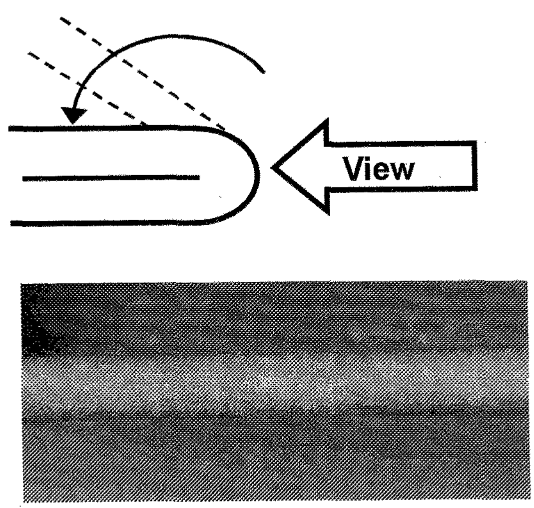


Fig.8 Surface of annealed A356 strip after 180 degrees bending.

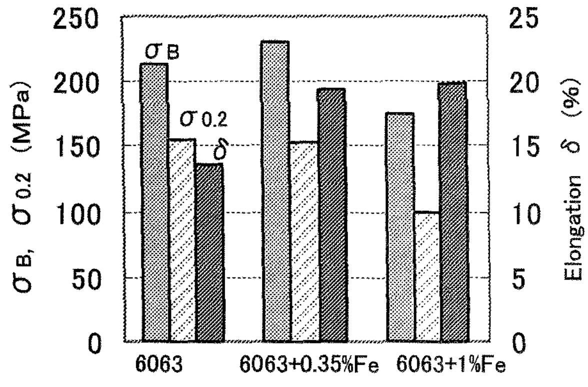


Fig. 9 Mechanical properties of 6063 and modified 6063 with impurity Fe. "6063+0.35%Fe" means that 0.35%Fe was added to 6063.

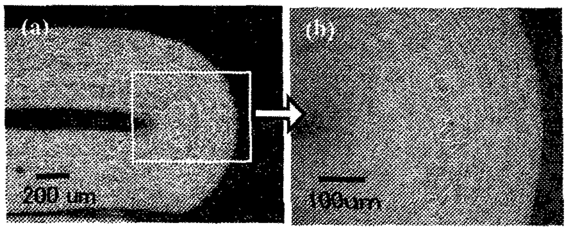


Fig. 10 180 degrees bending of modified 6063-T6 with 3%Fe as impurity: (a) cross section of bent strip and (b) enlarge of (a).

4.4 Improvement of deterioration by impurities

Fe was added to 6063 as an impurity. This modified 6063 was cast as model alloy of recycled aluminum alloy. Figure 9 shows mechanical properties of 6063 and modified 6063. +0.35%Fe denotes that 0.35%Fe was added as impurity. T6 heat treatment was performed. The mechanical properties of 6063+0.35%Fe are superior to those of 6063. The tensile strength and proof stress of 6063+1%Fe are inferior to those of 6063. However, the 6063+1%Fe exhibits good elongation. The Fe that was added as an impurity precipitated as fine grains by the effect of rapid solidification of high-speed roll casting. Therefore, deterioration of mechanical properties by addition of Fe as an impurity was prevented. The tensile strength and proof stress of 6063+1%Fe are lower than those of 6063. In 6063+1%Fe, T6 heat treatment did not increase strength. Fe might be combined with Si, and Si content is insufficient for T6 heat treatment. Figure 10 illustrates 180 degree bending of 6063+3%Fe strip of T6 condition. Cracks did not occur at outer surface, and the strip was not broken. The strip was bent without breaking when Fe was added in amounts up to 5%.

5. CONCLUSIONS

A high-speed twin roll caster of vertical type was designed and assembled to cast aluminum alloy thin strip. Several devices were adopted to realize rapid solidification of the strip. Casting was performed, and ability of the high-speed twin roll caster was estimated. Aluminum alloy having a very wide freezing zone, such as A5083, could be cast at speeds from 60 m/min to 150 m/min. Strip thickness ranged from 1.5 mm to 3.5 mm. The microstructure of the strip was not columnar, but equiaxed. The results demonstrate that the high-speed twin roll caster can improve the deterioration by impurities.

ACKNOWLEGMENTS

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