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Strip casting using a single roll caster equipped with a scraper

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ABSTRACT

Purpose: Purpose of this paper is to investigate the ability of a single roll caster equipped with a scraper. The purpose of the development of the single roll caster equipped with a scraper is casting of the strip without centre line segregation and porosity and with sound free solidified surface. The single roll caster can cast the strip without the centre segregation and porosity. However, the conditions of the free solidified surface and the thickness distribution are not sound. The scraper was adopted in order to improve the free solidified surface. Investigation of the effect of the scraper and the properties of the roll cast strip is the purpose of this paper.

Design/methodology/approach: A scraper was developed to improve the free solidified surface condition. The scraper scribed the semisolid metal on the free solidified surface to make the free solidified surface flat. The scraper was made from mild-steel-plate, and it was coated by the insulator sheet of 2 mm-thick. The scraper was pushed to free solidified surface by the constant load.

Findings: The scraper was very useful to improve the free solidified surface. AA5182 aluminium alloy strip could be cast at the speed up to 40 m/min. There was no centre segregation and porosity. There was no difference between the roll contact surface and the scribed surface. The mechanical properties of the roll cast strip were as same as those of strip made from D.C. cast slab. Hi-content Al-Mg alloy like Al-10 mass%Mg, which cannot be cast into the strip by the twin roll caster without centre segregation, could be cast into the strip without defect.

Research limitations/implications: Metal which was investigated was only aluminium alloy. It is not clear that this process is useful to other alloys like steel, copper et. al.

Practical implications: This process may be able to be used instead of the D.C. casting and the twin roll casting. Especially, this caster is useful the strip casting of the Al-Mg alloy.

Originality/value: The single roll caster equipped with a scraper is original development. This caster may be useful for aluminium and magnesium sheet making companies.

Keywords: Casting; Single roll caster; Scraper

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1. Introduction

A twin roll caster has the advantages of process saving, energy saving and rapid solidification [1-12]. However, the twin roll caster has the disadvantages of center segregation, edge cracks, and ripple marks appearing on the surface. It is difficult to improve these defects. In contrast, a single roll caster is free from these defects. Moreover, the equipment cost of the single roll caster is much more economical than that of the twin roll caster. The disadvantage of the single roll caster is that the free solidified surface is not flat and the thickness distribution is worse [13-14].

In this study, we mounted a scraper on the single roll to improve the free solidified surface of the strip. The fundamental properties of the strip cast by the single roll caster equipped with the scraper were investigated [15]. The trial casting of the 600 mm width strip was operated to investigate the utility of the scraper to wide strip. Moreover, the casting of Al-10mass%Mg alloy, which is seemed to be difficult to cast without center segregation by the twin roll caster, was tried.

The single roll caster equipped with a scraper (SRCS) of the present study has some advantages besides center line segregation and porosity less comparing with the conventional twin roll caster for aluminum alloy (CTRCA) [1-13]. One is higher roll speed. The roll speed of the CTRC is slower than 5 m/min. The roll speed of the SRCS is up to 40 m/min. This roll speed is slower than a vertical type high speed twin roll caster, but much high than that of the CTRCA [16-21]. The other advantage is that the process cost is economy. The cost of the roll is less than half. The frame of the SRCS does not need stiffness like the CTRCA.

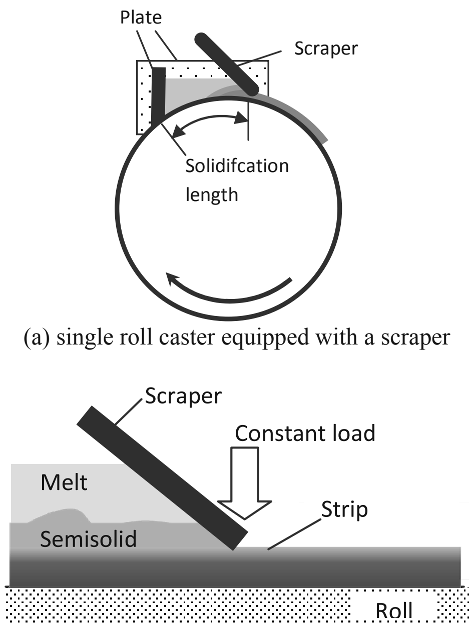
In the present study, the fundamental properties of the SRCA and cast strip are shown.

2. Experimental conditions

Schematic illustrations of the single roll caster equipped with a scraper and the scraper scribing the free solidified surface, as well as a photograph of the scraper, are shown in Fig. 1. The roll was made from mild steel. The diameter of the roll was 1000 mm and the width was 200 mm. Typically, parting material is used in the twin roll caster to prevent the strip from sticking to the roll. In this study, parting material was not used, as sticking did not occur. A melt pool was made on the roll by three plates and the scraper. The plates were mild steel plate 3.2 mm in thickness and covered by an insulator sheet. The solidification length was the distance between the back plate and the scraper.

As shown in Fig. 2, two kinds of scrapers, named Type A and Type B, were used. The tip of the Type A scraper was covered by the insulator sheet. The tip of the Type B scraper was mild steel plate. The width of both scrapers was 100 mm. The scraper made contact with the free solidified surface of the strip under a constant load. The effect of the load on the free solidified surface was investigated. The unit width load ranged from 0.13 N/mm to 1.1 N/mm. The roll speed, which is the most important factor in roll casting, ranged from 10 m/min to 40 m/min.

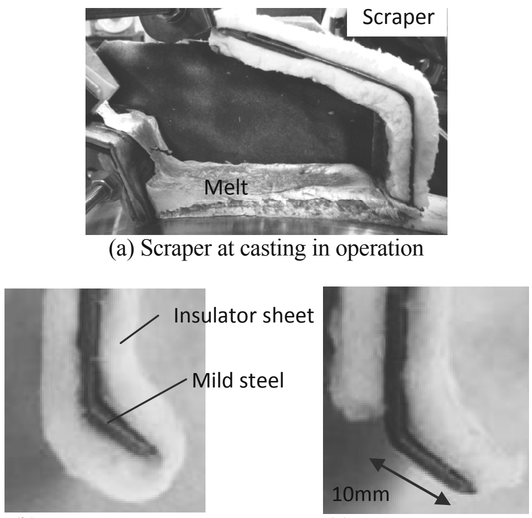
The free solidified surface and the cross section of the as-cast strip were observed. The as-cast strip was cold rolled down to 1 mm without annealing. A tension test, a bending test and a deep drawing test (cup test) were conducted on the cold rolled and annealed strips.



(a) single roll caster equipped with a scraper

(b) Enlarged view around the scraper

Fig. 1. Schematic illustration showing a single roll caster equipped with a scraper



(a) Scraper at casting in operation

(b) Scraper :Type A (c) Scraper :Type B

Fig. 2. Photograph showing the scraper at casting in operation, two kinds of scraper

AA5182 aluminum alloy was used to investigate the feature of the SRCS. This alloy has the tendency for center segregation when the strip is cast using a twin roll caster. Al-10mass%Mg alloy was cast to investigate the ability as this alloy more difficult to cast the strip without defects by the CTRCA.

Casting of 600 mm width strip was tried to investigate the ability of SRCS for industrial use. The mild steel roll, which diameter and width was 600 mm, was used.

3. Result and discussion

3.1. Fundamental properties

The free solidified surfaces are shown in Fig. 3. The effect of the scraper load is shown in (a), (b) and (c). When the scraper load was 0.13 N/mm (load of the unit width), the melt leaked. The free solidified surface was scribed and the surface became flat when the scraper load was higher than 0.46 N/mm.

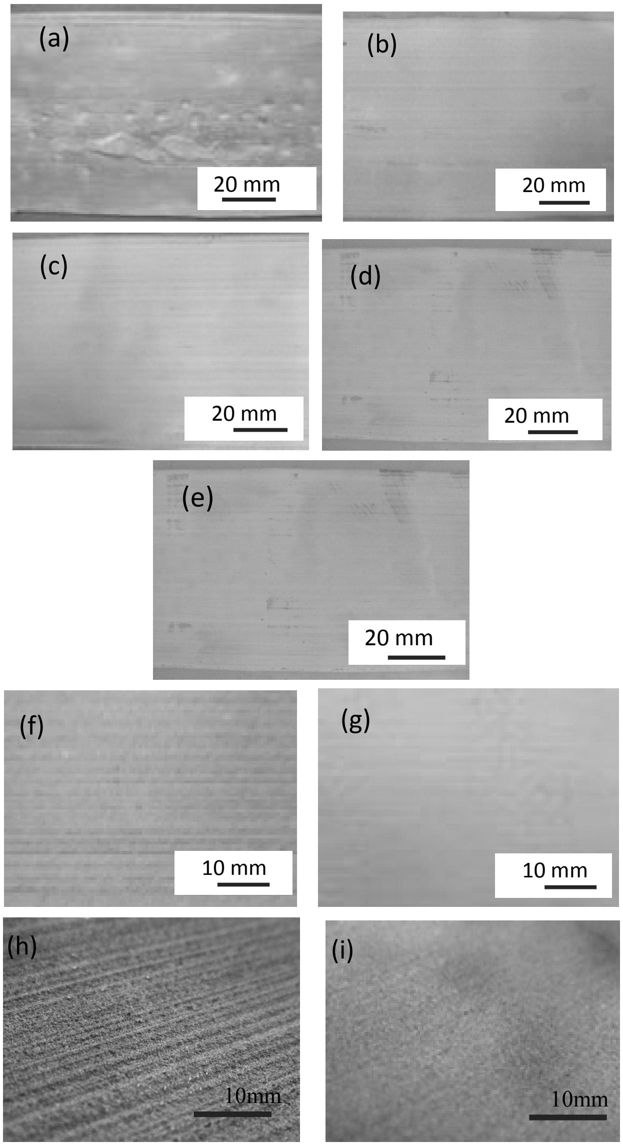


Fig. 3. Effects of the conditions on the scribed free solidified surface. Roll speed: (a), (b), (c), (f), (g): 20 m/min, (d), (e): 40 m/min. Scraper load; (a): 0.13 N/mm, (b):0.46 N/mm, (c), (d), (e), (f), (g): 1.1 N/mm. Type of scraper: (a), (b), (c), (d), (e), (f) and (h): Type A, (g) and (i): Type B. (h) and (i) are enlarged view of (f) and (i), respectively

The effect of the roll speed is shown in (b), (c), (d) and (e). Here, (b) and (c) were cast at 20 m/min, and (d) and (e) were cast at 40 m/min. The roll speed had no effect on the scribed surface.

The surfaces of (f) and (h) were scribed by the Type A scraper, and (g) and (i) were scribed by the Type B scraper. The surface scribed by the Type B scraper was better than that by the Type A scraper. Wear of the Type B scraper was not observed. Sticking of the melt to the tip of the Type A scraper did not occur, and so it was thought that a reaction between the melt and the Type A scraper did not occur.

The effect of the scraper load on the roll contact surface of the as-cast strip is shown in Fig. 4 for the Type A scraper. Voids are seen on the roll contact surface. The occurrence of the voids shows a wetting condition between the melt, and the roll was not sound. The voids improved as the scraper load increased. Depression of the voids by the scraper was one of the improvements. In the roll casting of aluminum alloy, roll coating of aluminum alloy occurs on the roll. The roll coating improves the wetting condition between the melt and the roll. The degree of roll coating becomes harder as the scraper load increased. Therefore, the roll contact condition improves as the scraper load increases.

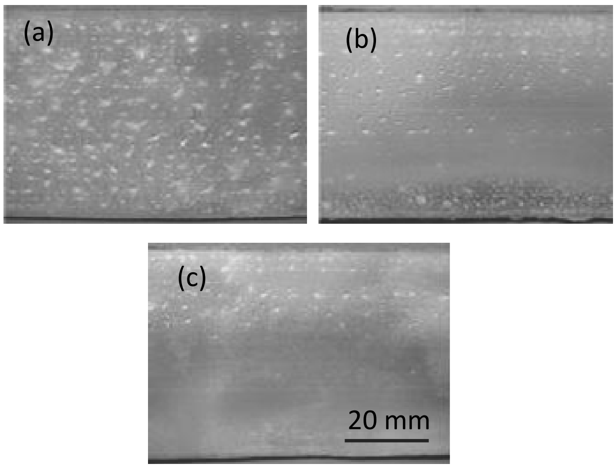
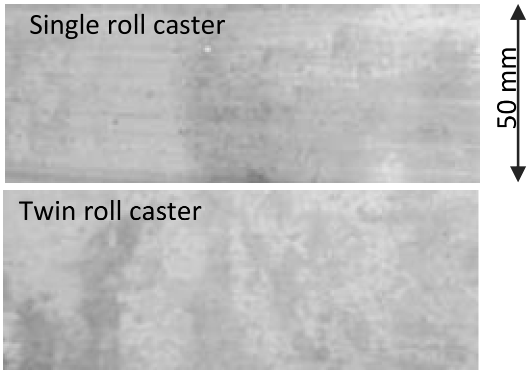


Fig. 4. Effect of the scraper-load on roll contact surface. Roll speed: 20 m/min, scraper-load (a): 0.13 N/mm (b):0.46 N/mm, (c): 1.1 N/mm. Type of a scraper: Type A

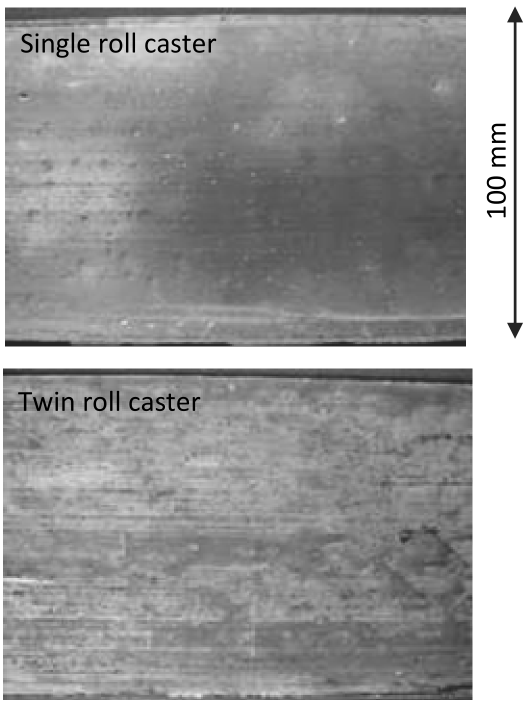
Figure 5 shows roll coating of the single roll caster of the present study and that of a twin roll caster, and also the roll contact surfaces of the strips. Parting material was not used. The roll coating of the twin roll caster was harder than that of the single roll caster. It was thought that the hot rolling of the twin roll caster made the roll coating harder. The roll coating was affected by the load, since the scraper load was much less than the roll load of the twin roll caster. When the roll coating was too hard, as in the roll of the twin roll caster shown in Fig. 5 (b), the strip surface became mottled. The surface of the strip cast by the single roll caster of the present study was better than that cast by the twin roll caster.

The effect of the scraper load on the cross section around the scribed surface of the strip is shown in Fig. 6. The porosity near the scribed surface became less as the scraper load increased.

Moreover, the scribed surface became flat. When the scraper load was 1.1 N/mm, a Mg-rich area appeared near the scribed surface. The effect of the scraper tip on the cross section around the scribed surface of the strip is also shown in Fig. 6. When the Type B scraper was used, the scribed surface became flat. The tip of the scraper, which was hard and flat, was sufficient to scribe the flat surface of the strip.



(a) Roll coating (surface of the roll)



(b) Surface of as-cast strip

Fig. 5. Roll coating and strip surface of the single roll caster and twin roll caster

The relationship between the scraper load and the strip thickness is shown in Fig. 7. The strip thickness became thinner as the scraper load became larger. When the load was larger than 0.8 N/mm, the decrease in thickness became smaller. This means the scraper scribed the soft semisolid layer, which had a thickness of approximately 0.5 mm. When the scraper load was too large, the strip stuck at the scraper. Therefore, the limitation of the scraper load was decided by the sticking of the strip.

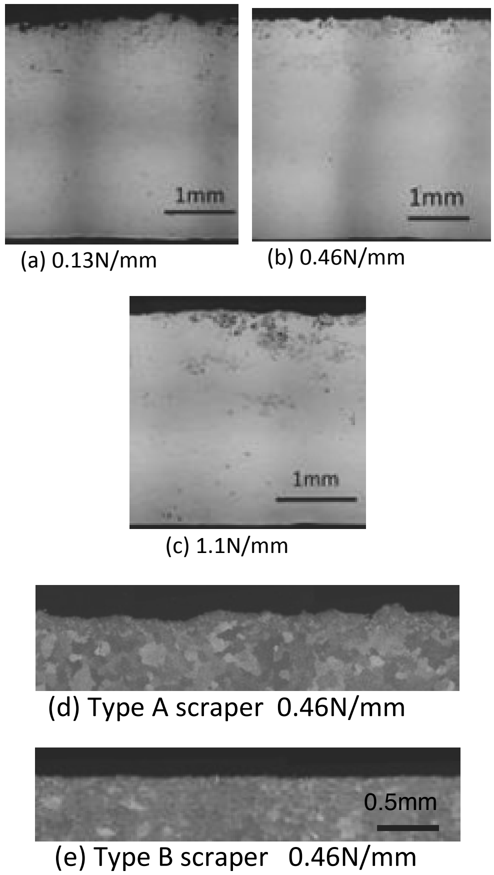


Fig. 6. Effect of scraper-load and scraper type shown in Fig. 2 on the cross section around the scribed surface of as-cast strip

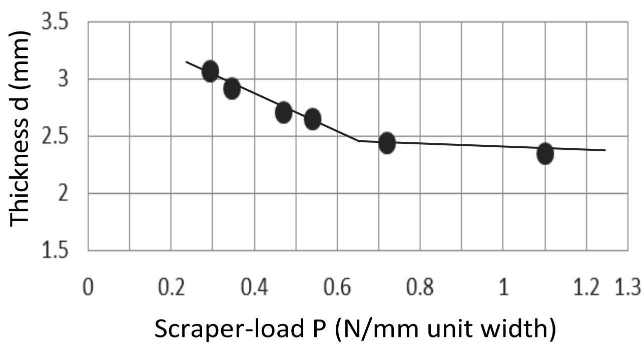


Fig. 7. Relationship between scraper-load and strip thickness (Type A scraper, Roll speed: 20 m/min)

The relationship between the roll speed and strip thickness is shown in Fig. 8. The Fig. 7 and Fig. 8 show the result of the type A scraper, and the type B scraper showed same tendency. The strip became thinner as the roll speed increased. This tendency is the same in both conventional single roll caster (without the scraper) and twin roll casters. The solidification time decreased as the roll speed increased. Therefore, the strip became thinner as the roll speed increased. Table 1 shows the relationship of the solidification length, roll speed, and strip thickness. The strip became thicker as the solidification length and the solidification time increased. In other words, the strip thickness could be controlled by the roll speed, scraper load, and solidification length. A large roll is suitable to make the solidification length long, and a large roll for the single roll caster can be made at a lower price than that for the twin roll caster, since the rigidity is not crucial for the roll of the single roll caster.

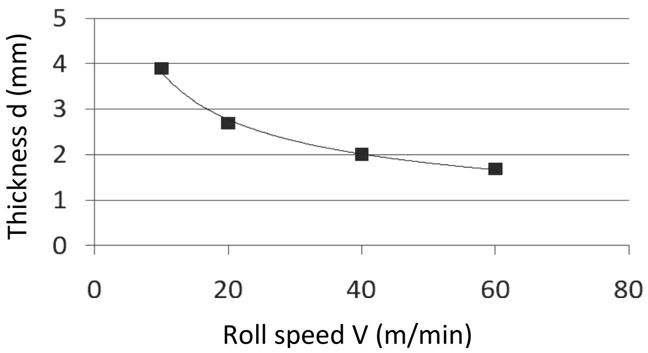


Fig. 8. Relationship between roll speed and strip thickness (Type A scraper, Load: 0.47 N/mm)

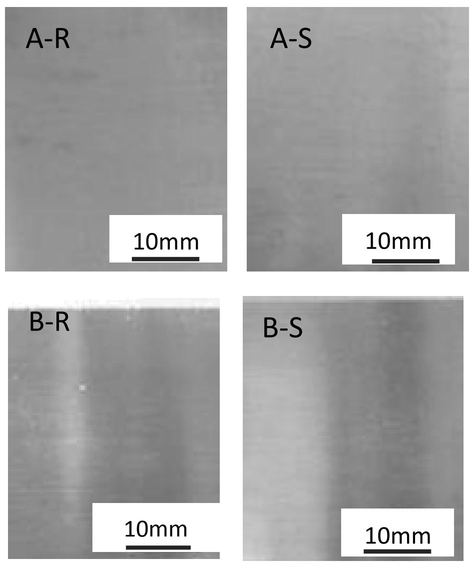


Fig. 9. Cold rolled surfaces of as-cast strip cold rolled down to 1 mm. "A" and "B" indicate the scraper type. "R" is the roll contact surface, and "S" is the scribed surface

The surfaces cold rolled down to 1 mm are shown in Fig. 9. No difference appeared between the roll contact surface and the scribed surface after cold rolling. The scribed surface using the Type A scraper was the same as that using the Type B scraper after cold rolling. Figure 10 shows the cross sections of the strips cold rolled down to 1 mm. The porosity near the scribed surface was depressed by cold rolling, and the scribed surface became flat. It is clear from the cross sections of the strips that the type of scraper did not affect the surface of the cold rolled strip.

Table 1.
Relationships among solidification length, roll speed, and strip thickness (Type A scraper)

Roll Speed (m/min)	Solidification length (mm)	Strip thickness (mm)
20	100	2.7
20	150	3.1
40	100	1.7
40	150	2.8

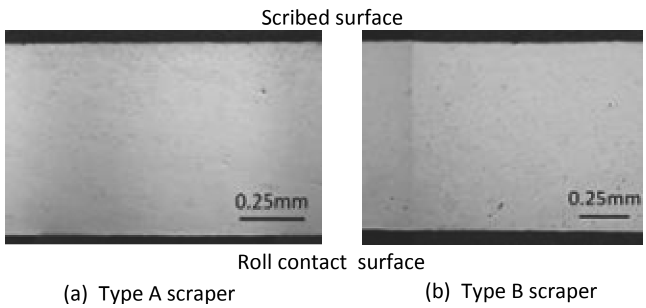


Fig. 10. Cross sections of the strip cold rolled down to 1 mm

Table 2.
Results of the tension test (cold rolled down to 1 mm, annealed at 380^{O}C for 30 s)

Scraper rype	Tensile stress (MPa)	Proof stress (MPa)	Elongation (%)
Type A	278	139	21.5
Type B	285	144	26.5

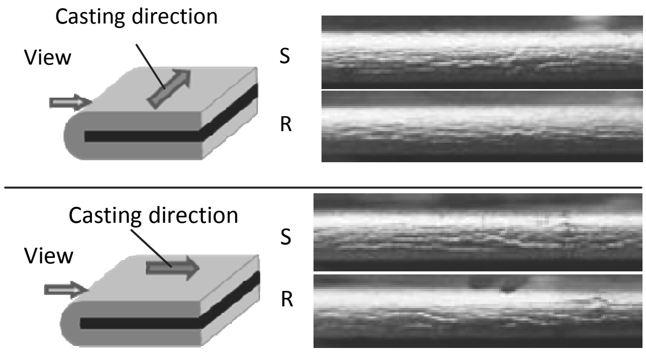
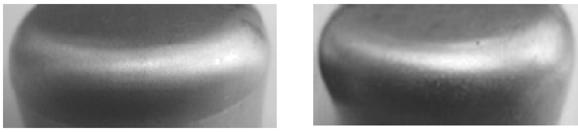


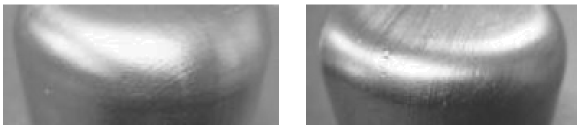
Fig. 11. Result of the bending test. The strip was cold rolled down to 1 mm, and annealed at 380^{O}C for 30 s before bending. The Type B scraper was used for casting. "S" indicates the scribed surface was the outer surface, and "R" indicates the roll contact surface was the outer surface

The results of the tension test are shown in Table 2. The result of the tension test of the strip cast using the Type B scraper was superior to that cast using the Type A scraper. The tensile strength of the strip with the smooth scribed surface was improved. The results of the bending test are shown in Fig. 11. No difference was seen between the scribed surface and the roll contact surface of the strip after cold rolling and annealing before the bending test. The scribed surface had the same bending strength as that of the roll contact surface. The results of the deep drawing test showed that this property was the same when the scribed surface was on the outer side and when the roll contact surface was on the outer side, as shown in Fig. 12. The limited drawing ratio reached 1.8. Therefore, the formability of the strip cast using the single roll caster equipped with the scraper was almost the same as that of the strip cast by DC casting.



Scribed surface   Roll contact surface

(a) Strip cast using a type A scraper was



Scribed surface   Roll contact surface

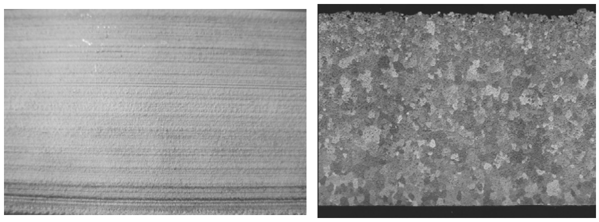
(b) Strip cast using a type B scraper was

Fig. 12. Deep drawing of annealed AA5182 strip. The thickness of strip was 1 mm, and the punch diameter was 32 mm. The LDR (limiting drawing ratio) was 1.8

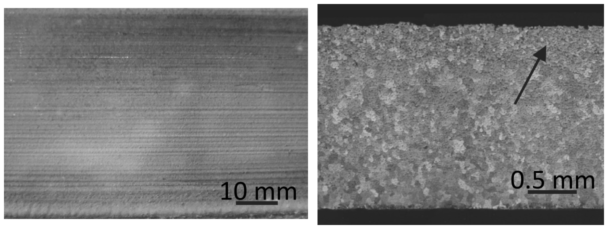
3.2. Al-10mass%Mg

Rolling of Al-10mass%Mg is very difficult as the Al-10mass%Mg is very hard. Therefore, the twin roll caster has advantage on the strip casting of Al-10mass%Mg as the twin roll caster can directly cast the strip from the molten metal. However, the twin roll cast Al-10mass%Mg strip has tendency of hard center segregation and porosity. The roll casting by the SRCS was operated at speeds up to 60m/min to investigate the efficiency against the Al-10mass%Mg alloy. Casting ability of Al-10mass%Mg was better than AA5182 when the STCS was used. The scribed surface and cross section of as-cast strip are shown in Fig. 13. The free solidified surface could be scribed into flat. The degree of the mushy condition increases as the Mg content increases. Therefore, the scribing of the free solidified surface became easier as the Mg content increases. Spherical primary crustal existed around the scribed surface. This may mean that the scribed surface did not completely solidify after scribing. The thickness of the area where the spherical primary crystal existed was thicker at roll speed of 60 m/min than 40 m/min. This shows that the thickness of the semisolid layer when the strip went through under the scraper became thicker as the roll speed became higher.

The cold rolling was tried on as-cast Al-10mass%Mg. Figure 14 shows the surface of the as-rolled strip. The as-cast Al-10mass%Mg strip could be cold-rolled down to 1mm without annealing. The crack occurred at the edges by the cold rolling. The annealing may be needed to prevent the crack at the edges.

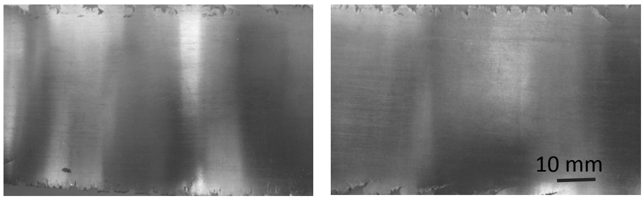


(a) roll speed: 40m/min, thickness: 2.0



(b) roll speed: 60m/min, thickness 1.7mm

Fig. 13. Scribed surface and cross section of as-cast Al-10mass% Mg strip. Scraper unit load: 0.22 N/mm, solidification length: 100 mm, strip width: 50 mm. Arrow shows the area where the spherical primary crystal existed



(a) scribed surface   (b) roll contact surface

Fig. 14. Surface of as-rolled strip. The as-cast strip shown in Fig. 13 (a) was cold rolled without annealing down to 1 mm

3.3. 600 mm width strip

Figure 15 shows the STCS to cast 600 mm width strip. The SRCS was very simple and compact. Figure 16 shows the photograph of casting of 600 mm width strip in operation. AA5182 aluminum alloy was cast. The roll speed was 10m/min, and solidification length was 150 mm. Both types of scraper A and B could be used. Average thickness of the strip was 3.8 mm. It became clear that the SRCS has the ability to cast wide strip. The basic structure of the scraper to cast 600 mm width strip was almost as same as that to cast 100 mm width strip. Burrs or crack usually occur at the edges of the strip cast by the twin roll caster. However, the strip cast by the SRCS was free from the burr and crack at edges.

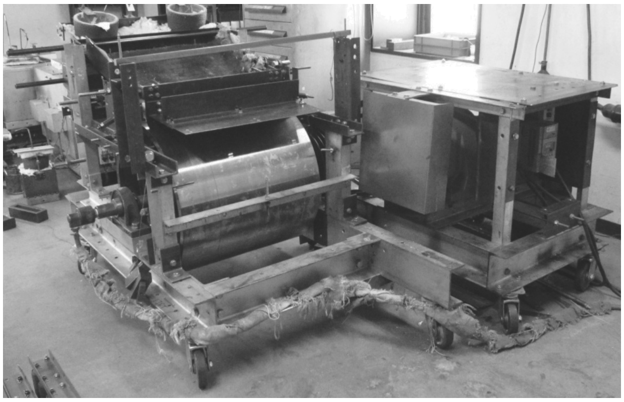


Fig. 15. Photograph of single roll caster equipped with a scraper which can cast 600 mm width strip. Size of the roll; diameter: 600 mm, width: 600 mm

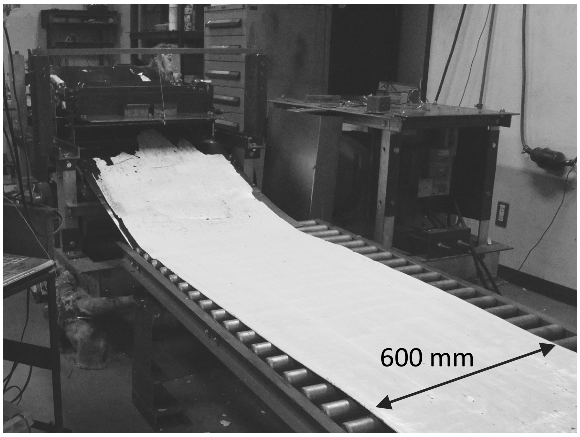


Fig. 16. Casting of 600 mm width AA5182 strip by a single roll caster equipped with a scraper

4. Conclusions

A single roll caster equipped with a scraper was developed in order to cast sound strip without centre segregation and porosity, and this purpose was attained. The mechanical properties of the strip cast by this roll caster were almost as same as those by D.C. casting. There was no difference between the scribed surface and the roll contact surface after cold rolling. Al-10mass%Mg alloy strip could be cast, and this shows the good potential of this caster. The scraper was applicable to the commercial size 600 mm width strip.

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