

Strip casting using a roll caster equipped with a scraper

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Abstract. An Al-Mg strip without center segregation could be cast using a single-roll caster equipped with a scraper at speed of 40 m/min. The scraper was useful for flattening a free solidified surface and for cooling the solidification layer by pushing the solidification layer to the roll. Clad strips consisting of 1) an Al-Mn base strip and an Al-Mg overlay strip and 2) an Al base strip and an Al-Sn-Cu overlay strip could be cast using an unequal-diameter twin-roll caster equipped with a scraper at speeds of 30 m/min and 15 m/min, respectively. The base strip and overlay strip were strongly bonded at the interface between the base strip and the overlay strip. The elements of the overlay strip did not diffuse into the base strip. The scraper played two roles in the casting of the clad strip: prevention of the mixture of two kinds of molten metal and making the surface of the base strip a semisolid of high solid fraction.

1 Introduction

Al-Mg alloy strip cast using a twin-roll caster has center segregation [1]. A scraper was proposed and attached to a single-roll caster to cast Al-Mg strip without center segregation [2,3]. The melt drag process uses a single-roll caster to cast a strip without center segregation. However, the thickness distribution is not uniform because the free solidified surface is not flat. In the melt drag process, cooling is insufficient due to poor heat transfer between the roll and the solidification layer because the solidification layer is not pushed into the roll, and the Al-Mg strip is easily broken. As a result, Al-Mg strip cannot be continuously cast using the conventional melt drag process. The thickness distribution and cooling of the strip can be improved by a scraper. The scraper scribes the semisolid layer on the solidification layer, and the thickness distribution and the flatness of the free solidified surface are improved. The heat transfer between the roll surface and the solidification layer becomes greater as the scraper pushes the solidification layer into the roll surface. As the result, the strip cooled enough to be cast continuously.

The scraper was attached to an unequal-diameter twin-roll caster to cast clad strip [4,5]. Two kinds of molten metals can be separated by the scraper and are not mixed. The scribed surface is a semisolid of high solid fraction. The bonding interface does not contact the oxidizing atmosphere due to the effect of the scraper. The solidification layers (two strips) are strongly bonded free from oxide film. In this manner, the scraper is very useful in the casting of both single strip and clad strip. The unequal-diameter twin-roll caster is suitable for scraper attachment and for casting of clad strip depending on the position and size of the rolls. A copper roll is used in order to increase late cooling of the strip in these casters. Therefore, the strips are rapidly solidified,

and the casting speed can exceed 15 m/min.

In the present paper, a single-roll caster and a twin-roll caster equipped with a scraper, as well as the properties of the single strip and the clad strip, are shown. The clad strip was cast using a vertical-type tandem twin-roll caster, and the strips cast by the two types of twin-roll casters were compared.

2 Roll caster

The single-roll caster equipped with a scraper and an enlarged view near the scraper are shown in Figs. 1 and 2, respectively [2,3]. The scraper was made of mild steel plate and was covered by an insulator sheet of 2 mm in thickness. The scraper scribed the semisolid layer on the solidification layer by a small load.

Two types of twin-roll casters to cast clad strip are shown in Figs. 3. A vertical-type tandem twin-roll caster (VTTRC) is shown in Fig. 3(a), and the unequal-diameter twin-roll caster equipped with a scraper (UDTRCS) is shown in Fig. 3(b) [4-8].

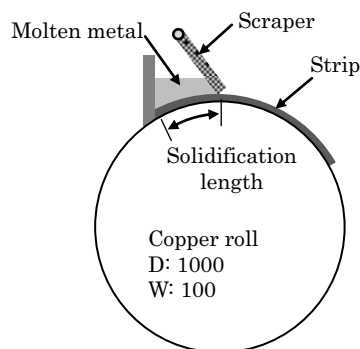


Fig. 1. Schematic illustration of a single roll caster equipped with a scraper

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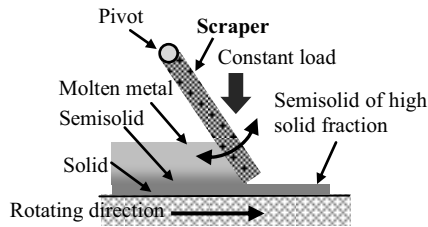
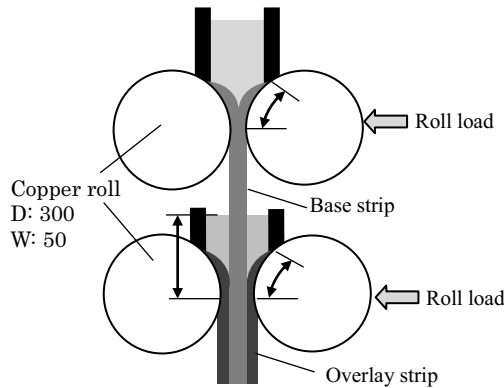
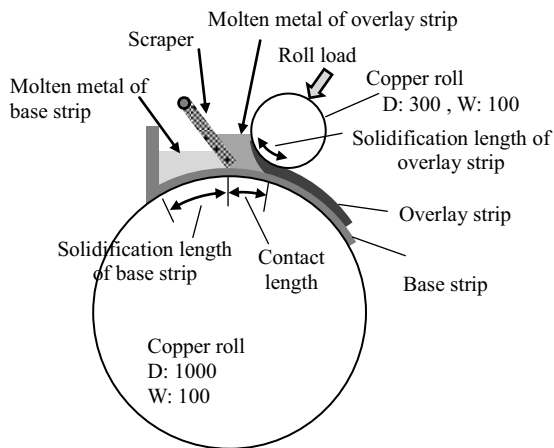


Fig. 2. Schematic illustration near the scraper



(a) Vertical type tandem twin roll caster



(b) Unequal diameter twin roll caster equipped with a scraper

Fig. 3. Schematic illustration of roll casters for casting clad strip

3 Experimental conditions

A single strip of Al-Mg alloy was cast using a single-roll caster equipped with a scraper, as shown in Fig. 1. The roll speed was 40 m/min, and the scraper load was 100 N. The solidification length was 200 mm. The casting temperature of the Al-Mg alloy was 705°C. A tension test, a cup test, and microscopy of the cross section of the strip were conducted on the strip, which was cold rolled down to 1 mm and annealed at 380°C for 1.8 ks. In the cup test, the diameter of the punch was 32 mm. The gage length and width of the test piece for the tension test were 31

mm and 15 mm, respectively.

Two types of clad strips were cast. One clad strip consisted of an Al-Mg alloy overlay strip and an Al-Mn alloy base strip, and the other clad strip consisted of an Al-Sn-Cu alloy overlay strip and an Al base strip. The clad strip consisting of Al-Mg and Al-Mn was cast at 30 m/min using the casters shown in Figs. 3(a) and 3(b). In Fig. 3(a), the solidification length was 60 mm, and the contact length was 100 mm. In Fig. 3(b), the solidification lengths of the base strip and the overlay strip were 100 mm and 60 mm, respectively. The contact length was 80 mm. The casting temperature of the Al-Mg and Al-Mn were 670°C. The roll load was 5 kN, and the scraper load was 40 N. The clad strip consisting of an overlay strip of Al-Sn-Cu and a base strip of Al was cast using the caster shown in Fig. 3(b). The casting temperatures of Al and Al-Sn-Cu were 684°C and 641°C, respectively. The solidification lengths of the base strip and the overlay strip were 190 mm and 170 mm, respectively. The contact length was 80 mm. The roll load was 5 kN, and the scraper load was 40 N. The roll speed was 15 m/min. A tension shear test was conducted on the clad strip of Al-Sn-Cu and Al.

The chemical compositions of the aluminum alloys are shown in Tables 1 through 4. The solidification temperatures are shown in Table 5.

Table 1. Chemical composition of Al-Mg alloy

Cu	Si	Mg	Zn	Fe	Mn	Ti	Bal.
0.00	0.06	4.81	0.00	0.07	0.45	0.03	Al

Table 2. Chemical composition of Al-Mn alloy

Cu	Si	Mg	Zn	Fe	Mn	Ti	Bal.
0.15	0.28	0.00	0.01	0.61	1.24	0.01	Al

Table 3. Chemical composition of Al

Cu	Si	Mg	Zn	Fe	Mn	Ti	Bal.
0.00	0.04	0.00	0.01	0.09	0.00	0.00	Al

Table 4. Chemical composition of Al-Sn-Cu alloy

Sn	Cu	Si	Mg	Zn	Fe	Mn	Bal.
40.40	0.97	0.01	0.00	0.00	0.03	0.00	Al

Table 5. Solidification temperature

Alloy	Solidus temperature	Liquidus temperature
Al-Mg	577°C	638°C
Al-Mn	643 °C	655 °C
Al	650°C	660°C
Al-Sn-Cu	228°C	610°C

4 Result and discussion

4.1. Single strip

Al-Mg strip could be continuously cast. The surfaces of as-cast strip are shown in Fig. 4. The scribed surface had no metallic luster and was dull. A ripple

mark existed at the roll contact surface, but not at the scribed surface. This may indicate that scribing by the scraper was steady state. No specific defect due to scribing occurred at the roll contact surface of the strip.

The cross section of as-cast Al-Mg strip cast by the single-roll caster is shown in Fig. 5. The grains near the roll contact surface were very fine. In other area, the grain size was almost uniform. Center segregation did not occur. A low degree of segregation of Mg occurred near the scribed surface. Cold rolling could be conducted, and the surfaces were indistinguishable after cold rolling.

The results of the tension test are presented below. In the casting direction, the tensile stress, proof stress, and elongation were 304 MPa, 155 MPa, and 26.5%, respectively. In the width direction, the tensile stress, proof stress, and elongation were 272 MPa, 140 MPa, and 16.8%, respectively. The mechanical properties of the casting direction were superior to those of the width direction.

The results of the cup test are shown in Fig. 6. Which surface was facing outward, i.e., the scribed surface or the roll contact surface, did not affect the limiting drawing ratio (LDR), which was 2.0.

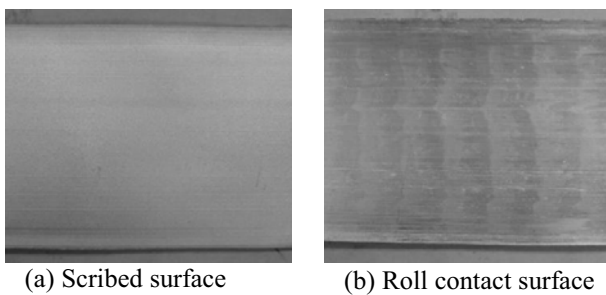


Fig. 4. Surface of as-cast Al-Mg strip cast by the single roll caster shown in Fig. 1

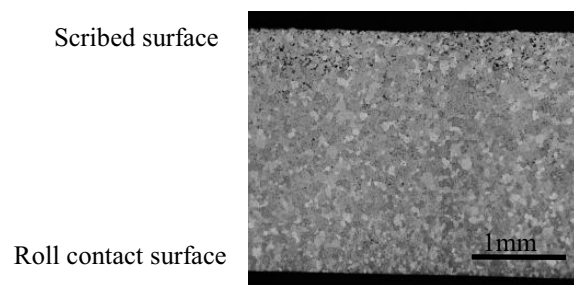


Fig. 5. Cross section of as-cast Al-Mg strip

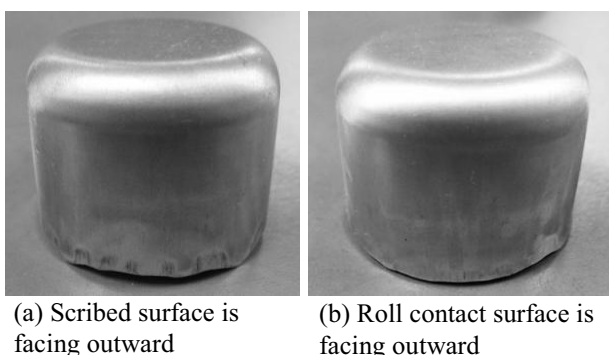


Fig. 6. Results of cup tests of Al-Mg strip

4.1 Clad strip

The cross sections of clad strips consisting of Al-Mg and Al-Mn are shown in Fig. 7. In the clad strip cast by the VTTRC, there were gaps between the Al-Mn base strip and Al-Mg overlay strip. On the other hand, there was no gap between the base strip and the overlay strip of the clad strip cast by the UDTRCS. The surface of the base strip was not heated to the temperature at which bonding with the overlay strip was possible in the VTTR. For example, the bonding temperature is the semisolid temperature. In the UDTRCS, the surface of the base strip is a semisolid of high solid fraction near the scraper. The surface of the base strip did not contact the oxidizing atmosphere. Therefore, the base strip is suitable for cladding. The scraper is useful for clad strip casting from two perspectives. One is that the surface of the base strip becomes a semisolid of high solid fraction. The bonding is easy, and mixture of the two types of aluminum alloy does not occur due to the effect of the high solid fraction. The other is that the surface of the base strip does not contact the oxidizing atmosphere, preventing the generation of oxide film. Clad strips consisting of various combinations of many types of aluminum alloy can be cast using the UDTRC.

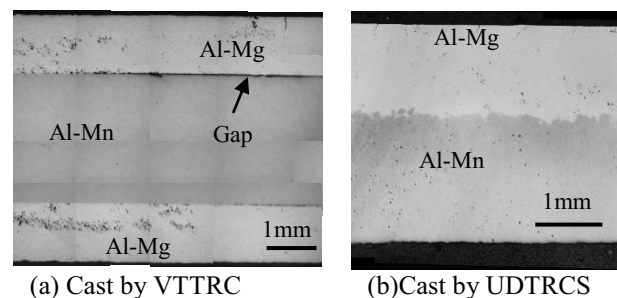


Fig. 7. Cross sections of clad strips

Casting of the clad strip consisting of Al-Sn-Cu and Al was attempted using the UDTRCS. The base strip was Al and the overlay strip was Al-Sn-Cu. The difference in solidus lines of the base strip and the overlay strip was more than 400°C. Some problems were predicted for casting. One was that the overlay strip of Al-Sn-Cu was not solidified by the heat from the Al base strip. If the Al-Sn-Cu solidifies, the strip thickness may become thinner. The temperature of the Al base strip after releasing the lower roll was higher than 500°C. This temperature is higher than the solidus line of Al-Sn-Cu. Therefore, the Al-Sn-Cu overlay strip may re-melt. The casting of clad strip is shown in Fig. 8. The forefront of the strip in the figure is the Al base strip. The overlay strip connected to the base strip at the middle part. Meandering and warping did not occur on the base strip.

The bonding of the overlay strip did not influence the base strip. The base strip and overlay strip were not hot rolled, because the roll load was very small. The small roll load was one reason for the non-occurrence of meandering and warping. The solidus line of the Al-Sn-Cu overlay strip is much lower than that of the Al base strip. The Al-Sn-Cu overlay strip did not completely solidify when the clad strip released from the roll. Therefore, the Al base strip was subjected to heat effect by latent heat from the Al-Sn-Cu overlay strip on the conveyer. However, meandering and warping of the clad strip did not occur. The heat effect by the Al-Sn-Cu overlay strip on the Al base strip was not large enough to have a heat effect on the Al base strip. The length of the non-steady area of the forming clad strip was only 100 mm. Re-melting and sweating did not occur at the Al-Mg-Cu overlay strip due to the heat from the Al base strip. Roll coating occurred. The Al-Mg-Cu overlay strip must be semisolid, but the strip did not stick to the roll.

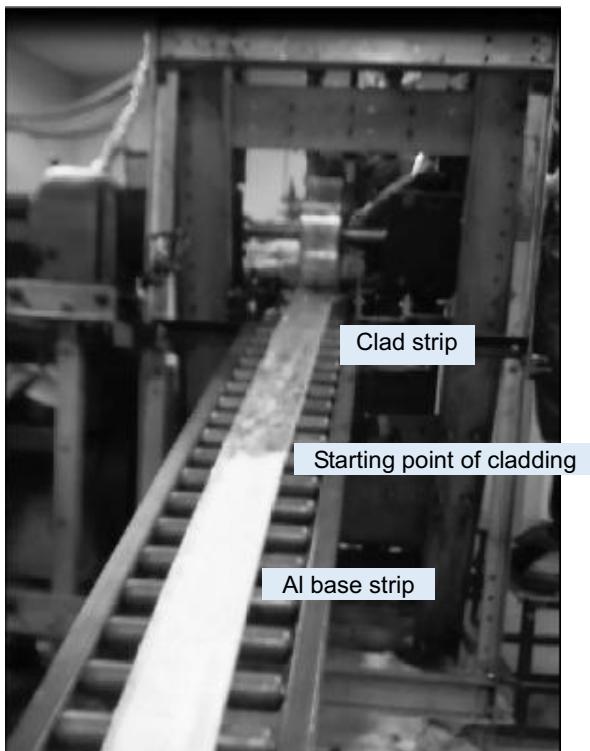


Fig. 8. Casting of clad strip in operation

The as-cast strip and the strip cold rolled down to 2 mm were used for the tension-shear test. The clad strip was not peeled by the cold rolling. The results of the tension-shear test are shown in Fig. 9. Breaking did not occur at the interface for either condition. This means that the two strips were strongly bonded at the interface. The roll load of the caster was very small. The two strips were not bonded by the hot rolling. The surface of Al was a semisolid of high solid fraction, which provided strong bonding. Waving of the interface was not caused by the cold rolling. The Al-Sn-Cu overlay strip did not completely solidify on the Al base strip after cooling by the roll, and the Al base strip solidified. The semisolid condition of the Al-Sn-Cu overlay strip did not influence the bonding ability.

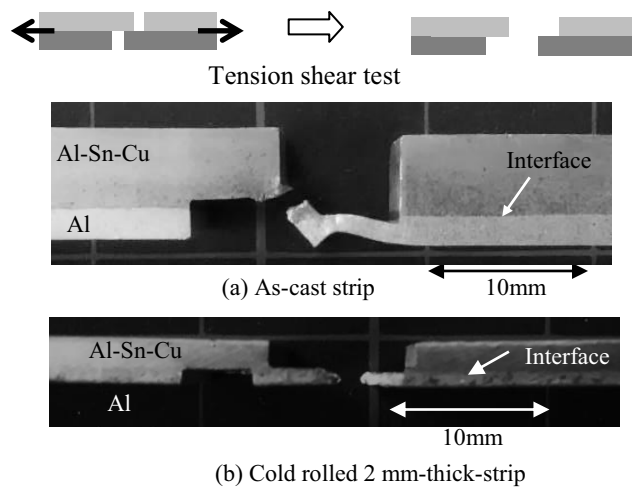
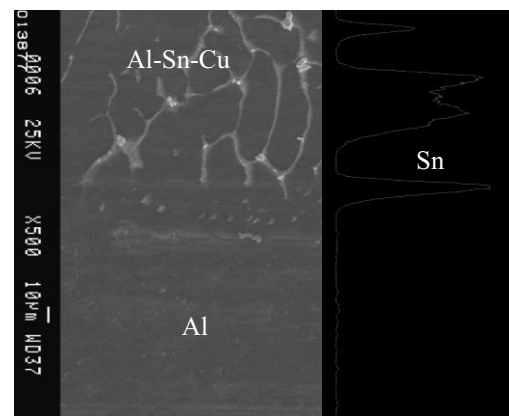
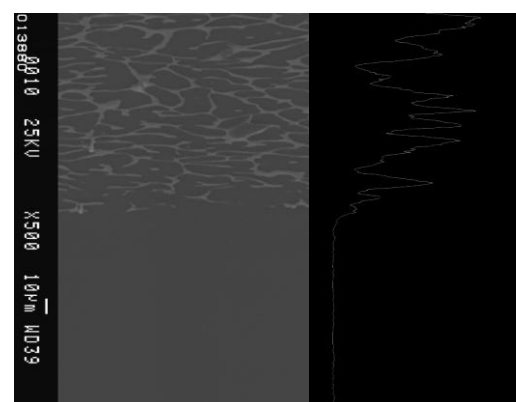


Fig. 9. Cross section of the clad strip after the tension shear test

The results of the line analysis of Sn near the interface of the as-cast strip and the cold rolled 2-mm-thick strip are shown in Fig. 10.



(a) Near interface of as-cast strip



(b) Near interface of cold rolled 2 mm-thick-strip

Fig. 10. Results of line analysis

The Sn did not diffuse into the Al base strip from the Al-Sn-Cu overlay strip. When the molten metal of the Al-Sn-Cu contacts the Al base strip, the surface of the Al base strip was a semisolid of high solid fraction. However, the Sn did not diffuse into the Al base strip. The casting temperature of the Al-Sn-Cu molten metal was lower than the solidus line of the Al base strip. The

semisolid layer of the surface of the Al base strip might have been immediately solidified by the Al-Sn-Cu molten metal when contacting the Al base strip. Therefore, the Sn did not diffuse into the Al base strip. However, excellent bonding was attained by the semisolid metal of the Al and the molten metal of the Al-Sn-Cu. The Al-Sn-Cu overlay strip was previously in semisolid condition on the Al base strip, and the Sn did not diffuse into the Al base strip during this time.

5 Conclusion

The Al-Mg strip without the center segregation could be cast at a high speed of 40 m/min using a single-roll caster equipped with a scraper. The scraper was very useful for flattening the free solidified surface and increasing the heat transfer between the roll and the solidification layer.

An unequal-diameter twin-roll caster equipped with a scraper can cast a two-layer clad strip with a clear interface. Two clad strips consisting of 1) an Al-Mg overlay strip and an Al-Mn base strip and 2) an Al-Sn-Cu overlay strip and an Al base strip were able to be cast at high speeds of 30 m/min and 15 m/min, respectively. In the tensile-shear test, the clad strip did not peel at the interface, but rather broke in the strip. In these clad strips, the base strip and the overlay strip were strongly bonded, and the bonding strength at the interface was stronger than that of the base strip or the overlay strip. The elements of the overlay strip did not diffuse into the base strip. The cause of the strong bonding and non-diffusion at the interface might be that the surface of the base strip was a semisolid of high solid fraction.

References

1. M. S. Kim, S. H. Kim, H. W. Kim, *Scripta Materialia* **152**(2018)
2. T. Haga, K. Akitsu, T. Yamabayashi, S. Kumai, H. Watari, *Key Engineering Materials* **44**(2010)
3. T. Haga, K. Akitsu, S. Kumai, H. Watari, *Advanced Materials Research*
4. *search* **445**(2012)
5. T. Haga, R. Kozono, S. Nishida, H. Watari, *Advances in Materials and Processing Technologies* **3** (2017)
6. T. Haga, K. Okamura, S. Nishida, H. Watari, K. Matsuzaki, *Materials Science Forum* **879**(2017)
7. T. Haga, R. Nakamura, S. Kumai, H. Watari, *Archives of Materials Science and Engineering* **37**(2009)
8. R. Nakamura, T. Haga, H. Tsuge, S. Kumai, H. Watari, *Materials Science Forum* **675-677**(2011)
9. T. Haga, T. Nakamura, S. Kumai, H. Watari, *Applied Mechanics and Materials* **52-54**(2011)