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Roll casting of a clad strip consisting of 5182 aluminium alloy

T. Haga*
Osaka Institute of Technology 5-16-1 Omiya Asahiku Osaka city 535-8585, Japan
* Corresponding e-mail address: oshio.haga@oit.ac.jp

ABSTRACT

Purpose: The investigation of the casting ability of the two layers and three layers clad strips consisting of the 5182 (Al-Mg) strip by the vertical type twin roll caster equipped with a scraper and the vertical type tandem twin roll caster at the speed higher than 30 m/min is one of the purposes. Another purpose is investigation of the casting conditions that affect the bonding condition of the 5182 strip to another aluminium alloy strip.

Design/methodology/approach: A twin roll caster equipped with a scraper and a vertical type tandem twin roll caster were designed, assembled, and the castings of clad strips consisting the 5182 strip were tried. The interface between the strips were observed by the optical microscope. The bonding strength between strips was investigated by the continuous bending test.

Findings: In the casting of the 5182 strip and the 3003 strip, the temperature of the 3003 strip influenced the bonding. When the temperature of the 3003 strip was lower, the 5182 strip was not bonded to the 3003 strip. In the casting of the 5182 strip and the 4045 strip, the porosity occurred near the interface. The temperature of the 5182 strip at the roll bite influenced the occurrence of the porosity. When the temperature of the 5182 strip was low, the porosity did not occur. The vertical type twin roll caster equipped with a scraper was suitable for the clad strip consisting of the 5182 and the 3003, and consisting of the 5182 and the 4045. The sound clad strips of the 5182 and the 3003, of the 5182 and 4045 could be cast using the vertical type twin roll caster equipped with a scraper.

Research limitations/implications: The size of the roll was laboratory size. Moreover, the amount of the poured molten metal was less 3kg. Therefore, there was no information about the commercial size clad strip in this paper.

Practical implications: The aluminium clad strip can be used to make component of the automobile by the press forming.

Originality/value: The twin roll casters that could cast two and three layers clad strips were original invention. It is shown that the clad strips consisting of the 5182 (Al-Mg) strip could be cast using the twin roll caster. The elucidation of the casting conditions that affects the bonding and porosity near the interface is original result.

Keywords: Casting; Twin roll caster; Clad strip

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The fabrication of the aluminium clad strip requires multiple processes and significant amount of energy. Therefore, the process saving and the energy saving have been demanded. The twin roll caster can cast the strip directly from the molten metal [1-12]. Therefore, the twin roll caster has advantages of the process saving and the energy saving. It is said that the productivity of the conventional twin roll caster for aluminium alloy (CTRCA) is very low. The roll speed of the CTRCA is usually slower than 5 m/min. This slow roll speed is cause of the low productivity. A vertical type high speed twin roll caster (VHSTRC) was proposed in order to improve the slow casting speed [13-19]. The VHSTRC can cast the aluminium alloy strip at the speeds ranging from 30 m/min to 150 m/min. The twin roll caster to cast three layers clad strip was proposed on the basis of the VHSTRC. This twin roll caster for the three layers clad strip is a vertical type tandem twin roll caster (VTTRC) [20-23]. One VHSTRC was mounted another VHSTRC in the VTTRC. The scraper was attached to the VHSTRC to cast the two layers of clad strip. The vertical type twin roll caster equipped with a scraper (VTRCS) and the VTTRC could cast the clad strip by one process [23-25]. Therefore, the VTTRC and the VTRCS have the advantage of the process saving and the energy saving. The three layers aluminium alloy clad strip consisting of 4045, 3003 and 4045 was could be cast without defects by the VTTRC. However, in the casting of the three layers clad strip consisting of 5182, 3003 and 5182, the 5182 overlay strip was not bonded to the 3003 base strip. In the casting of the three layers clad strip consisting of 4045, 5182 and 4045, the 4045 overlay strip was bonded to the 5182 base strip, and the porosity occurred near the interface. However, there was no defect in the two layers clad strip consisting of the 5182 strip cast by the VTRCS. In this paper, the cause of the defects which occurs in the casting of the three layers clad strip containing 5182 strip was investigated.

2. Twin roll casters

2.1. Vertical type high speed twin roll caster

Schematic illustration of the vertical type high speed twin roll caster (VHSTRC) and a vertical type twin roll caster for steel (VTRCSt) are shown in Figure 1 [13-19]. One of the properties of the VHSTRC is the use of the front dam plate. The front dam plate is useful to improve the oscillation of the meniscus contacting to the roll. The oscillation of the meniscus can be reduced by the hydrostatic pressure of the molten metal head.

The surfaces of the as-cast 5182 strip cast at 90 m/min by the VTRCSt and the VHSTRC are shown in Figure 2. There are the areas, where the contacting condition between the roll and molten metal was not good by the oscillation of the meniscus, on the surface of the strip cast by the VTRCSt. The bad contacting area on the surface of the strip cast by the VHSTRC was improved by the effect of the front nozzle plate.

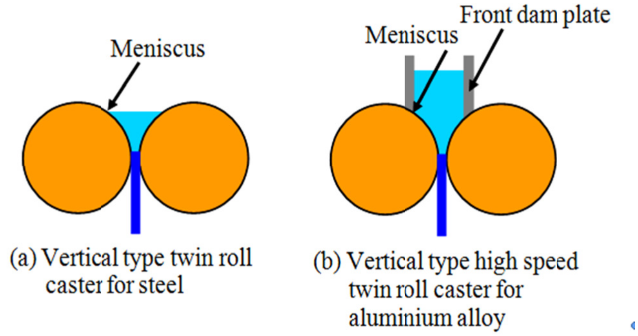


Fig. 1. Schematic illustration of a vertical type twin roll caster for steel and a vertical type high speed twin roll caster for aluminium alloy

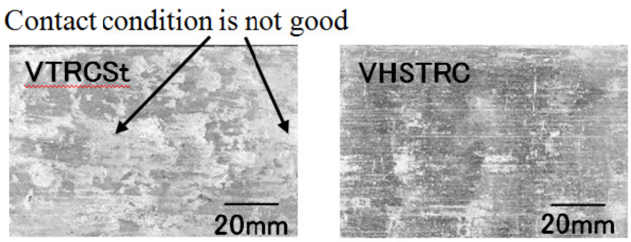
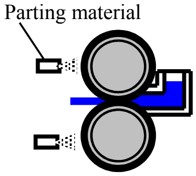
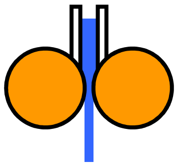


Fig. 2. Surfaces of as-cast 5182 strips cast at 90 m/min by a vertical type twin roll caster for steel and a vertical type high speed twin roll caster for aluminium alloy

The Comparison of the VHSTRC with a conventional twin roll caster for aluminium alloy (TRCA) is shown in Table 1 [1-12]. In the TRCA, the importance is attached to the hot rolling. In the VHSTRC, the importance is attached to the rapid solidification. The copper rolls are used to achieve the rapid solidification by the higher thermal conductivity. The parting material is not used as the strip does not stick to the roll. The roll temperature does not increase up to the temperature at which the strip sticking occur. The parting material becomes heat resistance between the roll and the material. Therefore, no-use of the parting material is suitable for the increase of the heat transfer. The contact condition between the roll and material becomes better by the use of the hydrostatic pressure in the VHSTRC. The better contacting condition between the roll and the material makes heat transfer greater. The improvement heat transfer between the roll and the material makes the cooling rate and the roll speed higher.

Table 1.
Comparison of a vertical type high speed twin roll caster with a conventional twin roll caster for aluminium alloy

	conventional twin roll caster for aluminium alloy	vertical type high speed twin roll caster
type		
Roll material	tool steel	copper alloy
Roll load (kN/mm)	1-10	0.05-2
Parting material	use	no-use
Roll speed (m/min)	<5	30-150
Cooling rate(°C/s)	700	1000-2000
Hydrostatic pressure	no-utilize	utilize

2.2. Vertical type tandem twin roll caster

Schematic illustration of the VHSTRC is shown in Figure 3, and photograph is shown in Figure 4 [20-23]. One VHSTRC is mounted on another VHSTRC. The base strip is cast by the upper twin roll caster and the overlay strips are cast by the lower twin roll caster.

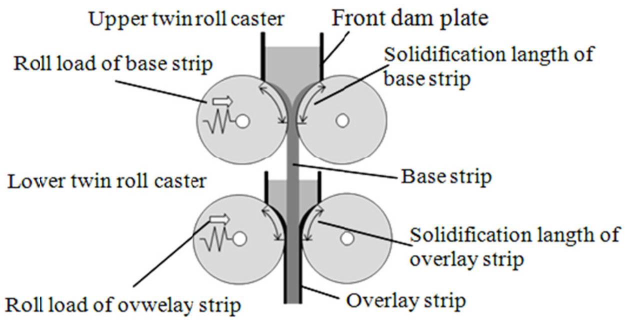


Fig. 3. Schematic illustration of the vertical type tandem twin roll caster

The molten metal of the base strip is poured at first. The molten metal of the overlay strip is poured after the base strip going into the roll bite of the lower twin roll caster. The importance is not attached to the hot rolling to achieve the bonding of the strips. The roll speed of the lower twin roll caster is as same as the roll speed of the upper twin roll caster. The solidification temperature of the base strip is higher than that of the overlay strip to prevent the melting of the base strip by the heat from the overlay strip.

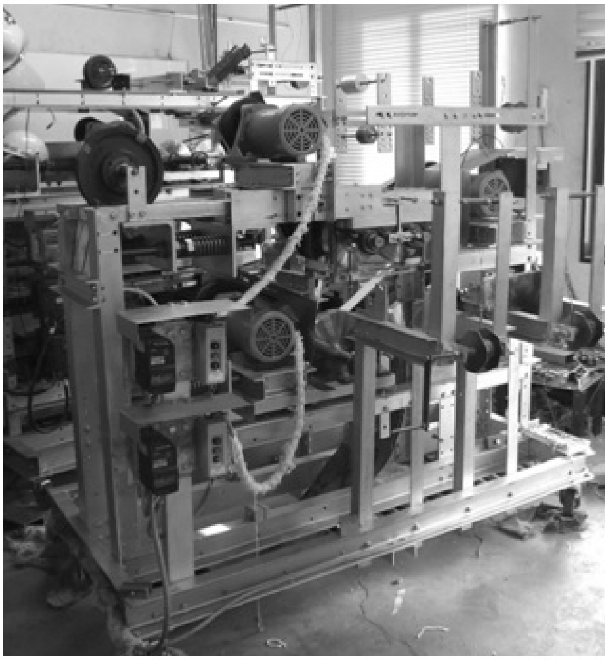


Fig. 4. Photograph of the vertical type tandem twin roll caster

2.3. Vertical type twin roll caster equipped with a scraper

The schematic illustration of the VTRCS is shown in Figure 5, and photograph is shown in Figure 6 [24,25]. The VTRCS can cast the two layers clad strip.

The property of the VTRCS is the scraper which is proposed to cast the clad strip. The scraper is shown in Figure 5, too. The scraper is supported by the furculum and, rounds around the furculum. The scraper is pushed to strip by the constant load. The scraper does not contact with the roll, the scraper is maintained at the gap of 1mm before the pouring of the molten metal.

The scraper traces the strip, and scribes the semisolid metal. The core of the scraper is made from the steel plate and it is coated by the insulator sheet to prevent the adhesion of the solidified metal and the reaction with metal. The BN is sprayed as the parting material on the insulator sheet. The scraper prevent the mixture of the two kinds of molten metal. The solid layer and thin semisolid layer are pulled from the gap between the scraper and the roll. The both rolls are rotated at the designated speed before the pouring of the molten metal. The molten metal of the scribed strip is poured at first, and the other molten metal is poured. The roll gap is set wider than scribed strip. The importance is not attached to the hot rolling for the bonding of the strips. The metal, which has higher solidification temperature, is cast using the scraper to prevent the re-melting of the metal of the strip which has lower solidification temperature. The molten metal of the metal which has lower solidification temperature contacts to the solidification layer of the metal which has higher solidification temperature. The scribed strip is not re-melted and the metal which has lower solidification temperature solidified. As the result, the clad strip with clear interface can be cast.

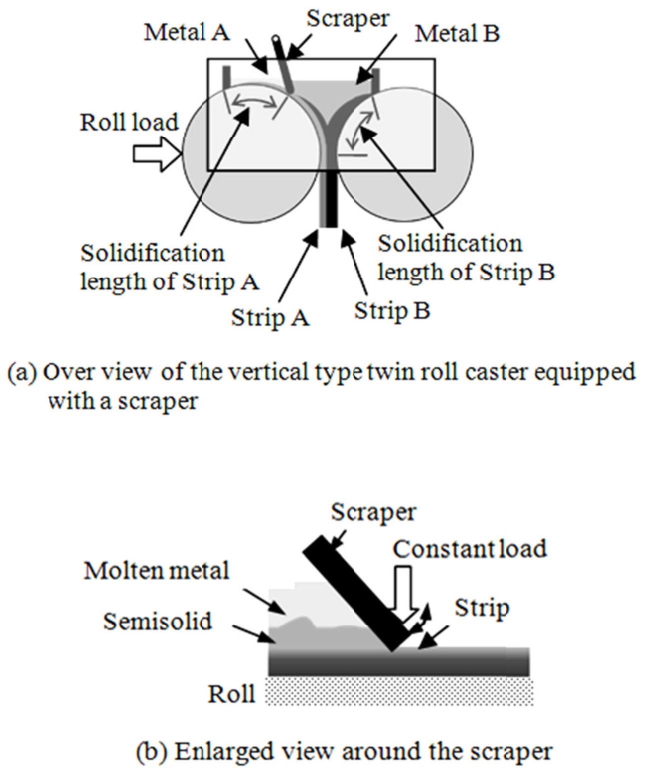


Fig. 5. Schematic illustration of the vertical type twin roll caster equipped with a scraper and enlarged view around the scraper

Fig. 6. Photograph of the vertical type twin roll caster equipped with a scraper

3. Experimental conditions

3.1. Vertical type high speed twin roll caster

A single strip of 5182 was cast to investigate the fundamental properties of the roll cast strip. The experimental condition is shown in Table 2. The casting was conducted at 30 and 60 m/min. The roll load was 0.2, 0.4, 1 and 2 kN/mm. The pouring temperature was 680°C. The copper roll was used and the parting material was not used. The microstructure of the as-cast strip was observed by the optical microscope.

Table 2.
Casting condition of the vertical type high speed twin roll caster

Roll material	copper
Roll size (mm)	diameter: 300, width: 20
Material	5182
Roll speed (m/min)	30, 60
Pouring temperature (°C)	585
Roll load (kN/mm)	0.2, 0.4, 1, 2
Solidification length (mm)	100
Parting material	no-use

3.2. Vertical type tandem twin roll caster

The three layers clad strip which base strip was 3003 and the overly strips were 5182 strips is shown as type A1, and

Table 3.
Casting condition of the vertical type tandem twin roll caster. Type A1. Base strip: 3003, Overlay strip: 5182

Roll material	copper
Roll speed (m/min)	30
Roll diameter (mm)	300
Parting material	no-use
Upper twin roll caster (base strip)	
Roll width (mm)	40
Base strip	3003, 3003+1% Mg, 3003+2.5% Mg
Pouring temperature (°C)	670
Solidification length (mm)	100
Roll load (kN/mm)	0.06
Lower twin roll caster (overlay strip)	
Roll width (mm)	42
Overlay strip	5182
Pouring temperature (°C)	650, 700
Solidification length (mm)	100
Roll load (kN/mm)	0.21

Table 4.
Casting condition of the vertical type tandem twin roll caster. Type B1. Base strip: 5182, Overlay strip: 4045

Roll material	copper
Roll speed (m/min)	
Roll diameter (mm)	300
Parting material	no-use
Upper twin roll caster (base strip)	
Roll width (mm)	40
Base strip	5182
Pouring temperature (°C)	650
Solidification length (mm)	100
Roll load (kN/mm)	0.06, 0.22
Lower twin roll caster (overlay strip)	
Roll width (mm)	42
Overlay strip	4045
Pouring temperature (°C)	610, 650, 700
Solidification length (mm)	100
Roll load (kN/mm)	0.22

casting condition is shown in Table 3. The three layers clad strip which base strip was 5182 and the overly strip were 4045 strips is shown as type B1, and casting condition is shown in Table 4.

In the type Al, the 3003 base strip was modified to lower the solidification temperature by adding Mg.

3.3. Vertical type twin roll caster equipped with a scarper

The two layers clad strip assembled from the 3003 strip and the 5182 trip is shown as type A2 and the casting condition is shown in Table 5. The two layers clad strip assembled from the 5182 strip and the 4045 trip is shown as type B2 and the casting condition is shown in Table 6.

Table 5.
Casting condition of the vertical twin roll caster equipped with a scraper. Type A2. Scribed strip: 3003, No-scribed strip: 5182

Roll material	copper
Roll speed (m/min)	20, 30
Roll diameter (mm)	300
Roll width (mm)	40
Roll load (kN/mm)	0.11
Parting material	No-use
Scribed strip	
Material	3003
Pouring temperature (°C)	670
Solidification length (mm)	100
Scraper load (N/mm)	0.5
No-scribed strip	
Material	5182
Pouring temperature (°C)	650
Solidification length (mm)	100

The cross section of as-cast strip was observed by the optical microscopy to investigate the occurrence of the bonding. If the strips were judged that strips were bonded by the appearance, the continuous bending test was conducted to investigate the bonding force. In the continuous bending test, the clad strip was continuously bent until broken, and the peeling of the strips at the interface around the broken area was observed. At first, the continuous bending test was conducted on the as-cast strip. If the peeling was not occur at the as-cast strip, the continuous bending test was conducted on the cold rolled strip down to 2 mm.

4. Result and discussion

4.1. Single layer 5182 strip

The cross section as-cast strip was shown in Figures 7 and 8. There was porosity at the centre area of thickness direction. The porosity became harder at the roll speed of 60 m/min than 30 m/min. The porosity was improved as the roll load became larger. The result shows that the casting ability of 5182 using the VHSTRC was not good. Roll of 30 m/min is better than 60m/min to cast sound strip. Therefore, 30 m/min was adopted to cast clad strip.

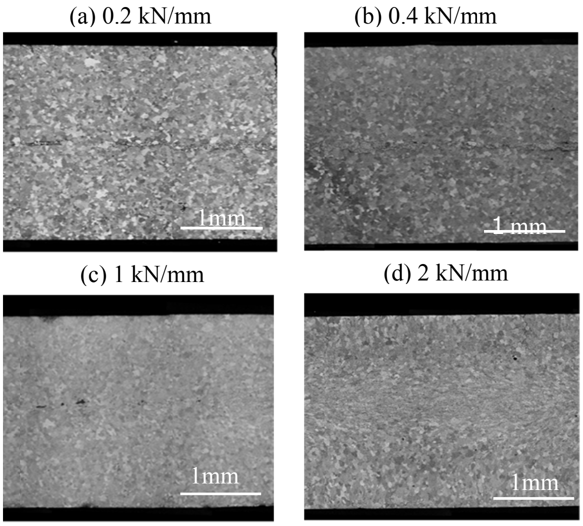


Fig. 7. Cross section of as-cast 5182 strip cast at 30 m/min

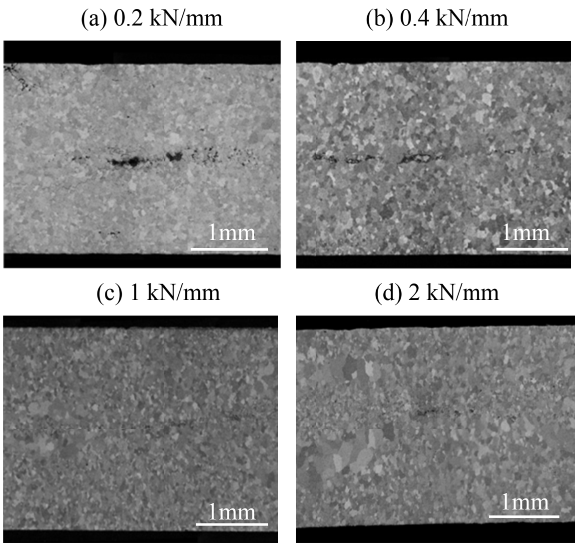


Fig. 8. Cross section of as-cast 5182 strip cast at 60 m/min

4.2. Three layers clad strip of 5182, 3003 and 5182

Influence of the pouring temperature of 5182 molten metal on the type A1 three layers clad strip consisting of 3003 base strip and 5182 overlay strip was investigated. Cross section of as-cast strip and the result of the continuous bending test are shown in Figure 9. The 5182 overlay strip was not bonded to the 3003 base strip in the condition that the poring temperature of 5182 molten metal was 650°C. In the condition that the poring temperature of 5182 molten metal was 700°C, the 5182 overlay strip was bonded to the 3003 base strip. However, the 5182 overlay strip was easily peeled off from the 3003 base strip by the continuous bending test. Bonding force was very weak. The increase of the pouring temperature of the 5182 molten metal was useful to improve bonding. The increase of the pouring temperature makes the temperature of the 3003 base strip higher. As the result, the bonding might be improved. The pouring temperature of the 5182 overlay strip higher than 700°C is inappropriate because the oxidation becomes remarkable. The improvement of the bonding condition by the 5182 overlay strip may be very difficult. The roll load of the upper twin roll caster influences on the temperature of the 3003 base strip. The temperature of the base strip becomes higher as the roll load becomes lower. The roll load of the upper twin roll caster was 0.06 kN/mm. This roll load was sufficiently small. If the roll load is set smaller than 0.06 kN/mm, the continuous casting of the strip becomes unable.

If the solidification temperature of the base strip becomes lower, the bonding condition may be improved. The influence of the solidification temperature of the base strip on the bonding was investigated. Mg was added to the 3003 to reduce the solidification temperature. 1% Mg and 2.5% Mg were added to 3003, and the clad strip was cast. The pouring temperature of 5182 molten metal was 650°C. The cross section of the three layers clad strip was shown in Figure 10. The bonding condition of the clad strip, which base strip was modified 3003 by addition of Mg, was better than the clad strip which base strip was 3003. It is estimated that the oxidation of the base strip became header by the addition of the Mg. The oxidation makes the bonding difficult. However, the result shows that the bonding became easy by the addition of Mg to the base strip. This result means that the bonding condition becomes better lower solidification temperature of the base strip.

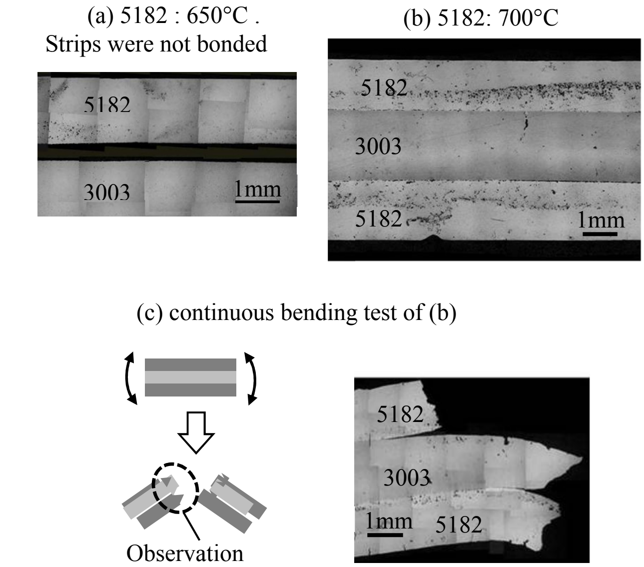


Fig. 9. Cross section of as-cast type A1 three layers clad strip consisting of the 3003 base strip and 5182 overlay strip, and result of continuous bending test

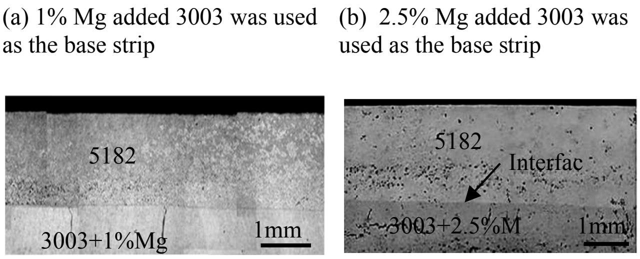


Fig. 10. Cross section of as-cast three layers clad strip consisting of the 5182 overlay strip and the modified 3003 base strip. Pouring temperature of the 5182 overlay strip was 650°C

4.3. Three layers clad strip of 4045, 5182 and 4045

Influence of the pouring temperature of the 4045 overlay strip and the roll load of the upper twin roll caster for the base strip on the interface between the 5182 base strip and the 4045 overlay strip was investigated. The cross section of the as-cast strip is shown in Figure 11. The porosity occurred at the interface. The temperature of the 5182 base strip is influenced by the roll load of the upper twin roll caster. The temperature of the strip becomes lower as the roll load becomes higher. In Figure 11 (d), the roll load of the base strip was higher than Figure 11 (b), and the porosity was improved. This result means that the lowering of the base strip improve the porosity.

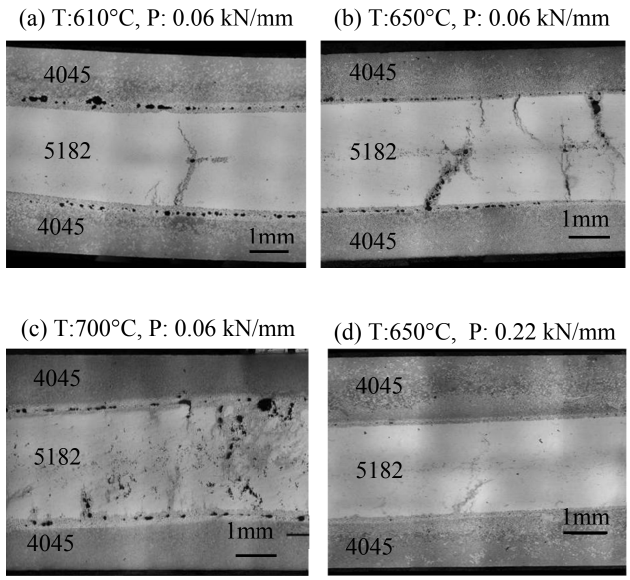


Fig. 11. Cross section of as-cast three layers clad strip consisting of the 5182 base strip and 4045 overlay strip. Pouring temperature of the 5182 base strip was 650°C. Roll load of the lower twin roll caster was 0.22 kN/mm. T: pouring temperature of the 4045 overlay strip, P: roll load of the upper twin roll caster to cast the base strip

There was not suitable pouring temperature of the 4045 overlay strip to prevent the occurrence of the porosity. The position of the porosity was influenced by the pouring temperature of the 4045 overlay strip shown in Figure 12. In the condition that the pouring temperature of the 4045 molten metal was 610°C and 650°C, the 4045 was solidified from the roll and the 5182 strip. The interface between the solidification layers existed in the 4045 overlay strip. Therefore, the porosity existed in the 4045 overlay strips. The solidified 4045 layer by 5182 strip, which is shown as SL2 in Fig. 12, was thinner as the 4045 molten metal temperature was higher. In the condition that the 4045 molten metal temperature was 700°C, the 5182 base strip was re-melted and reaction with 4045 molten metal occurred. The porosity occurred at the reacted layer.

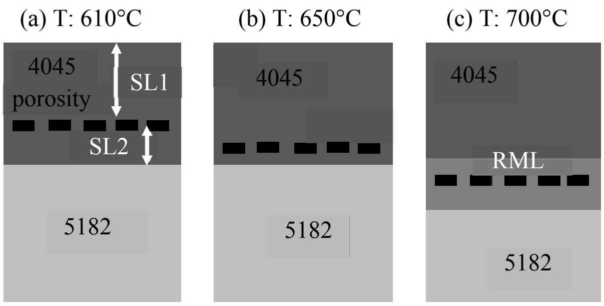


Fig. 12. schematic illustration of porosity occurred at the three layers clad strip shown in Fig. 11. T: poring temperature of 4045 molten metal, SL1: solidified layer by the lower roll, SL2: solidified layer by 5182 strip, RML: re-melted and reacted layer

Figure 13 shows the result of the continuous bending test of the as-cast three layers clad strip consisting of the 5182 base strip and 4045 overlay strips. The 4045 overlay strips was not peeled off from the 5182 base strip. The three layers clad strip had porosity. However, the bonding strength was not so weak.

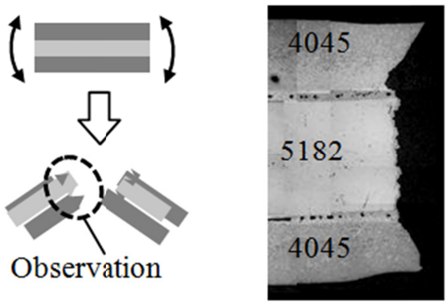
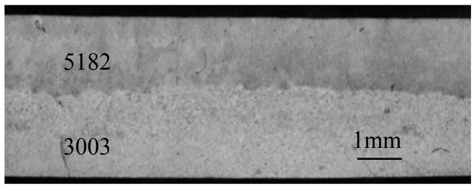


Fig. 13. Result of the continuous bending test of the three layers clad strip consisting of 5182 base strip and 4045 overlay strip

4.4. Two layers clad strip of 5182 and 3003

Two layers clad strip consisting of 5182 strip and 3003 strip could be cast continuously at the speeds of 20m/min and 30 m/min by the VTRCS. The cross section of the clad strip at the 20m/min, and the result of the continuous bending test were shown in Figure 14. The 5182 strip was bonded to the 3003 strip. The 5182 strip was not peeled from the 3003 strip by the continuous bending test. The bonding condition of the clad strip consisting of 5182 strip and 3003 strip cast by the VTTRC was not better. The bonding force was very weak. However, the clad strip consisting of 5182 strip and 3003 strip cast by the VTRCS was strongly bonded. The difference between the VTTRC and the VTRCS is the condition of the 3003 strip. In the VTTRC, the surfaces of the 3003 strip contacted to the rolls, and the surfaces were solidified and cooled by the rolled. The molten metal of the 5182 contacted to the cooled surface of the 3003 strip. In the VTRCS, the molten metal of the 5182 did not contact to the roll-contact surface of the 3003 but contacted to the scribed surface of the 3003 strip. The point A on the scribed surface shown in Figure 15 might be semisolid condition with high solid fraction. Therefore, the temperature of the point A was high enough to be bonded by the 5182 strip. The excellent property of the VTRCS is that the temperature of the scribed surface can be set at the temperature which is suitable for bonding. The temperature of the position at which another molten metal starts the contact can be controlled. For example, in Figure 15, the temperature of the position B is lower than the position A. The temperature of the scribed surface becomes lower as the distance from the scraper becomes longer. The temperature of the position at which another molten metal starts the contact can be controlled by the position of the meniscus of the molten metal as shown in Figure 16. When the position of the meniscus is lower, the temperature of the contact-start position on the scribed surface becomes lower.

(a) cross section of the as-cast clad strip



(b) result of the continuous bending test of the as-cast clad strip

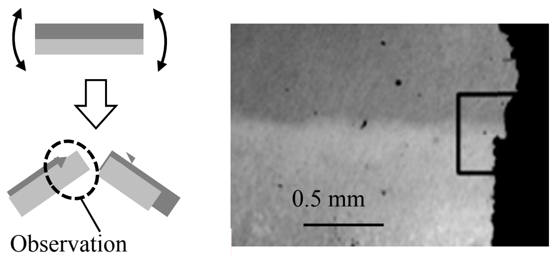


Fig. 14. Cross section and the result of the continuous bending test of the as-cast two layers clad strip consisting of the 3003 strip and the 5182 strip

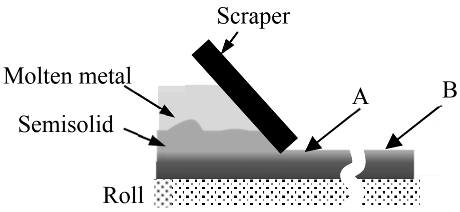


Fig. 15. Schematic illustration showing the temperature of the scribed surface. Temperature at position B is lower than position A

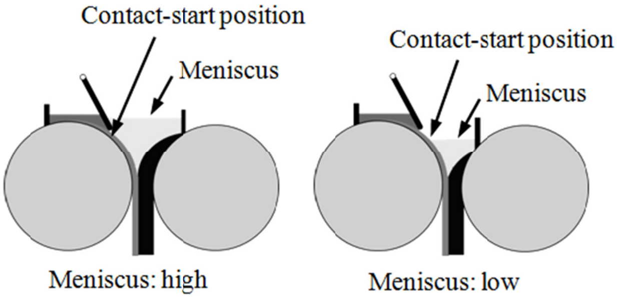


Fig. 16. Schematic illustration showing the relationship between the position of the meniscus and the contact-start position

4.5. Two layers clad strip of 5182 and 4045

Two layers clad strip consisting of 5182 strip and 4045 strip could be cast continuously at the speed of 30 m/min by the TRCS. The cross section of the as-cast strip is shown in Figure 17. The porosity did not occur at the interface. It came out from Figure 17 that the 4045 strip solidified both from the roll surface and 5182 strip. The 4045 layer solidified from the 5182 strip of the two layers clad strip was thicker than that of the three layers clad strip. This means that the temperature around the interface between the 5182 strip and the 4045 strip cast by the VTRCS was lower than that cast by the VTTRC. It is estimated that the porosity did not occur by the effect of the sufficient cooling at the interface. The 5182 strip of the two layers clad strip was directly cooled from the roll at the roll bite. On the other hand, in the three layers clad strip, the 5182 strip was not directly cooled by the roll at the roll bite of the lower twin roll caster. The cooling of the interface of the two layers clad strip was better than the three layers clad strip, and this caused good result.

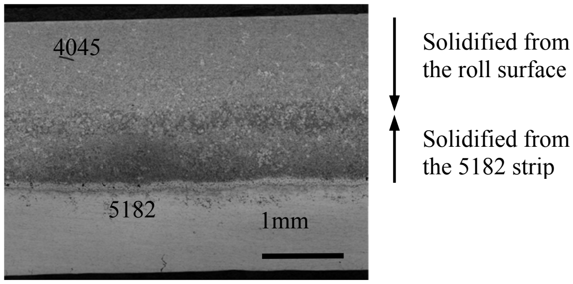


Fig. 17. Cross section of two layers clad strip consisting of the 5182 strip and 4045 strip

5. Conclusions

Casting of the 5182 single layer strip, the two layers clad strip and the three layers clad strip consisting of the 5182 strip were tried by the vertical type twin roll caster at higher roll speed. The casting ability of the 5182 strip by the vertical type high speed twin roll caster was investigated before the casting of the clad strip.

The 5182 single strip could be cast at the speeds of 30 m/min and 60 m/min by the vertical type high speed twin roll caster. The porosity became worse when the roll speed increased or the roll load decreased.

The casting of the 5182, 3003 and 5182 three layers clad strip was tried by the vertical type tandem twin roll caster at the speed of 30 m/min. The clad strip, which had sufficient bonding force, was not cast. The 5182 strip was bonded to the Mg added modified 3003 base strip which had lower solidification temperature than the 3003. These reason show that the 3003 base strip was not heated up to the suitable temperature for the bonding by the 5182. The vertical type tandem twin roll caster equipped with a scraper could cast the two layers clad strip which 5182 strip was strongly bonded to the scribed 3003 strip at the speeds of 20 m/min and 30 m/min. The scribed 3003 surface temperature was high enough for bonding with the 5182 strip. Therefore, excellent bonding was attained.

The casting of 4045, 5182 and 4045 three layers clad strip was tried at the speed of 30 m/min. The porosity occurred around the interface. The position of the porosity was influenced by the temperature of the 4045 molten metal. When the pouring temperature of the 4045 molten metal was high, the surface of the 5182 base strip was melted and the porosity occurred in the 5182 strip. When the pouring temperature of the 4045 molten metal was low, the 4045 solidified on the 5182 base strip and the porosity occurred in the 4045 overlay strip. The vertical type tandem twin roll caster equipped with a scraper could cast the two layers clad strip without porosity around the interface between the scribed 5182 strip and the 4045 strip at the speed of 30 m/min. The cooling condition influenced on the occurrence of the porosity. The vertical type tandem twin roll caster equipped with a scraper was suitable to cast clad strip of the 5182 and the 4045 without the porosity around the interface.

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Additional information

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