Archives of Materials Science and Engineering

Volume 62
Issue 1
July 2013
Pages 36-44

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

A vertical type twin roll caster for an aluminium alloy clad strip

T. Haga [a,*], R. Nakamura [b], S. Kumai [c], H. Watari [d]

[a] Osaka Institute of Technology, 5-16-1 Omiya Asahiku Osaka city 535-8585, Japan
[b] Graduate School of Tokyo Institute of Technology, Japan
[c] Tokyo Institute of Technology, Japan
[d] Gunma University, Japan
* Corresponding e-mail address: haga@med.oit.ac.jp

Received 20.05.2013; published in revised form 01.07.2013

ABSTRACT

Purpose: of this paper: Twin roll casters that can cast two layers and three layers clad strip of aluminium alloys were invented. One of the purposes of this paper is to report that the two layers and three layers clad strip could be cast by the twin roll caster of this study. The investigation of the characters of these casters and the clad strips was purpose of this paper, too. The connecting at the interface between the strips was most important in the casting of the clad strip. Therefore, the attention was paid on the conditions of the interface.

Design/methodology/approach: A vertical type tandem twin roll caster and a twin roll caster equipped with a scraper were designed, assembled and tested. Castings of the two layers clad strip and the three layers clad strip directly from molten metal were tried using these twin roll casters. The connecting strength between strips was investigated by the continuous bending test and the cold rolling. The diffusion and re-melting at the interface was investigated by the SEM-EPMA.

Findings: The twin roll casters invented in this study could cast the two layers and three layers clad strips directly from molten metal. These clad strips had clear interface between the strips. This means that the mixing of the two alloys did not occur at the interface. The diffusion of elements of the each strip into another strip did not occur at the interface. The connecting strength was enough to endure the peeling at the interface by continuous bending. The clad ratio could be controlled by the solidification length up to 10:1. Two layers clad strip assembled from Al-Mg alloy strip and another aluminium alloy strip could be cast without defect by the effect of the scraper. The three layers clad strip which base strip had lower melting point than that of the overlay strip could be cast.

Practical implications: The three layers clad strip, which base strip is 3003 aluminium alloy and overlay strips are 4045 aluminium alloy, can be used for the brazing sheet of the radiator of the automobile. The twin roll caster of this paper could cast this type of clad strip. The process saving and the energy saving can be attain by the twin roll caster of this paper. The clad ratio between the base strip and the overlay strip was smaller than 10:1.

Originality/value: The twin roll casters that could cast two and three layers clad strips were original invention. using the twin roll caster.

Keywords: Casting; Twin roll caster; Clad strip

Reference to this paper should be given in the following way:

T. Haga, R. Nakamura, S. Kumai, H. Watari, A vertical type twin roll caster for an aluminium alloy clad strip, Archives of Materials Science and Engineering 62/1 (2013) 36-44

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The clad strip is made by many processes. For example, a sheet is made by DC (direct chill) casting, homogenization, scalping, hot rolling and cold rolling. The clad strip is made from single strips by cleaning, edge-welding, hot rolling and cold rolling. In this way, many machines are used and much energy is wasted. However, there is no innovation for process and energy saving in the fabrication of the clad strip.

A twin caster can cast a strip directly from the molten metal [1-12]. Therefore, the twin roll caster has advantage of the process saving and energy saving. The fabrication of the clad strip using the roll cast strip can eliminate the many processes in the process of making the strips. This idea is very useful. The cladding of two or three strips is not easy and not simple process. Therefore, the elimination of cladding process is hoped.

The research of the roll casting, including the twin roll caster for clad strip, has been continued more than 20 years by our group [13-22]. A vertical type high speed twin roll caster (VHSTRC) was invented [18-21]. The casting speed of the conventional twin roll caster for aluminium alloy (CTRCA) is usually slower than 5 m/min. On the other hand, the VHSTRC can cast the strip at the speed higher than 30 m/min. A twin roll caster to cast clad strip was developed based on the VHSTRC. Therefore, the twin roll casters for the clad strip can cast the clad strip at the speeds higher than 20 m/min.

In this paper, characteristic of the twin roll caster which can cast the two layers or three layers clad strip is shown. Clad ratio is one of the important factors of the clad strip. How to setting the clad ratio when the clad strip was cast by the twin roll caster is shown. In the fabrication of the aluminium alloy clad strips by hot rolling, it is said that the connecting of aluminium alloy which contains Magnesium, for example 5182 aluminium alloy, is very difficult. The oxidation of the surface of the Al-Mg alloy is harder than other aluminium alloys. The oxide film between the strips interrupts the cladding. Moreover, the flow stress of Al-Mg alloy is greater than other aluminium alloys. In these reasons, the cladding of Al-Mg alloy by hot rolling is very difficult. Therefore, the cladding process which is suitable for Al-Mg alloy is demanded. The clad strip assembled from the Al-Mg alloy and the other aluminium alloy could be cast using the twin roll caster invented in this study. A point to cast clad strip assembled from the Al-Mg is shown in this paper, too.

2. A twin roll cater for three layers clad strip

2.1. Characteristics of a vertical type tandem twin roll caster and cast clad strip

A vertical type tandem twin roll caster (VTTRC) for clad strip is shown in Fig. 1. One vertical type high speed twin roll caster (VHSTRC) was mounted on the other VHSTRC. A base strip is cast upper twin roll caster and the overlay strips are cast by the lower twin roll caster. The strip thickness is decided by the roll speed and the solidification length. The solidification length is decided by the position of a nozzle-plate. The roll-load of unit width of the CTR is larger than 1 kN/mm. On the hand, the roll-load of the unit width of the lower twin roll caster of the VTTRC is smaller than 0.2 kN/mm. In this way, the roll-load for the cladding of the VTTRC is very small. The roll-load of the lower twin roll caster of the VTTRC is not enough large to operate hot rolling to connect the strips.

Comparison of the strength of the oxide film between the surface of the as-cast single strip and interface of the strips of the three layers clad strip cast by the VTTRC was operated. Stacked single strips of A356 aluminium alloy cast using the VHSTRC was heated up to semisolid condition of 580ºC for one hour. 500 g of dead weight was put on the stacked strips. Strips were not connected as shown in Fig. 2a. The oxidation at the surface of the strips enables the connecting of the strips. The three layers clad strip was heated up to semisolid condition, too. The interface between the strips became not clear, and was not confirmed. The oxide film might be re-melted. The oxide film at the interfaces of the three layers clad strip must be weaker than that of the surface of the single strip.

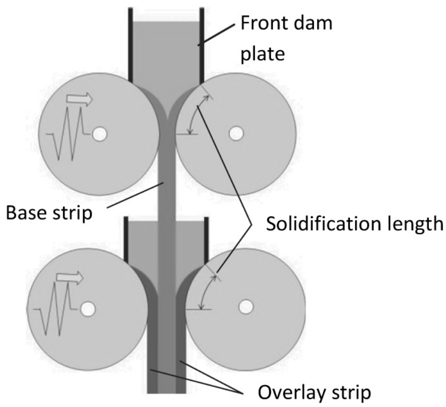

Fig. 1. Schematic illustration of a vertical type tandem twin roll caster

Three layers clad strip was cast using the VTTRC shown in Fig. 1. The base strip was 3003 aluminium alloy and the overlay strip was 4045 aluminium alloy. Casting temperature of the 3003 and 4045 was 670°C and 625°C, respectively. The melting point of the base strip was higher than that of the overlay strip. The solidus line and liquidus line of these alloys are shown at Table 1. The roll speed was 30 m/min. The solidification length of the upper twin roll caster was 120 mm, and that of the lower twin roll caster was 25 mm. The roll load of the upper and lower twin roll caster was 2.2 kN. Fig. 3 shows cross section of as-cast three layers clad strip and the result of the line analysis of Si. 4045 contains Si and 3003 does not contain Si. It is clear from the line analysis that the Si of the 4045 overlay strip did not diffuse in to the 3003 base strip. There was no mixed zone between the 3003 base strip and 4045 overlay strip. The 3003 base strip was not re-melted by the melt of 4045.

Fig. 4 shows the result of the continuous bending test until broken. The 4045 overlay strip did not peel off from the 3003 base strip. There must be oxide film on the 3003 base strip when the 300 base strip went into the melt pool of 4045 at the lower twin roll caster. However, this oxide film was very thin or very week, and the connecting between the base strip and the overlay strip was not interacted by the oxide film.

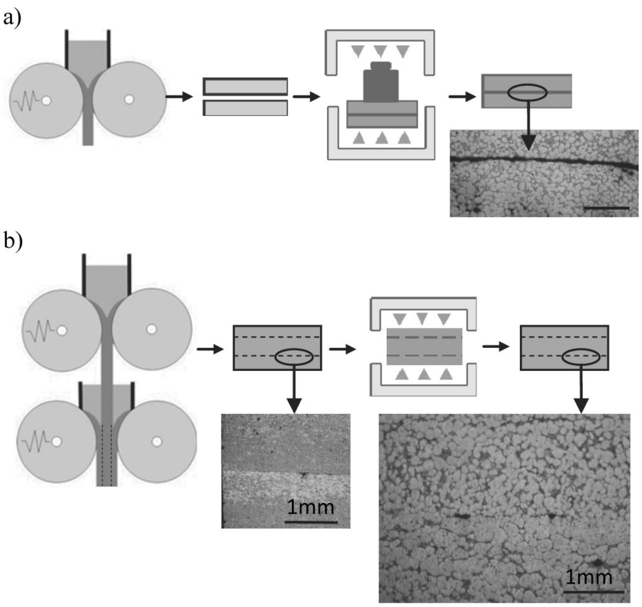

Fig. 2. Comparison of the condition of the oxide film between the surface of the single strip cast by VHSTRC and interface of the strips of the three layers clad strip cast by the VTTRC. Used alloy was A356 aluminium alloy; a) Stacked single strips of A356 alloy were heated up to 580°C for one hour. The strips were not connected; b) Three layers clad strip of A356 alloy was heated up to 580°C for one hour. Interface between the strips was not clear

Table 1.
Solidus line and liquidus line of aluminium alloys

Aluminium alloy	Solidus line	Liquidus line
3003	628C	655C
A356	575C	610C
4045	575C	595C
5182	577C	638C

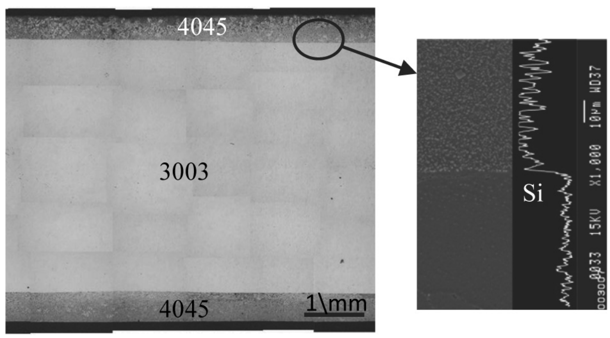

Fig. 3. Cross section of the three layers clad strip and result of the line analysis of Si around the interface

Fig. 5 shows the cross section of the three layers clad strip, too. The base strip of the Fig. 5 is thinner than that of the Fig. 3, and the overlay strip of the Fig. 5 is thicker than that of the Fig. 3. The difference of the thickness of the strip did not affect the connecting and the condition of the interface.

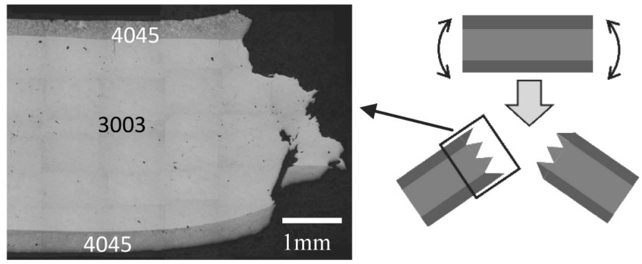

Fig. 4. Cross section of as-cast strip broken by the continuous bending

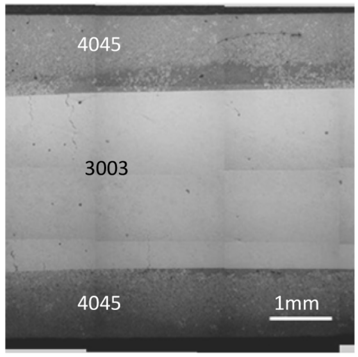

Fig. 5. Cross section of three layers clad strip

When the melting point of the base strip was higher than that of the overlay strip, the base strip was not re-melted. The sound three layers clad strip was could be cast. The three layers clad strip, which base strip had lower melting point than that of the overlay strip, was tried. The base strip was 4045 and the overlay strip was 3003, and the base strip was A356 and the overlay strip was 3003. The three layers clad strip, which three strips were same alloy, was cast. The alloys were A356 and 4045. The cross section of these types of three layers clad strip was shown in Fig. 6.

When the melting temperature of the base strip was lower than that of the overlay strip, the alloy of the base and overlay strip mixed as shown in Fig. 6a and b. The base strip might be re-melted by the heat from the overlay strip. In Fig. 7, the melting temperature of the base strip 3003 was higher than that of the overlay strip 4045, and casting temperature 700°C of melt of 4045 overlay strip was higher than the liqudus line 655°C of base strip 3003. However, the base strip was not re-melted. Re-melting of the base strip was not decided only by the relationship between the melt temperature of the overlay strip and the liqudus line of the base strip. Relationship between the liquduslines of the base strip and the overlay strip might affect the re-melting of the base strip. When the liquidus line of the overlay strip was higher than that of the base strip, the base strip was re-melted. The releasing temperature of the latent heat of solidification of the overlay strip affected the re-melting of the base strip.

Three layers clad strip, which base strip and overlay strip was same alloy, was cast. The 3003 and A356 were used. The cross section of these three layers clad strip were shown in Fig. 6c and d. When the liquidusline of the base strip and overlay strip was same, the base strip was not re-melted. When the releasing temperature of the latent heat of the overlay strip was not higher than the liqudus line of the base strip, the base strip was not re-melted.

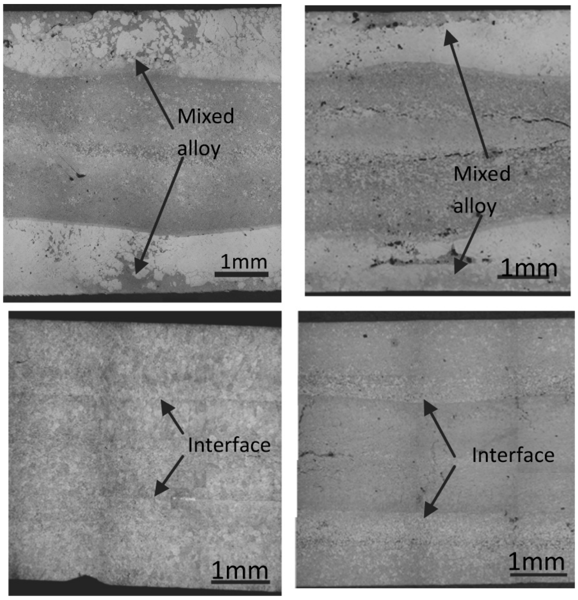

Fig. 6. Cross section of the three layers clad strip cast by the twin roll caster of Fig. 1

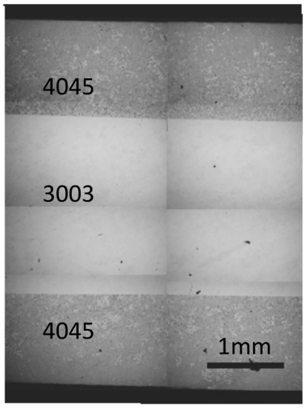

Fig. 7. Cross section of the as-cast tree layers clad strip. Casting temperature 700°C of melt of 4045 overlay strip was higher than the liqudus line 655°C of base strip 3003. Roll speed was 30 m/min

It is said that fabrication of the clad strip assembled from Al-Mg alloy and other aluminium alloy by the hot rolling is very difficult, because the surface of the Al-Mg alloy strip is covered by the strong oxide film. Casting of the three layers clad strip assembled from Al-Mg ally strip and other aluminium alloy strip was tried to investigate the influence of Al-Mg alloy on the connecting of the strips. Cross section of three layers clad strip, which element strip was Al-Mg alloy (5182), is shown in Fig. 8. When 5182 was base strip and A356 was overlay strip, the base strip looked like re-melted and was reacted with the melt of the overlay strip A356, and porosity occurred at the interface as shown in Fig. 8a. Relationship between the oxide film on the base strip 5182 and the porosity was not clear. The three layers clad strip with sound interface could not be cast when the base strip was 5182(Al-Mg) strip. When 5182 was overlay strip and 3003 was base strip, the overly strip did not connected to the base strip. When the melt of 5182 contacted to the base strip 3003, the melt of the 5182 might be oxidized and the oxide film prevented the connecting. When 5182 (Al-Mg alloy) was overlay strip, connecting condition became worse. Al-Mg was not suitable for the fabrication of the three layers clad strip using the twin roll caster of Fig. 1.

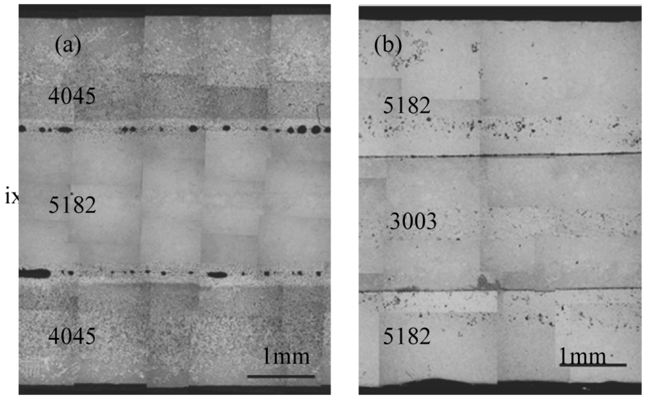

Fig. 8. Cross section as-cast three layers clad strip. Casting temperature is as below, 4045:610°C, 5182:650°C, 3003:670°C. Roll speed was 30 m/min

2.2. Control of clad ratio

In the casting of the three layers clad strip using the vertical type tandem twin roll caster of Fig. 1, the clad ratio of the base and the overlay strip is controlled by the solidification length. The thickness of the solidification layer is show as Equation (1).

$$d = K\sqrt{t} \tag{1}$$

where:
d - thickness of the solidification layer
t - solidification time
K - experimental solidification constant

The solidification time t is decided by the solidification length L and roll speed V as shown Equation (2). The Equation (1) is show as Equation (3):

$$t = L / V \tag{2}$$

where:
L: solidification length
V: roll speed

$$d = K\sqrt{L / V} \tag{3}$$

The thickness of the base strip is shown as Equation (4). Suffix “B” shows the base strip and “O” shows overlay strip.

$$d_B = 2K_B\sqrt{L_B / V} \tag{4}$$

The thickness of the overlay strip is shown as Equation (5).

$$d_O = K_O \sqrt{L_O / V} \tag{5}$$

The clad ratio Cr is show as Equation (6).

$$Cr = d_B / d_O \tag{6}$$

where:
Cr: clad ratio.

The experimental solidification constant was decided by the experiment at the conditions as below. Roll speed was 30 m/min. Roll load was 2.2 kN. Casting temperature of 3003 and 4045 was 670°C and 625°C, respectively. Three layers clad strip assembled from 3003 base strip and 4045 overlay strip is used as a brazing sheet for the radiator of the automobile. Therefore, 3003 and 4045 were chosen in this study. In the brazing sheet assembled from 3003 base strip and 4045 overlay strip, the clad ratio is usually ranging from 8 to 10.

Table 2.
Experimental solidification constant

Strip	Alloy	Solidification constant K
Base strip	3003	K_B=32 mm/min$^{0.5}$
Overlay strip	4045	K_O=25 mm/min$^{0.5}$

The clad ratio Cr becomes larger as the solidification length of the base strip L_B becomes longer. The solidification length was controlled by the position of the front dam plate. The surface of the strip becomes better when the position of the front dam plate is smaller than 60°. This reason is as below. The meniscus of the melt at the tip of the front dam plate becomes stable when the position of the front dam plate is smaller than 60°. The solidification length of the base strip becomes longest when the position of the front dam plate is 60°. The position of the front dam plate is shown in Fig. 9.

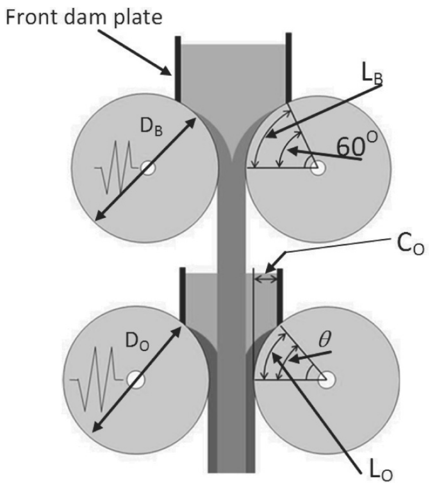

Fig. 9. Schematic illustration showing the Clearance Co and position of the front dam plate θ , roll diameter D_B and D_O, solidification length L_B and L_O.

The clad ratio Cr becomes larger as the solidification length of the overlay strip L_O becomes shorter. When the clearance of the Co, which is shown in Fig. 9, becomes too narrow, the pouring of the melt of the overlay strip becomes difficult. The clearance Co must be wider than 3 mm to pour the melt. The minimum clearance Co was 3 mm at the laboratory size twin roll caster. The shortest solidification length of the overlay strip L_O is decided by the clearance Co. When the clearance Co is 3 mm, the solidification length L_O becomes shortest. Relationship between the position of the front dam plate of the lower caster θ and the solidification length L_O is shown by Equation (7) and (8).

$$cos\theta = 1 - 2C_O/D_O \tag{7}$$

$$L_O = \pi D_O \theta / 360° \tag{8}$$

where:
θ - angle showing the position of the front dam plate of the lower twin roll caster for the overlay strip,
C_O - front dam plate clearance of the lower twin roll caster for the overlay strip,
D_O - Roll diameter of the lower twin roll caster for the overlay strip.

Relationship among roll diameter, front dam clearance Co and clad ratio Cr is shown in Fig. 10. Fig. 10 was calculated from Equation (4), (5), (6), (7) and (8) using the numbers of Table 2. The roll diameter D_B and D_O is same. The front dam plate of the upper roll caster for base strip is 60°. When the roll diameter D_B and D_O is same and front dam plate clearance Co is 3 mm, the roll diameter D_B and D_O must be larger than 700mm to attain the clad ratio larger than 8. However, 3 mm of Co is too narrow for the factory size caster. In factory size caster, Co must be wider than 10 mm. When the Co is 10 mm, the roll diameter D_B and D_O must be larger than 2000 mm to attain he clad ratio larger than 8. When Co is 10 mm, 10 of clad ratio cannot be attained by the roll diameter smaller than 4000 mm. The roll diameter larger than 1500 mm is too large for the vertical type tandem twin roll caster.

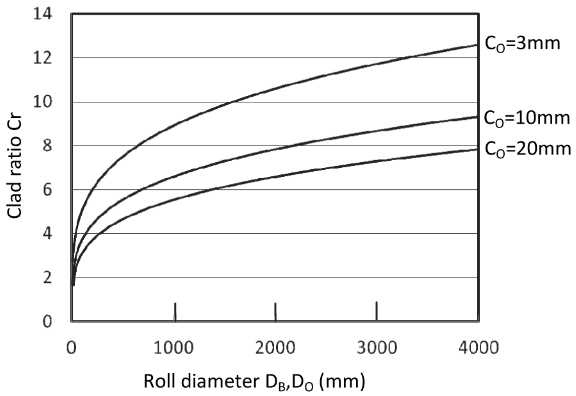

Fig. 10. Relationship among roll diameter, front dam clearance Co and clad ratio Cr. The roll diameter D_B and D_O is same. The front dam plate of the upper roll caster for base strip is 60º

Some devises are needed to realize the clad ratio 8 using the roll smaller than 1500 mm of diameter. Attention was paid on the relationship between the solidification length Lo and the roll diameter of the lower twin roll caster D_O. When the front dam plate clearance is constant, the solidification length Lo becomes shorter as the roll diameter D_O becomes smaller as shown in Fig. 11. It is estimate that the roll diameter D_B must be larger than the roll diameter D_O to make the clad ratio Cr larger. Relationship among front dam plate clearance Co, roll diameter D_B and D_O was calculated from Equation (4), (5), (6), (7) and (8) using the numbers of Table 2. The clad ratio *Cr* was set at 8. Result is shown in Fig. 12.

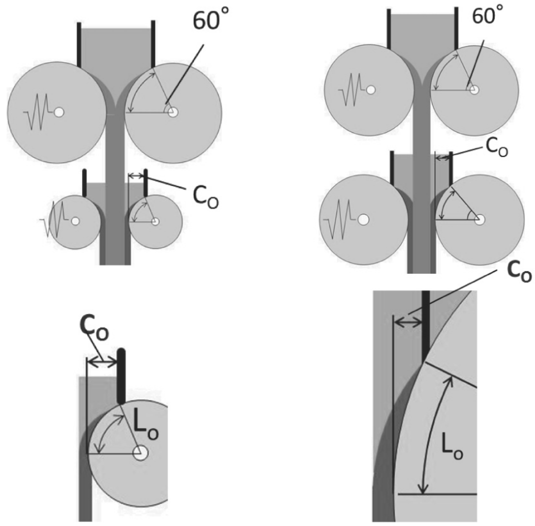

Fig. 11. Schematic illustration showing the relationship between the solidification length L_O and front dam clearance C_O

Fig. 12 shows that the combination of 250 mm of D_O and 800 mm of D_B enables 8 of clad ratio Cr when front dam plate clearance Co is 10 mm. It is very useful to make D_O smaller than D_B in order to attain the clad ratio greater than 8. The clad strip of Fig. 3 has clad ratio of 10. The casting conditions of Fig. 3 are as below. The solidification length L_B and L_O was 120mm and 25 mm, respectively. The roll diameter D_B and D_O was 300 mm and 100 mm, respectively. The front dam plate clearance C_O was 3 mm. In this way, the clad ratio Cr can be controlled at wide range by the combination of Larger D_B and smaller D_O.

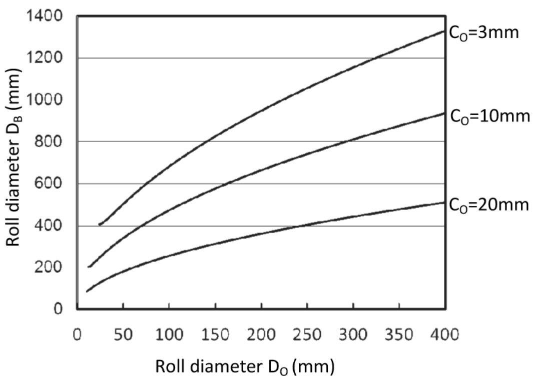

Fig. 12. Relationship among the front dam clearance C_O, roll diameter D_B and D_O. Clad ratio Cr is 8

3. A twin roll cater for clad strip which base strip has lower melting point than overlay strip

The sound three layers clad strip, which base strip has lower melting than that of the overlay strip, could not be cast by the vertical type tandem twin roll caster. It is essential to cast sound clad strip that the melt of the alloy of the lower melting point contacts to the solidification layer of the alloy of higher melting point. The clad strip casting of Fig. 6 did not satisfy this essential condition. The VTTDC cannot satisfy this essential condition. Therefore, a twin roll caster equipped with scrapers was invented to cast sound three layers clad strip which base strip has lower melting point than that of the overlay strip [22]. This twin roll caster is shown in Fig. 13. The twin roll caster equipped with scrapers satisfies the essential condition.

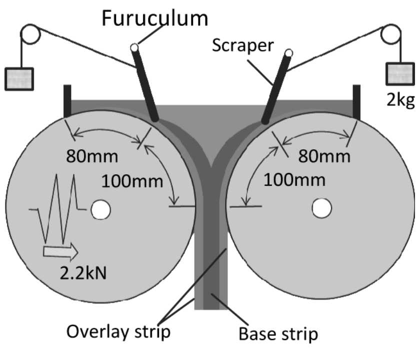

Fig. 13. Schematic illustration showing a twin roll caster equipped with scrapers

The enlarged view around the scraper is shown in Fig. 13. The scraper moves around the furculum to prevent the troubles. The gap between the scraper and the roll changes by the thickness of the solidification layer. If the gap between the scraper and the roll, troubles mentioned below occurs. It is difficult to control of the thickness of the solidification layer constant. When the solidification layer becomes thicker than proper thickness, the solidification layer sticks at the scraper. When the solidification layer becomes thinner than proper thickness, the melt leaks from the gap between the scraper and the solidification layer. The scraper traces the thickness of the solidification layer to prevent the sticking and leak. Scribed surface may be semisolid condition. Solid fraction controlled by the load of the scraper.

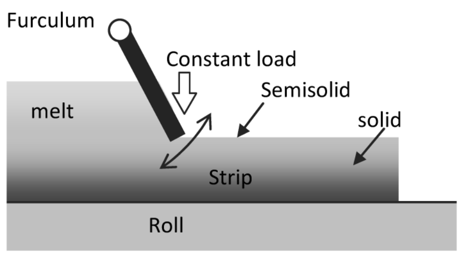

Fig. 14. Schematic illustration showing around the scraper

Strip casting using the twin roll caster of Fig. 13 was tried. The experimental condition is shown at Table 3. The base strip was A356 and the overlay strip was 3003. The three layers clad strip could be cast continuously. The cross section as-cast strip is shown in Fig. 15. The mixed zone of the materials of the base strip and the overlay strip like Fig. 6b did not exist. The twin roll caster of Fig. 13 was useful to cast the three layers clad strip which base strip had lower melting point than that of the overlay strip. However, the base strip of Fig. 15 is too thin. The melt of the base strip did not directly contact to the roll, and was indirectly cooled and solidified by the solidification layer of the overlay strip.

Table 3.
Experimental conditions to cast three layers clad strip by the process of Fig. 13

Roll speed	30 m/min
Pouring temperature of A356	615°C
Pouring temperature of 3003	670°C
Solidification length A	80 mm
Solidification length B	120 mm
Roll load	2.2 kN
Dead weight	2 kg

A vertical type tandem twin roll caster equipped with scrapers shown in Fig. 16 was developed based on the twin roll caster of Fig. 14 to increase the thickness of the base strip. The base strip cast by the upper twin roll caster was inserted into the lower twin roll caster. Therefore, the base strip became three layers and the clad strip became five layers. The melt of the base strip of the lower caster connected the base strip cast by the upper twin roll caster and the overlay strips like bond.

The cross section of as-cast five layers clad strip cast by the twin roll caster of Fig. 16 is shown in Fig. 17. The second, third and fourth solidification layer were A356 and became the base strip. The base strip of Fig. 17 became thicker than that of Fig. 15.

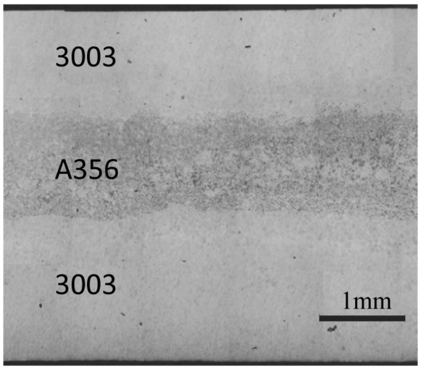

Fig. 15. Cross section of the three layers clad strip cast by the twin roll caster of Fig. 13

The result of the line analysis of Si around the interface between the A356 and 3003 of the clad strip of Fig. 17 is shown in Fig. 18. The interface between the A356 and 3003 was clear. The Si of the element of A356 did not diffuse into the 3003. The interface of Fig. 17 cast by the twin roll caster of Fig. 16 was not flat compared with the interface of the clad strip cast by the twin roll caster of Fig. 1. However, the interfaces of the strip cast by twin roll caster of Fig. 16 was almost as same as the interface of the strip cast by the twin roll caster of Fig. 1.

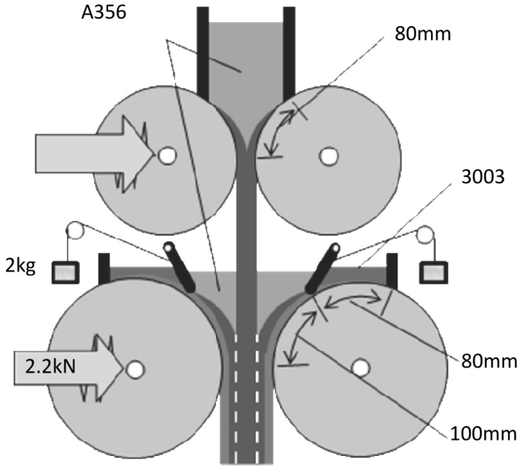

Fig. 16. Schematic illustration showing the vertical type tandem twin roll caster equipped with scrapers to cast five layers clad strip which base strip has lower melting point than that of the overlay strip

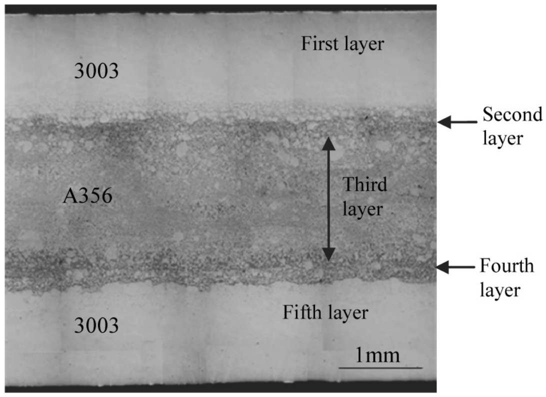

Fig. 17. Cross section of as-cast five layers clad strip cast by the twin roll caster of Fig. 16

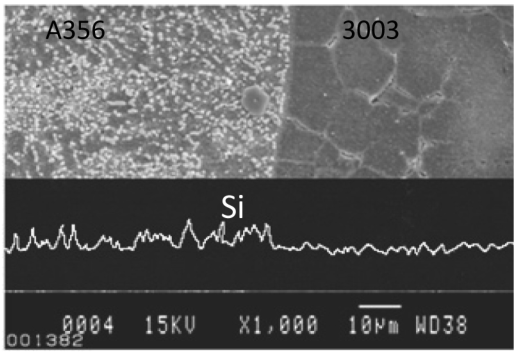

Fig. 18. Line analysis of Si around the interface between the A356 strip and 3003 strip of clad strip shown in Fig. 17

4. Twin roll caster for the clad strip assembled from Al-Mg alloy

It is very difficult to connect the Al-Mg strip with aluminium alloy strip using the hot rolling by the cause of the oxide film on the Al-Mg alloy strip. The twin roll caster of Fig. 1 could not cast the sound clad strip assembled from Al-Mg alloy, too. The strips were not connected at the interface or porosities occurred at the interface. It may be essential that the Al-Mg alloy strip does not connect to the atmosphere to cast sound clad strip. The twin roll caster equipped with a scraper is very useful to realize this condition. The twin roll caster shown in Fig. 19 was used to test the effect of the scraper. In Fig. 19, the strip of alloy A contact to the melt of alloy B without contact to the atmosphere. The 5182 aluminium alloy was used as the Al-Mg alloy. In Fig. 19, the alloy-A has higher melting point than alloy-B.

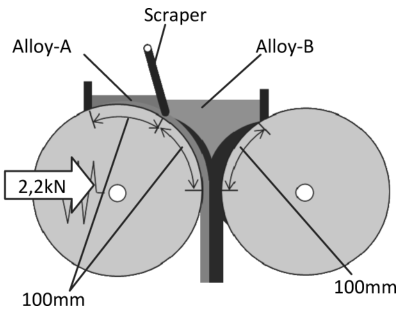

Fig. 19. Schematic illustration of a twin roll caster equipped with a scraper

The two layers of a clad strip was cast from 5182 and 4045 using the twin roll caster of Fig. 19. Roll speed was 30 m/min. The casting temperature of the 5182 and the 4045 was 650°C and 610°C, respectively. In Fig. 19, alloy A was 5182 and alloy B was 4045. Other conditions are shown in Fig. 19. The clad strip could be cast like the single layer strip. Cross section of the as-cast clad strip assembled from 5182 and 4045 is shown in Fig. 20. When the clad strip was cast from the 5182 and the 4045 using the twin roll caster shown in Fig. 1, the porosity occurred at the interface as shown in Fig. 8a. However, there was no porosity at the interface of the strip of Fig. 20. The roll load was 2.2 kN, and this load was too small to depress the porosity. Therefore, the porosity did not occur. The 5182 strip of Fig. 8a contacted to atmosphere between the upper and lower twin roll caster, and the surface of the 5182 strip was oxidized. The oxidized surface of the 5182 strip contacted to the melt of the 4045. As the result, the porosity occurred at the interface. On the other hand, the 5182 strip of Fig. 20 did not cot tact to atmosphere, and the surface was not oxidized. The melt of the 4045 contacted to the non-oxidized surface of the 5182 strip. Therefore, the porosity did not occur.

SEM image and result of the line analysis around the interface of the 5182 and 4045 strip of Fig. 20 is shown in Fig. 21. There was no mixture alloy of 5182 and 4045at the interface. The Mg of the element 5182 did not diffuse in to the 4045 strip, and Si of the element of 4045 did not diffuse into the 5182 strip. The eutectic Si of 4045 was globular and very fine. The size of eutectic Si was smaller than 3 μm. This was the effect of the rapid solidification. The twin roll caster of Fig. 19 had the excellent cooling ability.

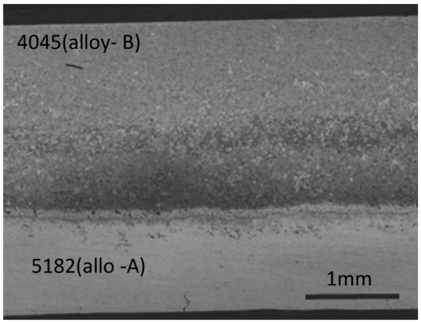

Fig. 20. Cross section of as-cast clad strip cast using the twin roll caster of Fig. 19

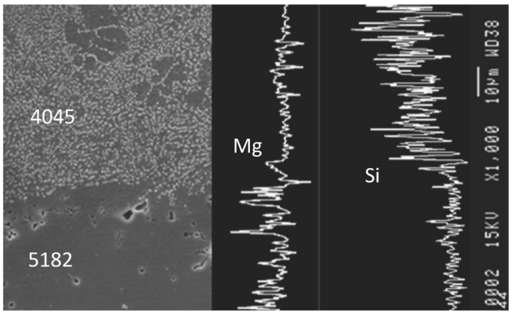

Fig. 21. SEM image and result of line analysis around the interface between the 5182 and 4045 strip

Casting of two layers clad strip assembled from 5182 and 3003 strip was tried by the twin roll caster of Fig. 19. The 3003 was alloy A and the 5182 was alloy B. Roll speed was 30 m/min. The casting temperature of the 5182 and the 3003 was 650°C and 670°C, respectively. The two layers clad strip of 5182 and 3003 could be cast. When the three layers clad strip was cast using the twin roll caster of Fig. 1, the 5182 strip was not connected with the 3003 strip as shown in Fig. 8b. However, the 5182 strip was connected with the 3003 strip when the twin roll caster of Fig. 19 was used. The cross section of as-cast two layers clad strip assembled from the 5182 strip and the 3003 strip was shown in Fig. 22. In the twin roll caster of the Fig. 19, the 3003 strip (corresponding alloy A) did not contact to the atmosphere and the surface was not oxidized. As the result, the 5182 strip can be contacted to the 3003 strip.

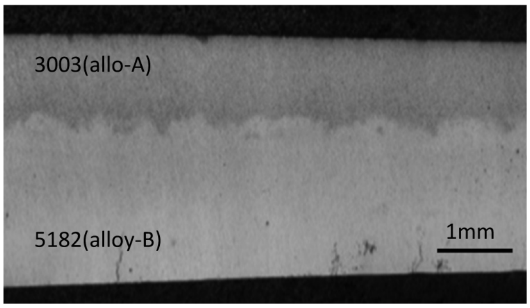

Fig. 22. Cross section of as-cast two layers clad strip cast using the twin roll caster of Fig. 19

5. Conclusions

A twin roll caster to cast aluminium alloy clad strip was invented based on a vertical type high speed twin roll cater. One was a vertical type tandem twin toll caster, another was a vertical type twin roll caster equipped with a scraper and the other was a vertical type tandem twin roll caster equipped with scrapers. Properties of these twin roll caster and clad strips were investigated.

The degree of the oxidation on the surface of the strip just released from the roll was less than the strip which temperature degreased down to the room temperature. Therefore, the clad strip could be cast using the vertical type tandem twin roll caster. The vertical type tandem twin roll caster could three layers clad strip. The base strip was cast by an upper twin roll caster, and the overlay strips were cast by a lower twin roll caster. The clad ratio could be controlled by the solidification length. The solidification length of the lower twin roll caster was set shorter in order to make the clad ratio greater. The solidification length of the lower caster became shorter as the roll-diameter of the lower caster became smaller, as the result the clad ratio became greater. 10 of clad ratio could be attained by the vertical type tandem twin roll caster.

When the three layers clad strip, which base strip had lower melting point than that of the overlay strip, was cast using the vertical type tandem twin roll caster, the base strip was re-melted. The scrapers were attached to the lower twin roll caster of the vertical type tandem twin roll caster. By the effect of the scrapers, the clad strip, which base strip had lower melting point than that of the overlay strip, could be cast without re-melting of the base strip.

It was difficult to cast sound clad strip from Al-Mg alloy using the vertical type tandem twin roll caster by the influence of oxidation on the surface of the strip. The scraper was equipped to the twin roll caster prevented the oxidation on the surface of the strip which contacted to melt of the other alloy. The Al-Mg alloy could be connected to the other alloy and sound clad strip could be cast by the effect of the scraper.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 24510107.

References

[1] R. Cook, P.G. Groock, P.M. Thomas, D.V. Edmonds, J.D. Hunt, Development of the twin-roll casting process, Journal of Materials Processing Technology 55 (1995) 76-84.

[2] M. Cortes, Pechiney-Junmbo 3CM, The new demands of thin strip casting, Light Metals (1995) 1161-1164.

[3] B. Taraglio, C. Romanowski, Thin-gage/high-speed roll casting technology for foil production, Light Metals (1995) 1165-1182.

[4] A.I. Nussbaum, Three-state-of-the-art Thin-gage high-speed roll caster for aluminum alloy sheet products, Light Metals 55(1997) 34-39.

[5] O. Daland, A.B. Espedal, M.L. Nedreberg, I. Alvestad, Thin gage twin-roll casting, process capabilities and product quality, Light Metal (1997) 745-752.

[6] P.Y. Menet, R. Cayol, J. Moriceau, Pechiney Jumbo 3CM ‘TM’ start-up of the Neu-Brisach thin strip caster, Light Metal (1997) 753-756.

[7] P. M. Thomas, P.G. Grocock, J.M. Bouzendorffer, Dynamic strip caster-An update on the operation of the roll caster at Eurofoil, Metall Plant Technology Internacional 20 (1997) 44-52.

[8] S. Hamers, D. Smith, C. Romanowski, G. Yildizbayrak, B. Taraglio, Twin roll casting of aluminum at 2.5 mm gauge, Production experience and process improvement, Light Metal (1999) 931-937.

[9] J. Benedyk, Thin strip casting for aluminum alloy sheet applications developed by Pechiney at Neuf-Brisach, Light Metal Age 59 (2001) 28-30.

[10] S. Hamer, C. Romanowski, B. Taraglio, Continuous casting and rolling of aluminium, Analysis of capacities, products ranges and Technology, Light Metal Age 60 (2002) 6-17.

[11] M. Duendar, O.E. Keles, B. Kerti, N. Dogan, Crystallographic texture development of twin-roll cast aluminum strips, Light Metal (2004) 723-724.

[12] Ch. Gras, M. Meredith, J.D. Hund, Microdefects for mation during the roll casting of Al-Mg-Mn aluminum alloys, Journal of Materials Processing Technology 167 (2005) 62-72.

[13] T. Haga, S. Suzuki, A twin roll caster to casting of clad strip. Journal of Materials Processing and Technology 138 (2003) 366-371.

[14] T. Haga, K. Takahashi, Downward melt drag twin roll caster, Journal of Materials Processing and Technology 157 (2004) 696-700.

[15] T. Haga, Casting of clad strip using a twin roll caster, Proceeding of the 33rd International Matador Conference 2000, 295-300.

[16] T. Haga, R. Nakamura, S. Kumai, H. Watari, Clad strip casting by a twin roll caster, Archives of Materials Science and Engineering 37 (2009) 117-124.

[17] T. Haga, M. Matsuo, D. Kunigo, Y. Hatanaka, R. Nakamura, H. Watari, S. Kumai, Journal. of Achievements in Materials and Manufacturing Engineering 34 (2009) 172-179.

[18] T. Haga, M. Ikawa, H. Watari, S. Kumai, High speed twin roll casting of Al-3Si-0.6Mg strip, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 337-340.

[19] T. Haga, M. Ikawa, H. Watari, S. Kumai, High speed twin roll casting of 6016 strip, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 371-374.

[20] T. Haga, M. Ikawa, H. Watari, S. Kumai, High speed twin roll casting of recycled Al-3Si-0.6M g strip, Journal of Achievements in Materials and Manufacturing Engineering 18 (2007) 7-12.

[21] T. Haga, Development of twin roll caster for light metals, Journal of Achievements in Materials and Manufacturing Engineering 43 (2010) 393-402.

[22] T. Haga, K. Akitsu, K. Kamakura, S. Kumai, H. Watari, Strip casting using a single roll caster equipped with a scraper, Journal of Achievements in Materials and Manufacturing Engineering 55 (2012) 26-32.