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Roll caster for the three-layer clad-strip

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ABSTRACT

Purpose: of this paper is to show the characteristics of two kinds of roll casters for three-layer clad strip of aluminium alloys. Moreover, the characteristics of these twin roll casters were compeered with the early type of roll casters for clad strip.

Design/methodology/approach: Design was tried to attain the fabrication of the roll casters to cast the three-layers-clad-strip. One caster was an unequal diameter roll caster equipped with a scraper. The scraper was adopted to prevent the mixture of different kinds of melts of the alloys. The scraper was used to cast the clad strip with clear interfaces between each strip. The other caster was a tandem type roll caster assembled from two vertical type twin roll casters. A vertical type of twin roll was mounted on the other vertical type of a twin roll caster.

Findings: Three layers of clad strips could be cast by two kinds of the roll casters developed in the present study. The casting speed was 20 m/min. This speed was much higher at the conventional twin roll caster for the aluminium alloys. Each strip of three layers clad strip was connected strictly. The element of clad strip did not peel at the interface by continuous bending. The as-cast clad strip could be cold-rolled. The element of alloys did not mix at the connecting interface of the strips. The casting conditions which affected the connecting of the strips and condition of interface were investigated and shown in this paper.

Research limitations/implications: The width of the strip was from 30 mm to 50 mm. The casting of the wide strip was not investigated. The alloy used in the present study was only aluminium alloys. The length of the cast strip was 3 m. The thickness of element strip was from 0.8 mm to 1.5 mm. The difference of the melting temperature of the alloys was within 50°C. The number of the layers was less than three layers.

Practical implications: The roll caster invented in the present study can be used for the fabrication of the clad strip. The clad strip is, for example, used for the brazing sheet of the radiator for the automotive industry.

Originality/value: There was not a report concerning the roll caster for three layers clad strip. The roll casters for clad strips shown in this paper were of an original process. Especially, the use of the scraper in the roll casting was original.

Keywords: Casting; Twin roll cater; Three layers clad strip; Interface of the clad strip

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The fabrication of the clad strip needs many processes and much energy. The strip is made of a slab by scrapping its surface, heat treatment, hot rolling and cold rolling. The strips are cleaned, edges of the strips are welded, and strips are connected by the hot rolling. If the strip can be made directly of the melt, energy can be saved. The roll caster can cast the strip directly from the molten metal [1-12]. Therefore, the roll casting is useful to save the energy in the fabrication of the clad strip. The development of the roll caster which can cast the clad strip was one of the solutions to reduce the energy to make the clad strip. However, there were only a few reports about the roll casting of the clad strip [13-16]. Especially, there was no report about the roll casting of a three layers clad strip.

In the present study, the invention of the roll caster, which can cast three layers of the clad strip, was tested. Two kinds of roll casters to cast three layers of clad strip were invented. One is an unequal diameter roll caster and the other is vertical tandem type of roll caster. The unequal roll caster was assembled from a lower large roll and two upper small rolls. The scraper is characteristic for this caster. The scraper was used to prevent a mixture from the different alloys [16]. The characteristic of the vertical tandem type of the roll caster is as below. A vertical type of the twin roll caster was mounted on another vertical type of the twin roll caster. Base strip was cast by the upper caster and the overlay strips were cast by the lower one.

Three layers clad strip was cast by these roll casters. The melting point of the base strip was higher than that of the overlay strips.

In this paper, characteristics of two kinds of roll caster and the clad strip are shown.

2. Roll casters for clad strips

2.1. Two layers strips

The process to cast clad strip by the conventional caster and the roll caster was shown in Fig. 1 [13-16]. The roll caster can cast clad strip within one process. It is clear that the roll casting of the clad strips has advantage of the process saving.

2.2. Roll caster for two layers clad strip

The roll casters, which can cast two layers of clad strip, are shown in Fig. 2. Modified types for three layers clad strip are shown, too. Some kinds of roll casters for clad strip were developed in this way. These casters have some characteristics, respectively. The characteristics were investigated to develop the roll caster which can cast three layers of clad strips.

The roll casters shown in (a), (b), (c) and (d) of Fig. 2 were designed, assembled and tested. (e) and (f) are only the idea. Fig. 2(e) is modified from (a) for three layers clad strip. The melting temperature of the upper strip must be lower than the lower strip in the process shown in Fig. 2(e). This reason is that the lower strip is melted by the heat from the upper strip, when the melting point of the upper strip is higher than lower strip. The melting point of the base strip (second strip) must be lower than that of the overlay strip (first strip). This restrict is not suitable for the fabrication of the three layers of clad strip. One of surfaces is free solidified surface. Therefore, surface condition is not sound. In these reason, Fig. 2(e) is not enough for the roll caster to cast three layers clad strip.

The process shown in Fig. 2(f) is better than (e). The alloy which melting point is higher than overlay strips can be chosen as the base strip. The surface temperature and surface condition are not the same at roll contact surface and free solidified surface of the base strip. The control of the semisolid condition at the free solidified surfaces of the overlay strip is not easy. The semisolid condition affects the bonding of the strips. The solid fraction of the free solidified surface of the overlay strips must be set low when three layers clad strip is cast.

In this way, (e) and (f) in Fig. 2 are not sufficient as the roll caster for the three layers clad strip. In this study, two kinds of roll casters were developed to cast three layers of the clad strips.

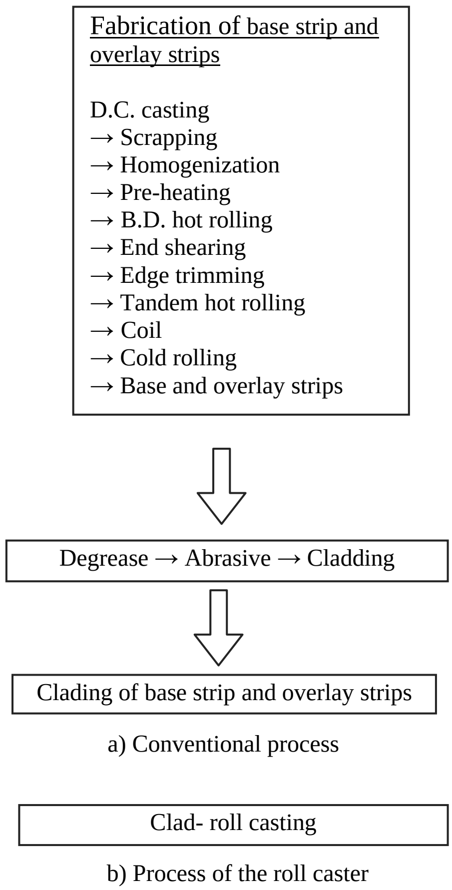
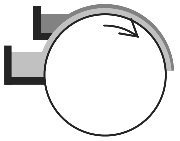
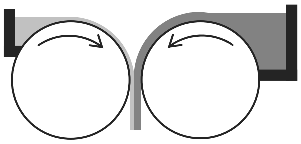


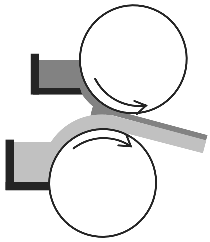
Fig. 1. Comparison of the process for making clad strip between the conventional process and the roll caster



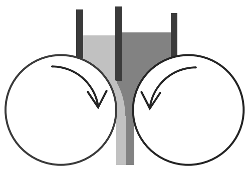
a) melt drag single roll type



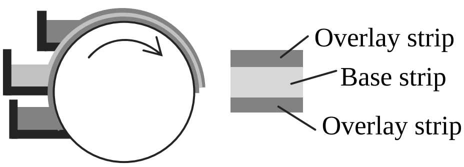
b) melt drag twin roll type



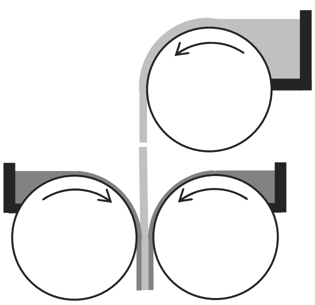
c) twin roll horizontal type



d) twin roll vertical type



e) melt drag single roll type for three layers

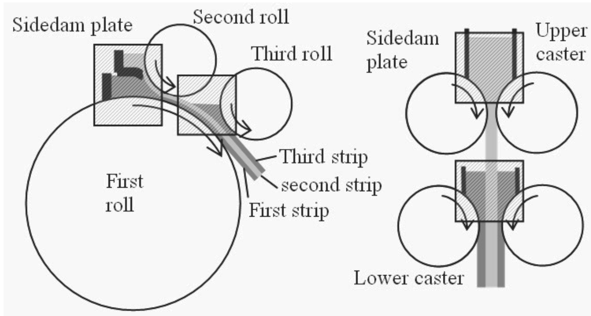


f) melt drag three roll type for three layers

Fig. 2. Roll casters for clad strips. (a), (b), (c) and (d) were tested; (e) is modified type for three layers from (a); (f) is modified type for three layers from (b); (e) and (f) are only the idea

2.3. Roll caster for three layers clad strip

An unequal diameter roll caster and a vertical tandem type roll caster were designed and assembled to cast the three layers clad strip. These casters are shown in Fig. 3. In the present study, properties of these two kinds of roll caster are investigated.



a) b)

Fig. 3. Roll castes to cast the three layers clad strip: a) unequal diameter roll caster, b) vertical tandem type roll caster

3. Unequal diameter roll caster

3.1. Properties of the caster

The unequal diameter roll caster is assembled from a large lower roll and two small upper rolls [17]. Each roll cast each strip. The large roll cast an overlay (first) strip. The second small upper roll cast a base (second) strip and the third small upper roll cast overlay (third) strip. A scraper was adopted to the first small upper roll. The scraper prevents the mixture of the melts of the base strip and the overlay strip. The scraper enables to separate the molten metal of the overlay and base strip. The scraper is shown in Fig. 4. The scraper rounds around the pivot. The scraper traces the solidified metal. When the scraper does not move, sticking of the solidified metal or a leak of the metal occurs. The sticking and leak is shown in Figs. 4 (b) and (c).

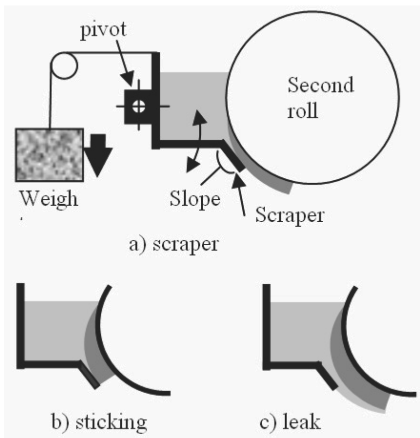


Fig. 4. Schematic illustration showing a function of the scraper

The melting temperature of the second strip is higher than that of the first and third strip. The second strip was completely solidified when the second strip was dragged being scraped. The scraper prevents the leek from melting. The temperature of the surfaces of the second strip became lower than the solidus line. The surface-temperature of the second strip must be higher than the solidus line to realize the bonding. The melt of the first and third strip must pre-heat the second strip up to the solidus line.

3.2. Scraper

The scraper was made of mild steel 3.2 mm thick [16]. The advantage of the mild steel was as below. Thin plate was made easy and the freedom of the shape was enough. The mild steel pate could be formed for suitable shape. The mild-steel plate was coated by the insulator paper. The insulator paper was used to prevent the reaction between the melt and mild-steel plate, and the cooling of the melt.

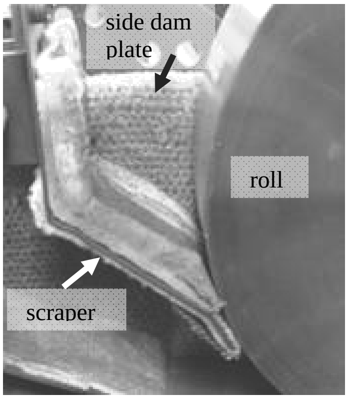


Fig. 5. Photograph of the scraper and sidedam plate

The plate was supported by the pivot. The scraper was pulled by the weight, and the scraper contacted to the free solidified surface of the second strip at constant force. The slope was attached to the tip of the scraper. The free solidified surface was completely solidified at the slope.

3.3. Size and position of the rolls

The side view of the unequal diameter roll caster is shown in Fig. 6. The first roll was large lower roll. The diameter of the first roll was 1500 mm, and the width was 50 mm. The diameter of the second roll and third roll was 250 mm, and width was 50 mm. The first roll was made from the mild steel, the second and the third roll were made from the copper. The thermal conductivity of the roll-material affects the temperature of the strip. The melt of the first strip must heat the second strip up to the temperature at which the strips can be connected. The surface of the second strip of the two-layer clad strip must be heated up to the temperature at which the second and the third strip can be connected. For that reason, the strips cannot be connected when the first roll cools strips too much. Therefore, the first roll was not made of copper but of steel.

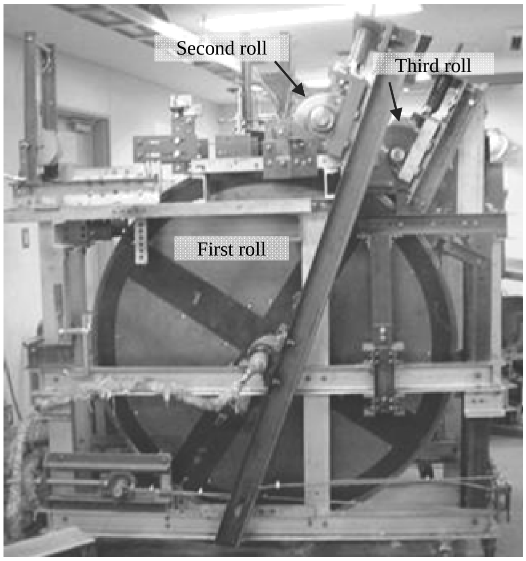


Fig. 6. Photograph of the unequal diameter roll caster

3.4. Experimental conditions

The experimental conditions are shown in Fig. 7 and at Table 1. The first strip and third strip was AA4045 and second strip was AA3003. This combination was the same as the brazing sheet of the radiator of the automobile. The solidification length, pouring temperature of the melt, load of small rolls and roll speed were decided by the result of the roll casting of the two layers clad strip. The molten metal was poured from the crucible through a launder in to the pool made by the side damplates and the other plate like scraper. The loads of the small rolls were very small. In this process, the strips were not connected by large force like connecting the hot rolling. The solidification of the molten metal between the strips is essential to connect strips. The loads of the small rolls were enough to solidify the melt between the strips. The second roll and the third roll were supported by the spring, and initial roll gap was set at 0.5 mm. This was useful to prevent the break out of the melt at the start of casting. Order of pouring of the melt was of the first, second and third strip. Three rolls were driven by a different motor. The rolls were rotated at casting speed before the start of the pouring of the melt. The roll speeds of the three rolls were all the same.

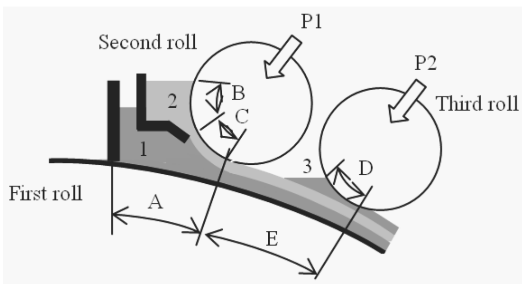


Fig. 7. Schematic illustration showing the experimental conditions of Table 1

Table 1.
Experimental conditions of Fig. 7

First roll	D: 1500 mm,	W: 50 mm,	mild steel
Second roll	D: 250 mm,	W: 50 mm,	copper
Third roll	D: 250 mm,	W: 50 mm,	copper
Solidification length A	100 mm		
Solidification length B	80 mm		
Contact length C	100 mm		
Solidification length D	80 mm		
Length between the small rolls E	300 mm		
Melt 1	AA4045,	pouring temperature 670°C	
Melt 2	AA3003,	pouring temperature 700°C	
Melt 3	AA4045,	pouring temperature 700°C	
Load P1	40 N/mm (unit width)		
Load P2	20 N/mm (unit width)		
Roll speed	20 m/min		

3.5. Result and discussion of the unequal diameter twin roll caster

The three layers of clad strip could be cast continuously by the unequal diameter twin roll caster. The casting ability of the three layers of the clad strip was almost the same as the single layer strip. The sticking of the strips did not occur at the small rolls. The alligator crack of the clad strip did not occur through the small rolls.

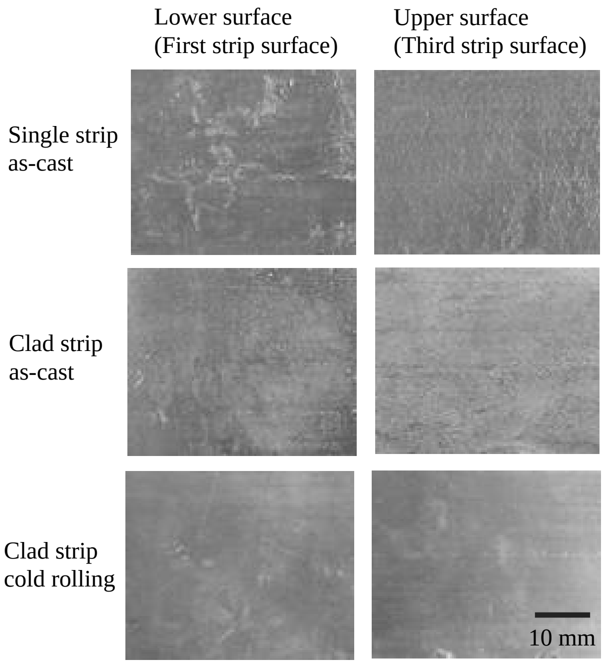


Fig. 8. Surface of single strip and clad strip. Material: AA4045

The surfaces of single strip and three layers of clad strip are shown in Fig. 8. The surfaces of cold rolled clad strip are shown, too. The surface of the clad strip was the same as the surface of the single strip. There was no defect which was specific on the clad strip. The defect did not occur at surfaces of the clad strip after cold rolling. The surface became sound by cold rolling.

The cross section of the three layers of clad strip was shown in Fig. 9. The interfaces between the strips were clear and linear. There was no clearance at the interface. The result of the line analysis at the interface shows that Si of the AA4045 did not diffuse to AA3003. The result of the continuous bending shows that peeling did not occur by the continuous bending. The melt of AA4045, that was an alloy of the first and third strip, did not melt the AA3003 of the second strip. The melting temperature of poured AA4045 was higher than liquidus temperature of the AA3003. However, the AA3003 strip was not melted. The thin surface might be melted, and diffusion area might exist. This diffusion area was too thin to be analysed by the line analysis. The contact time between the melt of AA4045 and the strip of AA3003 was about 0.24 s, and strips were contacting to the roll. In these reasons, the AA3003 strip was not melted and diffusion area was very thin. However, the strips were connected strictly.

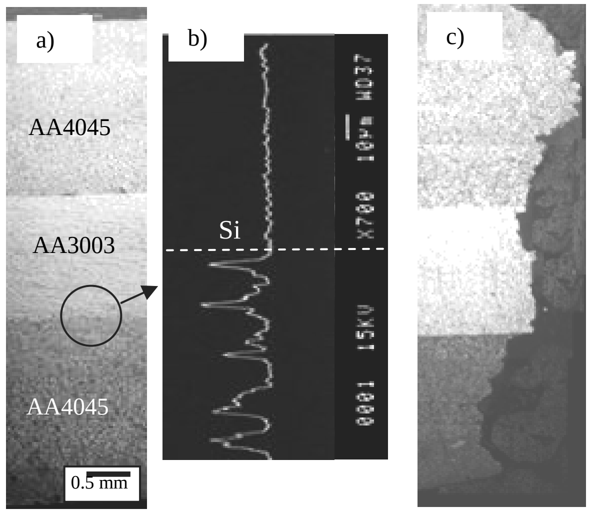


Fig. 9. Cross section of as-cast three layers clad strip. (a) as-cast clad strip, (b) line analysis of Si around the connecting interface, (c) broken area after continuous bending

The as-cast clad strip was cold rolled down to 0.5mm, and it was kept at 540^{O}C for 1 hour in order to inspect blisters. The occurrence of the blister shows the existence of vacancy where strips were not connected. Result was shown in Fig. 10. When the casting condition was not proper, the blister occurred. However, when the casting condition was proper, there was no blister. This means connecting condition was sound. The sound three layers clad strip could be cast by the unequal diameter roll caster.

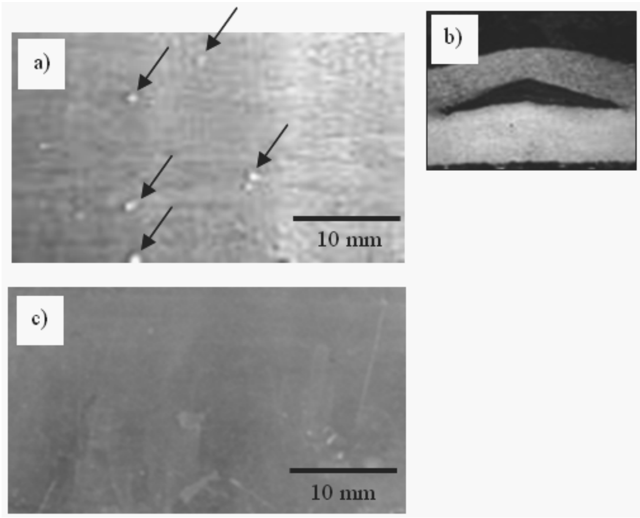


Fig. 10. Investigation of non-connected point by the blister-check. The as-cast three layers clad strip was cold-rolled down to 0.5 mm, and it was heated for 1 hour at 540°C. (a) casting condition was not proper. Arrow shows blister. (b) Cross section at the blister. (c) Result of the sound three layers clad strip. There is no blister

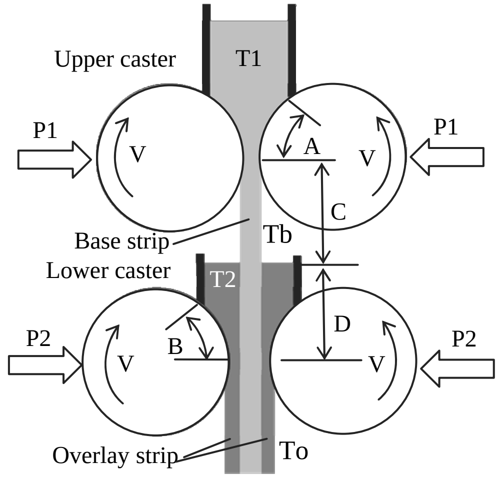
4. Vertical tandem type roll caster

4.1. Properties of the caster

The property of the vertical tandem type roll caster was the tandem position of the vertical type twin roll casters [18-21]. The both sides of the second strip (base strip) were directly solidified by the rolls. Therefore, the both surfaces were flat. In the unequal diameter twin roll caster, one surface was directly cast by the roll. Special equipment like the scraper is not needed. It is easy to make base strip (second strip) thicker.

4.2. Connecting conditions

There are some conditions that affect the strip connecting. The most important factor of the connecting is temperature of the base strip (second strip). Therefore, conditions that affect the temperature of the base strip concerns the connecting of the strips. The conditions that affect the connections are shown in Fig. 11. The base strip temperature Tb must be higher than the temperature to attain the connection with the overlay strips. The base strip was cast by the upper caster. The solidification length A affects the temperature of the base strip. The longer the solidification length A, the lower the temperature of the base strip Tb. The temperature of the base strip becomes higher as the roll speed becomes greater. The base strip goes through the cooling length C at shorter time as the roll speed increases. As the result, the cooling time of the base strip becomes shorter, and the decrease of the temperature of the base strip becomes lower. The longer the cooling length C, the greater the decrease of the Tb. The Tb becomes lower as the P1 becomes greater. The Tb becomes higher as the heating length by the melt of the overlay strip D becomes longer. The temperature of the overlay strip Tc becomes lower as the solidification length B becomes longer. The connecting condition of the base strip and the overlay strip becomes better as the load of the lower caster P increases. The T1 increases as the melting temperature of the overlay strip T2 becomes higher.



A: solidification length of base strip (second strip).
B: solidification length of overlay strip (first and third strip)
C: cooling length of base strip
D: heating length by melt of the overlay strip
V: roll speed
T1: melt temperature of the base strip
T2: melt temperature of the overlay strip
Tb: temperature of the base strip
To: temperature of the overlay strip
P1: load of upper caster
P2: load of lower caster

Fig. 11. Schematic illustration showing the parameter

4.3. Experimental conditions

The photograph of the tandem vertical type of the roll caster is shown in Fig. 12. The small roll-diameter was decided to reduce the cooling length C which is shown in Fig. 11. The experimental conditions of the tandem vertical type of the roll caster are shown in Table 2. The experimental conditions were decided from casting data of the unequal diameter roll caster and the vertical type twin roll caster. The width of the roll of the lower caster was wider than that of the upper roll caster in order to make reduce the interference by the side dam plate of the lower roll caster on the base strip.

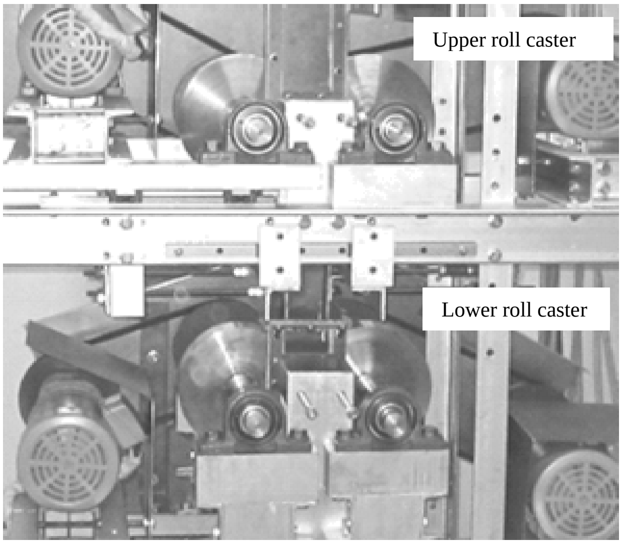


Fig. 12. Photograph of the tandem vertical type roll caster

Table 2.
Experimental conditions of the tandem vertical type of the roll caster

Upper roll caster
Roll: diameter: 200 mm, width 40 mm, copper
Solidification length: A: 40 mm
Load P1: 21 kN
Alloy AA8079 melt temperature T1: 700°C
Lower roll caster
Roll: diameter: 200 mm, width 50 mm, copper
Solidification length B: 80 mm
Load P2: 21 kN
Alloy AA6062 melt temperature T1: 750°C
Roll speed V: 20, 30, 40 m/min
Cooling length C: 370 mm
Heating length by melt of the overlay strip D: 50, 100 mm

4.4. Result and discussion of the tandem vertical type of a twin roll caster

The three layers of clad strip could be cast continuously by the tandem vertical type of the roll caster. The surface of the clad strip was the same as that of the single strip. The clad strips are cast at 30 m/min and 40 m/min are shown in Fig.13.

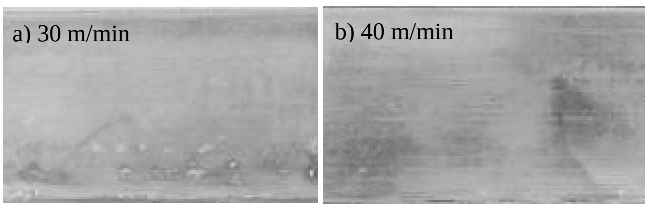
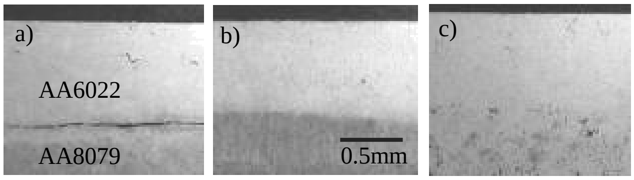


Fig. 13. Three layers clad strip cast by the tandem vertical type of the roll caster

The cross sections of as-cast clad strips are shown in Fig. 14. It is clear that the roll speed affected the connection of the base strip and the overlay strip. The base strip was not connected with the overlay strip at the speed of 20 m/min (ref. Fig. 14(a)). The interface between the base strip and the overlay strip was not clear at speed of 40 m/min (ref. Fig. 14(c)). Mixed zone of the AA8079 (base strip) and AA6022 (overlay strip) might be existed. The base strip was connected with the overlay strip at the speed of 30 m/min. The interface between the base strip and the overlay strip was clear. There was no clearance and mixed zone at the interface. When the temperature of the base strip was lower than proper temperature for the connection, the strips were not connected like in the Fig. 14(a). When the base strip was higher than the proper temperature, the base strip was melted by the heat from the overlay strip, and the interface was not clear Fig. 14(c). When the base strip was of proper temperature, strips were connected with clear interface.



V:20 m/min	V:30 m/min	V: 40 m/min
C/V: 1.11 s	C/V: 0.74 s	C/V: 0.56 s
D/V: 0.30 s	D/V: 0.20 s	D/V: 0.15 s

Fig. 14. Effect of roll speed on the connection of the base strip and the overlay strip. V: roll speed, C: cooling length of base strip, D: heating length by melt of the overlay strip (ref. Fig. 11), C/V: time to go through the C, D/V: time to go through the D

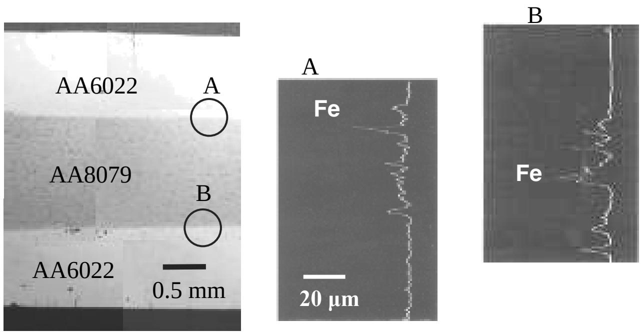


Fig. 15. Result of the line analysis of the as-cast clad strip. The line analysis was operated at the interface of AA8079 and AA6022 strip. Fe is the element included in the AA8079

The line analysis was operated at as-cast strip of the condition of Fig. 14 (b). Result of the line analysis of Fe is shown in Fig. 15. The Fe is the element of the AA8079 strip. The Fig. 15 shows that the Fe did not diffused from the AA8079 to the AA6022. This may mean phenomena as below. The pouring temperature of the melt of the AA6022 was higher than the liquidus line of the AA8079. The contact time between the base strip (AA8079) and the melt of the overlay strip (AA6022) was shorter than 0.2 s. The thin part of the surface of the base strip may be melt. The remelted thickness was very thin, and diffused thickness of Fe was very thin. Therefore, the Fe could not be analysed by the line analysis. The intermetallic may be crystallised at the mixed zone of the two kinds of metals. The intermetallic may make the property worse. Therefore, clear interface without mixed zone is needed in this clad strip.

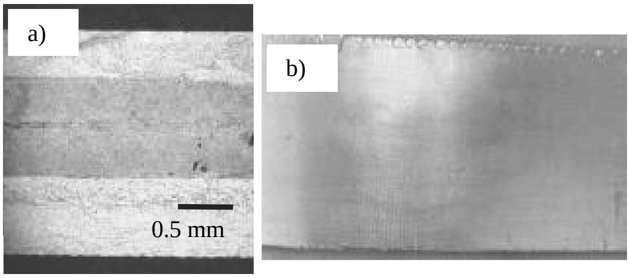


Fig. 16. Cross section and surface after cold rolling

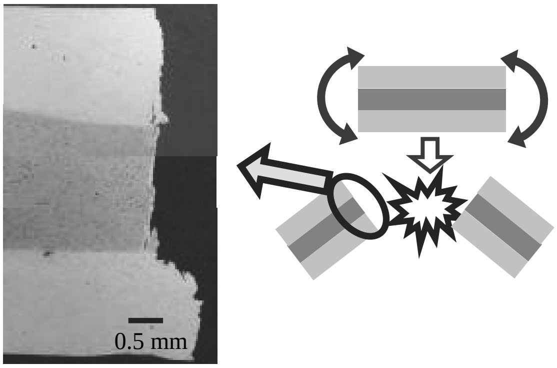


Fig. 17. Cross section of as-cast clad strip after continuous bending test until it is broken

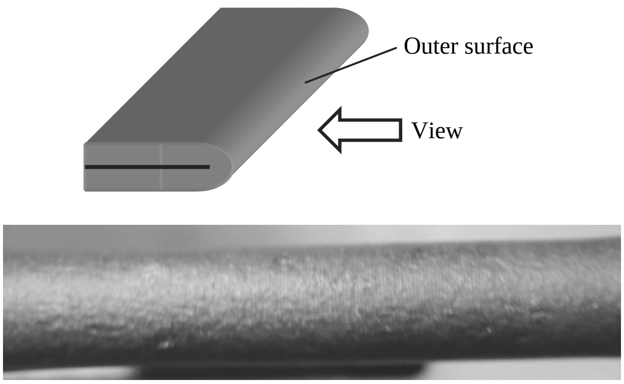


Fig. 18. 180 degrees bending test. Photograph shows the outer surface after 180 degrees bending. The as-cast strip was cold rolled down to 1mm, T4-heat treated and bent

The cold rolling was operated to the as-cast strip. The cross section and surface are shown in Fig. 16. The as-cast clad strip was not separated at interface between the strips. This means that the strip was connected strictly at the interface. The reductions of the base strip and the overlay strip were almost the same. The surface became sound after cold rolling.

Continuous bending was operated to investigate the connections of the strips. The as-cast strip was continuously bent until it was broken. The cross section of the broken one is shown in Fig. 17. The crack did not occur at the interfaces of the strips of the broken area. The strips were connected strictly at the condition of clear interface.

AA6022 strip is usually used for the body sheet of the automobile. Three layers clad strip assembled from AA6022 and AA8079 is the one of the model of utility of the recycled aluminium alloy. The recycled aluminium alloy contains more Fe than the product before recycle. The AA8079 contains Fe. Therefore, the AA8079 was assumed as the model of recycled AA6022. The reason why the AA6022 is used for the body sheet of the automobile is that AA6022 has good forming ability. The hem forming is one of 180 degrees bending. The hem forming ability of the AA6022 comes from the Fe content which is less than 0.2%. The Fe content of the recycled aluminium alloy increases and the ability of hem forming becomes worse. If the Fe content at the surface of the recycled strip is less than 0.2%, the ability of the hem forming may be sufficient. In this reason, the base strip was AA8079 and overlay strips were AA6022 in the three layers clad strip. The 180 degrees bending test was operated on the three layers clad strip, which was cold-rolled down to 1 mm from as-cast strip and T4-heat treated before bending. The outer surface of 180 degrees bent strip is shown in Fig. 18. The crack did not occur at outer surface. The three layers clad strip has the ability to be used for the body sheet. This means that the clad strip may become one of methods to resolve the problem of utility of the recycled aluminium alloy, when the clad strip was made by the roll caster. The economy clad strip can be made by the roll caster with energy saving.

5. Conclusions

Two kinds of roll casters to cast three layers of clad strip were developed in the present study. They are the unequal diameter roll caster and the tandem vertical type roll caster. These casters could cast three layers of clad strip. The interfaces between the element strips of the clad strip were clear. The diffusion of element of each strip did not occur to other strip at the interface. Each strip of the clad strip is connected tightly. The three layers clad strip could be cold rolled.

The casting conditions, which affect the connection and interface between the elements strips, were investigated. Pouring temperature of the melt and roll speed were important factors.

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