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Development of a twin roll caster for light metals

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ABSTRACT

Purpose: Purpose of this paper is to show the development of a twin roll caster for aluminium alloy. One of the developments was the increase of the roll speed. The increase of the roll speed was essential to improve the low productivity of the twin roll caster. Limitation of the alloys, which can be cast into the strip, could be enlarged by the method to increase the roll speed. The method to increase the roll speed was useful to increase the cooling rate of the cast strip. The devices to increase the roll speed were shown in this paper. Other development was invention of the twin roll caster to cast clad strip. The twin roll casters to cast two layers clad strip, three layers clad strip and five layers clad strip were invented.
Design/methodology/approach: Increase of roll speed was attained by the use of a copper roll and a nozzle, operation of the low temperature casting and non-use of parting material. A scraper was adopted to the twin roll caster for clad strip to prevent the mixture of the molten metals and to control the surface condition. The devices to increase the roll speed were useful for the roll caster to cast clad strip.
Findings: The aluminium alloy strip could be cast at the speeds up to 90 m/min. The aluminium alloy which has wide freezing zone like Al-25%Si could be cast into the strip. Two layers, three layers and five layers of clad strips could be cast.
Research limitations/implications: The roll casters were laboratory size. Therefore, it was not clear of the ability of the casting of the long size and wide size strips.
Practical implications: The productivity of aluminium alloy strip is increased. The property of the aluminium alloy strip is improved. The aluminium alloy, which was too brittle to be formed into the plate, will be cast into strip directly from melt. The process and energy to make the brazing sheet will be saved by the roll caster of the present study.
Originality/value: The invented roll casters, devices for casting and properties of the cast strips are original.
Keywords: Casting; Twin roll caster; Clad strip; Aluminium alloy

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1. Introduction

The research concern to the twin roll caster has been done more than ten years at the material processing laboratory of the Osaka Institute of Technology. Some of the results of the research are introduced in this report.

The conventional twin roll caster for aluminium alloy (CTRCA) has advantages of process saving and rapid solidification [1-12]. However, CTRCA has disadvantages, too. The disadvantages of the CTRCA are low productivity and limitation of the alloys which can be cast into the strip. Improvements of these disadvantages were tried. A vertical type high speed twin roll caster for aluminium alloy (VHSTRCA) was designed and assembled to improve these disadvantages [13-17]. Some devices were tried and adopted to the VHSTRCA. They were use of copper roll, non-use of parting material, use of hydrostatic pressure and operation of low temperature casting. The methods to increase the cooling rate of the metal were adopted to increase the roll speed. The roll speed of the VHSTRCA could be increased up to 90m/min. The increase of the cooling rate was useful to enlarge the aluminium alloys which can be cast into the strip. Aluminium alloys which freezing zone was very wide like Al-25%Si could not be cast into the strip by the CTRCA as the melt was not solidified and break out occurred. The Al-25%Si could be cast into the strip by the VHSTRCA.

The many processes are essential to make clad strip by the conventional process. Therefore, the process saving has been demanded for energy saving. The roll caster is useful to reduce the processes to make the strips of the elements of the clad strip. If connecting can be operated simultaneously with the strip casting using only one caster, many processes and much energy may be saved. Two kinds of roll casters to cast the clad strip were invented [18-22]. Two layers, three layers and five layers clad strips could be cast. The casting of the clad strip without mixed zone of alloys at the interface of the strips and with the clear interface was tried.

In this paper, properties and devices of VHSTRCA and the roll caster for clad strip are shown. The characteristics of the roll cast strips are shown, too.

2. Vertical type high speed twin roll caster for aluminium alloy (VHSTRCA)

2.1. Properties and devices of the VHSTRCA

The schematic illustration of the vertical type high speed twin roll caster for aluminium alloy (VHSTRCA) is shown in Fig. 1. Some devices were adopted to the VHSTRCA to increase the cooling rate of the metal. This reason was as below. The increase of the cooling rate was essential for the increase of roll speed and enlargement of aluminium alloys which can be cast into the strip.

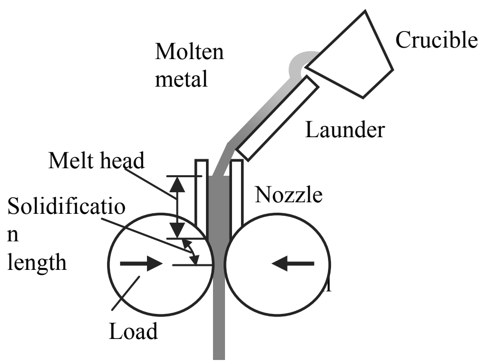

Fig. 1. Schematic illustration of a vertical type high speed twin roll caster for aluminium alloy (VHSTRCA)

The most important devices to increase the cooling rate were use of copper roll and non-use of parting material. Tool steel for hot working is usually used as the material of the roll for the conventional twin roll caster for aluminium alloy (CTRCA) [1-12]. Parting material is sprayed on the roll to prevent the sticking of the strip to the roll in the CTRCA. The thermal conductivity of the copper is much larger than that of the tool steel. Therefore, the surface-temperature of the copper roll is kept lower than that of the tool steel roll. The heat flow from the melt to the roll increases as the roll temperature becomes lower. The sticking of the strip to the roll depends on the surface temperature of the roll. When the surface of the roll is heated up to the critical temperature, the sticking of the strip occurs. When the copper roll was used at proper condition, the sticking of the strip did not occur. The parting material was not essential for the copper roll. The parting material becomes heat resistance between the roll and the melt. Therefore, the parting material decreases the cooling rate of the strip. In this way, the use of copper roll significantly contributes the increase of the cooling rate.

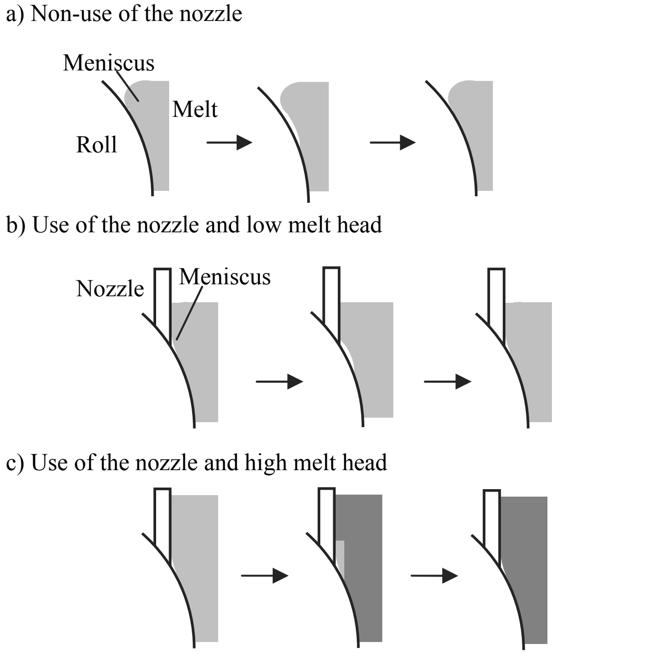

Fig. 2. Schematic illustration showing the effects of the use of nozzle and melt head on the vibration of the meniscus

The hydrostatic pressure was utilized to make the contact condition between the roll and the melt better. The hydrostatic pressure was gotten by the melt head of the melt pooled on the roll by nozzle plates and side dam plates. The meniscus of the melt at the contact-start-point between the melt and the roll became stable as the hydrostatic pressure became higher. The meniscus became unstable as the roll speed increased, and the ripple mark occurred on the surface of the strip. Therefore, the melt head must be higher as the roll speed becomes higher. Schematic illustration of the vibration of the meniscus is shown in Fig. 2. The heat transfer between the roll and the melt becomes greater at the higher melt head as the contact condition between the roll and melt becomes better. The strip cast using the nozzle to get hydrostatic pressure was thicker than the strip cast non-using the nozzle. This means heat transfer between the roll and the melt becomes larger. The effect of the use of the nozzle on the surface of the strip is shown in Fig. 3. The nozzle is useful to make the strip constant thickness. The bouncing of the position of the melt surface does not affect the solidification length when the nozzle is used as shown in Fig.4.

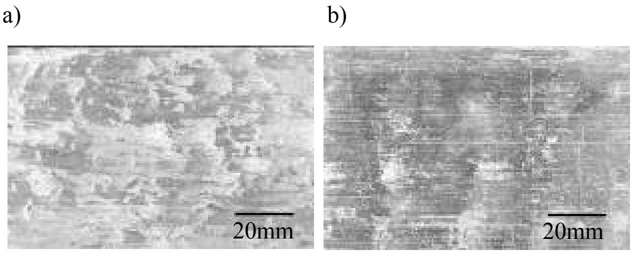

Fig. 3. Photographs of the strip surface of AA5182 strip cast by a vertical type twin roll caster at the speed of 90m/min. (a) cast non-using the nozzle, (b) cast using the nozzle at the melt head of 100 mm

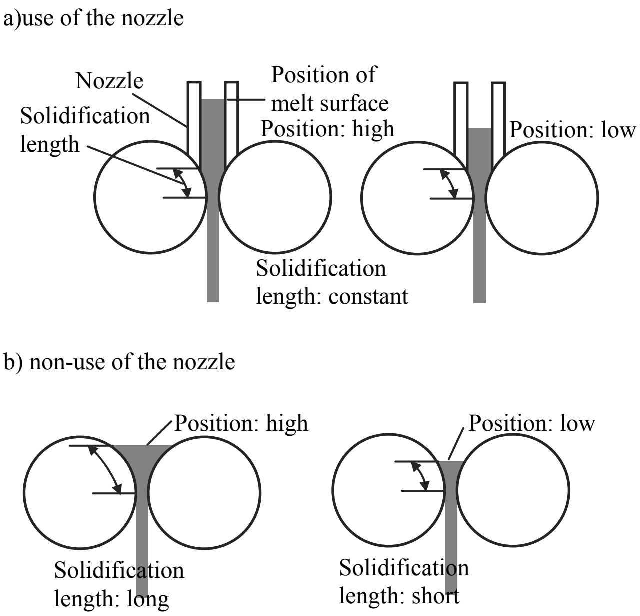

Fig. 4. Schematic illustration showing the effect of the nozzle on the constancy of the solidification length against the bouncing of the position of the melt surface

Low temperature casting was useful for the high speed roll casting. The specific heat which is taken away by the roll becomes less as the melt temperature becomes low. Solidification time of the strip becomes shorter. As the result, the roll speed can be set higher. When the low temperature casting is operated by the CTRCA, the nozzle may be plugged by the solidified metal as the moving ratio of the metal is low. In the VHSTRCA, the moving ratio of the metal is very high, and the solidification did not occur in the nozzle.

2.2. Microstructure of the strip cast by the VHSTRCA

The microstructure of the cross section of the strip cast by the VHSTRCA was different from that of the cast by the CTRCA. In the CTRCA, the microstructure is deformed by the hot rolling, and the interface exists between the upper and lower solidification layers. In the VHSTRCA, the microstructure was not deformed as the rolling load was very small, and the cross section consisted of three layers as shown in Fig. 5. Figure 5 shows microstructure of the cross section of Al-3%Si-0.3%Mg as-cast strip. The rolling load of the VHSTRCA is smaller than 1kN/(mm unit width). The microstructure of the centre layer was globular structure. This globular structure was typical structure of the low temperature casting. The microstructure of the both side layers of the centre layer was almost equiaxed structure.

The microstructures of the cross section of as-cast A356 strip and of strip after cold rolling and T-6 heat-treatment are shown in Fig. 6. The eutectic Si is shown in Fig. 6, too. The eutectic Si of as-cast Si was very fine and globular. The size of the eutectic Si of as-cast strip was smaller than 2 μm as shown in Fig. 6 (b) and(c). The eutectic Si after the cold rolling and T6 heat treatment is smaller than 5 μm as shown in Fig. 6 (e). There was no marked difference in the size of eutectic Si between the centre layer and other areas. This shows that the cooling ability of the VHSTRCA was very excellent, and the strip could be rapidly solidified until centre of the thickness. The microstructure of the cross section of A356 strip did not become completely uniform at the thickness direction after operation of cold rolling and T6 heat treatment as shown in Fig. 6(e).

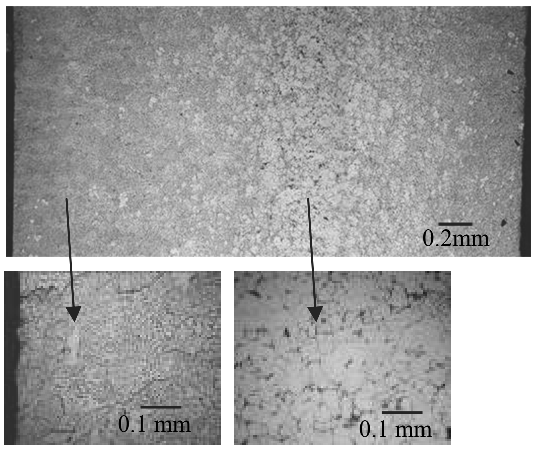

Fig. 5. Cross section of Al-3%Si-0.3%Mg as-cast strip by the VHSTRCA at speed of 60 m/min

The microstructures of AA6063 and AA6063 to which 2%Fe added are shown in Fig. 7. The Fe added AA6063 is the model of recycled aluminium alloy. The grain of the Fe added AA6063 was smaller than that of the AA6063. This was the effect of the increase of the content of the elements. The acicular Fe-contained intermetallic crystallized in the ingot cast using an insulator mould. However, the acicular Fe contained intermetallic did not crystallize in the 2%Fe added AA6063.

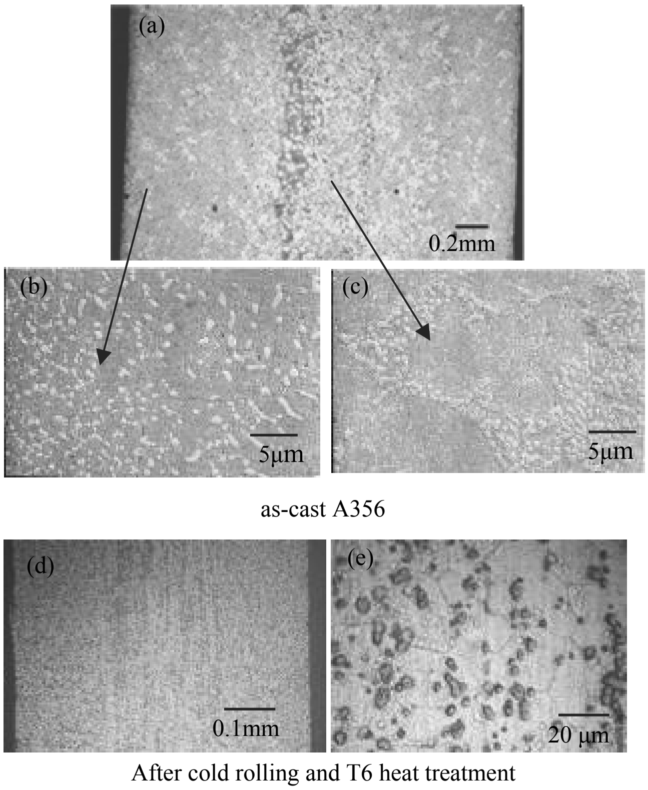

Fig. 6. Microstructure of cross section A356 strip cast by the VHSTRCA. (a), (b) and (c): as-cast, (d) and (e): after operation of cold rolling down to 1mm and T6 heat treatment

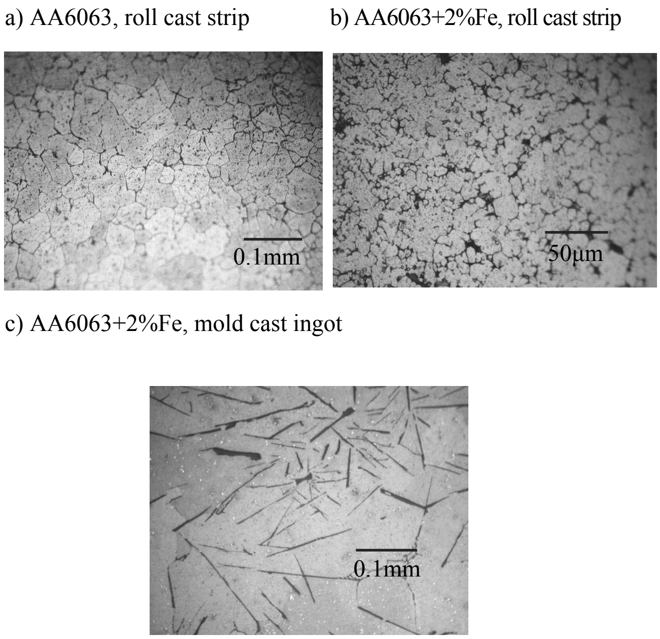

Fig. 7. Microstructure of AA6063 and Fe added AA6063

2.3. Mechanical properties of the strip cast by the VHSTRCA

The eutectic Si of A356 strip cast by the VHSTRCA was very fine as shown in Fig. 6. Therefore, A356 strip had good formability. The result of the deep drawing is shown in Fig. 8. The L.D.R. (Deep Drawing Ratio) was 2.0. This value shows that A356 strip has the sufficient formability for the press forming. 180 degrees full bending was operated on the T4 heat treated strip of 0.5 mm thickness. The crack did not occur at outer surface.

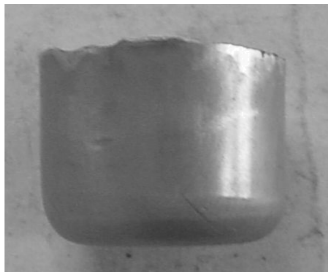

Fig. 8. Deep drawing of roll cast A356 strip. The as-cast strip was cold rolled down to 1 mm, and T4 heat treatment was operated. The punch diameter was 32 mm

Result of tension test of AA6063, 0.35%Fe and 1.0%Fe added AA6063 is shown in Fig. 9. The elongation usually decreases with the increase of impurity Fe. However, the elongation of the 0.35%Fe added AA6063 was superior to that of AA 6063. The grain size became smaller by addition of the impurity Fe. The impurity which contained Fe became fine by the excellent cooling ability of the VHSTRCA, and the impurity might disperse uniformly. As the result, the elongation was improved. Moreover, the tensile strength and proof stress were improved by the dispersion hardening. When the content of the impurity Fe is 1%, the aging effect was not attained. Most of the Si was contained in the AlSiFe imtermetallic, and content of precipitated Mg_2Si was not enough to reinforce.

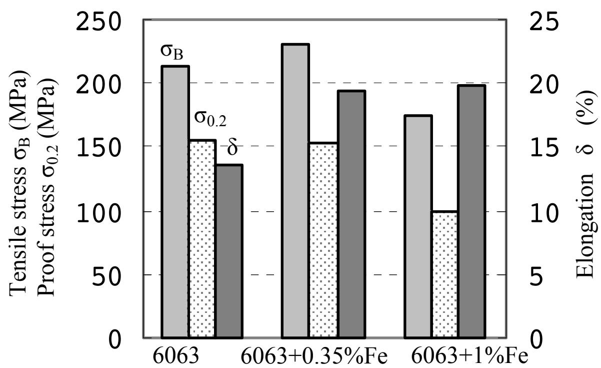

Fig. 9. Mechanical properties of AA6063 and modified AA6063 with impurity Fe with T6 heat treatment. The as-cast strip was cold rolled down to 0.5 mm, and T6 heat treatment was operated on the strip

2.4. Roll casting of Al-25%Si-4%Mg strip

Al-25%Si-4%Mg hyper eutectic alloy has properties of low thermal expansion and high wear resistance. This alloy is very hard and brittle, and the operation of the cold rolling on this alloy is difficult as the strip is broken. Powder metallurgy is usually used to make plate. This alloy has wide freezing zone. The flow stress at the semisolid condition is low until near to the solidus line. Therefore, the strip casting of the Al-25%Si-4%Mg by the CTRCA is difficult as break out of the melt easily happens.

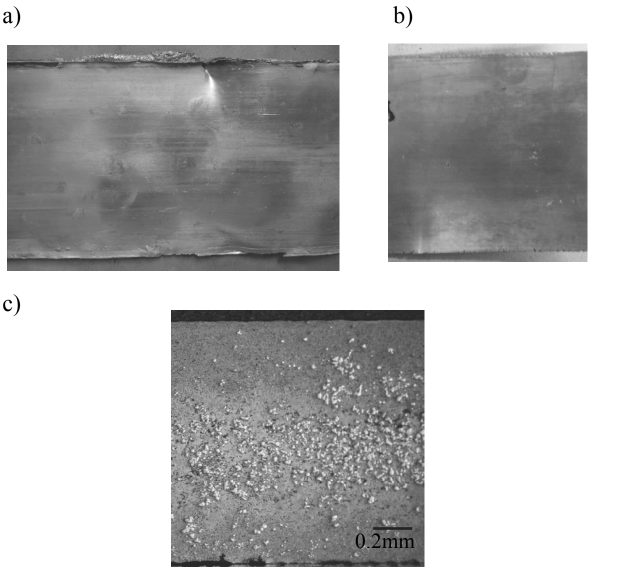

Fig. 10. Surface and cross section of Al-25%Si-4%Mg strip cast at speed of 20 m/min. (a) surface of as-cast strip, (b) Surface of cold rolled surface after annealing, (c) cross section of as-cast strip

The strip casting of Al-25%Si-4%Mg using the VHSTRCA was tried. The Al-25%Si-4%Mg strip could be cast at the speeds up to 30 m/min. The surface of as-cast strip is shown in Fig. 10. The Al-25%Si-4%Mg strip had metallic lustre. The as-cast strip could not be cold rolled as the as-cast strip was broken. The annealed strip could be cold rolled. The condition of annealing was at 450^{o}C for 8 hours. The eutectic Si was very fine. Therefore, the ductility was improved up to the possibility of the cold rolling. The cross section of the as-cast strip is shown in Fig. 10, too. The most of the primary Si exists at the centre of the thickness direction. The primary Si was smaller than 20 μm.

2.5. Roll casting of Al-SiCp alloy

The Al-SiC$_p$ alloy has advantages of the low thermal expansion, better thermal conductivity and high wear resistance. However, the Al-SiC$_p$ has disadvantage, too. The plate is very expensive as the plate is made by repeated operation of hot rolling. The economy plate of Al-SiC$_p$ has been demanded. The twin roll caster can cast thin strip directly from the molten metal. Therefore, the twin roll caster has ability for making the economy plate. The roll casting of Al-SiC$_p$ strip was tried.

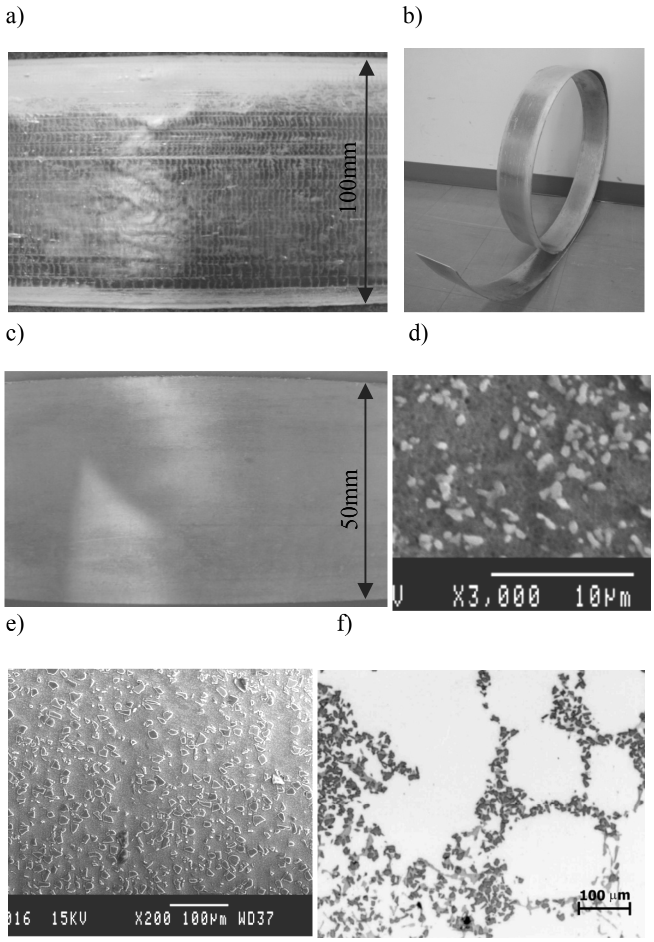

Fig. 11. Surface and microstructure of Al-20vol%SiC$_p$ strip cast by the VHSTRCA at speed of 60m/min. Matrix is A359 aluminium alloy. (a) surface of the strip, (b) coiled 2mm-thickness and 100mm-width strip at diameter of 460mm, (c) surface of cold rolled strip after annealing at 500^{o}C for 8 hours, (d) SEM image of eutectic Si of as-cast strip, (e) SEM image of cross section of as-cast strip showing the dispersion of SiC$_p$, (f) microstructure of mould cast Al-20vol%SiC$_p$ ingot observed by the optical microscope

The Al-20vol%SiC$_p$ strip could be cast at the speeds up to 90m/min. The strip cast at 60m/min is shown in Fig. 11. The casability of Al-20vol%SiC$_p$ strip was almost as same as the matrix aluminium alloy. The surface-defect caused by SiCp was not existed as shown Fig. 11 (a). The as-cast strip could be coiled at the diameter of 460mm as shown in Fig. 11 (b). This shows the possibility of the coil-to-coil rolling. The annealed strip could be cold rolled down to 1mm without broken as shown in Fig. 11 (c). The surface could be improved by the cold rolling. The eutectic Si of as-cast strip was very fine. The size of eutectic Si is smaller than 2μm. Therefore, ductility became better and the cold rolling could be operated. The dispersion of the SiC$_p$ of the strip was more uniform than that of the mould cast ingot as shown in Fig. 11 (e) and (f). The SiC$_p$ exists in the eutectic area and does not exist in the primary Al of the roll cast strip. The primary Al of theroll cast strip was smaller than that of the mould cast ingot. Therefore, the SiC$_p$ of the roll cast strip dispersed uniformly.

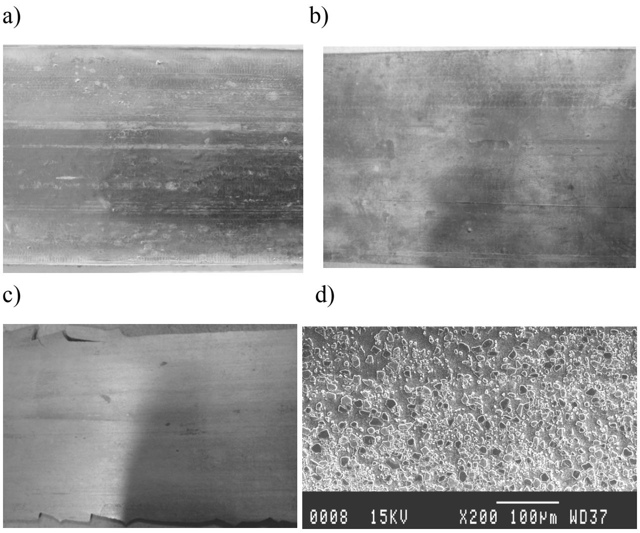

Fig. 12. Surface and dispersion of SiC_p of the roll cast Al-30vol%SiC_p strip at the speed of 60m/min. Thickness was 1.7mm. (a)surface of as-cast strip, (b)surface of hot rolled strip at 500°C, thickness: 1.5mm, (c)surface of cold rolled strip after hot rolling, (d)SEM image of the cross section of as-cast strip showing the dispersion of SiC_p

The Al-30vol%SiC_p strip could be roll-cast at the speeds up to 90m/min. The surface of as-cast strip is shown in Fig. 12(a). When the content of SiCp was 30vol%, the metallic luster was poor than 20vol%. The cold rolling could be operated on the hot rolled strip as shown in Fig. 12 (b) and (c). There was tendency that the edges were broken. The dispersion of the 30vol%SiC_p was uniform as shown Fig. 12 (d). The VHSTRCA ws useful to cast Al-SiCp strip with uniformly dispersed SiC_p.

3. Unequal diameter roll caster to cast clad strip

3.1. Two layers clad strip

The many processes are needed to make the clad strip. Therefore, the process saving is demanded to save energy. The twin roll caster can cast strip directly from melt. Therefore, the twin roll caster is useful to save the process in the fabrication of the clad strip. If the cladding of the strips can be done with the casting of the strips at the same time, much energy can be saved. The roll caster to cast the clad strip was developed. Schematic illustration of the twin roll caster to cast the two layers of clad strip is shown in Fig. 13. The device of casters shown in Fig. 13 is the use of a scraper. Only the solidified layer or semisolid layer could be dragged by the effect of a scraper. The scraper moved depends on the thickness of the solidified layer to prevent the leak of the melt. The contact force of the scraper to the solidified layer was kept constant by the dead weight to make the solid fraction on the scribed surface constant. The two kinds of molten metal are not mixed by the use of the scraper. The scribed surface of AA6022 strip is shown in Fig. 13(e).

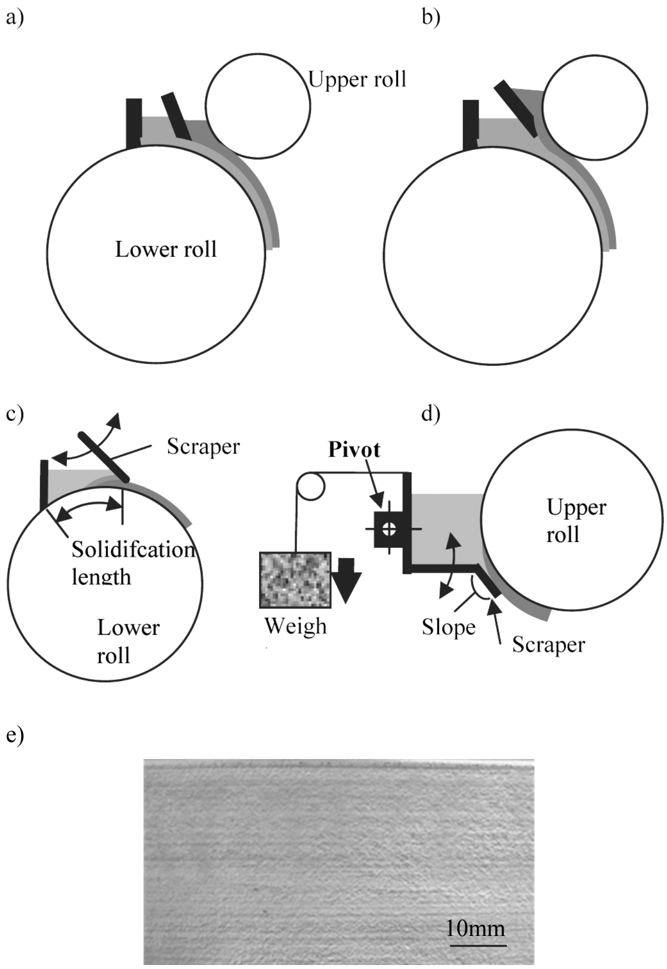

Fig. 13. Schematic illustrations showing the twin roll caster to cast two layers clad strip. (a) the liquidus line of the metal solidified by a lower roll is higher than that of the upper roll.(b)the liquidus line of the metal solidified by the lower roll is lower than that of the upper roll. (c) around the scraper of (a), (d) around the upper roll of (b), (e) scribed surface of AA6022 strip

It is clear that melt did not exist on the scribed surface. In the casters of Fig.13 (a) and (b), the surface of the strip, which liudas line was higher than the other metal, was scribed. The molten metal, which liquidasu line was lower, heated the scribed surface of other strip up to the temperature suitable for the cladding but lower than the melting point. The scribed surface immediately contacts to molten metal of the other alloy after went through under the scraper. This may be useful to prevent the oxidation of the scribed surface. The roll-load need to connect was lower 150N/(mm unit-width). This shows that the strips are not connected by the hot rolling.

The cross section of the two layers clad strip is shown in Fig. 14. The two layers clad strip could be cast using the both roll casters shown in Fig. 13 (a) and (b). The interface of the clad strip was clear. This shows that the two kinds of molten metal were not mixed by the effect of the scraper. The scraper was useful to cast the clad strip with the clear interface.

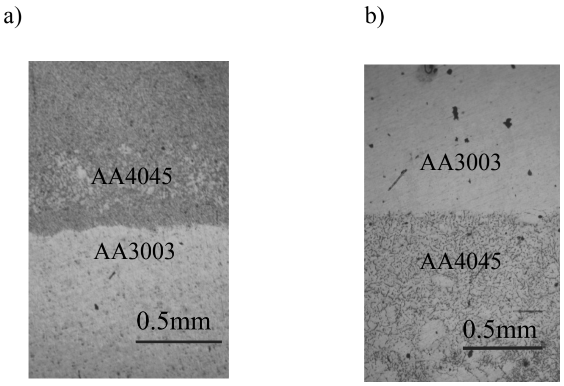

Fig. 14. Cross section of the two layers clad strip cast by the roll caster shown in Fig. 13 (a) and (b). (a) clad strip cast by Fig. 13(a), (b) clad strip cast by Fig. 13(b)

3.2. Three layers clad strip - liquids line of base strip is higher than that of overlay strip

The roll caster to cast the three layers clad strip was developed. This caster is suitable to cast the clad strip as below; the liquidus line of the base strip is higher than that of the overlay strip.

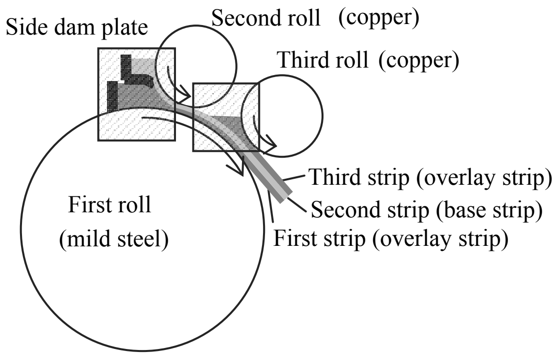

Fig. 15. Schematic illustration showing the roll caster to cast the three layers clad strip. This caster is suitable to cast clad strip as below. The liquidas line of the base strip is higher than that of the overlay strip

Schematic illustration of the roll caster to cast three layers clad strip is shown in Fig. 15. The base strip was cast by the second roll. The overlay strips were cast by the first and third roll. The surfaces of the base strip were heated up to the temperature which was suitable for the cladding. The scraper was attached to the second roll. The strip could be dragged from the gap between the second roll and the scraper, and the melt was not dragged. Therefore, the mixture of the melt of the base strip and overlay strip did not occur. The choice of the melt temperature of the overlay strips is important to cast the three layers clad strip with the clear interfaces. The melt temperature of the overlay strip must be usually lower than the temperature which is10 degrees higher than liquidus line of the base strip. Moreover, the pouring temperature of the overlay strip must be higher than the solidusline of the base strip in case most of the coupling of aluminium alloys. The melt of the overlay strips heated the base strip up to the temperature suitable for the cladding, and the three strips were connected.

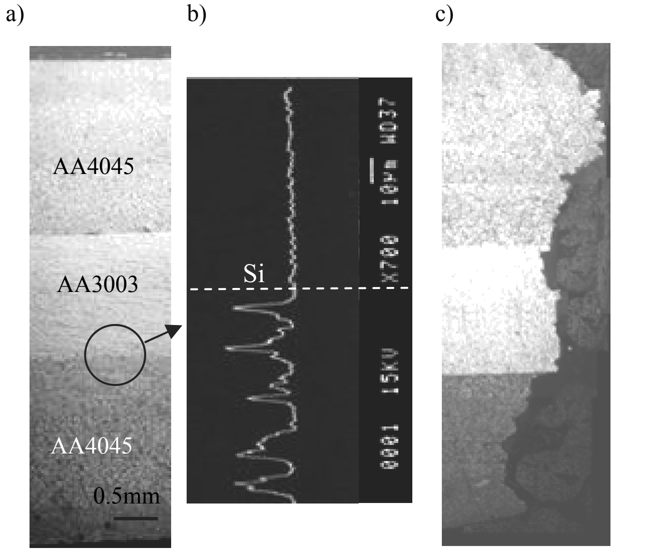

Fig. 16. Cross section of as-cast three layers clad strip cast at speed of 20m/min using the roll caster of Fig. 15. (a)as-cast clad strip, (b)line analysis of Si around the connecting interface, (c)broken area after continuous bending

The cross section of the three layers clad strip cast by the roll caster of the Fig. 15 is shown in Fig. 16. It is clear that the clad strip is assembled from three layers. The interfaces between the strips (layers) were clear, and the mixed zone of metals did not exist. The result of the line analysis at the interface is shown in Fig. 16 (b). The Si, which is the element of theAA4045 of the overlay strip, did not diffuse to the base strip of AA3003. This means that the base strip AA3003 was not melted by the melt of the overlay strip. The result of the bending test is shown in Fig. 16(c). The clad strip was continuously bent until broken, and the cross section of broken area is shown. The crack did not occur at the interfaces. This shows that the strips were connected firmly at the interface.

3.3. Three layers clad strip - liquids line of base strip is lower than that of overlay strip

The three layers clad strip, of which base strip has lower liquidus line than the overlay strip, cannot be cast by the roll caster shown in Fig. 15, because the bae strip is melt by the molten metal of the overlay strip. Therefore, the roll caster to cast the three layers clad strip of which base strip has lower liquidus line than overlay strip, was developed. This caster is shown in Fig. 17. The scraper was used to prevent the mixture of melts, too. In the Fig. 17, the first strip is cast by the method of Fig. 13(a), and the third strip is cast by the method Fig. 13(b). The melt of the second strip (base strip) heat the first and third strip up to temperature suitable for clading, and melt of second strip simultaneously solidified.

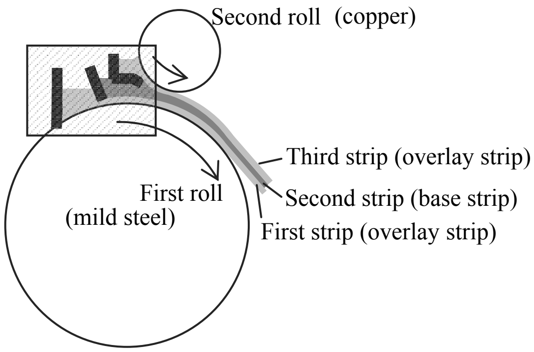

Fig. 17. Schematic illustration showing the roll caster to cast the three layers clad strip. This caster is suitable to cast clad strip as below. The liquidas line of the base strip is lower than that of the overlay strip

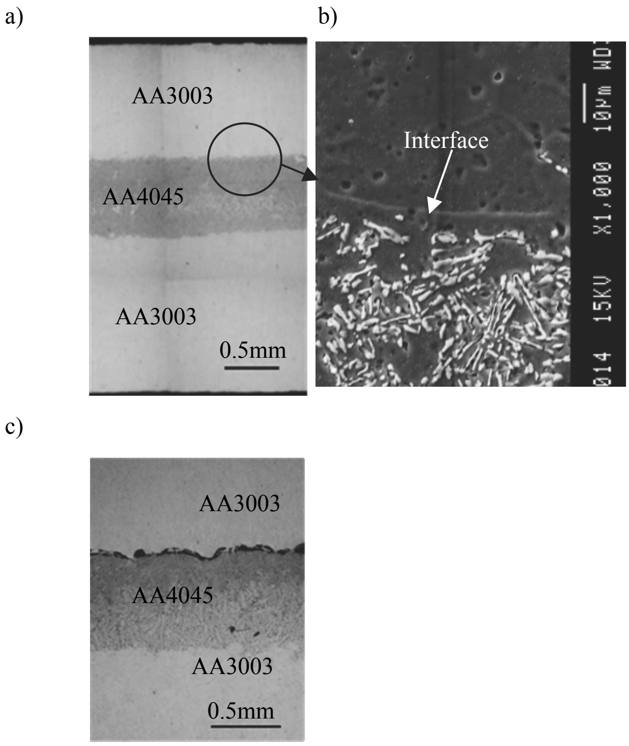

Fig. 18. The cross section of the three layers clad strip cast by the roll caster of the Fig. 17; the first roll was made from mild steel and the second roll was made from the copper roll. (a) melt temperaure of the second strip was 655°C, (b) enlarged view around the interface of the clad strip , (c) melt temperaure of the second strip was 630°C

The cross section of three layers clad strip cast by the roll caster of Fig. 17 is shown in Fig.18. When the melt temperature of the AA4045 of second strip (base strip) was 655°C, the second strip was connected to first and third strips (overlay strips). The interface between the strips was clear, and gap did not exist at the interface. When the melt temperature of the second strip was 630°C, the second strip was connected to the first strip, but was not connected to the third strip. The firast strip was solidified by the mild-steel roll, and third strip was solidified by the copper roll. Therefore, the temperature of thid strip was lower than that of the first strip. The heating by the 630°C-melt of the second strip was enough to connect the firast strip to second strip, but was not enough to connect the third strip to the second strip.

4. Vertical tandem type roll caster to cast clad strip

4.1. Two layers clad strip

A vertical tandem type roll caster was designed and assembled. In the case the liqudus line of the base strip is higher than that of the overlay strip, the vertical tandem roll caster is suitable to cast the clad strip. Schematic illustration of the vertical tandem type twin roll caster is shown in Fig. 19. The advantage of this caster for the comparision with the unequal diameter roll caster shown in Fig. 15 is as below. The both surfaces of the base strip were solidified by the roll. Therefore, the interface between the strips are flat. The scraper is not needed, and the process and the operation are simple. The base strip can be thicker. The controll of the temperature of the base strip is easier than the unequal diameter twin roll caster. However, the vertical tandem type roll caster has disadvantage, too. The casting of the two layes clad strip is difficult.

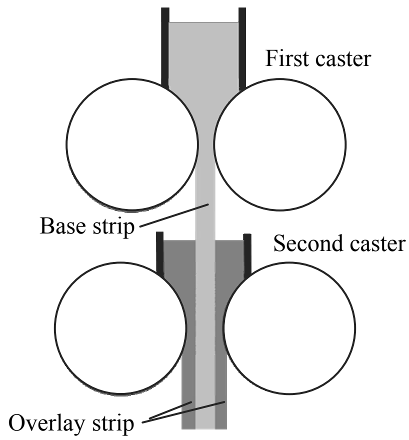

Fig. 19. Schematic illustration of the vertical tandem type roll caster to cast three layers clad strip

The cross section of the three layers clad strip cast by the vertical tandem type roll caster is shown in Fig. 20. The strips were connected, and the interfaces were clear. The clad strip shown in Fig. 20 was cast at speed of 30m/min. When the roll speed was 20 m/min, the gap occurred at the interface between the base and overlay strip. The surface temperature of the base strip was too low when the base strip contacted with the overlay strip. The contact time between the roll and the base strip was long and base strip was cooled lower than suitable temperature for the cladding when the roll speed was 20 m/min. When the roll speed was 40 m/min, the base strip was melted and interface between the strips was not clear. The temperature of the base strip was too high when the base strip contacted with the overlay strip.

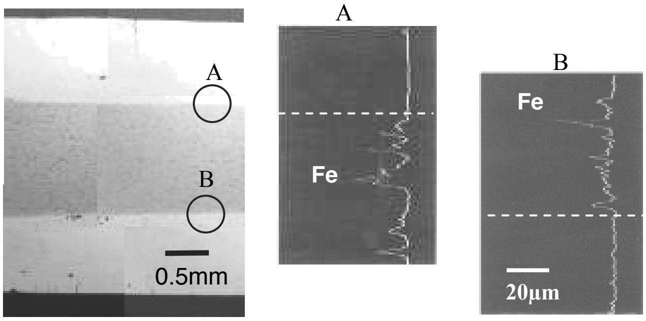

Fig. 20. The cross section of the as-cast three layers clad strip, and the result of the line analysis of the interfaces. The line analysis was operated at the interface of AA8079 and AA6022 strip. Fe is the element included in the AA8079

4.2. Five layers clad strip

The vertical tandem type twin roll caster, which has first, second and third caster as shown in Fig. 21, could cast five layers clad strip. The five layers clad strip could be cast from mono alloy, two kinds of alloys and three kinds of alloys.

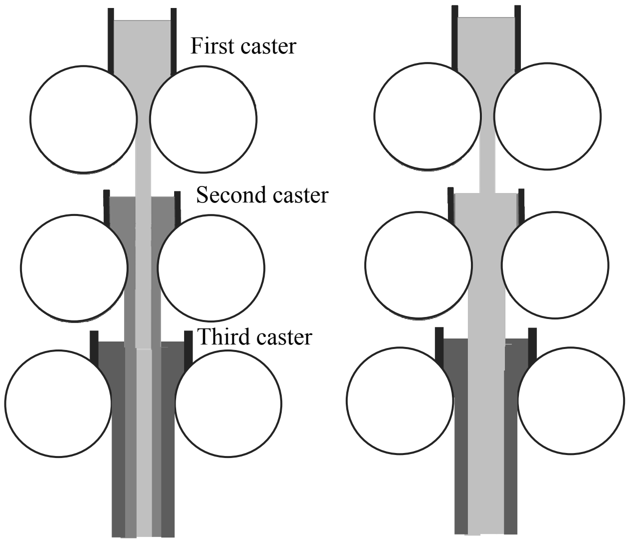

Fig. 21. Schematic illustration of the vertical tandem type roll caster to cast five layers clad strip. (a) clad strip cast from three kinds of alloys, (b) clad strip cast from two kinds of alloys

The cross section of the three layers and five layers clad strip are shown in Fig. 22. In the Fig. 22, (a) is three layers clad strip and (b) is five layers clad strip. These clad strips were made from AA3003 and AA4045. In the five layers clad strip of Fig. 22 (b), the second, third and fourth strip are AA3003, and these strips are base strip. The first and fifth strips are AA4045, and these strips are overlay strip. The clad ratio between the base strip and overlay strip of Fig. 22(b) is larger than that of Fig. 22(b). The five layers clad strip is useful to control the clad ratio. The five layers as-cast clad strip could be cold rolled down to 1mm. The cross section of the cold rolled strip is shown in Fig. 22(c). The strips were not peeled at interface by the cold rolling. This shows that the strips were firmly connected.

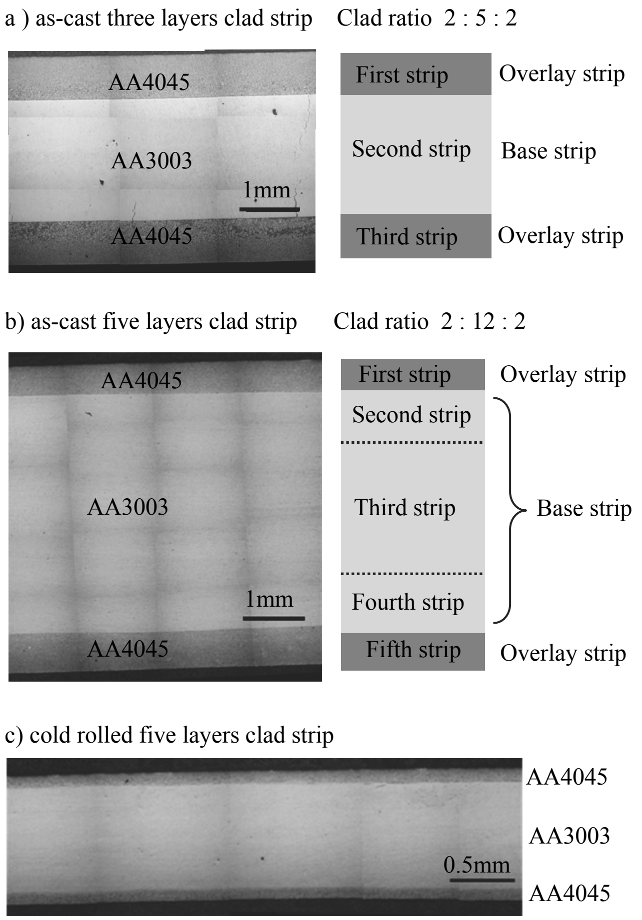

Fig. 22. Cross section of the three layers clad strip and five layers clad strip. (a)three layers clad strip, (b)five layers clad strip, (c) cold rolled five layers clad strip

5. Conclusions

The increase of the roll speed of the twin roll caster for aluminium alloy was attained by some devices. The roll speed increased up to 90m/min. The improvement of the cooling ability of the roll was most important factor to increase the roll speed. The microstructure became fine, and the ductility of the strip was improved by the use of the copper-roll without parting material. The roll caster of the present study was useful to improve the mechanical properties of the recycled aluminium alloy as the impurity made be fine. The roll casting of the aluminium alloy, which has wide freezing zone and the low flow stress at the semisolid condition, was very difficult by the conventional twin roll caster. However, the twin roll caster of the present study could cast the strip at the speeds higher than 30 m/min.

Two kinds of roll casters to cast the clad strip were developed. The two layers, three layers and five layers clad strip could be cast directly from the molten metal. The interface between the strips was clear, and the diffusion of the element of the strip into other strips did not occur. The strips were not peeled at the interface by continuous bending until broken. This means that the strips were connected firmly.

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 and Technology 55/2 (1995)76-84.

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

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

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

[5] O. Daaland, A.B. Espedal, M.L. Nedreberg, I. Alvestad, Thin gage twin-roll casting, process capabilities and product quality, Light Metal Age (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 Age (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, Metal Plant Technology International 20 (1997) 44-52.

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

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

[10] S. Hamer, C. Romanowski, B. Taraglio, Continuous casting and rolling of aluminum: 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 Age (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 and Technology 167 (2005) 62-72.

[13] T. Haga, M. Matsuo, D. Kunigo, Y. Hatanaka, R. Nakamura, H. Watari, S. Kumai, Roll casting of 5182 aluminium alloy, Journal of Achievements in Materials and Manufacturing Engineering 34/2 (2009) 172-179.

[14] T. Haga, H. Watari, S. Kumai, High speed twin roll casting of Mg alloy strip by a vertical type twin roll caster, Journal. of Achievements in Materials and Manufacturing Engineering 15 (2006) 186-192.

[15] 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.

[16] 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.

[17] T. Haga, M. Ikawa, H. Watari, S. Kumai, High speed twin roll casting of recycled Al-3Si-0.6Mg strip, Journal. of Achievements in Materials and Manufacturing Engineering 21/1 (2007) 7-12.

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

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

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

[21] T. Haga, R. Nakamura, S. Kumai, H. Watari, Clad strip casting by a twin roll caster, Archives of Materials Science and Engineering 37/2 (2009)117-124.

[22] R. Nakamura, T. Yamabayashi, T. Haga, Roll caster for three-layer clad-strip, Archives of Materials Science and Engineering 41/2 (2010) 112-120.