

Fabrication of High Aluminum Content Mg alloys using a Horizontal Twin Roll Caster

H. Harada, S. Nishida, T. Nagumo, M. Endo, and H. Watari

Abstract—This study was aimed for investigating of manufacturing high aluminum content Mg alloys using a horizontal twin roll caster. Recently, weight saving has been key issues for lighter transport equipments as well as electronic component parts. As alternative materials to aluminum alloys, developing magnesium alloy with higher strength has been expected. Normally high Aluminum content Mg alloy has poor ductility and is difficult to be rolled because of its high strength. However, twin roll casting process is suitable for manufacturing wrought Mg alloys because materials can be cast directly from molten metal. In this study, manufacturing of high aluminum content magnesium alloy sheet using the roll casting process has been carried out. Effects of manufacturing parameter, such as roll velocity, pouring temperature and roll gap, on casting was investigated. A microscopic observation of the crystals of cross section of as cast strip as well as rolled strip was conducted.

Keywords—AZ91, AZ111, AZ121, Magnesium alloys, Twin roll casting

I. INTRODUCTION

RECENTLY, weight saving has been key issues for lighter transport equipment's as well as electronic component parts. As alternative materials to aluminum alloys, developing magnesium alloy with higher strength has been expected [1] [2]. Normally high Aluminum content Mg alloy has poor ductility and is difficult to be rolled because of its high strength. However, twin roll casting process can be cast directly from molten metal. In this study using the roll casting process is suitable for manufacturing wrought Mg alloys because materials can be cast directly from molten metal.

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The twin roll casting process has some advantages that capital-investment spending, low running cost, space-saving, and energy-saving. The twin roll casting was focused how to achievement near-net-shape manufacture [3].

In this study, manufacturing of high aluminum content magnesium alloy sheet using the roll casting process has been carried out. Effects of manufacturing parameter, such as roll velocity, pouring temperature and roll gap, on casting was investigated. A microscopic observation of the crystals of cross section of as cast strip as well as rolled strip was conducted.

II. THE CONVENTIONAL TWIN-ROLL CASTER

Shown in Fig.1 the conventional twin-roll caster is one of twin-roll process. This caster has a number of advantages compared to conventional manufactured method. This conventional twin-roll caster is able to cast directly from molten metal to thin strip. This caster could be low capital-investment spending of beginning. This caster was used parting material. Roll is made from Tool-steel. Heat-transfer coefficient of this caster is 30W/mK. Roll velocity is 1-3 m/min. Characteristic of this caster cast high loading. The conventional twin-roll caster was difficult to make high aluminium content magnesium alloy strip.

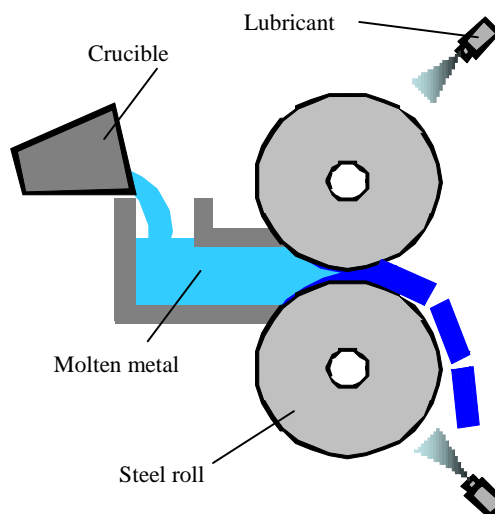


Fig. 1 A conventional twin roll caster

III. EQUIPPED MOVABLE NOZZLE WITH A HORIZONTAL TWIN ROLL CASTER USED IN THIS STUDY

A schematic illustration of the horizontal twin-roll-caster is shown in Fig.2. A horizontal-type twin-roll caster equipped with a nozzle. This nozzle was movable. The twin roll size of the roll was $\phi 300 \text{ mm} \times W150 \text{ mm}$, Copper rolls were used. Coefficient of thermal conductivity is 390 W/mK . This caster was able to rapidly solidify the molten metal as the cooling power of a roll was improved compared with the conventional twin roll caster using Tool-steel roll. Therefore this caster is possible to cast at low road. Galling of roll was decrease by low road. Upper roll was able to move to up and down. Strip was rolled by spring force. Couple of spring was used, and one of rate of spring was 10 kN/mm Lower roll was fixed. The rolling load was very small. This small load means that hot rolling was not used [4]. adjustment of sheet thickness did not use pressure. Adjustment of sheet thickness was roll velocity and solidification length. A casting nozzle was used for set the solidification length precisely. The nozzle was set at the upside of the roll. This is to adjust the thickness of freeze layer. Then heat insulating cloth was pasted to the nozzle and side-dam-plate. Thickness of heat insulating is 1.8 mm . Molten metal pool was consisted of upper nozzle, lower nozzle and side-dam-plate. Nozzle and side-dam-plate was made of mild steel. Side-dam-plate was pressured to roll by spring as rate of spring was 0.15 kN/mm . One of side-dam-plate was used three of spring. This side-dam-plate adjust shake, and prevent casting fin. Lubricant was not used, because of decrease heat transfer. Oxide coating of Mg prevent adherence. This was caused by small road. This nozzle is useful to increase the hydrostatic pressure [5]. This leads to improvement of heat transfer between the roll and the molten metal. The hydrostatic pressure prevents part of solidification from clog up

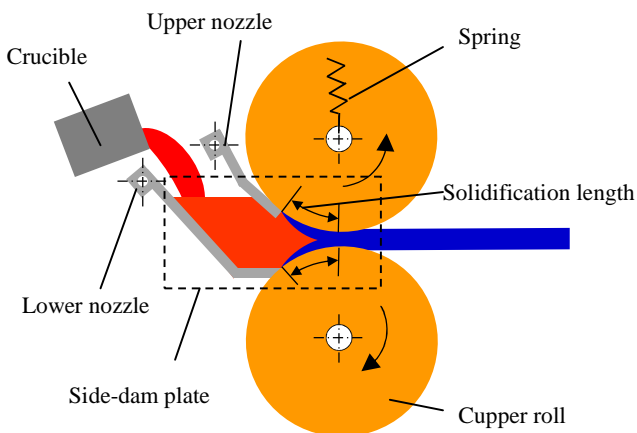


Fig. 2 A horizontal twin roll caster

IV. EXPERIMENTAL CONDITION

Experimental conditions are shown in Table I and Table II. Table I shows experimental condition of AZ91D for casting material. Table II shows experimental condition of high aluminum content Mg alloys. High aluminum content Mg was

using AZ111 and AZ121. Experimental condition number of #1, #5, and #6 was defined as base fabrication condition.

As cast strip is carried out hot rolling after keeping at 673 K 12 hours an electric furnace. Strip was kept 673 K at hot rolling. Each pass at hot rolling was rolled after keeping 673 K 30minute. Reduction of each pass was 10% . Rolling direction was rotated 90 degree at the casting direction. Using cold roll method that roll does not heating. To decrease friction resistance that roll was splayed the BN. Cross section of as cast strip and as rolled strip was observed by optical microscope.

TABLE I
 EXPERIMENTAL CONDITION OF CASTING OF AZ91D

Experimental No.	#1	#2	#3	#4
Roll velocity[m/min]	16	8	16	
Super heat [K]	5		-5	5
Initial gap[mm]	3			1
Solidification length[mm]	50			

TABLE II
 EXPERIMENTAL CONDITION OF CASTING OF HIGH AL CONTENT

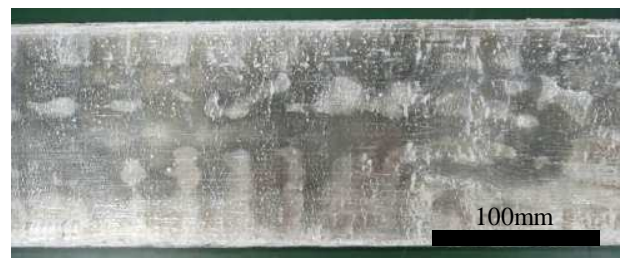
Experimental No.	#5	#6	#7	#8
Material	AZ111	AZ121		
Roll velocity[m/min]	16			48
Super heat [K]	5	15		5
Initial gap[mm]	3			1
Solidification length[mm]	50			

V. RESULT END DISCUSSION

It was possible to produce AZ91D, AZ111, AZ121 magnesium alloys using a horizontal twin roll caster. Thickness of experimental number #1 was 4.5 mm . Thickness of experimental number #5 was 4.0 mm . Thickness of experimental number #6 was 4.6 mm . As cast strip are shown Fig.3. Experimental number #1 is shown Fig.3. (a). Experimental number #5 is shown Fig.3. (b). Experimental number #6 is shown Fig.3. (c). All of Fig.3 was upper roll side.



(a) Experimental number #1, AZ91D



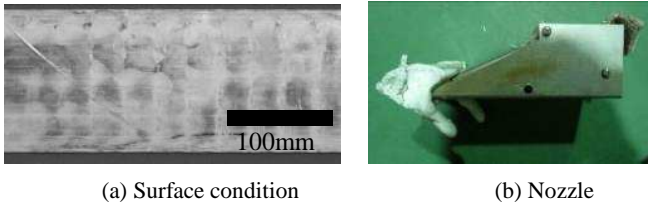
(b) Experimental number #5, AZ111



(c) Experimental number #6, AZ121

Fig. 3 Surface condition of as cast strip, observed upper roll side
 (a) Experimental number #1 AZ91D, (b) Experimental number #5 AZ111, (c) Experimental number #6 AZ121

In case of fixed nozzle was occurred break-out between roll and nozzle. In this case of surface condition of as cast strip and nozzle are shown Fig.4. It can be observed ripple mark. It seems to be effect of meniscus by shake at the casting. In case of movable nozzle was not observed ripple mark at the surface and also break-out between roll and nozzle.

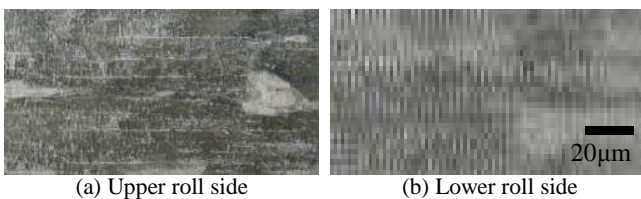


(a) Surface condition

(b) Nozzle

Fig. 4 Experimental number #6, AZ121, (a) It can be seem ripple mark at surface condition of as cast strip, (b) Condition of break-out

As cast strip of experimental number #2 of surface condition are shown Fig.5. Thickness of experimental number #2 was 5.7 mm. And also surface condition of as cast strip was observed ripple mark at lower roll side. It is able to be seemed that contact angle of roll and nozzle was smaller than upper roll side.



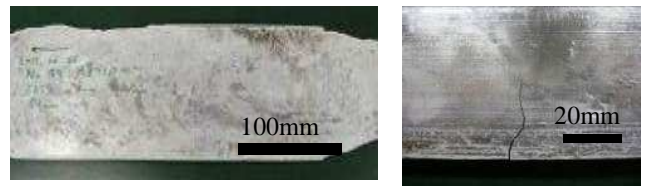
(a) Upper roll side

(b) Lower roll side

Fig. 5 Surface condition of experimental number #2, AZ91D, (a) It can be seem ripple mark

As cast strip of experimental number #3 and #4 are shown Fig.6. Experimental number #3 was semisolid casting. At the super heat was under -5K that fluidity was decrease and difficult to casting. Surface condition of as cast strip was white turbidity.

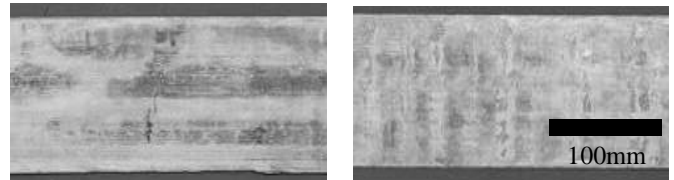
As cast strip of experimental number #7 is shown Fig.7 (a). Super heat was 15 K. Brilliance area of as cast strip of experimental number #7 decrease as compare to experimental number #6. As cast strip of experimental number #8 is shown Fig.7 (b). It was possible to cast continuously at the high roll velocity. Length of strip was 4000 mm. Thickness of as cast strip was 2.0mm.



(a) Experimental number #3

(b) Experimental number #4

Fig. 6 Surface condition of as cast strip, (a) As cast strip of experimental number #3 at upper roll side, (b) As cast strip of experimental number #4 at upper roll side



(a) Experimental number #7

(b) Experimental number #8

Fig. 7 Surface condition of as cast strip

Fig. 8 shows the surface condition of as rolled. AZ111 magnesium alloys, it was possible to roll strip by hot rolling, there are no crack. It was possible to carry out the hot rolling from as cast strip to 0.5 mm thickness.

Fig. 9 shows the cross section of AZ91D. Grain size is observed near the surface and near the middle in the thickness direction. The average particle diameter was 47 µm at upper roll side, 30 µm at middle region, 59 µm at lower roll side. It seems to be caused by shear force due to freeze layer of upper and lower.

Fig. 10 shows cross section of as rolled. Average grain size of 15 % reduction was 80-100 µm. Average grain size of 40 % reduction was 50µm. Average grain size of 80 % reduction was 20-30µm. Crystal grain became fine by rolling reduction. Crystal grain kept 673 K 12 h before hot rolling was grown about twice compared with cross section of as cast strip.

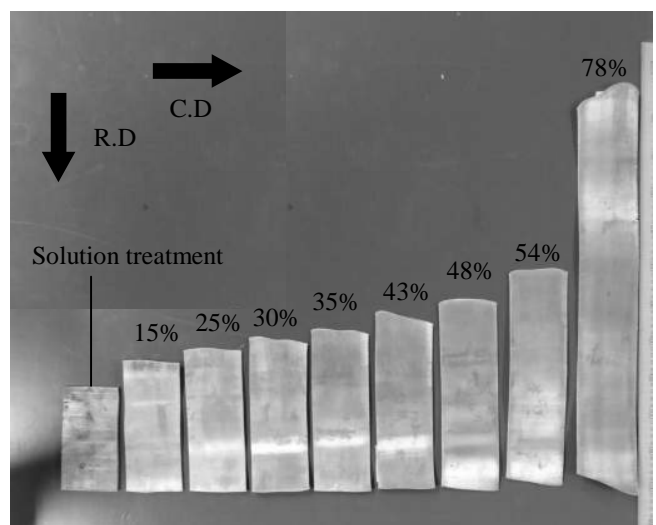
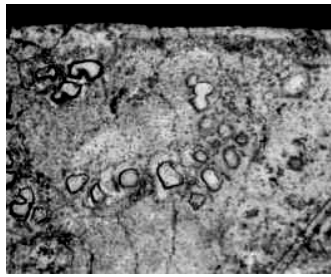
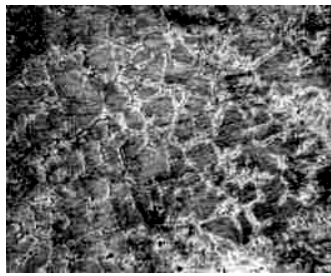


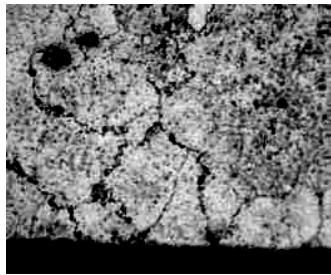
Fig. 8 Surface condition of as rolled each reduction



(a) Upper roll side



(b) Middle region



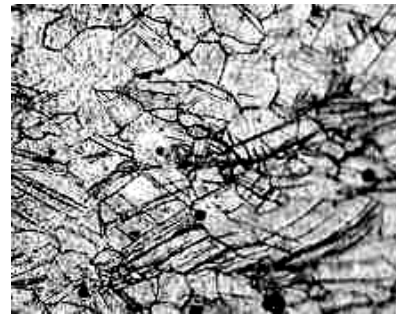
(c) Lower roll side

50µm

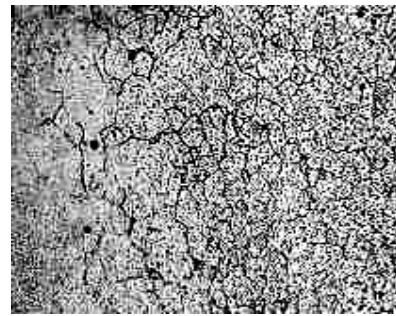
Fig. 9 Cross section of AZ91D as cast strip, experimental number #1
 (a) The average particle diameter was 47 µm at upper roll side, 30 µm at middle region, (b) The average particle diameter was 30 µm at middle region, (c) The average particle diameter was 59 µm at lower roll side



(a) Reduction 15 %



(b) Reduction 40 %



(c) Reduction 80 %

50µm

Fig. 10 Surface condition of as rolled of each reduction, (a) Average grain size of 15 % reduction was 80-100 µm, (b) Average grain size of 40 % reduction was 50 µm, (c) Average grain size of 80 % reduction was 20-30 µm

VI. CONCLUSION

Continuous fabrication of strip as AZ91D, AZ111, and AZ121 magnesium alloys was possible by using a horizontal twin roll caster. To improve the surface condition by using a movable nozzle was possible. Optimum experimental condition of AZ91D magnesium alloy was possible to be applied to the experimental condition of AZ111, AZ121 magnesium alloys.

As cast strip of AZ111 magnesium alloy after heat treatment was possible to be rolled up to 0.5 mm thickness.

REFERENCES

- [1] T. Ozaki, S. Kamado, Y. Kuroki, T. Tanaka, M. Imuta, "Development of a New High-Strength Magnesium Alloy" *IHI technical review*, Vol.51 No.1, 2011,
- [2] H. Watari, T. Haga, Y. Shibue, K. Davay, N. Koga, "Twin roll casting of magnesium alloys with high aluminum contents" *Journal of Achievements in Materials and Manufacturing Engineering*, Vol.18, 2006, pp. 429-422.
- [3] T. Haga, "Twin roll casters for aluminum alloys" *Journal of Japan Institute of Light Metals*, Vol. 59, No. 9, 2009, pp. 509-520
- [4] H. Watari, R. Paisarn, T. Haga, K. Noda, K. Davey, N. Koga, "Development of manufacturing process of wrought magnesium alloy sheets by twin roll casting" *Journal of Achievements in Materials and Manufacturing Engineering*, Vol.20, 2007, pp. 515-518
- [5] T. Haga, H. Watari, S. Kumai, "High speed roll casting of Mg alloy strip by a vertical type twin roll caster" *Journal of Achievements in Materials and Manufacturing Engineering*, Vol.15, 2006, pp. 186-192.