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High speed roll casting of Mg alloy strip by a vertical type twin roll caster

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ABSTRACT

Purpose: The possibility of high speed roll casting of AZ31, AM60 and AZ91 was investigated. Warm deep drawing of roll cast magnesium alloy was operated. and formability of roll cast magnesium strip was cleared.
Design/methodology/approach: A vertical type high speed twin roll caster was used. The roll casting was operated in the air atmosphere. The casting speed was from 60 m/min up to 180 m/min. Low temperature casting was adopted to realize high speed casting.
Findings: Strip thinner 3 mm with 100 width could be cast continuously. The casting ability became better with increasing content of Al. Roll cast Mg alloy strips could be hot-rolled down to 0.5 mm. AZ31 as-cast strip could be thinner down to 0.5 mm only by three times of hot rolling. Deep drawing was operated with three kinds of Mg alloy at 250°C, and LDR value was larger than 2.0. It was shown that deep drawing of AZ91 alloy for casting was possible.
Research limitations/implications: There was tendency that cracks occurred at the center in the thickness direction as Al content increased.
Practical implications: Sheet metal forming of magnesium alloy with high content Al can be realized.
Originality/value: It was shown that possibility of high speed roll casting of magnesium alloy, and warm deep drawing of roll cast AZ91 strip.
Keywords: Strip casting; Twin roll caster; Magnesium alloy; Sheet metal; Deep drawing

1. Introduction

Hot-rolling is essential to make Magnesium alloy sheet from slab. Heating of magnesium alloy is needed on every ho-rolling pass. Therefore, magnesium alloy sheet is very expensive. Reducing number of hot-rolling is very useful to make the magnesium sheet economy. Thin strip, which is thinner than 5 mm, can be cast by a twin roll caster. If the magnesium alloy strip can be cast using the twin roll caster, the twin roll caster is very useful to reduce the cost of magnesium sheet. Sheet of AM60 and AZ91 for commercial is not existed. The reason that hot roll of AM60 and AZ91 from slab is difficult. Products made from AM60 and AZ91sheet became stronger than that of AZ31 sheet. If AZ91 sheet could be used for press product, fractionation of magnesium alloys in recycle becomes easy. Most of magnesium alloy products can be made from AZ91 alloy. Sheet forming of AZ91 alloy was tried in the present study. A vertical type high speed twin roll caster was used in the present study to cast thin strip. The high speed twin roll caster (HSTRC) can cast the aluminum alloy strip at speeds higher than 60 m/min. Magnesium alloy was cast at speeds higher than 60 m/min. Low temperature casting was adopted on the casting. The low superheat casting was useful to increase the casting speed and safety. In the present study, ability of roll casting of magnesium alloy, and mechanical properties of roll cast strip were investigated.

2. Experimental conditions

Schematic illustration of the high speed twin roll caster (HSTRC) is shown in Fig.1 [1-5]. The HSTRC was vertical type one. A cooling slope was used to do low temperature casting. Molten metal poured from a crucible was cooled on the cooling slope [6-11]. The super heat of the metal in the nozzle was about 5 ^{O}C. The low temperature casting is suitable for increasing the casting speed and safety. The molten metal was kept lower than 700 ^{O}C. The magnesium does not burn at the temperature lower than 700 ^{O}C. Therefore, the roll casting was operated in the air. The vertical type is suitable for low temperature casting. The reason is that clogging of the nozzle by the solidified metal does not easily occur, and casting was not stopped.

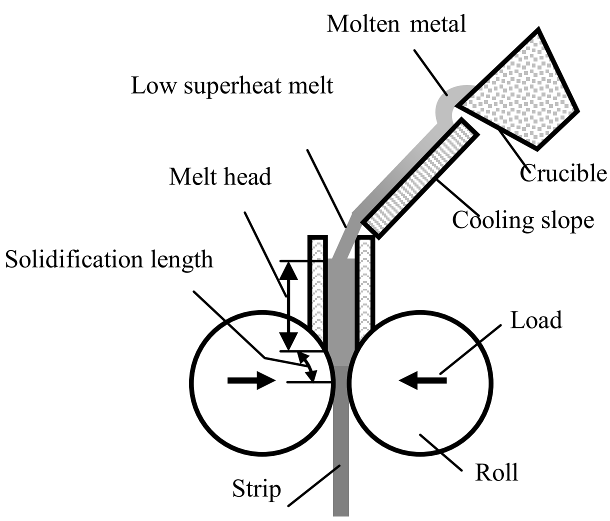

Fig.1. Schematic illustration of a high speed twin roll caster

A nozzle was adopted with the HSTRC [3-5]. The contact area between the air and the molten metal became small by the nozzle. This was useful to pretend the oxidation of molten metal. Oxide floated on the melt, and the oxide did not included by the rotating roll. The contact condition between the roll and the melt at the nozzle tip becomes better by the static pressure of the melt head. As the result, heat transfer between the roll and strip becomes better, and the strip temperature becomes lower. The contact length between the roll and melt can be kept strictly, when the melt head bounces. This means that strip thickness can be kept constant easily. These are the effect of the nozzle. The copper rolls were used. Thermal conductivity of the copper is large, and the copper is suitable for the material of the roll. In the conventional twin roll caster for aluminum alloy, the lubricant is used on the roll surface to pretend the sticking of the strip to the roll. The magnesium alloy strip tends not to stick to the roll. Therefore, the lubricant was not used. Non-use of the lubricant makes the heat transfer greater, as the lubricant is the heat resistance between the roll and the strip.

3. Roll casting of AZ31

3.1. High speed roll casting of AZ31

High speed roll casting of AZ31 was operated in the air. The melt did not burn in the nozzle for the casting. AZ31 could be cast into the strip at speed ranging from 60 m/min up to 180 m/min. Figure 2 shows an as cast strip cast at 150 m/min. The strip could be cast continuously. The surface was oxidized and becomes black when the surface temperature was high. The as cast strip did not burn. The oxidized surface became clean easily by cleaning of pickling. Figure 3 shows 180 degrees bending of AZ31 as cast strip. Radius curvature was about 15 mm. The as cast AZ31 strip had ductility. Figure 4 shows relationship between the roll speed and strip thickness. The strip became thinner as the roll speed became higher. When the roll speed was higher than 80 mm, the strip became thinner than 2.0 mm. Thin strip of magnesium alloy could be cast by the HSTRC. Cast ability of AZ31 was as same as that of the aluminum alloy like 5083. The HSTRC has the ability to improve the productivity of the magnesium sheet.

Fig. 2. An as cast strip of AZ31. Length was about 5 mm. Roll speed was 150 m/min. Width was 100 mm

3.2. Hot rolling of AZ31

Hot rolling was operated to the as cast strip. A 2-Hi small mill was used for hot rolling. The diameter of the roll was 70 mm. rolling speed was 5 m/min. The rolls were not heated. The lubricant was not used. The as cast strip was heated in the electric furnace at 350^{O}C for 2 hours and immediately hot rolled. The strip was not cleaned by pickling. The as cast strip was hot rolled from 1.7 mm down to 1.0 mm by one pass. This rolled strip was heated at 350^{O}C and immediately hot rolled without holding time. The thickness was reduced from 1.0 mm down to 0.7 mm. The 0.7 mm thick strip was heated up to 350^{O}C and was immediately hot rolled without keeping at 350^{O}C from 0.7 mm down to 0.5 mm. The roll cast AZ31 could be thinned down to 0.5 mm only by three-passes. This shows that number of the hot rolling could be reduced drastically. The surface of the strips after each hot rolling is shown in Fig. 5. The strip surface showed weak metallic luster after hot rolling, and did not become black by oxidation.

Fig. 3. 180 degrees bending of as cast AZ31 strip at radius curvature of 15 mm

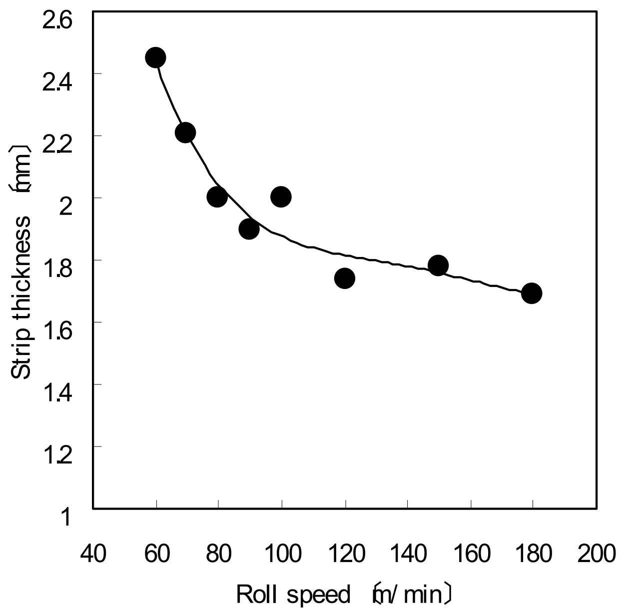

Fig. 4. Relationship between roll speed and thickness of AZ31 as cast strip. Contact length was 80 mm

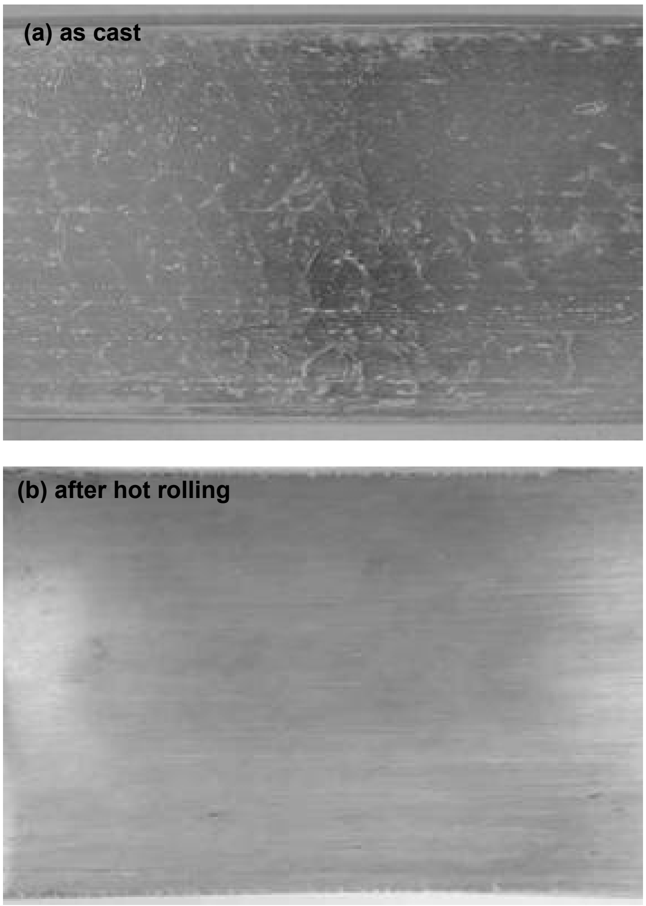

Fig. 5. As cast and hot rolled AZ31 strip. Pass schedule of hot rolling is as below. 1st pass: 350 ^{O}C-1h from 1.7 mm to 1.0 mm, 2nd pass: 350 ^{O}C-0s from 1.0 mm to 0.7 mm, 3rd pass: 350 ^{O}C-0s from 0.7 mm to 0.5mm

The microstructure of the cross section of the as cast strip and after hot rolling was shown in Fig. 6. Spherical structure existed as band zone at the center in the thickness direction of as cast strip. This spherical structure resembled to the structure of semisolid casting. However, this spherical structure is very smaller than that of the semisolid casting. Globular grain existed at both side of the band area. The no-uniformity of the structure at thickness direction is the character of the strip cast by the HSTRC. The microstructure after hot rolling is shown in Fig. 6, too. The microstructure became almost uniform at thickness direction, and became very fine. Only three times hot rolling could change the cast structure into the forming structure.

3.3. Mechanical properties of roll cast AZ31 strip

Tension test and deep drawing were operated to the roll cast AZ31 strip. Figure 7 shows relationship between rolling temperature and result of the tension test. Rolling temperature was

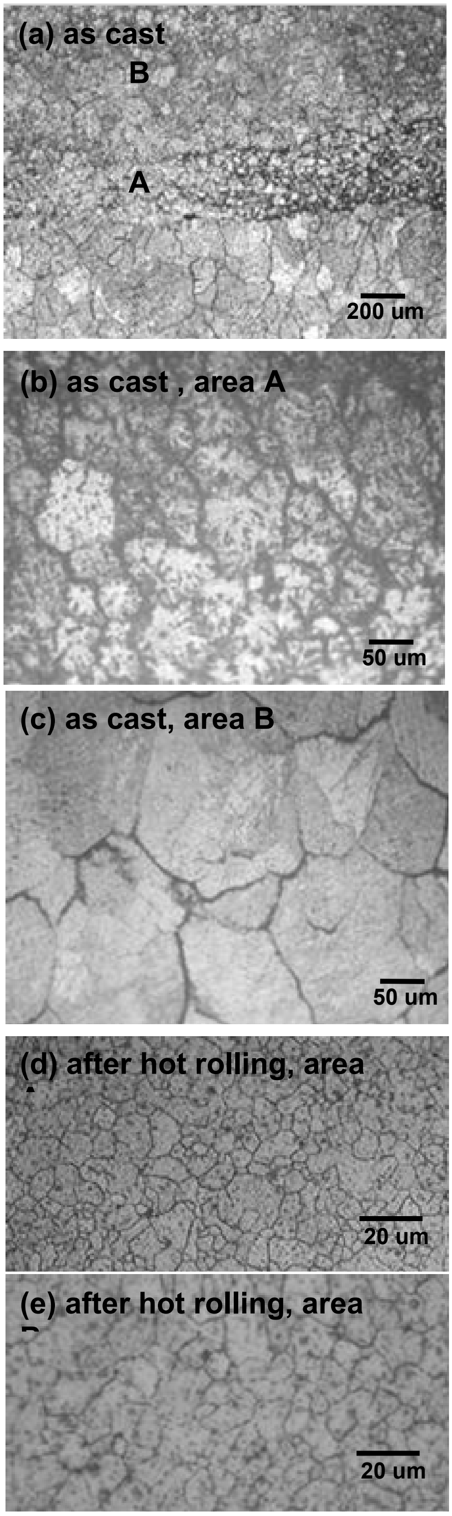

Fig. 6. Microstructure of as cast and hot rolled AZ31 strip. Pass schedule of hot rolling is as below. 1st pass: 350 ^{O}C-1h from 1.7 mm to 1.0 mm, 2nd pass: 350 ^{O}C-0s from 1.0 mm to 0.7 mm, 3rd pass: 350 ^{O}C-0s from 0.7 mm to 0.5mm

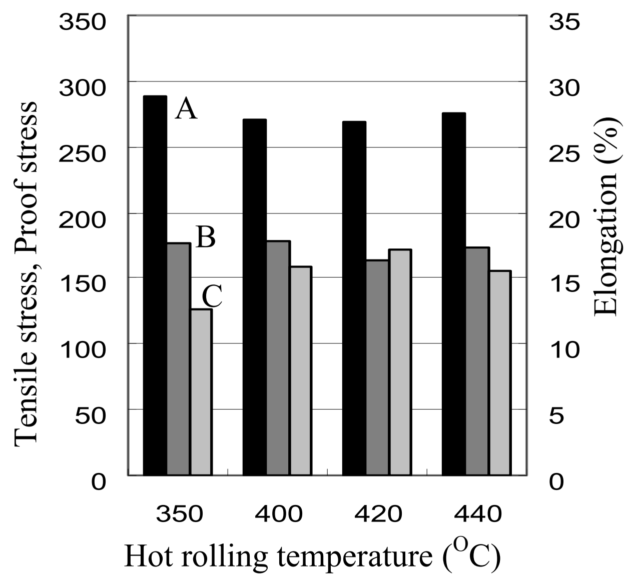

Fig. 7. Influence of temperature of hot rolling on tension test of AZ31 sheet. Pass schedule of hot rolling and annealing is as below. 1st pass: holding-1h from 1.7 mm to 1.0 mm, 2nd pass: holding-0s from 1.0 mm to 0.7 mm, 3rd pass: holding-0s from 0.7 mm to 0.5mm, annealing: 300^{O}C-1h. Specimen is as below. Gage length: 20mm, width 10mm, thickness: 0.5mm. A: tensile stress, B: proof stress, C: elongation

350 ^{O}C, 400^{O}C, 420 ^{O}C and 440 ^{O}C. The as cast strip hot rolled down to 0.5 mm by the three passes. Pass schedule of hot rolling is as below, 1st: from 1.7 mm to 1.0 mm, 2nd: from 1.0 mm to 0.7 mm, and 3rd: 0.7 mm to 0.5 mm. Holding time at each pass is as below, 1st: 1 hour, 2nd: no holding time, 3rd: no holding time. The hot rolled strip was annealed at 300 ^{O}C for 1 hour before tension test. Tension test was operated at room temperature. Size of the specimen is as below, thickness is 0.5 mm. gage length was 20 mm, and width was 10 mm. When the rolling temperature was 350 ^{O}C, elongation was worse than other temperatures. Tensile strength and proof stress were not affected greatly by the rolling temperature. The microstructure of the specimen used for tension test, which was hot-rolled at 350 ^{O}C and 440 ^{O}C, is shown in Fig. 8. The grain size of the specimen hot rolled at 440 ^{O}C was larger than that hot rolled at 350 ^{O}C. The grain grew and became large by the heating up to 440 ^{O}C. The elongation was better when the grain size was large. It seemed that the grain size did not influence the mechanical properties significantly.

Schematic illustration of a experimental apparatus for the deep drawing is shown in Fig. 9. A die and a blank holder were heated from inside by a heater, their temperature was 250 ^{O}C. A punch was cooled by flow water from inside. The punch speed was 1.2 mm/sec. Teflon sheet of 0.05 mm thick was used as the lubricant. The condition of the rolling and heat treatment of the blank was as same as that of the specimen of the tension test. Relationship between rolling temperature and LDR (Limiting

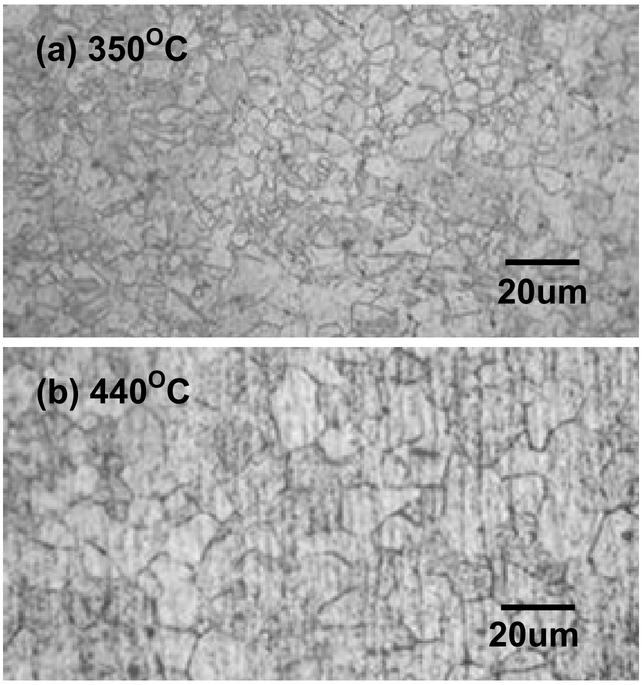

Fig. 8. Influence of temperature of hot rooling on microstructure of AZ31 sheet. Pass schedule of hot rolling and annealing is as below. 1st pass: holding-1h from 1.7 mm to 1.0 mm, 2nd pass: holding-0s from 1.0 mm to 0.7 mm, 3rd pass: holding-0s from 0.7 mm to 0.5mm, annealing: 300^{O}C-1h

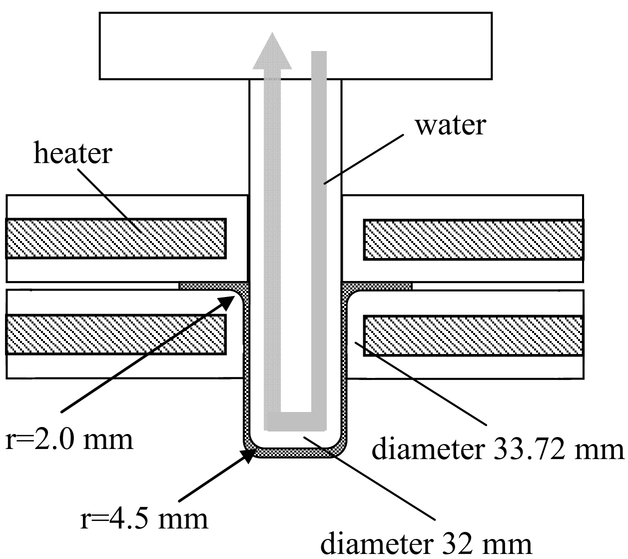

Fig. 9. Schematic illustration of experimental apparatus for hot deep drawing. Puch speed was 1.2 mm/s. Heating temperature was 250 ^{O}C. Lubricant was Teflon sheet

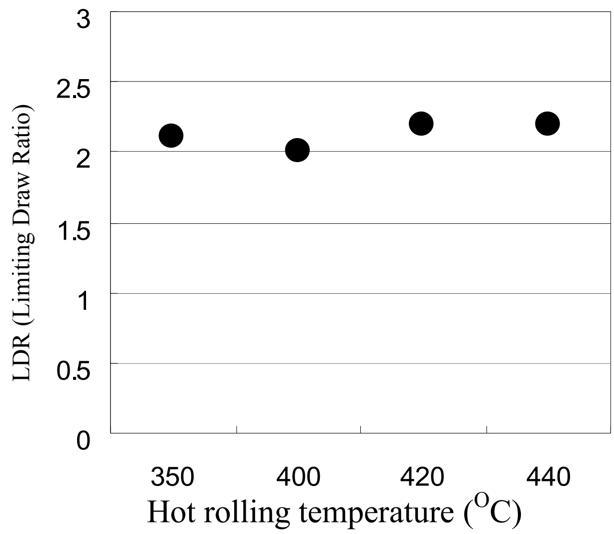

Fig. 10. Influence of temperature of hot rooling on LDR (Limiting Draw Ratio)of AZ31 sheet at hot deep drowing. Work temperature was 250 ^{O}C. Puch speed was 1.2 mm/s. Lubricant was Teflon sheet. Pass schedule of hot rolling and annealing is as below. 1st pass: holding-1h from 1.7 mm to 1.0 mm, 2nd pass: holding-0s from 1.0 mm to 0.7 mm, 3rd pass: holding-0s from 0.7 mm to 0.5mm, annealing: 300^{O}C-1h

Fig. 11. AZ91 as cast strip. Roll speed was 90 m/min. Thickness was 1.5 mm

Draw Ratio) is shown is shown in Fig. 10. LDR was larger than 2.0. This value is enough for sheet forming. The rolling temperature did not remarkably influence on the LDR.

4. Roll casting of AM60 and AZ91

Roll casting of AM60 and AZ91 was tried using the HSTRC. AM60 and AZ91 could be cast continuously in to the strip.

Castability became better as the content of the Al increased. The solidification type changes from skin formation type to mashy type. The mashy solidification type of alloy is suitable for the HSTRC of the present study. The metallic luster was rich as the Al content increased. The surface becomes black by oxidation when the temperature of the surface of the strip is high. This tendency was depressed by addition of Al. This reason is estimated that the liquids line becomes lower as Al content increases. Therefore, the surface temperature of the strip, when which released the roll, becomes lower as the Fe content increases. Figure 11 shows the as cast strip of AZ91. Figure 12 shows hot rolled strip of AM60 and AZ91. The as cast strip of AM60 and AZ91, which thickness was 1.5 mm, was hot rolled down to 0.5 mm by four passes. The deep drawing was operated to hot rolled strip of AM60 and AZ91. The condition of the deep drawing was as same as that of AZ31. AM60 and AZ91cup made by hot drawing were shown in Fig. 13. LDR of both of AM60 and AZ91 sheet was 2.0. Deference in ductility in hot work between the AZ31 and AZ91 becomes smaller than that of cold work.

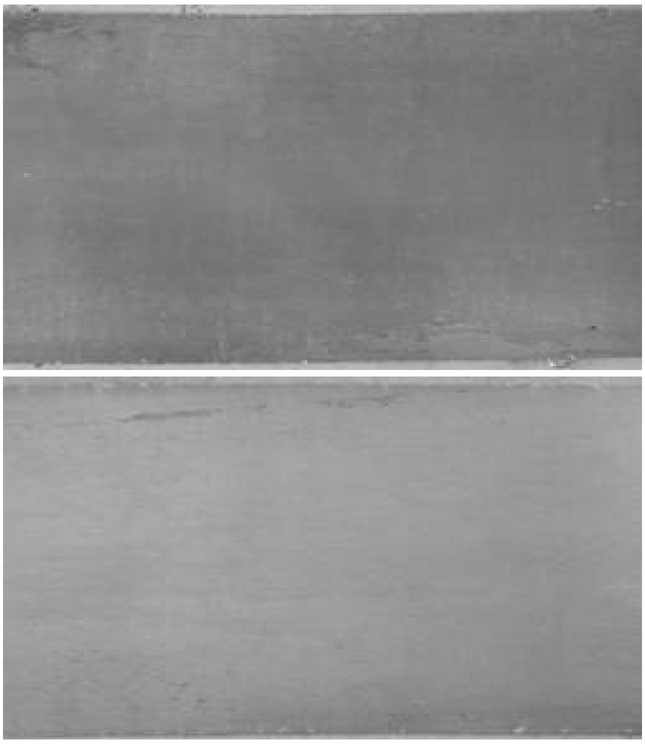

Fig. 12. Hot rolled AM60 and AZ91 sheet. Holding temperature, holding time and reduction of each pass was as below, 1st pass: 420 ^{O}C-1h from 1.5 mm to 1.2 mm, 2nd pass: 420 ^{O}C-0s from 1.2 mm to 0.9 mm, 3rd pass: 420 ^{O}C-0s from 0.9 mm to 0.7 mm, 4th pass: 420 ^{O}C-0s from 0.7 mm to 0.5 mm

5. Defect of as cast strip

When the casting conditions are not proper, the strip broke at center area in thickness direction. Center line crack is shown in Fig. 14. Figure 14 (a) shows the photograph by optical microscope, (b) shows schematic illustration of the (a), and (c) shows cross section of the broken strip after continuous bending. The center line crack occurred at the interface between the band area and other parts. The center line broken was pronounced as the content of Al increased. The roll gap and the road from the roll influenced the center line crack. The center line crack was pronounced as the roll gap became narrow, and the road became greater. The center line crack is under investigation, now.

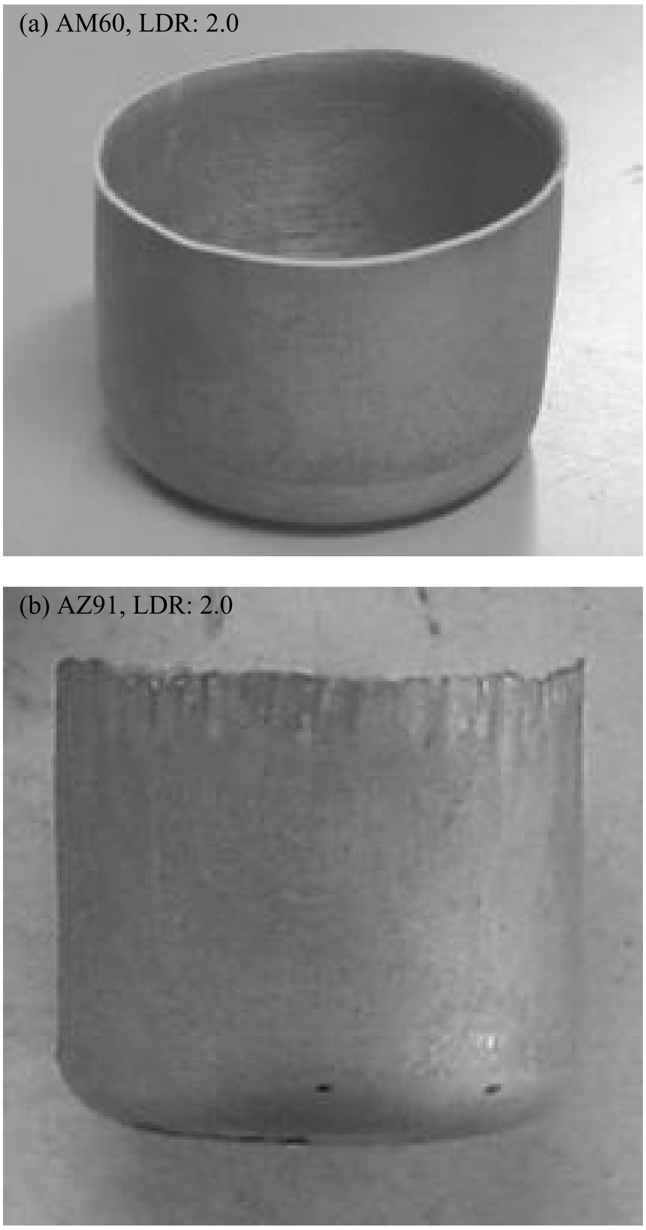

Fig. 13. Hot deep drowing of AM60 and AZ91. Work temperature was 250 ^{O}C. Puch speed was 1.2 mm/s. Lubricant was Teflon sheet

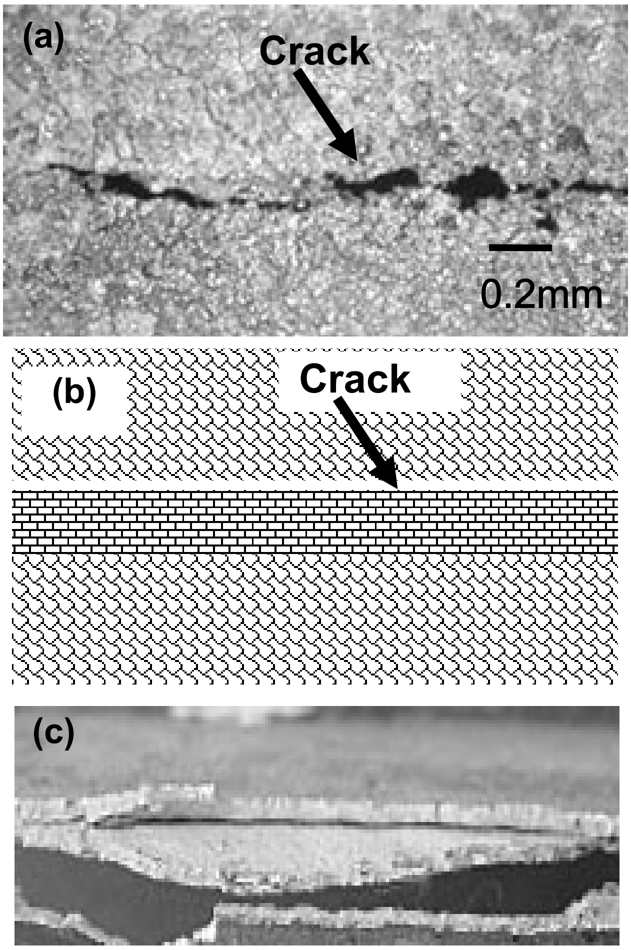

Fig. 14. Center line crack of as cast strip. (a) shows the photograph by optical microscope, (b) shows schematic illustration of the (a), and (c) shows cross section of the broken strip after continuous bending.

6. Conclusions

A high speed twin roll caster was used to cast thin strip of magnesium alloy. The strip of AZ31, AM60 and AZ91 could be cast at speed ranging from 60 m/min to 180 m/min. The strip thickness was thinner than 2.0 mm when the roll speed was higher than 80 m/min. The as cast strip of AZ31, AM60 and AZ91 could be hot rolled down to 0.5 mm only by four passes. LDR (Limiting Draw Ratio) of deep drawing using the hot-rolled sheet was greater than 2.0. Center line crack occurred when the casting condition was not proper. The roll gap and the force from the roll were concern to the center line crack.

References

[1] T. Haga, Journal of Materials Processing Technology, 137 (2003) 92-95.
[2] T. Haga, Journal of Materials Processing Technology, 133(2003) 103-107.
[3] T. Haga, Journal of Materials Processing Technology, 140 (2003) 610-615.
[4] T. Haga, Journal of Materials Processing Technology, 143 (2003) 895-900.
[5] T. Haga, Journal of Materials Processing Technology, 153 (2004) 42-47.
[6] T. Motegi, N. Ogawa, K. Kondo, et.al., Proceedings of the ICAA6, 1998, 297-326.
[7] T. Haga, Journal of Materials Processing Technology, 111 (2001) 64-68.
[8] T. Haga, Journal of Materials Processing Technology, 118 (2001) 165-168.
[9] T. Haga, Journal of Materials Processing Technology, 130 (2002) 558-561.
[10] T. Haga, Journal of Materials Processing Technology, 130 (2002) 581-586.
[11] T. Haga, Journal of Materials Processing Technology, 130 (2002) 594-598.