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Twin roll casting of magnesium alloys with high aluminum contents

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Manufacturing and processing

ABSTRACT

Purpose: The purpose of the work is to establish a manufacturing process and technology to facilitate the economical manufacture of high-quality magnesium sheet alloys with high aluminum contents, such as AZ61 and AZ91. The aim of the work is to establish a twin roll casting technology to facilitate the manufacture of AZ61 and AZ91 magnesium sheet alloys economically whilst maintaining high quality.
Design/methodology/approach: A horizontal type twin roll caster was used to manufacture thin magnesium alloy sheets of AZ61 and AZ91. Pair of copper alloy roll and pure copper roll was used for the horizontal type twin roll caster. A closed type tundish was set to the roll caster to keep stable contact of molten magnesium with upper and lower rolls.
Findings: The experiment results clarified that AZ61 and AZ91 sheets can be manufactured by twin roll casting process. The product sheet thickness in the present experiment is 2.0 to 4.5 mm for AZ91, 2.5 to 5.0mm for AZ61. Mill stiffness and a method of predicting the cast sheet's thickness were investigated to determine the appropriate manufacturing conditions. The microstructure of AZ61 cast strips was equiaxed structure and the crystal sizes are different depending on cross section observed. The dendric and equiaxed microstructure were seen in the microstructure of AZ91 cross section. The intermetllic Mg17Al12 was seen in the grain boundary in AZ91 when roll speed was very slow. The grain size of the manufactured wrought magnesium alloys sheet was less than 10 micrometers. The obtained magnesium alloy sheet exhibited an equivalent limiting drawing ratio in a warm-drawing test. The limiting drawing ratio of AZ61 was 2.6 and 2.4 for AZ91.
Research limitations/implications: The suitable roll speed was from 9m/min to 15m/min in manufacturing AZ91 and AZ61 strip using copper alloy rolls. When in use of pure copper roll, strips were cast between 6m/min and 20m/min for manufacturing AZ61 and AZ91. The superheats in the experiment were 15ºC and 30ºC. The cast strips should be hot rolled at 300ºC.
Originality/value: value In this experiment, it is clarified that AZ61, AZ91 sheets can be manufactured by twin roll casting. These cast sheet can be hot rolled and the manufacturing process by twin roll casting enable to manufacure thin magnesium sheet alloys with high aluminum contents. It has been found that the manufactured cast AZ61 and AZ91 have good formability by a warm deep drawing test.
Keywords: Casting; Plastic forming; Magnesium alloys; Twin roll caster

1. Introduction

In recent years, total weight reduction approach has been a key issue for car manufacturers to cope with more and more stringent requirements for fuel economy. The use of aluminum has progressively increased there have been major developments in plastics plastics composites in stead of the steel and iron products. On the other hand, the steel and iron companies have fought back by developing methods to maximise the superior strength of ferrous materials by reducing section thickness and designing parts for lowest weight in relation to strength and fatigue requirements. In Ultra Light Steel Auto Body -Advanced Vehicle Concept (ULSAB-AVC) program [1] that has started since 1994, the report conclude that ULSAB-AVC is identifying lightweight applications for advanced high-strength steels that offer significantly higher strength, better formability, and greater energy absorption for critical crash management applications than the mild or high-strength steels. However, more and more efforts to achieve total weight reduction in car industries are necessary.

Magnesium is 36% lighter per unit volume than aluminum and 78% lighter than iron. When alloyed, magnesium has the highest strength-to-weight ratio of all the structural metals. Moreover, because of the ease of recycling of metallic materials, magnesium has received global attention from the standpoint of environmental preservation. Also car manufactures have expected developing magnesium alloys with high strength as well as better creep registance. The aluminum contents in commercial magnesium alloys ranges from 1 to 9 %, the low-aluminum alloys having the best formability, the high-aluminum reasonably good castability and high strength. There are smany research papers about AZ31 (3%Al, 1%Zn) magnesium alloy deformation. The AZ91 magnesium alloy normally used for die casting because of its good castability. In this paper, magnesium alloy with high aluminum contents, such as AZ61 (6%Al,1%Zn) and AZ91 (9%Al, 1%Zn) sheets were manufacture by twin roll casting because wrought magnesium AZ61 and AZ91 are difficult to be manufactured by extrusion due to its high aluminum contents. The purpose of the work is to establish a manufacturing process and technology to facilitate the economical manufacture of high-quality magnesium sheet alloys with high aluminum contents, such as AZ61 and AZ91. The aim of the work is to establish a twin roll casting technology to facilitate the manufacture of AZ61 and AZ91 magnesium sheet alloys economically whilst maintaining high quality.

The authors investigated the effectiveness of twin roll strip casting for magnesium alloys [2,3]. This paper describes the twin roll casting technology of magnesium alloys that contains relatively high weight ratio of aluminum, such as AZ61 and AZ91. The cast magnesium alloy sheets were hot-rolled in an elevated temeparature to investigate the appropriate hot-rolling conditions for producing high-quality strip using a purpose-built strip-casting mill. The influences of such process parameters as materials of roll, casting temperature, and roll speed are ascertained. A simple method of predicting the convection heat transfer coefficient between casting rolls and molten metal is introduced. A warm deep drawing test of the cast magnesium sheets after being hot rolled was performed to demonstrate the formability of the magnesium alloy sheets produced by a roll strip casting process. The microstructure of the manufactured wrought alloy sheets was microscopically observed to investigate the effects of the hot-rolling conditions on crystal growth in the cast products.

2. Experimental procedure

2.1. A horizontal type twin roll caster

A horizontal type twin roll caster was used to manufacture thin magnesium alloy sheets of AZ61 and AZ91. Pair of copper alloy roll and pure copper roll were used for the horizontal type twin roll caster. Figure 1 illustrates the horizontal twin roll strip casting process used in the experiment. A source of molten metal feeds into the space between a pair of counter-rotating internally cooled rolls. The principle dimensions of the horizontal twin roll caster are presented in Table 1. L_c in Fig. 1 indicates the contact length between rolls and the molten metal. Table 2 presents the experimental conditions for investigating appropriate manufacturing conditions to successfully produce magnesium alloy sheets by twin roll strip casting. Super heats of 15°C and 30° were selected to find the best casting conditions, as indicated in Table 2. Temperatures of the molten magnesium in the crucible and tundish were measured by thermo-couples. Roll casting speeds were varied from 6m/min to 15 m/ in order to examine which roll speed was appropriate for solidifying the molten magnesium. The roll gap between the upper and lower rolls was determined to be from 1.5mm to 5.5mm by simple calculation results based on a basic solidification theory. No shielding gases were used in the experiment.

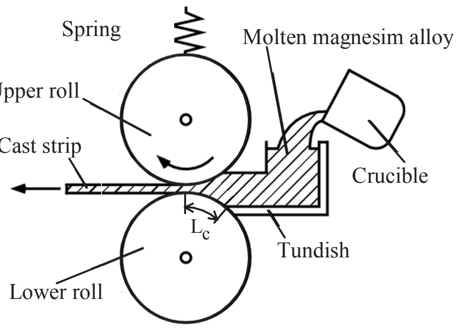


Fig. 1. Schematic illustration of a horizontal type twin roll caster

Table 1.
Dimensions of roll caster and tundish

Rolls	
Materials	Pure copper, Copper alloy
Upper roll (mm)	Φ300*150
Lower roll (mm)	Φ300*150
Roll speed (m/min)	0-60m/min (Max.)
Spring constant (N/mm)	10009
Roll contacting length (mm)	50
Tundish	
Material	Insulator, Mild steel

Table 2.
Experimental conditions

Tested materials	AZ61A	AZ91D
Casting temperature (°C)	640,625	626,611
Super heat (°C)	15, 30	
Roll speed (m/min)	6, 9, 12, 15	
Roll gap (mm)	1.6-5.5	
Roll contacting length (mm)	50	

Table 3.
Physical properies of tested materiale

Tested materials	AZ61A	AZ91D
Density (kg/m^3)	1.81*10^3	1.77*10^3
Liquidus temperature (°C)	610	596
Solidus temperature (°C)	495	470
Specific heat (J/kg • °C)	1040	1040
Thermalconductivity (W/m·°C)	80	72
Latent heat (kJ/kg)	373	373

2.2. Tested materials and its refining process

The material used in the experiment was AZ61A and AZ91D. The physical properties of the materials are listed in Table 3. Magnesium ingots were heated to 660°C in a crucible with an electric furnace. In the magnesium melting process, magnesium oxide and other suspended nonmetallic matter were removed with flux that preferentially wet the impurities and carried them to the bottom as sludge. After the refining process, the molten magnesium metal in the crucible was carried to the roll caster and poured onto the cooling slope to manufacture magnesium strip.

2.3. Hot-rolling process after twin roll strip casting

The hot-rolling process was performed to obtain wrought magnesium alloy sheets with globular and fine microstructures to be used for plastic forming. The cast strip sheets were milled to obtain sheets with 2.0mm thickness to remove oxide film. The cast strip was heated and rolled in the hot-rolling process. Rolling temperatures were varied from 250°C to 350°C. The milled sheet was rolled until the sheet became 0.5mm thick. Finally, the rolled magnesium sheet was annealed at 350°C for two hours, and cooled in an electric furnace. A 5m/min roll speed was chosen in the hot-rolling process. At 250°C, cracks were seen during the hot-rolling process, even though the reduction was less than 25%. The total redution was 75% in 3 paases in the hot rolling process. The reduction of 1st pass was 40%, 45% for 2nd pass and 25% for 3rd pass.

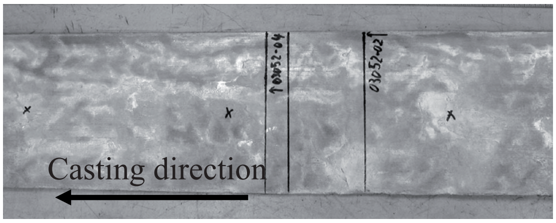


Fig. 3. Surface condition of cast AZ91D

3. Result and discussions

3.1. Surface conditions of cast products and shape defects

Figure 3 presents a photograph of the surface condition of AZ91D cast products manufactured by a roll caster with copper alloy rolls. The product shown in Fig. 3 was manufactured at a roll speed of 9m/min and a casting temperature of 656°C. It is seen that the surface of the cast sheet in Fig. 3 did not react much with oxygen in the air, even though no cover gas was used for shielding the cast magnesium in the strip casting. On the surface of the cast sheets were small cracks that were difficult to identify with the naked eye.

Figure 4 present photographs of a typical crack ooocued in manufactruing process of AZ91A. The typical crack as shown in Fig.4 was like a alligator mouse. The crack occurred at interface between the mid of cast sheet and upper and lower roll surface side parts. It is considered that the cracks were occurred by a different deformation resistance between the mid part of the section and upper and lower roll surface side parts. The both upper and lower roll surface side parts were solidified due to rapid cooling by contact between molten magnesium and rolls, although the solidification of the mid part of the strip section was not completed. We believe that the solid fraction of mid part of the strip was less than that of upper and lower roll surface side parts after solidification. It is concluded that there was a different deformation resistance between the mid part of the section and upper and lower roll surface side parts.

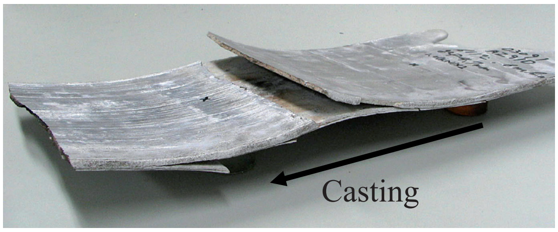
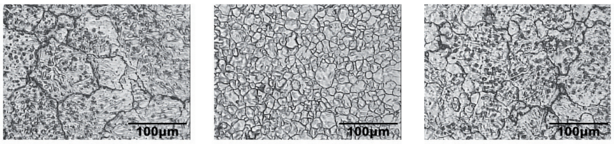


Fig. 4. Crack occurred in cast AZ91D strip

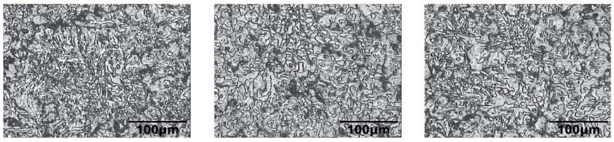
3.2. Microstructure of cast sheet

Figures 5(a), 5(b) and 5(c) present photographs of the microstructures of cast AZ91D sheets obtained by twin roll casting at a roll speed of 9m/min. It can be seen that microstructure of the cast sheet was dendritic and equiaxed structure strucure, however the grain size are different between both upper and lower roll side and mid of section. The equiaxed strucure are seen near roll surfaces and grain sizes around roll surface was about 100µm. However vary fine microstrucutures under 10µm are seen in the mid of the section the cast sheet. Figures 6(a), 6(b) and 6(c) present photographs of the microstructures of cast AZ91D sheets obtained by twin roll casting at a roll speed of 15m/min. The microstructures are different in Figs. 6(a), 6(b) and 6(c) comparing with the photogoraphs in Figs. 5(a), 5(b) and 5(c). In Figs. 6, the microstructure was similar to the microstrucure that often observed in the case of sand casting. In Figs.6, the intermetllic $Mg_{17}Al_{12}$ was seen in the grain boundary in AZ91D. As swhon in the Figs. 5, Figs.6, the microstructure was not always uniform in a cross section, however a homogenious microstructure could be successfully obtained after hot rolling process.



(a) Upper roll side (b) Mid of cross section (c) Lower roll side

Fig. 5. Microstructure of cast AZ91D sheet (v=9m/min)

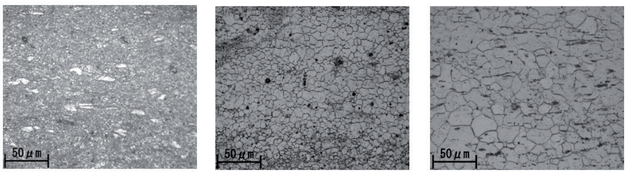


(a) Upper roll side (b) Mid of cross section (c) Lower roll side

Fig. 6. Microstructure of cast AZ91D sheet (v=15m/min)

3.3. Microstructure of hot rolled sheet

Figures 7 present photographs of the microstructures of hot rolled sheets after the roll strip casting process using a copper-alloy caster. The sheet depicted in Fig. 7(a) was hot rolled at 250°C, and no annealing process was used. In Fig. 7(b), the cast sheet was hot rolled at 300°C. The photo in Fig. 7(c) was hot rolled at 350°C. We can see that the crystals became larger due to recrystallization when rolling temperature increases as shown in in Figs. 7. In Fig. 7(a), it is seen that there are very fine grains as well as large grains. The grain sizes are not uniform in Fig. 7(a). The microstrucure in Fig. 7(b) is uniform and the mean grain sizes was 5μm in Fig.7(b).



(a) T_r=250°C (b) T_r=300°C (c) T_r=300°C

Fig. 7. Microstructure of hot rolled AZ91D cast sheet manufacture by different hot rolling temperatures

3.4. Plastic formability of obtained wrought magnesium alloy sheet

After the cast magnesium sheets were hot rolled, a warm deep-drawing test was performed to examine the forming characteristics of the magnesium alloy sheets produced by twin roll strip casting.

The diameter of the punch was 28.8mm. A lubricant solution was used. The limiting drawing ratio was investigated by a deep-drawing test at 250°C. A drawing speed of 30mm/s was chosen in the test. Figure 8 shows a result for a warm deep drawing test of AZ91D alloy sheets after hot rolling. When rolling temperature was 300°C, a limiting drawing ratio of 2.4 was obtained in the warm deep-drawing test, as indicated in Fig. 8. The result presented in Fig. 8 suggests that the wrought magnesium alloy sheets AZ91D that were hot rolled after the strip casting process had a good plastic formability. Similar results were obtained for AZ61A hot rolled sheets. It has been found that a limiting drawing ratio of 2.6 was possile in the warm deep drawing test of AZ61A.

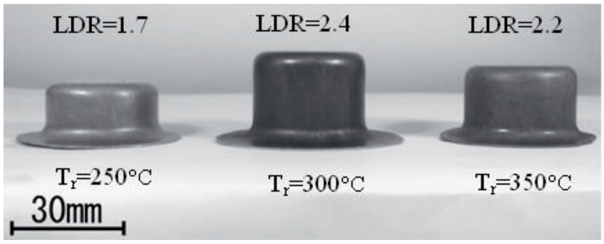


Fig. 8 Cups drawn in a warm deep drawing test in terms of hot rolling temperatures (AZ91D)

4. Conclusions

Magnesium alloys with high aluminum contents such as AZ61 and AZ91 were cast by using a horizontal twin roll caster. The obtained cast sheets were hot rolled, and a warm deep drawing test was performed to demonstrate the effectiveness of twin roll strip casting of magnesium alloys with high aluminum contents. A limiting drawing ratio of 2.4 was obtained in the warm deep-drawing test for AZ91 and a limiting drawing ratio of 2.6 was also obtained for AZ61.

References

[1] http://www.ulsab-avc.org/ , ULSAB-AVC Results

[2] H.Watari, K. Davey, M. T. Alonso Rasgado, T. Haga, Semi-solid manufacturing process of magnesium alloys by twin-roll casting, Journal of Materials Processing Technology, Vol 155-156, 2004, p1662-p1667.

[3] H.Watari, R. Paisarn, N. Koga, T. Haga. K. Davey, M.T.Alonso Rasgado, Forming characteristics of cast magnesium alloy sheets manufactured by roll strip casting process, Key Engineering Materials Vols. 274-276, 2004, p379-p384.