Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 20
ISSUES 1-2
January-February
2007

Development of manufacturing process of wrought magnesium alloy sheets by twin roll casting

H. Watari [a,*], R. Paisarn [b], T. Haga [c], K. Noda [d], K. Davey [e], N. Koga [f]
[a] Gunma University, 1-5-1 Tenjin-cyo, Kiryu, Gunma 376-8515 Japan
[b] King Mongkut's University of Technology Thonburi 91 Pracha-u-tid road, Bangmod, Thungkru Bangkok 10140, Thailand
[c] Osaka Institute of Technology, 5-16-1 Omiya Asahiku Osaka, 535-8585 Japan
[d] Toyohashi University of Technology, 1-1 Hibarigaoka, Tenpaku-cyo, Toyohashi, 441-8580 Japan
[e] The University of Manchester, PO BOX 88 Sacville Street, Manchester, M60 1QD, United Kingdom
[f] Nippon Institute of Technology, 4-1 Gakuen-dai, Miyashiro-machi, Minami saitama-gun, Saitama-ken, 345-850, Japan
* Corresponding author: E-mail address: watari@me.gunma-u.ac.jp

Received 02.11.2006; accepted in revised form 15.11.2006

Manufacturing and processing

ABSTRACT

Purpose: The purpose of the work is to development of a strip casting technology for manufacturing magnesium alloy sheets. The aim of the work is to establish a manufacturing process and technology to facilitate the economical manufacture of high-strength magnesium sheet alloys.
Design/methodology/approach: A horizontal type twin roll caster was used to manufacture magnesium alloy sheets. Pair of copper alloy roll, pure copper roll and steel roll was used for the horizontal type twin roll caster. The diameter of the rolls was 300mm and the width of rolls was 100 and 150mm.
Findings: The magnesium alloy sheets could be succcessfully manufactured by the horizontal twin roll caster. The product sheet thickness in the present experiment was 2.0 to 5.0mm. The equiaxed microstrucure was observed in cast magnesium alloys when a pair of copper and cupper aolly rolls were used. The mean grain size of the cast magnesium alloys strip was from 30 to 60 micrometers. After hot rolling process, the grain size was reduced to about 10 micrometers. The obtained magnesium alloy sheet indicated a good plastic formability by a warm-drawing test.
Research limitations/implications: The superheat in the experiment was between 15ºC and 30ºC, also an appropriate hot rolling temperature was 250ºC for AZ31, AZ61 and AM60, 300ºC for AZ91.
Practical implications: The proposed manufacturing process was effective from the view point of economical manufacturing process as well as of formation of rapid solidification microstructures. Introducing the twin roll casting technology enable to manufacture magnesium sheet alloys with high aluminum contents, such as AZ61, AM60 and AZ91.
Originality/value: AZ31, AM60, AZ61 and AZ91 wrought magnesium alloy sheets can be manufactured economically by twin roll casting. These cast sheet can be hot rolled and the proposed manufacturing process enables manufacturer to manufacure thin magnesium alloy sheets with high aluminum contents such as AM60, AZ61 and AZ91.
Keywords: Casting; Plastic forming; Twin roll casting; Magnesium alloys

1. Introduction

A voluntary agreement was reached between the European Commission and the European Car Manufacturers Association (ACEA) to reduce average carbon dioxide emissions of new passengers cars to 25% below 1995 levels by 2008, in 1998. Agreements have also been reached between the European Commission and the Japanese Automobile Manufacturers Association (JAMA) and the Korean Automobile Manufacturers Association (KAMA). However, the target average of carbon dioxide emissions of less than 140g/km in 2008 is a very challenging goal. 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. This can be achieved utilizing materials possessing high strength and low weight. 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. Furthermore, magnesium has received global attention from the standpoint of environmental preservation because of the ease of recycling of metallic materials. Utilization of magnesium alloys has mainly depended on casting technology, for instance, thixo-forming. However, demands have been raised in automotive and electronics industries to reduce the total product weight [2-3]. Automobile manufacturers have tried to evaluate the suitability of magnesium alloys for replacing steel and aluminum for automotive structural and sheet applications. Some of them have already made magnesium components for practical use. Unfortunately, the major barrier to greatly increased magnesium alloy use in cars is still primarily high manufacturing cost. One of the keys to solving this problem is to establish a twin roll casting technology to facilitate the manufacture of magnesium sheet alloys economically whilst maintaining high quality.

The authors have investigated the effectiveness of twin roll strip casting for magnesium alloys [4-6]. This paper describes the development of twin roll casting technology for magnesium alloys such as AZ31, AM60, 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 horizontal twin roll casters. 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. Manufacturing processes

2.1. Twin roll casters

In 1948, Hunter Engineering introduced a twin-roll caster for the production of aluminium strp. In the early mashines, the water-colled casting rolls were arranged horizontally and were fed from below below by means of a refractally feeder tip. The roll diametr of the earliest mashines was 600mm and the rolls were clamped together hydraulically with a force of approximately 6000 kN [7]. It is reported that the strip produced from this type of machine was typically 6 mm thick and of up to 1500 mm wide. Fig.1. shows various types of twin roll caster that can be used for producing magnesium alloy sheets. The twin roll caster in 3C method is essatially a slow, 2-high rolling mill where feedstock is molten aluminum and the end product is cast aluminum strip of 6-10mm thickness. In this types of twin roll caster, the separating force is normally more than 1 kN per 1 mm strip width. The melt drag twin roll caster is a roll caster that is equiped with a upper roll caster with a single roll (lower roll), a supply of molten metal is delivered to the surface of a rotating roll that is internally water-cooled. The molten metal is dragged onto the surface of the lower roll to form a thin strip of metal, which cools on contact with the surface of lower roll. The horizontal twin roll caster with copper rolls has used for manufacturing magnesium alloy sheet by authors [8-14]. The separating force of the horizontal twin roll caster was about 0.1 kN/mm. The roll speed of this type of roll caster is about 10-20m/min, which is more than ten times quicker than that of 3C type of twin roll caster.

	Conventional twin roll (3C method)	Melt drag twin roll (Opened type)	Horizontal twin roll (Copper roll) (Closed type)	Vertical Twin roll (Copper roll)
Thickness	more than 6mm	less than 6mm	2.5mm-5mm	1.5-3.0mm
Materials	only AZ31	AZ31,AM60 AZ61,AZ91	AZ31,AM60 AZ61,AZ91	AZ31,AM60 AZ61,AZ91
Roll speed	up to 1m/min low speed	5-10m/min high speed	10-20m/min high spped	100m/min very high speed
Separating force	1kN/mm	0.1kN/mm	0.1kN/mm	0.1kN/mm

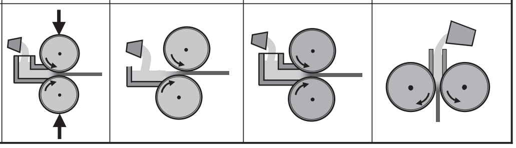

Fig. 1. Various types of twin roll caster

Also, the vertical type twin roll caster was used for producing relatively thin magnesim alloy strip. The roll speed of veritical twin roll caster reaches 100 m/min and the strip produced from this type of machine was typically less than 3mm thick [15]. Although the choice of the twin roll caster depends on the quality and types of strips that is needed in the manufacturing companies, both the horizontal and the vertical type twin roll caster would be useful because of its high roll speed when in considering practical manufacturing process for magnesium alloy sheets. Once the strip is coiled, the coiled cast strip will be hot rolled again and thus the globular and fine microstructures to be used for plastic forming will be obtained.

2.2. Hot-rolling process

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 pases in the hot rolling process. The reduction of 1st pass was 40%, 45% for 2nd pass and 25% for 3rd pass.

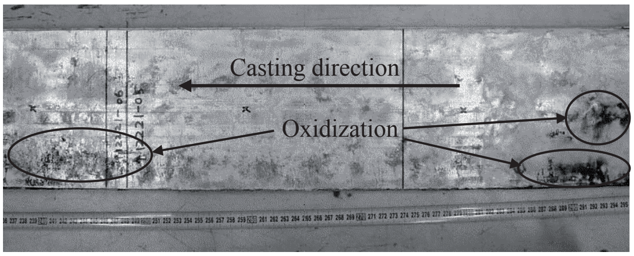

Fig. 2. Surface condition of cast AZ61

3. Results and discussions

3.1. Surface conditions

Figure 2 presents a photograph of the surface condition of AZ61 cast products manufactured by a roll caster with copper alloy rolls. The product was manufactured at a roll speed of 12m/min and a casting temperature of 645°C (superheat was 35°C). It is seen that the surface of the cast sheet in Fig. 2 did not so much oxidised even though no cover gas was used for shielding the cast magnesium in the strip casting process [4-5]. On the surface of the cast sheets were small cracks that were difficult to identify with the naked eye in the case that roll speed was 15 m/min. It is considered that occurrence of the small cracks depends on the cooling rate of the surface of the strips, cracks were not observed in other manufacturing condition of AZ61, from 6-12 m/min. In the case of AZ91, a typical crack (separation of bothe solidified layer) occurred in manufactruing process [8-10]. The typical crack observed in the cast AZ91 was like a alligator mouse. The crack occurred at interface between the mid of cast sheet and upper and lower roll surface side parts. 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.

3.2. Microstructure of cast sheet

Figures 3a, 3b and 3c present photographs of the microstructures of cast AZ61 sheets obtained by twin roll casting at a roll speed of 9 m/min. It can be seen that microstructure of the cast sheet was equiaxed structure, however the grain size are from 50 to 100μm around the roll surface side. However smaller grain are seen in the mid of the cross section. When the velocity become larger, very fine microstructure in the mid of cross section can be seen.

3.3. 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 AZ61 alloy sheets after hot rolling. When rolling temperature was 300°C, a limiting drawing ratio of 2.7 was obtained in the warm deep-drawing test, as indicated in Fig. 4.

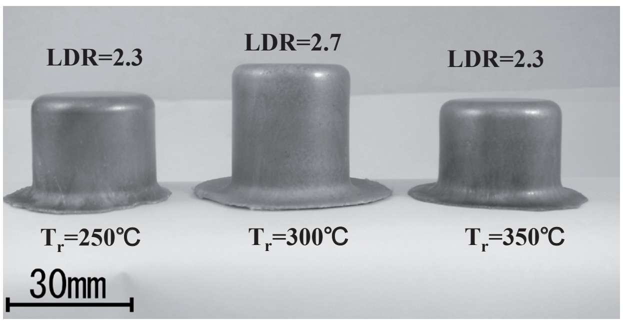

Fig. 4. Cups drawn in a warm deep drawing test in terms of hot rolling temperatures (AZ61)

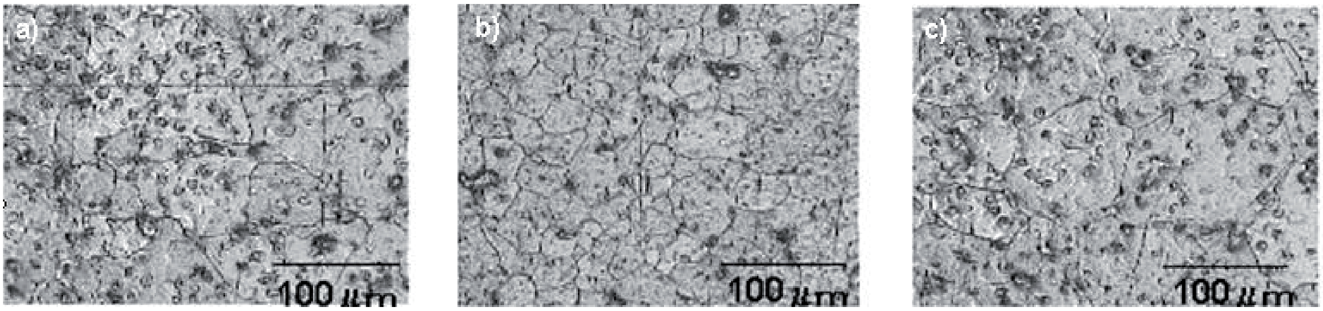

Fig. 3. Microstructure of cast AZ61 sheet (v=9m/min): a) upper roll side, b) mid of cross section, c) lower roll side

The result presented in Fig. 4 suggests that the wrought magnesium alloy sheets AZ61 that were hot rolled after the strip casting process had a good plastic formability. Similar results were obtained for AZ91 hot rolled sheets. It has been found that a limiting drawing ratio of 2.4 was possible in the warm deep drawing test of AZ91 [12-13].

4. Conclusions

Magnesium alloys such as AZ31 ,AZ61, AM50 and AZ91 were cast by using by a 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. It has been clarified that the obtained wrought magnesium alloy sheet indicated an equivalent plastic formability by a warm-drawing test.

References

[1] http://www.ulsab-avc.org/, ULSAB-AVC Results
[2] E. Doege, K. Dröder, Sheet metal forming of magnesium wought alloys - formability and process technology, Journal of Materials Processing Technology 115 (2001) 14-19.
[3] S. Yoshihara, H. Yamamoto, K. Manabe, H. Nishimura, Formability enhancement in magnesium alloy deep drawing by local heating and cooling technique, Journal of Materials Processing Technology 143-144 (2003) 612-615.
[4] H. Watari, T. Haga, S. Izawa, T. Iwashita, M. Nakayama, Twin roll strip casting of semi-solid magnesium alloys, Proceedings of the European Metallurgical Conference EMC 2003, Germany, 2003, 423-436.
[5] H. Watari, K. Davey, M. T. Alonso Rasgado, T. Haga, S.Izawa, Semi-solid manufacturing process of magnesium alloys by twin roll casting, Proceedings of the Advances in Materials and Processing Technologies (AMPT 2003), Dubline, Ireland, 2003, 720-723
[6] H. Watari, N. Koga, K. Davey, M.T. Alonso Rasgado, T. Haga, Warm deep drawability of magnesium alloy sheets manufactured by semi-solid roll strip casting, Proceedings of the 12th International Scientific Conference "Achievements in Mechanical & Materials Engineering" AMME2003, Gliwise-Zakopane, 2003,1027-1032
[7] R. Cook, P.G. Grocock, P.M. Thomas, J.D. Hunt, Development of the twin roll casting process, Journal of Materials Processing Technology 55 (1995) 76-84.
[8] 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), 379-384.
[9] H.Watari, N. Koga, R. Paisarn, T. Haga, Formability of Magnesium alloy sheets manufactured by semi-solid roll strip casting, Materials Science Forum Vols. 449-452 (2004), 181-184.
[10] H.Watari, K. Davey, M.T. Rasgado, T. Haga, S. Izawa,, Semi-slid manufactruing process of magnesium alloys by twin-roll casting, Journal of Materials Processing Technology 155-156 (2004) 1662-1667.
[11] H. Watari, T. Haga, N.Koga, K. Davey, Continuous strip casting of magnesium alloys by a horizontal twin roll caster, Proceedings of the International Conference on Continuous Casting of Non-Ferrous Metals, Neu-Ulm, Germany, 2005, 70-76.
[12] H. Watari, T. Haga, K. Davey, N. Koga, T. Yamazaki, Effects of production parameters on characteristics of magnesium alloy sheets manufactured by twin roll casting, Journal of Achievements and Manufacturing Engineering, Vol 16, Issue 1-2 (2006), 171-175.
[13] H. Watari, T. Haga Y. Shibue, K. Davey, N. Koga, Twin roll casting of magnesium alloys with high aluminium contents, Journal of Achievements and Manufacturing Engineering, Vol 18, Issue 1-2 (2006), 419-422.
[14] H. Watari, T. Haga, K. Davey, T. Haga, M.T.Alonso Rasgado, Warm deep drawing of wrought magnesium alloy sheets produced by roll strip-casting process, International Journal of Mashine Tools & Manufacture 46 (2006), 1233-1237.
[15] T. Haga, H. Watari, S.Kumai, High speed twin roll casting of Mg Alloy strip by a vertical twin roll caster, Journal of Achievements and Manufacturing Engineering, Vol 15, Issue 1-2 (2006), 186-192.