

# Forgeability of AZ Series Magnesium Alloy produced by Twin Roll Casting

Nao Ozawa<sup>1</sup>, Shinichi Nishida<sup>1</sup>, Toshio Haga<sup>2</sup>, Junshi Ichikawa<sup>1</sup>, Yuta Kashitani<sup>1</sup>,  
Ryosuke Okushima<sup>1</sup>, Yujiro Nitta<sup>1</sup>, Atsuhiko Aoki<sup>1</sup>, Yuto Takigawa<sup>1</sup>, Hayato Aso<sup>1</sup>,  
Hideto Harada<sup>1</sup>, Akihiro Watanabe<sup>1</sup>

<sup>1</sup>Department of Mechanical Science and Technology, Gunma University, Japan

<sup>2</sup>Osaka Institute of Technology, Japan

**Abstract**— Plastic forming of magnesium alloy is hardly reported because of its low forgeability. The productions of magnesium alloy are mainly produced by casting. Typical wrought magnesium alloy is AZ31. Magnesium-aluminum alloy indicates maximum elongation when the composition includes 3% aluminum. When the magnesium alloy includes over 3% aluminum, its elongation slightly decreases. Therefore, AZ31 that include 3% aluminum and 1% zinc is generally used for plastic forming. The more increasing aluminum composition, the larger 0.2% proof stress becomes. However its forgeability is decreasing because of precipitation of  $\beta$  phase such as Mg<sub>17</sub>Al<sub>12</sub>. It is supposed that the  $\beta$  phase is refined by rapid cooling casting process such as twin roll casting. In this paper, the magnesium alloy thick sheet of AZ91, AZ121 and AZ131 for hot forging, that include 9%, 12% and 13% aluminum composition respectively, was produced by twin roll strip casting process. And the forgeability of high aluminum containing magnesium alloy was investigated by die forging. As a result, it was possible to forge their magnesium alloys.

**Keywords**—Magnesium alloy AZ91 AZ121 AZ131, Hot forging, Twin roll strip casting, Forgeability

## I. INTRODUCTION

Magnesium alloy is getting the attention because it is the lightest weight structural material. Forgings has some properties such as the high toughness and the high productivity. However, the forgings of magnesium alloy is hardly reported [1]-[5]. The elongation at room temperature of magnesium is smaller than that of aluminum or steel because magnesium has hexagonal close-packed structure which slip plane is almost limited to basal plane. The production of magnesium alloy is generally by casting. Therefore the demand of wrought magnesium alloy is little. The examples of wrought magnesium alloy are AZ31, AZ61 and AZ80. Magnesium-aluminum alloy indicates maximum elongation when the composition includes 3% aluminum.

When the magnesium alloy includes over 3% aluminum, its elongation slightly decreases. Therefore, AZ31 that include 3% aluminum and 1% zinc is generally used for plastic forming. The more increasing aluminum composition, the larger 0.2% proof stress becomes. However its forgeability is decreasing because of precipitation of  $\beta$  phase such as Mg<sub>17</sub>Al<sub>12</sub>. It is supposed that the  $\beta$  phase is refined by rapid cooling casting process such as twin roll casting. In this paper, the magnesium alloy thick sheet of AZ91, AZ121 and AZ131 for hot forging, that include 9%, 12% and 13% aluminum composition respectively, was produced by different diameter twin roll strip casting process. And the forgeability of high aluminum containing magnesium alloy was investigated by die forging.

## II. TWIN ROLL STRIP CASTING

Fig.1 shows the photograph of different diagram twin roll strip caster. Three kind of magnesium alloy, AZ91 (Mg-9Al-1Zn), AZ121 (Mg-12Al-1Zn) and AZ131 (Mg-13Al-1Zn), were casted by this experimental device. The target thickness of cast strip is over 14.5 mm. Both roll materials are copper. Upper roll diameter is 300 mm. Lower roll diameter is 1000 mm. Both roll width is 100 mm. Upper roll solidification length is 100 mm. Lower roll solidification is 350 mm. Roll speed is 2 m/min. Fig.2 and Fig.3 show the AZ131 cast strip. The length of cast strip was over 1 m. And the thickness was over 20 mm. It was possible to cast the other magnesium alloy strips.

## III. FORGING EXPERIMENTAL CONDITIONS

Fig.4 shows the servo press machine (SDE1522, AMADA MACHINE TOOLS CO.,LTD.) for hot forging. The maximum pressure loading of this machine is 1500 kN. Stroke length is 225 mm. Generally, in hot forging, the blank forging material is forged soon after taking from heating furnace. In this study, hot forging was operated with the heating die by inserted the cartridge heater to control the forging temperature. Fig.5 shows the photograph of forging die. Heating temperature was

350°C. The die temperature was controlled by PID control and coolant water. The forging blank was kept to be 350°C before forging in the heating die.



Fig.1: Photograph of different diagram twin roll strip caster

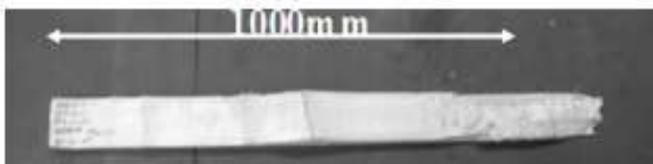


Fig.2: AZ131 magnesium alloy strip produced by twin roll caster



Fig.3: Cross section of roll casted AZ131 strip



Fig.4: Servo press machine (SDE1522, AMADA MACHINE TOOLS CO.,LTD.)

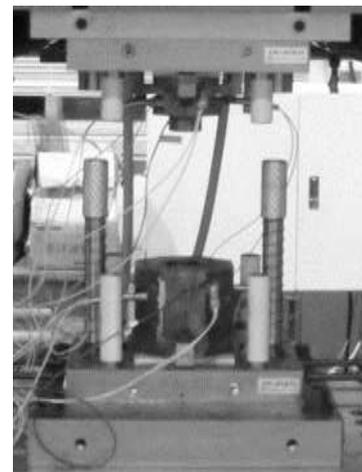


Fig.5: Forging die

The forging blank was cut by wire electrical discharge machine. Outer diameter of blank is 50 mm. The thickness was 14.5 mm. The strip was cutting by a lathe to make the blank with the thickness 14.5 mm from 20 mm. Fig.6 shows the design of forging die. This die shape was the simulated scroll for the car air conditioner compressor. The maximum scroll wall thickness was 5 mm, and the minimum wall thickness was 2 mm. The wall thickness was slightly changed from center to outer. The designed value of wall height was 25 mm. Table 1 shows the experimental conditions. Press length was 9.5 mm. Forging temperature was 350 °C. Forging was operated after measuring temperature of die. Forging motion was selected as constant speed motion. Punch speed was 10 mm/sec. Lubricant was used. The lubricant was applied to forging blank by brush before setting into the die. Keeping time in the die was 2 min. The

temperature of forging blank was same to the temperature of heating die.

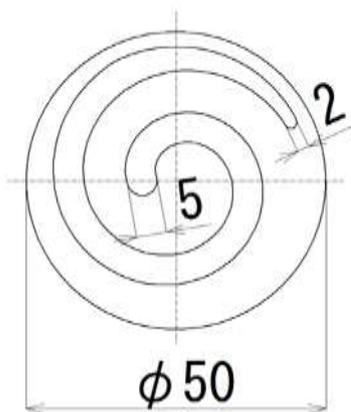


Fig.6: Design of simulated scroll (wall height 25 mm)

Table.1: Experimental Conditions

Test No.	1	2	3
Material	AZ91	AZ121	AZ131
Size /mm	□50×t14.5		
Extrusion length /mm	9.5		
Die height position /mm	430		
Temperature /°C	350		
Motion	Constant speed motion		
Velocity /mm•s <sup>-1</sup>	10		

#### IV. RESULTS AND DISCUSSIONS

Fig.7 shows the photographs of forged magnesium alloy. The notable difference for the forged shape was not observed. In addition, forged scroll height had not difference. However, the cracks was observed on the surface of forged AZ131, white circle shown in Fig.7. Tensile stress was occurred to the direction of radial and circumferential on the surface of top of scroll wall, so that the stress was biaxial tensile stress. It was supposed that the crack was caused by biaxial tensile stress because of the poor formability of magnesium alloy. And it was supposed that the crack was caused not only at final stage of forming but also at the stage of forming the scroll wall. The crack was might cause at the maximum forging load (press length 1.7 mm). Because the surface enlargement of the scroll tips was not changed during forging, thus the tensile stress on the surface of tip was not increase rapidly. It was possible to forge the thick strip of AZ91, AZ121 and AZ131 magnesium alloy produce by the different diagram twin roll caster. It is needed to research the forging condition to prevent the crack.



Fig.7: Forged parts (Left: AZ91, Center: AZ121, Right: AZ131)

Fig.8 shows the relationship between the forging force, punch position and time of AZ91. Forging started at the punch position 9.5 mm. The maximum load 469 kN was observed at press length 2.1 mm (punch position 7.4 mm). After peak load, the forging load was downed to finish forging. Forging force was almost constant after press length 5.2 mm (punch position 4.3 mm). Forging load might be rapidly increased after completely filling in the die. This forging was not filled completely, thus the forging load was not increased after press length 2.1 mm. Fig.9 shows the relationship between the relationship between the forging force, punch position and time of AZ121. Fig.10 shows the relationship between the

relationship between the forging force, punch position and time of AZ131. The maximum forging load of AZ121 was 431 kN, and the that one of AZ131 was 448 kN. The notable difference of maximum forging load was not observed about each amount of aluminum content. It was supposed that the variation of forging load was caused by coating technique of the lubricant.

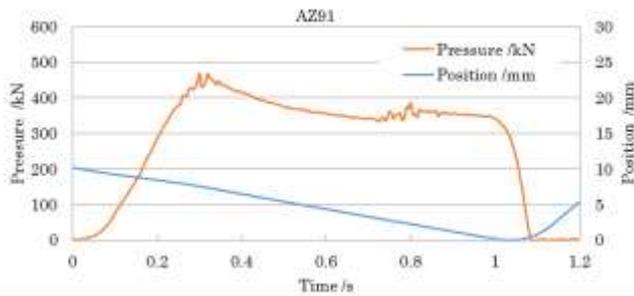


Fig.8: Pressure-Time and Slide position-Time diagram (AZ91)

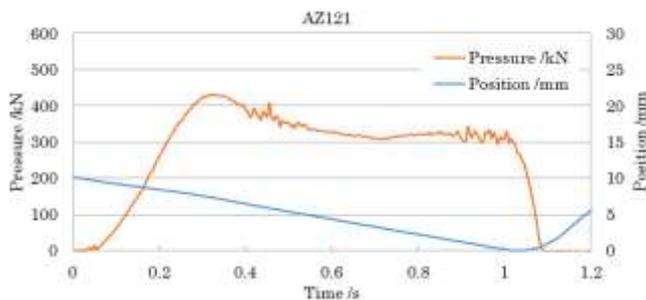


Fig.9: Pressure-Time and Slide position-Time diagram (AZ121)

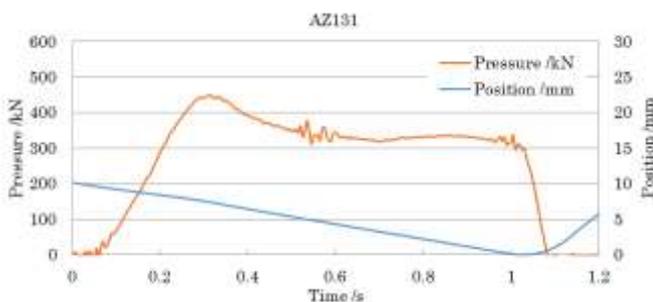


Fig.10: Pressure-Time and Slide position-Time diagram (AZ131)

## V. CONCLUSION

The magnesium alloy thick sheet of AZ91, AZ121 and AZ131 for hot forging, that include 9%, 12% and 13% aluminum composition respectively, was produced by different diameter twin roll strip casting process. And the forgeability of high aluminum containing magnesium alloy was investigated by die forging. It was possible to produce the magnesium alloy strip with over 20 mm thickness by different diagram twin roll strip caster. It was possible to forge the thick strip of AZ91, AZ121 and AZ131 magnesium alloy produce by the different diagram twin roll caster. The notable difference for the forged shape was not observed. The cracks was only observed on the surface of forged AZ131. The notable difference of maximum forging load was not observed about each amount of aluminum content.

## REFERENCES

- [1] Jing Zhang, Hao Huang and ChengBo Yang, Effects of hot ring forging on microstructure, texture and mechanical properties of AZ31 magnesium alloy, *Materials Science and Engineering: A*, 679(2), 2017, 20-27.
- [2] Juqiang Li, Juan Liu and Zhenshan Cui, Microstructures and mechanical properties of AZ61 magnesium alloy after isothermal multidirectional forging with increasing strain rate, *Materials Science and Engineering: A*, 643(3), 2015, 32-36.
- [3] A. Salandari-Rabori, A. Zarei-Hanzaki, S.M. Fatemi, M. Ghambari and M. Moghaddam, Microstructure and superior mechanical properties of a multi-axially forged WE magnesium alloy, *Journal of Alloys and Compounds*, 695(5), 2017, 406-413.
- [4] Anna Dziubińska, Andrzej Gontarz, Karina Horzelska and Paweł Pieško, The Microstructure and Mechanical Properties of AZ31 Magnesium Alloy Aircraft Brackets Produced by a New Forging Technology, *Procedia Manufacturing*, 2, 2015, 337-341.
- [5] K.B. Nie, K.K. Deng, X.J. Wang, F.J. Xu, K. Wu and M.Y. Zheng, Multidirectional forging of AZ91 magnesium alloy and its effects on microstructures and mechanical properties, *Materials Science and Engineering: A*, 624(29), 2015, 157-168.