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Study on the Production of Aluminum Components by Direct Rheo Die Casting with Electromagnetic Stirrer

Joong-Suk Roh[1], Min Heo[2], Chul-Kyu Jin[3*], Jin Ha Park[4], Chung-Gil Kang[5]

〈Abstract〉

This paper relates a rheo die casting using electromagnetic force, which is one of the representative semi-solid methods for aluminum. The most important factors in electromagnetic stirring would be the melt temperature, sleeve temperature, electromagnetic force, and input time. The effect of the temperature of molten alloy on the direct rheo-casting is assessed in this study. The temperature of the molten alloy is set to 590 ℃ with a solidification of 40%, 600 ℃ with 30%, and 610℃ with less than 20%. Under the condition of 590 ℃ with a solidification of 40%, the whole molten alloy is solidified, causing non-forming during forming process. Meanwhile, under the condition of 600 ℃, where the solidification was 30%, appropriate amount of molten alloy is solidified, filled well into the mold, resulting in good forming, while at 610 ℃ with the solidification of 20%, the molten alloy is not sufficiently solidified and scattered away. The investigation of the defects inside the product with the help of the X-ray equipment shows that the electromagnetic stirring at 590 ℃ with a solidification of 30% produces many air-pores inside the product.

Keywords : Aluminum alloy, Rheo die casting, Electromagnetic stirrer, Semi-Solid forming

3* Corresonding Author, School of Mechanical Engineering, Kyungnam University
E-mail: cool3243@kyungnam.ac.kr

1. Introduction

Although fuel efficiency and exhaust gas reduction technologies are being applied to the engines of internal combustion engine vehicles, the ultimate target of the automobile industry is reducing the weight of the vehicle itself rather than improving engine efficiency.

Currently, automobile materials are being converted from iron-based materials to lightweight aluminum in domestic and foreign countries alike [1-10].

Particularly, the semi-solid forming technology using electromagnetic stirring, which can manufacture high-strength, high-toughness aluminum alloy parts, is gaining worldwide attention by Korea being the first to succeed in mass-production application to domestic automobile models [11-17].

Among them, rheology forming technology can improve the mechanical properties of the product by more than 10-15% compared to the existing one by spheroidizing and minimizing the dendritic structure generated during solidification, rendering it possible to reduce weight by reducing product thickness through this mechanical property improvement [18-23].

However, in manufacturing semi-melt slurry, the industry is demanding the development of a new concept of rheology forming process due to increased production cycle time, excessive production cost, liquid segregation, and increased initial investment cost. Therefore, in this study, rheo-casting, in which the A356 alloy in a strongly stirred semi-solid state was directly filled into the cavity, was carried out by the use of electromagnetic stirring instead of slurry preparation.

2. Material

The material used in the semi-melting slurry manufacturing experiment was A356 alloy, a cast aluminum alloy with a large solid-liquid coexistence area. A356 alloy has good fluidity in the high-liquid coexistence area and can improve mechanical strength through heat treatment; therefore, it is used in parts requiring strength and reliability, such as the knuckles, arms, and housings of automobiles.

Table 1 shows the composition of the A356 alloy. The liquidus and solidus temperatures of the A356 alloy are 553 ℃ and 617 ℃, respectively. The solidification range of A356 alloy is 67 ℃.

3. Experiment

Figure 1 shows the direct die casting experiment method using electromagnetic stirring. First, the current input of the electromagnet shows how to operate the six poles by using the controller. In this paper,

Table 1. Chemical composition of A356 alloy (wt %)

Si	Mg	Ti	Fe
6.65	0.35	0.12	0.08
Sr	**Zn**	**Pb**	**Ni**
0.022	0.02	0.016	0.01
Mn	**Cu**	**Sn**	**Cr**
0.008	0.008	0.007	0.001
Ca	**Al**	**Solidus Temperature**	**Liquidus Temperature**
0.0008	Bal	553 ℃	617 ℃

the magnetic flux density of the stirrer was 700 Gauss, and the symmetrical poles were simultaneously input to set the molten alloy to rotate in the counterclockwise direction.

Afterwards, the molten alloy in the heating furnace was rapidly injected into the stirrer using a molten alloy ladle, with the electromagnetic stirring soon started. Simultaneously, the temperature was measured upon insertion of a thermocouple in the center of the molten alloy. The temperature of the molten alloy in the heating furnace was 690 ℃. The temperature of the molten alloy that was started by electromagnetic stirring was 670 ℃. When the desired stirring time was achieved, stirring was stopped. In this paper, the end time of stirring was set to 591 ℃ with a solidification of 40%, 601 ℃ with a solidification of 30%, and 607 ℃ with a solidification of 20%.

Stirring was completed and the tip was raised using the controller to fill the molten alloy into the die. During forming, the injection pressure was 30 bar, the temperature of the die was 300 ℃, and the manufactured product was tensile test specimen 14. It was produced so that two tensile specimens could be produced in one cavity.

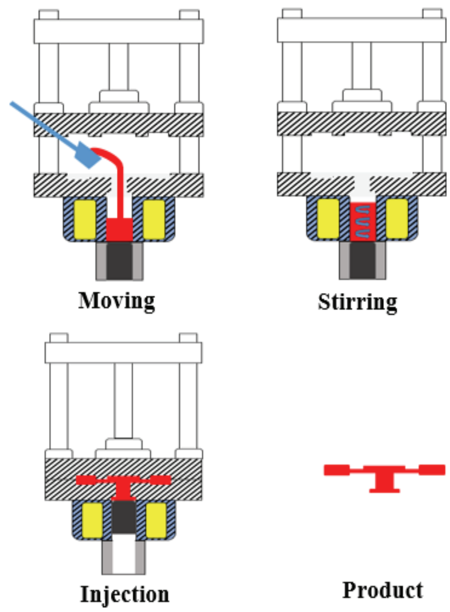
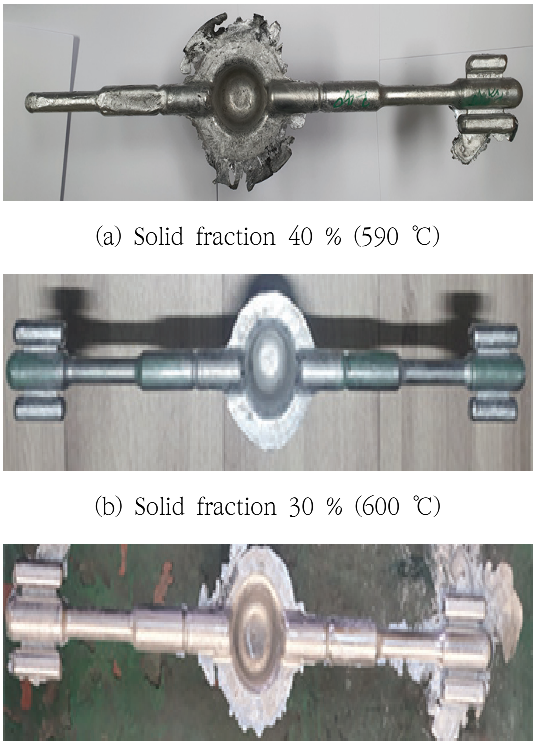


Fig. 1 Process of direct rheo die casting using EMS

4. Experimental Results

4.1 Formality

Figure 2 shows the results of the forming in a direct die casting experiment using the electromagnetic stirring. Under the conditions of 590 ℃ with the solidification of 40%, non-forming occurred in the product during the forming process because the molten alloy



(a) Solid fraction 40 % (590 ℃)

(b) Solid fraction 30 % (600 ℃)

(c) Solid fraction 20 % (610 ℃)

Fig. 2 The appearance of the product

was solidified in the sleeve during electromagnetic stirring. Furthermore, the color of the product surface appeared dull since the forming pressure of the product was not completely transmitted from the surface of the product. Likewise, injection molding could not be performed because some of the molten alloy adhered to the sleeve. Under the condition of 600 ℃, where the solidification rate was 30%, the die was well filled and product was formed well due to the proper amount of solidification, whereas sufficient pressure was transferred, so that good surface could be obtained. Under the condition of 610 ℃ with a solidification of 20%, molten alloy was not sufficiently solidified, and scattering occurred. In addition, the melt in the sleeve hardened during stirring when the experiment was conducted at a temperature of 590 ℃ or higher with a solidification of 50% or higher, making injection molding impossible and potentially damaging the equipment. Meanwhile, with the experiment at lower than 610 ℃ with the solidification lower than 20%, the safety of the experimenter became a problem due to the large amount of scattering.

4.2 Mechanical Properties

Table 2 summarizes the mechanical property values of products formed by electromagnetic stirring under the conditions of 30% and 20% solidification achieved in this study. The experimental results showed that the mechanical property values of products formed by the electromagnetic stirring were relatively low. These low physical property values might have impaired the mechanical properties of the product due to the inflow of air or oxide into the product during electromagnetic stirring or during the filling of the stirred molten alloy into the cavity of the die.

Table 2. The mechanical properties of product

Temperature(℃)	Elongation (%)		YS (MPa)		UTS (MPa)	
	max	ave	max	ave	max	ave
610	4.5	3.7	267	259	326	310
600	7.4	5.6	281	268	327	321

4.3 Defects Analysis

To investigate the cause of the poor physical properties of the electronically formed product, the inner part of the product was examined through X-ray equipment. The internal inspection of the product was conducted by X-Ray transmission test with the Toshiba Tosray-150 HS equipment, and the final filled portion, which would have defects, was intensively examined. Figure 3 shows the photographs of defects observed inside the product using X-ray equipment. The measurement results of the inner part of the product showed that many air-pores produced in the product were electronically stirred at 590 ℃ with the solidification of 30%. It might have been due to the inflow of the air-pores during filling stage and long stirring time of the molten alloy. In addition, the air inside the die cavity might have not discharged smoothly to the air vent during the molten alloy filling.

(a) Solid fraction 30 % (600 ℃)

(b) Solid fraction 20 % (610 ℃)

Fig. 3 The pictures by X-ray of product

5. Conclusions

A study on formability was conducted through a direct rheo-casting process using electromagnetic stirring. The experimental results are as follows.

(1) During electromagnetic stirring under the conditions of 590 ℃ with a solidification of 40%, non-forming occurred in the product during the forming process because the molten alloy was solidified in the sleeve.

(2) Under the condition of 600 ℃ with the solidification of 30%, proper amount of molten alloy was solidified, leading good filling of the molten alloy into the die, which could achieve a good forming performance while sufficient pressure was transferred, resulting in good product surface quality.

(3) Under the condition of 610 ℃ with a solidification of 20%, the molten alloy

could not be sufficiently solidified, initiating scattering.

(4) The observation of the inner side of the product with the help of X-ray equipment revealed that many air-pores formed in the product electromagnetically stirred at 590 ℃ with a solidification of 30%, which caused the poor mechanical properties in the final product.

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