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레오다이캐스팅에 의한 알루미늄 부품의 평가

서판기* · 정용식* · 강충길**

Evaluation of Aluminum Part by Rheo Die Casting

P. K. Seo, Y. S. Jung and C. G. Kang

Abstract

In rheo forming process, slurry making is very important factor because the microstructure of slurry affects the quality of final products. To control the microstructure of slurry, slurry making by new rheo die casting was studied. In new rheocasting method, processes parameters are degree of overheat in molten metal, cooling condition, high frequency induction heating condition and cup temperature. Microstructures according to these parameters were observed. By image analysis, equivalent diameter and roundness of grain were investigated and discussed. To find out mechanical properties of grain controlled aluminum part by rheo die casting, tensile tests were carried out to the T6 heat treatment.

Key Words : Rheo Die Casting, Microstructure, Grain Controlled Material

1. Introduction

In semi-solid forming process, there are two processes such as thixo forming and rheo forming. In thixo forming, materials fabricated by continuous casting process with electromagnetic system are mainly used. Therefore, the cost of feedstock material is very high. Also, there are disadvantages such as limited selection of alloy, billet reheating cost, non-destructive control cost, the difficulty of scrap recycling and billet loss during reheating process. On the contrary, the rheo forming process on-demand slurry like not only cast alloy but also structural alloy can be used and the recycling of scrap is much easier [1].

In the rheo forming process, molten alloy is directly cooled from the liquid state to the mushy state. Therefore, reheating process can be removed compared to the thixo forming process. Grain controlled material was made by mainly 3 steps like pouring, cooling and temperature adjustment. These steps are included many process parameters. Pouring temperature is lower than that of conventional casting process. During pouring, molten metal is solidified at the surface of pouring cup. Grain can be controlled as globular microstructure by air blow cooling. Finally, the temperature of slurry is adjusted as proper temperature for rheo die casting by high frequency induction heating [2].

In this paper, to overcome the disadvantages of thixo forming process and apply the rheo forming process, continuous fabrication process of grain controlled aluminum material with above-mentioned three steps has been studied.

* 부산대학교 정밀기계공학과 대학원
** 부산대학교 기계공학부

2. Experiment

The material used in this paper is A356 aluminum alloy. It is mainly used for the thixo and rheo die casting, because it has good fluidity, formability and mechanical properties [3]. The chemical compositions of A356 aluminum alloy are shown in Table 1. Its liquidus and solidus temperature are 615 and 547℃ respectively.

Table 1 The chemical compositions of A356 alloy

Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
7.0	0.2	0.2	0.1	0.35	0.1	0.2	Rem.

Fig. 1 shows the process for cleaning and preheating a cup. To make satisfactory slurry, it is necessary to wash remaining slurry and preheat the cup. Firstly, remaining slurry is blown out by air and the cup is cooled down. If slurry is still onto the cup, it is completely removed in brushing process. During the air blowing and brushing, the cup is cooled down. Therefore, the cup should be preheated to prevent the temperature of molten metal from abruptly decreasing. Also, to easily extract the slurry from the cup, spray is necessary. Finally, the cup is carried into the slurry-making turntable by transfer robot.

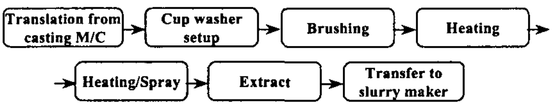


Fig. 1 Process for cleaning and preheating a cup in the washing turntable

Table 2 shows conditions for cleaning and preheating a cup in washing turntable. The each holding time of cup washer setup, brushing, heating and heating/spray is 53, 4, 46 and 49 seconds. Total time is 152 seconds. In the washing turntable, five cups are continuously prepared to make satisfactory slurry.

Table 2 Conditions for cleaning and preheating a cup in washing turntable (unit: [sec])

Cup washer setup	Brushing	Heating	Heating /spray	Total time
53	4	46	49	152

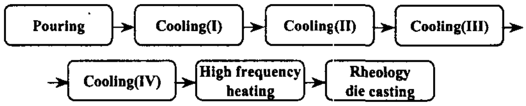


Fig. 2 Process for fabricating slurry in the slurry-making turntable

Fig. 2 shows the process for fabricating slurry in the slurry-making turntable. At first, the molten metal in the holding furnace is poured into a cup by ladler. The molten metal above liquidus temperature is cooled by mushy state with the four cooling stages. In each cooling stage, different cooling time is applied to prevent the temperature of slurry from abruptly varying. After cooling stages, to control the microstructure of slurry, the high frequency induction heating is used. During the high frequency induction heating, the temperature of slurry is slowly cooled down to reach the suitable temperature in the rheo die casting and make a globular microstructure. Finally, grain controlled slurry is taken out to the die casting machine and a part is formed into the die cavity.

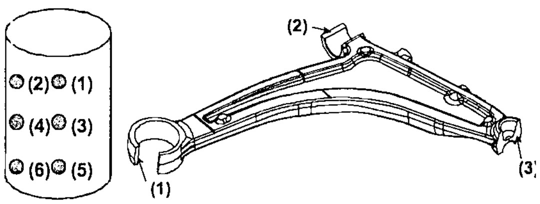
Table 3 Experimental conditions for fabricating slurry in the slurry-making turntable ([sec])

No.	Cooling time				High frequency heating		Total time	Rheology die casting
	t_1	t_2	t_3	t_4	t_h	Power [kW]		
1	40	20	10	5	50	6	125	-
2	50	30	10	10	50	4	150	-
3	50	30	20	13	50	2	163	Forming
4	50	35	25	15	50	2	175	Forming
5	50	40	30	20	50	2	190	Forming
6	50	40	30	15	50	2	185	Forming
7	30	20	10	7	60	3	127	Forming
8	30	20	10	7	60	3	127	Forming
9	10	10	0	3	60	3	83	Forming
10	10	10	5	3	60	3	88	Forming

Table 3 shows the experimental conditions for fabricating slurry in the slurry-making turntable. Pouring temperature of molten metal is from 648 to 653℃ and degree of superheat is about 35℃. In each experiment, cooling times (t_1 - t_4) of four cooling stages were largely varied from 0 to 50 seconds. High frequency heating time (t_h) was set as 50 seconds in longer cooling times and 60 seconds in the shorter cooling times so that the temperature deviation between outer and inner of slurry could be reduced. During high frequency heating, 800 Hz, heating power was varied from 2 to 6 kW. Total time at each experiment is from 83 to 190 seconds and therefore, the cycle time for rheo die casting is reduced and adjusted according to the solidification time of a part.

3. Experimental results

After making slurry, rheo die casting was carried out in the 840 ton horizontal die casting machine. Microstructures of slurries and lower arm parts were investigated. Positions for microstructure observation in slurry and lower arm part were marked in Fig. 3.



(a) Slurry (b) Lower arm part

Fig. 3 Positions for microstructure observation

Fig. 4 (a) shows the microstructures at each position of slurry in the case of No. 4 experimental condition. In all positions of Fig. 4 (a), dendrite structures were not observed and the morphologies of Al particle were globular and partly rosette type. Compared between inner zone (positions (1), (3) and (5)) and outer zone (positions (2), (4) and (6)), Al particles were more globular in inner zone. It was considered that due to the cooling rate of outer zone was more than inner zone, the time that Al particles were globular was enough at inner zone and therefore. Fig. 4 (b) shows the microstructures at final filling position of lower arm part in the case of No. 4 experimental condition. At the final filling position, the casting defects like incomplete filling phenomena, liquid segregation and air porosities are often occurred. However, it was found that these defects were not observed and Al particles were uniformly distributed.

For the quantitative analysis of microstructures of slurries and lower arm parts, equivalent diameter and roundness of grains in the slurries and were investigated by image analysis. The size of grain has an effect on the viscosity and yield strength, and its average value is expressed as equivalent diameter (D_{eq}). With smaller equivalent diameter, the viscosity of slurry decreases and yield strength increases. Roundness is defined by the ratio of the circumference to the area of grain. If it is 1, grains are completely globular.

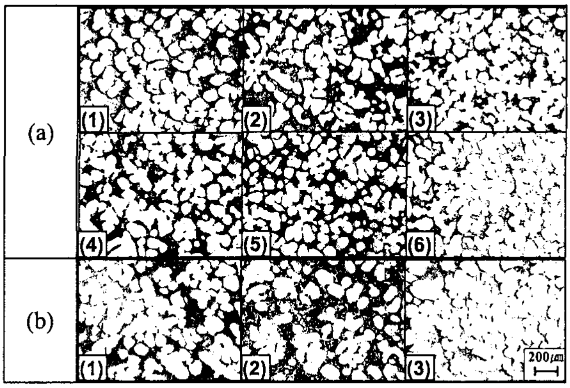
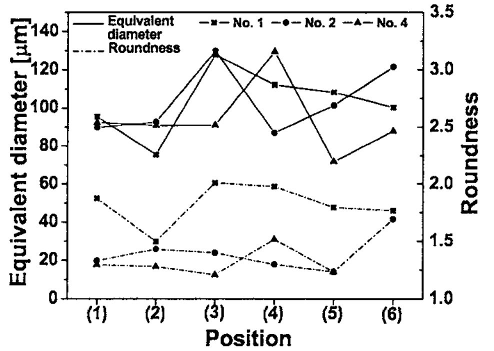
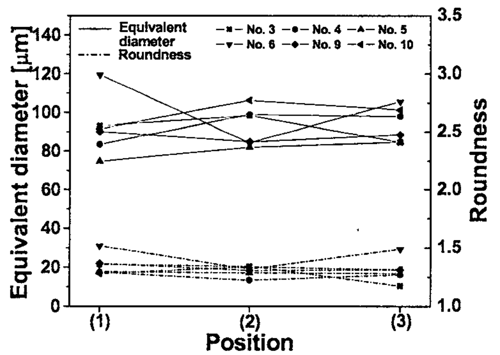


Fig. 4 Microstructures at each position in the case of No. 4 experimental condition: (a) slurry; (b) lower arm part



(a) Slurry



(b) Lower arm part

Fig. 5 Equivalent diameter of grain and roundness in slurries and lower arm parts according to the experimental conditions

Fig. 5 (a) and (b) show the equivalent diameter of grain and roundness in slurries and lower arm parts. Average equivalent diameter was about (100±30) ㎛ in slurries and (93±25)㎛ in the lower arm parts. Average roundness was 1.5 in the slurries and 1.3 in the lower arm parts. In particular, roundness in the lower arm parts was almost uniform regardless of the experimental conditions. Both equivalent diameter and roundness were higher and had a wider difference in the slurries. It is found out that during the rheo die casting, globularization of aluminum grains still progresses and therefore, roundness in the parts decreases in comparison with slurries.

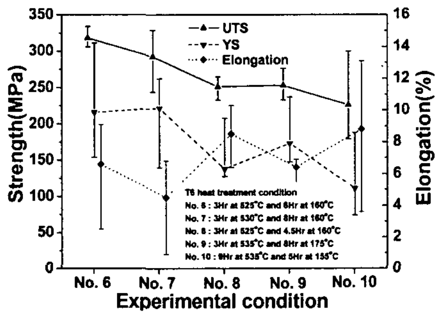


Fig. 6 Ultimate tensile strength, yield strength and elongation with T6 heat treatment to the experimental conditions

After rheo die casting, T6 heat treatments were carried out with various conditions and mechanical properties were investigated through tensile tests. Fig. 6 (a) and (b) show the average values and deviation of ultimate tensile strength, yield and elongation with T6 heat treatment according to the experimental conditions. In No. 6 condition, 318 MPa of UTS, 215 MPa of YS and 6.6% of elongation were obtained. The relation of YS to elongation showed wholly opposite tendency. As aging time was longer, elongation decreased. The aging time and temperature for simultaneously achieving excellent YS and elongation are considered as (5-6) Hr at (160-170) ℃.

4. Conclusions

Continuous fabrication experiments of grain controlled aluminum material for rheo die casting were carried out by various conditions. Through these experiments and analysis, following results were obtained.

(1) To continuously fabricate grain controlled aluminum material, each process parameter for cup cleaning and preheating was set and total time was 152 seconds. The temperature of cup preheated was about 200℃ to prevent abrupt decrease of molten aluminum.

(2) In the experiments for fabricating slurries, grains of aluminum material could be controlled by cooling times (t_1-t_4) and high frequency heating time and power. Total times in the slurry making process were from 83 to 190 seconds and cycle time for manufacturing a part could be reduced in comparison with thixo die casting.

(3) Equivalent diameter was (100±30) ㎛ in slurries and (93±25) ㎛ in the lower arm parts. Roundness was 1.5 in the slurries and 1.3 in the lower arm parts.

(4) Mechanical properties of lower arm parts, manufactured by grain controlled aluminum material, with T6 heat treatment were 318 MPa of UTS, 215 MPa of YS and 6.6% of elongation.

Acknowledgements

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