スリーブ内で半凝固スラリーを生成するアルミニウム合金ダイカスト法の開発

著者	LEE　JUNGSOO
学位授与機関	Tohoku University
学位授与番号	11301甲第17201号
URL	http://hdl.handle.net/10097/00096968

氏　　　　　　　名	い　　じょんす 李　　定 洙
研究科，専攻の名称	東北大学大学院工学研究科（博士課程）金属フロンティア工学専攻
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論 文 審 査 委 員	主査　東北大学教授　安斎　浩一　東北大学教授　及川　勝成 東北大学教授　コマロフ・セルゲイ

論文内容要約

From the past, a number of studies and efforts to develop the high strength and toughness of die casting products comparable to forgings for the lightweight automobile. However, there is a decrease of quality due to some defects such as shrinkage, air entrapment, etc. on the conventional die casting process. Herein semi-solid die casting process is expected as the next generation of die casting technology that combines the high quality and advantage of cost compare to conventional die casting process which cannot achieve the required quality and cost until now.

Therefore, Ube industry has been developed Ube's New Rheocasting Process (NRC) and commercialized. Semi-solid slurry is made by pouring the molten metal gently near liquidus temperature into the metal vessel and can obtain the globular primary structure by controlling the temperature for slow cooling [1].

However, it needs huge, expensive equipment and long time to make the semi-solid slurry. And also, this method is not enough to make many nuclei, therefore there is a limitation to refine the globular structure. Accordingly, we have been studying Nano-cast and Cup-cast process [2-3]. They use electromagnetic and self-stirring, respectively, in order to increase the number of nuclei and subsequent advantage of quality and making cost of products. Furthermore, semi-solid slurry is made rapidly and easily with small size grains in the processes. However, Nano-cast process still needs the additional equipment to make semi-solid slurry. And also, distribution of temperature in the cup is not homogeneous to make high-volume slurry by Cup-cast process.

Consequently, we developed the new semi-solid die casting method recently which is named Sleeve process [4]. We can obtain the fine globular Al(diameter: under 50㎛) and very-fine globular Al phase(diameter: under 15㎛) by controlling the conditions such as sleeve filling ratio (SFR), shot time lag (STL), pouring temperature of molten metal and etc. without any additional equipment. Thus Sleeve process is expected to use for lightweight of automobile parts. However there is no study about the reason of occurrence of very-fine globular Al phase in Sleeve process. Therefore, the purpose of this study is to figure

out the mechanism of microstructure formation and apply to the various Al alloys on Sleeve process.

This study is composed of total 6 chapters in which a result of experimentally investigating and considering formation mechanism of unique microstructure being occurred in die-casting product when casting with semi-solid die-casting process (hereinafter called sleeve process) that is characterized by making semi-solid slurry in shot sleeve of cold chamber die-casting machine was summarized.

In chapter 1, introduction, characteristics, disadvantage of semi-solid die-casting process and technical task to be solved were summarized and such process having been proposed in the past was explained and its advantage, necessity of clarifying formation mechanism of microstructure not yet clarified were described.

In chapter 2, when AC4CH alloy that is most widely used for semi-solid die-casting process is casted by sleeve process, globular Al phase finer than conventional process was occurred and its occurrence condition was explained. Microstructure of AC4CH(Al-7%Si-0.45%Mg) alloy castings with different semi-solid die casting conditions (Sleeve filling ratio : SFR and Shot time lag : STL) was investigated to figure out the generation mechanism of very-fine globular α-Al (diameter : under 15μm). As shown in Fig.1, in the case of SFR 10% with STL 10 seconds a larger number of very-fine globular α-Al were observed with globular α-Al (diameter : under 50μm) at product surface than that of SFR 30 and 50% with STL 10 seconds. Those very-fine globular α-Al size were about 5μm in the product surface and under 15μm in the product center. The size of very-fine globular α-Al at product surface in the case of SFR 10% with STL 0 second was coarser than that of STL 10 seconds and the size was under 15μm. Consider the results of above, it was considered that there were the conditions to promote the generation of very-fine globular α-Al in the melt at the stage of reaching the eutectic temperature in case of the low sleeve filling ratio. It was clarified that in case of SFR10% and STL 10 seconds, a microstructure in which fine globular Al phase having size of under 50μm and very fine globular Al phase were mixed was occurred.

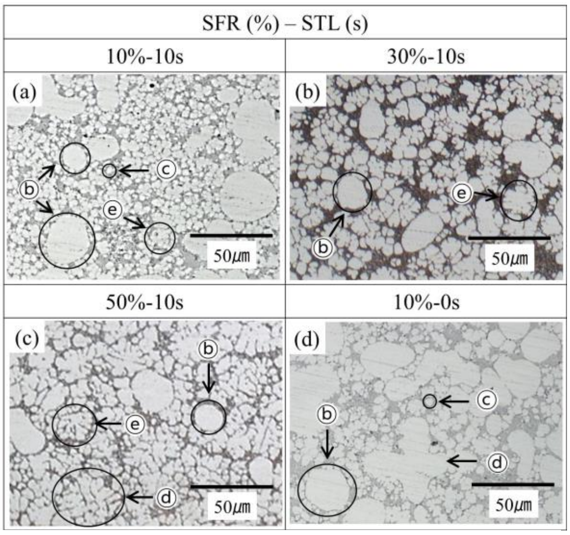

Fig. 1 Typical microstructure of product surface at each sleeve filling ratio.
(a) 10%-10s, (b) 30%-10s, (c) 50%-10s, (d) 10%-0s.

In chapter 3, a mechanism that in sleeve method, very fine globular Al phase was occurred was considered through an experiment. AC4CH alloy is composed of about 50wt% of primary α-Al and remaining of Al-Si eutectic. However, it was confirmed that generation amount of eutectic in microstructure obtained by sleeve process was smaller than conventional process. Therefore, a hypothesis was established as follows. Fine globular primary α-Al (about 50μm) was crystallized at first over eutectic temperature, and then very fine globular Al (about 5~15μm) that would be crystallized as eutectic Al in conventional process was crystallized form the melt of eutectic composition. In addition, as it was reported in the past research that AlP was become a nucleus in crystallization of Al-Si eutectic cell [5], casting experiment was performed with the small amount of P. Furthermore, Si contained amount of Al phase and aggregation substance of P at product surface of AC4CH (Al-7%Si-0.45%Mg) alloy castings which were cast with different semi-solid die casting conditions (Sleeve filling ratio : SFR and Shot time lag : STL) were investigated to figure out the generation mechanism of very-fine globular Al phase (diameter : under 15μm).The results are as follows. In the case of SFR 10% with STL 10 seconds, a number of very-fine globular Al pahse (diameter : under 10μm) with contained Si over 2at.% were observed at product surface than that of SFR 30 and 50% with STL 10 seconds. AlP which could be a nucleus of eutectic Si was eliminated when P was aggregated as AlP in the melt. Therefore it was difficult to form eutectic Si even if the temperature of melt was reaching the eutectic temperature. Consequently, eutectic undercooling was occurred easily, moreover, degree of undercooling was more increased because of the die-cast product. Furthermore, eutectic structure was difficult to occur since Si was highly contained in crystallized α-Al. As a result, it is considered to be a number of very-fine Al phases were occurred.

In chapter 4, in order to verify the hypothesis of chapter 3, Al-Si eutectic alloys with various amount of phosphorus(less than 1ppm and 15ppm) was prepared by using high-purity aluminum and silicon. The generation mechanism of very-fine globular α-Al that occurs in a commercial alloy containing P was considered by using gravity casting and die casting.

First, as a result of static casting experiment without flow of molten metal, very fine globular Al phase was not crystallized, even though the melt was poured into the mold on eutectic temperature 577℃. As a next step, casting experiment accompanying dynamic flow using snake-like metal mold was performed. In case of using eutectic A1-Si alloy ~~to~~ which was added P under 1ppm, it was revealed that when injecting semi-solid slurry(SFR10%) being cooled near to eutectic temperature(Temperature of melt before shot: 578℃) in shot sleeve at gate speed over 200m/s, very fine globular Al phase was crystallized abundantly in the casting surface. However, very-fine globular α-Al phase was not occurred when gate speed was under 100m/s. In addition, in case of the Al-Si eutectic alloy with P 15ppm, very-fine globular α-Al phase was not occurred even shot molten metal at eutectic temperature into the mold with high gate speed(200m/s) without P flocculation as mentioned chapter 3. Therefore it is considered that injecting the molten metal into the mold at the eutectic temperature has two effects for generation of the very-fine globular Al phase. 1) In the alloys containing P, nucleus of α-Al is generated easily because eutectic Si is hardly generated by the flocculation of AlP which became a nucleus of the eutectic Si. 2) Many nuclei are easily generated and released from the mold by injecting the eutectic molten metal into the mold at gate speed over 200m/s.

In chapter 5, a result of semi-solid casting experiment by sleeve method using ADC12 alloy that is used over 90% as Al-Si alloy for die-casting was explained. ADC12 that is Al-Si alloy containing 9.6-12.0 wt% of Si is near to eutectic composition and as even semi-solid slurry was unable to be manufactured by conventional process, it was unable to be applied to semi-solid casting. Casting experiment was performed by changing injection speed and casting temperature based on SFR 15%, STL 10 seconds.

In chapter 6 is a conclusion of this thesis. We figure out the mechanism of microstructure transformation at Sleeve process and confirm the possibility of semi-solid die-casting for ADC12 alloy.

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