한국소성가공학회 2004년도 추계학술대회 논문집 pp.148~151

전자 교반과 결정립 미세화에 의한 반용융 A356 재료의 결정립 크기 비교

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A Comparison of the Grain Size of Semisolid A356 Aluminum Alloy Obtained by EMS Stirring and Grain Refinement

Z. Yang, P.K. Seo, J.H. Ko, Y.S. Jung and C.G. Kang

Abstract

Different kinds of feedstock of semisolid a356 aluminum alloy manufactured by EMS stirring only, inoculation of Al-5Ti-B only and combination of inoculation and EMS stirring were investigated. It is found that the grain size of these feedstock are 350μm for EMS casting only, 320μm for inoculation by Al-5Ti-B, and 100μm for the combination of EMS stirring and inoculation of Al-5Ti-B master alloys .The microstructure of the sample obtain by combination of inoculation and EMS system show the best homogeneousness and finest grains.

Key Words : Semisolid Metal Process, EMS Casting, Inoculation, A356 Aluminum Alloy.

1. Introduction

Semisolid metal process (SSP) is an excellent near net-shape forming process. After thirty years development, researchers have gotten a comprehensive knowledge about the SSP [1-3]. Generally the SSP has the advantages over the squeeze casting and the high-pressure die casting (HPDC) at low die erosion, less trapped gas and less oxide inclusion, short cyclic time. And the SSP has the advantages over the forging at the more complex shape of parts, low die stress, long die life, low energy consumption, and so on. SSP has already achieved commercial success in the automobile industry, computer and cellular phone industries, and aviation industry. [3] As the scale of the SSP industry expanded, the cost became so critical that it directly decides the future of the SSP. If the cost cannot compete with squeeze casting and HPDC, its advantages on quality will fade. Compared with the squeeze casting and the HPDC, the extra expense of the thixocasting or the rheocasting is used to prepare the feedstock. In the thixocasting process, the billet is prepared by EMS stirring casting, cutting and reheating. The two-step preparation is proved to be expensive. In the rheocasting, extremely high stirring is thought to be necessary. Tools consumption and energy consumption is a potential cost to the SSP. So it is important to find a cheaper way to prepare qualified semisolid slurry. In order to investigate the possible way to decrease the cost of preparation of semisolid slurry, semisolid slurries were prepared by

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EMS casting and the inoculation of Al-5Ti-B. And the microstructure was compared by the large-scale orientation determination [4].

2. Experiment

2.1 Alloy and EMS system

A356 is the widely used aluminum alloy for SSP. A standard commercial A356 aluminum alloy was used in this work. The solidus and liquidus of A356 are 823K and 890K, respectively. The volume percentage of the primary phase is about 56%. The master alloy is commercial Al-5Ti-B alloy with 5 wt% Ti and 1 wt% B.

(a)

(b)

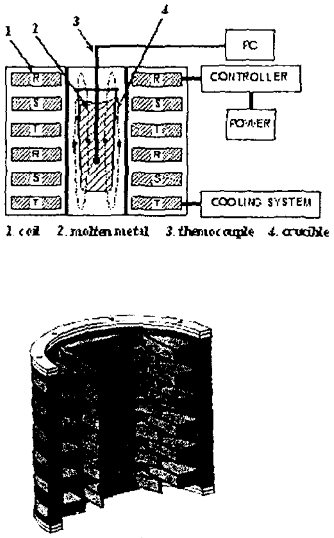

Fig. 1 Sketch of the EMS system, (a) draft of the system, (b) 3-dimension modeling of EMS system.

The EMS system, as shown in Fig. 1, was a three-phase twelve-pole electromagnetic stirrer, which created a vertical stir. The unloaded magnetic induction was linearly increased as the current of the stirring coils was elevated. This linear relation between current and magnetic induction can be explained by the equation of $B=\mu I/4\pi R$, where μ and R are the induction coefficient and the induction distance. They are constants here. When the current of the stirring coils reached 100A, the unloaded magnetic induction was about 0.1T.

2.2 Stirred cooling process

In the EMS casting without inoculation, the alloys were overheated to the primarily set temperatures. Then 2.4 kg melting A356 alloy were poured into a stainless steel (304) mould with an inner diameter of 80mm and a thickness of 3mm. Electromagnetic stirring was started immediately after pouring. The stirred cooling process could be separated to four steps: pouring, stirred cooling, ripening holding, quenching.

The a356 alloy inoculated by Al-5Ti-B was also investigated in this work. The aluminum alloy was overheated to 30oC above the primarily set temperature. Al-5Ti-B master alloy was put into the melting metal at the weight percentage of 0.1 wt.%.. N2 gas was then blown into the melting alloy to degas and refine the alloy. One group of samples was obtained without stir; the other group of samples was solidified under the EMS stirring for a period of time. Totally three solidification condition were investigated.

2.3 Microstructure

Samples of the size of 10x10x40mm were cut off from the billets along the horizontal section in the middle of the billets. In order to distinguish the size of disfigured dendrites, the samples were etched by 0.5ml HF in 100ml water for 20s, then etched with 35g $FeCl_3$ in 200ml water for 15s. At last the samples were cleaned by 50ml HNO_3 in 50ml water. The disfigured dendrites reflected different color under four lamps with the colors of red, yellow, blue and green. An Olympus stereomicroscope equipped with an camera was used to take photograph of the microstructure

3. Results

Fig. 2 shows the microstructure of the EMS casting without inoculation of Al-5Ti-B. It can be seen that the rheocasting structure is grain refined by stirring. The rheocasting structure is composed of small disfigured dendrites. The disfigured dendrites contain several globular branches. The grain size is about 350μm.

Fig. 3a shows the microstructure of the sample only inoculated by 0.1 wt.% Ti. The structure is composed of small dendrites. The morphology of the inoculated structure is a little different from the sample obtained by

EMS casting. The most remarkable feature is that the dendrite is very clear. It seems that the increase of Ti above 0.1 wt.% have little effect on grain size. The general grain size is about 360μm. Fig. 3b-d shows the microstructure of the sample inoculated by 0.1 wt.% Ti and then stirred by EMS system for 10 s to 60 s.

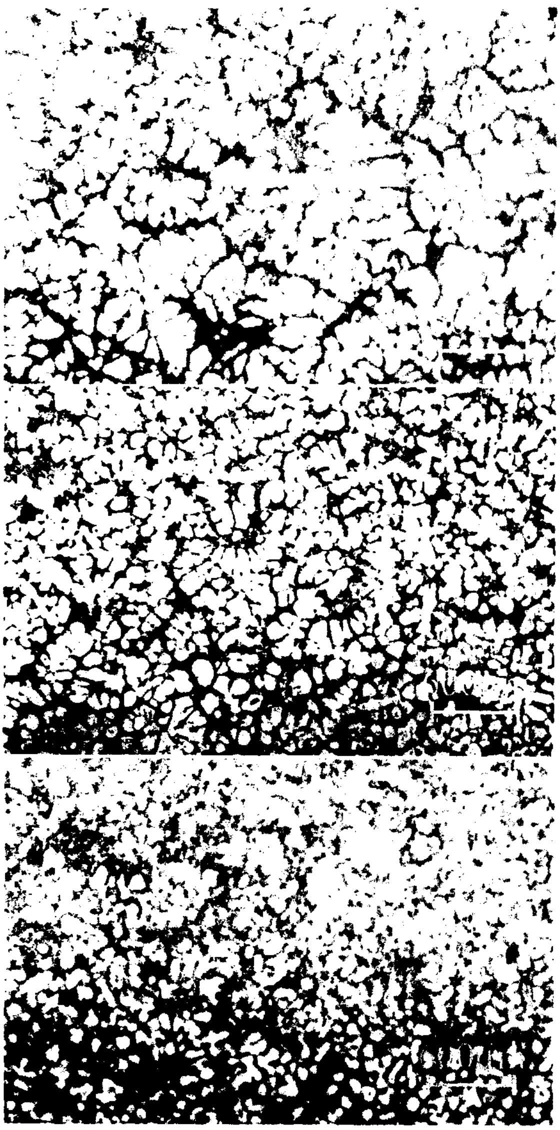

Fig. 2 Microstructure of the a356 rheocasting structure stirred under the vertical stirring of the magnetic induction of 0.1T for (a) 0 s, (b) 20 s, and (c) 60 s.

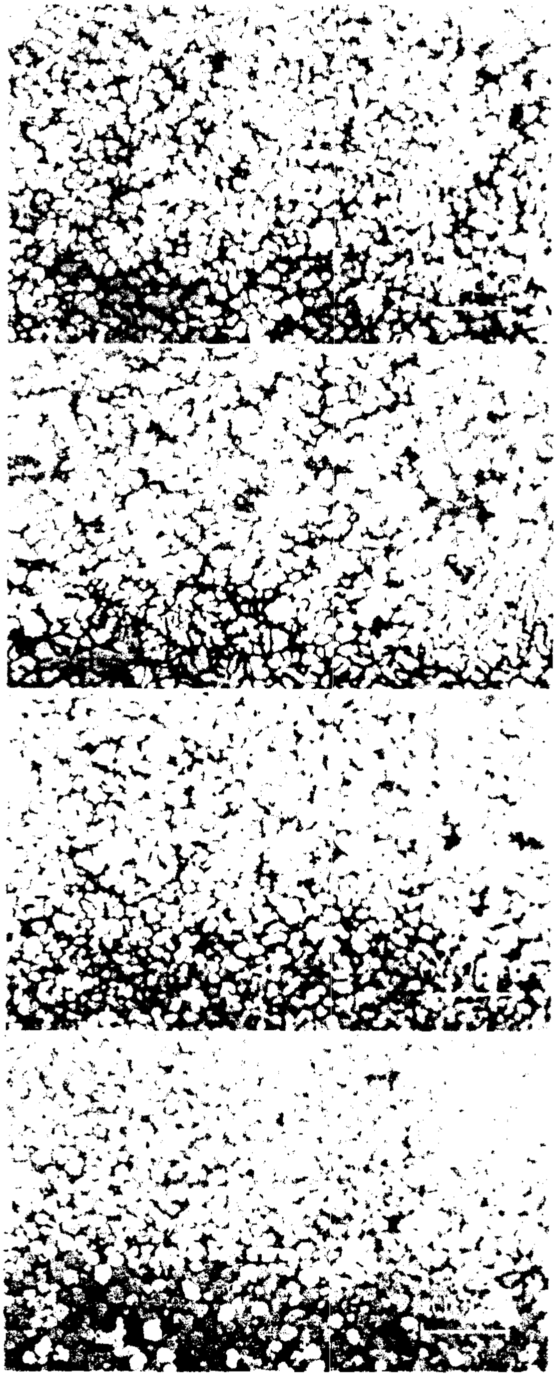

Fig. 3 Microstructure of the a356 rheocasting structure inoculated by Al-5Ti-B at the Ti wt.% of 0.1, and stirred under the vertical stirring of the magnetic induction of 0.1T for (a) 0 s, (b) 10 s, (c) 20 s and (c) 60 s.

It is interesting to find that the short time stirring increase the grain size.Long time stirring, on the contrary, decrease the grain size. The grain size of the alloy obtained by inoculation and EMS stirring is the finest one. The grain size is about 100μm.

4. Discussions

In the thixocasting process, the feedstock must experienced two steps before casting. Magnetohydrodynamic stirring and induction heating. Each step consumes large mount of energy. The cost of thixocasting is very high. In recent year, new rheocasting process includes Thixmolding system and Rheomoulding system are designed to save the reheating process. However equipment of mechanical stirring system is also very expensive. Meanwhile mechanical stirring is not suitable for preparing high temperature alloy.

Many efforts now have been made to investigate the possible of substituting the mechanical stirring by EMS system [5]. However, the inhomogeneous structure of EMS casting is the clearest drawback. It makes the quantity control very difficult. Inoculation is a very good way to solve this problem. It is found that the inoculation at low cooling rate without stirring can obtain the fine equiaxied microstructure. However, structure of the sample inoculated by Al-5Ti-B without stirring show that another kind of inhomogeneousness caused by temperature gradient occurs without stirring. The surface solidifies first and the center solidifies later. Without reheating, this kind of structure is not suitable for rheocasting. Consequently, inoculating combined with EMS stirring is tried. The results show that the microstructure obtained by inoculating and EMS stirring has a very good microstructure.

It is interesting to found that the alloy inoculated by Al-5Ti-B has an abnormal coarse structure when it was stirred for short time (about 10 s). Usually stirring before casting will increase the efficiency of master alloy [6], however the stirring before solidification in our experiment increased instead of decreased the grain size. The authors think that stirring made the distribution of Ti and B in the liquid aluminum more homogeneous, and the stirring may diminish the inhomogeneous nucleation process. Only when the temperature decreased to a much low point, the inhomogeneous nucleation began to work again.

5. Conclusions

(1) Feedstock of semisolid metal obtained by EMS stirring only, inoculation of Al-5Ti-B only and combination of inoculation and EMS stirring were investigated. It is found that the grain size of these feedstock are 350, 360, 100, respectively.
(2) The microstructure of the sample obtained by combination of inoculation and EMS system show the best homogeneousness.

Acknowledgements

The invaluable support of National Research Laboratory (NRL) Program of Thixo-Rheo Forming and the invaluable financial support of the Ministry of Science & Technology (MOST) are greatly appreciated.

References

(1) M.C. Flemings, 1991, "Behavior of Metal Alloys in the Semisolid State", Metall. Trans. A, Vol. 22, pp. 957~981.

(2) D.H. Kirkwood, 1994, "Semisolid Metal Process", Inter. Mater. Rev., Vol. 39, pp. 173~189.

(3) Z. Fan, 2002, "Semisolid Metal Processing", Inter. Meter. Rev., Vol.47, pp. 49~85.

(4) E.J. Zoqui, M.T. Shehta, M. Paes, V. Kao and E. Es-Sadiqi, 2002, "Morphologic Evolution of SSM A356 during Particle remelting", Mater. Sci. Eng. A, Vol. 325, pp. 38~69.

(5) Z. Yang, C.G. Kang and P.K. Seo, 2004, "Evolution of The Rheocasting Structure Determined by Large-Scale Orientation Determination", Scripta Materialia, submitted.

(6) B.S. Murty, S.A. Kori and M. Chakraborty, 2002, "Grain Refinement of Aluminum and Its Alloys by Heterogeneous Nucleation and Alloying", Inter. Meter. Rev., Vol. 47, pp.1~29.