

Study on rheo-diecasting process of 7075R alloys by SA-EMS melt homogenized treatment

G Zhihua^a, X Jun^b, Z Zhifeng^c, L Guojun^d and T Mengou^e

General Research Institute for Non-Ferrous Metals, Beijing, China

Email: ^agzhzsm@msn.com, ^bxujun@grinm.com, ^czhangzf@grinm.com, ^dliuguojunx@163.com, ^emenciustang@126.com

Abstract. An advanced melt processing technology, spiral annular electromagnetic stirring (SA-EMS) based on the annular electromagnetic stirring (A-EMS) process was developed for manufacturing Al-alloy components with high integrity. The SA-EMS process innovatively combines non-contact electromagnetic stirring and a spiral annular chamber with specially designed profiles to in situ make high quality melt slurry, and intensive forced shearing can be achieved under high shear rate and high intensity of turbulence inside the spiral annular chamber. In this paper, the solidification microstructure and hardness of 7075R alloy die-casting connecting rod conditioned by the SA-EMS melt processing technology were investigated. The results indicate that, the SA-EMS melt processing technology exhibited superior grain refinement and remarkable structure homogeneity. In addition, it can evidently enhance the mechanical performance and reduce the crack tendency.

1. Introduction

The current shape cast components usually contain a coarse and non-uniform microstructure and various casting defects, offering poor mechanical performance. A grand challenge is to develop solidification processing technologies which can ensure a fine and uniform as-cast microstructure free from cast defects, so that the cast products can be either directly used in the as cast state, or only require minimal thermo-mechanical processing [1]. Characterized by non-pollution, non-contact, low cost, precisely control and easy combination with industry, electromagnetic stirring (EMS), which is considered as a main melt conditioning method for gaining fine casting products, has been successfully applied in industry [2-5]. However, inhomogeneous microstructure still occurs in the casting products especially large-sized ones due to the skin effect resulting from electromagnetic induction. To solve the problem, an advanced metal melt conditioning process, namely, the annular electromagnetic stirring (A-EMS) was developed, and an intensively forced shearing could be achieved at a higher shear rate inside the annular chamber at the commercial frequency. The A-EMS process exhibits better grain refinement and microstructure homogeneity. Moreover because of the intrinsic characteristics of electromagnetic stirring, electromagnetic force in the melt showed the circumferential distribution. The circumferential flow was strong, but the axial flow and radial flow were weak. It was inevitable that temperature gradient and composition gradient distributed along the radial and axial directions [6-9]. To solve the problem, the spiral annular electromagnetic stirring (SA-EMS), an optimized A-EMS, was developed. Compared with A-EMS, the new electromagnetic stirring melt processing technology (SA-EMS) could not only avoid the skin effect efficiently, impose a high shear rate and a high intensity of turbulence to the liquid metal, but also could cause alloy melt flow to turbulent flow eventually, leading to temperature field and composition field of alloy melt in



the whole melt volume distribute uniformly by means of specially designed spiral profiles. In this paper, the solidification microstructure, mechanical properties and crack tendency of 7075R alloy die casting connecting rod conditioned by the SA-EMS melt processing technology were investigated.

2. Experiment

The nominal chemical composition of the experimental 7075R alloy is shown in table 1. The liquidus and solidus temperature measured by DSC of the test alloy are 641° C and 477° C.

Table 1. Nominal chemical composition of the test alloy (wt. %)

Element	Zn	Mg	Cu	Cr	Fe	Si	Ti	Mn	Al
Content	5.69	2.28	1.63	0.18	0.24	0.36	0.12	0.27	Bal

The experimental procedures were as followed: The 7075R alloy melt was prepared in a clay graphite crucible in an electric resistance furnace. The metal melt was held at 750°C for ~2 h to be homogenized. By using a graphite rod, the dross was removed from the surface of the melt, and the metal melt was stirred manually for purposes of composition uniformity. Predetermined melt was transferred to two small stainless steel crucibles which are preheated to 400°C for conducting experiments (see figure 1). One was directly poured into the die-casting chamber without electromagnetic stirring and the cooling core rod (N-EMS) when the melt was cooled to 650 °C. The other one was conditioned by the SA-EMS from 750°C to 650°C, then the melt was poured into the die-casting chamber. Stirring current was 30A and stirring frequency was 50HZ. The mould temperature was 350 °C. The injection speed was 2m/s. All of them were die-casting formation and cooled to the room temperature. The die-casting connecting rod was cut along the longitudinal section.

Microstructures observation and hardness analysis will be carried out at six different positions, as shown in figure 2. The samples were cut, ground and polished using a standard metallographic technique. The samples were anodized with Barker's reagent (4% HBF₄ in distilled water) and then viewed under polarized light using a Zeiss optical microscope. A Zeiss optical imaging system was utilized for the optical microscopy observations and the quantitative measurements of the microstructure information. HBE-3000A electronic Brinell hardness tester was carried out to test the hardness of the samples.

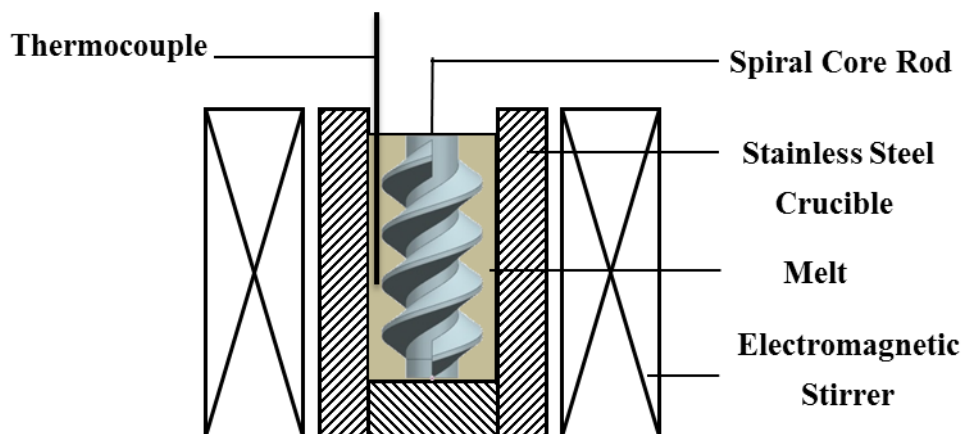


Figure 1. Schematic diagram of SA-EMS melt conditioning experimental device.

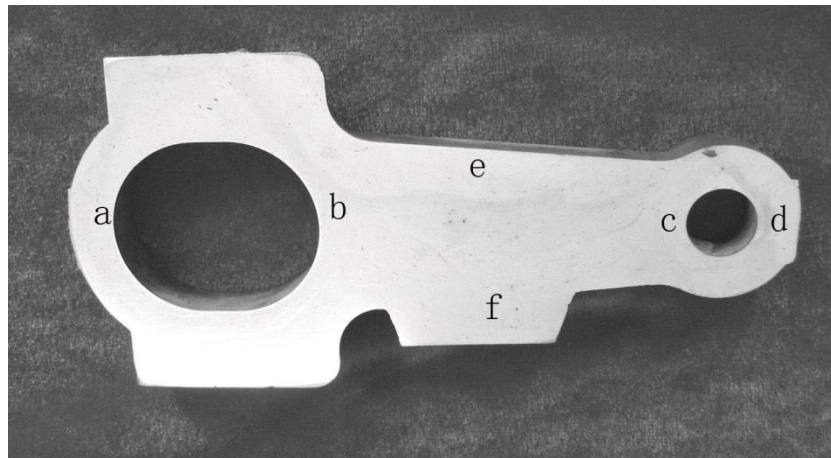


Figure 2. Rheo-diecasting connecting rod and sampling locations.

3. Results

Figure 3 shows the microstructures distribution of conventional die-casting part in six different positions. As can be seen, the size and morphology of microstructures in different positions is very non-uniform, and it is also very non-uniform in the same position, including coarse dendrite grains and small equiaxed grains. But for the SA-EMS rheological die-casting part, as shown in figure 4, the microstructures in different positions are very fine and uniform, and the microstructures are composed of fine equiaxed grains at the same position. Figure 5 shows the grain size and hardness distribution of the parts at different positions under the N-EMS and SA-EMS conditions. As can be seen, compared with common die-casting forming (N-EMS), under the condition of SA-EMS, the microstructures of rheo-diecasting part distributed uniformly fine and showed little difference in different position. Brinell hardness of rheo-diecasting parts increased significantly, and also showed little difference in different positions.

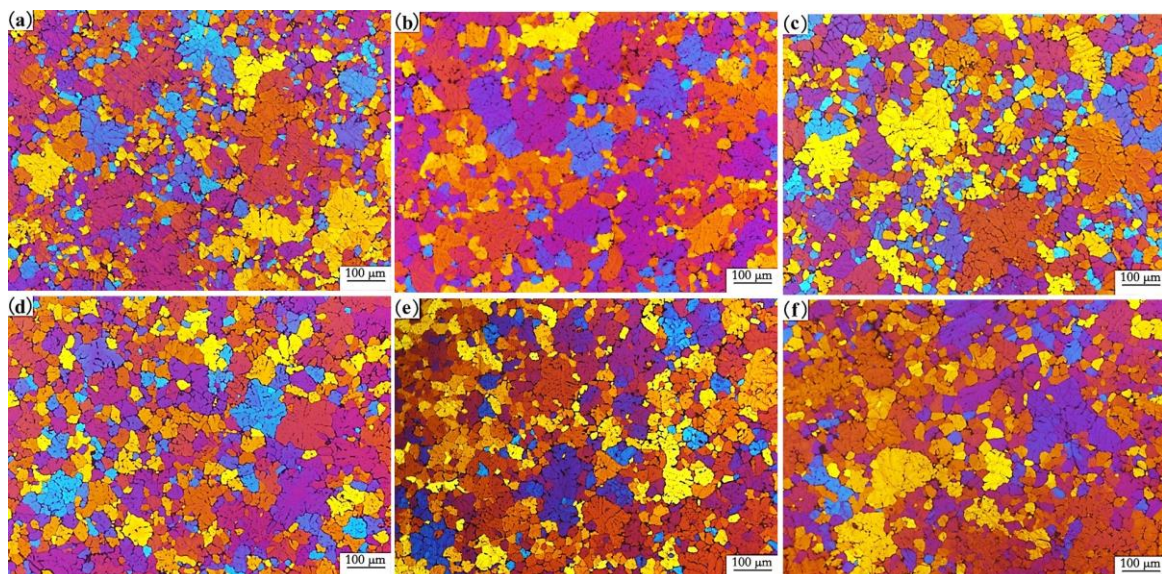


Figure 3. Microstructures of die-casting part (N-EMS) in six different positions.

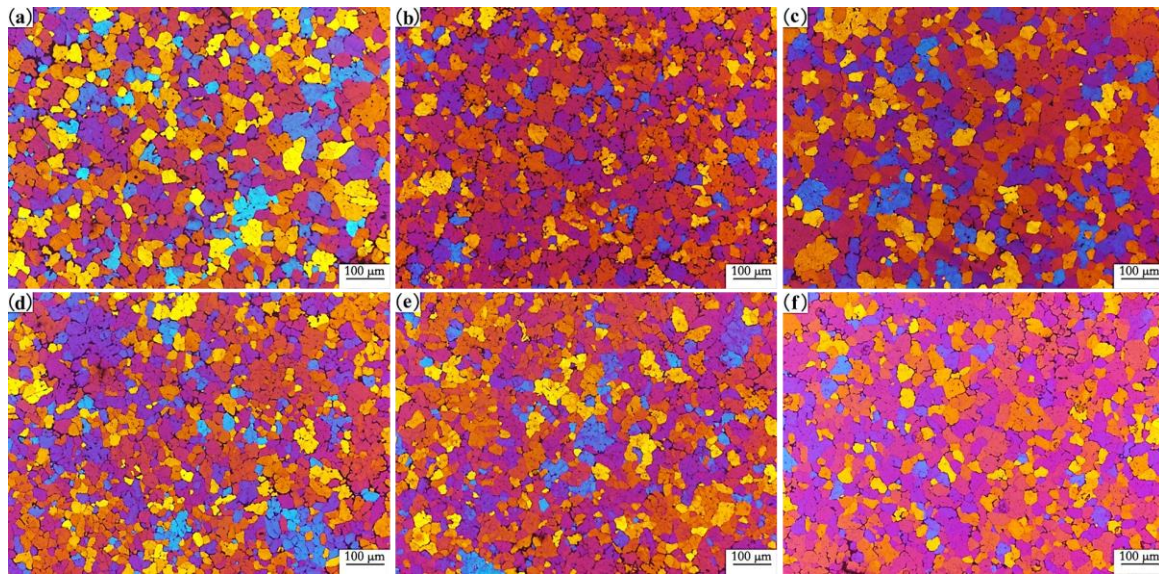


Figure 4. Microstructures of rheo-diecasting part (SA-EMS) in different positions.

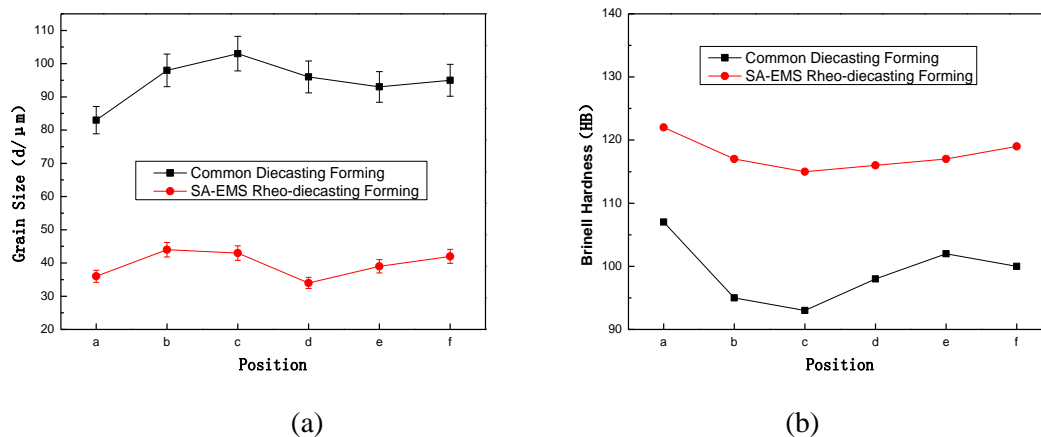


Figure 5. Distribution of grain size and hardness in different positions of die-casting parts under conditions of N-EMS and SA-EMS: (a) grain size, (b) hardness.

Figure 6 shows the crack tendency of die-casting parts under the N-EMS and SA-EMS conditions. On the basis of the above research, we can know that the thick-thin wall transition zone of connecting rod part is at the b and c positions, and the change of microstructures is very big, easily leading to cracking (seeing figure 6a). But for the SA-EMS rheological die-casting part, as can be seen from figure 6b, there are no obvious cracks in b and c positions, and the crack tendency significantly decreased. This is because the solidification microstructures of the connecting rod part after the SA-EMS processing become very fine and uniform and show little differences in different position, and the crack is not easy to produce.

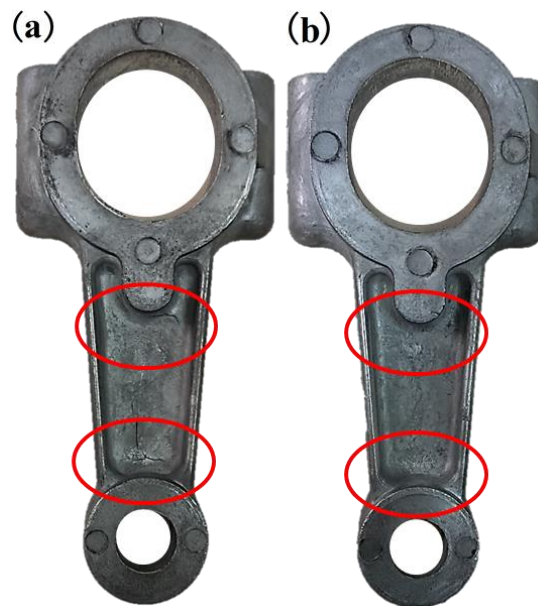


Figure 6. The crack tendency of die-casting parts under different melt treatment (a) N-EMS, (b) SA-EMS.

4. Discussion

For the N-EMS sample, according to the classical nucleation theory, nucleation behaviour is triggered by thermal undercooling through the mould wall. Once the superheated liquid metal is poured and in touch with the relatively cold mould surface, "Big Bang" nucleation takes place, and numerous nuclei are created. However, the majority of those nuclei are dissolved into the oncoming superheated liquid, and only a small proportion of nuclei in the vicinity of the mould surface can survive, resulting in columnar and coarse dendritic structures [10]. However, the fluid flow inside the SA-EMS unit is characterized by a high shear rate and high intensity turbulence where large interfacial area provides improved heat transfer and strong dispersive mixture. This intensive melt shearing ensures the temperature field, chemical composition field and tiny heterogeneous particles of the melt extremely uniformly distribute throughout the entire volume of the melt. Under such conditions, heterogeneous nucleation will take place throughout the whole volume of the liquid metal, and all the nuclei created will have a chance to survive and eventually contribute to the microstructural refinement. After nucleation, numerous nuclei will compete for growth by consuming the liquid around them. And the initial spherical growth will continue until the instability of the solid/liquid interface occurs [11, 12]. Due to the effective nucleation, solidification may have completed before reaching this instability. Therefore, the effective volume nucleation of the melt after intensive shearing usually results in fine and equiaxed grains throughout the entire casting.

5. Conclusions

The SA-EMS melt processing technology could avoid the skin effect efficiently, impose a high shear rate and a high intensity of turbulence to the liquid metal and increase the area of heat dissipation of unit volume melt by means of innovatively combining noncontact electromagnetic stirring and an spiral annular chamber with specially designed profiles, so that the conditioned liquid metal has uniform distribution of temperature field, chemical composition field and tiny heterogeneous particles. The SA-EMS process exhibits superior grain refinement and remarkable structure homogeneity. In addition, it can evidently enhance the mechanical performance and reduce the crack tendency.

Acknowledgements

This work was financially supported by the National Basic Research Program of China (973 Program) (No.2011CB606302) and International Science and Technology Cooperation Program of China (2013DFA51370).

References

- [1] Fan Z, Xia M, Zhang H, Liu G, et.al. 2009 Melt conditioning by advanced shear technology (MCAST) for refining solidification microstructures. *International Journal of Cast Metals Research*, **22**, 221(4): 103-107.
- [2] Kang C G, Bae J W, and Kim B M 2007 The grain size control of A356 aluminum alloy by horizontal electromagnetic stirring for rheology forging. *J. Mater. Process. Technol.*, 187-188: 344.
- [3] Zoqui E J, Paes M, and Es-Sadiqi E 2002 Macro-and microstructure analysis of SSM A356 produced by electromagnetic stirring. *J. Mater. Process. Technol.*, 120: 365.
- [4] Steinbach S and Ratke L The effect of rotating magnetic fields on the microstructure of directionally solidified Al-Si-Mg alloy. *Mater. Sci. Eng. A*, 2005, 413-414: 200.
- [5] Jia Q M, Zheng Y L, Chen J Y 2001 *Electromagnetics*. Beijing: Higher Education Press, 262. (in Chinese)
- [6] Xu J, Zhang Z F, Bai Y L, et al. 2008 A Device of Preparing Semi-Solid Alloy Slurry or Billet: China Patent, 2008101 16181. 9.. (in Chinese)
- [7] Bai Y L, Xu J, Zhang Z F, Shi L K 2009 Annulus electromagnetic stirring for preparing semisolid A357 aluminum alloy slurry. *Trans. Nonferrous Met. Soc. China.*, 19(5): 1104
- [8] Zhu G L, Xu J, Zhang Z F, Bai Y L 2009 Annular electromagnetic stirring--a new method for the production of semi-solid A357 aluminum alloy slurry. *Acta Metallurgica Sinica* (English Letters), 22(6): 408
- [9] Tang M O, Xu J, Zhang Z F, Bai Y L 2011 Effects of annulus gap on flow and temperature field in electromagnetic direct chill casting process. *Trans. Nonferrous Met. Soc. China.*, 21(5):1123
- [10] H T Li, M Xia, Ph Jarry, G M Scamans, and Z Fan 2011 Grain refinement in a AlZnMgCuTi alloy by intensive melt shearing: A multi-step nucleation mechanism. *Journal of Crystal Growth*, 214: 285-292.
- [11] Fan Z, Liu G, 2005 Hitchcock M Solidification behaviour under intensive forced convection. *Materials Science and Engineering: A*, 413-414:229-235.
- [12] Fan Z, Liu G, Hitchcock M, Das A 2007 Solidification behaviour under intensive forced convection. *Materials Processing Under the Influence of External Fields*, 201-212.