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Novel Grain Refining Process using Ti Clusters generated by Ultrasonic Cavitation

Jeong IL YOUN[1], Young Ki LEE[1], Young Jig KIM[1]*,
Jeong Wook PARK[2] and Woo Chun KIM[2]
[1] School of advanced materials science and engineering, Sungkyunkwan University,
2066 Seobu-ro, Jangan-gu, Suwon, Gyeonggi-do 16419, Korea.
[2] R&D Center, DR AXION Co., Ltd., 55 Sannam-gil, Ulju-gun, Ulsan 45010, Korea.

Grain refinement is the essential process to improve mechanical properties of castings. Nucleation enhanced ultrasonic melt treatment (NEUMT) proposed in this study increases refining efficiency through heterogeneous nucleation by the formation of proper intermetallic compounds in the complete melt. Ti clusters were supplied by the cavitation erosion on the surfaces of the sonotrode, and were simultaneously mixed uniformly into the melt. These particles act as potential nuclei and refine the structure.

Keywords: *Grain refinement, Cavitation, Ultrasound, A356 Al alloy, AZ31 Mg alloy.*

1. Introduction

Research to improve mechanical properties of Al alloys has been performed, and it is well accepted that grain refinement is a very effective method for improving structural uniformity, strength and ductility [1]. Especially, the removal of dissolved hydrogen from the Al alloys melt is also critical to the production of high quality casting [2]. The study to apply the ultrasound in casting process has been studied for the last a decade [3,4]. The application of ultrasound in casting process has been focused on not only the degassing but also the grain refinement, and especially the grain refinement has been mainly studied on the point of view the mechanism that the dispersion of the broken particles of dendrite resulting from the ultrasound injection during solidification or the state which is the coexistence of solid and liquid phase of metal [5]. However, this makes effectiveness low to adapt in industry, and in addition the degassing by ultrasound never performs well because the fluidity of melt extremely dropped. Based on this research back ground, we applied a new processing concept, *Nucleation Enhanced Ultrasonic Melt Treatment* (NEUMT), which is based on the novel paradigm of the sonotrode, to use ultrasound during normal Al casting processes. This paper discusses the effect of NEUMT on grain refinement of Al alloys, especially A356 and A390, and degassing of the alloys. The mechanism of the NEUMT based on the analysis of the chemical composition and the microstructure of the alloy were involved in this paper.

Element	A356	A390
Si	6.9	16.9
Cu	0.2	4.3
Mg	0.4	0.5
Mn	0.1	0.1
Fe	0.1	0.1
Al	Bal.	Bal.

Table 1 Chemical composition of A356 and A390 aluminum alloy. (mass%)

2. Experimental procedure

The experimental system for NEUMT which can generate and inject the ultrasound in metal melts. The frequency of the system is 20 kHz and the maximum power output is about 1900 W/cm^2. A356 and A390 Al alloys were selected as the material to be investigated in this study, and the chemical compositions are shown in Table 1. The about 500 g alloy ingot was melted at 700 °C for A356 and 750 °C for A390 alloy. After the ingot melting, Ultrasound was injected for 0~600 seconds, and the melt is poured into the steel mold. The sonotrode was rod shaped with a length of 360 mm and a diameter of 40 mm, and was made of commercial purity Ti.

3. Results and Discussion

Fig. 1 shows the the grain refinement mechanism of NEUMT. The process makes full use of cavitation effect to supply the nuclei in the Al alloys melt without a separate process for refiner feeding. The atoms and

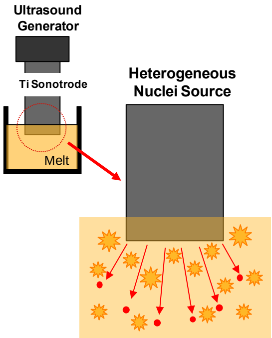

Fig. 1 Grain refinement mechanism of NEUMT process by Ti sonotrode.

clusters parted from the sonotrode by the cavitation erosion are uniformly distributed in the melt by acoustic streaming, and react with the melt and form proper intermetallic compounds that can act as heterogeneous nucleation sites. Fig. 2 shows the macrostructure of A356 alloy after NEUMT for 300 seconds and as-cast without NEUMT. The result shown in figure suggests that NUMT is very effective to obtain very fine grains of A356 alloy in a short time. The grain size of A356 and primary Si size was measured by the image analysis to characterize NEUMT effect as the size with time, and the results was represented at Fig. 3. The grain size of A356 without NEUMT was about 760 μm, however, the size decreased with increasing the process time and reached to about 100 μm. The size was maintained after the time in spite of increasing of NEUMT time. The effect of NEUMT on the refining was clear to the

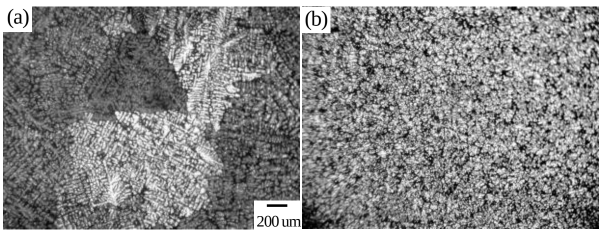

Fig. 2 Macrostructure of A356 alloy; (a) without NEUMT and (b) NEUMT for 300 seconds.

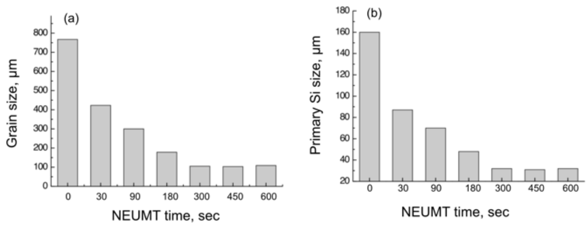

Fig. 3 (a) Grain size of A356 and (b) primary Si size of A390 alloy as NEUMT time.

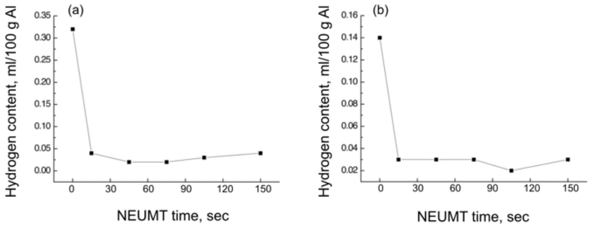

Fig. 4 Hydrogen content in melt with NUMT time: (a) A356 and (b) A390.

hypereutectic alloy, A390 as well. With NEUMT, the hydrogen contents decreased sharply with increasing process time in just few seconds and then reached a plateau hydrogen content, which corresponds to the steady-state hydrogen concentration. The results shown in Fig. 5 suggest that NUMT time for degassing of aluminum melt was extremely short. Degassing in the aluminum melt by NEUMT can be explained by the cavitation effect. Cavitations are made by the formation of tiny discontinuities or cavities in the melt, known as cavitation bubbles. In a melt containing dissolved gases, hydrogen atoms diffuse into the cavitation bubbles at the bubble/melt interface during the nucleation and growth stage of the cavitation bubbles where they form molecular hydrogen. The hydrogen molecules and/or bubbles float to the melt surface due to their buoyancy and are then removed.

4. Conclusion

The effect of NEUMT was normalized by the grain size and hydrogen content at various experimental conditions, and these data could be the guideline of the process. The grain size was decreased to a half by NEUMT for just dozens of seconds, and the more fine structure has shown with the more process time. When the initial hydrogen concentration was 0.32 ml and 0.15 ml at A356 and A390 without degassing, respectively, the hydrogen contents decreased dramatically to 0.02 ml/100 g Al with increasing NEUMT time in a few seconds.

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