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Effect of Solute Dispersion on Grain Refinement of Al Alloys by Ultrasound

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1. Introduction

The study to apply the ultrasound in casting process has been studied for the last a decade [1]. The application of ultrasound in casting process has been focused on the degassing and 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 [2]. However, this makes effectiveness low which is the most important basis 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 have studied to modify the process which can apply in normal casting process, and finally established the process by the new design of the sonotrode. The process named as NUMT (Nucleation Ultrasonic Melt Treatment) is that the ultrasound is injected into Al alloy melt with the special sonotrode. The most important phenomenon of ultrasound injection in liquid is the cavitation effect and the acoustic streaming, but these effects could not have been used in the previous study because of the restriction on the flow caused by the injection condition which only could be the state of the semisolid [3]. But, the ultrasound injection into full melt makes it possible to use these unique effects completely and then a lot of new ideas can be suggested as the new process. From this point of view, NUMT could be the most effective process because the process can do the melt treatment for grain refinement and degassing simultaneously from hypo-eutectic to hyper-eutectic Al-Si alloys without the concerns on the alloy composition by using the cavitation and acoustic streaming effect. This paper involves the effect of NUMT process on grain refinement and degassing of aluminum alloy the mechanism based on the analysis of chemical composition and the microstructure of the alloy.

2. Experimental procedure

Fig. 1 shows the experimental system for NUMT which can generate and inject the ultrasound in metal melt, for Al casting. The frequency of the system is 20 kHz and the maximum power output is 1900 W/cm^2. The system is consisted of three parts, ultrasound generator, sonotrode and cooler. The ultrasound generator is the piezoelectric device laminated three layer lead zirconate titanate (PZT) as the Bolt-Clamped Langevin Ultrasonic Trans -ducer Type (BLT). The experimental alloys are A356 and A390 aluminum alloy and the chemical compositions are shown in Table I. The about 500 g alloy ingot was melted by the electric resistance furnace with using a graphite crucible and the A356 alloy was melted at 700 °C and A390 was 750 °C, respectively. The frequency of the ultrasonic generator is 20 kHz at 25 °C and about 19 kHz at 700 °C, and the ultrasonic power up to 1900 W/cm^2.

Table Ⅰ. Chemical composition of A356 and A390 aluminum alloy (wt%)

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.

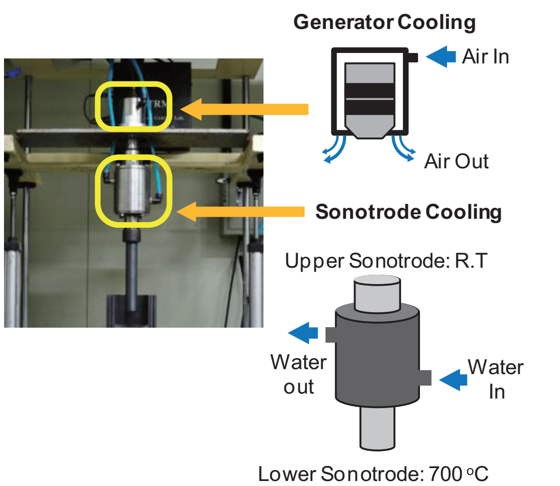

Fig. 1. Photograph of NUMT system

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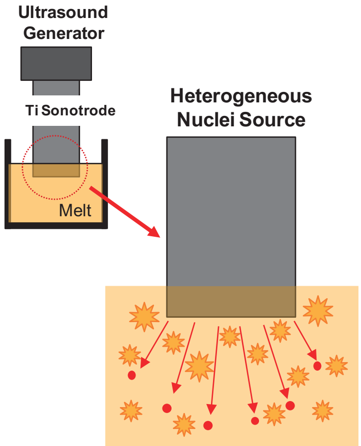

Fig. 2. Grain refinement mechanism of NUMT process by Ti sonotrode.

3. Results and discussions

Fig. 2 shows the mechanism of NUMT, especially, the grain refinement mechanism. NUMT process makes good use of the cavitation conversely to supply Ti substrates in the melt that can act as nucleation sites by the adaption of the sonotrode made of pure Ti for the grain refinement. Fig. 3 shows the macrostructure of A356 alloy after NUMT for 300 seconds and as-cast without NUMT. 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 NUMT effect as the size with time, and the results was represented at Fig. 4. The grain size of A356 without NUMT was about 760 µm, however, the size decreased with increasing NUMT time and reached to about 100 µm after NUMT for 300 seconds. The size was maintained after the time in spite of increasing of NUMT time. Fig. 4 (b) shows the primary Si size of A390 alloy with NUMT time. The result was similar with A356. The primary Si size of about 180 µm which was shown without NUMT became smaller with increasing NUMT time to about 30 µm by NUMT for 300 seconds too and kept the size. The mechanism of the grain refinement of A356 and A390 alloys by NUMT is based on the role of the Ti injected in melt by the process. Ti content in melt was analyzed by inductively coupled plasma mass spectrometry at each NUMT conditions of A356 and A390. Ti content increases with NUMT time from 0.08 wt% for 30 sec to 0.31 wt% for 600 sec of NUMT time linearly. The effect of Ti on grain refinement of A356 is very clear. The size of grains is decreased with NUMT time, but the size does not decreased more after NUMT for 300 seconds. With NUMT, the hydrogen contents decreased sharply

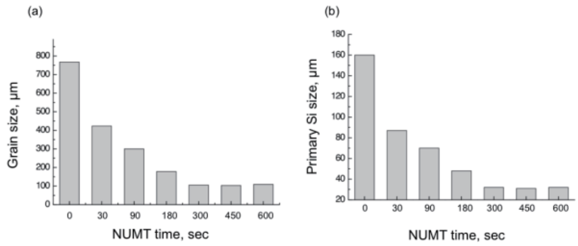

Fig. 3. (a) Grain size of A356 and (b) primary Si size of A390 alloy as NUMT time.

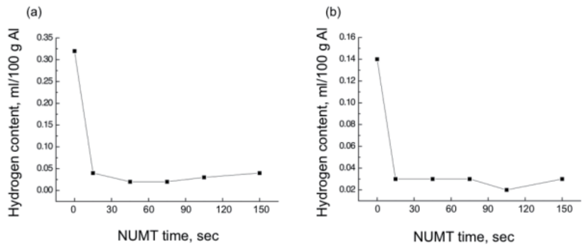

Fig. 4. Hydrogen content in melt with NUMT time: (a) A356 and (b) A390

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. It is supposed that the high effectiveness of NUMT degassing results from the pressure of the cavities produced in negative pressure.

4. Conclusion

The effect of NUMT 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 NUMT 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 NUMT time in a few seconds and then reached a plateau of hydrogen content.

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