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Primary Si Refining of A390 Al alloy by Using Sacrificial Sonotrode in High Intensity Ultrasound

Jeong IL Youn[1‡], Young Ki Lee[1], Young Jig Kim[1], Woo Chun Kim[2], and Jung Wook Park[2]
([1]School of Advanced Materials Science and Engineering, Sungkyunkwan Univ. Korea;
[2]R&D Center, DR AXION Co., Ltd., Korea)

1. Introduction

Hypereutectic Al-Si alloy, especially A390, has become a candidate material for the potential applications including aeronautical and automotive because of the interesting properties such as high wear resistance, low thermal expansion coefficient, good corrosion resistance and castabillity [1]. The high wear resistance arising from the hard primary Si particles comes at the price of extremely poor machine tool life. To minimize machining problems while exploiting outstanding wear resistance, the primary Si particles must be controlled to a uniform small size and uniform spatial distribution. The ways to minimize the size of silicon phases were studied, including modification, rapid cooling, electro magnetic stirring, and spray forming. Modification was normally used in commercial hypereutectic Al-Si alloys by adding phosporous compound, such as AlP and CuP, into melt. Howerever, the addition of the elements generates the unhealthy gas. The application of ultrasound for grain refinement Al and Mg alloys has been studied for the last a decade, and the mechanism of these processes has been explained as cavitation effect and acoustic streams in the melt. Especially, the effective grain refining condition was only obtained in special casting conditions, either during melt solidification or by holding the melt in a semisolid state, in order to fracture dendrite arms to form the various particles for nuclei. In this study, a new process, nucleation enhanced ultrasonic melt treatment (NEUMT) using sacrificial sonotrode in full melts not the semisolid state is suggested for refining of primary Si in A390. This process is based on the novel paradigm of the sonotrode eroded into the melt intentionally, and these particles act as the nuclei.

2. Experimental procedure

The chemical composition of A390 Al alloy is shown in Table I. The about 500 g alloy ingot was melted by the electric resistance furnace with using an graphite crucible and the A390 was melted at 750 °C. The furnace temperature for alloys melting was varied as the NEUMT time because the melt temperature increased with an increase ultrasound injection time by high intensity vibration energy. As the results, the pouring temperature could be controlled uniformly. 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 1.2 kW. The sonotrode made by Ti was used to inject the ultrasound into alloy melt. When the temperature of the aluminum melt was reached at the experimental condition, the sonotrode was immersed into the melt about 20 mm in depth. The sonotrode was heated for 10 minutes at just above the melt before dipping into melt, and also held in melt for 10 minutes to maintain the melt temperature before NEUMT. After cooling to the room temperature in air, the specimens were prepared to observe the macro and microstructure at each condition. The micro and macro structure of A390 was observed after etched by 0.1 % HF and Poulten's reagent (HCl 12 ml + HNO_3 6 ml + HF 1 ml + water 1 ml), respectively. The microstructure of A390 was mainly observed with a perspective on the variation of the size of the primary Si without the special chemical etching. The primary Si size of A390 was measured by the image analysis software, Image-Pro Plus (Media Cybernetics Inc., U.S.A), to characterize on microstructure.

3. Results and discussions

The effect of ultrasound on the microstructure in A390 alloy is very clear as shown in Fig. 1. The primary Si of the microstructure of A390 alloy without NEUMT was very coarse and non-uniform

Table I. Chemical composition of A390 Al alloy.

Elements	Content (wt%)
Si	16.9
Cu	4.3
Mg	0.5
Mn	0.1
Fe	0.1
Mg	Bal.

Younj1@skku.edu

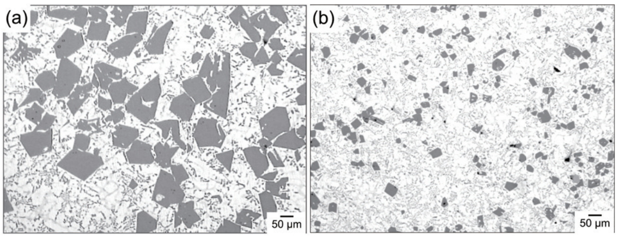

Fig. 1. Refining of primary Si of A390 (a) without and (b) with NEUMT

As shown in Fig. 1 (a). In addition, the primary Si was conglomerated in some area in Al alloy matrix. The average length of primary Si was about 150 μm. As compared with this microstructure, the primary Si of A390 alloy with NEUMT was very small and dispersed uniformly in Al alloy matrix without adding other chemical refiners as shown in Fig 1 (b). The effects of the NEUMT of the alloy melt on microstructure refinement of primary Si were increased with injection time. The apparent effect on the refinement of the primary Si was appeared to be injected for about 2 minute. The optimized injection time for refinement of primary Si was 5 minutes at these experimental conditions and the primary Si size was about 30 μm, and the size was similar after then time. The modification of eutectic Si phase in A390 can be established by Fig. 2. It is very obvious that the distribution of eutectic Si is changed to the very uniform with NEUTM as well.

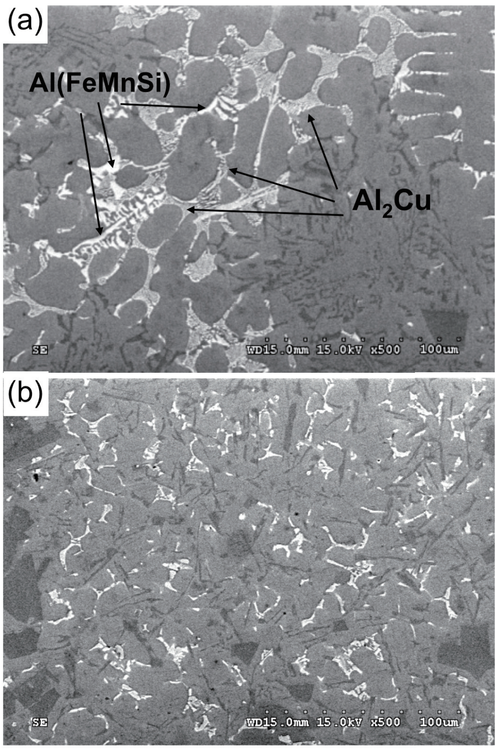

Fig. 2. Distribution of intermetallics of A390; (a) without and (b) with NEUMT

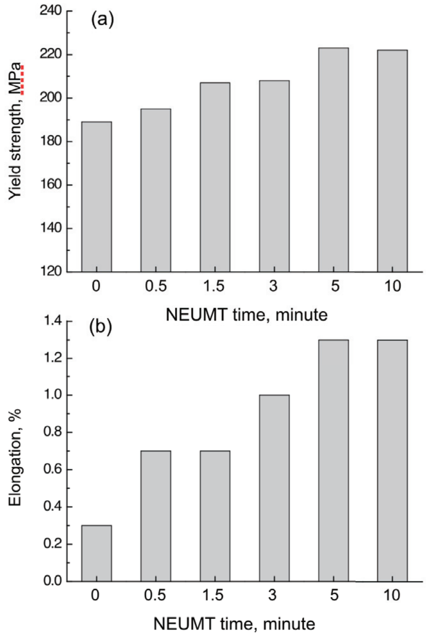

Fig. 3. Result of tensile test with increasing NEUMT time; (a) yield strength and (b) elongation

Fig. 2 also shows the distribution variation of intermetallic phases of A390, such as Al_2Cu, AlFeMn, with and without NEUMT. Intermetallic phases were formed as shape of dendrites, and the phases were linked each other like a net as shown in Fig. 2 (a). In contrary, Fig. 2 (b) clearly shows that these phases were uniformly distributed and effectively dispersed in aluminum matrix. It thought that uniformly dispersed intermetallic phases were enhanced the mechanical properties, especially elongation. The tensile strength was improved significantly with increasing NEUMT time, and especially elongation was dramatically promoted. the tensile strength was increased about 20 % than without NEUMT. It's thought that the improvement of these mechanical properties was mainly related to the distribution of the fine and uniform silicon, intermetallic phases, and the decrease of grains.

4. Conclusion

Primary Si size of about 180 μm of A390 Al alloy which was shown without NEUMT became smaller with increasing injection time to about 30 μm by the NEUMT for 5 minutes and kept the size. NEUMT makes also distribute the eutectic Si and intermetallics of the alloys in aluminum matrix very uniformly.

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