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Effect of Ultrasonic Frequency on Energy Efficient Range in Molten Aluminum Alloy

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1. Introduction

The ultrasonic technology is very attractive for refining light alloys such as the widely used Al and Mg alloys [1]. Increasing of ultrasonic intensity is very essential to acquire higher efficiency of melt treatment for treat more melts in same time [2]. But, the industrial application of the ultrasound, especially casting process, has been hindered by a fundamental concern, i.e., the lack of understanding and control of ultrasonic attenuation in an alloy melt. Attenuation factor is contribution parameter of the intensity that depends on medium, and determining the efficient range of the ultrasound. Similar to its propagation in water, when an ultrasonic wave travels through a liquid metal, its amplitude and intensity diminish or attenuate with distance. The consequences are that ultra sonication is confined to a limited volume of the liquid metal beyond which the intensity is insufficient to induce desired structural refinement. It is thus important to understand the attenuation process for the design of a performing ultrasonic system on a commercial scale. The first step is to be able to quantitatively characterize the ultrasonic attenuation behavior in a liquid metal. However, for A356 alloy, there is no research about ultrasonic attenuation, especially the effect of ultrasonic frequency on that. This study is focused on the evaluation of attenuation factor and efficient range of the ultrasound at different frequency to improve efficiency of ultrasonic melt treatment. The attenuation coefficient was calculated as the equation proposed in previous study, and the results are verified by the experiments Firstly, ultrasound with different frequencies were injected into Si oil with viscosity 350 cS to visualize attenuation and measure efficient range. Relationship between frequency and attenuation coefficient were derived from the experiments. The results were revised and confirmed through experiments on A356 with various ultrasonic frequency.

2. Experimental procedure

The attenuation coefficient of an ultrasonic wave in a liquid by the addition of a viscous component and a thermal component was calculated as the the Stokes–Kirchhoff relation [3] as shown in Eq (1),

$$\alpha = \alpha_v + \alpha_T = \frac{2\pi^2}{\rho c^3}\left[\frac{4}{3}\eta + \lambda_T\left(\frac{1}{c_v} - \frac{1}{c_p}\right)\right]f^2 \qquad (1)$$

and the definition of the parameters is summarized in Table I. Comparing the calculation results with the actual phenomena in the metal melts, Si oil of 350 cS for the visible modeling and A356 alloy for establishment of the energy efficient range were selected. To characterize and quantify the effect of ultrasonic frequency on the attenuation coefficient, the frequency was controlled as 15, 20, and 25 kHz.The sonotrode made by Ti was used for the experiments. To inject the ultrasound into alloy melt, 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 the ultrasound injection. The ultrasonic melt treatment was carried

Table I. Parameters for the calculation of the attenuation coefficient as Eq. (1).

Parameters	unit	Si oil	A356 Al alloy
ρ, *Liquid density*	g/m^3	968,000	2,420,000
c, *Speed of sound in the liquid*	m/s	986.2	4561
f, *Frequency*	kHz	15, 20, 25	15, 20, 25
η, *Viscosity*	g/ms	33.95	1.045
λ_T, *Thermal conductivity*	J/smK	0.16	84
c_v, *Specific heats at constant volume*	J/gK	1.46	1.16
c_p, *Specific heats at constant pressure*	J/gK	1.46	1.16

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Table II. Calculation results of the attenuation coefficient as Eq. (1) of Si and A356 Al alloy.

	Si oil		A356 Al alloy	
Fre-quency	α, (m^{-1})	*x, (m)*	α, (m^{-1})	*x, (m)*
15 kHz	2.16×10^{-4}	1604.5	2.69×10^{-8}	2.57×10^{7}
20 kHz	3.85×10^{-4}	900.2	4.78×10^{-8}	1.45×10^{7}
25 kHz	6.01×10^{-4}	576.6	7.47×10^{-8}	9.27×10^{6}

out for 3 minutes at each frequency. The specimens were prepared to observe the macro structure to establish the effective ultrasonic depth.

3. Results and discussion

In theory, the reduction in ultrasonic amplitude with propagation distance in a liquid medium may assume a variety of forms. In this experiments, the propagation distance was just limited as the distance which can be generated the cavitation bubbles, because the refining mechanism of the ultrasonic melt treatment was based on the phenomena at almost experiments. Table II shows the calculation results of the attenu- ation coefficient of Si and A356 Al alloy as the various parameters shown in Table I. The distance of the half level of the injected ultrasonic energy, *x*, in Si oil was calculated as 1600, 900, and 600 meter at 15, 20, and 25 kHz ultrasonic frequency, respectively. But, the actual distance of the effective range as shown in Fig. 1 was extremely short. The measured distance as marked in Fig. 1 was 43, 34, and 25 millimeters. At the A356 alloy, the difference more increased. The distance of the half level of the energy, *x*, was calculated as more than 900 kilometers. The refining range was just a few centimeters as shown in Fig. 2. The reasons of the difference between the calculation and the measurement are not clear, however, the equation which has been used to predict the effective energy range should be revised.

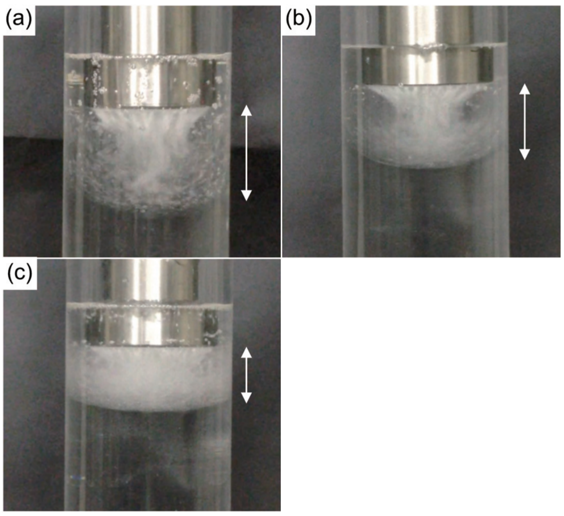

Fig. 1. Measurement of the efficient range of ultrasonic energy in Si oil of viscosity 350 cS; (a) ultrasonic treatment at 15 kHz, (b) 20 kHz, and (c) 25 kHz

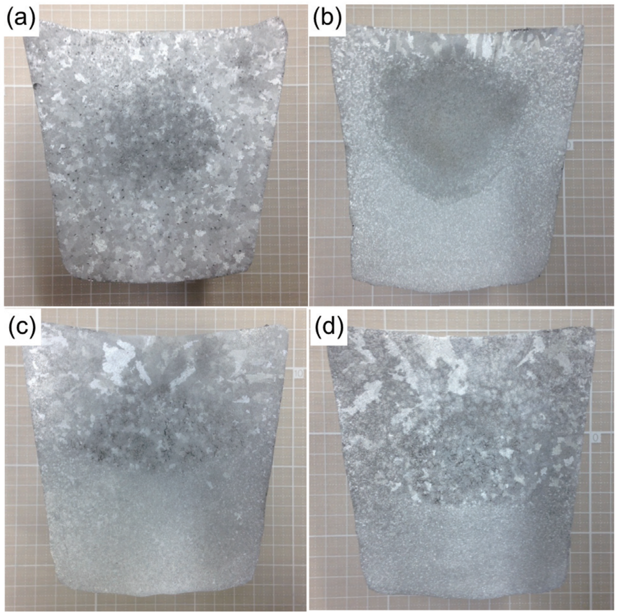

Fig. 2. Measurement of the efficient range of ultrasonic energy in A356 Al alloy; (a) cast without ultrasonic melt treatment, (b) with ultrasonic melt treatment at 15 kHz, (c) 20 kHz, and (d) 25 kHz

4. Conclusion

This study is focused on the calculation of the attenuation factor and efficient range of the ultrasound at different ultrasonic frequency. The attenuation coefficient was calculated as the various physical parameters, and the results are verified by the experiments. However, the difference of the both results shows the revision of the equation based on the experiments.

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