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Experiment and Modeling to Assess Ultrasonic Attenuation Factor in Molten Aluminum Alloy

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1. Introduction

It has been studied that high-intensity ultrasonic melt treatment offer a promising tool to improve the refining structure of metal, and therefore its mechanical properties. There are some papers which has shown that the introduction of the ultrasonic melt treatment of molten hypo- and hyper-eutectic Al-Si alloys can significantly refine their structure and improve their quality [1,2]. The propagation of the ultrasound is accompanied with loss of the ultrasonic energy. The amplitude and intensity of the ultrasonic wave decreases exponentially with the propagation distance, and the exponential factor is the loss coefficient or sound absorption or attenuation factor. Attenuation factor depends on medium, and determining the efficient range of the ultrasound [3]. 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 the ultrasonic treatment 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. In addition, the factor should be considered to simulate the process modeling through various numerical programs. 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 experiment and the modeling. 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 factor of an ultrasonic wave in a liquid by the addition of a viscous component and a thermal component was suggested as the the Stokes–Kirchhoff relation [4] as shown in Eq (1), and the parameters are summarized at Table I. Comparing the results of the theoretical calculation with the actual phenomena, firstly, Si oil of 350 cS was selected for the visible modeling, and the energy efficient range of A356 alloy could be established as the results. 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. The ANSYS Fluent module was used to simulate the ultrasonic melt treatment, especially, streaming and the efficient range in the melt. The inlet condition was fixed as the medium velocity. 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.

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

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}

3. Results and discussion

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 trapped in the high viscosity oil, 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 attenuation coefficient of Si and A356. 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 measured distance of

Table III. Experimental results of the attenuation coefficient of Si oil.

Intensity	1600 W		2000W	
Fre-quency	α, (m^{-1})	*x, (m)*	α, (m^{-1})	*x, (m)*
15 kHz	1207	34	998	43
20 kHz	1484	28	1291	34
25 kHz	2148	18	1627	25

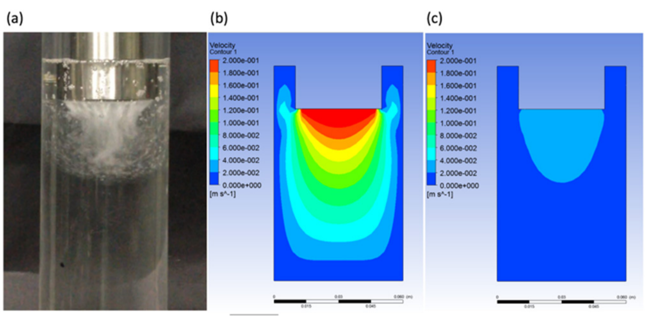

Fig. 1. (a) Experimental results, (b) the modeling of calculation attenuation factor and (c) after correction

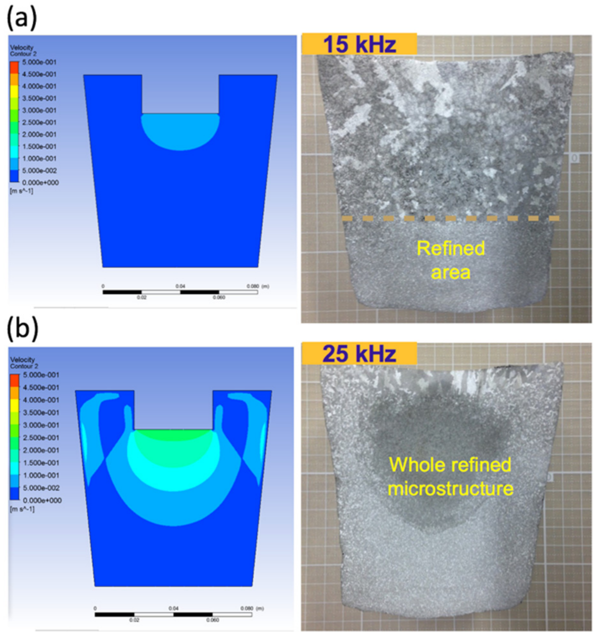

Fig. 2. Comparing of ANSYS simulation result by the revised attenuation factor with castings of A356; (a) 15 kHz and (b) 25 kHz.

the effective range was extremely short as shown in Table III. The reasons of the difference between the calculation and the measurement was supposed as the results from the threshold energy to expand the cavitation bubbles, however, the equation which has been used to predict the effective energy range should be revised. The attenuation factor was revised as the experimental results to apply as the modeling parameter. Figure 1 and 2 show the simulation modeling results and these figures indicate the acceptable result on the factor.

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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