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Modeling of effective energy range with the ultrasonic frequency and the amplitude

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1. Introduction

The application of ultrasound to casting process can improve the quality of the casting through the effects of grain refinement, degassing, wetting, deagglomeration and dispersion. [1] For treating large volume of liquid metal, CFD study has recently developed an analysis tool capable to model acoustic streaming and cavitation in liquid metal. In general the cavitation zone is a very small region in fluid, acoustic streaming is main factor for scale-up of ultrasound process because that is a non-linear physical effect which can assist in effective dispersion of cavitation bubble with propagation of the ultrasonic wave in liquid. But previous studies of CFD have limited theoretical model revision to accurately predict cavitation phenomenon. Acoustic streaming in liquids is generally governed by the ultrasonic intensity, and the ultrasonic intensity is determined by eq. (1).

$$I = \frac{1}{2}\rho c(2\pi f A)^2 \qquad (1)$$

where ρ is the density of propagation medium, c is the speed of ultrasound in the propagation medium, f is the ultrasonic frequency, and A is the ultrasonic amplitude. [2]

Therefore, this study is focused on the effect of ultrasonic frequency and amplitude on acoustic streaming. The acoustic streaming velocity in fluid was measured using Particle Image Velocimetry (PIV) and CFD modeling was performed to predict the acoustic streaming in fluid by ultrasonic injection.

2. Experimental Procedure

In an experimental environment, the opaque molten metal is not accessible with PIV technique for flow velocity measurement. Many liquid properties related to fluid flow are similar to water and aluminum. [3] Therefore, in this study, water was used instead of liquid metal. To predict the effect of fluid characteristics and ultrasonic injection conditions on the acoustic streaming, the fluid density was controlled as 1, 1.2, 1.6, 1.8 g/cm^3, the resonant frequency was controlled as 15, 20, and 25 kHz, and the amplitude was controlled as 20, 28,

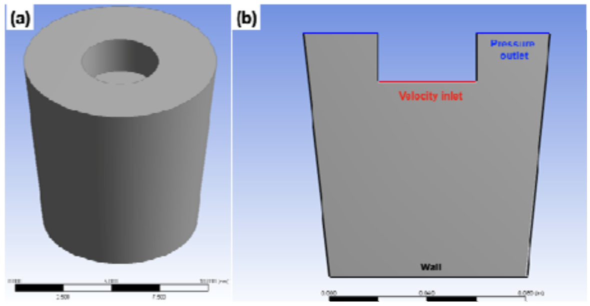

Fig. 1. (a) Schematic diagram of geometry, (b) Boundary conditions (z axial symmetric).

38, 48, 66 μm. CFD modeling was performed by ANSYS Fluent software to predict the acoustic streaming in the fluid. Fig. 1 shows the three-dimensional computational geometry and boundary conditions used in present study. The measured flow velocities were used as velocity inlet conditions for CFD modeling and the top of the vessel is specified with the pressure outlet (gauge pressure = 0 kPa).

3. Result and Discussion

Fig. 2 shows the acoustic streaming velocities directly under the sonotrode with fluid density at various ultrasonic amplitude. The acoustic streaming velocity is inversely proportional to fluid density, and which increases linearly with increasing amplitude at same fluid density. Slope But as shown in Fig. 3, the ultrasonic frequency did not significantly affect the flow velocities.

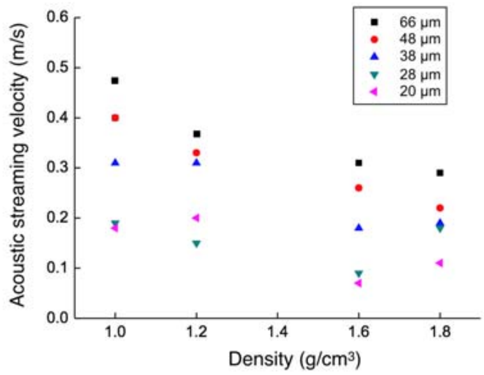

Fig. 2. Variation of acoustic streaming velocity with fluid density at various ultrasonic amplitudes

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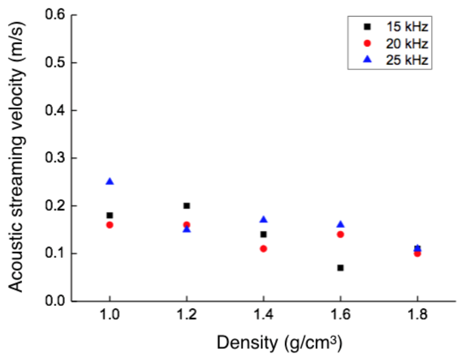

Fig. 3. Variation of acoustic streaming velocity with fluid density at various ultrasonic amplitudes

Fig. 4 shows the contour plots of velocity magnitude with ultrasonic injection conditions and fluid densities. As shown in Fig. 4, the flow velocities directly under the sonotrode increased linearly with 0.28, 0.30, and 0.35 m/s as the ultrasonic amplitude increases. But the ultrasonic frequency did not significantly affect the flow velocities. As the density of the fluid increased especially, the flow velocity decreased sharply at 0.35, 0.23, 0.17, and 0.13 m/s.

To predict the effective energy range of the fluid according to the ultrasonic injection time, Dense Discrete Particle Model (DDPM) simulation was performed. The content of particles added in the fluid was determined by result of erosion quantification experiment. Fig. 5 and 6 show the effective energy range of ultrasound according to the ultrasonic injection time. The effective energy range of the ultrasound increased rapidly with the increase of the ultrasonic amplitude, however the change of the effective energy range according to the ultrasonic frequency hardly occurred.

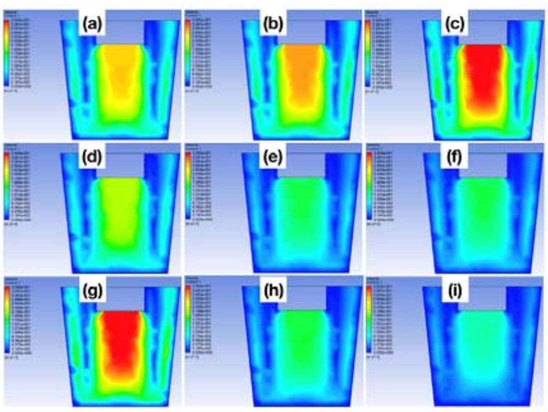

Fig. 4. Contour plots of velocity magnitude; (a) 15 kHz 38 µm, 1g/cm^3, (b) 15 kHz 48 µm, 1g/cm^3, (c) 15 kHz 66 µm, 1g/cm^3, (d) 15 kHz 20 µm, 1g/cm^3, (e) 20 kHz 20 µm, 1g/cm^3, (f) 25 kHz 20 µm, 1g/cm^3, (g) 15 kHz 66 µm, 1g/cm^3, (h) 15 kHz 66 µm, 1.8g/cm^3 and (i) 15 kHz 66 µm, 2.4g/cm^3

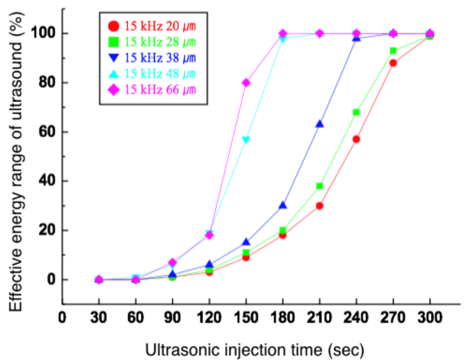

Fig. 5. Effective energy range of ultrasound with ultrasonic injection time at various ultrasonic amplitudes

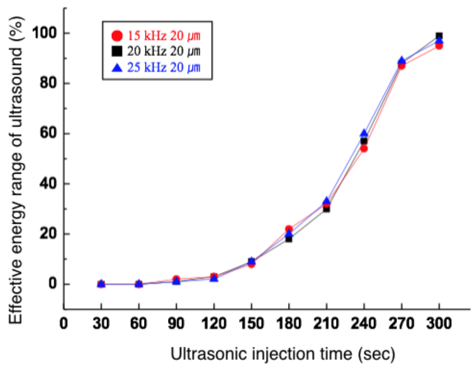

Fig. 6. Effective energy range of ultrasound with ultrasonic injection time at various ultrasonic frequency

4. Conclusion

The acoustic streaming velocities were quantified with variation of fluid density and ultrasonic amplitude and frequency. Based on the quantified results of acoustic streaming velocity, CFD modeling was performed to predict the acoustic streaming in the fluid. Through CFD modeling, we predicted the variation of the acoustic streaming velocity in the fluid and the variation of effective range according to the application time. Ultrasonic amplitude and density of fluid have a great effect on acoustic streaming, but ultrasound frequency has no effect.

References

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