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静電浮遊法を用いた二重液滴内のコア相とシェル相の振動特性の相関

Interaction between Core and Shell Phases Oscillation of Compound Droplet using Electrostatic Levitation

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1. Introduction

In the quality control of metals, understanding the interfacial phenomena and interfacial tension measurement are deeply rerated, therefore very important.

In the interfacial tension measurement of liquid metals, since the sample is high temperature, problems regarding to a container is appeared. In order to solve these problems, containerless processing is being researched, and interfacial tension measurement of molten iron covered by oxide is performed using ELF (Electrostatic Levitation Furnace) in ISS1). In this experiment, interfacial tension is obtained by applying the results of surface oscillation of compound droplet, which called core - shell droplet which mimics the molten iron - slag interface, to the theoretical equation derived by Saffren et al2).

The results show that there are differences in the estimated interfacial tension obtained by this method depending on the viscosity and radius ratio. However, the cause of the difference in the estimated value is not clear yet. Therefore, the objectives of present study is to clarify the cause of this difference from pressure distribution by numerical simulation, the oscillation behavior of core - shell droplet.

2. Numerical simulation

In this study, since the focus is on oscillation of free oscillation of core - shell droplet, the effects of external forces are not considered, and oscillation due to only interfacial tension is considered. Under this assumption, using VOF (Volume of Fluid) method by analyzing the shell surface and a core - shell interface of core - shell droplet, governing equations are following,

$$\nabla \cdot \boldsymbol{U} = 0 \tag{2}$$

$$\rho\left(\frac{\partial \boldsymbol{U}}{\partial t} + \boldsymbol{U} \cdot \nabla \boldsymbol{U}\right) = -\nabla P + \mu \nabla^2 \boldsymbol{U} + \boldsymbol{F}_\sigma \tag{3}$$

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (\alpha \boldsymbol{U}) = 0 \tag{4}$$

where $\boldsymbol{U}$ is velocity vector, ρ is density, t is time, P is pressure, α is volume fraction of each phase called the VOF function, and $\boldsymbol{F}_\sigma$ is the force due to interfacial tension or surface tension from the previous assumption. In the VOF method, the CSF (Continuum Surface Force) model, which uses surface tension and interfacial tension as volume force, is generally used, and they are considered as forces expressed in eq (5).

$$\boldsymbol{F}_\sigma = \sigma\kappa\nabla\alpha \tag{5}$$

where σ is interfacial or surface tension, κ is curvature.

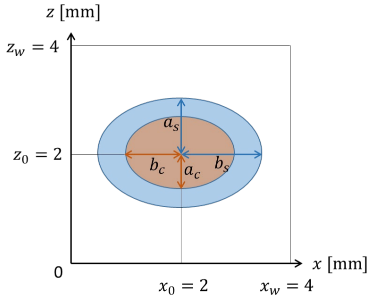


Fig.1 A concentric three fluid system

Under the above governing equations, the oscillation simulation of the droplet is simulated as shown in **Fig.1**. The boundary conditions for this system are

$$u = 0\,, \frac{\partial w}{\partial x} = 0\,, \frac{\partial \alpha}{\partial x} = 0 \quad \left(x = x_w \cdot x = 0\right) \tag{6}$$

$$\frac{\partial u}{\partial z} = 0\,, w = 0\,, \frac{\partial \alpha}{\partial z} = 0 \quad \left(z = z_w \cdot z = 0\right) \tag{7}$$

where u and w are the x and z direction components of the velocity vector $\boldsymbol{U}$. The initial condition is specified as an ellipse with centers x_0 and y_0, and the length of major and miner diameters as a_c and b_c for the core phase, and a_s and b_s for the shell phase. In addition, the radius ratio is defined as the ratio of the diameters on the major and minor axes ($a_S/a_C = b_S/b_C$).

Using the above governing equation and boundary conditions, OpenFOAM, a fluid analysis software based on the finite volume method, was used. Among them, multiphaseInterFoam, which is a solver to analyze multiphase flows in more than three phases using the VOF method, was used. The physical properties used in this study are shown in **Table1**, where interfacial tension is estimated from antonov's law[3)] as shown in eq (8). In this study, these properties were set from the viewpoint of focusing on the effect of the radius ratio and to stabilize the calculation.

$$\sigma_{12} = |\sigma_1 - \sigma_2| \tag{8}$$

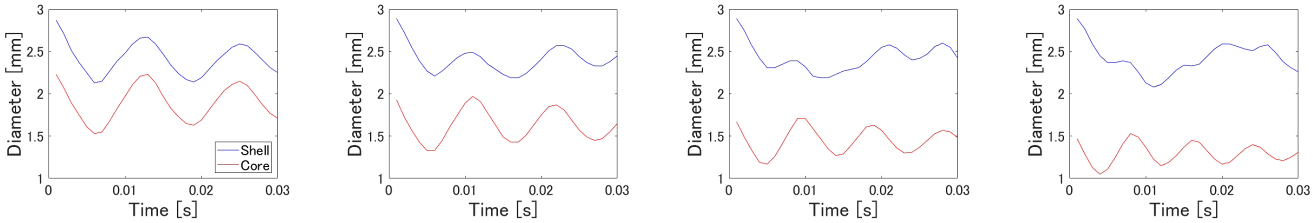
Table1 physical properties of core and shell liquids

	Core liquid	Shell liquid
Surface tension [mN/m]	70.0	20.0
Interfacial tension [mN/m]	50.0[3)]	
Density [kg/m^3]	1000	1000
Viscosity [mPa · s]	1.0	1.0

3. Results and discussion

3.1 Oscillation behavior

Through simulations, oscillation of core - shell droplets were obtained. In this simulation, the length of diameter at a point of $x = x_0$was obtained and plotted over time as shown in **Fig 2**.



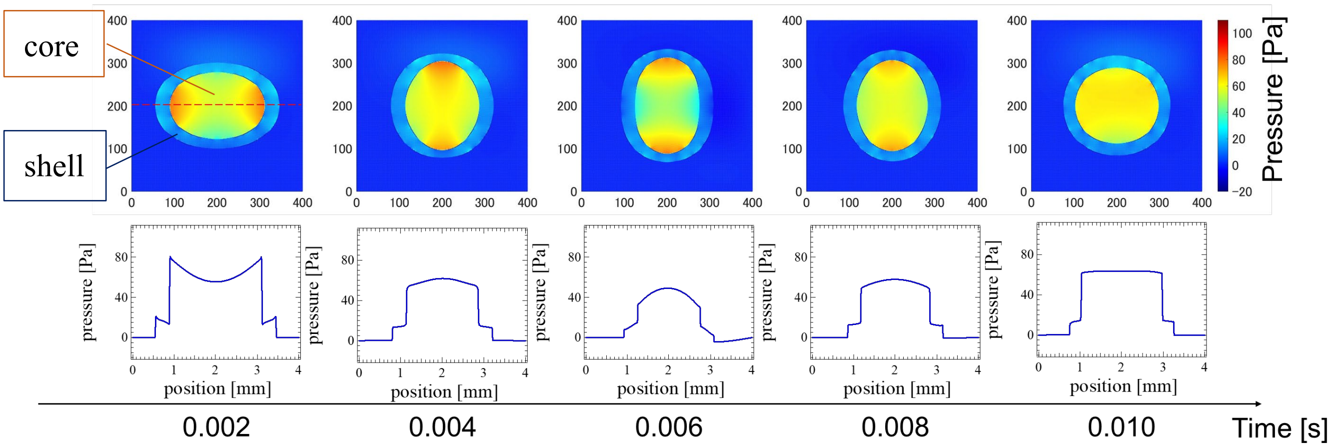
(a) radius ratio is 1.3 (b) radius ratio is 1.5 (c) radius ratio is 1.7 (d) radius ratio is 1.9

Fig 2 Oscillation behavior about each radius ratio

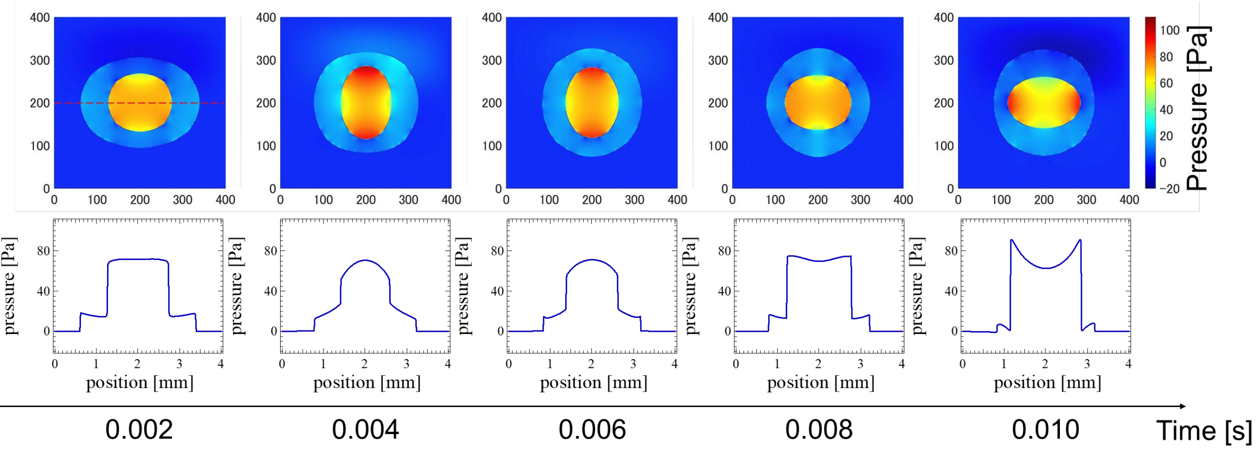
The oscillation phase difference between the core and shell is observed when radius ratio is high. This result suggests that the core oscillation have a significant affect to the surface oscillations when the radius ratio is small, while the shell oscillation is expected to dominate when the radius ratio is large.

3.2 Pressure distribution

In the oscillation behavior of core - shell droplet, the effect of pressure from the core on the oscillation of the shell surface was considered. To consider this effect, the pressure distribution at $z = z_0$, which is the pressure distribution at the equatorial plane of the droplet, is obtained as a time series. These results are shown in **Fig 3**.



(a) radius ratio is 1.3



(b) radius ratio is 1.7

Fig 3 Time series pressure distribution

From these results, it can be seen that the upward and downward convex shapes are repeated. This shows that the shape of the droplet is repeated. In addition, it can be seen that the pressure of atmosphere, shell and core phases have a stair shape. This suggests that pressure is separated at the phase boundary and interfacial tension is acting at each interface.

When the radius ratio is small, the pressure distribution is similar at the core - shell interface and the shell surface, but when the radius ratio is large, a case in which the pressure distribution is not similar between the core - shell interface and the shell surface, such as when the pressure at the core - shell interface is smaller than the pressure in the core, but the pressure at the shell surface is higher than the pressure in the shell phase, has been confirmed. It is found that when the shell surface is within the distance of the pressure influence from the core - shell interface, it affects the shell surface oscillation.

4. Conclusion

We confirmed that the oscillation phase of core and shell are different when the radius ratio is large. Differences of the pressure distribution were also observed with the differences of oscillation phase. The reason for these differences is that the effect of the core - shell interface oscillation on the shell surface oscillation changes with the radius ratio.

References

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