Supplemental Material S1: Similarity Principle

When the experimental model is similar to the actual model, meaningful data can be obtained from the experimental model. The condition for similarity is that the corresponding points in the two models comply with geometric similarity, kinematic similarity and dynamic similarity. Then the experimental model can be used to simulate the actual model.

In this paper, water can be used to simulate the aluminum alloy melt[1]. The detailed analysis is as follows.

1. Geometric Similarity

The condition of the geometric similarity is that the ratio of the dimensions between the experimental model and the actual model is equal everywhere. The smelting furnace is a 265mm diameter of the cylindrical crucible, so the transparent cylindrical container with a diameter of 260mm is used as the furnace model, which ensures that the geometric dimensions of water and melt are similar.

2. Motion similarity

Motion similarity is that the velocity ratio of a mass point in the experimental model and the actual model is constant. At this time, the velocities of the two mass points meet the following requirements: the direction is the same, and the ratio is constant. The kinematic viscosities of alloy aluminum melt at 725 ℃ and water at room temperature are $5.1 \times 10^{-7}m^2/s$ and $1 \times 10^{-6}m^2/s$ respectively [2], which are approximately equal. Then the velocity ratio of the particles in the two models can be kept the same, which conforms to motion similarity.

3. Dynamic similarity

Dynamic similarity means that the corresponding points in the two models are subject to the same direction of the force that is proportional to the size. The force between fluid flows is mainly viscous force. According to the Reynolds Criterion, the ratio of force between the fluids can be converted into the ratio of the Reynolds numbers between the particles of the fluids. The Reynolds number in water simulation and melt can be expressed as $\mathrm{Re}_1 = \frac{\rho_1 \bullet v_1 \bullet l_1}{\eta_1}$ and $\mathrm{Re}_2 = \frac{\rho_2 \bullet v_2 \bullet l_2}{\eta_2}$ respectively. Then, the ratio of the Reynolds numbers is

$$k = \frac{\mathrm{Re}_1}{\mathrm{Re}_2} = \frac{\rho_1}{\rho_2} \bullet \frac{v_1}{v_2} \bullet \frac{l_1}{l_2} \bullet \frac{\eta_2}{\eta_1} = \frac{\rho_1}{\rho_2} \bullet a \bullet b \bullet \frac{\eta_2}{\eta_1} .$$

where ρ_1 is the density of water, v_1 is the velocity of a mass point in the water, l_1 is the diameter of a transparent container, η_1 is the dynamic viscosity of water, ρ_2 is the density of aluminum melt, v_2 is the velocity of a mass point at aluminum melt, l_2 is the smelting furnace and η_2 is the dynamic viscosity of the aluminum melt.

According to the above analysis, *a* and *b* in the formula are constant. Therefore, k is also a constant. Tzanakis et al. [3] proposed water and aluminum share the closest flow properties as their close Reynolds numbers. The dynamic similarity of water and melt are similar. The parameters of the two fluids are shown in Table 1.

In summary, water at 20 ℃ and aluminum alloy melt at 725 ℃ comply with the similarity law of geometric similarity, motion similarity and dynamic similarity. Therefore, water can be used to simulate aluminum melt at superheat for verification experiments.

Table S1. Two kinds of fluid parameters [3]

Solution	Density (kg/m^3)	Dynamic viscosity (Pa· S)	Kinematic viscosity(m^2/s)
20℃ water	1.0×10^{3}	1.02×10^{-3}	1×10^{-6}
725℃ Aluminum	2.357×10^{3}	1.196×10^{-3}	5.1×10^{-7}

References

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