Experimental investigation of shape control criteria for wire fabrication of alloys by the dewetting micro-pulling-down method

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Background:

The micro-pulling-down method in a system with low wettability with the melt (dewetting μ-PD method) enables rapid growth of metallic crystals (~several hundred mm/min). The grown crystals show a single-crystal or unidirectional solidification structure, which allows deformation of brittle high melting point alloys that fracture at grain boundaries, as well as improved oxidation resistance and reduced recrystallization degradation, and are expected to be used in thermocouples and resistive heating wires [1-3]. On the other hand, in a system with low wettability, the melt does not spontaneously pass through the die and the meniscus cannot be directly observed because of the solidification interface existing inside the die, thus optimization of crystal growth conditions is more difficult than in the conventional μ-PD method where the meniscus is exposed. Therefore, it has been necessary to establish a guideline to improve the shape controllability of crystals in order to use this method as an alternative to the conventional plastic forming method.

To address this issue, the authors used the Young-Laplace equation to obtain the necessary conditions for the angle for shape stabilization by determining the relationships among crystal diameter, bond number, dimensionless pressure ΔP at the capillary, and contact angle for the meniscus shape that can be achieved in the die. Through the series of analyses, it was found that the diameter predicted from the static contact angle is less than 70% of the diameter actually obtained by crystal growth, suggesting the existence of a shape stabilization process due to the action of the dynamic contact angle. On the other hand, it is difficult to observe and predict the dynamic contact angle and its velocity dependence, especially for high-temperature melts. Therefore, in this study, we attempted to estimate the state of the meniscus inside the die from the wire diameter obtained under certain crystal growth conditions and its variation, and to explain the cause of the variation.

Results & Discussion:

First, we estimated the growth angle α_{gr} for Ir and Ru using a tetra-arc furnace. Second, the change in diameter of Ir was observed by the μ-PD method using a zirconia crucible under low pressure conditions ($\Delta P < 1$). In the conventional μ-PD method, the crystal diameter typically decreases with increasing growth rate, whereas the crystal diameter tends to increase with increasing growth rate. This suggested that the crystal diameter asymptotically approaches the die hole diameter as $\theta_{adv} + \alpha_{gr} \rightarrow \pi$ due to the velocity dependence of the dynamic contact angle θ_{adv}. In addition, from crystal growth under high-pressure conditions ($\Delta P > -2\cos\theta$), we found that the crystal diameter decreased with decreasing the pressure, and that the striations on the wire surface were caused by oscillations in the solidification vector. We also report on the effects of addition of other alloying elements.

References

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