DENDRITE GROWTH WITH ARBITRARY SYMMETRY IN TWO DIMENSION CASE

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The growth of a free dendrite having a non-axisymmetric morphology with arbitrary symmetry in a pure substance is considered with the interfacial effect of anisotropy and in the absence of convective flow. Theoretical predictions are compared with simulations provided by a phase-field model.

The present work addresses the problem of the theoretical analysis of dendrites having a non-axisymmetric morphology with arbitrary symmetry [1], and its comparison with simulation. This choice is motivated by the recent development of a phase-field model (PFM) for ice dendrite growth in supersaturated atmosphere [2, 3], which is adapted to the thermal growth of ice dendrite in undercooled water in this work.

$$\Delta T=\Delta T_T (P_g)+(4d_0 T_q)/\rho(P_g) +(2D_T P_g)/(\mu_k \rho(P_g)). \qquad (1)$$

Equation (1) represents the supercooling balance which solution determines the product of the main crystal growth parameters V and ρ as a function of the undercooling ΔT, but does not give the information about the dependences ρ(ΔT) and V(ΔT) in a separate form. For this reason, we need to use a second equation providing a criterion of stable dendrite growth, by means of the solvability theory [4]. In this case, we come to a generalized selection criterion for the sharp interface model (ShIM) in the form:

$$\sigma^*= (\sigma_0 \alpha_d^{7/n} A_n^{7/n}) / [1+a_1 \alpha_d^{2/n} A_n^{2/n} P_g (1+(\delta_0 D_T \beta_0)/d_0)]^2 \qquad (2)$$

This combination is the composed function of V and ρ, anisotropy of surface energy and other physical parameters characterizing the growth of dendrites [1]. We also analyze the dendrite growth mode that is controlled by the kinetic contribution which in turn is proportional to β_0 (see eq. (3.16) in [1]).

Figure 1 shows the comparison of the analytical calculations of V and ρ with the symmetry n=6 and PFM simulations of the tip velocity V and curvature diameter ρ, as a function of the undercooling ΔT. Analytical and numerical results are in good agreement for V and ρ simultaneously. This is particularly noteworthy, considering that the values of V and ρ are connected in the analytical model through Eqs. (1) (undercooling balance) and (2) (selection criterion), whereas a priori, these are independent in the PFM. In more details, a disparity between analytical and numerical results can be seen for the lowest and highest undercoolings prospected by PFM. First, for high undercoolings ($\Delta T > 60$ K), PFM simulations overestimate V compared to analytical calculations. This might stem from the PFM model that is valid for low undercoolings where kinetics effects are small, but lead to incorrect tip velocities at higher undercoolings where kinetics effects cannot be neglected. Second, PFM calculations of ρ become wrong at low undercoolings (ΔT < 32 K). This stems from the break down of the tip fitting by a parabola to estimate ρ from the simulated dendrite at such ΔT.

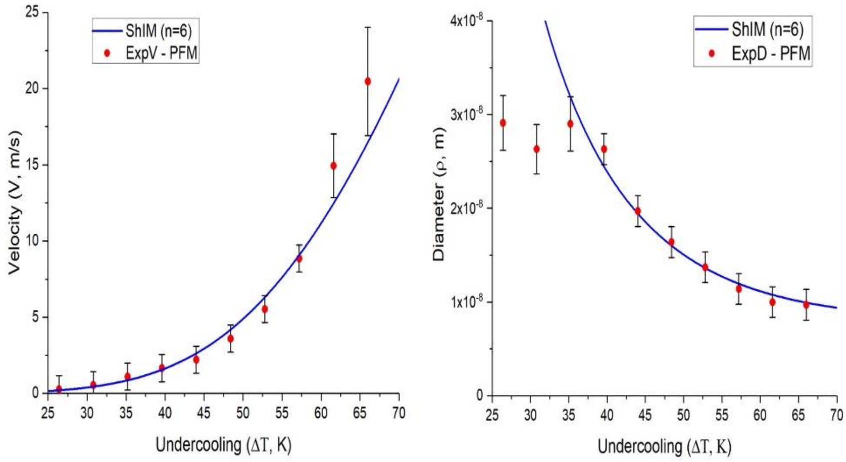

Fig. 1. Comparison between the present analytical calculations (ShIM) and PFM simulations of the tip velocity V and curvature diameter ρ, as a function of the undercooling ΔT for the 6-fold symmetry (n=6).

Overall, by comparing the present theoretical model to PFM simulations, we show in this work that the growth of dendrites having a non-axisymmetric morphology with the 6- fold symmetry is satisfyingly described by the sharp interface model (ShIM) introduced in this study.

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