Effect of Natural Convection on Dendrite-Bubble Interaction

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Abstract: The interaction between solidifying dendrite and rising bubble is investigated by adopting a multiphase-field lattice Boltzmann method. The bubble changes the dendrite skeleton by hindering the solid growth, including entrapped in the dendrite root, tilting growth towards the neighboring bubble, forming the knot structure, and growing along the radial direction of the bubble. The bubble in the columnar dendrite array with random orientation distribution has larger effects on the average primary dendrite arm spacing. A phase diagram is proposed to distinguish different interaction regimes. The size of the closed liquid phase region is further measured to evaluate the porosities tendency and guide how to reduce the porosities.

Keywords: Solidification; Bubble; Magnesium; Phase-field simulation

Introduction

Prediction and control of gas porosity defect during solidification is challenging but has attracted increasing interest for decades. The gas porosity deteriorates material properties by reducing loading area, causing stress concentration, and increasing fracture sensibility [1, 2].

Based on the employed multiphase-field lattice-Boltzmann approach, the objective of this work is to discuss the multiphase competitive growth under convection.

Experimental procedure

The multiphase-field model introduces three order parameters with the sum of one to denote the solid, liquid, and gas phases [3]. The Mg-6wt.%Gd alloy with sixfold symmetry pattern is simulated. The nucleation process of both dendrite and bubble is ignored. A circle seed is planted at the top side and the dendrite solidifies directionally from top to bottom. A circular bubble is released at the lower part.

Result and discussion

Figure 1 shows the typical multiphase simulation result and the solute concentration distribution along the direction indicated by the horizontal arrow in Figure 1a at different times. The dendrite presents semi-sixfold pattern and the bubble rises to the interdendritic root. Local concentration extreme is observed at the solid-liquid interface due to solute repartition. The solute concentration at the top closed region reaches local extreme, because the bubble impedes solute transport towards elsewhere.

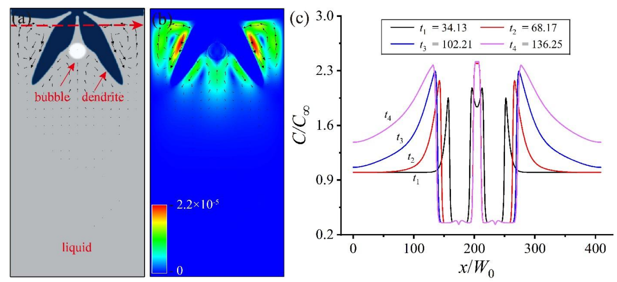

Figure 1. Typical multiphase simulation result. (a)-(b) Multiphase-field and flow field. The arrows denote the flow velocity vectors. Solute concentration distribution along the direction indicated by the horizontal arrow in Fig. 1(a) at different times.

Figure 2 shows the multiphase contours under different combinations of the growth orientation and the undercooling. When the flow intensity is fixed, the larger the undercooling, the more complex the dendrite morphology and also the larger the distance between the bubble-dendrite striking position and the seed center. The developed dendrite arms entrap the bubble in the solid skeleton. Different interaction behaviors, including the tilting growth towards the neighboring bubble, the formation of the knot structure, and the radial growth along the bubble boundary, can be observed as the growth orientation increases.

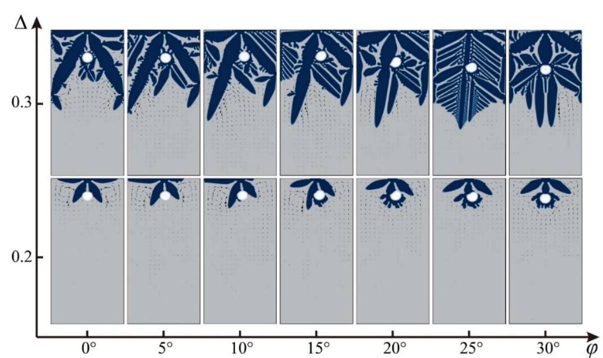

Figure 2. Multiphase contours under different growth orientations and different undercoolings. The flow intensity g/g0 = 1. The undercoolings Δ = 0.2 and 0.3, and the growth orientations φ change from 0° to 30° with the interval of 5°. The arrows denote the flow velocity vectors.

The relative position between the bubble and the dendrite seed center along the *x* axis affects the multiphase interaction by changing the striking position. The change of the relative position is similar to the change of the growth orientation, i.e., changing the contact point between the rising bubble and the dendrite.

Figure 3 shows the change of primary dendrite arm spacing (PDAS). Both the change of the dendrite orientations and the change of the bubble position can cause different PDAS, further illustrating the important influence of the striking position on the interaction between the growing dendrite and the rising bubble.

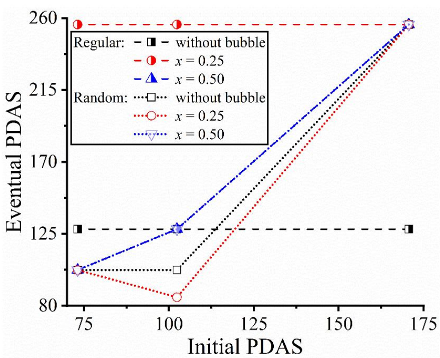

Figure 3. Change of the average primary dendrite arm spacing (PDAS) under different settings.

Figure 4 shows the dendrite-bubble interaction cases. The increase of Δ, g/g_0, and φ results in increasing the number of the primary dendrite arms, including forming the knot structure and growing along the radial direction. By providing a summary of different interaction results identified, the phase diagram shown in Figure 4 can be depicted to distinguish different cases.

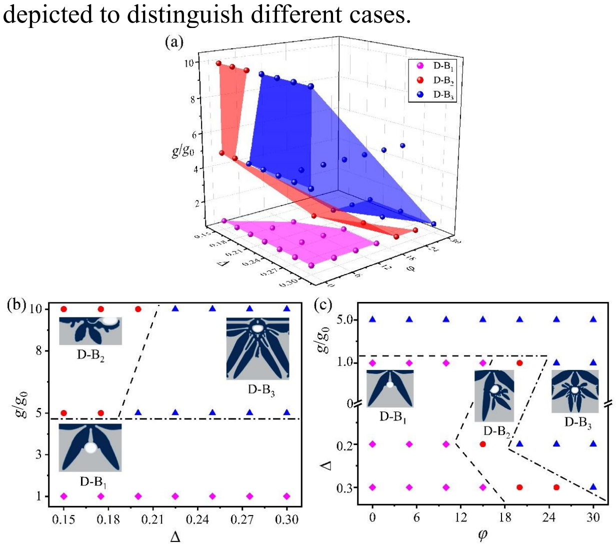

Figure 4. Phase diagram of the dendrite-bubble interaction regimes. (a) 3D diagram; (b)-(c) 2D projection.

Conclusion

(1) The bubble rises to the interdendritic region and deforms to adapt the arm surface as well as changes the solid skeleton. As the dendrite grows, the bubble is entrapped in the dendrite skeleton.

(2) The growth orientation affects the multiphase interaction by changing the striking position between the bubble and the dendrite, which is similar to that caused by the change of the relative position between the bubble and the dendrite.

(3) A phase diagram is proposed to distinguish different interaction regimes based on the summary of different interaction results identified.

Acknowledgments

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