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Real Time Observation of Dendritic Solidification in Real Alloys by Synchrotron Microradiography

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Introduction

The opacity of metallic materials has left mysteries unsolved in alloy solidification. The growing solid phase in the liquid – dendrites cannot be seen in real time by conventional methods. Here we present progress in real time microradiography of dendritic solidification in Sn-Bi and Al-Cu alloys by using synchrotron radiation at national facilities (CHESS and APS). Dendrite morphology and evolution can be well resolved both in time and space. The observations provide unambiguous understanding towards alloy solidification.

Methods and Materials

When X-rays pass through a solidifying alloy sample, image contrast is produced mainly from the composition difference between the solid and the liquid. The solute partitioning during alloy solidification produces the image contrast that is necessary to distinguish the solid from the liquid in microradiography. [1-2] In this work, dendritic solidification in Sn-13wt%Bi and Al-25wt%Cu alloys were observed in real time.

Fig. 1 shows schematically the experimental setup on the bending magnet line of sector 33-(UNICAT) of APS at ANL. The setup was composed of a solidification furnace and an advanced X-ray imaging system. After the X-rays pass through a solidifying sample, the shadow image of the dendrites is recorded by the detector and the camera.

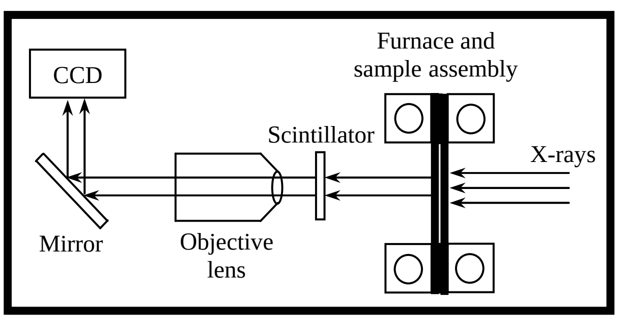

Fig. 1. Schematic of experimental setup at the APS.

Results

Real time observations of dendrite growth under various thermal conditions were carried out at CHESS and APS. Fig. 2 shows directionally growing dendrites in Sn-13%Bi alloy, where a moment of dendrite fragmentation was captured. In Fig. 3, the sample was held at a constant temperature in two-phase region, dendrite coarsening by coalescence can be seen. Local solidification occurred to the liquid grooves between dendrite arms. Fig. 4 shows growing dendrites in Al-25%Cu alloy. Interestingly the dendrites floated to the top of the sample as soon as they were formed in the liquid, indicating the solid is less dense than the liquid.

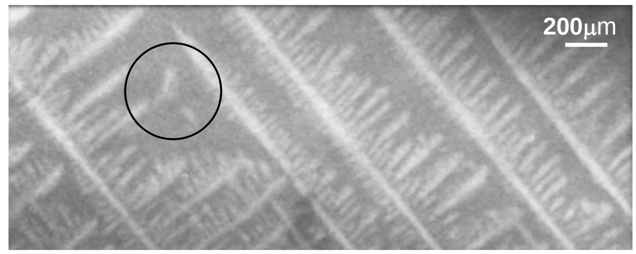

Fig. 2. Dendrite fragmentation during directional solidification

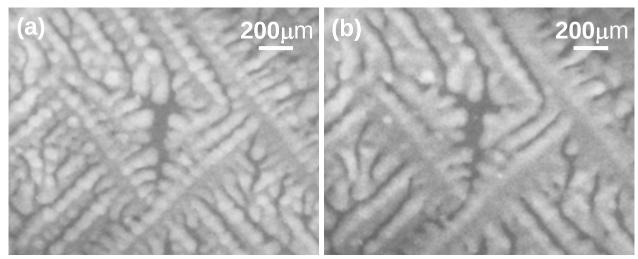

Fig. 3. Dendrite coalescence in Sn-13%Bi alloy

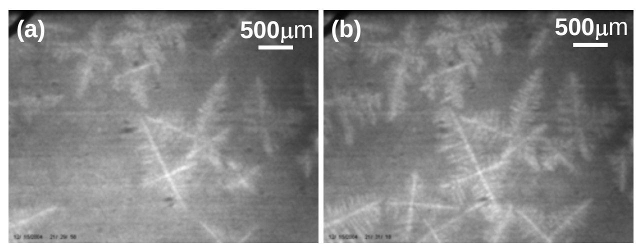

Fig. 4. Growth of equiaxed grains in Al-25%Cu alloy

Discussion

The real time synchrotron microradiography well resolved dendrite morphology during alloy solidification. An important feature of dendritic solidification is dendrite coarsening. The dendrite arm spacing (DAS) increases versus solidification time. The DAS has a strong effect on the mechanical properties of alloy castings. Coarsening mechanisms include dendrite remelting, coalescence and fragmentation. The driving force behind the coarsening is the Gibbs-Thomson effect. As we can see, these mechanisms were observed and kinetics of coarsening can be quantitatively measured from the images. The technique developed in this research has many potential applications in the study of alloy solidification. The third generation synchrotron source at APS provides the possibility of observing dendrite growth in 3-D in real time in real alloys. (Movies can be found at http://www.engr.uconn.edu/~binli)

[1] B. Li, H. D. Brody, A. Kazimirov, Phys. Rev. E. 70, 062602 (2004).
[2] B. Li, H. D. Brody, A. Kazimirov, Met. Trans. A. 37A, 1039 (2006).