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Dendritic solidification and fragmentation in undercooled Ni–Zr alloys

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Abstract

Kinetics of dendritic solidification and fragmentation of dendritic crystals in undercooled Ni–Zr samples are studied. Using the capacitance proximity sensor technique and a high-speed-camera system, the dendrite growth velocity has been measured as a function of initial undercooling in solidifying droplets processed by the electromagnetic levitation technique. Analyses of solidified droplets give evidence to a transition from coarse grained dendrites to grain refined dendrites (CG-GR) at small undercooling, a transition from grain refined dendrites to coarse grained dendrites (GR-CG) at moderate undercooling, and to a second transition from coarse grained dendrites to grain refined dendrites (CG-GR) at a higher undercooling. Predictions of a sharp-interface model are compared with the results of experiments on Ni–Zr samples.

Keywords: Dendrite; Solidification; Diffusion; Undercooling; Alloy; Model

1. Introduction

Solidification of undercooled Ni–Zr alloys has been investigated recently [1,2] at small concentrations of Zr. Dendritic growth velocities V have been measured in Ref. [1] as a function of undercooling ΔT in levitated droplets of $Ni_{99}Zr_1$ (numbers indicate at.%) alloys using electromagnetic levitation technique (see overview [3]). The results have been described within the LKT/BCT model of dendrite growth [4,5]. With increase of the undercooling, solute trapping becomes important in rapid solidification which leads to deviation from local chemical equilibrium at the solid–liquid interface. In the LKT/BCT model of dendrite growth [4,5], this phenomenon is introduced by the solute partitioning function $k(V)$ which adopts interfacial diffusion speed V_{DI} as a kinetic parameter of solidification [6]. The diffusion speed V_{DI} has been independently determined by pulsed laser experiments [1] on thin specimens for the $Ni_{99}Zr_1$ alloy. Together with preliminary used parameters of Ni–Zr alloys, the measured results for V_{DI} encouraged the prospects of a parameter-free test of the LKT/BCT model. In addition, the dendritic structure of solidified droplets from $Ni_{99.5}Zr_{0.5}$ and $Ni_{99}Zr_1$ alloys has been evaluated [2] to find morphological transitions in dendritic pattern. The results of metallographic analysis were compared with the predictions of Karma's model [7,8] of grain refinement *via* dendritic fragmentation.

Further progress on experimental measurements and theoretical description of dendritic growth and fragmentation in Ni–Zr alloys is presented in this paper. First, the photo-diode technique as used in Refs. [1,2] is improved by application of capacity proximity sensor (CPS) and by a high-speed camera (HSC) to measure dendritic growth velocity in levitated droplets. Second, the dendrite growth kinetics is tested experimentally to verify the idea that small amounts of impurity may enhance the solidification velocity of diluted alloys in comparison with the solidification velocity of pure systems. Third, the predictions of a model for rapid dendritic growth [9], which assumes deviation from local equilibrium at the interface and in the solute diffusion field are compared with the experimental dendrite velocities in Ni–Zr alloys. Fourth, metallographic analysis of solidified samples is made to measure the size of the dendritic structure and to evaluate critical undercoolings for dendritic fragmentation and coarsening. These findings for various Ni–Zr alloys extend previous investigations [1,2] on kinetics of solidification and fragmentation of dendritic crystals.

2. Experimental details

An electromagnetic levitation facility was used to undercool the samples and to measure the velocity of solidification, the standard setup is described elsewhere [10,11]. In contrast to the

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