Study of Phase Separation Theory of Alloys and its Applications

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Abstract： The in-situ metal matrix composite materials have become one of the hot topics in the field of materials science and engineering due to their advantages of high thermodynamic stability, excellent performance, and low production cost. Phase separations， which include the liquid-liquid phase separation, liquid-solid phase separation, and solid-solid phase separation, are the main approaches for the development of the in-situ composite materials. The thermodynamic and kinetic characteristics of all these phase separation processes are similar. Among them, the liquid-liquid phase separation is the most complicated one. The theories on the microstructure formation during the liquid-liquid phase separation can be used to describe the other two kinds of phase separations. We investigated the phase separation process in depth. This report elaborates on the microstructure formation, key affecting factors and controlling methods of liquid-liquid phase separation process. It makes a simple introduction to the application of the theoretical research results in the development of the materials needed nowadays.

Keywords: In-situ composite, phase separation alloy, solidification, magnetic field, electric pulses

1 Introduction

Phase separations, which includes the liquid-liquid phase separation, liquid-solid phase separation, and solid-solid phase separation, are the main approaches for the development of the in-situ composite materials. The thermodynamic and kinetic characteristics of all these phase separation processes are similar. Among them, the liquid-liquid phase separation is the most complicated one. The theories on the microstructure formation during the liquid-liquid separation can be used to describe the other two kinds of phase separations. We investigated the solidification of the liquid-liquid phase separation alloys. This paper will elaborate the microstructure evolution during the liquid-liquid phase transformation, its key affecting factors and the possibility to control the microstructure formation by using the static magnetic field and electric pulses (ECPs).

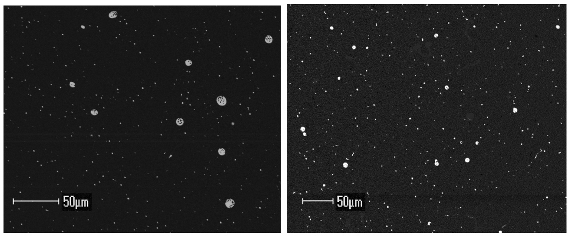
2 Experimental procedure

Directional solidification experiments were carried out with Al-5t%Pb alloy and Bi-10%Cu-10%Sn (wt.%) by using a Bridgman type solidification setup with a magnetic field producer and an ECPs producer. The Al-5t%Pb alloy sample was prepared by melting pure Al and Pb in a graphite crucible, heating the melt to 950^{o}C, holding temperature for 30 minutes to form a homogeneous liquid and then withdrawing the crucible into a bath of a Ga-In-Sn liquid alloy. The Bi-10%Cu-10%Sn alloy sample was prepared by melting pure Cu, Bi, and Sn in an alumina crucible, heating the melt to 900^{o}C, holding temperature for 30 minutes to form a homogeneous liquid and then withdrawing the crucible into the Ga-In-Sn liquid alloy bath. The temperature profile in the samples was measured by the thermocouples locating inside the melt.

3 Result and discussion

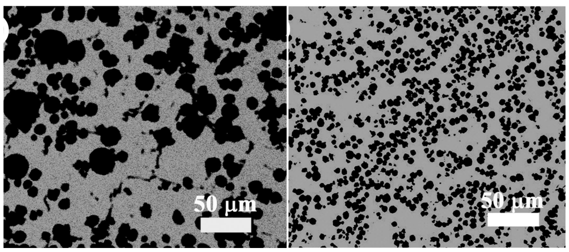
Fig. 1 shows the microstructures of the sample solidified at the rate of 5mm/s in a static magnetic field 0T and 0.3T. The black phase is α-Al and the white phase is the Pb-rich particles. The microstructures demonstrate that the magnetic field causes a decrease in the size of the Pb-rich particles. The magnetic field causes a refinement of the in-situ Pb particles. Fig. 2 shows the microstructures of the Bi-10%Cu-10%Sn samples solidified at the rate of 8mm/s with or without the effect of ECPs. The results indicate that ECPs promote this alloy to form a well dispersed microstructure [1].

The microstructure formations were calculated. The results demonstrate that there exists an undercooling region in front of the Solid/Liquid interface and the nucleation of the Minority Mhase Droplets (MPDs) occurs around the peak of the undercooling, as shown in Fig. 3. The nucleation and growth of the droplets lead to a decrease in the supersaturation and thus the nucleation occurs only in a small region. After nucleation the droplets grow and coarsen as they move towards the solidification interface until they are caught by the S/L interface.



(a) (b)

Fig.1 Microstructures of Al-5%Pb alloy solidified at the rate of 5 mm/s in magnetic field of 0 T (a) and 0.3 T.



(a) (b)

Fig.2 Microstructures of Bi-10%Cu-10%Sn alloy solidified at the rate of 10 mm/s without ECPs (a), and with ECPs of 50 Hz and 30,000 A/cm2.

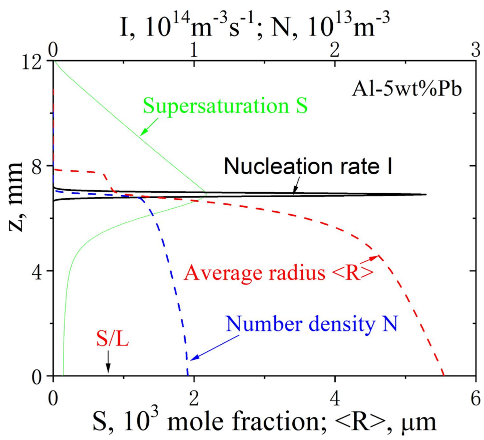


Fig.3 Supersaturation, nucleation, number density and average radius of the MPDs in front of the solidification interface along the central longitudinal axes of the sample.

The static magnetic field affects the microstructure formation mainly through the suppression of convections. It causes a more uniform distribution of the nucleation rate and the number density of the MPDs along the sample's radial direction, as shown in Fig. 4. It also causes a decrease in the size of the maximum droplet in front of the solidification interface. All these are favorable for the formation of a well dispersed microstructure. ECPs mainly affect the microstructure formation through changing the nucleation behaviors of the MPDs. They cause an increase in the nucleation rate of the Cu-rich droplets during the liquid-liquid phase transformation and promote the formation of a well dispersed solidification microstructure, as shown in Fig. 5.

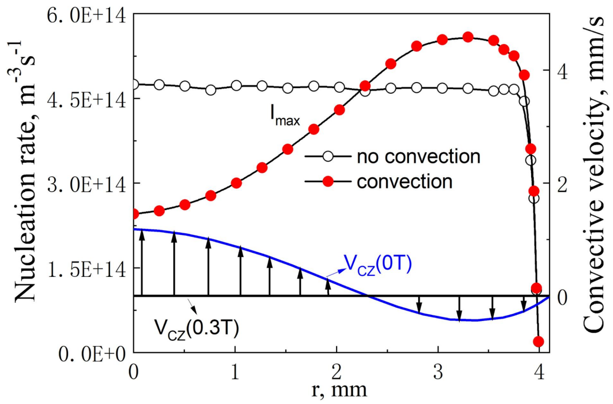


Fig. 4 Variation of the maximum nucleation rates of the Pb-rich droplets and the z vector of the flow velocities at the corresponding position with the sample radial direction.

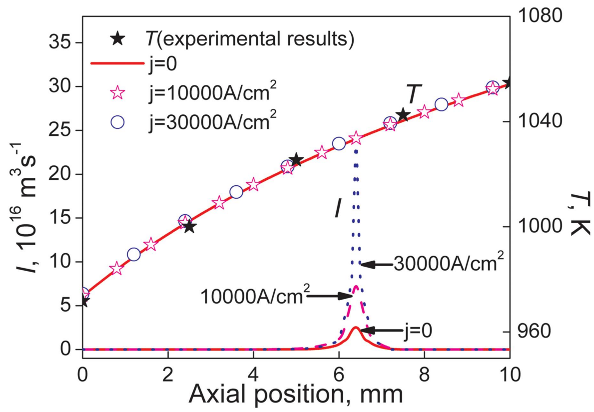


Fig. 5 Temperature profile in front of the solidification interface and nucleation rate of precipitated phase droplets (I) during solidifying Bi-10%Cu-10%Sn alloy.

4 Conclusion

The microstructure formation during the liquid-liquid phase transformation is a result of the concurrent actions of the nucleation, growth, Ostwald ripening, motions and collision-and-coagulations of the MPDs. Both a static magnetic field and ECPs can be applied to control solidification process and microstructure of the liquid-liquid phase separation alloys.

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References

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