SOLIDIFICATION OF Zn-Pb ALLOY UNDER SIMULANT MICROGRAVITY CONDITION OF ORTHOGONAL ELECTRIC AND MAGNETIC FIELDS①

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ABSTRACT Solidification experiments have been done with Zn-Pb alloy under the simulant microgravity condition of orthogonal electric and magnetic fields. Computer simulation has been carried out for the processes of the coarsening of the dispersion droplets and the formation of the gravity segregation during cooling this kind of alloy in their liquid-liquid temperature regions. Experiments and analyses show that electric and magnetic fields properly selected can decrease the coarsening rate of dispersion droplets greatly and slow down the velocity at which the gravity segregation is formed.

Key words solidification electric and magnetic fields computer simulation

1 INTRODUCTION

Monotectic alloy is a broad kind of material and many of them have particular physical and mechanical properties[1-4]. But until present, they have few practical applications because only ingot with serious gravity segregation can be obtained when they solidify under general ground conditions. In recent years, great attentions have been paid to the studies of this kind of material and a lot of research work has been carried out under microgravity condition in space[5-8]. But up to date, people are not very clear about the coarsening process of the dispersion droplets and the phase separation of monotectic alloy. Therefore, it is very meaningful to do some further research in this field.

Solidification experiments will be done with Zn-Pb monotectic alloy under the simulant microgravity condition of orthogonal electric and magnetic fields in this paper, and computer simulation will be carried out for the process of the coarsening of the dispersion droplets.

2 EXPERIMENTAL AND RESULTS

Zn-Pb binary alloy has been used as the experimental material. Fig. 1 shows the schematic of the experimental set[9]. The electric and magnetic fields were charged with two a. c. -d. c. converters so that their parameters can be adjustied separately.

The experimental procedure is as fol -

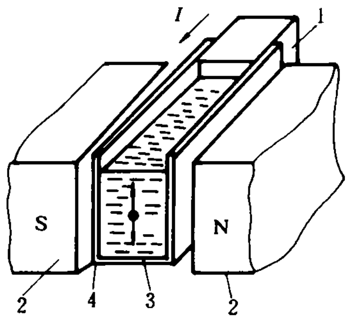

Fig. 1 Principle drawing of experimental set-up
1—electrode; 2—magnetic field; 3—melt; 4—crucible

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lows: first, put the prepared alloy into the crucible and heat it to temperature above its immiscible temperature gap. Then homogenize the melt by holding temperature for 30~40 min. Finally cool the melt at 1 ℃/s in orthogonal electric and magnetic fields.

It was found that when solidified under general ground conditions, only sample with serious gravity segregation can be obtained. Orthogonal electric and magnetic fields can change the solidification structure greatly. When the densities of electric and magnetic fields are smaller, there is still a part of Pb phase deposited to the bottom of sample during the solidification. When the densities of electric and magnetic fields are in a certain region, sample in which Pb-rich particles distribute homogeneously can be obtained, as shown in Fig. 2. Analyese show that the average particle radii in Zn-2%Pb sample and Zn-4%Pb sample are 2.45 and 3.47 μm respectively.

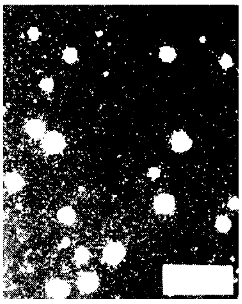

Fig. 2 Structure of Zn-2%Pb sample solidified in proper electric and magnetic fields

3 DISCUSSION

3.1 *Principle of Simulating Microgravity Condition by Electric and Magnetic Fields*

One knows that when cooling a homogeneous monotectic alloy melt into its immiscible temperature gap, it will transform to a suspension of dispersion droplet in the matrix. From now on, these dispersion droplets will grow through diffusion and coagulate through collision between droplets.

Orthogonal electric and magnetic fields change the resultant force suffered by a droplet[9]. If the densities of electric and magnetic fields are properly selected, the resultant force suffered by a droplet will tend to zero. Under this condition the melt will seem to be in space and there is no deposition or floating of droplets in it.

Certainly, it is very difficult to find the electric and magnetic fields' densities J_0 and B_0 with which the specific gravity difference between the two liquids can be compensated completely during the solidification process because the physical parameters of an alloy change from time to time. Generally, if alloy melts solidified in electric and magnetic fields with densities J and B, one can use a constant K_b indicating the extent to which the specific gravity difference between the two liquids is compensated.

$$K_b = 1 - (\boldsymbol{J} \times \boldsymbol{B})/(\boldsymbol{J}_0 \times \boldsymbol{B}_0) \quad (1)$$

When K_b equals 1, the alloy solidifies under common ground condition. When K_b equals 0, the specific gravity difference between the two liquid phases is compensated completely during solidification. General K_b is between 0 and 1, and the Stokes moving velocity of a droplet can be given by equation (2):

$$v_{sd}(r_p) = K_b v_s(r_p) \quad (2)$$

where $v_s(r_p)$ is the Stokes moving velocity of a droplet with radius r_p when solidifying under common ground condition.

3.2 *Coarsening of Dispersion Droplets When Solidified in Electric and Magnetic Fields*

Defining the droplets' radius distribution function $f(r_p, t)$ as equation (3), one can find that it satisfies equation (4) in the coarsening process[9].

$$f(r_p, t) = n(r_p, r_p + \Delta r_p, t)/\Delta r_p \quad (3)$$

$$\frac{\partial f(r_p, t)}{\partial t} = -\frac{\partial[f(r_p, t)\dot{r}_p]}{\partial r_p} - \int_0^{\infty} V_c(r_p, r_{p1}) \times f(r_p,t)f(r_{p1},t)\mathrm{d}r_{p1} + \frac{1}{2}\int_0^{r_p} V_c(r_{p1}, r_{p2})f(r_{p1}, t) \times f(r_{p2}, t)(\frac{r_p}{r_{p2}})^2\mathrm{d}r_{p1} \quad (4)$$

$$r_{p1}^3 = r_{p2}^3 = r_p^3$$

where $n(r_p, r_p + \Delta r_p, t)$ is the number of droplets with radii between r_p and $r_p + \Delta r_p$; $V(r_p, r_{p1})$ is the synthetical collision volume between droplets with radii r_p and r_{p1} which can be determined through the migration velocities of droplets.

Supposing the initial distribution of droplets' radius can be given by equation(5), one can obtain the distribution function of droplets' radius at any time by solving equation(4).

$$f(r_p, t=0)=A_0\exp\{[(r_p-\bar{r}_p)/(\varepsilon\bar{r}_p)]^2/2\} \quad (5)$$

where A_0 and ε are constants.

For Zn-4%Pb alloy, if the initial average droplet radius $\bar{r}_p$ and constant ε equal 1 μm and 0.15 respectively, and the melt cools from 522 ℃ at the rate of 1 ℃/s, the relation between the coarsening rate of droplet and the average droplet radius obtained by solving equation(4) is shown in Fig. 3. It can be seen that the larger the average droplet radius is, the greater the effect of the electric and magnetic fields on the coarsening rate is. When solidified under the general ground condition(K_b = 1), the coarsening rate of droplets increases when the average droplet radius is larger than 2.4 μm. Fig. 4 shows the relation between the diffussion growth rate of droplet and the average droplet radius. Comparing the corresponding curves in Figs. 3 and 4, one can find that the main factor which leads to the coarsening rate of droplets increasing is the gravity coagulation. When orthogonal electric and magnetic fields are applied, the coarsening rate of droplets decreases greatly, see Fig. 3.

The relations between the average radius of dispersion droplets and the melt's temperature for different K_b are shown in Fig. 5. Calculations indicate that when Zn-4%Pb alloy melt is cooled at a rate of 1 ℃/s in orthogonal electric and magnetic fields with K_b equal to 0.05, the average radius of Pb - rich particles

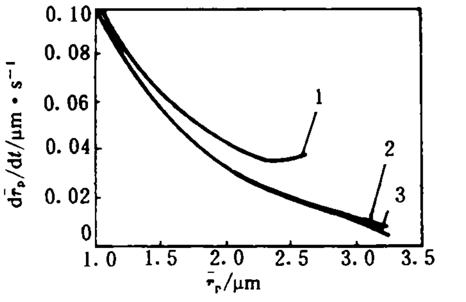

Fig. 3 Relation between droplet coarsening rate and average droplet radius
1— K_b = 1; 2— K_b = 0.2; 3— K_b = 0.05

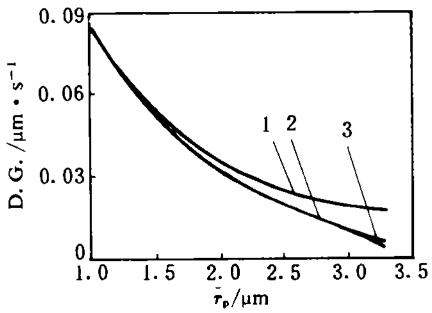

Fig. 4 Relation between droplet diffusion growth rate(D. G) and average droplet radius
1— K_b = 1; 2— K_b = 0.2; 3— K_b = 0.05

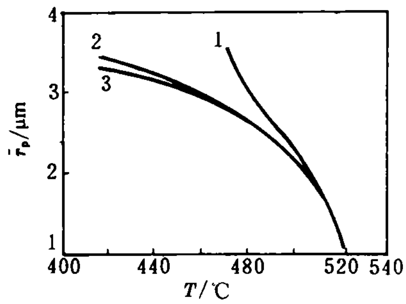

Fig. 5 Relation between the average droplet radius and the melt's temperature
1— K_b = 1; 2— K_b = 0.2; 3— K_b = 0.05

in the solidified sample is proximately 3. 3 μm. This is in good accordance with the experimental result.

3. 3 *Formation of Gravity Segregation When Solidified in Orthogonal Electric and Magnetic Fields*

In the solidification process of monotectic alloy, the dispersion droplets deposit when they are coarsening. The amount of the dispersion phase deposited to the bottom of the sample at time t can be given by equation(6).

$$K_s = \frac{1}{W_0 h}\int_0^t dt \int_0^\infty V_{sd}(r_p) f(r_p, t) \frac{4}{3}\pi r_p^3 dr_p \quad (6)$$

where W_0 is the volume fraction of Pb-rich phase of the alloy.

For Zn-4%Pb alloy, substituting the relation between the average droplet radius and the time (given by Fig. 5) into equation (6), and supposing the droplets' radius satisfies equation (5) with ε equal to 0. 35, calculations give the relations between the deposited Pb phase and the melt's temperature for different K_b. It can be seen that the amount of the Pb-rich phase deposited to the bottom of the sample increases quickly when solidified under general ground condition. When solidified in orthogonal electric and magnetic fields, the deposition velocity of droplet decreases greatly, and sample in which Pb-rich particles distribute homogeneously can be obtained.

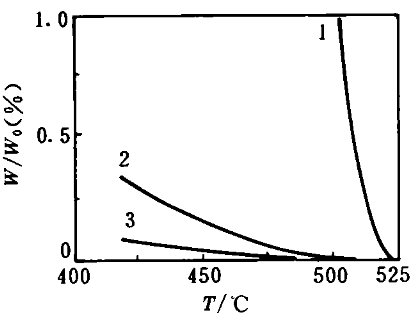

Fig. 6 Relation between the deposited Pb-rich phase and the melt's temperature
1— K_b = 1; 2— K_b = 0. 2; 3— K_b = 0. 05

4 CONCLUSIONS

(1) When a monotectic alloy melt solidifies under the general ground condition, the dispersion droplets coarsen rapidly through the gravitational coagulation.

(2) Orthogonal electric and magnetic fields can be used to compensate the specific gravity difference between the two liquid phases, and simulate microgravity condition. Under this condition dispersion droplets coarsen mainly through diffusion growth, and therefore the coarsening rate is small.

(3) Orthogonal electric and magnetic fields can not only decrease the coarsening rate of the dispersion droplets, but also slow down the formation rate of the gravitational segregation. Therefore it is easy for us to obtain sample of monotectic alloy in which the dispersion droplets distribute homogeneously.

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