COLLISION COARSENING OF DISPERSION DROPLETS IN SOLIDIFICATION PROCESS OF MONOTECTIC ALLOY[①]

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ABSTRACT A synthetical mathematic model describing the collision coarsening of the dispersion droplets in the solidification process of monotectic alloys has been put forward. Numerical simulation has been carried out for Zn-Pb alloy. It was found that when the average droplet radius is smaller than 1 μm, Brownian ripening plays important role and the influence of gravity level on the coarsening rate of droplet is very weak. Otherwise, gravitational and Marangoni coagulations are the main factors of collision coarsening.

Key words: Zn-Pb alloy solidification collision coarsening

1 INTRODUCTION

A homogeneous monotectic alloy melt will transform to a suspension of dispersion droplets in a matrix melt when cooled into its immiscible temperature region. From now on these droplets will coarsen through diffusion growth[1, 2] and coagulate through collision between droplets[2, 3]. Studies have shown that the diffusion growth can not lead these droplet to coarsen seriously[1, 2], and collision coagulations are the main factors on which the solidification structure depends[2, 3]. To understand this coagulation coarsening process deeply, a synthetical numerical model which includes Brownian ripening, gravitational and Marangoni coagulations has been put forward in this paper, and computer simulation has been carried out with Zn-Pb monotectic alloy for the solidification processes both under ground condition and under microgravity condition in space.

2 NUMERICAL MODEL

The collision coagulation is the result of the movements of droplets itself if the convection of the matrix melt is very weak, and generally there exist three kinds of collision ripenings, that is Brownian ripening[4], gravitational and Marangoni coagulations[3, 5-9]. When the temperature gradient is perpendicular to the gravity direction, the collision volume between droplets is shown in Fig. 1. The collision volume between droplets for these three kinds of collision ripenings can be given by eq. (1).

$$V_{cb}(r_p, r_{p1}) = 4KT(1 + r_p/(2r_{p1}) + r_{p1}/(2r_p))/3\eta_{ext} \qquad (1a)$$

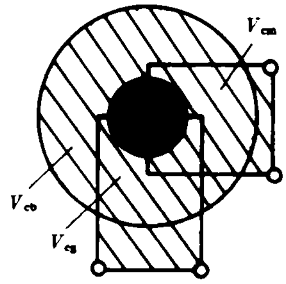

Fig. 1 Sketch of synthetical collision volume

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$$V_{cg}(r_p, r_{p1}) = \pi(r_p + r_{p1})^2 \Delta V_s \qquad (1b)$$

$$V_{cm}(r_p, r_{p1}) = \pi(r_p + r_{p1})^2 \Delta V_m \qquad (1c)$$

where V_{cb}, V_{cg} and V_{cm} are respectively Brownian, gravitational and Marangoni collision volume between droplets with radius r_p and r_{p1}, K is Bolzman constant, T is the absolute temperature, η is the viscosity of the matrix melt, ΔV_s is the difference of the Stokes depositing velocities of droplets with radius r_p and r_{p1}, ΔV_m is the difference of the Marangoni migration velocities of droplets with radii of r_p and r_{p1}.

Generally these three kinds of collision mechanisms play roles in the coarsening process at the same time. The synthetical collision volume V_{cz} is the sum of the parts of the three kind collision volume which does not over lap[10].

Defining the distribution function of droplets' radius as eq. (2), one can find that it satisfies eq. (3) in the process of the collision coarsening of droplets.

$$f(r_p, t) = n(r_p, r_p + \Delta r_p, t)/\Delta r_p \qquad (2)$$

where $n(r_p, r_p + \Delta r_p, t)$ is the number of particles with radii between r_p and $r + \Delta r_p$ per unit volume at time t.

$$\frac{\partial f(r_p, t)}{\partial t} = \frac{1}{2}\int_0^{r_p} V_{cz}(r_{p1}, r_{p2}) f(r_{p1}, t) \times f(r_{p2}, t)\left(\frac{r_p}{r_{p2}}\right)^2 \mathrm{d}r_{p1} - \int_0^{\infty} V_{cz}(r_p, r_{p1}) f(r_p, t) \times f(r_{p1}, t)\mathrm{d}r_{p1} \qquad (3)$$

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

3 NUMERICAL SIMULATION RESULTS AND ANALYSES ON COLLISION COARSENING UNDER GRAVITY OR MICROGRAVITY CONDITIONS

Supposing the initial distribution of droplets' radius satisfies eq. (4), calculations with Zn-5 wt.-% Pb alloy melt at 530 ℃ in which the initial average droplets' radius equal 0.7 μm and 2 μm, and the temperature gradient of 0.4 ℃/cm give the relation between the average droplet radius and time led by collision ripening, as shown in Fig. 2 and Fig. 3.

$$f(r_p, 0) = A_0 \exp\{-[(r_p - \bar{r}_p)/(0.1\bar{r}_p)]^2/2\} \qquad (4)$$

where A_0 is a constant.

It can be found that when the average droplets' radius is smaller than 1 μm, the effects of gravitational and Marangoni coagulation are very weak, and Brownian ripening is the main factor which led the droplets to coarsen. Therefore the gravity level nearly has no effect on the coarsening process, as shown in Fig. 2. With the increase of the average droplet radius, the effect of the gravitational and Marangoni coagulation increases, while that of the Brownian ripening decreases. When the average droplet radius is greater than 1 μm, the gravitational coagulation plays important role in the collision coarsening process, as shown in Fig. 3. Under this condition the gravity level affects the collision coarsening rate of droplet greatly. The gravitational coagulation is still the main factor of collision coarsening of droplet when the gravity level is $10^{-1} g_0$ for system in which the average radius of dispersion droplets is 2 μm. Calculation showed that when the gravity level is below $10^{-2} g_0$, droplets coarsen mainly through Brownian ripening.

4 CONCLUSIONS

(1) There exist three kinds of collision

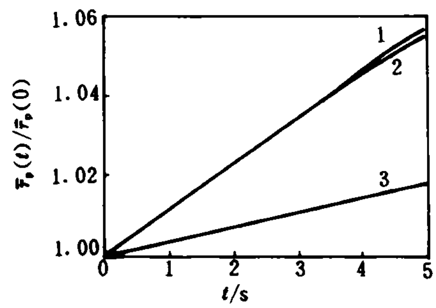

Fig. 2 Relation between average droplet radius and time ($r_p(0) = 0.7$ μm)

1—Synthetical; 2—Brownian; 3—Gravitational

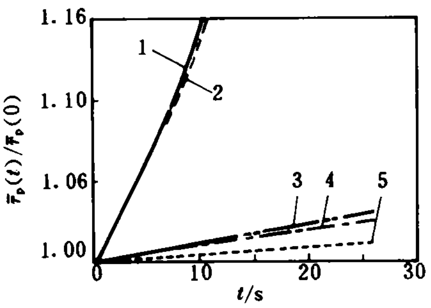

Fig. 3 Relation between average droplet radius and time($r_p(0)=2\,\mu m$)

1—Synthetical;
2—Gravitational;
3—$10^{-1}g_0$ Synthetical;
4—$10^{-1}g_0$ Gravitational;
5—Brownian

coarsening mechanisms of the dispersion droplets when cooling a monotectic alloy melt into its immiscible temperature region, they are Brownian ripening, gravitational and Marangoni coagulations. These collision processes can be considered synthetically on the basis of collision volume between droplets.

(2) For Zn-5 wt.-% Pb alloy, when the average droplet radius is smaller than 1 μm, Brownian ripening plays important role in the collision coarsening process, and the effect of the gravitational and Marangoni coagulations increase with the increase of the average droplet radius. When the average droplet radius is larger than 1 μm, gravitational coagulation of droplets is the main factor of collision coarsening.

(3) When the average droplet radius is smaller than 1 μm, gravity level nearly has no influence on the coarsening process, and for system in which the average radius of the dispersion droplets is larger than 1 μm, gravity level affects the droplet coarsening rate greatly.

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