Behavior of Fe-rich phase during rapid solidification of Cu–Fe hypoperitectic alloy

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Abstract

Powders of $Cu_{85}Fe_{15}$ alloy were manufactured by using the high-pressure gas atomization technique. The microstructures of the powders have been investigated. It is indicated that the liquid–liquid phase transformation takes place in the atomized droplets smaller than $224\,\mu m$ in diameter. The size of Fe-rich spheres decreases and their number density increases with the decrease of the powder size. A model has been developed to describe the microstructure evolution in the atomized droplets during a cooling through the metastable miscibility gap. Calculations have been performed with $Cu_{85}Fe_{15}$ alloy. The experimental and simulated results have been discussed in detail.
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1. Introduction

Cu–Fe alloy is a kind of high strength and high electric conductivity material [1–3]. It is also indicated that this alloy exhibits giant magnetoresistance and other outstanding physical properties when the ferromagnetic Fe-rich phase is dispersed in the form of nanosized particles in the paramagnetic Cu-rich matrix [4]. It has great potentials to be used as material for magnetic recording, optical devices and sensors [5,6]. The application of the Cu–Fe alloy has, however, been limited because generally serious segregation of components takes place during solidification. Recent researches indicated that rapid solidification technique has great potential in the manufacturing of this alloy with expected microstructure [7].

The Cu–Fe alloy system is well known as a peritectic system [8]. It also exhibits a metastable miscibility gap in the undercooled liquid state, as shown in Fig. 1. When a single-phase liquid is undercooled into the miscibility gap, it separates into two liquids: one is Cu-rich (L_1) and the other is Fe-rich (L_2). Although a lot of researches on Cu–Fe

alloy have been carried out [9–12], most of them focused on the thermodynamic aspect. Up to date, little is known about the kinetics of the liquid–liquid phase transformation. We have developed in this paper a numerical model to describe the microstructure evolution during a cooling of the Cu–Fe alloy melt through the metastable miscibility gap. This model is a new version of the model developed by Zhao et al. It takes into account the effect of the volume fraction of the minority phase droplets on their diffusional growth rate. The formation of the microstructure in an atomized droplet has been calculated. Rapid solidification experiments have been done with Cu–Fe alloy by using the high-pressure gas atomization technique. The numerical calculations have been compared with the experimental results.

2. Experimental procedure

Atomized powders of $Cu_{85}Fe_{15}$ alloy were prepared by high-pressure N_2 gas atomization. The diameter of the powder is in the range from 20 to $280\,\mu m$. The powders were meshed and polished for the observation of the microstructure. The microstructural characterization was done using

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scanning electron microscope equipped with an energy dispersive X-ray analysis.

3. Experimental results

For $Cu_{85}Fe_{15}$ alloy, if the undercooling of the single-phase liquid is less than 71 K, liquid–solid transformation takes place in the atomized droplet (see Fig. 1). The experimental results showed that the microstructure consists of the primary γ-Fe and the peritectic reaction product in the atomized powder of diameter ranged from 224 to 280 μm, while γ-Fe dendrites and Fe-rich spheres coexist in the powder of diameter ranged from 180 to 224 μm. The microstructure of an atomized powder of 200 μm in diameter is shown in Fig. 2. The compositions of the Fe-rich and Cu-rich liquid phases vary according to the binodal line with the decrease of temperature. The undercooling of the Fe-rich liquid is larger than that of the Cu-rich liquid (see Fig. 1). The Fe-rich phase solidifies, therefore, first during cooling through the metastable
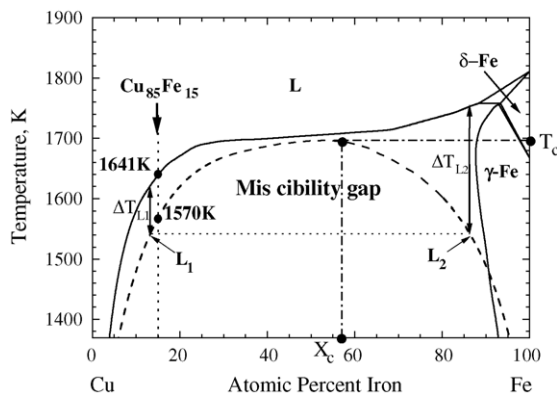
miscibility gap and γ-Fe grows then directly from the Fe-rich spheres into the matrix liquid, as shown in Fig. 2.

The undercooling of the atomized droplet increases with the decrease of the size of the atomized droplet. The liquid–liquid phase transformation takes place completely in the atomized droplets with diameter in the range from 20 to 180 μm. Fig. 3(a and b) shows the microstructures in the powders of 110 and 30 μm in diameter, respectively. The black spheres are Fe-rich spheres and the other is Cu-rich matrix. It is indicated that the minority phase spheres are homogenously dispersed in the matrix phase. The mean diameters of the Fe-rich spheres in Fig. 3(a and b) are about 0.72 and 0.41 μm, respectively. The size distribution of the minority phase spheres has been determined by the stereological method [13] and the results are shown in Fig. 4. The diameter of the Fe-rich spheres ranges from 0.27 to 1.17 μm in the powder of 110 μm in diameter, while it ranges from 0.15 to 0.63 μm in the powder of 30 μm in diameter. The fitted size distribution is close to a normal distribution, as shown by the solid line in Fig. 4.

Fig. 1. The phase diagram of Cu–Fe alloy. The dashed curve under the liquidus is the binodal line. X_c is the critical concentration 57 at.% Fe and T_c is the critical temperature, 1694 K [10]. L_1 and L_2 are the Cu-rich phase and Fe-rich phase, respectively. ΔT_{L_1} and ΔT_{L_2} are the undercoolings corresponding to L_1 and L_2.
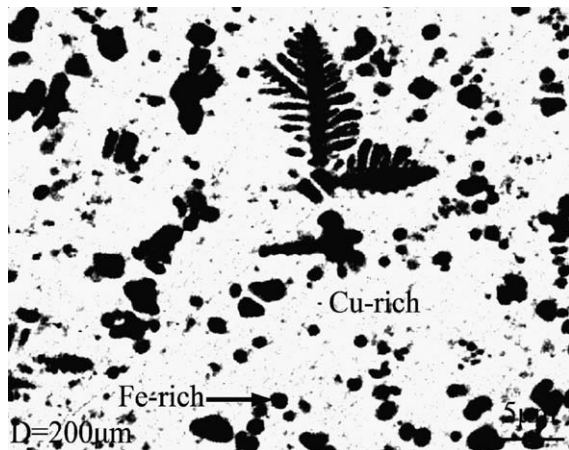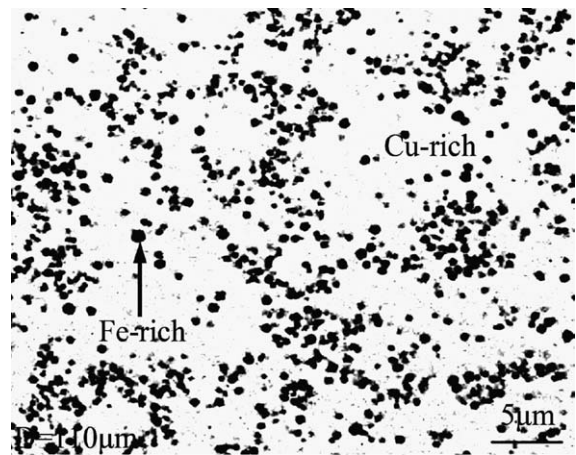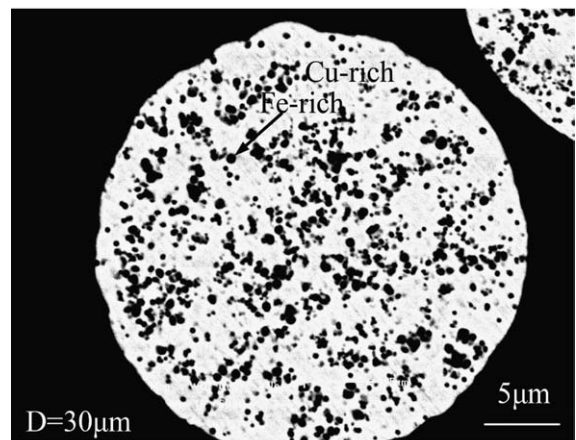

Fig. 2. The microstructure of $Cu_{85}Fe_{15}$ powders of 200 μm in diameter.

Fig. 3. The microstructures of $Cu_{85}Fe_{15}$ powders of 110 μm (a) and 30 μm (b) in diameter.