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静磁場重畳電磁浮遊技術を用いた Cu 基合金の相分離挙動に及ぼす諸因子の影響

Study on the Effects of Operational Factors on Phase Separation Behavior in Molten Cu-based Alloys using an Electromagnetic Levitator Superimposed with a Static Magnetic Field

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1. Introduction

Cu-based alloys such as Cu-Co and Cu-Fe alloys have a metastable miscibility gap in the undercooled state. Once the homogeneous melt is undercooled below the binodal line, the melt separates into two liquid phases, i.e., phase separation occurs. Melt convection in the molten alloys strongly affects the phase separation structures as well as the composition, the cooling rate, and the degree of undercooling. However, the correlation between the phase separation structures and melt convection is not clarified in detail.

In the previous studies [1)-3)], the correlation between the phase separation structures and melt convection of $Cu_{80}Co_{20}$ [1), 2)] and $Cu_{80}Fe_{20}$ [3)] alloys was investigated, using an electromagnetic levitation (EML) technique superimposed with a static magnetic field. In this technique, melt convection in the levitated molten samples can be controlled by the static magnetic field. From these studies. it was revealed that the phase separation structures of Cu-based alloys changed markedly with a static magnetic field. It was speculated that the marked change of structure is due to the laminar-turbulent transition of melt convection, herein magnetohydrodynamic (MHD) convection, in the molten alloys. Nevertheless, in the previous studies [1)-3)], only the cross-section of the solidified samples, i.e. the 2D phase separation structures, have been observed using a scanning electron micrograph (SEM). Therefore, the 3D structures of Cu-Co alloys were observed using neutron computed tomography (CT) [4)].

In this study, neutron CT of phase separation structures in solidified $Cu_{80}Fe_{20}$ alloys was performed, where the solidified samples were prepared by solidifying from the undercooled state using the EML technique superimposed with a static magnetic field. The effect of melt convection on the phase separation structures of Cu-based alloys were investigated, comparing the 3D structures between $Cu_{80}Co_{20}$ and $Cu_{80}Fe_{20}$ alloys. In addition, the effect of cooling rate on the relation between the phase separation structures and melt convection was also investigated, although the structures were limited to 2D ones observed by SEM.

2. Experimental method

Figure 1 shows a schematic diagram of the electromagnetic levitator superimposed with a static magnetic field [1)-3)]. A $Cu_{80}Fe_{20}$ solid sample of 5 mm or 6 mm diameter was levitated and melted in an Ar atmosphere with 5 vol% H_2. Then, the levitated molten sample was cooled and solidified by blowing a gas mixture of He and Ar-5 vol% H_2 under a given static magnetic field. The static magnetic field was generated by a superconducting magnet to control the convection, particularly MHD convection, in the levitated molten sample, and ranged from 0 to 10 T.

The 3D and 2D phase separation structures in the solidified samples were observed by neutron CT and SEM, respectively. Here, neutron CT experiments were performed by using the energy-resolved neutron imaging system, RADEN, in the Materials and Life Science Experimental Facility (MLF) of Japan Proton Accelerator Research Complex (J-PARC).

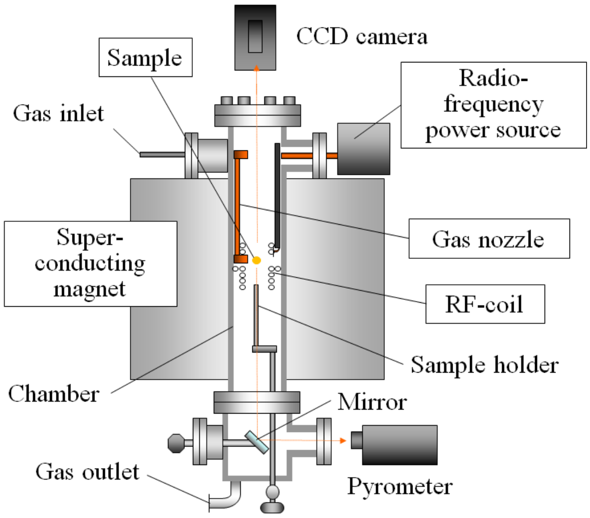

Fig. 1 Schematic illustration of an electromagnetic levitator superimposed with a static magnetic field.

3. Results and discussion

Figure 2 shows the 3D images of phase separation structures in $Cu_{80}Co_{20}$ [4] and $Cu_{80}Fe_{20}$ alloys solidified under the static magnetic fields of 0.5 T and 3.0 T. The diameter of the sample was 5 mm and the cooling rate was approximately 30 K/s. The darker area in each image is the Cu-rich phase and the brighter areas are the Co-rich or Fe-rich phases. In both alloys, the fine Co-rich or Fe-rich phases dispersed in the matrix of the Cu-rich phase at the static magnetic field of 0.5 T. In contrast, a few larger coalesced Co-rich or Fe-rich phases appeared at 3.0 T, as observed by SEM in the previous studies [1-3]. Such change of phase separation structures with the static magnetic field is due to the laminar-turbulent transition of convection in the molten alloys. In addition, compared the shapes of Cu-depleted phases between $Cu_{80}Co_{20}$ and $Cu_{80}Fe_{20}$ alloys at 3.0 T, the Co-rich phases in $Cu_{80}Co_{20}$ alloy were considerably elongated along the direction of the static magnetic field, whereas the shape of Fe-rich phases in $Cu_{80}Fe_{20}$ alloy was close to a sphere. The difference in the phase separation structures between $Cu_{80}Co_{20}$ and $Cu_{80}Fe_{20}$ alloys at relatively high static magnetic field might be due to the difference in the physical properties, particularly the magnetic susceptibility and interfacial tension.

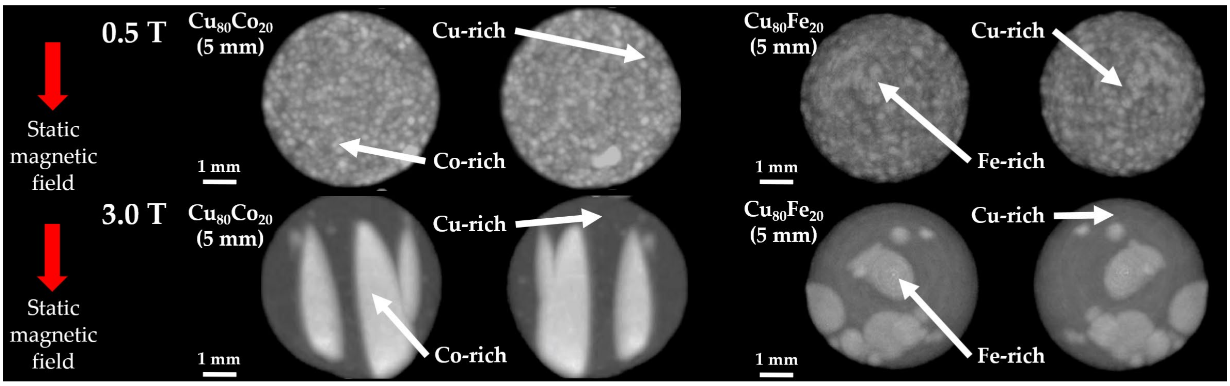

Fig. 2 3D images of phase separation structures of $Cu_{80}Co_{20}$ (5 mm) and $Cu_{80}Fe_{20}$ (5 mm) alloys by neutron CT, viewed from two different angles.

Figure 3 shows the relation between the static magnetic field and the Sauter mean diameter of phase-separated Fe-rich phases in $Cu_{80}Fe_{20}$ alloy. The Sauter mean diameter was calculated from the SEM image of the cross-section of the sample. To investigate the effect of the cooling rate on the phase separation structures, the results at the cooling rate above and below 20 K/s are separately shown for the sample with a diameter of 5 or 6 mm. It was considered that the effect of the sample diameter is small because of the high thermal conductivity of the sample. At the relatively low static magnetic field, the effect of the cooling rate was small, since the structures are affected by turbulent flow. In contrast, at the relatively high static magnetic field, the higher the cooling rate, the smaller the Sauter mean diameter of the phase-separated Fe-rich phases. This is because the structures were quenched in the early stage of the phase separation and coalescence due to the high cooling rate.

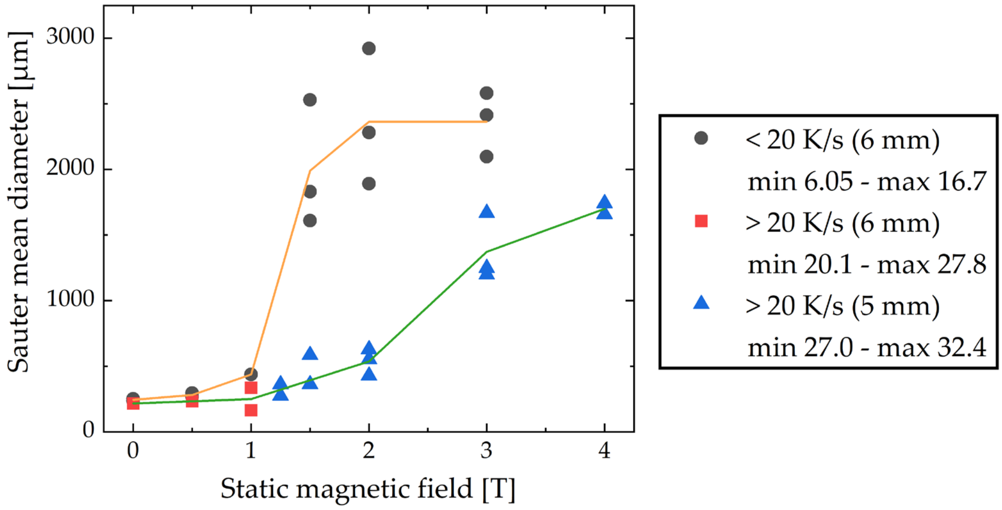

Fig. 3 Relation between static magnetic field and Sauter mean diameter of phase-separated Fe-rich phases in $Cu_{80}Fe_{20}$ alloy.

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