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Interdiffusion coefficient of liquid In-Sn under high magnetic field

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In this research, convection damping under static magnetic field was studied by actual experiments and by numeral simulation for the purpose of measuring reliable diffusion coefficients in melt. Applying 4T of static magnetic field, the convection was almost damped, and the measured diffusion coefficient nearly equal to that in microgravity environment. More equality of diffusion coefficient could be obtained by applying magnetic field horizontally.
Key words: Static magnetic field, diffusion coefficients, convection, numerical simulation.

1. Introduction

It is necessary to measure reliable diffusion coefficient in melt, but diffusion process is sensitive to convection, so data obtained on earth may be much different from the data obtained in microgravity environment. The temperature dependence on earth is Arrhenius law, but that in microgravity environment is power law. Therefore, reliable data of diffusion coefficients are required for the purpose of revealing the diffusion mechanism in liquid metals, but there is much difficulty in experiment in microgravity environment. A capillary method is tried to reduce convection on earth, but it is not effective sufficiently.

It is well known that static magnetic field reduces convection in liquid metal [1], which may makes it a good substitute for microgravity conditions. In this report, the effect of magnetrohydrodynamics effect in static magnetic field on damping convection for measurement with accuracy and validity of using static magnetic field for measuring diffusion coefficients is reported.

2. Experimental

Frohberg *et al.* reported the self / inter-diffusion coefficient of In-Sn alloy in microgravity environment [2]. The characteristic of this system is small difference between their consistencies, the effect of solutal convection is so small that only thermal convection is concerned. First, we measured the diffusion coefficient of In-Sn alloy in static magnetic field with a capillary method. Fig. 1 shows experimental configuration. Two In-Sn alloy cylinders (10mm in length and 1mm in diameter) with different compositions (In-15at% Sn and In-25at% Sn), were put together into a graphite capillary and pressed by a graphite plug in order to avoid Marangoni flow during the process as shown in Fig. 2. Thermocouple was attached in the graphite to control power supply. Static magnetic inductions are 0T and 4T. The bore of the magnet was 30cm, put forge in it and heated sample. The specimen was set as its axis is parallel to gravity vector to keep concentration symmetry with respect to the axis. The heat treatment processes were as follows: first, heat the sample quickly to diffusion temperature, then hold the temperature for 20minutes. Finally, quench the sample to room temperature by airflow. Fig. 3 shows temperature history in the capillary. The concentration distribution of the samples was analyzed along the axis by EDS. The inter-diffusion coefficient was calculated through obtained data.

3. Numerical Simulation

Numerical simulations for describing detail of diffusion and convection at the same condition have done. The software of numerical simulation was FIDAP 8.6.2, which was based on a finite element method using thermal/physical transport equation. The mesh used in calculation is shown in Fig. 4. The number of mesh was 1395 and the shape of mesh was a half of cylinder. Temperature gradient was 1℃/cm (as center is hot). Diffusion temperature was 1000℃, and diffusion time was 10minutes.

3. Results and discussion

3.1 Experiment

Fig. 5 shows the experimental result of diffusion coefficient. By applying 4T of magnetic field vertically, almost same temperature dependence of diffusion coefficient to the microgravity environment was obtained. The effect of applying magnet field was sufficient to damp convection. In high temperature range, the diffusion coefficient in magnet field was lower than that of Frohberg. The experiment range of Frohberg was under 1000℃. Higher temperature range may show different temperature dependence. By applying magnet field, temperature range of measurement extends easily, so it's relatively easy to confirm the temperature dependence at the higher value.

3.2 Simulation

The results of numerical simulation are shown in Table1. It shows the max velocity of convection in various conditions. These results show convection velocity in any magnet condition was higher than space. For damping convection, it is more effective to reduce gravity than applying magnetic field. But even in the case of vertical magnetic field, convection velocity is reduced, and in the case of horizontal magnetic field, convection velocity is very small enough to be a diffusion-dominated condition.

There was little difference in max velocity of convection between 15-25at% alloy and 0-100at% alloy. Difference of composition had no effect to the result of diffusion coefficient at least this system. That's means the effect of solutal convection is so small comparing to that of thermal convection that it can be ignored, at least in this system.

4. Conclusion

Experiment data showed us that diffusion coefficient under 4T of vertical magnetic field was very close to that of microgravity environment. It also showed us that temperature dependence at the higher temperature value was different from Frohberg. Numerical simulation showed more effective way to apply magnetic field. The effect of applying magnetic field horizontally was still lower than microgravity environment, but it would be sufficient to damp convection, so it is interesting that more brake is applied to convection, how diffusion coefficient change and that how similarity of micro-environment and magnet field is obtained.

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References

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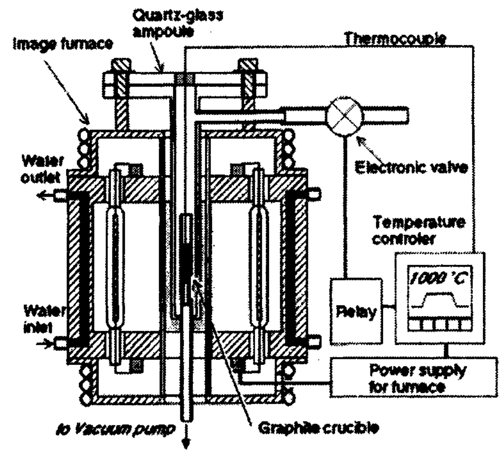

Fig. 1 Experimental configuration

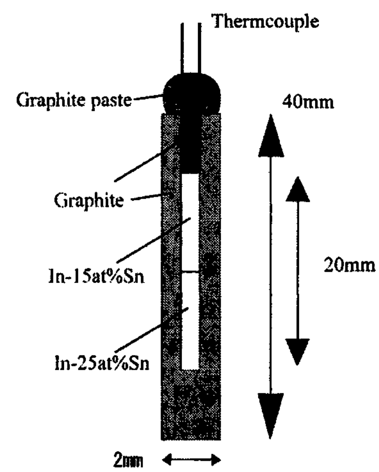

Fig. 2 Specimen

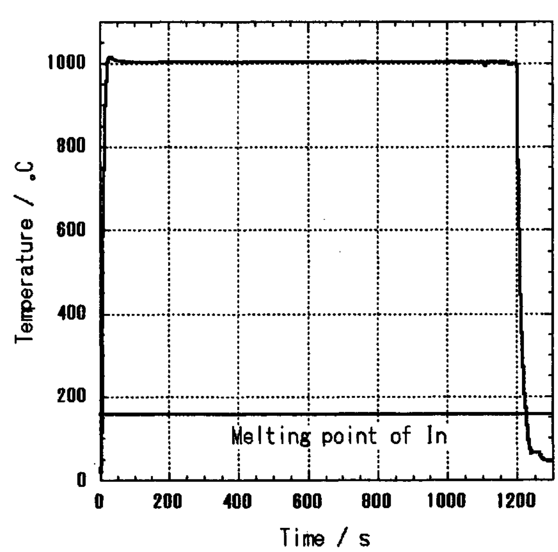

Fig.3 Temperature history of sample (1000℃)

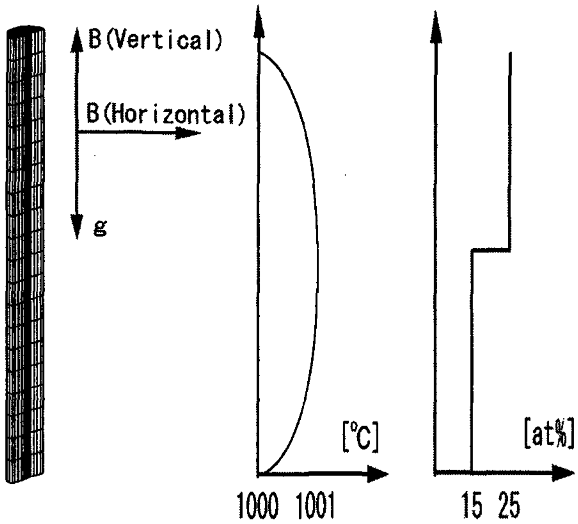

Fig.4 Meshes and temperature/concentration gradient

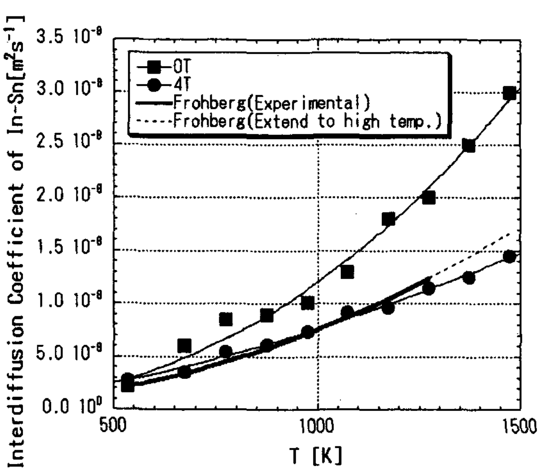

Fig.5 Result of experiment

Table I Result of Simulation

Diffusion couples [at%]	Specimen condition	Max velocity of convection [m/s]
15-25	1g, 0T	6.2×10^{-3}
15-25	1g, 4T(Vertical)	5.6×10^{-3}
15-25	1g, 4T(Horizontal)	4.4×10^{-7}
15-25	10^{-4}g, 0T	6.0×10^{-9}
0-100	1g, 0T	6.2×10^{-5}
0-100	1g, 4T(Vertical)	5.6×10^{-5}
0-100	1g, 4T(Horizontal)	4.4×10^{-7}
0-100	10^{-4}g, 0T	6.0×10^{-9}

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