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Cu-Fe 合金融体の表面張力測定:
ISS での Thermal Storage プロジェクトに向けて

Surface Tension Measurement of Molten Cu-Fe Alloys: A Key Step for succeeding the Thermal Storage Project at the ISS

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1. Introduction

Utilizing industrial waste heat can result in significant reductions in energy consumption and greenhouse gas emissions by repurposing it in diverse applications. A promising approach to amplify these benefits is the development of high-temperature latent heat energy storage, which can enhance energy density and conversion efficiency. Fe-Cu binary alloy has potential as high-temperature latent heat storage materials.[1,2] This alloy exhibits a metastable miscibility gap over a wide composition range in the undercooled liquid state. If small Cu-rich droplets can be dispersed within the Fe-rich liquid phase during the undercooled immiscible liquid region and then solidified as they are, it could utilize the latent heat by melting and solidifying only those Cu-rich particles that are encased in the outer shell of the Fe-rich solid. Accurate and precise measurements of the thermophysical properties of molten Fe-Cu alloys are currently underway in the microgravity environment using the electrostatic levitation furnace (ELF) installed on the Japanese science module 'KIBO' of the International Space Station (ISS), named 'ELF-Thermal Storage'.[3]

In the present study, we investigated the variation in sample composition due to the evaporation of molten Fe-Cu alloys at high temperature was investigated using electromagnetic levitation (EML) on the ground. Furthermore, we measured the surface tension of molten Fe–Cu alloys as functions of sample composition, temperature, and oxygen partial pressure (P_{O_2}) of measurement atmosphere. The purpose of this study was to obtain preliminary data to ensure the success of the microgravity experiment in the ELF-Thermal Storage project.

2. Experimental Procedure

A piece of high purity electrolytic iron was electromagnetically levitated with a high purity oxygen-free copper simultaneously. These are then uniformly melted under an Ar-He mixed gas with a P_{O_2} of 10^{-2} Pa, flowing at 2L/min. The temperature of the droplet was controlled by adjusting the partial pressures of argon and helium gases. After maintaining the levitated droplet at a target temperature for various periods, it was rapidly solidified by blowing high-purity helium gas at 20 L/min. The chemical composition of the solidified sample was analyzed by using inductively coupled plasma optical emission spectrometry (ICP-OES).

For measuring the surface tension, the oscillation behavior of the droplet was captured from the top using a high-speed video (HSV) camera. The P_{O_2} was controlled using a gas phase equilibrium between H_2 and CO_2, which were mixed with the Ar-He gas. The frequencies of the surface oscillations and translational oscillations were analyzed from the HSV images using fast Fourier transformation (FFT). The surface tension of molten Fe–Cu alloys was calculated from these frequencies using the Rayleigh equation[4)] and the Cummings and Blackburn calibration.[5)]

3. Results and discussion

Figure 1 shows the variations in the copper composition for the levitated samples with initial compositions of Fe–25at%Cu and Fe–33at%Cu, after being maintained in the liquid state at high temperature. The copper composition of the samples decreases almost linearly with time. This decline becomes more pronounced as the sample temperature increases. This trend suggests that copper in the molten alloy evaporates more readily than iron, especially at higher temperature.

Figure 2 exhibits the surface tension of molten Fe-Cu alloys measured at the P_{O_2} of 10^{-4} Pa, as functions of temperature and sample composition. Our previous results on the surface tension of liquid iron and copper are also shown with solid lines. The surface tension of liquid iron measured at the P_{O_2} of 10^{-4} Pa increases with elevating temperature. This is due to that although oxygen adsorption lowers the surface tension of liquid iron at lower temperatures, oxygen is desorbed from the melt surface due to a decrease in the equilibrium oxygen adsorption reaction. As a result, the surface tension approaches the pure state value of the surface tension free from oxygen adsorption at elevated temperatures. A similar trend of increasing surface tension increases with temperature is observed for molten Fe-Cu alloys. However, at higher temperatures, the surface tension of molten Fe-Cu alloys decreases as the copper composition increases. This would be attributed to the fact that less effect of oxygen adsorption on the surface tension of liquid copper compared to that of liquid iron.

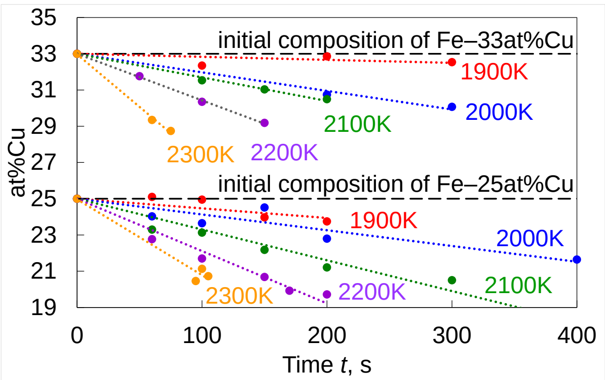

Fig.1 Variations in the copper composition for the levitated molten Fe-Cu alloys with initial compositions of Fe–25at%Cu and Fe–33at%Cu, maintained at high temperatures.

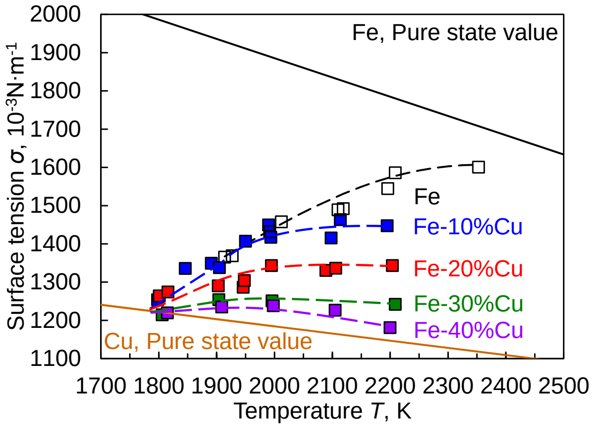

Fig.2 The surface tension of molten Fe-Cu alloys measured at the P_{O_2} of 10^{-4} Pa.

4. Summary

To obtain preliminary data for the ELF-Thermal Storage project, the variation in sample composition for molten Fe-Cu alloys due to evaporation was examined by EML. Furthemore, the surface tension of molten Fe-Cu alloy was measured. As a result, copper in the molten alloys evaporated more preferentially than iron, which was more pronounced at higher temperatures. The surface tension of the molten Fe-Cu alloys, measued at the P_{O_2} of 10^{-4} Pa, increased with rising temperature due to oxygen adsorption/desorption reaction similar to the behavior observed for liquid iron. An incrase in the copper composition of the alloy decreased the surface tension at elevated temperatures.

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