JASMAC
Conference of the Japan Society of Microgravity Application

PS21

国際宇宙ステーションでの Thermal Storage ミッションにおいて測定した Fe-Cu 合金融体の熱物性値

Measurement of Thermophysical properties of molten Fe–Cu alloys during the “Thermal Storage” Mission on the International Space Station

黒澤修也 [1]，清宮優作 [1]，菅原陸 [1]，殿岡和己 [1]，伊藤輝 [1]，小澤俊平 [1]，
杉岡健一 [2]，白鳥英 [3]，石川毅彦 [4]，小畠秀和 [5]

First name LASTNAME1, Second AUTHOR1, Third AUTHOR1,2 and Last AUTHOR2

[1] 千葉工業大学，Chiba Institute of Technology,
[2] 富山県立大学，Toyama Prefectural University
[3] 東京都市大学，Tokyo City University
[4] 宇宙航空研究開発機構宇宙化学研究所，Institute of Astronautical Science, JAXA
[5] 同志社大学，Doshisha University

1. Introduction

The Fe–Cu binary alloy, known for exhibiting a metastable miscibility gap over a wide composition range in the undercooled liquid state, presents a unique microstructural behavior. When small Cu-rich droplets are dispersed within an Fe-rich liquid matrix in the undercooled immiscible liquid region and subsequently solidified in this state, the alloy emerges as a promising candidate for high-temperature latent heat thermal energy storage applications.[1)2)] In such alloys, the Cu-rich phase, encased by an outer shell of Fe-rich solid, can be selectively melted and solidified to utilize latent heat effectively.

Understanding and controlling which phase—Cu-rich or Fe-rich—becomes dispersed or continuous, as well as managing their replacement, shapes, and the number of droplets, require precise measurements of surface tension, interfacial tension, density and viscosity of the liquid phases. To address this, our study focuses on accurately and precisely measuring the thermophysical properties of molten Fe-Cu alloys using electrostatic levitation aboard the International Space Station (ELF-ISS).

2. Experimental procedure

Small spheres of Fe-25at%Cu and Fe-50at%Cu alloys, each approximately 2 mm in diameter, were prepared by arc melting. A positively charged spherical sample was suspended between three pairs of electrodes using electrostatic forces under microgravity conditions using ELF-ISS. The sample was heated and melted by the radiation from semiconductor laser beams from four directions. To minimize the effects of oxygen adsorption on the surface tension of the molten sample, an $Ar\text{-}H_2$ pressurized atmosphere at 2×10^5 Pa was used to lower the oxygen partial pressure of the atmosphere.

The density of each droplet was calculated by dividing the mass of the sample by its volume as determined from the sample image, assuming the molten sample was axisymmetric.

Surface and interfacial tensions were calculated from the frequencies of the surface oscillations of the droplet, based on methodologies proposed by Rayleigh and further developed by Egry et al. These ossifications were induced by superimposing a sinusoidal excitation voltage onto the levitation electric field.

The viscosity of the molten samples was calculated from the damping time of the surface oscillation.

3. Results and discussion

We successfully measured the density, surface tension, and viscosity of molten samples under microgravity conditions. The density of molten Fe-25at%Cu and Fe-50at%Cu alloys linearly decreased with increasing temperatures. An increase in the copper composition led to higher densities, a trend that aligned well with data reported in the literature by Kobatake et al., Watanabe et al., and Vyukhim et al.

The temperature dependence of the surface tension for molten Fe-25at%Cu alloy is slightly convex upward curve, as shown in Fig. 1. A similar temperature-dependent trend was observed for the Fe-50at%Cu alloy sample; however, its surface tension is lower than that of molten Fe-25at%Cu alloy. These measurement results align well with terrestrial studies using the electromagnetic levitation technique. At lower temperatures, copper atoms would tend to segregate at the surface, decreasing the surface tension of molten alloy. As the temperature increases, the melt would experience enhanced mixing. In this scenario, the surface tension may increase with rising temperature, given that the surface tension of pure liquid iron is higher than that of liquid copper.

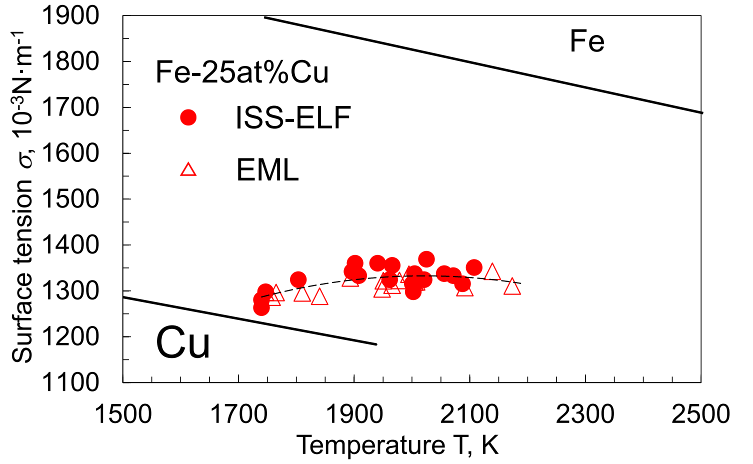

Fig.1	The temperature dependence of the surface tension for molten Fe-25at%Cu alloy

The viscosity of molten Fe-25at%Cu and Fe-50at%Cu alloys are decreased with elevating temperatures as well as those for pure liquid iron and copper. The increase in copper composition lowers the viscosity.

Despite successful measurements of surface tension, density, and viscosity, the interfacial tension between the separated Fe-rich and Cu-rich liquid phases could not be measured due to challenges in exciting surface oscillations at the low temperatures necessary for observing the metastable separation of these phases. The natural frequencies of the two liquid phases, as predicted from ground experiments, may not have been accurately estimated. We hope to further investigate this issue and consider an attempt to measure the interfacial tension under microgravity conditions in the future.

Acknowledgements

This research was partially funded by the Japan Society for the Promotion of Science (JSPS) KAKENHI under Grant No. P20H02453. Additionally, part of this work was supported by a research grant from the Japan Institute of Copper. The authors wish to express their gratitude to the ISS crew members and the ground operation staff for their invaluable support during the onboard experiments.

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