JASMAC
Conference of the Japan Society of Microgravity Application

P18

ISS 搭載 ELF による酸化物融体の液滴振動解析と熱物性の温度依存性

Thermophysical property of molten oxide by oscillating drop method using electrostatic levitation furnace (ELF) in ISS

佐藤令奈[1]，石渡涼[1]，佐藤諒平[1]，清水颯希[1]，羽染博道[1]，渡邉匡人[1]，石川毅彦[2]，小山千尋[2]，
織田裕久[2]，伊藤剛[2]，
Reina SATO[1], Ryo ISHIWATA[1], Ryohei SATO[1], Satsuki SHIMIZU[1], Hiromichi HASOME[1], Masahito WATANABE[1], Takehiko ISHIKAWA[2], Chihiro KOYAMA[2], Hirohisa ODA[2] and Takeshi ITO[2]
[1] 学習院大学理学部, Faculty of Science, Gakushuin University
[2] 宇宙航空研究開発機構，JAXA

1. Introduction

Oscillating drop method under microgravity conditions is very useful for the precise measurements of thermophysical property of high-temperature liquids by the conditions in containerless and non-contacting. Using oscillating drop method, the surface tension is obtained from the frequency of the surface oscillations and the viscosity is obtained from the damping time constant of them. For typically high temperature liquids of molten metals and oxides used in the fields of materials processing, it is required the measurements of thermophysical properties for improvement of processing conditions using computational simulations. Recently, calculation of phase diagram (CALPHAD) system requires combining the thermodynamics data for phase diagram with the thermophysical property data to progress to the useful integrated system for materials research and engineering. For these requirements, the thermophysical property measurement of the molten metals and oxides precisely are important. Adopting oscillating drop method under microgravity conditions, we can recently use the experimental facilities installed in the international space station (ISS) of the electromagnetic levitation (EML)1) and the electrostatic levitation (ESL)2). Now, we are using a levitation facility of ESL called the electrostatic levitation furnace (ELF) installed in ISS-Kibo to measure thermophysical properties of molten oxides3). From our several times ELF experiments using molten oxides samples, we found the followings.

Applying molten oxide to oscillating drop method is difficult for high viscosity of them because quick damping surface oscillation by its high viscosity. For the difficulties, decreasing viscosity in high temperature regions is way to obtain surface oscillation date for thermophysical property measurements. However, we cannot adopt much high temperature conditions for the oscillating drop method because of composition changing molten oxides by increasing evaporation at high temperature. On the other hand, it is difficult to adopt oscillating drop method in the microgravity to precisely measurement of thermophysical properties of samples, which have only the small electric charge on the surface. Since surface oscillation is generated by the translational motions by the periodically external forces, in ESL method Coulomb force with the constant frequency voltage applying into electrodes generates the surface oscillation by the periodically translational motion of levitated molten samples. Achieving this motion of levitated samples in ESL system in the microgravity, the enough charge on the sample surface needs their translational motion with the same frequency of the voltage applying into the electrodes. For the even small charge case, the translational motion of samples delays with the applying electric field frequency, therefore the surface oscillation could not have enough amplitude to detect the damping of oscillations. For these reasons, we are considering to apply resonant oscillation analysis4) for surface oscillation data with changing the excitation oscillation frequency.

In this presentation, we show the results of oscillating drop experiments in ELF using molten and discuss about their features and about applying the resonant oscillation analysis in future.

2. Surface oscillation of levitated molten oxide in ELF under different conditions

We performed the oscillating drop experiments of various compositions molten oxides, SiO_2:CaO:Mn_3O_4:TiO_2 for welding flux and SiO_2:CaO:FeO for steel-refining processes systems, using ELF in ISS with systematically various conditions of the oscillating drop on May 2021 and July 2022. Procedures of the oscillating drop experiments were the same as the previous reports5,6). For the oscillating drop experiments in ELF, the surface oscillation is generated by the voltage applied into the electrodes with the half frequency of the surface oscillations6). **Figure 1** shows the surface oscillation data of molten oxides for SiO_2:CaO:Mn_3O_4:TiO_2=27:7:13:53 wt.% (flux10) and SiO_2:CaO:FeO=10:10:80 wt.% (Ox16) with the different frequency of the electric fields. For flux 10 samples, we obtained an ideal surface oscillation data, which has a single frequency and fitted by a single decay-time constant in amplitude damping regions, for the surface tension and the viscosity acquisitions. On the other hand, for Ox16 samples, their surface oscillation amplitude is smaller than that of flux10, and the amplitude are different with the applying frequency of the electric fields. Applied frequency of 120Hz was large different from the surface oscillation frequency by the surface tension, therefore the amplitude of the surface oscillation was not enough generated. For the case of 160Hz, since the frequency was closed to the surface oscillation frequency by the surface tension, the large amplitude of surface oscillation was generated, and we identified the damping of oscillation. We also found for Ox16 samples the resonant phenomena with changing the applying frequency. Comparting damping time between flux10 and OX16, Ox16 had long time damping of the surface oscillation, this means that Ox16 is low viscosity rather than flux10. Therefore, smaller amplitude of Ox16 with 160Hz even close to resonant frequency rather than that of flux10 would be attributed by the small electric charge on Ox16 surface. **Figure 2** shows an original data of the surface oscillation shown in **Figure 1**. (**Figure 1** was obtained from the processing original data using the bandpass filter.) **Figure 2** was obtained from the intensity changing of 2-dimensional detectors observed the sample by the backlight illuminating6). In ELF system the backlight illuminating to the sample is not completely parallel beams, therefore the intensity was also changed by the translational motion of samples. For the case of the sample position closing to the detector, intensity is decreased and for the case of the sample position far from the detector, intensity is increased. From comparing flux10 and Ox16 intensities during the external force applying, for the case of flux10 intensity changing is almost the same amplitude around the constant value on the other hand for the case of Ox16 large intensity changing is observed during the external force applying. This attribute the difference of the electric charge on the surface7) between flux10 and Ox16. The flux10 droplet had much amount of electric charge on the surface, therefore the position of droplet was kept constant by the electric field by the electrodes and the enough amplitude of the surface oscillation was observed. On the other hand, for Ox16 electric charge amount is smaller for keeping the constant position, therefore applying the external force timing droplet was large translationally moved. Therefore, enough amplitude of the surface oscillation was not observed. From these results, we propose that for small electric charge on the sample surface case, the resonant frequency finding method, in which the surface oscillation is generated by the weak electric fields as the external force with the change of frequency, is applied.

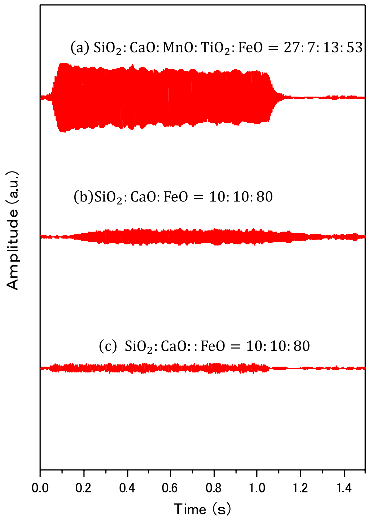

Figure 1. Surface oscillation of molten oxides in ELF: (a) SiO_2:CaO:Mn_3O_4:TiO_2=27:7:13:53 wt.% with 82x2 Hz, (b) SiO_2:CaO:FeO=10:10:80 wt.% with 79x2 Hz and (c) SiO_2:CaO:FeO=10:10:80 wt.% with 60x2 Hz.

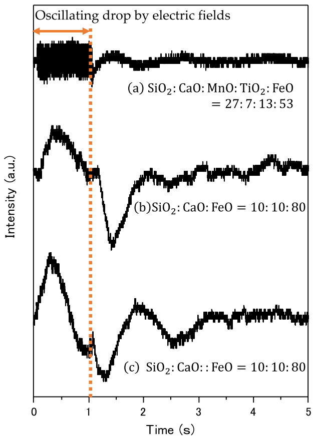

Figure 2. Original data of oscillating drop experiments detected intensity changing on 2-dimensional detector from backlight illuminating samples: (a) SiO_2:CaO:Mn_3O_4:TiO_2=27:7:13:53 wt.%, (b)and (c) SiO_2:CaO:FeO=10:10:80 wt.%.

3. Conclusion

We performed on board experiments of the oscillating drop method under microgravity of $SiO_2:CaO:Mn_3O_4:TiO_2$=27:7:13:53 wt.% and $SiO_2:CaO:FeO$=10:10:80 wt.% systems using ELF in ISS. From the experiments, we obtained the ideal surface oscillation data for the surface tension and the viscosity acquisitions of $SiO_2:CaO:Mn_3O_4:TiO_2$=27:7:13:53 wt.%. On the other hand, the small amplitude of surface oscillation was observed for $SiO_2:CaO:FeO$ system. This was attributed the small electric charge on the surface for $SiO_2:CaO:FeO$ system. For small electric charge samples, we propose the resonant frequency finding method using the weak electric field the external force.

References

1) W. Soellner and W. Aicher: The Electromagnetic Levitator Facility (EML) on Board the ISS, Metallurgy in Space, H.-J. Fecht and M. Mohr Eds, Springer Nature (2022).
2) T. Ishikawa and P.-F. Paradis: Electrostatic Levitation on the ISS, Metallurgy in Space, H.-J. Fecht and M. Mohr Eds, Springer Nature (2022).
3) S. Taguchi, H. Hasome, S. Shimizu, R. Ishiwata, R. Inoue, M. Yamada, M. Watanabe, T. Matsushita, T. Ishikawa, H. Oda, C. Koyama and T. Ito: Temperature Dependence of Molten Oxides Density Measurement using ELF in ISS with Temperature Correction Based on Its Emissivity, Int. J. Microgravity Sci. Appl., in submitted.
4) S. Hakamada, A. Nakamura, M. Watanabe and F. Kargl: Surface Oscillation Phenomena of Aerodynamically Levitated Molten Al_2O_3, Int. J. Microgravity Sci. Appl., **34** (2017) 340403, DOI: https://doi.org/10.15011/ijmsa.34.4_340403
5) C. Koyama, T. Ishikawa, H. Oda, H. Saruwatari, S. Ueno, M. Oshio,Y. Watanabe and Y. Nakata: Densities of liquid lanthanoid sesquioxides measured with the electrostatic levitation furnace in the ISS, J. Amer. Ceram. Soc., **104** (2021) 2913, DOI: http://10.1111/jace.17674.
6) T. Ishikawa, C. Koyama, H. Oda, H. Saruwatari, P.-F. Paradis: Status of the Electrostatic Levitation Furnace in the ISS -Surface Tension and Viscosity Measurements, Int J. Microgravity Sci. Appl., **39** (2022) 390101, DOI: hyyp://doi.org/10.15011/jasma.39.390101.
7) T. Ishikawa, C. Koyama, H. Tamaru, H. Saruwatari, M. Ohshio, Y. Nakamura: Status of the Electrostatic Levitation Furnace in the ISS – Evaluation of Sample Position Control–, Int J. Microgravity Sci. Appl., **35** (2018) 350205, DOI: https://doi.org/10.15011//jasma.35.350205.