JASMAC Conference of the Japan Society of Microgravity Appllication

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Fe 二元系合金融体の表面張力に対する温度・組成・酸素の影響

Effects of Temperature, Composition, and Oxygen on Surface Tension of Molten Fe-based Binary Alloys

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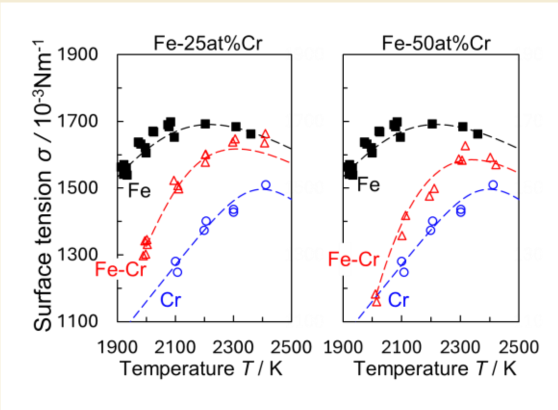

Abstract: The surface tension of molten Fe–Cr binary alloys was measured using electromagnetic levitation (EML) under controlled oxygen partial pressure of $P_{O_2} \approx 10^{-5}$ Pa. This method avoids contamination of the sample from the supporting materials and enables evaluation of oxygen adsorption effects. All molten alloys exhibited an upward-convex-shaped temperature dependence of surface tension, similar to pure iron and chromium, due to temperature-dependent oxygen adsorption and desorption. At high temperatures, surface tension approached the composition-weighted average of the pure metals, while at lower temperatures it approached that of pure chromium. This tendency was more pronounced with increasing chromium content, reflecting its higher oxygen affinity.

Keywords: Surface tension, High–temperature melt, Marangoni convection, Oxygen adsorption

1. Introduction

Surface tension plays a critical role in various high-temperature melt processes involving a free surface, such as welding and brazing, because it serves as the driving force for Marangoni convection[1]. This convection strongly influences the solidification geometry, microstructure, and overall material integrity[2, 3]. Accurate values of surface tension and its temperature coefficient are therefore essential for improving and optimizing these processes through numerical modeling.

Electromagnetic levitation (EML) has been recently employed for accurate and precise surface tension measurements, as it eliminates contamination from supporting materials even at elevated temperatures and allows the influence of oxygen adsorption from the atmosphere to be evaluated[4-7]. However, most previous measurements have focused on pure metallic melts, and data for molten alloys remain scarce.

In this study, we focused on Fe-based binary alloys, which are important structural materials often joined by welding, and investigated the relationship among surface tension, temperature, composition, and oxygen partial pressure in molten Fe–Cr binary alloys.

2. Experimental procedure

Fe-Cr binary alloys were prepared by arc melting from high-purity iron and chromium, each with a purity of 99.9 mass% or higher. The ingots were cut into nearly cubic pieces of about 1 g, and then chemically etched in a Nital solution using an ultrasonic cleaner, followed by rinsing in acetone. A sample was electromagnetically levitated and subsequently melted under a flowing mixture of Ar–He–H_2–CO_2 gases at 2 L·min^{-1}. The oxygen partial pressure (P_{O_2}) of the gas was controlled *via* the gas-phase equilibrium between H_2 and CO_2, and confirmed at the gas inlet using a zirconia-type oxygen sensor operated at 1008 K, accounting for the temperature dependence of P_{O_2}. The droplet temperature was controlled by adjusting the partial pressures of argon and helium gases, which have different thermal conductivities, using a monochromatic pyrometer. After both droplet temperature and P_{O_2} stabilized, the oscillation behavior of the droplet was recorded from above using a high-speed video (HSV) camera. The oscillation frequencies of m = 0, ±1, and ±2 for the l = 2 mode and the translational modes were obtained *via* fast Fourier transformation (FFT) of the HSV image sequences[8-10]. Surface tension of molten samples was calculated from these frequencies using the Rayleigh[11] equation, with calibration according to Cummings and Blackburn[12].

3. Results and discussion

Figure 1 shows the surface tension of molten Fe–25 at% Cr, Fe–50 at% Cr, and Fe–75 at% Cr alloys measured under $P_{O_2} \approx 10^{-5}$ Pa. For comparison, the surface tension of molten pure iron and chromium measured under the same P_{O_2} are also shown. The surface tension of both molten iron and chromium exhibit an upward-convex ("boomerang-shaped") temperature dependence, which is attributed to temperature-dependent oxygen adsorption reaction. Oxygen adsorption lowers the surface tension at lower temperatures, but as temperature increases, oxygen gradually desorbs from the melt surface, leading to a temporary increase in surface tension. Once oxygen adsorption becomes negligible at high temperatures, surface tension decreases with further temperature rise.

Molten Fe–Cr alloys show a similar upward-convex dependence, consistent with the behavior of pure molten iron and chromium. At high temperatures, their surface tensions are close to the composition-weighted average of the pure metals, whereas at lower temperatures they approach that of pure chromium. This tendency becomes more pronounced with increasing chromium content, likely due to the higher oxygen affinity of chromium compared to iron and the greater favorability of oxygen adsorption at lower temperatures.

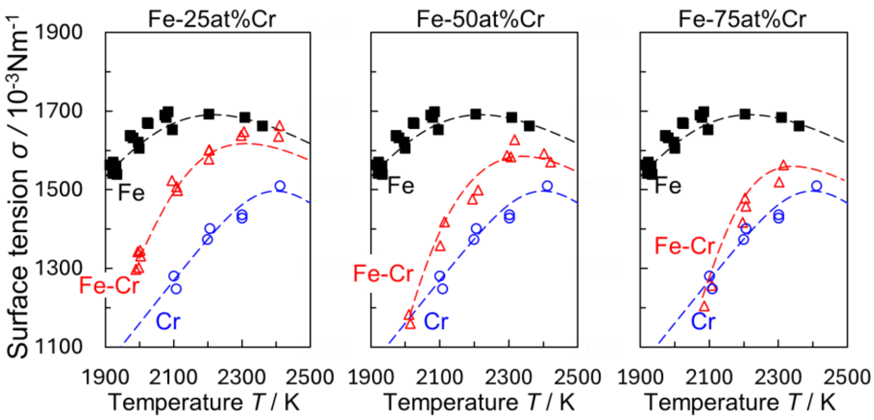

Figure 1. Surface tension of molten Fe–25 at% Cr, Fe–50 at% Cr, Fe–75 at% Cr alloys measured at $P_{O_2} \approx 10^{-5}$ Pa, along with that of molten pure iron and chromium measured under the same P_{O_2} condition.

4. Conclusions

The surface tension of molten Fe–Cr binary alloys was measured using electromagnetic levitation under controlled oxygen partial pressures. All compositions exhibited an upward-convex temperature dependence of surface tension, similar to that observed for pure molten iron and chromium, due to temperature-dependent oxygen adsorption and desorption at the melt surface. At high temperatures, the surface tension of the alloys approached the composition-weighted average of the pure metals, whereas at lower temperatures it approached that of pure chromium, with the effect becoming more pronounced as chromium content increased.

Acknowledgments

This work was partially supported by JSPS KAKENHI under Grant No. 20H02453. Part of the results was obtained through the Basic Research Utilization Program for materials research using the Electrostatic Levitation Furnace onboard the Kibo module of the International Space Station, as part of a call for proposals issued by JAXA.

Conflicts of Interest

The authors declare no conflict of interest.

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