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Fe–Cr 合金融体の表面張力に及ぼす組成と酸素吸着の影響

Effects of Composition and Oxygen Adsorption on Surface Tension of Molten Fe–Cr Alloys

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1. Introduction

Welding of stainless steel is indispensable for the manufacture of structures in various fields. In heavy and medium industries, such as shipbuilding, automotive, pipelines, and pressure vessels, welding is often performed using shielding gases like CO_2, typically in combination with other gases. This technique, known as Metal Active Gas（MAG）welding, is used to protect the weld pool from atmospheric contamination. The presence of CO_2 gas stabilizes the welding arc through a thermal pinch effect, as its decomposition reaction is endothermic. The gas also contributes to achieve deeper weld penetration. This is because the adsorption of oxygen, generated by the decomposition reaction, induces an inward flow in the weld pool by altering its surface tension. However, the effect of oxygen adsorption on the surface tension of high-melting-point materials, such as stainless steels, has not been fully investigated. This is primarily due to the difficultly of preventing contamination of the sample from the supporting materials at elevated temperatures when using conventional container techniques.

In this study, we measured the surface tension of molten Fe–Cr alloy, which are the main components of stainless steels, under a containerless condition by the oscillating droplet method using electromagnetic levitation. The purpose of this study was to examine the effects of sample composition, temperature, and oxygen adsorption on the surface tension of the molten sample.

2. Experimental procedure

An ingot of Fe–Cr alloy was prepared from high-purity iron and chromium, each with a purity of 99.9 mass% or higher. The ingot was cut into a nearly cubic shape with a mass of about 1 g, and then chemically etched in a Nital solution using an ultrasonic cleaning machine, followed by cleaning with acetone. The sample was electromagnetically levitated and then melted under a mixed gas of Ar–He–H_2–CO_2 flowing at a rate of 2L/min. The oxygen partial pressure of the gas (P_{O_2}) was controlled through the gas phase equilibrium between H_2 and CO_2. To confirm the P_{O_2} of the inlet gas, a zirconia-type oxygen sensor was used, operating at 1008 K, considering the temperature dependence of the P_{O_2} of the gas. The temperature of the droplet was controlled by varying the partial pressures of argon and helium gases, which have different thermal conductivities, using a monochromatic pyrometer. After the indicated temperature and P_{O_2} values had become constant, the oscillation behavior of the droplet was observed from above using a high-speed video (HSV) camera. The frequencies of the surface oscillations and those of the center of gravity were analyzed from time-sequenced data of the HSV images using fast Fourier transformation (FFT). The surface tension of molten Fe-Cr alloy was calculated from these frequencies using the Rayleigh equation [1)], calibrated with the Cummings and Blackburn equation [2)].

3. Results and Discussion

Figure 1 displays the surface tension of molten Fe–Cr alloys, measured by EML at a P_{O_2} of 10^{-6}. As the sample temperature rises, the surface tension of molten iron increases up to about 2100 K, after which it begins to decrease. Although oxygen adsorption decreases the surface tension of molten iron at lower temperatures, oxygen desorbs from the melt surface with increasing temperature due to the exothermic nature of its adsorption reaction. This leads to a rise in surface tension, approaching the pure state value of surface tension. Consequently, the surface tension decreases above about 2150 K, when oxygen adsorption becomes less effective.

In the Fe-Cr alloy, an increase in chromium content leads to decrease in surface tension. However, an increase in the surface tension with temperature is consistently observed regardless of the sample composition. This result can be linked to the inward flow observed in MAG weld pool. The surface tension of molten alloy is the highest at the high temperature region of the pool center and lowest at the low temperature region of the pool edges. In this case the thermocapillary Marangoni convection flows radially from the edge to the center in a weld pool.

4. Summary

The effect of temperature, sample composition and oxygen adsorption on the surface tension of molten Fe-Cr alloys were measured by oscillating droplet method using EML at P_{O_2} of 10^{-6} Pa. The surface tension of molten alloy increases with increasing temperature due to oxygen adsorption and desorption reaction, regardless of sample composition. The surface tension of molten Fe–Cr alloy was decreased as the chromium content was increased.

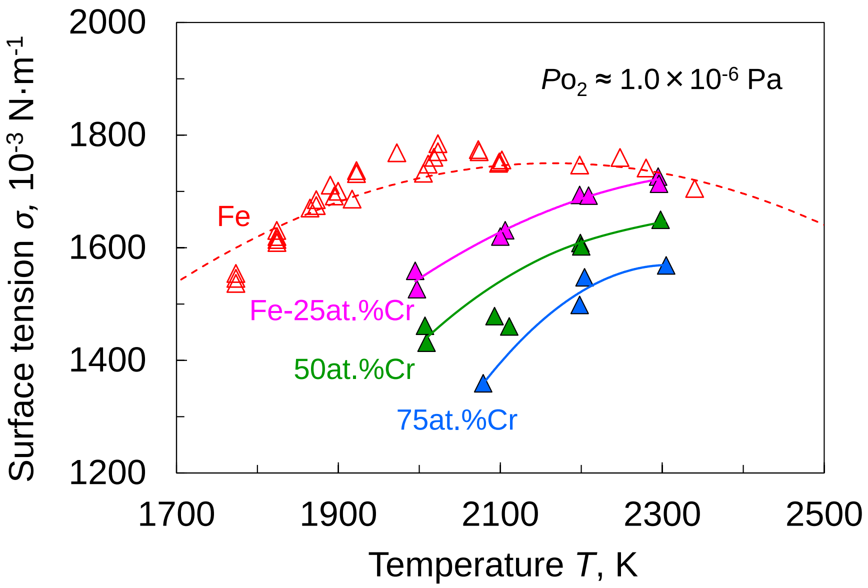

Figure 1. Surface tension of molten Fe-Cr alloys measured under the Po_2 of 1.0×10^{-6} Pa, as functions of temperature and sample composition

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References

1) Lord Rayleigh: On the Capillary Phenomena of Jets. Proc. R. Soc. Lond., 29 (1879) 71,DOI: https://doi.org/10.1098/rspl.1879.0015
2) D.L. Cummings, D.A. Blackburn: Oscillations of magnetically levitated aspherical droplets. J. Fluid Mech, 224 (1991) 395, DOI: https://doi.org/10.1017/S0022112091001817