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電磁浮遊法を用いた Al および Al-Si 融体の表面張力測定

Surface Tension Measurement of Molten Al and Al-Si Alloys Using Electromagnetic Levitation

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1. Introduction

Al-Si alloys are utilized in various products manufactured through high-temperature melt processes such as casting, additive manufacturing, and brazing, due to their unique properties including low density, high thermal conductivity, low thermal expansion, and excellent heat and wear resistance. Despite the critical role of surface tension in optimizing these processes, the relationship between the surface tension of molten Al-Si alloys, temperature, and composition remains poorly understood. Even for pure aluminum and silicon, the fundamental components of these alloys, significant discrepancies are observed in reported surface tension values. Notably, our group has recently reported accurate and precise surface tension data for liquid silicon by completely preventing sample contamination from the container and considering the effect of oxygen adsorption from atmosphere. The large discrepancies in the reported data for the surface tension of liquid aluminum may be attributed to challenges in suppressing oxidation in the easily oxidizable aluminum and contamination from containers at high temperatures.

In this study, we measured the surface tension of molten Al-Si alloys, ensuring free of sample sample contamination from the container, using the oscillating droplet method with electromagnetic levitation (EML). This approach accounted for the effects of sample evaporation and oxygen adsorption. The aim of this study was to elucidate the relationship between surface tension, temperature, and alloy composition.

2. Experimental procedure

Al-Si alloys were prepared through arc melting using high-purity raw materials of 99.99 mass% aluminum and semiconductor-grade silicon with an electrical resistance of 3200 Ω cm, under high-purity argon gas at an oxygen partial pressure (Po2) of 10-7 atm. The resultant Al-Si alloy was cut into rectangular samples measuring 5x5x6 mm and each weighed approximately 400 mg. These samples were chemically cleaned in an aqueous solution of nitric fluoride and subsequently cleaned with acetone using an ultrasonic cleaner. A piece of the sample was then placed on a quartz holder inside the electromagnetic levitation (EML) chamber. After the atmosphere within the chamber was replaced with a high-purity Ar-He gas mixture at Po2 of 10-7 atm, the sample was electromagnetically levitated and melted under the gas flowing at a rate of 2 L/min. Semiconductor laser heating was superimposed on the levitated sample to enhance heating. The temperature of the levitated droplet was controlled by varying the output power of the laser, and the partial pressure of argon and helium gases. A monochromatic pyrometer was used to measure the temperature of the levitated droplet. The emissivity setting of the pyrometer was adjusted so that the plateau temperature observed during remelting the sample in repeated melting and solidification cycles matches the equilibrium liquidus temperature of the alloy. The oscillation behavior of the droplet was monitored from above at 500 fps for 16 sec using a high- speed camera. The frequencies of the surface oscillations of m = 0, ±1, and ±2 for the l = 2 mode, and those of the center of gravity were analyzed from time-sequential data of the HSV images. The surface tension of the droplet was calculated from the frequencies using the Rayleigh equation[1)] and the Cummings and Blackburn calibration[2)].

3. Results and Discussion

Figure 1 illustrates the typical temperature history of a pure aluminum sample that was repeatedly melted and solidified using EML. The pyrometer signal becomes corrupted at around 55 seconds as the sample begins to melt. The detected temperature is higher than that of the equilibrium melting point of aluminum (933 K) due to the presence of an oxide layer with higher emissivity. Once all the solid aluminum has melted, the temperature readings stabilizes with reduced signal noise. However, at around 95 seconds, the signal becomes largely corrupted again as the Al2O3 oxide layer gradually disappear through the high temperature reaction: Al2O3 →Al2O(g)+O2(g).

When the molten sample cools, it experiences a large undercooling followed by recalescence, observed around 180 seconds. Upon subsequent remelting of the solidified sample, the pyrometer signal reflects the equilibrium melting point of aluminum, closely matching the maximum temperature noted after recalescence. These observations underscore the importance of removing the oxide layer for accurate and precise temperature measurements of molten aluminum alloys using a pyrometer.

Figure 2 shows the surface tension of molten Al-Si alloys as a function of temperature and sample composition. The surface tension of liquid aluminum decreases linearly with increasing temperature. The absolute values and the temperature coefficient of surface tension measured in this study align well with those reported by Pottlacher's group.

The surface tension molten Al-Si alloys also decrease as the sample temperature rises. An increase in silicon composition lowers the surface tension and the absolute value of the temperature coefficient. This reduction in surface tension, observed with increasing Si composition, exhibits additive behavior across the measured temperature range.

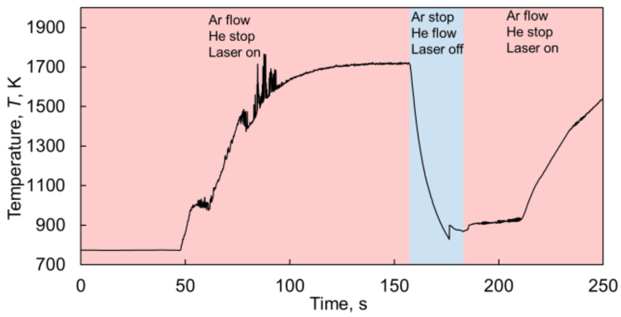

Figure 1 Typical temperature history of a pure aluminum sample that was repeatedly melted and solidified using EML.

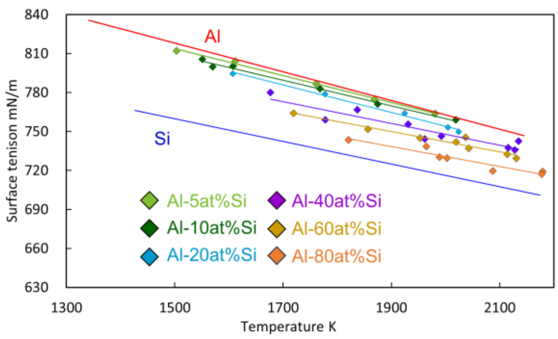

Figure 2 Surface tension of molten Al-Si alloys as a function of temperature and sample composition.

Acknowledgements

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