The Wettability of Molten Al and Sn on Solid Substrates Under High Magnetic Fields

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Abstract: This study investigated the wetting behavior of molten Al (paramagnetic) and Sn (antimagnetic) on Al2O3 and SiO2 substrates under high magnetic fields. It was observed that the contact angles of the Sn/Al2O3 and Al/Al2O3 systems both significantly decreased under high magnetic fields. The contact angle of the Sn/Al2O3 system exhibited a linear decrease with the increase in magnetic flux density, while the Al/Al2O3 system showed a non-linear decrease. With or without a high magnetic field, the contact angles of the Al/Al2O3 system both decreased with the increase in temperature. Without a high magnetic field, the contact angles in the Sn/Al2O3 system decreased with temperature, whereas under high magnetic fields, they increased with temperature. Additionally, at different isothermal temperatures, as the magnetic flux density increased, the contact angle of the Al/SiO2 system gradually decreased. Whereas, there was no clear pattern of change in the contact angle of the Sn/SiO2 system. Specifically, at an isothermal temperature of 263 °C, as the magnetic flux density gradually increased, the contact angle of the Sn/SiO2 system gradually increased. Furthermore, high magnetic fields, in conjunction with material characteristics and temperature, couples to influence the wetting behavior of molten metal on a solid substrate.

Keywords: Wettability; High magnetic fields; Molten metal; Ceramics; Contact angle

1 Introduction

Wettability is a major parameter in the fields of materials, metallurgy, biology, and manufacturing. The contact angle (θ), which is a measure of wettability, can be derived from Young's equation [1]. Wettability can be modified by increasing the temperature [2], modifying the ambient atmosphere [3] or substrate surface properties [4], or by adding active elements to molten metal [5]. However, these techniques may alter the intrinsic characteristics of a system or fall short of meeting practical usage requirements. Therefore, there is an urgent need to develop new methods of modifying wettability, possibly based on novel mechanisms.

Recently, high magnetic fields, considered a form of high-energy physics field, have been shown to change solid-liquid and liquid-vapor interfacial energy [6, 7]. Therefore, utilizing a high magnetic field to regulate wetting behavior is highly feasible.

The present study assessed variations in the contact angle of molten Al and Sn on Al_2O_3 and SiO_2 substrates in conjunction with high magnetic fields. This work examined the effects of magnetic flux density and isothermal temperature on wettability.

2 Experimental procedure

In this experiment, Al and Sn cylinders with dimensions of φ3 mm × 3 mm were selected as the molten metal. The substrate materials chosen were single-sided polished Al_2O_3 and SiO_2 substrates with a purity of 99.99 wt.% and dimensions of 20 × 20 × 3 mm³. The experiment utilized a custom-designed contact angle measurement device under HMFs [8]. Prior to each trial, the substrates and metals were cleaned by ultrasonication in alcoholic, following which the specimens were placed in the vacuum chamber of the apparatus and the chamber was evacuated to a pressure of 4.0×10^{-4} Pa. Subsequently, the superconducting magnet was initiated, and the required magnetic flux density was applied to the apparatus. Finally, the chamber was heated to the required isothermal temperature after which this temperature was maintained for 30 min. Real-time observations were performed during this period while photographic images were captured using a charge coupled device camera. The equipment was then allowed to naturally cool and, when the furnace temperature dropped below the melting point of the molten metal, the superconducting magnet was turned off. Upon further cooling to room temperature, the vacuum system was vented and the sample was retrieved.

3 Result and discussion

Figure 1 shows that after utilizing a 6 T magnetic field,

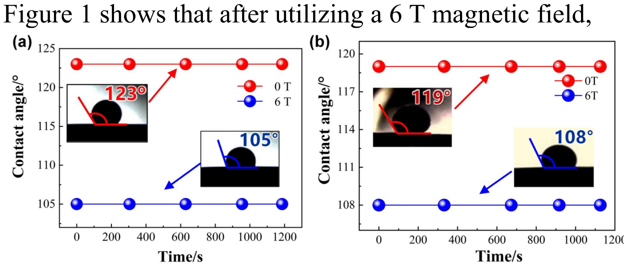

Figure 1. The changes in contact angles of molten (a) Al and (b) Sn on an Al_2O_3 substrate with increasing isothermal time in the presence or absence of a high magnetic field.

the equilibrium contact angles of molten Al and Sn on the Al_2O_3 substrate significantly decreased, reducing by 18°

and 11° respectively. Additionally, the morphology of molten Al and Sn transformed from spherical when no magnetic field was present to flattened spheres under a 6 T high magnetic field**.**

Figure 2 shows that the contact angle of the Sn/Al_2O_3 system exhibited a linear decrease with the increase in magnetic flux density, while the Al/Al_2O_3 system showed a non-linear decrease.

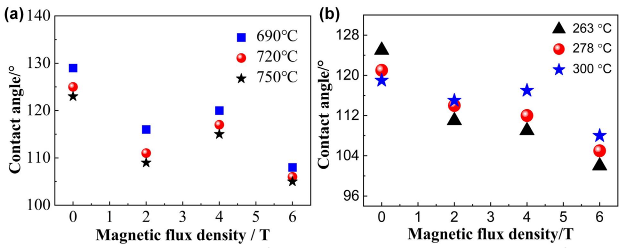

Figure 2. The variation of contact angles with magnetic field intensity for (a) Al/Al_2O_3 and (b) Sn/Al_2O_3 systems at different isothermal temperatures.

Figure 3 shows that the contact angle of the Al/Al_2O_3 system decreased with increasing isothermal temperature regardless of the presence of a high magnetic field. Conversely, in the absence of a high magnetic field, the contact angles in the Sn/Al_2O_3 system decreased with temperature, while under high magnetic fields, they increased with isothermal temperature.

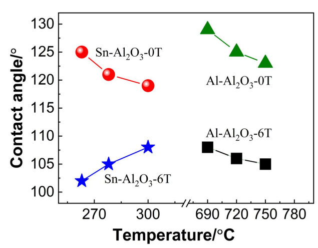

Figure 3. The variation of contact angles of molten Al and Sn on Al2O3 substrates with increasing isothermal temperature in the presence or absence of a high magnetic field.

Figure 4 shows that at different isothermal temperatures, as the magnetic flux density increased, the contact angle of the Al/SiO_2 system gradually decreased. In contrast, there was no clear pattern of change in the contact angle of the Sn/SiO_2 system.

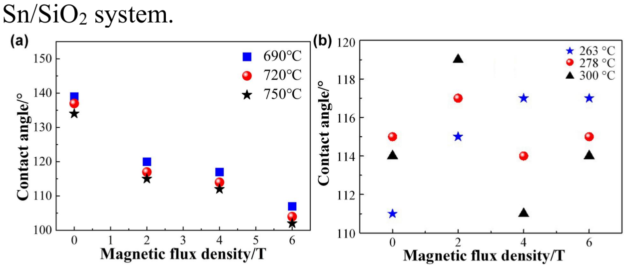

Figure 4. The variation of contact angles with magnetic field intensity for (a) Al/SiO_2 and (b) Sn/SiO_2 systems at different isothermal temperatures.

Specifically, Figure 5 shows that at an isothermal temperature of 263 °C, as the magnetic flux density gradually increased, the contact angle of the Sn/SiO_2 system gradually increased.

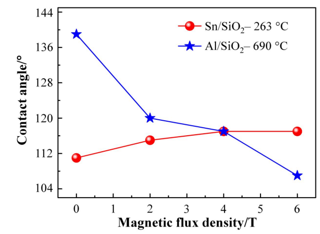

Figure 5. The variation of contact angles with magnetic field intensity for Al/SiO_2 at 690 °C and Sn/Al_2O_3 at 263 °C.

4 Conclusion

The utilization of high magnetic fields significantly affected the wettability of two molten metals with opposite magnetic properties on different substrates, generally leading to a decrease in contact angle. Additionally, magnetic flux density, material characteristics, and temperature collectively affected wettability.

5 Acknowledgments

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