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Wetting behavior of aluminium and filtration with Al_2O_3 and SiC ceramic foam filters

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Abstract: The wetting behavior between liquid aluminium and substrates made from industrial Al_2O_3 and SiC based ceramic foam filters (CFF) was investigated. The same CFF filters were also tested in plant scale filtration experiments. The wetting experiment results show that the SiC based filter material is better wetted by liquid aluminium than the Al_2O_3 based filter material. This indicates that the improved wetting of aluminium on a filter material is an advantage for molten metal to infiltrate the filter during priming. Also, better wetting of Al-filter might increase the removal efficiency of inclusions during filtration due to better contact between filter and metal. Non-wetted inclusions are easier to be removed.

Key words: filtration; wettability; aluminium; Al_2O_3 filter; SiC filter; Al_2O_3 inclusion; Al_4C_3 inclusion

1 Introduction

Filtration is one of the most typical refining processes to eliminate the undesired impurities from aluminium alloys. The filtration process has a complex mechanism influenced by hydrodynamic factors such as fluid flow, turbulence, surface and body forces, as well as chemical and metallurgical interactions among the inclusions [1], the filter media [2], and the liquid metal [3]. In this work, the wetting behaviour of aluminium, as a combination of surface and body forces, was investigated to improve the aluminium filtration.

There are two sequential events for inclusion removal: 1) transport of inclusion to the filter inner wall, and 2) attachment of inclusions to the wall. The wetting between aluminium and filter may change the fluid flow pattern, as well as inclusions in the fluid. Aluminium may push inclusions towards the filter wall, where inclusions can be captured. If the viscous drag on inclusion is not higher than the capture forces, the inclusions will be retained on the filter walls. Hereby, the wetting factors can be divided into two factors: the wetting of Al-inclusion and the wetting of the Al-filter.

This work focuses on the wetting of Al-inclusion (Al_2O_3 and Al_4C_3) and Al-filter (Al_2O_3 and SiC based filter), and its influence on the aluminium filtration behaviour.

Al_2O_3 and Al_4C_3 are two of the most typical inclusions in aluminium. In a previous work, BAO et al [4] had investigated the wetting between aluminium and various solid substrates. The contact angle of molten aluminium on alumina and graphite had been measured in high vacuum of 1.01325×10^{-3} Pa in the temperature range of 1000−1300 °C. Aluminium is readily oxidized (Reaction (1)) even if the oxygen partial pressure is as low as 1.01325×10^{-44} Pa at the filtration temperature of 700 °C [5]. Such a low oxygen partial pressure is difficult to be achieved experimentally. Nevertheless, the oxide layer on the surface of a molten aluminium drop can be removed, if the outgoing flow of gaseous Al_2O, according to Reaction (2), is greater than the incoming flow of oxygen. The equilibrium partial pressure of Al_2O, according to Reaction (2), is 4.357 Pa at 1000 °C. Since BAO et al [4] held the total pressure in the furnace under 1.01325×10^{-3} Pa, the oxide skin on the aluminium drop evaporated. This makes it possible to measure the contact angles between molten aluminium and substrates without an oxide skin on the aluminium. To describe the wetting behaviour of the Al-inclusion system at lower

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temperatures used in filtration and casting aluminium, a semi-empirical calculation was employed. The calculated contact angles at 700 °C are around 97° for alumina and 92° for vitreous graphite. It is also stated that the wettability of these systems with respect to time goes through steps of 1) de-oxidation of the alumina layer, 2) surface reactions: Al_4C_3 formation, and 3) the stable contact on the interface [6]. In conclusion, Al_2O_3 and Al_4C_3 inclusions both are non-wetted by aluminum at the casting temperature.

$$4Al(l)+3O_2 \rightarrow 2Al_2O_3 \tag{1}$$

$$Al(l)+Al_2O_3 \rightarrow 3Al_2O(g) \tag{2}$$

In the present work, the contact angle between molten aluminium and two types of ceramic foam filter materials at 1100 °C and 1200 °C was measured using the same sessile drop technique as used in an earlier study [4]. Four filtration experiments using two types of CFF filters were carried out and were presented here. The inclusion removal in the same two types of filter was discussed.

2 Experimental

The filters are shown in Fig. 1. These two types of filters were produced in the same production line by the same filter manufacturer, giving similar porosity and wall thickness. The Al_2O_3 based filter contains 85%−90% of Al_2O_3, approximately 6% of P_2O_5, approximately 6% of SiO_2, and approximately 1% of K_2O+Na_2O (mass fraction). The SiC based filter contains 58%−64% of SiC, 5%−9% of Al_2O_3, and 29%−33% of SiO_2. The wettability of the same sintered flat materials received from the same supplier was tested in the wetting furnace. No grinding was involved. The wetting apparatus essentially consisted of a horizontal graphite tube, where aluminium on the substrate was placed, surrounded by graphite radiation shields for heating, located in a water-cooled vacuum chamber. The chamber was fitted with windows to allow a digital video camera (Sony XCD-SX910CR) to record the shape of the droplet. The contact angles and linear dimensions of the images were measured directly from the image of the drop using Video Drop Shape Analysis software. We assumed symmetry of the drop. After the experiments no asymmetry was observed.

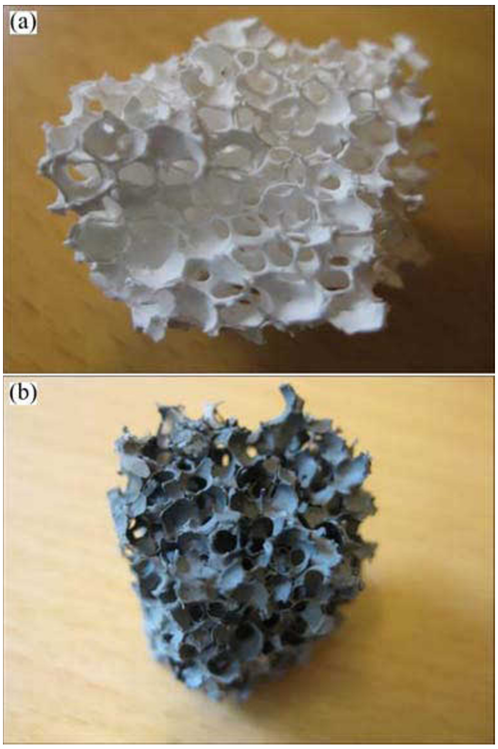

Fig. 1 Morphologies Al_2O_3 based filter (a) and SiC based filter (b)

The wetting experiments were carried out with the substrate of 99.999% pure aluminium (mass fraction). The aluminium rod with a diameter of 2 mm was cut into small pieces around 2 mm in length, then polished by 30 μm sandpaper and cleaned with ethanol in order to prevent further oxidation. When the wetting furnace attained a vacuum of 1.01325×10^{-3} Pa, the sample was quickly heated to 950 °C in about 80 s to remove the oxide layer, and then heated to 1100 and 1200 °C at a heating rate of 50 °C/min. In all the experiments, the contact angle of the droplet was recorded simultaneously during the isothermal period at 1100 and 1200 °C.

Four plant scale filtration experiments were performed with these two types of 10"×10"×2", 30ppi filters: Experiments 1 and 3 with the Al_2O_3 based filter and Experiments 2 and 4 with the SiC based filter. All experiments lasted for 1 h. The aluminium alloy contained approximately 1.00% of Mg, 0.14% of Fe, and 0.07% of Si (mass fraction). The contents of other elements were all less than 0.05%. Two Liquid Metal Cleanliness Analysers (LiMCA) II [7] which gave on-line information for inclusion level were positioned before and after the filter. Two lasers positioned before and after the filter bowl gave the metal height (pressure drop) in the launder. Finally, a thermocouple positioned in the launder measured the temperature after the filter. The filter in the filter bowl was preheated by a gas burner in the lid to avoid thermal shock and freezing of the metal when filtration started. When the metal primed the filter, it filled the lower space of the filter bowl, and went out into the launder again, as indicated in Fig. 2. In 1 h filtration, three groups of PoDFA samples were taken at time 0 min, 30 min, and 60 min before and after the filter. 1.25 kg of metal was pushed through the PoDFA filter disk with under pressure. The surface area of the inclusions and the types of the inclusions were examined after it solidified.