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Effect of Oxidation on the Wettability Change with Metal Surfaces

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1. Introduction

In the nuclear reactor systems, critical heat flux (CHF) and nucleate boiling heat transfer coefficient (NBHTC) are considered as criteria of thermal safety margin and efficiency of the power plants, respectively [1]. Regardless of the long history in this research area, it is still difficult to understand both phenomena due to complexity of respective mechanism in the boiling heat transfer. Recently, wettability change on the surface has known to affect the boiling heat transfer significantly. Thus, in order to understand effect of wettability change on the boiling phenomena, oxidation effect on the wettability change on the metal surface is investigated experimentally, which helps understanding the characteristics of the CHF and NBHTC during the oxidation process.

2. Effect of the wettability in the nucleate boiling

2.1 Influence of the wettability during nucleate boiling

Pioro et al. reviewed major parameters affecting heat transfer during nucleate pool-boiling. The parameters of interest include heat flux, saturation pressure, and thermophysical properties [2]. Unlike the thermo-physical properties of a working fluid, the effects of surface characteristics are not in a comprehensive step of quantification.

Phan et al. investigated the effects of surface wettability on pool boiling heat transfer [3]. They suggested concepts of the macro- and micro- contact angles. Focusing on the macro-contact angle, it was suggested that a new correlation dealing with the bubble departure diameter as a function of the contact angle. In addition, it was mentioned that the optimum of HTCs occurs at contact angles of 90^o and 0^o. They concluded that the contact angle suggested is the major parameter affecting the CHF and HTC.

Patil and Vittala reviewed the boiling behavior in terms of surface energy [4]. Their results showed that the HTC enhancement was observed with increasing in surface energy for distilled water. On the other hand, the HTC decreased with increasing in surface energy for alcohols.

In the present study, contact angles on stainless steel grade 316 surfaces with and without oxidation have been measured to evaluate wettability change.

2.2 Surface energy

As mentioned earlier, contact angle is one of the key parameters to determine the degree of wettability. For several decades, many researchers have studied to explain wettability qualitatively and quantitatively. The Young's equation shows a relationship between contact angle and surface energy as given below in terms of the interfacial surface energies of σ_{sv}, σ_{lv}, and γ_{sl}.

$$\sigma_{sv} = \gamma_{sl} + \sigma_{lv}\cos\theta \quad (1)$$

Eq. (1) could also be modified in a thermodynamics point of view, namely the equation of state as given in Eq. (2), which was determined empirically with abundant contact angle data. This Eq. (2) was implemented in the contact angle measurement software of EasyDrop Contact Angle Instrument of Krüss.

$$\cos\theta = -1 + 2\sqrt{\frac{\sigma_s}{\sigma_l}}e^{-\beta(\sigma_l-\sigma_s)^2} \quad (2)$$

3. Experimental results

Six samples were prepared to measure contact angles. The test material is stainless steel grade 316 and the size of each specimen is 2 cm in length, 1 cm in width, and 0.3 mm in thickness. Two groups of samples were prepared to consider roughness effect and oxidation effect. The first group consists of three specimens oxidized for 0, 4, and 8 hours with pre-etching process before oxidation process. The second group specimens undergo the identical 0, 4, and 8 hours oxidation but without pre-etching process. Note that the oxidation process was performed with pure oxygen at 500 ^{o}C and pre-etching was conducted using hydrochloric acid to change the surface roughness of the sample. A description of the test specimens is listed in Table 1.

Table 1: Description of Six Test Samples

Test ID	Group	Oxidation Time [hour]
SS316-B01	Pre-etching	0
SS316-B02	No etching	0
SS316-B03	Pre-etching	4
SS316-B04	No etching	4
SS316-B05	Pre-etching	8
SS316-B06	No etching	8

After the oxidation process, contact angles of the specimens were measured to evaluate the wettability

changes. 5 ml of sessile water droplets on the stainless steel surfaces were observed using EasyDrop Contact Angle Instrument by Krüss.

In general, a tendency of decreasing in the contact angle was observed for the surfaces experienced the oxidation process. The surfaces with pre-etching process are shown in Fig. 1. In addition, the contact angles on the surfaces without pre-etching process are shown in Fig. 2. Two specimens which experienced oxidation process show remarkably reduced contact angles. The contact angles become nearly 0^{o} for the cases of eight-hour oxidation as shown in Figs. 1 and 2.

In the comparison of two bare surfaces without oxidation, the specimen SS316-B01 which experienced the pre-etching process shows the lower contact angle than the specimen SS316-B02. However its effect becomes negligible when the metal surface is oxidized.

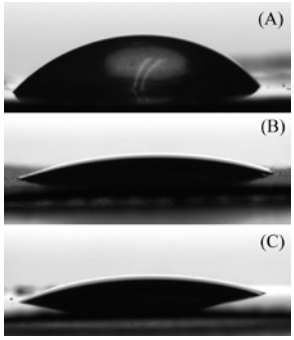

Fig. 1. Visual changes in contact angles on the surface of stainless steel grade 316 with pre-etching process after: (a) no oxidation, (b) 4 hrs oxidation and (c) 8 hrs oxidation.

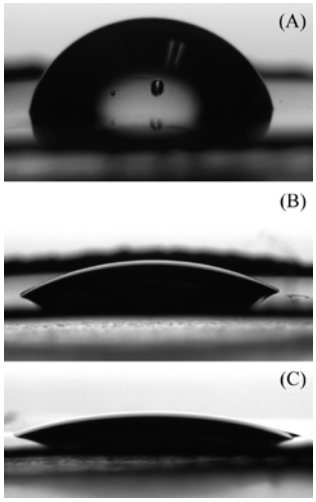

Fig. 2. Visual changes in contact angles on the surface of stainless steel grade 316 without pre-etching process after: (a) no oxidation, (b) 4 hrs oxidation and (c) 8 hrs oxidation.

Figure 3 shows a quantitative comparison and the changes in contact angle as described above. Furthermore, changes in surface energy calculated by Eq. (2) are presented in Fig. 4. It is seen that increase of surface energy becomes saturated when the oxidation time exceeds 4 hours. A more study is needed to explain the saturation of oxidation process.

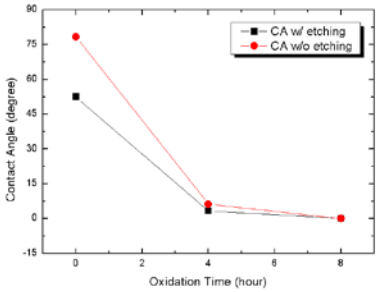

Fig. 3. Variation of contact angle with oxidation time for the cases of pre-etching and no-etching processes

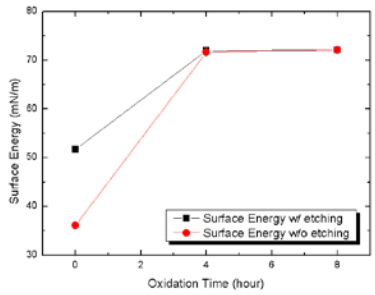

Fig. 4. Variation of surface energy with oxidation time for the cases of pre-etching and no-etching processes

4. Conclusions

The effect of oxidation on the wettability change was investigated by measuring the contact angles on the stainless steel grade 316 surfaces. It is found that the surfaces of the metal surfaces experienced oxidation process become wettable due to the increased surface energy. In addition, the pre-etching treatment increases the surface wettability. However, its effect is saturated at 4-hour of oxidation. It is concluded that both oxidation and etching processes increase the surface wettability.

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