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RADIATION INDUCED SURFACE ACTIVITY PHENOMENON (2nd report: Radiation Induced Boiling Enhancement)

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ABSTRACT

To delineate the effect of Radiation Induced Surface Activity (RISA) on boiling phenomenon, surface wettability in high-temperature environment or Leidenfrost condition and critical heat flux (CHF) of oxide metals irradiated by gamma rays were investigated. When the temperature of the heating surface reaches the wetting limit temperature, water-solid contact vanishes because of a stable vapor film between the droplet and the metal surface, i.e., a Leidenfrost condition. The wetting limit temperature increased with integrated irradiation dose. The CHF of oxidized titanium was improved up to 100% after 800 kGy ^{60}Co gamma ray irradiated. Radiation Induced Boiling Enhancement (RIBE) phenomenon was firstly confirmed through the experiments.

Keywords: Radiation Induced Boiling Enhancement (RIBE), Metal oxides, Critical heat flux, Leidenfrost condition

INTRODUCTION

Improving the limit of boiling heat transfer or critical heat flux requires that the cooling liquid can contact the heating surface, or a high-wettability, highly hydrophilic heating surface, even if a vapor bubble layer is generated on the surface. From this point of view, investigation on surface wettability was performed by use of metal oxides irradiated gamma ray. In our previous study, contact angle, an indicator of macroscopic wettability, was measured by image processing of the images obtained by a CCD video camera. Oxidation on the surfaces was carried out by plasma jetting for 40 seconds. The results showed that the surface wettability on metal oxide pieces of titanium, zircalloy No. 4, SUS-304 and copper improved significantly by Radiation Induced Surface Activity (RISA) phenomenon. Highly hydrophilic conditions on the test pieces were achieved after 500 kGy irradiation of ^{60}Co gamma ray. The contact angle decreased linearly with integrated irradiation. The RISA effect was lost, and the wettability decreased, after the end of irradiation [1].

In this study, the wetting limit temperature and life of a water droplet on the heated surface of a metal oxide pieces were investigated.

EXPERIMENT FOR LEIDENFROST CONDITION

The experiments were conducted using a lead-bismuth pot and a high-speed video camera to check the wettability under high-temperature conditions (Fig. 1). Titanium, SUS-304, zircalloy No. 4 and copper plates of 20×20 mm in surface area and 0.5 mm in thickness were used as the test pieces. Oxidation on the surfaces was carried out by plasma jetting for 40 seconds. An X-ray photoelectron spectroscopy study confirmed that a rigid oxide coating, e.g., rutile TiO_2 for titanium, exists on the metals. The test pieces were irradiated by ^{60}Co gamma rays with set radiation intensity and period. Gamma-ray facilities in the University of Tokyo and Kyoto University, with radiation intensities varing in range of 0.1-20 kGy/hr, were used in the experiment.

Figure 2 shows the phenomena map of the droplet on the surface of oxide-titanium before and after 250 kGy irradiation. When the surface temperature 360^{o}C, the droplet keeps to be spherical and stable film condition is achieved for both before and after irradiation conditions. When 300 ^{o}C, the droplet on the test piece after irradiation loses stable film condition . When 260 ^{o}C, the droplet on irradiated condition splashes into small ones and the temperature for irradiated test piece is already under the limit wetting temperature [2]. When 235 °C, the droplet on the irradiated condition contacts the surface and no splashes, contrary to non irradiated test piece. The phenomena map shows that the criteria temperature or Leidenfrost temperature increases about 50 °C after gamma ray irradiation. When the temperature of the heating surface reaches the wetting limit temperature, water-solid contact vanishes because of a stable vapor film between the droplet and the metal surface, i.e., a Leidenfrost condition. The wetting limit temperature increased with integrated irradiation dose, as shown in Fig. 3-4. The temperature decreased after the end of irradiation , in the same manner as in the room-temperature experiment for contact angle measurements. Observation by camera showed the droplet on a gamma-ray irradiated surface was more stable than that on a non-irradiated surface.

CRITICAL HEAT FLUX EXPERIMENT

CHF experiment in the pool boiling condition under the atmospheric pressure was carried out for the test section was 0. 2 mm in thickness, 3 mm in height, and 60 mm in length (Fig. 5). Oxidation on the surfaces was carried out by plasma jetting for 40 seconds.

Figure 6 shows the critical heat flux of oxide titanium against integrated irradiation dose. The results showed that CHF of oxidized titanium was improved up to 100% after 800 kGy ^{60}Co gamma ray irradiated. We call this effect "Radiation Induced Boiling Enhancement (RIBE)". In the figure, K is defined as Eq. (1) from interfacial stability analysis conducted by Zuber, e.g., K=0.13 is derived [3].

$$q_{max} / \rho_v h_{lg} \left[\sigma g (\rho_l - \rho_v) / \rho_v^2 \right]^{1/4} = K \qquad (1)$$

Before conducting CHF experiment, contact angles of the test pieces were measured to show the relationship between the wettability and CHF. As shown in this Fig. 7, CHF in the present experiment increases with surface wettability in the same manner as Liaw and Dhir's result [4].

CONCLUSION

To delineate the effect of Radiation Induced Surface Activity (RISA) on boiling phenomenon, surface wettability in high-temperature environment or Leidenfrost condition and critical heat flux (CHF) of oxide metals irradiated by gamma rays were investigated. When the temperature of the heating surface reaches the wetting limit temperature, water-solid contact vanishes because of a stable vapor film between the droplet and the metal surface, i.e., a Leidenfrost condition. The wetting limit temperature increased with integrated irradiation dose. The CHF of oxidized titanium was improved up to 100% after 800 kGy ^{60}Co gamma ray irradiated. Radiation Induced Boiling Enhancement (RIBE) phenomenon was firstly confirmed through the experiments.

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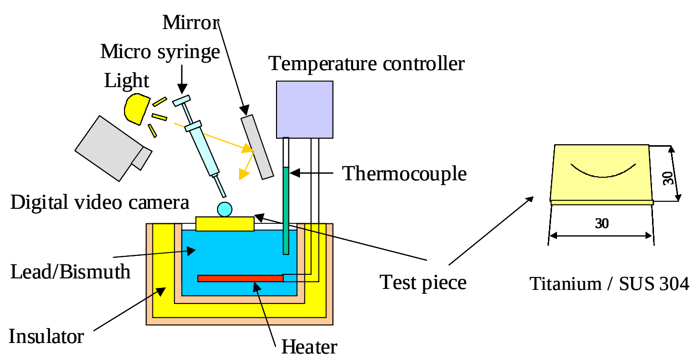

Fig. 1 Apparatus for Leidenfrost condition

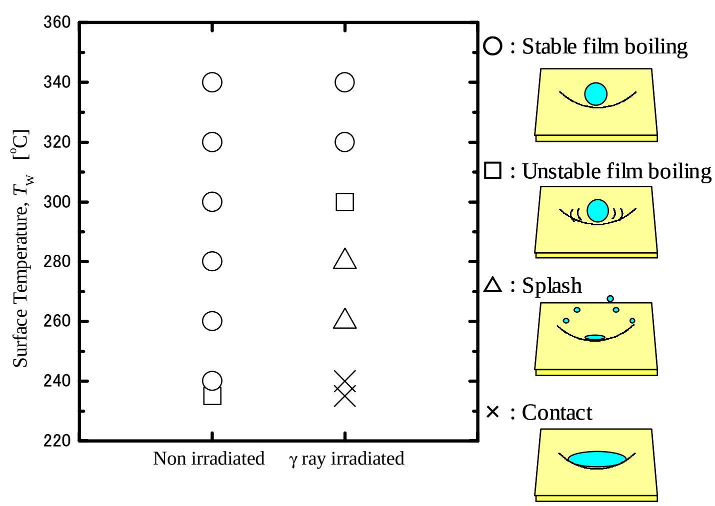

Fig. 2 Phenomena map of Leidenfrost condition (Titanium, before and after 250 kGy γ ray irradiation)

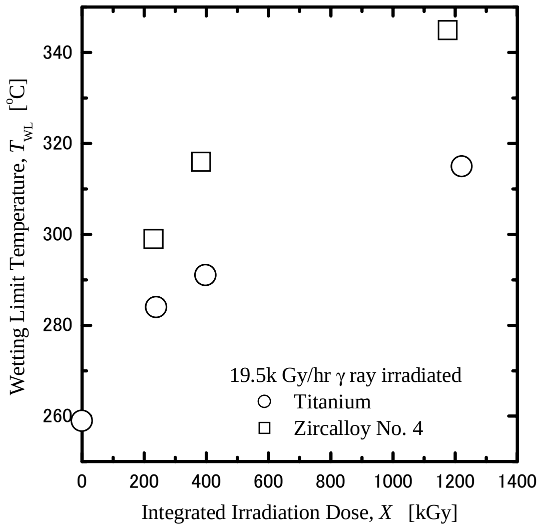

Fig. 3 Effect of integrated irradiation dose on wetting limit temperature (19.5 kGy/hr)

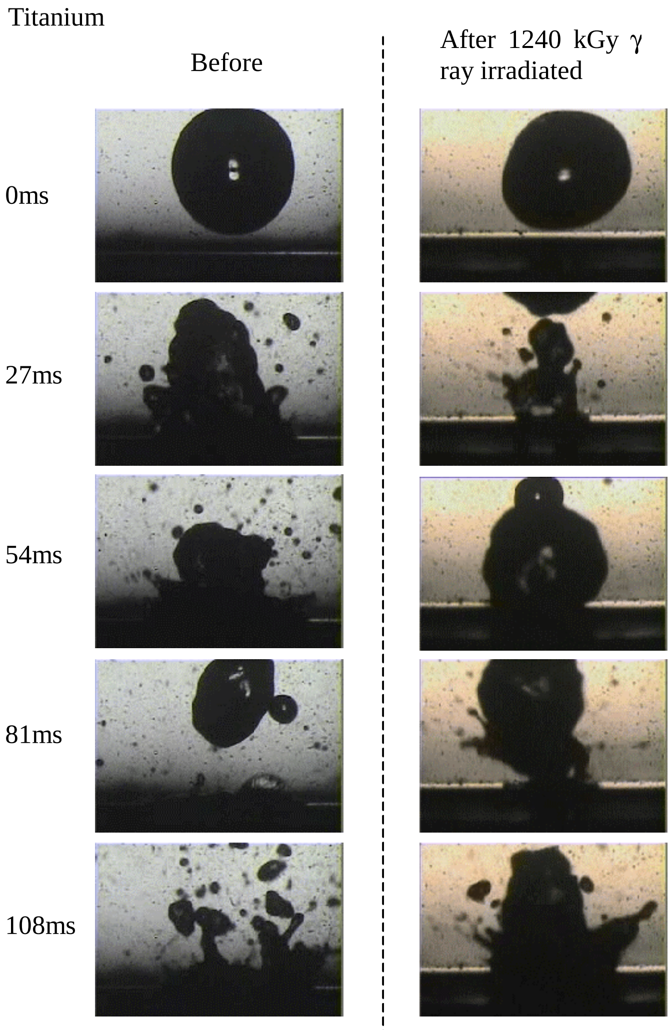

Fig. 4 Life of droplet on the heated surface

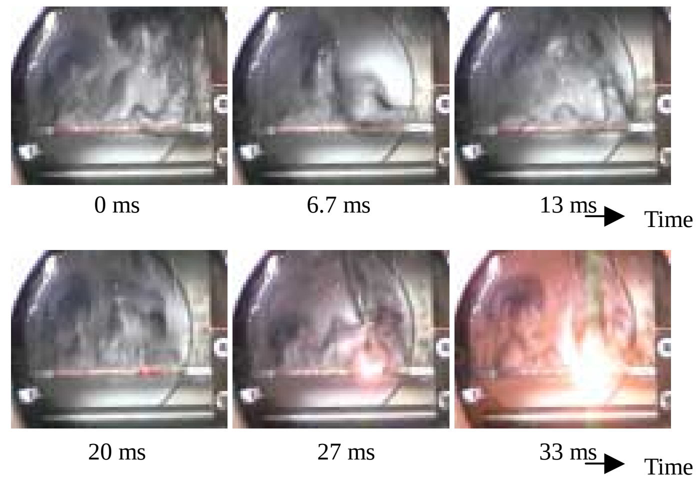

Fig. 5 Photographs in boiling condition

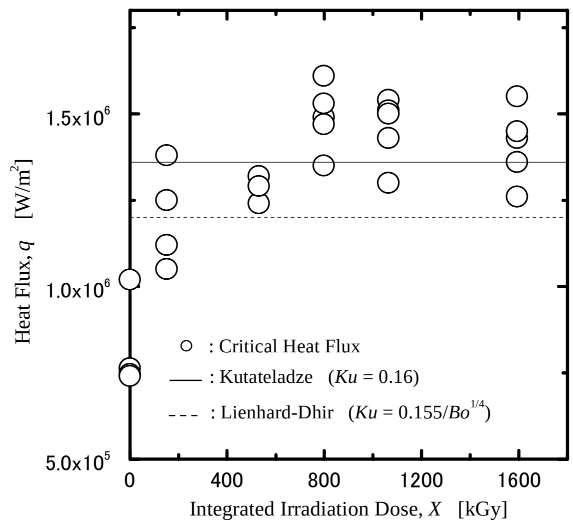

Fig. 6 Improvement of CHF by γ ray irradiation (TiO_2)

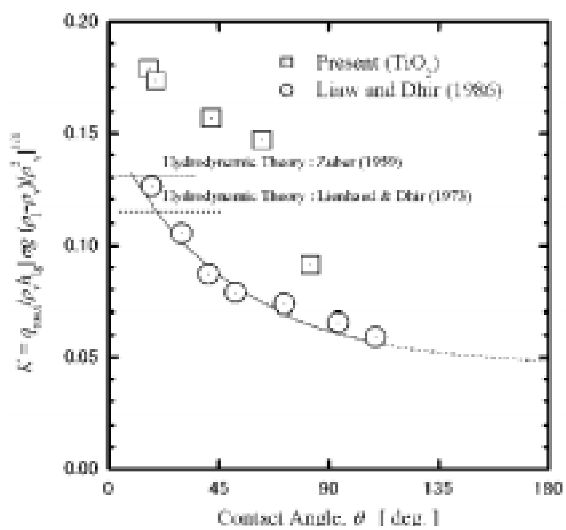

Fig. 7 Contact angle and CHF