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Measurement on nano scale by scanning probe microscope for obtaining real ice adhesion force

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ABSTRACT

It is important to know a real ice adhesion force on a cooling solid surface. When an ice adhesion force is measured by giving a shearing force at the interface between the solid surface and ice, there is a possibility that a measured ice adhesion force is an apparent value including a force that destroys ice due to unevenness of the surface. Thus, to measure the ice adhesion force without influence of the surface unevenness, one of the authors developed a method for measuring the ice adhesion force on the nano scale by using a scanning probe microscope. In this paper, ice adhesion forces to copper oxide and hard glass test plates were measured at −5 °C on the nano scale by this method, and the real ice adhesion forces could be measured. Moreover, the representative value of proper shearing stresses obtained by real ice adhesion forces divided each ice adhesion area was given.

Mesures à l'échelle nano grâce à un microscope à sonde locale pour obtenir la force d'adhérence réelle de la glace

Mots clés : Adhérence ; Glace ; Surface accidentées ; Echelle nano ; Microscope à sonde locale (SPM)

1. Introduction

Many technological troubles are caused by ice adhesion to a cooling solid surface. Therefore, it is a pressing matter to clarify the mechanism of ice adhesion. In an attempt to better understand the ice adhesion phenomena, in particular, the ice adhesion force on a cooling solid surface, studies have been conducted by many researchers (Jellinek, 1959; Matsumoto and Kobayashi, 2007; Matsumoto and Daikoku, 2009; Aoyama et al., 2006 (in Japanese); Yoshida et al., 1993 (in Japanese); and Yoshida et al., 2000 (in Japanese)). And the relationship between the surface roughness of an aluminum base (AA2024) with various coatings and the ice adhesion force has been clarified (Zou et al., 2011). Kulinich et al. showed that the

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ice adhesion forces on an aluminum bases (AA6061) with superhydrophobe treated with ZrO_2 and Ag nano-particles have been affected by the difference between advancing and reducing contact angles rather than by contact angle (Kulinich and Farzaneh, 2009). Moreover, it has been confirmed that the reduction effect of the ice adhesion force can be maintained for a long time by the aluminum bases (AA6061-T6) treated with superhydrophobe by coatings made from organo-silane and TiO_2 (Kulinich and Farzaneh, 2011; Farhadi et al., 2011).

However, past studies, including the above-mentioned ones, have focused on the ice adhesion force, which was measured by giving the shearing force at the interface between the cooling solid surface and the ice on the macro scale. When the ice adhesion force is measured by the above method on the macro scale, there is a possibility that the real ice adhesion force cannot be obtained because of remaining ice on the cooling solid surface caused by the surface unevenness of the cooling solid. However, if an ice size is fairly small, it can be expected that the surface shape will become relatively even for the ice.

In this paper, in order to obtain real ice adhesion forces to the copper and glass test plate, measurements of ice adhesion forces are carried out on the nano scale, based on the measurement method developed by one of the authors, using a scanning probe microscope (SPM) (Matsumoto et al., 2012). And authors investigate whether the measured ice adhesion forces are real values or not. Furthermore, for both test plates, shearing stresses obtained by the measured ice adhesion forces divided each ice adhesion area are estimated, and they are compared with those on the macro scale (Matsumoto and Kobayashi, 2007).

2. Experimental system and method

As details of the experimental system including the SPM (SPM 9600, Shimadzu Corporation) used in the study and experimental method and procedure have been provided in previous reports (Matsumoto et al., 2012), the authors will only provide a brief explanation here.

2.1. Experimental setup

The experimental system is shown in Fig. 1 (Matsumoto et al., 2012). As shown in Fig. 1, the main body of the SPM is placed in a chamber. The humidity is controlled at a desired value (2.12 g m^{-3}) by the inflow of wet nitrogen gas at a specific humidity into the chamber and by forced circulation of the nitrogen gas by a fan. The pressure in the chamber is controlled by the dry nitrogen gas and by a vacuum pump. During measurement, a constant experimental atmosphere can be maintained in the chamber. The surface temperature of the sample holder is controlled by a ceramic heater and liquid nitrogen. The surface temperature of the test plate cannot be directly measured because a temperature sensor is placed in the vicinity of the ceramic heater. Therefore, the surface temperature is determined on the basis of the relationship between the sensor temperature and the surface temperature of the test plate obtained beforehand.

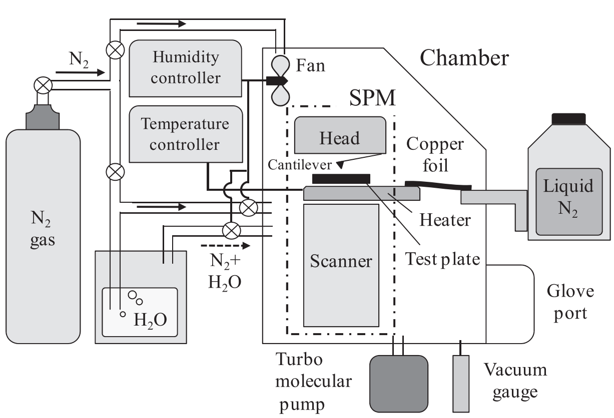

Fig. 1 – Experimental system (Matsumoto et al., 2012).

In this paper, hard glass and copper test plates were used, with dimensions of 10 mm × 10 mm × 1 mm. The copper test plate surface is oxidized (Matsumoto et al., 2009). Hereafter, the words “glass” and “copper” represent a hard glass and copper oxide, respectively.

Grease with a high thermal conductivity is applied to the bottom of the test plate, and the greased test plate is placed on the sample holder.

2.2. Experimental method

The pressure in the chamber is lowered to less than 100 Pa by the vacuum pump after the experimental system is setup. The surface temperature of the test plate is then cooled to a specified temperature by filling the liquid nitrogen tank with liquid nitrogen. Next, the surface temperature of the test plate is adjusted to 20 °C by controlling the ceramic heater, and the humidity in the chamber is maintained at the desired value (2.12 g m^{-3}) by the inflow of wet nitrogen gas into the chamber immediately after the pressure in the chamber is returned to atmospheric pressure by the inflow of dry nitrogen gas. And then, the surface temperature of the test plate is cooled to the desired value again, after which the shape and the adhesion force of the ice formed from condensed water droplets are measured.

The experimental conditions are shown in Table 1 (Matsumoto et al., 2012). The scanning procedure of a probe attached to the end of a cantilever is shown in Fig. 2.

As shown in the figure, the probe starts scanning on the first line at the upper left corner of the scanning range and then moves to the upper right corner in the X direction at a fixed scanning speed and a fixed number of measurement points. The scanning is called a “trace”. The probe follows the same track back to the scanning start point immediately after

Table 1 – Experimental conditions.

Test plate	Copper oxide, Hard glass
Dimension of test plate	10 mm × 10 mm × 1 mm
Scanning range	10 μm × 10 μm
Scanning speed	20 μm s^{-1}
Number of measurement points	256 × 256
Surface temperature of test plate	−5 °C
Pressing force of probe against test plate (LFM mode)	1000 nN