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Study on measurement of frost dimensions/distribution and frost crystals scraping force using scanning probe microscope (investigation on influence of humidity)

Koji Matsumoto [a,*], *Masato Honda* [b], *Yoma Ito* [c], *Daisuke Shirai* [b]

[a] *Department of Precision Mechanics, Chuo University, 1-13-27 Kasuga, Bunkyo-ku, Tokyo 112-8551, Japan*
[b] *Chuo University, 1-13-27 Kasuga, Bunkyo-ku, Tokyo 112-8551, Japan*
[c] *IHI Marine United Inc., 3-22-23 Kaigan, Minato-ku, Tokyo 182-0022, Japan*

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ABSTRACT

Frosting to a cooling solid surface is often unavoidable and is severe problems. Thus, in order to control the frosting, it is necessary to clarify the mechanism of frosting, both scientifically and technologically. Furthermore, when investigating this mechanism, knowing how frost crystals start to form and grow is very important, therefore, frosting from generation to primary growth stage must be clarified. Since frost crystals dimensions are very small in their generation and primary growth stage, it is essential to conduct these investigations at the micro scale level. In this study, using a scanning probe microscope (SPM), frost crystals dimensions/distribution and scraping force of frost crystals, were measured under fixed surface temperatures, comparing influence of humidity with that of surface temperature via a method proposed by one of the authors. Then, correlations among the above frost crystals dimensions/distribution and scraping force were clarified, comparing with influence of cooling solid surface temperature.

Etude de la mesure des dimensions et de la distribution des cristaux de givre et de la force de raclage utilisant un microscope à balayage (étude de l'influence de l'humidité)

Mots clés : Givre ; Collement ; Sublimation ; Humidité ; Structure

* *Corresponding author*. Tel.: +81 3 3817 1837; fax: +81 3 3817 1820.
E-mail address: matsumoto@mech.chuo-u.ac.jp (K. Matsumoto).

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1. Introduction

The formation of frost on cooling surfaces can cause various problems, such as heat exchanger performance degradation and operation obstruction of various transport equipments that are often difficult to resolve. Thus, to control frosting, it is first necessary to clarify the mechanism of frost formations on cooling surfaces.

Many researchers have studied frosting phenomena under various conditions. For example, Hayashi & Aoki and Aoki et al. have investigated the classification of frost growth processes based on the structure of the frost layer and the growth theory of the frost layer (Hayashi and Aoki, 1977, and by Aoki et al. (1979)). Furthermore, there have been proposals of various frost layer models (Shimomura et al., 2003), and studies on frosting from various other viewpoints have also been carried out (Byeongchul et al., 2004; Hermes et al., 2009; Yaomin et al., 2012).

To clarify the mechanisms of frosting, knowing how the frosting process starts, and how frost crystals grow, are very important factors. Thus, it is first necessary to clarify frosting phenomenon, from generation to its primary growth stage. Furthermore, as frost crystals dimensions can be expected to be very small until the primary growth stage, it is essential to investigate frosting phenomenon on the micro scale level. The primary growth process of frost crystals was previously studied (Seki et al., 1984, 1985), but those studies were inconclusive. It is very difficult to quantitatively measure frost crystals dimensions/distribution and scraping force until the primary growth stage because they are extremely small.

In a previous study, frost crystals dimensions/distribution and the scraping force of frost crystals were quantitatively measured on the micro scale level by a scanning probe microscope (SPM) under fixed humidity, varying cooling solid surface temperatures, via the method developed by one of the authors (Matsumoto et al., 2013). And influence of humidity, as well as influence of cooling solid surface temperature, must be investigated to clarify the phenomenon of frosting, from generation to its primary growth stage.

Thus, in this study, frost crystals dimensions/distribution and scraping force are again investigated via SPM under fixed surface temperatures, and varying humidity levels, after which correlations among frost crystals dimensions/distribution and scraping force, as well as the influence of humidity on those correlations, are clarified, comparing influence of humidity with that of cooling solid surface temperature.

2. Experimental apparatus and procedure

2.1. *SPM measurement principle and modes*

The measurement principle of SPM is shown in Fig. 1 (Matsumoto et al., 2011). The small deflection, as well as the bending and twisting of the cantilever, are measured by the SPM during the process of scanning the probe on the sample plate surface. These abovementioned interactions can be evaluated sensitively based on the optical lever method, in which the laser beam reflecting from the back of the cantilever is detected by a photodiode detector, as shown in Fig. 1. At that time, the displacement of the reflecting laser beam is amplified by the lever principle. Thus, using the SPM, an atomic or molecular level spatial resolution can be obtained.

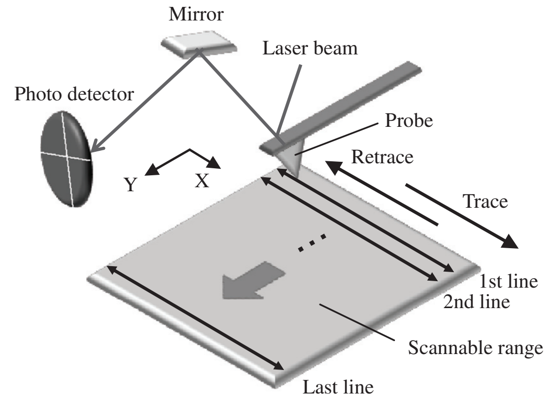

Fig. 1 – Measurement principle of SPM (Matsumoto et al., 2011).

As shown in Fig. 1, the probe is normally scanned at a fixed speed in the X-direction from the upper left corner of the scannable range to the upper right corner along a fixed number of measurement points. Then, after reaching the upper right corner, the probe is immediately rescanned along the same track back towards the original point. Such reciprocating scans are referred to as “trace” and “retrace” processes, respectively. In trace and retrace processes, different data are obtained. After the retrace process is complete, the probe is moved downward in the Y-direction along a fixed

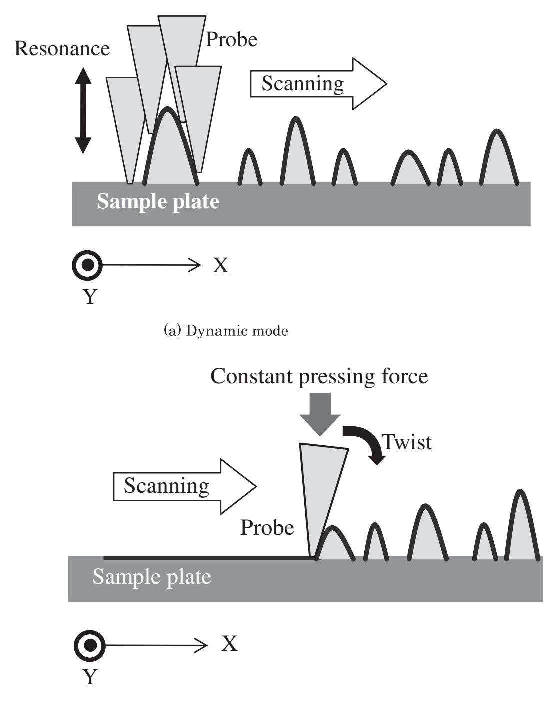

Fig. 2 – SPM measurement modes (Matsumoto et al., 2011). (a) Dynamic mode (b) LFM mode.