Frost Damage in Roof Tiles in Relatively Warm Areas in Japan

Water Absorption and Freezing-Thawing Experiments

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Introduction

- Moisture inside building materials significantly influences the durability of building envelopes. In cold regions, accumulated moisture sometimes freezes in the building materials, causing serious damage.

- Frost damage has been observed
  - not only in cold regions but also **in relatively warm areas** in Japan, such as Kyoto.
  - mainly **in roof tiles**.
- A roof is usually open to the sky, thus, its temperature is significantly influenced by night sky radiations.

Introduction (continued)

- This presentation is part of a study that investigated the causes of frost damage in roof tiles from a hygrothermal perspective.
  - The potential for frost damage in roof tiles in a relatively warm area where the minimum temperature is only slightly below 0 ℃ has been reported.
  - In this paper, water supply to the roof tiles and moisture transport in the material are emphasized.

In the field of materials science and technology, standard freezing-thawing test has been conducted to examine frost resistance of various building materials.

In this paper…

✓ The characteristics of frost damage in areas of mild climate are investigated by field surveys.

✓ Both standard and new freezing-thawing tests are conducted.

✓ New test is based on the results of a field survey and two types of water absorption experiments.

CONTENTS

2.
FIELD SURVEY OF DETERIORATION OF ROOF TILES

- Outline of field survey
- Characteristics of deterioration

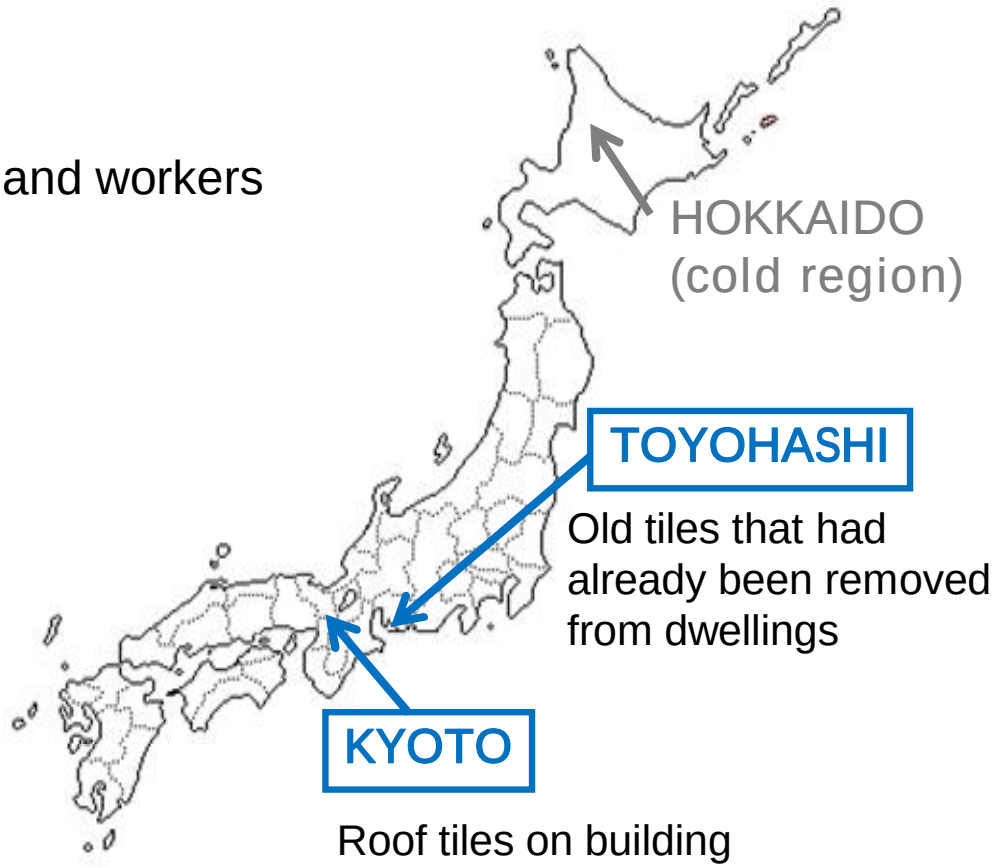
Outline of field survey

- Site of Field Survey: KYOTO and TOYOHASHI

  (both are relatively mild climate region, the average outdoor temperature in winter is around 5 ℃.)

- Methods:
  - Record photographically
  - Interview with local manufacturers and workers familiar with traditional roof tiles

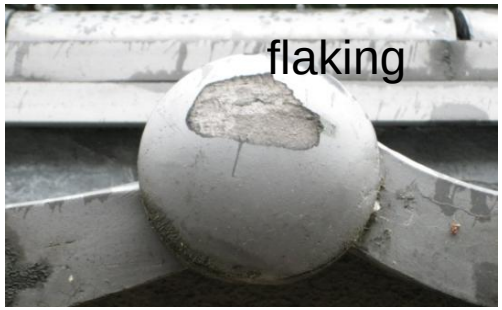
Various types of roof tiles



Characteristics of deterioration

- Typical deterioration (survey in Kyoto)

Frost damage ?



Minor circular spallings

Old pantiles removed from the dwellings

KYOTO

TOYOHASHI

Rain water, which penetrate into the tile body through the areas of spalling, can accelerate the frost damage.

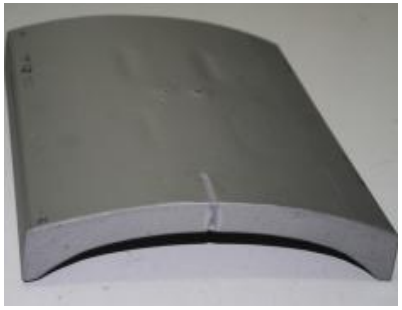
3.
STANDARD FREEZING-THAWING TEST

- Test specimens, testing apparatus and procedure
- Results

Specimens and Testing apparatus

- Purpose of standard freezing-thawing test is to examine the characteristics of frost damage in roof tiles.
- Test specimens: **Silver oxidized roof tiles** (Firing temperature: 1,070 ℃) covered with a thin carbon film as a waterproof surface

Pantile



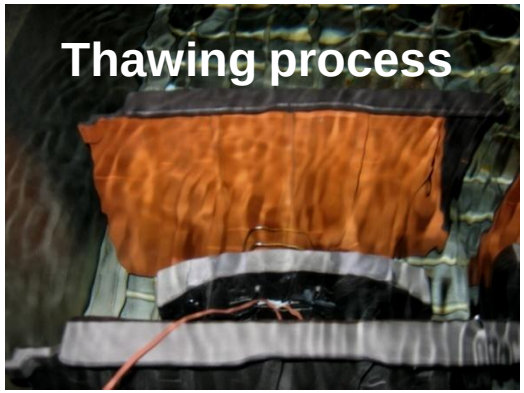
Plain tile

- Testing apparatus： According to JIS A 1435 ‘Test methods for frost resistance of exterior wall materials of buildings (Freezing and thawing method)’

Preconditioning
Immerse specimens in water for 24 hours

→ nearly saturation

1 cycle

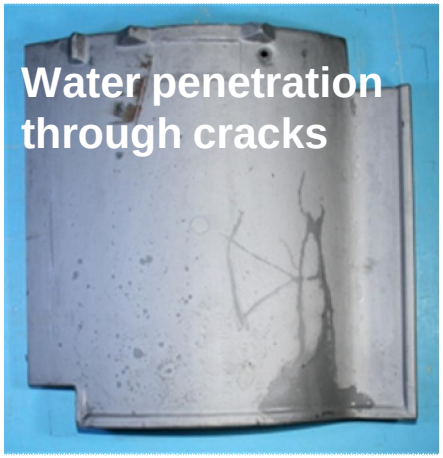


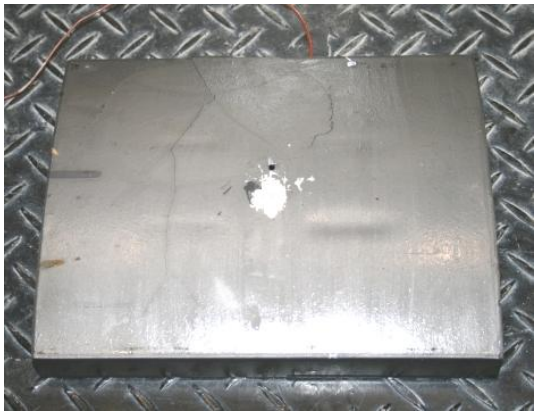
−20 ℃ cold air for 100 min

10 ℃ water for 80 min

Results

- Appearance after 30 cycles





Larger and more serious cracks
than those found in the field survey

Specimens were saturated
with water before freezing

sufficient ice was generated
in freezing process

cause severe damage

Is standard test method not suitable for evaluating actual damage to roof tiles ?

In Chap. 5, a new method is proposed.

A roof tile generally has a surface finish to prevent rain water from penetrating. The finish should be seamless.

Before propose a different freezing-thawing test method, two simple experiments were conducted to check the water absorption characteristics of tiles.

The characteristics were examined by numerical analysis.

4. WATER ABSORPTION EXPERIMENT

- Experiment under outdoor conditions
- Laboratory experiment

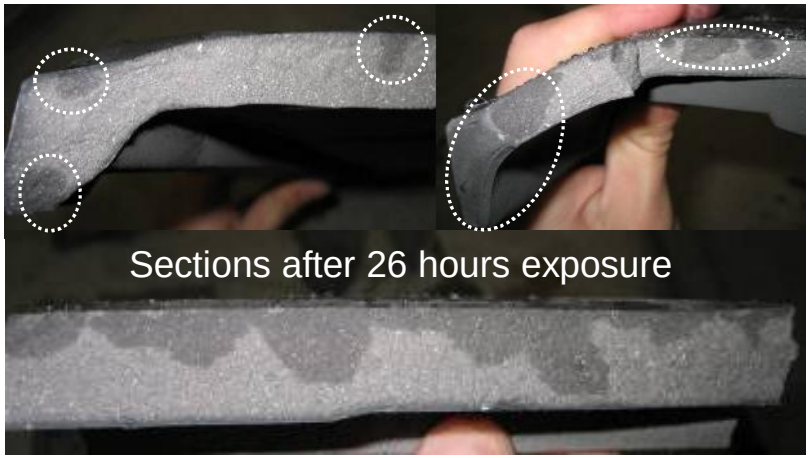
6. NUMERICAL ANALYSIS OF WATER ABSORPTION PROCESS

Water Absorption Experiment

Experiment under outdoor conditions

non-uniform distribution

In Katsura Campus, Kyoto University



Sections after 26 hours exposure

- Weather: cloudy with intermittent rain.

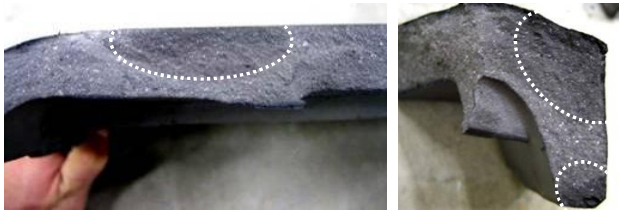
The area that absorbed water is clearly distinguished

Laboratory experiment

Water replenishment

Wet towel

non-uniform distribution



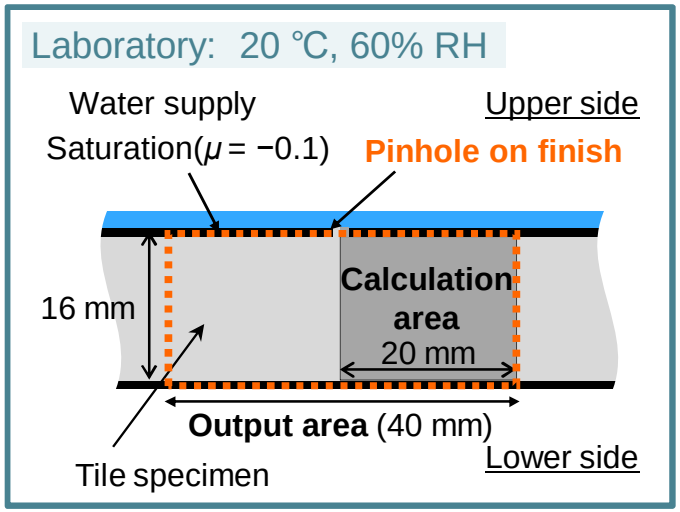
after 9 hours

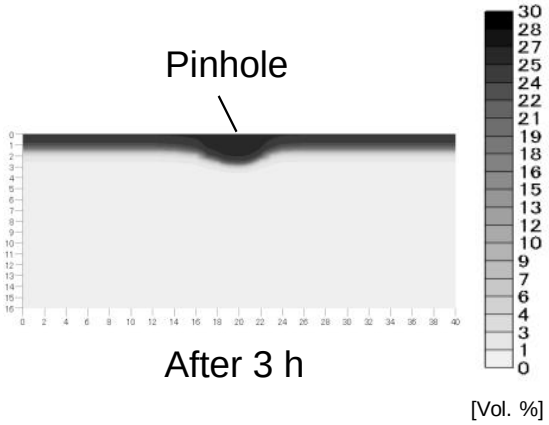
Does water penetrate through invisible pinholes on the surface finish ?

after 3 days

Numerical analysis of water absorption process

- The laboratory experiment is simulated using the equations of simultaneous heat and moisture transport. .





Does non-uniform moisture distribution lead to damage such as minor spallings ?

If invisible pinholes are randomly distributed on the surface finish, the moisture content will show non-uniform distribution.

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* Equations of simultaneous heat and moisture transport (Matsumoto et al. 1993)

<Moisture balance>

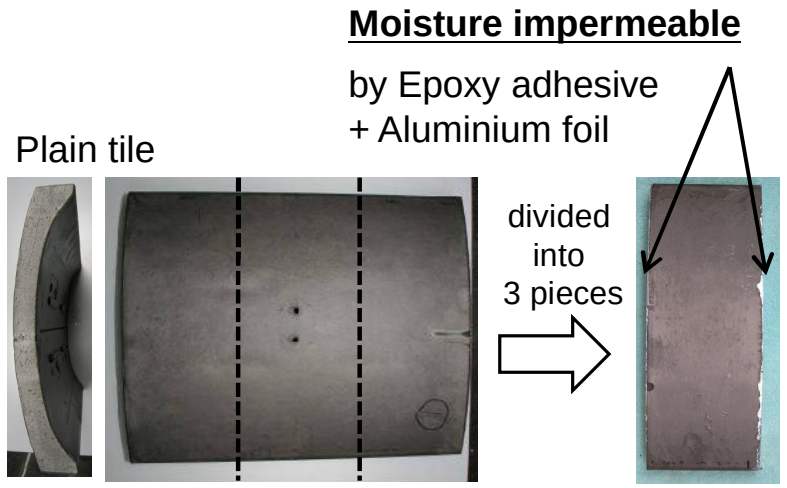
$$\left(\frac{\partial \rho_l \psi}{\partial \mu}\right)\frac{\partial \mu}{\partial t} = \nabla\left(\lambda'_{Tg}\nabla T\right) + \nabla\left\{\left(\lambda'_{\mu g} + \lambda'_{\mu l}\right)\nabla\mu\right\}$$

<Energy balance>

$$\left(c_s\rho_s\psi_s + c_l\rho_l\psi_l\right)\frac{\partial T}{\partial t} = \nabla\left(\lambda\nabla T\right) + H_{gl}\left\{\nabla\left(\lambda'_{Tg}\nabla T\right) + \nabla\left(\lambda'_{\mu g}\nabla\mu\right)\right\}$$

5.
PROPOSED NEW FREEZING-THAWING TEST

- Test apparatus and procedure
- Results

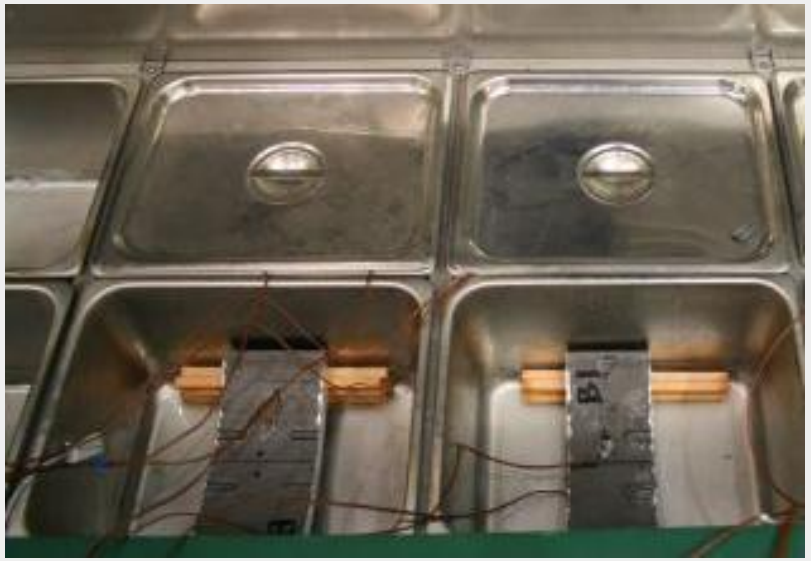


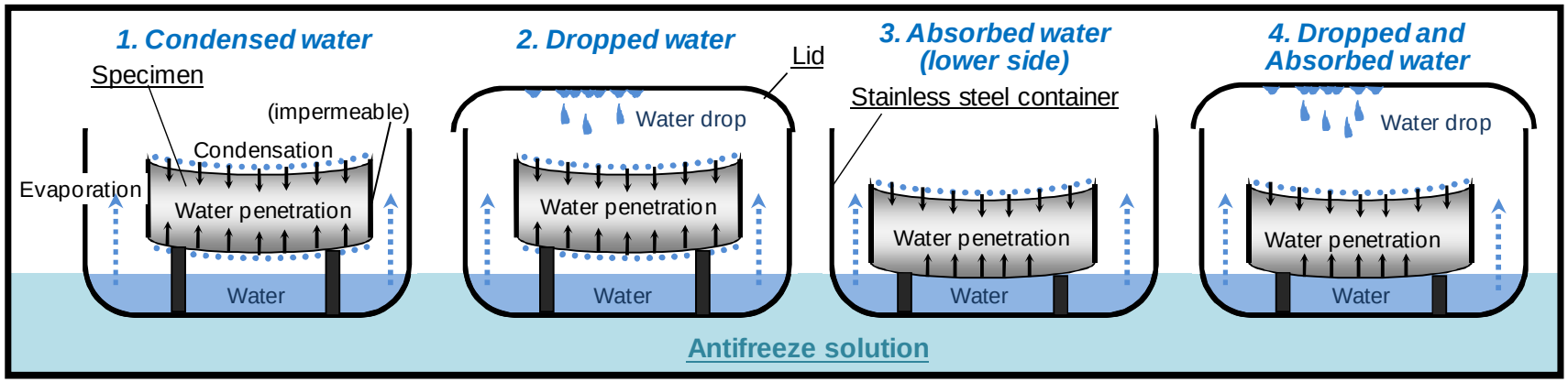
Test apparatus and procedure

- Four types of water supply
  - Pattern 1:Only surface condensation
  - Pattern 2: Condensed water on the lower surface of the lid drops to the upper surface of the specimen
  - Pattern 3: lower surface of the specimen is immersed approximately 5 mm below the water surface
  - Pattern 4: Pattern 2+ Pattern 3

The amount of water supplied increases successively from Pattern 1 to 4.

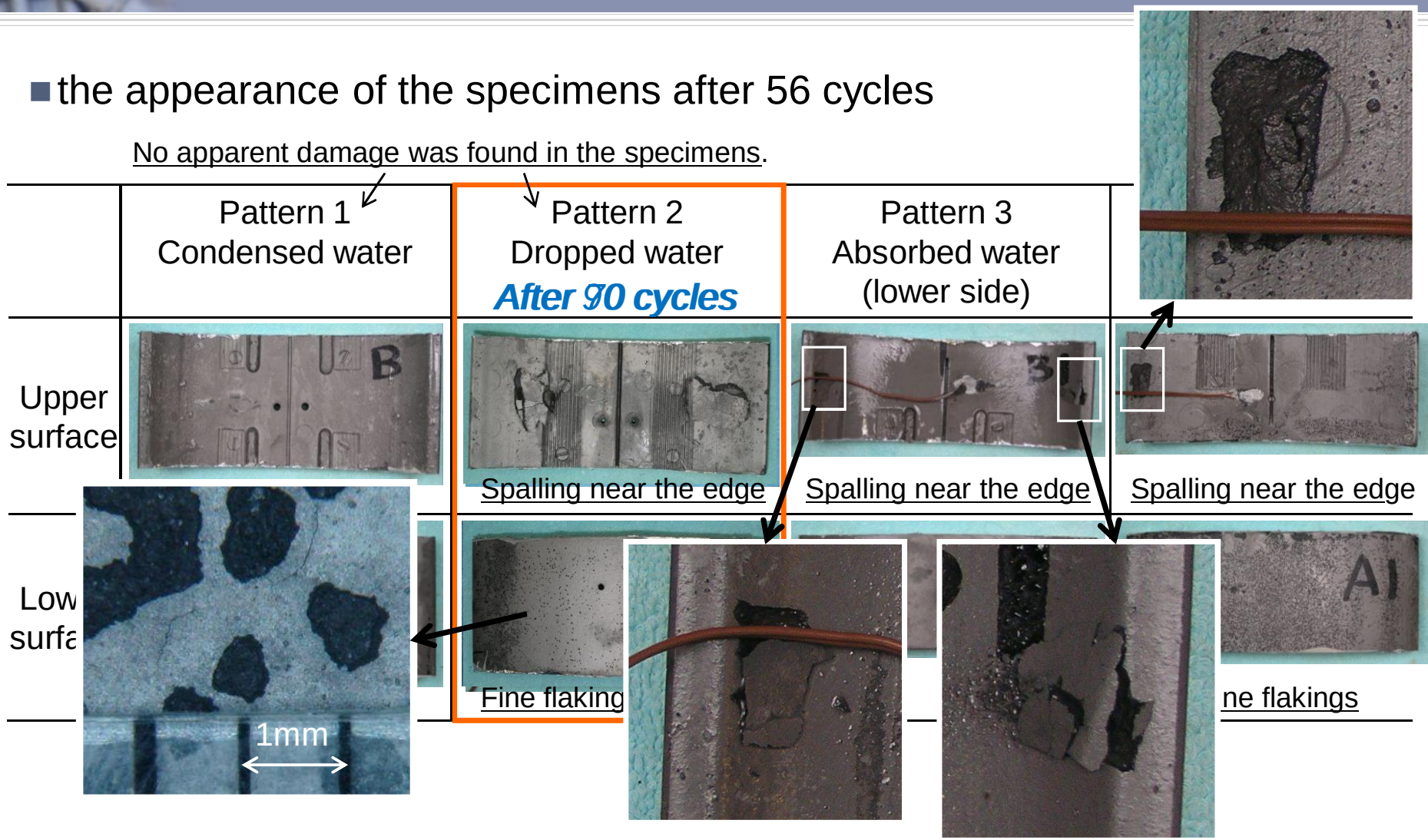
Test apparatus based on ***RILEM TC 176*** ,
'Test Methods of Frost Resistance of Concrete'





Results

- the appearance of the specimens after 56 cycles



Even small droplets can cause spalling similar to that found in actual conditions if droplets continuously fall on the specimens.

Conclusions

- In this paper, the characteristics and causes of frost damage in roof tiles were investigated through field surveys, two types of freezing-thawing test, water absorption experiments in outdoor and indoor environments and a numerical analysis.
  - The field survey showed that minor spalling seems to be typical of damage caused by freezing.
  - Characteristic damage could not be simulated by a standard freezing-thawing test. Thus, the standard test might be unsuitable for evaluating actual roof tile damage.
  - The results of water absorption experiments showed that the water content might increase locally due to random invisible pinholes in the surface finish, and the results were confirmed by a simple numerical analysis.
  - A new test is proposed on the basis of these experimental results. This test showed that small water droplets could cause damage similar to that found in the field.

When the water content inside a tile increases locally and the temperature decreases below the freezing point, freezing can occur only in local areas having high water content, causing minor spalling.

THANK YOU

FOR YOUR ATTENTION

INTRODUCTION (continued)

- A roof is usually open to the sky.
- The roof surface temperature is significantly influenced by night-sky radiation.
- The temperature drop causes surface condensation on the roof tiles, which can be seen especially in the early morning.

Frost damage may also occur in a relatively warm area where the minimum temperature is only slightly below 0 ℃.

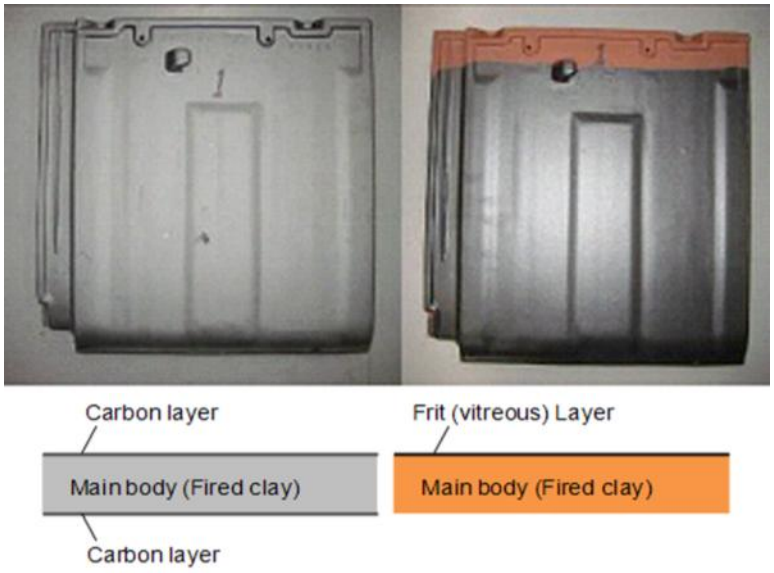
- This presentation is a part of the results of our investigation of the causes of frost damage to roof tiles from a hygrothermal perspective.
- In order to understand the freezing-thawing process, it is necessary to know the moisture transport characteristics of a roof tile.

INTRODUCTION (continued)

- In general, the Japanese roof tile has a surface finish whose moisture transport property is significantly different from that of the main body.
- The purposes of this paper is…
  - To determine the influence of the surface finish on moisture transport characteristics by measuring the water permeability of tiles with and without surface finishes.
  - To investigate the influence of entrapped air in the material on water transport.
- 2 types of Japanese roof tiles with surface finish was measured.

Silver oxidized tile **Frit tile**

Carbon layer
(approximately 10 μm thick)
adhered by deoxidization in
the final process of baking



Frit layer
(approximately 10 μm thick)
vitreous surface

Firing temperature
1070 ℃