FUNDAMENTAL STUDY FOR CONTROLLING ASR EXPANSION BY SILANE PENETRANT SYSTEM

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Abstract

This experimental study examined effective application of silane penetrant to structures affected by alkali silica reaction. Model specimens simulating a real structure were exposed outdoors for 19 months, with or without penetrant application and with or without exposure to natural rain. Expansion ratio was measured at different depths from the application surface to determine the range of effectiveness of silane penetrant in expansion control. Relative humidity in the holes made in the specimens was measured as the index of internal moisture content which could influence the expansion behavior.

The experiment demonstrated that application of silane penetrant was effective in reducing moisture in concrete and controlling expansion even with exposure to rain. Range of effectiveness was found to reach a depth of about 200 mm in moisture reduction and about 250 mm in expansion control.

Keywords: ASR, silane, exposure, expansion ratio, relative humidity

1   INTRODUCTION

Silane penetrant which is also known as penetrating sealant is frequently used for the purpose of controlling water absorption and expansion in concrete structures affected by alkali silica reaction (ASR). Silane penetrant inhibits water permeation and absorption, while allowing water vapor to permeate. This contributes to reducing moisture content in concrete and preventing water absorption and expansion of alkali silica gel, thereby controlling expansion of concrete.

A hydrophobic layer forms in concrete impregnated with silane penetrant for a depth of several millimeters from the surface and prevents water permeation and absorption [2]. This layer consists of alkyl groups which are formed pointing outward on the surface of concrete or micropore [2].

Although ASR expansion control effect of silane penetrant and other surface protection systems is known from early experiments using specimens, it is pointed out that the effect is limited on massive members which have large ratios of volume to surface area [3]. Real structures have very different volume to surface area ratios from usual experiment specimens. This means significant difference may exist in the expansion control effect of same silane penetrant when applied to existing structures.

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The purpose of this study was to evaluate the range of effectiveness of silane penetrant in moisture reduction and expansion control experimentally, using specimens prepared to simulate real structures. Discussion extends to the expected effect of silane penetrant in practical application to existing structures.

2 EXPERIMENT METHOD

2.1 Experimental factors

A beam on a road bridge pier was assumed in this study, and conditions similar to those of the real structure were reproduced in the experiment. Each specimen had dimensions of $200 \times 200 \times 600$ mm as described in Figure 1, with its top surface assumed to be the outer surface (top surface) of the beam. The specimens were sealed on the side and bottom surfaces to prevent penetration or escape of moisture through them, simulating the actual conditions of a pier beam where water was supplied only through the top surface.

Table 1 shows the experimental factors and measurement items of the specimens included in this report. There are six specimens of three different types with or without treatment and with or without rain exposure. Specimens with treatment were prepared by applying silane penetrant at the time when their average top surface expansion ratio reached 0.15%. All specimens were exposed outdoors, with rain shelter provided to those for no rain exposure.

2.2 Mix proportions and materials used

Table 2 shows the mix proportions used for the concrete specimens. This mix design was selected for its significant ASR expansion behavior known from previous experience. Normal portland cement was used, and gravel was a 6:4 mix of reactive to non-reactive aggregates. Equivalent alkali content (R_2O) was adjusted to 9.0 kg/m³ by adding NaCl. Andesite from Hokkaido was used as the reactive aggregate for its content of tridymite, a highly reactive silica.

2.3 Preparation of specimens

Forms were removed one day after concrete casting, and markers for expansion ratio measurement were attached to two side surfaces and top surface of each specimen (Figure 1). Initial expansion ratios (baseline lengths) were measured two days after concrete casting.

The specimens were subjected to accelerated expansion after the baseline length measurement at a temperature of 40 °C and a relative humidity of 95% or above until average expansion ratio reached 0.15% in two directions on the top surface. It took almost seven weeks to complete the accelerated expansion. Cracks were found in all specimens by the fifth week when expansion ratio reached 0.05%. Cracks continued to increase, and white precipitate was observed at the seventh week.

After a target expansion ratio of 0.15% was reached, waterproof coating (super flexible, acrylic rubber based surface coating material) was applied to the surfaces of individual specimens, except for the top surface. The silane penetrant shown in Table 3 was applied to the top surface of the two test specimens, and all specimens were cured indoors at room temperatures for one week.

2.4 Exposure method

The outdoor exposure site was on the rooftop of a three-story building located in Osaka City. Exposure was conducted for a continuous period of 19 months, starting in March 2008 and ending in September 2009 after 78 weeks. The specimens were placed with their top (application) surfaces facing upward as shown in Figure 2. Rain-exposed specimens were exposed to normal outdoor conditions including rain, while rain-sheltered specimens were provided with rain shelter.

Average daily low and high temperatures during the exposure period were around 5 °C and around 30 °C, respectively, according to the information from the Osaka Weather Station of Japan Meteorological Agency Automated Meteorological Data Acquisition System (AMeDAS). Cumulative precipitation was about 2000 mm for the entire exposure period, with high precipitation recorded during summer time when the temperature was high.

2.5   Measurement items and methods

Measurement items included expansion ratio, mass change ratio, internal relative humidity, and cracking behavior (drawing, and crack density per width range) as shown in Table 1. Contact-type strain gauge was used for measuring the expansion ratio, and electronic balance (capacity: 60 kg; minimum indication: 0.01 kg) was used for measuring the mass change ratio.

Temperature-humidity sensor was used for measuring the relative humidity and temperature. The device consisted of a capacitive polymer sensing element and a band-gap temperature sensor which were seamlessly coupled to an A/D converter and a serial interface circuit. Accuracy tolerance for relative humidity at 25 °C was ±1.8% in the range from 10% to 90% RH or was larger outside this range, with a maximum of ±4.0% at 0 or 100% RH. As shown in Figure 3, the sensor was attached to the tip of a specially manufactured aluminum probe which was designed so that the tip would fit snug against the inner wall of the measurement hole. Every time the probe was inserted, the measurement hole was sealed with putty to prevent moisture loss. The specimens were moved one day before measurement into a room where the temperature was maintained in a range of 20±2 °C. The sensor was inserted on the day of measurement, and measurement was taken at 120 minutes from the insertion after the reading stabilized. All measurement holes were plugged with rubber, covered with paraffin, and sealed with putty for protection during the exposure.

All items except for cracking behavior were measured at intervals which were determined with the time from the start of exposure as well as seasonal factors taken into account. Measurement was made every week for the first four weeks, every two weeks until the 26th week, every four or five weeks until the 64th week, and every two weeks for the rest of the exposure period.

3   EXPERIMENTAL RESULTS AND DISCUSSION
3.1   Relative humidity change

Figures 4 to 6 show change in internal relative humidity for each specimen type. Figures 7 to 10 show the same data sorted by depth from the top (application) surface. Findings are described by specimen type below.

Non-treated rain-sheltered specimen (Figure 4)

Relative humidity remained low at first, started to increase in September, and decreased after reaching a peak in December. The first decrease until September was likely due to moisture evaporation through the top surface, hydration, and/or water absorption by the gel. After the early stage of exposure, relative humidity was higher as the depth from the top surface increased. However, humidity difference between subsequent depth positions was found to be smaller at larger depths. With the mass change described below taken into account, moisture evaporation through the top surface was considered to be the major cause of the decrease in relative humidity.

Silane-treated rain-exposed specimen (Figure 5)

Tendencies in relative humidity were very similar to those found in the non-treated rain-sheltered specimen. Relative humidity was higher as the depth increased until 200 mm from the top (application)

surface. This revealed that the silane penetrant applied performed properly, preventing water permeation and absorption and allowing moisture vapor permeation successfully. This result suggests that application of silane penetrant is as effective as providing rain shelter.

Non-treated rain-exposed specimen (Figure 6)

Relative humidity change at depths below 200 mm from the top surface was similar to those in the other two types. However, there were increases attributable to moisture penetration in the upper 100 mm. Relative humidity started to increase in late August at 50 mm and about two weeks later at 100 mm, suggesting a possible penetration of moisture through the top surface.

Humidity reduction effect of the treatment (Figure 11)

Figure 11 shows the amount of relative humidity reduction in the specimen impregnated with silane penetrant at the 78th week, using the values of the non-treated rain-exposed specimen as control. The relative humidity reduction effect of the silane penetrant application in outdoor environment with exposure to rain was found to be about 13% RH at 50 mm from the top (application) surface and to be smaller as the depth from the top (application) surface increased, until the difference with the non-treated specimen was zero at a depth slightly above 200 mm.

3.2   Mass change

Figure 12 shows mass change ratios in the specimens in which relative humidity was measured. The non-treated rain-exposed specimen exhibited the smallest mass reduction ratio, and which was in good agreement with the small reduction in its relative humidity. Mass change was minor during a period from September to March in the non-treated rain-exposed specimen or during a period from November to February in the other two specimen types. However, mass reduction attributable to moisture loss was obvious on a long term basis.

3.3   Expansion ratio change

General tendencies

Figures 13 to 15 show expansion ratio change from the start of outdoor exposure. The values are averages of each pair of specimens. General tendencies were consistent with the relative humidity change, with smaller expansion ratios at smaller depths in the non-treated rain-sheltered and silane-treated rain-exposed specimens in which practically no moisture penetration through the top (application) surface was expected. In contrast to this, expansion ratio was larger at smaller depths in the non-treated rain-exposed specimens in which moisture penetration through the top surface was expected.

As for seasonal factors, expansion rates corresponding to the gradients of curves shown in Figures 13 to 15 reached a peak generally in summer time (in or around July), showing an obvious correlation with the temperature. As seen from the diagrams, expansion proceeded at a higher rate during the summer of the second year as compared to the first summer. Possible causes may include reduced moisture content of the specimens and decreased residual expansion potential from the first year as shown in Figure 4.

Expansion control effect of the treatment

Figure 16 shows cumulative change in expansion ratio in individual specimens from the start of outdoor exposure up to the 78th week. The values are averages of each pair of specimens. The difference in expansion ratio change between the silane-treated rain-exposed specimens and non-treated rain-exposed specimens can be considered to indicate the expansion control effect of the silane penetrant. The expansion

control effect was found to decrease as the depth from the top (application) surface increased, being zero at a depth around 250 mm. This depth range was close to 200 mm in which reduction of relative humidity was observed.

Expected expansion control effect of silane penetrant in real structures

The following is a discussion of expected ASR expansion control effect of silane penetrant in practical application to existing structures based on the experimental results.

The range of effectiveness of silane penetrant in moisture reduction was found to be about 200 mm from the surface. This is adequately larger than a standard cover thickness for normal road bridge piers which is about 100 mm. Therefore, it is possible that aggravation of internal environment corrosive to stirrups or other outermost reinforcing steel will be prevented by silane penetrant application.

It would be basically difficult to suppress internal concrete expansion of an existing structure if the concrete already contains an adequate amount of moisture for expansion at the time of repair. However, repair agent applied will still have a preventive effect against penetration of deteriorating substances through the surface due to moisture transfer, reducing the possibilities of further development of expansion or steel corrosion. Consequently, it is expected that application of silane penetrant would be effective in controlling development of deterioration from the viewpoint of a whole structure system.

4 CONCLUSIONS

Alkali-adjusted concrete specimens containing reactive aggregate were prepared and exposed outdoors for 19 months. Prior to exposure, test specimens were treated with silane penetrant, and all specimens were subjected to accelerated expansion. Major findings are described below:

- Silane-treated rain-exposed specimens exhibited very similar tendencies to non-treated rain-sheltered specimens in relative humidity, mass change ratio and expansion properties. This suggests that silane penetrant exhibits its moisture reduction and expansion control effects in structures exposed to rain, and also that application of silane penetrant has an equivalent effect to providing rain shelter.
- Moisture reduction and expansion control effects of silane penetrant were smaller as the depth from the top (application) surface increased. However, its range of effectiveness was found to reach about 200 mm in moisture reduction and about 250 mm in expansion control.
- The range of effectiveness of silane penetrant in moisture reduction was found to be larger than a standard cover thickness for normal road bridge piers. Therefore, silane penetrant application is considered to prevent surface expansion in structures exposed to rain and aggravation of internal environment corrosive to steel, thereby controlling development of deterioration of a whole structure system.

5 REFERENCES

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[3] Miyagawa, T., Hisada, M., Sugashima, A. and Fujii, M.: Control of alkali aggregate expansion by using water repellent. Proceedings of the 10th Japan Concrete Institute: Vol. 10, No. 2: 767-772. (in Japanese)

TABLE 1: Experimental factors and measurement items							
Name of specimen	Treated or non-treated	Outdoor exposure conditions	Number of specimens	Measurement items			
				Expansion ratio	Mass change	Relative humidity	Crack behavior
Non-treated rain-sheltered	Non-treated	under the roof	2	Both specimens	Both specimens	Only one specimen	Both specimens
Silane-treated rain-exposed	Silane penetrant	on the rooftop	2				
Non-treated rain-exposed	Non-treated	on the rooftop	2				

TABLE 2: Mix proportions of concrete specimens									
W/C (%)	s/a (%)	Air (%)	Slump (cm)	Unit weight (kg/m³)					
				W	C	S	G		Air entraining agent
							Reactive	Non-reactive	
50.0	44.0	4.0±1.5	8.0±2.5	150	300	813	641	421	3.0

TABLE 3: Specifications of silane penetrant	
Composition	Alkyl alkoxy silane: 40%; isopropyl alcohol + methyl alcohol: 60%
Quantity of standard application	0.336 g/m²
Number of standard application	3
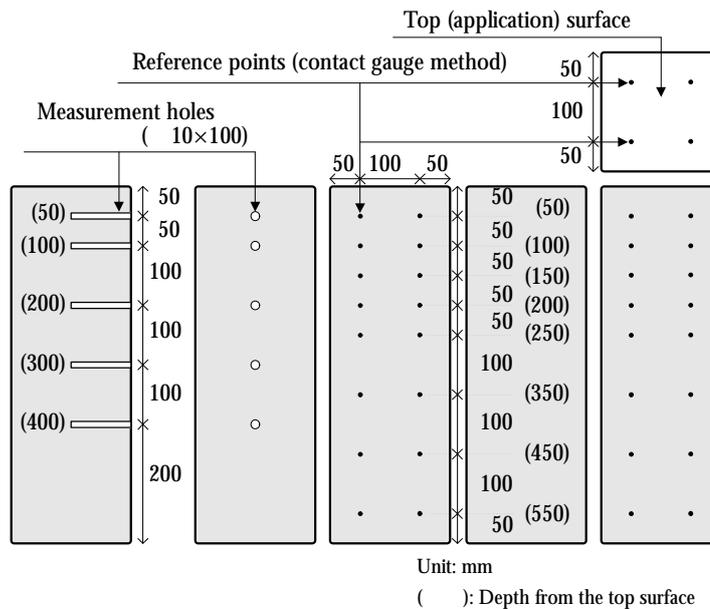
FIGURE 1: Dimensions of concrete specimens

Rain-exposed   Rain-sheltered

FIGURE 2: Concrete specimens exposed outdoors (rain-exposed and rain-sheltered)

FIGURE 3: Temperature-humidity sensor
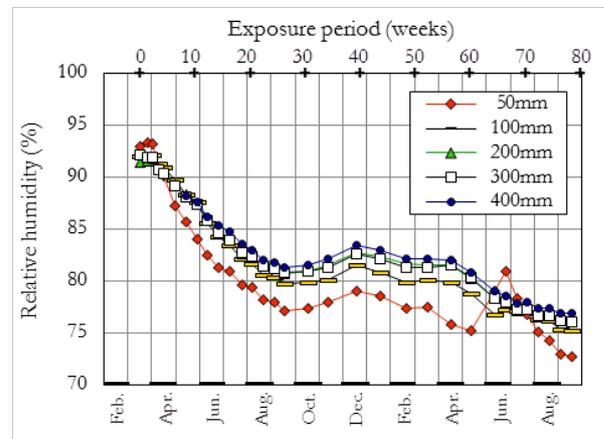
FIGURE 4: Relative humidity change
(non-treated rain-sheltered)
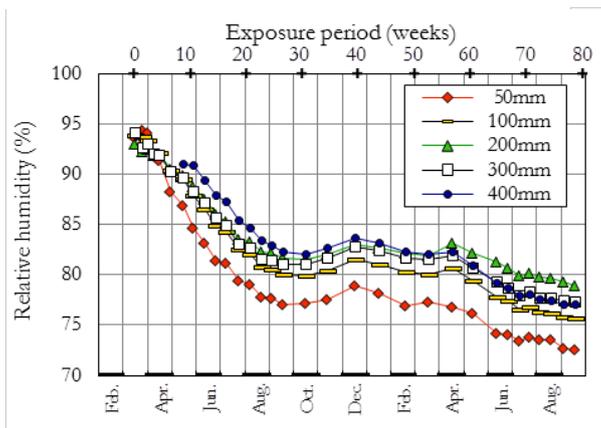
FIGURE 5: Relative humidity change
(silane-treated rain-exposed)
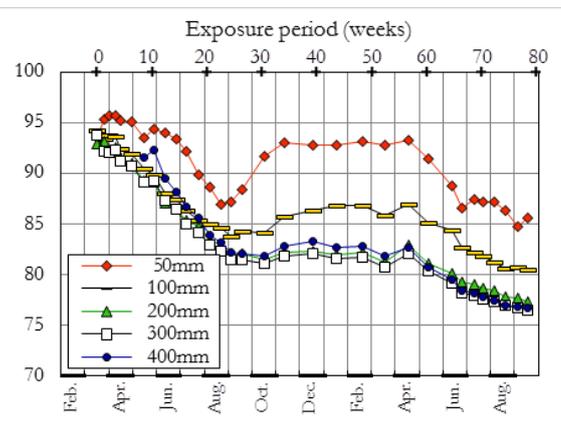
FIGURE 6: Relative humidity change
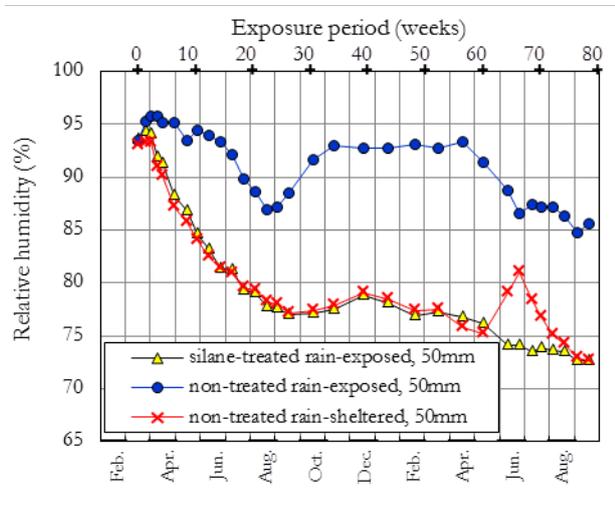(non-treated rain-exposed)

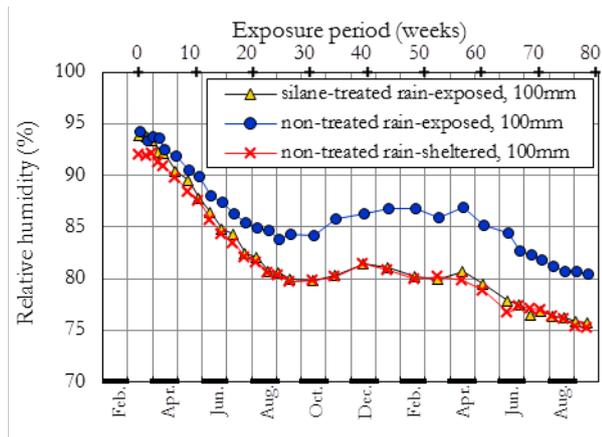FIGURE 7: Relative humidity change (50 mm from the top surface)
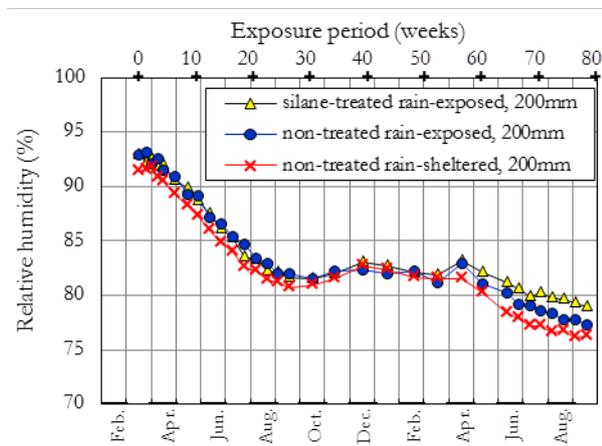

FIGURE 8: Relative humidity change (100 mm from the top surface)

FIGURE 9: Relative humidity change (200 mm from the top surface)
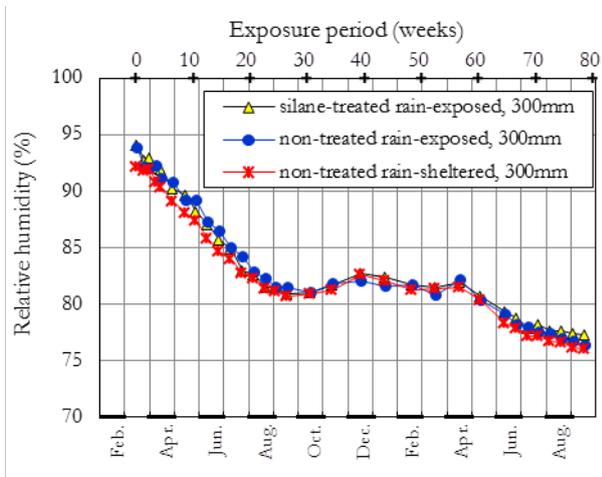
FIGURE 10: Relative humidity change (300 mm from the top surface)
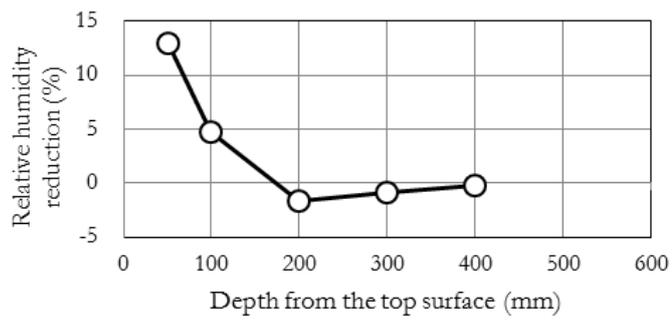
FIGURE 11: Relative humidity reduction effect of treatment
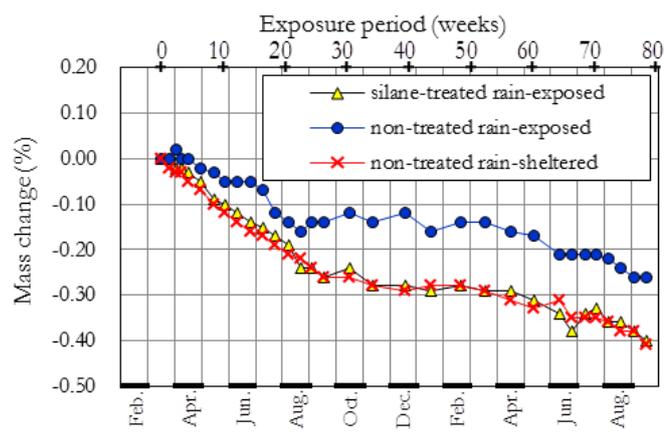
FIGURE 12: Mass change
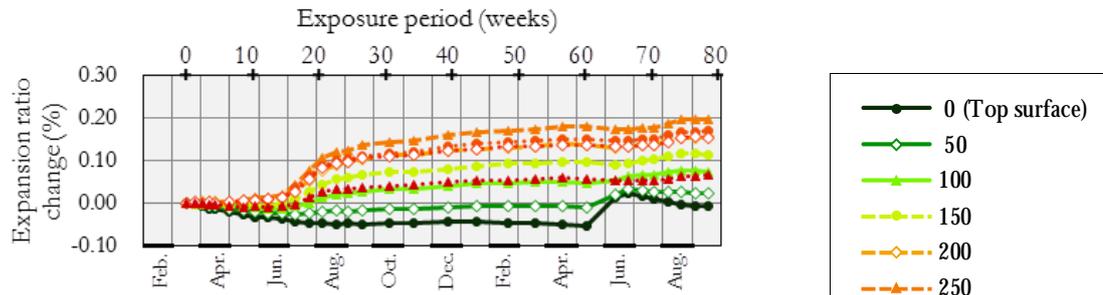
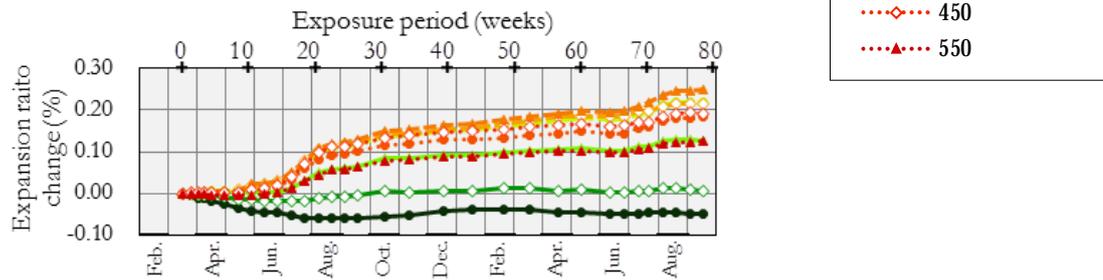FIGURE 13: Expansion ratio change (non-treated rain-sheltered)

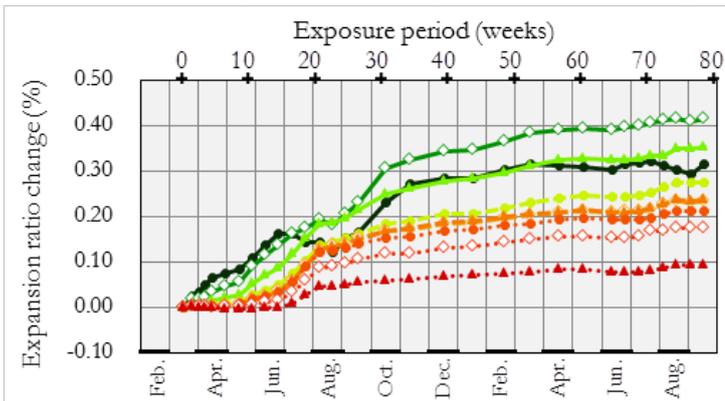FIGURE 14: Expansion ratio change (silane-treated rain-exposed)

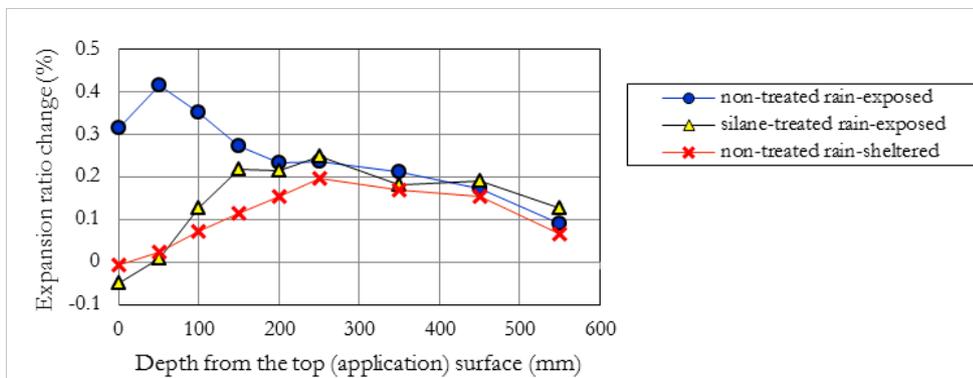FIGURE 15: Expansion ratio change (non-treated rain-exposed)

FIGURE 16: Expansion control effect of treatment (78th week)