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Study on Drying Shrinkage Strain and Moisture Transfer in Concrete with Finish Coating Materials

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ABSTRACT

This study investigated the relationship between the drying shrinkage strain and moisture transfer in concrete with various finish coating materials. This was done by measuring the moisture content of the coated concrete, which was exposed to 20°C and 60% RH in a climate-controlled room. In addition, the drying shrinkage strain and weight loss ratio of the specimens were monitored for over 4 yr. Based on the experimental results, a numerical analysis study was conducted on moisture transfer in concrete with various finish coating materials, and the drying shrinkage strain of the concrete was estimated. The results showed that finish coating materials had a preventive effect against the drying shrinkage strain of concrete in the period shortly after the start of drying. However, the preventive effects of these materials against water evaporation from concrete and drying shrinkage strain lost their effectiveness after about 4 yr.

Keywords. Drying shrinkage, Finishing materials, Moisture transfer, Indoor exposure, Numerical analysis

INTRODUCTION

To estimate cracking in concrete structures, it is important to know the drying shrinkage strain of the concrete under the actual conditions of the structure. Many reinforced concrete buildings have had finishing materials installed on the surface, which have preventive effects against drying shrinkage. It is important to consider the effects of these finishing materials on the drying shrinkage of concrete when estimating cracks in reinforced concrete buildings. However, there are very few reports on the effects (Imamoto, 1994). In this study, drying shrinkage tests were conducted for 50 mo (over 4 yr) on concrete specimens with finish coating materials; the tests measured the moisture content of the concrete specimens. A numerical analysis based on diffusion theory was also conducted on the drying shrinkage strain of the concrete with finish coating materials. This paper discusses the effects of finish coating materials on the drying shrinkage strain of concrete based on these results.

EXPERIMENTAL METHODS AND MATERIALS

Table 1 presents the plan of experiments. The moisture content of concrete specimens with various finishing materials was measured; these specimens were exposed to a 20°C, 60%

RH-controlled room. The drying shrinkage strain and weight loss of the specimens was monitored for over 4 yr (50 mo). The mix proportion and properties of the concrete are listed in Table 2, and a list of the finish coating materials used is given in Table 3. The size of the specimens was 10 × 10 × 40 cm. All specimens were water-cured at 20°C for 14 d, then air-cured at 20°C and 60% RH for 3 d. Finishing material was applied to four sides of a 10 × 40 cm specimen using the standard methods and epoxy resin was installed to the other two sides. The finishing materials selected were commonly used finishing materials for reinforced concrete buildings in Japan. The measurement of the length change due to drying shrinkage was done according to JIS A 1129-3. Filter paper specimens were also made simultaneously with the concrete specimens for vapor permeability tests (Senbu, 1996). The results are presented in Table 3.

Table 1. Plan of Experiments

Sign of Specimen	Tests
N	■□
TC-E	■□ ∗
W-TC-E	■□ ∗
ML-E	■ ∗

■: Drying shrinkage test (according to JIS A 1129-3)
□: Measurement of moisture content in concrete
∗ : Vapor permeability test

Table 2. Mix Proportions and Properties of Concrete

W/C (%)	S/A (%)	Unit weight (kg/m^3)*1				Admixture*2	Air (%)	Slump (cm)	Strength (N/mm^2)
		W	C	S	G				
50	44.7	185	370	760	877	C×0.1%	4.0	18.0	32.3

*1: Cement: Oridinary Portland Cement (ρ: 3.16g/cm^3), Coarse Aggregate: Crushed stone (ρ: 2.70g/cm^3), Sand: River Sand (ρ: 2.59g/cm^3)
*2: AE Water reducing agent

Table 3. Properties of Finish Coating Materials

Type*1	Symbol	Amount (kg/m^2)			Vapor Permeability (g/m^2・24 h)
		Base	Main	Top	
Exterior Thin Coating Material E	TC-E	—	1.4	—	188
Waterproofed Exterior Thin Coating Material E	W-TC-E	0.15	1.4	—	29
Multilayer Coating Material E	ML-E	0.15	1.5	0.38	122

*1: According to JIS A 6909

Figure 1 shows a diagram of a specimen that is set up for measurement of temperature and relative humidity in the concrete surface. The size of the specimens was 7.5 × 7.5 × 40 cm. Finish coating materials were applied to three of the 7.5 × 40 cm specimen sides using standard methods and aluminium tape was stuck on the other three sides for waterproofing. A small logger with sensor was installed in each specimen to measure the temperature and relative humidity; the diameter of the logger was 15 mm. The logger measured the temperature and RH every 15 min.

Drying shrinkage strain is generally measured from the strain of the concrete after 1 wk of water curing following casting. In this study, however, the prime water curing period was 2 wk, and the drying shrinkage test was started 6 d after prime curing for installation of finishing materials. In the study, the 'test start time' was defined to occur at 6 d after prime water curing was completed.

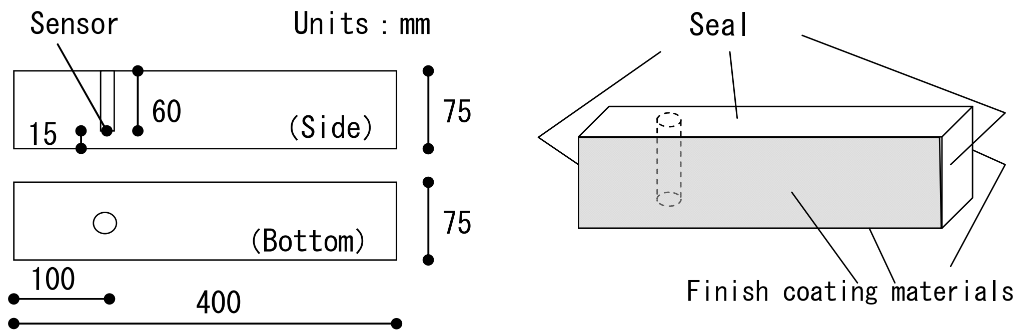
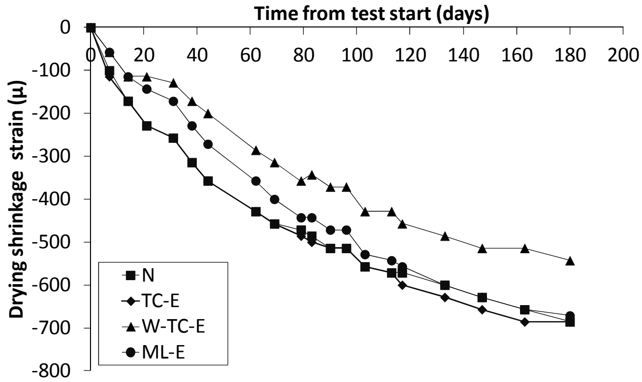


Figure 1. Diagram of specimen set-up for measurement of temperature and relative humidity

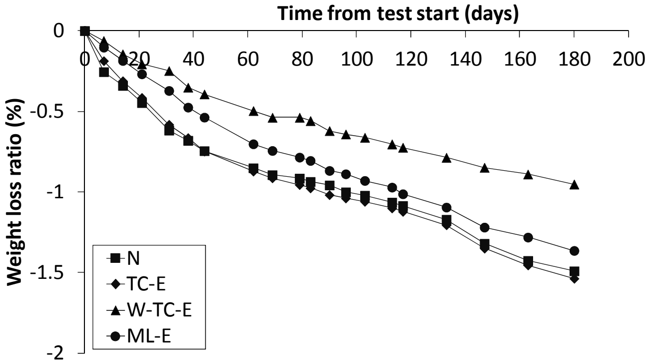
RESULTS AND DISCUSSION OF EXPERIMENT

Results of Drying Shrinkage Tests (6 Months)

The changes in the drying shrinkage strain and the weight loss ratio after the test start time are shown in Figures 2(a) and (b). According to the figures, the drying shrinkage strain of all concrete specimens with finish coating materials was observed to be less than the drying shrinkage strain in the N (no finishing materials) specimen. In addition, the weight loss ratio of the specimens with finishing materials was smaller than that of the N specimen; this demonstrated the positive effects of the finish coating materials in decreasing water evaporation from the concrete. These findings are consistent with those of a previous study (Imamoto, 1994), which pointed out that the decrease in the drying shrinkage of concrete due to finishing materials was based on their preventive effect against water evaporation from the concrete.



(a) Drying shrinkage strain



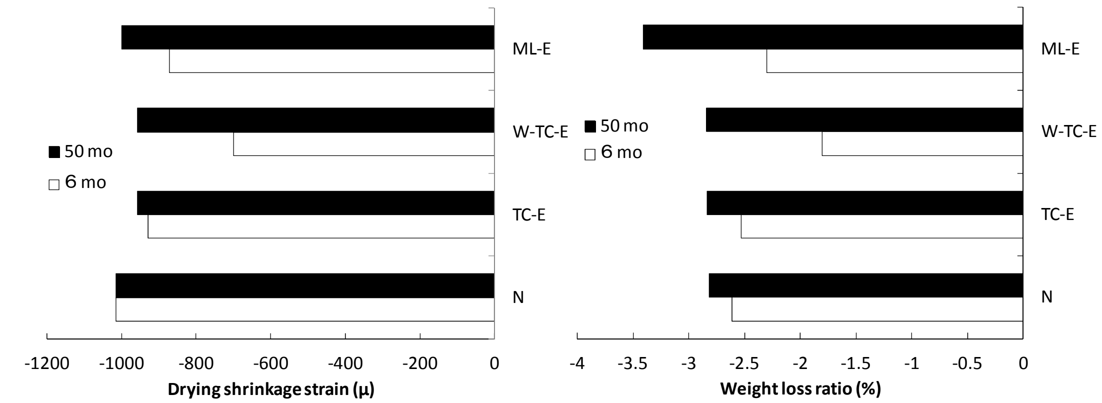
(b) Weight loss ratio

Figure 2. Results of drying shrinkage tests for 6 mo

Results of Drying Shrinkage Tests (50 Months)

Figure 3(a) shows a comparison of the drying shrinkage strain at 6 mo and at 50 mo from the drying start time. A comparison of the weight loss ratio for the two time periods is shown in Figure 3(b). To focus on the behaviour related to drying shrinkage after the start of drying, these figures showed the time from the drying start, not the time from the test start. The weight loss ratio in Figure 3 was obtained by subtracting the initial weight of the specimens with finishing materials from the weight obtained in the test.

For the N specimen, there was no observed difference between the drying shrinkage strain at 6 mo and that of 50 mo. The reason for this was not clear; however, it seemed likely that the temporary high relative humidity that occurred due to mechanical trouble with the air conditioner affected the drying shrinkage strain. The drying shrinkage strain and weight loss ratio of specimens with finish coating materials at 50 mo were close to the strain of the N specimen. This appears to indicate that the use of finish coating materials had no effect in preventing the progress of drying shrinkage strain in concrete over a long period.

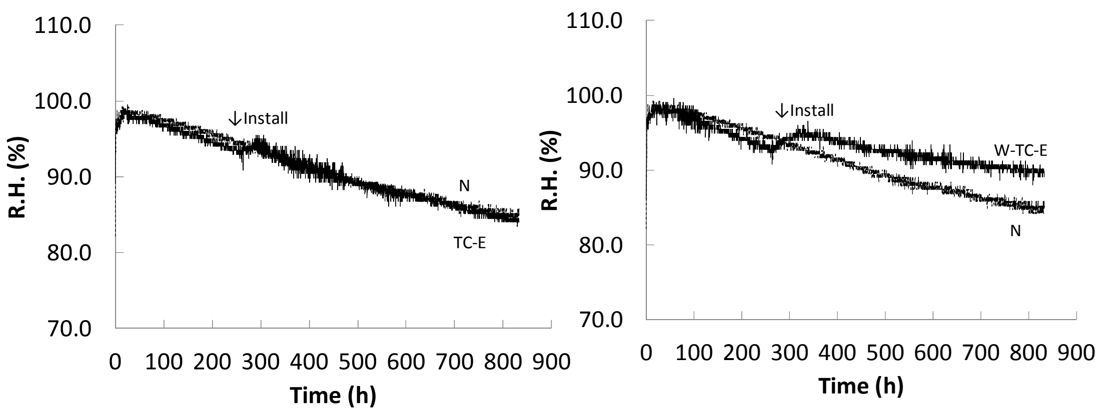


(a) Drying shrinkage strain **(b) Weight loss ratio**

Figure 3. Comparison of drying shrinkage tests at 6 and 50 mo

Measurement Results of Moisture Content in Concrete

Figures 4(a) and (b) show the change of humidity in the concrete surface after prime curing. These figures show that the humidity in the concrete surface was decreased by drying. They also show that the humidity was increased by the installation of finishing materials. It appeared that the moisture content of the concrete surface became high. A previous study pointed out that the moisture content of the concrete surface became high if the concrete surface had low vapor permeability finishing materials applied (Hashida, 1991). The finishing materials increased the moisture content in the surface part of the concrete, which appeared to affect the drying shrinkage strain.



(a) N & TC-E **(b) N & W-TC-E**

Figure 4. Change in humidity in concrete surface after prime curing

NUMERICAL ANALYSIS THEORY AND CALCULATIONS

In addition to the experiment, a numerical analysis was carried out of the drying shrinkage strain; this analysis was based on diffusion theory and the results of the experiments. The analysis method was a one-dimensional mass transfer analysis using the difference method. Table 4 lists the conditions used for the numerical analysis. The subjects of the analysis were the N, TC-E, and W-TC-E specimens, for which the change in temperature and relative humidity were measured. The analysis model is shown in Figure 5.

Table 4. Conditions of numerical analysis

Concrete	Finish coating materials	Thickness (mm)	Moisture conductivity (mm^2/s)
W/C 50%	N	—	0.82
	TC-E	1.4	0.52
	W-TC-E	1.3	0.01

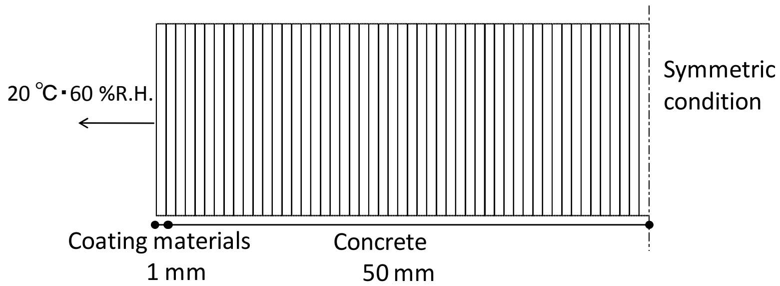


Figure 5. Analysis model

The fundamental equation used for moisture transfer in concrete was equation (1), based on the work of Akita (1990):

$$\partial R/\partial t=\partial/\partial x\ (D\cdot\partial R/\partial x) \qquad (1)$$

where

R: Relative moisture content (%), as expressed by the following equation:

$R=\psi/\psi_s\times 100$;

ψ: Moisture content (%);

ψ_s: Moisture content in saturated concrete (%);

t: Time (s);

x: Distance from drying side of specimen (mm);

and

D: Moisture conductivity (mm^2/s).

The initial condition was given by equation (2) and the boundary condition by equation (3):

$$R(x) = 100 \qquad (2)$$

$$\partial R/\partial n + \alpha_m\ (H_s - H_o) = 0 \qquad (3)$$

where

n: Normal vector of drying side;

α_m: Moisture transfer coefficient (mm/s; 3.4);

H_s: Relative humidity in surface exposed to drying (%);

and

H_0: Relative humidity in air (%).

According to Akita (1990), the relationship between relative humidity and moisture content is expressed in equation (4):

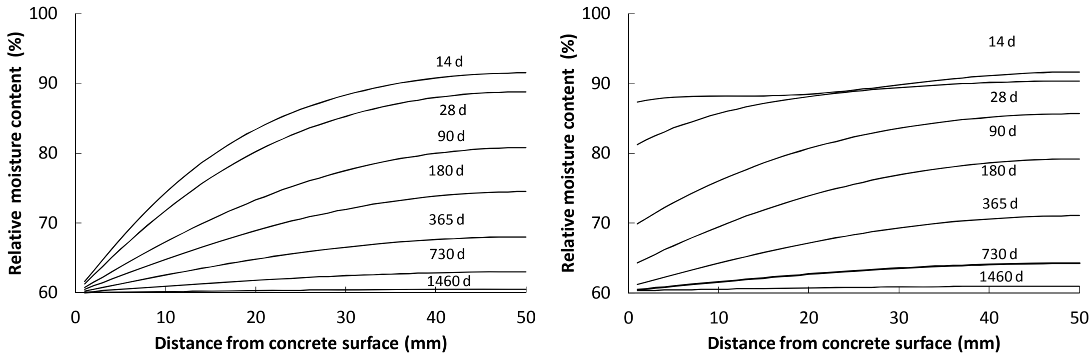
$$R = 296/(109 - H) - 447(21 + H) + 0.295H + 42.1 \quad (4)$$

Moisture transfer in the finishing material was assumed to be the same phenomenon as that in concrete; therefore, equation (1) was used with the moisture conductivity for finish coating materials. The moisture conductivity was determined by fitting to experimental results. The determined moisture conductivity is shown in Table 4.

The conditions of temperature and relative humidity in air were 20°C and 60% RH. The relative moisture content of the concrete with a finish coating material was calculated for 1500 d from the drying start, to investigate the change in moisture content in the long term.

RESULTS AND DISCUSSION OF NUMERICAL ANALYSIS

Figures 6(a) and (b) show the analysis results for the relative moisture content in the concrete of the N and W-TC-E specimens at 14, 28, 90, 180, 365, 730, and 1460 d from the drying start. A high relative moisture content was observed in the surface of concrete with finishing materials applied. This behaviour was also observed in the experimental measurements of the moisture content; therefore, it appears that this analysis was able to simulate the experimental results. The finish coating materials, especially W-TC-E, which had low vapor permeability, kept the moisture content high in the concrete surface for a while. Thus, they prevented water evaporation from the concrete at the early stage of drying. However, the moisture content of the specimens with finish coating materials was close to that of the N specimens, and the moisture content in all specimens reached an equilibrium state to 60% RH in air at 1460 d from the drying start. Therefore, it appears that the preventive effect of finish coating materials against water evaporation from concrete was not effective after about 4 yr.



(a) N **(b) W-TC-E**

Figure 6. Analysis results of relative moisture content in concrete

According to a previous study (Imamoto, 1994), there was a high correlation between the drying shrinkage strain and the weight loss ratio of concrete. An attempt was therefore made in this study to estimate the drying shrinkage strain based on the analysis results.

For the estimation, the 'decreased relative moisture content' was defined, which was calculated by subtracting the average of the relative moisture content from 100% in each part of the analysis model. Figure 7 shows the relationship between the decreased relative moisture content obtained from the analysis and the weight loss ratio obtained from the experiments. A high correlation was seen between the two, which shows that it is possible to estimate the weight loss ratio if the relative moisture content is obtained from the numerical analysis.

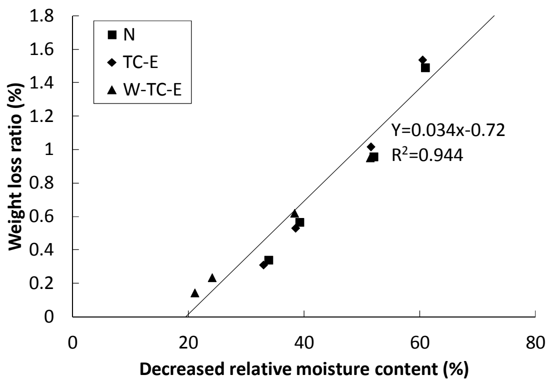


Figure 7. Correlation of weight loss ratio (experimental) to relative moisture content in concrete (from numeric analysis)

Figure 8 shows the relationship between the drying shrinkage strain and the weight loss ratio over a 50-mo period; this relationship was observed to be linear. If it is assumed that the drying shrinkage strain was caused by water evaporation from the concrete, then it is possible to estimate the drying shrinkage strain from the weight loss ratio using the relationship shown in Figure 8.

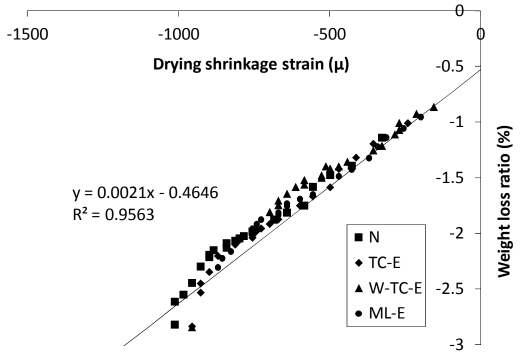


Figure 8. Relationship between drying shrinkage strain and weight loss ratio for 50 mo (experimental)

Figure 9 shows the estimated drying shrinkage strain for 180 d using the relationships shown in Figures 7 and 8 and the relative moisture content obtained from the numerical analysis results. In this figure, the plotted symbols show the drying shrinkage strain obtained from the experiments and the line indicates the estimated value. It appears that the estimated drying shrinkage strain was sufficient to express the experimental values. Figure 10 shows the estimated drying shrinkage strain for 1500 d. The estimated value was larger than the experimental value. This may have been due to the influence of the temporary high relative humidity resulting from mechanical trouble with the air conditioner, as mentioned above. Revised values calculated from measured weight loss ratio and the relationship shown in Figure 8 are also shown in Figure 10. The estimated values from analysis and the revised values of drying shrinkage strain converged. Therefore, it appears here also that the preventive effect of finish coating materials against drying shrinkage strain was not effective after about 4 yr.

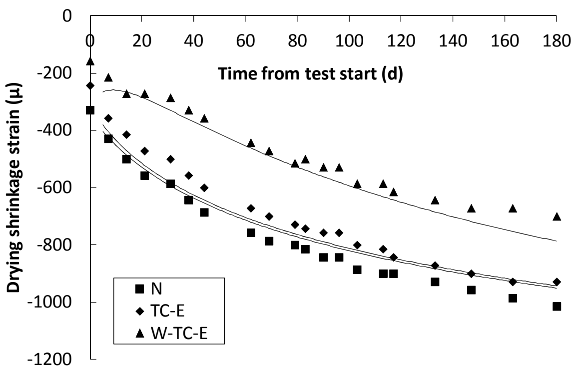


Figure 9. Comparison of estimated and measured drying shrinkage strain for 180 d after test start

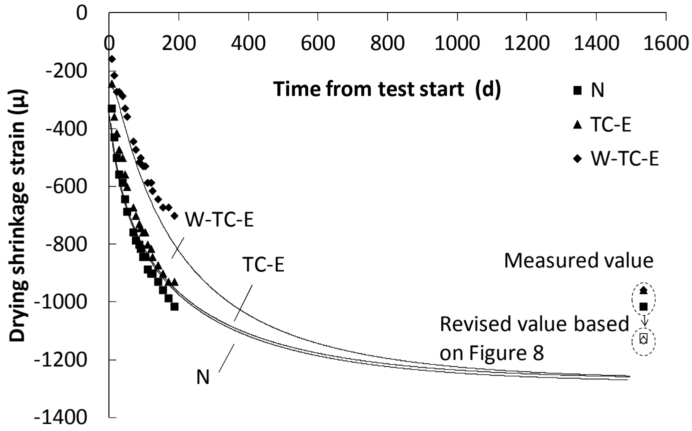


Figure 10. Estimated drying shrinkage strain for 1500 d

CONCLUSIONS

Based on our study, the following conclusions can be made:

(1) Finish coating materials have a preventive effect against the drying shrinkage strain of concrete during the initial period after the drying start.

(2) A high correlation was observed between the weight loss ratio and the drying shrinkage strain. This correlation can be used to estimate the drying shrinkage strain from the moisture content, which is related to the weight loss ratio in concrete.

(3) According to the results of our experiment and analysis, the preventive effects of finish coating materials for water evaporation from concrete and for drying shrinkage strain were not effective in the long term (i.e. beyond about 4 yr).

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