- Technical Paper -

EVALUATION OF COVERCRETE OF EXPANSIVE CONCRETE WITH EXTERNAL RESTRAINT BY SURFACE WATER ABSORPTION TEST

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ABSTRACT

Covercrete quality of medium scale wall specimens of normal and expansive concrete was evaluated by using surface water absorption test (SWAT). Importance of restraint was clearly exhibited in case of expansive concrete, by the comparison among the results of a wall specimen subjected both to internal and external restraint, a wall with only internal restraint, and a wall without any restraint. Also, effects of humidity and moisture on the results of SWAT were analyzed to support the effectiveness of SWAT for practical inspection.

Keywords: expansive concrete, covercrete, surface water absorption test, restraint, moisture content

1. INTRODUCTION

Durability of concrete structures is largely affected by cracking. Expansive additive has been used to counteract this problem by compensating shrinkage of concrete. When sufficient restraint is present, expansion in concrete produces chemical prestress in concrete. At the time of drying shrinkage, due to the effect of expansive additive, defects like micro-cracking might be reduced and at the same time quality of covercrete might be improved. In this paper the effect of expansive additive on improving covercrete quality and restraint effect are analyzed.

Quality of covercrete is analyzed by surface water absorption test (SWAT), proposed by the authors [1]. Comparison of covercrete quality is carried out between normal concrete wall specimens and expansive concrete wall specimens. The restraint effect on the performance of expansive additive is analyzed by SWAT. For this purpose the results of wall specimens subjected to both internal restraint due to reinforcement and external restraint due to the base slab are compared with wall specimens with only internal restraint, and with wall specimens without any restraint.

SWAT is more or less affected by moisture condition of target concrete. Therefore, in this research, the effect of moisture on the results of SWAT is studied for concretes ranging from good to poor quality.

2. SURFACE WATER ABSORPTION TEST

Effects of expansive additive on improving the microstructure of concrete are analyzed using a simple and completely non-destructive surface water absorption test with variable water head developed by Hayashi, et al. [1]. The test device consists of a water cup with graduated tube. Inside diameter of the cup is 80 mm and height of the tube from center of the cup is 300 mm. Once the apparatus is filled with water, drop in water level is recorded for 10 minutes started at 10 seconds after the starting of the filling time. From the observed data the Water Absorption Factor (WAF) is calculated that is defined as “the rate of water absorption in ml/m^2/s”.

Mechanism of water transport is capillary absorption under the application of water head. The following equation proposed by Levitt [2] for the Initial Surface Absorption Test (ISAT) was based on the mechanism of the viscous flow through fine capillary and is also applicable for this test.

$$y = at^{-n} \tag{1}$$

where,

- y : instantaneous rate of water absorption at any time in ml/m^2/s
- t : time in seconds
- n : coefficient regarding the reduction of rate of water absorption with passage of time
- a : y-intercept: water absorption rate at 1 second

When Eq. (1) is plotted on a log-log scale a straight line is obtained with slope “*n*” and y-intercept “*a*”. The value of “*a*” varies according to the quality of the surface concrete. It is observed that value of “*a*” is high for concretes with surface micro-cracking and is less for the concretes without micro-cracking. According to Levitt [2] the value of “*n*” varies between 0.3-0.7 (0.5±0.2). However, it is realized that the value of “*n*” is related with the moisture content and the distribution of microstructure in depth direction from the surface. In addition to indices “*a*”, and “*n*”, another index “*WAF)10*”, the instantaneous rate of water

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absorption in ml/m^2/s at 10 minutes is also calculated from the test data. It represents the overall quality of covercrete.

Levitt had also considered the instantaneous rate of water absorption at 10 minutes with constant 200 mm water head to evaluate the quality of covercrete. Further more ISAT needs certain destructive arrangements to fix the assembly during the site application. Table 1 [3] shows his qualitative rating criterion of covercrete according to ISAT.

Table 1 ISAT covercrete quality rating criterion [3]

Conc. absorption	ISAT results (ml/m^2/s)			
	Time after starting test			
	10 min	30 min	1 h	2 h
High	> 0.5	> 0.35	> 0.2	> 0.15
Average	0.25-0.5	0.17-0.35	0.1-0.2	0.07-0.15
Low	< 0.25	< 0.17	< 0.1	< 0.07

According to Dhir, et. al. [4] only surface layer up to 10 to 15 mm can be tested by surface water absorption test. However, this depth can be sufficient to distinguish the materials and curing condition.

3. RESTRAINT EFFECT IN EXPANSIVE CONCRETE

3.1 Specimen Details

To study drying shrinkage cracking behavior, normal concrete and expansive concrete wall specimens were prepared by Suhara, et al. [5]. Specimens consisted of two reinforced wall specimens with base slab. Base of both specimens were made by using expansive concrete whereas one wall was made of expansive concrete and the other was of normal concrete. To compare the effect of external restraint due to base slab, two more reinforced walls were prepared with normal and expansive concrete without base. Furthermore, to compare the effect of internal restraint due to reinforcement, two more wall specimens were made of normal and expansive concrete without reinforcement and without base slab.

Dimensions of all the wall specimens and test locations are shown in Fig. 1. Information of all the walls regarding the type of concrete, designation, date of placing, presence of reinforcement, size and horizontal and vertical reinforcement ratios are given in Table 2.

3.2 Mix Proportions

Mix proportion details of both expansive and normal concrete walls and base slabs are given in Table 3. In order to ensure the cracking due to drying shrinkage in the wall, low W/B ratio was used in footing slab and nearly max allowable water content was used for more drying shrinkage of wall.

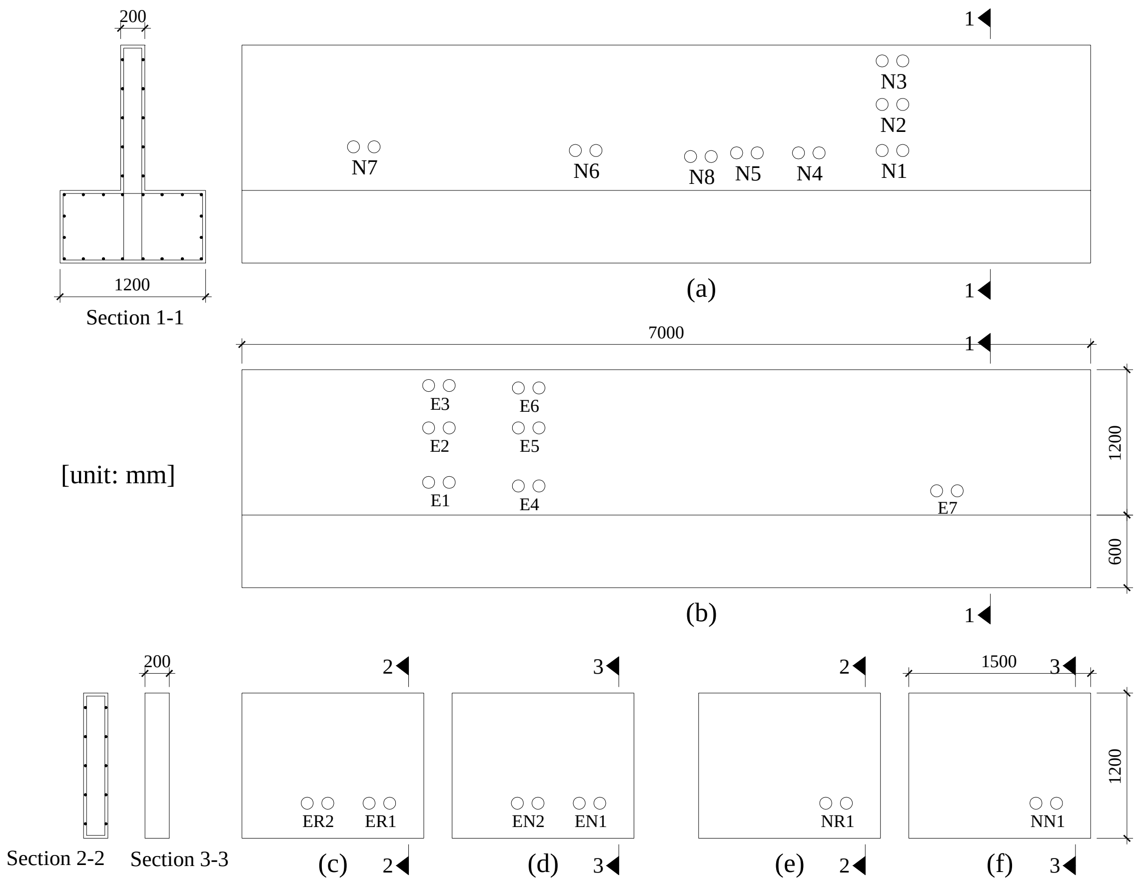


Fig. 1 Dimensions of walls and location of test points

Table 2 Wall details

Wall name	Description (conc. type)	Element	Placing date	Reinf.	Size (mm) H × B × L	Reinf. ratio (%)	
						Ver.	Hz.
N	Wall + Base (normal)	Wall	2011/07/06	Yes	1200 × 200 × 7000	0.48	0.30
		Base	2011/05/31	Yes	600 × 200 × 7000	0.40	0.55
E	Wall + Base (expansive)	Wall	2011/07/06	Yes	1200 × 200 × 7000	0.48	0.30
		Base	2011/05/31	Yes	600 × 200 × 7000	0.40	0.55
ER	Wall (expansive)	Wall	2011/07/06	Yes	1200 × 200 × 1500	0.48	0.30
EN	Wall (expansive)	Wall	2011/07/06	No	1200 × 200 × 1500	-	-
NR	Wall (normal)	Wall	2011/07/06	Yes	1200 × 200 × 1500	0.48	0.30
NN	Wall (normal)	Wall	2011/07/06	No	1200 × 200 × 1500	-	-

Table 3 Mix Proportions

Element	Air (%)	W/B (%)	s/a (%)	Max. Agg. (mm)	Unit content (kg/m^3)					
					C	W	S	A	[1]A.E.	[2]E.A.
Base slab	4.5	42.4	45.1	25	407	181	752	934	4.27	20
Normal wall	4.5	55	49.7	25	329	181	869	896	3.29	-
Expansive wall	4.5	55	49.7	25	309	181	869	896	3.29	20

[1]A.E. is air entraining agent
[2]E.A. is low added type expansive additive

3.3 Curing details

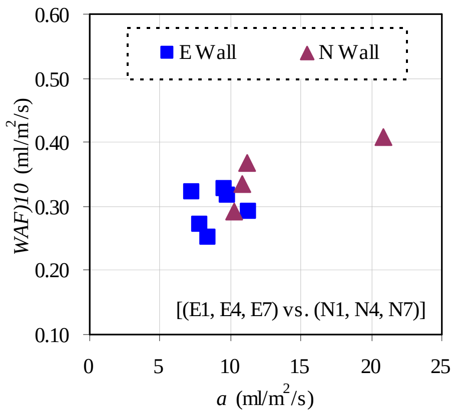
All specimens were placed, compacted and cured in a room under normal ambient conditions. Form was removed at the age of 7 days for base slabs and at the age of 5 days for walls after placing the concrete.

3.4 Observations and Discussions

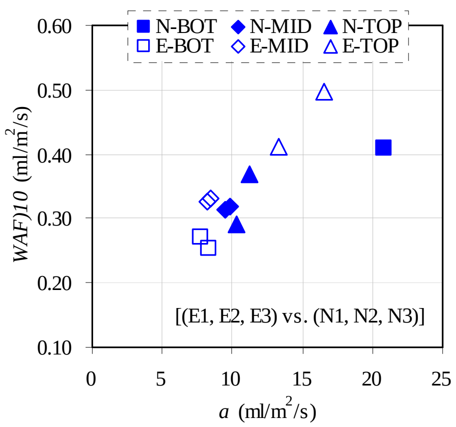
In order to evaluate the restraint effect in expansive concrete, SWAT was conducted on the wall specimens. At the time of the testing, the age of the wall specimens was 99 days and that of wall bases was 135 days.

In Fig. 2a the SWAT results at the bottom of normal and expansive concrete walls with bases are shown. Values in the brackets are representing the points selected on walls for comparison. Due to the presence of chemical prestress effect, expansive concrete wall showed better performance and less scatter than normal concrete wall. During the test it was observed that at one of the two locations each for point N1 and N7 of normal concrete wall, water was leaked through micro-cracks, which was not plotted in Fig. 2a. Those slight micro-cracks were visually observed in normal concrete wall with base when the surface got wet with acetone. Expansive concrete showed much better covercrete performance than normal concrete.

Fig. 2b is showing the comparison of performance of normal and expansive concrete walls with bases with respect to height. In this figure SWAT results of both walls are compared at bottom, mid, and top. Significant difference in SWAT indices "*a*" and "*WAF)10*" was observed at bottom, which was due to the presence of restraint effect in expansive concrete. However, at mid the difference was not significant and at top due to the combined effect of segregation,



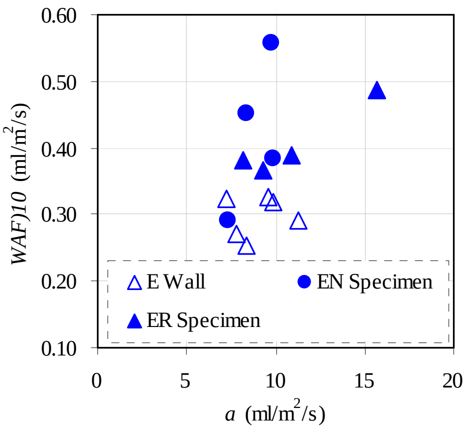
(a) at bottom only



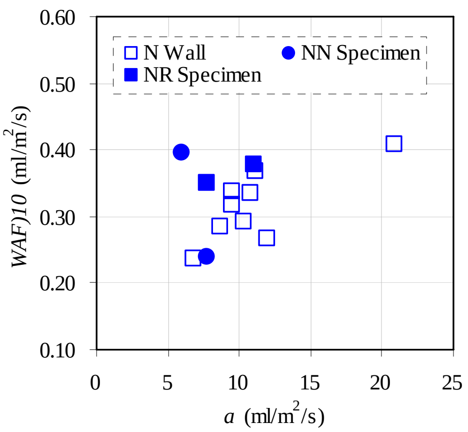
(b) at bottom, mid and top

Fig. 2 Improvement of covercrete by expansive additive bleeding, and less restraint, expansive concrete showed worse performance.

The effect of degree of restraint on the performance of expansive concrete specimens is shown in Fig. 3a and the effect in normal concrete in 3b. All points at the bottom of walls are considered for comparison. Difference in the performance can be distinctly observed in case of expansive concrete, and the wall specimen with reinforcement and external restraint showed the best performance. However, in case of normal concrete wall, adverse effect of external restraint was observed. In Fig. 3b two test results with water leakage due to micro-cracks (N1, N7) were not plotted. When drying shrinkage proceeds, normal concrete wall with reinforcement and external restraint may show poorer quality due to further micro-cracking.



(a) for expansive concrete



(b) for normal concrete

Fig. 3 Effect of restraint on covercrete quality

Two points N3 and N8 on normal concrete wall with base slab were tested 24 hrs. after the previous test at the same location. The objective was to see the effect of 24 hrs. drying after 10 min. wetting on the results of SWAT. Point N8 was of relatively good quality than point N3. Results of two tests, with 24 hrs. interval at exactly same locations are shown in Fig. 4.

It is noted that both the points showed less values of indices "*a*" and "*WAF)10*". However, the

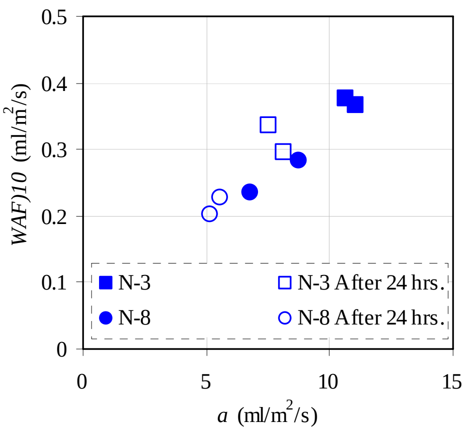


Fig. 4 Effect of drying on SWAT

change was not significant to disturb the qualitative rating of concrete according to ISAT criterion given in Table 1 for N3. Whereas, it may change the qualitative rating according to ISAT criterion as was for N8. From these results, it was decided to extend this investigation for concrete, raging from relatively good quality to relatively very poor quality to understand deeply the effect of moisture content on SWAT for practical use. The detailed investigation is presented in the following section.

4. EFFECT OF MOISTURE ON THE RESULTS OF SWAT

Results of SWAT vary as the moisture condition of the concrete changes either due to rain or due to change in humidity. BS 1881 [6] and Dhir, et al. [4] recommended that for site testing the surface shall be tested after a period of at least 48 hrs. during which no water has fallen onto the test surface. Furthermore, according to Dhir, et al. [4] minimum air drying period of 7 days, preferably 14 days, should be secured for reading taken on the site, and even then some variations in the results can still be expected.

Hence, it is important to know in detail the effect of moisture condition on SWAT. However, the main purpose of this research is to show the effectiveness of SWAT for practical use to detect the effect of expansive additive to improve covercrete quality. For this purpose, a study is conducted on OPC concrete column specimens to show the effect of moisture content is not significant.

4.1 Specimen Details

Two OPC concrete column specimens were used to observe the variation in the results of SWAT either due to humidity or wetting for short time. Two groups consisting of 12 points in total on each column were selected out of 128 points. 6 out of 12 points were representing relatively good quality and other 6 were representing relatively poor quality in one column. Fig. 5 is representing one face of the column with all test locations on it.

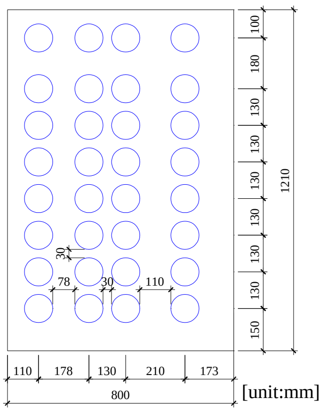


Fig. 5 Dimensions and test locations on one face

4.2 Mix Proportions

Mix proportion details of OPC concrete is given in Table 4.

Table 4 Mix Proportions

Cement type	Unit content (kg/m^3)					W/C (%)	s/a (%)
	C	W	S	A	*A.E.		
OPC	286	157	819	1064	1.13	55.0	44.4

* A.E. is air entraining agent

4.3 Curing Details

Both the column specimens were placed in two layers and were cured in lab under normal environmental conditions. Form was removed at the age of 7 days, and then, one of the column specimens was exposed to open weather outside the lab so it was subjected to sunlight and rain. At the age of 159 days this column specimen was again transferred into the lab. In this paper, the column placed inside the lab for the whole time is referred as inside column and the other as outside column.

4.4 Experiment Details

At the age of 164 to 175 days SWAT was conducted on all 128 points of each column. At that time it was summer season with 25°C average lab temperature and around 70% relative humidity. SWAT was again conducted on the selected 12 points on each column at 357 days in winter season. During testing in winter, the average lab temperature was 8°C and relative humidity was around 45%. Furthermore, these 12 points were divided into two groups of 6 points for each column. At the age of 357 days all the points in each group were tested and then after 24 hrs. half points of each group were tested and remaining half were tested after 48 hrs. The 10 minutes test results at 357 days were considered as reference and compared with the test results on the same points after 24 hrs. and 48 hrs. Experimental plan is shown in Table 5.

4.5 Observations and Discussions

To compare the effect of humidity, results in summer season are compared with those in winter season in Fig. 6. In this figure 1, 2, 3 and 4 are representing four groups in Table 5 and "S" and "W" are representing summer and winter respectively. In general, insignificant change was observed in both indices "*a*" and "*WAF)10*" due to the passage of time and due to the change in humidity. Also, the qualitative rating by "*WAF)10*" remained the same as was observed in the summer season.

However, it was observed that values of "*a*" for groups 1 and 2 were almost same though the values of "*WAF)10*" were larger in winter. As mentioned in section 2, index "*a*" represents the quality of the surface concrete and index "*WAF)10*" shows the quality of covercrete with some depth. The increase in the values of index "*WAF)10*" is showing more drying of inside concrete in winter.

Furthermore, it was observed that values of "*a*" in group 3 and 4 for inside column were reduced, showing improvement in the quality of surface layer concrete. On the other hand in the depth direction no improvement was observed as almost similar results for index "*WAF)10*" were obtained in summer and winter. The improvement shown in the really thin layer of surface concrete exhibited in "*a*" could be due to the improvement of density of microstructure by carbonation.

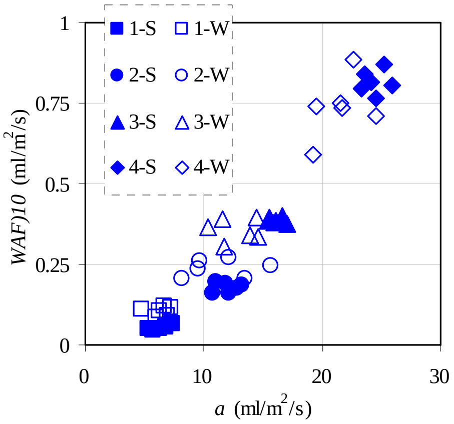


Fig. 6 Effect of humidity

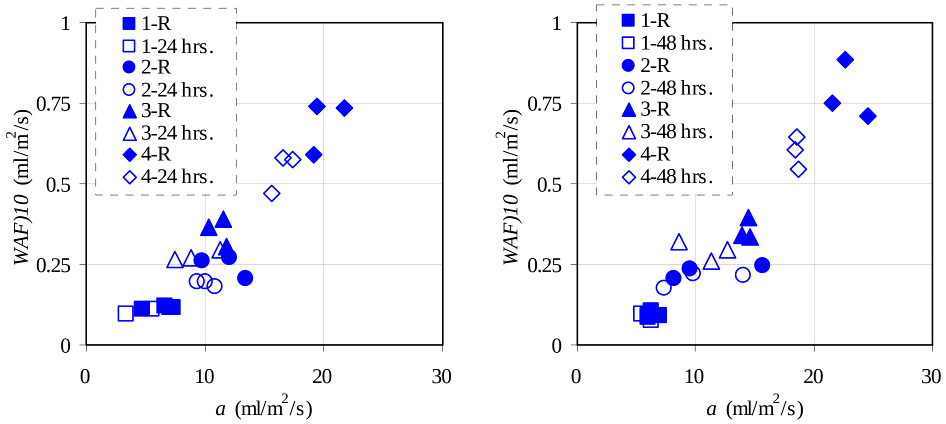
In order to check the effect of short term wetting on the results of SWAT, 10 minutes test results at the age of 357 days are compared to the results with 24 hrs. and 48 hrs. interval on the same point as shown in Fig. 7a and 7b for all 4 groups of two columns.

In Fig. 7, "R" is representing results at the age of 357 days as reference for comparison with the results at 24 hrs. and 48 hrs. In this investigation, variation in the results of SWAT at 48 hrs. was smaller than at 24 hrs. Also, the short term wetting did not apparently disturb the qualitative rating of concrete.

From Fig. 7 it was observed that the change in the results of SWAT after 24 hrs. and 48 hrs. in case of good quality concrete was relatively less than that of poor quality concrete. Almost similar values of index "*WAF)10*" after 24 and 48 hrs. for group 1 indicate that the inner concrete was not wet after the interval. Smaller values of index "*a*" after 24 hrs. are representing that only thin surface layer of concrete was still wet however, after 48 hrs. this thin layer was also

Table 5 Experiment Details

Column	Group No.	No. of points	*WAF)10* at 160 days (ml/m^2/s)	No. of points tested at		
				357 days (Ref.)	358 days (After 24 hrs.)	359 days (After 48 hrs.)
Outside	1	6	< 0.10	6	3	3
	2	6	0.10-0.25	6	3	3
Inside	3	6	0.25-0.50	6	3	3
	4	6	> 0.50	6	3	3



(a) 24 hours interval (b) 48 hours interval

Fig. 7 Effect of moisture on SWAT results

dried as the results were almost same as the reference test. Whereas, in case of poor quality concrete decrease in both indices "*a*" and "*WAF*)10" showed that the surface concrete as well as inner concrete were wet even after 48 hrs.

Slight effects of moisture content were observed in some comparisons, however they were not significant and did not disturb qualitative rating of covercrete. The authors believe SWAT can be used for practical use, such as to evaluate the difference of covercrete quality due to the effect of expansive additive.

5. CONCLUSIONS

(1) SWAT can be used to distinguish the effect of restraint in case of expansive concrete. As the degree of restraint increased, the quality of covercrete of expansive concrete was improved.

(2) Less scatter in the results of SWAT in case of expansive concrete and smaller values of indices "*a*" and "*WAF)10*" than normal concrete were caused by micro-crack free covercrete due to prestress effect in expansive concrete.

(3) Covercrete quality of normal concrete was harmed by increasing the degree of restraint and micro-cracking was slightly generated due to restraint.

(4) It was confirmed that the qualitative rating of covercrete by SWAT was not disturbed by the change of humidity or the short term wetting prepared in this research.

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