Water Penetrability into Concrete Surface and Interface between Concrete and Repair Materials

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As water is related to many deterioration mechanisms affecting concrete structures, knowledge of water movement behavior in concrete is very useful for the effective maintenance of these structures. In this study, based on many data obtained from monitoring sensors embedded in concrete samples, it was clarified that properties of water penetration into concrete surfaces differ according to component materials, mixing proportions and curing methods of the concrete. It was also made clear that water penetration behavior into the interface between the concrete and the section repair materials depends on pretreatment methods applied before addition of the restoration materials.

Keywords: concrete, fly ash, water, penetration, repair, durability, maintenance

1. Introduction

Many factors influence the deterioration of concrete structures such as corrosion of rebars by carbonation or salt attack, freezing damage, alkali-silica reaction and so on, and the presence of “water” has a significant influence on each of these causes. Accordingly, effective maintenance control of concrete structures relies heavily on understanding the behavior of water in concrete. Figure 1 shows an example of exposed rebars on the surface of a concrete structure. Rebar corrosion due to carbonation is frequently observed on this type of structure in the areas where water has splashed. This is because when water penetrates into concrete and reaches a rebar, it accelerates rebar corrosion. Figure 2 shows these phenomena. Thus, preventing water penetration to avoid contact with the rebars is essential, and knowledge of the depth of water penetration is required.

On the other hand, section repair methods are one of the most popular methods for repairing concrete structures. This method assumes that water does not generally penetrate into the repair material due its high resistance to penetration (see Fig. 2). However, it is considered that water penetrates relatively easy into the interface between concrete and the repair material. For that reason, it is important to clarify the water penetration properties of repaired concrete structures including those into interfaces. Properties will differ according to the substrate treatment methods employed, such as removal methods for degraded concrete, pretreatment methods before the setting of cross sectional repair materials, and so on.

This study attempts to clarify the penetration properties of water into concrete and the interface between concrete and repair materials through various examinations by using concrete specimens. In water penetration tests, concrete containing fly ash (FA) was also adopted in addition to ordinary Portland cement concrete clarify the water penetration behavior of FA-added concrete because this type of concrete is considered to have the different water penetration properties. Other tests on concrete and repair

materials, focused on substrate treatment methods applied before addition of repair material, because it is assumed that the treatment methods significantly affect water penetration properties [1].

Fig. 1 Exposed rebars in areas subject to water splashing

Fig. 2 Relationship between water penetration and steel bar corrosion

2. Test methods

2.1 Test of Water penetration into the concrete surface

2.1.1 Specimens prepared

Three types of specimens, namely cubes of 100 x 100 x 100 mm, regular prisms of 200 x 200 x 150 mm, and

Table 1 Mixing proportions of the specimens

(a) Ordinary Portland Cement (OPC)

Name	W/C (%)	s/a (%)	Unit weight (kg/m ³)					Admixture C × %	
			W	C	S ①	G		A ①	A ②
						①	②		
OP60	60	47	155	259	886	623	415	0.25	0.00050
OP50	50	45	155	310	831	631	420	0.25	0.00075
OP40	40	43	155	388	765	631	420	0.25	0.00200

W/C : Water to cement materials ratio, s/a : Sand-total aggregate ratio

(b) Fly Ash added version (FA)

Name	W/B (%)	s/a (%)	Unit weight (kg/m ³)					Admixture C × %	
			W	C	FA	S ②	G ③	A ①	A ②
FA60	60	47	150	213	37	878	1019	0.25	0.006
FA50	50	45	150	255	45	821	1032	0.25	0.006
FA40	40	43	150	319	56	756	1032	0.25	0.008

W/B : Water to binder materials ratio, s/a : Sand-total aggregate ratio

cylinders of 100 mm x 200 mm were used for these tests. Table 1 shows the mixing proportion of the specimens, (a) using only ordinary Portland cement (OPC), and (b) for with added FA. When FA was added, 15 % of OPC was replaced with FA. The regular prism specimen (200 x 200 x 150 mm) was equipped with resistive sensors inside (see Fig. 3). The sensors were embedded in the specimen at 10, 30, 50, 70 mm from the surface. Each sensor was wrapped in mortar made by removing coarse aggregate sifted out from the concrete but with the same mixing proportions.

2.1.2 Curing

Specimens were removed from the molds after 1 day. Then three types of curing were applied to age the concrete up to 28 days. The first was dry curing at 20 degrees centigrade and 60% relative humidity (referred here after as “atmospheric”), while the second and third were conducted in sealed conditions and in water at the same 20 degrees centigrade, respectively. After curing, all the specimens were kept at 20 degrees centigrade and 60% relative humidity up until aged to 83 days. In addition, the specimens in which sensors were embedded were wrapped in plastic tape leaving only the top and bottom exposed after being aged to 76 days.

Fig. 3 General image of immersing tests

2.1.3 Immersing and compressive strength tests

After having being aged to 83 days under the environmental conditions described above, the bottom parts of the specimens were immersed in water up to a depth of 10 to

20 mm for 7 days (see Fig. 3). This test simulated penetration of water such as rainfall or water leakage into concrete from the outside, caused by capillarity. Three types were measurement were taken: firstly, water penetration depth and mass variation for the cube specimens. Water penetration depth was gauged from the depth of the red region colored by the reaction of chemicals to water. The second was water content measured in the regular prism. Water content was measured with a water content meter. Cube and regular prism specimens were measured at 0, 3, 6 and 12 hours and 1, 2, 3 and 7 days after having been immersed in water. The third was compressive strength when aged to 28 days.

2.2 Tests at the interface between concrete and repair materials

2.2.1 Specimens prepared

Specimens are provided with a combination of various surface treatments between concrete and repairing materials as shown in Fig. 4. Table 2 shows the mix proportion of the based concrete. Two types of repairing materials (product A and B respectively) are used. The mixing proportions and execution techniques of the materials were determined as required. After applying repairing materials, all specimens were kept at 20 degrees centigrade and 60% relative humidity to age them up to 2 days.

Table 2 Mixing proportions of the based concrete

W/C (%)	s/a (%)	Unit weight (kg/m ³)				Admixture C × %	
		W	C	S	G		
					1305	2013	
50	45	152	304	833	724	634	0.25
							0.002

*1 : Water reducing agent, *2 : Auxiliary agent

Fig. 4 Production method of the samples with concrete and repair materials

2.2.2 Coefficient of air and water penetration and SEM observation

After curing, air permeability tests on the surface of concrete were conducted according to the Torrent two-chamber vacuum-cell method. The testing sites were at the center of the interface between the concrete and the repairing material. The testing sites were smoothed by sanding before the tests. After the air permeability tests, cylindrical concrete cores of 100mm x 200mm were cut out from the air permeability test sites of the specimens. These cores were then tested with a water permeability test machine according to the input method or output method. Further electron microscopic observations were made focusing on the interface between the concrete and the repairing material.

3. Results and discussion

3.1 Water penetration into the concrete surface

3.1.1 Water penetration depth and mass change

Figure 5 shows the state of water penetration into the split surface after spraying a reagent which turns purple in the presence of water. Water penetration depth on the upper side was deeper than on the bottom because of bleeding. Water penetration depth was determined by a measurement taken at the center of the split surface, to avoid influence of bleeding and water flowing along the surface. Figure 6(a) and (b) show the relationship between water penetration depth and mass change in OPC and FA. Water penetration depth has a strong positive correlation with mass change. On the other hand, the inclination of the approximate straight line is time dependent and these inclinations increase over time. Because inclination of the approximate straight line for FA is smaller than for OPC,

Fig. 6 Relationship between mass change and concrete mass water content

FA is known to have higher water penetration resistance. In the next chapter, effect of changing mixing proportions and curing methods on water penetration will be described.

At the setting of the sample

Fig. 5 Situation of water penetration into the split surface of the specimen

3.1.2 Concrete water mass content

Figures 7 to 9 show the change in mixing proportions of the concrete mass water content of the specimens for the different mixing proportions over time. These figures show the change starting from one day before the immersion test, in order to give the concrete mass water content before immersion.

Water content at 10 mm depth of the “OP60 atmospheric” specimen increased just after immersion. Then, water content in the specimens increased with depth, at 30, 50 and 70 mm. These phenomena made it possible to determine correctly water penetration time into concrete. As for the specimens with like-for-like mixing proportions, for those subject to high-quality curing such as in sealed

Fig. 7 Change of concrete mass water content (W/B=60 %) with the passage of time

Fig. 8 Change of concrete mass water content (W/B=50 %) with the passage of time

Fig. 9 Change of concrete mass water content (W/B=40 %) with the passage of time

conditions or underwater, water penetration depth was smaller than in specimens cured in atmospheric conditions. Furthermore, it was found out that fly ash-mixed concrete specimens, a sufficient degree of curing provides more resistance to water penetration than that in case of concrete specimens made with ordinary Portland cement only.

3.1.3 Relationship between compressive strength and water penetration depth

Figure 10 indicates the relationship between compressive strength after the 28 days curing and water penetration depth of OPC concrete. Water penetration depth of concrete is generally inversely proportional to compressive strength of the concrete. However, with respect to OP60 underwater curing and OP50 atmospheric curing specimens, their water penetration depths are different even though they have similar compressive strength. Therefore it is difficult to estimate the water penetration depth of concrete from the compressive strength of the concrete.

Fig. 10 Relationship between compressive strength and water penetration depth (OPC)

3.2 Water penetration into the interface between concrete and repair materials

3.2.1 Coefficient of air permeability

Figure 11 shows the relationship between substrate treatment methods and the coefficient of air permeability. The air penetration resistance of the concrete mass near the interface significantly differs with the substrate treatment method used before application of the repair material. Coefficient of air permeability of specimens with primer coating is relatively low compared with those having received other types of treatment. However, specimens with chiseled off treatment have high air permeability, because the air permeability resistance is decreased presumably due to fine cracking in the concrete mass. With respect to specimens pretreated with epoxy resin, silane

type penetrant and silicate type penetrant, no significant differences were observed compared to specimens without any treatment.

Fig. 11 Relationship between substrate treatment method and coefficient of air permeability

3.2.2 Coefficient of water penetration

Figure 12 indicates the relationship between substrate treatment method and coefficient of water penetration. The data of the coefficient of water penetration were obtained by the so-called output method which is applied to the concrete discharging water after applying 1MPa water pressure for 48 hours. In case where the concrete does not discharge water, the coefficient of water penetration is obtained by the input method by using average water penetration depth.

The relationship between substrate treatment methods and coefficient of water penetration is similar to that between the treatment method and air permeability except the specimens with the silane type penetrant because this penetrant has high resistivity to water but is ineffective for reducing air permeability. Consequently the effectiveness

Fig. 12 Relationship between substrate treatment method and coefficient of water permeability

of repairs are critically affected by differences in substrate treatment methods.

3.2.3 SEM observation at the interface

Figure 13 shows the backscattered electron image of specimens with and without primer coating at the interface between the concrete and the section repair materials by using scanning electron microscope. The substrate treatment of these specimens was "laitance removal" and dried at 20 °C. The interface of the specimen with primer coating was better filled than without any coating. Primer coating is effective for preventing water from moving from the repair material to the concrete mass after setting of the repair material. Therefore, primer coatings are useful for obtaining high resistance to water penetration at the interface between concrete and section repair materials.

Fig. 13 Difference in the state of filling at the interface with the presence of a primer coating

4. Conclusions

The results obtained in this study can be summarized as follows:

- (1) Water penetration properties into the concrete differ significantly with curing methods as well as mixing proportions. The resistance of concrete to water penetration can be increased by maintaining moist conditions during the curing process.
- (2) When 15 % of the cement is replaced with fly ash, water penetration resistance increases, and exceeds that of concrete made with ordinary Portland cement alone, when the concrete is cured in sealed conditions.
- (3) The water penetration depth in concrete is generally inversely proportional to the compressive strength of the concrete. However, there are some cases where water penetration depths of concrete differs even though their compressive strengths are similar; consequently, it is difficult to estimate water penetration depth of concrete from the compressive strength of the concrete.
- (4) The water penetration resistance of the concrete mass near the interface significantly differs with the substrate treatment method applied before adding the repair material; the use of a primer enhanced the water penetration resistance; however when the concrete surface was chiseled off by using an electric pick gun, the water migration resistance decreased presumably due to fine cracking generated in the concrete mass.

Judging from the above-mentioned results, it is fairly certain that a maintenance control technology can be developed taking the effect of “water” into consideration and that it will be possible to predict the behavior of deterioration depending on the conditions of subject structure, allowing necessary measures to be taken based on these predictions.

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