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Evaluation of Durability Properties by Binder Composition of Combined Deterioration Concrete Such as Carbonation and Salt Damage†

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In this study, mixing design was proportioned with the various water-binder ratio 0.55 binder compositions corresponding to type I cement without any supplementary materials (OPC), type II cement with 50 % blast-furnace slag replacement (BFS50), type III cement with 15 % fly ash replacement (FA15) and ternary cement with type III cement, 15 % fly ash and 35 % slag replacement (BFS35/FA15). This study is carried out to compare individual deterioration test with combined deterioration test and to investigate the effect of the permeation of deterioration factors such as CO_2 and chloride ion under the combined deterioration environments. After setting up various deterioration factors and levels such as carbonation, salt damage and the repetition of drying-wetting, items such as carbonation, chloride ion penetration were evaluated under the combined deterioration environments. The results showed that carbonation and chloride ion penetration depth were increased according to the combined deterioration environments.

Keywords: Binder composition, Salt damage, Carbonation, Combined deterioration.

INTRODUCTION

Recently, several studies on reducing the effects of various deterioration factors on the designed service life of concrete structures have been performed and various other studies have been conducted on deterioration factors and durability improvement of concrete[1,2]. However, most of these studies are based on acceleration-test methods using individual deterioration factors, such as salt damage or carbonation. Thus, the problems inherent in not recreating the complex deterioration environment the structures actually face are being recognized.

Furthermore, mixed materials are being used to enhance the cost effectiveness and performance of ready-mixed concrete, but methods for examining the durability of mixed-type concrete have not yet been systematically established.

Recently, specification design methods (standard specifications) of concrete are being converted to performance-based durability design (performance specifications), owing to a recognized need for the establishment of performance design methods that consider complex deterioration, with assumptions based on factors from real-world environments.

Therefore, this study was conducted, in conjunction with a general study on the complex nature of concrete durability, to evaluate the changes in durability characteristics and the acceleration of concrete deterioration from salt damage and carbonation, in relation to how ordinary portland cement (OPC) and mixed-type cement binders are constituted.

EXPERIMENTAL

In this study, to evaluate the environmental factors and level of deterioration of concrete under isolated and complex deterioration conditions related to salt damage and carbonation, a system for comparative analysis of the differences in reduced durability associated with these conditions was developed (Fig. 1). Decreases in durability were evaluated by transposing and applying the isolated deterioration test, as described in the experimental section.

The physical properties of materials used in this study are given in Table-1. In order to produce the 10 % NaCl needed for immersion in brine, 99 % pure NaCl was used. Moreover, to ensure the necessary flexibility and proportion of air in the

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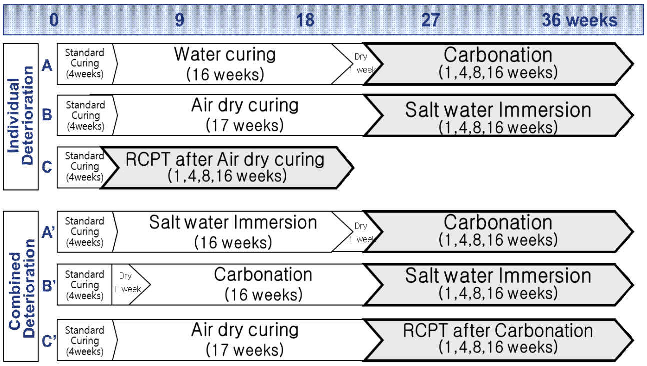

Fig. Process of this study

TABLE-1
PHYSICAL PROPERTIES OF MATERIAL

Physical properties	OPC	FA	BFS	Aggregate	
				Coarse	Fine
Specific surface (cm^2/g)	3.300	2.926	4.379	-	-
Specific gravity (g/cm^3)	3.15	2.13	2.91	2.65	2.56
Size (mm)	-	-	-	25	5
Absorption (%)	-	-	-	0.82	1.01
Fineness modulus	-	-	-	6.02	3.03

concrete, a naphthalene-based high-performance water reducing agent and AE agent were used.

Concrete: In this study, for the concrete mixture, a compressive strength (fck) of 21MPa, which is commonly used today in construction sites, a water/binder ratio of 55 % and a unit quantity of 178 kg/m^3 were used to observe the deterioration conditions in concrete in a relatively short period of time, as shown in Table-2. Also, the concrete mix was formulated depending on how the binder was constituted as follows:

Preparation of specimen: For evaluating durability properties at a combined deterioration, we manufactured Ø 100 mm × 50 mm and 100 mm × 100 mm × 400 mm specimens.

TABLE-2
PROPORTION OF THE CONCRETE MIXTURES AND PROPERTIES OF THE FRESH CONCRETE

Concrete type (binder composition)	Type I (OPC 100)	Type II (FA15)	Type III (FA15+BF S35)	Type IV (BFS 50)
Water/Binder (%)	55	55	55	55
Water (kg/m^3)	178	178	178	178
Cement (kg/m^3)	324	275	162	162
Fly-ash (kg/m^3)	-	49	49	-
Blast-furnace slag (kg/m^3)	-	-	113	162
Fine aggregate (kg/m^3)	846	837	834	842
Coarse Granite (kg/m^3)	911	901	899	908
Unit weight (kg/m^3)	2.700	2.680	2.700	2,730
Slump (mm)	175	185	200	210
Air content (%)	3.59	3.86	3.62	3.71
28d Compressive strength (MPa)	23.60	20.90	20.09	23.08

The specimens were cured under water for 4 weeks, then air dry curing was conducted up to each period at a steady temperature and humidity chamber set as 20 ± 2 °C, R.H. 60 ± 5 %.

Test methods: Fig. 2 shows the test method of RCPT (rapid chloride penetration test) after accelerated carbonation test[5].

For measuring the deterioration area of the sample from carbonation and salt damage, 1 % phenolphthalein-alcohol and 0.1 N $AgNO_3$ solutions were used.

Moreover, to confirm the pore structure before and after carbonation, the mercury intrusion porosimetry (MIP) method was used to measure the porosity of the pore structure.

RESULTS AND DISCUSSION

Fig. 3 shows the changes in carbonation depth from chloride-ion penetration. In comparison with the control sample, in which only accelerated carbonation was tested, the carbonation depth showed a significant increase, causing an accelerated rate of carbonation. Accelerated carbonation depth due to carbon dioxide, after chloride-ion penetration, showed increase

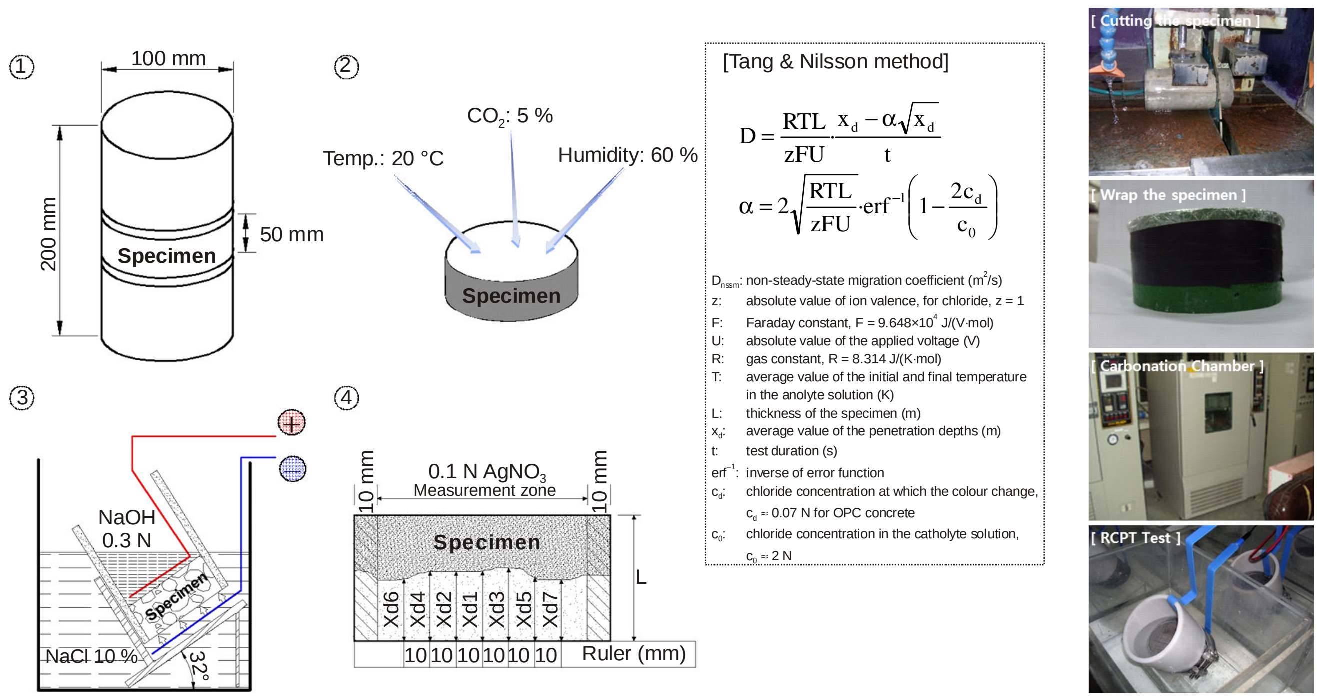

Fig. 2. Test method of rapid chloride penetration test after carbonation

in depth of deterioration from carbonation, compared to the case without chloride-ion penetration.

These results verified experimentally that the dissociation of solubility of bound chloride and the concentration phenomenon of chloride ions cause an increase in chloride-ion penetration depth.

Fig. 4 shows the changes in chloride-ion penetration depth related to carbonation. The penetration depth increased in comparison to the sample that underwent immersion aging in brine alone.

As indicated in Fig. 5, when carbonation occurred first, chloride ions exhibited a tendency of rapid penetration and, after accelerated carbonation, the diffusion coefficient value of chloride ions from the rapid chloride permeability test also increased. Therefore, acceleration of chloride-ion penetration by carbonation was observed.

Fig. 6 shows the changes in pore-structure properties due to carbonation. In comparison to the pore structure prior to carbonation, the sample, in which carbonation had occurred, showed an enlarged appearance of capillary pores with sizes of 10-1000 nm.

Although carbonation causes accumulation of reactive deposits inside the pore structure to reduce the overall porosity, the conditions just mentioned change the pores to a capillary structure, making it easier for substances to penetrate and thereby allowing increased diffusion of chloride ions, in comparison to isolated immersion in brine.

Conclusion

• When evaluating the durability based on carbonation alone, the use of mixed materials for the binder was found to be disadvantageous. However, in certain conditions, such as

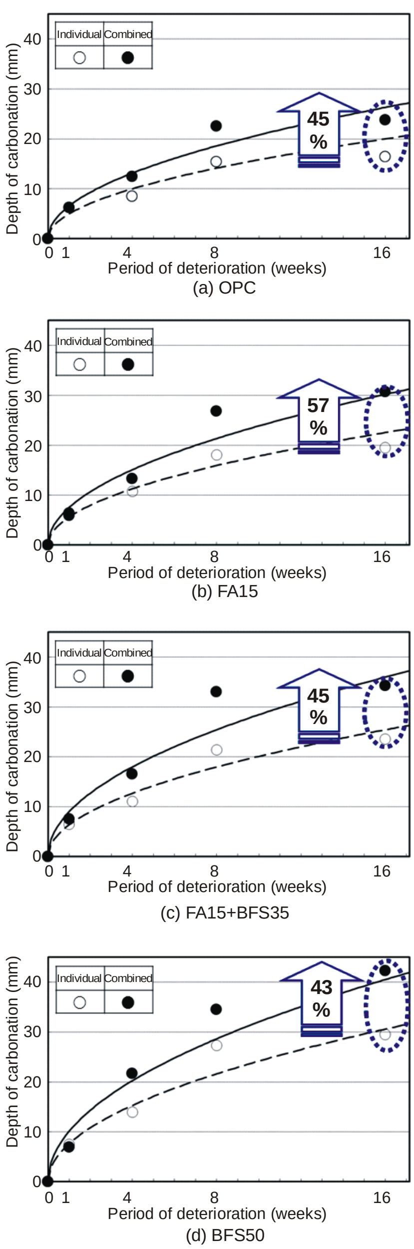

Fig. 3. Carbonation depth after chloride ion penetration (A-A')

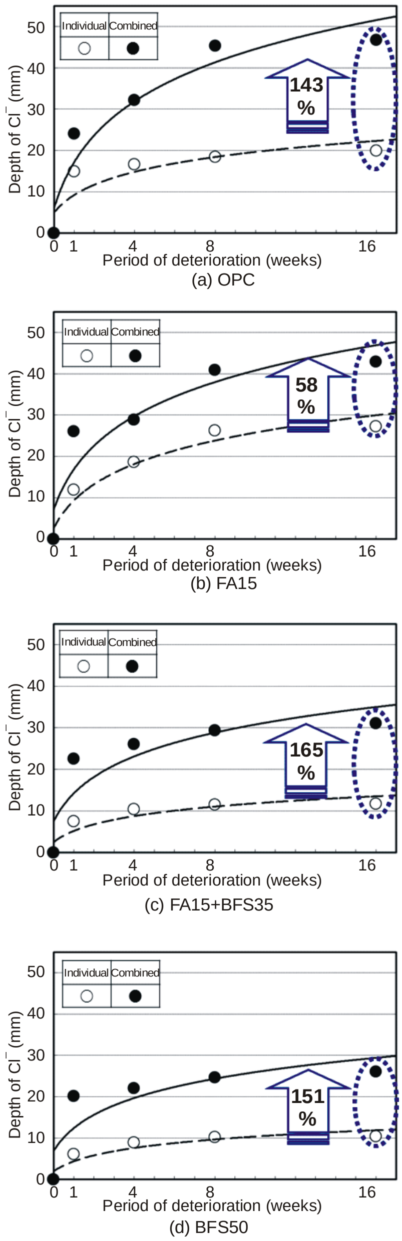

Fig. 4. Chloride ion penetration depth after carbonation (B-B')

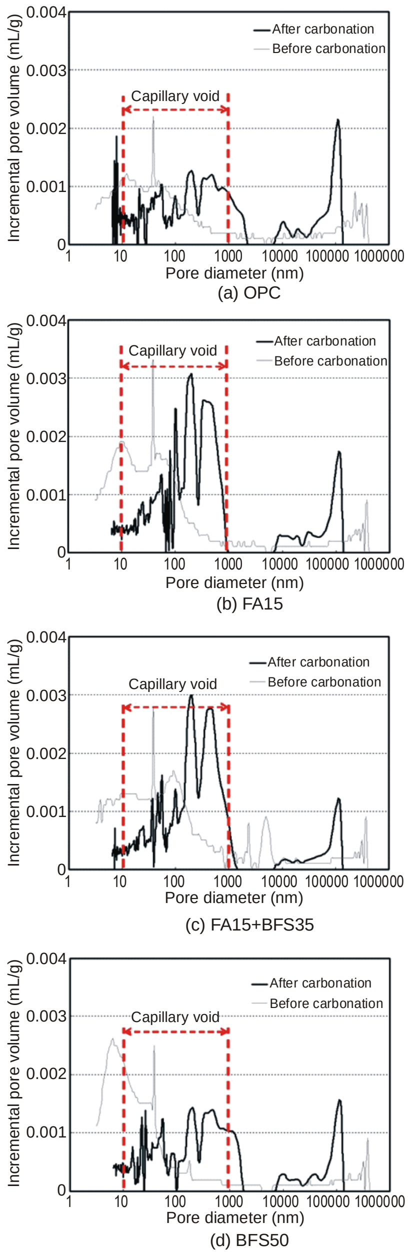

Fig. 5. Pore structure properties change with carbonation

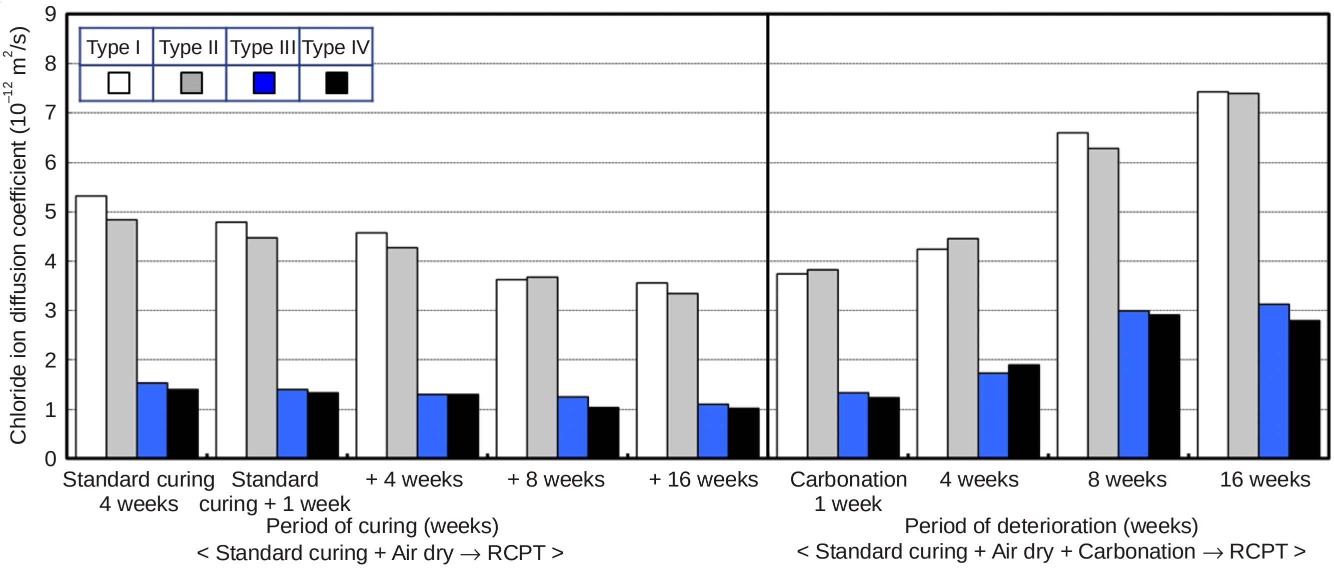

Fig. 6. Changes in the chloride ion diffusion coefficient by the carbonation (C-C')

marine environments, it is apparent that the use of mixed material as a binder should be taken into consideration.

• In environments, where both salt damage and carbonation occurred, an accelerated decrease in durability was observed. In environments where both salt damage and carbonation occurred, an accelerated decrease in durability was observed. Therefore, to establish the performance-based durability design methods for more durable and longer-lasting concrete structures, it is necessary to evaluate the durability of concrete by considering complex deterioration environments.

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