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Transport Properties of Steam Curing Concrete Using Mineral Admixtures

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ABSTRACT

Steam curing has been used widely in the precast concrete industry. However, investigations on steam curing concrete focused mainly on their strength development. Research on durability of steam curing concrete, particularly on mixes using mineral admixtures, is somewhat limited.In this study, transport properties and mechanical properties of concretes using mineral admixtures under different steam curing conditions were measured. Normal Portland cement, high early strength Portland cement, ground granulated blast-furnace slag and fly ash were used. Steam curing conditions were varied by changing the preliminary curing time, temperature drop rate and curing method after steam curing. Transport properties, such as oxygen gas diffusion coefficient and water diffusion coefficient were measured. Moreover, mechanical properties, such as compressive strength, static elastic modulus and dynamic elastic modulus were measured. From the experimental result, the degree of the influence that the differences in steam curing conditions give to transport properties varies according to the types of binder. It was confirmed that transport properties might decrease remarkably in comparison with the case of a standard steam curing condition.

Keywords: steam curing, transport property, mineral admixture

1.0 INTRODUCTION

Various performances of concrete greatly receive not only the material and mixing but also the qualities of construction and the influences of the curing condition. Considering the aspect of that point, quality of the precast concrete (hereafter, PCa) product manufactured at the factory is stable than the cast-in place concrete (hereafter, cast-in place). However, the share of PCa product is no more than about 13% in Japan. The use of PCa product has not been expanded though the PCa product has advantages. Considering a present social situation such as requirement of highly durable concrete structure, reduction of environmental loading and lack of skilled worker, it is thought that there are many chances to be used the PCa product as an improvement method of the present social situation in future (Japan Concrete Institute, 2009).

In this research, to clarify the influence of type of binder, water to binder ratio and curing condition on the carbonation depth of steam-cured concrete used generally in the manufacturing of PCa product, experimental investigation has been carried out. Moreover, the carbonation depth of specimens simulated cast-in place and PCa product assumed design standard strength was compared.

2.0 OUTLINE OF THE EXPERIMENT

2.1 Materials and Mix Proportion

<u>Materials</u>
Two types of binder were used. One was ordinary Portland cement (hereafter, “N”). The other was mixture of 65% of ordinary Portland cement and 35% of ground granulated blast-furnace slag 6000 (JIS A 6206) (hereafter, “NB”). Sea sand and crushed stone were used as fine and coarse aggregate, respectively. As a chemical admixture, high-range water-reducing admixture was used as a chemical admixture in the Non-AE (air-entraining) concrete simulated the PCa product. Air-entraining and water-reducing admixture was used in the AE concrete simulated cast-in place. The quality of materials is shown in Table 1.

<u>Mix Proportion</u>
Mix proportion is shown in Table 2. In the Non-AE concrete assumed the PCa product, target air content was 2.0%, water to binder ratios were 0.30, 0.35, 0.40 and 0.45, sand-total aggregate ratios were 0.45, 0.36, 0.37, and 0.38, respectively. In the AE concrete assumed cast-in place, target air content was 4.5%, water to binder ratio was 0.55, sand-total aggregate ratio was 0.40. In any case, quantity of water per unit volume of concrete was

Table 1. Material

Item	Type	Quality
Cement	Ordinary Portland cement	Specific gravity 3.15, Specific surface area 3240cm^2/g
Admixture	Ground granulated blast-furnace slag 6000	Specific gravity 2.91, Specific surface area 5920cm^2/g
Fine aggregate	Sea sand	Specific gravity 2.56, Percentage of absorption 1.87%, Fineness modulus 2.47
Coarse aggregate	Crushed stone	Specific gravity 2.76, Percentage of absorption 0.69%, Fineness modulus 6.66
Chemical admixture	High-range water-reducing admixture	Carboxyl group-containing polyether compound
	Air-entraining and water-reducing admixture	Complex of lignin sulfonic acid compound and polyol

Table 2. Mix proportion

Mix proportion Symbol	Binder Type	Design strength (N/mm^2)	Actual measurement air content	Water to binder ratio *W/B*	Sand-total aggregate ratio *s/a*
N30	N	–	1.9%	0.30	0.45
NB30	NB	–	1.7%		
N35	N	–	2.0%	0.35	0.36
NB35	NB	–	2.1%		
N40	N	30	2.4%	0.40	0.37
NB40	NB	30	1.9%		
N45	N	–	2.1%	0.45	0.38
NB45	NB	–	1.6%		
N55	N	30	5.0%	0.55	0.40
NB55	NB	30	4.7%		

Table 3. Curing condition

Curing condition symbol	Curing method	Prepositive time (h)	Heating rate (°C/h)	Maximum temperature (°C)	Maximum temperature retention time (h)	Cooling rate (°C/h)	Method of the post curing
【A-D】	Steam curing	3	20	65	4	4.5	Air curing (20°C, R.H.60%)
【S28】	28 days, standard curing (20°C underwater curing) → Air curing (20°C, R.H.60%)						
【S7】	7 days, standard curing (20°C underwater curing) → Air curing (20°C, R.H.60%)						

constantly 165kg/m^3. Amount of chemical admixture was adjusted in order that slump might be 8cm (In case water to binder ratio was 0.30, slump flow might be 650mm).

2.2 Curing Condition

The curing condition is shown in Table 3. In steam curing, prepositive time was 3 hours, cooling rate was 4.5°C/h, and the method of the post curing was air curing (20°C and 60% in humidity). In this research, the steam curing was imitated by giving a prescribed temperature history in constant temperature and humidity apparatus (90-95% in humidity). And the temperature history was given in close state sealed up the vinyl sheet to prevent moisture dissipation from the test specimen. In all the curing conditions, the post curing was carried out after being demolded at 24±0.5 hours. 【S28】 specimen, as a comparison with steam cured specimen, was cured by standard curing (20°C water curing) up to 4 weeks and cured in the air(20°C and 60% in humidity) until 8 weeks. 【S7】 specimen, as specimen assumed the curing conditions of cast-in-place, was cured in water (20°C) up to 1 week and cured in the air (20°C and 60% in humidity) until 8 weeks.

In this research, the specimens name is shown by "The mixing sign 【the curing condition sign】".

2.3 Setting of Specimens Simulated Cast-in Place and PCa Product Assumed the Same Design Standard Strength

In general, the compressive strength of steam cured concrete is inferior to that of standard cured concrete in case of the same type of binder and water to binder ratio, as shown in previous literatures of authors (Sasaki, 2011 and Okano, 2012). In the PCa product industry it is general to make PCa product in lower water to binder ratio concrete because of recovering loss of strength. Therefore, even if design standard strength of concrete structures is the same, water to binder ratio of concrete structure made in cast-in place concrete differs greatly from that of PCa product. According to the authors' researches, compressive strength at 14 days of concrete made by 0.40 water to binder ratio and steam curing assumed PCa product is almost equal to compressive strength at 28 days of concrete made by 0.55 water to binder ratio and standard curing assumed cast-in-place. It corresponds to 30N/mm^2 design standard strength. Because the moist curing period is about 7 days in actual civil engineering structure (Japan Society of Civil Engineers, 2013), specimens with 0.55 water to binder ratio and cured 【S7】were assumed as the cast-in place concrete and compared to specimens assumed as the PCa product with the same strength level.

2.4 Experiment Item

<u>Compressive Strength</u>
Compressive strength was measured according to JIS A1108:2006 "Method of test for compressive strength of concrete". The size of the test piece was φ100×200mm.

<u>Accelerated Carbonation Test</u>
Accelerated carbonation depth was measured in accordance with JIS A1153:2012 "Method of The accelerated carbonation test for concrete". The size of the test specimen was 100×100×400mm. number of test specimen was 2 specimens. The temperature, relative humidity and CO_2 concentration in the carbonation chamber were kept at 20ºC, 60% and 5%, respectively. Carbonation depth was measured at 1, 2, 4, 8, 13 and 26 weeks after the start of the accelerated carbonation test.

3.0 RESULTS AND DISCUSSION

3.1 Compressive Strength

Test results of compressive strength of each mixing and curing condition concrete are shown in Table 4. Though the specimens of compressive strength and accelerated carbonation test are not same batch concrete by reason of maximum capacity of constant temperature and humidity apparatus, materials of each test specimens are the same lot. In general, PCa product is managed by compressive strength at 14 days unlike cast-in place concrete that managed by compressive strength at 28 days. Therefore, in case of concrete assumed the PCa product the compressive strength at 14 days is showed in Table 4, and in case of concrete assumed cast-in place the compressive strength at 28 days is showed. From test results, the compressive strength of N40 【A-D】 and NB40【A-D】 became higher than design standard strength 30N/mm^2, and the compressive strength of N55【S28】and NB55【S28】became lower than design standard strength.

3.2 Carbonation Depth by Accelerated Carbonation Test

<u>Influence of water to binder ratio</u>
The influence of water to binder ratio on carbonation depth of steam curing concrete【A-D】by accelerated carbonation test is shown in Fig. 1 with each type of binder. The larger water to binder ratio, the larger carbonation depth in each type of binder. Moreover, the carbonation depth of concrete used NB as binder is larger compared with N. According to Kishitani's experiment, the speed of carbonation is assumed to become nearly 0 in case of concrete that binder N is used, water to cement ratio is 0.38 or less, and standard curing is subjected (Kishitani, 1963). In this research, it was confirmed that there is the same tendency in steam cured concrete【A-D】 and large difference in carbonation depth between water to binder ratio 0.35 and 0.40.

<u>Influence of water to binder ratio and curing condition</u>
The influences of water to binder ratio and the curing condition on carbonation depth by accelerated carbonation depth test are shown in Fig. 2 with each type of binder. The carbonation depth of steam curing concrete is larger than that of the standard curing in case of the same of type of binder and water to binder ratio. From Fig. 1, it is understood to be able to improve carbonation depth of steam curing concrete 【A-D】 by reducing the water to binder ratio. Moreover, in case of NB55, carbonation depth of NB55 【S7】and NB55 【S28】 are greatly unlike. In the area with comparatively large water to binder ratio (about 0.55) of NB, it has been understood that there is a possibility that water supply until 28 days greatly influences carbonation depth.

Table 4. Compressive Strength

Mix Proportion Curing Condition Symbol	Specimen Type	Compressive Strength（N/mm²） Measurements Age（day） 14	28
N30【A-D】	PCa product assumption	54.9	–
NB30【A-D】		54.6	–
N35【A-D】		46.5	–
NB35【A-D】		50.0	–
N40【A-D】		37.1	–
NB40【A-D】		40.1	–
N45【A-D】		30.6	–
NB45【A-D】		35.3	–
N40【S28】	For comparison reference	53.2	58.9
NB40【S28】		45.5	56.3
N55【S28】		26.0	29.7
NB55【S28】		22.9	30.8
N55【S7】	Cast-in place assumption	–	29.1
NB55【S7】		–	26.7

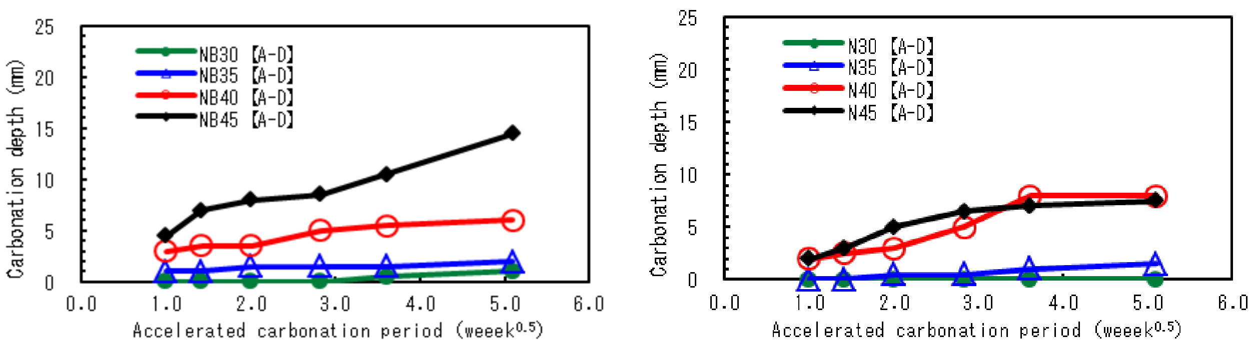

Fig. 1. Influence of water to binder ratio on the carbonation depth

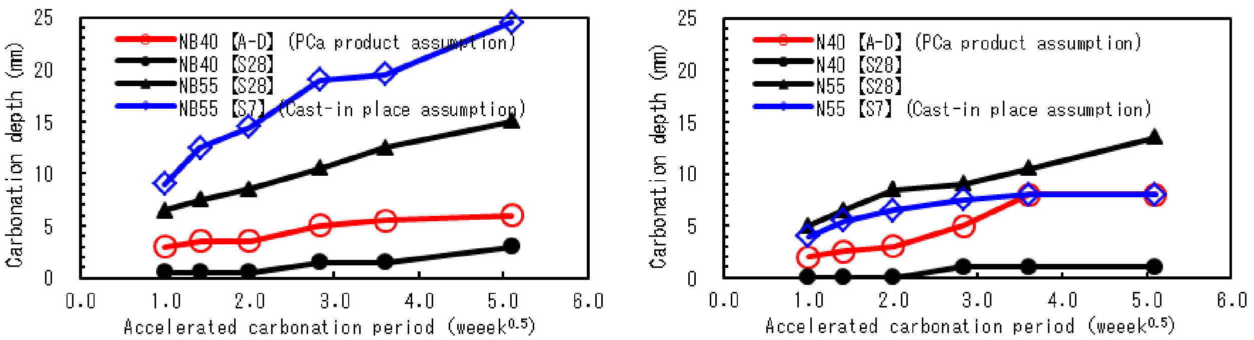

Fig. 2. Influence of curing conditions and water to binder ratio on the carbonation depth

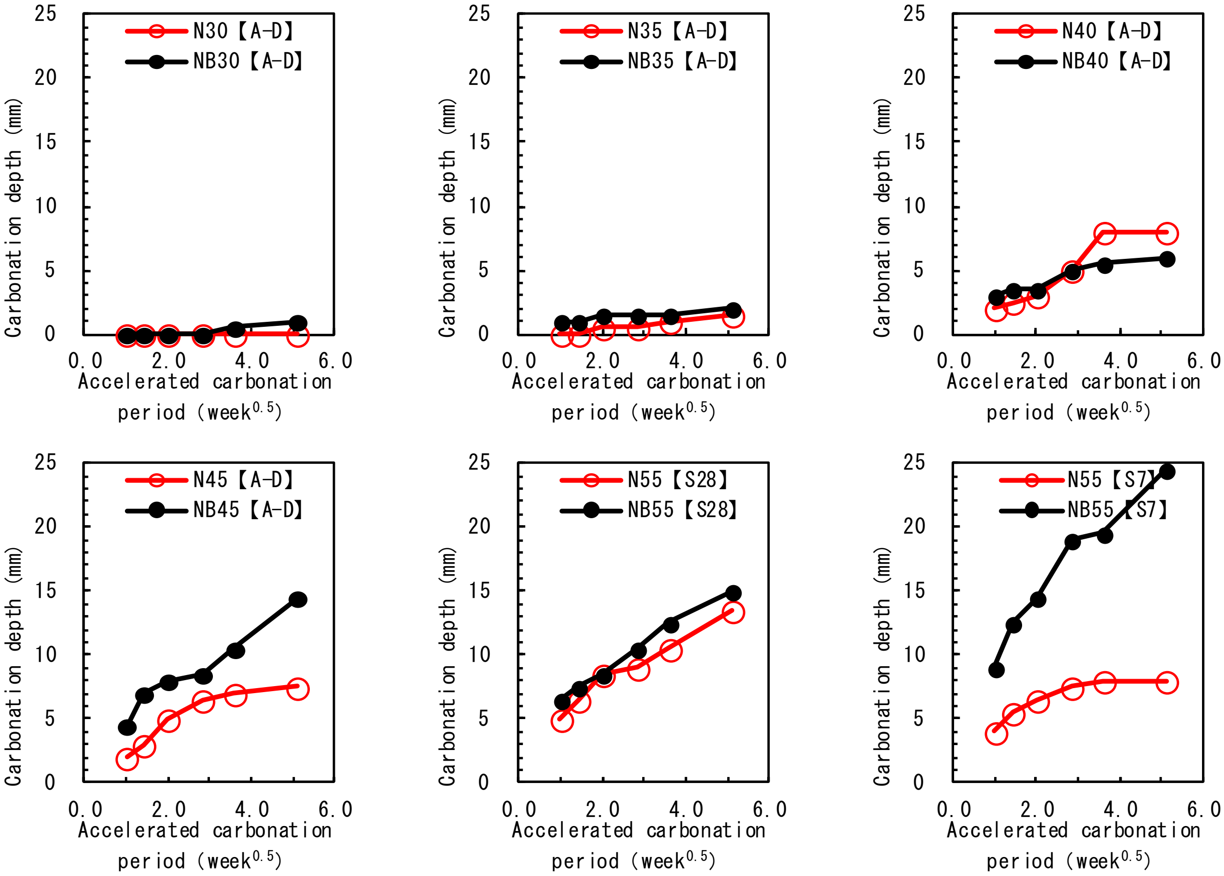

Fig. 3. Influence of type of binder on the carbonation depth

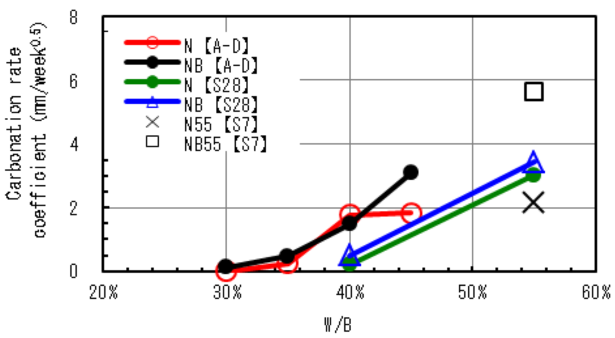

Fig. 4. Relation of water to binder ratio and carbonation rate coefficient

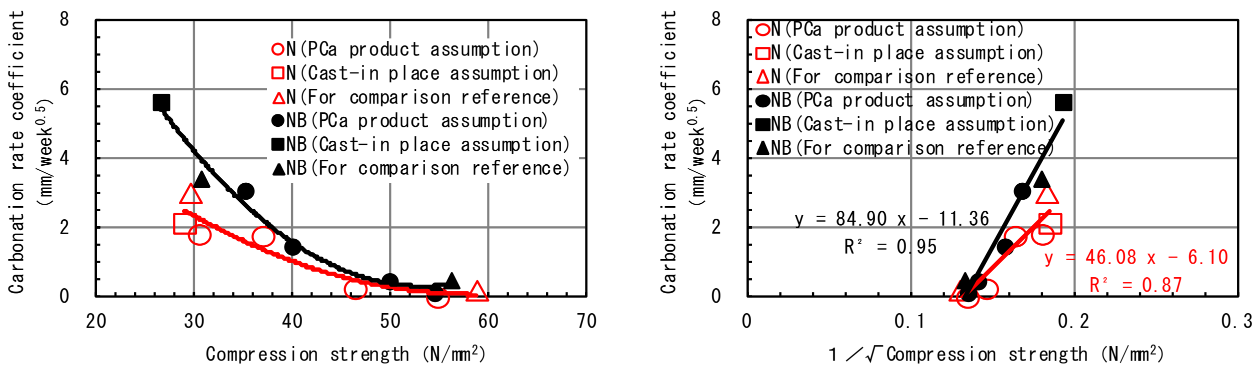

Fig. 5. Relation between the carbonation rate coefficient and the compressive strength or the inverse of e square root of the compressive strength

Relation of compressive strength and carbonation rate coefficient, and comparison of carbonation of concrete assumed PCa product and cast-in place

The relation of the compressive strength or the reciprocal of the square root of compressive strength and the carbonation rate coefficient is shown in Fig. 5. It is understood that the carbonation rate coefficient increases rapidly as compressive strength becomes small. Moreover, though a lot of findings have been obtained about the relation between compressive strength and carbonation rate coefficient up to now (Shimazoe, 1992), in this research carbonation rate coefficient have a linear relation to reciprocal of the square root of compressive strength and a strongest correlation.

If cast-in place concrete (55【S7】) and concrete assumed PCa product (40【A-D】) are compared, it is understood from Fig. 2 that the carbonation depth of concrete assumed PCa product is smaller. This difference might have been caused by the difference of compressive strength, and it is thought from Fig. 5 that the carbonation rate coefficient is close to the same if compressive strength of the specimens is the same. It can be said that the carbonation rate coefficient is close to the same without depending on curing condition if type of binder is the same and compressive strength is close to the same. Therefore, it can be said that PCa product has almost exactly the same durability as cast-in place concrete if design standard strength and thickness of concrete cover is the same.

4.0 CONCLUSIONS

In this research, the following conclusions were made:

(1) The relation between the compressive strength and carbonation depth was clarified. And it has been understood that the same durability of PCa product and cast-in place if the binder of concrete, the design standard strength and thickness of concrete cover is same.

(2) It has been understood that the type of binder has small influence on carbonation depth and water to binder ratio has large influence on carbonation depth in case of concrete cured standard curing condition or if water to binder ratio is 0.40 or less.

(3) It is possible to improve carbonation process by setting smaller water to binder ratio though curing conditions influence the carbonation rate coefficient. And in this research the carbonation rate coefficient of steam cured concrete become nearly 0 in case water to binder ratio is 0.30 or less.

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