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Durability testing of concrete containing Lignin, BNS or PCE based water reducing admixtures after 5 years exposure under various conditions

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ABSTRACT

The authors study the properties of hardened concrete incorporating polycarboxylate or naphthalenesulfonate-based superplasticizer, using lignosulfonate-based AE water reducing agent as a control. This paper discusses the experimental results of concrete durability up to the age of 5 years, following standard curing and artificial sea water curing, and under normal external exposure and exposure in a splash zone. As a result, there is not a big difference in high durable properties between polycarboxylate and naphtarensulfonate, different components of superplasticizer. In addition, the experiment suggests that the concrete incorporating polycarboxylate type of superplasticizer yields equal or higher durability than that of the concrete which incorporates lignosulfonate-based AE water reducing agent. Thus, the authors consider that the reduction of unit water content due to the use of superplasticizer will lead to the enhancement of the properties of hardened concrete.

Keywords. concrete durability, BNS, lignin-based, PC-based superplasiticizer, exposure

INTRDUCTION

There is a growing interest in the enhancement of the durability of concrete structures. Superplasticizers have been on the market for 20 years. In that time, various improvements to and studies of superplasticizers have been made. However, most of these concern the fresh properties of concrete; there are only a few studies that systematically explain its hardened properties. In the CANMET International Conference on superplasticizers held in Berlin, the problem the early diffusion of salt into concrete that incorporates PC was pointed out as an issue affecting long-term durability. The authors studied the properties of hardened concrete incorporating polycarboxylate (PC) or β-naphthalenesulfonate-based superplasticizer (BNS), using lignin sulfonate-based AE water reducing agent (LG) as a control. This paper discusses the experimental results of concrete up to the age of 5 years, following standard curing and artificial sea water curing, under conditions of normal external exposure or exposure in a splash zone.

OUTLINE OF THE EXPERIMENT

Materials and mixture proportion. Table 1 shows the materials used. The following admixtures were used in the experiment: Lignin sulfonate-based AE water-reducing agent (LG), β-naphthalene sulfonate-based superplasticizer (BNS) and polycarboxylate-based superplasticizers (PC-1, PC-2, and PC-3). Table 2 shows the mixture proportion of concrete. Concrete at a W/C = 50% was used for the experiment. The target slump was 18 cm and the target air content was 4.5%. The general water reduction ratio for normal-strength concrete at a W/C ≒ 50% is approximately 12% through the use of AE water-reducing agent and 18% if a superplasticizer is used. Accordingly, the unit water contents for the use of AE water-reducing agent and superplasticizer were determined to be 181 kg/m3 and 169 kg/m3, respectively in the experiment.

Table 1 Properties of materials

Cement	Ordinary portland cement Density : 3.16g/cm^3 , blaine : 3300cm^2/g
Fine aggregate	Land sand Density : 2.59g/cm^3 , absorption : 2.04%, solid volume percentage: 68.2%, F.M. : 2.74
Coarse aggregate	Crushed stone Density : 2.65g/cm^3 , absorption : 0.67%, solid volume percentage: 61.9%, F.M. : 6.60, M.S. : 20mm
Admixture	LG Lignosulfonate and polyols based AE water reducing agent
	BNS B-naphthalenesulfonate(Mw:8000) based superplasticizer
	PC-1 Copolymer of methacrylic acid and methacrylic EO ester based superplasticizer
	PC-2 Copolymer of methacrylic acid and methacrylic EO ester based superplasticizer [Slump retaining type]
	PC-3 Copolymer of acrylic acid, maleic acid and unsaturated alcohol EO ether based superplasticizer

Table 2 Mixture proportions

admixture	W/C (%)	s/a (%)	Unit content (kg/m^3)			
			W	C	S	G
LG	50.0	46.0	181	362	785	943
BNS		47.0	169	338	826	954
PC-1,2,3						

Curing condition. Four curing conditions were used: standard curing, artificial sea water curing, normal external exposure (JCS-SC7 Classification D) and exposure in a splash zone (JCI-SC7 Classification A). NaCl: 24.5 g, MgCl2･6H2O: 11.1 g, Na2SO4: 4.1 g, CaCl2: 1.2 g, and KCl: 0.7 g was solved into 1 litter of solution to prepare the artificial sea water. The artificial sea water was put in a resin water tank placed outside, and the specimens were immersed in the tank. The site for normal outdoor exposure (in the grounds of our Development Center) is on flat ground in a residential area, and is 2.5 km inland from the sea coast. Curing in a splash zone was carried out in Shizuoka Prefecture in Japan. For standard curing, the specimens were removed from their moulds two days after they had been poured. For artificial sea water curing, normal exposure and exposure in a splash zone, the specimens were cured under sealed curing at 20 degrees C^{o} until 28 days. After they were removed from the moulds, they were cured until the specified age under each curing condition. The following items were measured: Compressive strength, Young's modulus, porosity (mercury penetration method), diffusion coefficient of water, Chloride ion content, and carbonation depth.

Compressive strength. φ10 x 20 cm specimens were used.

Young's modulus. The same specimens for compressive strength were used.

Porosity and Chloride ion content. Under artificial sea water curing, normal external exposure, and exposure in a splash zone, porosity and Chloride content were measured. As shown in Figure 1, 2.5cm lengths were cut from the top and bottom of the specimens. The surfaces (except for the top surface) were coated with epoxy resin. Using specimens cut to pieces 1 cm thick, the Chloride ion content was measured. Porosity was measured using the 1 cm thick pieces cut from the top surface. Pieces of the specimens subjected to standard curing were cut out of the center of the specimens to measure the porosity.

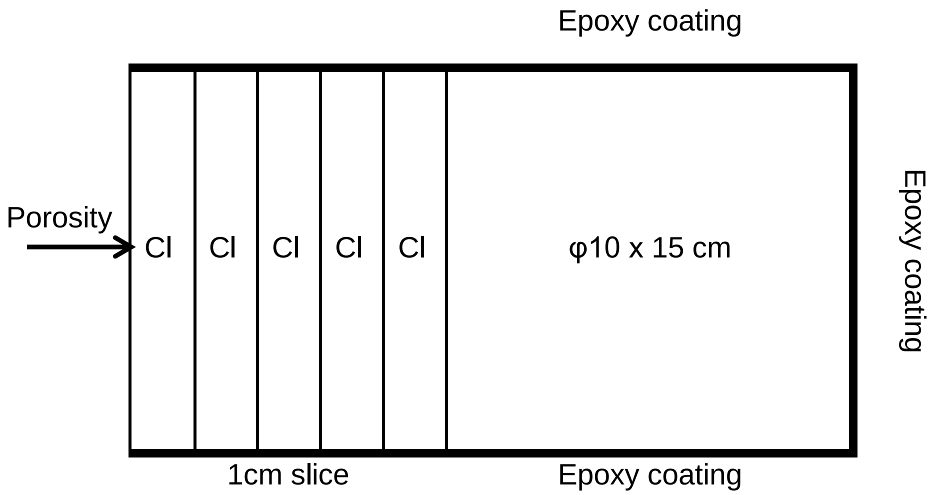

Figure 1 Specimen for measuring porosity and Chloride ion

Diffusion coefficient of water. Using φ10 x 20 cm specimens, the diffusion coefficient of water was measured by the Input method. The diffusion coefficient of water was obtained from the depth of water permeation by applying water under a pressure of 1 N/mm^2 for 48 hours for standard curing, artificial sea water curing and exposure in a splash zone; and for 24 hours for normal external exposure.

Carbonation depth. The specimens used for compressive strength and Young's modulus were split into two pieces in the middle of the top surface. Phenolphthalein solution was sprayed onto the surface of the sections to indicate the depth of carbonation

RESULTS AND DISCUSSION

Compressive strength. Figure 2 shows the relationship between the age of the concrete and its compressive strength. For specimens cured with artificial sea water, the compressive strength of the specimens containing BNS was slightly higher than that of the PC specimens. On the other hand, there was no difference between BNS specimens and each PC one for specimens cured under normal external exposure or exposure in the splash zone. For the standard cured specimens, PC-3 yielded the highest compressive strength. As a result, BNS or PC showed equal or higher strength development than that of LG under each curing condition. Under each curing condition, decrease of strength was not confirmed up to 5 years.

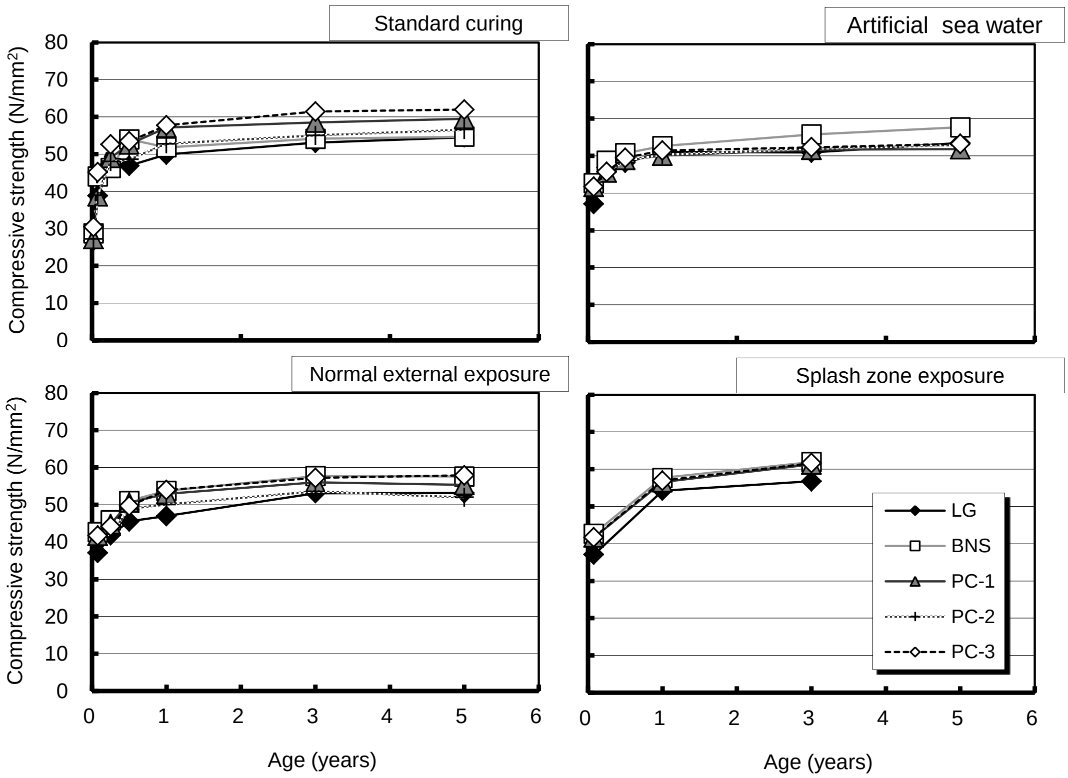

Figure 2 Relationship between the concrete age and the compressive strength

Young's modulus. Figure 3 shows the relationship between the compressive strength and Young's modulus. It also shows the curve that connects the values mentioned in the standard specifications for concrete structures established by the Japan Society of Civil Engineers.

The values of all the admixtures are up to 10% above or below of the standard, the slope between the compressive strength and Young's modulus showed is sharper than JSCE's slope. There are no major differences between the admixtures. At the age of 5 years, the ratio of Young's modulus to compressive strength under normal external exposure was smaller than that under standard curing and artificial sea water curing.

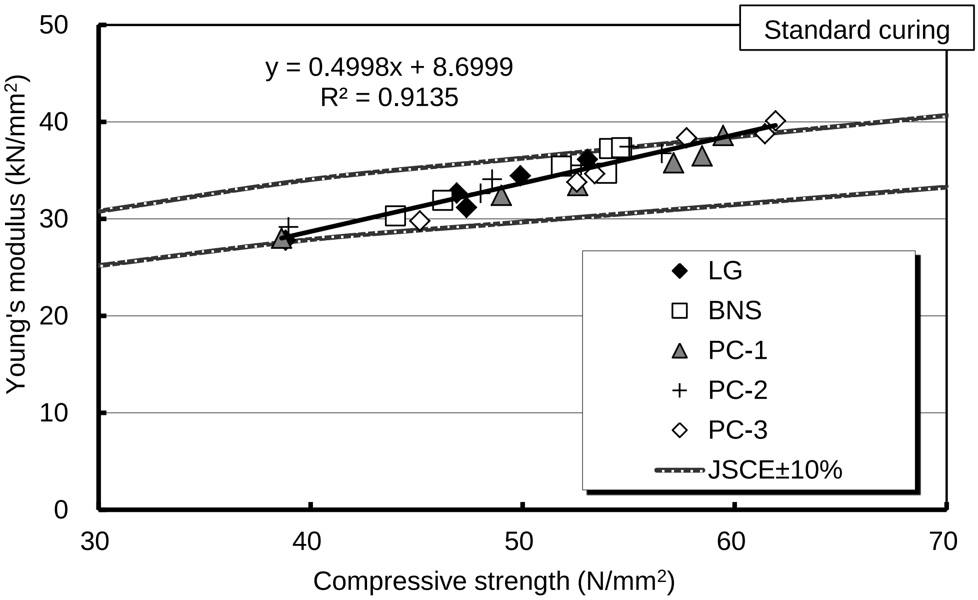

Figure 3 Relationship between the compressive strength and Young's modulus

Porosity. Figure 4 shows the relationship between the age of the concrete and its porosity volume under normal external exposure condition. The pore volume of specimens are decreased up to 1 year, these are almost constant after 1 year. The structure of porosity of specimen containing BNS and PCE based superplasticizer are slightly closer than that of LG.

Figure 5 shows the percentages of pore volume of pores 0.1μm or more in diameter and pores 0.1μm or less, out of total pore volume. The figure shows the data of 3 years under exposure in the splash zone and these of 5 years under other curing condition. In the specimens subjected to artificial sea water curing and under normal external exposure, BNS specimens showed a slightly larger volume of pores 0.1μm or less. PC specimens showed equal or higher values than that of LG specimens, therefore it is considered that PC forms equal or finer pore structures than that of LG. (Due to the loss of the specimens, no data on BNS under exposure in a splash zone was recorded.) Figure 6 shows the comparisons of total pore volume, in terms of the pore size of 0.1μm or less. There is no clear difference in the pore volume due to the kind of admixture.

Diffusion coefficient of water. Figure 7 shows the comparison of diffusion coefficient of water under four curing conditions. Following standard curing and artificial sea water curing, there is no major difference about the diffusion coefficient of water. Under normal external exposure and exposure in a splash zone, LG specimens showed much higher coefficients than did BNS and PC ones.

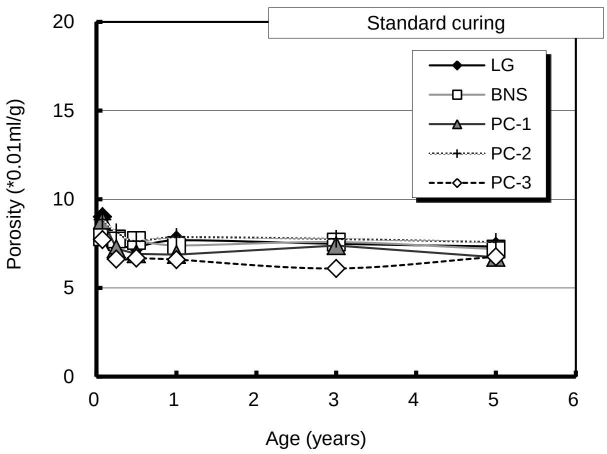

Figure 4 Relationship between the concrete age and the pore volume

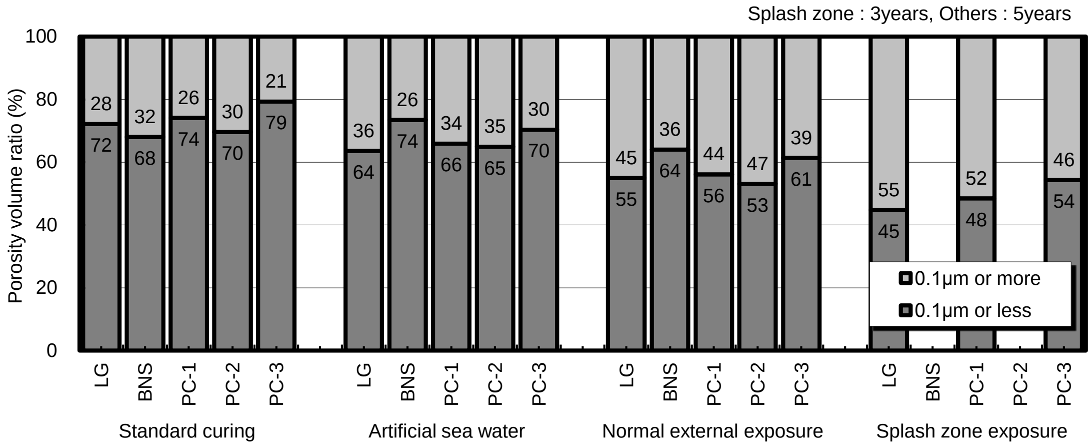

Figure 5 Percentages of the volume of pores 0.1μm or more in diameter and pores 0.1μm or less, out of total pore volume

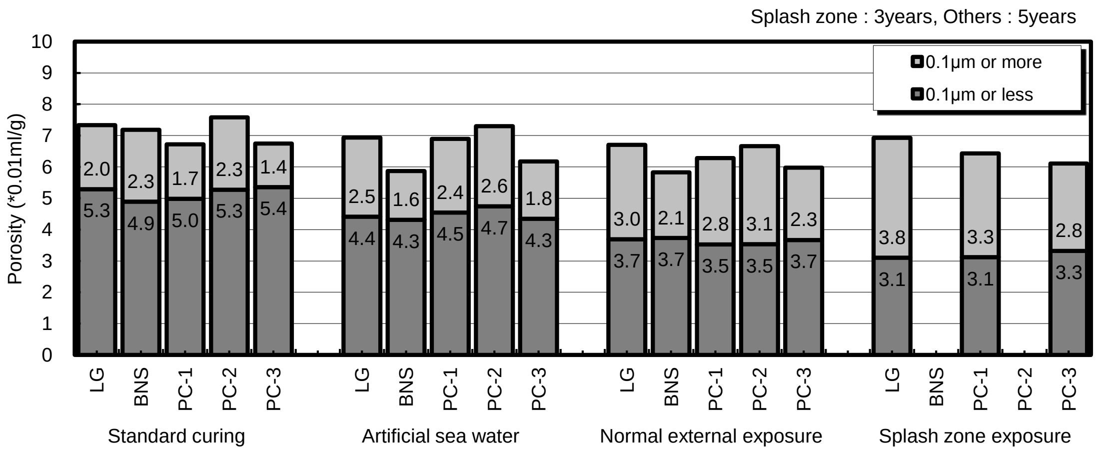

Figure 6 Comparisons of total pore volume, in terms of the pore size of 0.1μm or less

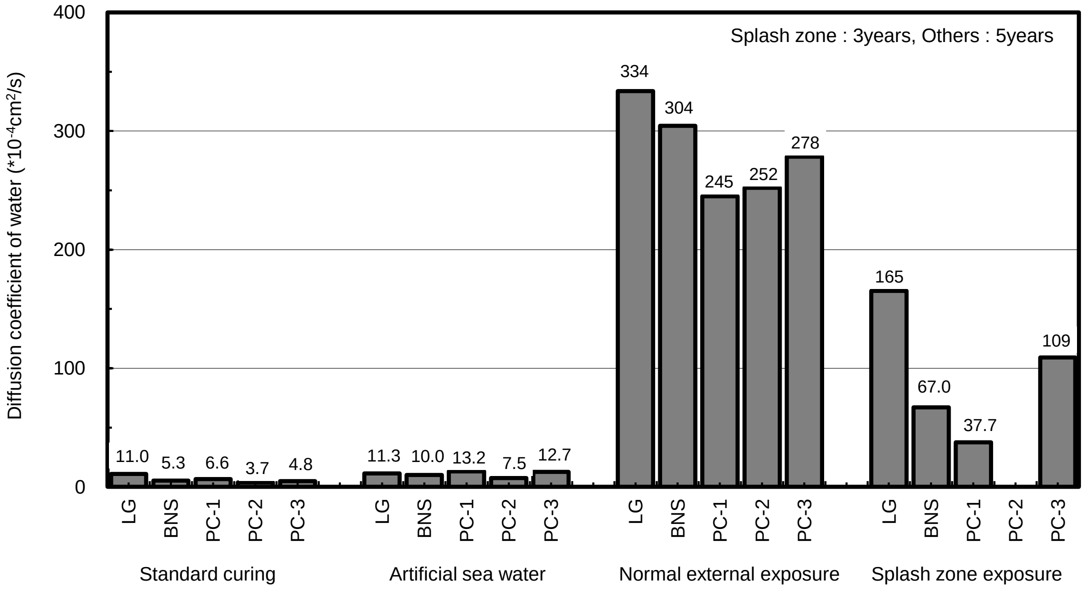

Figure 7 Comparison of diffusion coefficient of water under four curing conditions

Chloride ion content. Figure 8 shows the relationship between the depth within the specimen and Chloride ion content. The results up to the age of 5 or 3 years didn't show the difference between LG, BNS and PC. Under normal external exposure, the permeation of Chloride ions near the surface (0 to 1 cm) was 0.009 to 0.018%. There was no difference in Chloride ion content between the admixtures due to airborne salinity.

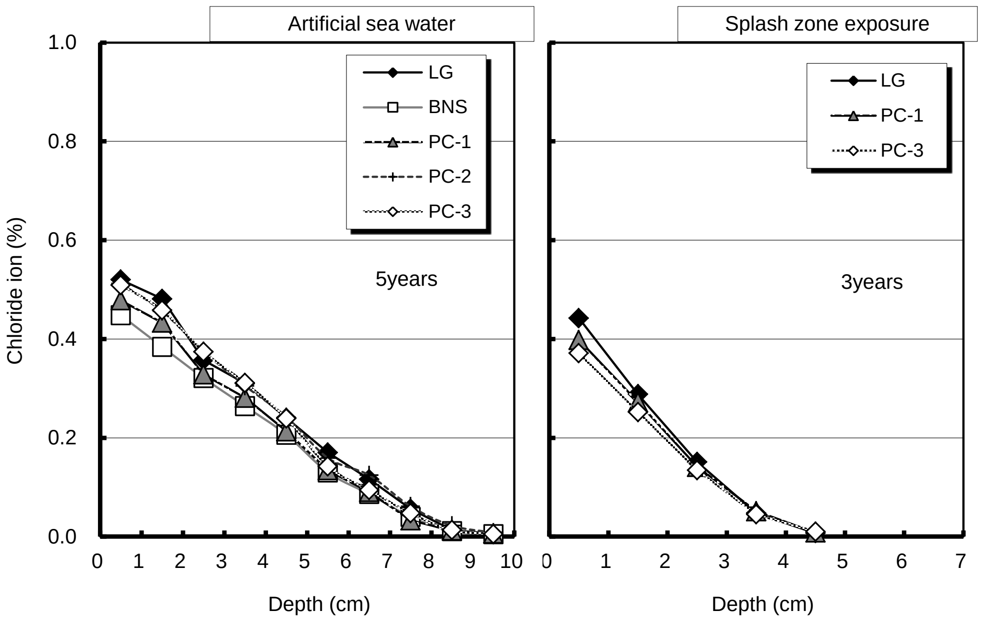

Figure 8 Relationship between the depth within the specimen and Chloride ion content

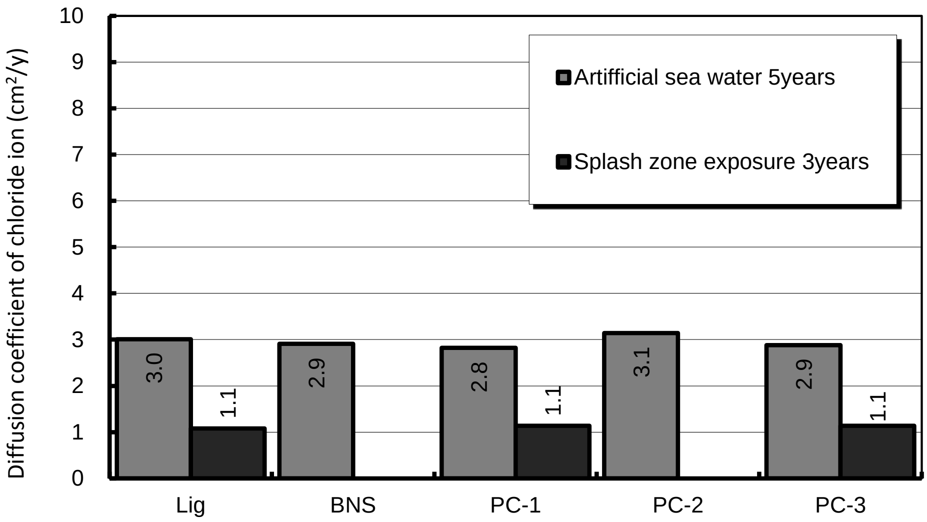

Figure 9 Comparison of diffusion coefficient of Chloride ion under four curing conditions

Figure 9 shows the comparison of diffusion coefficient of Chloride ion under four curing conditions. The results up to the age of 5 or 3 years didn't show the difference between LG, BNS and PC. The diffusion coefficient of Chloride ion content of all specimens is almost equal under each curing condition. There was no difference due to the component of admixture for Chloride ion permeability. These values under exposure in splash zone were almost equal to the results which are 0.65 to 1.35cm^2/year by Sato. The percentages of Chloride ion content in the part of 0 to 2cm from the surface of specimen under exposure in the splash zone to unit cement weight were 2.0 to 2.5%. These values are slightly lower than data which is 3 to 5% of the age of 10 years by Mohammed's study.

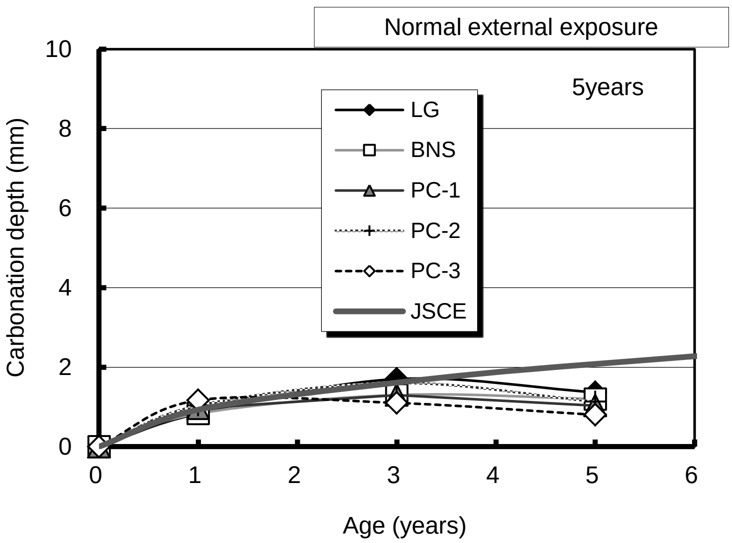

Figure 10 Relationship between the age of concrete and the carbonation depth under normal external exposure

Carbonation. Figure 10 shows the relationship between the age of concrete and the carbonation depth under normal external exposure. The carbonation depths were about 1.0 to 1.5 mm up to the age of 5 years. The carbonation depths of specimens containing BNS and PC up to the age of 5 years were slightly lower than that of LG. This suggests that carbonation resistance is improved by using superplasticizers. It also shows the curve that connects the values mentioned in the standard specifications for concrete structures established by the JSCE. The experimental results up to the age of 5 years were lower than the curve mentioned by the JSCE.

CONCLUSION

The experimental results show that concrete incorporating superplasticizers has a higher density and a higher resistance to carbonation compared with concrete incorporating an AE water reducing agent. However, a clear trend was not observed in the results of the Chloride ion concentration and water permeability measurements. Further studies of pore structure and permeation should be made where concrete of a more advanced age is examined.

There was no major difference due to the different components of the superplasticizers (BNS or PC). Each type of superplasticizers yielded equal or higher durability than did the AE water-reducing agent. The reduction of unit water content due to the use of superplasticizers will enhance the properties of hardened concrete.

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