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Improvement of Properties of B-Type Blast Furnace Slag Cement Concrete by Internal Curing

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ABSTRACT

The present study aims to investigate the effect of porous ceramic roof material waste (PCA) as an internal curing material replacing a part of coarse aggregates on the compressive strength, porosity and shrinkage of B-Type blast furnace slag cement concrete (BB).

The result showed that the compressive strengths of BB with 10% replacement of PCA as coarse aggregate (BB-G10) were 0.81, 0.93 and 1.09 times as high as that of ordinary Portland cement concrete (NC) and 1.05, 1.08 and 1.13 times as high as that of BB without PCA (BB) at 3, 7 and 28, days, which were exposed to drying at the age of 3 days after cured under sealed condition. The result also showed that the pores volumes of BB-G10 and BB-G20 decreased by 17% and 20% compared with that of BB without PCA, and the internal curing with PCA was not effective in reducing autogenous shrinkage of BB.

INTRODUCTION

As an implementation of the laws regarding to the recycling of material and the promotion of procurement of eco-friendly goods in construction industry in Japan, blast furnace slag has been applied to concrete structures for public need, mainly in the form of B-Type blast furnace slag cement containing ground granulated blast furnace slag with the replacement ratio of 30-60% in mass in accordance with JIS R 5211. It has been known that the hydration reaction of B-Type blast furnace slag cement concrete (BB) is slower than that of ordinary Portland cement concrete (NC). The BB usually needs a longer wet curing treatment at the early ages to develop the required performances(JSCE 1996). On the other hand, it is often complained by residents surrounding a construction site about construction noise, traffic congestion and so on, which may result in insufficient wet curing after remoulding at early ages and consequently, result in low quality concrete.

In the last decade, studies on application of artificial light-weight aggregate or super absorbent polymer particle as an internal curing material have been actively carried out for the purpose of reducing early age shrinkage of low water to cement (W/C) ratio concrete (Weber 1996, Jensen 2001). This internal curing technique may be effective in improving BB quality, especially when BB is exposed to the air at early ages.

In Chugoku district in west Japan, "Sekishu Kawara", which is a roof material made of clay has been produced about 20,000 ton per year, 10% of which are demolished due to thermal cracking induced damage, and expected to be recycled.

The waste aggregate produced from roof material, designated as porous ceramic aggregate (PCA) hereafter, has been reported to be effective in reducing autogenous shrinkage as well as developing compressive strength of high strength concrete (HSC)(Suzuki 2008). According to the report, PCA may be useful as an internal curing material for improving qualities of BB, which needs comparatively longer wet curing.

Having the above-mentioned situation in mind, the present study aims to investigate how PCA as an internal curing material replacing a part of coarse aggregate is effective in improving the performances of B-type blast furnace slag cement concrete (BB) in terms of strength, porosity and autogenous shrinkage.

EEPERIMENTAL PROGRAM

Materials

The properties of materials used in this study are listed in Table.1. Ordinary Portland cement (C) was used to make reference concrete(NC) for comparison with the B-type blast furnace slag cement concrete (BB), whose replacement ratio of blast furnace slag is 40-45% in mass. Crushed quartz (QS) mixed with limestone (LS) sand was used as fine aggregate and crushed gravel (NCA) was used as coarse aggregate, which was replaced with PCA by 10 and 20% of the total volume of coarse aggregate for the purpose of internal curing. The PCA was 8-9% in water absorption after being immersed for 7 days and about 20% in crushing value obtained in accordance with BS test method, the latter of which is approximately intermediate value between 10% of natural aggregate and 40% of artificial light weight aggregate.

Mixture proportion

Table 2 tabulates mixture proportions of four types of concretes, which were prepared in this study. The water to cement ratio(W/C) was fixed to be 0.55. BB-G10 and BB-G20 denote BB whose replacement ratios of PCA are 10 and 20% for total volume of coarse aggregate, respectively. The unit contents of water and cement were 175kg/m^3 and 318kg/m^3 for all types of concrete, respectively. Total amounts of water absorbed in PCA were 7.6kg/m^3 for BB-G10 and 15.3kg/m^3 for BB-G20.

Exposure condition

In order to investigate the effect of exposure conditions on the quality of concrete, 3 types of exposure conditions, i.e. sealed, exposed to drying at the age of 3 days and exposed to drying at the age of 7 days were set up as shown in Fig.1. The air

Table.1 Material Properties

Materials	type	Properties	Notation
Cements	Ordinary Portland Cement	Specific gravity: 3.16	C
		Specific surface area: 3390cm^2/g	
	B-type blast furnace slag cement	Specific gravity:3.02	BB
		Specific surface area: 3650cm^2/g	
Fine aggregates	Crushed Quartz	Surface-dry Specific gravity: 2.60	QS
		Water absorption: 1.06%	
	Crushed Limestone	Surface-dry Specific gravity: 2.65	LS
		Water absorption: 1.22%	
Coarse aggregates	Crushed gravel (Sandstone)	Surface-dry Specific gravity: 2.62	NCA
		Water absorption: 0.69%	
		Crush rate: 12%, Aggregate size: 5-20mm	
	Porous ceramic coarse aggregate	Surface-dry Specific gravity: 2.24	PCA
		Water absorption: 8.58%	
		Crushing value: 21%, Aggregate size: 5-20mm	
Chemical admixtures	Air entraining agent	Polyalkylene glycol derivative	AD
	Air entraining and water reducing agent	Lignin sulfonic acid compound and polyol complex	

Table.2 Mixture proportion of concrete

Mix name	W/B	Unit weight (kg/m^3)								Slump (mm)	Air (%)
		W	C	BB	S	LS	S+LS	NCA	PCA		
NC	0.55	175	318	-	499	339	838	942	-	7.1	4.3
BB	0.55	175	-	318	492	334	826	942	-	11.1	4.9
BB-G20	0.55	175	-	318	492	334	826	753	162	10.3	5.0
BB-G10	0.55	175	-	318	492	334	826	848	81	10.7	4.8

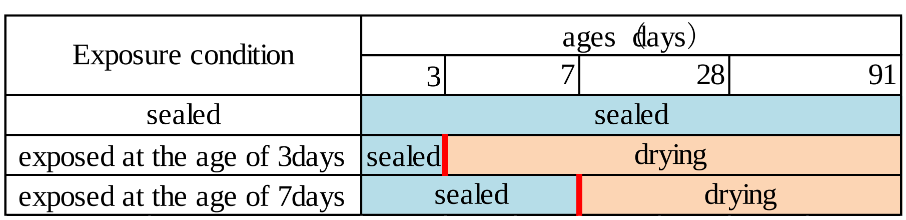


Fig.1.Exposure conditions

temperature and relative humidity were 20±1℃ and 60±5% for all conditions.

Testing procedure

(1) Compressive strength and Young's Modulus

Compressive strength and Young's Modulus test were carried out at the ages of 3, 7 and 28 days in accordance with JIS A 1108 in which cylindrical specimens with diameter of 100mm and height of 200mm were used.

(2) Porosity

The pore volume of concrete was measured using Mercury Intrusion Porosimetry (MIP). The samples for this test were taken of less damaged part of the above-mentioned cylindrical specimens tested.

(3) Shrinkage strain

Shrinkage strain was measured from early ages up to 91 days using prismatic concrete specimens (100×100×400mm), for which laser-type displacement transducers with the accuracy of 0.001mm were used for the first three days after setting and then a contact strain gage with the minimum graduation of 0.001mm was used. The shrinkage strain was evaluated by considering the temperature change induced strain in which thermal expansion coefficient was assumed to be 10×10^{-6}/℃.

RESULTS AND DISCUSSION

Compressive strength

Figs. 2, 3 and 4 show the effect of internal curing on compressive strengths of BB at the ages of 3, 7 and 28 days, exposed to drying at the age of 3, 7 days and sealed in turn. Their left, middle and right figures show th e compressive strength development of all concretes, the compressive strengths of BB, BB-G10 and BB-G20 normalized by that of NC and those of BB-G10 and BB-G20 by BB, respectively.

According to these figures, the compressive strengths of BB with and without PCA were lower than those of NC at the ages of 3 and 7 days, while the strength of BB-G10 was s lightly improved. This should be due to the fact that BB hydrates slowly, unit cement

content of the present concrete with W/C of 0.55 is not so much and, consequently, internal

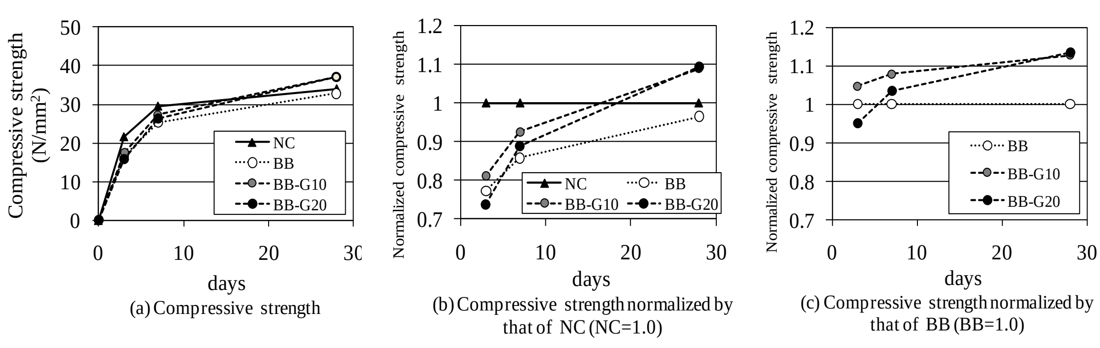
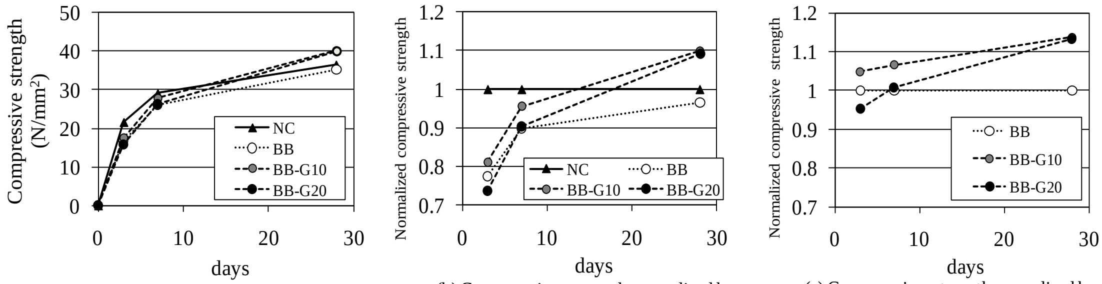


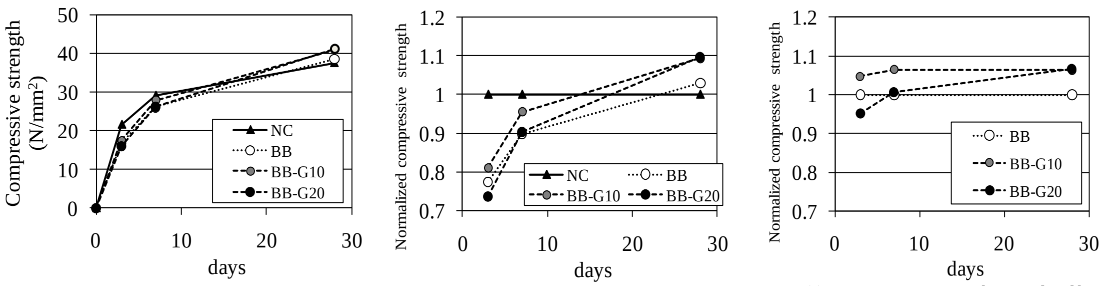
Fig.2. Effect of internal curing on compressive strength of concrete exposed to drying at the age of 3 days

curing water is hardly consumed at early ages. However, at the age of 28 days, the compressive strengths of BB with PCA were obviously higher than those of BB and NC



(a) Compressive strength (b) Compressive strength normalized by that of NC (NC=1.0) (c) Compressive strength normalized by that of BB (BB=1.0)

Fig.3. Effect of internal curing on compressive strength of concrete exposed to drying at the age of 7 days



(a) Compressive strength (b) Compressive strength normalized by that of NC (NC=1.0) (c) Compressive strength normalized by that of BB (BB=1.0)

Fig.4. Effect of internal curing on compressive strength of sealed concrete

independent of the exposure condition as well as the replacement ratio of PCA, which should be owing to the contribution of internal curing. On the other hand, these figures also show that, from the viewpoint of comparison of the compressive strength between BB without PCA and that with PCA, the internal curing contributes to improving the strength even at the age of 3 days in case of the replacement ratio of 10%, and furthermore, the difference between BB-G10 and BB-G20 for the effect of the age at drying on the strength development seems unclear.

Porosity

Total pore volume and pore volumes for specified several pore sizes of BB-G10 and BB-G20 at the age of 28 days are shown in Fig.5. The percentage of each pore volume with specified several pore sizes for total pore volume is also indicated in the figure. A value above each bar graph is total pore volume and a value in the bracket is the ratio of total pore volume of each concrete with the internal curing to that of BB without the internal curing.

According to Fig.5 (a), the total pore volume of BB which was exposed at the age of 3 days, was decreased by the replacement of PCA. The percentages of reduction were 17% for BB-G10 and 20% for BB-G20, respectively. The differences between BB-G10 and BB-G20 for total pore volume and pore volumes for specified several pore sizes were not so considerable

In case exposed at 7 days, the total pore volume of BB-G10 was the smallest. As is shown in Fig.5(c), the effectiveness of internal curing was hardly seen when specimens were cured under sealed condition.

Therefore, it could be said from the above result that the internal curing with PCA for B-type blast furnace slag cement concretes is effective in decreasing the pore volume, especially when BB is exposed to drying at early age, which depends slightly on the replacement ratio of PCA.

Relationship between compressive strength and pore volume

As it is reported that the compressive strength of BB declines with the increase of pore volume with the size larger than 0.02μm(Uchikawa 1990), Fig.6 shows the compressive strength and pore volume with the size larger than 0.02μm of specimens with internal curing at the ages of 7 and 28 days, normalized by those of BB without PCA, which were exposed to drying at 3 and 7 days, and sealed, respectively. Each value of compression strength plotted in the figure is the averaged value of three specimens and that of pore volume is measured with one sample consisting of 30-45 sample pieces taken of three specimens after compression test.

According to the figure, the normalized compressive strength exposed at 3 days and measured at 7 days increased particularly in case of BB-G10, while the pore volume also increased, which is inconsistent with the previous study(Uchikawa 1990). However, measured at 28 days, the normalized compressive strength increased by more than 10% by the internal curing, corresponding to the decrease by more than 15% in normalized pore volume, independent of the replacement ratio of PCA. In case exposed at 7 days and measured at 28 days shown in Fig.6 (b), the increase of normalized compressive strength and the decrease of normalized pore volume, which are almost the same as those exposed at 3 days, were observed without the case with the replacement ratio of 20%. When the specimens were cured in sealed condition, both

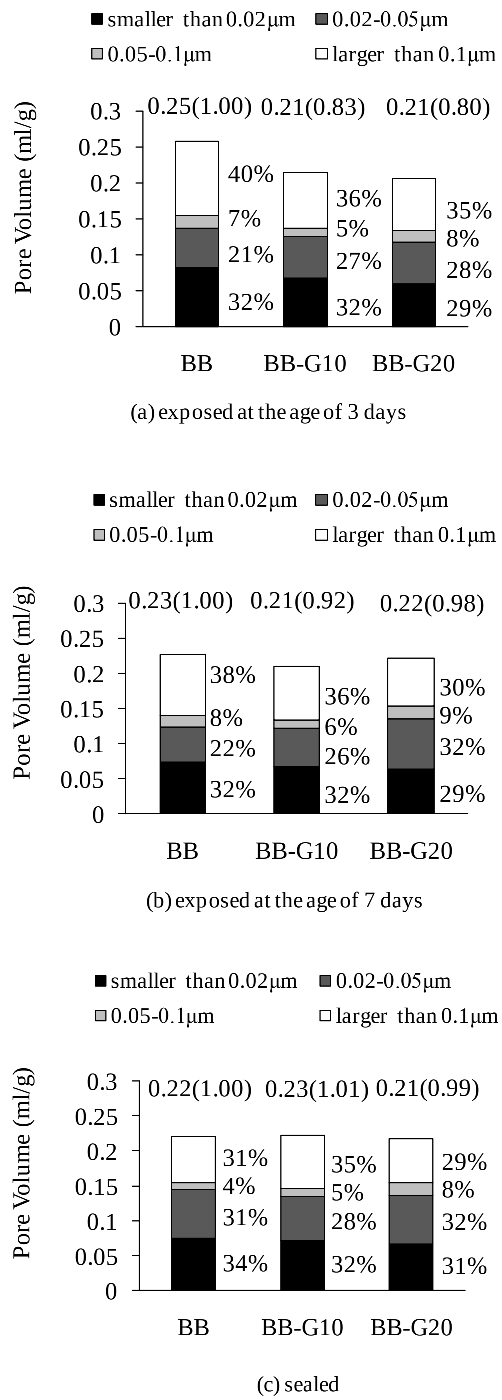


Fig.5 Pore volume of mixtures at the age of 28 days

the normalized strength and pore volume of BB-G10 increased and, however, those of BB-G-20 were approximately one at the age of 7 days, and those at the age of 28 days tended to

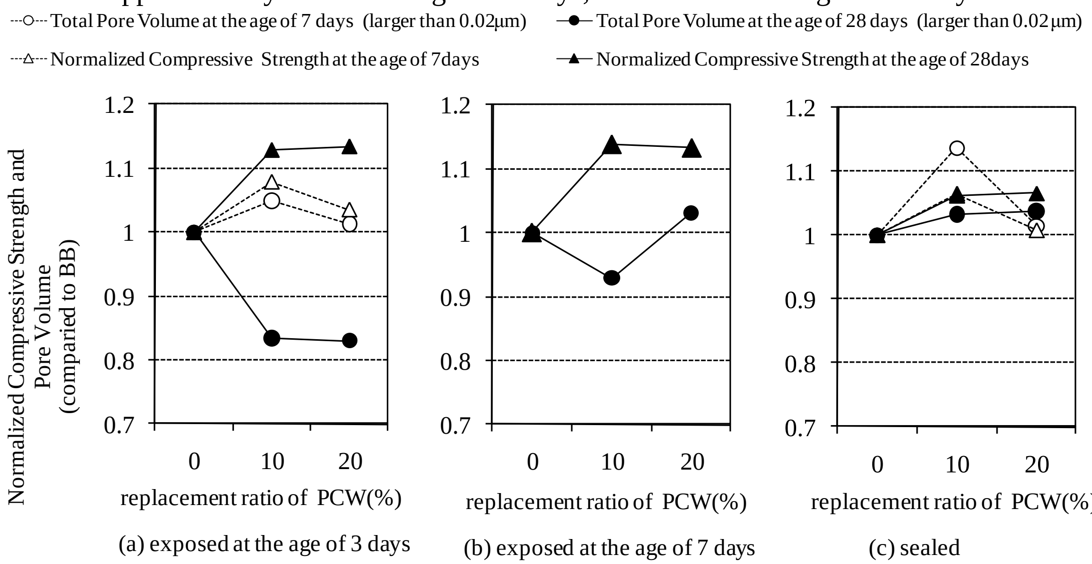


Fig.6. Effect of internal curing by PCA on the compressive strength and the pore volume with the size larger than 0.02 μm of B-type blast furnace slag cement concrete

increase with the increase of replacement ratio.

Shrinkage

Fig.7 shows the effect of PCA on autogenous and drying shrinkages of BB and NC. The solid lines indicate autogenous shrinkage and the dashed lines indicate drying shrinkage after exposed at the age of 3 days.

From this figure, it is found that autogenous shrinkages of both BB and NC without the internal curing didn't develop markedly and were slightly smaller than those of BB with the internal curing, since the expansion strains of BB and NC were slightly larger than those of BB-G10 and BB-G20. This implies that the internal curing did not contribute to reducing autogenous shrinkage. One of the reasons may be explained by the fact that W/C of the present concrete was 0.55, and self-desiccation resulting in the development of autogenous shrinkage hardly occurred in the capillary pore owing to the sufficient capillary water.

Shrinkage strains of BB with PCA after drying were almost the same as BB without PCA like the case of NC, though the pore volume of the former with the size below 0.05μm is about 8% smaller than that of the latter, in which the tension in the capillary pore with the size below 0.05μm is known to produce shrinkage(Mehta 1993).

CONCLUSIONS

The following conclusions are drawn within the limit of the present experiment;

(1) The internal curing used PCA replaced coarse aggregate by 10% and 20% in volume was effective in improving the compressive strength of B-type blast furnace slag cement concrete(BB), at latest, at the age of 28 days, independent of the exposure condition.

(2) The compressive strengths of BB with 10% replacement of PCA as coarse aggregate (BB-G10) were 0.81, 0.93 and 1.09 times as high as that of ordinary Portland cement

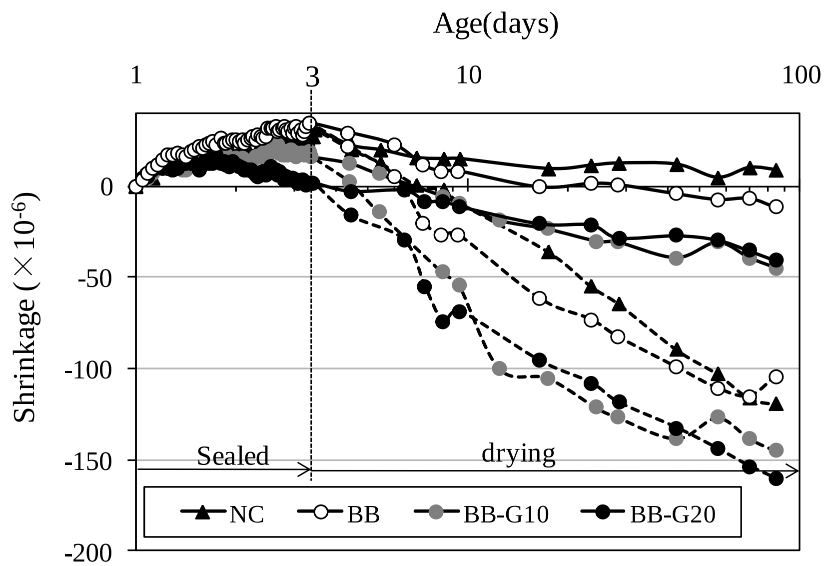


Fig.7 Shrinkages of Mixtures

concrete (NC) and 1.05, 1.08 and 1.13 times as high as that of BB without PCA (BB) at 3, 7 and 28 days, which was exposed to the air of 20±1℃ and 60±5%RH at the age of 3 days after cured under sealed condition.

(3) The internal curing used PCA replaced coarse aggregate was effective in decreasing the pore volume at the age of 28 days independent of the replacement ratios of 10% and 20%, when exposed to drying at the age of 3 days. However, exposed at 7 days and cured under sealed condition, the effectiveness of the internal curing was not considerable.

(4) The internal curing used PCA replaced coarse aggregate was not effective in reducing autogenous shrinkage, which could be explained by comparatively high water/binder ratio of the present concrete.

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