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Effectiveness of Porous Ceramic Waste as an Internal Curing Material for Fly Ash Concrete

Shohei Seiki [1], Tatsuya Nukushina [2], Seddik Meddah [2], Ryoichi Sato [2]

[1] 3-9-1, Kagamiyama, Higashi-hiroshima, Hiroshima, 739-0046, , Energia Economic & Technical Research Institute, The Chugoku electric power co.,inc. E-mail: <274994@pnet.energia.co.jp>.

[2] 1-4-1 Kagamiyama, Higashi-Hiroshima, Hiroshima, 739-8527, Dept. of Social and Environmental Eng, Graduate School of Engineering, Hiroshima University. E-mail: <nuku-concrete039@hiroshima-u.ac.jp>,<seddik-meddah@hiroshima-u.ac.jp>, <sator@hiroshima-u.ac.jp>.

ABSTRACT

This study aims to investigate experimentally how internal curing by Porous Ceramic Aggregate (PCA) made of roof material wastes is effective in enhancing properties of fly ash concrete like compressive strength, pore structure and shrinkage. Longer moist curing is needed for fly ash concrete to develop the required performance. In this study three exposure conditions, namely sealed condition, exposure to the air at 3 days and 7 days are adopted.

Results showed that internal curing by PCA was effective in developing compressive strength after the age of 28 days under sealed condition as well as in reducing autogenous shrinkage, and tended to increase slightly the pore volume under sealed condition.

INTRODUCTION

As the amount of coal ash that is produced yearly is more than 7 million tons, utilization of this by-product is required.

It is well known that the use of fly ash (FA) in cement matrices could reduce the heat of hydration and improve their consistency as well as the long-term strength [Ayers et al 1994; JSCE 1999]. These benefits are only observed if it is cured in moist conditions so $Ca(OH)_2$ and SiO_2 react sufficiently and form calcium silicate hydrate (C-S-H).

However, formwork tends to be removed in the early stages after placing concrete in order to shorten the construction period and keep costs down.

Internal curing can be applied to high-performance concrete (HPC) [Bentz et al 2005] to reduce early age shrinkage due to self-desiccation in pores of cementicious materials. Artificial lightweight aggregates[Philleo 1991] or super absorbent polymer particles[Jensen and Hansen 2001] have been used as internal curing materials.

In chugoku district in west Japan, about hundred thousand ton per year of “Sekishu Kawara” has been produced, which is a roof material made by baked clay. Ten percent of the product are rejected due to thermal cracking and have to be recycled. The demolished roof material has 8-9% of water absorption and about 20% of crushing value, the latter of which is approximately intermediate value between 10% of natural aggregate and 20% of artificial lightweight aggregate. The roof material waste aggregate, designated as porous ceramic aggregate(PCA) hereafter, has been reported to be effective in reducing autogenous shrinkage as well as developing compressive strength of HSC[Suzuki, Meddah and Sato 2009]. According to this report、PCA may be useful as an internal curing material for improving qualities of FA concrete.

Recently in Japan, PCA has been applied to HPC as an internal curing material in order to reduce autogenous shrinkage. According to the previous studies, PCA exhibits excellent characteristics as an internal curing material, contributing to not only developing compressive strength higher than 150 N/mm^2 but also reducing significantly autogeneous shrinkage [Suzuki et al. 2008].

The purpose of this study is to investigate how PCA as an internal curing material replaced a part of coarse aggregate by 20% and 40% in volume is effective in improving FA concrete qualities in terms of strength, early age shrinkage and pore structure, in which three exposure conditions, namely sealed condition, exposure to the air at 3 days and 7 days are adopted.

TESTS PROGRAM

Materials

Materials' properties used in the present study are shown in Table 1 and Table 2 Ordinary Portland cement (OPC) was used. OPC was partially replaced with Fly ash (FA) as a mineral admixture. Crushed quartz (QS) and limestone (LS) sands were used as fine aggregates. Hard sandstone (NCA) was employed while porous ceramic coarse aggregates (PCA, Figure 1) were also applied for internal curing purpose. PCA is a material recycled from cracked roof tile made by burning clay. PCA was immersed in water for three days for saturation purpose and the water absorption was 8-9% in mass.

Fig.1. Porous ceramic Ceramic coarse Coarse aggregates Aggregates (PCA)

Table 1. Materials

Materials	Type	Properties	Notation
Cement	Ordinary Portland Cement	Specific gravity: 3.16 Specific surface area: 3260cm^2/g	OPC
Mineral admixture	Fly ash	Specific gravity: 2.13 Specific surface area: 3200cm^2/g	FA
Fine aggregates	Crushed Quartz	Surface-dry Specific gravity: 2.60 Water absorption: 1.13%	QS
	Crushed Limestone	Surface-dry Specific gravity: 2.70 Water absorption: 0.93%	LS
Coarse aggregates	Crushed gravel (Sandstone)	Surface-dry Specific gravity: 2.67 Water absorption: 0.56% Crushing value: 12% Aggregate size: 5-20mm	NCA
	Porous ceramic coarse aggregate	Surface-dry Specific gravity: 2.24 Water absorption: 8.58% Crushing value: 21% Aggregate size: 5-20mm	PCA
Chemical admixtures	Air-entraining and water reducing agent	Lignosulphonate Polymer	LP
	High- range water reducing agent	Polycarboxylate Polymer	SP

Table 2. Chemical Compositions

Materials	Chemical compositions							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
OPC	20.8	5.2	3.0	64.4	1.4	2.2	0.3	0.4
FA	64.6	25.0	4.2	1.1	0.5	0.3	0.4	1.6
PCA	72.5	18.5	3.4	0.5	0.5	0.0	0.5	2.6

Mixture proportion and curing conditions

(1) Mixture proportion

In the present study, two water/binder ratios (W/B) of 0.50 and 0.30 were chosen.

Six kinds of concrete for W/B of 0.50 and four kinds of concrete for W/B of 0.30 were made, respectively. Table.3 tabulates the mix proportion of the ten concretes investigated herein. While the W/B and the content of cement is different from one concrete to another concrete, the unit content of water was kept constant (165kg/m^3) for all the concretes. Fly ash (FA) was blended with Ordinary Portland Cement (OPC) by 20% and 10% as a supplementary material, which are designated as FA20 and FA10, respectively. Control concrete made with OPC was designated as NC. Concretes internally cured with the PCA were denoted as PC20 and PC40, whose numbers of 20 and 40 represent the percentages of replacement of PCA for the total volume of coarse aggregate.

Control Concrete made with Portland cement was designated as NC. Concretes internally cured with PCA were denoted as PC20 and PC40.

Table 3. Mixture Proportion of Concrete

Comment [xxx1]: Give details of the abbreviations in this table, e.g. QS

Designation	W/B	Unit content (kg/m^3)											slump	Air
		W	C	SP	LP	FA	QS	LS	QS+LS	NCA	PCA	ΔW in PCA	(mm)	(%)
NC	0.50	165	330	0	4	0	504	349	853	961	0	0	95	5.5
FA20		165	264	0	3	66	491	340	831	961	0	0	80	3.5
PC20FA20		165	264	0	4	66	491	340	831	769	163	14	129	3.1
PC40FA20		165	264	0	3	66	491	340	831	577	325	28	81	4.1
FA10		165	297	0	5	33	497	344	841	961	0	0	154	6.0
PC20FA10		165	297	0	4	33	497	344	841	869	163	14	88	4.5
NC	0.30	165	550	4	0	0	532	368	900	795	0	0	590×610	1.3
FA20		165	440	4	0	110	510	353	864	795	0	0	710×680	0.4
PC20FA20		165	440	4	0	110	510	353	864	636	134	11	540×540	1.3
PC40FA20		165	440	4	0	110	510	353	864	477	269	23	590×640	0.6

(2) Curing conditions

All kinds of concrete specimens were sealed. In addition, two types of drying condition (Temperature of 20℃ and 60% relative humidity) were done in this study. The next method consisted of the first three days under sealed conditions followed by standard drying. The final method consisted of the first seven days under sealed conditions followed by standard drying.

Testing procedures

(1) Compressive strength

Compressive strength test was carried out in accordance with JIS A 1108 in which cylindrical specimen of Ø 100mm × 200mm was used and loaded at the ages of 7, 28 and 28 days.

(2) Porosity

Porosity of the concrete was measured using mercury intrusion porosimetry (MIP) technique. The specimens tested were the fragments of concrete recovered from the concrete specimens subjected to a uniaxial compressive strength test.

(3) Measurements of free deformation

Free deformation (autogenous and drying) was measured on prismatic concrete specimens (100×100×400 mm). During the first two days of measurement, a laser transducer with an accuracy of 1 μm was used. After two days, a contact-type strain gauge was used to measure the change in length of concrete prisms. Measurement was performed on specimens cured under two types of curing conditions. The first group of specimens was kept in sealed conditions until 91 days, while the second group was subjected to standard drying conditions after seven days of sealed curing.

Temperature change throughout the whole testing period was measured with thermocouples centred in concrete specimens. The total volume change measured was corrected using a common value of a coefficient of thermal expansion of 10×10^{-6}/℃ according to the JCI recommendations [JCI, 2002].

RESULTS AND DISCUSSION

Compressive strength

Effect of internal curing by porous ceramic waste aggregate

(1) W/B=0.50

Firstly, influence of the replacement ratio of FA on compressive strength development of concrete with W/B=0.50 cured in sealed condition is depicted in Figure 2 According to the figure, the compressive strength of FA concrete with the replacement ratio of 10% is almost similar to that of NC, while, in case of the replacement ratio of 20%, lower and higher compressive strengths of FA concrete are observed at the age of 7 and 91 days compared with those of NC, respectively.

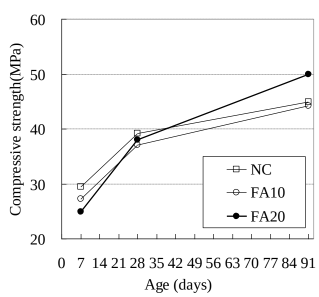

Fig.2. Influence of Replacement Ratio of FA on Compressive Strength of Sealed Concrete (W/B=0.50)

The compressive strength development of FA concrete internally cured by PCA replaced by 20%(PC20FA10) is demonstrated in Figure 3(a), compared with those of NC and FA10, and, furthermore, the compressive strength developments of FA10 and PC20FA10 normalized by that of NC are also indicated in Figure 3(b). The former figure shows that the compressive strength of PC20FA10 exceeds those of NC and FA10 slightly even at the ages of 7 days and remarkably at 28 days and 91days. As is also shown in Figure 3(b), the compressive strength of PC20FA10 normalized by that of NC increases from 1.03 at 7 days to 1.19 at 91 days. These results show that the internal curing by PCA is effective in enhancing the compressive strength of FA concrete.

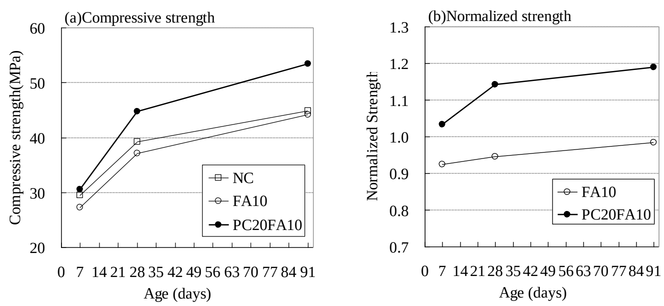

Fig.3.Effect of Internal Curing by Porous Ceramic Waste Aggregate on Compressive Strength of Sealed FA10 Concrete (W/B=0.50)

The compressive strength development of FA concrete internally cured by PCA replaced by 20% and 40% is demonstrated in Figure 4(a), compared with those of NC and FA20 without PCA, and furthermore, the compressive strength development of each FA concrete normalized by that of NC is also indicated in Figure 4(b). According to Figure 4(b), the internal curing by PCA is not effective in developing the compressive strength at the early age of 7 days for both replacement ratios of PCA. However, the replacement ratio of 20% of PCA is effective after 28 days, while that of 40% after 91 days. The reason for the latter could be explained by the larger amount of internal curing water for concrete with W/B=0.50. Comparing the result shown in Figure 4(b) with Figure 3(b), it could be said that the most appropriate replacement ratio of PCA, particularly for the early age strength, should be determined considering the replacement ratio of FA and W/B.

(2) W/B=0.30

The compressive strength development of FA concrete with W/B=0.30 internally cured by PCA replaced by 20% and 40% is demonstrated in Figure 5(a), compared with those of NC and FA20, and furthermore, the compressive strength development of each FA concrete normalized by that of NC is also indicated in Figure 5(b).

As is shown in Figure 5(b), the compressive strength of FA concrete with the replacement ratio of 20% (PC20FA20) exceeds that of NC over time from 7-91 days, which is different from the result obtained from concrete with W/B=0.50. The result in Figure 5(b) also means that the appropriate replacement ratio of PCA depends on W/B.

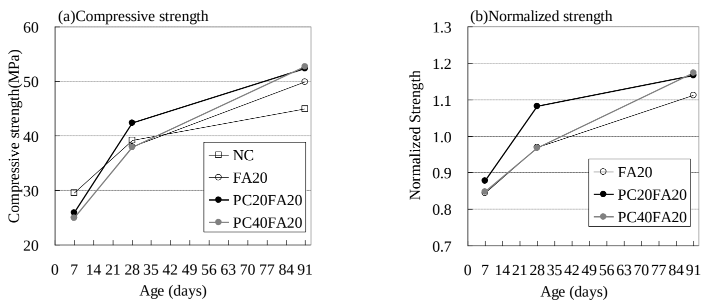

Fig.4. Effect of Replacement Ratio of Porous Ceramic Waste on Compressive Strength of Sealed FA20 Concrete (W/B=0.50)

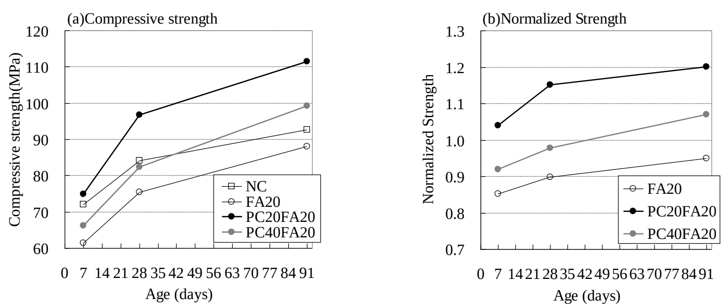

Fig.5.Effect of Replacement Ratio of Porous Ceramic Waste on Compressive Strength of Sealed FA20 Concrete (W/B=0.30)

Influence of curing condition

(1) W/B=0.50

Effect of the age at exposure to drying on compressive strength development of PC20FA10 and PC20FA20 is demonstrated in Figure 6.

Compressive strength of both PC20FA10 and PC20FA20 exposed to drying at 3 days develop the slowest from 7 days to 28 days and reach the lowest strength, compared with other cases, in which no strength development from 28 days to 91 days is observed.

In the case of PC20FA10 and PC20FA20 under the drying exposure at the age of 7 days, the compressive strength developed steadily from the age of 7 to 28 days and reached the similar value of that of concrete with sealed condition at the age of 28 days. The development of strengths from the age of 28 to 91 days of both concrete exposed to drying was slower than that of concrete under sealed condition.

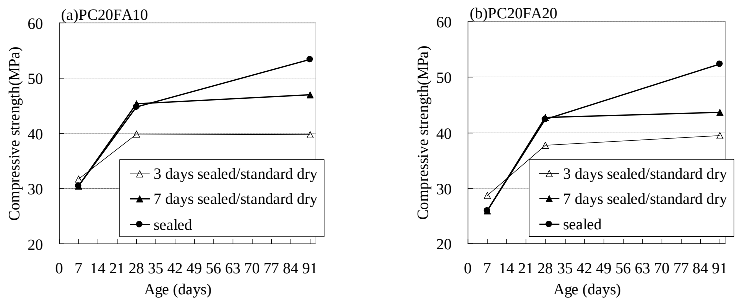

Fig.6.Effect of the Age at Exposure to Drying on Compressive Strength Development of PC20FA10 and PC20FA20 (W/B=0.50)

(2) W/B=0.30

Effect of the age of drying exposure to the development of compressive strength of PC20FA20 is demonstrated in Figure 7.

As shown in Figure 7, the compressive strength of PC20FA20 which was exposed to drying at the age of 3 days showed the slowest development compare with those of concrete with other types of curing condition. The development of compressive strength of PC20FA20 with W/B of 0.30 which was exposed to drying at 7 days showed a similar tendency from the one of PC20FA20 with W/B of 0.50 from the age of 7 to 28 days. Moreover, the results of concrete with W/B of 0.30 tended to gain higher increase of the compressive strength compared to the ones of concrete with W/B of 0.50.

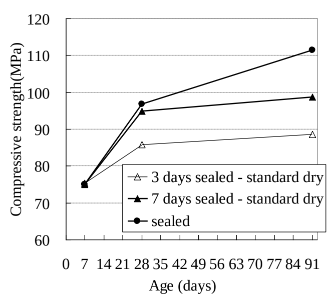

Fig.7.Effect of the Age at Exposure to Drying on Compressive Strength Development of PC20FA20 (W/B=0.30)

Porosity

The results of total porosity and pore size distribution tests are shown in Figure 8. The indicated values represent the ratio of pore volume for each type of concrete.

Figure 8(a) shows that the use of FA resulted in a decrease of the relative coarse porosity (more than 0.1μm) as compared to that of the control mix (NC). Due to replacement a part of PCA, the pore volume hold in concrete increased compared to that of FA10, but the amount or volume of coarse porosity (more than 0.1μm) decreased.

As shown in Figure 8(b), total pore volume is increased with the use of PCA. This was because the concrete with PCA contained higher amount of finer pores (0.02-0.05μm and less than 0.02μ m) than those without PCA.

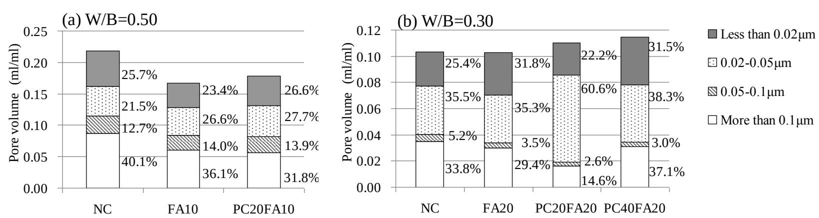

Fig.8.Pore Size Distribution (Under Sealed Conditions)

Free deformation

(1) Dry shrinkage

Figure 9 shows the changes of drying shrinkage strain of concrete specimens with W/B of 0.50 after the age of drying condition. It is known that some high water absorption aggregates cause a high drying shrinkage strain [Oka et al., 2004].

The development of drying shrinkage strains of FA concrete (FA10 and PC20FA10) were slightly smaller than that of normal cement concrete (NC). As for concrete with PCA (PC20FA10), the drying shrinkage strain was almost similar to that of concrete without PCA (FA10). It can be seen that the drying shrinkage strain did not increase with the use of PCA.

(2) Autogenous shrinkage

The effect of PCA on autogenous shrinkage strain of FA concrete with W/B of 0.30 is demonstrated in Figure 10. The figure shows the development of autogenous shrinkage strain which was measured in concrete specimens under sealed condition for 91 days. The addition of PCA as an internal curing agent greatly contributed to the reduction of autogenous shrinkage strain. The difference of autogenous shrinkage strain among concrete with and without PCA can be clearly identified.

By increasing the proportion of PCA from 20 to 40% resulted in a slight decrease of the magnitude of expansion. Since the concrete with 20% of PCA has a finer pore distribution than that with 40% of PCA, it is inferred from this data that the concrete with 20% of PCA expanded more than that with 40% of PCA.

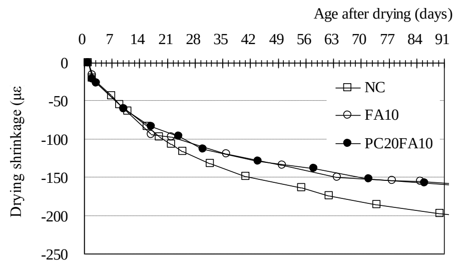

Fig.9. Drying Shrinkage Strain, W/B=0.50

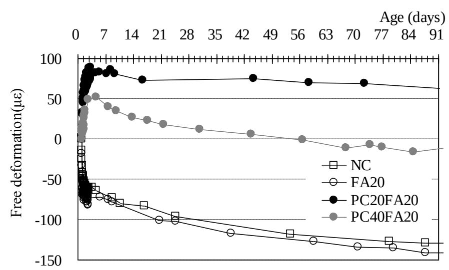

Fig.10. Autogenous Shrinkage Strain, W/B=0.30

CONCLUSIONS

FA concrete with PCA used as internal curing agent was experimentally studied in regards to the compressive strength, porosity and shrinkage development. The following conclusions are as follows:

1. The incorporation of internal curing by PCA in FA concrete was effective in developing compressive strength after the age of 28 days under sealed condition.

2. For a certain period of age, the compressive strength of FA concrete cured by PCA which was exposed to drying conditions at early ages was slightly similar to that of concrete under sealed condition.

3. Compared to the concrete without internal curing, the concrete with additional PCA as an internal curing agent showed a substantial increase of finer pores.

4. There was no significance difference in the development of drying shrinkage by using PCA as high water absorption material.

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