研 究 速 報

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Factors Affecting Change in Compressive Strength of Mortar due to Carbonation

炭酸化によるモルタルの圧縮強度変化に影響する要因

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1. Introduction

Influence of carbonation on development of compressive strength of mortar depends on many factors. In the present paper, three factors (type of cement, initial water curing and concentration of CO_2) have been observed. If the effect of those factors on development of compressive strength of mortar due to carbonation can be understood, they can be controlled to obtain the desirable conditions such as high early strength or high final strength and to avoid the decrease of strength. Microstructure of carbonated mortar has also been measured since it has a strong relationship with compressive strength. By observing change in compressive strength and microstructure of carbonated mortar, it was found that carbonation also affects the matrix strength (strength of material with zero porosity).

2. Experimental Work

2.1 Materials and Mix Proportions

Cements used in the experiments were ordinary portland cement (OPC), 50% and 75% portland blast-furnace slag cement (50% and 75% PBFSC). Chemical composition of both the ordinary portland cement and the ground granulated blast-furnace slag are given in Table 1. Standard Toyoura sand was used as fine agregate. Mortar with water-binder ratio of 0.6 were prepared. Mix proportions of mortar are given in Table 2 (in reference 2).

Table 1 Chemical compositions and physical characteristics of OPC and GGBFS

	Ordinary Portland Cement	Ground Granulated Blast-furnace Slag
Ig. loss	1.2 %	---
Insol.	0.4 %	---
SiO_2	21.9 %	34.3 %
Al_2O_3	5.0 %	14.6 %
CaO	64.2 %	42.2 %
Fe_2O_3	2.8 %	0.2 %
MgO	1.7 %	6.4 %
Specific Weight	3.15	2.90
Specific Surface Area	3230 cm^2/g	4010 cm^2/g

Table 2 Mix proportions of mortar (60% W/C ratio)

% slag content	Cement (kg/m^3)	Water (kg/m^3)	Slag (kg/m^3)	Sand (kg/m^3)	Initial curing period
0	598	359	------	1196	0 and 27 days
50	297	356	297	1187	
75	148	355	444	1178	

2.2 Fabrication and Curing

All the specimens were cast as cylinders of diameter 5 cm and height 10 cm. After curing for one day in the moist room at 20°C, specimens were demolded and half of them were initially cured in water for 27 days. Then, slices with about 2 mm thickness were taken out from the middle portion of specimen (about 3 cm from top and bottom surface). Slices and cylinders were exposed to various environments (air with 0.07% CO_2, water, carbonation chambers with 1% and 10% CO_2 and cyclic—one week in carbonation chamber with 10% CO_2 and one week in water—) with constant humidity of 60% and temperature of 20°C.

2.3 Measurement

After exposure, compressive strength and carbonation

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depth were measured at the ages of 1, 4, 8, 12, 20, 28 and 52 weeks. Three cylinder specimens were used at each condition of exposure for compressive tests, and the average values for compressive strength tests are obtained at each condition. Porosity of sliced mortars, measured by mercury porosimetry, were determined at the ages of 4, 12, 28 and 52 weeks.

3. Experimental Results

Experimental results reported in this paper are only up to the age of 28 weeks. It was found that those factors (type of cement, initial water curing and concentration of CO_2) affect the compressive strength of specimens simultaneously. Therefore, the effect of each factor cannot be observed separately. However, at first, compressive strength of specimens which were not initially cured in water was observed to find out what concentration CO_2 and type of cement give highest strength or lowest strength. The same thing can be done for specimens which were initially cured 27 days in water.

3.1 Specimens which were not initially cured in water

At the age of 28 weeks, all cylinder specimens which were exposed to high concentration of CO_2 (1% and 10% by volume) have been completely carbonated (phenolphthalein was used to distinguish carbonated portion from uncarbonated portion). However, OPC mortar specimens which were exposed to high concentration of CO_2 still have light red color, somehow different with red color which indicates uncarbonated portion, especially in the center of specimens and this phenomenon had been found since 8 weeks age of exposure and did not change until 28 weeks age of exposure. It may indicate that some amount of $Ca(OH)_2$ in mortar is still intact. But cylinder specimens which were exposed to air, with 0.07% CO_2, have carbonated portion from ±40% to ±75% which depends on type of cement.

It can be seen from figure 1 that OPC mortar which were exposed to higher concentration of CO_2 gives the higher compressive strength. On the other hand, it is reversely true for 75% PBFSC mortar, while those which were exposed to 1% CO_2 seemed to give the highest compressive strength for 50% PBFSC mortar. It can be said that accelerated carbonation process can improve compressive strength of OPC mortar, but it can be harmful for mortar made of high concentration of slag. One of the reasons why OPC mortar which were exposed to higher concentration of CO_2 have higher compressive strength is its lower total pore volume (see figure 2). However, in the case of 75% PBFSC mortar, it cannot be explained merely by looking at total pore volume or pore size. As figure 3 shows that total pore

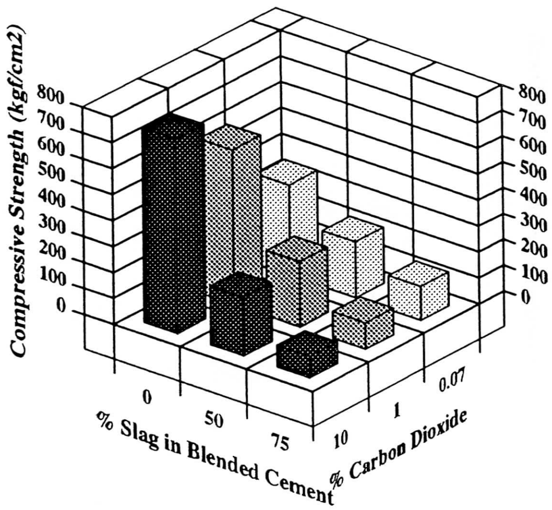

Figure 1 Compressive strength of mortar witout initial water curing at 28 weeks exposed period

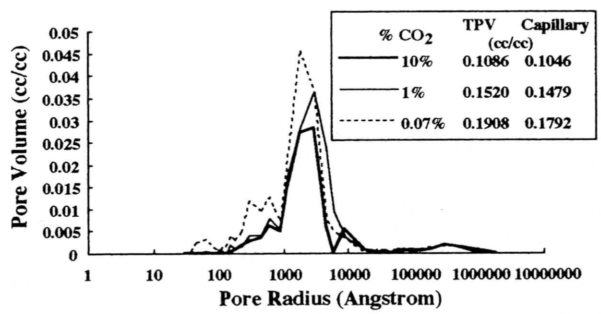

Figure 2 Pore size distribution of carbonated OPC mortar without initial water curing at 28 weeks exposed period

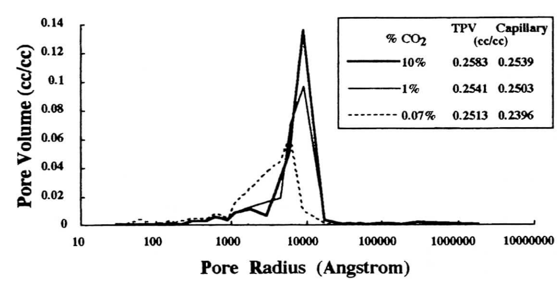

Figure 3 Pore size distribution of carbonated 75% PBFSC mortar without initial water curing at 28 weeks wxposed period

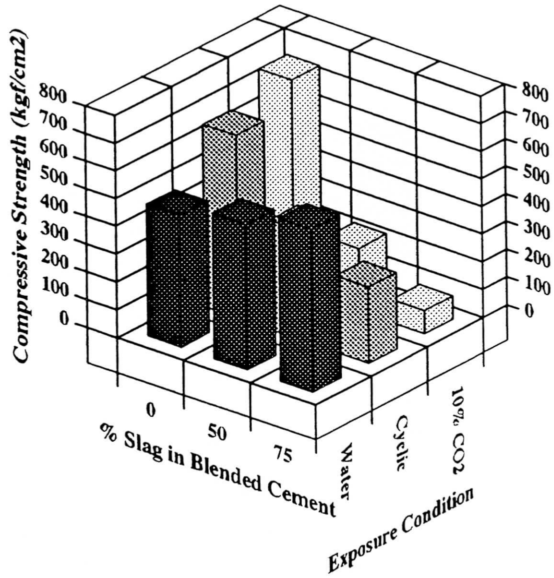

Figure 4 Compressive strength of mortar without initial water curing at 28 weeks exposed period

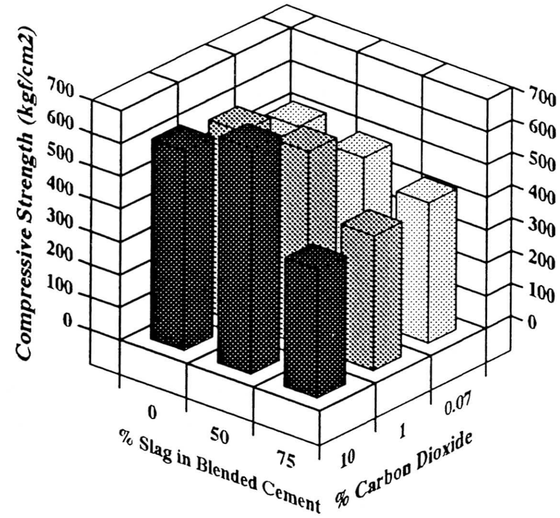

Figure 5 Compressive strength of mortar with initial water curing at 28 weeks exposed period

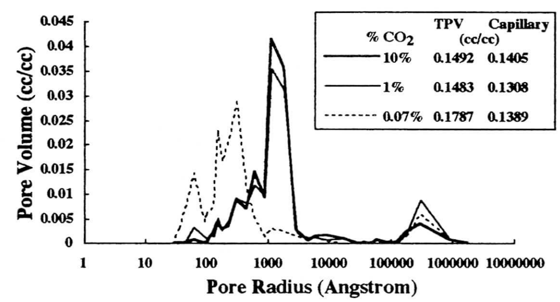

Figure 6 Pore size distribution of carbonated 75% PBFSC mortar with 27 days initial water curing at 28 weeks exposed period

volume and pore size of 75% PBFSC mortar exposed to 1% and 10% CO_2 are similar, those mortar should have the different matrix strength. It may be related to phase composition or others.

All the mortar cylinder specimens which were exposed to cyclic condition have not been completely carbonated. Carbonated portion of cylinder specimens made of OPC, 50% and 75% PBFSC are ±25%, ±80% and ±95% respectively. And their compressive strength are somewhere in between those which were exposed to 10% CO_2 and water (see figure 4).

3.2 Specimens which were initially cured for 27 days in water

Almost all specimens which were intially cured for 27 days in water have not been completely carbonated after 28 weeks age of exposure with 75% PBFSC mortar specimens which were exposed to 1% and 10% CO_2 as exemption. However, one thing which can be said is that accelerated carbonation somehow improves compressive strength of mortar made of OPC and 50% PBFSC. But it still decreases compressive strength of mortar made of 75% PBFSC (as shown in figure 5). Microstructure of those sliced specimens have also been observed in order to explain the phenomena. Figure 6 shows that 75% PBFSC mortar which exposed to 1% and 10% CO_2 have similar total pore volume (slightly different in capillary porosity) and pore size. Therefore, matrix strength of mortar exposed to 1% CO_2 seemed to be higher than those exposed to 10% CO_2.

Carbonated portion of OPC, 50% and 75% PBFSC mortar exposed to cyclic condition are ±25%, ±45% and ±85% respectively. However, as figure 7 shows, their compressive strength are somehow greater than those which were exposed to 10% CO_2 or water with 75% PBFSC as exemption. This may be explained by looking at their microstructure. Figure 8 shows pore size distribution of carbonated OPC mortar with 27 days initial water curing after 28 weeks age of exposure from which can be seen that capillary pore volume (100Å~100000Å) of mortar exposed to cyclic condition is lower than those exposed to 10% CO_2 or water although total pore volume of mortar exposed to 10% CO_2 and cyclic condition is similar. Therefore, influence of pore size less than 100Å on compressive

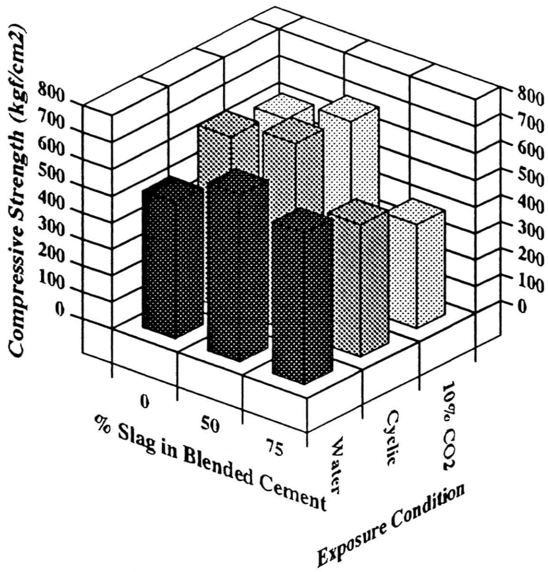

Figure 7 Compressive strength of mortar with initial water curing at 28 weeks exposed period

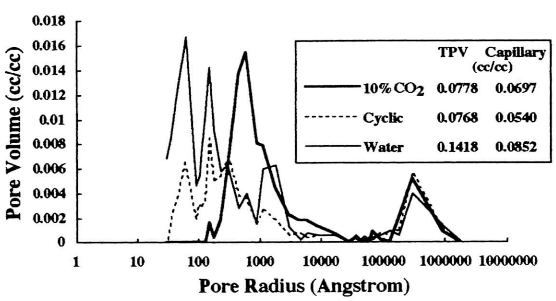

Figure 8 Pore size distribution of carbonated OPC mortar with 27 days initial water curing at 28 weeks exposed period

strength of mortar can be ignored.

4. Conclusions

The experimental results which was obtained after 28 weeks ages of exposure can be summarized as in the following:

1) Accelerated carbonation increases compressive strength of mortar made of OPC. Such kind of behaviour is more pronounced for those which were not initially cured in water. However, reverse behaviour was found for mortar made of 75% PBFSC.

2) The effect of carbonation on compressive strength of mortar made of 50% PBFSC seems to depend on initial water curing. By giving enough initial water curing, the increase of compressive strength can be obtained.

3) The cyclic exposure condition can give high compressive strength for mortar made of OPC or 50% PBFSC with enough initial water curing.

4) In most cases, increase of compressive strength of mortar coincides with decrease of its pore volume and/or pore size. However, carbonation also changes the matrix strength (characteristic strength) as shown in the experimental results.

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