

Relationship between Porosity and Progress of Carbonation Depth of Mortar

Jong Herman CAHYADI, Graduate Student, University of Tokyo
Taketo UOMOTO, Professor, University of Tokyo

1. Introduction

Carbonation depth of concrete was widely related to the square root of exposure period, $x = A \cdot t^{0.5}$, where x = carbonation depth, t = exposure period, A = coefficient of carbonation rate. However, the value of A may not be constant when the diffusivity of CO_2 is not constant with time and space. Since diffusivity of CO_2 much depends on porosity, change in porosity due to carbonation may affect A value time to time.

2. Experimental work

Material and Mix Proportions

Cements used in the experiments were OPC (ordinary portland cement) and blended cements/PBFSC (50% and 75% ground granulated blast-furnace slag by mass). Standard Toyoura sand was used as fine aggregate. Mortar with water-binder ratio of 0.6 were prepared.

Specimen and measurement

After casting, mortar cylinders of diameter 5 cm and height 10 cm were cured in moist room at 20°C for one day and then demolded. Subsequently, the cylinders were cured in water for 0 and 27 days. Afterwards, slices with about 2 mm thickness were taken out from the middle portions of specimen (about 3 cm from top and bottom surface). Then, specimens were conditioned in various environments (air with 0.07% CO_2 , carbonation chambers with 1% and 10% CO_2) with constant humidity of 60% and temperature of 20°C. After exposure, compressive strength and carbonation depth (phenolphthalein was used to distinguish carbonated portion from uncarbonated portion) were measured at the ages of 1, 4, 8, 12, 20, 28, 52 weeks. Pore size distribution of sliced mortar, measured by mercury porosimetry, were determined at the ages of 4, 12, 28 and 52 weeks.

3. Results and Discussions

The progress of carbonation depth of specimens is shown in Figs. 1 and 2. Specimens without initial water curing have been completely carbonated at 4 weeks exposure period when they are exposed to high concentration of CO_2 . The square root relation between carbonation depth (x) and exposure period (t) failed to coincide well with experimental data. The square root relation is derived by assuming that diffusivity of CO_2 is constant with time and space. However, as already known, pore structure of mortar changes due to carbonation and it much depends on concentration of CO_2 , type of cement and initial water curing¹.

The change in pore structure should have a certain effect on diffusivity of CO_2 . Therefore, the modified square root relation was proposed by considering the change of diffusivity of CO_2 due to change in pore structure. The modified square root relation is:

$$x = a \cdot t^{0.5} f(t) \quad (1)$$

where; x = carbonation depth, t = exposure period, $f(t)$ = function of exposure period, and a = constant. By introducing $f(t)$ which can be any function of exposure

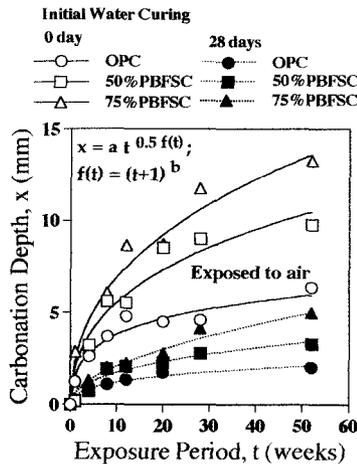


Fig. 1 Progress of Carbonation Depth

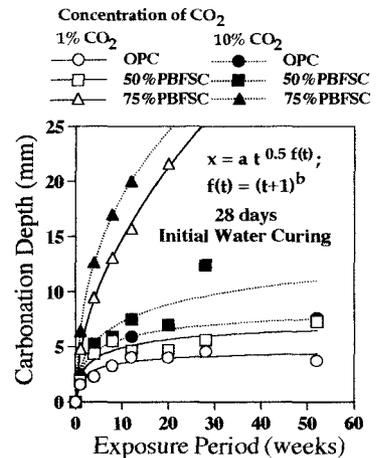


Fig. 2 Progress of Carbonation Depth

period (t), diffusivity of CO₂ may change time to time which much depends on pore structure. In this present paper, $f(t) = (t+1)^b$ was used. The positive value b may indicate the increase of diffusivity of CO₂ with time which can be related to the increase of porosity. Reversely, the negative value of b may indicate the decrease of diffusivity of CO₂ or decrease of porosity. Tab. 1 shows the b value of specimens exposed to various concentration of CO₂. For specimens made of OPC and 50%PBFSC (initially cured in water for 28 days), the b values are always negative due to reducing of porosity. However, those which exposed to high concentration of CO₂ (1% and 10% by volume) have larger absolute b value than those exposed to air (0.07% CO₂). The larger absolute b value means the more prominent change in porosity. For specimens made of 75%PBFSC (initially cured in water for 28 days), the absolute value of b are small regardless of concentration of CO₂. It means the porosity changes only slightly due to carbonation. Fig. 3 shows more clearly how change in porosity affects the value of b as it has been explained. The relation between capillary porosity and coefficient carbonation rate (using normal square root relation) at the same age is shown in Fig. 4. Theoretically, for one dimensional, the progress of carbonation depth can be expressed as follows,

$$x = A \cdot t^{0.5} \quad \text{or} \quad x = k \cdot (Dt)^{0.5}; \quad k = A / (D^{0.5}) \quad (2)$$

where k is constant and D is diffusivity of CO₂. If the relation between capillary porosity and coefficient carbonation rate (A) is linear, the diffusivity of CO₂ will be the linear function to square of porosity. Such kind of relationship is quite close to the one proposed by Papadakis². Diffusivity of CO₂ depends on CO₂ concentration (C) since porosity of carbonated mortar is affected by C. Therefore, the equation " $x = k \cdot (Ct)^{0.5}$ " should be modified³.

4. Conclusion

Progress of carbonation depth of mortar much depends on change in porosity due to carbonation. The diffusivity of CO₂ may not be constant due to decrease or increase of porosity. If the experimental data of carbonation depth is available, the modified square root relation can be used to understand how pore structure changes time to time due to carbonation. The understanding of change in porosity due to carbonation is very useful to predict progress of concrete strength.

Acknowledgment

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References

1. Uomoto, T. and Cahyadi, J. H., "Change in Microstructure of Mortar due to Carbonation," Proceedings of The 49th Annual Conference of The Japan Society of Civil Engineers, 5, 1994, pp. 470-471.
2. Papadakis, V. G., Vayenas, C. G., Fardis, M. N., "Physical and Chemical Characteristics Affecting the Durability of Concrete", ACI Materials Journal, Vol. 88, No. 2, Mar.-Apr. 1991, pp. 186-196.
3. Uomoto, T. and Takada Y., "Factors Affecting Concrete Carbonation Rate," Durability of Building Materials and Components 6, Vol. 2, Oct. 1993, pp. 1133-1141.

Tab. 1 The a and b value of modified square root relation

a value		0.07% CO ₂	1% CO ₂	10% CO ₂
b value				
0 day Initial Water Curing	OPC	1.51		
	50% PBFSC	1.95		
	75% PBFSC	-0.04		
	PBFSC	2.36		
28 days Initial Water Curing	OPC	0.45	1.67	2.56
	50% PBFSC	-0.06	-0.19	-0.15
	75% PBFSC	-0.03	-0.15	-0.10
	PBFSC	0.64	4.53	6.54
		+0.01	+0.01	-0.04

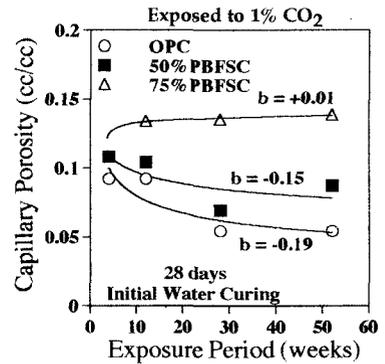


Fig. 3 Progress of Capillary Porosity

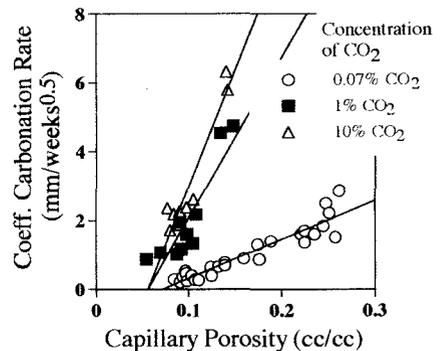


Fig. 4 Coeff. Carb. Rate vs Cap. Porosity of OPC/PBFSC Mortar