V - 77

INFLUENCE OF RELATIVE HUMIDITY ON CARBONATION OF CONCRETE WITH VARIOUS WATER-CEMENT RATIO

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1. Introduction

Carbonation of concrete which initiates the reinforcement corrosion is much affected by ambient relative humidity. It is usually believed that ambient relative humidity around 50% gives maximum carbonation since it is supposed to supply enough water for reaction between $Ca(OH)_2$ and CO_2 but provide insufficient water to hinder diffusion of atmospheric CO_2 through pores of concrete. However, Mihashi et. al. [2] showed that value of *critical ambient relative humidity*, which gives maximum carbonation, decreases with decreasing of water-cement ratio. In this paper, such kind of phenomenon is observed through mathematical modeling.

2. Mathematical Modeling

In this paper, mathematical model of carbonation process has been constructed with focusing on diffusion of atmospheric CO_2 through pores of concrete, its reaction with $Ca(OH)_2$, reduction of pore volume due to solid product of carbonation and water movement in concrete. Differential equations can be formulated as follows,

$$\frac{\partial C_1}{\partial t} = \frac{\partial}{\partial x}(D_1 \frac{\partial C_1}{\partial x}) + f(K(t)) \tag{1}$$

$$\frac{\partial C_2}{\partial t} = \frac{\partial}{\partial x}(D_2 \frac{\partial C_2}{\partial x}) \tag{2}$$

$$\frac{\partial C_3}{\partial t} = - K(t) \tag{3}$$

where subscripts 1,2,3 represent carbon dioxide, water and calcium hydroxide. C and D represent concentration and diffusion coefficient respectively. Equation (1) represents diffusion of atmospheric CO_2 through air pores of hardened concrete then consumed by its reaction with $Ca(OH)_2$. D_1 is not constant but depends on change porosity of concrete due to carbonation and amount of water in pores of hardened concrete [4]. Equation (2) represents nonlinear water diffusion in hardened concrete due to drying process [1] which relative humidity is used as the parameter. Therefore, relationship between evaporable water content and relative humidity [6] is applied to obtain evaporable water content in concrete. Equation (3) represents the changing of $Ca(OH)_2$ content in concrete due to its reaction with CO_2. K is reaction rate between $Ca(OH)_2$ and CO_2 which depends on amount of water [5]. By solving equations (1 ~ 3) simultaneously, distribution of $Ca(OH)_2$ content can be known time by time. Therefore, the progression of carbonation depth with time can be known.

3. Calculation Results and Discussion

The progression of carbonation of concrete in various ambient relative humidity (30%, 40%, 50%, 60%, 70% RH), normal temperature (20 ~ 25°C) and normal concentration of CO_2 (0.05%) has been calculated by using this model. Mix proportion of concrete used in this case is supposed to follow what shown in table 1.

Table 1. Mix Proportion of Concrete

W/C (%)	s/a (%)	Density (kg/m^3)			
		W	C	S	G
70	49	184	263	908	978
60	47		307	854	996
50	45		368	795	1005

Calculation results show that the value of *critical ambient relative humidity* which gives maximum carbonation depth decreases with decreasing water-cement ratio (shown in figure 1). Experimental data shown by Mihashi et. al. [2] also gives same phenomenon. This can be explained as follows; in low relative humidity (≤ 50% RH), for the same cement type, evaporable water content in hardened concrete per g cement changes slightly with water-cement ratio [6]. An example of relationship between relative humidity and evaporable water content in cement paste per g original cement content is shown in figure 2 [6]. However, in mix proportion of concrete, decreasing of water-cement ratio usually means increasing of cement content. Therefore, decreasing of water-cement ratio increases evaporable water content in hardened concrete with low relative humidity. The value of critical ambient relative humidity depends on optimum water content in hardened concrete which is less enough not to inhibit the ingress of carbon dioxide but still much enough for reaction between CO_2 and $Ca(OH)_2$. This means that increase of evaporable water content (cement content) will decrease the value of *critical ambient relative humidity*. In other words, decrease of water-cement ratio will decrease the value of critical ambient relative humidity.

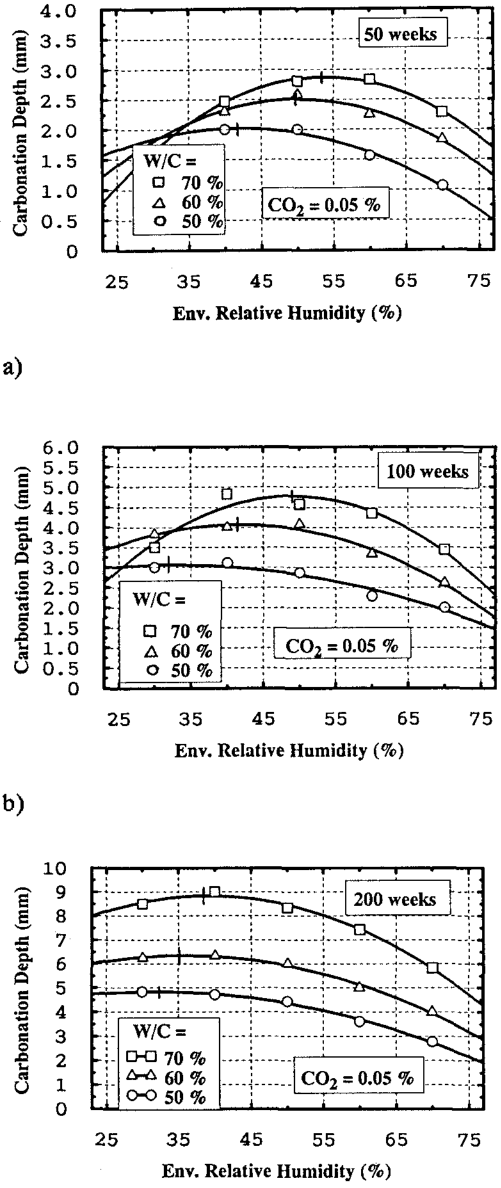

Figure 1. Carbonation Depth vs Ambient Relative Humidity (various W/C Ratio)

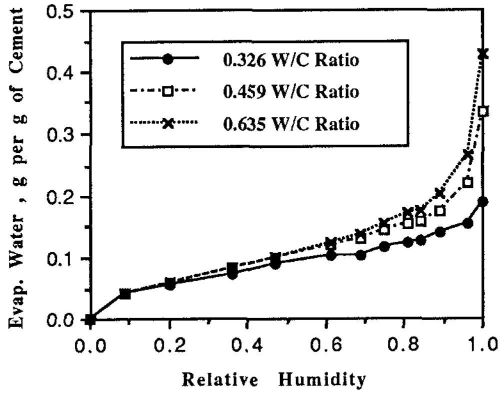

Figure 2. Water Evaporable Content vs Relative Humidity (various W/C Ratio)

4. References

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