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Determination of Chloride Diffusion in Carbonated Concrete Containing Silica Fume

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ABSTRACT: The deterioration of concrete structures is a non-linear and complex phenomenon which is caused by different phenomena. Carbonation is known as one of the major reasons of concrete deterioration. Carbonation has two different effects on concrete structures. Carbonation may have a positive effect against corrosive materials because of its effect in reducing the concrete porosity by changing calcium hydroxide to calcium carbonate. On the other hand, carbonation may have a major role in improving corrosion by reducing the pH of concrete and omitting of passive layer. Although literatures on carbonation have been vast, there are so few studies in carbonation of concrete containing silica fume. In this research the effect of carbonation in reducing of the porosity of concretes containing silica fume was studied. For this reason, concrete specimens with different water to binder ratios (w/c = 0, 0.35 and 0.5) and silica fume percentage (S.F = 0%, 5% and 10%) were made and carbonated in different ages (28 and 90 days). The porosity of carbonated concretes compared with control specimens by different experiments. Finally, a mathematical model for concrete porosity reduction under carbonation phenomena was developed based on experimental results.

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1-Introduction

Carbonation effect on chemical and physical properties of concrete has been the subject of many researches [1-15].

The main purpose of this paper is to investigate the physical effects of carbonation on the penetration of chloride into concrete and changes in concrete physical properties, such as porosity variations in concrete. The research method is based on laboratory methods. The general trend is that concrete specimens in both fully carbonated forms and non-carbonate ordinary concrete, are exposed to the chloride ion. Chloride profiles are obtained at a specific time and a change in the concentration of chloride is obtained. In this way, the relationship between the concentration of chloride in carbonated concrete and non-carbonated concretes can be achieved.

2-Experimental Program

ASTM Type I-425 Portland cement with a specific gravity of 3.15 and silica-fume with a specific gravity of 2.90 was used. Nine mix designs, each with a cementitious material content of 400 kg/m3, were used. The W/CM ratios were 0.35, 0.4 and 0.5. The silica fume replacements for cement on a dry mass basis were 0, 7% and 10%. Table 2 shows the properties of various mixture designs in this investigation.

3-Experimental Methods

Bulk diffusion test was carried out after 9 months. The specimens were exposed to chloride ions in 3 different conditions for more than 270 days. The environmental conditions were submerged, tidal and atmospheric zones. Chloride content in concrete mass at various depths was determined according to ASTM C114. Chloride diffusion coefficient was calculated based on Fick's second law. Table 1 shows average Dcl of 3 specimens for three environmental conditions after 9 months.

The specimens were exposed to high concentration of CO2 in 60% relative humidity for more than 1 month. To find a relationship between concrete durability parameters and chloride penetration coefficient, the RCPT, compressive strength and capillary absorption tests were carried out on both carbonated and non-carbonated specimens.

To find a parametric function between Dcl in non-carbonated concrete and mix design parameters, the β index defined as Equation 1:

$$\beta = \frac{(D_{cl})_{non-carbonated} - (D_{cl})_{carbonated}}{(D_{cl})_{non-carbonated}} \tag{1}$$

The relation between β values and concrete mix proportion (W/C and S.F content) may be supposing as Equation 2:

4-Conclusions

- Carbonation can reduce chloride diffusion coefficient in concrete to 50% of non-carbonated concrete depending on the water cement ratio(W/C).
- Increasing the amount of S.F content in concrete decreases the effect of carbonation on porosity reduction of concrete.
- A quadratic function with concrete mix proportion (W/C and S.F contents) developed to predict the effect of carbonation on Dcl variations. The model can be useful in prediction of Dcl in carbonated concrete.

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Table 1: Average chloride diffusion coefficient results

Mix ID	D_{cl} (mm^2/year) (submerged)	D_{cl} (mm^2/year) (atmospheric)	D_{cl} (mm^2/year) (tidal)	D_{cl} (mm^2/year) (submerged)	D_{cl} (mm^2/year) (atmospheric)	D_{cl} (mm^2/year) (tidal)
	Non - carbonated			Carbonated		
M-35-0	105	57	153	67	42	104
M-35-7	101	50	131	82	43	111
M-35-10	89	37	87	77	33	79
M-40-0	311	57	340	177	34	204
M-40-7	119	54	160	80	36	112
M-40-10	104	40	105	89	27	93
M-50-0	451	87	323	180	35	129
M-50-7	343	80	285	151	35	125
M-50-10	228	67	243	119	46	141

$$\beta_{submerg} = 0.15 - 0.1 * \left(\frac{W}{C}\right) - 1.35 * (S.F) + 2 * \left(\frac{W}{C}\right)^2 + 0.164 * (S.F)^2 + 6.23 * \left(\frac{W}{C}\right).(S.f) - 0.78 * \left(\frac{W}{C}\right).(S.f)^2 - 7.05 * \left(\frac{W}{C}\right)^2.(S.F) + 0.9 * \left(\frac{W}{C}\right)^2.(S.F)^2$$

(a3)

$$\beta_{atmospheric} = -1.82 + 8.5 * \left(\frac{W}{C}\right) + 6.29 * (S.F) - 7.33 * \left(\frac{W}{C}\right)^2 - 0.1 * (S.F)^2 - 3.41 * \left(\frac{W}{C}\right).(S.f) + 0.52 * \left(\frac{W}{C}\right).(S.f)^2 + 4.50 * \left(\frac{W}{C}\right)^2.(S.F) - 0.67 * \left(\frac{W}{C}\right)^2.(S.F)^2$$

(b3)

$$\beta_{tidal} = 0.133 - 0.40 * \left(\frac{W}{C}\right) - 1.22 * (S.F) + 2.67 * \left(\frac{W}{C}\right)^2 + 0.145 * (S.F)^2 + 5.53 * \left(\frac{W}{C}\right).(S.f) - 0.68 * \left(\frac{W}{C}\right).(S.f)^2 - 6.12 * \left(\frac{W}{C}\right)^2.(S.F) + 0.76 * \left(\frac{W}{C}\right)^2.(S.F)^2$$

(c3)

$$\beta = \sum_{i=0}^{2}\sum_{j=0}^{2} a_{i,j}.\left(\frac{W}{C}\right)^i.(S.F)^j \qquad (2)$$

By minimizing the error function in Equation 3, the function can be written as follows:

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