V-76   WATER AND CHLORIDE ION PENETRATION
IN SATURATED AND UNSATURATED CONCRETE

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1. INTRODUCTION

Water present in the concrete pores within the concrete matrix plays an important role in the transport of chloride ions and/or oxygen to the level of reinforcing steel bars, and thus in the reinforcement corrosion in concrete. Whereas the water serves as a medium for the chloride ions to diffuse into the concrete, it is "seen" as a solid wall by the oxygen. The results presented here are a part of a study being carried out to gain a better understanding of chloride penetration into the concrete matrix under different conditions.

2. EXPERIMENTAL PROGRAMME AND METHOD

The experimental programme is aimed to clarify the relation between the transport of chloride ions and the movement of water. 10cm x 10cm x 40cm concrete specimens were cast using the mix given in Table 1. All specimens were cured in water at 20°C for 4 months. Then, half the specimens were dried out by first leaving them in air (20°C) for 5 days and subsequently in an oven (80°C) for about 3 weeks. All specimens were then epoxy-coated leaving only one face (10cm x 40cm) uncovered for allowing the diffusion of water or chloride ions. The "wet" specimens were then again stored in water for 2 months, before all the specimens were immersed in water containing 3.3 or 15% by weight of NaCl. After 1 month of immersion, a hole was drilled into the specimens, and the total chloride content was determined at different depths.

Table 1: Mix Design

W:C	W	C	S	Agg	f_c'	E
40	214	534	852	903	563	3.7
70	220	314	937	885	296	2.6

Notes:
1) W, C, S and Agg. in Kg/m^3
2) f_c' in kg/cm^2.
3) E in 10^5 kg/cm^2

3. RESULTS

3.1 Water Absorption and Drying

After demolding, the specimens were weighed from time to time to determine the amount of water absorbed or expelled during curing, drying or at the time of immersion in salt water. Figures 1, 2 and 3 show typical plots of the change in weight (i.e. the water absorbed or expelled) vs. time, for the specimens with the water-cement ratio of 40% and 70%. During curing when the hydration of the cement is going on, the asbsorption is greater and more rapid in D4 compared to D7, possibly because of it's greater cement content (fig. 1). But once the hydration is more or less complete, the expulsion (fig. 2) and the absorption of salt water (fig. 3) is easier in D7, because it has

Fig. 1 Water absorbed during curing

greater and possibly bigger pores. It is interesting however, to note that the ratio of the water finally remaining (considering the water initially present, absorbed during curing and expelled during drying) to the cement is the same in the two cases, 25% and 23% for the w:c of 40% and 70% respectively, before immersing the specimens in salt water.
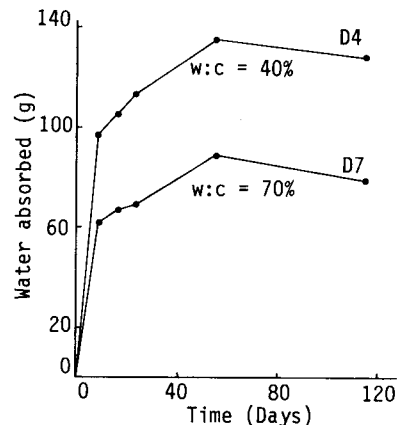
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3.2 Chloride Ion Penetration

The chloride concentration after a time "t" at distance "x" from the boundary, C(x,t), is often obtained using Fick's law (1), i.e.,

$$C(x,t)=C_0(1-erf(x/\sqrt{4Dt})) \ldots (1),$$

where, C_0 is C(0,t), D is the diffusion coefficient and erf is the error function.

Fig. 4 shows the plots for C(x,t) vs. x, for the initially "dry" and "saturated" specimens immersed in 3.3% and 15% NaCl solutions. This figure reveals that:

1) In the specimens that were initially dried, the chloride concentration at any depth is much greater than the wet ones, indicating that the chlorides penetrated the concrete matrix with the permeating water and at a much greater speed than expected in the case of diffusion by concentration gradient. Using the relation between the error and the normal distribution function (2), it is possible to determine the C_0 and D in eq (1). Profiles calculated using these C_0 and D match well with the observed profiles shown in Fig. 4 for the "wet" specimens. In the case of "dry" specimens, eq. (1) predicts much lower values than those observed, possibly because of the inherently different penetration mechanism at work.

2) Other things being the same, higher w:c ratio leads to greater chloride penetration, because of differences in pore structure, etc..

3) Higher salt concentration does lead to higher degree of penetration, but not necessarily a higher diffusion coefficient (Table 2).

Further experiments, including cyclic exposure to salt water in the laboratory and exposing identical specimens near the sea. are now in progress to clarify the role of water in the chloride ion penetration in concrete.

Table 2: C_0, D for "wet" specimens

NaCl Conc.	w:c 40%	w:c 70%
3.3%	1.2, 0.093	0.75, 0.293
15%	2.8, 0.083	1.8, 0.357

Note: C_0 is % by wt. of concrete
D is $10^{-6}cm^2/s$

4. REFERENCES

1. Crank, J., "The Mathematics of Diffusion", 2nd Ed., Oxford Press, 1986
2. Nagano, H. and Naito, T., "Diagnosis Method for Chloride Contaminated Concrete Structures", Intl Conf. on Conc in Marine Env, London, Sept. 1986
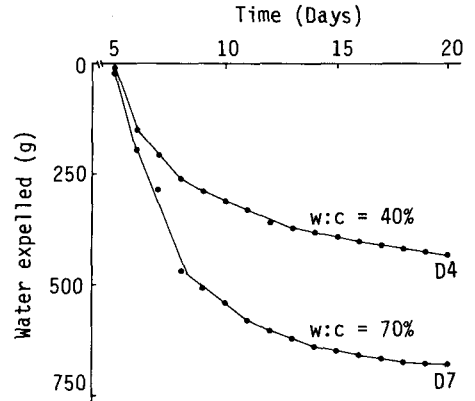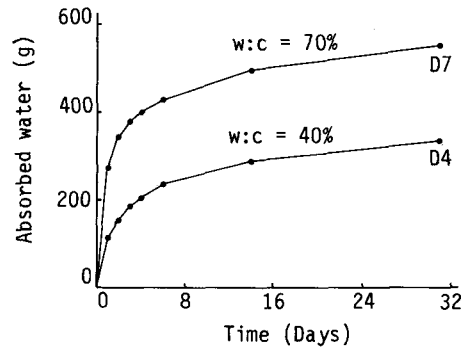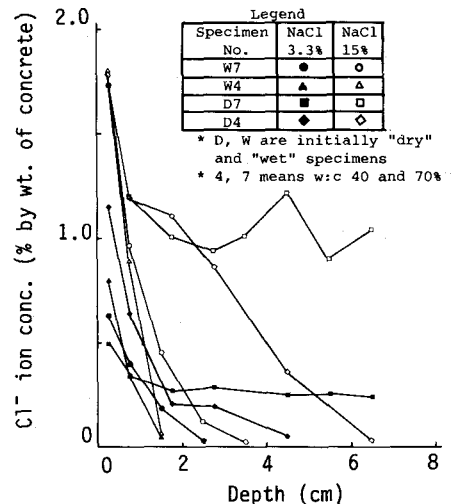
Fig. 2 Water expelled during drying

Fig. 3 Absorbed salt water vs. time

Fig. 4 Chloride penetration profiles