Appendix 3: CANADA

Durability aspects of high-performance concretes for a waste repository

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The IRUS facility for the disposal of low level radioactive waste at the Chalk River Nuclear Laboratories in Ontario, Canada relies on the durability of concrete for the required 500 years of service life. A research programme based on laboratory testing to design a durable concrete and assess its long-term behaviour was initiated in 1988. This appendix discusses the methodology to assess the long-term behaviour of concrete, and some initial observations. Longevity predictions for concrete formulations based on diffusion testing are also presented.

The service life of concrete is dependent on a slow rate of deterioration and is influenced by the quality of concrete and the service environment. Factors such as cement type, cement content and water-to-cement ratio can affect the diffusion rate of ionic species into concretes. In addition, service life will depend on the failure criteria adopted. After examining the major failure mechanisms for the repository concrete, corrosion of reinforcement was selected as the mechanism for the failure of the waste repository structure. Chloride ions in the presence of oxygen can initiate corrosion of reinforcement and failure of the reinforced concrete components. The failure criteria chosen for the concrete was the time taken for the aggressive ions to reach the reinforcing steel by diffusion through the concrete cover (75 mm thick).

Experimental

1. Binders:
   Portland cement Type 10 and 50, silica fume and blast furnace slag were used for the three concrete systems described in this paper. The nomenclature and composition of cement systems are listed in Table A.2.

2. Aggregates:
   An unblended sand consisting mainly of quartz and feldspar was used. A limestone coarse aggregate of somewhat variable composition was used. Tests conducted were similar to those for the fine aggregate and the results were satisfactory.

3. Concrete:
   Three concrete systems (S1, S2, S5) were each prepared at four different water-cement ratios: 0.35, 0.42, 0.5 and 0.60, denoted as mix 1, 2, 3 and 4 (M1, M2, M3, M4).

The cement contents for S1, S2 and S5 are as follows: S1 (M (1-4)): 485, 370, 335 and 280 kg/m^3. S2 (M (1-4)): 383, 338, 338 and 275 kg/m^3; S5 (M (1-4)): 437, 359, 325, and 259 kg/m^3. A target slump of 125–150 mm was maintained for all mixes.

Two concrete prisms, 75 × 75 × 280 mm, were cast for each mix and each exposure condition. Prior to immersion in the test solutions, the prisms were coated with wax on all sides but one, to allow a unidirectional ingress of chloride or sulphate ions. On the basis of an analysis of the repository service environment, the following major degradation parameters were selected for laboratory testing of concrete specimens:

— sulphate ions, chloride ions, several agents in combination,
— leaching of calcium hydroxide by water, carbon dioxide reactions.

Ionic profiles and depth-of-penetration measurements (determined by EDXA) in concrete showed that reasonably accurate results can be obtained and predictions of ionic ingress made. There was some scatter in the experimental results, because of the difficulty of locating the reaction front in concrete test specimens, due to the tortuous path of ionic ingress through dense concrete. However, there was enough consistency and redundancy in the system to obtain fairly accurate results. The procedure following the diffusion path around the fine and coarse aggregate particles, using the scanning electron microscope and electron microprobe for analysis, was successful. The rate of penetration of aggressive ions into the concrete was evaluated by determining the reaction zone front with time of exposure in the solution baths. Prediction of long term concrete behaviour involves the extrapolation of current data, based on the assumption that long-term processes (not currently identified) will not invalidate the extrapolation. Figure A.1 shows the rate of diffusion of chloride ions into test concretes and extended regression lines for longevity predictions.

Conclusions

The following can be concluded from the experimental data:

— Hydrated blended cements mortars had diffusivities up to 25 times lower than equivalent. Type 10 hydrated Portland cement mortars and that the lowest diffusivities were obtained.
— Median pore diameter and $Ca(OH)_2$ content were ranked in the same order for the three cement systems (S5<S2<S1), and were similar to the ranking for electrical conductivity and diffusivity.
— Lower water-to-cement ratios in concrete systems decreased the diffusion rate of ions, and sulphate ions seemed to inhibit the rate-of-penetration of chloride ions.
— On the basis of the physical test results and the diffusion test data, System 5 concretes, with a 75% blast furnace slag replacing Type 50 cement and 3% silica fume blend, ranked the lowest with respect to permeability, and provide maximum resistance to degradation. System 5 mix 2 was selected as the candidate high-performance concrete for the repository construction. The experimental results indicated that this concrete would meet the 500 years service life requirement.

TABLE A.2. NOMENCLATURE AND COMPOSITION OF CONCRETE SYSTEMS

Concretes	Cement type	Blast furnace slag	Fly ash	Silica fume	Curing time
System 1 (S1)	Type 10 100%	0	0	0	14 days
System 2 (S2)	Type 50 90%	0	0	10%	14 days
System 5 (S5)	Type 50 22%	75%	0	3%	28 days

Mix 1 (M1) = 0.35 w/c　　Mix 3 (M3) = 0.50 w/c
Mix 2 (M2) = 0.42 w/c　　Mix 4 (M4) = 0.60 w/c

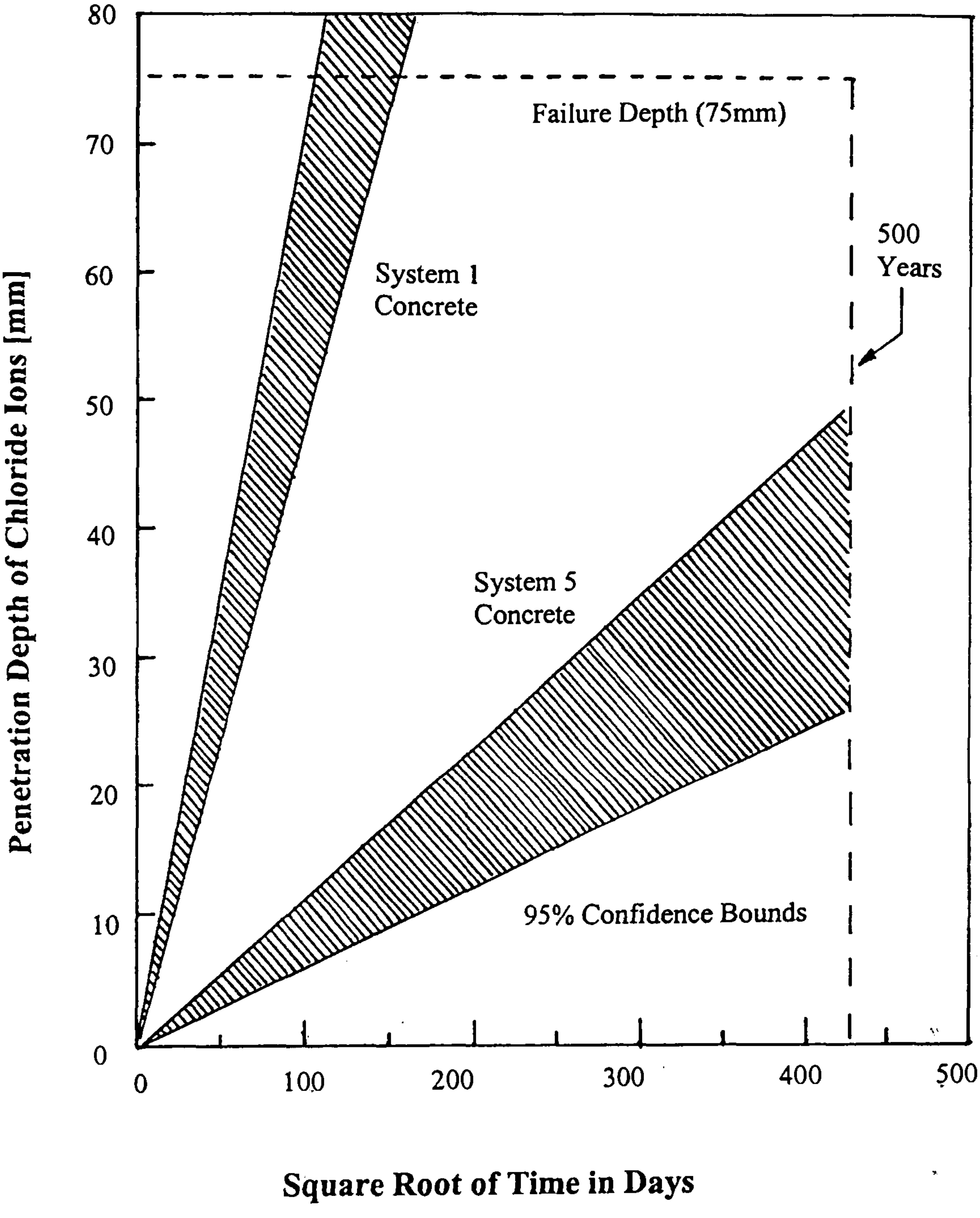

FIG. A.1. Extended regression lines; exposure of concrete specimens in 5 g/l chloride bath.