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Chloride Ingress in Blast Furnace Slag Cement in Marine Concrete Structures

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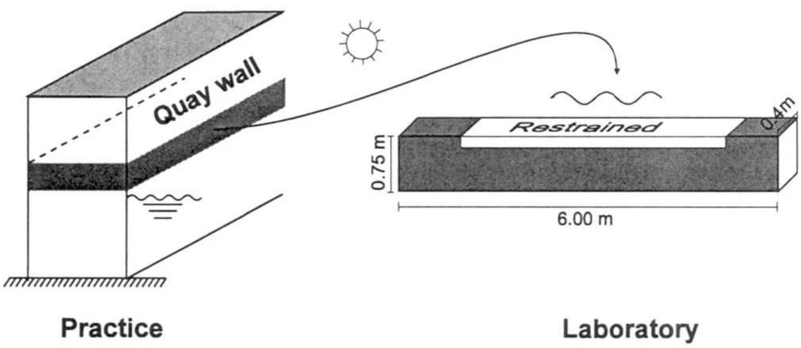
Abstract

Numerous reports about unsatisfactory performance of reinforced concrete structures subjected to marine environment reveals that the existing design codes and recommendations do not always adequately meet the real requirements for long term durability of such structures. The interaction between the materials and structure as a whole on the one hand and the climatic conditions to which the structure is exposed on the other hand, is a key point to be considered in any durability assessment of marine reinforced concrete structures. Splash/tidal zone of marine structures is the most critical part of these structures in terms of susceptibility to damage due to chloride-induced corrosion of reinforcement. In the parts of the structures subjected to alternate wetting and drying the chloride ions move into concrete relatively fast. Furthermore, in concrete members, temperature and shrinkage may introduce deformations. When such deformations are restrained, stresses will occur. So, the dominant cause of unanticipated cracks in concrete elements is the natural restraint of deformations in concrete structures.

In an experimental study, performance of different concretes exposed to a simulated marine environment is investigated. The severe marine conditions were simulated by alternating drying/wetting with salt water and heating/cooling cycles. One of the key points in this investigation is that chloride penetration is studied in full-scale concrete elements of which deformations, caused by temperature and drying and wetting, are naturally restrained (see Fig.). The (micro-) cracks induced by thermal stresses may increase the permeability and promote chloride ingress into concrete.



"Presentation of practice oriented full scale experimental research and the restrained temperature induced deformations at the top of the beam"

Variables in this study are the level of restraint in specimens, temperature, cement type and curing conditions. All concrete specimens, including large beams and small cubes, are subjected to alternate wetting and drying cycles to simulate the marine condition. In addition, temperature variations are applied to some specimens. In total 90 complete exposure cycles of wetting and drying plus heating and cooling are applied to large beams (from one side) and to small cubes. The applied exposure condition consists of a drying period of 42 hrs followed by a wetting phase of 6 hrs with salt water containing 5% NaCl. The drying phase is a thermal regime characterized by a temperature swing from 20 °C to 60 °C within a period of 12 hrs. This simulates, with some acceleration, the aggressive marine environment in hot regions with varying daily temperature including direct solar radiation.

Two types of concretes, one with ordinary Portland cement and one blended with 70% blast furnace slag cement, cured with different conditions, are used in this experiment. Two curing regimes, i.e. standard curing and elevated temperature curing, are imposed upon the specimens. In standard curing, the specimens were exposed to room temperature and humidity, for 14 days. In the case of elevated temperature curing, concrete beams and cubes were exposed to the controlled environment with a temperature of 38 °C and relative humidity of 50%, also for 14 days, to simulate the curing conditions in tropical regions.

Observations after one month and six months of exposure showed that no significant microcracks had occurred at the surface of the concrete beams. Comparison of the chloride measurements in large elements and small specimens, both exposed to temperature and hygral variations, showed that (non-intensive) microcracks at the surface layers due to restraint of temperature-induced deformations, did not promote chloride penetration rate in the large specimens noticeably. The effect of microcracking, induced by temperature variations, on the rate of chloride penetration seems to be less than what has been suggested in the literature, at least with this particular test and boundary conditions. The pronounced effect of temperature cycles, however, was found to be more through the pore structures of the concrete than through the minor microcracks.

Slag cement concrete performed better than Portland cement concrete in the simulated aggressive marine environment. Furthermore, the elevated temperature curing had a substantial effect on promoting the chloride transport in concrete with Portland cement. In slag concrete, however, the elevated temperature curing did not show increase in ingress rate.

Regarding the numerical simulation, with *time dependent* values of the chloride diffusion coefficient and surface chloride content it was found that the error function solution to Fick's second law of diffusion can, with sufficient confidence, be used for non-steady state situations, such as the simulated marine condition in the performed experiment.

In the paper the focus is only made on the beneficial use of Portland cement blended with the slag cement and the satisfactory performance of slag concrete in comparison with concrete made with only Portland cement is highlighted. The "achieved chloride diffusion coefficients" for some of the specimens of both concrete types are also presented and compared. The effect of other parameters, mentioned above, has been discussed in other papers which are referred in this paper.

The results of this investigation, in the light of the experimental and numerical simulation, contribute to conclude that when designing any structure which will be exposed to sea water, unblended Portland cement concrete can not be expected to protect the steel for long term. Many other authors on the basis of site investigations have made the similar finding on performance of marine structures made with slag cement concrete with lower w/b ratio. The results confirm that tropical marine environment provides more aggressive conditions to the concrete and enhances the deterioration rate and hence shortens the service life of structures. Ground granulated blast furnace slag concrete (or concrete with other supplementary materials, like silica fume) should always be used in such an environment.