The durability of white Portland cement to chemical attack

In terms of volume, the severest conditions that reinforced concrete structures are subjected to usually involve some form of attack by chlorides. These include marine environments, roads and bridges exposed to de-icing salt, etc. The time it takes for the chlorides to reach the reinforcement is the main parameter used to predict the service life of the concrete structures.

Much effort has been spent in understanding the processes resulting in the ingress of chlorides in concrete structures exposed to aggressive environments, and in predicting its service life. However, to date it has not been possible to accurately predict the time for chloride ions to reach the reinforcement of concrete structures without carrying out extensive and time consuming laboratory experiments to calibrate the service life models.

A thermodynamic model for the phase equilibria in hydrated Portland cement based on application of the phase rule, was developed and then verified experimentally during this investigation. The experiments were conducted on three types of Portland cement with varying composition (one grey and two white Portland cements). This approach was extended to include the reactions resulting in the binding of chlorides and alcalis. The model’s accuracy to predict chloride binding in Portland cement pastes at any content of chloride, alcalis, sulfates and carbonate was verified experimentally, and found to be consistent with available data in the literature. Furthermore, the model was shown to be equally valid for the phase assemblage identified in 25 year old PC pastes exposed to NaCl.

Chloride binding in Portland cement pastes is highly dependent on the content of alcalis; the higher content of alcalis the lower amount of bound chloride at any total content of chloride. Contrary to conventional wisdom, the content of alumina was shown to only play a relative minor role in the overall extent of chloride binding, as the major part of chloride is bound by the C-S-H phase.

As alcalis are transported at a much slower rate into concrete than chlorides, low-alcali Portland cements should be used in aggressive environments containing chlorides. Furthermore, owing to the minor effect of alumina on chloride binding, low-alcali low-aluminate Portland cements could arguably be recommended for aggressive marine environments providing maximum protection to both chloride transport and sulfate attack.

The increased chloride binding capacity obtained by reducing the alcali content of the cement also reduces the ratio of chloride to hydroxyl ions in the pore solution (i.e. ratios at 0.50-0.60 are typically given as the chloride threshold value for reinforcement corrosion) as long as the content of alcalis is lower than Na2Oeq < 0.30-0.35. This occurs even though the initial pH of the pore solution is of course also lower at these low alcali contents.

The model was introduced into an existing finite element model for the ingress of chlorides into concrete accounting for its multi-component nature, and the composite theory was used for predicting the diffusivity of each ion based on the phase assemblage in the hydrated Portland cement paste. Excellent agreement was found between the chloride ingress and phase assemblage profiles predicted by the model, and those determined experimentally on w/p 0.45 Portland cement pastes exposed to 650 mM NaCl for 70 days.