Modelling of chloride transport & Implications on Service Life Prediction

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Chloride transport into concrete is controlled mainly by the availability of chloride ions on the surface and properties of cover concrete such as diffusivity, porosity and ionic concentration of pore fluid. Figure 1 below identifies a range of variables that has a direct impact on chloride transport.

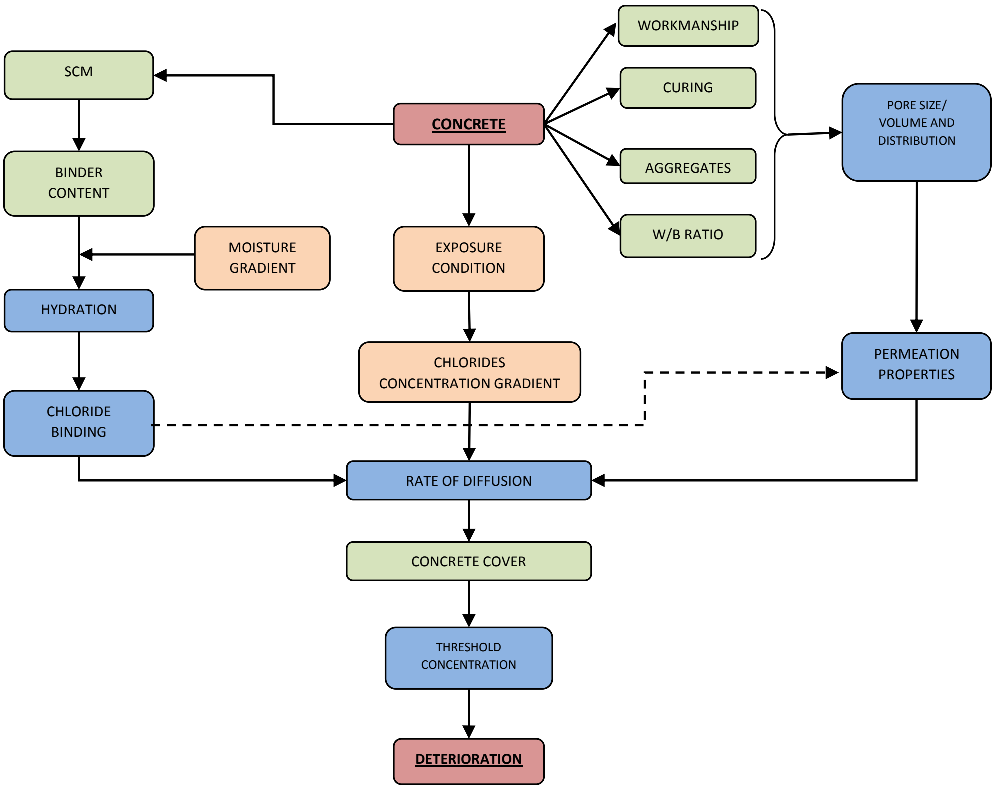

Figure 1 Shows the factors/variables which have a significant influence on the chloride transport and the interconnectivity of variables

Chloride Transport Modelling It is possible to model the flow of chlorides into concrete if these variables are known or can be quantified. For simplicity in modelling, often a mechanism of transport such as diffusion is assumed as predominant for concretes with sufficient cover depth. This assumption allows engineers to use Fick's second law (Eq. 1) of diffusion to model the flow of ions especially when the flow is non-steady state.

$$\frac{\partial c}{\partial t} = -\frac{\partial}{\partial x}\left(-D\frac{\partial c}{\partial x}\right) \qquad \text{(Eq.1)}$$

The assumption is that the medium is homogeneous and does not change with time (i.e. D is constant) as well as assuming simple boundary conditions, such as the boundary is semi-infinite and one side of the medium is exposed to a solution with constant chloride concentration, the engineering solution of Eq. 1 is given in Eq. 2.

$$C_{(x,t)} = C_s\left[1 - erf\left(\frac{x}{\sqrt{4Dt}}\right)\right] \qquad \text{(Eq. 2)}$$

where,
$C_{(x,t)}$ is the chloride concentration at depth x at time t, mol/m^3; C_s is the surface chloride concentration, mol/m^3; erf is the error function, found in mathematical handbooks; D is the diffusion coefficient, m^2/s.

The diffusion coefficient (D) is referred to as the non-steady state diffusion coefficient D_{nssd} (or apparent diffusion coefficient D_a). For example the chloride concentration ($C_{x,t}$) at a depth x at any time t can be predicted using Eq. 2 by substituting the values for D and Cs. By changing x and t one can determine the spatial distribution of chloride ions in the concrete at any time *t* known as the chloride profile (refer to Figure 2). Whilst this methodology is adequate for a structure with sufficient information about the variables are available, such over simplifications leads to errors in most structures. For example, the D is a time dependent variable as the concrete matrix matures over time and D will continue to decrease with time. Also the Eq. 2 does not take into account the binding capacity of concrete which refers to the retention capacity of concrete.

Software available for modelling – There are several software/excel file available for carrying out the modelling. Life 365 V2.2 is one of the simplistic and easy to use model with a set of database that allows users to just input mix design rather than transport variables and it also takes into account the reduction in D with time. More sophisticated models exist such as ClinConc and STADIUM that simultaneously takes into account the critical variables and give a reasonably reliable prediction. However very sophisticated experimental set-up is required for determining/quantifying some of the variables and the number of variables that these models employ will guarantee headache. Some of the emerging research indicates that these models can be reworked to take very few but critical variables and still achieve reliable chloride profiles as output. The presentation will outline some of these developments.

Service Life - The service life of a concrete structure is defined as the time from construction until a critical limit of a user defined technical property is reached. In the case of structures in chloride environments this user defined property is spalling or the reduction in load carrying capacity due to reinforcement corrosion. This deterioration of a RC structure consists of two phases; the initiation phase and the propagation stage. Adopting a conservative approach service life is taken as time until corrosion initiates i.e., duration of initiation phase.
An example is given below in Figure 2 for a structure exposed to North Sea. For this structure the first the chloride diffusivity was determined and other variables are selected based on the information available through mix design and exposure condition. Chloride profiles obtained from the structure from initial years are used to fine tune the model, so that reasonably accuracy can be achieved for prediction for later years.

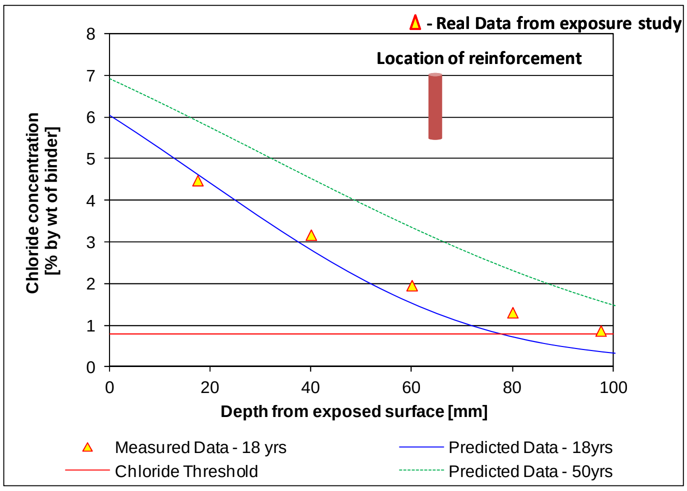

Figure 2 Shows the real and predicted chloride concentration vs depth after 18 years of exposure and predicted chloride profile after 50 years of exposure. The 18 year data is used to validate the model before proceeding into a service life prediction for 50 years or more.

Note: Model used in Figure 2 is ClinConc

Further - The presentation will cover the role of variables in chloride transport and a new methodology for reducing the number of variables required in modelling. More importantly, how the test data and modelling can be employed for specifying concrete for chloride environments. The same methodology can be applied for predicting the remaining service life of structures.