Comprehensive Model for Ageing of Reinforced Concrete Structures under Final Disposal Conditions

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Introduction

Multiple engineered barriers ensuring the safety of low- and intermediate-level waste repositories (Figure 1) located at 100 meter depth in the bedrock are required by YVL 8.1 2003 to be serviceable for at least 500 years after the facilities are sealed. Engineered barriers mainly consist of concrete structures. However, there is a lack of direct experience in reinforced concrete structures with a service life even close to that demanded, as reinforced concrete has been used as construction material for buildings for a little less than 150 years. This requires that the design work and justification shall be based on understanding of the fundamental ageing mechanisms of reinforced concrete under such conditions.

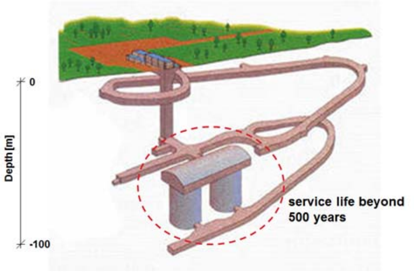

Figure 1 Layout of the low- and intermediate-level waste repository (Kari 2009)

Conventional methods do not describe the deterioration of such structures accurately enough, as the interaction of various deterioration mechanisms is not considered. Thus, a question to be answered is the effect of the interaction between different mechanisms on ageing of reinforced concrete. For a long time period this can only be achieved with a mathematical model.

Materials and methods

The model was constructed by applying the various ageing theories that were available in the literature leading to a group of partial differential equations. The solution of the model is based on the use of the finite element method, which is an application of weighted residuals. In simulation were used commonly available software and PCs. The validation of the model was performed by using the results of experiments that were partly made in this research project.

The methods used in the experimental part of the research were a titration of chlorides (Leinonen 2010), electron microanalyser, a gravimetric method for sulphate analyses, mercury intrusion porosimetry, Environmental Scanning Electron Microscope (ESEM) combined with an Energy Dispersive Spectrometer (EDS) and ordinary measurements concerning concrete carbonation.

Three different kinds of concretes exposed to two different kinds of exposure solution were used for validation. Concrete mixes consisted of three different binder combinations with constant water-to-binder and aggregate-to-binder ratios. Silica fume (Micropoz) and/or blast furnace slag (KJ400) were used partly as a cement replacement in two mixes, while one mix consisted of pure sulphate-resisting cement as a binder. The solutions contained either only chlorides or chlorides combined with sulphates and magnesium.

The estimation of the durability of disposal facilities was performed by assuming conservative boundary values and conditions. Carbonation was presumed to last 50 years during the operating phase of the repository. The length of the post-closure period, when the structure is submerged and exposed to various mechanisms of ageing, was assumed to be 500 years. The modelling was performed for the same test concretes that were used in the validation. Initial values of the model and the mesh used in the calculations are presented in Figure 2.

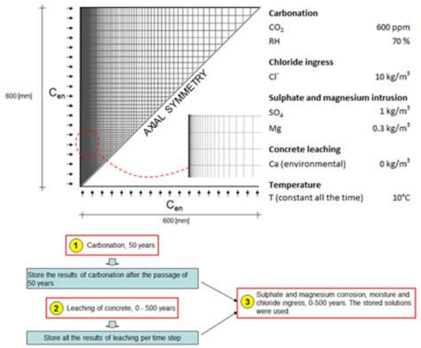

Figure 2 Initial values of the model and the mesh used in the calculations (Kari 2009)

Results

The principal result of the study is a theoretical model that combines different deterioration mechanism of concrete. The obtained model is solved stepwise in time domain. The numerical implementation was made by applying a commercially available computer code. Thus, the model is exploitable publicly for simulations. In the numerical implementation particularly conditions of underground disposal facilities were kept in mind. This affected deterioration parameters included in to the implemented model. The ageing mechanisms considered were (Figure 3): the carbonation of concrete by air; moisture ingress; chloride penetration; concrete corrosion caused by both sulphate and magnesium intrusion, and the leaching of cement paste compounds into groundwater.

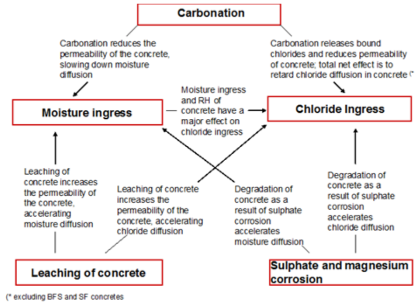

Figure 3 Main ageing mechanisms and interaction (Kari 2009)

The model can also be used to describe deterioration caused by a single ageing mechanism and for a time period typical for ordinary reinforced concrete structures. In addition, the effects of concrete admixtures, in this case silica fume and blast furnace slag, were included in the model. Therefore, as a by-product, the latest knowledge about the ageing mechanisms discussed were collected and analysed in the study. The finite element implementation is basically three dimensional, although the analyses made were two dimensional as the primary research objective was to explain the importance of interaction of various ageing mechanism of reinforced concrete structures under final disposal conditions.

Conclusions

The results received emphasize importance to consider interaction between different ageing mechanisms of reinforced concrete, particularly in cases such as disposal facilities where the service life required may be hundreds of years. The deterioration caused by the combination of aging mechanisms is significantly more harmful than the ageing induced by a single mechanism as has been shown in Figure 4.

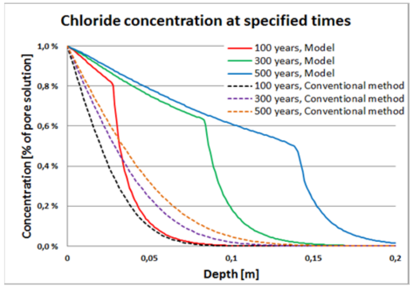

Figure 4 Chloride concentration at specified times; Model vs. conventional method (Kari 2009)

The mathematical methods based on a group of differential equations can be used to simulate the interaction of different ageing mechanisms. The use of the model developed is not restricted to reinforced concrete structures under disposal conditions, but it can be used also in the design and lifetime management of new or existing nuclear power plants. The model can also be adapted for design and lifetime management of conventional concrete structures.

Further research is needed to improve the reliability and applicability of the model. As the model is based on the intercoupling of diffusion equations, the effective porosity is a dominating parameter. A future challenge is to understand and model its variations on the surface layer of the structure. The model will be developed by including both inherent and epistemic uncertainty of concrete material into model by statistical methods. The determination of the required amount of chlorides in the pore water for the initiation of reinforcement corrosion under the particular disposal environment in Finnish bedrock will be beneficial for improving the knowledge of structural ageing process.

Literature cited

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For further information

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