Nordic Concrete

Research

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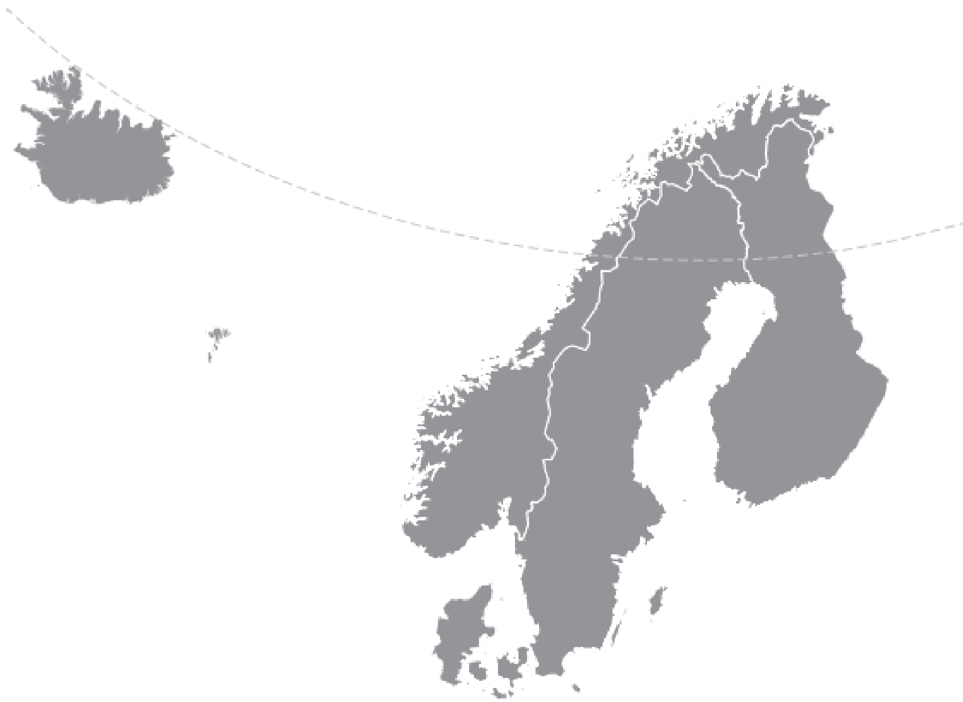

Nordic Concrete Federation

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Early age crack assessment of concrete structures: Experimental and theoretical approaches

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ABSTRACT
The present paper contains a brief overview of work performed within the Ph.D. thesis *"Crack assessment of concrete structures: experimental investigation of decisive parameters"* (2010 – 2016). The main objective of the Ph.D. thesis was to assess early age strain development, stress development and cracking sensitivity of various fly ash concretes by using laboratory experiments and analytical approaches.

Key words: Early age concrete, Cracking, Modelling, Shrinkage, Testing.

1. INTRODUCTION AND OBJECTIVE

The present paper constitutes a brief overview of work performed within the PhD thesis *"Crack assessment of concrete structures, experimental investigation of decisive parameters"* [1], submitted and accepted at the Norwegian University of Science and Technology (NTNU) in 2016.

Concrete in the hardening phase is subjected to volume changes caused by thermal dilation and autogenous deformation. If these volume changes are restrained they may lead to stress development, where the amount of stress generated in a given time interval is dependent on the degree of restraint and the viscoelastic properties of the concrete. If the generated stress exceeds the tensile strength, cracking may occur, which may further lead to functionality-, durability, and esthetical problems. The volume changes of concrete and the associated cracking risk can be predicted by the use of calculation methods to assess the early age structural behaviour of concrete. On the basis of such calculations and corresponding laboratory experiments, proper choice of concrete type, mineral additives and execution methods on-site can be taken to minimize or avoid cracking. The main objective of the currently described Ph.D. work was to assess the strain- and stress development and crack risk of the concrete by using laboratory experiments and analytical approaches.

2. INVESTIGATED CONCRETES AND EXPERIMENTAL TEST PROGRAM

Investigated concretes
Five concretes with a varying amount of fly ash, 0%, 17%, 25%, 33% and 45%, were investigated (the fly ash content is given as percentage of the total amount of “cement + fly ash”). The fly ash content was increased by replacing cement with fly ash 1:1 by weight, while keeping the water-to-binder ratio and the cement paste volume constant, 0.4 and 292 l/m^3, respectively. All concretes contained 5% silica fume (by weight of cement + FA).

Mechanical testing
An extensive experimental test program was performed on the above listed concretes as a part of the described PhD-work. The performed tests include heat development, compressive strength, tensile strength, E-modulus in tension and compression, creep in tension and in compression, autogenous deformation development and restrained stress development. The obtained test results were used to establish parameters for property development models to be used as input for restrained stress calculations.

The Temperature-Stress Testing Machine (TSTM)
The currently performed experimental test program also included numerous tests in the Temperature-Stress Testing Machine (TSTM), which was reconstructed and verified as a part of the described Ph.D. work [2]. The reconstruction provided a more advanced management of the experiments and more extensive output from each test. By applying a representative degree of restraint and temperature history, the TSTM is now able to directly simulate the stress development of a given section of a concrete structure. In addition, the TSTM can be used as the answer for early age stress calculations, thus allowing for an evaluation and/or calibration of 1) the chosen calculation approaches and 2) the appurtenant material parameters determined from the previously described experimental test series. The TSTM has shown to provide reliable results and very good reproducibility.

3. BASIS FOR RESTRAINED STRESS CALCULATIONS

The majority of the performed stress calculations and corresponding TSTM tests were carried out under semi-adiabatic conditions, i.e. the concrete specimens were subjected to a realistic temperature history during testing. These temperature histories were found based on semi-adiabatic calorimeter test results, and they represent the hatched area on the wall structure illustrated in Fig. 1 (left).

The property developments for compressive strength, tensile strength and E-modulus were modelled by Eq. 1, based on the obtained experimental test results. Eq. 1 is a modified version [3] of CEB-FIP MC 1990 [4].

$$X(t_e) = x(28) \cdot \left\{ \exp\left[s \cdot \left(1 - \sqrt{\frac{672 - t_0}{t_e - t_0}} \right) \right] \right\}^n \qquad (1)$$

where $X(t_e)$ is the mechanical property as a function of maturity t_e. X(28) is the property at 28 days, s and n are curve-fitting parameters, and t_0 is the start time for stress development

Three different calculation approaches were used to simulate the uniaxial stress development in the TSTM: 1) a specially designed 1D calculation program run in Excel, 2) the special-purpose program CrackTeSt COIN and 3) the multi-purpose FE program DIANA. For all calculation approaches, the time-dependent stress response of concrete was modelled based on the theory of linear viscoelasticity for ageing materials. The calculated stress developments were further compared to the corresponding stress development measured in the TSTM, and such forming a basis for evaluation of the calculation approaches as well as the determined model parameters.

The tested concretes were further compared and evaluated by their crack index, C_i. The crack index was defined as the time-dependent ratio of the self-induced tensile stress of the concrete $\sigma(t)$ to its average tensile strength $f_t(t)$ as expressed by Eq. 2.

$$C_{\mathrm{i}}(t) = \frac{\sigma(t)}{f_t(t)} \quad (2)$$

4. TEST RESULTS AND CORRESPONDING CALCULATIONS

Good agreement was found between early age stress developments calculated with Excel, CrackTeSt COIN and DIANA. The calculations also gave good agreement with the corresponding stress development measured in the TSTM, Fig. 1 (right).

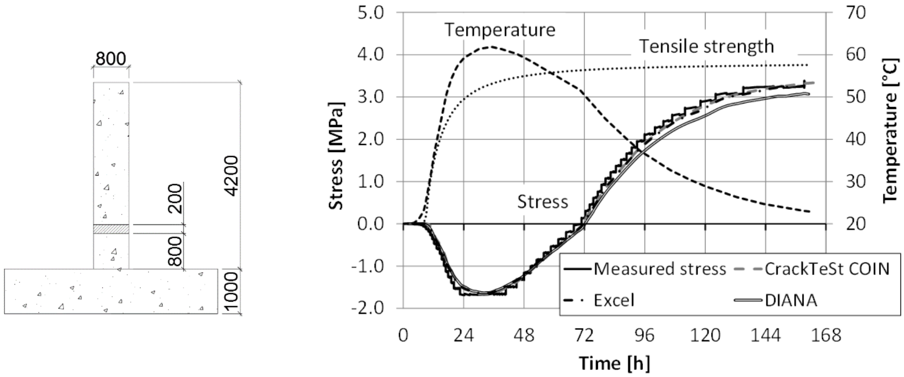

Figure 1 – Calculation example, massive concrete wall (left), Measured and calculated stress development in the TSTM (right)

Fig. 2 shows measured stress development (left) and determined crack index (right), for three of the tested concretes: *ANL 17% FA*, *ANL 24% FA* and *ANL 33% FA*. For the tested concretes, the tensile stresses generated under restrained conditions were found to be decreasing with increasing fly ash content. Also when seen in combination with the correspondingly reduced tensile strength, the cracking sensitivity (the crack risk) of the concrete was found to be systematically decreasing with increasing fly ash content for the given structural case. Consequently, by using laboratory experiments and analytical approaches, the cracking sensitivity of a concrete could be assessed and reduced with the use of mineral additives, which in the current study was exemplified by fly ash content.

It was also found that both mechanical properties and autogenous deformation were affected by realistic temperature curing conditions in a way that could not be correctly adjusted for by using the maturity principle. Using 20 °C isothermal values for autogenous deformation under realistic conditions would underestimate the volume change and thus also the corresponding tensile stress generation.

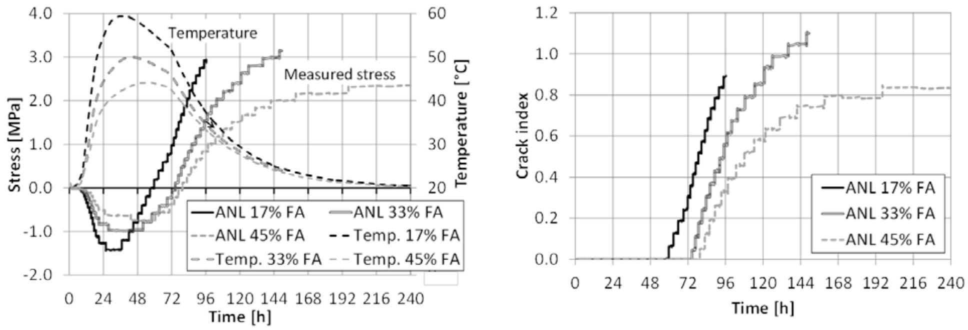

Figure 3 – Measured and calculated stress development in the TSTM (left) and corresponding crack index (right)

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