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Editorial

Early age concrete—properties and performance

This issue contains papers dealing with different aspects of properties and performance of concrete at early age. These papers cover recent research and developments that are both academically rigorous and relevant to practitioners.

The main driving force for early-age cracking in cement-based materials is the chemical reaction of cement with water. In hardening cement-based materials with low water/cement ratio, on-going cement hydration can lead to self-desiccation shrinkage if the internal humidity drops below 100%. Depending on the magnitude of self-desiccation shrinkage, the development of the mechanical properties, and on the degree of internal or external restraint, early-age cracking may occur in these concretes. Self-desiccation can only lead to significant shrinkage stresses if the cement-based material behaves as a solid.

An additional driving force leading to volume change and stress development is associated with the exothermic hydration reactions that cause thermal gradients within the concrete mass. The superposition of shrinkage and thermal dilation should be considered with respect to early age cracking sensitivity.

Early-age shrinkage and cracking in cement-based materials is receiving renewed attention due to the development of modern concretes which are more sensitive to cracking immediately after setting, as well as the advent of new additives such as shrinkage reducing admixtures and fibers which mitigate early age cracking in conventional and high performance concretes. This early age cracking sensitivity in modern concretes is to a large extent the result of the low water/binder ratio and higher cement content typical of High-Strength/High-Performance Concrete (HSC/HPC). Lower water/binder ratio will increase autogenous shrinkage and higher cement content will increase ultimate drying shrinkage of HSC/HPC and other concrete materials such as shotcrete.

With the modern developments in concrete science and technology, it has become apparent that the approach to evaluate the risk for early age cracking can no longer be based on the determination of free shrinkage at early age. A much more comprehensive approach, addressing control, design and testing is required, taking into account fundamental processes on the microscopic level and engineering characteristics of the cementitious system, as well as structural considerations, which induce restraint.

The papers presented in this issue address a wide range of questions, from Portland cement quality and production to concrete practices. The first group of papers cover *early-age deformations, stresses and heat evolution in cement-based materials*; while the later papers cover *early-age cracking in cement-based materials*.

Y. Ballim and P.C. Graham (South Africa) present an assessment of the range and extent of variation of heat evolution of nominally similar cement clinkers from a range of cement production facilities in the country. Using a finite difference heat model, the authors indicate the implications of the measured heat characteristics of the cement for early-age temperature distributions in large concrete elements.

Ø. Bjøntegaard, T.A. Hammer and E.J. Sellevold (Norway) discuss free deformation measurements and show that different types of measuring errors are involved, where, for instance, reabsorption of bleed water is an important one, and a standard test procedure should therefore describe how to handle the effect of bleeding. They found that it is possible to obtain fairly good reproducibility within one laboratory using the same test rig, whereas a Round-Robin test program showed that it is far more difficult to produce similar results from different laboratories measuring on the same concrete.

An applicability of degree of hydration concept and maturity method for thermo-visco-elastic behaviour of early age concrete is discussed in the paper by *G. De Schutter (Belgium)*. Whereas the degree of hydration concept and the maturity method are often treated as two competitive approaches for dealing with properties of early age concrete, it is shown that both methods principally yield the same results. In this way, together with the well-known applicability for strength and stiffness development, both methods now can be recognized as valid tools for modelling the total thermo-visco-elastic behaviour of early age concrete.

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The paper by *P. Lura and J. Bisschop (The Netherlands)* concerns the origin of eigenstresses in Lightweight Aggregate Concrete (LWAC) caused by autogenous deformation and drying shrinkage. The differences between LWAC and Normal Weight Concrete (NWC) are discussed.

R. Mabrouk, T. Ishida and K. Maekawa (Japan) propose a solidification model based on the microphysical information of temperature, hydration ratio, porosity, saturation, isotherm and other properties, in order to predict behavior of hardening young concrete. The solid model deals with cement paste as the solidified finite fictitious clusters having each creep property.

The objective of the paper by *A.K. Schindler, J.M. Ruiz, R.O. Rasmussen, G.K. Chang and L.G. Wathne (USA)* is to present recent improvements made to the temperature prediction model, and to illustrate that this model can be used to predict the in-place temperature development in Portland cement and fast-setting hydraulic cement concrete paving applications. To validate the temperature model, the concrete temperatures measured in the field were compared to the concrete temperatures predicted with the temperature model.

V. Slowik, E. Schlattner and T. Klink (Germany) experimentally investigate early age shrinkage of cement paste using Fibre Bragg Gratings—strain sensors within optical fibres, which are embedded in cement paste specimens. In this way, shrinkage strains can be measured starting from the beginning of the setting.

B. Tamtsia, J.J. Beaudoin and J. Marchand (Canada) investigate short-term creep and shrinkage strains at early age on hydrated Portland cement pastes prepared with different water–cement ratios (0.35 and 0.50). An analytical model, which accounts for load-induced hydration effects, is developed in order to predict the creep coefficient of normal and high-strength cement pastes from early age data.

The formation of microstructure in cementitious materials is simulated by *G. Ye, P. Lura, K. van Breugel and A.L.A. Fraaij (The Netherlands)* with a numerical model. Simulation results have been verified by measuring the evolution of the ultrasonic pulse velocity. It is shown that two critical processes take place. The first is the percolation threshold of the solid phase. The second is the full connectivity of the solid phase. The conclusions are drawn regarding the potential of numerical simulation models in the study of early age cementitious materials for quantitative analysis of hydration processes.

S. Zhutovsky, K. Kovler and A. Bentur (Israel) in their paper continue a series of works with the goal to develop the internal curing strategy by eliminating autogenous shrinkage of high-strength concrete while using the smallest possible amount of presoaked lightweight aggregate. They discuss the effect of the properties of the cement paste matrix on the effectiveness of internal curing.

On projects involving restrained concrete such as bridge decks, the risk of cracking can be reduced by selecting low-crack portland cement. This is discussed in the paper by *R.W. Burrows, W.F. Kepler, D. Hurcomb, J. Schaffer and J.G. Sellers (USA)*. It is concluded that a 12-h semi-adiabatic compressive strength test and a 12-h chemical shrinkage test measure the thermal cracking tendency of Portland cement and can be used to select low-crack Portland cement for important projects involving restrained concrete.

A Finnish test arrangement has been used by *E. Holt and M. Leivo (Finland)* to measure linear and volumetric deformations of concrete immediately after mixing. The slabs are tested in either drying or autogenous conditions. Results show that both drying and autogenous shrinkage can be significant in certain early age scenarios. Environmental factors greatly affect drying shrinkage, while material properties affect autogenous shrinkage.

The paper by *A.B. Hossain and J. Weiss (USA)* describes how the well-known ring test may be used to provide quantitative information about stress development that may be used to assess the potential for cracking in concrete. The authors compare the residual and theoretical elastic stress levels and provide information about the extent of stress relaxation in a material.

An effect of the addition of ultrafine cement and short fiber reinforcement on shrinkage, rheological and mechanical properties of Portland cement pastes is discussed in the paper by *J. Kaufmann, F. Winnefeld and D. Hesselbarth (Switzerland)*. It is found that fibers increase the ductility significantly and improve shrinkage and strength properties. The excellent rheological properties of the cement matrix containing ultrafine cement also allow a conventional mixing of composites with high fiber content.

R. Lackner and H.A. Mang (Austria) develop and apply a three-dimensional material model for the simulation of early-age cracking: from the constitutive law to numerical analyses of massive concrete structures. The intrinsic material function serves as input for the calibration of the Rankine fracture criterion formulated in the framework of chemoplasticity.

L. Østergaard, D. A. Lange and H. Stang (Denmark, USA) use a fracture mechanics approach to determine early-age stress-crack opening relationships for high performance concrete in order to understand better the crack propagation following the initial crack formation and to determine more precisely how detrimental any given initial crack will be for the structure under analysis.

A. Schwartzentruber, M. Philippe and G. Marchese (France) study different possibilities to reduce the cracking tendency: PVA fibers, glass fibers, metallic fibers and an expansive admixture. Two ways are to reduce the cracking tendency are discussed: reducing restrained tensile stress and/or increasing tensile strength. The first can be obtained by using moderate dosage of expansive admixtures and/or glass fibers, the second by using high dosage of metallic fibers.

M. Sule and K. van Breugel (The Netherlands) investigate an effect of reinforcement on early-age cracking in high-strength concrete. In order to visualise the crack formation in the early phase, cracks are impregnated with fluorescent epoxy. It is shown that reinforcement can induce the formation of smaller cracks, postponing the moment at which major cracks are formed. Finally, a procedure is discussed for quantifying the effect of reinforcement decreasing the risk of through-cracking at early age.

V. Waller, L. d'Aloïa, F. Cussigh and S. Lecrux (France) use well-known maturity method based on the Arrhenius law, in order to predict and control the risk of cracking in cement-based materials through the use of numerical tools such as the Finite Element program.

Most of the papers listed above address *early-age concrete properties and performance* mainly from five points of view:

- driving forces,
- engineering properties,
- analytical models,
- testing techniques and
- special cementitious systems.

The broad international representation of the papers in this special issue (19 papers from 14 countries from Europe, North America, Africa and Asia) demonstrates that the behavior of early age concrete is a hot topic of interest to the engineering and research community. Researchers and practitioners are becoming aware of the great importance of understanding and prediction of the properties and behavior of early-age concrete for durable construction. This special issue clearly highlights the trend in the research community to provide a greater focus on issues of technological significance, based on fundamental scientific concepts, which are of need to the engineering community to solve problems of early age cracking.

Guest Editors
Konstantin Kovler
Faculty of Civil and Environmental Engineering
Technion-Israel Institute of Technology
Technion City
Haifa 32000, Israel
Tel.: +972-4-8292971; fax: +972-4-8324534
E-mail address: cvrkost@tx.technion.ac.il

David A. Lange
Department of Civil and Environmental Engineering
University of Illinois, 2122 NCEL, MC-250
Urbana, IL 61801, USA
Tel.: +1-217-3334816; fax: +1-217-3339464
E-mail address: dlange@uiuc.edu

Henrik Stang
Department of Civil Engineering
Technical University of Denmark
Brovej, Building 118
DK-2800 Kgs.
Lyngby, Denmark
Tel.: +45-4525-1735; fax: +45-4588-3282
E-mail address: hs@byg.dtu.dk