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ASSESSMENT OF THE THERMAL SPALLING RISK OF CONCRETE STRUCTURES DURING FIRE BY MEANS OF A FINITE ELEMENT MODEL

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ABSTRACT

A very characteristic mode of concrete damage at high temperature, especially for the materials characterized by a low intrinsic permeability, like for example HPC or UHPC, is the so called thermal spalling. Authors of the paper have recently extended their mathematical model of concrete at high temperature [1] to take additionally into account Load Induced Thermal Strain (LITS) [2]. In the model concrete is treated as a multi-phase system with the voids of the skeleton filled partly with the liquid water and partly with the gas phase. The liquid phase consists of bound water and capillary water. The gas phase is a mixture of dry air and water vapour, and is assumed to be an ideal gas. Different physical mechanisms governing the liquid and gas transport are clearly distinguished. All the important phase changes of water, as well as the related heat and mass sources (or sinks) are considered. Changes of the material properties caused by temperature and pressure changes, concrete damage, as well as coupling between thermal, hygral, chemical and mechanical phenomena are taken into account.

Recently some simplified mechanisms of concrete damage and some spalling indexes have been proposed in [3] to give a quantitative assessment of the spalling risk in heated concrete structures. Five different spalling indexes can be defined, assuming different simplified models of the spalling mechanism or considering the main key factors influencing development of the phenomenon. The spalling index *Is1* is based on the pressure-induced shear model taking into account the gas pressure and the material damage. The internal geometry is described by the L_r/b ratio, where L_r is the length of compressed zone and b its thickness. The spalling index *Is2* is based on the buckling mode of damage and additionally takes into account the Euler's stress, the compressive stress in the surface layer, and the compressive strength. The internal geometry is defined by the $(L_r/b)^2$ ratio. The spalling index *Is3*, based on fracture mechanics, with internal geometry characterised by the $L_r s/h$ ratio, takes into account the averaged values of elastic energy and specific energy of fracture, and local value of damage parameter. The ratio s/h characterizes micro-geometry of a fracture, [3]. The spalling indexes *Is4* and *Is5* are heuristic and consider the following key factors favouring development of the thermal spalling: local values of the gas overpressure, mechanical damage parameter, averaged (from the heated surface to a given position) values of transversal traction stresses, and

constrained elastic energy. The factors impeding thermal spalling are averaged values of traction strength, and specific fracture energy. The spalling index *Is5* has the same form as *Is4*, but it omits effect of the specific fracture energy. To analyze the thermal spalling risk, we have performed, with the numerical model [1-2], computer simulations, based on the NIST laboratory tests for two different types of concrete: MIX-1 and MIX-2, [3]. During the tests all specimens of the MIX-1 experienced the thermal spalling, while only one of the four specimens of the MIX-2 spalled. The results for the first material were used to determine the internal geometry parameters in such a way, that the values of all spalling indexes were equal to one at the time and position corresponding to their real values during the tests [3]. Using the results of our simulations, we determined the evolutions of mechanical damage parameter, gas pressure and elastic energy of constrained strains, which are considered to be the key factors influencing thermal spalling risk, as well as the spalling indexes, for the two analyzed concrete mixes. Exemplary results, concerning the mechanical damage and spalling index *Is5* are presented in Fig. 1. As can be seen, the values of spalling index obtained indicate much higher risk of the thermal spalling occurrence for the MIX-1 than for the MIX-2, what is in a good agreement with the experiment. For all the other spalling indexes the results obtained were similar, but the most precise indication of the time and position of the spalling was obtained for the *Is5* index, what was not possible considering the mechanical damage evolution, Fig.1.

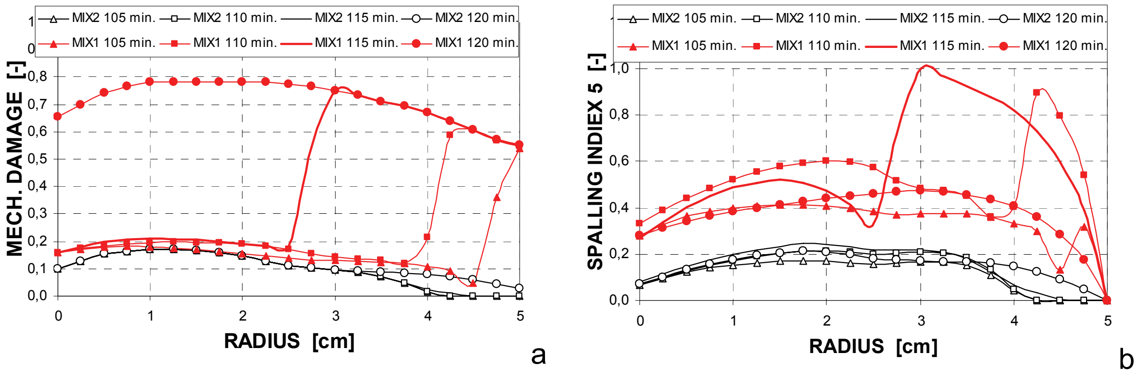

Figure 1. Comparison of the evolution of mechanical damage and spalling index Is5, obtained from the simulation of the NIST tests [4], for the two analyzed types of concrete: MIX-1 (red solid lines) and MIX-2 (thin lines).

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