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A MESO-SCALE APPROACH TO THE THERMO-MECHANICAL MODELLING OF CONCRETE

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ABSTRACT

Concrete subjected to combined compressive stresses and temperature loading exhibits compressive strains, which are considerably greater than for concrete subjected to compressive stresses alone. This phenomenon is called thermal transient creep or load induced thermal strain and is usually modelled by macroscopic phenomenological constitutive laws which have only limited predictive capabilities. This paper presents a meso-scale modelling approach in which the macroscopically observed thermal transient creep results from the mismatch of thermal expansions of the meso-scale constituents. The meso-structure of concrete is idealised as a two-dimensional three phase material consisting of aggregates, mortar and interfacial transition zones (ITZ). The nonlinear material response of the phases are described by a damage-plasticity interface model. The meso-scale approach was applied to analyse compressed concrete specimens subjected to uniform temperature histories and the analysis results were compared to experimental results reported by Thelandersson [1].

Meso-scale modelling of strongly heterogeneous materials like concrete is computationally very demanding. Continuum formulations for the description of fracture, especially at the interface between materials of significantly different stiffness, is difficult and can be accompanied by severe numerical problems. Therefore, a lattice approach, which is based on rigid bodies connected by springs, is applied in the present study [2, 3]. The heterogeneity of the material is described by spatially varying material properties of the lattice elements with respect to their position within the meso-structure. Consequently, the present lattice model combines random rigid body spring models with the heterogeneous microstructure approach used in [4]. Aggregates, mortar and interfacial transition zones are modelled as separate phases with different material properties. For each lattice element, a nonlinear stress-strain relation based on a combination of damage and plasticity is prescribed, which is similar to a continuum damage-plasticity model proposed by Grassl and Jirasek [5]. However, instead of the tensorial stress-strain relation of continuum approaches, a vectorial stress-strain relationship is prescribed. This damage-plasticity interface model was originally proposed for the multiscale modelling of concrete subjected to cyclic loading in [6] and is extended in the present study to describe the influence of thermal expansion.

This paper illustrates that the three-phase meso-scale modelling approach with a damage-plasticity model for mortar and interfacial transition zones is capable of describing the fracture process of concrete in compression. Furthermore, the mismatch of the thermal expansion of aggregates, mortar and interfacial transition zone is sufficient to describe the macroscopically observed thermal transient creep. No phenomenological damage mechanism is required to model the experimentally observed experiments. Finally, the path-dependence of the thermal-mechanical loading is described qualitatively correctly by the model. Overall, the proposed three-phase meso-mechanical approach seems to be capable of capturing the main characteristics of concrete subjected to thermal loading and the results indicate that the mismatch of thermal expansion has a strong influence on the load induced thermal strains.

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