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Micro-Meso-Macro Modelling of Composite Materials

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ABSTRACT

Multi-scale models can be extremely helpful in the understanding of complex materials used in engineering practice. In the presentation the basic theoretical strategy is developed. Possible finite element methods to solve such problems are explained in detail and discussed. These are based on homogenization techniques but also on true multi-scale solutions.

The developed methodology is then applied to a specific engineering material which is concrete. This construction material has to be investigated on three different scales, the hardened cement paste, the mortar and finally the concrete. Here a successive two-stage approach is followed in which first the multi-scale model of the cement paste and mortar is applied. The resulting homogenization can then used in a multi-scale mortar-concrete model.

The model for the hardened cement paste is based on a three–dimensional computer–tomography at the micrometer length scale. For this a finite element model is developed with different constitutive equations for the three parts unhydrated residual clinker, pores and hydrated products. The volume fraction of the hydrated products is approximately 84 Vol.%. For this part, a visco–plastic material model of Perzyna-type including damage is applied. The other two parts are described with a linear–elastic material model.

The constitutive equations at the micro–scale contains inelastic parameters, which cannot be obtained through experimental testings. Therefore, one has to solve an inverse problem which yields the identification of these properties. For computational efficiency and robustness, a combination of the stochastic genetic algorithm and the deterministic Levenberg-Marquardt method is used. In order to speed-up the computation time significantly, a client-server based system is used. Hence, all calculations are distributed automatically within a network environment.

The resulting constitutive parameters on the micro-scale are then used in the homogenized constitutive model for the mortar. But also in the multi-scale model for the mortar. Both results are compared with each other but also with experimental data.

A further interesting application occurs when the micro-structure of the cement paste is filled partly with water and a freezing process takes place. Due to frost, the moisture inside the microstructure freezes. A constitutive model for ice is applied to the water filled parts of the microstructure is then developed. The expansion of the ice leads to damage in the micro–structure which yields an inelastic material behavior on the macro–scale. If such a calculation is performed for different moistures and temperatures, a correlation between moisture, temperature and the inelastic material behavior is obtained. Numerical examples show, that the developed approach reproduces the material behavior realistically.