Eigenstress-based Anisotropic Damage Modelling of Concrete at the Meso-scale

Mohammed Hammad[1*], **Udo Nackenhorst**[1]

[1] Institute of Mechanics and Computational Mechanics, Leibniz University Hanover, Appelstraße 9A, 30167 Hanover, Germany, mohammed.hammad@ibnm.uni-hannover.de

Concrete is a complex multi-scale composite material that exhibits different mechanical behaviour at different levels, where the behaviour at one level can be explained by the structural behaviour at the lower level. At the meso-scale, concrete is typically modelled as a three-phase heterogeneous material consisting of aggregate particles, a cement mortar matrix, and a weak and very thin layer around the coarse aggregate particles, referred to in the literature as the interfacial transition zone (ITZ).

Experimental studies have shown that the microstructure of concrete has a large number of cracks before any external loading. These micro-cracks are caused by the micro-tensile stresses (eigenstresses) that develop in the concrete during the pre-loading phase due to endogenous shrinkage and drying shrinkage[1,2], as a result of mismatch of physical and mechanical parameters of adjacent phases of concrete (cement matrix, aggregate and ITZ).

The irreversible deformations observed experimentally after cyclic loading of concrete under uni-axial compression are often explained in the context of computational plasticity and the mechanics of ductile damage [3]. In this work, a new hypothesis is proposed to physically explain the permanent strains observed experimentally in cyclic fatigue of concrete. This hypothesis is based on *the release of the initial residual stress (eigenstress)* due to damage development in the elastic phase.

To examine the extent to which the presence of eigenstress may be the cause of the irreversible displacements that characterize the cyclic compressive behaviour of concrete, a continuum thermodynamically consistent elastic-brittle anisotropic damage model is implemented for the cement mortar and a three-dimensional analysis of the concrete is performed at the mesoscale considering the early damage of concrete in the pre-loading phase.

The coarse aggregates in the 3D mesostructure model are assumed to be spheres and randomly generated considering the shape, distribution and volume fraction of the aggregates. A linear elastic non-damaging material model is assigned to the aggregates. Intrinsic cohesive interface elements with zero thickness are inserted along the aggregate-cement mortar interfaces to represent the ITZ. The ITZ is associated with a bi-linear traction-separation law.

For the damage model of the cement matrix, the effective strain space is used based on the equivalent strain energy hypothesis, and a fourth-order damage effect tensor is employed to relate the strains in the effective and damaged configurations. Satisfaction of the first and second laws of thermodynamics is ensured. The Helmholtz free energy is introduced as a thermodynamic state potential that depends on the strain tensor as an observable and the internal state variables of damage evolution and damage hardening. The evolution of the conjugate thermodynamic forces is determined by the assumption of the physical existence of a damage dissipation potential. The Lagrangian minimisation approach is used to derive the laws of damage evolution and hardening for the proposed model. This model is implemented as a user-defined material subroutine (UMAT) in the advanced finite element software Abaqus. The results obtained from the mesoscopic numerical simulations are then compared with experimental observations

References

[1] Slate, F. O. and Matheus, R. E., Volume changes on setting and curing of cement paste and concrete from zero to seven days, In Journal Proceedings 64 (1967) 34–39.

[2] Hsu, T. T., Slate, F. O., Sturman, G. M., & Winter, G, Microcracking of plain concrete and the shape of the stress-strain curve, In Journal Proceedings 60, 2 (1963) 209–224.

[3] Chen, Q., Zhang, Y., Zhao, T., Wang, Z., & Wang, Z., Mesoscale Modelling of Concretes Subjected to Triaxial Loadings: Mechanical Properties and Fracture Behaviour, Materials 14, 5 (2021) 1099.