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Meso-mechanically motivated nonlocal models for modelling of the fracture process zone in quasi-brittle materials

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ABSTRACT

Objective description of softening due to initiation and propagation of defects such as microcracks or microvoids can be based on continuum damage models with special enhancements serving as localization limiters. One class of such models replaces the local values of a certain internal variable by the nonlocal values defined by a weighted spatial averaging integral. Previous experimental results for fracture of quasi-brittle materials [1] suggest that the size and shape of the fracture process zone is not a material property but depends on the specimen boundaries and the stress state. Although the averaging integrals in the nonlocal models can be altered inversely to match the experimentally observed boundary effect [2], the mechanics of the failure process is not well understood. Thus, the resulting nonlocal models cannot be used to make predictions outside the available range of experimental results. Predictions with nonlocal models can only be justified if the averaging operators which are used to determine the stress are based on mechanics of the meso-structure which governs the fracture process.

A meso-scale analysis is performed to determine the fracture process zone, and the effects of the boundaries on the size of the fracture process zone will be studied. The macroscopic fracture process zone originates from stiff inclusions within a soft matrix, whereby the fracture process zone is of a similar size to the biggest inclusions. Since the inclusions in most heterogeneous materials are randomly located, meso-scale simulations differ considerably. Therefore, there is no obvious link between a deterministic macroscopic fracture process zone predicted by a nonlocal continuum model and that obtained from a single stochastic meso-scale simulation. Consequently, the principle of scale separation does not hold for the case of the fracture process zone. Therefore, the deterministic solution is obtained from an average of simulations, so that a statistically representative description of the macroscopic fracture process zone is obtained.

The mechanical response of the matrix, the inclusions and the interface between the matrix and the inclusions is modelled by a discrete lattice approach [3], which is computationally efficient for the description of the fracture process on the meso-scale. The interface between inclusions and matrix is described by placing the connection of the rigid bodies along the boundary. Elastic and inelastic responses are modelled by springs which connect rigid bodies. The inelastic response of the springs is described by a damage approach, which corresponds to a continuous reduction of the stiffness of the

springs. Heterogeneity caused by inclusions smaller than the chosen resolution is modelled by means of an autocorrelated random field [4].

Firstly, the fracture process in an infinite domain is approximated by an analysis of a two-dimensional cell with periodic boundary conditions. Additionally, periodicity of the discretisation is prescribed to avoid influences of the boundaries of the periodic cell on fracture patterns. The results of these analyses are then used as reference cases for subsequent two-dimensional structural analyses of three-point bending beams, where the boundary conditions are varied ranging from smooth to angular notched to sharply notched boundaries.

The results of the meso-mechanical analyses are compared to nonlocal models proposed in the literature and deficiencies of existing models are identified.

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