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MODELING OF FAILURE FOR COMPOSITES BY EXTENDED FINITE-ELEMENT METHOD AND LEVEL SETS

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Summary. *Composites or multi-phase materials are characterized by a particular heterogeneous microstructure. Materials like fiber reinforced concrete or polymers are typical examples. They usually have a complex anisotropic material behavior already in the elastic regime. The failure modes of these materials are governed by different micromechanical effects. Among these are debonding and cracking of the different material constituents.*

1 INTRODUCTION

It is obvious that the applicability of a numerical model for the simulation of materials depends on the scale of observation. In the present contribution the extended finite-element method (X-FEM) [1] coupled to the level set method [2] is used for the numerical simulation of a composite material, known as textile-fiber reinforced concrete. Different material scales are classified in order to motivate the applied modeling technique. The present numerical approach allows to model arbitrary internal features of solids like material interfaces, sliding surfaces or cracks without the need of conforming meshes. It addresses the modeling of material interface failure and cracks in the constituents. The level set method is used for their geometrical description. The X-FEM is employed to enrich the finite-element approximation by appropriate functions through the concept of partition of unity. The combination of both, X-FEM and level set method turns out to be very natural since the enrichment can be described and even constructed in terms of level set functions.

The overall mechanical behavior of composites in the linear as well as the nonlinear regime is not only governed by the material properties of the components and their bonds but also by the material layout. The applied numerical model allows a considerable flexibility concerning the variation of the material design and consequently of the mechanical behavior of the composite. Two-dimensional numerical examples are presented to demonstrate the versatility of the proposed method simulating textile-fiber reinforced concrete.

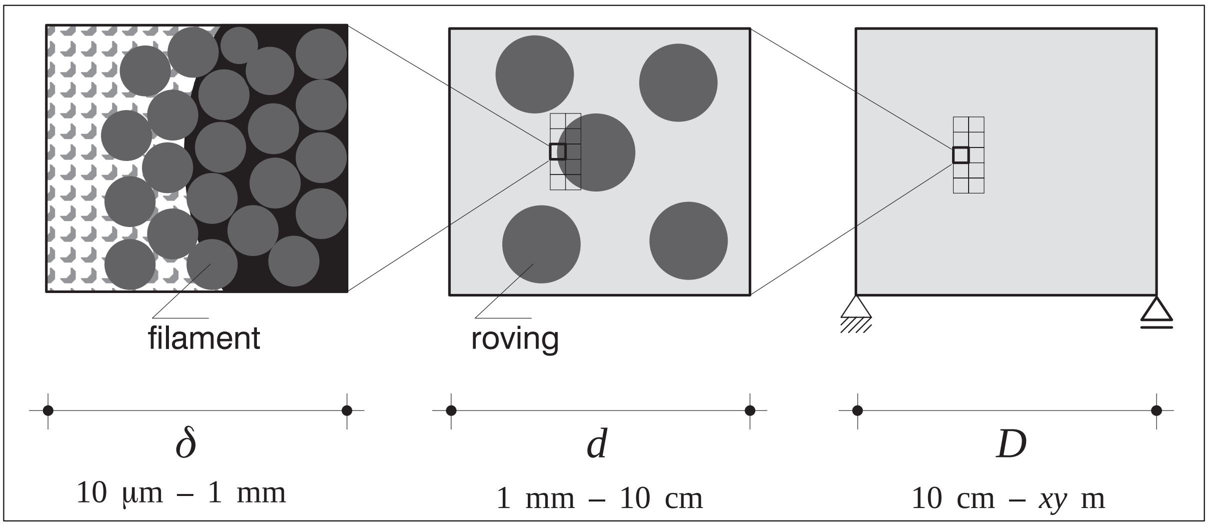

Figure 1: Typical observation scales for FRC

2 MODELING TEXTILE-FIBER REINFORCED CONCRETE

Textile-fiber reinforced concrete (FRC) is a composite material which consists of rovings yarned of several hundreds of textile filaments and a special fine grade concrete. In order to clarify and to understand the mechanical behavior, especially the failure mechanisms, one has to zoom into the material and its local response. In figure 1 typical observation scales for FRC are classified. Visualizing the micro scale δ of the composite material, its extremely heterogeneous structure can be revealed. Apparently, not only the concrete-matrix but also the fiber-reinforcement is characterized by an outmost inhomogeneous structure. In the present study, the composite is modeled on the meso scale d. On this scale, the fine concrete matrix can be assumed to be homogeneous. Thus, only two homogeneous constituents are distinguished, namely the cement matrix and the rovings as isotropic aggregates. As a sufficient approximation, their shape can be described by conic sections, for example as circles in the simplest case. Modeling the composite material on the meso scale the development of matrix cracks and the debonding between roving and matrix describe the most important failure modes. The potential development of damage within the roving should play a minor role and could be described in combination with the interaction law of roving and matrix.
Now, the kinematic description for material interfaces and cohesive cracks which do not have to conform to the applied finite element mesh is discussed. From figure 2 it is obvious that Ω_2 correspond to the inclusion-phase and Ω_1 to the matrix-phase. The boundary Γ is composed of $\Gamma_{\bar{\mathrm{u}}}$, $\Gamma_{\bar{\mathrm{t}}}$, Γ_{c} and Γ_{m} so that $\Gamma = \Gamma_{\bar{\mathrm{u}}} \cup \Gamma_{\bar{\mathrm{t}}} \cup \Gamma_{\mathrm{c}} \cup \Gamma_{\mathrm{m}}$. The boundary $\Gamma_{\mathrm{m}} = \cup_i \Gamma_{\mathrm{m},i}$ is given as the union of k perfectly bonded material interfaces $\Gamma_{\mathrm{m},i}$ where $i = 1, k$. The boundary $\Gamma_{\mathrm{c}} = \cup_j \Gamma_{\mathrm{c},j}$ is composed of l crack segments $\Gamma_{\mathrm{c},j}$ with $j = 1, l$. These crack segments can describe matrix cracks as well as interfacial cracks which are

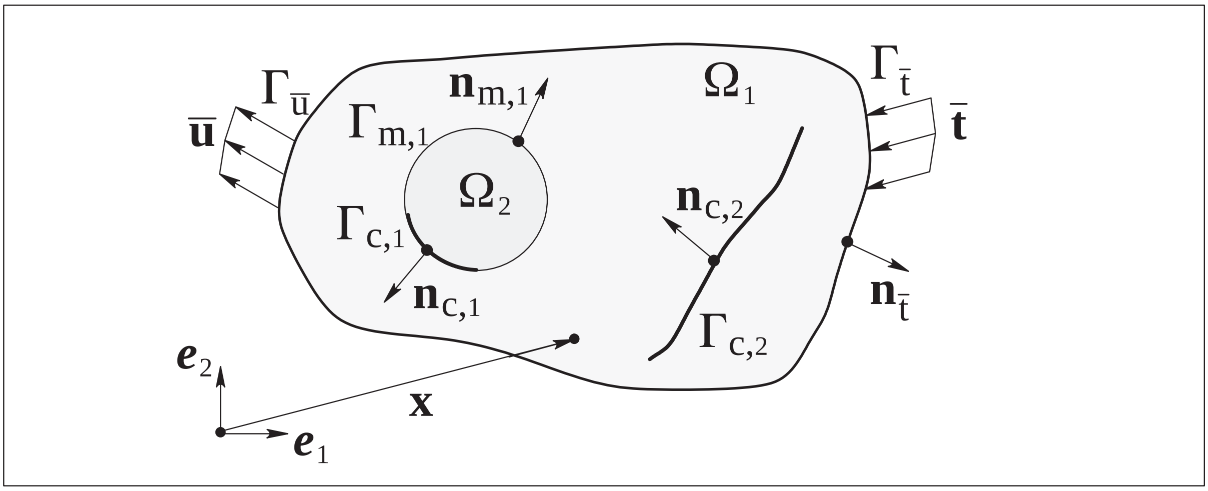

Figure 2: Domain Ω of composite material with matrix and interface crack

only allowed to emerge and grow along the well-known material interfaces $\Gamma_{m,i}$. In order to model the kinematics of both features, the material interfaces and the cracks the following displacement field has to be applied, cf. for example [3] and [4] or [5].

$$\mathbf{u}(\mathbf{x},t) = \hat{\mathbf{u}}(\mathbf{x},t) + \sum_{i=1}^{k} \chi_{\mathrm{m},i}(\mathbf{x})\, \tilde{\mathbf{u}}_i(\mathbf{x},t) + \sum_{j=1}^{l} \chi_{\mathrm{c},j}(\mathbf{x})\, \tilde{\tilde{\mathbf{u}}}_j(\mathbf{x},t) \tag{1}$$

In order to accommodate the mechanics of arbitrarily located material interfaces $\chi_{\mathrm{m},i}$ must be a 'ridge' function to provide discontinuities in the displacement derivatives. $\chi_{\mathrm{c},j}$ has to be chosen as the Heaviside step function $\mathcal{H}_{\mathrm{c},j}$ centered at the crack $\Gamma_{\mathrm{c},j}$ to generate a discontinuous displacement field. $\tilde{\mathbf{u}}_i$ and $\tilde{\tilde{\mathbf{u}}}_j$ are additional nodal parameters. Both functions can be developed respectively described using appropriate level set techniques, see e.g. [3] and [6].

3 NUMERICAL EXAMPLES

In this section, we want to apply two structural problems to demonstrate the versatility of the present approach. It should be mentioned that the traction-separation law based on Wells & Sluys [7] is used to account for the cohesive cracks. The matrix cracks are supposed to emerge and propagate according to Rankine's failure criterion. So, it is reasonable to assume that the direction of cracking is perpendicular to the 'nonlocal' maximum principal stress obtained from a smearing process over an adjacent domain. In figure 3 two mesostructures are depicted which are loaded in uniaxial horizontal tension using the same structured mesh. On the left, the failure of a structure which contains four rovings is illustrated. In this example, cracking of the matrix was precluded. On the right, a structure with one inclusion is shown. Here, we traced four matrix cracks initiated by the debonding process and growing perpendicular to the loading axis which

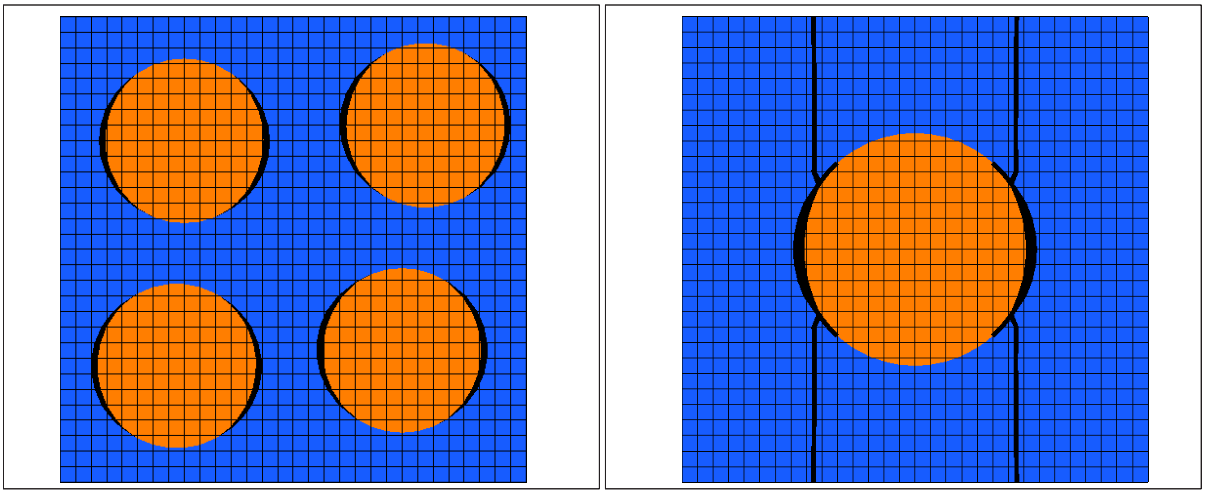

Figure 3: Illustration of composite failure

is the direction of the nonlocal maximum principal stress.

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