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A PHASE-FIELD MODEL FOR THE MULTISCALE ANALYSIS OF FRACTURE IN SHORT GLASS FIBER REINFORCED POLYMERS

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Abstract
Understanding and modeling the fracture mechanical behavior of short glass fiber reinforced polymers (SFRPs) is challenging: the strong heterogeneity induced by the manufacturing process causes a tight coupling of the material microstructure to the effective response on the component scale. Aiming to account for this microstructural complexity, fracture is approached using a multiscale approach. To resolve the microstructure induced anisotropy and its relationship with the macroscopic material behaviour, an isotropic phase-field fracture model is extended via the fiber orientation interpolation concept. The approach is fed by micromechanical simulations calibrated by experimental data. A validation of the proposed approach is obtained by means of numerical investigations compared to experimental findings.

1. Introduction
Short glass fiber reinforced polymers (SFRPs) are widely used in industrial applications. To ensure a reliable design of SFRP components subjected to complex operational loads, the knowledge of their failure mechanisms and their operating limits is of great importance. Typically manufactured in an injection molding process, SFRP components exhibit locally varying microstructural configurations [1], e.g., fiber orientations, fiber volume contents, and fiber length distributions, which render fracture modeling a challenging task. In this work, we focus on fracture in SFRP components subjected to monotonic loads. The modelling task is approached by a multiscale approach that aims to resolve the relationship between the microstructure and the macroscopic behaviour of the material. Hence, we extend the established, isotropic phase field models of brittle fracture [2-5] towards the anisotropic case making use of the fiber orientation interpolation concept [6]. The developed model is implemented in the commercial finite element package Abaqus with the algorithmic approach suggested in [7]. To create the database, the anisotropic elastic coefficients are obtained from previously executed micromechanical simulations on realistic microstructures [1] using the efficient microscopic solver FeelMath [8]. The performance of the simulation method is demonstrated by means of several numerical analyses.

2. Results
The application of the method is carried out in a two-phase procedure. In an offline phase, the domain of possible microstructural configurations is discretized by a finite set of synthetically generated microstructures [1] which forms the basic structure of the database. Micromechanical simulations on these microstructures are then carried out using FeelMath [8] to fill up the database with the required anisotropic coefficients. In an online phase, the fracture mechanical computations on the component scale are carried out using the database as an input. To access the database, the knowledge of the local microstructural configuration must be available. Therefore, microstructural information stemming from either X-ray micro-computed tomography (µCT) [9] or from an injection molding process simulation is mapped onto the structural finite element mesh prior to the execution of the macroscopic fracture simulation. Aiming for a good prediction quality of the suggested method, special attention is paid to the parameter identification routine. The microstructure-dependent deformation and fracture mechanical behavior of SFRPs is analyzed using samples, i.e., dogbones and compact tension samples, that are cut from injection molded plates with different orientations with respect to the main flow direction. Starting with a microstructural characterization, µCT scans are performed to identify the geometric key parameters, e.g., fiber orientation tensor, fiber volume content, and fiber geometry. In a first step, tension tests are executed to obtain the

deformation behaviour of the SFRP. With known geometry of the microstructure we can identify the material parameters of the individual phases, i.e., polymer matrix and glass fibers, governing the deformation behavior of the composite. Once the parameters are identified and micromechanically validated, the database is generated and macromechanical database simulations are carried out to validate the deformation behavior of the SFRP. The missing anisotropic fracture mechanical properties are determined on the composite level in a second step by means of compact tension tests. Numerical analyses demonstrate the prediction quality of the proposed method and the limitations of the underlying assumptions.

3. Conclusions

SFRP report complexity in various ways. In order to characterize their macroscopical response, a microscopic look into their inner structure is needed. An innovative approach is proposed using an offline training of a database plus a fiber interpolation concept to take into account the heterogeneity of the material. The approach is fully integrated into the seamless simulation chain for SFRPs ranging from the injection molding process to the structure mechanical fracture analysis. The limitations of the approach stemming from the underlying assumptions are quantified and further development needs are identified.

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