MICROMECHANICAL MODELING OF THE FRACTURE PROCESS IN ADVANCED METAL SANDWICH PLATES USING FFT-BASED HOMOGENIZATION

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Abstract

The fracture behavior of the complex core material of Hybrix™ sandwich plates was investigated by micromechanical modeling using FFT-based homogenization. A method for generating virtual Representative Volume Elements (RVEs) based on experimental observations was developed and the homogenization results were compared to experiments in peel mode I. The applicability of micromechanical simulations to the optimization of fracture properties of the Hybrix™ core is discussed.

1. Introduction

Hybrix™ sandwich plates (manufacturer: Lamera AB, Sweden), consisting of a porous, polymeric fiber-binder core and metal face sheets, allow for a similar processing as standard metal plates at a significant weight reduction. For this reason, the material is advantageous for use in safety-relevant lightweight structures. The plates can be adapted to different applications by changing production parameters, such as the core thickness, fiber and binder content and also the face sheet material. Furthermore, the fracture properties of the core material are crucial for the structural integrity of the plates and they also depend on the production parameters. Homogenization techniques and micromechanical modeling can be used to reduce the experimental effort during the development process of materials by linking the mechanical properties of the constituents and the geometry of the microstructure to the macroscopic material properties. In this work, we use FFT-based computational homogenization to model the fracture behavior of the Hybrix™ core at the microscale, whereas the core layer is considered as a (finite thickness) cohesive zone at the macroscale. This modeling approach at the macroscale is typically used for adhesive layers, but should be well suited in the present case as well. As for adhesives, it is expected that only the out-of-plane response is relevant for the structural behavior of the plate owing to a negligible stiffness and strength compared to the metal face sheets. Within this homogenization approach, the whole thickness of the cohesive zone must be considered in the microscale model, which typically yields a thickness dependent Traction-Separation Law (TSL), but also ensures the existence of a RVE for each given thickness. Moreover, a model for the generation of virtual RVEs using the production parameters of the plates as input data was developed and the results from FFT-based homogenization are compared to experimental results from Double Cantilever Beam (DCB) tests. The results are limited to peel mode I fracture only in the current work.

2. Modeling, simulations and results

The virtually generated RVE of HybrixTM core with a thickness of 1.5 mm is depicted in Fig.1a. The RVE consists of 22% binder, 13% fibers and the remaining volume consists of pores. The data were obtained experimentally from microscopy and microtomography. First, the fiber structure is generated, whereby fiber overlap, curvature and deviations from a given fiber distribution are minimized simultaneously. Then, the binder is added using morphological operations until the specified volume fraction is reached. In the final step, thin voxel layers with a significantly higher stiffness than the core are added in through thickness direction in order to suppress the intrinsic periodic boundary conditions of the FFT-based micromechanics solver and to approximate constant displacement boundary conditions caused by the stiff metal face sheets. The required parameters for the material models of fibers and binder on microscale were identified using local microindentation experiments, whereby the mechanical response could not be clearly distinguished. For this reason, the same model parameters were used for both polymeric materials. The mechanical behavior was assumed to be elastic- perfectly plastic with a nonlocal, implicit gradient damage model and a linear damage evolution. Both the FFT-based micromechanics solver for the homogenization of mechanical properties and the solver for the Helmholtz-type damage regularization were implemented in Fortran as parallel code. The coupled problem is thereby solved in a staggered fashion. The resulting TSL is presented in Fig. 1b. Owing to the intrinsic periodic boundary conditions, the resulting damage field and crack within the microstructure is also periodic, which is an unrealistic assumption of the homogenization scheme used.

a) b)

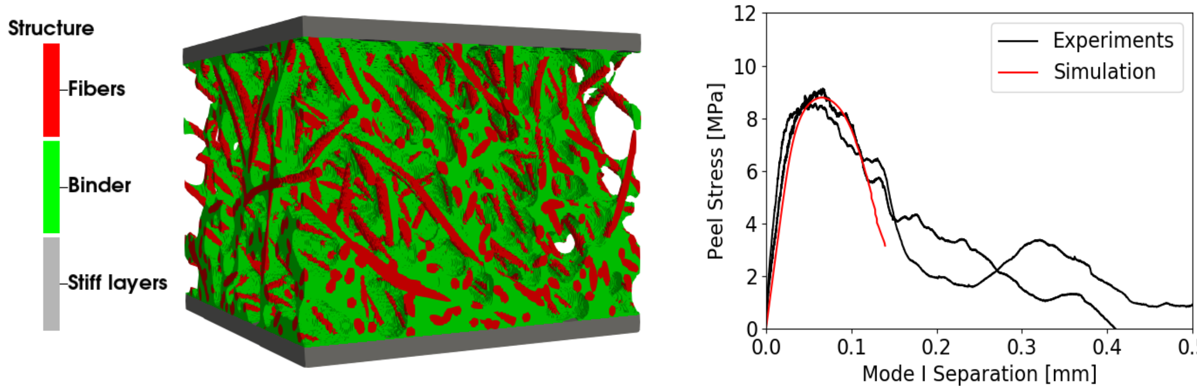

Fig.1 – (a) Virtually generated RVE of the Hybrix™. (b) Comparison simulation results and DCB tests.

The experimental results from reinforced DCB tests are shown in Fig. 1b in comparison to the simulation results. For the experiments, Hybrix™ plates were bonded to steel adherents and the quasi-static tests were performed at a rate of 30 µm/s at the load introduction points. The resulting TSLs were obtained using the J-integral computed from the external loads, and bending angles and measurements of the crack opening displacement (COD). Experiments and simulation show a good agreement under mode I loading despite the unrealistic assumption mentioned above. However, the material parameters for the damage evolution law cannot be obtained from microindentation yet and therefore, owing to the lack of further data on the constituents, the parameters were calibrated using the initial slope of the damaging part in the experimental TSL. In addition, the observed computational time for the full simulation, which was carried out on a standard workstation, was comparably high and is thus probably not practical to support the optimization of the material at the current stage. However, the computational time needed until the crack starts propagating within the microstructure was still in the range of a few hours.

3. Conclusions and outlook

A procedure for the virtual generation of RVEs of the Hybrix™ core in combination with the FFT-based homogenization for cohesive zones was developed and could act as a future starting point for an optimization of given fracture properties with respect to production parameters. Nevertheless, the effect of the unrealistic assumption of a periodic crack needs to be further assessed. For this purpose, a comparison with mode III or mixed-mode experiments might be added. Furthermore, it is intended to perform further simulations on a computer cluster in order to significantly reduce the computational times. However, the optimization with respect to the crack initiation might be already possible and the results can still contribute to a better understanding of fracture behavior of the Hybrix™ core.

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