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MICROMECHANICAL FAILURE MODELLING OF COMPOSITE MATERIALS USING HFGMC

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The heterogeneous structure of composite materials at the micromechanical level determines failure initiation and damage progression processes at the structural level. In order to improve the failure analysis of complex composite structures, a two-scale damage prediction procedure has been developed. The methodology is based on the High Fidelity Generalized Method of Cells (HFGMC) model which belongs to a group of computationally efficient semi-analytical micromechanical models [1-3]. The HFGMC model is capable of accurately capturing the stress and strain field within the Repeating Unit Cell (RUC) of the composite material, thereby enabling efficient failure prediction analysis on the micromechanical scale [2]. The methodology has been developed with the aim of modelling high velocity impact damage on aeronautical structures using Abaqus/Explicit to perform the structural level computations. The link between the finite element macro-level analysis and the micromechanical model has been achieved with the user material subroutine VUMAT, which for each material point performs micromechanical calculations based on the applied macroscopic strain given by the FE analysis. As a result, failure processes of complex composite structures have been modelled using micromechanical principles. Figure 1 shows an example of micromechanical stress distribution predicted using the HFGMC model.
The first step in the micromechanical damage modelling is application of failure criteria, which are predicted within the RUC of the HFGMC model. Several constituent based failure initiation criteria, which have been used throughout the literature [2-5], have been implemented in the methodology. Failure initiation in the matrix is predicted using the 3D Tsai-Hill criterion, MultiContinuum Theory (MCT) criterion, 3D Hashin strain based criterion and maximal principal strain criterion. The MCT theory defines also a criterion for fibre subcells, while other failure theories employ relatively simple maximal strain and maximal stress criteria in fibre direction. Additionally, the multi-axial damage evolution model for matrix subcells, introduced in [2], has been adapted for the presented micromechanical model. The damage progression model has been further improved by inclusion of the crack band model in order to enforce objectivity of the HFGMC discretization during the post-peak deformation [5]. The results of the failure and degradation models have been compared with World Wide Failure Exercise (WWFE) results [6].
The micromechanical modelling approach is particularly suited for modelling of high strain rate effects in composite materials, since these effects influence only the matrix. The modified Bodner-Partom viscoplastic material model [7] has been included in the methodology in order

to account for these effects.

Evaluation of the implemented micromechanical failure models has been performed using a standalone application of HFGMC in which the micromechanical model has been decoupled from Abaqus/Explicit. This application differs from the two-scale version as the macro-scale strain tensor increment has been simulated in the same form in which the VUMAT provides the input for the two-scale model. The standalone application is intended for calculation of failure surfaces in the homogenized macroscopic stress state as to enable comparison with the WWFE results. The evaluation of micromechanical matrix failure criteria revealed that the MCT and Hashin strain based criteria agree very well, while the 3D Tsai-Hill criterion indicates failure initiation at significantly higher stress values. The comparison with WWFE results illustrates the importance of the modelling of progressive material degradation in the micromechanical damaging processes. Although micromechanical failure criteria predict the onset of damaging processes in only a single subcell, the obtained results show that a large number of the subcells satisfy the failure initiation criterion at the same load state. Consequently, damage processes are initiated in a large part of the RUC for the same macroscopic loading condition and correct modelling of the progressive degradation of mechanical properties at the micromechanical scale is necessary to obtain reliable results.

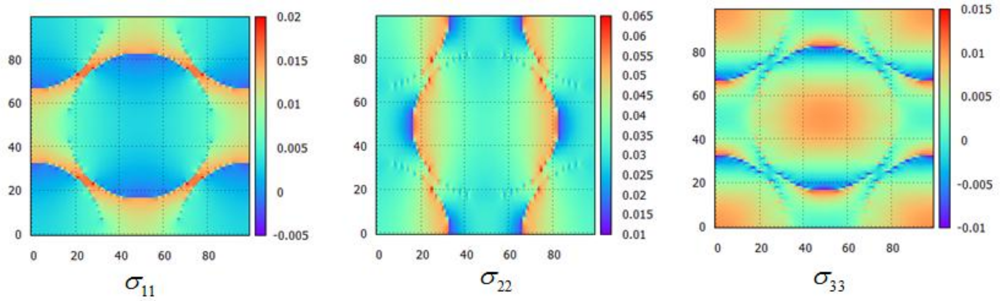

Figure 1. Distribution of micromechanical normal stresses in the RUC for a macro-level strain state that indicates failure initiation using the 3d Tsai-Hill criterion [GPa].

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