Microscale modeling of time-dependent failure in unidirectional composites under off-axis loading

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Testing unidirectional (UD) composite material under different off-axis angles allows for covering a range of different stress states with a single setup. When strain-rates and stress levels are also varied, complex failure behavior is exposed, particularly for thermoplastic composites that display a markedly time-dependent response. To investigate the characteristics of the failure behavior, this contribution presents a micromechanical framework for modeling off-axis failure of UD composites.

The micromodel is a representative volume element (RVE) defined as a thin slice oriented perpendicularly to the fibers. Periodic boundary conditions are set on the RVE, allowing for periodicity in microcracking as well [1]. The thermoplastic matrix is represented with the Eindhoven Glassy Polymer (EGP) material model [2], whereas a transversely isotropic constitutive model is used for carbon fibers [3]. It is assumed that the material undergoes finite deformations locally and in a homogenized sense, therefore the microstructure changes orientation during the loading process. A constant strain-rate with globally uniaxial stress is imposed on the material under an evolving off-axis angle by means of a dedicated arclength model [4].

To model failure of the composite material, interelement cohesive surfaces are inserted on the fly. A cohesive zone initiation criterion based on the local rate of deformation in the polymer matrix is proposed [5]. The model performance is compared with experiments on a thermoplastic UD carbon/PEEK composite system tested at different off-axis angles and strain-rates.

Next, the framework is applied to simulation of creep rupture. Although creep deformation due to the viscous nature of the polymer matrix can be represented with the EGP model, predicting creep rupture requires two additions to the framework. Firstly, the creep rupture process is triggered by inserting cohesive segments with a criterion based on the critical free energy of the polymer matrix. Secondly, viscous degradation of the cohesive surfaces is included in the formulation. The rupture time is defined as the moment when the homogenized creep strain-rate reaches a minimum value. The model results are again compared with experiments, performed at different off-axis angles, stress levels and temperatures. Finally, the effect of the change in RVE orientation due to finite deformations on the creep response is illustrated.

References

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