A micromechanical model to study the rate-dependent failure mechanisms of carbon fiber reinforced polyvinylidene fluoride

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Carbon fiber reinforced polyvinylidene fluoride (PVDF) is a composite material that combines the high strength and stiffness of carbon fibers with the high temperature tolerance and excellent chemical resistance of PVDF. Due to these beneficial material properties, carbon fiber reinforced PVDF is used for energy transport in the offshore industry. Although the material is used in a variety of engineering applications, its failure behaviour is not very well understood.

To investigate the material response to different loading conditions, uniaxial tensile and compression tests were performed at different constant loading rates at different ambient temperatures. Also the orientation of the carbon fibers with respect to the loading direction was varied. Results from transverse loading experiments, i.e. when the fibers are oriented perpendicular to the loading direction, revealed that the composite exhibits brittle failure with a small strain at failure. Furthermore, the transverse tensile strength of the composite is much lower than the yield stress of bulk PVDF [1]. Analysis of the fracture surface of the tested specimens revealed bad adhesion between the carbon fiber and the PVDF matrix. Especially in loading cases where the matrix response is dominant, this results in poor performance of the composite.

To better understand the failure behaviour of carbon fiber reinforced PVDF at the fiber scale, a micromechanical model of the composite is used in finite element simulations. A 3D representative volume element (RVE) with a number of fibers embedded in a matrix is defined. The geometric properties of the microstructure, e.g., fiber radius and fiber volume fraction, are derived from microscopic scans of the composite. The fibers are modelled using a transversely isotropic material model. For an accurate description of the matrix, the intrinsic behaviour of PVDF is modelled using an elasto-viscoplastic constitutive model that is able to describe the rate-dependent behaviour of PVDF at different temperatures and under different loading conditions [2]. The bad adhesion between fibers and matrix is incorporated in terms of cohesive zone elements at the fiber-matrix interfaces. An appropriate traction-separation law is used to describe the constitutive response of the cohesive elements.

Periodic boundary conditions were applied in combination with a macroscopic uniaxial strain, as introduced in [3]. This enables the simulation of off-axis uniaxial loads on a unidirectional composite, using only a thin slice of the 3D RVE. Both tensile and compression loads were applied at different constant strain rates and for different temperatures, similar to the experiments. Finally, volume averaging theory is used to calculate the macroscopic stress, which is compared to the experimental stress-strain response.

The simulation results show that the model can adequately describe the temperature- and rate-dependent non-linear response of carbon fiber reinforced PVDF. Furthermore, the addition of cohesive zone elements enables the description of the brittle failure response of the composite at different loading conditions.

References

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