
Time-dependent mechanical behaviour and failure of PVDF composites

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Abstract

Many demanding applications, operating in harsh conditions, require sustainable materials with superior efficiency and performance. High-performance fiber reinforced composites are increasingly attractive due to their high strength-to-weight ratio, design flexibility, and corrosion resistance. This class of materials are excellent candidates for storing and transporting green hydrogen, by means of carbon-overwrapped pressure vessels and thermoplastic composite pipes. Carbon fiber-reinforced polyvinylidene fluoride (PVDF) is a light weight material that shows great promise for these applications. The strong carbon fibers offer the required strength to the composite. The semi-crystalline thermoplastic PVDF matrix serves over a wide temperature range, and its corrosion and chemical resistance allows its usage in extreme conditions. Combining experimental results and multi-scale simulations, this presentation focuses on the analysis of the rate- and temperature dependent behaviour of unidirectional (UD) carbon fiber-reinforced PVDF at different loading conditions. To characterize the matrix, a 3-dimensional (3D) elasto-viscoplastic constitutive model is used to describe the rate- and temperature dependent behaviour of pure PVDF, with a deformation-dependent activation volume and Eyring viscosity. The material parameters were experimentally identified at three specific temperatures, 23, 55 and 75°C, by means of uniaxial compression and tensile tests. The model is validated with independent experiments, revealing an accurate description of the temperature dependent behaviour.

In order to establish a multi-scale framework, the fibre distribution in the composites was analyzed with optical and electron microscopy. Using this data, a 3D micromechanical FE model was developed by generating a representative volume element (RVE) and the earlier developed constitutive models. Appropriate boundary conditions are used, allowing for off-axis uniaxial loading. In parallel to the simulations, dedicated compression test were carried out on the composite at different strain rates and temperatures, revealing poor adhesion between the fibers and the matrix. Accordingly, interfacial decohesion has been incorporated in the RVEs. To enhance the stability of such complex failure simulations, a novel energy dissipation-based arc-length solver was developed applicable to time-dependent models. The average engineering stress-strain response from the RVE simulations with nominal fiber volume fraction is compared to experimental data and a reference model with perfect fiber-matrix adhesion. Transverse tensile simulations are in line with the experiments. Investigation of the local response reveals that damage initiated at many fiber-matrix interfaces, but localizes at a few only. The equivalent plastic strains in the matrix remain limited. Transverse tensile simulations on a model with lower fiber volume fraction reveal lower local stresses in the matrix and lower tractions at the interface, whereas the model

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with higher fiber volume fraction results in more damaged interfaces, accompanied by higher overall stresses in the matrix. For most fiber orientations, the model reveals that damage localization is more present for off-axis loading, whereas it is more evenly distributed for transverse tension.

The developed model helps in unravelling the fiber-matrix failure initiation and evolution at the microscale, but would benefit from an extension allowing for matrix damage. In this form, this multi-scale model will be instrumental for the development of PVDF-based fiber reinforced materials.