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EXPERIMENTAL INVESTIGATION AND NUMERICAL SIMULATION OF HYGROTHERMAL AGING IN FIBER-REINFORCED COMPOSITES

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Predicting mechanical degradation of fiber-reinforced composites caused by hygrothermal aging (exposure to high temperatures and moisture ingression) is a challenging task for which no comprehensive solution is currently available. Physical and chemical phenomena (*e.g.* plasticization, hydrolysis, interface debonding) acting at the microscopic length scale and at different time scales with different degrees of reversibility interact nonlinearly and lead to complex macroscopic degradation behavior. Therefore, realistic prediction of composite material durability requires microscopic mechanical tests and observation techniques as well as high-fidelity multiscale and multiphysics numerical models.

This work investigates the phenomenon of hygrothermal aging in unidirectional composites through a combination of micro- and macroscopic experiments and multiscale numerical modeling. Composite samples are immersed in hot water for different durations and tested both directly after aging as well as after being redried. The effects of aging on the fiber-matrix interface adhesion are investigated through single-fiber fragmentation tests in dry and saturated specimens and interfacial properties are obtained through reverse modeling. The aging mechanisms responsible for degradation are investigated through a fractographic study on aged specimens using X-ray 3D computed tomography.

Describing the resultant time- and moisture-dependent behavior with an all-encompassing phenomenological macroscopic constitutive model is a difficult task. This renders bottom-up homogenization strategies (numerical homogenization) inadequate for the problem at hand. Aging is therefore simulated with computational homogenization (FE^2), which offers an alternative approach by promoting a continuous link between scales, precluding the need for macroscopic constitutive assumptions. This multiscale stress model is coupled with a macroscopic diffusion analysis that computes the evolution of the water concentration field. A viscoelastic/viscoplastic/damage model is used to describe the resin at the microscale and cohesive-zone elements with friction are employed at the fiber-matrix interfaces. To reduce the exceedingly high computational cost of the FE^2 approach, the micromodels are accelerated by a combination of two model-order reduction techniques. The resultant predictions are compared with experimental results.