Fractional evolution of damage anisotropy in anisotropic hyperelasticity: theory and validation for roofing felts

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This contribution presents a constitutive framework for finite-strain materials in which elastic anisotropy and damage anisotropy are described independently within anisotropic hyperelasticity. Two structural tensors are introduced: one for the directional elastic response and one for the evolving directional damage state. The free-energy function is decomposed into an undamaged hyperelastic part and a damage-related energy loss part, which provides an objective and thermodynamically admissible description. The main novelty is a time-stress-fractional evolution law for anisotropic damage. The direction of damage growth is determined by a Riesz-Caputo fractional derivative with respect to the stress state, while the temporal history of damage can be represented by a Caputo fractional derivative with respect to time. As a result, the model can capture both stress-induced directional effects and memory in damage evolution. Because the evolution equations do not admit a general closed-form solution, a numerical approximation is derived and prepared for implementation in an Abaqus subroutine. The formulation is then examined through a parametric study for an isotropic hyperelastic solid and validated against uniaxial tension tests for roofing felts, which exhibit pronounced elastic and damage anisotropy due to orthogonal fibre reinforcement. The results show that the proposed approach can reproduce finite-strain behaviour together with direction-dependent degradation, making it a promising tool for anisotropically damaged hyperelastic materials.

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