Electro-mechanical behaviour of fractional viscoelastic and anisotropic dielectric elastomers

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Abstract

Dielectric elastomers, widely used as smart materials in soft actuators (1), face significant challenges that limit their performance. Fiber-reinforced dielectric elastomers, with their anisotropic behavior, offer enhanced mechanical properties, such as faster response rates under electric fields (2). While many studies incorporate hyperelasticity and anisotropy, time-dependent viscoelastic effects are often included to improve material models. Classical viscoelastic models can describe these effects accurately in specific cases, but fractional viscoelasticity offers a more powerful alternative. By assuming a power-law relaxation spectrum, fractional viscoelasticity reduces the number of required parameters while effectively capturing a continuous distribution of timescales (3). This study presents a unified framework for modeling the coupled nonlinear electro-mechanical behavior of fiber-reinforced anisotropic dielectric elastomers with fractional viscoelastic effects. The approach builds on an anisotropic hyperelastic nearly-incompressible model and employs a multiplicative decomposition of the deformation gradient, incorporating fractional viscoelasticity to model time-dependent mechanical responses with minimal number of additional parameters. The weak form is derived for efficient numerical implementation using the open-source finite element platform FEniCSx. Validation through dynamic deformation simulations, including electro-mechanical instability and bending, demonstrates the favorable influence of anisotropy on actuation performance, the capability of fractional viscoelasticity to capture complex time-dependent behavior, and the computational efficiency of the developed framework. This work provides a foundation for future extensions to thermal and magnetic couplings, advancing the modeling of soft active materials.

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