

All You Need Is an Unequal Biaxial Test: Full-Field Coverage Characterization of the Energy Domain in Hyperelastic Isotropic Materials

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Abstract

We present a full-field coverage characterization of isotropic hyperelastic materials, representing a critical rethinking of mechanical characterization aimed at identifying the effective constitutive response function of a material. All stress measures are expressed as combinations of response functions, which themselves are combinations of derivatives of the strain energy function with respect to principal stretches or strain invariants. Our goal is to directly trace the derivatives of the energy function from experiments and only then infer a plausible functional form of the strain energy. Rather than focusing on individual experimental tests, the emphasis is shifted to the kinematic paths traced by these tests within the strain energy domain. In this new approach, the idea is to emphasize that material response functions are defined over a domain—either the stretch or strain-invariant domain—and that not all experimental tests are capable of tracing and visualizing this domain. Standard tests—such as uniaxial tension/compression, simple shear, and equi-biaxial tests—have inherent limitations, as they explore only a narrow, one-dimensional path in the energy domain. Such tests do not allow the entire energy domain to be explored. All you need is an unequal-biaxial test. The proposed full-field coverage characterization is achieved through a single unequal-biaxial experiment, from which the effective material response can be reconstructed using simple equilibrium relations, enabling exploration of the entire strain energy domain. For incompressible materials, the strain energy function and its derivatives define two-dimensional surfaces over the stretch or strain-invariant

space. To emphasize this concept, we introduce the analogy of a mountain relief surveyed by a terrestrial drone, highlighting the inadequacy of sparse, one-dimensional sampling strategies associated with standard tests. The methodology is supported by *in silico* experiments, in which datasets generated from a known strain energy function are treated as experimental measurements. The results demonstrate that the full-field coverage characterization establishes a new paradigm for identifying hyperelastic behavior, providing a more faithful and comprehensive reproduction of soft material responses than conventional simultaneous fitting of standard tests.

Keywords:

hyperelasticity isotropic materials strain invariants kinematic paths strain energy biaxial tests soft materials