Experimental Validation of the EUCLID approach for Unsupervised Discovery of Hyperelastic Constitutive Laws

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Abstract

We validate the approach for data-driven automated discovery of isotropic hyperelastic constitutive laws proposed in [1]. This unsupervised approach needs only displacements and global force data acquired through digital correlation techniques and mechanical tests. Few tensile tests on rubber specimens with different geometries are performed and the obtained data is used to discover the unknown constitutive law of the material. In order to prove the reliability of the approach, the experimental results of additional tests not involved in the discovery phase are compared to those obtained by introducing the obtained law in a finite element computation.

Introduction

Data-driven approaches enabled by machine learning tools and facilitated by the large availability of data through modern experimental techniques are raising a rapidly growing interest in computational solid mechanics. Particularly interesting is the possibility to automatically discover constitutive laws bypassing any operator bias or personal choice. In this context, a new approach which aims to automatically discover constitutive material models is presented in [1] and termed *EUCLID* (Efficient Unsupervised Constitutive Law Identification and Discovery). The approach delivers interpretable models, i.e., models that are embodied by parsimonious mathematical expressions based on sparse regression of a large catalog of candidate functions, and is based on unsupervised learning, i.e., it takes as input only experimentally measurable data in the form of full-field displacements, as obtainable e.g., from digital image correlation (DIC) techniques, and global force data delivered by mechanical testing machines.

Unsupervised discovery is achieved by enforcing the constraints stemming from physics, including balance of linear momentum and additional constraints for the elastic strain energy. Also, sparsity of the solution is achieved by l_p regularization combined with thresholding, which calls for a non-linear optimization scheme whose hyperparameters are partially determined by imposing physics-based constraints.
The advantages of the proposed approach are evident considering that the classical calibration procedures (e.g. [2]) require tests specifically designed to induce simple stress states that can be easily investigated by means of few local measurements. However, to obtain a significant sampling of the allowed stress-strain space, biaxial testing machine and a significant amount of tests are needed [2]. Conversely, using EUCLID along with a full field measurement technique a simple test performed on a single specimen is sufficient to calibrate the model, provided that its geometry is sufficiently complex to promote locally a multiaxial state of stress.

Experimental methods and objectives

In the original paper [1], the approach is demonstrated adopting in-silico data obtained from finite element computations. Here, we aim at its validation using experimental data. To this end, mechanical tests are performed on different specimens made of natural rubber and with increasing geometrical complexity (Fig. 1). All the tests are performed under pure tensile load, however the presence of different circular holes promotes the required multiaxial state of stress. The displacement field is measured with a DIC sensor (Fig. 2), while the applied global force is monitored using a load cell (Fig. 3).

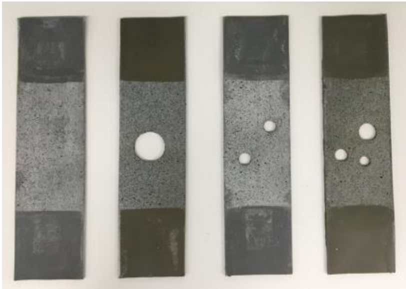

Fig. 1: Adopted rubber specimens with increasing geometrical complexity

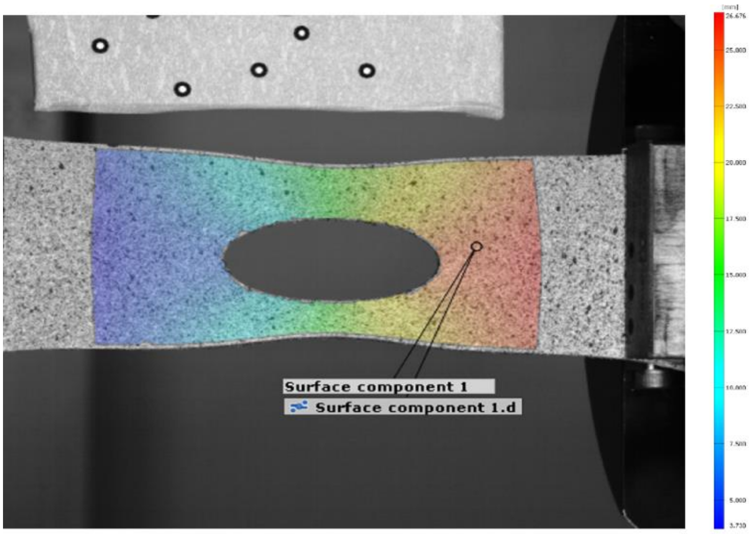

Fig. 2: Displacement field evaluated by DIC analysis during a tensile test

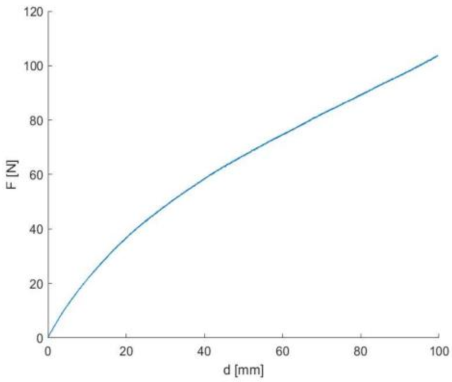

Fig. 3: Force – displacement curve measured by the tensile machine

In the present contribution, the effects of the geometrical complexity and of the DIC spatial and temporal resolutions are investigated. Also, the obtained law is used to predict both simple standard tests as well as additional experimental tests not involved in the discovery phase. The comparison of these numerical results with the corresponding experimental evidence is used to prove the reliability of the proposed approach.

References

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