COMPUTATIONAL, IMAGE-BASED, AND EXPERIMENTAL STRESS-STRAIN COMPARISONS OF ELASTOMERS

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Introduction

Elastomeric materials possess mechanical and imaging properties that closely mimic the non-linear and time-dependent biological tissue properties [Bergstrom et al, 2001]. While biaxial tests have been mainly used to characterize such materials, many studies focused on uniaxial tests, due to the difficulty to precisely control boundary conditions in two-dimensions (2D) [Sachs, 2000]. In addition to uniaxial experimental work, computational methods including finite element simulations, have been employed to characterize the mechanical behavior of biomaterials, due to their ability to account for complex geometries and anisotropic materials [Yin, 1981]. This study is among the first that compares in a quantitative fashion experimental, image-based, and computational methodologies for the uniaxial characterization of elastomers.

Methods

Experimental Setup: One urethane (40×11×4.5 mm^3) and one polyvinyl alcohol (PVA) (12×8.4×2.8 mm^3) sample were mounted on a Universal Testing Machine (UTM) (EZ20, Lloyd Inst, UK) and they were subjected to ten consecutive cycles of uniaxial loading. During loading, the top grip of the UTM was extended by a maximum of 16 mm for the urethane and 11 mm for the PVA sample, requiring tensile forces of 22.6 and 1.5 N respectively.

Image-based calculations: Before mounting the urethane to the UTM, a rectangular grid was drawn on its surface (Fig. 1). During UTM loading the sample was filmed at 30 frames per second with a camera (NVGS57, Panasonic, JP). A tracking algorithm (Matlab Inc, USA) allowed detection of the grid's crosspoints, enabling the calculation of the developed regional strain [Humphrey et al, 1987].

Simulations: The uniaxial loading was simulated by importing the 3D geometry of the samples in Patran (MSC Software Corp, USA). For the boundary conditions definition, one end of the sample was fixed, while a force was assigned to extend the other end, according to the UTM force recordings. The materials were treated as incompressible [Ogden, 1972] and their properties were derived by fitting a two-parameter (urethane) and one-parameter (PVA) Ogden constitutive law [3] to the mean stress-strain curves (post pre-conditioning), according to the equation:

$$\sigma = \sum_{p=1}^{M} \mu_p \left(\lambda^{\alpha_p} - \lambda^{-\alpha_p/2}\right) \qquad (1)$$

where σ is the Cauchy stress, μ_p, α_p are the model's coefficients and λ is the principal stretch ratio. The calculated coefficients were then imported in Patran and the simulation setup was solved using Nastran (MSC Software Corp., USA).

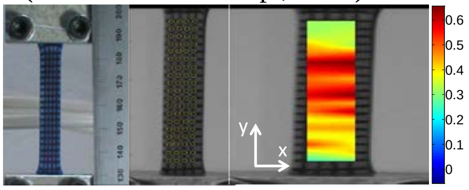

Figure 1: (Left) Photograph of the experimental setup, (mid) detected crosspoints of the grid drawn on the sample's surface and (right) image-based strain field at full extension of the urethane sample.

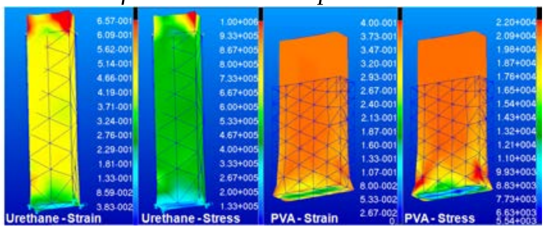

Figure 2: Simulated strain and stress fields for the urethane and PVA samples at 40% extension.

Results

The extension of the urethane sample yielded maximum strain and stress values of 40 % and 0.45 MPa. At such extension, the image-based method resulted in a maximum strain of 45 % (Fig. 1), while the simulations led to a 45 % strain and a stress of 0.48 MPa (Fig. 2). The PVA's bulk stress response measured using the UTM (at 40% extension) was 21 kPa, while the simulated responses yielded a 36 % strain and a stress of 20 kPa (Fig. 2). At 40 % strain, the thickness of both samples was reduced by less than 16 % as assessed by imaging. The error differences between the UTM-measured and the simulated strain were 12.5 % and 11 % for the urethane and PVA samples, respectively, while the corresponding stress differences were 6.7 % and 4.1 %.

Conclusion

The presented methodologies accurately estimate the stress and strain for the uniaxial characterization of biomaterials.

References

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