Homogeneity & Biofidelity of Fabric-Reinforced Elastomers as Arterial Mechanical Reference Materials

M. Loeckx[1,2a], H. Fehervary[2], L. Labey[3] and N. Famaey[1,2]

[1]Soft Tissue Biomechanics group, Dep. of Mechanical engineering, KU Leuven, Belgium;
[2]FIBEr, KU Leuven Core facility for biomechanical experimentation, Belgium;
[3]Biomechanical Engineering of Assistive Devices, Dept. of Mechanical engineering, KU Leuven, Belgium

[a]matijs.loeckx@kuleuven.be

Introduction

A wide range of mechanical test methods is used to characterize arterial tissue, which results in a large dispersion in reported material parameters. This variability cannot be attributed solely to biological differences and therefore limits the suitability of these parameters for regulatory or predictive computational models. High methodological variability obscures physiologically meaningful trends and reduces the reliability of simulations, potentially leading to incorrect conclusions and even treatments.

To separate methodological from biological variability, a suitable reference material is needed. However, commercially available synthetic materials do not exhibit biofidelic mechanical behaviour (e.g., anisotropy, strain-stiffening). Though promising in terms of biofidelity [1], fabric-reinforced elastomers have not yet been evaluated following ISO standards. As a result, essential metrics such as variability, homogeneity, and stability remain unknown.

Materials and methods

Fabric-reinforced elastomer sheets were produced by embedding either single fabrics or combinations of fabrics into a 2-mm-thick layer of Ecoflex 00-30 or Ecoflex 00-50. Two types of knitted fabrics were used: a rib knit fabric (95% cotton, 5% elastane) and a tricot fabric (96% TENCEL™ Lyocell, 4% elastane). In case of a combination of fabrics, they were stacked such that the course direction of one fabric was oriented perpendicular to that of the other.

After production, all sheets were stored in a closed container for 14 days before testing. Mechanical tests followed the C^{4}Bio consensus protocol [2]: punched dogbone samples underwent uniaxial tensile testing starting with 10 preloading cycles of 8 mm displacement (~30% strain), followed by a stretch until failure. Tests were performed at a displacement speed of 1.33mm/s (~5%/s) in the course direction of the fabric or in both principal directions when two fabrics were used. Throughout testing, images were recorded and afterwards analysed using DIC-software (VIC 2D, Correlated solutions) to obtain accurate strain measurements.

Variability was quantified by first sampling each stress-strain curve to 100 evenly spaced strain points ranging from 0 to the maximal strain reached by at least 3 samples. At each point, the standard deviation was normalized to the mean stress, and the overall variability metric was defined as the average of these normalized deviations across all points. The resulting variability was then compared with that obtained from biological C^{4}Bio samples (porcine aorta) previously tested with the same protocol within our research group.

Results

The mean stress-strain curve (full line) and the standard deviation (shaded area) of the fabric reinforced elastomers are shown in Figure 1 and the variability is reported in Table 1.

	Composition	**Variability [%]**
Biological	C^{4}Bio porcine aorta samples tested within our research group	25.37
E30Rc	Ecoflex 00-30 + Rib knit (course)	6.31
E30Tc	Ecoflex 00-30 + Tricot (course)	3.18
E50Rc	Ecoflex 00-50 + Rib knit (course)	3.82
E50Tc	Ecoflex 00-50 + Tricot (course)	2.87
E30RcTw	Ecoflex 00-30 + Rib knit (course) + Tricot (wale)	5.18
E30RwTc	Ecoflex 00-30 + Rib knit (wale) + Tricot (course)	6.26

Table 1: Variability metric of the different materials

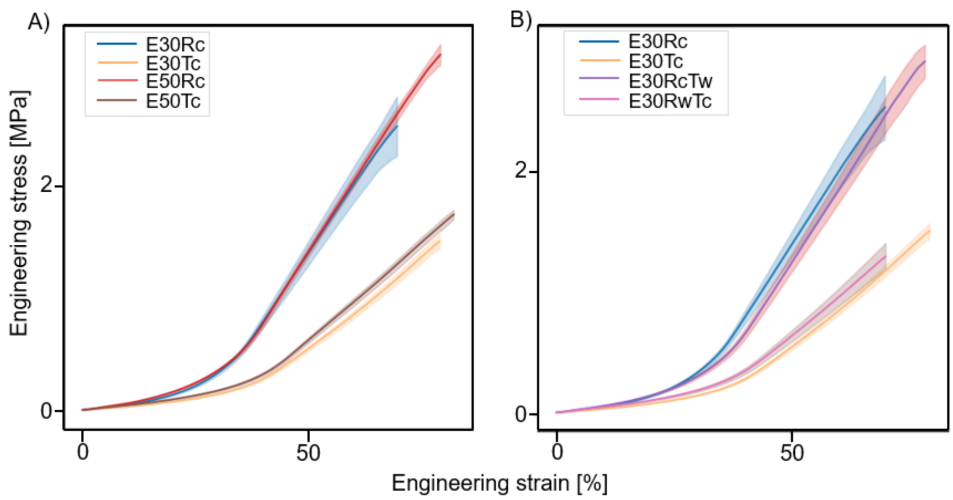

Figure 1: Stress-strain curves of the synthetic fabric-reinforced elastomers. A) Different fabrics and Ecoflex, B) Combining different fabrics within one sheet

Conclusion

This study demonstrates that embedding knitted fabrics into Ecoflex enables stress–strain behaviours that closely resemble those of arterial tissues. By adjusting the fabric type, orientation, and by combining different fabrics within a single sheet, the mechanical response can be precisely tuned toward the desired arterial behaviour. Changing the elastomer grade had only a minor effect on the overall response, with Ecoflex 00-50 being slightly stiffer than Ecoflex 00-30, indicating that optimizing the fabric composition and production parameters is more critical than optimizing the elastomer type.

In addition, this study demonstrates that fabric-reinforced elastomers can be produced with markedly lower variability than biological arterial tissue, with all tested formulations showing a variability reduction of 74% to 89% compared to the mechanical testing of porcine aorta within our research group. These results indicate that such composites have strong potential as candidate reference materials for arterial mechanical testing. Before they can serve this purpose, however, further work is needed to assess long-term stability and batch-to-batch homogeneity. Nonetheless, the present findings represent an important first step toward a validated, biofidelic reference material capable of distinguishing methodological from biological variability in soft tissue biomechanics.

Acknowledgements

Samples were mechanically tested at FIBEr. The equipment used was funded by Research Foundation Flanders (FWO: AKUL/15/25)
This work is supported by OPSTAMET, KU Leuven (C2M/24/031)

References

[1] D Zhalmuratova et al.: *Mimicking "j-Shaped" and Anisotropic Stress-Strain Behaviour of Human and Porcine Aorta by Fabric-Reinforced Elastomer Composites,* ACS Appl. Mater. Interfaces Vol. 11 (2019).
[2] N. Famaey et al.: *Community challenge towards consensus on characterization of biological tissue: C⁴Bio's first findings*, J. Biomech, Vol. 194 (2026).