A combined experimental and numerical method for tailoring the multi-scale mechanical properties of soft solid liquid composites

Eléonore Cauquil[1], Luca Kiener[1], Jonas Hofmann[1], Fabrizio Spano[2], Barbara Röhrnbauer[1]

[1] Institute of Mechanical Systems, School of Engineering, ZHAW Zurich University of Applied Sciences, Winterthur, Switzerland

[2] Institute of Computational Physics, School of Engineering, ZHAW Zurich University of Applied Sciences, Winterthur, Switzerland

BACKGROUND

Solid liquid composites are motivated by a variety of multi-physics applications including research in mechanobiology [1]. From a mechanical perspective, liquid inclusions in a matrix affect both its global and local properties - the latter seen as local stiffness variations. It is known that stiffness variations in substrates are sensed by cells and incite cell migration so-called durotaxis [2]. To investigate this complex interplay, detailed knowledge is needed on the local mechanical properties of the substrate. In this study, a combined experimental and numerical approach is proposed to characterize and tailor the local and global mechanical properties of a soft solid liquid composite.

RESULTS

The numerical model was shown to excellently reproduce both, the global force response, and the local deformation pattern (Figure). Apart from the parameter of the Neo-Hookean model, no fitting of parameters was needed resulting in a simple and robust modeling approach. The parameter study revealed the potential to tailor a wide variety of biaxial global stiffnesses (0.20-0.44 MPa) and to finetune local stiffness gradients.

DISCUSSION and CONCLUSIONS

Current limitations are the reproducibility of the PDMS properties and the small experimental basis (n=3). However, the feasibility of the approach as well as the excellent predictive capabilities of the model have been shown. This experimental and numerical framework shall be used to investigate phenomena such as durotaxis incited by specifically tailored stiffness gradients and thus, contribute to quantitative research in mechanobiology.

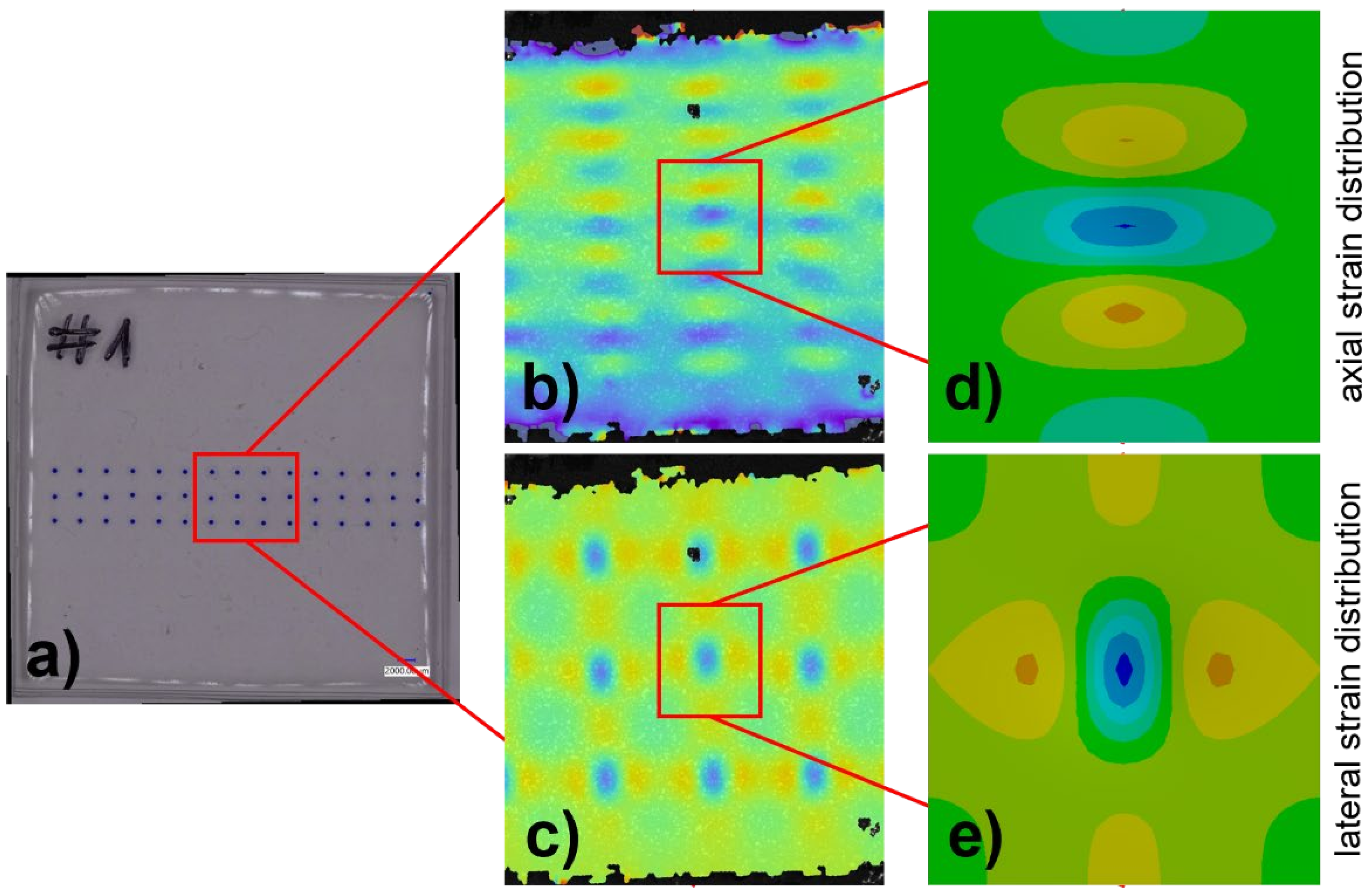

Figure: a) Soft solid liquid composite sample, **b, c)** experimental results: local distribution of the strain components at global nominal axial strain of 10% evaluated by digital image correlation, **b)** local axial strain range: 7-12%, **c)** local lateral strain range: -4-2.5%, **d), e)** numerical results: local distribution of the strain components (**d)** axial, **e)** lateral) at global nominal axial strain of 10% derived by the numerical model of a representative unit cell, the scaling is the same in **b) d)** and **c) e)**.

METHODS

Polydimethylsiloxane (PDMS) membranes with a regular pattern of liquid inclusions of two different sizes (1.1mm, 0.5mm) were produced according to the procedure reported in [3]. Planar tension tests were performed resulting in a biaxial state of stress, representative for loading conditions of biological membranes. After preconditioning during 9 cycles, samples were strained quasi-statically to 30% nominal strain. In addition to the global force and displacement data, local deformations were evaluated using a digital image correlation system.

A numerical model based on a representative unit cell approach was built using a commercial finite element software (Ansys Workbench 2021 R1). The unit cell was modeled as a 3D cuboid containing a spherical inclusion. For the PDMS, a Neo-Hookean material was chosen, which was fitted to test data of pure PDMS using a commercial software (MCalibration, PolymerFEM). The liquid inclusion was modeled using built-in element types (HSFLD242). The model was validated applying both the global force response and the local deformation pattern. A numerical parameter study was performed, varying the size and density of the inclusions.

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CONTACT

Prof. Dr. Barbara Röhrnbauer

barbara.roehrnbauer@zhaw.ch

zh aw School of Engineering

IMES Institute of Mechanical Systems