Design and testing of 3D-printed micro-architectured sheets

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Soft elastomers readily change their shapes in response to external stimuli, such as mechanical load or heat. Their high toughness and capability to withstand large deformations have been harnessed in a wide range of emerging fields including stretchable electronics, soft robotics and biomimetics. Furthermore, imparting elastic sheets with a micro-architecture enables the creation of materials with unusual characteristics, such as extreme extensibility, deployability and auxeticity. In this work, we study the evolving pattern transformation under uniaxial loading at finite strain of rubber sheets with a periodic pattern designed using a topology optimization procedure. More specifically, we experimentally and numerically investigate the contribution of the mesoscale architecture by observing the effective behavior up to extreme effective deformation, identifying material parameters and comparing the effective behavior with the desired properties announced in the optimization.

For the optimal shape design process, we use the level set method to identify material distribution and track boundary changes within the context of the smoothed interface. The combination of the level set method and the shape derivative obtained in the smoothed interface context allows capturing, within the unit cell, the topological changes that take place.

The obtained unit cells were smoothened, enhanced using standard image processing techniques, and were periodically arranged into rectangular specimens. Rubber specimen were manufactured using either polymer stereolithography 3D printer or laser cutting.

Regarding the experimental aspects, a set of dedicated experimental and numerical tools were adapted for this purpose. First, a series of mechanical tests were performed on a universal Instron testing machine, combined with a specific designed setup for the shear. Specimen were loaded in a quasi-static regime up to 50% effective strain. Image processing techniques and a robust digital image correlation (DIC) analysis were used for patterned sheets at large strain, that are filled with voids, to detect the geometry contour and measure full-field displacements and strain during the test. The results were compared with FE-analysis, undertaken using a hyperelastic incompressible Mooney-Rivlin constitutive law. The numerical results remarkably grasp the experimental response, and appear as a good indicator to assess the impact of the manufacturing process, geometry non-linearity and base material non-linearity on the final properties.

In a nutshell, this work is a key attempt to validate and identify from experimental and numerical data, a material model for a rubber sheet with a periodic micro-structure at large strain.

References

F. Agnelli, A. Constantinescu and G. Nika, “Design and testing of 3D-printed micro-architectured polymer materials exhibiting a negative Poisson's ratio” *Contin. Mech. Thermodyn.,* 11 (2019).