Mechanical characterization and sensitivity of critical parameters in inflatable soft elliptical snap-through

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Abstract

Soft materials have many engineering applications due to their favourable mechanical properties like flexibility, energy absorption, and storage, not to mention that they are easy to manufacture and have a low cost of prototyping. These characteristics make such materials the perfect basis for designing complex mechanical systems, addressed as soft robotics (1,2).

However, describing the exact behaviour of these materials is a complex task, as they exhibit nonlinear stress-strain characteristics, which are often paired with nonlinear geometric- and loading conditions. By exploiting unstable configurations of these hyperelastic materials, we can enhance the response of the fluidic actuators, which are widely used in soft robots.

In this contribution, the snap-through instability of soft elliptical shells due to inflation is investigated using numerical, analytical and experimental approaches. The goal of this contribution is to analyse the critical (loading- and geometric) parameters and their sensitivity, which determines the main characteristics of the snap-through.

The applied soft materials (soft elastomers, silicones) in soft robotics applications show highly nonlinear elastic behaviour that can be accurately modelled by hyperelastic constitutive models. However, analytical solutions for the thick-wall shell buckling problem can only be derived for specific, simpler hyperelastic models (e.g. Neo-Hookean or Varga models), which can only characterize the material nonlinearity in a limited way (4,5). For highly nonlinear hyperelastic materials, the Ogden hyperelastic model can be adopted (6), which defines the strain energy density function as a series of principal stretches with positive and negative powers. By utilizing this property and reformulating the model in a mathematically favourable way, a consistent hyperelastic model is provided, which is then used to solve the snap-through problem of thick-walled hyperelastic shells.

Secondly, a general finite element approach is proposed by combining the RIKS method and the fluid cavity contact formulation for the fluid-structure interaction in Abaqus to investigate the behaviour of a wide variety of loading- and geometric conditions, and the sensitivity of both the geometric and loading parameters for the snap-though. Finally, the numerical simulations and the analytical predictions are compared with experimental investigations using a self-developed fluidic control board, which provides the possibility to apply

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different loading- and control approaches.

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