Direct stress and yielding determination in inflatable membranes of arbitrary shapes

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Structural membranes are ubiquitous due to their ultralow weight and ability to undergo large deformations, with applications ranging from novel civil constructions to advanced aerospace systems, including biomedical devices, soft robotics, stretchable electronics, and tissue engineering. Although they are widely employed to withstand severe hygrothermal and mechanical loading conditions, the remarkably incomplete understanding of their governing deformation mechanisms before, after and at the onset of yielding represents a limit in the development of such innovative systems. In particular, most engineering and biological membranes are found in non-axisymmetric and statically indeterminate inflatable systems, whose stress state assessment requires knowledge of the constitutive material model, often unknown a priori.

In this work, we introduce a forward elastostatic method for the direct stress measurement in homogeneous thin shells of arbitrary shapes undergoing large deformation [1]. The stress state in statically indeterminate thin shells is proven to be directly measurable without knowing the material model, as it results independent of the material properties in incompressible solids and only dependent on the Poisson's ratio in compressible materials. The formulation is numerically implemented and experimentally validated for the finite inflation of planar elliptical membranes made of hyperelastic and elastoplastic materials. Further, the method is coupled with a newly developed imaging technique to directly measure the yield stresses in thin films through bulge tests. Such technique relies on the abrupt strain localization occurring during the inflation of circular and elliptical elastoplastic films [2], theoretically proven through a finite strain solution, numerically and experimentally validated on a wide range of materials.

References

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