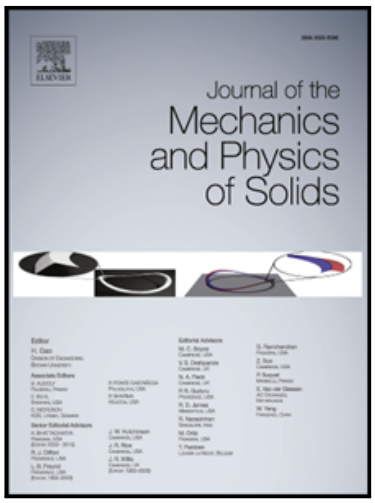

The Mullins effect in the wrinkling behavior of highly stretched thin films

Eszter Fehér, Timothy J. Healey, András A. Sipos

PII: S0022-5096(18)30500-3
DOI: 10.1016/j.jmps.2018.07.009
Reference: MPS 3388

To appear in: *Journal of the Mechanics and Physics of Solids*

Received date: 12 June 2018
Revised date: 12 July 2018
Accepted date: 14 July 2018

Please cite this article as: Eszter Fehér, Timothy J. Healey, András A. Sipos, The Mullins effect in the wrinkling behavior of highly stretched thin films, *Journal of the Mechanics and Physics of Solids* (2018), doi: 10.1016/j.jmps.2018.07.009

The Mullins effect in the wrinkling behavior of highly stretched thin films

Eszter Fehér[a,b], Timothy J. Healey[c], András A. Sipos[a,b]

[a] *Department of Mechanics, Materials and Structures, Budapest University of Technology and Economics, Műegyetem rkp. 1-3. K261, Budapest, 1111, Hungary*
[b] *MTA-BME Morphodynamics Research Group, Budapest, Hungary*
[c] *Department of Mathematics, Cornell University, Ithaca, 14850 USA*

Abstract

Recent work demonstrates that finite-deformation nonlinear elasticity is essential in the accurate modeling of wrinkling in highly stretched thin films. Geometrically exact models predict an isola-center bifurcation, indicating that for a bounded interval of aspect ratios only, stable wrinkles appear and then disappear as the macroscopic strain is increased. This phenomenon has been verified in experiments. In addition, recent experiments revealed the following striking phenomenon: For certain aspect ratios for which no wrinkling occurred upon the first loading, wrinkles appeared during the first unloading and again during all subsequent cyclic loading. Our goal here is to present a simple pseudo-elastic model, capturing the stress softening and residual strain observed in the experiments, that accurately predicts wrinkling behavior on the first loading that differs from that under subsequent cyclic loading. In particular for specific aspect ratios, the model correctly predicts the scenario of no wrinkling during first loading with wrinkling occurring during unloading and for all subsequent cyclic loading.

Keywords: wrinkling, thin films, pseudo-elastic sheets, Mullins effect

1. Introduction

The need for finite-deformation nonlinear elasticity in the accurate modeling of wrinkling phenomena in highly axially stretched thin elastomer sheets was recently demonstrated, cf. (Healey et al., 2013; Li and Healey, 2016; Sipos and Fehér, 2016). The 2D membrane model is that of geometrically exact nonlinear elasticity, while the fine thickness of such sheets manifests itself in an extremely small bending stiffness. This is in contrast to the well-known Flöppl-von Kármán (FvK) model (von Kármán, 1910), employing linear infinitesimal elasticity in the membrane part that also incorporates a nonlinear term in the gradient of the out-of-plane displacement. The FvK model has a long and successful track record in the prediction of buckling and initial post-buckling behavior of classical plates and shells.

Of course the wrinkling of a flat sheet is also a buckling phenomenon. Nonetheless, as shown in (Healey et al., 2013; Li and Healey, 2016), the FvK model leads to qualitative errors in the prediction of wrinkles for that particular class of problems. A bifurcation analysis in