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Bistability of orthotropic shells with clamped boundary conditions: an analysis by the polar method

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Abstract

Multistable shells have been recently proposed as an effective solution to design morphing structures. We describe a class of shallow shells which are bistable after one of their sides, initially curved, is clamped along a flat line. Supposing the shell being assembled as a composite laminate, we show how the anisotropy of the material can influence the multistable behaviour and the robustness of stable configurations. Specifically, we focus on orthotropic laminated shells using the polar method for a complete representation of the anisotropic elastic properties. Two experimental prototypes have been produced and tested to validate our analytical and numerical results.

Keywords: Morphing Structures, Multistability, Polar method, Orthotropy.

1. Introduction

One of the emerging challenges in structural engineering is to design structures able to face quite different operating conditions. This goal can be achieved by resorting to morphing structures *i.e.* structures capable of updating their geometric configuration in order to satisfy some performance requirements. Even if morphing structures are becoming more widespread in some areas of structural engineering (see [5, 16]), much remains to be done to properly design and implement this kind of systems.

Morphing structures can be realized by means of multistable shells, *i.e* elastic surfaces that exhibit more than one equilibrium configuration. These configurations can then be maintained without applying external actions. Since actuation is required only to switch between the alternative stable states and it could be realized with a limited actuation force (*e.g.* by triggering instability phenomena, or by exploiting displacement amplifications due to geometrical nonlinearities), multistable shells turn out to be a cheap way to get structural systems capable of considerable shape change.

Multistability in shells stems from a complex interplay between geometric nonlinearities and elastic properties, and it can be achieved in various ways combining initial natural curvatures of the shell and curvatures induced by pre-stresses (such as plastic deformations or multi-physical couplings [11]). Moreover, multistability is highly sensitive to boundary conditions and the anisotropy of the constitutive material can play an important role [23]. The global stability scenario, the number of the stable equilibrium configurations, their shapes and their 'robustness', depends on such choices and should be completely known to properly design the morphing system. However stable states usually have quite different shapes and the transition

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