Multi-scale Failure Analysis of Ultra-thin Composite Coilable Shell Structures

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ABSTRACT

In designing large deployable structures for space applications, coilable thin shells are promising for their low areal density and high packaging efficiency. An example of a deployable shell is the Triangular Rollable and Collapsible (TRAC) boom, whose cross-section is composed of two ultra-thin tape springs (70-100μm), bonded together on one of the edges along the length [1,2,3]. During packaging, these structures are coiled around a rigid circular hub, with diameter in the order of $40mm$. In the coiling and unfurling processes, changes in curvatures and bending/twisting moments are induced in the composite laminate, which can lead to ply-level delamination in the bonded region, and/or kinking in the composite. The latter, which is the focus of this study, is induced by macroscopic bending in the structure, which can lead to local fiber microbuckling, on the compressive surface of the laminate [4]. This in effect leads to the formation of localized cracks, which reduce the load bearing capability of the structure. These failure modes constrain the packaging efficiency of coilable shell structures. To better understand the kinking behavior of the composite under bending/twisting loads, along with its effect on the post-collapse region, the separation of scales approach is applied. The relation between the curvature loads on the *shell* structure (macro-scale) and the local ply-level *continuum* model (micro-scale) is established analytically using the Hill-Mandel condition. Utilizing the concept of a representative volume element (RVE) at the ply-scale, loading is applied on the microstructure numerically, which produces macroscopic bending/twisting. This in turn induces localization, or kinking at the ply-scale. The importance of geometric and a positive-definite material nonlinearity, on the formation of this instability is discussed. In addition, the effects of fiber imperfections are analysed numerically.

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