Experimental and numerical analysis of the bending response of tape springs against a notched indenter

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Paper ID: 334
Symposium S7: Mechanics of soft materials and structures

Abstract

The rigidity of cylindrical shells plays an important role in designing industrial products or even in the mechanical functionality of living organisms. Geometrically nonlinear response of shells is observed when we bend an open cylindrical shell or a tape spring. Upon small deformation, the tape spring bends uniformly. When the applied moment (or indenting force on three-point bending) reaches the critical value, the bending deformation is localized and then the tape spring snaps. Despite the number of studies on the mechanical performance of tape springs, the effects of the geometry of indenters have not been clarified so far. Here, we perform a three-point bending test for tape springs, using the rigid indenters of circular-notched caps to uncover the role of the indenter geometry. We find that the width and radius of the cap play an important role in the bending response of the tape spring. When the radius of the cap is sufficiently larger or smaller than that of the tape spring, the tape spring is nearly indented by a point or line, followed by smooth snap-through buckling. In contrast, when they are comparable, the tape snaps abruptly or even stretch without undergoing snap-buckling. We find that the deformation modes are classified by the simple scaling argument, indicating that the subtle interplay of elasticity and geometry of the tape and the indenter geometry could rule the complex deformation modes. In addition, we perform numerical analysis to clarify the effect of the friction between the indenter and the tape spring. We use the finite element method (FEM) for numerical analysis and the material point method (MPM) for contact. The numerical results show quantitative agreement with the experiments, indicating the accuracy of the sensitive experiments, such as buckling. Our findings would be applicable in predicting the large and reversible deformation of open cylindrical shells appearing in several engineering applications hinges in deployable or origami structures. We believe that the tunable buckling behavior in tape springs could be useful in enlarging the design space of industrial applications such as deployable structures.

Keywords:

Tape spring Snap buckling Elasticity Material Point Method