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Postbuckling analysis of 3D braided composite cylindrical shells under torsion in thermal environments

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Abstract

A postbuckling analysis is presented for a 3D braided composite cylindrical shell of finite length subjected to torsion in thermal environments. Based on a micro–macro-mechanical model, a 3D braided composite may be as a cell system and the geometry of each cell is deeply dependent on its position in the cross section of the cylindrical shell. The material properties of epoxy are expressed as a linear function of temperature. The governing equations are based on a higher-order shear deformation shell theory with a von Kármán–Donnell-type of kinematic nonlinearity and including thermal effects. A singular perturbation technique is employed to determine the buckling loads and postbuckling equilibrium paths. The numerical illustrations concern the postbuckling behavior of perfect and imperfect, braided composite cylindrical shells with different values of geometric parameter and of fiber volume fraction in different cases of thermal environmental conditions. The results show that the shell has lower buckling loads and postbuckling paths when the temperature-dependent properties are taken into account. The results reveal that the temperature changes, the fiber volume fraction, and the shell geometric parameter have a significant effect on the buckling load and postbuckling behavior of braided composite cylindrical shells. They also confirm that the torsional postbuckling equilibrium path of a moderately thick shell is stable and the shell structure is virtually imperfection–insensitive.

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Keywords: 3D braided composites; Cylindrical shell; Thermal effect; Postbuckling; Torsion

1. Introduction

A new class of composite material known as braided composites has been received considerable attention. Textile composites are manufactured by fabrication methods derived from the textile industry. Unlike laminated composites, in which cracking and debonding may occur at high temperature due to the material property mismatch at the interface of two discrete materials [1,2], the textile composites are able to eliminate the delamination due to the inter-lacing of the tows in the through-thickness direction. Numerous investigations for determining their physical, mechanical and thermal properties are available in the literature, see, for example [3–6]. Braided composites are now developed for general use as structural components in space and underwater exploration, offshore structures due to their light weight and easy handling secure their place in the industry. One of the problems deserving special attention is the study of the postbuckling of cylindrical shells subjected to mechanical edge loads and in thermal environments.

Many buckling studies of composite laminated shells subjected to axial compression and/or external pressure are available in the literature. However, relatively few have been made on the torsional buckling of composite laminated shells. This is due to the fact that the solution becomes more complicated in the case of cylindrical shells under torsion. Tabiei and Simitses [7,8] calculated the torsional buckling loads of moderately thick laminated

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cylindrical shells based on the classical, first-order and higher-order shear deformation shell theories. Huille et al. [9] calculated the torsional buckling loads of thick-walled composite pipes by using the Ritz method. Mao and Lu [10] presented buckling analysis of a laminated cylindrical shell subjected to torsion under mixed boundary conditions based on the first-order shear deformation shell theory. Tan [11] studied torsional buckling of thin and thick shells of revolution based on the classical and first-order shear deformation shell theories. Park et al. [12] also performed torsional buckling analysis of composite cylindrical shells by using nonlinear finite element method. Moreover, Harte and Fleck [13] examined the deformation and failure behavior of glass fiber epoxy braided composite tubes under axial compression, torsion and their combination and found in torsion and in combined compression–torsion, the tubes fail by fibre microbuckling. In [13], the two-dimensional (2D) performs offer good responses to plane stress states. However, to obtain thicker composite parts or more complex shapes, it becomes necessary to stack or join different 2D layers, and coexistence in a laminate of stiff and strong plies with a relatively weak matrix interface is really harmful. In fact, the loaded braiding cells may play a great role in moderately thick shells. A close scrutiny among the references reveals that to date, no investigation can be found for postbuckling of moderately thick braided composite cylindrical shells subjected to torsion in thermal environments and with temperature-dependent material properties.

In the present study, we focus on the 3D braided composite cylindrical shells subjected to torsion. A 3D braided composite model is established, from which four interior cells and two surface cells are performed (see Fig. 1). We assume that the cross section of multifilament braiding yarns is elliptical and all yarns in the braided preform have identical constituent material, size and flexibility. The temperature field considered is assumed to be a uniform distribution over the shell surface and through the shell thickness. The material properties of epoxy are expressed as a linear function of temperature. The governing equations are based on Reddy's higher-order shear deformation shell theory with a von Kármán–Donnell-type of kinematic nonlinearity and including thermal effects. A singular perturbation technique is employed to determine the buckling loads and postbuckling equilibrium paths. The nonlinear prebuckling deformations and initial geometric imperfections of the shell are both taken into account. The numerical illustrations show the full nonlinear postbuckling response of braided composite cylindrical shells under torsion in thermal environments.

2. Theoretical development

A traditional 2D triaxial braided composite laminate of a certain desired thickness is formed by overbraiding layers each with a specified braiding angle can be serially superimposed in order to form a multi-layer braid. Unfortunately, the problem of these multi-layer braids consists in the interlaminar weakness or in other words in its sensitivity to delamination. To overcome this problem, 3D braiding technique, in which the braiding yarns interlock through a volume of material, is developed.

Based on the movement of carriers, we analyzed the yarn traces systematically in 3D tubular braided preforms using the control volume and control surface method similarly reported by Wang and Wang [5]. A new micro–macro-mechanical model of unit cells was established. The macro-cell of the model is further decomposed into simpler elements, here called unit cells, whose stiffness is calculated from the geometry of the fiber tow and the stiffness of the constituents and yarn cross section changes into an elliptic shape due to interaction between two yarns. According to the load-sharing relations between the unit cells, the macroscopic stiffness is then calculated. In this model, a 3D braided composite may be as a cell system and the geometry of each cell is deeply dependent on its position in the cross section of the cylindrical shell. We assume that the yarn (fiber tow) is transversely isotropic and the matrix is isotropic, from which the stiffness matrix can be expressed as

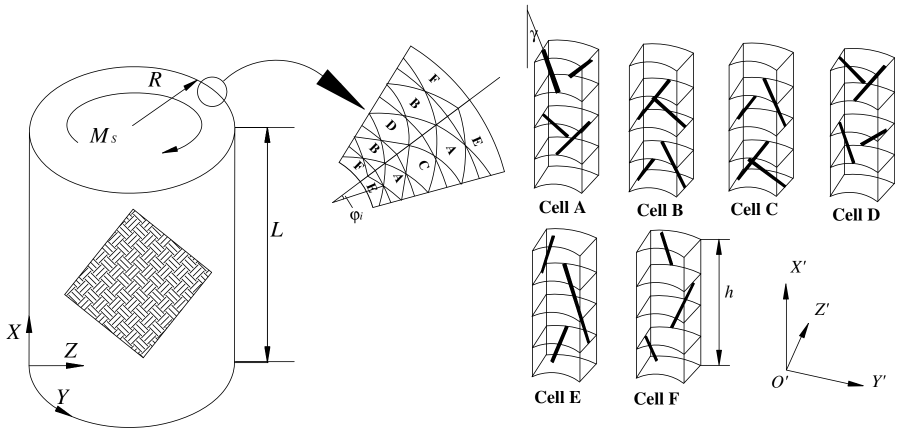

Fig. 1. Configuration of a braided composite cylindrical shell under torsion and its coordinate system and unit cells for the interior (cell A–D) and the surface (cell E–F).

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