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Technical Note

On the buckling of cracked composite cylindrical shells under axial compression

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Abstract

Potential sensitivity of the buckling behavior of cracked composite cylindrical shells to service life cracking is explored by carrying out linear buckling analysis. Computational models of cracked composite cylindrical shells are developed by exploiting a special meshing scheme in which the element size is reduced incrementally from the element size employed in the uncracked region by approaching the crack tip. The effect of crack size and orientation, as well as the composite ply angle on the buckling behavior of cylindrical shells under axial compression is investigated. The results provide some insight into designing a composite laminate, which enhances the load capacity of cylindrical shells and minimizes their potential sensitivity to the presence of defects.

Keywords: Cracked cylindrical shell; Laminated composite; Buckling behavior; Finite element model

1. Introduction

Fiber-reinforced composites have been used extensively in various fields of modern engineering due to distinct structural advantages they offer. One such a field is aerospace engineering where structures are mostly assemblies of shell structures. Comprehensive understanding of the mechanical behavior of composite shells is vital to assure the integrity of these structures during their service life. Several studies have focused on predicting optimum laminate configurations for enhancing the load capacity of composite cylindrical shells under various loading conditions such as pure axial compression [1–6], combined axial compression and torsion [7–9] and transverse load [10]. Here, we focus on another important aspect associated with buckling behavior of composite cylindrical shells; its potential sensitivity to the presence of a crack. Presence of defects such as cracks, which may develop during manufacturing or service life of composite cylindrical shells, could severely affect the buckling behavior of structures not only by reducing their load carrying capacity but also by introducing local buckling at the crack region [11,12]. In addition, many of the aerospace shell structures comprise cutouts due to functionality requirements. Considering the effect of these cutouts on buckling and post-buckling behavior of composite cylindrical shells is vital for assuring safe operating conditions during the service life of these structures [14]. In general, reinforcements around cutouts have been used to suppress the local buckling in composite shells. However, a recent study by Hilburger and Starnes [15] revealed that certain reinforcement configurations could lead to an unexpected increase in the magnitude of local deformations and stresses in the shell and a subsequent reduction in the buckling load. These recent results further emphasize the importance of understanding the mechanisms driving the buckling and post-buckling behavior of composite cylindrical shells comprising defects and cutouts. In this study, the potential sensitivity of buckling behavior of axially-compressed cylindrical shells to the presence of a through crack is investigated, emphasizing on the role of composite ply angle.

Linear eigenvalue analyses are carried out for composite cylindrical shells under axial compression, which is the most significant and common type of loading considered

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for theoretical buckling studies on shells and plates, using finite element methods. It is noteworthy that the potential sensitivity of buckling behavior of cylindrical shells on the presence of defects highly depends on loading condition [11,12] and it is conceivable that the results presented here would not be applicable under other loading conditions. The computational models of cracked cylindrical shells are generated by employing the meshing scheme proposed by Estekanchi and Vafai [11] in which the element size reduces incrementally from the constant element size employed in the uncracked region by approaching the crack tip, Fig. 1. One of the main advantages of this meshing scheme is the simplicity it offers for generating the computational models, which is indeed crucial for studies entailing large number of computational models. The validity of this approach for studying the buckling behavior of cracked thin plates and shells are established in [11,12]. Eight-node shell element, which has six degree of freedom at each node and quadratic deformation shape in both in-plane directions, is employed in the computational models. In the employed meshing scheme, the orientation of the elements is preserved at different levels of mesh zooming as shown in Fig. 1. An alternative approach is based on gradual change of the element orientation at each zoom level. The latter approach is shown to be more effective and accurate for fracture mechanics studies, while the former approach is capable of capturing the main features of local buckling and deformation of cracked cylindrical shells with a remarkable fidelity [11]. Through cracks are modeled by allowing the relative displacement and rotation (in all six degrees of freedom) of the neighbor nodes located at two edges of the crack. A mesh sensitivity study is carried out to ensure the independence of the results on the computational mesh. The calculations are performed using ANSYS (ANSYS, Inc., Canonsburg, PA), a commercial finite element package. The nodes located at the boundary are allowed to move in the cylinder axial direction while other degrees of freedom are constrained to zero. The computational model of the cylindrical shell has the length of $L = 6.0$ m and the radius of $R = 1.0$ m. The composite is taken as linear elastic material with the elastic moduli of $E_1 = 53$ GPa in the fiber direction and $E_2 = 17.75$ GPa in transverse to the fiber direction with the Poisson ratio of $\nu_{12} = 0.25$ (representing typical Fiberglass composites). The ply thickness of the composite is 0.125 mm with the laminate stacking of $[\theta/-\theta]_3$ (θ is measured from the cylinder longitudinal direction), which is antisymmetric about the middle surface, corresponding to the total thickness of $t = 0.75$ mm.

The potential failure mechanisms of cracked composite cylindrical shells are (i) Euler buckling with a wavelength related to the cylinder length, (ii) surface buckling with a wavelength smaller than the cylinder length, (iii) local buckling in the crack region, and (iv) material failure, such as plasticity and delamination. The cylindrical shell under study clearly falls in the range of intermediate length for which the Euler buckling is not the dominant mechanism of failure. This is validated using the developed finite element model. Buckling of the cylindrical shell with a wavelength smaller than the cylinder length of the composite cylindrical shell (surface buckling) is studied in Section 2, while the local buckling behavior of the cracked cylindrical shell is explored in Section 3. The material failure is not considered in this study. It is noteworthy that the current

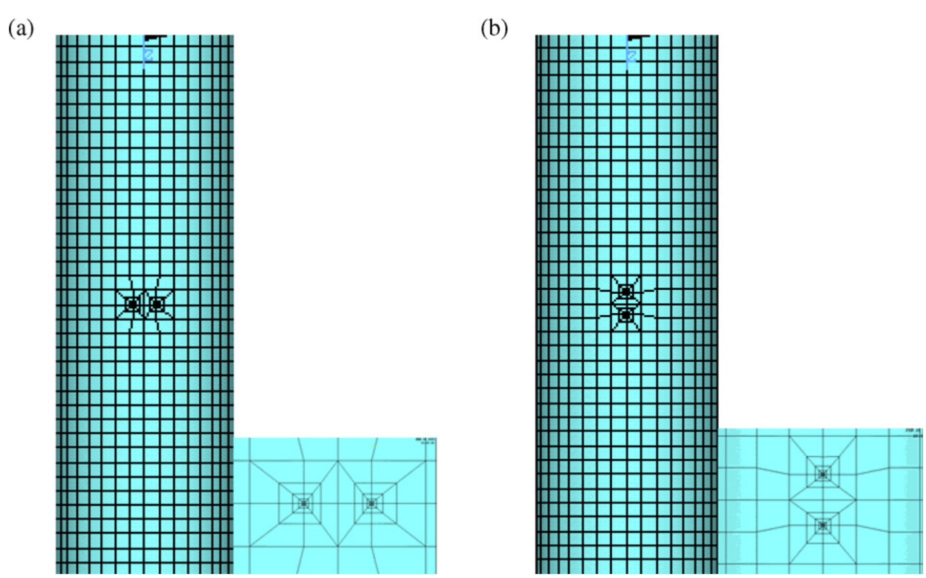

Fig. 1. Computational models of a cylindrical shell with (a) a circumferential crack and (b) an axial crack, developed by employing a special meshing scheme at the crack region proposed by Estekanchi and Vafai [11]. The computational model comprises 38 elements in circumferential and longitudinal directions. In the crack region, the element size is reduced to 1/2 of its original size with five level of zooming which results in crack tip element size of 1/32 of those used in the uncracked region.