Buckling Analysis of Anisogrid Cylindrical Shell under Thermal Load

Modern composite materials with a high specific strength and stiffness allow creating space structures with the weight efficiency which is not achievable by their metallic analogues. Particularly, the combination of high mechanical properties of composites with the lattice design concept makes it possible to qualitatively improve the structural performance of aerospace and satellite elements. The development of composite lattice structures, their design principals and aerospace applications are thoroughly described. Analytical, numerical and experimental studies related to mechanical analysis and optimal design of these structures can be found in a number of works. Composite structures used in space applications experience large cyclic temperature fluctuations which might result in undesirable thermal deformation and buckling leading to functioning degradation. For example, this issue is of primary importance for space telescopes which the main load-bearing component is usually a thin-walled lattice cylinder. Investigation of buckling resistance is crucial as the buckling failure can occur at the stress level significantly less than the compressive strength of materials used. This study aims to numerically investigate the buckling behavior of anisogrid cylindrical shells with two rigidly clamped edges under uniform thermal loading. Finite element modeling is used to assess the critical temperature value depending on the number of helical ribs and their orientation angle.

FINITE ELEMENT MODEL

The anisogrid lattice of the shell under consideration consists of a repeating symmetrical pattern of intersecting circumferential and helical ribs (Fig. 1). Helical ribs are oriented at ±f angle with respect to the shell axis and circumferential ribs pass through the midpoints of segments between the intersection nodes of helical ribs. The number of helical ribs inclined at the same direction is n_s. The width of helical and circumferential ribs is denoted as δ_s and δ_r, respectively. All ribs have the same height h. The elastic moduli of materials of helical and circumferential ribs are E_s and E_r, respectively, and the corresponding coefficients of thermal expansion are α_s and α_r.
A three-dimensional numerical model of the anisogrid lattice cylinder is constructed by means of the MSC Nastran finite element analysis software [12]. The two-node BEAM finite element (FE) is used to represent the ribs. The element has three translational and three rotational degrees of freedom per node. The steps to build the cylinder finite element model are shown in Fig 2. First, a FE model for the repetitive unit cell of the lattice structure consisting of two segments of circumferential and helical ribs is created (Fig. 2a). At this step the unit cell geometry, elastic and thermal properties of the rib materials as well as the FE mesh density (element size) are specified. By using the periodicity of the lattice structure, the FE model of the whole shell is formed by copying the unit cell elements in circumferential and axial directions as shown in Fig. 2b and Fig. 2c.The computational model is completed by specifying the boundary conditions: a uniform temperature rise (from ambient conditions) for all nodes in the model and fully constrained nodes at both edges of the shell (Fig. 2d).

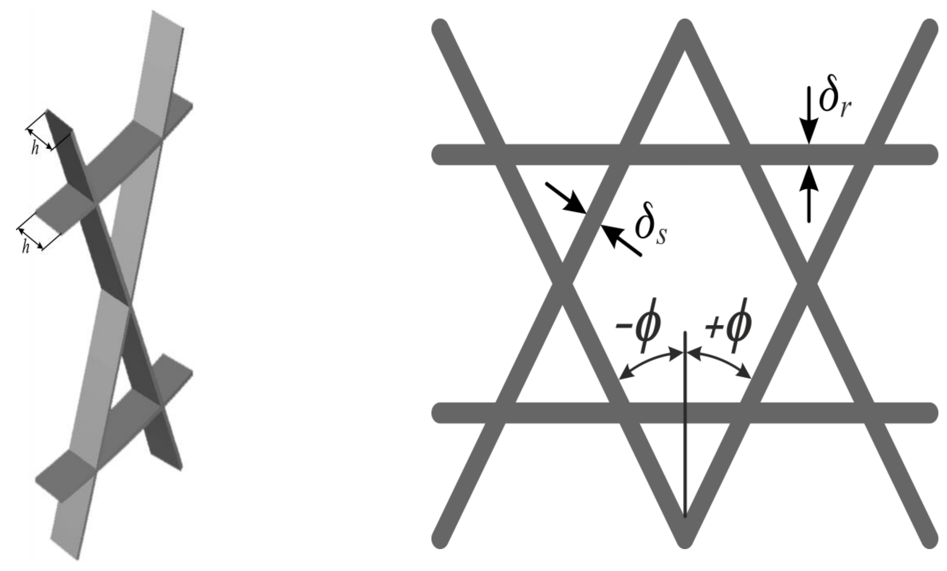
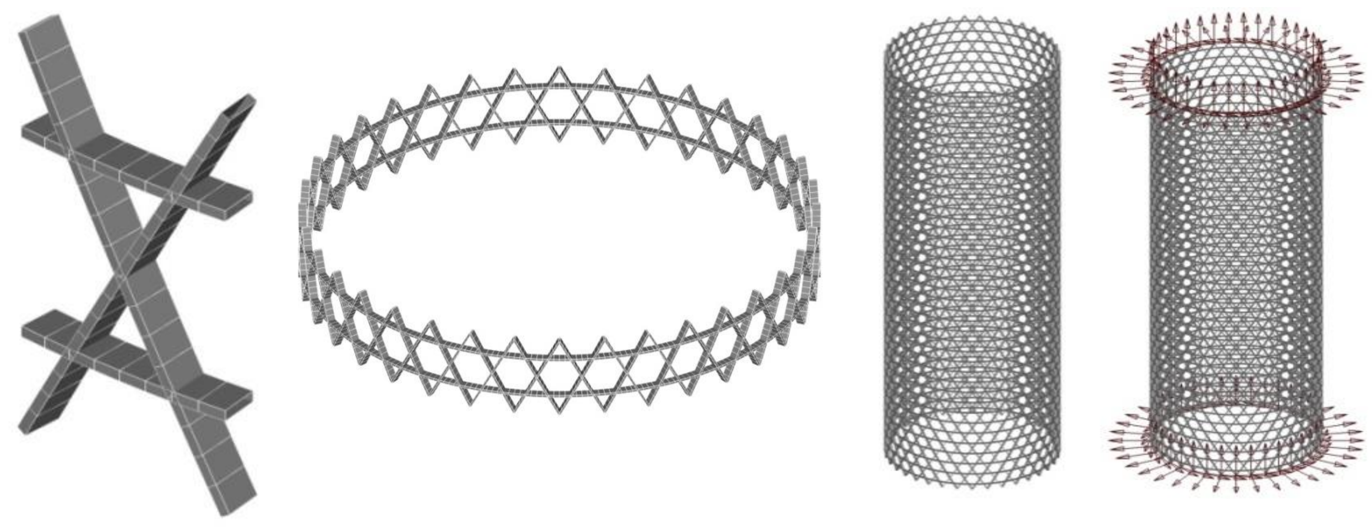


FIGURE 1. Geometric parameters of the lattice structure



(a) (b) (c) (d)

FIGURE 2. Sequence of building the finite element model

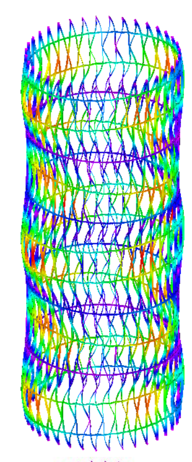
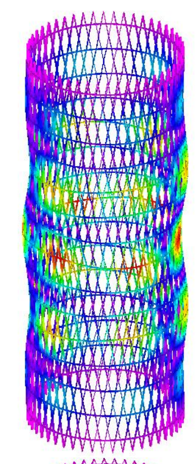
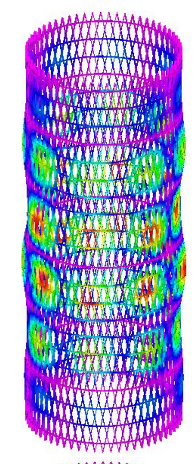
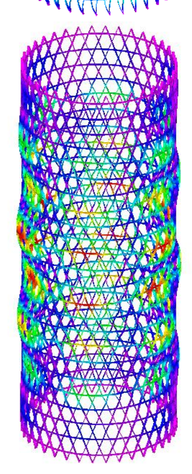
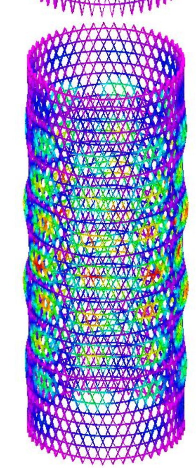
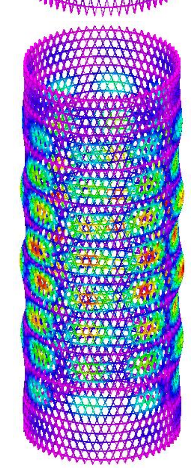
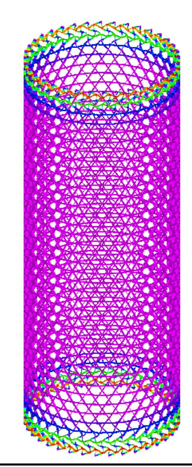
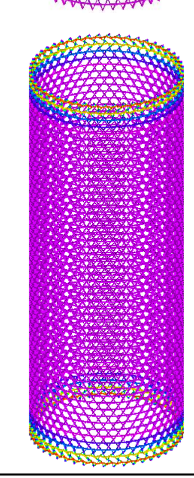
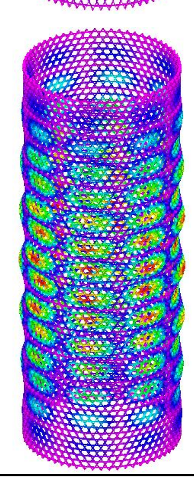
RESULTS AND DISCUSSION

Using the finite element model described above, the critical buckling temperature for anisogrid cylindrical shells with various parameters of the lattice structure can be computed. As a practical case, consider the buckling problem of the main load-bearing component of a space telescope, which is the shell having the length of 3 m and the diameter of 2 m. Here, the clamped boundary conditions reflect the effect from massive equipment attached to the shell edges.
The shell is manufactured by carbon filament winding technique. The following parameters are used in calculations: h = 16 mm, $\delta_s = \delta_r$ = 4 mm, $E_s = E_r$ = 170 *GPa*, $\alpha_s = \alpha_r = 3.5 \cdot 10^{-6}$ 1/C°. The helical ribs orientation angle φ and the number of ribs n_s are the variable parameters in the calculations. The angle φ takes values of 10°, 15°, 20°, 25° and 30°, while n_s is 36, 48 and 60. The size of the finite element is 10 mm in all considered cases. The FE model with φ = 10° and n_s = 36 contains the minimum number of finite elements – 25920, while 67320 beam elements are used to model the shell having φ = 30° and n_s = 60.

TABLE 1. Critical buckling temperature (C°)

Helical ribs orientation angle, ϕ	Number of helical ribs, n_s		
	36	48	60
10	386	530	833
15	739	1115	1410
20	1213	1907	2475
30	2632	4425	5620

TABLE 2. Buckling mode shapes of anisogrid lattice shells

ϕ	Number of helical ribs, n_s: 36	48	60
10°			
20°			
30°			

The computed critical temperatures at which the anisogrid lattice cylinder buckles are given in Table 1. As seen from Table 1, the critical temperature increases with increasing orientation angle of helical ribs. Increasing their number also improves the thermal buckling resistance of the shells. It should be mentioned that values of the critical buckling temperature well exceed the temperature range that normally occur in the spacecraft hull when it is orbiting. Thus, it is hardly possible that shells with the given anisogrid lattice structures will loss stability under thermal loading from solar radiation. However, the presence of additional compressive mechanical loads will decrease the allowable operation temperatures.

CONCLUSION

The article presents the results of numerical study on the buckling response of the anisogrid lattice cylindrical shells under thermal loading. A parametric finite element analysis has been performed to evaluate the influence of the lattice structure parameters on the critical buckling temperature. The critical buckling temperature has been found increases with increasing number of helical ribs and their orientation angle with respect to the shell axis. It has been demonstrated that after the loss of stability different buckling mode shapes of the shell can be realized depending on the lattice structure.

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