BUCKLING AND IMPERFECTION-SENSITIVITY OF AXIALLY COMPRESSED CYLINDRICAL SHELLS WITH COMPLIANT CORES

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Summary The extent to which the mechanical properties and dimensions of compliant cores influence the load-carrying capacity and imperfection-sensitivity of axially compressed cylindrical shells is analyzed numerically for a wide range of configuration parameters. It is found that a comparatively thin layer of core material is sufficient to achieve substantial increases in the buckling loads while at the same time the imperfection-sensitivity is significantly smaller than for the unfilled shell.

Recently, the production of high porosity metal foams and integrally filled metal-foam sandwich panels have received considerable attention, and it is estimated that foam-filled structural components of this type will have decisive advantages over more established thin-walled constructions relying on honeycomb cores or discrete stiffener arrangements to achieve the required weight-strength ratios.

Unfortunately, little comparative data exist to verify the high weight-saving expectations often associated with components filled with metal foams. An exception are the results obtained in [1] which suggest that for practical purposes foam core sandwich constructions may have a - comparatively modest - weight-strength advantage over optimized skin-stringer configurations only under fairly exceptional - and largely impractical - design conditions. This conclusion was reached on the basis of idealized model analyses following the classical concepts of structural index and minimum-weight design and therefore may be somewhat conservative.

In fact, the results reported in [2] suggest that for sandwich shells and curved sandwich panels there may indeed be a practically significant loading range for which optimized sandwich constructions employing metal foam cores do have a distinct weight advantage over metal stringer constructions. However, these results also indicate that the imperfection sensitivity is essentially as severe as for the corresponding monocoque cylinder. Thus, in this case, too, there seems to be an "unhappy coexistence of efficient shell design and the curse of imperfection-sensitivity (B. Budiansky)".

On the other hand - even though not directly concerned with weight-strength optimized configurations and imperfection-sensitivity - the work on comparatively thick-walled foam-filled cylindrical shells reported in [3,4] indicates - on the basis of simplified analytical model analyses and experiments on rubber cylinders filled with rubber foam - that compliant foam cores having fairly high porosities and low moduli may not only lead to remarkable increases in the load-carrying capacity of cylindrical shells but also to a reduction in their notorious imperfection-sensitivity. If this conclusion could be shown to be true for other material combinations and configurations as well, it would have far-reaching consequences because it could lead to substantially reduced knockdown factors and to considerably higher design loads for this type of structural component.

To shed more light on this question, the presentation explores the extent to which the mechanical properties and dimensions of compliant core materials may influence the load-carrying capacity and imperfection-sensitivity of axially compressed cylindrical shells in detail (Fig. 1). It starts from the fundamental imperfection-sensitivity analyses presented in [5,6] which treated the buckling and initial postbuckling behavior of long axially compressed circular cylindrical shells containing an initial geometric imperfection in the shape of the classical axisymmetric bifurcation mode. As is well known, these analyses quantitatively established the severe imperfection-sensitivity of this shell configuration and thus provided a theoretical basis for the empirical knockdown factors widely used in the design of thin-walled structures (e.g. [7]).

To validate the computational model employed in the subsequent analyses, the first part of the presentation is concerned with a detailed comparison of the numerical results with those of the well-known (semi-) analytical buckling and imperfection-sensitivity analyses for monocoque cylindrical shells presented in [5,6]. Based on a comparatively high mesh-density and taking into account a significant number of close or nearly coincident buckling modes, excellent agreement with the classical bifurcation and imperfection-sensitivity results were obtained for a wide range of radius-to-thickness ratios and imperfection amplitudes (Fig. 2).

Subsequently we explore the buckling behavior and imperfection-sensitivity of axially compressed circular cylindrical shells completely or partially filled with compliant core material along the lines of the work presented in [3,4]. Comprehensive numerical results - based on computational models using dense meshes for the two-dimensional shell elements as well as the three-dimensional volume elements for the compliant core material - are presented for a wide range of configuration parameters, such as the shell and core thicknesses, the respective material moduli, the imperfection amplitudes, etc.. They permit the conclusion that a comparatively thin layer of compliant core material may be doubly beneficial because it leads not only to a substantial increase in the bifurcation stress of the partially or completely filled perfect shell compared to that of the perfect unfilled one but also - and somewhat unexpectedly - to a significant reduction in imperfection-sensitivity, as can be seen from Figs. 3 and 4, where results are plotted for a radius-to-thickness ratio of 100 and a ratio of the core to shell moduli of 1/100. Analogous results are obtained for other parameter combinations, and the relative load-carrying increases are found to be most pronounced for large values of R/t.

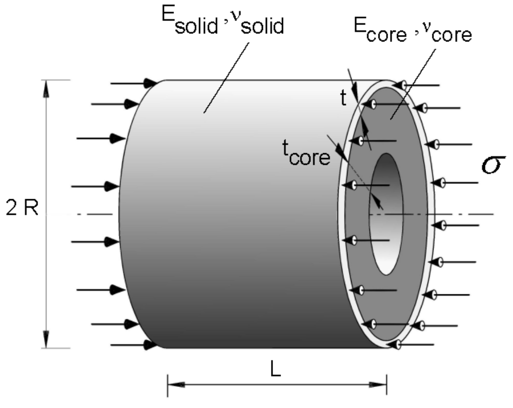

Fig. 1 Shell and load configuration

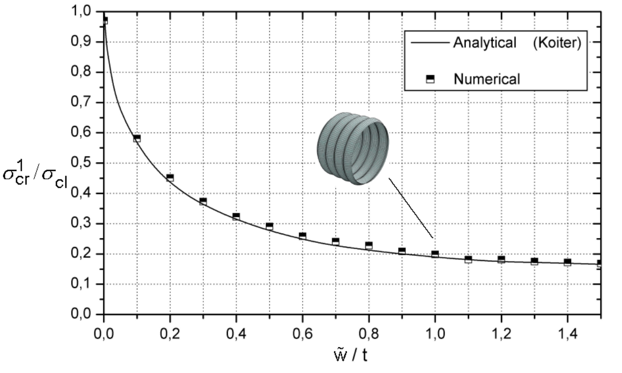

Fig. 2 Imperfection sensitivity of the unfilled shell. Analytical vs. numerical results

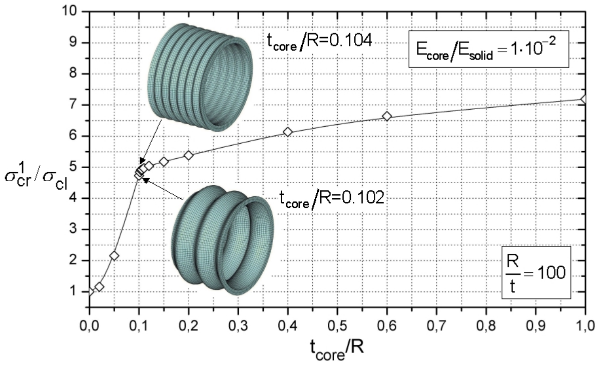

Fig. 3 Influence of the core-thickness on the bifurcation stress of the perfect configuration (relative to the classical buckling stress of the unfilled cylindrical shell)

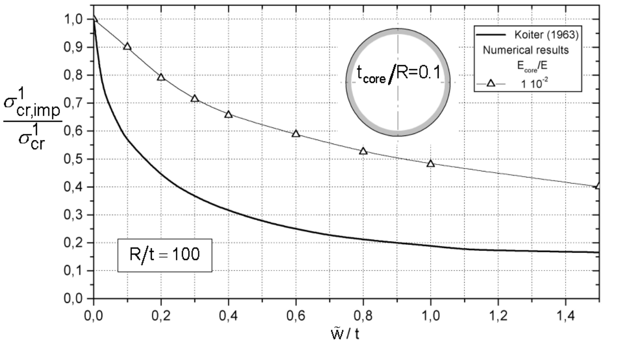

Fig. 4 Imperfection-sensitivity of the imperfect partially filled shell compared to the imperfection-sensitivity of the unfilled shell

References

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