



Finite element simulation of metallic cylindrical sandwich shells with graded aluminum tubular cores subjected to internal blast loading

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ABSTRACT

The LS-DYNA software was employed to analyze the dynamic responses of a sandwich cylindrical shell system under internal blast loading. The system consisted of metallic face sheets and graded aluminum tubular cores with different wall thicknesses. The response of this system was also compared with that of conventional ungraded ones. The dynamic response of graded cylindrical shells with a series of different core arrangements is reported in this paper. The deformation and blast resistance of the structures were discussed in detail, and the optimum sandwich configuration was obtained. The core layers, which had thickness-tapered arrangement from the inner to the outer layer, were favorable for the energy dissipation and the out face-sheet deflection. Finally, two new response types were defined based on the core compression consequence, which is unique to sandwich structures with graded cores.

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1. Introduction

Metallic sandwich structures are widely used for energy absorption components in aerospace, marine, and railway systems because of their low density, high specific strength, and effective energy absorption. The cores of these sandwich structures are commonly made of foams [1–5], honeycombs [6], corrugated plates [7], or truss lattices [8,9]. The dynamic responses of such sandwich composites under blast loading have been extensively investigated [10–15]. In recent years, stepwise-graded materials, in which the material properties vary gradually or layer-by-layer within the material itself, were utilized as core materials in sandwich composite systems. However, in these function-graded sandwich structures, the cores are often made of graded foams [16–21] and corrugated plates [22]. Zhang et al. [22] analyzed the dynamic response of sandwich steel plates with three kinds of corrugated core arrangements that consisted of identical core densities and were then subjected to dynamic air pressure loading. It was found that the smoothly tapered graded core from the impact end to the distal end has the smallest maximum back face deflection. Liu et al. [18] investigated the dynamic responses and blast resistance of all-metallic sandwich-walled hollow cylinders with graded aluminum foam cores and compared them with those of conventional ungraded

ones. When graded and ungraded cylinders are subjected to identical air blast loadings, the radial deflection of the former is smaller than that of the latter, whereas the blast resistance of the former is stronger than that of the latter. Li et al. [19] investigated the dynamic responses of metallic sandwich spherical shells with graded aluminum foam cores under inner blast loading. The results indicated that the density-tapered arrangement of foam cores from inside to outside can enhance the mechanical property of spherical shells under inner blast loading.

Metallic tubes, rings, and systems composed of aforementioned elements have also been proven as good impact energy absorption components [23,30] because of their low cost, ready availability, and energy absorbing efficiency compared with other deforming elements [25]. The use of circular tubes in energy absorbing systems has been extensively investigated. For example, metallic tubes can be stacked laterally as an energy absorbing system in highways against possible collision from vehicles [26]. However, existing studies on the tube systems subjected to lateral crushing are primarily concerned with numerical or analytical model of simple systems [24–26]. For most of the tube applications, they are axially crushed, and a large number of deformation modes have been proposed and examined [27–29]. The behavior of a chain of rings with a rigid support at one end and subjected to an impact loading at the other end has been studied by using the modified one-dimensional structural shock theory, and the rings are constrained to collapse in essentially a simple four-hinge mechanism [24–26]. The response of the sandwich tubes with metallic foam cores under internal explosive loading was investigated

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by Shen et al. [33]. The deformation of the sandwich tubes occurred sequentially from the inner tube to the outer one, and the results demonstrated that for a given amount of TNT charge, the sandwich tubes, as a blast chamber, can have better blast resistance than a monolithic wall of the same mass.

In the present study, the commercially available finite element (FE) code LS-DYNA 971 was employed to investigate the dynamic responses of a metallic cylindrical sandwich shells with graded aluminum tubular cores subjected to internal blast loading. The cores were small tubes of the same diameter. The thickness of the tubes for each layer within the core was varied to achieve a graded core. A finite element analysis (FEA) for the deformation of the structures was formulated and used to obtain the optimum sandwich configurations.

2. FEA model

2.1. Geometric modeling

The FEA model was built using commercial software ANSYS and LS-Prepost. Only 1/8 of the sandwich cylindrical shells with graded aluminum tubular cores were modeled because of the symmetry in the structures and loadings. The inner and outer radii of the sandwich cylindrical shell were $110(R_{in})$ and $147(R_{out})$ mm, respectively. The height of the structure was $H=380$ mm. Six different graded configurations (a to f) were considered by changing the wall thickness of the three core layers (C1/C2/C3), from the inner most to outer most. For instance, the core arrangement of configuration a (Fig. 1) was 2–1–0.5 mm (LMS) from C1 to C3, and that of configuration f was 0.5–1–2 mm (SML), where L, M, and S refer to the tubular core layer with 2, 1, and 0.5 mm wall thicknesses, respectively. In addition, three ungraded sandwich shells with uniform core configurations (U_1 to U_3) were modeled for comparison. The outer diameter of each tubular core was $\varphi=11$ mm, and the thickness of both the inner-face-sheet (IFS) and the outer-face-sheet (OFS) was 2 mm. The explosive used in the simulation had a spherical shape. Unless otherwise specified, the mass of the TNT was $W=30$ g. The explosive was detonated at the inner center of the structure.

2.2. Element, contact, and boundary conditions

Eight-node solid elements with reduced integration were used for the cores and the face-sheets. The number of solid elements was 129,600. The meshed model is shown in Fig. 2. Representative nodes located separately on the IFS (nodes I1 to I7), OFS (nodes O1 to O7),

and the interfaces between layers (node N1 and N'1) were selected for the radial velocities and deflections (Fig. 2).

Symmetric boundary conditions about x - y , x - z , and y - z planes were imposed (Fig. 2). Automatic surface-to-surface contact options were generally used for sandwich cylindrical shell, whereas the automatic single surface contact option was used for the tubular cores.

The mesh density was selected when further refinements did not appreciably improve the accuracy of the calculations. In Fig. 3, which shows the radial deflection history at node O1 on the OFS, the mesh density corresponding to the red line (with a total number of elements 129,600) was considered sufficiently fine. Hence, this mesh density was adopted for all the simulations in this paper.

No experimental or FEA studies have been conducted on the dynamic response of the cylindrical sandwich shells with graded aluminum tubular cores. In the present study, the tubular cores were under lateral impact loading, and the face sheets were under inner impact loading. Alternatively, the FEA model and the FE method were validated at two kinds of loading conditions. Numerous studies have investigated cylindrical shells at tow loading conditions. Yuen et al. [34] performed a series of experimental and FEA investigations on cylindrical shells subjected to external localized blast loads. Langdon et al. [35] analyzed the dynamic response of cylinders under inner blast loading. The FEA and experimental results of Yuen [34] and Langdon [35] are compared in Fig. 4 to validate the FEA

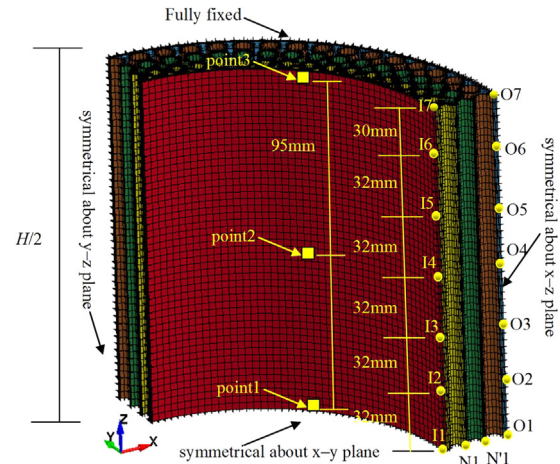


Fig. 2. FEA model of the sandwich cylindrical shell.

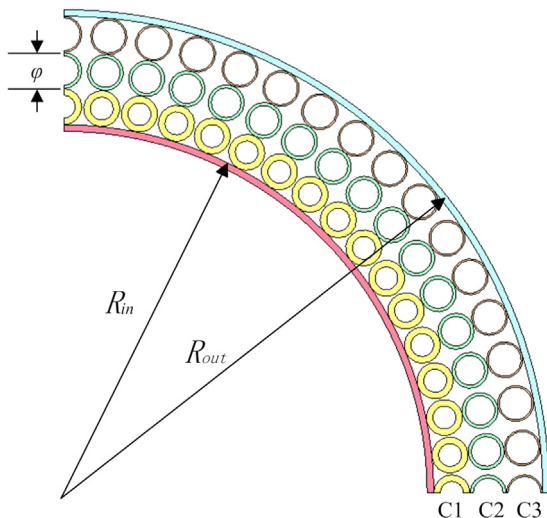


Fig. 1. Geometric model of the sandwich cylindrical shell (configuration a).

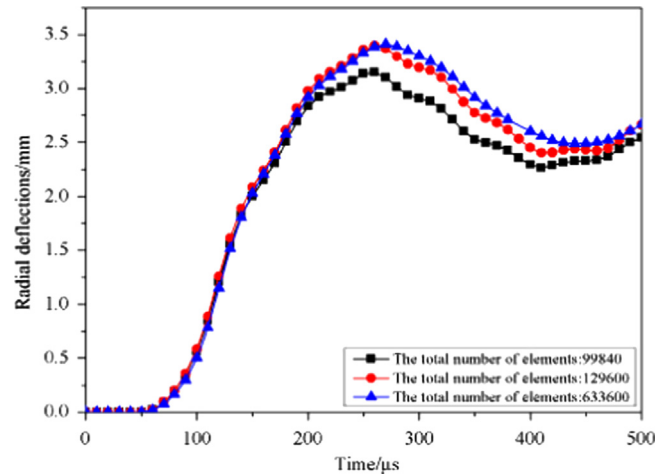


Fig. 3. Radial deflections of the O1 node on the OFS with different mesh size. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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