

HYDROSTATIC IMPLOSION PHENOMENA IN SANDWICH COMPOSITE STRUCTURES

Shyamal Kishore¹ and Arun Shukla²

¹Dynamic Photomechanics Laboratory, Department of Mechanical, Industrial and Systems Engineering, University of Rhode Island, USA, shyamal_kishore@uri.edu

²Dynamic Photomechanics Laboratory, Department of Mechanical, Industrial and Systems Engineering, University of Rhode Island, USA, shuklaa@uri.edu

1. INTRODUCTION

Composite sandwich structures have been of considerable interest for underwater applications. In general composite materials have high specific strength and stiffness, as well as very good corrosion resistance. Sandwich structures comprise of relatively low density material bonded between two face-sheets of higher strength or density. They offer several benefits in cases where buckling is the critical mode of failure. Underwater implosion phenomenon has been gaining recent attention especially for structures made of composite materials. Studies show that implosion of structures can release potentially dangerous high pressure pulse waves and can damage nearby structures [1]. Due to the improved buckling strength and low stiffness to weight ratio of composite structures they are ideal for underwater hydrostatic applications. It is hence imperative that the implosion behavior of these structures be well understood for such applications.

Some studies addressing this need have been performed, however they all have dwelled on the problem either analytically or numerically [2]–[5]. Additionally, though there has been some work on the shock initiated implosion of underwater cylinders, there is still no experimental work that investigates implosion of composite sandwich structures [6]–[9]. Recently, DeNardo et al. [10], carried out hydrostatic and shock initiated implosion experimental studies on double-hull composite structures. However, the authors considered only the case where the composite facesheets were not bonded to the foam core. The strength of the structure and the mechanics of its collapse can be altered by the inclusion of adhesive bonding between the layers of the sandwich. This study aims to address this knowledge gap experimentally by carrying out hydrostatic implosion experiments of sandwich structures made out of concentric carbon-epoxy cylinders with adhesively bonded light-weight closed cell PVC foam cores of different densities.

2. EXPERIMENTAL DETAILS

All the specimens in this study use filament-wound carbon-fiber/epoxy cylinders for their inner and outer facesheets, and are manufactured by Rock West Composites (West Jordan, UT). Both the inner and outer cylinders have a general purpose [$\pm 15/0/\pm 45/\pm 15$] layup, with a 1.7 mm wall thickness. The outer cylinder has a 60.4 mm ID and the inner cylinder a 38.6 mm ID. In hydrostatically-initiated implosion experiments, the specimens have a 279-mm unsupported length, which encourages a mode 3 collapse and gives more foam core crushing. The outer cylinder has a random, black-and-white speckle pattern for DIC. The PVC foam cores used in the specimens are from the closed-cell Divinycell H series of foams, as produced and provided by DIAB, Inc. (DeSoto, TX). Foam cores are bonded to composite cylinders using a two part epoxy supplied by Loctite, and achieve 24.13 MPa strength after 24 hours of curing time. The adhesive is applied between the inner surface of the outer tube and the outer surface of the foam core and between the outer surface of the inner cylinder and inner surface of the foam core (see Fig. 1). The weight changes due to the application of epoxy in the assembly were recorded.

All implosion experiments are conducted in a 2.13m diameter spherical pressure vessel with a maximum pressure rating of 6.89MPa designed to provide constant hydrostatic pressure throughout the collapse event (see Fig. 2). Several Plexiglass windows mounted about the midspan of the pressure vessel allow the specimens to be viewed by cameras and adequately lit by two high-powered lights. The specimens are sealed using two aluminum end caps and suspended horizontally in the center of the pressure vessel. To measure the changes in local pressure during the collapse event, several high-pressure blast transducers (PCB 138A05, PCB Piezotronics, Inc., Depew, NY) are mounted at different locations about the specimen both axially and circumferentially (see Fig. 1). The vessel is then flooded with filtered water, leaving a small air pocket at the top. Once the vessel is filled, nitrogen gas is introduced into the air pocket to pressurize the enclosed water. The pressure inside the vessel is increased at a gradual rate until the specimen collapses.

Two digital high-speed cameras (Photron SA1, Photron USA, Inc.) are mounted normal to the viewports outside the tank and at an angle of 17° from one another. These are used to record stereoscopic images of the collapse event at frequencies on the order of 40,000 frames per second, and the images are later analyzed using 3-D DIC software (VIC 3D 2012, Correlated Solutions Inc.) to determine full field displacements across the outer surface of the specimen.

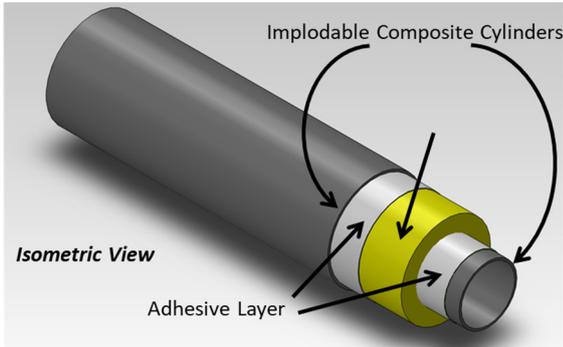


Fig. 1: Schematic of the Sandwich Composite Structure geometry.

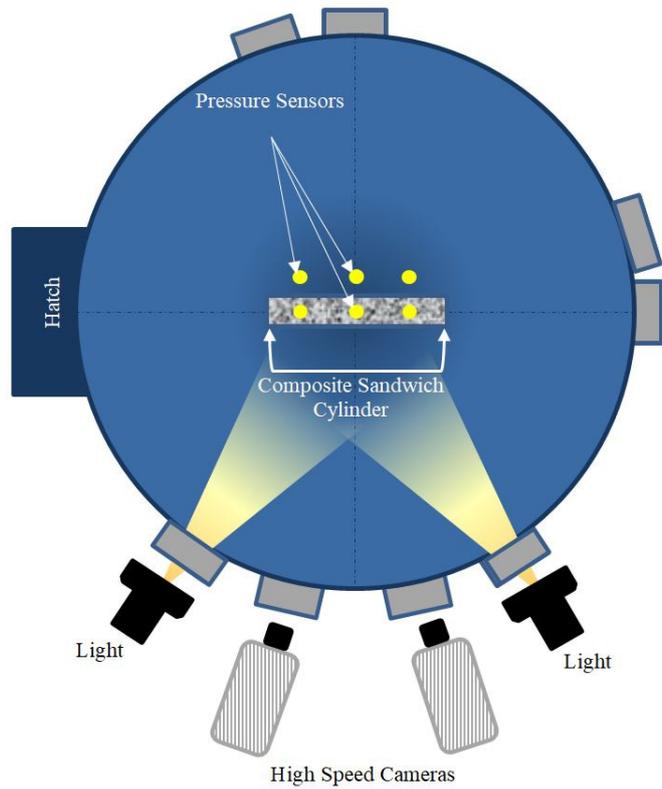


Fig. 2: Experimental facility.

3. RESULTS AND CONCLUSIONS

Experiments have been performed with increasing core foam densities. The outer and the inner tubes collapsed in all cases of the experiments performed. A typical experiment is shown in Fig. 3, showing the progressive stages of collapse of a sandwich structure with H35 foam filled core. Adding the adhesive bonding significantly increased the collapse pressures of the sandwich structures, as in the case of H35 foam filled core, where the collapse pressure was increased by 22% when compared with the case of H35 foam filled double hull structure reported by DeNardo et al [10]. Similarly, in the case of H60 foam filled core, the same comparison showed a 48% increase. As the foam density was increased the collapse pressures increased non-linearly and the improvement to the buckling strength performance was greater for the cases of higher foam densities.

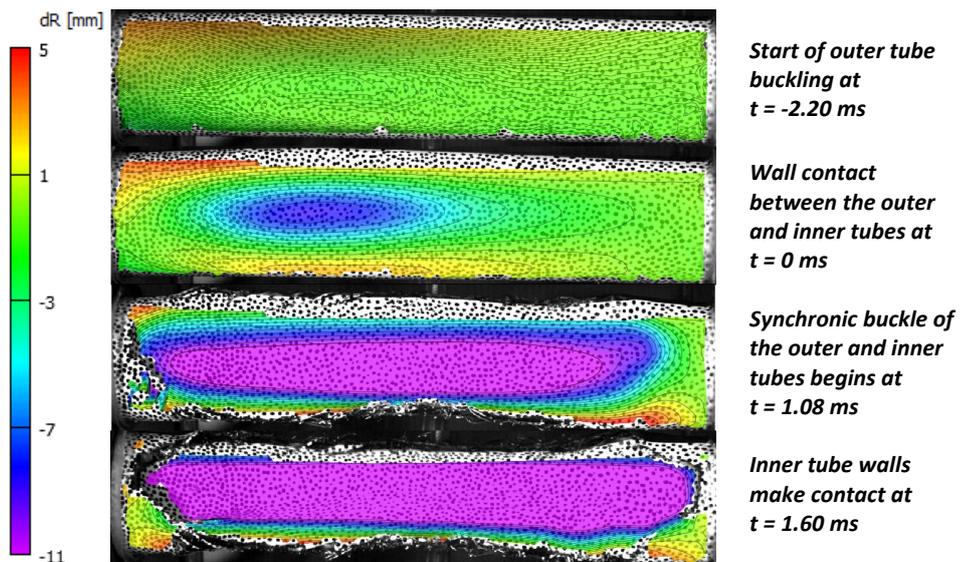


Fig. 3: dR contours (showing change in radial location of a point) of collapse of H35 foam filled Sandwich Composite Structure.

In all of cases, the outer tube as well as the inner tube collapsed in mode 3. DeNardo et al [10], reported that in cases where the inner tube imploded, they always did in mode 2. Due to the significant increase in the buckling strength there was also much greater energy in the primary collapse, i.e., collapse of the outer tube, which affected the stability of the inner tube. This indicates that the inclusion of bonding between different constituents not only increased the stiffness but also drove the collapse mode of the second tube.

4. ACKNOWLEDGEMENTS

The authors would like to acknowledge the Office of Naval Research and Dr. Yapa D.S. Rajapakse for providing financial support to conduct this research under the Grant No # N00014-17-1-2080.

REFERENCES

- [1] S. E. Turner and J. M. Ambrico, "Underwater Implosion of Cylindrical Metal Tubes," *J. Appl. Mech.*, vol. 80, p. 11013, 2012.
- [2] J.-H. Han, G. a. Kardomateas, and G. J. Simitzes, "Elasticity, shell theory and finite element results for the buckling of long sandwich cylindrical shells under external pressure," *Compos. Part B Eng.*, vol. 35, pp. 591–598, 2004.
- [3] G. A. Kardomateas and G. J. Simitzes, "Buckling of Long Sandwich Cylindrical Shells Under External Pressure," *Jam*, vol. 72, no. 4, pp. 493–499, 2005.
- [4] M. Ohga, A. Sanjeeva Wijenayaka, and J. G. A. Croll, "Reduced stiffness buckling of sandwich cylindrical shells under uniform external pressure," *Thin-Walled Struct.*, vol. 43, no. 8, pp. 1188–1201, 2005.
- [5] K. Arjomandi and F. Taheri, "Stability and post-buckling response of sandwich pipes under hydrostatic external pressure," *Int. J. Press. Vessel. Pip.*, vol. 88, no. 4, pp. 138–148, 2011.
- [6] N. G. Pegg, "Effects of impulse duration and combined impulse-hydrostatic pressure on buckling stability of cylindrical structures," *Sh. Res.*, vol. 38, no. 2, pp. 164–171, 1994.
- [7] J. M. Brett and G. Yiannakopoulos, "A study of explosive effects in close proximity to a submerged cylinder," *Int. J. Impact Eng.*, vol. 35, pp. 206–225, 2008.
- [8] C. F. Hung, B. J. Lin, J. J. Hwang-Fuu, and P. Y. Hsu, "Dynamic response of cylindrical shell structures subjected to underwater explosion," *Ocean Eng.*, vol. 36, no. 8, pp. 564–577, 2009.
- [9] M. Pinto, S. Gupta, and A. Shukla, "Study of implosion of carbon/epoxy composite hollow cylinders using 3-D Digital Image Correlation," *Compos. Struct.*, vol. 119, pp. 272–286, 2015.
- [10] N. DeNardo, M. Pinto & A. Shukla, "Hydrostatic and shock-initiated instabilities in double-hull composite cylinders", *Journal of the Mechanics and Physics of Solids*, <https://doi.org/10.1016/j.jmps.2017.10.020>