2021 DSTA dys-ta.com
16th INTERNATIONAL CONFERENCE
Dynamical Systems Theory and Applications
December 6-9, 2021, On-line

Optimization of Sandwich Structures under Blast Loading

ROMESH C. BATRA

Department of Biomedical Engineering and Mechanics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA [ORCID: 0000-0002-7191-2547]

Abstract: Sandwich structures with stiff face sheets and a soft core have high specific energy absorbing characteristics that can be used either as standalone or as bumpers to protect valuable assets. Optimization of materials of the fiber-reinforced face sheets and of the core, their thicknesses, and fiber orientations subject to constraints of given total thickness and areal mass density results in a lightweight blast-resistant design. Challenging issues include characterization of the blast wave produced by detonating a charge, clamping conditions at the edges, failure criteria for different materials, measures of energy dissipated, validation of mathematical models, verification of numerical algorithms, consideration of geometric and material nonlinearities and of uncertainties in values of various parameters, and damage initiation and progression till ultimate failure. We will present team's work completed by using an equivalent single-layer third order shear and normal deformable plate theory, Tsai-Wu failure criteria, honeybee inspired Nest Site Selection Optimization (NESS) algorithm, and the finite element method.

Keywords: Doubly-curved sandwich shell, parameter uncertainties, ANOVA, progressive damage

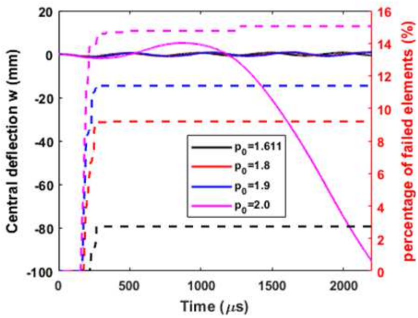
1. Introduction

Sandwich structures have wide-ranging applications in civil, aerospace and automotive industries due to their high specific stiffness, strength and tailorability of material properties. Designing them optimally against extreme loads is challenging due to complex interactions among a large number of variables involved. It requires synthesizing results of deformations found using a plate theory, computing stresses from displacemens, constitutive relations, and a stress-recovery scheme, identifying when and where a failure initiates first, progressively degrading material properties of a failed material point, and determining when a structure has collapsed. Reviewing the literature on these topics is beyond the scope of the abstract.

We have optimized transparent armor against low velocity impact using genetic algorithms [1], composite laminates with unidirectional fiber-reinforced plies for the first failure load [2] using the NESS, and one and two core sandwich structures exposed to blast loads with fiber-reinforced facesheets and either balsa wood, or honeycomb or foam core [3]. Whereas 3-dimensional (3D) deformations were anlyzed in [1], a third-order shear and normal deformable (TSNDT) equivalent single layer (ESL) theory was employed in [2] and [3] with the transverse shear stresses computed using a one-step stress recovery scheme (SRS). In all cases the failure criteria employed 6 components of the stress tensor but delamination between adjacent plies was not considered. The transparent armor was modelled as a thermo-elasto-visco-plastic material and its 3-D finite transient deformations were analyzed using the commercial finite element (FE) software, Lsdyna, with a user defined subroutine for the constitutive relation. Infinitesimal deformations of the other three structures were analyzed with the in-house developed FE software by using the Tsai-Wu failure initiation criteria and progressively degrading the material elasticities. The FEs in which the material strength had reduced to zero at all of its integration points were deleted from the analysis domain.

	Failure load (MPa)	Failure position
(1)Design j1 (non-uniform & instantaneous)		
transient	1.773	B,C (bottom surf.)
static	1.865	B,C (top surf.)
(2)Design k1 (non-uniform & rise time)		
transient	1.848	B,C (bottom surf.)
static	1.841	B,C (top surf.)
(3)Design l1 (uniform & rise time)		
transient	0.811	B,C (top surf.)
static	0.678	B,C (top surf.)

2. Results and Discussion



Referring the reader to [3] for details, results in the Table illustrate the effect of boundary conditions, inertia forces, and load distribution on the top surface of the plate. The plots in the figure show that at the collapse load the deflection of the centroid of plate's back surface rapidly increases in time when nearly 13% of the material has reached its ultimate stress.

3. Concluding Remarks

We have successfully developed an algorithm to design lightweight one- and two-core sandwich structures subjected to blast loads, and computed their collapse loads. With an increase in the uncertainty in values of material parameters from 10% to 30%, the median first failure load drops from 6.1 MPa to 5.84 MPa. The validation of the mathematical and numerical models by comparing the computed damage with the experimental one is very challenging because of several failure modes involved that cannot be accurately delineated during tests.

Acknowledgment: The financial support of the work from the Office of Naval Research through grants N000142012876 and N000141812635 with Dr. Y. D. S. Rajapakse as the Program Manager to Virginia Polytechnic Institute and State University is gratefully acknowledged.

References

[1] G. O. Antoine and R. C. Batra, Optimization of transparent laminates for specific energy dissipation under low velocity impact using genetic Algorithm, *Composite Structures*, 2015, **124:** 29-34.

[2] U. Taetragool, P. H. Shah, V. A. Halls, J. Q. Zheng, R.C. Batra, Stacking sequence optimization for maximizing the first failure initiation load followed by progressive failure analysis until the ultimate load, *Composite Structures* 2017, **180**:1007-1021

[3] L. Yuan, R.C. Batra, Optimum first failure load design of one/two-core sandwich plates under blast loads, and their ultimate loads, *Composite Structures* 2019, **224**: Art. No. 111022.

[4] L. Yuan, U. Taetragool, R. C. Batra, Optimum first failure loads of one- and two-core doubly curved sandwich shells, *AIAA J.* 2020, **58:** 3665-3679