Comparative Computational Study of Composite Sandwich Panels with Varying Auxetic Core and Orientations Subjected to Air Blast Loading

COMPARATIVE COMPUTATIONAL STUDY OF COMPOSITE SANDWICH PANELS WITH VARYING AUXETIC CORE TOPOLOGIES AND ORIENTATIONS SUBJECTED TO AIR BLAST LOADING

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Abstract
A preliminary computational study has been conducted which investigates the dynamic response of sandwich panels with cores constructed of varying cellular topologies subjected to air blast loading. Six different cells were selected for comparison. Of these, the hexagonal cell represents a conventional core topology, whereas the other five are "auxetic" geometries with negative Poisson's ratios. Following the application of a blast load, the double-arrowhead core geometry produced the lowest peak deflection.

1. Introduction

Explosions, both deliberate and accidental, pose a significant threat to the security of military personnel and civilians, as well as marine vessels, flight vehicles, government buildings, airports and other infrastructure. Following the detonation of an explosive there is a rapid reaction where explosive matter is converted into very hot, dense and high-pressure gas [1]. Explosions present an extreme loading scenario which must be carefully considered by structural designers. Assuming the blast source is sufficiently distant from the target structure, the imposed pressure over time may be represented using the Friedlander equation of exponential pressure decay (Eq. 1) [2].

$$P(t) = P_m\left(1 - \frac{t}{t_p}\right)e^{-\alpha t/t_p} \quad (1)$$

Here P_m, t_p and α describe peak pressure, positive phase duration and waveform parameter respectively. A pressure-time history is represented in Fig. 3. Modern blast protective structures must be capable of combining response mitigation and energy absorption, whilst being lightweight and preferably portable. Sandwich panels have been developed for blast protection purposes as they combine high stiffness and energy absorption capabilities with relatively low weight. Typically, a sandwich structure consists of a thick, low density core between two thin outer face sheets [3]. In recent years auxetic materials have been proposed as promising core structures under severe loading conditions, such as blast [4]. Auxetic structures are a subdivision of meta-materials which possess a negative Poisson's ratio [5]. Imbalzano et al. [6] investigated the response of auxetic cored sandwich panels under blast loading and were shown to absorb twice the amount of impulse energy, with a 30% reduction in back sheet deformation, when compared to an equivalent mass monolithic panel. More recently, Imbalzano et al. [4] further analysed sandwich panels comparing auxetic re-entrant geometry and conventional hexagonal cores. The auxetic re-entrant geometry provided enhanced impact resistance under blast loading. As a result, initial studies have shown that auxetic structures have superior energy absorbing capacity compared to standard (e.g. honeycomb) cores. As these previous studies have investigated metallic sandwich structures, this paper focuses on the development of a blast-resistant sandwich structure where the core is made from an auxetic composite metamaterial.

2. Numerical Study

The present numerical study (conducted using the Abaqus® finite element system [7]) investigates the maximum back face sheet deflection of sandwich panels under air blast loading (Fig. 1). The cellular core topologies investigated are presented in Fig 2. and include the conventional (hexagonal) unit cell and several auxetic unit cells. Table 1 outlines the geometry of the unit cells presented in Fig. 2 and used within this study. The thickness of each unit cell, t, and the thickness of the core, t_c, remained constant at 1 mm and 30 mm. Each panel is a square with sides of equal length, 250 mm. Each face sheet was composed of four 0.25 mm thick, carbon fibre reinforced polymer fabric (0°/90°) layers. Ply properties used within this study are E_1 = 70 GPa, E_2 = 70 GPa, G_{12} = 5 GPa, G_{13} = 5 GPa, G_{23} = 31.8 GPa, ν_{12} = 0.1 and ρ = 1600 kg/m^3 [8]. The core was constructed from 3-D printed carbon fibre with material properties: E_c = 54 GPa, ν_c = 0.35 and ρ_c = 1400 kg/m^3 [9] in the loading direction (z-axis).

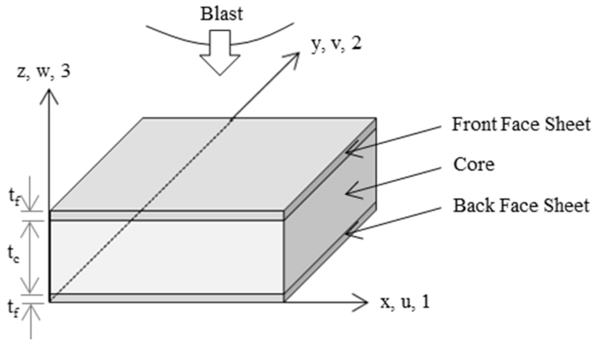

Figure 1. Geometry of Sandwich Panel.

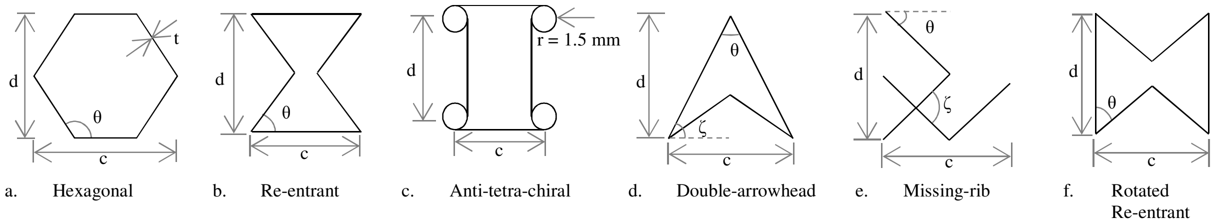

Figure 2. Schematic diagram unit cell topologies.

A uniformly distributed pressure load (Eq. 1) was applied to the front face sheet. Within this study a blast was simulated where P_m, t_p and α are 2 MPa, 0.0018 seconds and 0.35, respectively. The duration of the pressure loading was 0.05 seconds. The edges of the front and back face sheets were simply supported, thus restricting displacement and allowing rotation of edge nodes. A perfectly bonded core-to-face sheet interface was assumed and surface-to-surface tie constraints were applied to connect the front face sheet to the core, and the core to the back face sheet. Quadrilateral shell elements with four nodes (S4R) and reduced integration were used to model both the core and face sheets, with five integration points through the geometry thickness. A mesh convergence study was conducted by analysing maximum panel deflection.

Table 1. Geometry and mass of panel compositions.

Cellular Topology	Panel Name	Mass m (kg)	Geometry θ (°)	ζ (°)	c (mm)	d (mm)
a. Hexagonal	HC_125	0.68	125	N/A	16.0	10.0
	HC_145	0.77	145	N/A	16.0	10.0
b. Re-entrant	RE_35	1.26	35.0	N/A	16.0	10.0
	RE_55	0.85	55.0	N/A	16.0	10.0
c. Anti-tetra-chiral	CH	1.16	N/A	N/A	9.00	9.00
d. Double-arrowhead	DA_45	1.29	45.0	67.5	10.0	12.1
	DA_60	1.06	60.0	60.0	14.0	12.1
e. Missing-rib	MR_45	0.94	45.0	90.0	10.0	10.0
	MR_60	1.24	60.0	120	5.77	10.0
f. Rotated Re-entrant	RR_55	1.24	55.0	N/A	10.0	8.80

3. Discussion of Results

The applied pressure loading over time is presented in Fig. 3. Following the application of pressure loading, each panel deflect towards the – z axis and begins to oscillate about its rest position. Fig. 4 presents the peak displacements of each panel measured at the central point of the back face sheet during the blast loading. Certain auxetic panels provide significant reduction in the back sheet deflection with the exception of MR_45 (whose mass was lower than MR_60). The DA_45 panel outperformed others with the lowest peak displacement value of -0.73 mm, as shown in Fig. 4. This was due to the high density packing of the repeated cells and therefore a greater overall panel mass. Auxetic cellular structures experience internal flexural deformation under the applied pressure, resisting deflection. The associated angle, θ, influences back sheet displacement. By increasing θ of the missing rib and hexagonal models, the maximum absolute deflection decreased. Conversely, by increasing θ of the re-entrant and double-arrowhead, displacement increases. It can be observed that auxetic cellular units provide comparable performance to the conventional honeycomb.

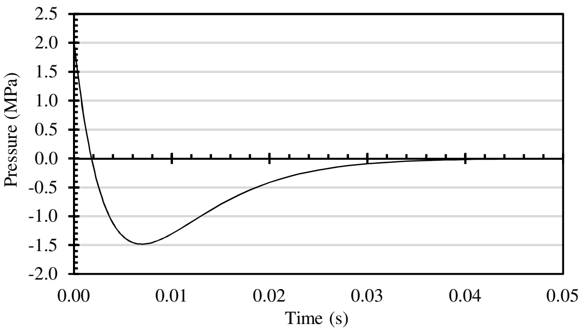

Figure 3. Applied blast load from Friedlander equation of exponential pressure decay.

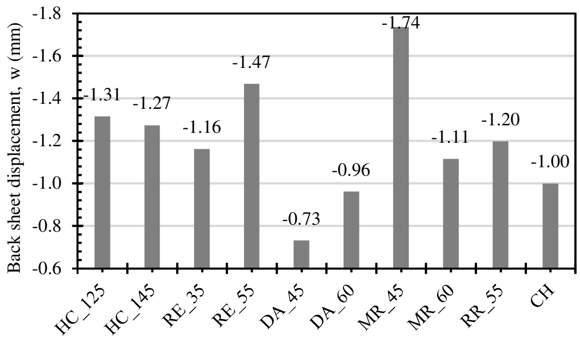

Figure 4. Maximum displacement of back face central position.

In Fig. 5, the peak back sheet displacement is presented with increasing peak pressure loads for CH, DA_45 and RR_55 (whose masses = 1.2 kg ± 0.1 kg). As expected, with increasing peak pressure, the maximum absolute back deflection increases. The DA_45 panel remained most effective at minimising the peak displacement. When $P_m = 10$ MPa the DA_45 provides a 68.0% and 44.7% reduction in absolute peak displacement over the CH and RR_55 panels respectively.

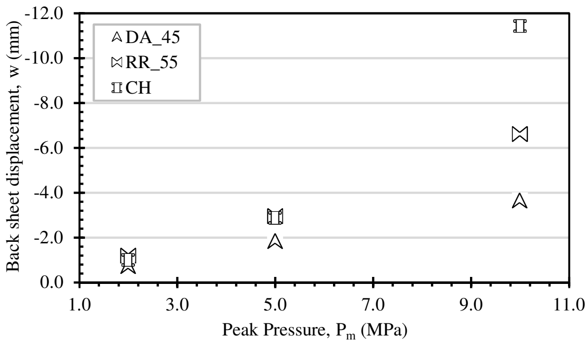

Figure 5. Maximum back sheet displacement with increasing peak pressure load.

4. Conclusions and Further Work

A preliminary computational study investigating the use of auxetic structures within sandwich panels under blast loading has been conducted. Varying core topologies were analysed under air blast loading. The critical parameter under investigation was peak displacement of the back face sheet. The results obtained suggest that auxetics provide interesting and promising structures under severe loading scenarios where the nature of their response is dependent upon geometry and the associated cell angle. The panel which provided the lowest absolute maximum deflection was the DA_45 where peak displacement = -0.73 mm. By increasing the peak pressure, the maximum displacement of the panel increases. The DA_45 panel again provides the greatest protection from blast in terms of maximum absolute displacement. This numerical model will be extended to investigate the evolution of damage in the core and face sheets under larger loading scenarios and include geometric optimisation of each unit cell. Further work will involve validation of this study using experimental air blast loading of 3D printed sandwich panels.

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