Composite Structures 183 (2018) 242–261

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Blast resistance of auxetic and honeycomb sandwich panels: Comparisons and parametric designs

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ARTICLE INFO

Article history:
Received 14 November 2016
Revised 22 January 2017
Accepted 6 March 2017
Available online 8 March 2017

Keywords:
Auxetic
Honeycomb
Blast resistance
Composite sandwich
Finite-element simulation
Negative Poisson's ratio

ABSTRACT

Equivalent sandwich panels composed of auxetic and conventional honeycomb cores and metal facets are analysed and compared for their resistance performances against impulsive loadings. The dynamic behaviours of these structures are numerically investigated, taking into account the rate-dependent effects. The Johnson-Cook model is employed to describe the dynamic responses of the composite sandwiches subjected to high strain-rate loadings. Analytical models are derived correlating unit cell geometrical parameters and crushing strengths of the representative panels at different impact velocities. Parametric studies are conducted to evaluate the performances of different sandwich panel designs under impulsive loadings. In particular, transmitted reaction forces and maximum stresses on the protected structure are quantified for various design parameters including the geometrical factors and the effective Poisson's ratios. A quarter of the panel is symmetrically modelled with shell elements and the CONWEP model is used to simulate the blast loading. Auxetic panels demonstrate interesting crushing behaviour, effectively adapting to the dynamic loading by progressively drawing material into the locally loaded zone to thereby enhance the impact resistance. Meanwhile, conventional honeycomb panels deform plastically without localised stiffness enhancement.

1. Introduction

Nowadays, the importance of smart materials and structures for energy-absorption in extreme events is growing more and more. Moreover, the design of structures both light in weight and able to mitigate both blast and localised impacts is a complex challenge [1–8]. The use of auxetic structures –i.e. characterised by negative Poisson's ratio– is an interesting opportunity to solve all these issues. These auxetic materials present an interesting and unique behaviour; they contract when compressed and expand if stretched [9]. Consequently, many mechanical properties, such as fracture toughness, indentation resistance, shear modulus and vibration absorption show enhanced performances [10–13].

Negative Poisson's ratio materials and structures have been investigated for protective purposes since their discovery. Many researchers looked into the behaviour of auxetic and conventional foams, demonstrating that auxetic foams present higher yield strength, lower stiffness and better energy absorption [14–19]. Other studies of auxetic structures in composite panels demonstrated improvements in static indentation, specifically in terms of stiffness, low impact velocities and resistance to fibre pull-out with localisation of damage, therefore overall requiring less maintenance [20]. Sandwich panels with certain auxetic cores have been analysed under static and dynamic loadings, including blast-induced shockwaves. Reduction of deformation, localisation of damage [21–23], better flexure response [24,25] –with lower effective shear modulus and higher maximum effective shear strain and better energy absorption have been obtained in different studies [21,22,26–30].

In general, cellular structures have shown better properties than the conventional monolithic materials, such as higher strength to weight ratio and energy absorption [31]. It is necessary to understand the benefits of auxetic composite panels compared to typical honeycomb composite structures for their performances against extreme loadings. Honeycomb structures have been used in a wide range of applications, from shock absorption to high temperature dissipation [31–34]. Specifically, they have been used for structural applications, due to their impact resistance and energy absorption properties. Analytical [35,36], experimental [37,38] and numerical [39,40] studies have been conducted to evaluate their mechanical behaviours. In-plane behaviour has also been

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http://dx.doi.org/10.1016/j.compstruct.2017.03.018
0263-8223/

investigated [36,39,41–45], where analyses show the importance of the cell-wall geometrical configurations.

The design and manufacture of lightweight composite structures for protective purposes has been a main interest for both defence and civilian applications, such as the protection of critical infrastructures or light weight armoured vehicles (Fig. 1). The sandwich structure, which is composed of crushable cores between two monolithic facet panels, is one of the most effective approaches for blast and impact protection. The frontal panel helps to distribute the impulsive load over the crushable core, dissipating a large amount of imparted energy, slows the shockwave and, therefore, prevents critical failure. A large number of studies on sandwich panels showed their better performance when compared with monolithic structures of similar areal mass [33,44,46–49].

From the manufacturing perspective, the 2D-based structures are simpler and less expensive to fabricate [50–52] compared to the three dimensional ones. In order to manufacture a 3D truss-lattice structure, more complex design processes are required, such as 3D printing or deformation forming –with perforated sheets punched to obtain the right shape. Instead, it is possible to manufacture these 2D composite panels through stamping or profile-rolling of sheet-metal blanks [27], slotting together steel sheets [53] or 3D printing. As the manufacturing process can be complex and expensive, the necessity of developing an initial design and understanding the dynamic responses of the hybrid auxetic composite sandwich panels is paramount.

In this paper, we will develop a numerical model to simulate hybrid auxetic composite sandwich panels under blast loadings and we will show a comparison with a conventional honeycomb sandwich panel. The well-known 2D re-entrant NPR structure [10] will be used and modelled in multiple layers for the core, and sandwiched between two metallic facets. Numerical models will be validated with analytical results. The last section will present a comparison of auxetic and conventional structures and some parametric studies on their geometric parameters to observe and explain their effect on blast resistance performance.

2. Numerical model

2.1. Unit cell descriptions

The two different types of unit cells investigated in this work are presented in Fig. 2. In particular, the honeycomb unit cell (HU) is one of the most typical cellular structures (Fig. 2b), while the auxetic unit cell (AU) with a re-entrant shape (Fig. 2a) is considered as the most popular structure exhibiting negative effective Poisson's ratio. Both structures have simple designs, which make them easier to manufacture and maintain at minimum cost. Due to the cellular structures, these panels are able to withstand large

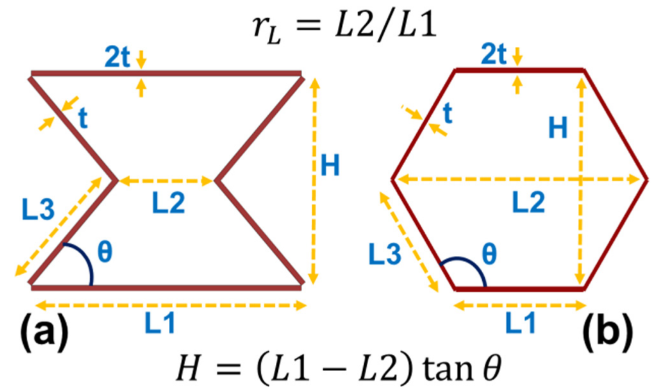

Fig. 2. Schematic design of 2D auxetic unit cell (AU) (a) and honeycomb unitcell (HU) (b).

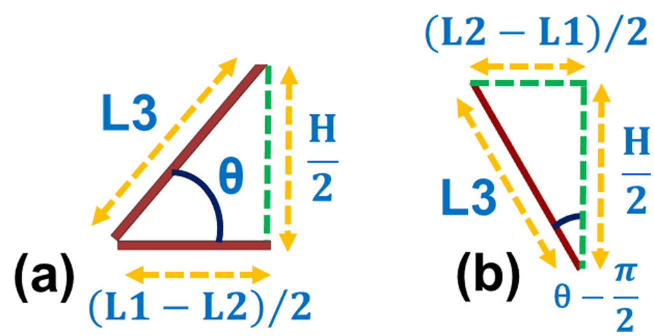

Fig. 3. Internal trigonometric relations of 2D auxetic unit cell (AU) (a) and honeycomb unitcell (HU) (b).

deformations, providing effective protection against extreme loads. Their simple geometries also allow a straightforward optimisation process through modifying geometrical parameters and material selections, given the total weight and thickness constraints.

Both unit cell configurations are characterised by the angle θ (from 30° to 70° for AU and from 120° to 160° for HU), the height H and the length ratio, $r_L = L_2/L_1$, (varying between 0.3 and 0.7 for AU and 1.5 and 3.5 for HU). The baseline AU shown in Fig. 2a is characterised by θ = 50°, H = 20 mm and r_L = 0.5, while the baseline HU shown in Fig. 2b is characterised by θ = 120°, H = 20 mm and r_L = 2.0. The thickness of the shells is denoted as t. These dimensions are chosen to prevent early internal contact, enabling the auxetic behaviours at large strains for the AU panels. The total height of the panel is constrained at 100 mm throughout this study. The length and width of the investigated panels are also fixed at 500 mm. The relative density, ρ^* –i.e. the ratio between

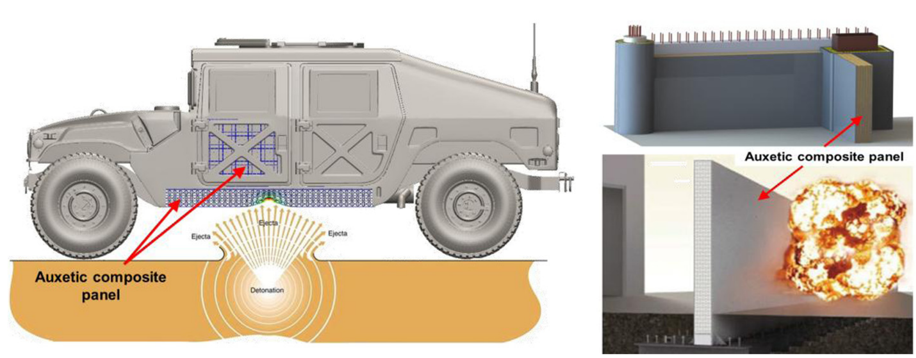

Fig. 1. An application of lightweight hybrid auxetic composite panels to improve the blast resistance of armoured vehicles and protective structures.