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Experimental study on the dynamic response of foam-filled corrugated core sandwich panels subjected to air blast loading

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ABSTRACT

Effective approaches to enhance the blast resistance of sandwich structures with corrugated cores were developed by adopting three different strategies to fill the spaces within cores with polymeric foam. The baseline unfilled panels and foam-filled panels were designed and fabricated, and finally subjected to air blast loading generated by detonating cylindrical explosive. Deformation modes and failure mechanisms of tested panels were investigated. Experimental results demonstrated that the panels with back side filling strategy did not show better blast performance compared with the unfilled panels, even though extra weight was expended due to the addition of foam fillers. The panels with front side filling and fully filling strategies encouragingly appeared to possess desirable blast resistance to prevent severe fracture under high intensity blast loading. This benefit should be attributed to the sufficient crushing deformation of foam fillers and the enhanced buckling resistance of core webs. In addition, a preliminary study has been conducted to investigate the effects of front face thickness on the blast performance of foam-filled panel. Attempts of allocating component mass and filling different material have been made to explore the potential of performance improvement.

1. Introduction

Sandwich structures, a type of innovative lightweight load-bearing structures, are widely applied in aerospace, building, marine and railway industries due to their high specific strength and stiffness, and good energy absorption potential [1–6]. These structures consist of two strong, stiff, thin face sheets and compressible cellular cores. In recent years, different kinds of micro-architectured materials have been developed to use as cores in sandwich structures. The commonly used cores of sandwich panels can be classified macroscopically into two groups, namely continuous (e.g., wood or metallic foams [7]) and discrete (e.g., honeycombs [8–12], prismatic trusses [13,14], and lattice trusses [15–17]) ones. It is well known that the benefits of sandwich structures depend on the properties of the base materials used to build them, the topology features of core, and the mass allocation between the faces and core.

Sandwich construction has been recognized as a promising concept to protect structures from the high intensity impulsive loads created by explosions in air or water [4,18]. Theoretical studies by Xue and Hutchinson [13,15], Fleck and Deshpande [19], and Qiu et al. [20,21] have shown that a well-designed sandwich beam and plate have attractive improvements in shock resistance relative to the monolithic counterpart of the same mass. They mainly arise from three beneficial effects: i) a fluid structure interaction (FSI) effect which can reduce the momentum impulse transmitted to the blast-loaded structures, ii) plastic energy absorption in the cellular core by crushing deformation, iii) the increased bending resistance due to the sandwich construction. Furthermore, subsequent experimental studies on the blast performance of sandwich structures with discrete cores, have confirmed the advantages and shown significant reductions in permanent deflections of sandwich structures compared with monolithic counterparts [9,17,22]. Jing et al. [23] conducted a series of experiments to investigate the shock resistance performance of sandwich panels with different cellular metallic cores, and drew a

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comparison with the monolithic plates. Results revealed that the aluminum honeycomb core sandwich panels are the best ones in terms of the permanent maximum deflection of back face. However, from the literature survey, it is seen that the sandwich structures fail to accomplish the task of keeping the structural integrity when the impulse intensity of shock wave is extremely high. Due to the inertially strengthening effect of truss members, the pyramidal lattice core sandwich panels are likely to undergo face sheet perforation deformation at the nodal attachments [17]. For the Y-frame and corrugated core sandwich plates under the high intensity simulated blast loading, visible tears were observed on the front face of the as-tested panels as a result of stress concentrations at the attachment points between the core and face sheets [24]. Efforts to reveal the deformation mechanisms underlying the blast performance of corrugated core sandwich panels also demonstrated that sandwich panels may fail catastrophically at lower values of blast loading compared with monolithic plates of equal areal mass [22,25]. Therefore, it is essential to exploit effective approaches for further improving the blast resistance of sandwich panels without heavy mass expense.

For the sandwich panels with foam cores, the blast performance can be improved by adopting an optimal stepwise graded foam core [26] or inserting ductile interlayer between the face sheets and foam core [27]. The sandwich panels with cellular cores have significant empty space within the core. So, a desirable envision to enhance the blast resistance of sandwich structures with cellular cores can be achieved by filling all or a part of this empty space with metallic or polymeric foams. This is a powerful way to combine the advantageous attributes of two different core materials to construct the so-called hybrid sandwich structures [28,29]. Recently researches revealed that the hybrid sandwich structures have some superior mechanical properties under static and dynamic loads [30–42]. It is inspiring that the foam filling could greatly increase the strength and energy absorption capability to levels larger than the sum of those of an empty corrugated core sandwich panel and the aluminum foam tested under compression separately [30]. The benefit should be attributed to the lateral support to the core members by foam filling. The existence of foam in hexagonal honeycomb rendered smaller space for the deformation of core walls, thus the foam filling resulted in both increase of number of folds and regularity of deformation [31,32]. For the foam-filled lattice composite panels under quasi-static axial compression loading, the foam filling can also restrict the local buckling of lattice webs, and thus the compressive strength of panels can be improved significantly [33]. Foam insertions also took positive effects on the bending resistance of hybrid panels. For instance, relative to the unfilled corrugated sandwich beams under three-point bending loads, aluminum foams filling led to a clear increase in bending stiffness, initial failure load, peak load, and the sustained load-bearing capacity after peak failure [34]. Recent four-point bending experiments demonstrated that the foam-filled lattice composite sandwich panels offer a notable merit in ultimate flexural capacity relative to the traditional sandwich panels with sole foam cores [35]. However, the reinforced stiffness of foam filled sandwich panels can lead to a slightly increased impact load on foam-filled specimens under low-velocity impact scenarios [36]. The ballistic performance of pyramidal truss lattice sandwich structures can be significantly enhanced by using the hard, and brittle ceramics as fillers. Part of kinetic energy of projectile can be dissipated by the comminuting and dilating of ceramic inserts [39,40]. Preliminary numerical assessment of the role of polymeric foams filling the interstices of the cores on the blast performance of honeycomb and corrugated core sandwich plates indicated that there is no clear advantage or disadvantage implemented by foam filling for structural purpose [41]. However, recent experimental and numerical studies have shown that the blast resistance of the corrugated core sandwich structures could be generally enhanced from the addition of foam filling, due to the improvements of buckling resistance and bending rigidity of the foam-filled corrugated core [42].

Inspired by the above researches, this study aims to evaluate the possible use of polyvinyl chloride (PVC) foam as filler to enhance the blast resistance of stainless steel corrugated core sandwich panels. Three filling strategies used to fill the empty space within the core were proposed. For comparison, the empty (unfilled) corrugated core sandwich panels were used as the baseline. The baseline unfilled panels and foam-filled panels were designed and fabricated, and finally subjected to air blast loading generated by detonating cylindrical TNT explosive of 55 g. Two stand-off distances (viz. 50 mm and 100 mm) were adopted to make a comprehensive evaluation of the influences of filling strategies on blast performance of panels. All tested panels were taken post-mortem examination to investigate the deformation/failure mechanisms underlying the overall response.

2. Panel design and fabrication

2.1. Design concept

The sandwich panel concept explored here is schematically illustrated in Fig. 1. The panel cores were assembled from a stainless steel corrugated sheet and prismatic, closed cell polymer foam inserts to form a hybrid metallic corrugation/foam-cored sandwich panel. The foam inserts serve the purposes of providing the supporting of core webs and the impact energy storage during subsequent blast tests.

The interstices of corrugated core were purposefully filled with polymer foam, aiming at exploiting a structure with superior blast mitigation performance. The empty (unfilled) corrugated core sandwich panels (see Fig. 2(a)) were identical to those used in Zhang et al. [43]. Here, they were considered as the baseline. Three different core filling strategies used in the study are schematically shown in Fig. 2(b)-(d). Fig. 2(b) displays unit cell profile of the sandwich panels with the polymeric foam prisms filling the back side empty space (enclosed by the back face sheet and corrugated core webs). The front side filled sandwich panels (see Fig. 2(c)) can be characterized as a hybrid panel with the front side empty space (enclosed by the front face sheet and corrugated core webs) filled with polymer foams. For the fully filled specimens, all interstices in core were filled with polymer foams, as shown in Fig. 2(d). The sample coding method used in the following sections is illustrated here. The code name of empty corrugated core sandwich panel is **EP**. These foam filled samples are named **BSFP**, **FSFP** and **FFP**, corresponding to the panels with back side filling, front side filling and fully filling strategies, respectively.

The face sheets and corrugated cores of the sandwich panels

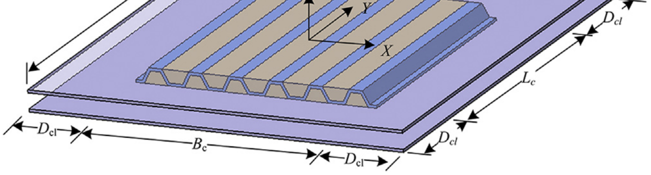

Fig. 1. Schematic of the polymeric foam fully filled corrugated core sandwich panel.
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