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Response of aluminium corrugated sandwich panels under air blast loadings: Experiment and numerical simulation

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ABSTRACT

Corrugated sandwich panels are widely used in various fields because such panels have lower density, easier fabrication methods and higher strength compared with monolithic plates. In this study, the dynamic response of corrugated sandwich panels under air blast loading was investigated using a ballistic pendulum system. Two configurations of the specimen were considered. The residual deflection of the back face sheet and the deformation/failure modes of the sandwich panel under different impulse levels were analysed. Finite element simulations were performed by using AUTODYN. The deformation process and energy absorption of the face sheets and the core were investigated in the numerical simulation.

1. Introduction

Metallic sandwich structures are extensively applied in various fields, such as aerospace, marine and railway systems, because these structures have low density, high strength and good energy-absorbing capability [1,2]. Thus, the dynamic response of sandwich structures must be investigated fully.

Numerous studies have been conducted on the quasi-static or dynamic mechanical properties of sandwich structures. Fleck [3] and Qiu [4,5] theoretically studied the sandwich beam and plate using the rigid-plastic assumption model, in which the response of the sandwich beam and plate can be split into three stages: fluid–structure interaction, core compression and structural dynamic response. Hutchinson [6] and Xue [7,8] compared the impact resistance of metallic sandwich plates and solid plates with the same weight. By using face sheet thickness, cell size and the relative density as design parameters, an optimal design was developed for the pyramidal truss and honeycomb sandwich panels. Nurick et al. [9,10] used a ballistic pendulum to investigate the response of circular honeycomb sandwich plates under blast loads and discussed the failure modes of the face sheet and the core. Zhu et al. [11] carried out dynamic tests to study the dynamic response of honeycomb sandwich panels under air blast loadings. Different deformation/failure patterns were obtained through the test. Shen et al. [12] used similar methods to investigate the response of aluminium foam sandwich curved panels under air blast loadings. Cui et al. [13] tested the metallic lattice sandwich panels under air blast loadings and found that tetrahedral lattice sandwich structures exhibited better impulsive resistance than hexagonal honeycomb sandwich plates. Jing et al. [14] investigated the deformation/failure modes of dynamically loaded sandwich beams. Large inelastic deformation, face wrinkle and core shear with interfacial failure were reported. Sohrab et al. [15,16] studied the failure mechanisms of corrugated all-composite sandwich structures at a quasi-static strain rate and pointed out that monolithic core members become stockier and more resistant to buckling as the density of the core increases, consequently diminishing the benefits of the hierarchical structure. Rubino et al. [17–19] investigated the dynamic behaviour of sandwich structures with Y-frame and corrugated cores. The results indicated that at high levels of projectile momentum, Y-frame and corrugated core sandwich beams of equal mass have similar dynamic performance in terms of back face deflection, degree of core compression and strain level. Liang et al. [20] optimised metallic sandwich panels with corrugated cores, which were subjected to blast loads by using the corrugation leg, corrugation angle, face sheet thickness, core thickness and corrugation pitch as design variables; the optimisation was performed using the Feasible Direction Method (FDM) coupled with the Backtrack Program Method (BPM). However, the existing studies are primarily concerned with

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numerical or analytical modelling, and few experimental investigations have been conducted on the blast-resistance of corrugated sandwich panels.

In the current study, a four-cable ballistic pendulum system was used to investigate the dynamic response of square corrugated aluminium sandwich panels under blast loads. Corrugated cores with two dimensions were considered. Finite element simulation was performed to study the response processes of the panels in detail, including deformation process and energy absorption of the face sheets and the core.

2. Experiment

2.1. Experimental procedure

The corrugated sandwich panels used in the experiments were supplied by Liming Honeycomb Composites Co., Ltd (Shenzhen, China). The face sheets and core were joined together with the hot melt adhesive membranes as shown in Fig. 1. In contrast to sandwich structures having honeycombs or metallic foams as the cores, corrugated sandwich panels present the following advantages: (1) the corrugated core can be easily processed; and (2) the face sheets exhibit high resistance to tension because of the continuous contact between the face sheets and the core. Thus, the corrugated sandwich panels are extensively applied in building design.

The face sheets and the core were made of AL-1200H18, and the mechanical properties are specified as follows: density $\rho = 2.71 \times 10^3$ kg/m^3, Young's modulus $E = 70$ Gpa, Poisson's ratio $\lambda = 0.33$, tensile strength $\sigma_b = 210$Mpa, yield stress $\sigma_{0.2} = 140$ Mpa. Fig. 1 shows the sketch of the sample. Two specimen configurations with different core dimensions (Table 1) were tested.

A four-cable ballistic pendulum system was employed to measure the impulse applied on the specimen. Details on the system can be obtained from the literature [11]. The system was composed of clamp frames, a steel beam and counterweight balance, and the system was suspended using four wire ropes, as shown in Fig. 2(a). The specimen was clamped to the frame by mounting 16 screws on the front of the pendulum. The explosive charge and detonator were mounted in front of the specimen. A laser displacement sensor (Micro-Epsilon LD1625-200) was installed behind the pendulum system to measure the translation of the pendulum. The impulse exerted on the front face of pendulum can be calculated from the recorded oscillation amplitude, and the effective impulse on the specimen can be further estimated from the exposed area of the specimen. A typical time–displacement curve measured by the sensor is presented in Fig. 2(b). The specimens were cut into square shape with dimensions of 300 mm × 300 mm, and the area exposed to the blast had dimensions of 250 mm × 250 mm.

2.2. Test results

Eight tests were conducted to test corrugated sheets with two different geometries. The results were analysed in terms of two

Table 1
Dimensions of the corrugated sheet used in the experiment (Unit: millimetres).

Configuration	H_f/Face sheet thickness	H_c/Core height	t/Core thickness	Length/ a	Length/ b	θ	Cell length/s
1	0.8	4	0.2	4	8	63.4	12
2	0.8	8	0.2	7	14	66.4	21

aspects: (1) residual deflection of the back face sheet (Section 2.2.1); and (2) failure modes of face sheets and the core (Section 2.2.2).

2.2.1. Residual deflection of the back face sheet

The maximum residual deflections of back face sheets under different impulses are listed in Table 2. As shown in Table 2, the impulse exerted on the specimen increases with increasing TNT mass and decreasing distance between the panel and TNT, and the residual deflections of back face sheet increases with the increasing of impulse. For configuration 1, when the impulse increases from 11.8 NS to 23.8 NS, the residual deflection increases by 221.4%. Meanwhile, for configuration 2, when the impulse increases from 13.2 NS to 26.7 NS, the residual deflection increases by 183.4%.

2.2.2. Failure modes

The failure modes of the face sheet and the core are discussed in this section.

i Failure modes of face sheets

Typical failure modes of the specimens under two impulse levels are shown in Figs. 3 and 4. No pitting failures were observed [11], and only global plastic deformations were produced. The topology of the panel reveals that the continuous support by the core provides the panel with a high resistance to tension. Consequently, cracks and tears can hardly occur on the face sheet. As shown in Fig. 3, as the explosive charge became closer to the panel ($R = 100$ mm), burn marks appeared at the centre of the front face sheet, and small tears were observed on the front and back face sheets. Meanwhile, as shown in Fig. 4, as the distance between the charge and the panel increased ($R = 200$ mm), no burn marks and tears were observed on the face sheet, although the charge mass and impulse increased as well.

Wrinkles can be observed in the boundary regions. As shown in Fig. 1, bending stiffness along the X-direction is higher than that along the Y-direction. Thus, the folding first takes place at the centre of boundary along the Y-direction.

ii Failure modes of the core

A typical failure mode of the core is plotted in Fig. 5. The entire panel can be divided into three regions as follows:

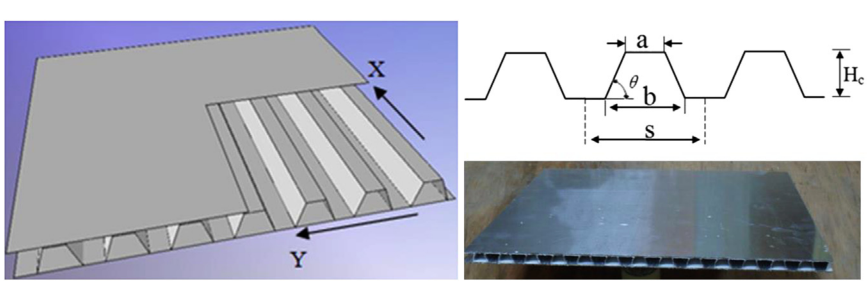

Fig. 1. Sketch of the specimen.