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A numerical simulation of the blast impact of square metallic sandwich panels

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ABSTRACT

This paper presents details and brief results of an experimental investigation on the response of square metallic sandwich panels with a cellular core under blast loading. Based on the experiments, corresponding finite element simulations have been undertaken using the LS-DYNA software. Detailed description of the models and simulation results is presented. In the simulation work, the loading process of explosive and response of the sandwich panels have been investigated. The blast loading process includes both the explosion procedure of the charge and the interaction with the panel. The structural responses of sandwich panels are studied in terms of two aspects: (1) deformation/failure patterns of the specimens; and (2) quantitative assessment, which mainly focuses on the permanent centre point deflection of the back face of the panels. In addition, a parametric study has been carried out to examine the contribution of plastic stretching and bending on the deformation history of the sandwich panels, as well as the effect of boundary conditions. A good agreement has been obtained between the numerical and experimental results, and thus the proposed FE model can be considered as a valuable tool in assessing and understanding the deformation/failure mechanism and predicting the dynamic response of square metallic sandwich structures subjected to blast loading.

1. Introduction

Metallic sandwich panels with a cellular core such as honeycomb have the capability of dissipating considerable energy by large plastic deformation under static or dynamic loading. The cellular microstructures offer the ability to undergo large plastic deformation at nearly constant nominal stress, and thus can absorb a large amount of kinetic energy before collapsing to a more stable configuration or fracture [1–3]. The responses of sandwich structures loaded by impact at a wide range of velocities have been extensively studied and documented in detail in the literature [4–7]. In recent years, increasing attention of both engineering communities and government agencies has turned to the resistance of sandwich structures subjected to blasts, due to enhanced chance of blast threats.

To date, the research on the performance of impulsively loaded sandwich structures is still very limited. A series of analytical models have been developed by Fleck and co-workers, to predict the dynamic response of a sandwich beam or circular sandwich panel under a uniform shock loading [8,9], or under a localised loading over a central patch [10,11]. Qiu et al. [12] and Xue and Hutchinson [13] conducted corresponding numerical simulations to validate these theoretical models. However, very few studies have been reported on square sandwich panels subjected to blast loads [14].

To investigate the behaviour of impulsively loaded square metallic sandwich panels, a large number of experiments have been conducted, and the experimental results were presented and discussed in detail in a separate paper [15]. Based on the experiments, corresponding finite element simulations were conducted using LS-DYNA software, and the simulation results are reported and discussed in this paper. In the simulations, the process of blast loading and response of sandwich panels are investigated. The blast loading process includes the detonation procedure of charge as well as its interaction with the panel. The structural response of sandwich panels are investigated in terms of two aspects: (1) deformation/failure patterns of specimens as observed in the tests; and (2) quantitative assessment, which is related to the permanent centre point deflection of back face. Finally, a parametric study is carried out to examine the contribution of plastic stretching and bending on the deformation history of the sandwich panel back face, as well as the effect of boundary conditions.

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2. Experimental procedure and results

The experimental procedure and results are briefly reviewed in the following two sub-sections.

2.1. Experimental procedure

The specimens used in the tests consist of two face-sheets and a core of honeycomb structure. The face-sheets were made from Al-2024 aluminium alloy, which was processed by annealing. The HexWeb® aluminium honeycomb core (made from Al-5052 and Al-3104 aluminium alloys) [16] comprises a 2D square array of hexagonal cells. A single honeycomb cell includes two critical geometric parameters, that is, cell length (l) and wall thickness (t), as indicated in Fig. 1(a); while (b) shows the geometry and dimension of sandwich panels, in which the side length (L) and thickness of core structure (c) are constant and equal to 310 mm and 12.5 mm, respectively. The face-sheets were manufactured with three different thicknesses (f): TN ($f=0.5$ mm), MD ($f=0.8$ mm) and TK ($f=1.0$ mm). The total number of specimens tested is 42.

The 310 mm × 310 mm sandwich panels were peripherally clamped between two square steel frames. The frame and whole clamping device are shown in Fig. 2(a) and (b), respectively.

In the experiments, a four-cable ballistic pendulum system was employed to measure the impulse imparted on the specimen as shown in Fig 3. The frames were clamped on the front face of the pendulum, and the charge was fixed in front of the centre of the specimen using an iron wire with a constant stand-off distance of 200 mm. With a TNT charge detonated in front of the pendulum face, the impulsive load produced by explosion would push the pendulum to translate. Based on the oscillation amplitude recorded by a laser displacement transducer, the impulse on the specimen can be further estimated. Another sensor known as PVDF pressure gauge, was mounted at the centre of the specimen's front face to measure the pressure–time history at this position. The whole process of explosion and loading was also recorded using a high speed video camera.

2.2. Experimental results

The experimental results were grouped into two categories: (1) the deformation/failure patterns of specimens observed in the tests; and (2) the measured/calculated quantitative results, i.e. the permanent centre point deflection of back face. It is shown that the face-sheets of all specimens exhibit large inelastic deformation, named Type I failure, which has been observed on monolithic beams and plates [17,18]. On the other hand, the deformed honeycomb core shows a progressive

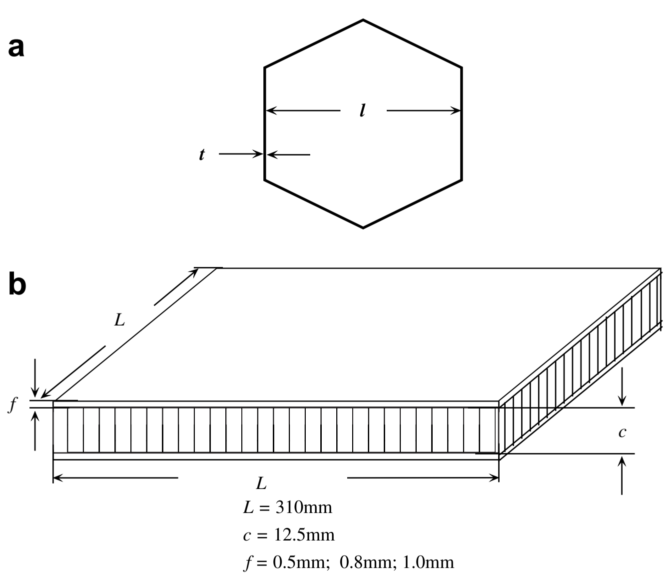

Fig. 1. Geometry and dimension of the specimen: (a) geometry and dimension of a single cell; (b) geometry and dimension of a square sandwich panel.

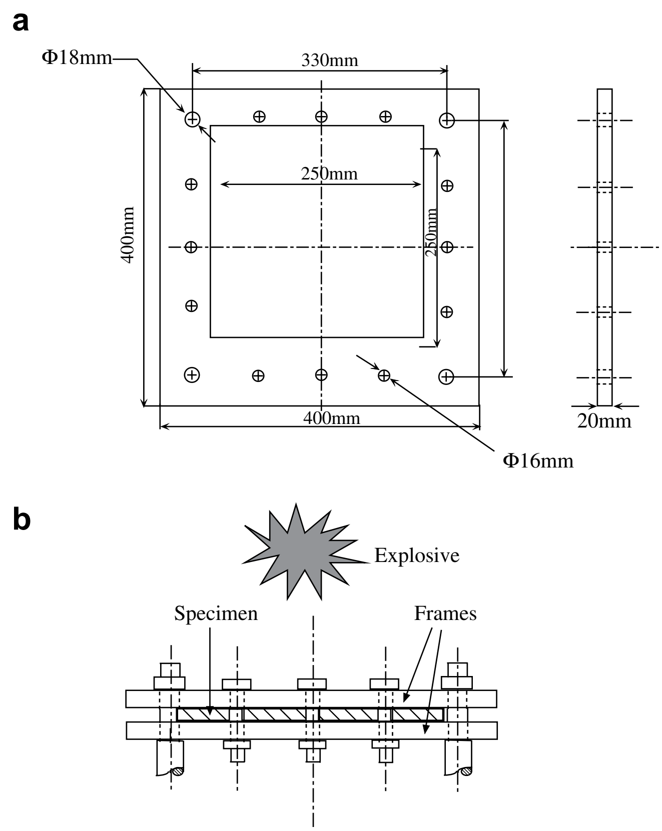

Fig. 2. Sketches of the steel frames and clamping device: (a) sketch of the frame; (b) sketch of the clamping device.

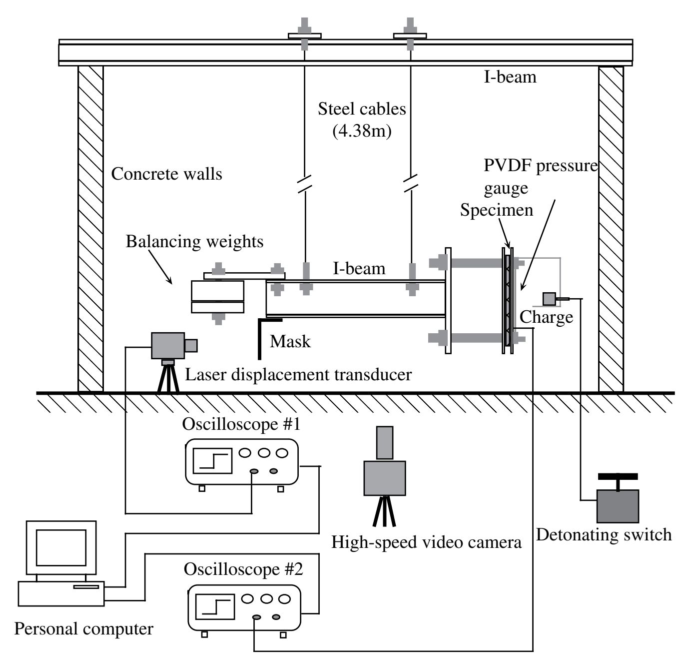

Fig. 3. Experimental set-up.