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An experimental study on the impact behavior of multilayer sandwich with corrugated cores

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ABSTRACT

This paper experimentally investigates multilayers corrugated core sandwiches under out-of-plane compressive impact loading. The manufacturing method of corrugated core sandwiches in our laboratory is presented at first and its mechanical behavior under quasi-static loading shows a good repeatability. A testing configuration on the basis of a 97 mm diameter and 8 m long Nylon Hopkinson pressure bar is proposed to host this large sandwich sample and to impose a nominal strain of 70% to multilayer sandwich samples of 45.5 mm long. High-speed imaging system provides their deforming modes and reveals the interactions between adjacent layers. Finally, testing results on 1060 aluminum corrugated core sandwiches are obtained under quasi-static and impact loadings. Significant rate sensitivity is observed and it can be reproduced by the numerical simulation. The bending of the interlayer plate is also observed, which contributes to reduce the force oscillation during successive folding.

1. Introduction

Corrugated core sandwiches are efficient lightweight structures widely used in civil and military applications. They attracted many academic interests in the past decades and a great number of investigations on various aspects of corrugated core sandwiches are reported in the open literature.

On the one hand, people are interested to predict their equivalent mechanical strength (with respect to monolithic structural component) in order to optimize the core microstructure or to obtain a macroscopic constitutive model that can be used in structural numerical analysis (Côté et al., 2006; Xue and Hutchinson, 2004b). The main investigating method consists in macroscopic testing on the representative structure under quasi-static compression/shear/bending loadings combined with observation/numerical analysis of the collapse of microstructures (Valdevit et al., 2004; Wiernicki et al., 1991).

On the other hand, the behavior of corrugated core sandwiches under impact loading are also desired because of their uses as energy absorbers. One of the largely studied loading cases is the localized indentation/perforation of clamped corrugated core sandwich plate/beam hit by projectiles or subjected to a concentrated impulse (Fleck and Deshpande, 2004; McShane et al., 2012; Rubino et al., 2008; Wadley et al., 2013b).

Another interesting loading case is the compressive shock loading due to blast/water pressure with explosion (Cui et al., 2012; McShane et al., 2010; Wadley et al., 2013a; Xue and Hutchinson, 2004a). Besides, as it is an out-of-plane compression, a natural idea is to use multilayer sandwiches instead of a single-layer one to better resist the shock loading. For example, Wadley and co-workers (Wadley et al., 2008) and Dharmasena and co-workers (Dharmasena et al., 2009) investigated the dynamic response of a multilayer prismatic structure to blast loads. Numerical analysis of multilayer sandwich is performed to study the interaction between layers. However, the lack of accurate/reliable experimental data is often reported in these shock tests. Tilbrook et al. (2007) reported a more controllable experimental work using a 76.2 mm diameter aluminum Hopkinson bar and a two-cell single layer sandwich specimens, due to impulse length limitation.

A reliable testing device is therefore desired to investigate multi-layer corrugated core sandwich under out-of-plane compressive impact loading. For this purpose, a large diameter (97 mm) and 8 m long Nylon Hopkinson pressure bar is proposed, where the impulse length is long enough to reach the compaction strain level of multilayer sandwiches. A bigger specimen can be hosted with more cells in one layer and signal/noise ratio is improved by the use of Nylon bar.

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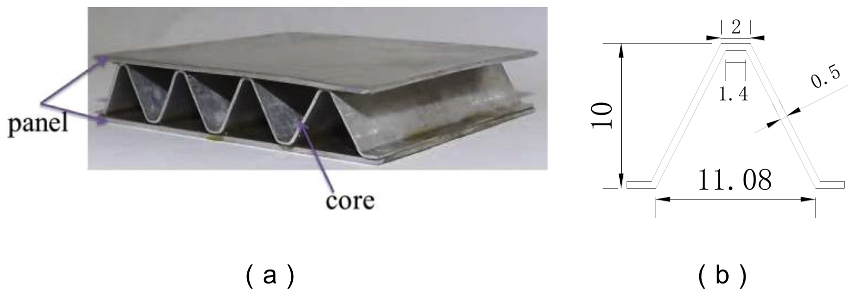

Fig. 1. The single-layer sandwich, (a) single-layer sandwich, (b) size of cell (unit: mm).

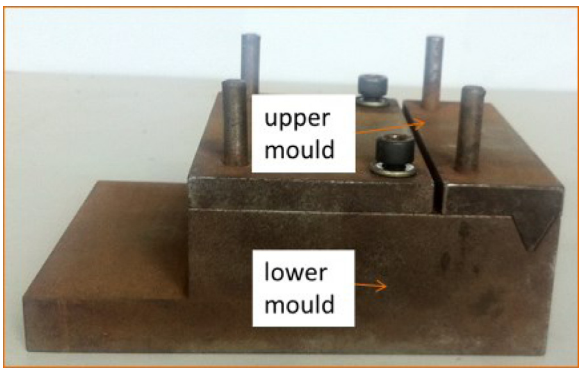

Fig. 2. Shaping mould of corrugated sheet.

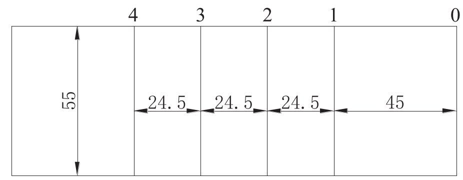

Fig. 4. Aluminum sheet size for corrugated sheet (unit: mm).

In this paper, the manufacturing process of corrugated core sandwich is presented at first. The large diameter Nylon direct impact Hopkinson bar setup will be reported in details with the necessary wave dispersion correction and the high-speed imaging system. Finally, experimental results on the rate sensitivity of single layer and multilayer sandwiches will be provided. Numerical simulations of these tests allows for the explanation of the observed rate sensitivity and interlayer interactions.

2. Corrugated sandwich specimens and its quasi-static behavior

The corrugated sandwich structure used in this study is composed of a core made of corrugated 0.5 mm thick 1060 aluminum sheet and 1 mm thick aluminum plate as top and bottom skin plates. A typical one-layer specimen is plotted in Fig. 1a. The 12 mm high one-layer specimen contains 4 cells and its cross section is a square of 55 mm by 55 mm. The geometric details of each cell are given in Fig. 1b.

Such a specimen size is determined by the limitation of the manufacturing restriction and the size of pressure bar used in the impact test. Previous study in open literature showed that the specimen size effect in testing cellular structure decreases deeply when specimen contains 4 or 5 cells in any direction (Gibson and Ashby, 1988). Our four-cell structure in a layer should satisfy this requirement of the minimum cell number.

2.1. Core manufacturing method

The corrugated core is made by bending the aluminium sheet in a mould (see Fig. 2).

The geometry of mould is given in Fig. 3, noting that the dimensions of the punch in the upper mould and the die in the lower mould are slightly different to take account of the thickness of aluminium sheet. A 0.5mm-radius round corners are made to prevent aluminium sheet from tensile failure due to the unavoidable friction. Only one cell is formed in a punch.

The aluminium sheets are cut into a rectangle shown in the Fig. 4 and different position lines are marked for the forming process of each individual cell.

The forming process of corrugated core is illustrated in the following. At first, the aluminum rectangle is put along the lower mould and located in order that the line No. 1(Fig. 4) meets the limit line (Fig. 5a). Afterwards, the bolts are fastened to clamp the sheet with the lower mould and the upper mould is put through the balancing pins (Fig. 5a). The balancing pins are used here to ensure the parallelism between upper and lower moulds during the punching. The whole punch-die system is put into a universal testing machine and compressed down for 9.5 mm at 0.1 mm/s, generating the first cell (Fig. 5b). The maximum compressive load is limited to 1500 N to prevent undesired over compression of the sheet. Such a process can be repeated by moving the sheet right-

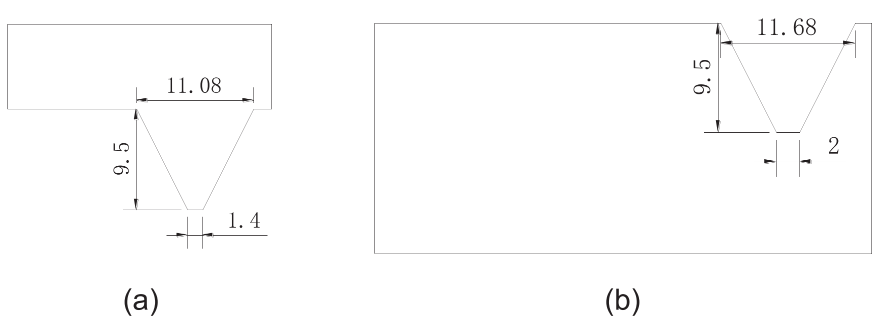

Fig. 3. Geometry of shaping mould (unit: mm), (a) upper mould, (b) lower mould.

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