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Dynamic response and failure of sandwich plates with PVC foam core subjected to impulsive loading

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ABSTRACT

This paper presents an experimental study on dynamic response of clamped sandwich plates with PVC foam core subjected to lab-scale impulsive loading. DIC-3D method and post-test are presented to investigate the permanent deformation, dynamic response and failure modes of the plates. Failure modes of PVC foam layers with three densities as well as front and rear metallic sheets are identified and discussed. Comparison methodologies concerning the blast resistance and energy absorption performance of four configurations in same mass with three densities and thicknesses are carried out. It is indicated that configuration 3 performs well in reducing permanent deformation of structure, and configuration 1 performs well in protecting the structure from destruction and have advantage in blast resistance under high impulsive intensity. The descending order of core densities have advantage in blast resistance than the core with ascending order of densities. Choosing the most efficient density, thickness and sequence of core layers is very helpful in structural optimization design, and especially in blast resistance for a prescribed load.

1. Introduction

Sandwich structures are commonly used in the design of commercial and military vehicles for a long time. And it is well known that sandwich plates possess a superior stiffness and strength to monolithic ones of the same mass. While light weight sandwich structures have attracted an amount of interests in multifunctional applications to exploit their superior mechanical property especially energy absorbing capability, and they are widely studied and used with various core materials in the past few decades [1–5].

In blast loading conditions, the deformation and failure modes of sandwich structures as well as monolithic plates, which brought about great influence on energy absorption mechanisms, played very important roles in blast resistance. Experimentally and numerically researches on metallic plates subjected to impulsive loading were carried out [6–12], and three main failure modes, including large ductile deformation (I), tensile-tearing and deformation (II) and transverse shear (III), as well as three submodes belonging to mode (II) were proposed. Research on sandwich structures with foam core showed that sandwich plates had more advantages in impact or blast resistance than monolithic plates [13–16]. Deshpande [17,18] proposed an isotropic constitutive model for the plastic behavior of aluminum alloy foams, and the response of sandwich plates subject to impulsive loading was investigated. Fleck [19] and Qiu [20,21] developed an analytical model for clamped sandwich plates subjected to shock loading both in air and in water, and divided the deformation response into three sequential stages, including fluid-structure interaction phase, core compression phase, and bending and stretching of plates. Base on the analytical model, comparative studies focusing on side lengths, relative density and thickness of core were carried out [22,23]. Dynamic response [24–26] and failure mechanisms [27,28] of sandwich structures with PVC foam core subjected to underwater impulsive loading is investigated. Damage evolution in composite materials was further investigated experimentally and computationally [29].

Lab-scale research had already used dynamically loading of metal foam projectiles to simulate water and air blast loading [16,30,31]. The objective of this paper is to investigate the dynamic response, failure modes and associated mechanisms, as well as quantifying the blast resistance of sandwich plates with PVC foam core subjected to impulsive loading experimentally. 3D-DIC method was used to obtain the areal dynamic deformation of sandwich plates. By identifying the failure modes of PVC layers with three densities, research on the effect of core density and thickness on response rates, blast resistance and energy absorbing capability were discussed and quantified.

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Table 1
Constructions of the four sandwich plates configurations.

Configuration	Front sheet (mm)	Core layer			Rear sheet (mm)
		1st	2nd	3rd	
1	0.5	H250			0.5
2a	0.5	H160	H80		0.5
2b	0.5	H80	H160		0.5
3	0.5	H80	H80	H80	0.5

2. Sandwich plates constructions and experimental setup

2.1. Sandwich plates constructions

Sandwich plates used in this research are made up of PVC foam layers and 5A06 aluminum alloy sheets. There are four configurations of sandwich plates in all. while front and rear sheets of the configurations are the same, which are both 5A06 aluminum alloy sheets of 0.5 mm in thickness, but the PVC cores layers are different, and three densities of PVC foams are used, which are 80, 160 and 250 kg/m^3. Table 1 shows the constructions of the four configurations, where configuration 1 stands for single H250 layer as core, and configuration 2a and 2b stands for double PVC core layers, which are H160 and H80 in reverse sequence, while configuration 3 contains triple PVC core layers, which are all H80. However, each PVC foam layer is 10 mm in thickness, and it can be included that the areal densities of these four configurations are nearly the same.

2.2. Experimental setup

By doing this research, a Φ40 mm one stage light gas gun mechanism-based projectile launching system is used to supply the initial energy to the metallic foam projectile. Because there are not any relevant test standards, a customized experimental setup is designed, and Fig. 1 showed the sketch of the apparatus employed. The blunt-nosed cylindrical projectile is made up of aluminum foam of 30 mm in length with a density of 0.35 g/cm^3, and a 10 mm-long PVC foam with a density of 0.08 g/cm^3 is glued at the back of the aluminum foam with epoxy resin to keep balance. The initial velocity of projectile is measured by laser-based optical devices and obtained by a vertical Phantom v310 high-speed camera system, and the camera is also used to capture the flying attitude of the foam projectiles, as shown in Fig. 1. The velocities calculated by the two system methods are in close agreement (within 3%). Each of the projectiles is weighted before the impact tests.

Fig. 2 shows the supported conditions and makeup of the sandwich structures. Square target with a side of 200 mm is clamped to

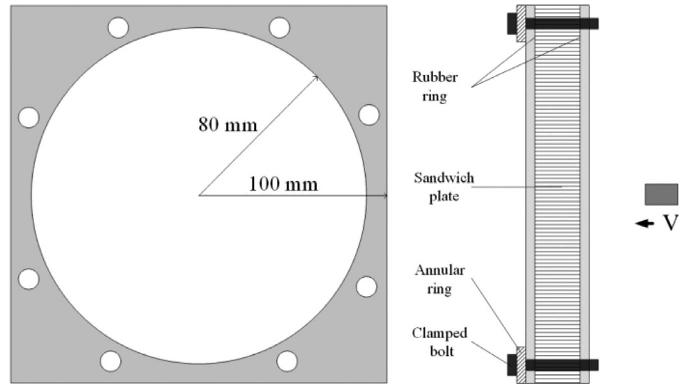

Fig. 2. Schematic illustration of sandwich plate and supported conditions.

an armor steel frame by means of eight equally spaced clearance bolts arranged on a 160 mm diameter pitch circle of the supporting frame, and two circular rubber rings are used to reduce the effect of stress concentration according to the supporting boundary.

Optical 3D deformation analysis software, Aramis, which is a non-contact and material independent measuring system, is introduced in this paper. The target sheet is painted high contrastingly before loaded, and two Photron Fastcam Sa-Z high-speed cameras are used in couple to capture the dynamic responses of the rear sheets of the sandwich plates, as shown in Fig. 1. From the images coupled with each other of the two high speed cameras, three dimensional digital image conversion, short for DIC-3D, is down by Aramis. Dynamic response, including deflection, strain, etc., is obtained. The selected frame rate is 36 000 frames per second with a resolution of 512 × 512 pixels.

3. Material properties

3.1. PVC foam

PVC foam and 5A06 aluminum alloy are the two materials used to form the sandwich plates in this research. Three different densities of Divinycell H PVC foam provided by Diab Co., Ltd. are chosen as the core material, and mechanical parameters of the PVC foam supported by Diab Co. Ltd. are listed in Table 2.

Quasi static compression tests of PVC foam with three densities are performed at electron universal testing machine by Zwick in 1 mm/min and in 100 mm/min, and dynamic compression tests for the three types of PVC foam are performed at Φ40 aluminum split Hopkinson pressure bar with an incident bar of 400 mm in room

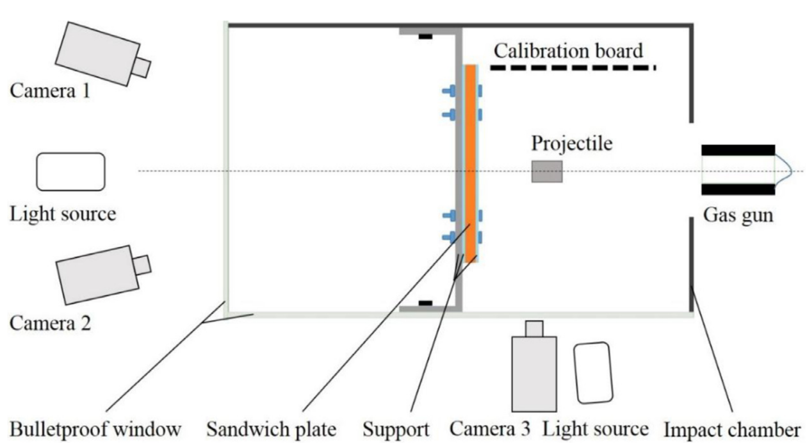

Fig. 1. Sketch of the apparatus employed.