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Response of aramid honeycomb sandwich panels subjected to intense impulse loading by Mylar flyer

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ABSTRACT

The deformation/failure modes and impact resistance of composite sandwich panels with titanium alloy plates and aramid honeycomb cores subjected to intense impulse loading were investigated experimentally using electric gun technique. A velocity measuring instrument, known as the velocity interferometer system for any reflector (VISAR), measured the velocity history at the mid-point of the back plates. Typical deformation/failure modes were analyzed and classified systematically, and then a comparison of structural deformation resistance between sandwich panels and plates of equivalent mass was studied. It was found that both the deformation/failure modes and the dynamic response of the plates were sensitive to the impact velocity. The impact resistance of sandwich panels could be improved by core crushing and deformation of the front plate. Finally, effects of impact velocity and boundary conditions on the dynamic response of sandwich panels were identified. It was worth noting that the fully clamped boundary reduced the damage extent of the front plate, but increased the local plastic deformation of the back plate.

1. Introduction

Sandwich panels, constructed from face plates with low density and high strength separated by light cores, are widely used in weight sensitive applications, such as aerospace, transportation and military, due to their superior energy absorption capability and other advantages of mechanical and physical properties. Aramid honeycomb, with excellent low density, flame retardance, radiation resistance and high strength properties, has been adopted as cores for high-performance aviation sandwiches with great success. For instance, DuPont Nomex and Kevlar honeycomb composite materials have been applied on the floor, aileron, engine cover, and inner wall of the cabin of an A380 [1]. Titanium alloy, as an important structural material in the aeronautic and astronautic industry, provided light density, high specific intensity and excellent resistance to corrosion. Therefore, titanium-aramid honeycomb sandwich panels can be applied in a space debris shield structure and a directed energy protection system, because they can absorb high impact energy, and also be utilized in a high radiation environment for a long time. Unfortunately, there are no studies investigating their dynamic response under impact loading.

Extensive experimental research has been performed to investigate the response of sandwich structures subjected to different types of dynamic loads. In their experiments, the loading modes can be divided into blast loading, projectile impact loading, and impulsive loading produced by the split Hopkinson pressure bar (SHPB). Zhu et al. [2] used a four-cable ballistic pendulum system to identify the effect of several key design parameters on the air blast response of sandwich panels with aluminum honeycomb cores. They concluded that skin thickness and core parameters had a significant influence on the deformation of the back face-sheet. Nurick et al. [3] also conducted experimental work on honeycomb sandwich panels subjected to uniform and localized blast loading. Their study indicated that, when compared to the air-core sandwiches loaded at the same impulse, the total deflection of the two face-plates was lower for sandwich panels with aluminum honeycomb cores. Hassan et al. [4] investigated the influence of varying core density on the blast resistance of PVC sandwich panels with aluminum alloy skins. The results indicated that damage within the sandwich panels became more severe as the density of the foam core increased. Avachat and Zhou [5] studied the effects of face-sheet thickness and shock conditions on the dynamic response of composite sandwich panels subjected to underwater impulsive loading generated by a simulator. The results showed that an optimal thickness of face-sheets existed such that, it maximized energy absorption in the core and minimized the overall deflection of sandwich plates with polymer foam cores and fiber-reinforced polymer composite face-sheets. Fan [6] carried out a series of close-in underwater blast tests performed on sandwich panels to investigate the blast resistance of metallic sandwich panels. It was found that the secondary pressure wave showed an inverse trend with face-sheet thickness, with a positive relationship

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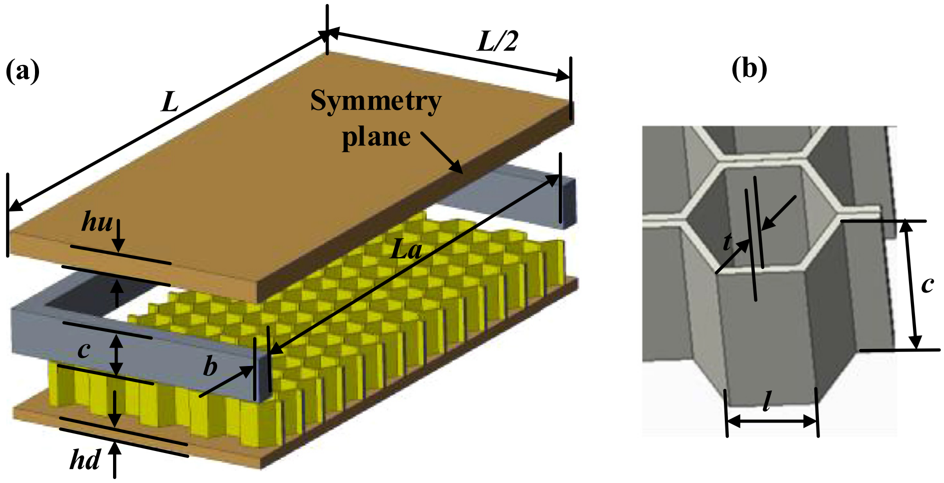

Fig. 1. Geometry and dimensions of the square specimens.

with core density. Research on the ballistic impact behavior of sandwich panels has been reported by Goldsmith and Sackman [7] and Hou et al. [8]. In their experiments, the effects of impact velocity, projectile shapes and boundary conditions on the ballistic limit and energy absorption of the panels during perforation were identified. Radford et al. [9] proposed an experimental technique to simulate shock loading on structures using metal foam projectiles. This experimental technique has been employed by Radford et al. [10] and Yahaya et al. [11] to investigate the dynamic behaviour of sandwich panels with metal foam or honeycomb. The split Hopkinson pressure bar (SHPB) technique is often used for studying the dynamic mechanical properties of the core materials. Deshpande and Fleck [12] used a standard SHPB set-up to investigate the response of aluminum foams (Alulight and Duocel). Mukai et al. [13] also used a standard SHPB arrangement to investigate Alporas foams obtained by direct foaming of aluminum melts with a blowing agent. Rate sensitivity was observed in their results.

Compared with the loading methods mentioned above, the kinetic energy of flyers driven by an electric gun [14] is higher, and the loading pressure and pulse width can be controlled by varying the thickness of flyer or by varying the charging voltage. Hence, the electric gun can be applied to simulate the impact of space debris and the attack of directed energy weapon. In this paper, an electric gun has been used to experimentally study the dynamic response of square sandwich panels, comprising two titanium alloy skin plates and an aramid honeycomb core. The experimental procedure and deformation/failure modes of specimens were first reported. Effects of the honeycomb core, impact velocity and boundary conditions on the dynamic response were then studied.

2. Experimental procedure

2.1. Specimen

The square specimens adopted in the tests comprised two face plates, a honeycomb core and a core support frame. Both the front and back plates were made of Ti-6Al-4 V (TC4) titanium alloy because of its excellent physical and mechanical properties [15]. The honeycomb cores were made of AC-KH-1.83–48 meta-aramid paper honeycomb manufactured by Aramicore Composite Co., Ltd. Jiangsu, China. Its compressive strength is 2.05 MPa and its shear strength at the L and W directions are 1.29 MPa and 0.86 MPa, respectively. Shear modules at the *L* and *W* directions are 88 MPa and 55 MPa [16]. To reduce the influence of the size effect on the results, a core support frame was designed. It could effectively constrain the lateral displacement along the boundary of the honeycomb core. The material was 45 steel.

Fig. 1 shows the dimension of sandwich panels employed in the tests and a single honeycomb cell. The thicknesses of core structure *c*, front plate *hu* and back plate *hd* are equal to 4 mm, 2 mm and 1 mm, respectively, wherein the total height *T* of a specimen is 7 mm. The side length *L* and the side length of core structure *La* are 50 mm and 46 mm; the corresponding bezel thickness of core support frame *b* is 2 mm. The core is comprised of a rectangular array of hexagonal cells. Mechanical properties of a single honeycomb cell are decided by two geometrical parameters, side length *l* and foil thickness *t*. In industry, aramid honeycomb is generally classified based on side length *l* and density ρ because of its low density. The three key parameter values of this meta-aramid honeycomb are side length $l = 1.83$ mm, density $\rho = 48$ kg/m^3, and foil thickness $t \approx 0.1$ mm. Affected by the production process of commercial cellular aramid, there are two double thick walls of a single cell after bonding, as shown in Fig. 1(b).

As indicated in Table 1, the specimens are divided into three groups. Groups A and C are the sandwich panels; Group B is comprised of plates of equivalent mass formed by the superposition of a front plate and a back plate. In this research, one or two groups were designed to study the effect of one particular factor on the dynamic responses of the panels. For example, Group A was organized to study the effect of impact velocity. Similarly, in Group A and C the effect of the boundary conditions was identified.

2.2. Experimental set-up

In this study, an electric gun with an energy of 14.4 kJ that was operational at the Institute of Fluid Physics (CAEP) was employed as the loading device [17]. A velocity measuring instrument, known as the velocity interferometer system for any reflector (VISAR), was used to measure the velocity–time history at the mid-point of the back of the specimen. The data of the tests were recorded by an oscilloscope.

The principle of the electric gun is based on a metal foil explosion by a large pulsed current. As illustrated in Fig. 2(a), the electric gun is connected to a series RLC circuit. After the triggering switch is turned on, the energy stored in the capacitor is released, and a large pulsed current generated. Furthermore, the foil is designed to be the minimum cross-sectional area of the bridge-foil load and the most resistive element in the circuit, as shown in Fig. 2(b). Thus, when the transmission line delivers the current from the capacitor bank into a foil, the foil absorbs most of the ohmic heating. If the discharge time