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Blast resistance of metallic sandwich panels subjected to proximity underwater explosion

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ABSTRACT

A series of close-in underwater blast tests were performed on sandwich panels consisting of two aluminum alloy face-sheets and a honeycomb core to investigate blast resistance of metallic sandwich panels. The blast resistance of sandwich panels was assessed in terms of structural deformation resistance represented by back face-sheet deflection and intensity of the secondary pressure wave, which is determined by the maximum velocity of the back face-sheet. It was found that the secondary pressure wave shows an inverse trend with face-sheet thickness while a positive relationship with core density, which is determined by foil thickness in this study. A failure mode map was adopted to indentify the effect of design parameters on the structural failure mechanism at this blast magnitude. Finally, a comparison of underwater blast resistance between sandwich panels and monolithic plates of equivalent mass was performed. The comparative study provided further experimental evidence for the benefit of sandwich construction in terms of deformation resistance and secondary pressure wave intensity even at high blast magnitude. It was also suggested that the benefit of deformation resistance was amplified with increase in equivalent thickness.

1. Introduction

Sandwich structures with two face-sheets and a metallic core exhibit superior energy absorption capability and high stiffness with a relatively low weight. Extensive studies have previously been conducted to investigate the response of sandwich structures with foam/honeycomb cores subjected to dynamic loadings [1–6]. All studies show that metallic sandwich plates exhibit excellent energy absorption performance compared to monolithic plates subjected to high velocity projectile impact and air blast. Zhu et al. [7] especially investigated effect of several key design parameters on structural response of sandwich panels with aluminum honeycomb core subjected to air blast. Their study indicated distinct dependence of plastic deflection of back face-sheet on skin thickness and core parameters, such as cell size and wall thickness. To enlarge the application range of sandwich constructions in submerged protection and naval engineering wherein sandwich structures are subject to more complicated and stronger dynamic loads, studies on its blast resistance to underwater impulsive loading were recently conducted. Espinosa [8] developed a laboratory scaled experimental method and designed a conical water-filled shock tube to probe the dynamic behavior of monolithic plates and applied scaling rules to mimic the dynamic response of submerged plates of realistic dimensions. Subsequently, Mori et al. [9,10] employed this method to study failure modes and the damage mechanism of sandwich panels, and furthermore provide the evidence for the benefits of sandwich construction in blast resistance. Leblanc and Shukla [11] used a similar water-filled shock tube, but with the shock wave generated by detonating a small explosive charge. Recently, Schiffer et al. [12] and Schiffer and Tagarielli [13,14] developed a transparent water-filled shock tube to allow laboratory-scale study of underwater blast loading on solid/sandwich plates, including dynamic response as well as the caviation events in shallow and deep water. It was also adopted to examine the 1D response of sandwich panels (air-backed and water-backed) in deep water and found that the FSI effect is also sensitive to the initial hydrostatic pressure in the fluid. Avachat and Zhou [15] studied the effect of face-sheet thickness and shock conditions (air-backed and submerged) on the dynamic response of composite sandwich panels to underwater impulsive loading generated by the simulator. The results show that there exists an optimal thickness of face-sheets, which maximizes energy absorption in the core and minimizes overall deflection of the structure for sandwich plates with polymer foam cores and fiber-reinforced polymer composite face-sheets. In addition, Wadley et al. and Dharmasena et al. [16–18] investigated the structural response of sandwich plates with lattice cores to underwater explosion loading. Loading pressure transmitted to the supports was monitored by load-cell

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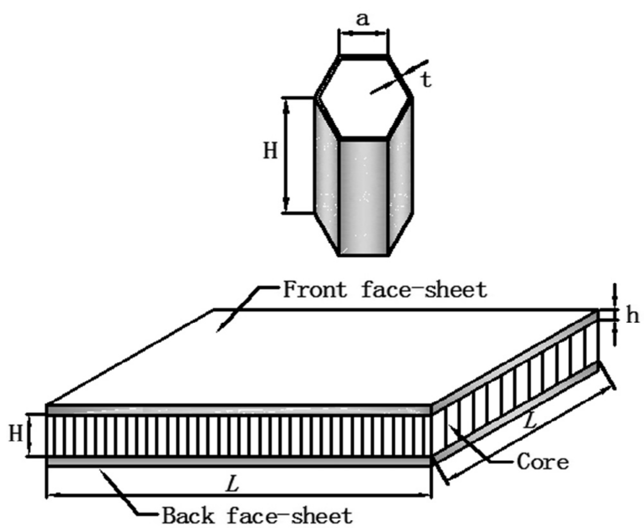

Fig. 1. Geometry and dimension of the specimens.

measurements, however, also made the structural response indistinct on account of additional constraints.

Nevertheless, studies on sandwich panels comprising of honeycomb cores subjected to proximity underwater explosion loading are quite limited. Besides, since the protected objects are behind the sandwich structures, the back face-sheet deflection was usually of interest. Therefore, blast resistance of sandwich panels was traditionally assessed in terms of the back face-sheet deflection. However, the protective layer could be quickly accelerated to a very high velocity under high intensity shock from water blasts, and thus a secondary pressure wave is emanated to the air-backed region by the moving plates. Air blast effects induced by the secondary pressure wave could also cause terrible damages to people behind the sacrifice layer. According to previous studies, mild contusion on human organs, especially on the eardrums, was observed when the overpressure reaches 2 kPa. As a consequence, the present work aims to investigate dynamic response and failure mechanism of square sandwich panels with skins and honeycomb cores. The face-sheets' thickness is varied under the conditions of constant material properties and core dimensions. In this research, the blast resistance of sandwich panels with different configurations was assessed with respect to both structural response and intensity of secondary pressure wave, which is determined by the back face-sheet velocity.

2. Experimental details

2.1. Specimens

The square specimens adopted in the tests consist of two face-sheets and a honeycomb core. The face and cores were bonded with epoxy resin adhesive. Both of face-sheets and the core were made of Al-5052 aluminum alloy, which has excellent shock resistance and anti-fatigue performance. The honeycomb core was composed of a rectangular array of hexagonal cells. Mechanical properties of a single honeycomb cell were decided by two geometrical parameters, side length (a) and foil thickness (t). Fig. 1 shows the dimension of a single honeycomb cell and the sandwich panels used in the tests. In this study, the side length of sandwich panel L and the core height H were 250 mm and 20 mm, respectively. However, the face-sheet thickness (h) and foil thickness (t) of cell wall were alterable to investigate their effects on the blast resistance of sandwich panels. As a consequence, specimens after blast tests were divided into two groups. Group 1 was arranged to study the effect of face-sheet thickness on structural blast resistance. Likewise, the effect of foil thickness was identified in Group 2. Besides, the same blast tests were also performed on a group of monolithic aluminum plates to investigate the structural blast resistance in comparison to sandwich panels. In order to obtain the blast resistance of monolithic plates of equivalent mass, plates with five different thicknesses ranging from 2 mm to 6 mm were used to study the effect of thickness on its blast resistance.

2.2. Experimental set-up

Fig. 2 is a schematic diagram of the experimental set-up. Rectangular sandwich panel was air-backed and peripherally clamped in a frame. The exposed area was of 170 mm in diameter. A back-sealed container of Φ170 mm × 500 mm in dimension, was employed to simulate the protected space beneath the specimens. A water filled PVC tube with a dimension of Φ170 mm × 250 mm was adopted as a water tank to generate underwater shock loading. The explosive charge with a mass of 3.1 g was submerged in the water tank and detonated vertically against the center of the specimen at a fixed blast distance $S = 50$ *mm*. The charge was composed of RDX and aluminum powder and paraffin wax with a mass content of RDX: aluminum powder: wax = 75%:20%:5%. As the water tank was broken and blown up in hundreds of microseconds, effect of the bubble pulse was eliminated out of consideration. Besides, the blast distance was 50 mm, less than the radius of water tank to avoid the influence of reflected wave from the tube wall. Pressure–time history at the mid-point of the specimen was monitored by a special sensor known as a PVDF pressure gauge, which was mounted at this point. The

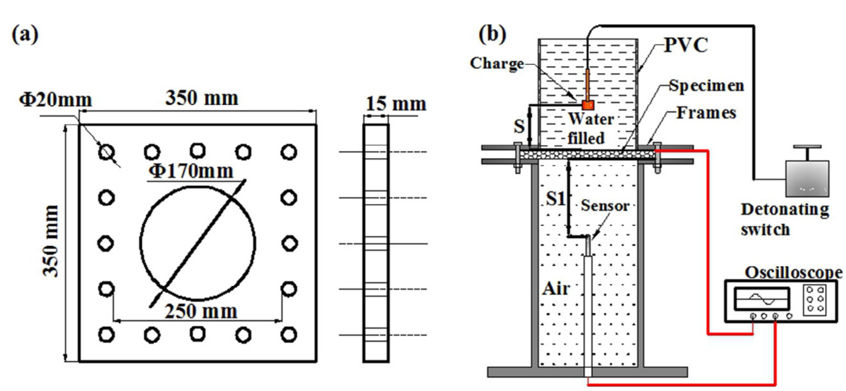

Fig. 2. Schematic diagram of fixture frame and the experimental system.