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# Experimental and numerical investigation of carbon fiber sandwich panels subjected to blast loading

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ABSTRACT

The objective of this paper is to investigate the structural response of carbon fiber sandwich panels subjected to blast loading through an integrated experimental and numerical approach. A total of nine experiments, corresponding to three different blast intensity levels were conducted in the 28-inch square shock tube apparatus. Computational models were developed to capture the experimental details and further study the mechanism of blast wave-sandwich panel interactions. The peak reflected overpressure was monitored, which amplified to approximately 2.5 times of the incident overpressure due to fluid-structure interactions. The measured strain histories demonstrated opposite phases at the center of the front and back facesheets. Both strains showed damped oscillation with a reduced oscillation frequency as well as amplified facesheet deformations at the higher blast intensity. As the blast wave traversed across the panel, the observed flow separation and reattachment led to pressure increase at the back side of the panel. Further parametric studies suggested that the maximum deflection of the back facesheet increased dramatically with higher blast intensity and decreased with larger facesheet and core thickness. Our computational models, calibrated by experimental measurements, could be used as a virtual tool for assessing the mechanism of blast-panel interactions, and predicting the structural response of composite panels subjected to blast loading.



## 1. Introduction

Sandwich panels, which consist of two thin facesheets adhered to a thick core, are increasingly used in blast protections due to their high specific stiffness and strength, as well as superior energy absorbing capacity [1]. In recent years, attention has been drawn from the blast loading response of monolithic structures [2–7] to that of sandwich panels. Dharmasena et al. [8] conducted explosive testing in the air to study the dynamic response of sandwich panels made of super-austenitic stainless steel alloy. They observed that the sandwich panel had a lower back facesheet deflection than the monolithic plate, and the advantages of sandwich panels were diminished after complete core crushing. Fleck and Deshpande [9] theoretically studied the dynamic response of steel sandwich beams subjected to air and underwater blast loading, and developed performance charts of the sandwich beams with different core materials. Zhu et al. [10] studied the blast loaded aluminum sandwich panel with a cellular core. The effects of plastic deformation and clamped *vs.* simply supported boundary conditions on the back facesheet deflection were presented through finite element modeling. Karagiozova et al. [11] numerically analyzed the behavior of clamped steel sandwich panels with the surface pressure history mimicking the blast loading situation, and stated that the load transfer to the back facesheet of the panel with specific core material depended on the load intensity, core thickness and flexibility of sandwich panels. The blast resistance of E-glass fiber sandwich panels with stitched foam core [12] or stepwise graded core [13], were studied through the shock tube experiments. The recorded transient displacement and the damaged sandwich panels resulted from blast loadings were compared. The aforementioned studies mainly focus on the blast load response of sandwich panels with metal facesheets. The investigations of composite sandwich panels are limited [12,13], even though they are frequently used in various engineering constructions [14–16]. Moreover, the repeatability of experimental results has seldom been ensured and few attempts have been made to investigate the structural response of sandwich panels using strain measurement techniques [17,18].

In this work, the structural response of carbon fiber sandwich panels subjected to blast loading was investigated using an integrated experimental and numerical approach. A total of nine experiments, corresponding to three different blast intensity levels (low, medium and high), were conducted inside our shock tube

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apparatus. To further elucidate the mechanism of blast wave-sandwich panel interactions, a 3D finite element (FE) model was developed to reproduce the shock tube experiment, and then calibrated by the measured pressure profiles and strains on the facesheets. Finally, a parametric study was carried out to examine the impact of blast intensity and panel geometry on the maximum deflection of the sandwich panel back facesheet.

## 2. Experimental procedure and results

### 2.1. Experimental procedure

A 711 mm or 28″ square shock tube apparatus with a length of 10 m (Fig. 1) was used to create the controllable blast loading. Detailed description of the shock tube and its calibration can be found in [19]. Briefly, the square shock tube consisted of four main components including the driver, transition and straight sections, as well as the catch tank. The straight section was divided into a test region and an extension region. The driver section contained pressurized gas which was separated from the transition section by several membranes. As membranes ruptured due to increased gas pressure, the rapid release of gas produced a shock wave, which travel down the transition and extension sections and then interact with the specimen placed in the test section. Finally, the shock wave exited the shock tube and entered the catch tank which absorbed and slowly released most of the shock energy and reduced the noise intensity.

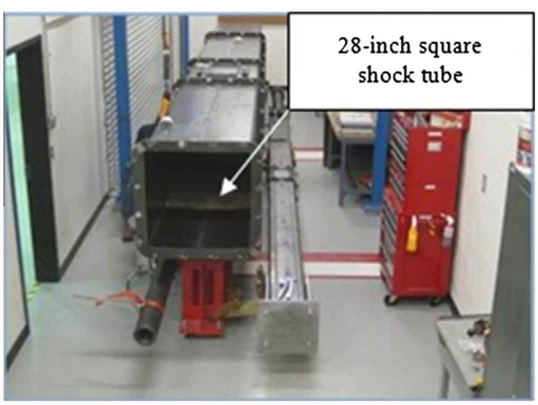


**Fig. 1.** A 711 mm (28″) square shock tube apparatus.

The 146 mm square sandwich panel, with four holes drilled close to the edges, was clamped by two L-shaped steel frames as specified in Fig. 2. The frames were then fixed onto the bottom of the test section in shock tube. The sandwich panel (CST Inc., Tehachapi, CA) used in the shock tests consisted of two facesheets with a thickness of 0.762 mm each and a foam core with a thickness of 6.35 mm. Rohacell 71 IG polyurethane (PMI) rigid foam was used as the core material, which was 100% closed cell and had constant shear strength through the thickness. The facesheets were fabricated from six-ply unidirectional carbon fiber prepreg tape (150 g/m$^2$ fiber areal weight and 35 wt% resin content) with a fiber orientation of 0–90° in alternating layers and cured at 250F onto the PMI cores.

Vishay SR-4 general-purpose strain gauges with a grid resistance of 350 ± 0.3% Ω and a gauge factor of 2.09 ± 0.5% were bonded at the center of front and back facesheets and connected to a Wheatstone quarter bridge to measure the transverse strain. Two piezoelectric pressure sensors (PCB 134A24) were used to record both the incident and reflected pressure histories. The sensor for measuring the incident pressure was mounted on the side wall of the shock tube with an offset of 0.2 m in front of the specimen, while the reflected pressure was measured by a sensor glued close to the right edge of the front facesheet, as labeled in Fig. 2. Three different blast intensity levels, referred to as low, medium and high, were generated by rupturing a stack of 2, 6 and 10 plies of 0.025 mm thick Mylar membranes. For each level of blast intensity, three repeated experiments were conducted on the same panel.

### 2.2. Experimental results and discussions

#### 2.2.1. Characterization of the incident and reflected waves

An important requirement of this study was the ability to produce repeatable and measureable blast loading conditions. The measured incident and reflected parameters were summarized in Table 1. The peak overpressure was determined by using a 100-point average of the maximum pressure values after the arrival of the shock front. This was typically about 8 μs after the shock arrival, which corresponded to the time for the shock to cross the sensor tip. The positive duration was referred to the time period with positive overpressure. The maximum impulse was calculated as the pressure-time integral over the entire positive duration. It

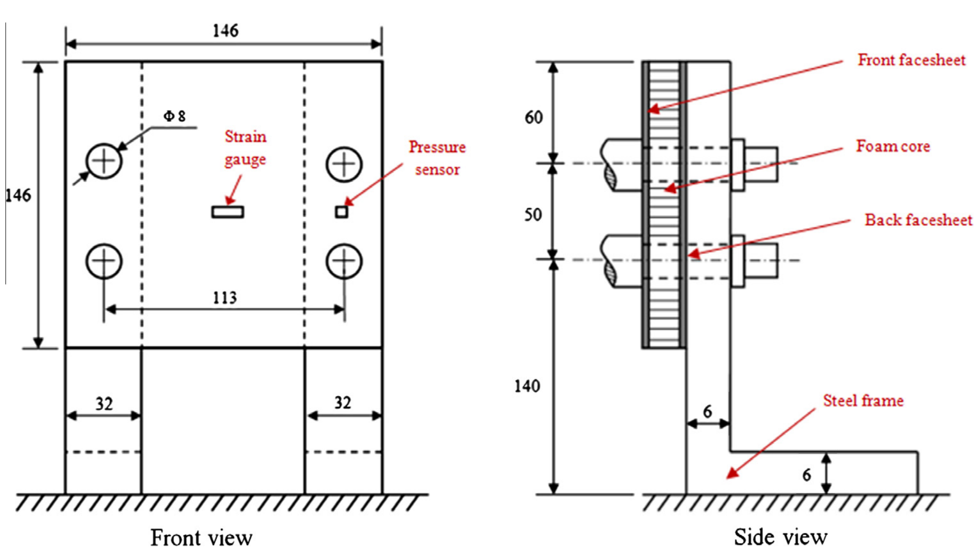


**Fig. 2.** Sketch of the clamping sandwich panel. All dimensions are in mm.