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Response of aluminium honeycomb sandwich panels subjected to foam projectile impact – An experimental study

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ABSTRACT

Aluminium honeycomb sandwich panels have potential applications as a protective mechanism that can be used to prevent failure of an important structure subjected to impact loading. Therefore it is important to fully understand the resistance of the sandwich panels subjected to impact loading conditions. The main objective of this work was to study the resistance of sandwich panels with different aluminium honeycomb cores, air sandwich panels (no core between the two face sheets) and monolithic plates of equivalent mass subjected to impact from foam projectiles. The deformation and the elastic spring-back of the honeycomb sandwich panels and the monolithic plates have been compared and discussed. The resistance of the panels and plates has been quantified by their back-face deflection with respect to the projectile impulse. Five different types of aluminium honeycombs have been used as the core material. The front-face sheet and the back-face sheet of the honeycomb sandwich panels are made of aluminium plate with 1 mm thickness. Cylindrical ALPORAS aluminium foams with a relative density between 9% and 11% are employed as the metal foam projectiles. They are fired at several hundred metres per second towards the centre of the panels and plates using a gas gun. The deflection histories of the back-face have been measured using a laser displacement sensor. From the deflection histories, the maximum deflection and the final deflection of the back-face can be distinguished. Deformation modes and failure modes of the individual component have been observed and classified into several categories. Moreover, the deflections of the honeycomb sandwich panels have been compared with deflections from air sandwich panels. It is found that the honeycomb sandwich panels outperform both the air sandwich panels and the monolithic plates within an impulse range of 2.25 kNsm^{-2} ~ 4.70 kNsm^{-2}. Outside this operational range, the advantages associated with employing the honeycomb sandwich panels as a protective structure upon impact of foam projectiles diminishes.

1. Introduction

There has been increasing interest in the design and development of impact resistance structures over the past decade. Sandwich panels with aluminium honeycomb cores have been identified as one of the potential candidate protective structures as they have a high strength to weight ratio and have a good energy absorption capacity [1]. However, their behaviour under impact loading remains to be fully understood. Radford et al. [2] developed an experimental technique to generate shock loading into a structure by using metal foam projectiles. More work has been carried out applying the method to study the dynamic response and energy absorption capacity of honeycomb sandwich beams [3–8] and honeycomb sandwich panels [9-11] with different core configurations. Curve sandwich panels were also used to absorb shock loading [12]. Recently, metal foam projectiles have also been used to mimic the impact of a sand column against a structure [13].

The use of metal foam is becoming popular in the transportation industry such as in the construction of high speed vehicles in order to reduce weight and to save fuel consumption without compromising the safety standard. However, during a collision, fractured foam can fly off at velocities up to several hundred metres per second and hit the surrounding structures, similar to what happened to the Columbia Space Shuttle in 2003 where a piece of

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foam from the protective layer of the fuel tank struck the wing edge that was made of ultra-strong carbon composite panels [14,15]. The accident took seven astronauts' lives. Such catastrophic failure could possibly be avoided if the data describing the threat of foam projectile impact had been available beforehand.

As a protective structure, the maximum deflection and the final deflection of the sandwich panels upon loading has to be clearly distinguished. The difference between the maximum deflection and the final deflection is known as elastic spring-back [16]. Using final deflection rather than maximum deflection as a design guideline has misled designers in optimising the capability of sandwich panels as a protective structure.

In this paper, ALPORAS aluminium foam projectiles have been used to impact the centre of aluminium honeycomb sandwich panels at several impact velocities by using a gas gun. Aluminium alloy plates have been used as the face sheets of the honeycomb sandwich panels. Previously, high strength stainless steel plates were used as the face sheets [3–8] and no failure of the face sheets was reported. The current study has employed aluminium face sheets to investigate face sheet failure. Deformation of the sandwich panels has been studied by analysing the deformation and the failure modes of the face sheets and the core for different core configurations, while the resistance of the sandwich panels has been studied by measuring the back-face deflection of the panels. The back-face deflection of the sandwich panels has also been compared with monolithic plates of equivalent mass and air sandwich panels. The air sandwich panel has a structure which consists of only two parallel plates (without core) at a distance similar to the core thickness of honeycomb sandwich panels. Finally the back-face deflection histories of the sandwich panels have been compared with the deflection histories of monolithic plates of equivalent mass to determine the benefit of using sandwich panels in reducing elastic spring-back. The histories of the back-face deflection have been captured experimentally by using a laser displacement sensor. The advantages and limitations of using sandwich panels in absorbing impact energy of foam projectile impact have been discussed.

2. Experiments

2.1. Equipment

The experimental set-up is shown in Fig. 1. The set-up consists of a nitrogen gas tank, a pressure regulator, a gas gun, a velocity meter, a sample holder and a laser displacement sensor. The nitrogen gas tank supplies nitrogen gas to the gas gun at a pressure prescribed in the pressure regulator to propel the projectile. The gas gun has a barrel length of 3 m and an inner diameter of 38 mm. The sample holder is a special fixture fabricated to fully clamp the samples (include honeycomb sandwich panels, air sandwich panels and monolithic plates) at the end of the barrel. Due to the clamping along the samples, the exposed area of the samples has been reduced to 250 mm × 250 mm from their initial dimension of 300 mm × 300 mm. There are a total of 16 M10 bolts on the clamp where 5 bolts are located at each side of the clamp, as shown in Fig. 1. Extra caution was taken when fastening them manually to ensure not crushing the foam along edges, but enough to hold the sample firmly and uniformly along all edges. The velocity meter is installed in-between the barrel and the specimen holder in order to measure the velocity of foam projectiles just before impact. The laser displacement sensor has been manufactured by Micro-Epsilon Messtechnik Germany (Type LD 1607-200) and has been used to record the back-face deflection history of the sandwich panels. It is capable of measuring up to ±100 mm deformation from its reference distance which is located at 340 mm from the unit. The accuracy of the sensor is 0.01 mm. The laser spot, which is pointing at the centre of the back of the sandwich panel, has a diameter of 2 mm.

2.2. Specimens

2.2.1. Aluminium foam projectiles

The projectiles were made of aluminium foam with the brand name ALPORAS that had a composition of Al–Ca5–Ti3 (wt.%). The projectiles were cylindrical in shape with a length of $l_0 = 50$ mm and diameter of $d = 37$ mm. The preparation process of the projectiles included: cutting, drying and weighting. The projectiles were cut from a large block of aluminium foam using EDM. After the cutting process, the projectiles were left to dry for several days (water was used in the wire cutting process) and were weighed several times until the readings became consistent.

The dimension and the mass of each projectile were then measured and the relative density was calculated accordingly before the tests. The relative density is defined as the ratio of the density of the foam to the density of aluminium, which is 2700 kgm^{-3}. Common cell morphological defects were observed on the foam projectiles such as misalignment and broken cell wall, and non-uniform cell wall thickness and cell size. In order to minimize these defects, only projectiles with a relative density in the range of 9%–11% were selected for the experiments. In this relative density range, the average cell size of the foam was 3 mm. A minimum ratio of the projectile size to the cell size of 5 is required in order to

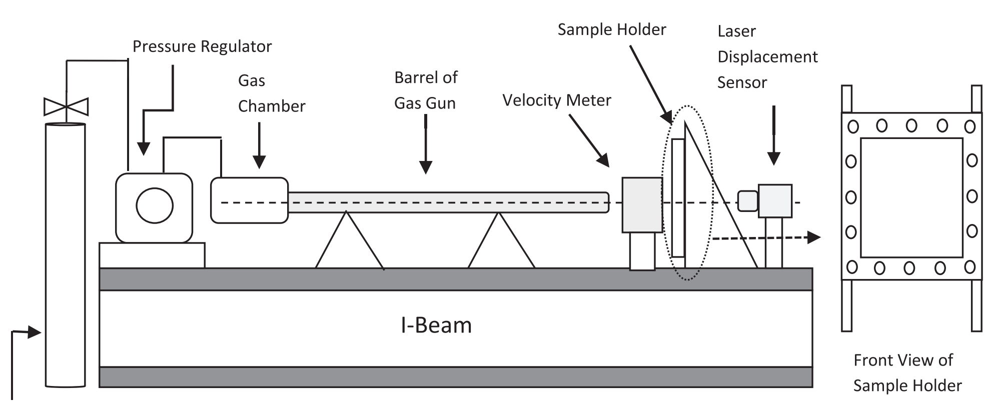

Fig. 1. Impact experimental set-up.