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Experimental and numerical investigation on indentation and energy absorption of a honeycomb sandwich panel under low-velocity impact

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ABSTRACT

The mechanical behavior of honeycomb sandwich structures under low-velocity impact is of great significance. An experimental and numerical investigation on surface deformation and energy absorption subjected to low-velocity impact is undertaken. A high-speed camera system is employed to record the acceleration attenuation process of the impactor, a projection profile system is introduced to measure the surface profiles of the panel and the depth of the ultimate indentation is obtained. A three-dimensional finite element model is constructed and validated by the experimental results. Indentation characteristics and energy absorption are analyzed and in good agreement with experimental data. Effect of adhesive layers on energy absorption is discussed and the contribution of the facesheets and the honeycomb core to the energy absorption process is analyzed separately. Results shown that the effect of adhesive layers on energy absorption is non-ignorable and the honeycomb core plays a dominant role in energy absorption. Most of the energy absorbed by the honeycomb sandwich panel is expended as plastic dissipation, and the rest is transformed into strain energy.

1. Introduction

Honeycomb structures are widely used as shock absorbers in airplanes and high speed trains due to their lightweight, high strength–mass ratio and favorable cushioning properties [1]. Impact energy is absorbed through large compressive deformation of materials and transformed into plastic strain energy. Crashworthiness is forcefully affected by the mechanical properties of the material, thickness of cell walls and the geometric parameters of honeycomb cell [2].

Honeycomb structures are especially susceptible and vulnerable to low-velocity impact loadings [3], which may be caused by tools falling down during maintenance, hail striking in service, unidentified objects impact when the plane is landing or taking off. The low-velocity impact damage is often internal and invisible, but can significantly reduce the stiffness, strength and fatigue life of the structures. For this reason, low-velocity impact was extensively studied in literatures [3–7].

Generally, investigations of low-velocity impact on honeycomb sandwich panels are conducted by employing experimental, numerical and analytical methods. Impact responses such as impact history, peak load and deformation at peak load are analyzed in many experimental and numerical studies. Foo et al. [5,8] introduced the spring-mass models and energy-balance model to predict the impact response, the impact load–time history is adopted to verify the accuracy of the finite element model. Wang et al. [9] characterized the contact force-history and absorbed energy, several impact responses such as impactor diameter, impact energy and sandwich panel configuration parameters were studied. Impact tests of exposed specimens were performed by Liu [10], the effects of exposure temperature, impact energy on the damage mechanism, absorbed energy and maximum impact force were analyzed. Finite element modeling is more convenient and efficient to obtain the honeycomb sandwich behavior compared to experiments.

In order to achieve efficiency and save time, an equivalent model of the honeycomb core is usually employed in numerical simulation. A amount of work has been presented by different researchers to predict the equivalent properties of the core in terms of geometric and material characteristics of honeycomb sandwich structures [11–14]. An equivalent monocoque shell theory was developed by Sun [15] to predict mechanical behaviors of the quasi-isotropic sandwich cylinder, including the deformation and the multi-mode failure criterion. An approach on identification of equivalent properties of honeycomb core using experimental modal data was proposed by Jiang [16], and the results were in good agreement with experimental data.

A homogenized model established by using equivalent properties can represent the macromechanical properties, but errors would have

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also been attributed to the continuum model especially when it is employed to identify local deformation such as indentation, because local deformation is very sensitive to the honeycomb core. Therefore, a geometrically accurate finite element model of honeycomb core becomes necessary. Nguyen et al. [17] simulated the force–time histories, size and depth of the permanent indentation for aluminum honeycomb sandwich panels subjected to low-velocity impact by using an accurate finite element model, and figured out that the structural response and impact damage resistance were sensitive to the core geometry. Detailed finite element models are used to examine the effect of the adhesive joint between the honeycomb core and the facesheets on load transfer and static response by Burton and Noor [18]. All researches demonstrate that a detailed model is valuable in studying the effect of core geometry on the honeycomb sandwich structure response.

A great number of impact problems were investigated to understand the energy dissipation patterns and energy absorption properties [19,20]. These studies are very important and necessary in order to build safer sandwich structures and evaluating existing ones for specific uses. It is found that during low-velocity impact events, honeycomb sandwich structures could convert, totally or partially, kinetic energy into other forms of energy, such as plastic deformation energy and elastic strain energy. Several energy absorption effectiveness factors such as core thickness, facing thickness and laminate thickness were investigated by Gilkie [21], and indicated that sandwich plates were substantially more resistant to impact failure than simple laminates. Goldsmith [22] experimentally studied the energy absorption in impact on sandwich plates and reported that the best correlation of energy absorption capacity without considering areal density was the energy absorbed per unit of crush.

In this paper, an experimental and numerical investigation is undertaken to study dynamic compression performance and energy absorbed by employing the aluminum honeycomb sandwich panel subjected to low-velocity impact. During the experimental investigation, a high-speed video system is employed to record the acceleration attenuation process of the impactor and a projection profile system is introduced to measure the surface profiles of the panel and to obtain the depth of the ultimate indentation. Meanwhile, a three dimensional micromechanical finite element model is developed, a convergence study, a constitutive material behavior study and an effect of adhesive layer study are conducted to ensure that results obtained by numerical method are correct and credible. In addition, practical utility of the modeling method is validated by experimental results and used to solve for the indentation characteristics and energy absorption property of the aluminum honeycomb sandwich panel under low-velocity impact.

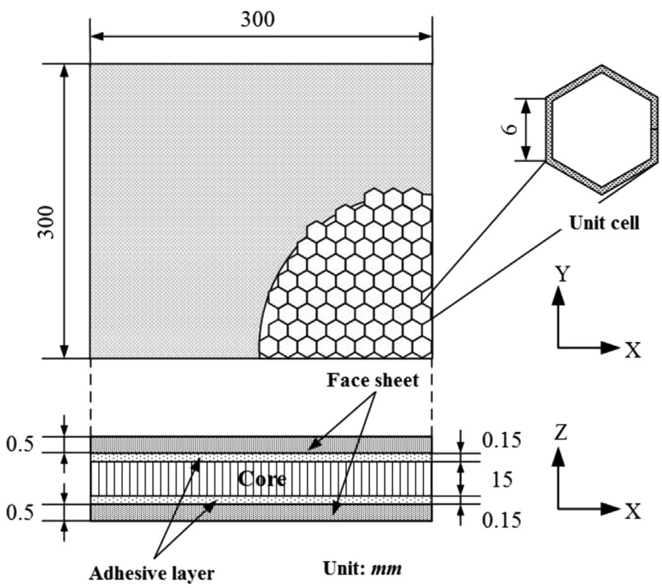

Fig. 1. The honeycomb sandwich panel.

2. Experimental investigation

In this section, an experimental investigation on an aluminum honeycomb sandwich panel subjected to low-velocity impact is undertaken.

2.1. Experimental procedure

2.1.1. Sandwich panel specimens

The specimens shown in Fig. 1 are made of aluminum alloy for both honeycomb core and facesheets, the core and facesheets are cemented by epoxy resin. Each panel measures 300 mm × 300 mm, with a thickness of 0.5 mm for each top and bottom facesheet, a hexagonal core thickness of 15 mm and a thickness of 0.15 mm for adhesive layer between facesheets and core. The side length and wall thickness of a unit cell are 6 mm and 0.07 mm, respectively. The density of aluminum honeycomb is 48.5 kg/m^3.

2.1.2. Experimental arrangement

The test system consists of three parts: a pendulum-impacting part, a high-speed video part and a three-dimensional shape measurement part. The pendulum-impacting part is shown in Fig. 2, which is composed of an aluminum sandwich panel specimen and a pendulum impactor hung on the supporting frame with a rigid wire. The aluminum sandwich panel specimen is clamped

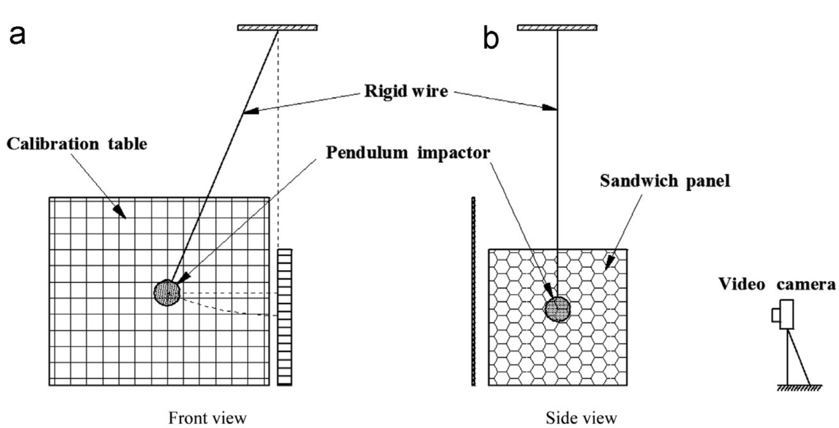

Fig. 2. Pendulum-impacting system.