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Flexural strength and energy absorption of carbon-fiber–aluminum-honeycomb composite sandwich reinforced by aluminum grid

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ABSTRACT

The full potential of carbon-fiber and aluminum-honeycomb sandwich panels and structures has been limited by the huge property mismatch between the high-stiffness carbon fiber and low-stiffness aluminum honeycomb. In this study, an orthogrid structure was added into the sandwich structure to raise the stiffness of soft honeycomb and therefore reduce the interfacial mismatch. The core then became an aluminum orthogrid structure filled with aluminum-honeycomb blocks. Three point bending tests were conducted to compare carbon fiber sandwiches with different types of core: (1) aluminum-honeycomb core; (2) aluminum-plate orthogrid core; and (3) aluminum-plate orthogrid core filled by aluminum-honeycomb blocks. The honeycomb filled orthogrid core sandwich was a bit heavier than the honeycomb or grid sandwich, but the critical load, specific strength and energy absorption ability were all improved. The results indicated that the honeycomb filled orthogrid core sandwich with carbon fiber face sheet could provide improved structural properties for thin walled engineering structures.

1. Introduction

Carbon fiber and aluminum honeycomb, which obtain complementary properties, are obvious candidates for composite sandwich structures in various applications such as automotive, marine, aerospace vehicle and light weight structures. The carbon-fiber face sheets are used to bear the structural loads. While the honeycomb core is used to reduce the total weight, to provide the shear stress transmission between the two face sheets, as well as other potential benefits e.g. effective energy absorption and shock mitigation [1–3]. The core material and its micro-geometry are designable, that could provide satisfied properties for various applications. Accordingly, extensive studies have been carried out to compare sandwich structures with different core materials and geometry, in order to select appropriate cores for various designing requirements [4]. Typical four-point bending test, analytical and numerical models of honeycomb sandwich panels were proposed by Abbadi [5]. It was worth mentioning that analytical and numerical homogenization approaches were used for computing the equivalent properties of the honeycomb core. Foo et al. [6] studied the linear elastic mechanical properties of Nomex-paper and Nomex-honeycomb structures, considering the effect of cells number and specimen size. Kaman [7] experimentally and numerically investigated the critical buckling loads of polyester resin-impregnated paper and aluminum honeycomb composite panels with various core densities and materials. It was illustrated that the critical buckling load of paper core panels was higher than that of aluminum core panels. Besides, buckling strength of the specimens increases with the increase of core density. Nomex honeycomb and foam sandwiches of different core densities were subjected to low-energy impact test by Akay [8].

Moreover, grid or lattice structures are also widely used as core for sandwiches. X-core panels consisting of pin reinforced polymer foam core with carbon-fiber face sheets were manufactured by Rice [9]. Comparisons between X-core sandwich panels and current sandwich materials (aluminum honeycomb, metal foam, and PVC foam) under the three-point bending condition demonstrated that the X-core sandwich panels provided advanced performance, but the manufacturing was high-cost and time-consuming [9]. Fan [10] conducted out-of-plane compression, in-plane compression and three-point bending experiments for testing and comparing mechanical behaviors of lattice grids cores, foams and honeycombs cores. The experimental results showed that the grid structures were much stiffer and stronger, yet heavier. It is worth mentioning that grid structures have been used in aerospace for their desirable mechanical behaviors [11], and those structures can be easily fabricated by the wet filament winding or the interlocking technology [12]. Furthermore, there

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are several available methods for analyzing and calculating the grid stiffened structures, like homogenization, smearing and finite element modeling [13–18].

Available literatures mentioned sandwich structures with a single type of core, which limits the full potential of the composite sandwich in one way or another due to sudden property mismatch between the core and face sheets. For example, honeycomb sandwich panels have desirable performance in energy absorption, thermal conductivity and acoustic damping, but weak in-plane properties. Sandwich panels with orthogrid cores are proven to have high mechanical properties, while they still need to be filled to provide more functions. Considering the engineering demands in various situations, desirable sandwich structures consisting of two types of core materials have recently been proposed to overcome the limitations [19,20].

However, combining two types of core materials lead to multiple interfaces between the components. Strong interface bonding at the multiple interfaces is essential for the sandwich structures and structural integrity. Our recent studies have shown that low-density short aramid fiber interleave is effective for suppressing premature interfacial delamination at the interface of carbon-fiber–aluminum-foam sandwich [21,22] and carbon-fiber–aluminum-honeycomb sandwich [23], where there is a sudden material property change between the face sheets and core.

In this study, we modify the interfacial mismatch between the stiff face sheets and soft core by adding two additional material components into the sandwich structures, i.e. by inserting a thin aramid-fiber tissue at the interface and by raising the stiffness of soft honeycomb core using an orthogrid structure made of aluminum plate. The core then becomes an aluminum orthogrid structure filled with aluminum-honeycomb blocks. While the thin aramid-fiber tissue is inserted in every interface between honeycomb, orthogrid and face sheets, i.e. there is no direct contact between face sheet, honeycomb and orthogrid. Three different sandwich structures are processed and tested: (1) the "base" carbon-fiber face sheets and aluminum-honeycomb core with interfacial aramid-fiber tissue reinforcement, (2) carbon-fiber face sheets and aluminum-plate orthogrid core with interfacial aramid-fiber tissue reinforcement, and (3) the final "combined" carbon-fiber face sheets and aluminum-plate orthogrid core filled by aluminum-honeycomb blocks, again with interfacial aramid-fiber tissue reinforcement.

Table 1
Properties of the aluminum honeycomb, aluminum plate, carbon-fiber epoxy face sheet and aramid fiber.

Properties (units)	Aluminum honeycomb [24]	Aluminum plate (6060T5) [25]	Carbon fiber/epoxy	Aramid fiber
Density (kg/m^3)	31	2700	1900	1400
Young's modulus (GPa)	0.075	69.5	200	131
Comp. strength (MPa)	0.9–1.5	–	–	–
Tensile strength (MPa)	–	110	1572	2655
Poisson's ratio, υ/υ_{12}	–	0.33	0.3	0.3

2. Experimental preparation and manufacturing

2.1. Materials

Aluminum honeycomb with 6.35 mm cell size, 0.06 mm cell wall thickness and 12 mm height was used as one of core materials in this study. The other core material involved was 6060T5 aluminum flat bar with 12×3 mm^2 cross section. As for face-sheet material, 200 T 2×2 twill weave carbon-fiber fabric with an areal density of 200 g/m^2 was employed. During the curing process, West System z105 epoxy resin was mixed with slow hardener 206 with the recommended ratio of 5:1. Using this epoxy resin compound, the carbon fiber fabrics were impregnated to form pre-preg. Aramid-fiber tissue was made by bonding Kevlar® fibers (approx. 2.54 cm in length, 8 g/m^2 areal density) together with a random distribution. The tissue was used as short-aramid-fibers reinforcement at interface. The mechanical properties of materials involved in this study are listed in Table 1 [24,25].

2.2. Manufacturing process and specimens

There were three types of cores involved in this study, including honeycomb core, orthogrid core and honeycomb filled orthogrid core. Five specimens were manufactured and tested for each type as an experimental group.

The three types of cores were prepared as follows. The plain aluminum-honeycomb cores prepared for honeycomb sandwich panels were 180 mm in length and 46 mm in width. While, the aluminum orthogrid used was built up by two 180-mm-length transverse ribs and four 46-mm-length longitudinal ribs. For honeycomb filled orthogrid cores, as shown in Fig. 1, the aluminum-honeycomb cores were cut into small pieces with suitable sizes for filling into the orthogrid accurately. The small pieces of honeycomb were then wrapped by aramid-fiber tissues, which were impregnated by the mixed epoxy resin mentioned in Section 2.1. The wrapped pieces of honeycomb were finally assembled into the orthogrid to form the integrated core.

The upper and bottom face sheets were produced from five carbon-fiber pre-pregs as mentioned in Section 2.1. Large piece of aramid-fiber tissues with the same dimension of face sheets were

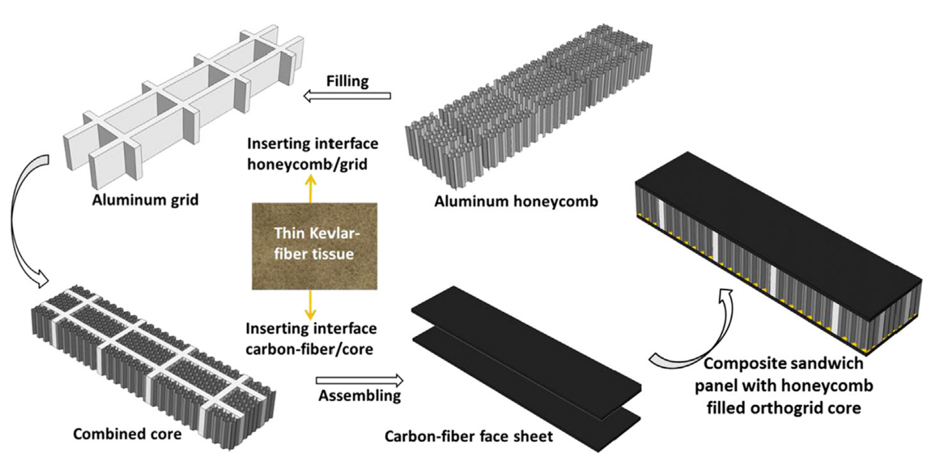

Fig. 1. Schematic of the fabrication process of sandwich panels with honeycomb filled orthogrid core.