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Interlocking orthogrid: An efficient way to construct lightweight lattice-core sandwich composite structure

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ABSTRACT

To construct weight efficient aerospace sandwich structures, interlocked orthogrid sandwich composite panels reinforced by carbon fibers were designed, made and tested. The orthogrid is weight efficient in flatwise compression for its strength is greater than usual three-dimensional (3D) lattice truss composite structures. Progressive crushing of the ribs endows the orthogrid long deformation plateau and great mean crushing force (MCF) while most of 3D lattice truss composite structures are usually brittle. Crushing models of lattice truss materials were developed to predict the MCF and it is found that the orthogrid composite has comparable or even better specific energy absorption (SEA) compared with 3D metallic lattice trusses. Forming continuous resin adhesive layers between the facesheets and the orthogrid, the orthogrid sandwich panel has stronger shear strength and is more weight efficient than usual 3D lattice truss sandwich panels jointed by adhesive joints in shear resistance. Through the research, it is concluded that interlocking orthogrid provides a simple but efficient way to construct lightweight sandwich composite.

1. Introduction

Recently, lightweight lattice truss composite sandwich structures attract attentions of many researchers in aerospace science and technology [1], who try their best to propose efficient method to make these lattice structures, including corrugated lattice truss structure [2], octet-truss lattice structure [3,4], 3D honeycomb grid structure [5], pyramidal truss structure [6–9], octahedral stitched truss structure [10]. Usually, 3D lattice truss structures are looked as the most weight-efficient structure, such as Octet-trusses, pyramidal trusses and tetrahedral trusses. Obeying stretching-dominated deformation mechanism, the effective strength and the equivalent Young's modulus are linear to their relative density. In-plane stretching service scenario is important for cellular lattice structure when it is applied as a dependent load-bearing structure, such as 3D space lattice structures [3], Iso-truss columns [11] and Isogrid cylindrical structures [12,13]. As these 3D lattice trusses are inserted into the core of a bended sandwich panel, it is found that the adhesive layer between the facesheets and the lattice trusses is dominant, more important than its compression strength in the case of lap shear and bending test scenarios. Thus, the weight efficiency is limited and the lattices face identical problems with traditional honeycombs and foams, which are assumed to be replaced by those stretching-dominated lattice structures. In other way, to construct a 3D lattice structure is so complex and expensive that the lattice cannot be produced at expected dimensions for engineering applications. All these shortcomings restrict the application of 3D lattice composite structure, although Li et al. [14] has successfully made 3D lattice-core sandwich cylinder, whose diameter is 625 mm.

On the contrary, planar grid composite is easily made and inexpensive [15–18]. Interlocking method inspired by Han and Tsai [15] simplified the making process and reduced the cost. Using carbon fiber reinforced plastics (CFRP), Fan et al. [19–21] made Kagome grid-core sandwich panels. The Kagome grid is stretching-dominated in edgewise compression. But the in-pane stretching-domination is not important for a core structure when the panel is bended. Out-of-plane compression and shear behaviors are the most concerned. So in this paper, interlocking orthogrid, a simple way to construct efficient lightweight sandwich

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structure was proposed and mechanical properties of CFRP orthogrid panels were revealed.

2. Interlocked orthogrid

To make the interlocked orthogrid, CFRP strips were firstly made by hot-pressing method. Prepreg carbon fiber (CFS15000) layers of $[0°/90°]_7$ were placed into the mould and cured at 120 °C for 4 h. Each layer is about 0.15 mm. From the CFRP supplier, unidirectional carbon fiber (CFS15000) layered laminate has tensile strength of 819.1 MPa, tensile modulus of 82.1 GPa, shear strength of 18 MPa and fracture strain of 1.42%. CFRP strip with layers of [0°/90°] has compression strength of 294 MPa from our own measurement [2].

The rib has trapezoid cross section and changing thickness, varying from 2 mm to 1 mm linearly, as shown in Fig. 1. The strip width is 10 mm. Slots distribute along the strip with spacing of 20 mm. The maximum width of the slot is 1.5 mm and the depth of the slot is 5 mm. The strips were then interlocked orthogonally to form the orthogrid. After that, the orthogrid was placed between two facesheets whose thickness is 1 mm. Adhesive, Epoxy resin YJ01, was applied to join the face sheet with seven layers of [0°/90°/0°/90°/0°/90°/0°] and the orthogrid. The sandwich panel was co-cured at room temperature for 12 h under a uniform compression force of 1.75 kN. After co-curing and removing the mould, the LTSP was fabricated. Through hot-pressing, a CFRP orthogrid sandwich panel was achieved. The relative density of the orthogrid, ρ^*, is

$$\rho^* = 2\frac{t}{d}, \tag{1}$$

where t is the mean thickness of the rib and d is the spacing between ribs. Usually, strength σ_s and Young's modulus E_s of the structure have following relations

$$\sigma_s = A\rho^*\sigma_M, \quad E_s = B\rho^*E_M \tag{2}$$

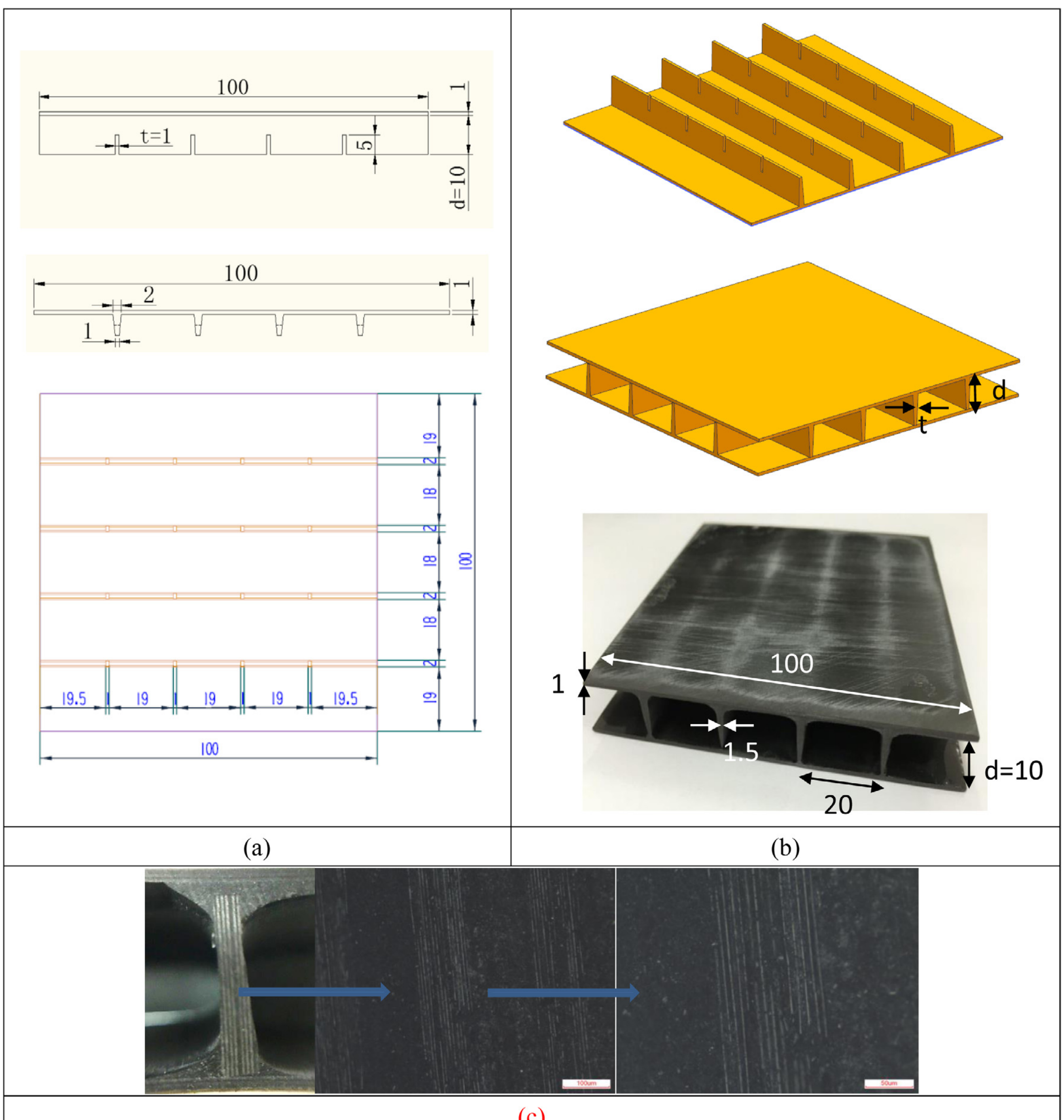

Fig. 1. (a) Rib structure, (b) orthogrid sandwich panel and (c) micro-fibers in the core pillar (Unit: mm).