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Bending behavior of graded corrugated truss core composite sandwich beams

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ABSTRACT

This study presented a new method for forming the graded corrugated truss core sandwich structures based on an auto-cutting and mould-press process. The bending stiffness, strength and failure mechanism were investigated. Analytical models were presented to estimate the performance and failure mode of the sandwich beams. In order to demonstrate sensitivity of geometric parameters on the bending behavior of the truss core sandwich beams, a uniform and two kinds of graded corrugated truss core sandwich panels were fabricated and tested to probe different failure modes. Results showed that the distributions of the truss cores have strong influences on the bending behaviors of the sandwich beams. The predicting results were also compared with the measurements investigated. In general, the measured failure loads showed good agreement with the analytical predictions, except the uniform truss core sandwich beam. The graded corrugated truss core sandwich structures investigated appear to be promising candidates for lightweight systems and multifunctional applications.

1. Introduction

Sandwich structures effectively provide lightweight stiffness and strength by sandwiching a low-density core between stiff face sheets. Metal foams and honeycombs are widely used for the cores of metallic sandwiches, and their fabrication and assembly processes have been well developed. Foams are generally cheap and easy to handle, and their large surface area and high damping make them preferable for thermal and sound insulation [1]. The honeycomb structure, which is a typical closed cell structure, has been widely applied to the structural parts of airplanes because of its high specific strength and light weight characteristics [2]. However, traditional sandwich made from foam or honeycomb cores with close-cells cannot accommodate free fluid movement through them. This limit on flow circulation imposes significant restrictions in thermal and transport properties preventing their deployment as functional structures. Therefore, fabrication of sandwich panels with open-cell core constructions with interconnected void spaces can extend the usage of sandwich panels to functional applications.

Lattice truss structures, such as pyramid, octet or Kagome truss have been proposed as potential replacements for conventional foam core, because they provide comparable strength and stiffness levels [3]. More importantly, they provide easy access to the core regions, which means that lattice cores can support additional functions, such as actuation and cooling. Metals lattice truss structures can be fabricated by investment casting or crimping of expanded metals and their performances have been evaluated under bending or compression [4].

Usage of fiber-reinforced composites in sandwich structures generally allows an additional weight reduction without jeopardizing the strength and performance of the structure. Carbon-fiber lattice structures have been made by hot-press molding of carbon-fiber prepreg materials and by a mechanical snap-fit method. Finnegan et al. [5] manufactured composite pyramidal truss core sandwich structures using a snap-fitted method. Fan et al. [6,7] reported a Kagome lattice composite composed of interlocked laminate ribs. Xiong et al. [8,9] fabricated carbon fiber composite pyramidal truss core sandwich structures by the molding hot-press method. Fan et al. [10], Yang et al. [11] and Xiong et al. [12] manufactured composite sandwich cylindrical shell with pyramidal truss-like cores. Xiong et al. [12] also studied the vibration and damping characteristics of free–free composite sandwich cylindrical shell with pyramidal truss-like cores using the Rayleigh–Ritz model and finite element method. Wang et al. [13] reported a carbon fiber reinforced polymer composite sandwich structures with pyramidal lattice core subjected to high velocity impact. Yin et al. [14] designed the stretch–stretch-hybrid hierarchical lattice cores that were fabricated with a two-step approach by assembling composite pyramidal lattice sandwiches into

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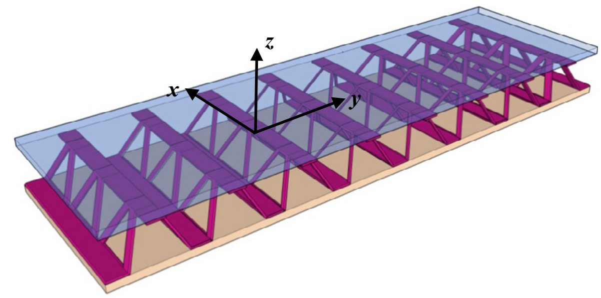
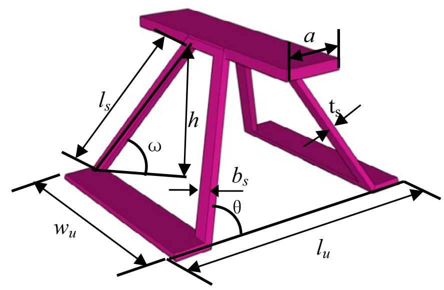
macroscopic truss configurations. Analysis of the out-of-plane compressive strength was finished in their work. Lei et al. [15] analyzed the local defect effect of carbon-fiber pyramidal truss core panel through experimental, theoretical and finite element analysis methods. Lee et al. [16] reported a new approach for fabricating truss cellular cores using pultruded unidirectional fiber-reinforced composite rods. George et al. [17] proposed a hybrid braided carbon truss/polymer foam core approach for fabricating carbon fiber reinforced polymer pyramidal lattice structures. Kim et al. [18] presented a new fabrication technique of composite sandwich panels based on truss woven method. They also estimated the stiffness and strength of this sandwich structure. In order to prevent the weak interface between the core and skins, Che et al. [19] manufactured a sandwich composites, whose upper and lower skins are integrated with the stitching yarns, and investigated their mechanical properties.

The previous works focused on the mechanical characteristics of lattice core sandwich structures with uniform unit cells, as shown in Fig. 1a. However, there are practical occasions which require the geometry of the unit cell change in one or two directions. So, it is necessary to develop appropriate methods to fabricate and investigate the mechanical behaviors of the truss core sandwich structures with non-uniform unit cells. But, due to the complexity of the problem caused by the non-uniformity, it is a challenging work. A new concept of the graded truss core sandwich structures, which have non-uniform unit cells in the cores, was firstly presented in our previous work [20]. These graded truss core sandwich structures were fabricated by a stitching and hot-press process, as shown in Fig. 1b. The graded truss cores of the sandwich structures were obtained by varying the stitching step and inclination angle for each pyramidal unit cell. Using this method, the skins are too thick and the structure is not weight efficient. Furthermore, this fabrication method is time-consuming because the specimens are hand-made. In order to improve efficiency and quality, a new method of fabricating graded truss core composite sandwich panels is introduced in this work. The method is based on an automatic cutting and mould-press process. The graded truss cores were obtained by varying the strut's width for each unit cell in this work, which is different with our previous work [20]. Analytical models are also presented to predict the stiffness, strength of the sandwich beams in three-point bending. The predicted deflections and collapse loads are compared with the measured values for the selected beam geometries.



(a) a graded corrugated truss core composite sandwich panel



(b) a unit cell

Fig. 2. Configuration of a graded corrugated truss core composite sandwich panel.

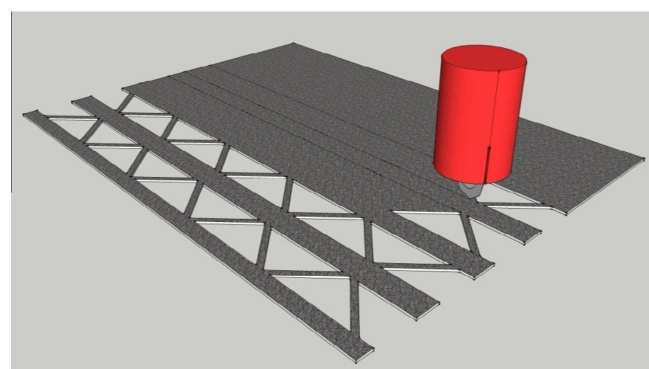
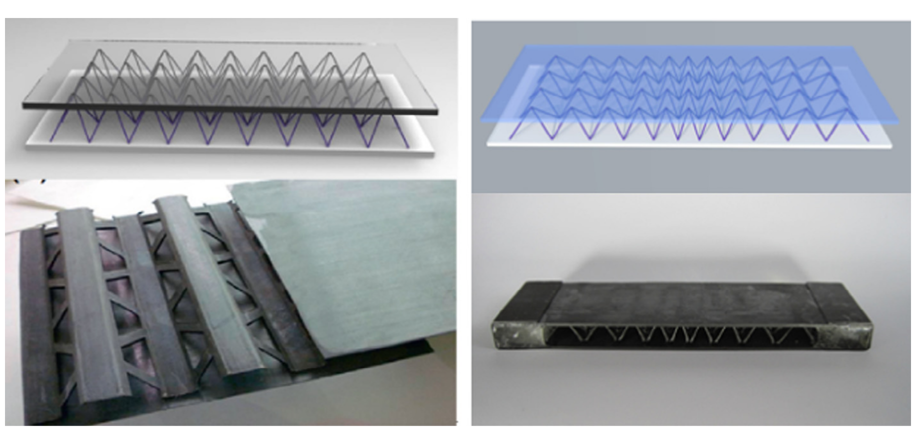


Fig. 3. Schematic of the manufacturing process of the graded corrugated truss core using the automatic tailor machine.



(a) a uniform truss core composite sandwich structure

(b) a stitched graded truss core composite sandwich structure

Fig. 1. The uniform and stitched graded truss core composite sandwich structures.