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Compressive and bending behaviours of wood-based two-dimensional lattice truss core sandwich structures

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ABSTRACT

In an effort to optimal the structure of wood engineering materials, wood-based two-dimensional lattice truss core sandwich structures made of wood composites and birch dowels were manufactured using a simple slotting and adhesive bonding approach. The out-of-plane compressive and bending behaviours of sandwich structures made of different facesheet materials were investigated. Analytical models were employed in this study to predict the compressive collapse strength and Young's modulus of the sandwich structures. The theoretical predictions of the compressive Young's modulus are in good agreement with experimental results based on the elastic deformation of the dowels. The failure modes of the sandwich structures are represented by the shear failure of the dowels and facesheets under out-of-plane compressive loads. The out-of-plane compressive behaviours of the sandwich structures demonstrate a good energy absorption capability which is an important factor for the safety of wooden construction. The bending behaviours of the sandwich structures indicate that the debonding of nodes was fatal to the sandwich structures, and the bending properties of the sandwich structures were found to depend on the fracture toughness of the adhesive and the strength of the facesheet materials used in their construction.

1. Introduction

Recently, lattice truss cores have been explored as a candidate core material because of their superior specific strength/stiffness and the large interconnected void space. Since the beginning, lattice truss structures have been designed and fabricated using high specific strength alloys such as titanium [1] and aluminium [2]. Wicks and Hutchinson have optimally designed such panels subject to prescribed combinations of bending and transverse shear loads [3]. In addiction, the quasi-static/dynamic mechanical response of lattice sandwich structures has been investigated by numerous scholars [4–10].

Recently, sandwich cores made of low-density carbon-fibre–reinforced composite (CFRC) lattices for ultra-light sandwich structures have also attracted significant interest [11–19]. Carbon-fibre lattice structures have also been made by hot-press molding of carbon-fibre pre-preg materials [11–15] and by a mechanical "snap-fit" method [18,19]. Fan et al. [20,21] manufactured a carbon-fibre–reinforced three-dimensional (3D) lattice core sandwich panel using an intertwining method. Finnegan et al. [16] manufactured pyramidal truss sandwich cores comprised of carbon-fibre–reinforced polymer (CFRP) laminates using a snap-fitting method. Analytical models describing the collapse of the composite cores by the Euler buckling, delamination failure of the struts have been developed. With respect to conventional sandwiches, Wang et al. [22] determined that aside from debonding between the facesheets and cores, the delamination of the facesheets is the primary failure mode of this sandwich structure. George et al. [23] revealed that the strength and moduli of hybrid cores are found to increase with foam density due to a combination of increase in foam strength and modulus and the retention of a more circular cross-section CFRP truss that is less susceptible to elastic buckling. Fan et al. [24] determined that cell dimensions, the fracture toughness of the adhesive and the strength of the sandwich skin decide the critical load capacity of a lattice core sandwich structure. To improve the shear performance of pyramidal lattice core sandwich structures, Sun and Gao [25] presented an improved pyramidal lattice truss core sandwich structure by introducing a series of parallel-distributed crossbars to core members. Li et al. [26] evaluated the structural response of an all-composite pyramidal truss core sandwich columns

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subjected to end compression. Xiong et al. [27] evaluated the bending performance of CFRC sandwich panels with pyramidal truss cores. Yin et al. [28] have presented a novel hybrid truss construction concept that incorporates a second-phase core material into trusses of carbon fibre (CF) composite pyramidal lattice (CPL) structures. Such lattice structures manufactured from either metal or carbon-fibre composites are tropically applied in the fields of high-speed traffic engineering and aerospace as candidate core material because of their superior specific strength/stiffness and their larger interconnected void space. However, fabrication of the lattice truss core sandwich structures using wood composites has not yet been reported in the field of wooden construction.

Wood is a highly efficient material. Its notable resistance under both compressive and tensile loads must be considered as being nearly unique with respect to its limited weight density. Owing to the ongoing substantial changes in the global forest resource structure and heightened concerns regarding anthropogenic climate change, the high-quality wood resources are rapidly diminishing while the demand for wood products and the environmental consciousness are constantly growing. Traditional wood engineering materials, including glued-laminated timber, flanged beam (I beam) and laminated veneer lumber (LVL), are popularly used as construction and building materials. Although some of the inherent disadvantages of wood materials have been mitigated, such as their low relative strength, high weight and price, these materials still cannot compete with other lightweight, high-strength building materials that are ideally suited for multi-functional applications. The question of how to optimise the structure of wood engineering materials therefore represents a worthy research project.

Wood-based sandwich structures have been explored as lightweight wood engineering materials because of their excellent stiffness and strength-to-weight ratios. Kawasaki et al. [29] has manufactured several wood-based sandwich panels using a low-density fibreboard core for structural insulated walls and floors. These constructed panels have been found to provide sufficient internal bond strength and excellent dimensional stability. Tagarielli et al. [30] revealed that the axial compression properties of balsa wood are highly strain-rate sensitive, providing a significant increase in dynamic strength compared with quasi-static behaviour, and the material's axial compression properties have been shown to be clearly superior to those of polyvinyl chloride (PVC) foams of comparable densities. Fernandez-Cado et al. [31] designed wood-based sandwich panels to withstand their self-weight and wind load, and thus avoid the question of creep. Kepler [32] investigated a concept for improving the shear stiffness properties of balsa core material for sandwich structures. O'Loinsigh et al. [33,34] have presented experimental and numerical investigations on a novel full-scale multi-layered timber beams with composite action achieved with welded-through wood dowels. Although the self-weight of these wood-based sandwich structures has been effectively reduced, their multifunctional applications are limited because of the closed-cell structure of their design. The aim of the present study is to initiate an investigation based on the design of a large interconnected void space structure by using wood composites to build the lattice truss core sandwich structures.

An outline of this paper is as follows. First, the mechanical properties of birch dowels and different facesheet materials, as determined by using a universal mechanical testing machine, are discussed. Second, the dowels and different facesheet materials are used to manufacture 2D lattice truss core sandwich structures and the manufacturing approach applied are described. Third, the measured out-of-plane compressive and bending behaviours of the sandwich structures examined by experimental methods are discussed. Finally, the analytical models developed by Finnegan et al. [16] and Wang et al. [22] are applied to the sandwich structures, and the results are compared with the experimental results.

2. Experimental program

2.1. Unit cell design

The unit cell design of the 2D lattice truss core used in the present study is shown in Fig. 1. The relative density of the 2D lattice truss core depends on the diameter d of the dowels, inclination angle ω, length l of the truss members, length l_0 of the dowels, depth c of the drilling hole, width b of the unit cell and the distance t between the adjacent dowels as shown below

$$\bar{\rho} = \frac{\pi d^2}{4b\sin\omega(l\cos\omega + t)} \quad (1)$$

$$l = l_0 - 2c \quad (2)$$

The geometrical parameters employed for the present study are $d = 10$ mm, $\omega = 45°$, $l_0 = 50$ mm, $c = 8.0$ mm, $b = 60$ mm, $t = 26$ mm in the present study, so the relative density of the lattice truss core $\bar{\rho}$ as 3.66%. We chose the geometrical dimensions of the unit cell lattice according to the ASTM: C365/C365M-11a standard, manufacture techniques and test machine. The maximum possible width of the out-of-plane compression test specimen, according to the limitations imposed by the ASTM: C365/C365M-11a standard was 60 mm. The reason why the depth $c = 8$ cm of the drilling hole was that it need to provide sufficient bonding area and keep the mechanical strength of the facesheets. In addition, the out-of-plane compression test specimen was compressed between two flat, parallel and rigid rounded platens with of 100 mm diameter. So, the maximum length of the compression test specimen was 100 mm.

2.2. Material properties and fabrication

Wood-based 2D lattice truss core sandwich structures were manufactured and investigated at the key laboratory of bio-based material science & technology (Northeast Forest University).

Poplar LVL panels and birch (*Betula platyphylla Suk*) sawn timber were used as the facesheets of the sandwich structures. The mechanical properties of the poplar LVL panel and birch sawn timber [35] are listed in Table 1. Birch dowels were used to construct the truss members of the sandwich structure. Column compression tests [36] were performed in which the specimens were compressed between two flat, parallel and rigid platens with end-clamping composed of birch dowels, as shown in Fig. 2. The load and cross-head movement of the test machine were measured. Birch dowels were assumed to be a taken as transversely isotropic material for the convenience of prediction. The properties of birch dowels used in the present study are listed in Table 2. The compressive collapse strength of the selected birch dowels was evaluated as 60.74–74.02 MPa, whereas the average mass and compressive Young's modulus were 2.27 g and 3326 MPa respectively.

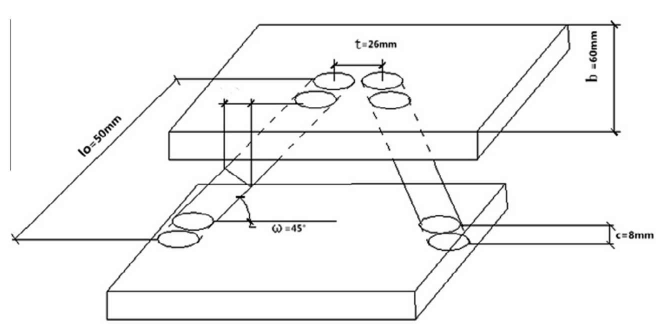

Fig. 1. Schematic of 2-D lattice truss core unit cell.