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A composite sandwich panel integrally woven with truss core

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ABSTRACT

In this work, a new fabrication technique of composite sandwich panels, named TWOS (Truss WOven Sandwich), was introduced, allowing access to the interior spaces of the cores and giving good resistance against face–core debonding, as well as high compressive and shear strengths. To evaluate the validity of TWOS, analytic solutions for its mechanical properties under compression, tension and shear loadings were derived, and specimens were prepared and tested. The equivalent strengths of the TWOS specimens under compression or shear were governed by the fracture behavior of the struts subjected to longitudinal compression. On the other hand, the equivalent strengths under tension were limited by the debonding which occurred near the face sheets. With consideration of the densities, the TWOS cores showed strengths and elastic moduli comparable to or even higher than those of conventional honeycomb cores, and substantially higher than those of Distance fabric cores and cores fabricated by angled stitching.

1. Introduction

Sandwich panels consisting of a pair of thin high-strength face sheets and a thick low-density core have been regarded as ideal structures because of their high strength and stiffness per weight. 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 insulations [1]. However, they lack strength and stiffness, limiting their application for heavy duty loading. A honeycomb is regarded as the optimal core material in terms of strength, stiffness, and lightness. However, access to its interior space for additional functions is limited.

A truss PCM (Periodic Cellular Metal) is a kind of cellular metal with a miniature truss structure, like a pyramid, octet or Kagome truss [2–4]. Its regular structure composed of constant struts provides strength and stiffness as high as those of a honeycomb, while its open-cell architecture provides accessibility to its interior space for additional functions such as heat dissipation [5]. Truss PCMs can be fabricated by investment casting or crimping of expanded metals or perforated sheets, and their performances have been evaluated under bending or compression [6]. In general, multi-layered structures with fine cells are preferred when trying to obtain the properties of homogeneous materials along with vibration suppression capability. However, the previous fabrication processes have been unable to produce multi-layered PCMs; they only stack multiple single-layered structures.

Recently, WBK (Wire-woven Bulk Kagome) was introduced as a type of truss PCM fabricated by using wires [7]. Specifically, helically formed wires are spin-inserted in six directions evenly-distributed in space to assemble a 3D Kagome truss-like multi-layered structure. The wires provide high strength without defects. WBK has a structure similar to that of a Kagome truss, one of the best structures possessing high strength per given weight. Hence, WBK is regarded as one of the best mass-producible truss PCMs. WBK can be assembled by wires of various materials such as stainless steel [7,8], aluminum alloys, spring steel [9], titanium [10], stainless steel tubes [11,12], and even fiber reinforced composite rods [13].

Generally, a composite sandwich panel is fabricated by adhesively bonding face sheets on both sides of a core. Polymeric foams and aluminum or composite honeycombs are widely used for the core [14]. Chevron folded cores are a recent addition, having attracted attention for their high strength and benefits provided by the semi-open structure and mass productivity [15,16]. On the other hand, a number of studies have also been done on composite truss PCM cores [17–19]. Unlike metallic wires, composite struts under compression are likely to show a substantial drop in strength and stiffness, if the fiber reinforcements aligned in the struts slightly bend [20]. Therefore, only straight struts formed by cutting a laminated plate [17], hot-press molding [18], or pultrusion [19] are used in truss PCM cores to support a compressive

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load. Nevertheless, the cores in the composite sandwiches cannot be joined with the composite face sheets by adhesive bonding as strongly as by welding or brazing, commonly used for metallic sandwiches. Particularly, composite truss PCM cores contact with the face sheets at points with small area, rather than on lines is as done by honeycomb cores or chevron folded cores. Consequently, the adhesive joints between a truss PCM core and the face sheets are likely to be more vulnerable to pull-out failure than the other sandwich combinations due to the tensile force acting in the struts, even if the ends of the struts are partly or completely inserted into the face sheets along grooves or through holes, respectively [17,21,22]. These countermeasures would limit the applications of truss PCMs in heavy duty loading, particularly in fatigue loading. In order to reinforce the adhesively joined sandwich, additional stitching or overall wrapping with continuous yarn are often used.

Other kinds of sandwich fabrication techniques do not bond cores adhesively, but weave cores with their face sheets. In one kind of technique, the two face sheets are connected to each other by lots of yarn in the core, which is interwoven with the face sheets. The technique stems from traditional velvet weaving. The face sheets and core are integrally formed at a single weaving process, as shown in Fig. 1(a). The product is hence called an Integrally Woven Sandwich, Woven Sandwich Fabric, Woven Textile Sandwich, or Distance fabric [23,24]. The weaving technique provides high resistance against face–core debonding, and enables mass-production. However, in general, these woven products have significantly lower strength under compression or shear than adhesively bonded sandwiches, because all the yarn in the core is curved even after the core has been stretched and impregnated by resin [25].

The second kind of technique uses Napco® technology, which is a process used in the manufacturing of 3D sandwich composites, based on transverse needle punching [26]. Unlike other technologies, Napco technology employs fibrous reinforcements from the face sheets. A set of needles regularly penetrates the sandwich structure from both sides, and the needles catch and carry yarn from the face sheets through the core material, as shown in Fig. 1(b). Once the 3D sandwich preform is produced, it is impregnated by a liquid resin. However, the strength and stiffness of the sandwich are noticeably low due to the imperfection-sensitive local buckling of the cylindrical reinforcements, which may lead to early collapse [27].

The third kind of technique is based on stitching, which has been used to reinforce traditional foam-cored sandwiches [28,29]. Typically, vertical stitches of yarn are added to reinforce the adhesively joined sandwiches, as mentioned above. However, in this technique, these regular stitches are not vertical, but are instead at an angle with the horizontal, creating a kind of 2D truss (Fig. 1(c)). In fact, the structural parameters (step, angle) determine the morphology of this pattern (number of layers of the truss structure extent and spacing between constitutive units). This stitched preform is then impregnated with a resin polyester through an RTM (resin transfer molding) process. In the second and third techniques, fibers or yarn penetrating through the face sheets provide simple reinforcement to existing foam cores, not for truss cores standing alone with open cells. Hence, the interior spaces of a core would not be accessible to additional functions.

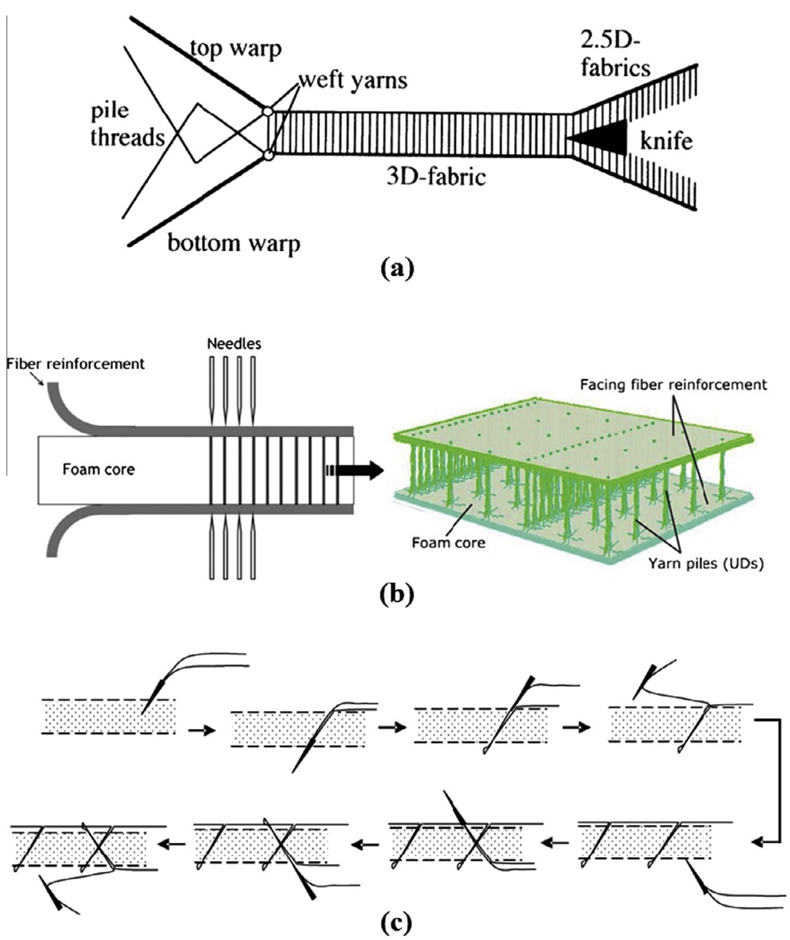

Fig. 1. Schematics of three techniques to fabricate composite sandwich panels by weaving cores with face sheets; (a) distance fabrics [25], (b) Napco® [26], and (c) angled stitching [28].