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The effect of temperature on the bending properties and failure mechanism of composite truss core sandwich structures

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ABSTRACT

The effects of temperature on the bending properties and failure mechanism of carbon fiber reinforced polymer composite sandwich structure with pyramidal truss cores were investigated and presented in this paper. The three-point bending tests of composite sandwich structures were performed at seven different temperatures, and the scanning electron microscope was used to examine the fiber-matrix interface properties in order to understand the deformation and failure mechanism. Then the effects of temperature on deformation modes, failure mechanism and bending failure load were studied and analyzed. The results showed that the temperature has visible impact on the deformation modes, failure mechanism, and bending failure load. The bending failure load decreased as temperature increased, which was caused by the degradation of the matrix properties and fiber-matrix interface properties at high temperature. The analytical formulae were also presented to predict the bending stiffness and failure load of composite sandwich structures at different temperatures.

1. Introduction

Fiber reinforced polymer composite sandwich structures have been widely used in aerospace and marine systems where lightweight structure is needed [1–5]. In recent years, the interest in sandwich structures has concentrated on lattice truss core sandwich structures which exhibit high specific stiffness, weight efficiency and potential multifunctional advantages [6–8]. Numerous cell topologies have been designed and manufactured, including Kagome [9], pyramidal [10], tetrahedral [11]. Researches have shown that lattice truss cores with stretching-dominated deformation are stiffer and stronger than the foam cores with bending-dominated deformation [12]. Moreover, their open-cell configuration allows heat exchange along the truss core, which provides an opportunity for the development of multifunctional structure [13]. Composite sandwich structures with lattice truss cores are commonly subjected to lateral loading during service, so the bending bearing capacity is especially important for these structures [14].

To date, a significant number of researches on the bending properties and failure mechanism of composite sandwich structure with lattice truss cores at room temperature have been carried out [15–17]. Fan et al. [18] investigated the bending behaviors of composite sandwich structure with Kagome lattice cores. They found that buckling, debonding and core shear dominate the mechanical behavior. Wang et al. [13] studied the bending properties of carbon fiber reinforced polymer composite sandwich structures with 2-D lattice truss cores. The results showed that the delamination of the top face sheet resulted in a sudden drop of the load. Xiong et al. [19] studied the bending response and failure behavior of composite curved sandwich structures with pyramidal truss cores by analytical modeling, experiments and computational simulations. The results showed that core debonding was the dominant failure mode. Sun and Gao [20] presented an experimental characterization of the bending load–deflection curves of all-composite pyramidal truss cores sandwich structures. The results showed that the deflection curves displayed a nonlinear fluctuant platform after an initial perfect linear stage. Many investigations on the bending properties and application of fiber reinforced polymer composite sandwich structures at room temperature have suggested their important role in future military engineering projects. However, composite sandwich structures are quite sensitive to high temperature, leading to a potential danger for aeronautical and naval application where high temperature environments can occur [21–25]. Therefore, the bending behaviors and failure mechanism of composite sandwich structures with lattice truss

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cores at high temperature should be investigated before they can be used with confidence in ships and aircraft. Unfortunately, little work has been done on the high temperature bending properties and the understanding of failure mechanism of composite sandwich structures with lattice truss cores. Thus, the present work is an attempt to fill this information needed.

In this paper, the high temperature bending properties of carbon fiber reinforced polymer composite sandwich structure with pyramidal truss cores were investigated. The three-point bending tests of composite sandwich structures were performed at temperatures ranging from 20 °C to 200 °C. The effects of high temperature on bending failure load, deformation mode and failure mechanism were studied and analyzed. Furthermore, the bending stiffness and failure load of composite sandwich structures at different temperatures were predicted and compared with experimental results.

2. Materials and experimental methods

2.1. Materials

Composite sandwich structures with pyramidal truss cores presented in this paper were fabricated from the unidirectional carbon/epoxy prepregs by hot-press molding technology. The truss cores were consisted of unidirectional composite struts. Top and bottom face sheets were interconnected with truss cores. Fig. 1 shows the schematic of the manufacturing process of composite strut. In order to fabricate the composite strut, the carbon/epoxy prepregs were cut into the required dimension by a sharp knife, and then the carbon/epoxy prepregs were rolled into composite strut with circular cross section as shown in Fig. 1b. The thickness of carbon/epoxy prepregs is 0.12 mm, and the diameter of composite strut is 2.5 mm. Subsequently, the composite struts were inserted into the holes of the mold as shown in Fig. 2a, and the ends of composite strut are embedded in the mid-plane of the face sheets as shown in Fig. 2b. The top and bottom face sheets were fabricated from 14-plies unidirectional carbon/epoxy prepregs with the stacking sequence $[0/90/0/90/0/90/0]_s$. Then, the truss cores and face sheets were cured together at 125 °C with constant pressure of 0.5 MPa for 1.5 h as shown in Fig. 2c. After curing, the molds were removed from composite sandwich structure with pyramidal truss cores as shown in Fig. 2d. Fig. 3 shows an example of the manufactured composite sandwich structure with pyramidal truss cores, and the truss cores and face sheets were fabricated in one process without bonding. The glass transition temperature (T_g) of the epoxy is about 140 °C, which is provided by the manufacturer (Beijing Institute of Aeronautical Materials, China). The schematic of the unit cell of pyramidal truss core is shown in Fig. 4. The relative density $\overline{\rho}$ of the pyramidal core depends on the diameter d of truss, inclined angle ω, length l of truss, and the distance k between two closest struts. The relative density $\overline{\rho}$ of the pyramidal core is calculated by

$$\overline{\rho} = \frac{\pi d^2}{\sin\omega\left(\sqrt{2}l\cos\omega + 2k\right)^2} \tag{1}$$

In present paper, the pyramidal core has $d = 2.5$ mm, $k = 7$ mm, $l = 21.2$ mm, $\omega = 45^\circ$, leading to the relative density of pyramidal core is 2.24%.

2.2. Experimental methods

The three-point bending tests at high temperature were conducted using INSTRON 5500R test machine with an INSTRON

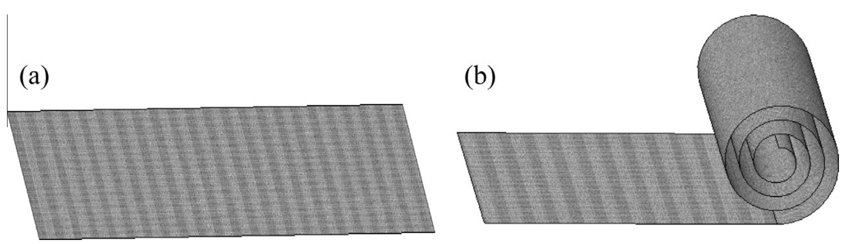

Fig. 1. Schematic of the manufacturing process of composite strut: (a) the carbon/epoxy prepregs were cut into the required dimension; (b) the carbon/epoxy prepregs were rolled into composite strut with circular cross section.

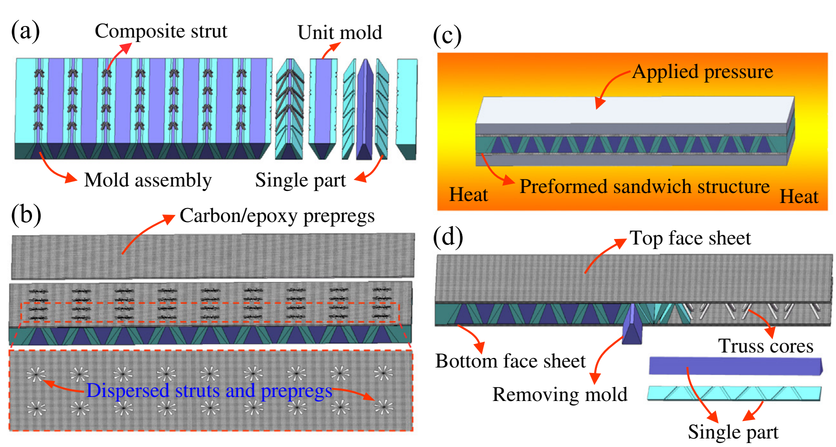

Fig. 2. Illustration of the manufacturing route for making composite sandwich structure with pyramidal truss cores: (a) the composite struts were inserted into the holes of the molds; (b) the ends of composite struts were dispersed and embedded into the face sheets; (c) the preformed sandwich structure was cured; (d) the molds were removed from the specimen after curing. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)