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Fabrication and bending behavior of thermoplastic composite curved corrugated sandwich beam with interface enhancement

Bing Du[a,b], Liming Chen[a,b,*], Jingyan Tan[a,b], Hao Zhou[c], Yang Zhao[a,b], Wenjun Wu[a,b], Weiguo Li[a,b,*], Daining Fang[d,*], Liliang Chen[e]

[a] College of Aerospace Engineering, Chongqing University, Chongqing 400030, China
[b] Chongqing Key Laboratory of Heterogeneous Material Mechanics, Chongqing University, Chongqing 400030, China
[c] Beijing Key Laboratory of Intelligent Space Robotic Systems Technology and Applications, Beijing Institute of Spacecraft System Engineering, Beijing 100094, China
[d] Institute of Advanced Structure Technology, Beijing Institute of Technology, Beijing 100081, China
[e] Chongqing Chang An Global R&D Center, Chang An Automobile Co, Ltd, Chongqing 400023, China

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ABSTRACT

Thermoplastic composite sandwich structures are being widely investigated due to their excellent properties such as recycling feasibility and high damage tolerance to meet the increasing demand for lightweight engineering components. Three-point-bending (TPB) behavior of glass fiber reinforced polypropylene curved corrugated sandwich beams taking account of the effects of core configuration and interface property were analytically and experimentally investigated. Analytical models were developed to predict the failure loads considering face sheet buckling/crushing, core buckling/crushing and core debonding. The curved axial corrugated sandwich beams (CACSB) and curved circular corrugated sandwich beams (CCCSB) were fabricated by hot-pressing and adhesive bonding. Interface enhancement was implemented by polypropylene glue stick insertion. Compared with unenhanced ones, the peak load of polypropylene glue stick reinforced (PPRGS) CACSB is 1.6 times and the maximum displacement before failure extends to 5.9 times. Failure maps were constructed to insight the failure modes of three configurations and also provide useful instruction for designing lightweight sandwich structures.

1. Introduction

Cellular structures haves wide use in many fields such as aerospace, navigation, transporting and construction etc. for their excellent specific stiffness, strength and multi-functional properties [1–4]. Apart from flat sandwich panels with cellular cores, curved sandwich panels are also extensively used as skins of ships, aerospace vehicles etc. Some studies of the curved sandwich panel with pyramidal truss core [5,6], honeycomb core [7], pyramidal kagome core [8], tubular core [9] and foam core [10,11] have been done.

Bending stiffness and strength play a vital role in determining the structural response of composite sandwich panels. Many studies about the bending behavior of flat composite sandwich panels with cellular cores have been reported [12–19], but most of which are concerned with fiber reinforced thermosetting composite. For fiber reinforced thermosetting composite sandwich panels subjected to TPB, skin fracture tends to render the brittle failure of sandwich panel and leads to that the residual strength stays at a low level comparing with the peak load [20,21]. Schneider et al. [18] manufactured thermoplastic CSB made from SrPET (Self-reinforced PET) with co-curing of core and face sheet. A ductile response after the peak load was found and meanwhile the load-displacement curve showed softening till a plateau load over the half of peak load was reached. This ductile response will be beneficial to the energy absorption capacity of thermoplastic sandwich panel.

The connection within a sandwich system includes adhesive bonding, mechanical fastening or a combination of both (known as hybrid bonding-fastening). Adhesive bonding is weight-saving and has lower fabrication cost, higher damage tolerance etc. [22,23] while mechanical fastening offers the advantages of easier assembly and disassembly and insensitive to surface preparation and environmental factors [24,25]. Hybrid bonding-fastening joint integrates the advantages of adhesive bonding and mechanical fastening and finds its wider application in many industry fields [26]. Apart from the simple adhesive bonding used to fabricate composite sandwich structures, many attempts have been made to improve the interface property between face sheet and lattice core. Xiong et al. [27] added aluminum frames between face sheets and core and effectively enhanced the shear strength of composite lattice truss core. Fan et al. [28] fabricated corrugated lattice truss composite sandwich panels and greatly enhance the shear strength of lattice sandwich panels without damaging the face sheet. The proposed approach

* Corresponding authors.
E-mail addresses: clm07@cqu.edu.cn (L. Chen), wgli@cqu.edu.cn (W. Li), fangdn@bit.edu.cn (D. Fang).

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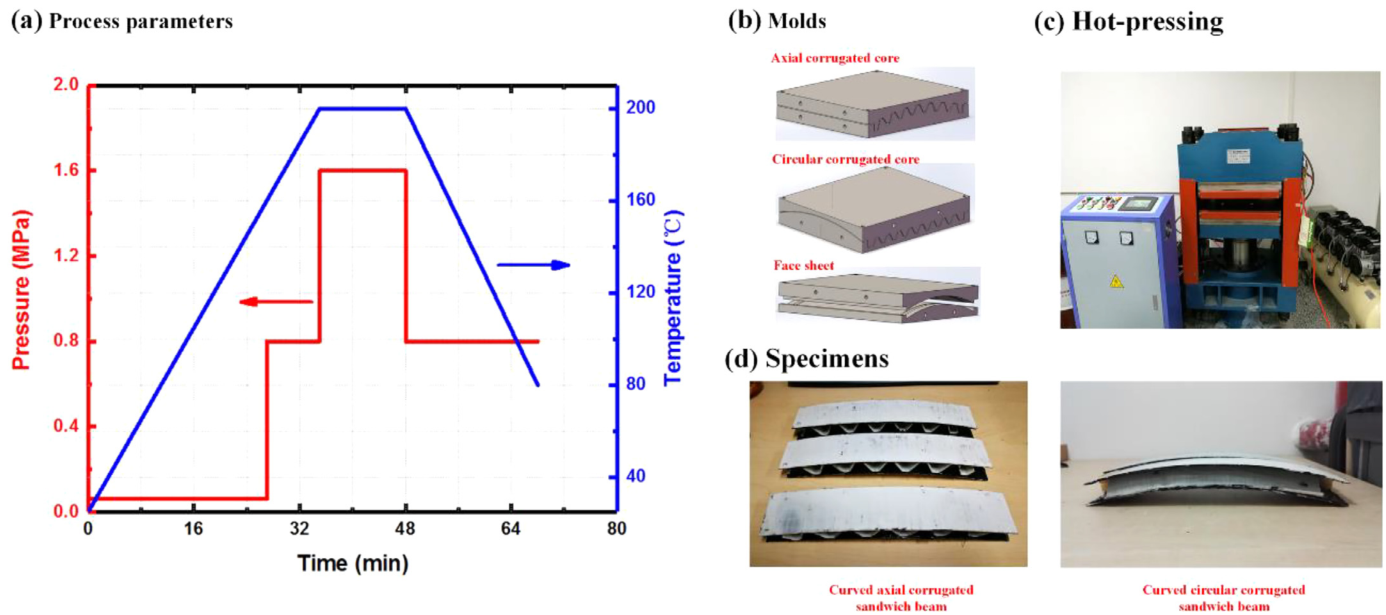

Fig. 1. The fabrication of two kinds of curved beams. (a)The process parameters of hot-pressing. (b) Molds. (c) Hot-pressing. (d) Fabricated specimens.

also changed the anisotropic corrugated core to the orthotropic corrugated lattice truss core. Both of them enhance the interface strength by enlarging the contact area. Schneider et al. [29] presented an approach where stringers were consolidated within the face sheet to offer support for the thermoplastic composite lattice truss core. They enhance the interface strength by changing the force condition.

However, to the knowledge of the authors, no research work about the bending behavior of curved thermoplastic composite corrugated sandwich beam has been reported. In present paper, the TPB tests were conducted to investigate the bending resistance and behavior of glass fiber reinforced polypropylene (GFRPP) curved CSBs with two core configurations namely axial and circular ones and different interface connection techniques namely adhesive bonding and glue stick reinforcement. Firstly, the details of fabrication process and TPB tests of curved CSBs are presented. Then, the bending resistance and failure modes of CACSBs and CCCSBs fabricated by adhesive bonding are investigated. Next, polypropylene glue stick reinforcement is introduced to CACSB and comparison is made between the reinforced ones and unreinforced ones. Finally, conclusions are drawn.

2. Fabrication and TPB tests

2.1. Fabrication

Curved face sheet and two kinds of corrugated cores namely axial and circular were fabricated by hot press method. Process parameters are shown in Fig. 1a. After then, both of counterparts were polished by sand paper and cleaned by ethyl alcohol, then bonded by adhesive MS1937 (Tonsan Adhesive, Inc.) after careful surface treatment and cured for 3 days with weight. The property of adhesive and prepreg is showed in Tables 1 and 2 respectively. Afterwards, the curved sandwich beams were cut into final shape by CNC carving machine and the schematic is shown in Fig. 1b–d.

The designed layup for both of face sheet and core is $[0/90]_3$. It should be noted that local fiber slip happened to the top layer whose direction was parallel to the circular direction during hot-pressing for the specimens. This can be avoided by rearranging the layup of unifiber prepregs to make the top and the bottom layers with axial direction or used woven fiber prepregs. In this paper, the actual layup used for both CACSB and CCCSB is [0/90/0/90/90/0].

Table 1
Adhesive property of MS1937 provided by Tonsan Adhesive, Inc.

Property	Value
Density	1.45 g/cm^3
Tack free time (@25 °C, RH50%)	5–20 min
Cure speed (@25 °C, RH50%)	4 mm/24 h
Elongation at break (GB/T528)	>200%
Tensile strength (GB/T528)	3.0 MPa
Shear strength (GB/T7124)	2.3 MPa

Table 2
Property of GFRPP prepreg provided by KINGFA Composites.

Property	Value
Density	1.5 g/cm^3
Weight fraction of fibers	60%
Thickness	0.3 mm
Young's modulus in longitudinal direction	28 GPa
Young's modulus in transverse direction	3.2 GPa
In-plane shear modulus	946 MPa
In-plane Poisson's ratio	0.064
Longitudinal tensile strength	750 MPa
Longitudinal compressive strength	160 MPa
Transverse tensile strength	15 MPa
Transverse compressive strength	50 MPa

The schematic of the TPB specimen and parameter of corrugated unit cell refers to [18] as shown in Fig. 2a and b with $h_c = 19$ mm, $l = 10$ mm and $\omega = 60°$ The relative density of the corrugated core can be calculated by Eq. (1).

$$\bar{\rho} = \frac{(h + l\sin\omega)t}{(h\cos\omega + l\sin\omega)(h + t)} \quad (1)$$

The length S and height H of the core are 230 mm and 24.4 mm. Though the width of unit cell is 42 mm, we set the width w to 52 mm in order to get wider adhesive zone for CCCSB and keep the same for CACSB. The length of the reinforced region S_0 in both ends is 30 mm. The parameters and mechanical property of specimens are showed in Table 3. Small dispersity of data is found and therefore the average of peak value and stiffness along with the corresponding coefficient of vari-