Composite Structures 152 (2016) 704–711

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Flexural performance of sandwich beams with lattice ribs and a functionally multilayered foam core

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ARTICLE INFO

Article history:
Received 29 September 2015
Revised 27 April 2016
Accepted 16 May 2016
Available online 17 May 2016

Keywords:
Lattice ribs
Functionally multilayered
Flexural
Sandwich beam
Energy dissipation
VARTM

ABSTRACT

This study focused on the flexural behavior of an innovative sandwich beams with GFRP skins, lattice ribs, and a functionally multilayered PU foam core (GLF beams). The lattice ribs, consisted of longitudinal and horizontal ribs, were arranged along the longitudinal direction of the beam. Eight beams, involving a control specimen, were tested under four-point bending to validate the effectiveness of the lattice ribs and functionally multilayered foam core for increasing the ultimate bending strength, stiffness and energy dissipation ability. Test results showed that compared to control specimen, a maximum of 143% increase in the ultimate bending strength can be achieved. The energy dissipation ability of the beam was increased greatly by the use of lattice ribs and functionally multilayered foam core. Meanwhile, unlike the conventional sandwich beam, GLF beams failed in a ductile manner. Furthermore, an analytical model was proposed to predict the bending stiffness and ultimate bending strength of GLF beams. The analytical results were agreed well with test results.

1. Introduction

Fiber reinforced polymer (FRP) composite sandwich beams have been extensively used in aerospace, ships, and automobile applications [1–9]. However, very limited attempts have been made to use these materials for structural beam element applications. The main reason could be that the currently used core materials are foam or light-weight woods, once the sandwich beams subject to out-of-plane bending loads, the deflection of sandwich beams are large due to their low Young's modulus.

To overcome these obstacles, a lot of studies have been conducted by many researchers. Sharaf et al. [10] studied the flexural behavior of sandwich beams with different polyurethane (PU) foam core densities. Test results suggested that the ultimate bending strength and stiffness of beams were improved significantly with the increase in foam density, but the beam costs and dead loads were also increased. Reis and Rizkalla [11] and Dawood et al. [12] developed a kind of sandwich beams consisted of glass fiber reinforced plastics (GFRP) skins, PU foam core and through-thickness fiber insertions. The interface delamination was prevented due to the use of the fiber insertions. However, the initial bending stiffness was hardly improved. Marasco et al. [13] proposed a novel sandwich panel strengthened with Z-fiber pins. The out-of-plane tension, shear and compression properties were studied. Tests results indicated that the beams with Z-pinned cores exhibited higher specific stiffness than conventional sandwich beams. Dweib et al. [14] proposed a sandwich beam consisted of GFRP skins, PU foam core and longitudinal GFRP ribs. Keller et al. [15] and Fam and Sharaf [16] investigated the flexural behavior of the novel kind of sandwich beams. Additionally, Wang et al. [17] studied the effects of longitudinal ribs thickness, space and height on the flexural behavior of the sandwich beams. These studies demonstrated that the longitudinal ribs can significantly increase the ultimate bending strength and stiffness of beams. However, all beams failed in a brittle manner, and in the meantime, energy dissipation abilities of them were low.

In order to improve the ultimate bending strength, stiffness and energy dissipation ability of the sandwich beams, a kind of sandwich beams consisted of GFRP skins, lattice ribs and functionally multilayered PU foam core (GLF beams) was developed in this study. The lattice ribs, composed of longitudinal and horizontal ribs, were arranged along the longitudinal direction to improve the bending and shear stiffnesses and the ultimate bending strength. The functionally multilayered PU foam core with gradient densities (150, 250, 350 kg/m^3) was adopted to improve the ultimate bending strength and stiffness. The high density foam core

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http://dx.doi.org/10.1016/j.compstruct.2016.05.050
0263-8223/

(350 kg/m^3) was placed at the compressive region and the lower density foam core (150 kg/m^3) was placed at the tensile region (see Fig. 1). The flexural behavior of GLF beams was studied. Eight beams with the same dimensions (1400 × 120 × 80 mm) were tested under four-point bending to investigate the ultimate bending strength, stiffness, failure mode, and energy dissipation ability. Meanwhile, an analytical model was proposed to predict the initial bending stiffness and ultimate bending strength under four-point bending. The accuracy of the model was verified through a comparison of the analytical and experimental results.

2. Experimental program

2.1. Material properties

The GFRP skins and lattice ribs consisted of [0/90] symmetric E-glass woven fiber (800 g/m^2) and HS-2101-G100 unsaturated polyester resin. The densities of the PU foam core are 150, 250, and 350 kg/m^3, respectively. The specimens were manufactured by means of vacuum assisted resin transfer molding (VARTM) process.

The mechanical properties of the GFRP skins were performed using tensile, compressive, and shear tests following the ASTM D3039 [18], ASTM D3410 [19], and ASTM D3518 [20] standards, respectively. The PU foam was performed using compressive and shear tests following the ASTM C365 [21] and ASTM C273 [22] standards, respectively. The details of test procedure were shown in our companion paper [9]. Tables 2 and 3 summarized the material properties of the GFRP laminate and PU foam core, respectively.

Table 2
Material properties of GFRP laminate and lattice ribs.

GFRP laminate	Yield strength (MPa)	Young's modulus (GPa)
Compression	168.21	21.09
Tension	291.60	22.68
Shear	52.13	8.80

Table 3
Material properties of PU foam core.

PU foam core		150 (kg/m^3)	250 (kg/m^3)	350 (kg/m^3)
Compression	Yield strength	1.22	2.83	4.87
	Young's modulus	35.42	80.59	117.96
Shear	Yield strength	0.54	0.79	1.03
	Young's modulus	16.22	24.32	32.68

2.2. Description of test beams and parameters

Eight beams with the identical dimensions (1400 × 120 × 80 mm) were fabricated and manufactured by the VARTM process in the Advanced Composite Structures Research Center at Nanjing Tech University (Fig. 1). The GFRP laminates and HS-2101-G100 unsaturated polyester resin were used for the skins and lattice ribs. The functionally multilayered foam core with 150, 250, and 350 kg/m^3 densities were gradient distributed along the height of a beam. The skins thickness (t_s = 4.8 mm) and lattice ribs thickness (t_r = 1.2 mm) of all specimens were identical.

Table 1 shows a summary of the test matrix and details of specimens. Specimen GLF-CON was a control beam with GFRP skins

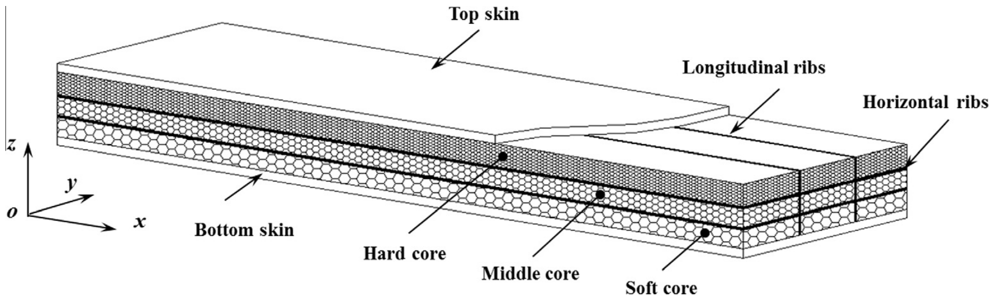
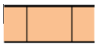
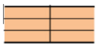


Fig. 1. The GLF beam with lattice ribs and different foam core densities.

Table 1
Summary of test matrix and parameters.

Specimen[a]	Illustration	L (mm)	B (mm)	Core thickness (mm)	Core density (kg/m^3)	Weight (kg)	Space of lattice ribs (mm)	
							Horizontal (s_h)	Longitudinal (s_l)
GLF-CON		1400	120	70	150	4.58	–	–
GLF-L1		1400	120	70	150	4.83	–	120
GLF-L2		1400	120	70	150	5.10	–	60
GLF-H2		1400	120	23/46	150	5.13	23	–
GLF-H2F3		1400	120	23/23/23	350/250/150	6.10	23	–
GLF-L1H2		1400	120	23/23/23	150	5.45	23	120
GLF-L2H2		1400	120	23/23/23	150	5.73	23	60
GLF-L2H2F3		1400	120	23/23/23	350/250/150	6.85	23	60

[a] GLF-*La*-*Hb*-*Fc*: *a* means the number of the longitudinal ribs, *b* means the number of the horizontal ribs, and *c* means the number of the foam core densities.