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Flexural behavior and water absorption of asymmetrical sandwich composites from natural fibers and cork agglomerate core

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ABSTRACT

This work addresses an experimental investigation concerning flexural and water absorption behavior of a novel low-cost green composite asymmetric sandwich. For specimen manufacturing, an agglomerate cork panel and natural fiber reinforcements, namely basalt and flax fiber were used. A bio-based epoxy resin was used as matrix and the specimens were manufactured using vacuum assisted hand lay-up. For some specimens the core material was altered allowing resin infiltration between the granules. Results show that both, the core type and specimens' stance influence the flexural behavior. More importantly, all specimens showed a very good energy absorption behavior during bending tests. The water absorption of the specimens was significantly reduced by the infiltration of resin inside the core material. These attractive performances reveal that the green composites based sandwich proposed in this work can be a good alternative to traditional ones.

1. Introduction

Environmental concerns and increasingly social pressure for the use of less harmful composites materials have aroused a paradigm shift towards using natural fibers as substitute for synthetic and nonrenewable reinforcements. This fact has given rise to what is commonly called "Green Composites", namely those obtained from lower environmental impact raw materials from biodegradable or renewable sources. Such ecofriendly raw materials can be naturals fibers extracted from plants as flax or hemp [1,2], or those having a mineral origin as basalt fiber. Natural fiber like hemp, sisal, basalt, has been extensively studied during the last years [3]. Recent developments in the field of composites materials have shown that "*Green Composites*" can be, from the viewpoints of mechanical performance, manufacturing costs and environmental footprint, a good alternative to traditional reinforcements [4–6]. Masoodi et al. [7] combined cellulose fibers with bio-based epoxy mainly obtained from co-products of bio-fuel production, and results showed significant mechanical properties. However, significant obstacles for structural applications of "Green composites" still exist. These obstacles include low thermal stability during processing, hydrophilic nature, poor adhesion with matrix and trustfulness in the use of natural fibers and their composites. Also, sandwich structures are increasingly used in transportation vehicles and civil infrastructures due to their high stiffness/strength-to-weight ratio. Nevertheless in most of these applications, sandwiches are mainly manufactured in the conventional symmetric configuration [8–10], besides only a few studies deal with the asymmetrical configuration [11–13]. The objectives of the present work are to manufacture basalt/flax/cork asymmetric sandwich via a low cost manufacturing process and to investigate the effects of the loading conditions during three-point bending tests and the water absorption behavior.

2. Materials and methods

For the present work, flax-cork-basalt (FCB) bio-based epoxy sandwiches have been manufactured using vacuum assisted hand lay-up process (Fig. 1). Basalt fiber fabric (400 g/m^2, Kammeny Vek, Russia) was used as reinforcement for one of the two face-sheets of the asymmetric sandwich panels. The other face-sheet was made of flax fabric (200 g/m^2, Lineo, Belgium). Bio-based epoxy resin system (SuperSap 100/1000, Entropy Resins) was used as matrix. SuperSap 100/1000 is a bio-based epoxy system with a bio-content per mass up to 37%, where petroleum-based raw materials have been substituted with bio-based ones. Commercially available cork board (CORECORK ®NL20, Amorim Corporation, Portugal) was selected as core material [14]. After the hand

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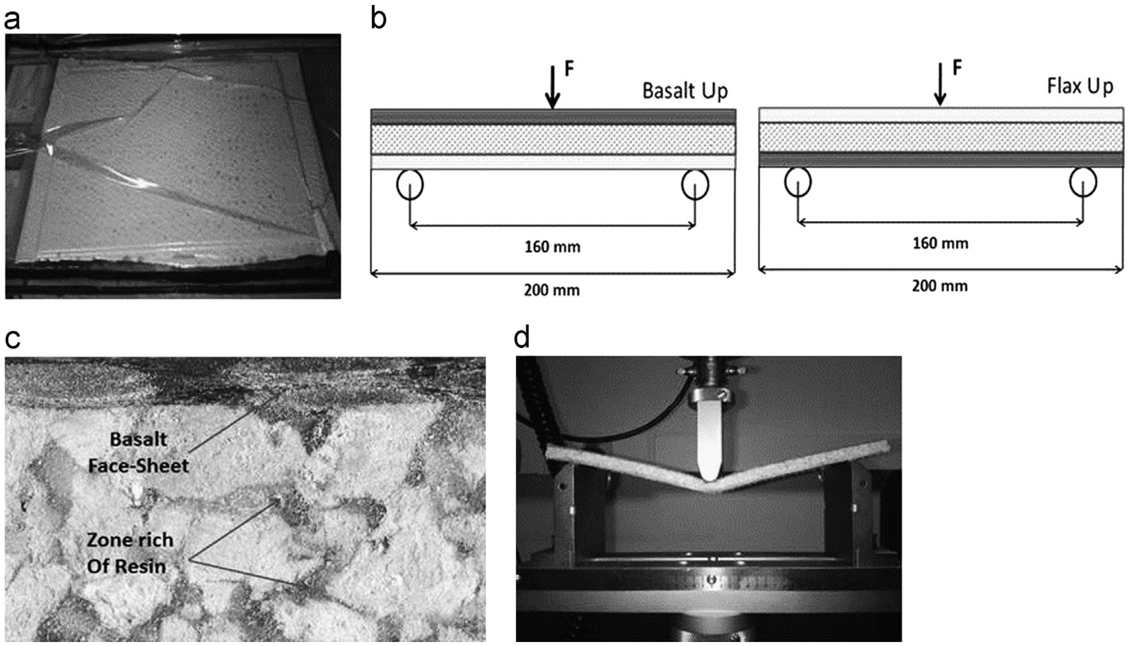

Fig. 1. (a) Bagging process, (b) test configurations, (c) resin infiltration inside core and (d) specimen during bending test.

Table 1
References and characteristics of the specimens.

Specimen	Manufacturing process [a]	Length (mm)	Wide (mm)	Mean thickness (mm)	Number of face-sheet layers[b]	Test[c] type and position of the sample[d]	Number of specimens
3 layers-modified core (**3L-MC**)	VA	200	30	8.52	3F/3B	TBT, FU,BU	10
2 layers-modified core (**2L-MC**)	VA	200	30	7.55	2F/2B	TBT, FU,BU	10
3 layers-original coated cor (**3L-OC**)	VAC	200	30	8.48	3F/3B	TBT, FU,BU	10
2 layers-original coated core (**2L-OC**)	VAC	200	30	7.54	2F/2B	TBT, FU,BU	10
Modified core (**MC**)	VA	25	25	5	–	FCT	5
Original coated core (**OC**)	Manual coating	25	25	5	–	FCT	5

[a] VA: vacuum assisted hand lay-up; VAC: vacuum assisted hand lay-up, with previous core coating.
[b] 2F/3F: 2/3 layers of flax, 2B/3B: 2/3 layers of basalt.
[c] TBT: three-point bending test; FCT: flatwise compression tests.
[d] Basalt Up (BU) or Flax Up (FU).

laying-up step, vacuum bagging operation was performed to ensure a good adhesion between each components of the sandwiches. This operation is a very important step in obtaining a good quality part. All the sandwich panels were removed from the vacuum bag after 24 h, and then post cured for 2 h at 50 °C in an oven. A second batch of specimens was obtained by the same manufacturing process, but the main difference resides in the fact that the cork sheets was previously coated with a very thin layer of resin and cured for 24 h at room temperature to prevent resin infiltration inside the core during vacuum bagging operation. The resulting $500 \times 900\ \text{mm}^2$ panels were cut into specimens of 200 mm length, 30 mm wide using diamond-tipped circular saw, see Table 1.

Flexural strength was determined for all the specimens, using three-point bending test method in accordance with ISO 14125. Tests were performed using Instron 5960 universal testing machine equipped with a 30 kN load cell at a rate of 2 mm/min (Fig. 1d). Since sandwich specimens were asymmetric, each type of specimen has been tested in two different stances (Basalt Up or Flax Up) as shown in Fig. 1b.

Flatwise compression tests on the two different core materials were performed following EN ISO 844 standard. Squared specimens of 25 mm sides were tested under controlled displacement at a rate of 0.5 mm/min. For each core type, ten identical specimens were tested and average result was obtained.

To determine the water absorption behavior, tests were conducted in accordance to ASTM D 570. Five specimens from the different sandwich panels were immersed in de-ionized water bath, at room temperature (23 °C) and atmospheric pressure. The amount of water absorbed was measured every 24 h for 12 days. After each time period, the specimens were taken out from the water and first dried using tissue paper to remove the excess of water on the surface before the weight was recorded (W_b). The same procedure was applied to specimens of infused (MC, *modified core*) and non-infused cork panels (OC, *original coated core*). The percentage of apparent weight gain was then calculated according to

$$\text{Water absorption } (\%) = \frac{W_a - W_b}{W_b} \tag{1}$$

3. Results and discussion

Effect of the manufacturing process on the core material: It was observed that for the core material without resin coating (OC), the