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SANDWICH PANELS WITH CORE IN ARUNDO DONAX AND SKINS IN FLAX FIBRE WITH RESIN

Letizia Crociati, DA, University of Bologna, Italy, letizia.crociati@studio.unibo.it
Thomas Jeannin, FEMTO-ST Universitè del Besancon, France, thomas.jeannin@femto-st.fr
Luisa Molari, DICAM, University of Bologna, Italy, luisa.molari@unibo.it
Vincent Placet, FEMTO-ST Universitè del Besancon, France, vincent.placet@univ-fcomte.fr

ABSTRACT

Sandwich panels are structures employed in many different applications. Here, sandwich panels with the core made of Arundo donax rings and the skins made of flax fibre reinforced epoxy composites are proposed. The influence of the surface roughness of the rings on the mechanical properties is investigated. Pull-off tests between the ring and the skin were carried out to understand how sandpaper polishing can affect the adhesion between the skin and the core. The sandwich panel is characterized by three points bending tests. The results show a significant influence of the polishing treatment on the ring lateral surfaces.

KEYWORDS

Sandwich panel; Arundo donax; Flax; mechanical properties; Roughness.

INTRODUCTION

Sandwich panels are usually light structures employed in many applications, in different scales, and typologies, due to their versatility given by the combination of many different materials. Many sandwich panels on the market are made with non-sustainable materials.
Nowadays climate change is a huge issue, for this reason, it is becoming more and more important to use sustainable materials. In this perspective, the use of natural materials like bamboo or Arundo donax (AD) can be a viable alternative (Nurdiah, 2016) (Molari et al., 2021). The use of these raw materials is limited by their shapes and dimensions. Their use in laminated structures or panels can overcome this issue.
In the present study, sandwich panels with the core made of AD rings and the skins made of flax fibre reinforced epoxy composites are studied, inspired by the idea proposed in (de Oliveira et al., 2020) in which the core was made of bamboo rings.
AD is a tall, perennial grass that can grow up to 10 m. The outer tissue of the stem (named culm) has a siliceous nature, hard and brittle with a smooth glossy surface that turns pale yellow when the culm is fully dried. Inside the culm, two tissue systems with different mechanical features can be distinguished. Sclerenchymatous fibres strengthen vascular bundles and are embedded in a matrix of lignified parenchyma. Each culm is a hollow cylinder with diameters from 1 to 4 cm divided by diaphragms (named nodes) in internodes 12-30 cm long (CABI, 2020).
Flax (*Linum Usitatissimum*) is one of the most widely utilised bio-fibres since prehistoric times (Libo **&** Chouw, 2014). In recent years, the use of bio-fibres, like flax fibre, as reinforcement in composites for engineering applications has gained popularity due to increasing environmental concerns. Flax fibres are cost-effective and offer specific mechanical properties comparable to glass fibres.

MATERIALS

Skins and Core preparations

The skin (see Figure 1(a)) of sandwich panels is made of a combination of flax fibre (Flaxtape from Ecotechnilin) and epoxy resin. Three layers of flax fibre (310mm x 198mm) are used for each skin, unidirectionally oriented with an axis of 0º. The matrix is composed of the epoxy polymer SR Green Poxy 56, and the hardener SD 7561 with a mass proportion of 100/36 in g. The total matrix mass is estimated to be the total fibre mass multiplied by a coefficient of 2.5. The manufacturing process of one skin starts with putting 1/4 of the matrix on the mould (200mm x 300mm) wrapped with Teflon coated tape (PTFE), then the first flax ply is put on it. This is repeated for the three layers, then a pressure of 60 bar is applied to the closed mould with matrix and flax fibre inside. The curing process begins with 15 minutes at 40ºC, then the temperature increases to 100º C for 1 hour, then, after the cooling down at room temperature, the skin is brought back to 100°C in the oven. It is possible to manufacture two skins with one mould at the same time, just separating them with an intermediate iron sheet coated with Teflon.
The core (Figure 1(b)) is made of internode portions of AD (13 mm long). Each ring is cut with a circular saw and polished with different sandpapers. The polishing of the lateral surface is done manually before cutting the cane, while the polishing of the cross sections is done mechanically by JET 16-32 Plus (Figure 1(c)).



(a) (b) (c)

Fig. 1. (a): Flax resin skin; (b): Ad Rings for core in a frame (300mm x200mm) before polishing; (c) Polishing setup.

Sandwich Panel Preparation

To build the panel all the rings constituting the core are posed in a wood frame of the same dimensions as the mould and the skins (300mm x 200mm) (Fig. 1(b)) and polished with P120 sandpaper (P120 as reported in the following) using JET 16-32 Plus (Fig.1(c)).
The sandwich panel (Fig. 2(b) and (c)) is then completed by two skins glued to the Arundo donax rings core with 59.1 g of PB 170 and 18.8 g of DM02 for one sandwich panel of 300 mm x 200 mm. The gluing process is applied by maintaining the panel at 100ºC for 1 hour, using a pressure of 149 bar applied to the panel (Fig 2(a)). The glue becomes a foam that goes into the Arundo rings.
The weights of final panels are reported in Table 1.

Table 1: Weights of the different manufactured panels.

Weights of Sandwich panels		Core [g]	Skins (x2) [g]	Total Glue [g]
Ring lateral surface	Natural	190,7	82,5	70,9
	Z80	200	76,3	70,9
	P120	197,2	78,3	70,9



(a) (b) (c)

Fig. 2 (a): Thermohydraulic press; (b): Sandwich panel core focus; (c): Sandwich panel skin focus.

METHODS

Roughness analysis of AD cross section

The first data collected are related to the surface roughness of the Arundo donax ring's cross section. An Alicona microscope is used for the quantitative aspects and a three-dimensional mapping, while a qualitative analysis is previously made with a Nikon Eclipse LV150 with a 5x lens.

Pull-Off tests

Pull-off tests are performed to understand the influence of the surface treatment of AD cross section on the resistance.
Two AD rings are glued to a 3cm x 3cm of flax skin obtained with 25 layers of flax (about 4mm thick) to avoid its failure (as shown in figure 3(a)). The combination of PB170 (5g) and the hardener DM02 (1.8g) is used as foaming glue. The sample are placed into pliers of the machine, then the glue is solidified during one hour in the preheated oven at 100ºC under a compression load of 50 N (Fig. 3(b)). The Pull-off tests have been performed at room temperature with Instron Electropuls (Fig.3 (a)) on different samples with different polishing treatments on their cross section. In particular, the pull-off tests were performed on two non-polished samples, two polished samples with P120 sandpaper, and two polished samples with P400 sandpaper. The pull-off test is performed in displacement control with a velocity of 0.60 mm/min.



Fig. 3. (a): Sample in the oven at 100°C before the pull-off test, (b): Sample after pull-off test;

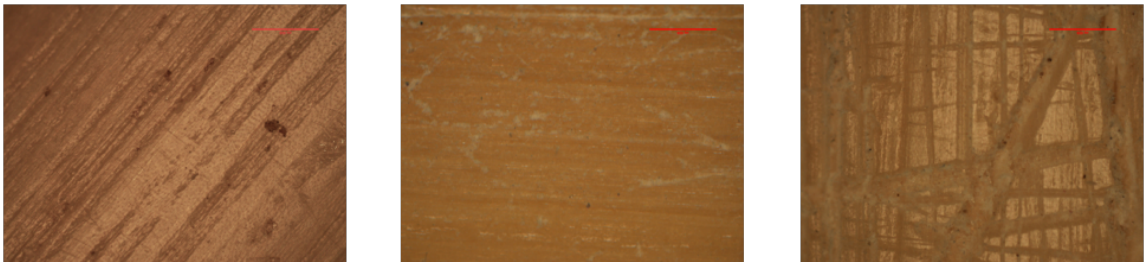
Three-point bending test

The three-point bending tests were performed on samples of the whole sandwich of about 300mm x 35mm x 14mm (4 specimens were cut from each panel manufactured). In the appendix, all the dimensions are reported. The procedure follows the ASTM C393-00 standards for the three-points bending test for long beam single-point load (in Fig. 4 the setup). The span length is 220mm.



Fig. 4. Three-point bending setup.

Another important aspect is how the lateral surface roughness affects the entire panel strength.
It is made a comparison between four samples with lateral surfaces not polished, four samples with lateral surfaces polished with P120 sandpaper, and four samples with lateral surfaces polished with Z80 sandpaper. In Fig. 5 a picture of the textures obtained with the different sandpapers.



(a) (b) (c)

Fig. 5. (a) Non-polished lateral surface (b) P120 polished lateral surface (c) Z80 polished lateral surface.

The core shear stress, the facing bending stress, and the flexural strain and stress and tangent modulus of elasticity are calculated.

The core shear stress τ is expressed as

$$\tau = \frac{P}{(d+c)b}$$

where P is the load, d is the sandwich thickness, c is the core thickness, and b is the sandwich width.

The facing bending stress σ is expressed as

$$\sigma = \frac{PL}{2t(d+c)b}$$

where t is the facing thickness, and L is the span length.

The flexural stress and strain are expressed as

$$\sigma_f = \frac{3PL}{2bd^2} \qquad \varepsilon_f = \frac{6Dd}{L^2}$$

where D is the deflection and L is the span length.

The tangent modulus of elasticity is expressed as

$$E_B = \frac{L^3 m}{4bd^3}$$

where m is the slope of the tangent to the initial curve of the load.

RESULTS

Analysis of the cross section surface

The analysis of the surface roughness of ring cross sections non-polished and polished is performed. Fig. 6(a) and (b) show the images taken with Nikon Eclipse LV150 with a 5x lens cross-section before polishing and after polishing with P120 sandpaper and the difference is obvious.

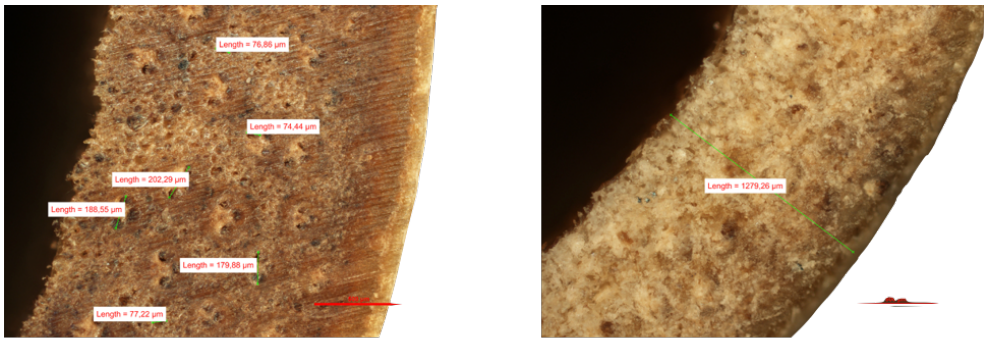
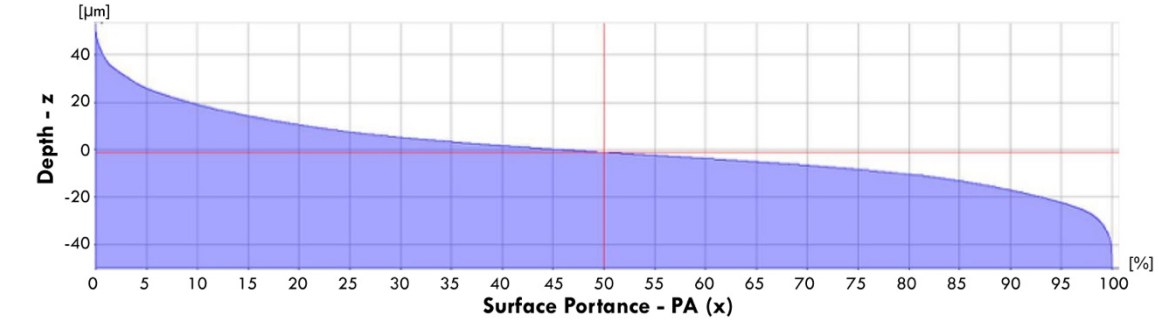
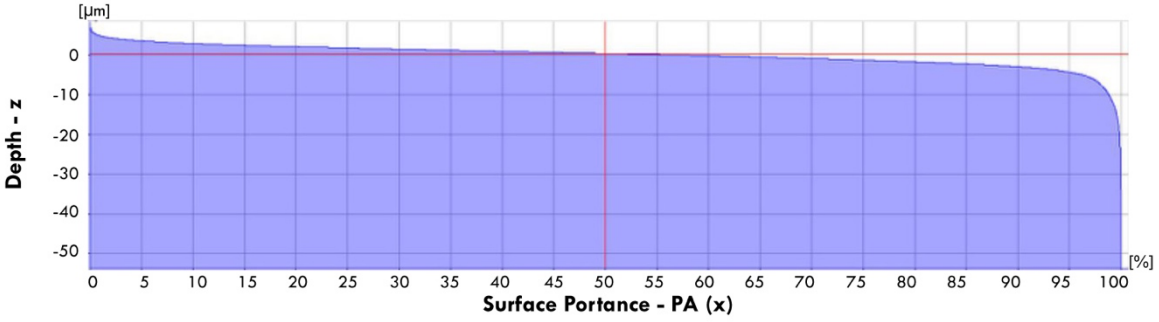


Fig. 6. (a) Non-polished surface; (b) polished surface with p120 sandpaper.

A quantification of this difference is given by Surface Portance, the exact amount of different depths calculated in µm which are upper and under the middle plane highlighted with a red horizontal line in Figs.7(a) and (b) and expressed in [%]. Figs. 7(a) and (b) reports the surface portance in a point of non-polished samples and polished samples respectively, The same difference in the graphs is obtained in other points. It is clear that the difference in the topography in polished samples is greater than that in polished ones.



(a)



(b)

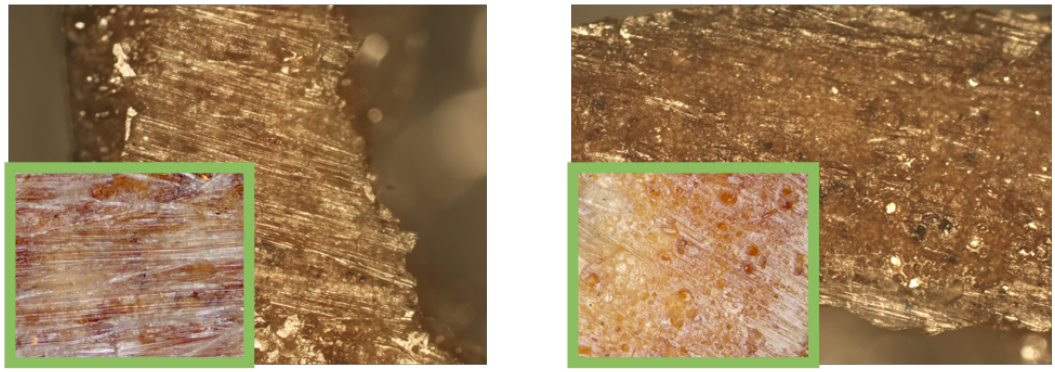
Fig.7. (a) Depth [µm] vs Surface Portance [%] versus (a) Polished specimen; (b) natural specimen.

Pull-Off Tests

Table 2 collects the maximum load reached with the pull-off tests. It shows that samples polished with P120 sandpaper resist more than 400N, while samples polished with P400 sandpaper and non-polished samples have a failure point at lower loads.
After the pull-off test, an analysis of the detachment surface on the ring cross section has been carried out. Fig. 8(a) shows the P120 polished sample and Fig. 8(b) the non-polished sample. The polished P120 samples have a substrate of the flax skin which covers almost the entire surface of the samples, while the natural samples have a cohesive failure of the glue substrate only a few flax fibres can be noted on the surface. For this reason, all the Arundo donax rings of the core have been polished with P120 sandpaper on the cross sections.

Table 2. Pull-off test results (all the specimens have very similar cross section's dimension so results are comparable).

	P400_1	P400_2	Natural 1	Natural 2	P120_1
Load [N]	151.0	256.0	385.2	235.2	499.1



(a) (b)

Fig. 8. *Cross section analysis after the pull-off test, images collected using Nikon Eclipse LV150 with a 5x lens* (a) *- substrate failure of flax fibre and resin skin on the P120 polished sample (b) cohesive failure due to the glue substrate on the non-polished sample.*

Three-Points Bending Test

Fig 9 shows the load-deflection and Tables 3 collects the deflection, load, core shear stress, facing bending stress, flexural stress and strain and modulus of elasticity obtained with three point bending tests.

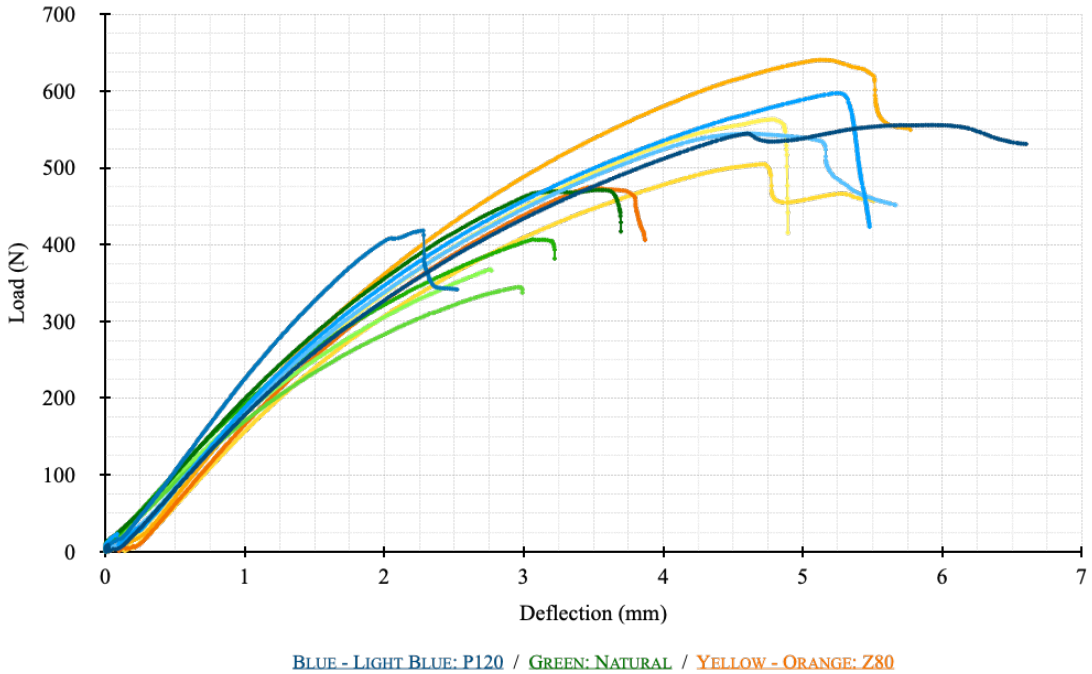


Fig 9. Load-displacement curves.

Table 3. Three-point bending tests: deflection, load, core shear stress, facing bending stress, flexural stress and strain and modulus of elasticity.

Spec.	Deflection [mm]	Load [N]	Core shear stress, τ [MPa]	Facing bending stress [MPa]	Flexural strength σ_f [MPa]	Elasticity modulus E_B [GPa]	Flexural Strain ε_f
Natural1	3.44	471.1	0.53	48.43	23.14	4.93	0.61
Natural2	3.17	406.4	0.44	40.60	19.28	4.39	0.57
Natural3	2.98	344.7	0.38	35.33	16.35	3.86	0.53
Natural4	2.73	367.6	0.41	37.34	17.45	4.14	0.49
Mean	**3.08**	**397.5**	**0.44**	**40.43**	**19.06**	**4.33**	**0.55**
St.dev	**0.30**	**55.3**	**0.06**	**5.76**	**2.98**	**0.45**	**0.05**
Z80 1	3.20	475.0	0.50	49.66	22.47	4.98	0.56
Z80 2	4.90	640.5	0.66	73.17	30.12	5.50	0.85
Z80 3	4.42	504.8	0.53	58.05	23.83	4.71	0.77
Z80 3	4.58	563.3	0.59	64.95	26.65	5.05	0.79
Mean	**4.28**	**545.9**	**0.57**	**61.46**	**25.77**	**5.06**	**0.74**
St.dev	**0.74**	**72.9**	**0.07**	**10.01**	**3.38**	**0.33**	**0.13**
P120 1	5.85	555.8	0.59	64.69	26.40	4.77	1.02
P120 2	2.17	418.2	0.44	48.36	19.97	6.03	0.37
P120 3	5.11	597.4	0.63	68.87	28.28	5.15	0.88
P120 4	4.52	544.6	0.57	63.17	25.99	4.93	0.78
Mean	**4.41**	**529.0**	**0.56**	**61.27**	**25.16**	**5.22**	**0.76**
St. Dev.	**1.59**	**77.2**	**0.08**	**8.94**	**3.60**	**0.56**	**0.28**

The average maximum load increases from 397.5 N for the natural samples to 545.9 and 529 for the polished samples with Z80 and P120 sandpapers, respectively. All the mechanical characteristics increase with the polishing treatment of the lateral surface, with an increase from 0.44 MPa to 0.56 and 0.57 MPa for the average values of the core shear stress, from around 40 MPa to 61 MPa for the facing bending stress, from19 MPa to around 25 MPa for the flexural stress and from 4 GPa to 5.1 and 5.2 GPa for the flexural Young modulus.
The data obtained with Arundo donax core are higher than those obtained with a similar setup with rings bamboo core in (de Oliveira et al, 2020) in which the reached flexural strength has an average value of around 9 MPa and an average flexural modulus around 3.2 GPa.
The lateral surface polishing treatment setup leads to different failure modes. In all the four natural samples, as shown in Fig 10(a), the main failure is debonding between the skins and the bamboo. The failure starts from the core, on the lateral surfaces of the rings and there is the debonding of the skins from the core. In the specimens with the polished lateral surface a similar behaviour is encountered with a buckling failure in the skin (as can be seen in Figs. 10(b) and (c)). This means that failure is not due to the core.

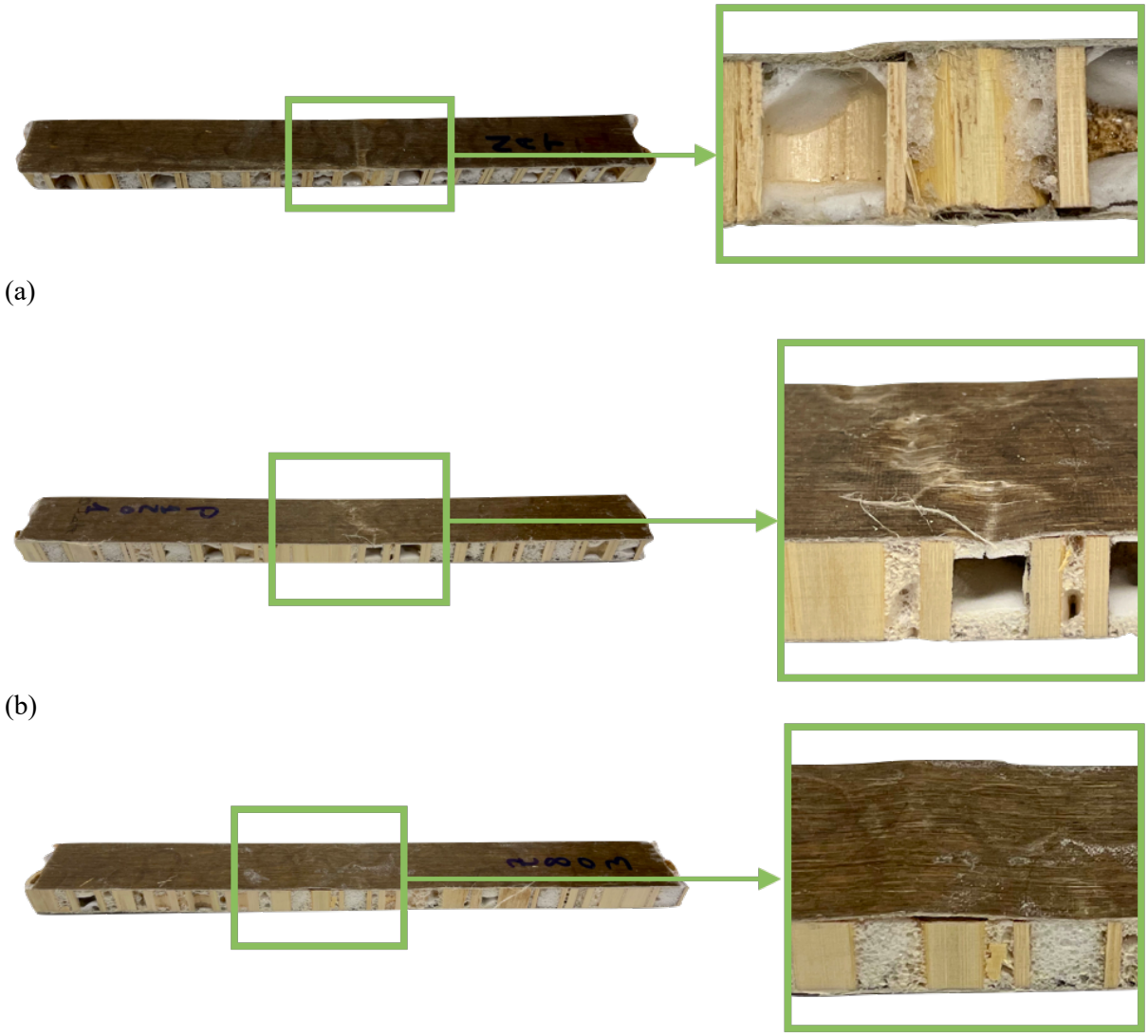


Fig. 10. The failure modes for (a) natural lateral surface (b) P120 polished lateral surface (c) Z80 polished lateral surface

CONCLUSIONS

A new panel with Arundo donax core rings is proposed. Its quasi-static bending properties are suitable for construction applications. Results show that the polishing treatments of the surfaces influence the adhesion properties in the core and between the core and the skins.
All the mechanical characteristics increase with the polishing treatment of the lateral surface. The core shear stress, the flexural stress and modulus increase of approximately 30% in average when the facing bending stress increase reaches 52%.
For future works the proposed panel could be a good option, AD can be a valid sustainable alternative because it is a very fast-growing plant, invasive in many parts of the world.
Also, less performing and less expensive skins like plywood could be chosen for applications in buildings.

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DATA AVAILABILITY

Data on which this paper is based is available from the authors upon reasonable request.

CONFLICT OF INTEREST

All papers shall include an author declaration of conflicts of interest; if there are no conflicts, please indicate this as follows:
The authors declare that they have no conflicts of interest associated with the work presented in this paper.

Appendix

Table.A1 Dimensions of the different specimens.

Sandwich Panel Samples Measurements	Lenght [mm]	Width [mm]	Thickness [mm]	Core thickness [mm]	Skins thickness [mm]	Mass [g]	Equivalent Density [g/cm^3]
Natural 1	303	32.6	14.3	13.1	1.2	55.5	0.393
Natural 2	293	33.3	14.4	13.2	1.2	52.1	0.371
Natural 3	295	32.7	14.3	13.1	1.2	53.3	0.386
Natural 4	295	33.0	14.3	13.1	1.2	53.4	0.384
Natural mean	**296.5**	**32.9**	**14.325**	**13.125**	**1.2**	**53.575**	**0.383**
Z80 1	300	35.3	14	12.9	1.1	59.8	0.403
Z80 2	300	35.4	14	13	1	59.3	0.399
Z80 3	300	35.3	14	13	1	58.1	0.392
Z80 4	300	35.2	14	13	1	59	0.399
Z80 mean	**300**	**35.3**	**14**	**12.975**	**1.025**	**59.05**	**0.398**
P120 1	300	35	14	13	1	55.4	0.377
P120 2	300	35.3	13.95	12.95	1	56.3	0.381
P120 3	300	35.4	13.95	12.95	1	58.1	0.392
P120 4	300	35.2	13.94	12.94	1	55.5	0.377
P120 mean	**300**	**35.225**	**13.96**	**12.96**	**1**	**56.325**	**0.382**