Composite Boat Hulls with Bamboo Natural Fibers

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Abstract: Bamboo laminates are made from bamboo strips (slivers) milled out from the bamboo wall core. The use of natural bamboo fibre in composites is on the rise. In the present study, the overall mechanical characteristics of bamboo fibers reinforced composites and sandwich for general marine applications were analysed. An accurate analysis of processing possibilities and statements has been conducted, evaluating the relationship between composites performances and processing characteristics. The effectiveness of vacuum bagging and compression moulding processes were analysed. Accurate chemical – physical and mechanical characterizations of bamboo based reinforced resins (epoxy) were conducted, analyzing also the variation of these properties during the materials ageing. Accelerate ageing tests were conducted on bamboo composites and sandwich specimens, obtaining the relationship between materials characteristics and ageing time. Finally, absorption tests (in distillate and sea water) were performed to simulate the effective environment in which bamboo based composites have to be applied, denoting that bamboo composites exhibit excellent resistance to the marine environment and their applications could make good inroads in the marine sector worldwide.
As applications, an hull panel and a spinnaker pole have been realised and respectively tested for impact and for axial compression load: successively a complete 6 meters boat hull has been realised in order to

analyze critical lamination points, vacuum performances and necessity of external treatments.

Keywords: natural fibers, bamboo fibers, nautical applications, absorption tests, accelerate ageing tests, spinnaker pole, boat hull.

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1 Introduction

The use of natural fibers such as jute, sisal, banana, hemp, ramie, coir etc. as reinforcements in plastics is increasing tremendously. Wood flour and other fibers are primarily used as fillers in thermoplastic decking, building materials, furniture & automotive components. Long agricultural fibers such as flax, kenaf, bast, hemp and jute are used as structural reinforcements in thermoplastic/thermoset composites as a replacement of glass fibre.

Other authors have studied the mechanical properties of lignocellulosic/polyester composites with well-defined fiber orientation (unidirectional or bidirectional) [Kline & Company Inc. (2000), Mishra et al. (2003), Mohanty et al. (2000), Mohanty et al. (2001), Nogata F. (1997), Principe A. (2004)]. The samples were produced either by wet lay-up or by press moulding of MgO thickened prepregs (similar to sheet moulding compound).

Bamboo [Bollettino AIB (2004), De Miranda (2006)] is one of the fastest renewable plants with a maturity cycle of 3-4 years, thus making it a highly attractive resource compared to forest hardwoods. Bamboo offers good potential for processing it into composites as a substitute of solid wood for structural uses [Schloesser (2000), O'Dell (1997), Drzal et al. (2004)].

The Bamboo is suitable as material for construction because it is sufficiently hard, strong and dimensionally stable. From a botanical point of view, bamboo is not wood but grass. Many Bamboo species exist, but the one used in technological applications is the *Phyllostachys Pubescens*, which can reach up to 20 meters of height and a diameter of 18 cm. The bamboo fiber cross-section is generally constituted by a near net of micro – openings which make it particularly sensitive to moisture absorption, but on the other hand the porous structure favours the wettability with matrices in composite applications.

The production of fibers unidirectional is sketched in fig. 1. Initially a primary process is done consisting in cross cutting, splitting and 2-D planning of the raw bamboo. Then management of thickness, sizing and sorting with a starch removal and moisture reduction are performed. Finally a light uniform spreading of resin and hot pressing are applied to ease dispatching and to control dimensional tolerance. This thermoplastic binder helps fiber preforms hold their shape and improves adhesion to the matrix.

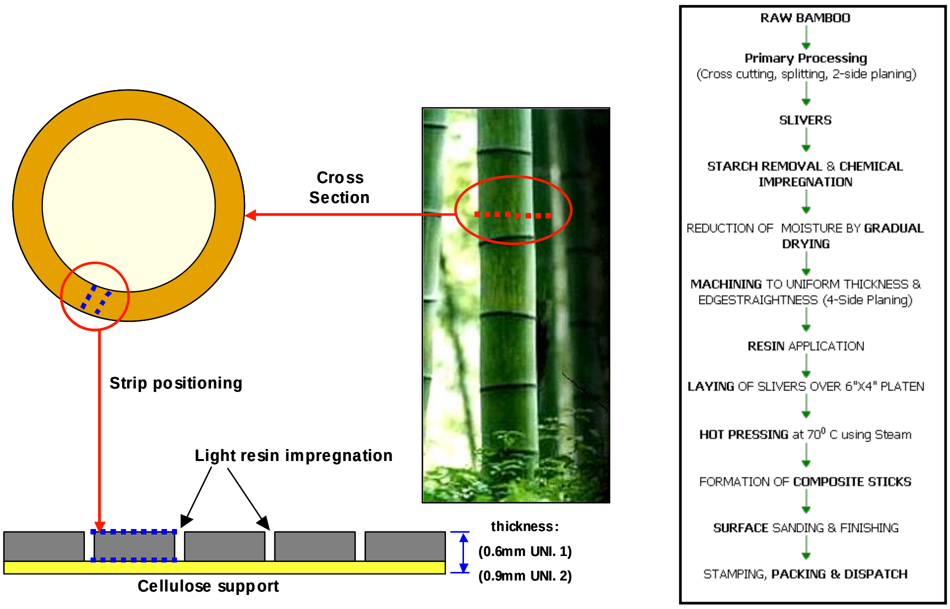


Fig. 1: Process fabrication of bamboo unidirectional

It has not been thought necessary, in this phase, to apply any chemical surface treatment neither physical treatment to bamboo fibers, considering that dry unidirectional fibers are already supplied with a light resin spreading that guarantees the necessary stability and the best adhesion to the used matrix.

Two standard thicknesses are available, according to bamboo plant thickness, "type 1" 0.6 mm thickness and "type 2" 0.9 mm thickness.

One of the objectives of this work was to identify, at least indicatively, all the process parameters that may influence the overall final mechanical characteristics of the composite: to such aim, together with vacuum bag technology, which appear suitable at least at this initial step, the hot pressing technology is then set up and utilised for comparison.

2 Experimental details: mechanical tests

Initially, raw bamboo unidirectionals (Type 1) have been tested on several specimens (more than 10) measuring 20 by 200 mm under tension (fig. 2), whose results are reported in Tab.1-a.

Fig. 2: Experimental tensile tests on raw bamboo unidirectional

Tab. 1 - a: Raw bamboo unidirectional tensile tests results.

	Mean Value	**Standard Deviation**	**± [%]**
Ultimate Tensile Strength [MPa]	58.34	1.58	2.70
Ultimate Strain [%]	1.74	0.12	6.90
Young's modulus E [MPa]	4517.17	634.36	14.04
Young's modulus $E_{1/3}$ [MPa]	5303.94	545.06	10.28

Tab. 1 - b: Some fibers characteristics (published data).

Fiber type	**Density (g/cm^3)**	**Elastic Modulus (GPa)**	**Specific Modulus**
E-glass	2.55	73	29
Hemp	1.48	70	47
Flax	1.4	60-80	43-57
Jute	1.46	10-30	7-21
Sisal	1.33	38	29
Coir	1.25	6	5
Cotton	1.51	12	8

Compared to other natural fibers, bamboo unidirectional, whose density is 0.68 g/cm^3, denotes an elastic modulus of 4.5 GPa and a specific modulus of 6.61. Despite these non-top characteristics, the main advantage of bamboo unidirectional over the other natural fibers is the excellent raw configuration which allows good result reproducibility and constant mechanical properties.
Secondly, the quantitative measurement of fiber-matrix interfacial adhesion has been analysed. Both direct and indirect methods have been utilised, i.e. fiber pull-out test and short beam interlaminar shear test (ILSS).
In the case of fiber pull-out test, however, such typology of test couldn't be applied; the utilised bamboo fibers, in fact, are not fiber bundles, from which a single fiber can be extracted, but unidirectional sheets. The entire system therefore is constituted by fibers tied together with cellulose, emicellulosa and lignin. For this reason, the direct test realised only simulates the phenomenon of the pull-out. The specimens realised are the one depicted in Fig. 3. Epoxy resin CAMATTINI EC 130 with 30% in weight curing agent W 340 have been utilised. 14 hours curing time at 25° C and 10 hours post-curing at 60° C have been applied.

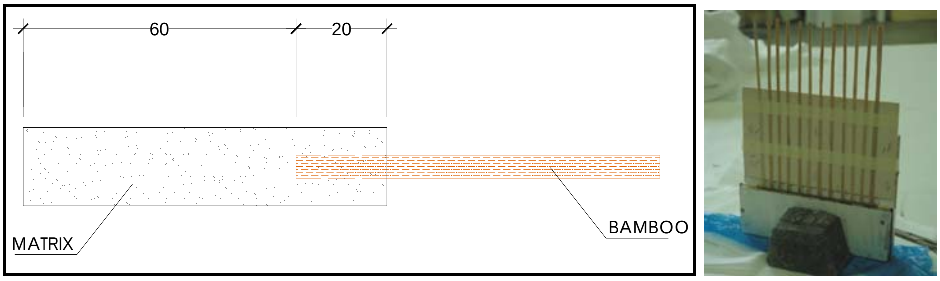


Fig. 3: Specimens for the pull-out test

The indirect method – the short beam interlaminar shear strength method – follows the ASTM normative [ASTM D 2344–84 (1989)]. Two specimen configurations have been realised: 12 layers $[0°/90°/0°/90°/0°/90°]_S$ for type 1 unidirectional with dimensions of 70(Length)x7.35(Width)x11.3(Thickness) mm and 8 layers $[0°/90°/0°/90°]_S$ for type 2 unidirectional with dimensions of 70(L)x7.65(W)x10.0(T) mm. A crosshead speed of 1.5 mm/min. was used. Pull-out tests and short beam interlaminar shear strength test provided consistent results shown in Tab. 2. A number of ten specimens for each type of laminate were tested.

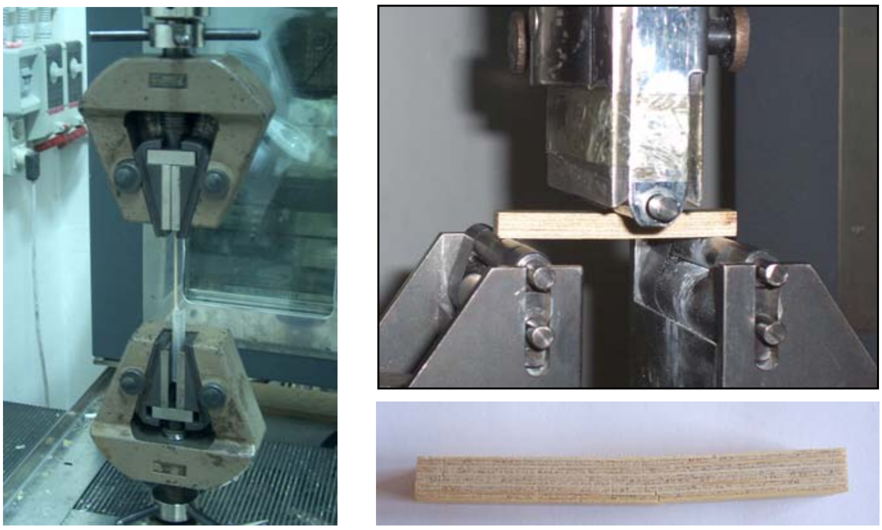


Fig. 4: Tests for the pull-out and for the ILSS analysis

As it can be seen from the following table, the ILSS increases as the reinforcement thickness increases, i.e. passing from type 1 to type 2 unidirectional, at constant pressure. This may be attributed to the greater fraction in weight of the matrix, which passes respectively from 23% to 38% [Quagliata M.J. (2003)].

Tab. 2: Results for the ILSS

SPECIMEN		**L [mm]**	**W [mm]**	**h [mm]**	**P [N]**	**ILSS [MPa]**
UNIDIRECTIONAL TYPE 1	**1**	70	7.35	11.30	407.62	3.69
	2	70	7.35	11.40	452.80	4.05
	3	70	7.20	11.35	383.35	3.52
	4	70	7.30	11.35	447.55	4.05
	5	70	7.30	11.40	373.49	3.37
	MEAN				412.96	**3.73**
	STANDARD DEVIATION				32.39	0.28
	STANDARD DEVIATION [%]				7.84	7.45
UNIDIRECTIONAL TYPE 2	**1**	70	7.65	9.90	506.67	5.02
	2	70	7.60	9.85	511.49	5.12
	3	70	7.60	10.00	536.15	5.30
	4	70	7.60	10.00	525.63	5.19
	5	70	7.60	9.60	533.68	5.49
	MEAN				522.72	**5.22**
	STANDARD DEVIATION				11.78	0.16
	STANDARD DEVIATION [%]				2.25	3.05

For the tensile tests, two configurations have been prepared with both technologies, one for each type of unidirectional.

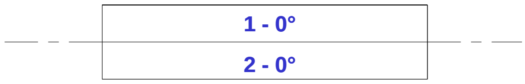


Fig. 5: Specimen cross section: stacking sequence

For the hot pressing technology, two pressure levels have been selected: 3 bar and 50 bar. This bunch of specimen - realised both with vacuum bag and with hot pressing at two pressure levels - allows to better understand process parameters - pressure, temperature and matrix content - influence on the final composite. All specimens for testing were cut from the flat section of the panel in such a way to ensure uniform fibre loading.

Fig. 6: Vacuum bag process for composite bamboo panels

Fig. 7: Hot pressing process for composite bamboo panels

Tensile tests on impregnated specimens measuring 20 by 200 mm were conducted according to ASTM normative [ASTM D 3039–76 (1995)] and flexural tests on sandwich specimens measuring 40 by 250 mm [ASTM C 393–62 (1988)] at the Civil and Environmental Engineering Department of the University of Perugia with load applied perpendicular to the surface of the fibre unidirectional; corresponding thicknesses depending upon described lamination. A crosshead speed of 2 mm/min. was used. The stress-strain curves were analyzed using a three-parameter hyperbolic tangent model that has been shown to accurately represent the stress-strain behaviour. The composite specimens were all tested to failure. Information collected in the tests included tensile strength at failure, tensile modulus, flexural strength, and flexural modulus. Tensile tests results are the following:

Tab. 3: Hot pressing impregnated bamboo unidirectional: tensile tests results (10 specimens were tested for each type of laminate)

	Mean Value	**Standard Deviation**	**± [%]**
Type 1 – 3 bar			
Ultimate Tensile Strength [MPa]	72.46	1.01	1.39
Ultimate Strain [%]	1.31	0.07	5.02
Young's modulus E [MPa]	5535.80	266.0	4.80
Young's modulus $E_{1/3}$ [MPa]	5400.24	961.18	17.80
Type 2 – 3 bar			
Ultimate Tensile Strength [MPa]	100.00	5.83	5.83
Ultimate Strain [%]	1.87	0.21	11.23
Young's modulus E [MPa]	5425.00	796.00	14.70
Young's modulus $E_{1/3}$ [MPa]	5511.00	1269.00	23.10
Type 1 – 50 bar			
Ultimate Tensile Strength [MPa]	74.78	3.65	4.88
Ultimate Strain [%]	1.772	0.13	7.09
Young's modulus E [MPa]	4719.01	461.61	9.78
Young's modulus $E_{1/3}$ [MPa]	5121.77	484.79	9.46
Type 2 – 50 bar			
Ultimate Tensile Strength [MPa]	100.11	9.12	9.11
Ultimate Strain [%]	2.68	0.16	5.82
Young's modulus E [MPa]	3741.11	409.67	10.14
Young's modulus $E_{1/3}$ [MPa]	4406.43	457.41	10.38

Tab. 4: Vacuum bag impregnated bamboo unidirectional: tensile tests results (30 specimens were tested)

Type 1 – Vacuum bag	**Mean Value**	**Standard Deviation**	**± [%]**
Ultimate Tensile Strength [MPa]	92.47	2.27	3.82
Ultimate Strain [%]	2.88	0.128	10.37
Young's modulus E [MPa]	5637	108.3	4.4
Young's modulus $E_{1/3}$ [MPa]	5689	98.3	3.4

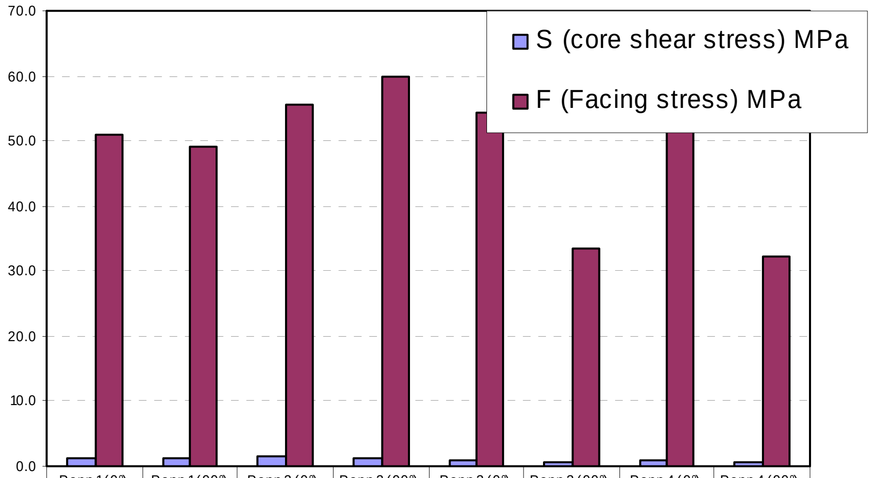
From the above results, a remarkable effect is denoted: as the stamping pressure increases, the tensile strength remains constant but the elastic modulus decreases; this variation can be attributed to the fact that the bamboo fiber reinforcement and its cellulose support are characterised by a porous structure which tends to be more impregnated as the pressure increases: this is confirmed by the fact that the weight fraction of the matrix increases from 23.5 % to 35.6 % passing respectively from 1 bar to 50 bar pressure. Therefore the Young's modulus decreases since the matrix denotes an elastic moduli equal at the half of the one of the reinforcement.

For the flexural tests, only 0.6 mm type 1 bamboo unidirectional has been utilised for sandwich realisation. Core material is a 6-12 mm 150 kg/mc balsa. The balsa comes in approximately 50 mm square blocks which are glued onto a scrim. The balsa is quite flexible and lays around most compound curves without giving any unfair surface. All specimens for testing, realised by vacuum bag, were cut from the flat section of the panel in such a way to ensure uniform fiber loading.

The lamination of the sandwich panels is $[0°/90°/0°/90°]_S$ plus an intermediate core of balsa for panels 1 and 2 and [+45°/0°/-45°]S plus an intermediate core of balsa for panels 3 and 4. Panels 1 and 3 were realized using a 12 mm balsa core, panels 2 and 4 were realized using a 6 mm balsa core.

20 specimens for each panel type were tested.

Results of the three-point bending tests on the realised sandwich are reported in Fig. 8. The experimental flexural strength – around 50 MPa - appears comparable to the tensile strength found with the tensile tests.



	Pann 1 (0°)	Pann 1 (90°)	Pann 2 (0°)	Pann 2 (90°)	Pann 3 (0°)	Pann 3 (90°)	Pann 4 (0°)	Pann 4 (90°)
S (core shear stress) MPa	1.1	1.1	1.4	1.3	0.9	0.6	0.9	0.6
F (Facing stress) MPa	51.0	49.1	55.5	59.8	54.2	33.4	55.0	32.3

Fig. 8: Stresses on sandwich subjected to three point bending test

3 Experimental details: physical tests

Bamboo composites were exposed to the harsh marine environment. Two kind of tests have been performed [Wang W. et al. (2005)]. Through the moisture absorption test – conducted according to UNI EN 2489 both with sea and distillate water - the variation of weight and of tensile strength have been recorded. Weight gain as a percent of initial weight is reported in Fig. 10.

(a) (b) (c)

Fig. 9: Absorption test: specimens (a), immersion basin (b), digital balance (c)

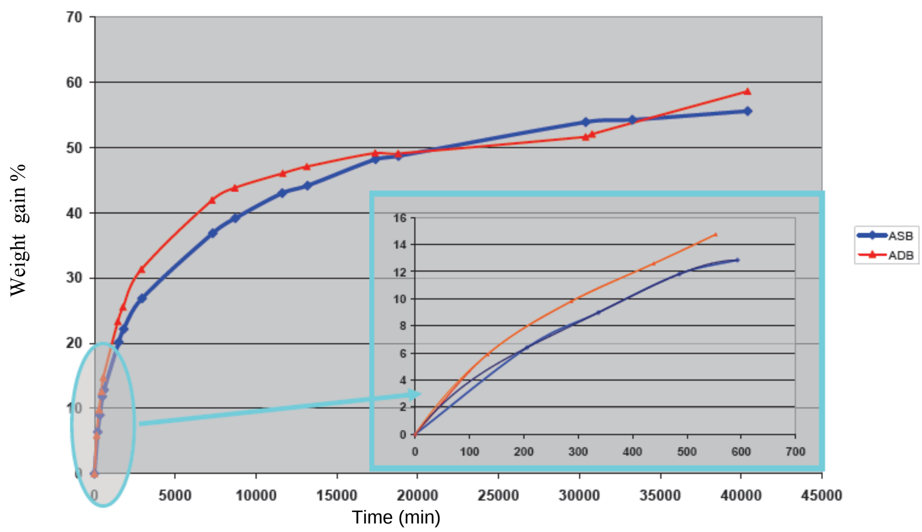


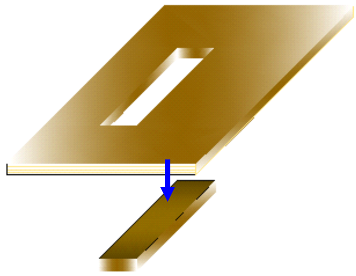
Fig. 10: Absorption test results on bamboo and epoxy resin specimen : (ASB: specimens in sea water; ADB: specimens in distillate water)

Even if the UNI EN 2489 does not specify the frequency at which the measurements should be taken, the first 12 hours (720 min.) may be particularly important, especially for the computation of the initial curve slope which leads to the computation of the water absorption speed (α) and then of the diffusion coefficient (D). At saturated condition, the bamboo and epoxy resin specimens have shown the following results:

Tab. 5: Absorption characteristics for bamboo composites at saturated condition (for each ageing time a minimum of five specimens were measured)

	Absorption speed (1/√t)	Diffusion coefficient (mm^2/sec)	Weight gain (%)
In distillate water	-0.0044	0.92	58.6
In sea water	-0.0028	1.04	55.6

It should be noted that most absorption happens along the specimen edges, where no matrix is present. For this reason, the tested specimen are tailored from the inside of the whole aged specimen (Fig. 11).
The difference of the results may be due to the presence of salts in the cellulose support: in sea water the osmotic equilibrium is reached earlier, stopping or at least lowering the absorption phenomenon.
In the tensile tests, constant results are obtained just after the first 120 hours and the total tensile strength decrease remains around -20 %.

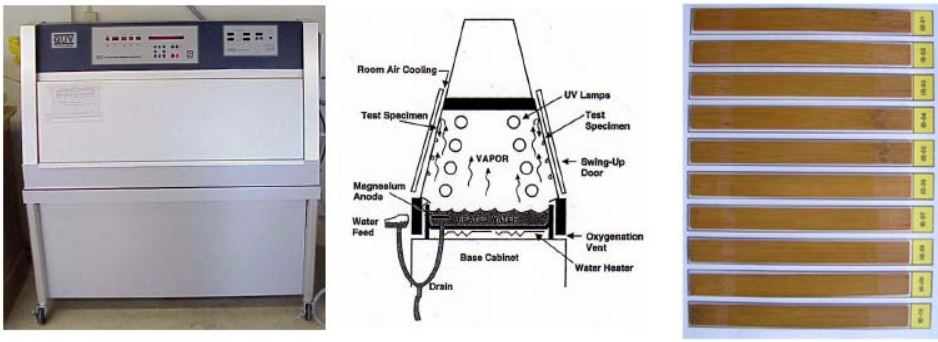


Time (min)	**Tensile Strength (MPa)**	
	Mean value	**Standard deviation**
0	92.47	22.74
7272	77.84	14.92
8683	75.74	5.14
16774	73.62	2.34
17364	72.94	20.66
18786	71.46	14.75
30377	72.57	3.59
30775	71.80	7.81
40395	71.97	25.80

Fig. 11: Tailoring of the specimen from the whole aged panel and tensile strengths for bamboo specimens subjected to absorption tests (for each ageing time five specimens were tested)

The accelerated ageing tests have been performed in the QUV Accelerated Weathering machine of the Q-Panel Lab Products company [ASTM D

4329-92 (1992)]. A minimum of 10 specimens for each ageing time were tested.



(a) (b) (c)

Fig. 12: Ageing machine (a); machine cross-section (b); bamboo specimens (c).

Three parameters have been strictly controlled: specimens temperature, flux density of the UVB fluorescent lamps and the moisture cycle. Each test lasted 720 hours (30 days) with the following cycle:

- 8 hours of irradiation with UVB-313 lamps (flux density = 0.8 W/m^2) at 140°F (60 ± 3°C) temperature;
- 4 hours of 100% humidity at 122°F (50 ± 3°C) temperature;

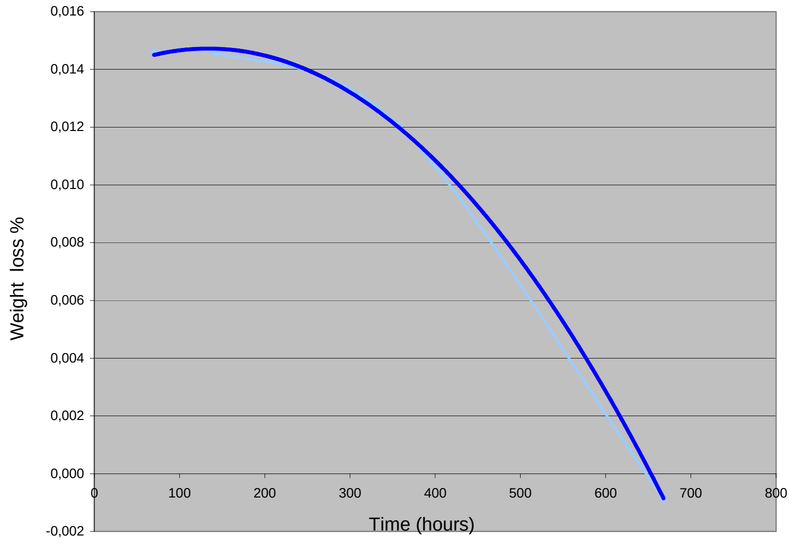


Fig. 13 - a: Diffusion curve.

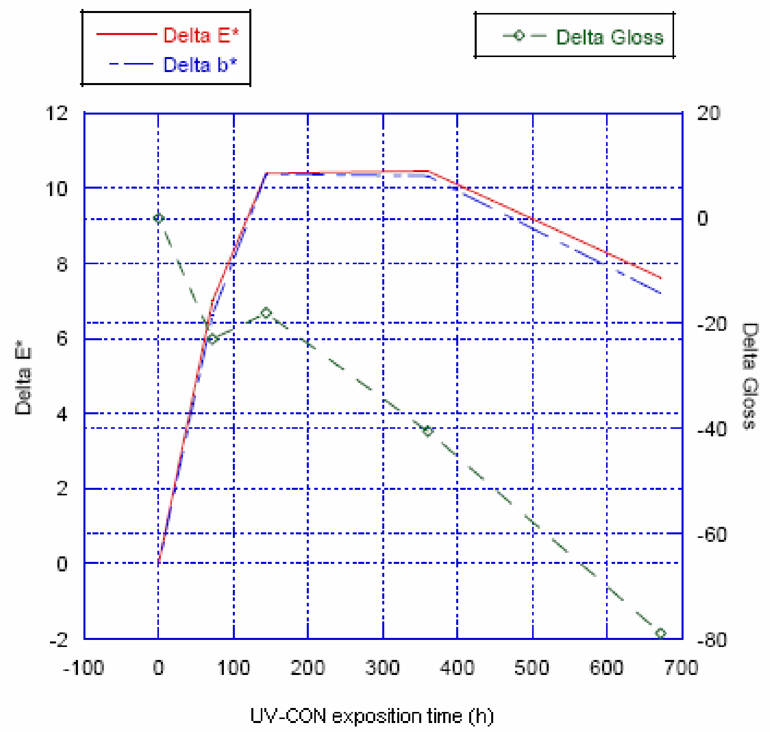


Fig. 13 - b: Colour- gloss specimens variation with time (the graph is referred at the Hunter system of colour and gloss representation: Delta b* represents the variation of saturation colour in the yellow scale, Delta E* represents the total variation of colour calculated as linear combination of each component variation: both are indicative of the specimens UV degradation ; finally the variation of gloss specimens has been represented)

The descending curve in Fig. 13 - a, which represents the loss of weight with time, is exclusively due to the degradation and detachment of the superficial polymeric matrix. This behaviour is confirmed by the opacity surface appearance and by the measurements of the specimen colour and gloss, made with a sphere spectrometer with a D65 illuminating source and an angle of measure of 10°.
The specimen colour, after an abrupt initial variation, presents a stabilization in the range comprised between 140 and 400 hours, accompanied with a constant decrement of the gloss (Fig. 13 - b). After 400 hours, a fast decay of the value of the gloss (all the specimen loose the superficial matrix layer and tend to be opaque) and an appearing recovery of the colour variation are recorded.
Tensile tests provided similar results of the absorption tests, i.e. a strength decrease around -20 %.

4 Examples

As applications, a spinnaker pole and an hull panel have been realised and respectively tested for axial compression load and for impact: successively a complete 6 meters boat hull has been realised in order to analyze critical lamination points, vacuum performances and necessity of external treatments.

The spinnaker pole (ϕ 250 mm) has been laminated on a female mould – one half after another half - with a stacking sequence of $[0°/30°/90°/30°/0°/90°/30°]_s$.

Total thickness obtained was 1 cm. Successively several (5) portions of the pole, each portion 50 cm long, have been obtained for compression tests. An ultimate compressive load of 550 kN, corresponding at a compressive stress of 70 MPa, has been recorded.

The numerical linear buckling analyses, conduced using bamboo and resin characteristics and simulating the lamination, well confirmed critical compression values obtained from the tests.

Fig. 14: Compression test on a spinnaker pole section

In order to verify the possibility to realize sandwich structures with adequate mechanical characteristics, 10 and 17 mm thick hull panels were realized, using respectively a 6 and 12 mm thick balsa core and two layers bamboo – epoxy skins.

Two different stacking sequences were used: panels 1 and 2 were realized using a stacking sequence of [0°/90°/0°/90°], and panels 3 and 4 were realized using a stacking sequence of [+45°/0°/-45°].

Panels 1 and 3 were realized using a 12 mm balsa core, panels 2 and 4 were realized using a 6 mm balsa core.

20 specimens for each panel type were tested. Flexural tests results are shown in Tab. 6.

Tab. 6: Flexural tests results on bamboo hull panels

	Thickness (mm)	Support span (mm)	Maximum load (N)	Core shear stress (MPa)		Facing stress (MPa)	
				Mean value	Standard deviation	Mean value	Standard deviation
Panel 1 (0°)	17.3	250	1200	1.1	0.108	51	3.34
Panel 1 (90°)	17.4	250	1143	1.1	0.075	49	3.00
Panel 2 (0°)	11.2	200	569	1.4	0.103	55	4.82
Panel 2 (90°)	10.5	200	492	1.3	0.143	60	5.58
Panel 3 (0°)	16.1	250	977	0.9	0.011	54	0.87
Panel 3 (90°)	16.2	250	601	0.6	0.038	33	2.35
Panel 4 (0°)	9.2	200	333	0.9	0.033	55	3.98
Panel 4 (90°)	9.6	200	217	0.6	0.021	32	1.93

Also impact tests were conduced on sandwich panels. 60 x 60 cm panels (5 specimens for each type of panel) have been tested in order to determine the energy gained by the specimen.
For the impact test, a 15 kg dart dropped from an height of 2 meters.

Fig. 15: Impact test on a sandwich panel.

Experimental results confirm that sandwich panels realized with bamboo fibers have an impact resistance comparable to those realized with the same core and artificial fibers (in nautical applications).
Similar sandwiches are, in fact, characterized by values of 2-6 J.

Tab. 7: Impact tests results on bamboo hull panels
(energy impact corresponds to the kinetic energy of the dart)

Specimen	Total thickness (mm)	Skin thickness (mm)	Core thickness (mm)	Energy (J)		Specific energy (J/mm)
				Mean value	Standard deviation	
Panel 1	17.4	2.7	12	2.75	0.205	0.158
Panel 3	16.2	2.1	12	1.23	0.084	0.076
Panel 4	9.6	1.8	6	1.22	0.105	0.127

Finally a complete 6 meters boat hull has been realised in order to analyze critical lamination points, vacuum performances and necessity of external treatments.

Fig. 16: The realised bamboo boat hull.

5 Life Cycle Assessment

Life Cycle Analysis (LCA), has become a fundamental tool to analyze the interaction between environmental conditions and industrial production. The LCA structure proposed by the ISO 14040 regulation can be resumed in four principal steps:

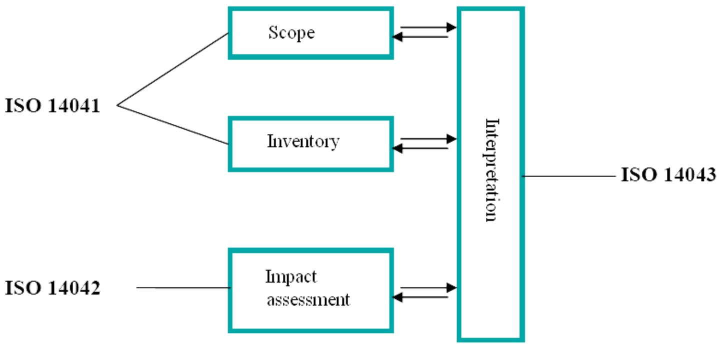


Fig. 17: The LCA structure proposed by the ISO 14040 regulation.

1) GOAL AND SCOPE DEFINITION, ISO 14041

The purpose of the present study is to evaluate the environmental impact of natural fiber - epoxy matrix reinforced composites for nautical application.
Functional unit: 1 kg of composite (700 gr. of bamboo, 300 gr. of epoxy resin).

2) LIFE CYCLE INVENTORY ANALYSIS

The inventory purpose is that to supply the life cycle phases data: raw materials supplying, production, carriage and distribution, use and maintenance, recycling, waste management.

3) LIFE CYCLE IMPACT ASSESSMENT

It's the process environmental impact study.
In the present study a complete evaluation of the bamboo – epoxy composite (BFRP – bamboo fiber reinforced composite) environmental impact has been conduced, comparing the eco – composite with a glass – epoxy composite (GFRP – glass fiber reinforced composite).
Functional unit for BFRP = 1kg
Functional unit for GFRP = 0.89kg

Specific effects that characterize all impact categories are defined as follows: global warming, stratospheric ozone depletion, acidification, nutrient enrichment, photosmog formation, human and eco-toxicity.

Tab. 8: Specific effects that characterize all impact categories for BFRP and GFRP (Units in Kilograms of equivalent specific substances)

	Units	**1 Kg BFRP contains**	**0.89 Kg GFRP contains**
Abiotic depletion	kg of Sb eq	$3.8 \cdot 10^{-2}$	$5.9 \cdot 10^{-2}$
Global warming (GWP100)	kg of CO_2 eq	-0.47	0.74
Ozone layer depletion (ODP)	kg of CFC-11 eq	-	$2.3 \cdot 10^{-9}$
Human toxicity	kg of 1.4-DB eq	$2.1 \cdot 10^{-3}$	$1.3 \cdot 10^{-2}$
Fresh water aquatic ecotox	kg of 1.4-DB eq	$1.6 \cdot 10^{-3}$	$4.7 \cdot 10^{-3}$
Marine aquatic ecotoxicity	kg of 1.4-DB eq	$2.5 \cdot 10^{-2}$	24.8
Terrestrial ecotoxicity	kg of 1.4-DB eq	$1.2 \cdot 10^{-7}$	$1.2 \cdot 10^{-4}$
Photochemical oxidation	kg of C_2H_2	$2,7 \cdot 10^{-4}$	$1 \cdot 10^{-4}$

Acidification	kg of SO_2 eq	$3,7 \cdot 10^{-3}$	$2,1 \cdot 10^{-3}$
Eutrophication	kg of PO_4--- eq	$1,2 \cdot 10^{-4}$	$4,7 \cdot 10^{-6}$

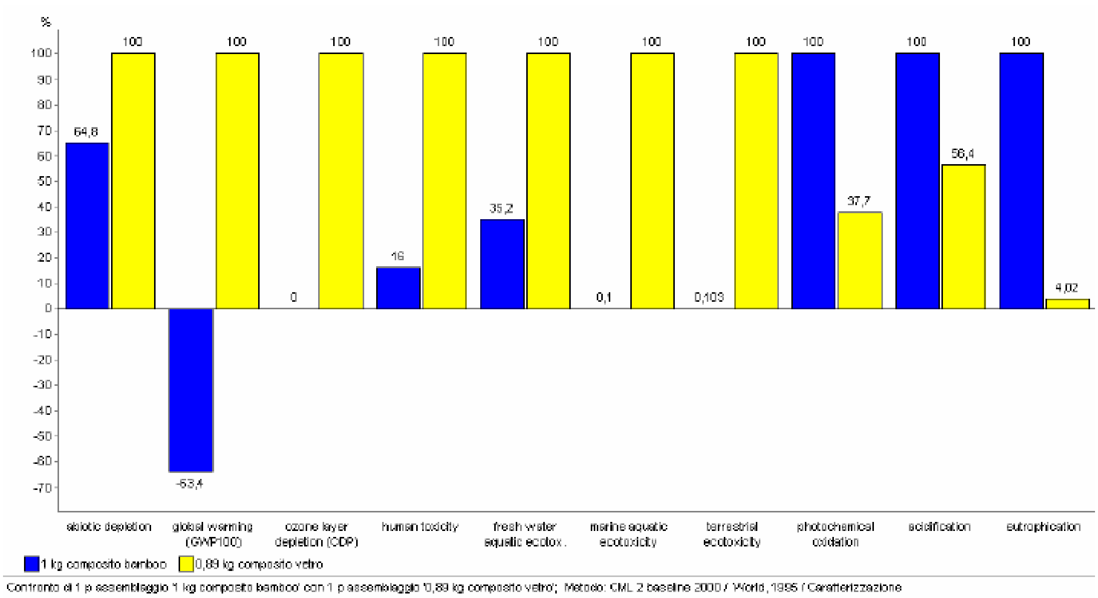


Fig. 18: Specific effects that characterize all impact categories for BFRP and GFRP.

The analysis, conduced on bamboo based and glass based composites, is simply an evaluation of the environmental impacts of laminates components [Lancaster P.A. (1981)]. A complete comparison between the eco – profiles of the glass and bamboo composites have been conducted using the index method, in order to obtain a set of comparable functional units.
The *CO_2 credit* method have been applied, considering the bamboo fibers presence; this method allowed to evaluate the environmental behaviour of bio – composites. Each kilo of the bamboo – fiber based composite contains a CO_2 credit of 0.47 kg (CO_2 eq) that will be returned only in the final burning phase.

6 Conclusions

All the numerous experimental tests gathered important information about the bamboo composites and the best process formulations. Moreover such tests constitute fundamental confirmation of the reliability of the material and of its usage in marine applications. The tests of accelerated ageing and water absorption have evidenced the resistance of the material adopted to the aggressiveness of the marine atmosphere; in the realization of real prototypes it is previewed however the utilisation of waterproofing treatments on the exposed parts, to the aim to improve the mechanical property of the composite.

Adhesion tests proved optimal ILSS value even without any particular fiber treatment: a value over 3.5 MPa allows the utilisation of such material in sandwich skins.

Future work could be directed to improve adhesion (using coating or fiber treatment) between the fiber and the matrix, to improve strength and impact resistance. Higher fiber volume fractions can be used to reduce resin usage, and properties of these higher fiber composites should be determined.

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