Production and experimental characterization of a new sandwich-structured composite with low environmental impact

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Abstract

The present work was conducted in partnership with the company FrontWave and included in the scope of a project that aims the development, production and experimental characterization of a new sandwich-structured composite material based in natural materials including stone and cork. Whereas, prior to the date of this work, had just been tested synthetic reinforcements and adhesives, in this study are incorporated natural fibers and bio-based resins which made it possible, for the first time, to study the technical, environmental and financial viability of this new solution. The experimental characterization focused on a mechanical behavior analysis occurred from bending tests through which were determined parameters such as maximum stress and apparent stiffness as well as the maximum deflection. In the case of asymmetrical sandwiches structures it was not possible to fully apply the existing standards for composite materials. The tests followed a testing methodology developed during the work and used either conventional mechanical testing systems or a new measuring displacements and strains system based on the method of digital image correlation. A comparison of various outcomes resulting from both methods was carried out and calculated a tendency for the deviation occurred between the resulting stiffness using each of these systems. The environmental impact was measured using the Life Cycle Assessment (LCA) technique and the costs implied in each studied typology, in material terms, all being presented for a short comparison. The three parameters culminate in a multicriteria analysis, which, after the allocation of importance and relative weights, distributed in four different ways (cases), leads to a global decision making indicator.

Keywords: Composite Material; Sandwich Structure; Natural Fibres; Bio-based Resins; Life Cycle Assessment.

1. Introduction

Environmental and sustainability issues of exploited resources have increasingly emerged and in this sense will the world continue to think. In engineering the contribution involves the research and development of systems that consume energy and other resources at a rate that does not compromise the environment, focusing on objectives such as waste, materials management, pollution prevention and product improvement.

Natural materials have been used to try to respond to the above problems and composite materials, by their nature, are usually the focus of the studies and developments towards evidencing less and less reliance on synthetic materials with high environmental impact. The natural fibres and bio-based resins have been the target of extensive study in recent years that have already discovered some applications to integrate, both structural and non-structural. The use of these materials involves a whole analysis that focuses not only environmental issues but also the technical capabilities and financial benefits or consequences in their employability.

In this work are produced and studied different variants of a sandwich-structured composite using natural materials and for structural purposes. The glass fibre and epoxy resin are compared with the flax fibre and a bio-based resin, performing an experimental characterization, a brief review of the life cycle and a cost comparison that in a multi-criteria analysis suggest a more suitable solution in view all these factors.

The work begins by introducing the concept of this new and innovative application studied and its fixed materials. It is made a literature review focused on the state of the art of natural fibres and bio-based resins as well as the sandwich structure and the life cycle assessment technique. Are presented in the following points the production methods used, the experimental characterization and results, Life Cycle Assessment (LCA), costs, the multi-criteria analysis and finally the conclusions and recommendations.

2. Background

2.1 Application concept

STORK is a concept that consists in a laminated composite material, and as such built in layers that enjoys the most appreciated and different characteristics from their main constituents: stone and cork. The adhesion of the two materials is done through the resin, it is strengthened by biaxial fibres and is presented as an innovative solution of low weight, high strength and long lasting allowing through their mechanical and physical properties a wide range of applications to a natural stone product.

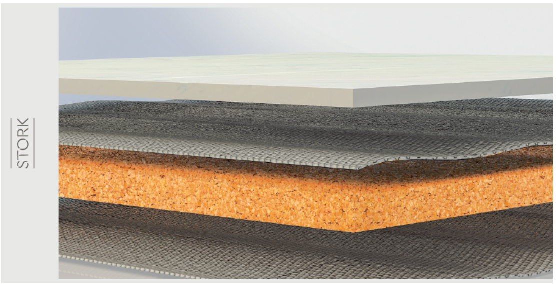

Figure 1 - STORK CAD model [1]

As a sandwich structure, the present application is composed of fibres which represent the thin faces and which give stiffness to the system as well as the adhesion between layers because they are embedded in resin, and the cork with a reduced density and thicker layer taking the role of core. The stone at the top gives it a purely aesthetic function, however giving to the panel an asymmetry.

2.2 Production method

The production method of such panels is done through the process of hand lay-up. The layers are unified through the quantity of resin calculated per the type of fibre and its weight, as well as the type of other layer than fibre, stone or cork, since the latter absorbs resin through its pores. A cure process is applied after the above procedure. In a first step the specimen is left for a certain time, called by gel time, at room temperature, this being necessary to obtain a typical viscosity of a gel. Subsequently is applied a pressure to the sample so that there is compression of the structure aiding their final quality, also at room temperature. The following is the post-cure cycle at a higher temperature obtained in an oven for a specified time, being all these data suggested by the resin manufacturer.

Laminations were made of stone tiles with the dimensions 300x300 mm^2 and 10 mm thick, and the specimens with the dimensions required for the experimental characterization obtained by lowering and cutting milling machines.

2.3 Variants studied

Seven different combinations were prepared as shown in the Table 1, with the layers of stone and cork remaining constant. The number 4 series, integrating a flax and PLA laminate, doesn't integrate this Table by reasons of the nature of this paper, being however explained in detail in the dissertation.

Table 1 - Different series studied

Variants			
Series	**Fibre**	**Weight (g/m^2)**	**Resin**
1	Flax UD	430/430	Epoxy
2	Flax UD	430/430	Bio
3	Glass	600/300	Bio
5	Flax BD	500/400	Epoxy
6	Flax BD	500/400	Bio
7	Glass	600/300	Epoxy

The first weight value represents the fibre weight for the layer between the stone and cork and the second one for the last layer, adhering to the cork. The glass fibre is biaxial as well as the flax BD (standing for bidirectional). The flax UD fibres are unidirectional which are perpendicularly arranged in the production of the composite. Both resins are epoxy types being one the so-called Bio 37% bio-based and the other a conventional one.

2.4 Specimen dimensions

The dimensions of the specimens were to meet ASTM C393 (Standard Test Method for Flexural Properties of Sandwich Constructions). The length was somewhat limited by the available tiles (300 mm) and the thickness by the application itself.

The standard indicates that the specimens should have a rectangular cross-section, the thickness thereof must equal the sandwich structure and the width should be greater than twice the thickness and three times the core thickness and less than half the distance between supports [2]. For a good use of the tile was imposed a width of 50 mm so that they could draw at least 5 samples per series, respecting the limitations mentioned above.

Note that the sample length is imposed by the standard as the distance between supports plus 50 mm, so the distance between supports was taken as 250 mm in the trials.

2.5 Bending test

Currently, the standards for flexural tests for existing sandwich structures will slightly against this concept to the extent that this does not present a longitudinal symmetry, result of not containing equal faces. The ASTM C393 standard contains a flexural stiffness calculation methodology for sandwich structures with different materials on both sides, but this method would require testing tensile strength to determine the Young's modulus thereof which could become lengthy and avoidable since the goal is to compare different constitutions of the same product. Thus, the calculation of the mechanical properties did not follow an existing methodology.

The bending test chosen was the four-point bending, wherein the specimen is supported by two supports spaced apart by 250 mm as already specified. The force is applied at two points equidistant from the supports, separated by a distance equal to one third of the distance between supports, the third point loading procedure, therefore 83.33 mm.

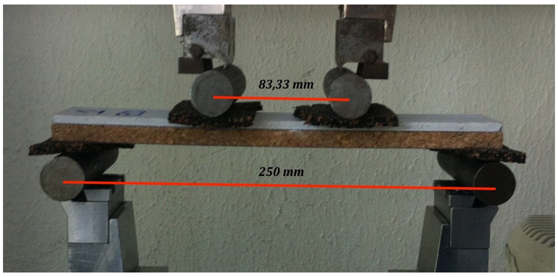

Figure 2 - Distances between supports

During the test shims are used between the sample and the support so that there is a buffer between the two preventing its contact by means of a less hard material, in this case rubber, which can be seen in Figure 2. This measure stems from the fact that the stone, little resistant material, suffers a crushing compression around the support.

2.6 VIC-3D

The VIC-3D is presented as a complete and innovative system for measuring the shape, displacement and strain of surfaces in three dimensions, including all required hardware. The three-dimensional measurements are prepared based on the method of digital image correlation. Using this method, the actual movement of the object is measured and is set in each point of the specimen surface, the Lagrangian strain tensor.

The VIC-3D is a system that can measure displacements and strains from arbitrary 50 micro up to 2000% strains and above of specimens having sizes comprised between 1 mm and 10 m [3]. Its preparation is simple and requires only a quick and flexible calibration procedure and the application of a pattern of spots on the surface to be analysed, prepared in this work through sprays. Without special lights or lasers this system does not require any contact with the specimen during testing.

Since the specimen's region of interest to analyse in the application inherent in this work is in the plane, the procedure was only to use a single camera for measuring the strain, using the background to the VIC system only in two dimensions.

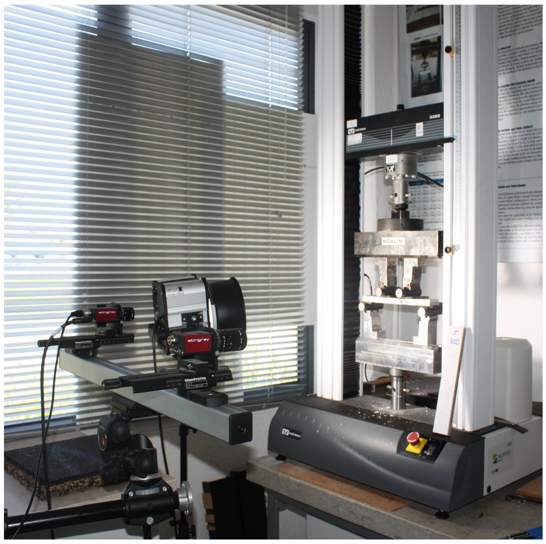

Figure 3 - Scheme setup for test with VIC system

3. Data processing

3.1 Experimental

3.1.1 Flexural strength

The criterion for the maximum stress applied corresponds to the one at which occurs cracking of the specimen in the cross section between the load application points circled in blue in Figure 4, being also possible to observe, in certain cases, a higher stress than the recorded according the presented criterion, however the apparent stiffness associated is significantly lower due to the sample's state of cracking, so it is important to highlight the importance of removing the certain value of maximum stress, as defined above, and not just the maximum value observed. The calculation is made through the equation for flexural strength of a rectangular sample under a load in a four-point bending (1).

During data processing it was detected strength falls along the tension vs. displacement curve, surrounded in red in Figure 4, clearly identified as coming from the reverse bending occurred at the ends of the sample, continuing the trial with a similar stiffness to that observed prior to the stress fall. This phenomenon occurs at the ends of the specimens when the cork tends to deflect downward, movement that the stone, with a higher stiffness, does not track and flexing in the opposite direction leading to delamination of the latter under the cork.

$$\sigma = \frac{3F(L - L_i)}{2bd^2} \qquad (1)$$

σ – Flexural strength
F – Force applied
L – Distance between supports
L_i – Distance between loading points
b – Specimen width
d – Specimen thickness

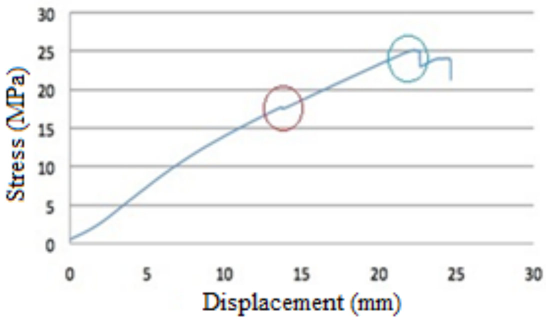

Figure 4 - Stress vs. Displacement graph with maximum stress and stress fall highlighted

3.1.2 Apparent stiffness

The apparent stiffness was calculated through the tension vs. displacement curve using the linear part of the curve to calculate the slope, having opted by the dominant slope of the curve, characteristic of the material, defining two points for its calculation, typically beginning in deflection of 3 mm, the extent to which the stiffness is presented as inferior, from the use of rubber between the support and the sample, where the test force initially deforms the shims and as a less hard material having an inferior stiffness, as seen in the initial slope of the graph presented in Figure 4.

Note that this method does not define a physical property of the material but a characterization and displays a result that can be compared relatively.

3.1.3 Maximum deflection

This parameter corresponds to the maximum displacement of the testing machine itself in the first method and the maximum displacement at mid span recorded by the VIC-3D in the case of the second method.

The use of VIC-3D requires a synchronization, in a programmed routine provided by FrontWave, of the data of the testing machine, strength, with the one of the visualization system, the displacement. After an import of data from the two methods are chosen for the coordinate and ordinate axes data from the VIC-3D and testing machine, respectively. The following is the synchronization and plot, concluding with an export to an excel file.

3.2 Environmental

The LCA procedure was based on the standard ISO 14040-2006 [4].

Starting with the definition of the functional unit, which responds to the need to quantify the product functionality by measuring its performance when executing the function associated with it, it is a reference to which the inputs and outputs are related, noting that this unit must be measurable [5].

In this case, the functional unit, considering the user's perspective, it is regarded as a service for the latter. Measuring, for all variants, the consumption of materials and emissions of unit processes associated with each product life cycle as well as the appropriate environmental impact, the functional unit was defined as "The production of raw materials and installing a panel 1 m^2 ".

Having defined the functional unit, it is intended to then compare the environmental efficiency associated with the provision of a panel of 1 m^2 of all the alternatives presented. After this setting, it is possible to calculate the amount of material required to fulfil this function.

The boundaries of the LCA are defined from cradle to gate, adding finally the transport phase of the finished product. The composite production phase (and also transport of raw materials to the plant) is not taken into account given that the purpose of the study is based on comparison of the composite material alternatives, i.e., with the same production process for all of these this simplification will not result in a significant error in the final analysis. It is noted that the same reasoning is taken to the package, assuming that the material surrounding the finished product is identical to any of the alternatives analysed. This stemmed from the fact that the decision of the production line of this material has not yet been properly thought out and completed by what the type of final packaging is unknown for now and the choice of any could lead to an unrealistic amount of environmental impact associated with packaging.

The end of life scenarios will be analysed qualitatively for the different cases. The qualitative analysis results from the lack of information regarding these scenarios in composite materials and as such databases also lack of information on processes that require high specificity.

The life cycle inventory will be focused over different materials involving all the alternatives studied, having been selected the environmental impact category of global warming potential, a process that represents a major environmental problem to mankind and is expressed by the temperature increase global planet that is occurring due to high anthropogenic emissions of greenhouse gases into the atmosphere. This impact is estimated by the carbon footprint inherent in the production of all components used and transportation of the final product. This footprint is measured in equivalent kilogram of carbon dioxide, which expresses the amount of greenhouse gas emitted in such processes equivalent in terms of the amount of carbon dioxide emissions.

3.3 Costs

Relatively to the costs, the budgets of the components involved in all production series developed in this work are presented, estimating then price levels for each square meter of composite itself. Since the production method is identical for all series are not accounted for the same costs. Note that the stone layer also did not come into consideration for its variety of cost dependent on the type of stone required for the application, recalling that this gives the composite material only their aestheticity.

3.4 Multicriteria analysis

In this work is presented a brief multicriteria analysis so that, as a tool to support decision-making, it can create choice indicators considering all necessary parameters. In the economic aspect, will be incorporated the costs, the environmental will count the carbon footprint and in mechanical terms the flexural strength and the apparent stiffness.

Since each parameter has a unit, they need to be properly nondimesnionalized to allow an assignment of weights depending on their importance, and finally compared in an overall analysis to be proposed the best solution.

In the nondimensionalization phase was proceeded to the allocation of 100% to the best case within each parameter and the respective percentages for the remaining series. Since the technical performance is divided into two parameters, the flexural strength and the apparent stiffness, it was assigned a weight of 50% to each and after individual nondimensionalization was scored, each of which together result in a total weighted score, which represents nondimensional technical performance for each series.

The difficulty of assigning importance weights to the considered analysis parameters that reflect the strategy of a company for the product as well as the sensitivity of the results obtained with such weights represent the biggest drawbacks normally assigned to a global assessment method based on a system of weights [6]. Thus, it excels this disadvantage with a range of possible scenarios proposed and is evaluated case by case. In a first instance, in an optimization point of view, weights are distributed equally, assigning a third each performance type: technical, environmental and economic. The following cases are based on three different strategic objectives:

Case A - This case is based on the mentality seen during the economic downturn since 2009, where the focus of the manufacturers moved away from sustainability issues to simply survive, that is a strategic objective of minimizing the cost of the product by assigning a 90% weight to the component economic and 10% technical, despising any environmental concerns.

Case B – A case more balanced and corresponding to the current strategies in general, assigning a value of 60% to the economic component, 30% technical and 10% for environmental issues.

Case C - A more futuristic case that addresses a sustainability strategy with 50% of its weight and 40 and 10% for technical and economic components, respectively.

4. Results

4.1 Experimental

Are outlined in Tables 2 and 3 the values of maximum stress, apparent stiffness and maximum displacement, all of which are presented as average values of the five specimens tested for each production series, except the second method whose results are the mean of two specimens tested with the VIC in the five. Additionally, it presents the standard deviation values (S) of each series. The results for the two distinct methodologies are shown separately and, for the second approach (VIC), maximum stress values are not shown since they are already incorporated in referring to the first method, i.e., in both methodologies stress values are directly proportional to the force transmitted by the testing machine and not dependent on the use of the VIC system. For reasons of sampling the maximum stress values are thus presented only the first methodology.

Table 2 - Parameters of interest obtained in the experimental characterization with methodology 1

Methodology 1 (INSTRON)			**Series**	**Parameters of interest**					
Fibre		**Resin**		Stiffness (MPa/mm)	S	$\sigma_{máx.}$ (MPa)	S	$\delta_{máx.}$ (mm)	S
Flax	Flax BD	Epoxy	5	0.795	0.171	20.9	4.4	26.1	1.6
		Bio	6	1.005	0.150	22.9	1.3	23.2	2.2
	Flax UD	Epoxy	1	0.933	0.124	20.6	3.8	23.3	2.7
		Bio	2	0.944	0.057	21.9	2.2	22.9	1.5
	Flax UD (Laminate)	PLA	4	-	-	-	-	-	-
Glass		Epoxy	7	1.798	0.039	30.0	1.5	18.9	0.9
		Bio	3	1.487	0.028	35.6	1.1	24.1	0.8

Table 3 - Parameters of interest obtained in the experimental characterization with methodology 2

Methodology 2 (INSTRON + VIC)			**Series**	Parameters of interest			
Fibre		**Resin**		Stiffness (MPa/mm)	S	$\delta_{máx.}$ (mm)	S
Flax	Flax BD	Epoxy	5	0.799	0.045	24.4	1.8
		Bio	6	1.036	0.109	19.2	0.3
	Flax UD	Epoxy	1	0.888	0.076	20.0	2.5
		Bio	2	0.813	0.011	20.1	2.9
	Flax UD (Laminate)	PLA	4	-	-	-	-
Glass		Epoxy	7	1.775	0.003	16.0	0.1
		Bio	3	1.492	0.022	21.8	1.2

Analysing the maximum stress is possible to observe an increase for all fibres during the use of bio-based resin instead of epoxy, being more evident for the glass fibre. The mechanical properties of natural fibres, lower than those of glass fibre, cause a lower maximum stress than the series produced with glass fibre, in the order of 35% when using the bio resin and 30% in the case of epoxy resin, being between different flax fibre solutions much like results.

The maximum displacements, for both methodologies, are presented inversely proportional to the stiffness measures with different resins, so as expected the strictest test specimens deflect less and less rigid flex more. A comparison between the different approaches to testing indicates that when using the VIC system are recorded maximum deflections below the method involving only a testing machine. This reduction arises from the fact that the testing machine measures the displacement of the complete test system, i.e., any movement of the machine is deducted as sample displacement, as the initial penetration is made on rubber shims and crushing or compression of the cork. In the second approach, the analysis in the snap-VIC2D software, to the captured images, is made only in a specific region of interest covering only the sample and therefore the measured displacement is less than the previous methodology. We can thus infer that:

$$\Delta l_{INSTRON} = \Delta l_{VIC} + \Delta l_{InitialPenetration} \quad (2)$$

To set a relation between the two apparent stiffness calculation methods a linear regression based on the average values of each methodology stiffness was calculated, indicating the following correlation:

$$Stiffness_{VIC} = 1.0454 \times Stiffness_{INSTRON} \quad (3)$$

The trend line, in Figure 5, shows that the calculated stiffness with the VIC system increases 4.5% compared to the calculated only with the mechanical testing machine.

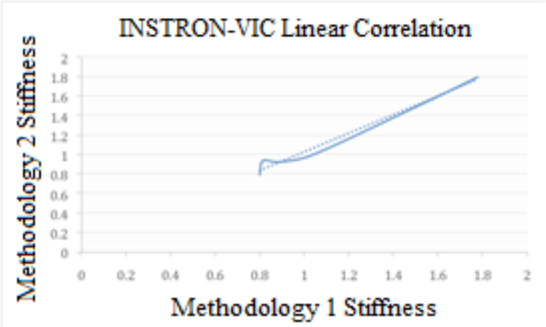

Figure 5 - Linear correlation between methodologies

When introduced the flax fibre is observed, compared with the glass fibre, a reduction in stiffness on the order of 35% when using the bio-based resin and in the order of 50% when using the epoxy. Among flax fibre solutions are observed higher stiffness for the series 5 and 6 (Flax BD).

The properties of the fibers employed in this study dictate the technical superiority of fiberglass compared to flax fibers BD and UD. Also taking into account the weights of fiber layers are not equal (600, 500 and 430 g / m2, respectively), from the small range of choice in the market, their contribution is of utmost importance in the results, with particular relevance the layer between the stone and cork where reinforcement is imperial.

4.2 Environmental

The amount of CO_2 equivalent for each alternative is obtained by multiplying the inventory values by the total mass of each series, i.e., adding all the masses relative to the components. To the resins, the mass is dependent on the type of fibre used, and the different fibre weights correspond to a different mass of resin to be used. Throughout the production of composite materials, it was observed a greatest absorption of resin by the natural fibres. Thus, defined empirical absorption coefficients for the natural fibres, multiplicative factor defined as the amount of resin required for the same area and glass fibre weight. For UD flax fibres perpendicularly exposed applies a factor of 2, since they require twice the resin compared with the glass fibre while the BD flax fibres is associated with a coefficient of 1.5.

Table 4 – Carbon footprint from cradle-to-gate for each series

Carbon Footprint (Cradle-to-grave)	Series 1	Series 2	Series 3	Series 5	Series 6	Series 7
kg CO_2 eq.	27,7	16,4	12,9	18,9	15,0	18,8

The values given in Table 4 add up the values of the CO_2 equivalent amount of the finished product resulting from its transport. The carbon footprint of the transport is calculated after multiplying the correspondent database value, 0.0658 kg CO_2 eq./t*km, by the composite's mass in tonnes and by 350 km assumed to be an average distance delivery of the product at nationwide level.

Table 5 -Total carbon footprint for each series

Carbon Footprint TOTAL	Series 1	Series 2	Series 3	Series 5	Series 6	Series 7
kg CO_2 eq.	28,2	16,9	13,3	19,4	15,4	19,2

The carbon footprint of glass fibre, according to the database used is similar to that of flax fibre, being even slightly lower, with the largest difference occurring in the resins, where the production of one kilogram of each differs in 4.06 kg of product's CO_2 equivalent kilogram. Environmental impacts are, of course, directly proportional to the part of the fibre resin absorption coefficient because, being fibres similar in carbon footprint, it is the matrix used and its quantity that dictate the overall value of the impact on each series production. Therefore, the series which minimizes the environmental impact is the number 3, with glass fibre and bio-based resin. As the mass of glass fibres and flax BD is the same, since all the weights makes a total of 900 g/m^2, the absorption coefficient of natural fibre causes the need for additional resin increasing its environmental impact. It is therefore concluded that any solution to the bio-based resin is more beneficial to the environment compared with the use of epoxy resin.

4.3 Costs

Table 6 – Total cost per series

Fibre		Resin	Series	Cost (€)			
				Fibre	Resin	Cork	Total m^2
Flax	Flax BD	Epoxy	5	[25-29]	[36-40]	[10-14]	[74-78]
		Bio	6	[25-29]	[37-41]	[10-14]	[76-80]
	Flax UD	Epoxy	1	[35-39]	[46-50]	[10-14]	[95-99]
		Bio	2	[35-39]	[48-52]	[10-14]	[97-101]
	Lamina		4	[68-72]		[10-14]	[79-83]
Glass		Epoxy	7	[11-15]	[23-27]	[10-14]	[47-51]
		Bio	3	[11-15]	[24-28]	[10-14]	[49-53]

From the Table 6 one can conclude that the costs of series 3 and 7, both produced with glass fibres, are presented as the lowest. In fact, abundance of glass fibre producers in the market of reinforcing fibres by existing full demand is such that the price per square meter is an advantage when compared with natural fibres. The latter are the opposite extreme regarding the existing competitiveness, not only by the lower current employability of them, but also the added difficulty in its production, directly influencing its shortage in the market. A costs distribution in these series is given a percentage of about 50% resin and about 25% for each of the remaining layers, cork and fibre.

An increase of about 50% in the cost is found in the series 5 and 6, where the cost of the bidirectional fibre flax is one of the factors responsible for this increase, as well as its absorption coefficient, which involves a larger amount of resin in its production. The same is seen for the series 1 and 2, however there is a greater difference in cost since the absorption coefficient is still larger and the fact that unidirectional requires four layers (two for each fibre layer) in order to obtain reinforcement in two perpendicular directions. Given the increased price of natural fibres, it is verified an average percentage of 36.5% of total costs for these, keeping 50% of the resin and lowering the percentage of cost of cork, at around 13.5 %.

4.4 Multicriteria

The nondimensionalized values can be seen in the Figure 6, followed by a diagram showing the series in the case where weights were equally distributed.

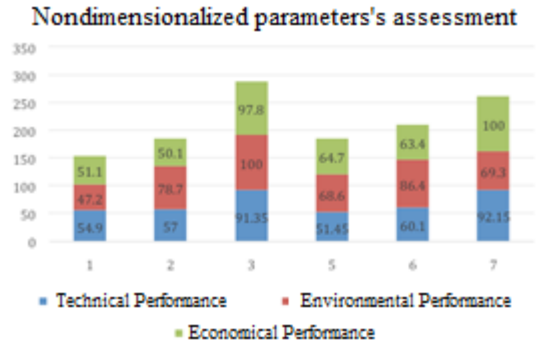

Figure 6 - Nondimensionalization of the parameters of interest

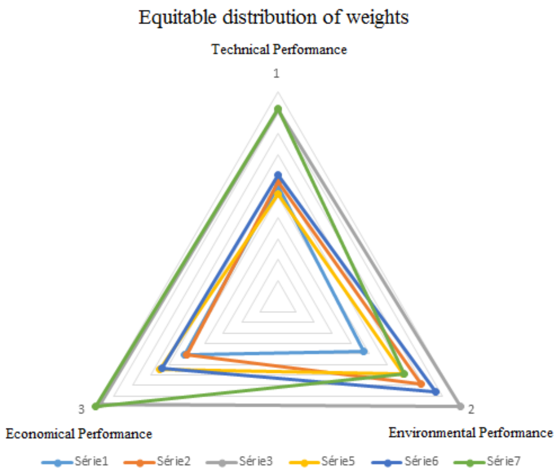

Figure 7 - Diagram with performance distribution for the optimization case

The weighted scores per series per case (A, B and C) are presented in the Table 7.

Table 7 – Nondimensionalization of parameters of interest

	Performance			Total Score		
	Technical	Environmental	Economical	Case A	Case B	Case C
Series 1	54,9	47,2	51,1			
Weighted	5,5	0,0	46,0	51,5		
	16,5	4,7	30,7		51,9	
	5,5	23,6	20,4			49,5
Series 2	57,0	78,7	50,1			
Weighted	5,7	0,0	45,1	50,8		
	17,1	7,9	30,1		55,0	
	5,7	39,4	20,0			65,1
Series 3	91,4	100,0	97,8			
Weighted	9,1	0,0	88,0	97,2		
	27,4	10,0	58,7		96,1	
	9,1	50,0	39,1			98,3
Series 5	51,5	68,6	64,7			
Weighted	5,1	0,0	58,2	63,4		
	15,4	6,9	38,8		61,1	
	5,1	34,3	25,9			65,3
Series 6	60,1	86,4	63,4			
Weighted	6,0	0,0	57,1	63,1		
	18,0	8,6	38,0		64,7	
	6,0	43,2	25,4			74,6
Series 7	92,2	69,3	100,0			
Weighted	9,2	0,0	90,0	99,2		
	27,6	6,9	60,0		94,6	
	9,2	34,7	40,0			83,9

It follows that in the case of optimization as well as B and C the most suitable series is the number 3, version produced with glass fibre and bio-based resin and that for the case A the more scored series is the number 7, designed using the same fibre, but with epoxy resin.

5.Conclusions

The best mechanical performance was naturally proved to be related to the glass fibre solutions due to their considerably higher mechanical properties, indisputable fact and which the flax fibres are not able to compete. The replacement of the synthetic epoxy resin by the bio-based one, allowed the maintenance of the mechanical performance in both cases of the natural and synthetic fibres. It has to be stressed the good score of the natural fibres in the composite material sandwich structure application studied in this work; it has been proven that their joint utilization with the biological based resin resulted in a 18% reduction in the apparent stiffness and with the synthetic epoxy resulted in a 22% reduction in the maximum strength, when compared with the series involving glass fibre, notwithstanding the disadvantage shown in the results of the high variability of the natural fibres, due to the high uncertainty level in their quality standardization.

The applied methodologies showed an increased 4,5% trend in the apparent stiffness results, with the visualization system VIC-3D employment, more precise in the displacement measurement. This correlation may be adapted as hypothesis for other case studies.

The most reduced ecological footprint, resulted to be the glass fibre series with the bio-based resin, having the latter significantly reduced the impact in relation to the epoxy utilization. The natural fibres, even though presenting a similar impact to the glass ones, lose ground to the latter due to the higher resin absorption in the production process, leading to a bigger impact; in the best cases of the two flax fibres tested it was registered a 1.5 absorption coefficient, showing an extraordinary 50% plus resin application when compared with the same case with glass fibres. Finished this fact, the worst ecological footprint relates to the flax fibres with an absorption coefficient of 2, case of the unidirectional fibres perpendicularly arranged.

The total materials acquisition costs for the different series conceptions showed two important conclusions: the first was that the bio-based resin resulted to perform equal or better in certain technical parameters, as well as a reduction of the ecological footprint, having a cost increase of only 4%. The second showed a lower cost for the glass fibre, this being contrary to the common idea of the potential lower cost for natural fibres (argument used as one of its advantages); Presently this is not the case due to their (natural fibres) less expanded and less competitive market, this resulting of the lesser use of these fibres, as well as from their high difficult production level.

The multicriteria analysis points to the election of the glass fibre solution with biological based resin in all proposed strategic cases, at the exception of case “A”, where the economic component reins over the technical and the ecological footprint is totally excluded from the strategic plan.

The conclusion is that the natural fibres, for structural applications, being technical inferior to the synthetic ones, will hardly replace them, even though this replacement is possible if the project requirements are met, even though presently they show an inferior performance in terms of cost and ecological footprint. One also concludes that the bio-based resins may be part of a solution for an environmental efficiency of the composite materials, maintaining the same mechanical performance and similar costs. The author recommends to FrontWave, according to the achieved results, the replacement of the synthetic epoxy resin, for the bio-based epoxy resin, in the production of any STORK concept variation.

It is suggested, for future research, a Life Cycle Assessment of this type of composite structures covering more categories of environmental impact, refining the analysis of it. If possible, because of insufficient uniformity in the market of natural fibres and resins focus the collection of specific data in situ in order to calculate and quantify the most relevant inputs and outputs associated with these natural products, reducing the system modelling uncertainties and strengthening the currently existing database of these products. It is highlighted the extreme importance of this task to a better understanding of the true impact of these "green" materials, knowledge that will certainly contribute to an expansion in the market, offering sufficient competitiveness to reduce their cost and compete, even in highly specialized industries such as the aerospace sector, with synthetic materials. The involvement of these materials may first be introduced in such a complex industry as air transports for non-structural applications as some already existing projects of aircraft interiors.

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