VACUUM INFUSED SANDWICH STRUCTURES BASED ON SISAL FABRICS

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Abstract: The materials sector usually seeks light, low cost and high performance materials and sandwich structures, which combine two external faces and a low density core, are an excellent choice for many applications. The aim of this study is to produce sandwich structures using a polyester matrix and sisal (*Agave sisalana*) fabrics with a PET core. Three types of sisal fabrics with distinct aerial density and architecture were produced for this work and their performance were compared with standard commercial glass-fiber fabric. The composite sandwiches were produced by vacuum infusion and characterized through longitudinal/axial compression and flexural testing. The obtained sandwich composites with sisal fabric showed mechanical performance similar or even superior than that of glass fibers for similar fiber volume fraction. Therefore, they were considered an attractive alternative for replacing glass fiber fabrics in selected industrial applications.

Keywords: *Sandwich structure, Sisal fabric, Polyester, Vacuum infusion.*

1 Introduction

Increasing environmental concerns have encouraged researchers to develop materials based on natural fibers such as sisal (*Agave sisalana*). The use of sisal fibers as reinforcement in polymeric composites has increased due to their low cost, biodegradability, favorable health and safety concerns, renewability and low specific weight that may even lead to higher specific strength and stiffness than glass fiber [1,2]. The production of fibers requires a small amount of energy at low CO_2 emission and there is little abrasion in the equipment during processing [3].

In recent years, the need for low weight constructions with high strength and durability has increased the demand for new materials and structural solutions, such as sandwich structures [4]. Sandwich panels is a class of composite that is obtained by attaching two thin but stiff facesheets to a lightweight and thick core. Fibers may be placed in the laminate skin to provide in-plane tensile and compressive strength to the panel. The core is made of a lightweight material, but its thickness provides the sandwich composite with high bending stiffness with overall low density [5].

Composite materials have been utilized in a variety of engineering fields such as marine, aeronautical and automotive industries [5–7]. They also have just been employed in civil engineering practices [8]. The use of sandwich panels as a civil construction material has often been overlooked in favor of traditional materials such as concrete and steel as these are relatively cheap and readily available. However, the advantages of sandwich panels over traditional building materials have started to become clear [9,10]. Composite materials are increasingly replacing traditional materials whose individual characteristics do not meet the growing demands for improved performance, safety, economy and durability. An innovative fiber composite structural sandwich panel has recently been developed for various civil applications. This new generation panels has potential applications in floors, bridge decks, walls and roofs based on multifunctional structural/insulation properties [10,11].

This paper presents experimental results related to the development of a polyester sandwich composite reinforced with sisal fabric, using polyethylene terephthalate (PET) as core material. The sandwich was produced via vacuum infusion molding aiming to produce a substitute for sandwich structures reinforced with glass fiber.

2 Materials and test methods

2.1. Specimen preparation

The materials used in the preparation of sandwich structures were: Polyethylene terephthalate foam core - PET, with 12 mm thickness, 80 kg/m^3 density. Orthophthalic unsaturated polyester resin (Uceflex UC 5530-M) and Butanox M50 catalyst. As reinforcement, three types of sisal fabric were produced: Plain weave and Twill weave (aerial density of 650 g/cm^2 and 1095 g/cm^2, respectively) and another sisal fabric with Plain weave (189 g/cm^2) too, developed by Cerchiaro [12]. For comparison, a unidirectional glass fiber fabric (330 g/cm^2) was also used.

2.2 Molding

The sandwich prototypes were molded using vacuum infusion (VI). The plates (600 × 600 mm) were produced using the Uceflex UC 5530-M resin with 1% Butanox M50. The reinforcements were stacked as shown in Fig. 1a, followed by a layer of *peel ply* and *air flow*. Afterwards, vacuum was applied (-0.1 to -0.05 bar) to ensure full filling (Fig. 1b-1c) and left for 1 h. Fig. 1d shows the demolding process. Table 1 displays the produced samples.

Fig. 2 presents the sandwiches composites reinforced with sisal fabric.

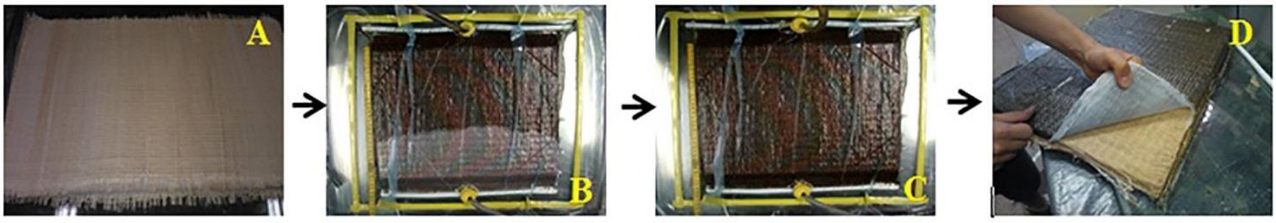


Fig 1. a) Fabric stacking; b) Initial resin flow; c) End of reinforcement filling; d) Composite demolding.

Table 1. Configuration of the samples.

Samples	Core	Reinforcement	Aerial density (g/cm^2)	Number of fabrics at each face	Sandwich thickness (mm)	%V_f at the faces
PET2TC	PET	Sisal Cerchiaro	189	2	15	22
PET1TSI	PET	Sisal Plain	650	1	15	34
PET1TSA	PET	Sisal Twill	1095	1	17	31
PET1TV	PET	Glass	330	1	13	48
PET2TV	PET	Glass	330	2	13.2	47
PET3TV	PET	Glass	330	3	13.5	48

%V_f – Volumetric fraction of reinforcement at the faces.

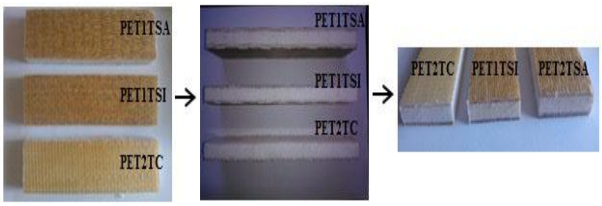


Fig. 2. Sandwiches composites reinforced with sisal fabric (PET1TSA, PET1TSI e PET2TC).

2.3. Experimental testing

Mechanical testing of the panels was carried out in a hydraulic universal testing machine Instron 3382, with 100 kN load capacity. The tests were: longitudinal compression parallel to the layers (ASTM C364-07), using 1 mm/min cross-head speed and five samples; and three point flexural (ASTM C393-11), using 3 mm/min cross-head speed and five samples. Student's t-test was used for the comparison of mean values.

3. Experimental results and discussions

In Table 1 shows that the volume fraction (%V_f) of sisal is smaller than compared to fiberglass, because the sisal is a natural fiber the impregnation by the matrix becomes harder, thus a greater expenditure of matrix occurs in the molding of the sandwich structures.

3.1 Longitudinal Compression Testing

The Load *versus* Displacement curves obtained are shown in Fig. 3. The initial strain data (without significant load) is due to the accommodation of samples in the text fixture. Vegetable reinforcement showed better defined curve, and synthetic reinforcement composites exhibited higher displacements with lower maximum loading. The loading results are used to calculate the ultimate strength of the samples according to the ASTM C364 standard

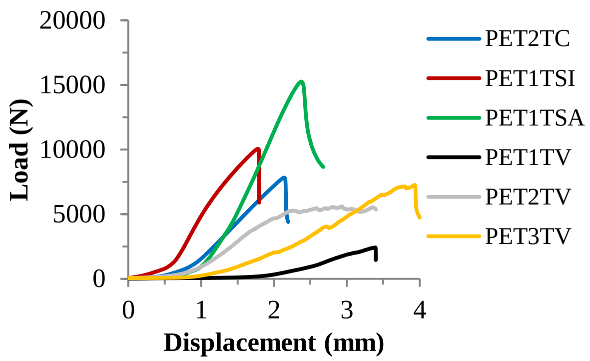


Fig. 3. Load *versus* Displacement curves of different sandwiches for longitudinal compression testing.

Fig. 4 shows the aspect of all samples just after testing. It is possible to see buckling deformation in the PET2TC sample, while delamination occurs on the faces of PET1TV. In the PET1TSI sample, buckling also occurs, followed by failure of the core, whereas crush at the top region of the composite occurred for all specimens of the PET2TV family, followed by delamination of the faces. Buckling of the material followed by failure of the faces and shear of the core displayed by the sample PET1TSA is very similar to that presented by PET1TSI. For PET3TV specimen, buckling and face delamination occurs leading to core failure.

Table 2 shows the mean values obtained with longitudinal compression testing as well as the

Student's t-test used to compare sisal and glass fabric reinforced samples. Sisal and glass fiber samples are compared according to the aerial density (g/cm^2), in this way is compared PET2TC with PET1TV, PET1TSI is compared with PET2TV and PET1TSA is compared with PET3TV. For samples PET2TC and PET1TV there is no significant difference between the results. Glass fiber fabric reinforced samples (PET2TV and PET3TV) showed significant differences in comparison with sandwich composites reinforced with sisal fabric. The thickness of the reinforced structures reinforced with sisal influenced the results, because despite withstand high loads, they are much larger than the thickness of structures reinforced with fiberglass fabric, reaching a difference of up to 20%.

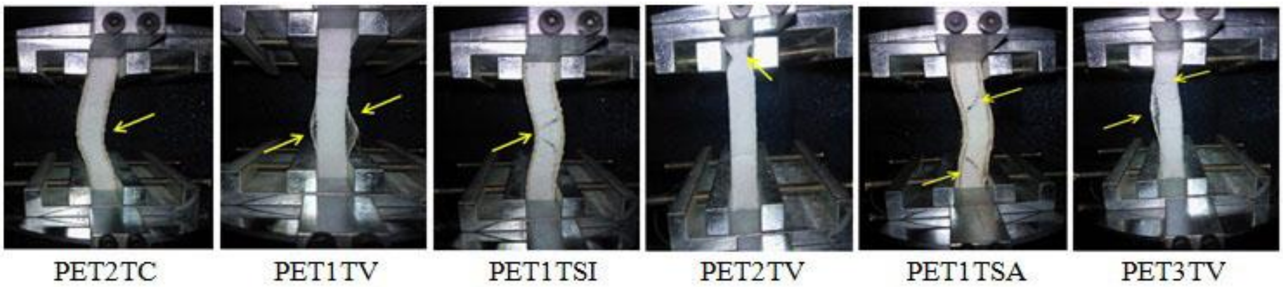


Fig. 4. Behavior of the samples during longitudinal compression testing.

Table 2. Student's t-test results for longitudinal compression test.

Variables	Mean		Student "t" test	Probability (%)
	PET2TC	PET1TV		
Ultimate Strength (MPa)	47.3	41.32	0.98	19.06 ns
	PET1TSI	PET2TV		
Ultimate Strength (MPa)	67.64	101.54	6.30	0.16**
	PET1TSA	PET3TV		
Ultimate Strength (MPa)	58.50	92.68	5.79	0.22**

**p≤0,01 ns – no significant.

3.2 Flexural Testing

In flexural testing, the samples showed ductile behavior, with poor linearity in the early stages, but with large ultimate strain in all curves (Fig. 5). Analyzing these curves, a better behavior of the samples with natural reinforcement (PET2TC, PET1TSI and PET1TSA) is noticed.

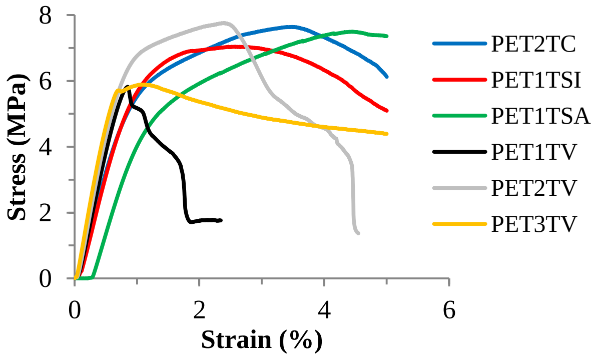
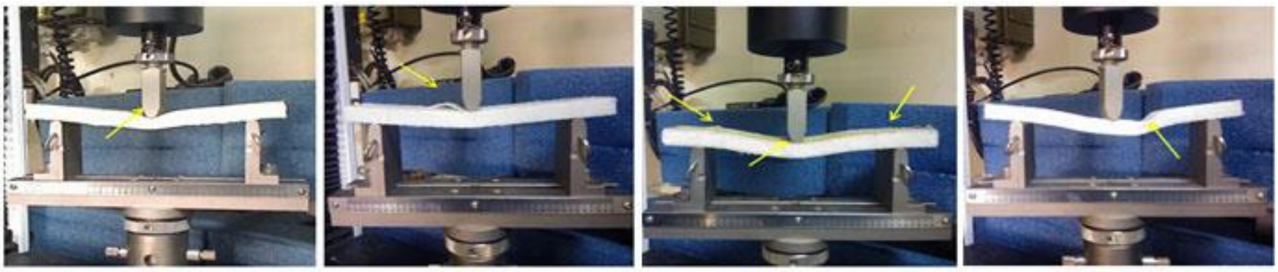


Fig. 5. Stress *versus* Strain curves in flexural testing.

Fig. 6 displays the visual aspect of some of the samples just at the end of testing. The PET2TC and PET1TSI shows very similar behavior, with crushing failure at the upper face and material severe deformation just before bending meaning that there is large energy absorption by the top layer which is not transmitted to the bottom layer. In PET1TV, detachment of the top layer occurs and, for PET1TSA, cracks appear at the top and bottom layers due to failure of the reinforcement. In PET2TV, failure occurs by disruption of the core which subsequently leads to the rupture of the reinforcement. In PET3TV failure occurs by rupture of the reinforcement, which leads to the appearance of cracks on the top surface.

In statistical analysis (Table 3), with respect to Core Shear Strength, PET1TV and PET2TC samples showed significant differences in their results, with the best result for PET2TC, regarding the Facing Stress, the difference is also significant, since the PET1TV presented the best result performance. Samples PET1TSI and PET2TV, with respect to Core Shear Strength showed no difference in their results, on the other hand facing stress the difference is higher, since PET2TV presented the best performance. For PET1TSA and PET3TV, Core Shear Strength shows differences, as PET1TSA has the best results, but PET3TV has a higher Facing Stress. The highest results of Core shear strength of the structures reinforced with sisal fabric is due to higher thickness of the facesheets, which reduce the stresses in the core.



PET2TC PET1TV PET1TSA PET2TV

Fig. 6. Samples behavior after flexural testing.

Table 3 Student's t-test results obtained with flexural testing.

Variables	Mean		Student "t" test	Probability (%)
	PET2TC	PET1TV		
Core shear strength (MPa)	0.47	0.31	2.78	2.49*
Facing stress (MPa)	23.74	45.36	4.27	0.65**
	PET1TSI	PET2TV		
Core shear strength (MPa)	0.49	0.45	2,08	5,3 ns
Facing stress (MPa)	24.40	55.68	28.36	0**
	PET1TSA	PET3TV		
Core shear strength (MPa)	0.70	0.37	20.66	0**
Facing stress (MPa)	18.94	37.34	37.94	0**

* p≤0,05. **p≤0,01. ns - no significant

4 Conclusion

The sandwich production process evidenced easy workability of the sisal fabric reinforcement, without risks to the employee, unlike the glass fabric which caused skin irritation. Regarding the preliminary mechanical behavior investigation, the composite sandwich reinforced with sisal fabric was found to be able to substitute those with glass fiber for specific applications.

In terms of failure modes, sisal fabric reinforcement sandwich composite did not show delamination, which means that there is a suitable bond between the layers and the core. However, due to the great variability of failure modes, a more thorough study is necessary.

In terms of final volume fraction reinforcement, composites reinforced with fiberglass were higher than, which can be justified with the better accommodation of the fabric layers, being a synthetic fabric there is greater uniformity of material. However, despite having a lower $\%V_f$, sisal fabric reinforcement sandwich composites showed similar and, sometimes higher results than the fiberglass fabric reinforcement sandwich composites.

Acknowledgments

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