

MECHANICAL CHARACTERIZATION OF VEGETAL COMPOSITES USING DIC

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Abstract. *The major area described in this paper is that of composite materials, specifically hybrid composites that use as matrix reinforcement one or more vegetable fibre types (Sisal, Ramie or Curaua). It is important for engineering to make use of materials that have a low environmental impact and are sustainable. Therefore, composites reinforced with two or more types of natural fibres have been on the focus of some research, in order to improve their resistance so that one day they can substitute products made with glassfibre composites in secondary applications. This paper shows a process of characterization of mechanical properties through the Digital Image Correlation (DIC) method in hybrid composites, which measures the displacements of the specimen without being in contact with it, such as the extensometers. The main objective is to compare force and displacement curves from universal test machine with the DIC method. The methodology applied was the use of GOM Correlate software, which for 2D applications, offers a free version as well as the free app GonnyCam to make the images of the specimen. These softwares have been used for measuring the displacements of hybrid composites in tensile tests. The great difference between these methodologies is related to the influence of the test machine in the yield properties of the material.*

Keywords: *Correlation of Digital Images, Hybrid Vegetable Fibre Composites, Sustainable Materials.*

1. INTRODUCTION

This study is relevant regarding materials that have a low environmental impact and are sustainable so that they can be used in engineering applications.

Thus, the use of vegetable fibres has been highlighted as reinforcement in composite matrices in order to replace the synthetic fibres, for example, glassfibre.

The plant fibres considered in this paper were Sisal, Ramie and Curaua. The use of natural fibres in composites have been studied recently, so further analysis will be necessary, such as: chemical treatments to improve fibre anchoring in the composite matrix; which fibre is the best, depending on the area and/or season, once the same fibre may have different resistances. For instance, the sisal fibre which ranges from 9.0 to 38.0 GPa for its linear elastic modulus and from 2.0 to 14.0% for its specific deformation (K. Senthilkumar et al., 2018).

For measuring the displacements in brittle materials, the use of extensometers is often difficult because these materials break without prior notice. Therefore, displacement is often measured by the test machine itself. However, considering the elasticity of the specimen, the elasticity of the grip and of the machine's bars, a non exact final Linear Elasticity for the material tested is observed (George E. Dieter., 1988).

Thus, the objective of this work is to present a simple experimental apparatus using DIC to measure in 2D the displacements of specimen in the tensile tests, as well as to compare measurements of displacements made by the traction machine (without the extensometer) and by the DIC method, showing the difference between those methods.

The DIC method compares two speckle patterns obtained before and after displacements of the specimen through photographs sequences (Ghousal and Moura, 2007). Speckle patterns are small random dots drawn on the specimen, black dots in a white background or white dots in a white background. This mesh of small dots is traced as the specimen deforms. The application methods for the speckle pattern are spray, pen or printed. New techniques for the DIC method

have been researched for simplification of the process, Gualtieri (2012) in his work presented some simple techniques of how to make the speckle pattern to improve and optimize the capture of the images. Many researchers use the DIC method for brittle materials, for example, Silva et al (2010) applied this method to study the mechanical behavior of sisal fibre cement composites.

2. METHODOLOGY

The methodology used to characterize the mechanical properties was the tensile test using the displacements measurement in the test machine itself, and also the measurement by the DIC method. Five specimens were fabricated for each type of hybrid composite, such as: Sisal, Sisal+Sisal, Sisal+Sisal with alkaline treatment (increased cohesion strength between the fibre and matrix), Sisal+Ramie, Sisal+Curaua and Sisal+Glassfibre. The Sisal+Glassfibre composite was used in order to compare the behavior of (synthetic) glassfibre with other vegetable fibres, once glassfibre is one of the most commercially used.

Sisal fibre was supplied by SisalSul (São Paulo, Brazil) in cross-ply ($0^{\circ}/90^{\circ}$ oriented sisal fibres) and the epoxy matrix was supplied by Barracuda Advanced Composites (Rio de Janeiro, Brazil). The other vegetable fibres were woven in the intralaminarily in the 0° orientation in a modified twill weave pattern in order to resist the traction stress. The standard used for the test and for preparation of the specimen was ASTM D 638 (2002).

The software used was the GOM Correlate, which for 2D displacements measurements, Vtech-Consulting offers its free version, and also the free app GonnyCam was used to take digital images. The preparation for the speckle pattern is shown in Figure 1 and the application method was White paint spray for the background while the black dots were made with a pen.



Figure 1. (a) Identification of each specimen with test direction. (b) Isolation tape. (c) White spray paint was used for the preparation of the Speckle pattern background. (d) Fan to dry white paint, speckle pattern made on each specimen, average width and thickness measurement, identification on envelopes for tracking the type of fracture, test date, test speed, etc.

In Figure 1-a, each specimen and test direction were identified; In figure 1-b, the parts which would not be painted were isolated with tape; In Figure 1-c, the specimen with the speckle pattern can be seen, the fan used to dry the white paint, notes on the identification of each specimen, describing the pattern, the technique measured by the transducer of the test machine and DIC, the photo numbers, the type of material used (reinforcement and matrix), test date, test speed

(5 mm/min according to the standard used), the load cell used (20 kN), the pre-load, and the average thickness, width and starting area measurements.

The next image, Figure 2 presents the experimental apparatus used in the tensile test of hybrid vegetable fibres composites. The machine was an EMIC DL30000.

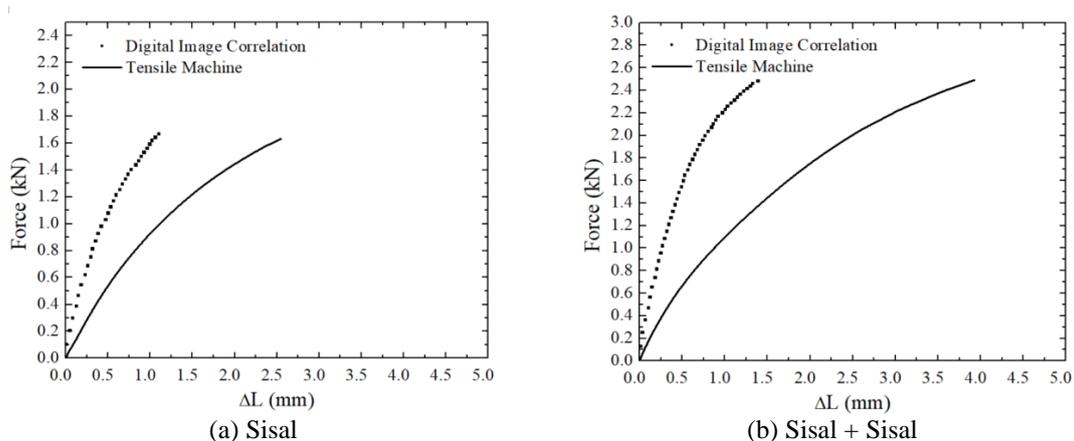


Figure 2. (a) Experimental apparatus for measuring the displacements of the specimen in the tensile test. (b) Detail of the specimen's image on the camera.

Figure 2-a shows the experimental apparatus in which (1) is the load cell used (20 kN), (2) there is a black cardboard to make a contrast in the background of the images, (3) the specimen tested, (4) the 13 MegaPixel digital camera used and the GonnyCam app which took 2 photos/second, (5) lighting and (6) pedestal. Figure 2-b shows the digital camera and the detail of the image recorded on the GonnyCam app. The camera's app recorded two photos per second of the specimen's displacement. The tensile machine recorded the test time, the applied force and the machine's displacements, that is, the specimen's displacements, the test claw and the test machine bars. It is important to mention that a Matlab's program was used to adjust the time recorded on the app to the time registered in the tensile machine.

3. RESULTS

Force versus Displacements graphs measured in both methods, can be seen in Figure 3.



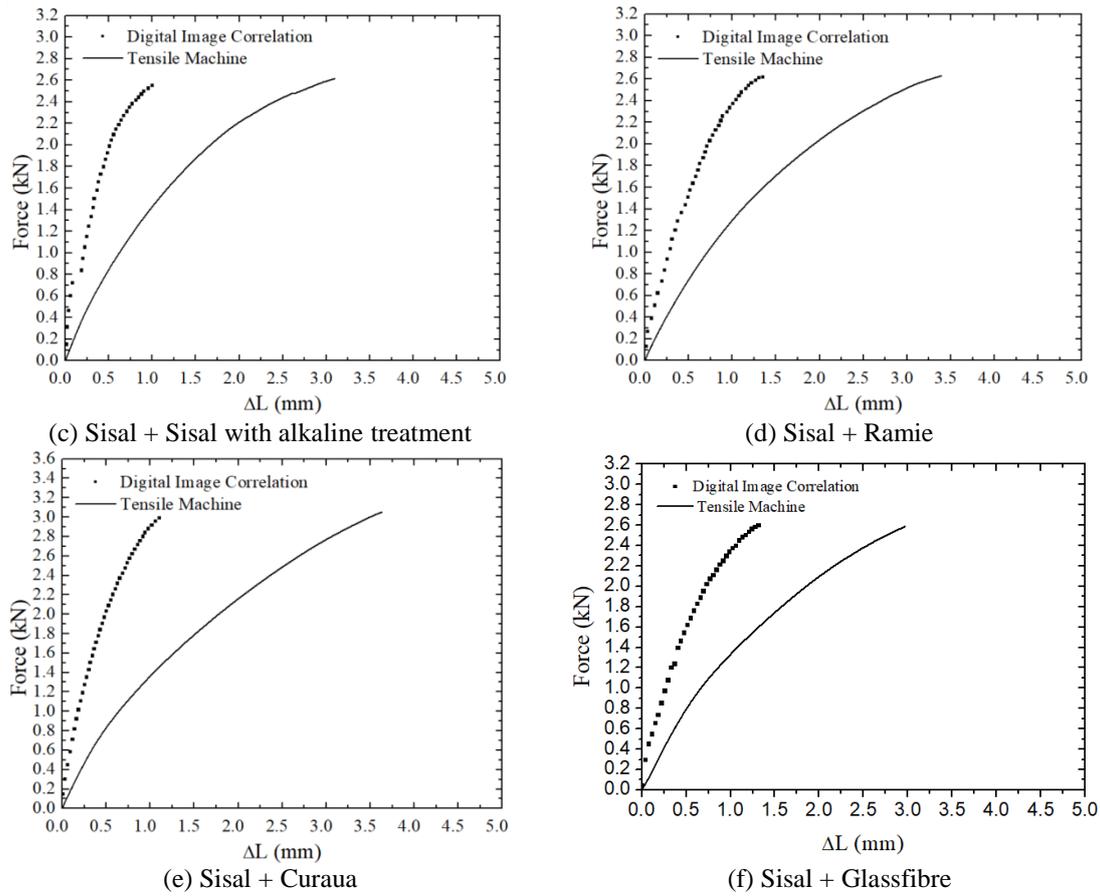


Figure 3. (a) Sisal; (b) Sisal + Sisal; (c) Sisal + Sisal with alkaline treatment; (d) Sisal + Ramie; (e) Sisal + Curaua and (f) Sisal + Glassfibre.

In all of the curves seen in Figure 3 it is possible to notice that there is a difference when force versus displacements is registered by the DIC (non-contact) method and by the results of the test machine with only the displacement data. As the slopes of the curves are different, it implies that the Elasticity Modules will also be different in each method of measurement. The reason for this difference of elasticity in the methodologies applied is due to the fact that when a specimen is tested in a traction machine without the extensometer or DIC method, the load is transmitted to the specimen but also to the machine, therefore, the specimen deforms first in the elastic regimen and then the plastic while the machine deforms in the elastic regimen. As an analogy with springs, the traction machine and the claws can be considered springs, while the specimen, being another spring, they are connected in series. As the DIC method is a technique to measure displacement without contact, it measures only the deformation of the specimen, finding the elasticity of the tested material (DIETER, 1988).

Comparing the Figures 3-a and 3-b, it is possible to see that when another fibre is added in the mesh of sisal, its mechanical resistance increases. For Figure 3-c (Sisal with alkaline treatment) there was no significant increase in mechanical resistance for tensile strength (comparison between Figures 3-b and 3-c). J.S.S. Neto et al. (2019) and R.A.A. Lima et al. (2019) have shown in their work about the effects of chemical treatment on the mechanical properties of hybrid composites of vegetable fibres, that certain treatments improve the mechanical characteristics of some natural fibres. The addition of ramie fibre also did not have a significant increase in mechanical resistance (Figure 3-d). Comparing the best mechanical behavior for the tensile test in the hybrid composites, the fibre combination that most approached Sisal+Glassfibre was Sisal+Curaua, that is, the most significant reinforcement was the Curaua fibre (Figure 3-e).

Table 1 shows the values for the Young's Modulus and standard deviation for both methods and the percent difference.

Table 1. Young's Modulus (GPa).

Hybrid composites	DIC	Machine	Percent difference (%)
Sisal	4.20 ± 0.61	1.11 ± 0.04	26.4
Sisal+Sisal	5.11 ± 0.53	1.38 ± 0.05	27.0
Sisal+Sisal Alcalinizado	6.30 ± 0.76	1.58 ± 0.10	25.1
Sisal+Ramie	4.79 ± 0.60	1.29 ± 0.04	26.9
Sisal+Curaua	5.55 ± 1.01	1.55 ± 0.04	27.9
Sisal+Glassfibre	6.30 ± 1.41	1.54 ± 0.12	24.4

4. CONCLUSION

This paper presented a simple and economical experimental apparatus for 2D applications for non-contact displacement measurements in mechanical tensile tests. The Force versus Displacement curves obtained by the DIC method proved to be more accurate regarding the behavior of the material (Hybrid Vegetable Fibre Composites), since the slope of the elastic part of the curves are different in each method (DIC and test machine), the Elasticity Modules are also different. As the materials tested are brittle, the non-contact DIC method proved to be more efficient for the displacement measurement. The best result regarding the combination of vegetable fibres for the reinforcement of hybrid composites was Sisal+Curaua. As contribution to the major area of mechanical testing, this work shows that it is important to be careful of the mechanical characterization analyses, in other words, in a traction test the use of an extensometer or a DIC method for example for the displacement measurement. Another contribution of this work for the materials area is to show and suggest that vegetable fibres are a good alternative in the substitution of glassfibre in secondary structures for engineering projects.

5. ACKNOWLEDGEMENTS

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