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Study of the mechanical behavior of starch-cotton fiber waste composite sheets

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ABSTRACT: In Africa, the cotton industry is one of the most important agricultural sectors. In Benin, a record 730,000 tonnes will be produced in 2020-2021, making the country the leading producer of the white gold in Africa. Although essential to the economy, fourteen types of residue from cotton processing remain unexploited. This waste is generally burnt by producers, which contributes to environmental pollution through the emission of greenhouse gases. To overcome this problem, we focused our work on recycling cotton fiber waste into a cotton fiber-starch composite material for use as false ceiling panels in the building industry, in place of the plywood generally used. To achieve this, we manufactured sheets from our composite material to determine mechanical properties such as modulus of elasticity and flexural modulus of rupture in accordance with NF EN 310. Three-point bending loading-unloading cycles were performed. The plates manufactured have dimensions of 300x300x100mm^3. The plates are manufactured with **«starch/water»** and **«starch/cotton fiber»** mass ratios respectfully equal to 0.25 and 1. We obtained a modulus of elasticity equal to 2830 MPa and a modulus of rupture equal to 11.53 MPa.

KEYWORDS: Composite material, cotton fiber, starch, numerical simulation.

1 INTRODUCTION

Statistical studies show that buildings are the second biggest emitters of carbon dioxide after industry [1]. As a result, the construction sector accounts for almost 39% of the world's carbon emissions [2]. In the current context of worsening climate change, reducing the construction sector's impact on the environment has become essential.

It is therefore necessary to find solutions to this problem, particularly in sectors with a high environmental impact. Composite materials are increasingly used in a wide range of applications, including aeronautics, aerospace, civil engineering, sports and leisure. [3] Today, there is a real interest in the use of materials of natural origin such as wood, raw earth, hemp, cotton, etc., as they can make a significant contribution to reducing greenhouse gas emissions through their ability to trap CO_2. It is therefore necessary to develop new construction systems that are more economically viable through the use of local materials, while also reducing environmental pollution through the use of eco-materials.

The use of natural resources in composite materials is becoming increasingly common. Industrial trends are leaning towards clean, environmentally-friendly products, hence the interest in incorporating natural products that are easily recyclable and biodegradable. [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15]. In addition to natural fibres, composites are sometimes made with biobased binders [16], [17], [18]. Also Mrs. Benitha Sandrine [19] has developed and characterized a hemp-starch eco-material for use in the building industry. She found that a good composite requires more water to facilitate mixing.

As for Nesrine Bouhamed, her work on "Elaboration and characterization of a composite material based on olive wood flour" addressed the improvement of the stiffness of PP/FBO biocomposites by increasing the fiber content and adding a coupling agent [20].

These few examples clearly demonstrate the importance of composite materials, and particularly natural fiber composites, in the construction sector.

The aim of our work here is to investigate the possibility of using the composite material "waste cotton-starch fiber" in the building industry as false ceiling panels. The aim is to determine the longitudinal modulus of elasticity (MOE) and the flexural modulus of rupture (MOR) of the waste cotton-starch fiber composite.

2 MATERIALS AND METHODS

2.1 COTTON WASTE: COTTON FIBRES

The cotton waste (Figure1) used in our work comes from fields and factories in Benin.

Fig. 1. Cotton waste

Ces déchets sont traités avec une défibreuse manuelle pour obtenir les fibres (Figure 2). Ces fibres ont une densité absolue de 0.29 g/cm3 et une teneur en eau de 12.71%. La densité absolue est mesurée conformément à la norme NF EN 1097-6 Juin 2001.

Fig. 2. Defibration

2.2 BINDER: CASSAVA STARCH POWDER

The starch used is produced from manioc collected from fields (Figure 3). It has a water content of 17.03%, with absolute and bulk densities of 1.26 g/cm^3 and 0.70g/cm^3 respectively.

Fig. 3. Cassava starch production

2.3 Composite Formulation And Preparation

Our previous work enabled us to select a formulation for our composite. In fact, to dose the binder, we used a starch/water mass ratio equal to 0.25. This led us to use 200g of starch powder for 800ml of water. The starch/cotton mass ratio used is 1, so the quantity of cotton fiber used for one formulation is 200g. Plates are produced in molds measuring 300x300x100 mm3. Each preparation is mixed manually. After preparing the binder for about 5 min, we leave it to cool for about 10 min before adding the defibered cotton fibers. Kneading is meticulous, ensuring that the starch penetrates all the fibers. This process takes between 5 and 10 minutes. The resulting mixture is then placed in the mold for compaction under a pressing force varying between 11 and 50 KN depending on thickness, in a hydraulic press. The material is demolded 5 min after the mold has been removed from the press. After demolding, the material is placed in an oven at 105°C for 24 hours. Once the composite has been removed from the oven, it is left to air dry in the laboratory for a week to allow any remaining water to escape. On the seventh day, the panel is put back into the mold and the whole assembly is placed back under the press to undergo compression under loads ranging from 500 to 2000KN. This is where we obtain the final shape of our panel, which has a relatively flat surface.

2.4 Analysis Methods

To determine the MOE and MOR moduli, we carried out three-point bending tests on specimens of dimensions (40*10*160 mm^3) in accordance with standard NF EN 310. Three-point bending tests were carried out using the "Recherche et Réalisations Rémy Sas" 3R didactic test press at EPAC’s Civil Engineering Department (Figure 1). This consists of a loading device and a computer for obtaining test data. We used a cylinder displacement speed of 0.4 mm/s.

Fig. 4. Press for three-point bending tests

We carried out tests on three different specimens.

Fig. 5. Test sequence

To calculate the MOE, we performed loading-unloading cycles with 20N steps, starting with 140N.

3 Results And Discussion

3.1 Plate Behavior Under Load Variation (Three Load-Unload Cycles Without Failure)

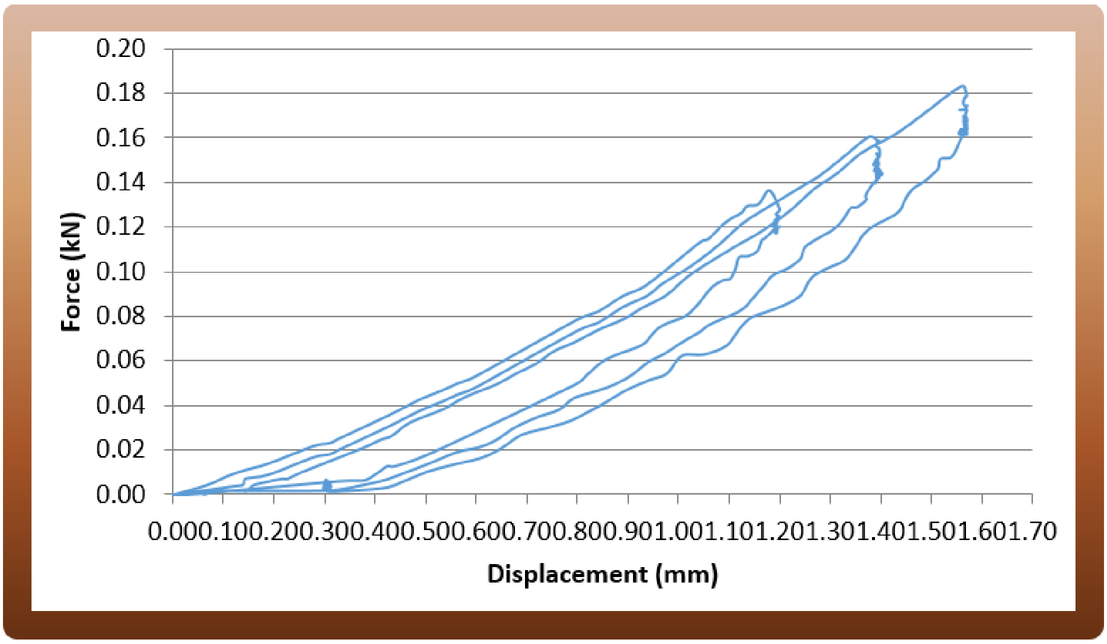

Fig. 6. ***Loading-unloading curves***

Figure 6 shows the loading-unloading curves for specimen A. It can be seen that three curves are represented in a reference frame, with the forces applied in the y-axis direction and the displacements generated in the x-axis direction. All the curves have more or less the same shape, but do not have the same extremum.

The first curve describes the action of a 140N load, and when it reaches the value indicated 140N, the first curve returns to its initial state.

The second curve describes the action of another 160N load, and shows that when it reaches the value indicated 160N, the first curve returns to its initial state.

Finally, the third curve describes the action of a 180N load. Like the first two, it returns to its initial state once the 180N value has been reached.

For each cycle we observe:

- The first part is linear, where force is roughly proportional to displacement;

- A second part indicating the return to the initial state after unloading.

For each cycle, a residual deformation is observed, which decreases from one cycle to the next. It is 0.05 mm for the first cycle, 0.02 mm for the second and 0.01 mm for the third. For a total deformation of 0.08 mm. The mechanical behavior curve of the plate under the effect of load variation is in harmony with those of the work of CHABI Edem [21]. However, we note that there is a difference in residual deformation at each cycle (0.20 mm for the first cycle, 0.10 mm for the second cycle and 0.08 mm for the third cycle: case of Cg3T whose mechanical characteristics are somewhat similar to our material).

3.2 Plate Behavior Under Load Variation To Failure

The curves obtained for each specimen from the Excel files generated by the computer are shown in Figures 7, 8 and 9 as follows:

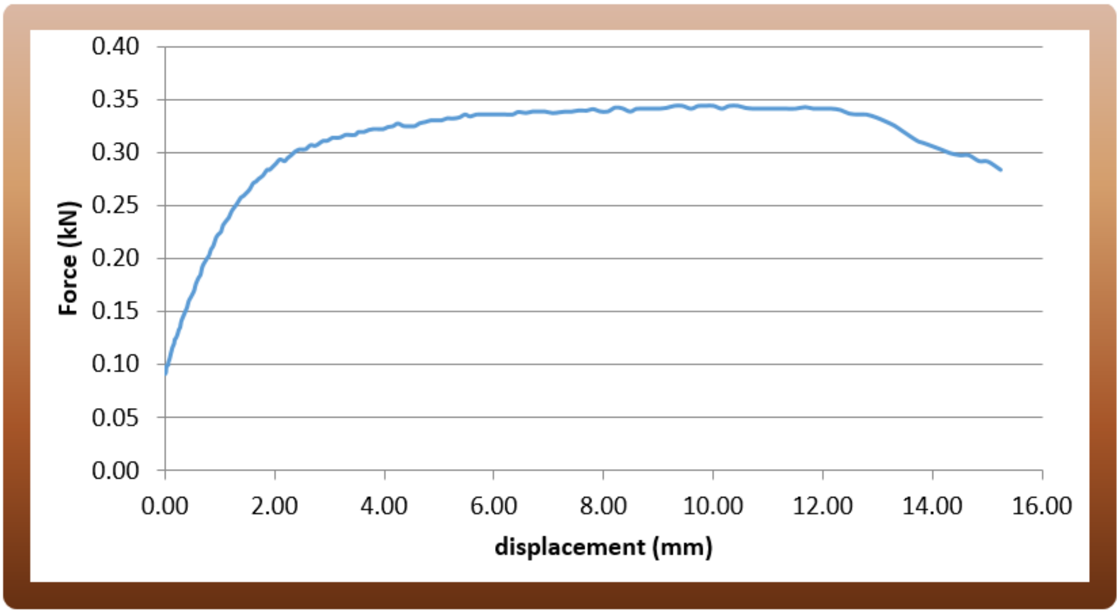

Fig. 7. Force-displacement variation curve from the A test specimen press

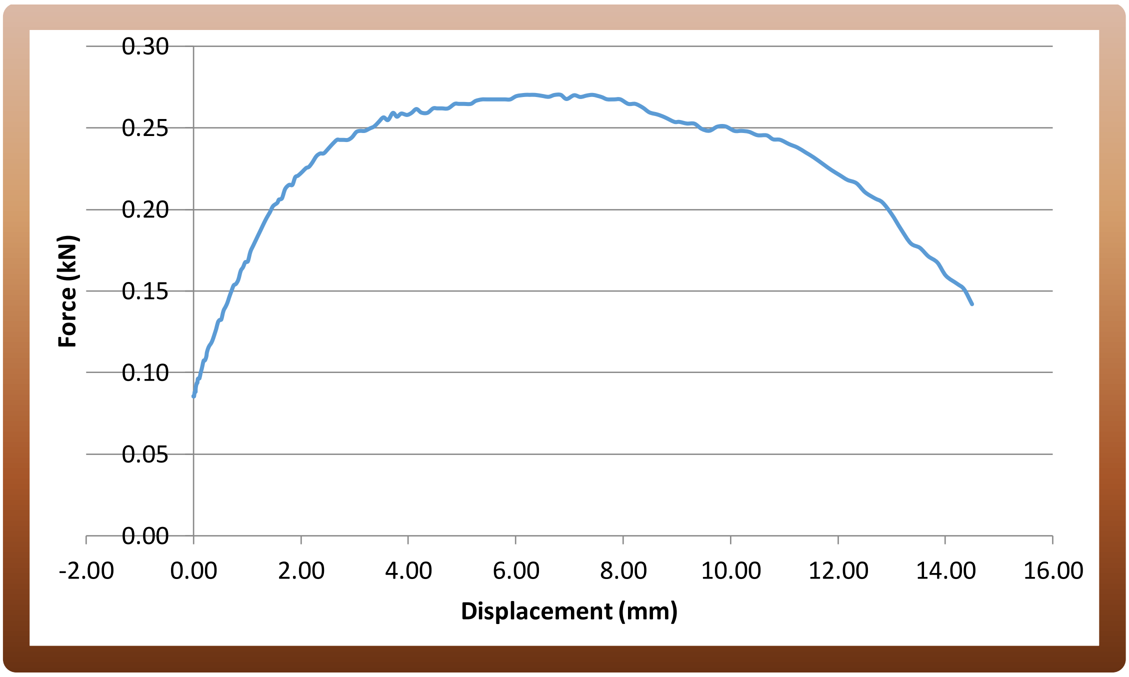

Fig. 8. Force-displacement variation curve from the press of specimen B

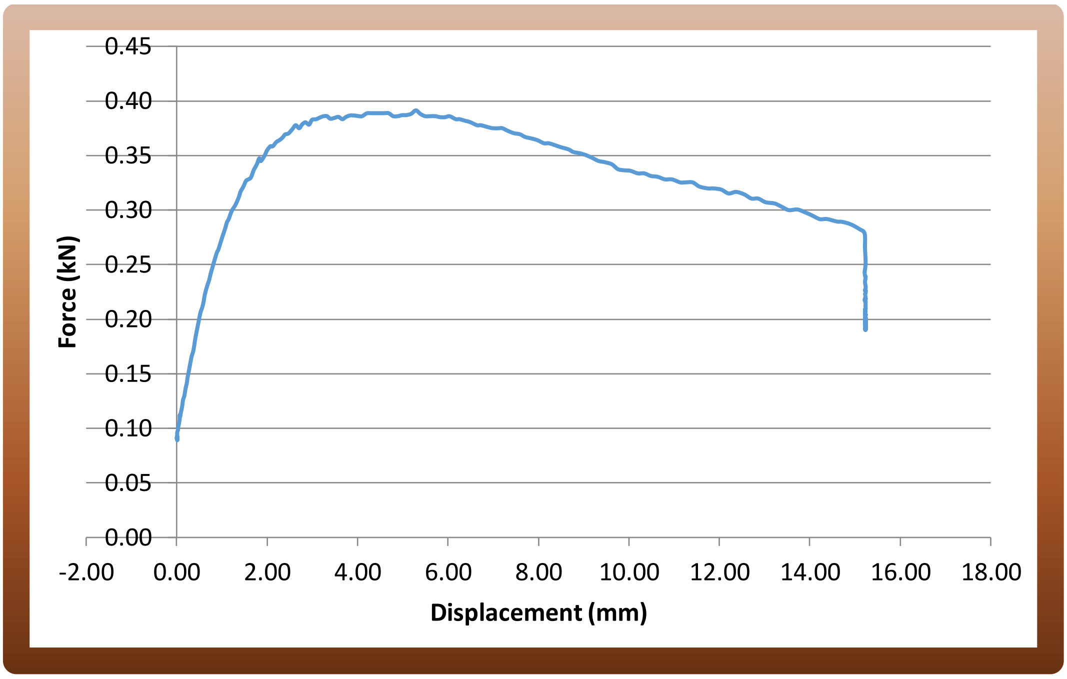

Fig. 9. Force-displacement variation curve from the press of specimen C

The three force-displacement curves obtained from the press for specimens A, B and C show more or less the same behavior, which can be divided into three areas:

In the first range, the three curves start at the point corresponding to an applied force of 100N, due to the sensitivity of the sensor in relation to the plate. These curves are linear for each specimen, up to a maximum value of 30N for specimen A, 25N for specimen B and 35N for specimen C.

In the second range, the slope of the curve drops sharply: displacements (arrows) become greater as a result of a small change in force.

And finally, in the third area, the force applied decreases as the displacement continues to increase. There is also a significant gap between the breaking points of the specimens.

We also note the presence of false points on the curves of the three test specimens, which need to be removed.

Once these curves have been obtained by the software, they need to be processed. The curves obtained after processing for three specimens are as follows:

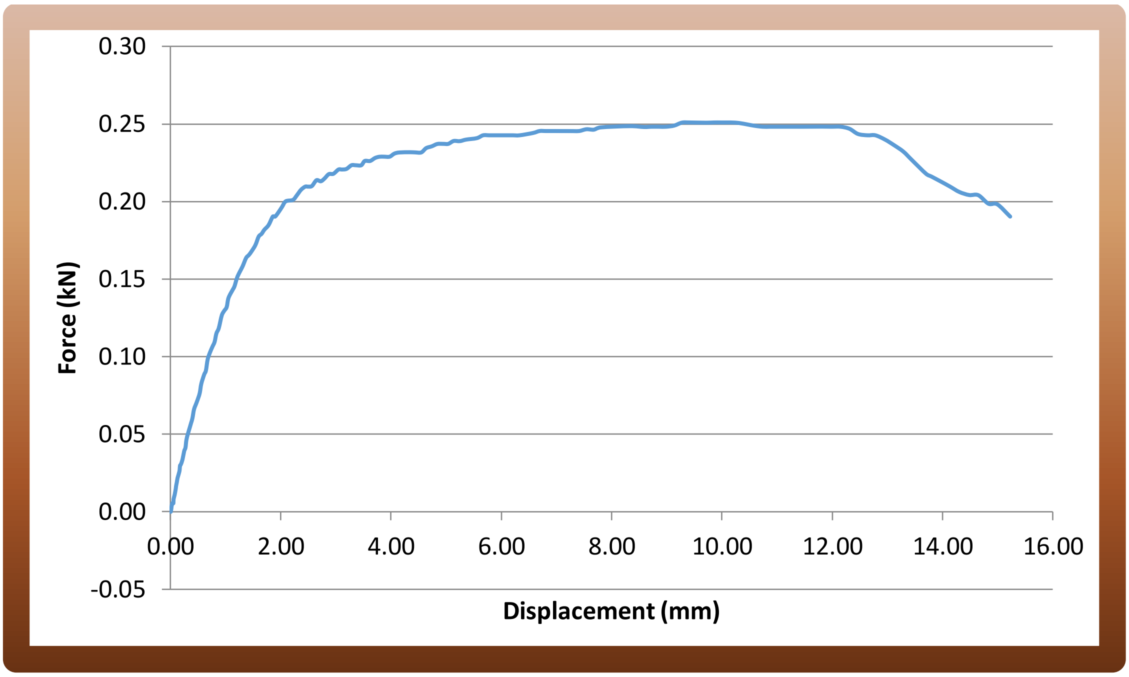

Fig. 10. Force-displacement variation curve after treatment of specimen A

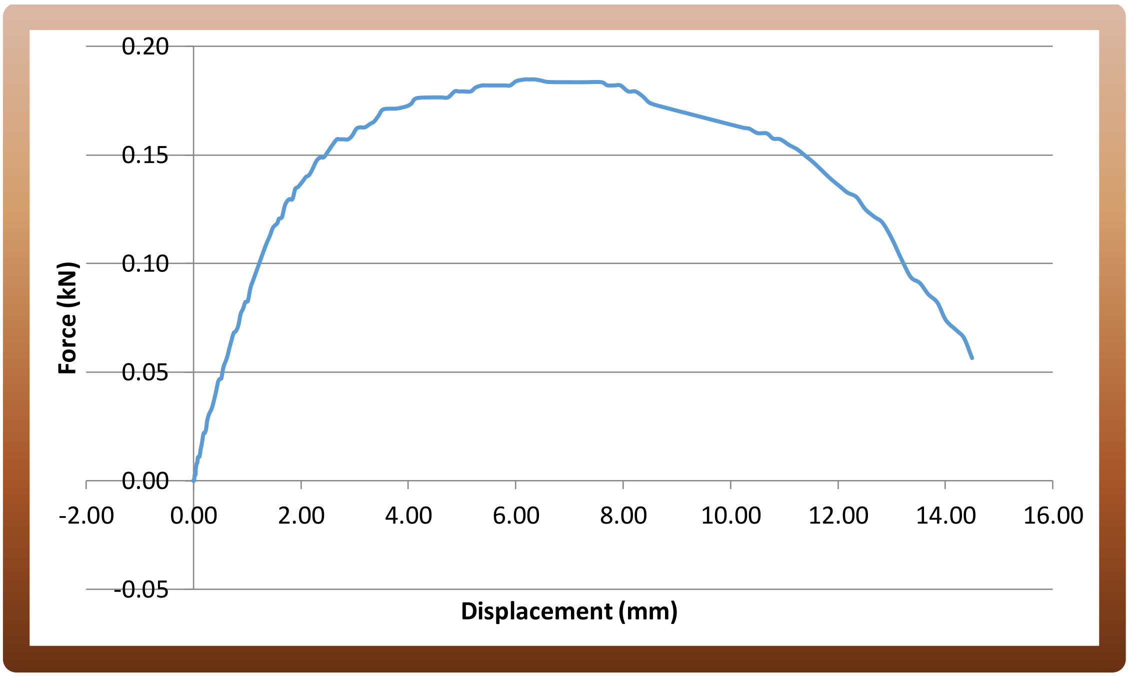

Fig. 11. Force-displacement variation curve after treatment of specimen B

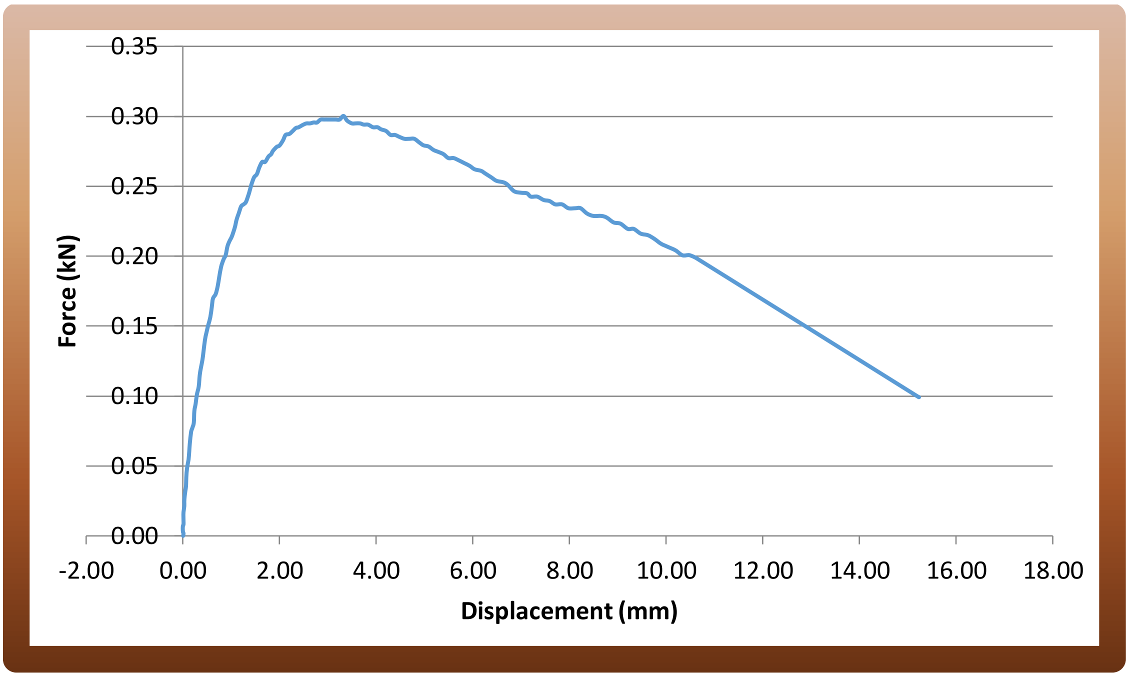

Fig. 12. Force-displacement variation curve after treatment of specimen C

The force-displacement curves of the test specimens (Figures 10, 11 and 12) illustrate the mechanical behavior of the plates under the effect of the application of a force until failure, and show different curves for each specimen. In fact, three domains can be distinguished for each specimen:

In the first range, the curve is linear for each specimen, indicating that we are in the elastic range. It can also be seen that the elastic range stops at a deflection of around 2mm in all three cases, although the force required to generate this deformation is different for each specimen (Specimen A: 20N; Specimen B: 15N; Specimen C: 25N).

In the second range, the slope of the curve drops sharply: the displacements (arrows) then become greater under the effect of a slight variation in force, indicating the material's transition from the elastic to the plastic range.

In the third area, the force applied decreases as the displacement continues to increase, indicating plate failure. We have therefore reached failure. There is also a significant gap between the breaking points of the specimens.

The irregularities observed in the curves of the specimens can be explained by the heterogeneous and anisotropic nature of the cotton fiber-starch composite material used in our specimens.

3.3 Modulus Of Elasticity And Modulus Of Rupture

From analysis of the curves processed (Figures 5, 6 and 7), we can deduce the moduli of elasticity (MOE) and rupture (MOR), which are presented in Table 1.

Table 1. Determination of modulus of elasticity and modulus of rupture

	Test tube A	Test tube B	Test tube C
Length (mm)	160	160	160
Width (mm)	40	40	40
Thickness (mm)	10	10	10
MOE modulus of elasticity (MPa)	2791	2205	3495
Average modulus of elasticity MOE_{moy} (MPa)		2830$\pm$ 646	
Modulus of rupture MOR (MPa)	11.7	10.2	12.7
Average modulus of rupture MOR_{moy} (MPa)		11.53$\pm$1.26	

4 CONCLUSION

Mechanical tests carried out on the composite have shown that it exhibits behaviors similar to other materials in the same category. These tests enabled us to determine the following characteristics: MOE =2830 MPa and MOR =11.53 MPa. These results show that the composite can be used as a particleboard. However, previous studies carried out on this composite have revealed that these panels are not suitable for working in a humid environment. They can only be used in a dry environment. Nonetheless, current findings on the modeling of transfer phenomena in panels in a humid environment could lead to the development of appropriate treatment methods (by coating), with a view to their wider use.

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