



(RESEARCH ARTICLE)



DEVELOPMENT AND PHYSICO-MECHANICAL CHARACTERIZATION OF A COMPOSITE MATERIAL BASED ON STARCH, COTTON FIBER AND RICE HUSK

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ABSTRACT

In a context where sustainability and ecology have become major issues in the building materials sector, agricultural processing generates a large quantity of by-products, such as cotton fibers and rice husks, which are often little or not at all valorized. Their disposal, in particular by incineration, contributes to environmental degradation. In a circular economy approach, this work proposes the valorization of these residues through the development of a bio-based composite combining starch, cotton fibers and rice husks. This material is intended for building applications, notably as a false-ceiling panel, as an ecological alternative to traditional plywood.

The study identified the optimal composition of the composite: 200 g of dry starch powder for 800 ml of water, used to make the glue, which is then reinforced with 175 g of cotton fibers and 60 g of rice husk.

The physical and mechanical characterization of the material revealed an absolute density of 1183 kg/m³ and a modulus of rupture (MOR) of 9.95 MPa, values that are satisfactory for use as particleboard. However, the material shows a significant thickness swelling of 30.71% after 24 hours of immersion in water, a rate far above the limits set by the ANSI 208.1-1999 standard. It can therefore only be used in dry environments.

Keywords: Bio-Based Materials, Panels, Mechanics, Sustainable Construction.

1 INTRODUCTION

In a context of growing environmental challenges, interest in bio-based materials in civil engineering is intensifying, with the aim of reducing the ecological footprint of conventional materials. The building and construction sector alone is responsible for approximately 39% of global carbon emissions, according to the United Nations Environment

Programme [1]. Faced with this climate emergency, the use of renewable resources in construction materials, such as wood, hemp, cotton or rice husk, is attracting growing interest [2]. These eco-materials have the advantage of storing carbon dioxide (CO₂) during their life cycle, thereby contributing to the reduction of greenhouse gases and to carbon neutrality [3].

The development of sustainable construction systems today aims to reconcile mechanical performance, economic profitability and the valorization of local resources, while limiting environmental impacts [4]. However, despite their availability and low cost, bio-based materials remain improvable, particularly in terms of dimensional stability and durability against moisture [5]. Their market, valued at approximately 4.3 billion dollars in 2022, shows strong growth potential driven by global ecological transition policies [6].

With this in mind, civil engineering is moving toward composites incorporating natural fibers and biodegradable binders, with a view to gradually replacing synthetic polymers and petrochemical resins [7]. In Benin, several under-exploited agricultural resources such as cassava starch, cotton fibers and rice husks have considerable potential for the design of ecological, local composite materials [8].

It is within this perspective that the present study falls, which aims to develop and characterize a composite based on starch, cotton fibers and rice husks. Although promising for applications in sustainable civil engineering, this material remains poorly documented, particularly with regard to its mechanical properties and its stability in the presence of moisture.

2 MATERIAL

Starch, cotton fibers and rice husks are the materials that are the subject of our study.

2.1 Starch

The starch used comes from Sèhouè, a village located in the commune of Toffo, a commune in southern Benin (*Figure 2*). The commune of Toffo, located in the Atlantique department, lies about 80 kilometers north of Cotonou. The commune of Toffo is bounded to the north by the commune of Zogbodomey, to the south by the commune of Allada, to the east by the commune of Zè, and to the west by the commune of Lalo. It is located at 6.9266° north latitude and 2.2707° east longitude, corresponding to the exact coordinates provided (*Figure 1*).

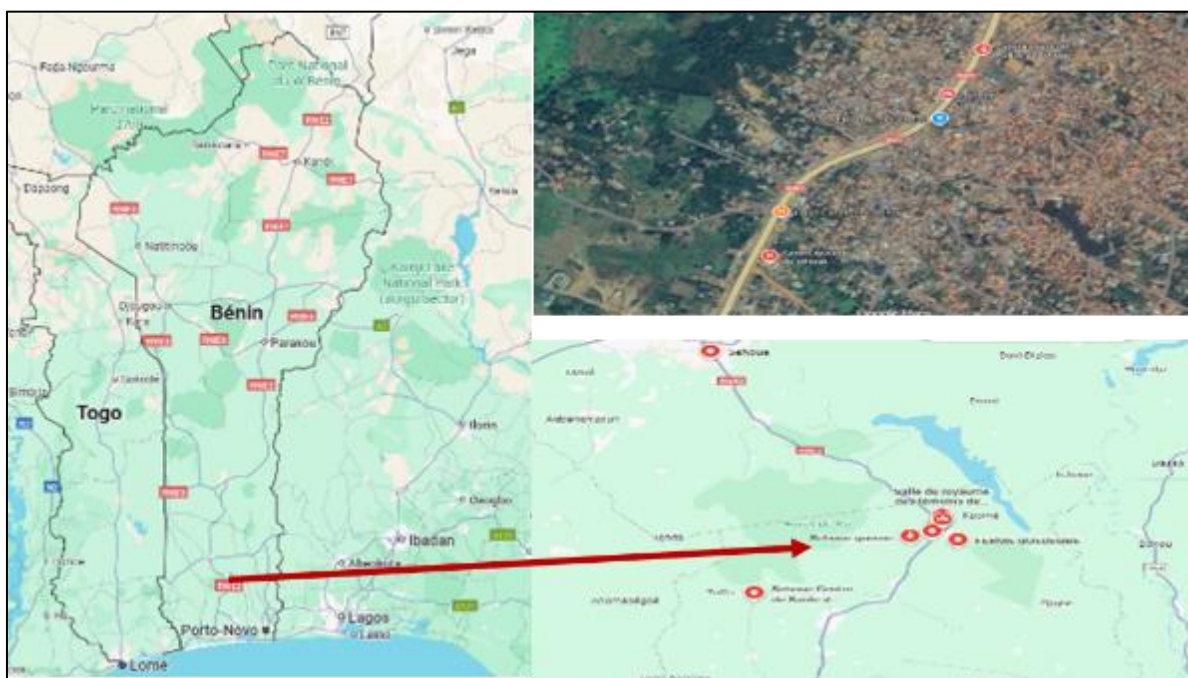


Figure 1: Location of the starch extraction site



Figure 2: Cassava starch

2.2 Cotton fibers

Cotton is mainly grown in northern and central Benin. For our study, it was collected around the SODECO ginning plant in Bohicon, located at 7.1671° N, 2.0672° E, in the Zou department, about 112 km north of Cotonou (*Figure 4*). The town of Bohicon is bounded to the north by the commune of Djidja, to the south by the commune of Zogbodomey, to the east by the commune of Za-Kpota, and to the west by the communes of Abomey and Agbangnizoun (*Figure 3*).

Once collected, the cotton was disentangled using a mechanical defibrator, in order to separate the intertwined fibers and prepare them for the following processing stages.



Figure 3: Location of the cotton sampling site



Figure 4: Cotton

2.3 Rice husk

The rice husks used in our study come from the rice hulling plant in Zogbodomey, located at 7.0691° N, 2.1145° E, in the Zou department, about 90 km north of Cotonou (*Figure 6*). The commune of Zogbodomey is bounded to the north by the communes of Bohicon, Za-Kpota and Covè, to the south by the communes of Lalo and Toffo, to the east by the communes of Ouinhi and Zagnanado, and to the west by the commune of Agbangnizoun (*Figure 5*).



Figure 5: Location of the rice husk sampling site



Figure 6: Loose rice husks

2.4 Methods

2.4.1 Equipment (tests and standards)

- Bulk density (NF EN 323).
- Density or absolute density (EN 1097-6).
- Water content (EN 322)
- Water absorption measurement of cotton fibers (EN 317)
- Determination of absolute density (NF EN 323)
- Dimensional stability (EN 324-1)
- Water absorption (EN 317)
- Three-point flexural test (NF EN 12390-5).

2.4.2 Manufacturing method

We developed a composite based on starch, cotton fibers and rice husk, with the aim of developing a lightweight and durable material suited to construction. Starch was used as the binder, while the rice husk and cotton fibers serve as reinforcement to improve the mechanical properties. Among several formulations, we retained an optimal composition: 200 g of starch, 175 g of cotton fibers and 60 g of rice husk, with 800 ml of water. The starch/total fibers ratio is 0.85 and the starch/water ratio is 0.25, ensuring good cohesion and effective impregnation of the fibers.

Preparation begins with the starch-water binder, heated for 5 minutes and then left to cool for 10 minutes before the fibers are added. Manual mixing, carried out for 5 to 10 minutes, ensures complete impregnation of the fibers by the starch. The mixture is then poured into $300 \times 300 \times 100 \text{ mm}^3$ molds and compacted under a hydraulic press with forces of 11 to 50 kN depending on the thickness.

After demolding, the material is dried in an oven at 105°C for 24 hours and then in open air for one week to remove residual moisture. On the seventh day, the panel is placed back in the mold and subjected to a final compression of 500 to 2000 kN, thus obtaining the final shape with a flat and homogeneous surface. These four steps correspond to the main fabrication steps described by [9].

2.5 Three-point flexural test method

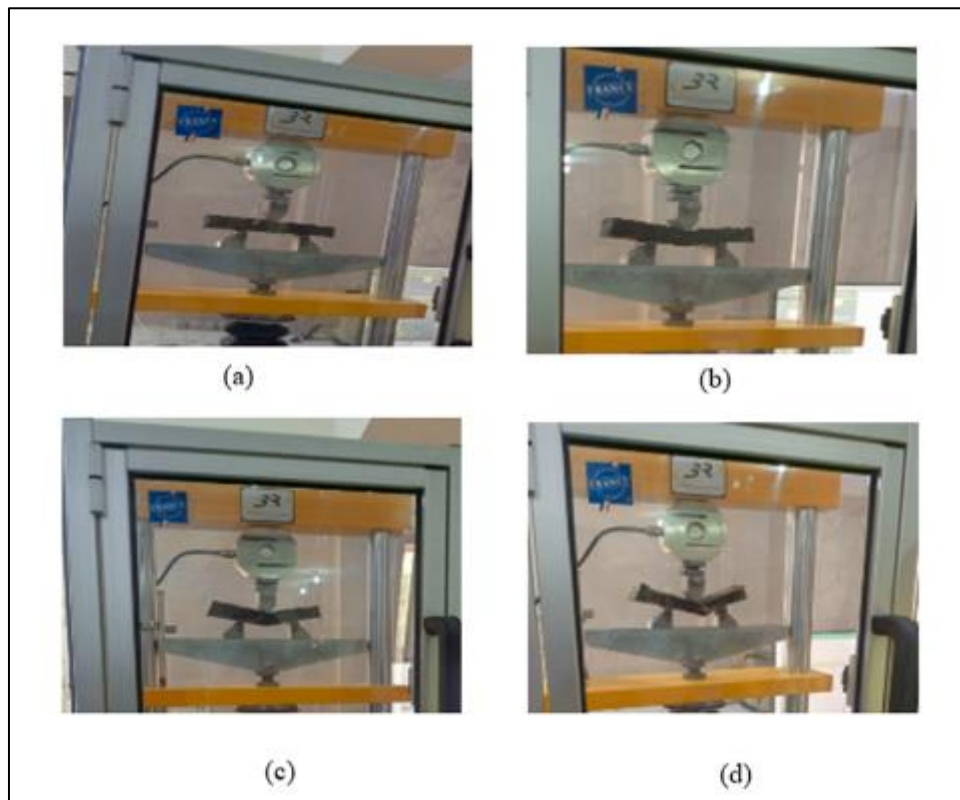


Figure 7: Flexural test process on a specimen: (a) specimen in its initial state; (b) specimen at an intermediate stage; (c) specimen at another intermediate stage; (d) specimen at failure

The test was carried out using a 3R teaching press (“Recherche et Réalisations Rémy Sas”) installed at the Civil Engineering Department of the École Polytechnique d’Abomey-Calavi (EPAC). This device, capable of applying a maximum load of 25 kN with an accuracy of 0.5%, is connected to a computer for data recording and analysis. During the experiment, a displacement rate of 0.4 mm/s was used.

During the test, three specimens, numbered No. 1, No. 2 and No. 3, were used. Their dimensions are 160 mm (a), 40 mm (b) and 10 mm (e), with a span between supports of 80 mm (L). Once the device is activated, the loading nose applies a progressive load to the center of the specimen until it fails (*Figure 7*).

3 RESULTS AND DISCUSSION

3.1 Starch

3.1.1 Bulk density of the starch

To obtain the bulk density of the starch, three tests were carried out, giving values of 0.711 g/cm³, 0.692 g/cm³ and 0.701 g/cm³ for tests No. 1, No. 2 and No. 3 respectively, with an average **m_{ap} = 0.701 ± 0.001 g/cm³**. This is confirmed by the results of [10], who found 0.70 g/cm³ for a starch–cotton fiber material.

3.2 Rice husk

3.2.1 Bulk density of the rice husk

To obtain the bulk density of the rice husk, three tests were carried out, giving values of 0.345 g/cm³, 0.338 g/cm³ and 0.338 g/cm³ for tests No. 1, No. 2 and No. 3 respectively, with an average **m_{ap} = 0.340 ± 0.004 g/cm³**. This value is in perfect agreement with that reported in the scientific literature by [11], who established the bulk density of rice husk at 0.34 g/cm³, thus confirming the reliability of our experimental results.

3.3 Cotton fiber

3.3.1 Absolute density

To determine the absolute density of the cotton fibers, three separate tests were carried out. These measurements gave values of 0.140 g/cm³, 0.144 g/cm³ and 0.141 g/cm³ respectively. The average value obtained is 0.142 ± 0.002 g/cm³. This low dispersion of results confirms the good reproducibility of the measurements and accurately characterizes the density of our fibrous material. This is confirmed by the results of [10], who found 0.141 g/cm³ for a starch–cotton fiber material.

3.3.2 Water content

The test was carried out on three cotton fiber samples denoted No. 1, No. 2 and No. 3. Table 16 presents the determination of the water content of the cotton fibers. The values obtained are 11.17%, 11.38% and 11.68% for samples 1, 2 and 3 respectively, giving an average **ω = 11.41% ± 0.26**. This is close to the results of [10], who found 13.20% for a starch–cotton fiber material.

3.3.3 Water absorption of cotton fibers

The test was carried out on three cotton fiber samples denoted No. 1, No. 2 and No. 3. Table 17 presents the water absorption of the cotton fibers. The values obtained are 453.333%, 456.250% and 464.286% for samples 1, 2 and 3 respectively, giving an average **Abs = 457.956 ± 5.672%**. This is close to the results of [10], who found 453.85% for a starch–cotton fiber material.

3.4 Formulation of the “cotton fiber–starch” composite material adopted for making the specimens

To make the specimens intended for the physical and mechanical characterization of the “starch–cotton fiber–rice husk” composite material, we adjusted the masses of starch, cotton fiber and rice husk in order to optimize the mechanical properties of the mixture. The different formulations tested are presented in the table below:

Table 1: The different formulations produced

Specimens	Mass of starch (m _a) in g	Mass of cotton fiber (m _f) in g	Mass of rice husk (m _{br}) in g	Volume of water (V _e) in ml	Ratio (M _A / M _{C+BR})	Ratio (M _A / M _E)
F1	200	180	70	1200	0.80	0.17
F2	150	170	55	800	0.67	0.19
F3	250	195	120	900	0.79	0.28
F4	200	175	60	800	0.85	0.25
F5	150	175	50	500	0.67	0.30

Among the formulations tested, F4, composed of 200 g of starch, 175 g of cotton fiber, 60 g of rice husk and 800 ml of water, is identified as optimal, because its starch/fiber ratio (0.85) ensures strong cohesion while incorporating enough reinforcement, and its starch/water ratio (0.25), as in the work of [12], guarantees balanced hydration for easy processing and good mechanical properties after drying, which makes it the most balanced and best-performing choice.

3.5 Physical characterization of the cotton fiber–starch–rice husk composite plates

3.5.1 Density of the cotton fiber–starch–rice husk plates

The tests were carried out with three plates No. 1, No. 2 and No. 3.

The density measured after immersion, corresponding to the absolute density of the plates, is $1.183 \pm 0.010 \text{ g/cm}^3$ (i.e., 1183 kg/m^3), according to standard ASTM D1554 [13].

The density obtained for our panels is higher than that reported by [14] in 2019, whose values ranged between 320 and 350 kg/m^3 . It also exceeds those measured by [15] for panels based on cotton stalks with bark (660.25 kg/m^3) and those based on kenaf stalks (639.37 kg/m^3). It also exceeds those measured by [12], who found 1130 kg/m^3 for a composite based on cassava starch and cotton fiber. Thus, the density of our panels proves to be higher than all of these previous results.

3.5.2 Dimensional stability

3.5.2.1 Water content

The values were obtained on three samples denoted No. 1, No. 2 and No. 3, and we obtained an average of $w = 5.20 \pm 0.617\%$. This complies with the requirements of standard EN 622, which prescribes a water content between 4% and 9%. This is confirmed by the results of [12], who found 4.7% for a starch–cotton fiber material.

3.5.2.2 Water absorption

The test, carried out on three samples denoted No. 1, No. 2 and No. 3, gives an average of $CA = 62.74 \pm 0.222\%$. This is confirmed by the results of [12], who found 62.88% for a starch–cotton fiber material.

3.5.2.3 Swelling in the three directions and volumetric swelling

The test was carried out on three samples denoted No. 1, No. 2 and No. 3. After 24 hours of immersion in water, the plates show swelling in all three dimensions (length, width and thickness), with a thickness increase of 30.71%. This value far exceeds the range recommended by standard NF EN 317, which lies between 7 and 14%. Consequently, it is advisable to use them only indoors, sheltered from moisture and bad weather. This is close to the results of [12], who found 44% for a starch–cotton fiber material.

3.6 Mechanical characterization of the “starch–cotton fibers–rice husk” composite material

3.6.1 Mechanical behavior of the plates under varying load up to failure (determination of the flexural modulus of rupture, MOR)

To determine the mechanical constants (MOR) of our material, three-point flexural tests were carried out on three cut specimens denoted No. 1, No. 2 and No. 3.

For each specimen, the press produced the curve characterizing the behavior of the plate during the test.

The force–displacement curves of specimens No. 1, No. 2 and No. 3 show similar behavior in three phases: a linear elastic domain (deformation ≈ 2 mm, forces from 210 to 320 N), a plastic domain marked by an abrupt drop in slope, and a post-failure domain where the force decreases while the displacement continues to increase. The differences between failures and the outlying points are due to the heterogeneity and anisotropy of the composite based on starch, cotton fibers and rice husk. After processing the curves (removal of anomalies and re-centering on the origin), the modulus of rupture (MOR) was determined for each specimen.

3.6.2 Determination of the modulus of rupture (MOR)

Table 2: Determination of the modulus of rupture (MOR)

	Specimen No. 1	Specimen No. 2	Specimen No. 3
Length (mm)	160	160	160
Width (mm)	40	40	40
Thickness (mm)	10	11	10
Modulus of rupture MOR (MPa)	10.2	9.42	10.23
Mean modulus of rupture MOR _{mean} (MPa)	9.95 $\pm$ 0.458		

The modulus of rupture (or ultimate flexural strength) obtained for the starch, cotton fiber and rice husk material is therefore: **MOR = 9.95 $\pm$ 0.458 MPa**. Although these values are lower than those reported by [12] and [16], they remain sufficient to consider using this composite as a particleboard-type material.

However, the analysis of the physical characteristics of this composite showed that the panels are markedly sensitive to moisture, making them unsuitable for use in a humid environment. They can therefore only be used in dry environments. Nevertheless, surface treatment solutions, such as the application of hydrophobic coatings, could be explored on the basis of the current results on the modeling of transfers in humid media, in order to improve their water resistance and broaden their fields of application.

4 CONCLUSION

In a context of scarcity of fossil resources and reduction of greenhouse gas emissions, the valorization of biomass represents a sustainable path for the development of new materials. This work focused on the development of a bio-based composite made of starch, cotton fibers and rice husk, intended for building applications.

The selected formulation (200 g of starch, 175 g of cotton fibers and 60 g of rice husk) made it possible to obtain panels with an average density of 1183 kg/m³ and a breaking strength of 9.95 MPa, reflecting a good compromise between lightness and mechanical strength. The material nevertheless shows low resistance to moisture, limiting its use to dry environments. Surface treatments could improve this durability.

Thanks to its lightness, its natural composition and its ease of manufacture, this composite appears to be an ecological and economical solution suited to uses such as partitions, false ceilings, door panels or hygrothermal insulation. It thus offers real potential for sustainable construction and for the valorization of local agricultural waste.

Finally, the results obtained open interesting prospects for future work, notably the improvement of moisture behavior, the study of aging over time, and the modeling of the material's viscoelastic behavior. These further studies would make it possible to optimize the composite's performance and strengthen its competitiveness against conventional materials in the building sector.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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- **Valéry k. DOKO:** Writing – review & editing, Supervision, Resources, Methodology.
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- **TAPSOBA David:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.
- **Thède AGBELELE :** Writing – review & editing.
- **Giovanni DANSOU :** Writing – review & editing.

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