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RESEARCH ARTICLE

CHARACTERIZATION OF THE PHYSICAL AND MECHANICAL PROPERTIES OF CORN COB PANELS PRODUCED WITH NERE POD HUSK (CGN) WITH THE INTEGRATION OF LOW-DENSITY POLYETHYLENE (PEBD)

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Abstract

The objective of this work is to valorize agricultural and agro-industrial residues, specifically maize cobs, an abundant resource in Togolese soil, for the manufacture of particleboard. The work initially consisted of grinding the maize cobs into flour and then producing several types of particleboard by varying the binder content, notably Néré pod husk (CGN) and low-density polyethylene (PEBD). The binder content used was: 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20%. The second phase of the work focused on determining the physical and mechanical characteristics of the panels produced through various tests, including (i) a water swelling test, which determined the thickness increase and absorption rate; (ii) the bending test for the determination of the modulus of elasticity (MOE) and the modulus of stress at break (MOR) and; (iii) the tensile test for the determination of the breaking strength (MOT) and elongation (A%).The obtained densities varying617.47 kg/m3 at 5% and 706.75 kg/m3 at 17.5% binder for néré pod husk; This classifies these panels in the category of medium and low density panels for commercial and industrial use as well as for use in doors (M-1, S; M-2, S; LD-1, 2)according to the American standard ANSI A208.1-(2009).Regarding the swelling, the rates obtained, ranging from 33.13% to 75.95%, show that the panels are not water resistant and can therefore only be used in a dry indoor environment, and their protection against humidity is necessary.The thresholds set by the ANSI A208.1-2009 standard for MOE and MOR were largely exceeded, and the results increase with the binder content. The same is true for MOT and elongation (A%).

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Introduction:-

Within the framework of economic and social development, the real challenges lie in sustainable development.

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This is only possible through the use of renewable and biodegradable materials, such as the unexploited agricultural residues that litter the agricultural areas of our West African sub-region, which is largely dedicated to agriculture. Among these agricultural residues, we note maize cobs, which, after the seasonal harvests, are of little use in our country, Togo.The corn cob is composed of three natural parts: the outer layer where the kernels are embedded, the heart which forms the lighter part, and a woody band that makes up the tougher part between the heart and the outer layer of the cob. The cobs are used by processing industries to extract furfurol, which is used in refining mineral oils and in synthesizing very hard resins used in anti-corrosion materials and in the manufacture of foundry molds. Other industries utilize the cob by producing granules or flours that are incorporated into adhesives, plastics, abrasives, cosmetics, and pharmaceuticals.

Thanks to agricultural and forestry resources, studies have led to the characterization of particleboard using different binders. Among these studies, we noted the'Use of aspen bark for the manufacture of particleboard (Emmie VILLENEUVE, May 2021). Development and mechanical characterization of kenaf stem particleboard and bioadhesives based on bone glue, tannin, or mucilage (NENONENE Amen Yawo, July 2009). Development and characterization of sawdust and kenaf stem particleboard with beaded bone glue and tannic extracts from néré pod pods (DROVOU Soviwadan, December 2012). The technical approach to valorizing secondary biomass from the cotton sector in the manufacture of particleboard.'(Sika Djatui Akouavi EKOUHOHO). Improving the impact performance of a starch-based biopolymer through the incorporation of Miscanthus giganteus fibers (Johnson, Tucker, N., Barnes, S. and Kirwan K., 2005). Most results concluded that particleboard can be used for multiple purposes such as decoration, furniture, and thermal and acoustic insulation.Thus, in order to optimally and sustainably valorize less exploited agricultural residues, we have opted for the study and improvement of the physical and mechanical characteristics of particle panels based on corn cobs with Néré Pod Pod (CGN) as a binder, as well as the integration of plastic materials (low density polyethylene).

Materials and Methods:-

Preparation of the cellulosic raw material:-

The corn cobs from shelling are first dried to reduce their moisture content and remove any foreign matter. Then, we crushed them manually before grinding them with the flail mill. The maximum material size that the RETSCH SK100 mill can handle is only 15 mm. Given the size of the cobs, we had to break them up with stones before grinding.



Figure 1: Treatment of stalks: a) dried; b) crushed; c) ground.

Preparation of the binder from the Néré Pod (CGN):-
The Néré pod is ground into a powder and stored away from moisture to prevent it from becoming a compact mass. It is then dissolved in a specific quantity of distilled water (20% of the total dry mass of 600g, i.e., 120g of water).

Preparation of low-density polyethylene (PEBD) binder:-
The low-density polyethylene (PEBD) used is made from plastic bags that previously contained drinking water, commonly known as "pure water." The plastic bags are cut into small pieces before being mixed with crushed cobs, with or without the néré pod husk, to manufacture the panels.

Preparation of the mixture for heat pressing:-
The dry matter (particles + binder) weighs 600 g and the mixing time is approximately 10 minutes. The required quantity of raffinate is weighed and added to the mixer bowl, where it is then added at concentrations that vary according to the mass proportion of binder to raffinate. The distilled water used to prepare the binder solution is present at a proportion of 20% by weight of the dry matter. This water also serves to moisten the plant material. The binder percentage varies from 5% to 20%, with increments of 2.5% starting at 5% binder. The binder solution is prepared with distilled water representing 20% of the total dry matter.


a)


b)


c)

Figure 2: Particle preparation: a) mixture of cobs and PEBD; b) Preparation for heat pressing; c) Finished panel.

The homogenized mixture is manually gravity-fed into a 31 cm x 31 cm square mold preheated to the temperature chosen for heat pressing. The mold, closed by a top plate, is placed between the two heating platens (moving lower platen, fixed upper platen) of the Carver hydraulic heat press (Fig. 3). The heat pressing operation is carried out at 160°C under a pressure of 11 bar. Once the temperature has stabilized, the panels are removed from the mold and characterized after cooling in ambient air. The panels were manufactured by varying the mass percentage of the binders. The percentages used were: 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20%.



Figure 3: CARVER Heat Press

Table 1 : Relative proportion of raw materials according to CGN binder content

Signdesignation	Mass of CGN binder (g)	Mass of corn cob particles (g)
P 5	30	570
P 7.5	45	555
P 10	60	540
P 12.5	75	525
P 15	90	510
P 17.5	105	495
P 20	120	480

Table2 : Relative proportion of raw materials according to CGN binder content and PEBD plastic blend

Sign designation	Mass of CGN binder (g)	20% (g) PEBD plastic blend	Mass of corn cob particles (g)
P 5	30	120	450
P 7.5	45	120	435
P 10	60	120	420
P 12.5	75	120	405
P 15	90	120	390
P 17.5	105	120	375
P 20	120	120	360

Sample preparation for testing:-

Once the panels are made, they are stored in a climate-controlled room for at least 48 hours before being cut into test specimens (Fig 4).The samples, cut to the dimensions required for the various tests, are placed in a controlled humidity atmosphere. The chamber conditions are a relative humidity of 65% and a temperature of 20°C ± 3, as required by ANSI A208.1–2016.

For each particleboard panel:-

- Determination of density: samples with dimensions of 50 mm × 50 mm.
- Three-point bending test (TPB test): samples with dimensions of 150 mm × 50 mm.
- Thickness swelling test (TS test): samples with dimensions of 50 mm × 50 mm.
- Tensile test: specimens measuring 150 × 20 mm.



Figure 4: The different test specimens for the following tests: a) flexure; b) swelling; c) tensile strength

Experimental designs:-
The various particleboard panels manufactured underwent physical and mechanical testing. These tests were carried out according to the standardANSI A208.1-2009.

Table 3 : Physical and mechanical tests

Tests	Properties	Standards
Bending test	Modulus of rupture (MPa) Modulus of elasticity (MPa)	ANSI A208.1-2009
Traction test	Maximum breaking stress	ANSI A208.1-2009
Physical properties	Swelling rate at 2 hours and then at 24 hours (%)	ANSI A208.1-2009
	Density (kg/m3)	ANSI A208.1-2009

Physical characteristics of the panels:-
Water inflation test:-
The swelling test consists of immersing six 50 mm x 50 mm test specimens of each panel, whose mass and thickness have been previously determined, in water. The mass and thickness of these specimens are then recorded after 2 and 24 hours of immersion. This allows the water absorption rate (TA) of the manufactured panels to be determined, as well as their thickness swelling rate (TS), which is determined according to standard EN 317.

Here is the expression for the swelling rate along with that of the water absorption rate:-

$$TS\ (\%) = \frac{e_2 - e_1}{e_1} \times 100 \qquad TA\ (\%) = \frac{m_2 - m_1}{m_1} \times 100$$

With:-
e_1: Thickness of the test specimen before immersion (mm); e_2: Thickness of the test specimen after immersion (mm);
m_1: Mass of the test specimen before immersion (g); m_2: Mass of the test specimen after immersion (g).

Determining density:-
The density of the panel is determined from the mass and dimensions of the 50 mm test specimens×50 mm.

It is obtained using the following relationships:-

$$\rho = \frac{M}{V} \qquad \text{Or} \qquad V = e \times l^2$$

M= mass of the test tube;
V= volume of the test tube;
e= thickness of the test specimen;
l=side of the test tube;
ρ = density of the panel.

Mechanicalcharacteristics of the panels:-
The mechanical characteristics selected for the engineered particleboard are their resistance to bending and tension.

Three-point bending test:-
The three-point bending test consists of subjecting a specimen, resting on two supports, to a gradually increasing load F applied at its midpoint. The deflection is measured as the load increases until the specimen breaks. The principle of the bending test is illustrated in Figure 5.

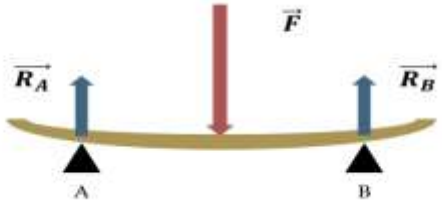


Figure 5: Principle of the three-point bending test

In our case, the three (3) point bending test involved six (6) 150 mm × 50 mm specimens of each type of panel manufactured.

The modulus of elasticity MOE:-

The mdulus of elasticity for particleboard is given by the following formula:-

$$MOE = \frac{(F_2 - F_1)l^3}{4be^3(y_2 - y_1)}$$

Or the force F is taken to be between 10 and 40% of the breaking forcewith:-

L: distance between the supports; b: width of the test specimen;
e: thickness of the test specimen; Fbreaking force;
F1= 10%F; F2= 40%F.

The MOR or σ breaking stress::-
Assuming a homogeneous and isotropic material, the breaking stress is given by the following formula:

$$\sigma = \frac{3Fl}{2be^2}$$

Traction test:-
The tensile test is undoubtedly the most fundamental of all mechanical tests. It serves to determine key mechanical characteristics such as the modulus of elasticity, tensile strength, Poisson's ratio, yield strength, elongation after break, and necking coefficient. In this study, we will focus on the first two characteristics, as required by the ANSI A208.1-2009 standard. The specimen is securely held by its ends between the jaws of the testing machine. As these jaws move apart, they exert a tensile force along the geometric axis of the specimen.

In our study, we used a specially designed test bench equipped with a dynamometer and a graduated scale for measurements. The tensile force F, controlled by the screw-nut system, is applied very gradually to the specimen

and measured at each instant along with the elongation. Δl corresponding using the dynamometer and the graduated ruler respectively.

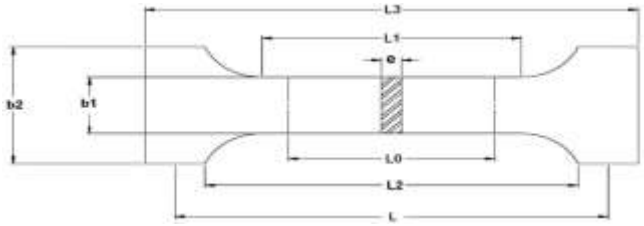


Figure 6 shows the geometry and characteristics of a tensile test specimen.

Figure 6: Tensile test tube

L= Reference length;
L= Spacing between tools;
L1= Length of the narrow calibrated part;
L2= Spacing between wide parallel parts;
L3= Total length;
b2= Width in the shoulder area;
b1= Width in the area of the reference length;
e= thickness of the test specimen.

The particleboard obtained is cut into 200 mm×50 mm specimens of each type of panel for tensile testing.

Young'smodulus E:-
Young's modulus is a coefficient that characterizes the elongation of a body subjected to tension. It is determined from relation (5.9).

$$E = \frac{\sigma}{e} = \frac{\frac{F}{S_0}}{\frac{\Delta l}{l_0}}$$

With:-
σ: tensile stress; S_0: initial section of the test specimen;
L_0: initial length of the test specimen; F: load or tensile force;
Δl: elongation of the test tube

MOT breakingstrength:-
The term "tensile strength" refers to the highest stress experienced by the specimen during the test. Its expression is:

$$\mathbf{R} = \frac{\mathbf{F_m}}{\mathbf{S_0}}$$

With :
FM: maximum load; S_0: initial section of the test specimen.

Statistical analyses:-
Statistical analysis of the data obtained during the various trials will allow us to assess the results and extract maximum information while maintaining a sound theoretical framework. For most experimental results, a statistical analysis, based on calculating the mean (σ), standard deviation (S), and coefficient of variation (CV), was performed to assess the degree of dispersion of the results. Table 5.4 provides guidance for evaluating the results based on the CV.$\bar{\mathbf{x}}$

Table 4: Evaluation of results based on CV

Degree of control	Coefficient of variation
Excellent	<5
Very good	5 to 10
Good	10 to 15
Poor	15 to 20
Bad	>20

The mean (μ), standard deviation (S) and coefficient of variation (CV) are calculated according to the following respective formulas:$\bar{\mathbf{x}}$

Average

$$\bar{\mathbf{x}} = \frac{\sum_{i=1}^{p} n_i x_i}{\sum_{i=1}^{p} n_i} \quad (5.9)$$

Standard deviation

$$\mathbf{S} = \sqrt{\frac{\sum_{i=1}^{p} n_i (x_i - \bar{x})^2}{\sum_{i=1}^{p} n_i}} \quad (5.10)$$

Coefficient of variation

$$\mathbf{CV = 100\ x\ \frac{S}{\bar{x}}} \quad (5.11)$$

Results and Discussions:-

Physical properties of the panels:'-

Density of corn cob particleboard:-

The density of the resulting corn cob particleboard varies between:-

- 617.47 kg/m3 at 5% and 706.75 kg/m3 at 17.5% binder for néré pod husk; This classifies these panels in the category of medium and low density panels for commercial and industrial use as well as for door use (M-1, S; M-2, S; LD-1, 2);
- 604.79 kg/m3 at 10% and 691.66 kg/m3 at 20% binder for low-density polyethylene; This classifies these panels in the category of medium and low-density panels for commercial and industrial use as well as for door use (M-1, S; M-2, S; LD-1, 2);
- 506.28 kg/m³ at 7.5% and 635.5 kg/m³ at 17.5% binder for the mixture of néré pod husk and low-density polyethylene. This classifies these panels in the category of low-density panels for use in door cores (LD-1, 2).

The curves showing the variation of density as a function of binder content are shown in the figure below.

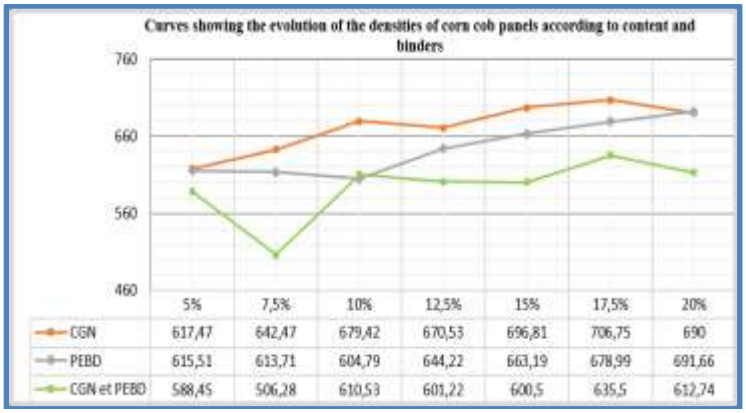


Figure 7: Curves showing the evolution of the densities of corn cob panels according to content and binders

From the curves in Figure 7, it can be seen that the corn cob panels with néré pod husks (CGN) have a higher density than the others. They are followed by the panels with low-density polyethylene (PEBD). Conversely, the panels made from mixtures of CGN and PEBD binders show a lower density compared to the other panels, as shown in the curves. These results are similar to those of Nenonene (2009) and Drovou (2012), who characterized the kenaf and sawdust panels with tannic powder from néré pod husks and tamarind bark.

Water swelling of corn cob particleboard:-

The study of the panels' water swelling yielded results detailed in the tables in the appendix. Two properties were studied: the thickness swelling (TS) and the water absorption rate (TA), after 2 hours and after 24 hours of immersion in water.

Thickness swelling (TS):-

The swelling test performed at 2 hours and 24 hours of immersion on the processed corn cob panels yielded swelling rates in thickness varying from:

- 33.13% to 60.73% in 2 hours and 48.16% to 75.95% in 24 hours for panels with néré pod pod (CGN);
- 18.38% to 40.43% in 2 hours and 26.20% to 51.5% in 24 hours for panels with low-density polyethylene (PEBD);
- 27.3% to 46.04% in 2 hours and 22.74% to 61.53% in 24 hours for panels with néré pod husk (CGN) and low-density polyethylene (PEBD).

The swelling in thickness after 2 hours and 24 hours of immersion of the test specimens in water, respectively, is illustrated byfigures 8 and 9 below.



Figure 8: Evolution of the swelling rate in thickness according to the contents and binders over 2 hours

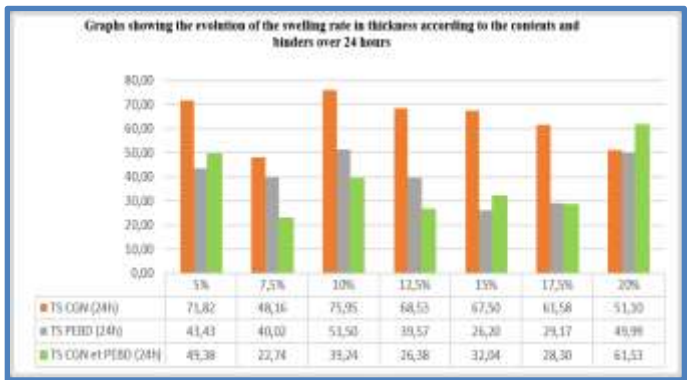


Figure 9: Evolution of the swelling rate in thickness according to the contents and binders over 24 hours

The data shows that corn cob panels made with CGN binder exhibit a higher swelling rate over 24 hours than those made over 2 hours. The same is true for PEBD-based panels, which also show higher swelling rates over 24 hours than over 2 hours. Corn cob panels made with CGN-PEBD binder blends have virtually identical swelling rates over 2 hours and over 24 hours.

Regarding Figures 8 and 9, it follows that the corn cob particleboard with néré pod husk (CGN) exhibited higher swelling rates than the others over 2 and 24 hours. All the panels swelled more than the 20% threshold required by

the standard, and the results obtained are consistent with those of Nenonene (2009) and Drovou (2012), who characterized the kenaf and sawdust panels.

Water absorption of corn cob particleboard (TA):-

The absorption test, carried out after 2 hours and 24 hours of immersion of the corn cob panels, yielded water absorption rates varying from:

- 113.64% to 175.78% in 2 hours and 128.87% to 198.58% in 24 hours for panels with the néré pod pod (CGN);
- 53.74% to 135.82% in 2 hours and 68.49% to 137.66% in 24 hours for panels with low-density polyethylene (PEBD)
- 96.38% to 141.22% in 2 hours and 98.04% to 155.10% in 24 hours for panels with néré pod husk (CGN) and low-density polyethylene (PEBD).

Thus, the maximum absorption rate varies from 107.46% to 175.78% in 2 hours and from 123.3% to 198.58% over 24 hours.The data shows that virtually all corn cob panels exhibit higher absorption rates over 24 hours than those subjected to absorption over a 2-hour period. Furthermore, all maximum absorption rates for all panels exceeded 100%, ranging from 107.45% to 198.58%. These results are more significant than those obtained by Nenonene (2009) and Drovou (2012), who respectively studied kenaf panels and sawdust with plant-based bioadhesives and bone glue beads.

Mechanical properties of the panels:-

Analysis and discussion of the flexural modulus of elasticity (MOE) of panels:-

The MOE values obtained from bending tests on corn cob panels vary according to the content and binders as follows:-

- 4,237 MPa (5%) to 6,164 MPa (17.5%) for panels with néré pod pod (CGN);
- 3,471 MPa (12.5%) to 4,578 MPa (7.5%) for panels with low-density polyethylene (PEBD);
- 2,944 MPa (7.5%) to 3,886 MPa (20%) for panels with néré pod husk (CGN) and low-density polyethylene (PEBD).

Thus, the minimum MOE value of 2,944 MPa (7.5%) is for panels with the mixture of CGN and PEBD binders, while the maximum value is obtained by panels based on néré pod husk (CGN) at 6,164 MPa (17.5%).
The evolution of the MOE values after the bending tests is illustrated in the figure10.

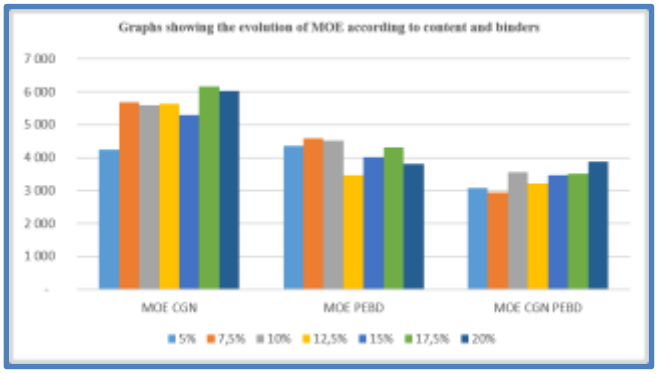


Fig 10: Evolution of the MOE according to the contents and binders

Figure 10 shows that corn cob particleboard with néré pod husk (CGN) has higher MOE values than other panels. Furthermore, the results indicate that MOE increases with binder content and exceeds the requirements of ANSI A208-1 (2009) (1725 MPa). In addition, the MOE results confirm those found by Drovou (2012), who reported an MOE value of 8900 MPa for sawdust.

Overall, in terms of ranking, panels with néré pod husk (CGN) come in first position followed respectively by panels with PEBD and panels of the CGN + PEBD mixture.

Analysis and discussion of flexural strength (MOR):-

The values of the modulus of rupture (MOR) obtained from bending tests on corn cob panels vary according to the content and binders as follows:-

- 14.8 MPa (5%) to 17.3 MPa (17.5%) for panels with néré pod pod (CGN);
- 18.7 MPa (5%) to 32.1 MPa (17.5%) for panels with low-density polyethylene (PEBD);
- 15.85 MPa (7.5%) to 21.35 MPa (20%) for panels with néré pod husk (CGN) and low-density polyethylene (PEBD).

Thus, the minimum modulus of rupture (MOR) of 14.8 MPa (5%) is obtained for the panels with CGN, while the maximum value is obtained for the PEBD-based panels at 32.1 MPa (17.5%). It follows that the panels with PEBD and the CGN + PEBD blend have the best flexural modulus of rupture (MOR) results.

The evolution of the MOR values following the bending tests is illustrated in Figure 11.

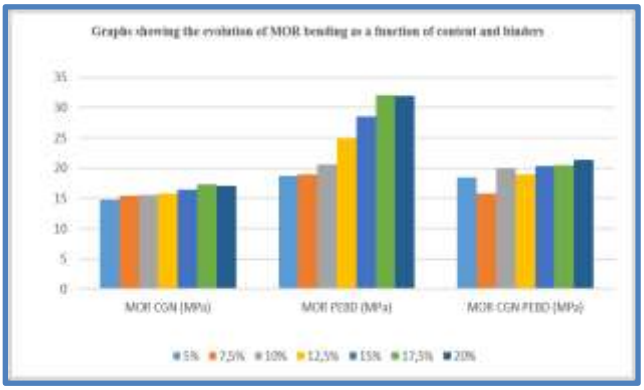


Fig 11: Evolution of MOR bending strength according to content and binders

Figure 11 shows that corn cob particleboard with a mixture of CGN and PEBD has higher modulus at break (MOR) values than other panels. Furthermore, the results indicate that the MOR increases with the binder content and exceeds the requirements of ANSI A208-1 (2009) (3 MPa). These results also confirm those obtained by Drovou (2012) in a study using bone glue in bead form and tannic extracts from néré pods on sawdust from various woods.Overall, in terms of ranking, low-density polyethylene (PEBD) panels come in first place followed respectively by panels with a mixture of CGN + PEBD and nere pod husk (CGN).

Analysis and discussion of the tensile strength of panels (MOT):-

The tensile strength (MOT) values obtained from tensile tests on corn cob panels vary according to the content and binders as follows:-

- 14 MPa (17.5%) to 15.5 MPa (10%, 15% and 20%) for panels with néré pod pod (CGN);
- 14.5 MPa (7.5%) to 24.5 MPa (20%) for panels with low-density polyethylene (PEBD);
- 15 MPa (7.5%) to 19 MPa (10% and 20%) for panels with néré pod husk (CGN) and low-density polyethylene (PEBD).

Thus, the minimum tensile strength (MOT) of 10 MPa is obtained for panels made from néré pod husk (CGN), while the maximum value of 24.5 MPa is obtained for panels made with low-density polyethylene (PEBD). It follows that the panels made with PEBD and the CGN + PEBD blend have the best tensile strength (MOT) results.

The evolution of the MOT values following the tensile tests is illustrated in Figure 12.

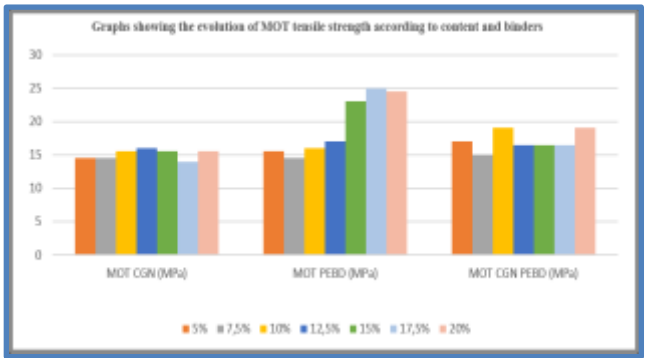


Figure 12: Evolution of the tensile strength MOT according to the content and binders

Figure 12 shows that corn cob particleboard made with low-density polyethylene (PEBD) has higher tensile strength at break (MOT) values than other panels. These are followed by blends of PEBD with néré pod husk (CGN). Panels with CGN binders exhibited lower tensile strength than those made with PEBD. The results are practically in line with the 11 MPa threshold set by ANSI A208.1 (2009) for these types of panels.

Analysis and discussion of the elongation due to tensile stress (A%) of the panels:-
The elongation values (A%) resulting from tensile stresses on corn cob panels vary according to the content and binders as follows:-

- 3.675 (20%) to 4.108 (12.5%) for panels with néré pod pod (CGN);
- 4.217 (7.5%) to 7.171 (20%) for panels with low-density polyethylene (PEBD);
- 4.263 (7.5%) to 5.613 (20%) for panels with néré pod husk (CGN) and low-density polyethylene (PEBD).

Thus, the minimum value of the elongation stress (A%) of 3.675 is obtained for panels based on néré pod husk (CGN) while the maximum value is obtained for panels with low density polyethylene (PEBD) at 7.171.

The evolution of the stress-stretch values (A%) at the end of the tensile tests is illustrated in Figure 13.

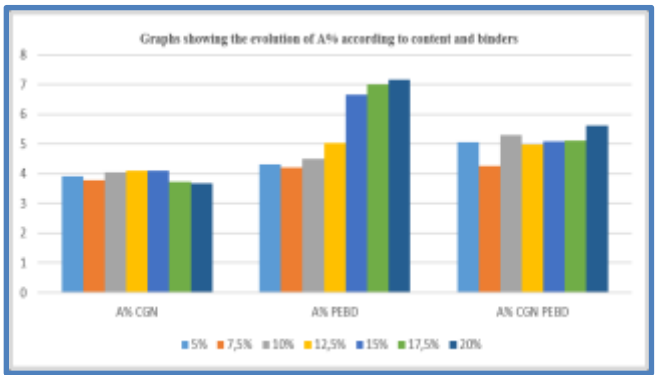


Fig 13: Evolution of elongation according to content and binders

Figure 13 shows that corn cob particleboard made from low-density polyethylene (PEBD) has higher tensile elongation (A%) values than the other boards. These are followed by blends of PEBD with néré pod husk (CGN). Boards with CGN binders exhibited lower tensile strength than those made from PEBD. The elongation (A%) results are virtually identical to the tensile strength (MOT) results, which meet the 11 MPa threshold set by ANSI A208.1 (2009).

Conclusion:-

The development of this topic further strengthens the long chain of research on the characterization of plant-reinforced composite materials, including particleboard, which has been developed by the Research Unit on Agroresources and Environmental Health (URASE) in recent years. It also demonstrates the feasibility of

particleboard using animal and plant-based binders that meet certain performance standards, specifically that of the American National Standards Institute (ANSI) A208.1- (2009). Our work consisted of developing and characterizing particleboard made from corn cobs, using néré pod husk (CGN) as a binder and incorporating low-density polyethylene (PEBD).

The results obtained during the experimental procedures allowed us to conclude thatThe mechanical properties of corn cob panels improve with the integration of low-density polyethylene (PEBD) and the increasing binder content ofthenéré pod pod (CGN), the panels produced are primarily used in dry environments within the building sector for thermal and acoustic insulation, decoration, and furniture. Thermo-acoustic characterization and resistance to environmental stresses remain essential investigations to more fully characterize the resulting panels and develop them into durable and high-performance industrial products.

Statements:-
Conflicts of interest: The authors declare that they have no conflicts of interest.

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