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(Research Article)

Study to improve the physical-mechanical behavior of corncob particleboard by adding recycled low-density polyethylene (LDPE)

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Abstract

The aim of this work is to improve the behavior of particleboard made from corn cobs, an abundant resource resulting from the valorization of Togolese agricultural and agro-industrial residues. The methodology adopted consists in manufacturing particleboard by grinding collected corn cobs into flour. The particles obtained will be used to manufacture different types of panels by varying the input parameter for panel production, i.e. the reclaimed low-density polyethylene (LDPE) content, in order to improve the performance of conventional particleboard. The LDPE content was varied from 5% to 20% in 5% increments. The next phase of the work involved determining the physical and mechanical characteristics of the panels produced by subjecting the cut samples to various tests, such as:

- Swelling test in water to obtain swelling thickness and water absorption rate ;
- Three-point bending test to determine modulus of elasticity (e) and maximum bending moment leading to rupture
- Traction test to characterize the modulus of maximum stress at break σr determined as a function of particle size and ldpe content. A total sample of 180 particleboards measuring 300 x 300 x 5 mm was tested. The densities obtained enable the corncob particleboards produced to be classified as high and medium density panels (m-1, s ; m-2, s) according to the american standard ansi a208.1-2009 [7][8]. As far as swelling is concerned, the particleboards have a low resistance to water, and can therefore only be used in dry interior environments, requiring protection against moisture. The thresholds set by ansi a208.1-2009 for modulus of elasticity e and modulus of rupture have largely been reached, and the results increase with increasing ldpe content for smaller grain sizes.

Keywords: Particleboard*;* Particle Size*;* Swelling Test*;* Modulus of Elasticity*;* Breaking Stress

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1. Introduction

The production of renewable composite materials that are harmless to human health and the environment is essential to help preserve nature for future generations. As a building material and natural composite (composed of lignin and cellulose), wood is an ecological and renewable material that has become an essential component of sustainable development. Today, wood-based materials are used in a variety of applications, in particular particleboard, which is the subject of this study. At the origin of particleboard research, work on particleboard has been steadily increasing since 1941, when it was industrially produced by the first plant in Bremen [1], [2], [3], [4]. The particleboard industry is particularly interesting for countries where forest resources are limited, because it allows maximum use to be made of wood waste as well as other species that would not otherwise have a profitable use [5, 6]. It is in this context that we have suggested the integration of recycled low-density polyethylene in the production of corncob particleboard. To

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assess the quality of the panels obtained, we thought it would be useful to characterize them physically and mechanically using standard tests.

2. Materials and methods

Various materials were used to produce the panels and to characterize the samples obtained.

2.1. Processing equipment

An electronic weighing scale;

A RETSCH SK100 type knife mill (Figure 1) equipped with a 5 mm mesh diameter sieve to reduce the cellulose matter to raffinate; it has a set of interchangeable sieves for the different particle sizes.

Figure 1 Brand Knife Crusher RETSCH

Open sieves: 2.5 mm; 1.6 mm; 0.8 mm

After passing through the RETSCH mill, we obtained granules with a size of 5 mm or less. The pellets thus obtained were sieved through sieves with gauges of 2.5, 1.6 and 0.8 mm (Figure 2) in order to classify them as follows:

$$2.5mm < g \leq 5mm$$

$$1.6mm < g \leq 2.5mm$$

$$0.8mm < g \leq 1.6mm$$

$$g \leq 0.8mm$$

Figure 2 Sieves: a) side view of the different sieves; b) top and botom view of the sieves

A CARVER manual hydraulic press (Figure 3) for particleboard thermoforming. It comprises two electrically heated platens, whose temperature is automatically controlled. Platen dimensions are 300 mm x 300 mm. Maximum press pressure of 10 tons (11 bar) is achieved via a hydraulic system.

Figure 3 CARVER thermo press

Baking paper was used as a non-stick lining for the inside of the mold;

As protective equipment, **heat-resistant gloves** are used to handle the molds, which are raised to a temperature of 160°C;

A caliper was used to measure the thickness of the particleboard;

Figure 4 A 1/50 caliper gauge

Finally, **the** usual laboratory **glassware** was used for various operations.

2.2. Particleboard characterization equipment

To characterize particleboard, we used a mechanical test bench equipped with various accessories for tensile and three-point bending tests.

This device consists of a rigid table resting on four legs, topped by four columns above which a plate is mounted. The columns are fitted with two height-adjustable slides (by means of locking screws), connected by two pins which will act as supports for the bending test specimen.

Figure 5 Particleboard characterization equipment

As shown in Figure 5, one end of the tensile test specimen is attached to a mobile crosshead whose movement is controlled by a screw-nut system, the other to the dynamometer attached to the table. The force applied to the specimen is measured by the dynamometer, and the corresponding elongation by a graduated ruler fixed to the table.

2.3. Methods

Panel production was carried out in the conventional way as established in work [3]. In this work, we present the methods used to characterize the physico-mechanical behavior of

2.3.1. Three-point bending test : Test principle

The three (3) point bending test consists of subjecting a sample resting on two supports to a gradually increasing load F applied to its center. The deflection is measured as the load increases, until the sample breaks.

The principle of the bending test is illustrated in Figure 6.

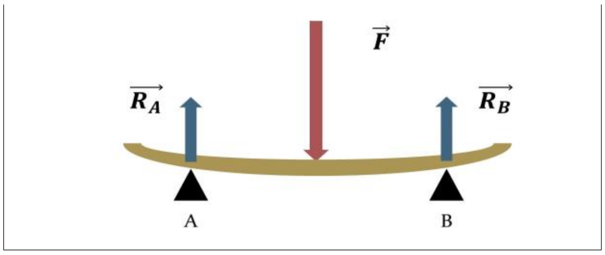

Figure 6 Principle of the three-points bending test

In our case, the three (3) points bending test involved seven (6) specimens of each type of panel manufactured.

The principle consists in placing the specimen on the supports and exerting a force on it, thus causing it to bend. A graduated ruler and associated dynamometer are used to measure the deflection and then the loads applied as the screw attached to the dynamometer is turned.

Once the test piece has broken, the process is repeated using another one.

2.4. Determining mechanical properties

2.4.1. The modulus of elasticity E

Assuming a homogeneous, isotropic material, the modulus of elasticity is given by the following formula:

$$E = \frac{Fl^3}{4be^3y} \qquad \textbf{(1)}$$

The NBN EN 310: 1993 standard for particleboard recommends a modulus of elasticity with a force F of between 10% and 40% of the breaking force.

Finally:

$$E = \frac{(F_2 - F_1)l^3}{4be^3(y_2 - y_1)} \qquad \textbf{(2)}$$

where

l: distance between supports; *b* : width of specimen;

e: specimen thickness; *F* : breaking force;

$F_1 = 10\% F$; $F_2 = 40\% F$

2.4.2. Determination of ▯▯ and ▯▯

The lengths y_1 and y_2 correspond to the arrows generated by forces F_1 and F_2.

They are determined by linear interpolation of the deflection values corresponding to the force values framing F_1 and F_2 as shown in Figure 7.

$$y_i = y_{max} - \frac{(y_{max} - y_{min})(F_{max} -}{F_{max} - F_{min}} \qquad (3)$$

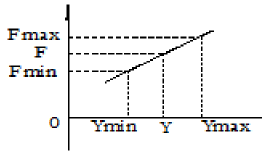

Figure 7 Determining the yi deflection by linear interpolation

2.4.3. The bending fracture stress σ_r :

Assuming a homogeneous, isotropic material, the breaking stress is given by the following formula:

$$\boldsymbol{\sigma_r} = \frac{3Fl}{2be^2} \qquad \textbf{(4)}$$

3.2 - Tensile test

The tensile test was fundamental to the mechanical characterization of this work. It was used to determine the main mechanical properties, such as modulus of elasticity, tensile strength, Poisson's ratio, yield strength, elongation at break and coefficient of stricture. In this study, we focused on the first two characteristics (modulus of elasticity, tensile strength) as required by ANSI A208.1-2009. The ends of the specimen are firmly held between the jaws of the machine, which move away from each other, thus exerting two opposing tensile forces along the specimen's longitudinal axis.

In this study, we used a purpose-designed test bench equipped with a dynamometer and a graduated ruler for measurement purposes. The tensile force **F** controlled by the screw-nut system is applied very progressively to the specimen. The force is measured with the dynamometer at each instant, while the corresponding *Δ*l elongation is recorded with the graduated ruler installed parallel to the axis of the test specimen.

Figure 8 shows the geometric characteristics of the type of specimen we used for tensile testing.

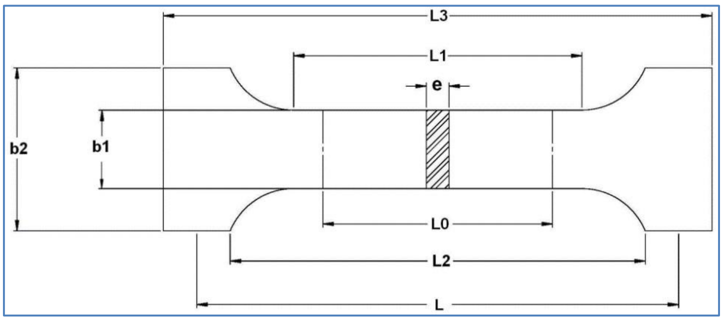

Figure 8 Tensile test sample

L_0 = Reference length; **L** = Tool spacing ; **L1** = Length of narrow calibrated section; **L2** = Distance between wide parallel sections **L3** = Total length; **b2** = Width in shoulder area ; **b1** = width in the area of the reference length; **e** = specimen thickness

The main mechanical properties were determined, namely modulus of elasticity and maximum stress at break.

Young's modulus E is a coefficient that characterizes the elongation of a body subjected to tensile stress in the material's behavior range where removal of the load allows the material to return to its initial shape. It is determined from relationship (5).

$$E = \frac{\sigma}{e} = \frac{\frac{F}{S_0}}{\frac{\Delta l}{l_0}} = \frac{F \times l_0}{\Delta l \times S_0} \qquad \textbf{(5)}$$

with :

σ: tensile stress ; S_0 : initial cross-sectional area of specimen;

l_0 : initial length of specimen; F: tensile load or force;

Δl: elongation of the specimen

2.5. Breaking strength σ_r

Fracture strength is the highest stress the specimen can withstand during the test. It is estimated as the maximum stress and its expression is:

$$\sigma_r = \sigma_m = \frac{F_m}{S_0} \qquad \textbf{(6)}$$

with: F_m: maximum load ; SS_0initial cross-section of specimen.

3. Results and discussion

Statistical analysis of the data obtained from the various trials undertaken will enable us to assess the results and draw out as much information as possible, while maintaining a sound theoretical framework.

For most of the experimental results, a statistical analysis based on the calculation of the mean (**xx**), standard deviation (S) and coefficient of variation (C_V), was carried out to assess the degree of dispersion of the results. Table 1 gives qualitative indications of results as a function of C_V.

Table 1 Assessment of results based on C_V

Degree of control	Coefficient of variation
Excellent	$C_V \leq 5$
Very good	$5 \leq C_V < 10$
Good	$10 \leq C_V < 15$
Poor	$15 \leq C_V < 20$
Wrong	> 20

The mean ($\overline{x}$), standard deviation (s) and are computed according to the following respective formulas:

Average value:

$$\overline{x} = \frac{\sum_{i=1}^{p} n_{i} x_{i}}{\sum_{i=1}^{p} n_{i}} \qquad (7)$$

standard deviation:

$$S = \sqrt{\frac{\sum_{i=1}^{p} n_{i}(x_{i}-\overline{x})^{2}}{\sum_{i=1}^{p} n_{i}}} \qquad (8)$$

coefficient of variation (C_V)

$$C_{v} = 100x\frac{S}{\overline{x}} \qquad (9)$$

The properties measured for these types of panels are the physical properties, i.e. physical appearance, density and water swelling, followed by the mechanical properties, i.e. modulus of elasticity E in flexure, modulus at break in flexure, tensile stress at break and Young's modulus of elasticity E obtained in the elastic zone of the tensile test. In the following paragraphs, each of the measured properties will be discussed after their statistical analysis. The results obtained for each of the mechanical properties under study will be compared with ANSI A.208.1-2022 standards [5]. Note that the parameter of study in this paper is the simultaneous influence of LDPE content and particle size.

The resulting panels take on the color of the corn cobs used to produce them. However, it should also be noted that the color of the low-density polyethylene has a slight influence on the color of the panels produced.

For the study of density, several results were obtained during the production of panels by varying the binder rate and the type of granulometry. The density ρ of corncob panels obtained in the course of this research varied according to particle size and binder rate:

- 565.8 kg/m^3 ≤ ρ ≤ 696.57 kg/m^3 for corncob panels 2.5 ≤ Ø ≤ 5 with low-density polyethylenes
- 572.32 kg/m^3 ≤ ρ ≤ 637.07 kg/m^3 for corncob panels 1.6 ≤ Ø ≤ 2.5 with low-density polyethylenes
- 642.13 kg/m^3 ≤ ρ ≤ 724.91 kg/m^3 for corncob panels 0.8 ≤ Ø ≤ 1.6 with low-density polyethylenes
- 799.62 kg/m^3 ≤ ρ ≤ 912.29 kg/m^3 for corncob panels Ø ≤ 0.8 with low-density polyethylenes.

The variation in density is proportional to binder content and particle size. According to the American standard ANSI A208.12009, corncob panels sieved at 0.8 are respectively classified as low (LD) and high density (H-3), medium density (M) for grain sizes below and above 1.6 of low-density polyethylenes. These results meet the requirements of American standard ANSI A208.1-2022.

These results are illustrated by the variation curves shown below (Figure 9):

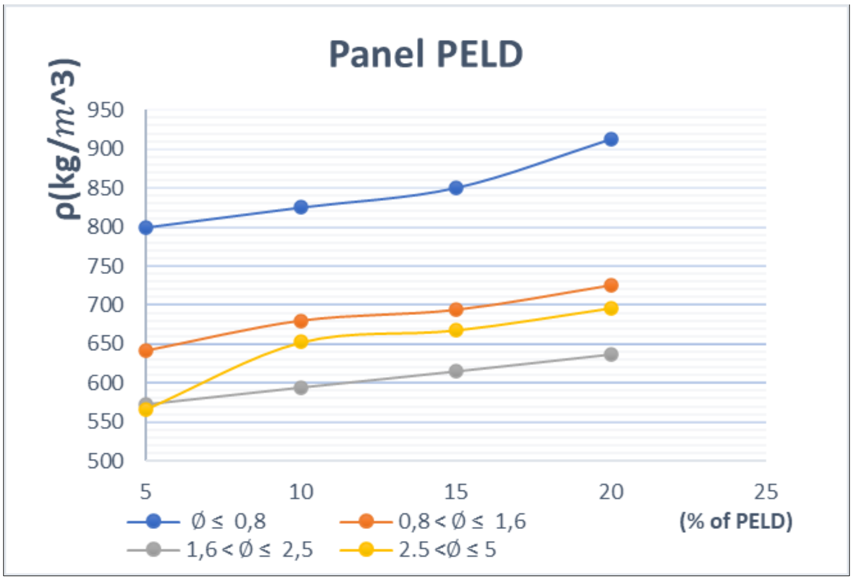

Figure 9 Density curves as a function of LDPE content and particle size with low-density polyethylene

Thickness swelling results expressed as percentages after two (2) hours and twenty-four (24) hours of immersion of the specimens in water are recorded in Table 2 and represented by the curves in Figure 10.

Table 2 Summary of swelling and water absorption values for particleboards immersed for 2 h and 24 h.

Particle size (mm)	**Swelling rate (%) after:**		**Water absorption rate (%) after:**	
	2 h	24 h	2 h	24 h
2.5 ≤ Ø ≤ 5	28,23 to 45,74	32,12 to 53,47	79,22 to 107,2	89,69 to 124,29
1,6 ≤ Ø ≤ 2,5	11,67 to 34,88	31,25 to 48,71	24,26 to 88,9	101,38 to 133,91
0,8 ≤ Ø ≤ 1,6	14,71 to 38,09	30,24 to 42,74	60,31 to 107,26	88,819 to 117,35
Ø ≤ 0,8	10,65 to 25,7	20,13 to 27,91	28,67 to 79,59	61,05 to 118,09

Particleboards manufactured with low-density polyethylene have a swelling rate that complies with the recommendations of the American standard ANSI A208.1-2022 for the thickness swelling of panels, which is 20% for 2 hours and 50% for 24 hours of immersion. In addition, swelling decreases at higher binder levels when LDPE is used.

Particle size is also an important factor in reducing swelling. Corncob panels sieved to Ø ≤ 0.8 have a significantly lower swelling rate than other sieved particles obtained with low-density polyethylene. This shows that panels made with low-density polyethylene can be used in humid environments, given their low sensitivity to water.

These results are illustrated by thickness swelling curves in Figure 10.

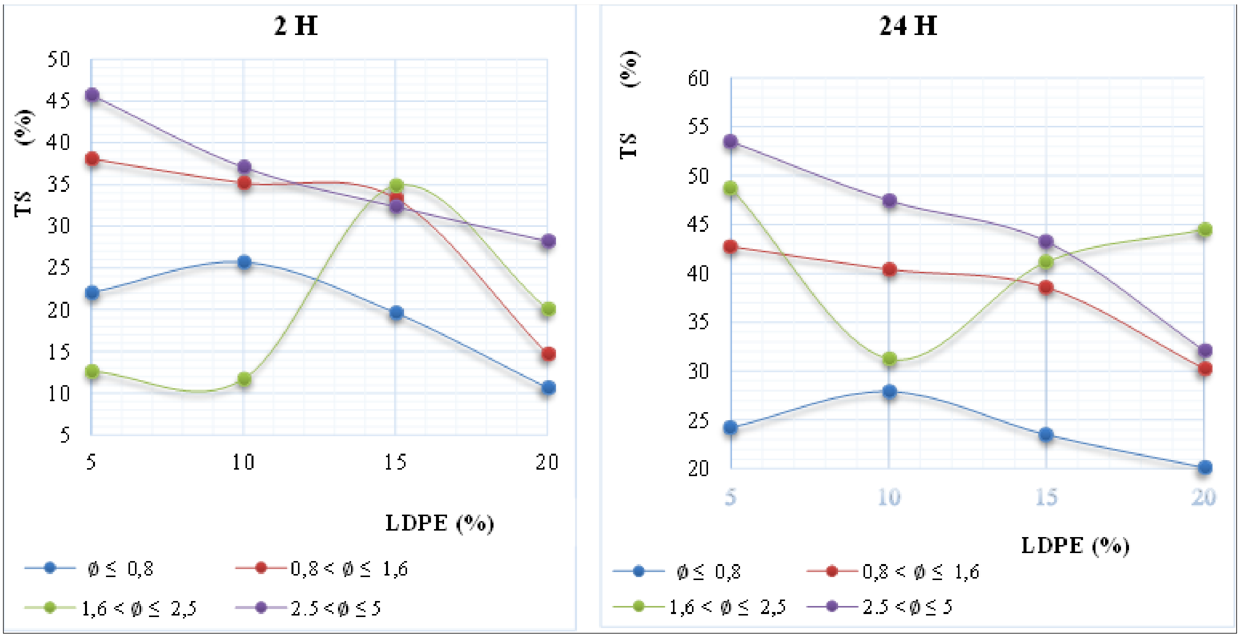

Figure 10 Variation curves for thickness swelling ratio (TS) as a function of LDPE ratio after 2 h and 24 h immersion with low density polyethylene

The results obtained for the water absorption of corn particleboard manufactured with LDPE are illustrated by the curves in Figure 11.

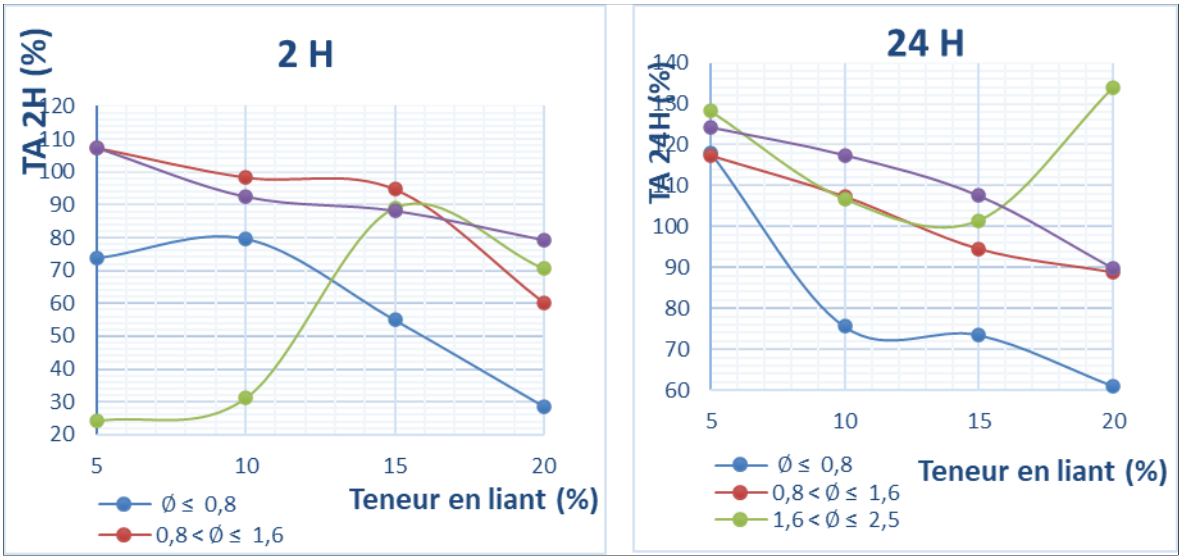

Figure 11 Variation curves for water absorption rate (TA) as a function of binder content after 2 hours and 24 hours immersion with low-density polyethylene.

The same phenomenon observed for thickness swelling also applies to water absorption. It should be noted that during the 24-hour immersion tests, panels made from low-density polyethylene reached water saturation. These results meet the requirements of American standard ANSI A208.1-2022.

The results obtained for the modulus of elasticity E and the modulus of rupture, which corresponds to the breaking stress, for corncob panels manufactured with low-density polyethylene are recorded in Table 3 and shown in Figures 7 and 8 respectively.

Table 3 Characteristic values of Young's modulus E and stress σ_r according to particle size for panels made with a variation in LDPE content from 5 to 20%.

Particle size in mm	Range of elastic modulus E obtained in MPa	Measured breaking stress σ_r (MPa)
2.5 ≤ Ø ≤ 5	1623,25 to 1872,24	20,75 to 22,38
1,6≤ Ø ≤ 2,5	1680,22 to 2293,92	13,44 to 21,65
0,8 ≤ Ø ≤ 1,6	1747,92 to 1986,13	18,63 to 23,68
Ø ≤ 0,8	2938,49 to 4245,93	26,86 to 35,97

The strength values obtained meet the minimum values prescribed by the American standard ANSI A208.1-2022. These values are respectively for modulus of elasticity E, and breaking stress σ_r , 2750 MPa and 23.5 MPa for high-density panels, 1725 MPa and 11 MPa for medium-density panels.

The curves in Figure 12 below illustrate elastic modulus E values as a function of binder content at different corncob grain sizes.

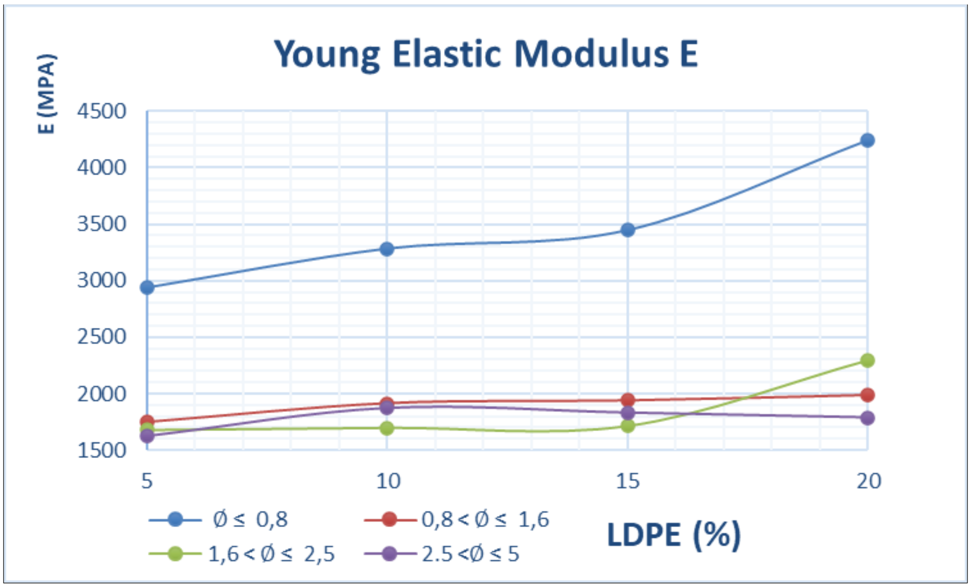

Figure 12 Variation curves for modulus of elasticity (E) as a function of binder content with low-density polyethylene (LDPE).

The curves obtained show that the E-modulus increases with the polyethylene content used. Note that panels made **with** low-density polyethylene have higher moduli of elasticity. The more the particles are separated from the finer fibers, the more elasticity they lose. This can be explained by the rigidity of corncob fibers**.** These results meet the requirements of the American standard ANSI A208.1-2022.

The curves in the figure 13 below illustrate maximum fracture stress as a function of binder content at different corncob grain sizes.

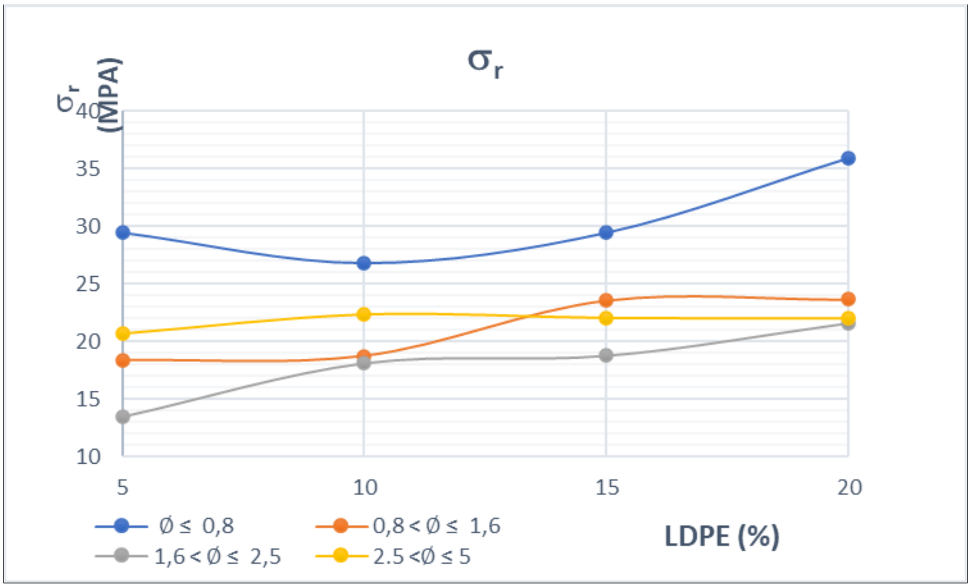

Figure 13 Variation curves for breaking stress σ_r as a function of binder content with low-density polyethylenes (LDPE).

The evolution of the breaking stress σ_r as a function of the LDPE content at different corncob particle sizes shows that the best strength moduli are obtained at 20%, for **low density polyethylene (LDPE).** These results also meet the requirements of American standard ANSI A208.1-2022.

4. Conclusion

For this project, which is part of a sustainable development approach, we have demonstrated, on the basis of scientific literature and various mechanical tests, that it is possible to manufacture particleboard from corn cobs, an agricultural residue. We therefore developed panels from these agricultural residues, reduced to particles of various particle sizes, to which low-density polyethylene (LDPE) was added at a rate incremented by 5 and varying from 5 to 20%. The 180 panels, 300 x 300 x 5 mm in size, have the advantage of being low-cost, thanks to the use of local raw materials, thus promoting local development in the country. The density particle boards enable them to be classified into three categories: high, medium and low density, according to production parameters that comply with ANSI standard A.1-2009.

To identify the areas of use for these particleboards, water immersion tests revealed their sensitivity to water, reflected in high swelling rates (>42%). Characterization by mechanical testing enabled us to determine the Young's modulus E and the maximum breaking stress. The results showed that the finer the particles, the better the panel's flexural and tensile properties, as well as its water resistance.

Thermo-acoustic characterization and resistance to environmental aggression are still essential investigations for a more complete characterization of the particleboards thus obtained, with a view to turning them into potential industrial products. To sum up, we need to pursue and deepen this research in order to implement this type of material in Togo.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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