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Optimization of the Implementation Process and Physical Properties of Cotton (*Gossipium hirsutum*) and Kenaf (*Hibiscus cannabinus* L.) Wooden Chipboard

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Abstract

The present study aims at valorizing two residues types of the foodless vegetable biomass which are abundant and very pollutant in Burkina Faso. To do it, first we try to identify the optimal values of chipboard elaboration parameters with kenaf and cotton stems by using a natural binder (the bone glue). Next we proceed to the elaboration of two panels types with optimized elaboration parameters. Besides we determine mechanical and thermal characteristics of elaborated panels with a view of an indoor thermal insulation application. Also it becomes necessary for us to determine by experimenting the thermal conductivity, Young's modulus, Coulomb's modulus, and the water inflation rate, taking into account some elaboration parameters on one hand and the correlation between mechanical and thermal properties on the other hand. Finally, the obtained results are compared with the panels properties values required by ANSI A 208.1-1999 standard.

Keywords

Chipboard, Cotton Wood, Kenaf Wood, Bone Glue, Mechanical Properties

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1. Introduction

Younquist *et al*., [1], (1987) [2], (1994) are among the first authors who have shown that agricultural residues such as wood kenaf and cotton stems could be used to produce particle board. Following them, A. Nenonene's work [3], (2009) has highlighted the influence of three parameters of development of kenaf wooden particle board associated with a natural matrix (bone glue). He has shown that the binder content, the moisture content and the pressing temperature impact on the physical and mechanical properties of the panels.

Chow's work [4], (1978) has shown that the mechanical properties of two types of panels were evolving with the development of the binder content. An increase of the humidity content in the panel drafting permits the phenol components reaction during the pressing before its combination with binders.

Malone *et al*., [5] (2006) have studied the chipboard thermal properties of certain types of wood. The results have shown that the thermal conductivity of panels was proportionally increasing with their density.

Morvan *et al*. (2006) [6], have shown that the properties of thermal transfers are directly linked to constituents, to the environment morphology (solid matrix and porous network) and to interactions between the different types of transfers existing in the material. The insulating properties of agricultural materials are quantified through two usual parameters: the thermal conductivity λ and the diffusivity a. These ones depend on intrinsic characteristics of constituents, the microstructure of the material and the preservation conditions (the role of water).

This work aims at characterizing completely the behavior of chipboard which is elaborated by thermo pressing from farming residues (crushing of kenaf stems or cotton stems) on the mechanical and thermal planes. The purpose is to validate the elaboration process by using them in the domain of the inside thermal insulation. Moreover it explores other possible ways of use in other domains (thermal insulation inside a dryer, automotive applications) taking into account some norms and rules in use for the different types of conception.

The obtained results are put down in this document by means of curves, charts and diagrams below.

2. Materials

2.1. The Kenaf and Cotton Stems

The barkless kenaf stems wood and the cotton stems wood are two ligneous and cellulose raw materials. They are from agricultural polluting wastes and an agricultural plantation of Bobo-Dioulasso area.

This choice is explained by the abundance of these wastes throughout Burkina territory and the environmental problems caused by their incineration in the fields.

About the bone glue, it is a commercial product obtained from the extraction of bone collagens in gelatin form. It is from a building and distribution company of building materials in Bobo known as SOL CONFORT DÉCOR Ltd.

It is used in this work as nonconventional binder to make chipboard because it respects the environment. Also it does not emit formaldehyde or noxious substance during the elaboration and the using stages of chipboard.

2.2. Elaboration and Characterization Materials Used

The kenaf and cotton stems are first chopped by a cutter-blower and then crushed in a knife crusher. We obtain some finer particles whose desired dimensions are gauged through a sieve of 5 mm nets.

The mass dosing of chipboard components is carried out by electronic scales whose weighing zone varies from 1 till 5000 g.

The shaping of panels is got from a manual hydraulic heat-press of CARVER brand whose characteristics are:

- maximum pressure is: 11 tons, at thermo regulated heating pans,
- equipped with a square mould of 300 mm (inside dimensions) each side.

A crusher of ***MARLEX*** brand is used to crush the beaded bone glue in order to facilitate its water dissolving which is made in an SAISHO electric kettle.

Some firing paper is used as non-stick and smoothing system of the panel face in order to line the mould interior with.

Finally diverse accessories such as heat-resistant gloves, a scraper, some brushes, a caliper rule and the laboratory glassware are also used.

A test bed of texture analyzer TxT2i brand which has a charging speed of two millimeters a second is used for the three points bending test and traction test. It is equipped with a program of automatic acquisition of data and plotting of curves. It permits to do registration of different points at the time of the distortion of tubes during the three points bending test and traction test.

The thermal conductivity was measured by the method of the hotplate kept thanks to a device designed for that purpose in the laboratory.

3. Method

3.1. Chipboard Elaboration Method and Implementation Optimization

The chipboard elaboration is done in conformity with the diagram of **Figure 1** below.

3.1.1. Kenaf Particles Preparation (*Hibiscus cannabinus* L.)

When they reach maturity, the kenaf stems are harvested and next dried in the sun for two weeks. Then, after the barks extraction (fiber) which represents 65 per cent of the total mass, the stems are chopped by a corn cutter-blower. The chopped wood is manually cleared out of the barks marks, and then preserved in the oven at 70˚C during 72 hours. The humidity rate after oven drying is 7 per cent. The chopped particles are next crushed in a knife crusher fitted with a sieve of 5 mm mesh of diameter so to result in a crush.

3.1.2. Cotton Particules Preparation

The cotton stems are got back from farms, dried in the sun and directly put in the oven for drying at 70˚C during 72 hours. The humidity rate after oven drying is 7 per cent. The stems are then coarsely chopped and properly crushed in a knife crusher to result in particles.

3.1.3. Binder Preparation

The bone glue which serves as binder for the material is crushed in powder (fine grains) with a Marlex's coffee mill. Next it is dissolved in a determined mass of prepared water. This mass of water corresponds to the desired humidity rate in the panel elaboration. It is set at 11 per cent in our study. Finally this mass of water is homogeneously mixed with the particles previously crushed.

3.1.4. Mast Preparation (Particles and Binder Mixing in a Thermopresser)

The mixture (cotton stems particles/kenaf + bone glue) has a total mass that is noted M. It is obtained by adding the glue solution to particles. The whole is next kneaded for 20 minutes in Laurent Perrier's kneader in order to get a homogenous mixture.

The obtained mixture is then put in a preheated square mould which dimensions are: 30 cm × 30 cm. Next it is packed down and the obtained packed form is called mast. A preheating temperature is applied to the mould and is equal to the panels pressing one.

3.1.5. Panels Thermopressing

The mould previously preheated at the pressing temperature is filled with the kneaded mixture. This mixture is first packed down in the mould to obtain the mast. The mould is next put back between the heating pans of the thermopressing. Then a constant pressure of 1.1 MPa is applied for a necessary time called pressing time in order to obtain the panel. For example, this pressing time is 20 mn for a temperature of 140˚C. After the panel

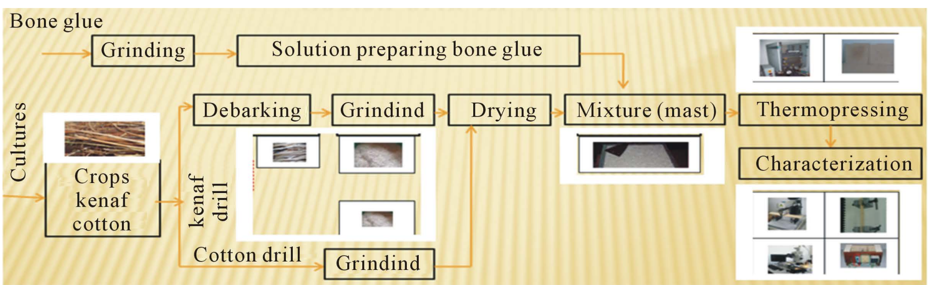


Figure 1. Diagram of the elaboration step and chipboard optimization adopted.

firing, it is removed from the mould. Then it is immediately weighed, labeled, its thickness measured and the firing time registered. It is next store in plastic packaging in order to limit humidity resumption.

3.1.6. Kenaf/Cotton Chipboard Characterization

Each plate weight is about 240 g and its dimensions are 300 × 300 × 5 mm.

The panel density is calculated by formula: the plate mass/plate volume.

- The inflation is determined by the plate thickness increasing after 2 and 24 total hours of immersing in water over test tubes of dimensions: 30 × 30 × 4 mm (cf. **Figure 2(c)**).
- The modulus of flexion elasticity (MOE) and the modulus of flexion rupture or flexion rupture strength (MOR) and the modulus of traction (MOT) are determined according to the norm NF EN 310 with the TA-Xi Analyzer test bed over test tubes of dimensions: 150 × 30 × 4 mm and 150 × 10 × 4 mm.
- The thermal conductivity is obtained by the method of the hotplate kept.

4. Results and Discussions

4.1. Particles Micrography

Some pictures taken with Nikon optical microscope (**Figures 3-5**) and **Table 1** give the particles characterization through their dimensional properties (length, diameter and shapes factor L/D). **Table 1** sums up the dimensional parameters of kenaf and cotton crushed particles.

4.2. The Physicochemical Characterization of Raw Materials

The physicochemical characterization of kenaf and cotton stems as well as the bone glue is summed up in **Table 2** and **Table 3**.

4.3. Thermal Properties of Raw Materials

4.3.1. Thermo Graphic Analysis (Temperature Effect on the Raw Material)

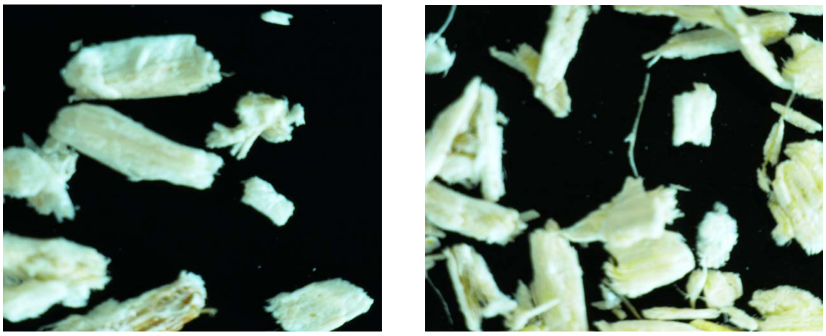
The blue curve in **Figure 6**, show the evolution of the mass loss of cotton stalks according to the temperature for a thermographic analysis under air. While that red indicates the evolution of the mass loss of cotton stalks according to the temperature for a thermographic analysis under nitrogen.

(a) (b) (c)

Figure 2. Test tubes for flexion (a), traction (b), testing and the inflation in water (c).

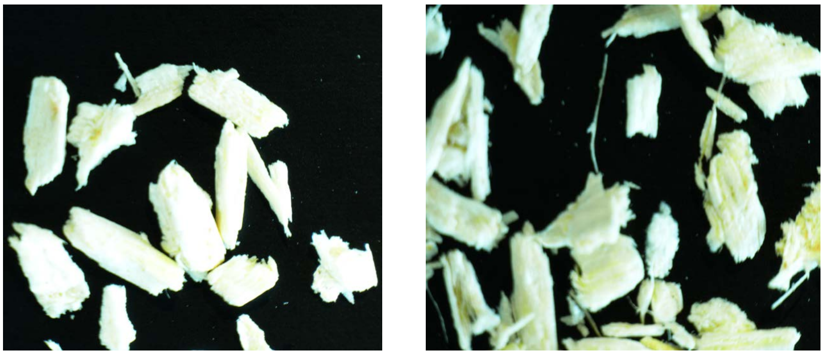
Table 1. Medium size of particles in the granulometric cut of cotton plant/kenaf stem crushes.

Category (granulometric cut)		Class (particles shape)	Length (µm)	Diameter (µm)	Shape factor (L/D)
Large	Pg > 1.6 mm	Large particles	4072 - 8643	1904 - 2977	2.59 - 4.54
Medium	1.6 mm > Pm > 0.25	Medium size particles	1500 - 5344	626 - 1436	3.16 - 5.48
Fine	Pf < 0.25	Fine particles	677 - 2236	84 - 538	4.80 - 5.21
Large	Pg > 1.6 mm	Long fibers	12,627 - 18,877	57.69 - 219	39 - 152
Medium	1.6 mm > Pm > 0.25	Medium fibers	6708 - 8964	50 - 176	46 - 89
Fine	Pf < 0.25	Short fibers	2042 - 2133	50 - 119	30 - 36



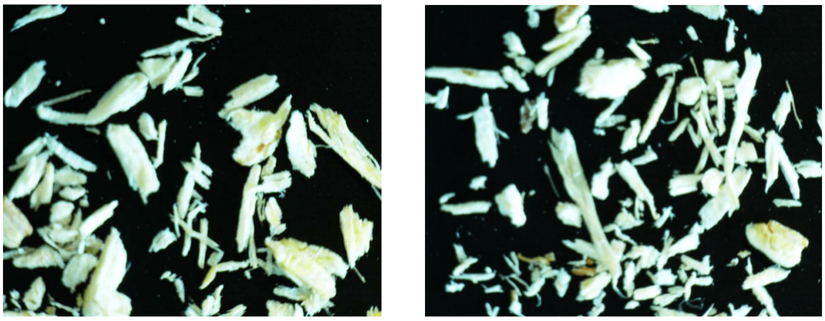
(a) (b)

Figure 3. Particles of large size (magnification: ×7.5). (a) Kenaf; (b) Cotton.



(a) (b)

Figure 4. Particles of medium size (magnification: ×10). (a) Kenaf; (b) Cotton.



(a) (b)

Figure 5. Particles of small size (magnification: ×10). (a) Kenaf; (b) Cotton.

Table 2. Chemical composition of source stems (kenaf and cotton): Danforth International, and TAPPI; Han, 1998, CTP, 1996 in Etude Agrice, 1998.

Types of fibers	Cellulose	Hemicellulose/pentosanes	Lignin	Ashes
Kenaf (wood)	37 - 49	18 - 24	15 - 21	2 - 4
Cotton (wood)	42.45	28.96	20.5	5.54

Table 3. Chemical composition of the bone glue.

Components	Unity	Content (% de MS)
Inorganic matter	(%)	2.45
Raw protein matter	(%)	94.10

The blue and red curves in **Figure 7** show respectively the same evolution in the case of cotton stems under the two same test conditions.

We notice that in the two cases, for a range of temperature included between 40˚C and 200˚C, each stem mass does not change. It means that we can operate with temperatures included in this interval without any risk of damaging the raw material.

4.3.2. Heat Flux Influence in Kenaf and Cotton Stems

The analysis of the calorimetric test results in **Figure 8** indicate the presence of two exothermic peaks respectively at 180˚C and 200˚C for kenaf and cotton stems. That is due to the lost of the sugar contained in these stems. However, this does not affect the properties of stems.

4.4. Implementation Optimization

Here we evaluate the influence of four parameters of implementation which are: the mast water content, the thermopressing temperature, the binder rate in the mixture and the panels firing time on mechanical and thermal properties of panels.

4.4.1. Mast Water Content Influence

The water content permits to obtain a homogeneous mixture between the binder and the particles in order to then make the mast. However, a too great humidity rate leads to a very long time of pressing, with important energy consumption and therefore a high cost panel.

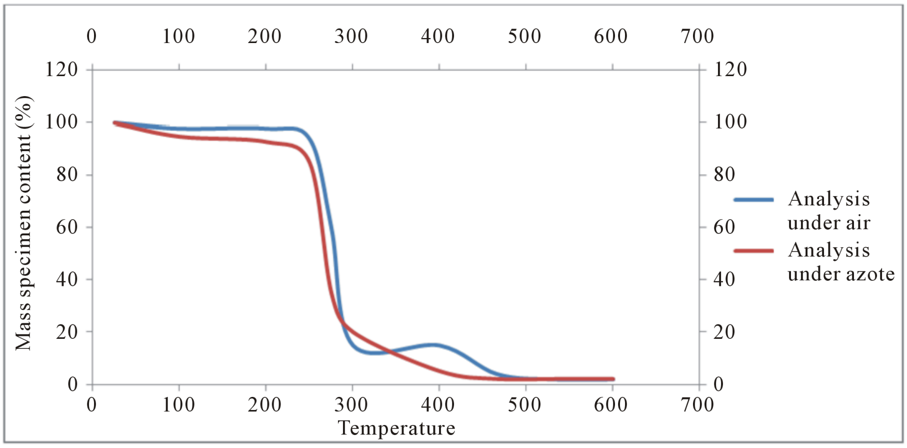


Figure 6. Curves of kenaf stem mass losing in thermo graphic analysis under air and nitrogen.

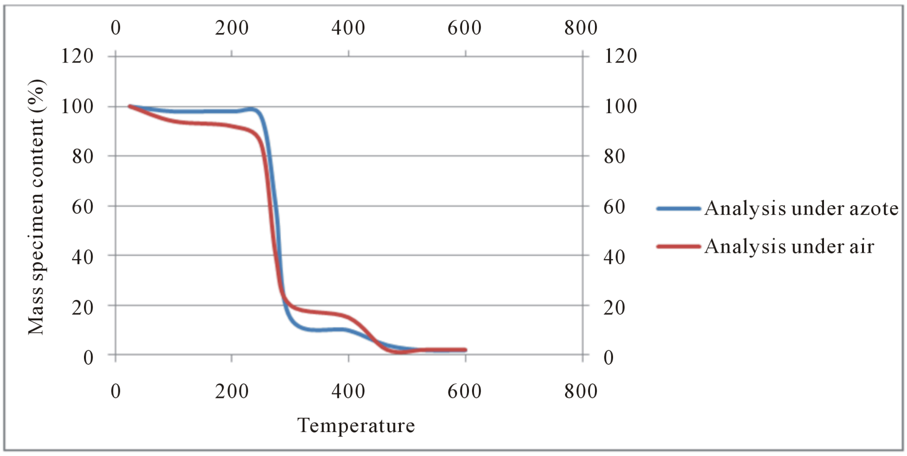


Figure 7. Curves of cotton stem mass losing in thermo graphic analysis under air and nitrogen.

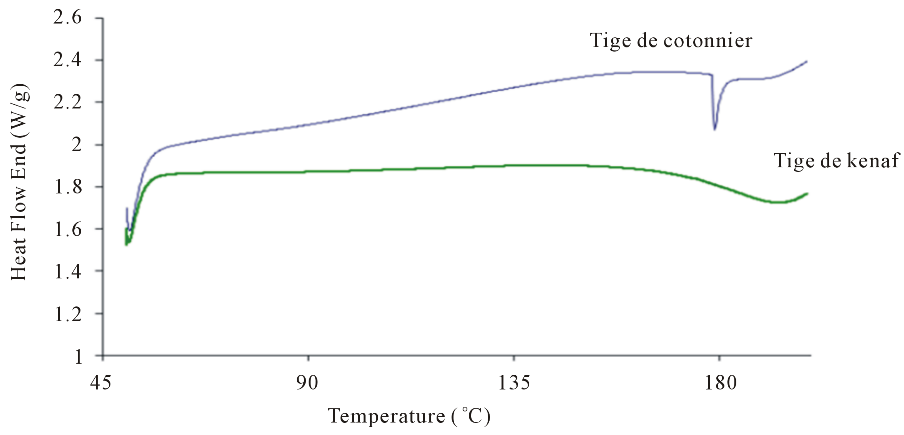


Figure 8. Curves of kenaf and cotton stem calorimetry.

Figures 9-11 show the physical and mechanical characteristics development of chipboard elaborated with different water contents varying from 5% to 33%.

First we notice that the water content has not a major impact on the density of chipboard. The density is on the order of 563 MPa. This is higher than the value recommended by AINSI A208.1-1999 standard which is of 550 MPa for the use of panels of weak density gotten with a UF resin.

We remark also that the modulus of flexion elasticity or modulus of Young (MOE) increases with the rise of water content. It reaches a maximal value of 1490 MPa for a mast water content which is 27%. Then it decreases for the other water contents higher than 27% (**Figure 8**). Finally, for mast water contents lower than 14%, MOE values are less than 550 MPa and therefore does not respect the AINSI A 208.1-1999 standard.

We also notice that the modulus of rupture (MOR) increases with the water content rise and reaches its maximal value of 14 MPa for a corresponding water content of 33% (**Figure 9**) in the mast.

In the light of these results, it appears clearly that the best values of physical and mechanical properties such as density, Modulus of Elasticity and Modulus of rupture are obtained with the mast water content equal to 27%. However, the pressing time (70 mn) required for this content seems very important for a factory production, that is why we recommend a water content rate of 20% which also guarantees high mechanical properties with a less important pressing time (20 mn).

The optimized water content fixed is 20%.

4.4.2. Temperature Influence on Density, Modulus of Elasticity and Modulus of Tearing

We evaluated the influence of the pressing temperature on the physical and mechanical properties of chipboard by using a scale of seven temperatures 120˚C, 130˚C, 140˚C, 150˚C, 160˚C, 170˚C and 180˚C, with a bone glue binder rate fixed at 10% and the water content in the mast fixed at 20%.

The results of physical and mechanical characteristics of kenaf and cotton stems chipboard determined by the different testing are put down in **Figure 12(a)** and **Figure 12(b)**.

According to **Figure 12(a)** and **Figure 12(b)**, the increase of the thermo pressing temperature from 120˚C to 140˚C has a beneficial effect on density and on all the mechanical characteristics but with a light increase of the inflation rate.

Densities contained in **Figure 12(a)** and **Figure 12(b)** allow us to classify the made panels in the category of weak density panels in accordance with ANSI A 208.1-1999 standard.

The modulus of flexion elasticity MOE (**Figure 13(a)** and **Figure 13(b)**) grows by 1417.2 MPa for a pressing temperature of 120˚C until a maximal value of 2232 MPa corresponding to a pressing temperature 140˚C. Then we observe a decrease of the MOE until 976.14 MPa corresponding to a pressing temperature of 180˚C.

In the scale of temperature growing from 120˚C to 140˚C, (**Figure 13** and **Figure 14**) MOE and MOR having respective values of 2232 MPa and 14.44 MPa are satisfactory according to ANSI A 208.1-1999 standard. However the thermo pressing times are high when compared with the conventional time used in firm which is on the order of 5 to 10 mn.

The temperature of optimal elaboration accepted is 140˚C.

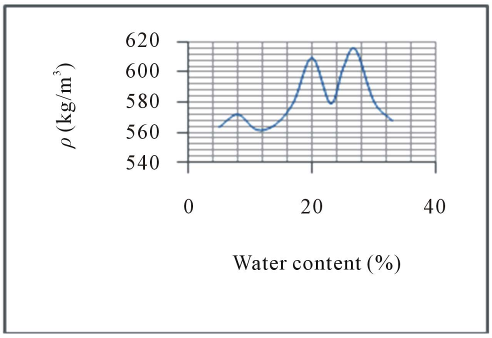


Figure 9. Water content influence on density.

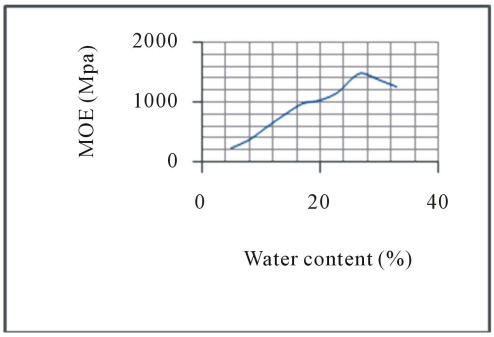


Figure 10. Water content influence on modulus of elasticity.

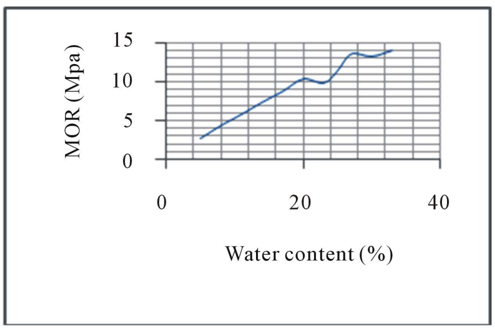
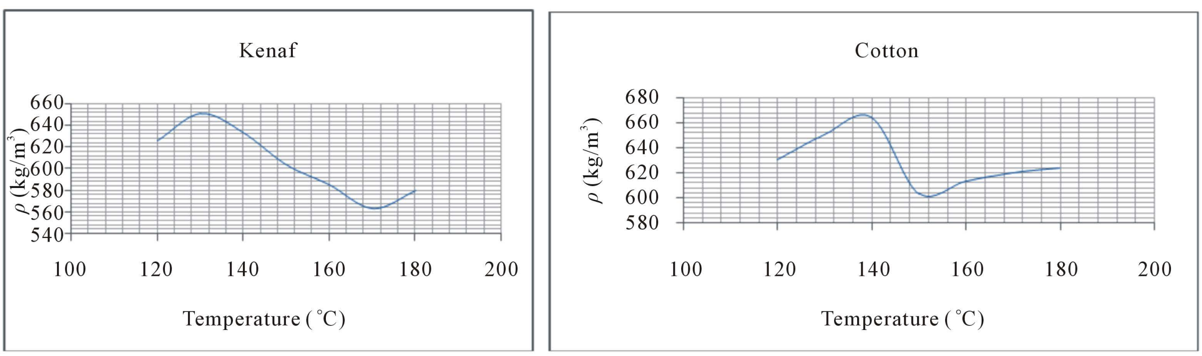
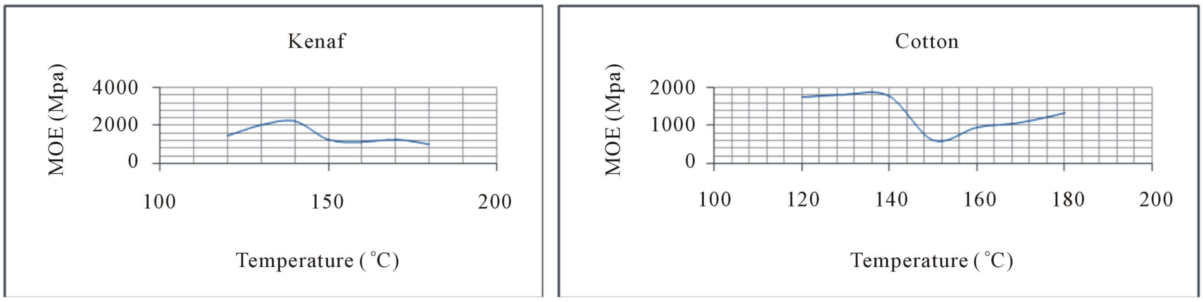


Figure 11. Water content influence on modulus of tearing.



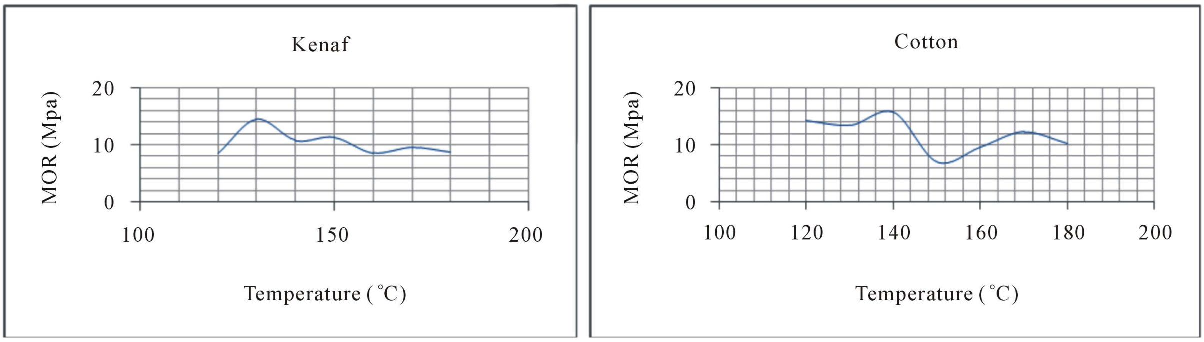
(a) (b)

Figure 12. Temperature influence on density.



(a) (b)

Figure 13. Temperature influence on MOE.



(a) (b)

Figure 14. Temperature influence on MOR.

4.4.3. Binder Rate and Temperature Influence

Five different rates of the binder (5%, 7.5%, 10%, 12.5% and 15%) have been used for the chipboard elaboration with a view to evaluating the impact of the binder rate on the physical and mechanical properties of the made panels. The obtained results are put down from **Figures 15-18**.

When the binder rates grow from 5% to 12.5%, we observe an increase of MOE and MOR which respectively reach values of 1950.78 MPa and 17.01 MPa. When the binder content is over 12.5%, there is a decrease of MOE and MOR. The best properties are obtained with the binder content which are 10% and 12.5% respectively for kenaf and cotton stem panels.

However the binder rate of 12.5% appears as the optimum in order to obtain maximal values of MOE and MOR.

Density of elaborated panels varies from 539.12 kg·m^{-3} to 703.704 kg·m^{-3} in accordance with the rate of the binder used.

The optimal binder rate identified is 12.5%.

4.4.4. Pressing Duration Influence

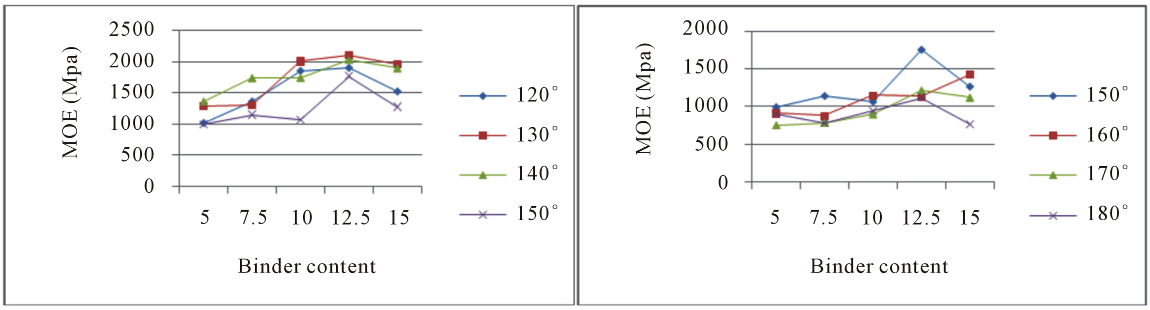
The pressing time also called firing time is highly linked to the mast water content, the thermopressing temperature and the binder rate. It is the minimum time which allows to obtain well built panels. We notice that if this time is insufficient, we obtain panels with defects (flocking, unrolling…).

The flocking is attributed to the presence of residual water vapour in the panel at the moment of the mould opening.

If temperatures are higher than 130˚C, the pressing time decreases to reach a minimum value for a binder rate of 10%, then it increases lightly. What shows the importance and influence of water contained in the binder.

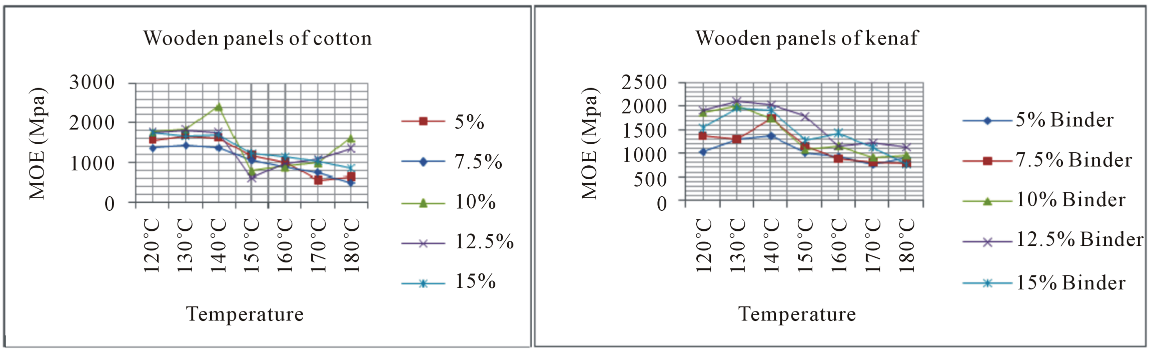
In **Figure 19**, we observe that for the mast water content fixed at 17% and the binder rate at 12.5%, we must proceed with a pressing temperature of 140˚C and a firing time of at least 20 mn. what permits to respect demands of standard and for economic reasons. These results relating to the binder rate influence and the pressing temperature are compatible with those found by Rigal, L. [7], et Kadja K. [8].

The optimum firing time is 20 mn.



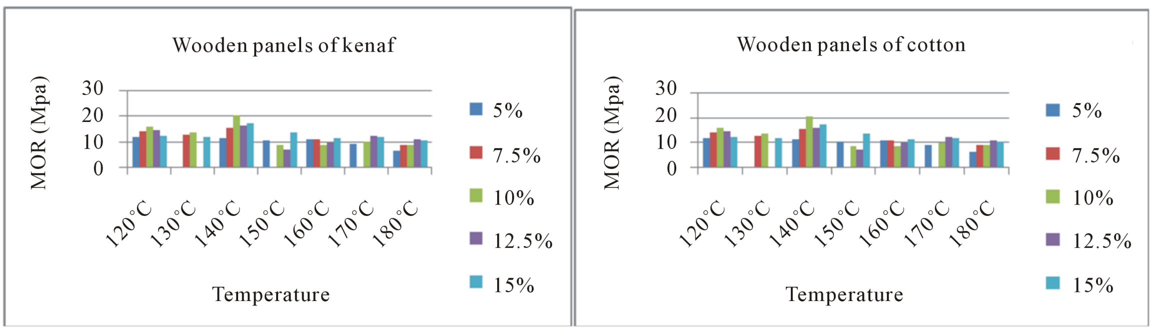
(a) (b)

Figure 15. Binder rate influence on MOE.



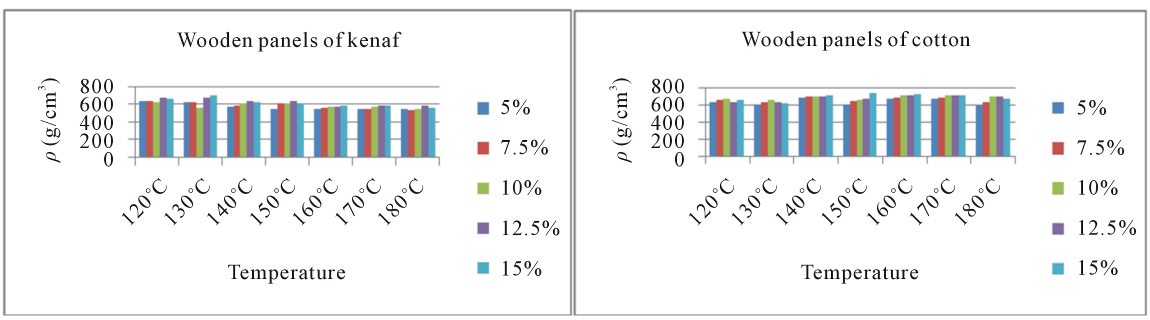
(a) (b)

Figure 16. Temperature and binder rate influence on MOE.



(a) (b)

Figure 17. Temperature and binder rate influence on MOR.



(a) (b)

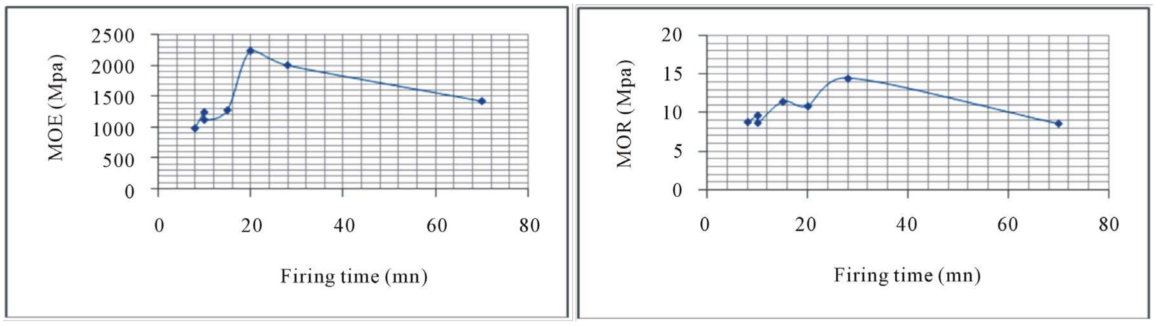
Figure 18. Temperature and binder rate on density ρ.

4.4.5. Pressing Temperature Influence on Density and the Thermal Conductivity of Panels

The thermal conductivity varies between 0.0684 and 0.0896 for kenaf panels. For cotton stem panels, it varies between 0.0889 and 0.1036. At this temperature, the obtained panels respect standard. The thermal conductibility of obtained panels (**Figure 20** and **Table 4**) being weak this results in a very low thermal expansion (Mark *et al.*), [9]. Density and porosity are two factors which impact on a predominant way the heat transfer. The maximum value $\lambda_{maxi} = 0.142$ and the minimum value $\lambda_{mini} = 0.0684$.

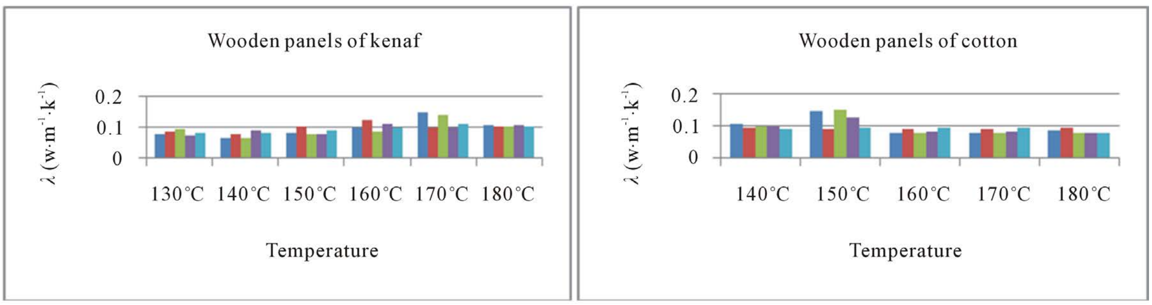
For T = 140˚C, we get panels with values of MOE, MOR and ρ in accordance with prescribed standards.

In literature, the thermal conductibility of chipboard is on the order of 0.12 W/m·K.



(a) (b)

Figure 19. Firing time influence on MOE and MOR.



(a) (b)

Figure 20. Temperature influence on the thermal conductivity.

Table 4. Pressing temperature influence on the thermal conductivity of panels.

	Thermal conductivity of panels (λ)					
Kenaf	0.0757	0.0649	0.0804	0.0987	0.1485	0.1052
	0.0838	0.0773	0.1042	0.123	0.0974	0.1004
	0.0947	0.0654	0.0779	0.0843	0.1395	0.1002
	0.0735	0.0898	0.0773	0.1096	0.096	0.1065
	0.0822	0.079	0.0893	0.0966	0.1123	0.1036
Cotton	0.1036	0.1452	0.0756	0.0756	0.0832	0.1036
	0.0908	0.086	0.087	0.086	0.0905	0.0908
	0.0944	0.1482	0.0777	0.0777	0.0777	0.0944
	0.0955	0.1254	0.0812	0.0812	0.0777	0.0955
	0.0889	0.0925	0.0912	0.0911	0.0777	0.0889
Temperature	130˚C	140˚C	150˚C	160˚C	170˚C	180˚C

Table 5. Summary of panels properties elaborated with optimized parameters.

Designation of the panel	Modulus of elasticity			Tearing constraint			Inflation in water (%)		Thickness	Density	Thermal conductivity λ (W/m.K)
	MOE (Mpa)	S	CV (%)	MOR (Mpa)	S	CV (%)	After 2 h	After 24 h	(mm)	ρ (kg·m^3)	
kenaf stem panel	2230.5	48.8	0.4	19.90	0.20	1.00	42	180	4.98	639.37	0.066
Barked cotton stem panel	1757.49	27.3	0.7	15.52	0.32	1.42	38.5	168	4.85	660.225	0.067

With: S = standard deviation; CV = Coefficient of variation.

5. Results of the Optimized Chipboard Implementation and Discussions

Table 5 gives the physical and mechanical characteristics of chipboard elaborated with the optimum parameters identified in the study.

First, we notice that the average density of the two panels types is higher than the value recommended by ANSI A208.1-1999 standard which is of 550 MPa for the use of panels of weak density obtained with the resin UF. That density is of 660.225 MPa for the barked cotton stem panel and of 639.37 MPa for the kenaf stem panel.

Also we observe that the modulus of flexion elasticity or young modulus MOE are at 1757.49 MPa and 2230.5 MPa respectively for the cotton and kenaf stem panel. These values are higher than those recommended by ANSI A208.1-1999 standard which is at 550 MPa. These results are similar to M.I MESNON *et al.*'s ones [10].

Furthermore we notice that the modulus of rupture (MOR) are respectively at 15.52 MPa and 19.90 MPa for the cotton and kenaf stem panel to 10 MPa which is recommended by ANSI A 208.1-1999 standard.

We observe that panels are very sensitive to water activity, what confirms the inflation results of panels.

The measured thermal conductivity coefficients are λ = 0.066 W/m.k for the kenaf stem panel and λ = 0.0667 W/m·k for the cotton stem panel. These values are under the one required by standard which is fixed at λ = 0.12 W/m·k: as a result, panels are in accordance with standard requirement for this parameter.

Finally the water inflation is respectively at 42% after 2 hours immersion and 180% after 24 hours immersion for kenaf stem panel and 38.5% after 2 hours immersion and 168% after 24 hours immersion for the cotton stem panel to 8% after 24 hours which is the value recommended by ANSI A 208.1-1999 standard.

6. Conclusions

The main objective of this work is to identify first the optimal values of chipboard elaboration parameters with kenaf and cotton stems by using a natural binder (the bone glue), then to proceed to the elaboration of two panels types with optimized elaboration parameters, and finally to determine mechanical characteristics of elaborated panels with a view of an indoor thermal insulation application.

To start, all panels have been elaborated in the prescribed conditions respecting optimum parameters identified in this study.

Next, we have evaluated physical and mechanical properties of panels.

A comparison of the results with the panels properties values required by ANSI A 208.1-1999 standard shows that our panels respect these requirements. However we notice an exception of the water inflation parameter which is unsatisfactory because the values obtained (38.5% et 42%) are greatly higher than the one recommended by AINSI A 208.1-1999 standard which is at 8% after two hours water immersion. As a result, the elaborated panels could only be used in a dried interior environment at the present stage. In a humid environment, they can have some exchanges between this environment and the panel because of its porous structure and its affinity between kenaf and cotton woods with water.

However, we can reduce sensibility in humid atmospheres by covering panels with wax and latex. But we must study influence of these coverings on the thermal conductivity coefficient.

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