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## THERMOCHEMICAL FRACTIONATION EFFECT ON MECHANICAL BEHAVIOUR OF BIOMATERIAL BASED COMPOSITES

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**ABSTRACT:** The necessity of natural resources protection impose to every country the use of renewable resources based alternatives as annual plants, agricultural and agro-industrial residues for human needs. The aim of this study is to obtain with local biomaterials, efficient flat composites which can be used as substitute of sawlog in furnishing and building works. Two categories of plant material were used: the fibrous material constitutes of core of *Hibiscus cannabinus* and the binding material from tannin based (*Parkia biglobosa* and *Pithecelobium dulce*) and from mucilage based (*Bombax costatum* and *Grewia venusta*). The parameters taken into account in the particleboard formulations were the physicochemical treatment of plant materials and the nature of the binders. The interest of this work is in the exploration of new sources of plants likely to be used as binders in the composites sector. Mechanical properties of the panels obtained were measured according to European standards. The interesting results obtained varied with the two types of variables and were in conformity with the American standards.

**Keywords:** Kenaf, Extrusion, Particleboard

### 1. INTRODUCTION

In the world, deforestation continues at alarming intervals (13 millions hectares per year between 2000 and 2005). But efforts are made to reduce significantly the loss of forest surface. However, Africa and South America remain the continents where the loss of forests is the widest. According to FAO reports, in 1993 the surfaces covered by dense forests were of 1400 km<sup>2</sup> and those of clear forests and raised savannah were 11 950 km<sup>2</sup>. But, in 1970, these areas were not any more larger than 5 040 km<sup>2</sup> (that is an annual rate of deforestation of 180 km<sup>2</sup>).

A little less than 20 % of annual exploitation of tropical forests is used for industrial wood (FAO, 1999). In sub-Saharan Africa, wood constitutes the first source of energy and building material. It is thus necessary to turn to alternatives such as the various composites and panels based on the use of agricultural and agro-industrial by-products and annual plants in order to reduce human pressure on natural forest (Gillah *et al.*, 2000, Mohanty *et al.*, 2002, Mazumder *et al.*, 2005). But, unfortunately these types of alternatives are lesser-known in developing countries namely those of Africa.

The main goal of these studies is to arouse the interest of the populations and the decision makers for the fibre and particle boards and to explore the possibilities of obtaining competitive panels which implementation will be adapted at the technological level of the under-developed countries.

But the specific aim of this work is to explore how thermo-chemical treatment-combined with chemical attack of the raw matter could affect the mechanical behaviour of kenaf and natural binders based particleboards.

### 2. OBJECTIVES

The scientific questions we attempted to answer specifically are the following:

- are tannin containing organs from *Parkia biglobosa* (Jacq.) Benth. pod and from *Pithecelobium dulce* Benth. stem bark and mucilage containing organs such as calyx of *Bombax costatum* Pellegr. & Vuillet and stem bark of *Grewia venusta* Fresen, enough adhesive to bind kenaf core particles for the manufacture of low density particleboards with bending mechanical properties meeting relevant standard requirements?
- can twin-screws extrusion of kenaf core with addition of chemical reagent, improve the mechanical characteristics of the panels obtained?

### 3. EXPERIMENTAL METHODS

#### 3.1. Materials

##### 3.1.1 Fibrous material

Particles used for the particleboards manufacturing were obtained from cultivation experiments of *Hibiscus cannabinus* L. (Kenaf), a Malvaceae belonging species which was carried out from May to August 2005 at the "Station d'Expérimentation Agropédagogique" (SEA) of "Ecole Supérieure d'Agronomie, Université de Lomé" in Togo.

##### 3.1.2. Tannin containing materials

Two types of plant material have been used as tannin containing materials in this work. The pod the fruit of *Parkia Biglobosa* and the stem bark of *Pithecelobium dulce*, both population protected legume species growing

wild in tropical savannah area. These plant organs were harvested in April 2005 at SEA.

### 3.1.3. Mucilage containing materials

The calyx of *Bombax costatum* and the stem bark of *Grewia venusta* were the mucilaginous materials used in this work. The two species grow wild in the Togolese savannah. The stem bark of *G. venusta* was collected from young plants in southern area of Togo in March 2005 and sun dried calyx of *B. costatum* were from northern Togo and bought in a local market also in March 2005.

## 3.2. Methodologies

### 3.2.1. Preparation of the bioadhesives

The binding vegetable materials were oven dried (70 °C; 48 hours), finely crushed using a RETSCH SM 100 type crusher equipped with a sieve of 2.5 mm mesh, and resulting powder kept dry at 50 °C in an oven until use.

### 3.2.2. Particles fractionation

#### 3.2.2.1. Mechanical fractionation

The core of *H. cannabinus* were oven-dried (70 °C, 48 hours) and milled into particles using the above crusher equipped with a 5 mm mesh sieve, which gave 67 % of particles and fibres with diameter varying from 0.25 to 1.60 mm, length from 1 to 7 mm for particles and length ranging from 5 to 19 mm for fibres.

#### 3.2.2.2. Thermo-mechanical and chemical fractionation

Thermo-mechanical fractionation combined with chemical treatment, responsible of material's internal structural modification was carried out in a CLEXTRAL BC 45 twin screws extruder. Before extrusion process, the kenaf core was firstly cut out in particles of relatively large size using an Electra type hammer mill. The coarse particles of kenaf core were introduced via a dosing hopper placed at the top of the first element of the cylinder which delivers the matter inside the sleeve. One per cent soda solution was continually added into the sleeve at the place desired using a DKM K20-2/PP/16 pump with a flow regulated to have a liquid / solid ratio of one (1). The binder consisting of the crude vegetable organs powder was also added or not added at the place desired with a flow regulated to have a fibre - binder proportion of 1-9. The temperature in the die was 60 °C. Resulting product was oven dried at 70 °C for 48 hours and kept dry at 50 °C in oven until use.

### 3.2.3. Elaboration of the particleboards

Two parameters affecting the mechanical properties of the panels were concerned in formulating the particleboards: the origin of natural binder (*P. biglobosa*, *P. dulce*, *B. costatum* or *G. venusta*) and the method of particles treatment (mechanical fractionation or extrusion).

#### 3.2.3.1. Preparation of the particleboard mat

In case of their use, the binders were incorporated at the rate of 10 % of fibre dry matter. For all types of panel, the *H. cannabinus* particles were mixed with the binder as appropriate according to the desired formulation of the panel and on the basis of 150 g initial

dry matter for each particleboard. A total of 40 g of water were used for humidification.

For the extrusion fractionation based type of panels, the binders were mixed to the particles during the extrusion process. This homogenous mixture was also mixed with 50 g of water.

In both cases, the mixture was done manually for 2 min then mechanically for 10 min using a PERRIER 721 mixer.

#### 3.2.3.2. Thermo-pressing of the panels

The mat was introduced in an aluminium mould (27 cm x 27 cm x 5 cm) electrically preheated at 180 °C. The mould was then closed and placed between two heating plates of a manual hydraulic thermopress of CARVER type (maximum pressure: 11 tons.m<sup>-2</sup>) and the pressure was gradually applied as follows: 5 tons.m<sup>-2</sup> for 60 seconds and then 10 tons.m<sup>-2</sup> for 4 minutes. The panel was then removed from the mould and weighted after cooling with ambient air.

#### 3.2.4. Mechanical testing of the particleboards

Six specimens of 150 mm x 50 mm and 6 specimens of 50 mm x 50 cm were cut from each particleboard according to the NF-EN 326-1 (1993) standard and conditioned at 20 °C, 65 % relative humidity for 14 days before testing. The 150 x 50 specimens were used for bending testing according to NF-EN 310 (1993) standard and the 50 x 50 specimens for internal bond strength testing in accordance with NF-EN 319, (1993) standard requirement. For both mechanical tests, a JFC type H5KT testing machine was used.

## 4. RESULTS AND DISCUSSION

Panel average density was  $435.62 \pm 21.85 \text{ kg.m}^{-3}$ . This type panel could be classified as low density particleboards (NF-EN 309, 2005) intended for a general use in dry medium. It can be used for insulation, ceiling and for wall coating. These panels density can be compared to those obtained by Sellers *et al.*, 1993. These authors reported panel density ranging from 300 to 500 kg.m<sup>-3</sup> for kenaf core particleboards manufactured respectively with Urea Formaldehyde (UF), Phenol Formaldehyde (PF) and Polymeric Diphenylmethane Diisocyanate (PMDI) resins.

### 4.1. Effect of the source of the natural binder on the panels mechanical properties

Comparing the binders, the panels can be classified in 3 categories (panels without binders added, panels containing mucilaginous binder and panels with tannic binder). Whatever the method of fractionation used, the modulus of bending elasticity (MOE) was more important for the panels containing a tannic binders than those containing mucilaginous binders whereas the latter showed a similar effect as adhesiveness panels (table 1).

The tannic binders showed the same prevalence on the bending strength (MOR) and on the internal bond strength (IB). But, for these two parameters, mucilaginous binders induced an improvement comparing with the results obtained on Binderless panels

Table I: Influence of the nature of the natural binder on the mechanical properties of the panel

Mechanical properties	MOE (MPa)		MOR (MPa)		IB (MPa)	
	N-Ext.	Ext.	N-Ext.	Ext.	N-Ext.	Ext.
Binderless Panel	344	1854	1.72	10.12	0.11	0.28
Tannin based Panels	433	2598	2.59	17.28	0.15	0.78
Mucilage based panels	353	1885	2.54	10.61	0.10	0.47

MOE: Modulus of bending elasticity; MOR: Bending strength; IB: Internal bond strength; N-Ext.: Non extruded matter; Ext. Extruded matter.

namely on the IB of matter extruded ones. Several authors reported that tannin based binder improves particleboard mechanical properties (Sowunmi *et al.*, 1996, Garnier *et al.*, 2001, Bisanda *et al.*, 2002, Li *et al.*, 2004) relating to the improving effect of tannin based binder (containing hardener or not) on the particleboards mechanical characteristics. The mucilaginous binders did not seem to influence the panels bending properties compared to that of panels without binder.

#### 4.2. Effect of the fractionation methods on the panels mechanical properties

In first global analysis, results obtained showed that the extrusion of the basic materials of the particleboards elaborated in this work improved in a largely significant way the mechanical properties of the panels.

##### 4.2.1. Fractionation effect on the panel modulus of bending elasticity

The treatment of the matter (fibre and binder plant organs) by extrusion in the presence of a solution of soda and at 60 °C and under pressure constraints, increased the modulus of bending elasticity (fig. 1) from 4 to 7 times in comparison with the values obtained on the panels made with kenaf core treated by single mechanical crushing.

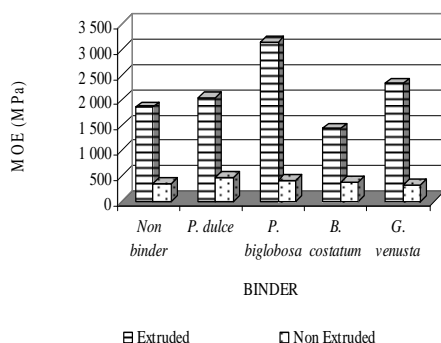


Figure 1: Effect of the fractionation process on the panel modulus of bending elasticity

For the panels based on single mechanical ground material, none average MOE values obtained (344; 463; 403; 382 and 323 MPa respectively for binderless, *P. dulce*, *P. biglobosa*, *B. costatum* and *G. venusta* based panels) had been able to reach the required value by American standard ANSI, 208.1, 1999 (550 MPa) for

this parameter. This situation can be explained by a low effectiveness of the mucilaginous material taken in a rough state. The use of these plants extracts would allow better appreciation of real adhesive effect of pectins on the panel's mechanical behaviour.

Conversely panels obtained with the extruded matter had largely exceeded (1,854; 2 041; 3,155; 1,439; 2,331 MPa respectively) this standard requirement. The best MOE value was reached with the panel containing the extruded mixture of kenaf core particles and *P. biglobosa* fruit pod. It clearly appeared that the extrusion treatment coupling with soda attack of the particles improved highly the panel's modulus of bending elasticity.

These results could be compared to that of Webber *et al.*, (2000) with kenaf-MDI particleboard (1731 MPa). But, with lower density panels, Sellers *et al.*, (1995) got MOE value lesser than ours (125 MPa) with conventional particleboard resins (UF, PF, PMDI). As for Xu *et al.*, (2003), MOE value (2,500 MPa) obtained with binderless kenaf particleboards using steam injection pressing process was higher than ours (1 854 MPa) on panels without binder made with extruded raw matter.

##### 4.2.2. Fractionation effect on the panels bending strength

The effect of extrusion is also very remarkable on the bending strength (Fig. 2) and the increase in this parameter was about 5 times the values measured on the panels with non extruded matter. Indeed, the MOR values obtained on the non extruded raw matter panels were very low and ranging from 1.72 to 3.17 MPa. As for the extruded raw matter panels, the MOR values varied from 8.07 for binderless panels to 23.02 MPa for the panel containing tannin crude organ from *Parkia biglobosa*. The average value of bending strength of extruded raw matter panels was 13.18 MPa. Except for the panels with *P. biglobosa*, all the values of MOR obtained with the other binders on the panels containing non-extruded matter are lower than that required by the standard (3 MPa). All the value of the extruded raw matter panels exceeded largely the ANSI 208.1 required value. These results namely extruded matter panels ones were closed to those obtained Webber *et al.*, (2000) (7.1 – 19.3 MPa) and Xu *et al.*, (2003) (12.6 MPa).

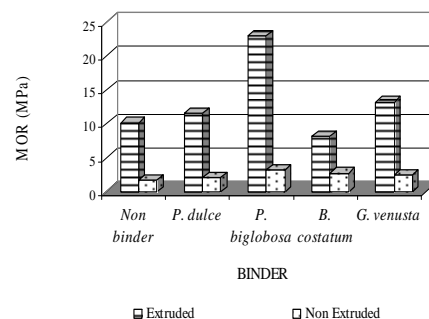


Figure 2: Effect of the fractionation process on the panel bending strength

##### 4.2.3. Fractionation effect on the panels internal bond strength

The internal bond strength of the panels also reflected the prevalence of the extrusion on the treatment by single mechanical crushing (Fig. 3). However, the ratio is less significant than that raised with the first two

parameters. But, *P. dulce* gave the best IB characteristic and close to the value induced by *P. biglobosa*. The panels with tannic adhesives gave better IB value than those with mucilaginous binder.

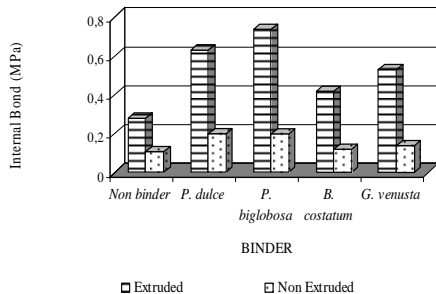


Figure 3: Effect of the fractionation process on the panel internal bond strength

The results obtained for IB varied from 0.12 to 0.28 MPa with 0.15 MPa as average value for the non extruded matter based panels and from 0.11 to 0.74 MPa with 0.52 MPa as average value for the extruded ones. All of the panels showed an internal bond strength value, higher than the American standard requirement (0.1 MPa). The internal bond strength values of non extruded matter panels were similar to that of Sellers *et al.*, (1995): 0.20 MPa) on low density panels made with kenaf core and conventional particleboard resin (UF, PF and PMDI). The panels made with extruded raw matter gave IB value closed to those reported by several authors (Webber *et al.*, 2000; Xu *et al.*, 2003).

## CONCLUSION

It can be concluded that whatever the nature of the binder, high-performance particleboard can be manufactured with kenaf core by using extrusion treatment combined with soda attack of the raw matter.

The tannic binders conferred to the panels more interesting mechanical properties than the mucilaginous ones. In the manufacturing of the particleboards, the tannic binders can be valid alternatives to the synthetic binders often more expensive and especially more prejudicial with environmental and human health. But the tannic material's effect has to be improved by using pure material such as extract or chemical modification of the matter or adding a hardener.

The mucilaginous binders did not seem to influence some mechanical properties of the panels namely bending parameters.

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