Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/12504
DOI URL: http://dx.doi.org/10.21474/IJAR01/12504

RESEARCH ARTICLE

VALORISATION OF BY-PRODUCTS OF THE COTTON SECTOR IN BENIN: DESIGN AND MANUFACTURING OF A DEFIBRATOR AND A THERMOPRESS FOR THE PRODUCTION OF INSULATION PANELS

Prof. Guy Clarence Semassou, Abdou Raimi Olayimika Ichola Alakouko and Dr. Edmond Claude Vodounnou
Laboratoire d'Énergétique et de Mécanique Appliquées (LEMA), 01 BP 2009 Cotonou, Université d'Abomey-Calavi, Bénin.

Manuscript Info

Manuscript History
Received: 19 December 2020
Final Accepted: 22 January 2021
Published: February 2021

Key words:-
Defibrator, Thermopress, Cotton by-Product, Manufacturing

Abstract

Cotton production is an important sector in the development of West African countries, particularly Benin. This waste constitutes an unused resource and a threat to the environment. The aim of this work is the design and manufacture of a defibrator and a thermopress for the valorisation of this waste into insulation panels. These two machines have been dimensioned and designed using TopSolid, Schemaplic, Matlab and RDM6 software. The defibrator is manual and enables the shredding of fiber waste and the extraction of impurities. The thermopress is manual and has an electric heating and temperature control system. It can form 30 mm thick panels with a surface area of 400 x 400 mm2 at temperatures up to 200 °C. These two equipments have made it possible to produce new bio-based materials that will help reduce the harmful effects of climate change.

Copy Right, IJAR, 2021,. All rights reserved.

Introduction:-

Nowadays, the problem of environmental protection concern all the world, especially in industrialized countries. The whole planet is aware of the harmful consequences related to the emission of greenhouse gases. According to statistic, buildings are the second largest emitters of carbon dioxide after industry [1]. That's why the fight against global warming necessarily involves buildings. In order to reduce the building's impact on the environment, the use of eco-materials will have to be developed. Therefore, it would be wise to look into the use of materials from natural origin such as plants (wood, straw, hemp, flax, rice husks, cotton by-products …) that are renewable, recyclable, sustainable and can contribute to limiting greenhouse gas emissions because of their ability to trap CO_2 [2-3]. In addition, the use of these bio-sourced materials will reduce construction costs.

In Benin, cotton waste are rejected into the environment. A proportion is simply burned by the population (figure 1) [4]. This bad practice contributes to the rise of CO_2 nature. It should be emphasized that this waste, even if it is biodegradable, poses problems in terms of environmental management [5-7].

Corresponding Author:- Abdou Raimi Olayimika Ichola Alakouko
Address:- Laboratoire d'Énergétique et de Mécanique Appliquées (LEMA), 01 BP 2009 Cotonou, Université d'Abomey-Calavi, Bénin.

Fig. 1:- (a) Discarded and burned crushing factory waste (b) Discarded textile factory waste [4].

In addition, several studies have shown that it is possible to manufacture building materials, particularly thermal and acoustic insulation materials, from cotton waste [8-12]. The use of insulation panels made from cotton waste requires a defibrator and a thermopress. The defibrator allows the separation of the fibers and their cleaning for the incorporation of a binder. The thermopress allows the shaping by thermocompression of the said panels. It is a very productive process that allows the stamping of composites, particularly adapted to composites coated with a thermoplastic resin and bio sourced materials [13].

In view of the cost and energy consumption of existing thermoforming press models [9,10,14-16], it would be better to design and manufacture a less expensive and energy-intensive thermoforming press so that artisans are able to produce insulation panels from these by-products.

This work is devoted to the design and manufacture of the defibrator and thermopress. Some materials based on these by-products were manufactured to validate the efficiency of the said machines.

Nomenclature:-

Elements	Symbols	Unity en IS
Manual force	Fm	N
Elemental force	Fe	N
Thermocompression force	Ft	N
Weight of the upper hot plate	P_c	N
Weight of the upper insulation plate	P_i	N
Weight of the U-iron of the spreader	P_{pal}	N
Weight of the spreader	P_p	N
Thickness of glass wool	e_l	mm
Thickness of the insulation plate	e_a	mm
Thermal conductivity of glass wool	λ_l	W/m.K
Thermal conductivity of steel	λ_a	W/m.K
Deformation	ε	
Surface or section	S	mm^2
Thermal expansion coefficient	α	$^oC^{-1}$
Diameter of the spreader axis	d	mm
Diameter of the square pitch screw	d_n	mm

Length of the square pitch screw	Lv	mm
Length of the square pitch nut	H	mm
Length of the pillars	L_M	mm
Elasticitylimit	Re	MPa
Maximum bending moment	$Mmax$	N.mm
Rail Height	h	mm
Thermal resistance	Rth	K/W
Coefficient of safety	s	

Materials and Methods:-

Materials:

Conventional machining and welding techniques were used to manufacture these two machines. As a matter of fact, the main materials used are as follows:

1. computer ;
2. CAD and calculation software (TopSolid; Matlab and RDM6) ;
3. electrical circuit design and simulation software (Schemaplic)
4. parallel turn ;
5. universal milling machine ;
6. hole drilling machine ;
7. welding station ;
8. angle grinder ;
9. calliper ;
10. angle ;
11. power saw ;
12. and machining accessories

Methodology:-

The design of the defibrator and the thermopress was the object of several technological choices taking into account the constraints imposed by the use and also the dimensioning of the main parts of these machines.

Thermopress study and dimensioning:

Mechanism type selection:

Hydraulic and pneumatic presses provide great efforts with very good precision, but their manufacture is very expensive for this use (thermopressing of panels) [17]. Moreover, this thermo-press is intended for the elaboration of laboratory samples, not for large production. It will thus be of mechanical type with a screw-nut system. Comparing the characteristics of the different types of threads, the square threads correspond to the screw-nut system of the thermo-press mechanism; because this type of thread has a very good efficiency and is adapted to the transformations of movements [18,19].

Thermo press functionning:

After the analysis of the thermoforming process, the synoptic diagram of its operation was created using TopSolid software (Figure 2a).

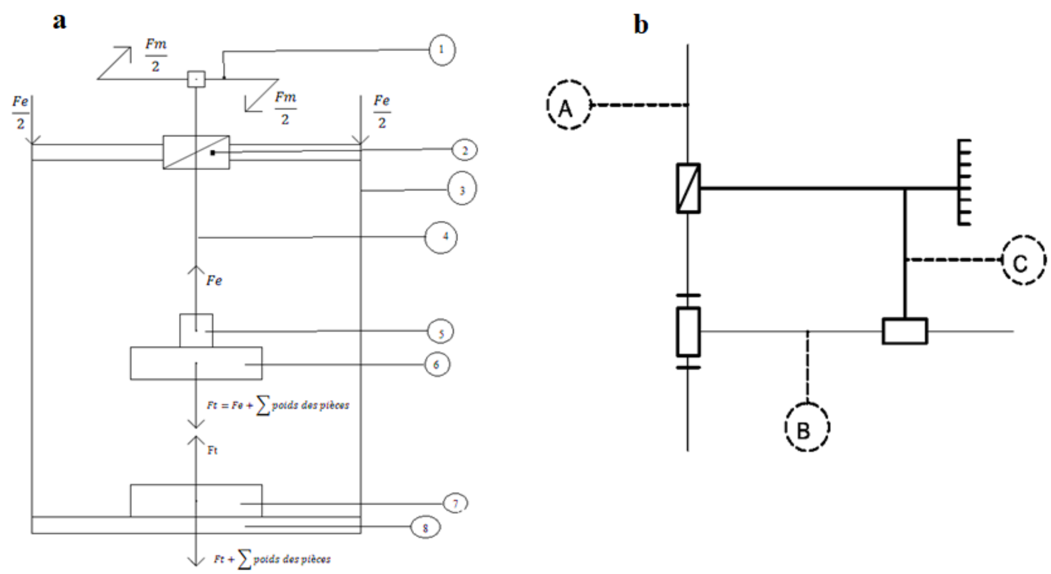

Fig. 2:- Thermo-press: (a) Synoptic diagram (b) Kinematic scheme.

Legend:
1: Crank; 2: Square thread nut; 3: Frame column; 4: Square thread screw; 5: Connecting piece; 6: Upper hot plate; 7: Lower hot plate and mold; 8: Table
A: Crank and screw (1+4); B: Crank + upper heating plate (5+6); C: Frame (2+3+7+8)
The thermo-press mechanism consists of several parts that form a total of three (3) equivalence classes (A, B, C) in the system. They have made it possible to have the kinematic diagram above (Figure 2b).

Dimensioning of the main parts:-
The thermopressing force Ft exerted on the material is a function of the manual force Fm and is given by the following expression

$$F_t = \frac{F_m.L_L.\pi}{Pas} + \sum Parts\ weight \quad (1)$$

With : L_L the length of the lever.

$$\sum Parts\ weight = P_C + P_i + P_{pal} + P_P \quad (2)$$

The following parts have been dimensioned with the conditions of resistance and the characteristics of the materials used [20-22] :

- the diameter of the spreader axis: ; $d \geq \sqrt{\frac{8.s.(P_c + P_i + P_{pal} + P_p)}{\pi.R_e}}$ (3)
- the diameter of the square pitch screw : ; $d_n \geq \sqrt{\frac{4.s.Fe}{\pi.Re}}$ (4)
- the length of the square pitch screw : ; $L_v < \frac{\pi.d_n^2}{16}\sqrt{\frac{\pi.E}{F_e}}$ (5)
- the length of the square pitch nut : ; $H \geq \frac{2.Fe.s}{\pi.d_n.R_e}$ (6)
- the length of the pillars : ; $L_M < 4.\pi.h^4\sqrt{\frac{0.032E}{F_e}}$ (7)

For the calculation of these different parts, the maximum value of the manual gripping force Fm for a normal man is 500 N [23].

Thermo-heating study:

The temperature of the thermopress

The compression temperature must be controlled during thermocompression. The physical, chemical and mechanical properties of the plates depend on the compression temperature. For thermocompression, the temperature must be below 180°C. Above this temperature, the mechanical properties of the plates drop. The best thermocompression temperatures are between 140°C and 180°C [9,10].

Thermal expansion of the upper hot plate

During heating, the hot plates expand. This expansion results in an increase in the dimensions of the plates. As the lower hot plate is free, the expansion will be unconstrained. Research has shown that the temperature variation and the variation of the dimensions of an object are related by the following relationship [20,24]:

$$\varepsilon = \alpha.\Delta T \quad (8)$$

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0} \quad (9)$$

ΔT is the temperature variation; $\Delta T = T - T_0$.

Insulation of hot plates

To avoid heat loss during thermopressing, thermal insulation of the hot plates is essential. This insulation can be done by using glass wool which will be inserted between the two plates (Figure 3).

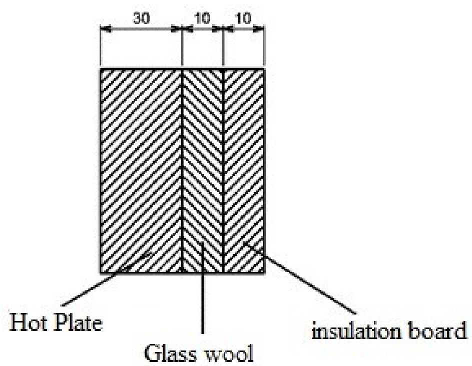

Fig. 3– Insulation of the hot plate

This insulation allowed the temperature on the upper surface of the plate to be lowered. It creates a thermal resistance to avoid losses.

$$R_{th} = \frac{e_l}{\lambda_l.S} + \frac{e_a}{\lambda_a.S} \quad [25] \quad (10)$$

Electrical circuit of the hot plate heating system:

An electrical circuit has been designed to regulate the temperature of the thermopress. This circuit maintains the temperature of the hot plates at the temperature chosen by the user. It consists mainly of a temperature regulator (thermostat) 0^0C - 400^0C, a contactor D-09: 220 V, a bipolar circuit breaker and heating resistors. The circuit has been designed using **Schemaplic** software.

Analysis and dimensioning of the defibrator:

Description and functioning:

The defibrator is manual. It consists of an upper spindle, a lower spindle, a frame composed of three supports, two guide shafts, four guide supports, two spindle holders and the assembly elements. It is made of a simple mechanism: a reciprocating translation movement. The upper spindle is set in reciprocating translation motion by the user. It is guided by the spindle holders which slide on the guide axes of the slide. Figure 4 shows the synoptic diagram of the defibrator.

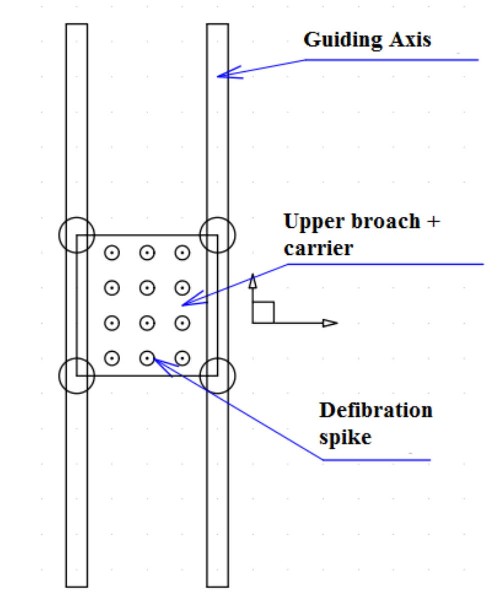

Fig. 4:- Synoptic diagram of the defibrator.

Dimensioning of main parts:
The defibrator has two axes that guide the upper broach. It is subjected to a lineal load that is uniformly varied (q) and dynamic. The dimensioning of the guiding axis has been done in the RDM6 software in the FLEXION menu. Figure 5 shows the static diagram of the guide axis.

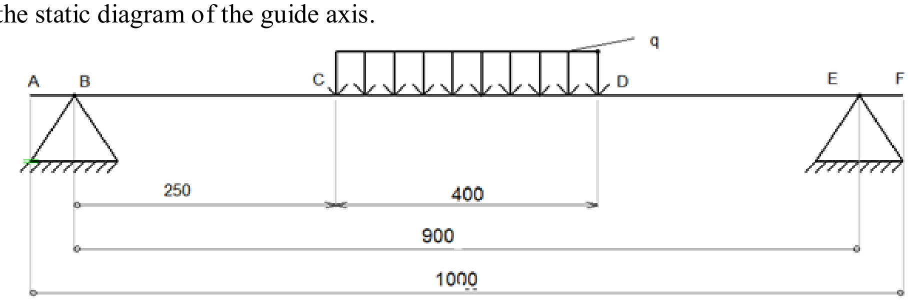

Fig. 5:- Guiding axis.

The bending strength condition of this beam is :

$$D \geq \sqrt[3]{\frac{32.s.M_{\max}}{\pi.R_e}} \quad [20] \qquad (11)$$

Design of the defibrator and the thermopress:
The design of the different parts was done in the TOPSOLID software, 2010 version, using the different results of the dimensioning of the parts. This software also allowed the assembly of the thermopress and the defibrator to simulate the operation of the mechanisms.

Manufacturing of the defibrator and the thermopress:
Both pieces of equipment were manufactured using the conventional mechanical manufacturing method. After the design, the ranges of machining of the different parts were established. The parts were manufactured with the necessary machine tools and tools. The machines were then assembled according to the different requirements of the design.

Results and discussions:-

Dimensions of the main parts of the defibrator and thermopress:

The analysis of the design and the dimensioning of the elements made it possible to know the characteristics and dimensions of the main parts. The results of the different dimensioning of the thermopress parts are in the following table.

Table 1:- Dimensioning of the thermopress.

Parts	Solicitations	Dimensioningresults (mm)	Choice (mm)
Square Pitch Screws	Compression	Root diameter $d_n \geq 42.30$	$d_n = 48$
	Buckling	Length $L_v < 1080.38$	$L_v = 455$
Square pitch nut	Shear	Nutheight $H \geq 18.63$	H=50
Pillar	Compression	Rail height $h \geq 38.40$	h= 60
	Buckling	Length $L_M < 10906.51$	$L_M = 660$

The choices made respect the conditions of resistance of the dimensioning and the availability on the Beninese market. For the defibrator's guide axis, the dynamic dimensioning allows us to have the critical position of the dynamic load (upper broach + carrier). From the RDM6 software, we can see the bending moments in the axis (Figure 6).

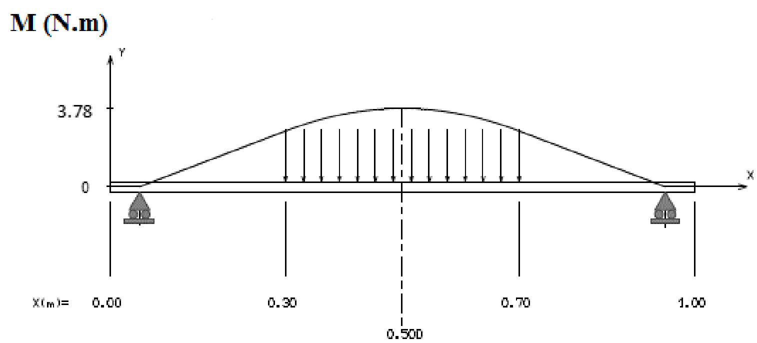

Fig. 6:- Bending moment in the guide axis (RDM6).

The critical cross-section is in the middle of the axis (xc=0.5 m) and the maximum bending moment is *Mmax = 3.78 N.m*. From the strength condition, the diameter is *D > 8.55 mm* and the choice of the corresponding diameter is 18 mm. This choice was made to limit the deformation in the middle of the guide axis. However, it should be pointed out that from a diameter of 14 mm, this deformation is 0.756 mm less than the unit. The choice of 18 mm is once again justified by the availability on the Beninese market.

Thermo-heating study:

In order not to limit the use of the thermopress too much, the maximum temperature has been limited to 200^{0}C. This limit keeps the temperature within the recommended range [9,10].

The initial length of the plates so that the final length L is equal to 400 mm at a temperature of 2000C was determined using expressions (8) and (9).

$$L_0 = 0{,}398m$$

The initial length of the hot plate is then 398 mm.

Using expression (10) and the thermal conductivity of the plates, we have $\lambda_l = 0{,}042\ W/m.K$, $\lambda_a = 45\ W/m.K$ and therefore, $R_{th} = 1{,}50\ {}^0C/W$ .Let be a reduction of $1{,}50\ {}^0C$ per unit of heat output.

Temperature monitoring circuit:
The monitoring circuit for the thermopress temperature is as shown in the following figure. It has been designed and simulated in the Schemaplic software.

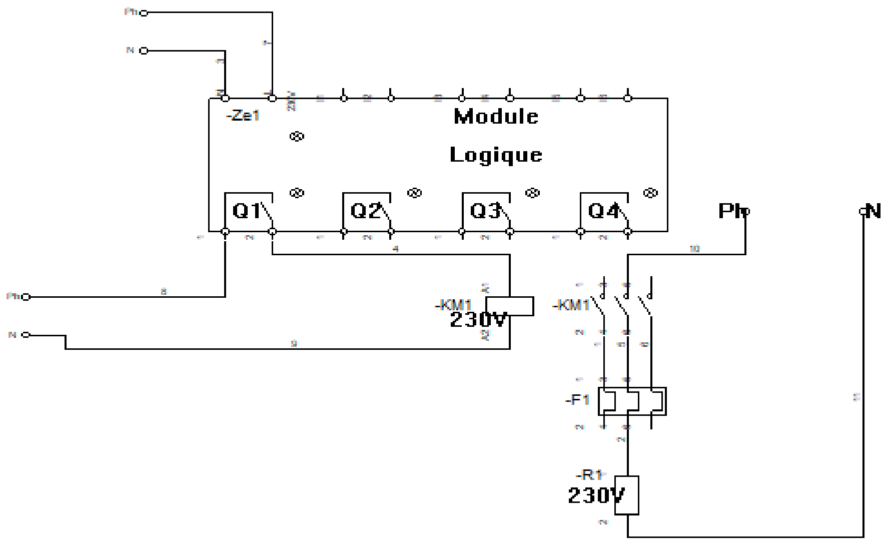

Fig. 7:- Thermopressing electric circuit.

Design and drawing of construction plans:
The results of the different dimensioning results have made it possible to design the different parts of the thermopress and the defibrator. The computer-aided design of the thermo-press and the defibrator is shown in the following figure:

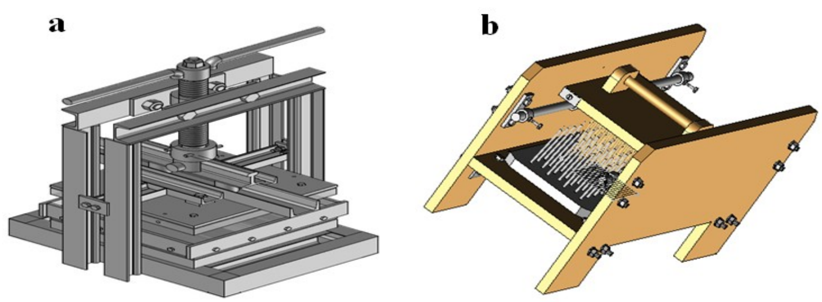

Fig. 8:- Design: (a) Thermopress (b) Defibrator.

Manufacturing of the defibrator and thermopress:
After the design of the thermo-press, the machining ranges were carried out and then the production started on the machine tools of the Abomey-Calavi Polytechnic's manufacturing workshop. The following figure shows the defibrator and thermopress.

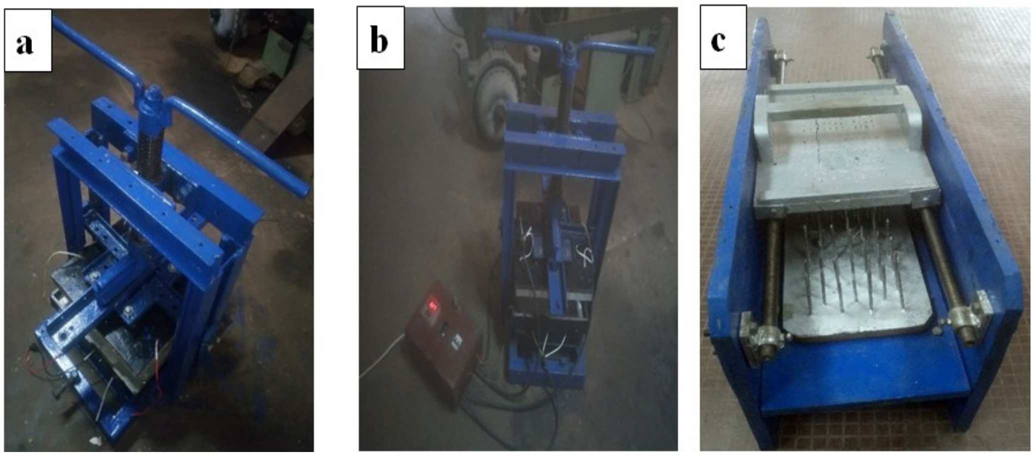

Fig. 9:- Thermopress (a,b) and Defibrator (b) after manufacturing.

Testing of the defibrator and thermopress:
To confirm the operation and performance of the machines manufactured, insulation panels were produced using them. Figure 10 shows these panels.

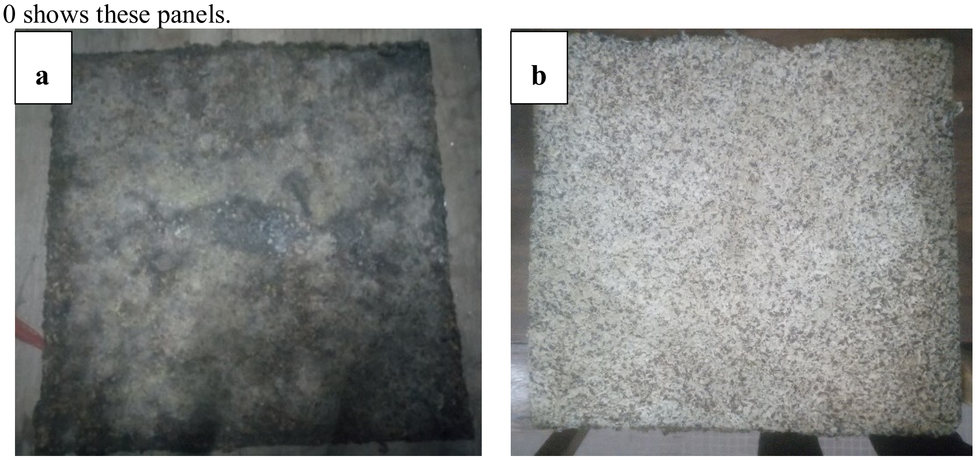

Fig. 10:- Panels made with the machines: (a) waste cotton fibres + manioc starch, (b) waste cotton fibres + glue waste from the textile factory.

Conclusion:-

This study has enabled the design and manufacture of two equipments that permit the valorisation of by-products of the cotton sector. This waste, added to a binder, could produce thermal insulation panels in buildings. The use of these panels in buildings would reduce the effect of CO_2 on the environment and solve some environmental problems. These materials must be characterised for compliance with the standards in vigour in the building field. However, the equipment manufactured is manual and is therefore intended for laboratory work. For a good performance of these machines, it will be necessary to improve them by making the defibrator motorised, the defibrator and the thermopress semi-automatic with a temperature and pressure control system.

References:-

1. T.T. Nguyen, Contribution à l'étude de la formulation et du procédé de fabrication d'éléments de construction en béton de chanvre, PhD Thesis, University of Bretagne - Sud, 2010.
2. Federation Francaise du Batiment, Les matériaux biosourcés dans le batiment, Paris, 2015.
3. Agence de l'environnement et de la maitrise de l'énergie, Guide des matériaux isolants, Paris, 2015.
4. G. Caroline, Restitution de Stage au Potemat, Training report, University of Abomey-Calavi, 2018
5. AgenceEcofin, agroindustrie/Coton, [On line] www.agenceecofin.com/coton/0706-57556-le-benin-devient-second-producteur-africain-de-coton-en-2017/18-avec-un-volume-de-597-986-tonnes [Access on 10.10.18].
6. J. Vodounou, Valorisation des résidus de cotonnier : Etude et conception d'un broyeur de tiges de cotonnier, Trainig report,University of Abomey-Calavi, 2013.

7. S. Chogou, Itinéraires techniques et pratiques paysannes dans les zones cotonnières du nord du Bénin,Inrab, 2011.
8. K. Borchani, Développement d'un composite à base d'un polymère biodégradable et de fibres extraites de la plante d'Alfa, PhD Thesis, École Nationale d'Ingénieurs de Sfax, 2016.
9. S. Soulama, Caractérisation mécanique et thermique de biocomposites à matrice polystyrène recyclé renforcée par des coques de cotonnier (Gossypium hirsutum L.) ou de particules de bois de kénaf (Hibiscus Cannabinus L.), PhD Thesis, University of Technology of Belfort, 2014
10. Y. Nenonene, Elaboration et caractérisation mécanique des panneaux de particules de tige de Kénaf et de bio adhésifs à base de colle d'os, de tannin ou de mucilage, PhD Thesis, University of Toulouse, 2009.
11. N. Dujardin, Un materiau biosourcé de choix : les fibres naturelles, caractérisation et application. 25èmes Journées Scientifiques de l'Environnement, L'économie verte en question. (2005) pp.1-11.
12. T. Mohamed, Contribution à la caractérisation thermo physique de matériaux bio isolants : Valorisation des déchets de bois de palmier, PhD Thesis, Centre d'Etude et de Recherche en Thermique Environnement et Systèmes, 2016.
13. J. M. Berthelot, Mécanique des Matériaux et Structures Composites, Le Mans, 2013 ,pp. 1-667.
14. Axyal, Thermocompression, [On line], www.axyal.fr/fr/technologie/thermocompression.fr[Access on 15.11.18].
15. Logistmarket, Presse dechet, [On line], www.logistmarket.fr/presse-dechets/586138570-cp.htm [Access on 15.11.18].
16. ExpoPermanent, Presse industrielle, [On line], www.usinenouvelle.com/expo/presses.html. [Access on 15.11.18].
17. Hounkpe, Conception et réalisation d'une presse d'emboutissage de moule (2) de tuile flamande Mécanique, Master Thesis,University of Abomey Calavi, 1998.
18. Souwin, Etude et conception d'une presse manuelle pour la destruction des produits non conforme à SOTIBE, Training report, University of Abomey Calavi, 2017.
19. Papa,Conception d'une presse pour la litière de filao, Master Thesis, Ecole Polytechnique de Thiès,1998.
20. J. L. Fanchon, Guide de mécanique. Nathan, 1998.
21. J. P. Mercier, G. Zambelli et W. Kurz, Introduction à la science des matériaux. Presses polytechniques et universitaires romandes, Third Edition, 2002.
22. F. Sidoroff, Mécanique des milieux continus. École Centrale de Lyon, 1980.
23. S. Wong,Valeurs de référence pour la force de préhension des Canadiens de 6 à 79 ans : Enquête canadienne sur les mesures de la santé 2007 à 2013.Statistique Canada. 27(10) (2016) 3-11.
24. L. Tremblay, La dilatation thermique. Collège Mérici, 2016.
25. Y. Jannot, Transfert Thermique.Ecole des Mines Nancy, 2012.
26. Agence de l'environement et de la maitrise de l'energie, Etat des lieux des agromatériaux pour la construction en region centre. Alter énergies France, 2011.
27. Institut National de la Statistique et de l'Analyse Economique, Production agricole, [On line]. www.insae-bj.org/statistiques/statistiques-economiques. [Access le 10.10.18].
28. Hebert Anne, CIRAD/Expo COTON itinérante, [On line]. Available: www.diplomatie.gouv.fr/fr/IMG/doc/ExpoCoton-FR.doc. [Access le 10.10.18].
29. Y. Lebaupin, Comportement à l'impact et post-impact d'un composite lin/Polyamide 11 élaboré par thermocompression, PhD thesis, University of Laval, 2016.