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Full Length Research Paper

Processing of a bio-sourced material and determination of its properties: compound of recycled polymer reinforced with vegetable stocks from non-food biomass residues

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The eco-material and bio-sourced material field has been enjoying a strong growth driven by tougher environmental regulations. The major challenge in this field relates to the replacement of the classical synthetic reinforcements (carbon, glass, kevlar,..) by natural reinforcements. In this approach, this study aims at using biomass residues from ginned cotton and plastics at end-of-life in order to develop streamlined functional structures. A compound of recycled polystyrene reinforced with cotton husks is produced by plastic injection. This study presents the mechanical and physical properties of this material. An Finite Element modelling of the behaviour of this material is developed with a view to optimizing its manufacturing and its properties. The interest is to develop recyclable materials from polluting biomasses with no market value to minimize their environmental impact while giving them a second life for various applications such as the production of vehicles' inner fittings, casings of cell phones, computers, photocopiers, etc.

Keywords: Bio-sourced materials, recycled polymers, compound, cotton husks.

INTRODUCTION

Burkina Faso is a predominantly agricultural country. Cotton farming is one of the main activities of farmers.

Ranked as the fourth cotton producer in Africa, Burkina Faso produces, on the average, 500,000 tons of

cotton per year. The ginning industry provides three main by-products, including:

the seeds: used for oil production,

the fibers: used by the textile industry,

the residues from the ginned cotton or "cotton husks": They represent 30% of the volume processed, and they are neither processed, nor developed; but they are burnt as fuel energy or to get rid of them; this is a major green house and environmental pollution problem due to the significant CO₂ emission.

The significant release of used plastics such as polypropylene into the environment also poses a threat to humans and their environment.

The study aims at collecting and processing used plastics and residues from ginned cotton.

The use of vegetable fibers in a composite material is not a new concept. Indeed, the mainstreaming of vegetable fibers (wood, linen, hemp) in thermoplastic or thermosetting materials to replace fiberglass is a concept that is already industrialized and marketed. Many a product has been developed and already functional in several sectors of activities, including the automotive sector, the civil engineering sector, the packaging sector, the industrial sector, etc..

Thus, there are composite materials developed with polymer matrix (synthetic or natural) and vegetable fiber reinforcements.

Our work aims to develop plant biomass residues and to recycle polystyrene plastic wastes.

To carry out this experimental study, we needed, first of all, to produce granulates from ginned cotton residues and recycled polystyrene.

The development of bio-composites linked by maize starch was described by: Holz RohWerkstoff, (2002);

Other authors such as Lei and al., (2008); Pizi and al., (1993) *Holzforschung*, and Stéphanie Wielland, (2007) and Amen Yaow NENONENE, (2009) worked on the development and the study of the thermal and mechanical properties of composites with plant tannin-based adhesives.

The development of composites with soya-based binders was also investigated by other authors such as Lorenz et al., (2006), Wescott et al., (2006), Madison Wisconsin, and Amaral-labat et al., (2008).

There are also soya protein-based composites developed recently by: Pizzi J. *AdhesionSciTechnol.*, (2006) and finally, there are semi-natural composites combining resin and natural fibers (hemp, linen, ...) or wood, partially or fully bio-degradable, which were equally developed and contribute to environmental protection.

To carry out this experimental study, we needed, first of all, to produce granulates from ginned cotton residues or from polyester. Then, we used the product obtained to develop the desired material using an injection moulding machine. A mechanical characterization of the material obtained allowed us to explore and to

determine its mechanical properties through various tests.

Finally, the experimental results achieved were used to feed into digital simulation models to predict the behaviour of the material developed, under the effect of various types of loads in a given context of use. The modelling tool used for this purpose is the ABAQUS calculation code.

MATERIALS

Raw materials

- **Residues from ginned cotton or cotton hulls**

The residues from ginned cotton were collected from the Bobo II ginning factory of SOFITEX. This factory, with a capacity of 150,000 tons, produces about 45,000 tons of ginned cotton residues. The mass density of the cotton husks is 0.61 g/cm³. The cotton husks are cleaned of dust, stones and other contaminants.

- **Recycled polystyrene for the matrix of the composite**

The polymer used for the matrix of composite materials is recycled Polystyrene. It comes from used packaging materials and other plastic products collected in the city of Bobo-Dioulasso. It is found in a significant quantity abandoned in nature. Its mass density is 0.80 g/cm³; its elastic modulus (E) is 800 MPa and its break elongation is 306% according to the ASTM D638 procedure. Its fusion temperature is in the region of 240°C.

- **Mixture**

The mass density of the mixture obtained (recycled Polystyrene + Cotton husks) is: 0.68 g/cm³. The moisture rate of the mixture obtained: for the development of a sample of 3.502g, 0.26g of water is added, i.e. a moisture rate of 7%. With this polymer and cotton husks, three types of composites are produced with a cotton husk weight ratio of 10%, 15% and 20%, respectively.

Devices used

Drying furnace

The furnace used for drying the cotton husks and the granulates, is of Heraeus K114 brand. It was set at about 90°C for 24 hours.



Figure 1. Granulates when exiting the granulator

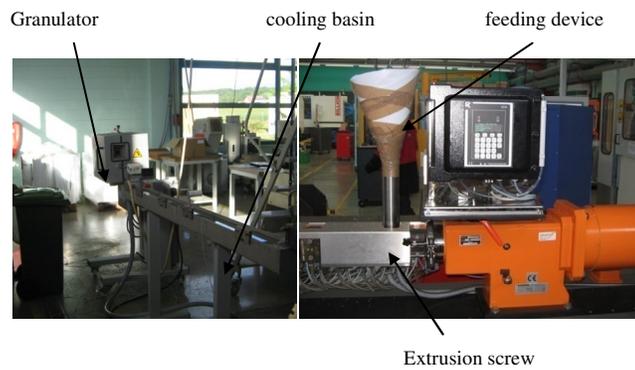


Figure 2. Assembly for the extrusion



Figure 3. Injection moulding machine

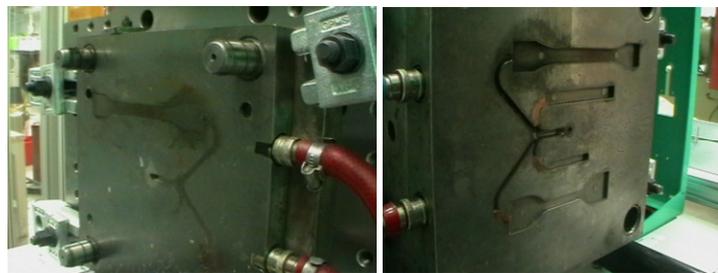


Figure 4. Footprint mold



Figure 5. Sample specimen

Microscope

The microscope used to take the photos of the fractures of samples is a Nikon Multizoom AZ100 microscope.

Grinder-mixer

The grinder used for grinding and mixing the mixed cotton husks and polymer is the RapidGranulator knife

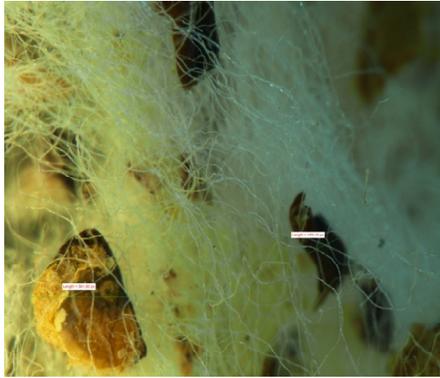


Figure 6-a: Image of hulls of cotton x40

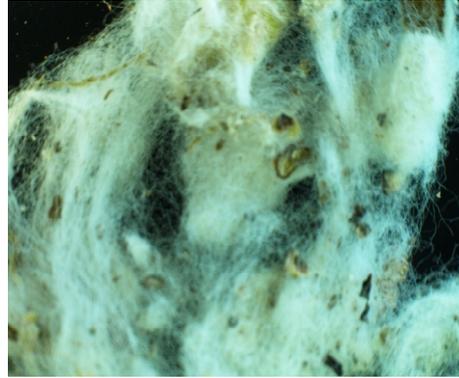


Figure 6-b: Image of hulls of cotton x10

Table 1. Dimensional parameters of cotton hulls

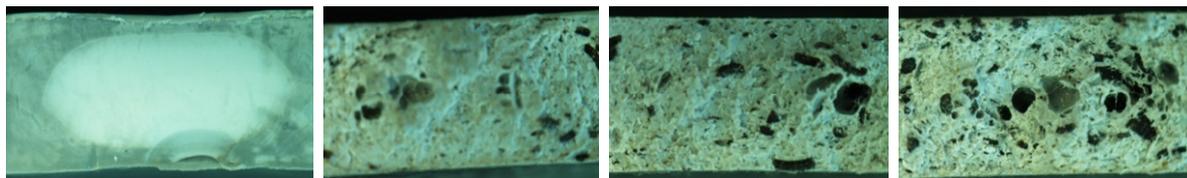
Category	Class (form of particles)	Length (µm)	Diameter (µm)	Form factor (L/D)
Cotton hulls	hulls (Particles)	605 - 2450	85 - 549	4,46 - 7,12
	Linter cotton (fibers)	2070	18	112,93

Table 2. Chemical composition

Cotton hulls	Constituents				
	Cellulose (%)	Proteins (%)	Waxes (%)	Physiological Sugars (%)	Other (%)
Husks	-	-	-	-	-
Linter fiber	95	1,6	0,9	0,3	2,2

Table 3. Properties of recycled polystyrene used in the study

Substance	Mass density (g/cm ³) (ISO 1183)	E Flexure (MPa) (ISO 178)	Rm (MPa) (ISO 527-2)	Impact IZOD (KJ/m ²) (ISO 180)	Elongation (%) (ISO 527-2)
Recycled polystyrene	0,79	800	4,439	23,52	25,52



Polystyrene

10% Cotton hulls
Low dispersion

15% Cotton hulls
Average dispersion

20% Cotton hulls
strong dispersion

Figure 7. Images of the inner structure of the material using a Nikon AZ100 microscope for 0%, 10%, 15% and 20% of cotton husks

mill.

Brabender gravimetric feeder.

Polymer feeder (the material)

The polymer feeder used to feed the extruder with mixed Polystyrene + Cotton husks is an A31-FW33 50-model

Extruder

The extruder used for mixing the polymer and the cotton husks is a co-rotating twin screw extruder of Leistritz

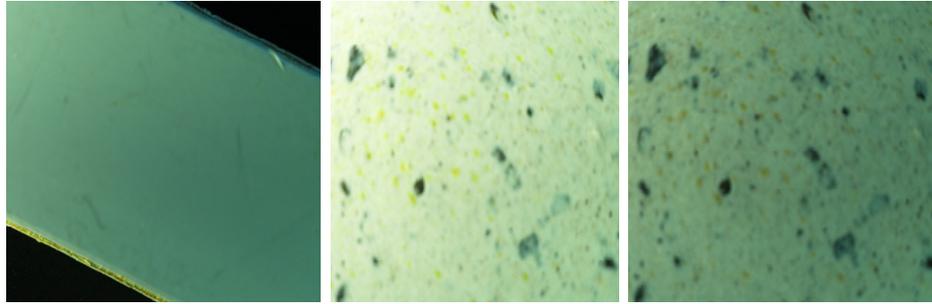


Figure 8. Microscope examination of the surfaces of the products injected

Table 4. Fulls Results of measures of density and the bending test

	Density (g/cm ³)				Flexural test			
					Flexural Modulus E (Mpa)			
	0%	10%	15%	20%	0%	10%	15%	20%
test N°1	0,765	0,689	0,68	0,67	800	1770,260	1771,480	1771,480
test N°2	0,82	0,718	0,64	0,621	812	1770,060	1771,500	1771,500
test N°3	0,79	0,659	0,6721	0,598	790	1770,690	1771,660	1771,520
test N°4	0,799	0,663	0,65235	0,615	821	1770,790	1771,100	1771,450
test N°5	0,697	0,676	0,607	0,6089	802	1771,060	1771,020	1771,460
Standard Deviation (S)	0,047	0,024	0,029	0,028	11,874	0,406	0,277	0,029
Average Values	0,794	0,701	0,68029	0,66258	805	1770,572	1771,352	1771,482
Values of (specific E) : E_s=E.ρ⁻¹					1013,853	2525,780	2603,818	2673,612

Table 5. Fulls Results of tensile test

Fibers ratio	TENSILE TEST											
	Modulus E _t (MPa)				Maximum Stresses (MPa)				Elongation at break (%)			
	0%	10%	15%	20%	0%	10%	15%	20%	0%	10%	15%	20%
test N°1	27,750	29,75	30,7	30,85	4,058	16,701	18,110	18,257	25,0420965	3,313	2,702	2,132
test N°2	27,000	29,85	30,8	30,78	5,002	17,150	18,045	18,347	25,9575707	3,311	2,704	2,135
test N°3	26,510	29,6	30,5	30,5	4,026	16,887	18,041	18,349	26,7995008	3,341	2,714	2,122
test N°4	27,200	30	30,98	30,65	4,089	17,253	18,045	18,347	24,9584027	3,312	2,703	2,131
test N°5	24,950	30,82	30,4	30,81	5,02	17,150	18,047	18,247	24,8844426	3,313	2,705	2,142
Standard Deviation (S)	1,065	0,479	0,232	0,143	0,523	0,227	0,030	0,053	0,83302829	0,013	0,005	0,007
Average Values	26,682	30,004	30,676	30,718	4,439	17,028	18,058	18,309	25,5283694	3,318	2,706	2,133
Specifics Values	33,604	42,801	45,092	46,361	5,590	24,291	26,544	27,632				

brand and ZSE-27 (L/D - 40) model.

of 4.50m/s.

Granulator

The device used to cut the extrudate into granulates is of Conair brand and of 304-model. It was set at a speed

Injection-moulding machine

The injection-moulding machine used to mould the test specimen and samples is an injection-moulding machine

Table 6. Fulls Results of torsion test

Torsion test				
Coulomb modulus G (MPa)				
	0%	10%	15%	20%
test N°1	0,3	0,3041	0,3102	0,410
test N°2	0,309	0,299	0,409	0,399
test N°3	0,298	0,3298	0,4198	0,430
test N°4	0,3899	0,2899	0,3999	0,4310
test N°5	0,3078	0,3078	0,4178	0,4350
test N°6	0,3001	0,3101	0,4342	0,4026
Standard Deviation (S)	0,065	0,079	0,232	0,143
Averages Values	0,317	0,312	0,321	0,341

Table 7. Fulls Results of impact test

IMPACT TEST								
	Modulus (MPa)				Impact Résistance (J/m2)			
	0%	10%	15%	20%	0%	10%	15%	20%
test N°1	18,257	18,110	16,701	16,701	23,4	19,257	18,110	14,701
test N°2	18,347	18,045	17,150	16,91	24	20,347	17,000	15,150
test N°3	18,349	18,041	16,887	16,887	23,2	18,349	16,041	14,887
test N°4	18,347	18,045	17,253	16,253	23,6	19,347	18,045	17,253
test N°5	18,247	18,047	17,150	16,15	23,4	18,247	17,047	14,150
Standard Deviation (S)	0,053	0,030	0,227	0,4227	0,303	0,856	0,857	1,190
Averages Values	18,309	17,858	17,028	16,5802	23,520	19,109	17,249	15,228

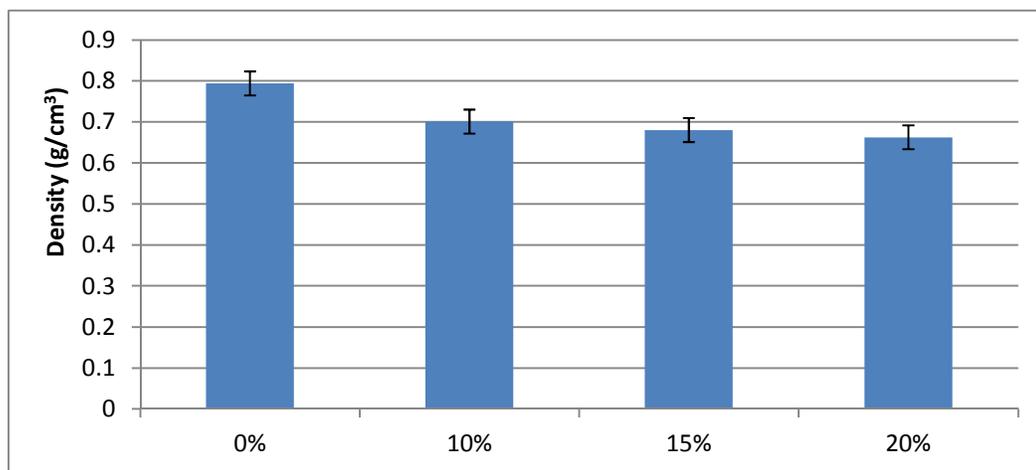


Figure 9. Trend of the mass density of the samples based on the rate of cotton hulls

of ARBURG 370 S 700-70 brand. This machine was used with a temperature curve of 160/175/175/175/180/180/180/180°C and an injection pressure of 2500 bars.

It has a closing force of 700KN and is provided with a hydraulic ejection system with a screw diameter of 150mm and 180mm; its electrical power is 15 KW.

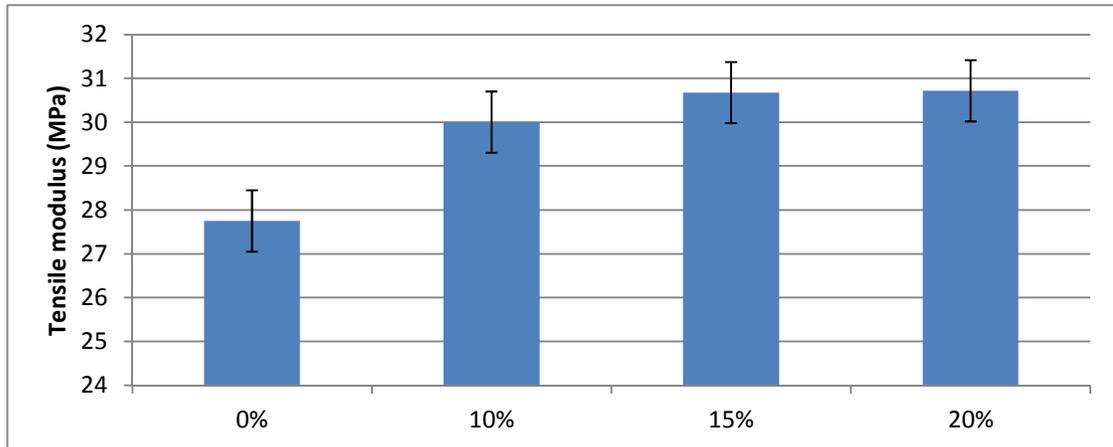


Figure 10. Tensile modulus for the composites with 10%, 15% and 20% of cotton hulls

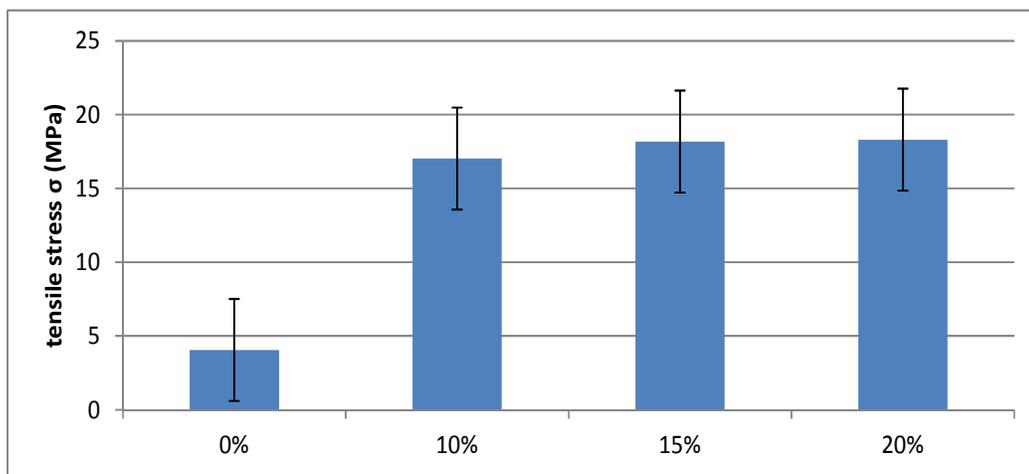


Figure 11. Highest stress for the composites with 0%, 10%, 15% and 20% of cotton hulls.

Mass density weight measuring device

The device used for testing mass density weight is a pycnometer of Mettler TOLEDO brand in accordance with the NF T 51 063 – B Standard.

Balance for measuring the moisture in the mixture

The device used for measuring the moisture content of the mixture is a Mettler TOLEDO balance

Devices for analyzing the tensile and flexural strengths

The devices used to test the tensile and flexural strengths are TXAi, EXPONENT STABLE MICRO SYSTEMS LTD and TA-XT2i Texture Analyser. For the

tensile and flexural tests, a speed of about 1 mm/min was used. The results were the averages as well as the standard deviation for the five repeated mechanical tests.

Tensile-testing

The mechanical tensile-tests were conducted using TXAi, EXPONENT STABLE MICRO SYSTEMS LTD device.

The tests carried out concern 5 standardized specimens developed by injection, which were stretched at room temperature until they break. The travel speed used was about 1 mm/min in order to get enough points. The characteristics of the test specimens used included the following: length: 150mm; width: 10mm and thickness: 4mm.

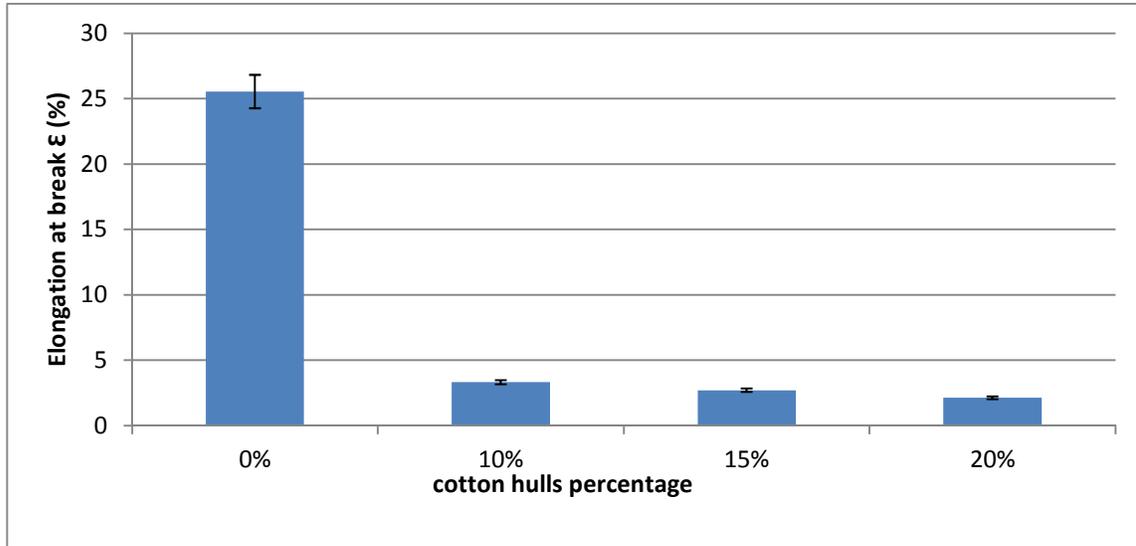


Figure 12. Elongation at break for composites with 0%,10%, 15% and 20% of cotton hulls.

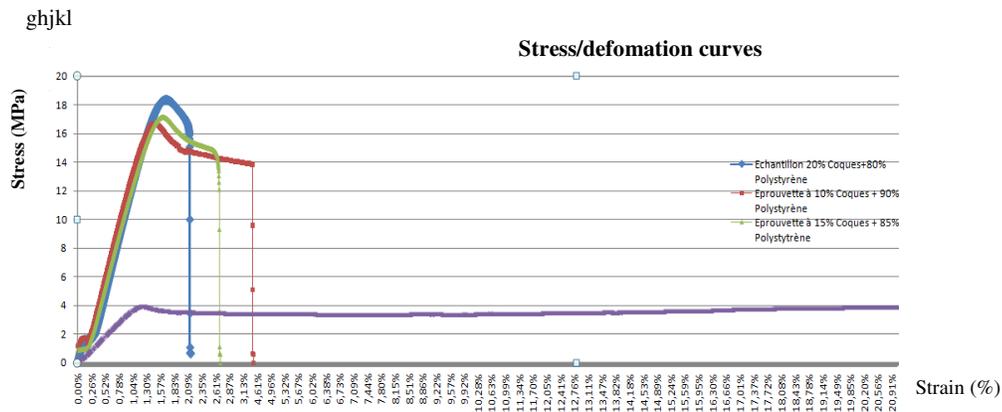


Figure 13. Trend of the tensile stress on the 3 samples prepared

Flexural testing

The flexural mechanical testing was carried out with a TA-XT2i TEXTURE ANALYSER device. The tests carried out concern 5 standardized specimens developed by injection. The travel speed used was in the region of 1 mm/min in order to get enough points. The characteristics of the test specimens used included the following: length: 150mm; width: 10mm and thickness: 4mm.

Device for analyzing the torsional strength

The mechanical torsion tests are conducted on a Torsiomat C10 torsion bench. The tests carried out concern 5 standardized specimens developed by injection. The travel speed used was in the region of 1

mm/min in order to get enough points. The characteristics of the test specimens used included the following: length: 150mm; width: 10mm and thickness: 4mm.

Device for analyzing impact resistance

The mechanical impact resistance test was conducted using ASTM standards for notched Charpy-type impact strength. The device used for the notch is a Dynisco device, ASN 120-m model. The notches were standardized according to ASTM D256 standards, i.e. a depth of 2.54 mm with an angle of 22.5 degrees. Thereafter, the impact tests were carried out using a Tinius Olsen device, Impact 104 model. In total, about ten samples of rectangular dimension, 12.7 mm by 125 mm in length, were fractured at room temperature.

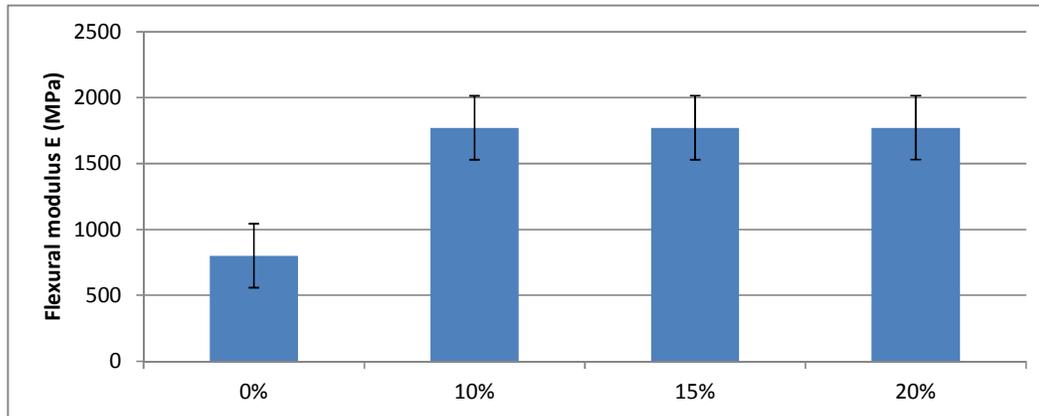


Figure 14. Flexural modulus for the composites with 0%, 10%, 15% and 20% of cotton hulls.

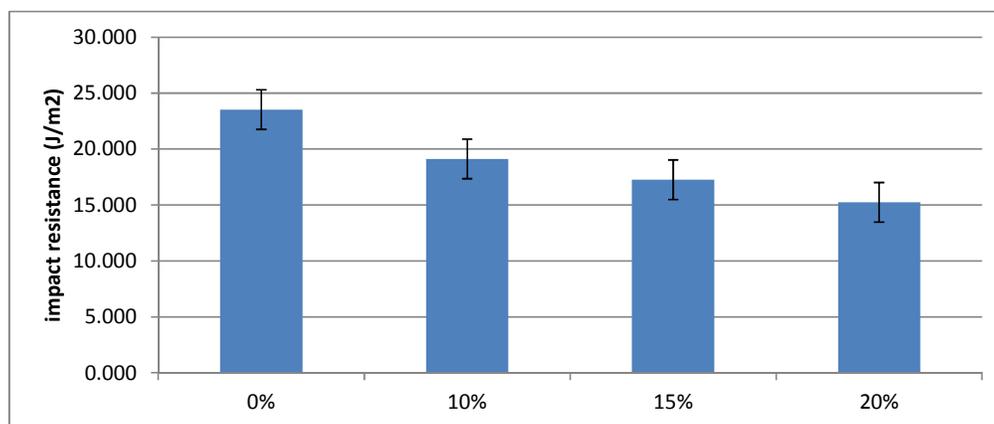


Figure 15. Impact resistance for composites with 0%, 10%, 15% and 20% of cotton husks.

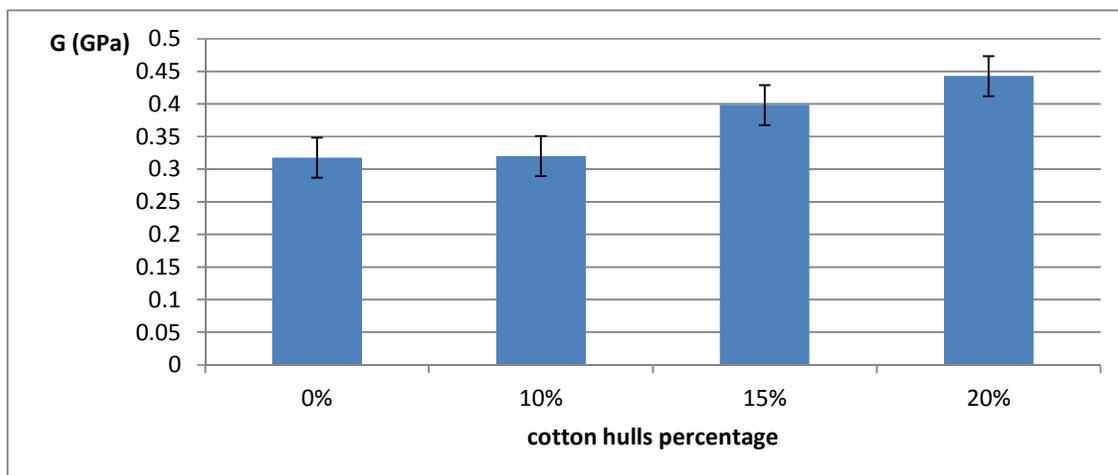


Figure 16. Trend of rigidity modulus based on the rate of fibers

Samples for determining impact resistance were first notched for easy break. The scale used was that of 23.08 Newtons (2.354 kg) with a capacity of 15 Joules. The results of the impact resistance test were the averages as well as the standard deviations for the repetitions of each composite.

METHODS

Preparation of the raw material

The cotton husks and the Polystyrene are, first of all, milled together in order to reduce their size using a Rapidgranulator knife mill. During this operation, the

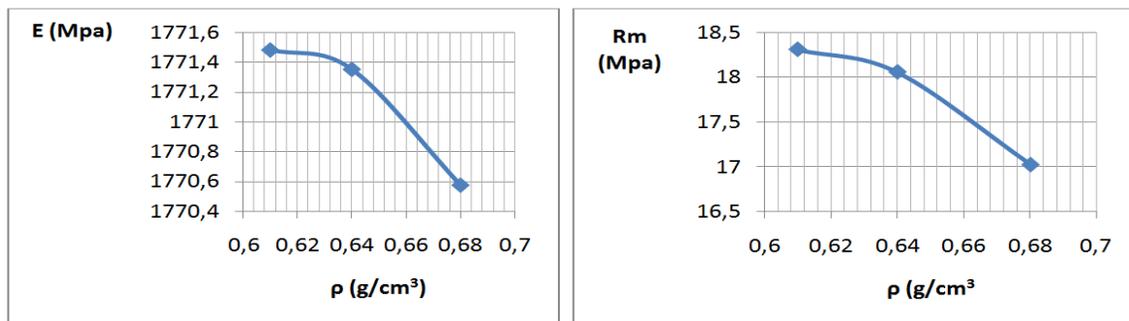


Figure 17. shows the influence of the composite's mass density, i.e. the influence of the cotton hulls rate on the Young's modulus and on the tensile strength of polystyrene/cotton husk composite.

Table 8. Table for comparing the mechanical properties of the composite (recycled PS +cotton husks) with other materials for various applications.

Material	Density g/cm ³ (ISO 1183)	E Flexural (MPa) (ISO 178)	Rm (MPa) (ISO 527-2)	Impact (KJ/m ²) IZOD 180	Elongation (%) (ISO 527-2)
PS standard (crystal)	1.05	2900	35 à 48	-	2 à 3
PS shock copolymer SB	1.04	1600 à 2500	16 à 36	4 à 6	20 à 60
PS recycled	1.01	1000 à 1200	18	20 à 26	≥ 200
PS recycled + cotton hulls (10% à 20%)	0.79	800	4	23.52	25.52
PS recycled + cotton hulls (10% à 20%)	0.71 to 0.66	1770 à 1771.48	17.02 à 18	15.22 à 19.109	2.13 à 3.3
PS + Hemp	-	3045 à 4226	38.9 à 40.4	12.7 à 17.6	1.92 à 2.26

Table 9. Specific properties of some materials

Material	Density g/cm ³ (ISO 1183)	Young's modulus E (GPa) (ISO 178)	Tensile strength Rm (MPa) (ISO 527-2)	Specific Module (E / ρ)	Specific Resistance (Rm / ρ)
Steel	7,9	210	340-2100	26,9	43-270
Glass fiber	2,35	72	700-2100	28.5	1380
Recycled polystyrene	0,79	0,800	4,439	1,039	5,76
PS + cotton hulls	0,662	1,771	18	2,9	29,50

mixture is cleaned of dust and other contaminants.

Three milled mixtures (Polystyrene+ Cotton husks) were prepared in the following proportions with a view to making the three samples of composites:

Cotton husks: 720g representing 20% of the total mass

Recycled polystyrene: 2880g representing 80% of the total mass

Cotton husks: 540g representing 15% of the total mass

Recycled polystyrene: 3060g representing 85% of the total mass

Cotton husks: 360g representing 10% of the total mass

Recycled Polystyrene: 3240g representing 90% of the

total mass

The volume weights of raw materials are determined using a pycnometer in accordance with the NF T 51 063 – B standard.

It is in this respect that the cotton husks were used as reinforcements in the composite material.

✓ Mass density of cotton husk = 0.61g/cm³

✓ Mass density of Recycled polystyrene = 0.79g/cm³

✓ Mass density of Mixture (Recycled Polystyrene + Cotton husks) = 0.66 g/cm³

• Moisture rate

The moisture rate is determined using a balance for measure moisture content.

0.26g of water in a sample of 3.502g, i.e. a moisture rate of 7%

Preparation of granulates: extrusion and granulation

The preparation of granulates is done on an extruder where the raw material (mixture of PS+Cotton husks) is, first of all, heated at 175°C by a feeder screw and injected into a spinneret. The speed of the screw is 95tr/mn. A 3 mm-diameter round rod corresponding to the inner diameter of the spinneret comes out the spinneret and is thereafter cooled with water in a water basin and then air-dried and cut in the form of granulates with a knife at the granulating station.

Parameters for extrusion

A Leistritz ZSE 27/40D-type twin screw extruder was used to produce a compound or extrudate from the mixture (recycled Polystyrene + cotton husks) obtained from the milling and then granulates were produced from the cut extrudate. The operating conditions used are illustrated in table 2. The extruder has eight temperature zones and the temperature curve used in our study is the following: 160/170/170/170/175/175/175/175°C starting from the mixture feeding zone to the spinneret. The material, when coming out of the spinneret, is cooled down in a water basin and then, cut into granulates by a knife on a cutting station called "granulator" of Conair brand. The granulates produced are represented in figure 1.

Assembly for extrusion

Figure 2 presents the assembly used during the extrusion. One can distinguish the feeding device, the extrusion screw, the cooling basin and the granulator.

Process of forming by injection – Preparation of the sample

The granulates of composites previously obtained are used to produce sample specimens in a ARBURG 370 S 700-70 injection machine (figure 3). These specimens were, afterwards, used in the various mechanical tests. Thus, one can produce parts of different forms depending on the moulds used. The parts are prepared using the following processing parameters: the injection flow is in the region of 15 cm³/s (one grade injection), the cooling time is 40 s, the cycle time is estimated at

47.93 s and the temperature of the injection screw is set at 180°C to avoid burning the cotton husks. The mould (figure 4) is cooled down to 50°C by circulation of cold water in the cooling circuit. The closing force of the mould adopted is 250 bars.

RESULTS

Microscopy of fibers (cotton hulls)

Photos taken with Nikon optic microscope (figure 6-a, 6-b) allow characterizing the fibers (cotton linter) and the hulls through the properties of their size (length, diameter and L/D-shape factors). Tableau 1 summarizes the size parameters of the cotton hulls.

Physicochemical characteristics of the raw materials

Chemical composition

Other properties of the fibers (cotton hulls)

- ✓ Mass density $\rho=1.51\text{g.cm}^{-3}$
- ✓ Water absorption: 25%
- ✓ Elongation : 7.1 à 8%
- ✓ E flexion : 5500 to 12600 MPa
- ✓ E_T : 287 to 800 MPa

Properties of polystyrene

Microscopy of the structure of the composites prepared

Photos taken with a Nikon AZ100 optic microscope allow observing the appearance of the fibers in the various compiste samples. figure 7 represents the typical surface of a sample fractured by the impact test. On this photograph, one can notice that with a lower fiber concentration (10%), the surface is relatively smooth and less fibers are exposed to the interface. The higher the concentrations, the rougher the surfaces and more husks are observed at the interface. There is a more random direction of the husks and this accounts for the improved mechanical properties.

Appearance of the fibers in the various composite samples. Figure 7 represents the typical surface of a sample fractured by the impact test for the composites. On this picture, one can notice that with a lower fiber concentration (10%), the surface is relatively smooth and less fibers are exposed to the interface. The higher the concentrations, the rougher the surfaces and more husks are observed at the interface. There is a more random direction of the husks and the fibers.

One observes the presence of fibers and husks as well as their distribution, which will not only affect the volume ratio, but will also, have direct effect on the mechanical

properties and the anisotropy of the composite.

Figure 8 shows the surfaces of the polystyrene injected alone and the prepared composites observed with an optic microscope.

Results of the mechanical tests

The results of the various mechanical tests are presented in the following pages. Only the figures will be presented in this section for subsequent comparison and discussions. The tables of complete results are attached as appendix to this document (table 4 at table 7).

Mass density

Figure 9 presents the values of the mass densities for each cotton husk concentration in the composites.

One compares if the content of the composites in fibers has an impact on the mass density of the composites. For the matrix alone, the average mass density is about 0.79g/cm^3 , while with 10% of cotton husks, the average is 0.701g/cm^3 . It decreases to 0.68g/cm^3 for 15% and to 0.66g/cm^3 for 20% of cotton husks. The content in cotton husks has an impact on the mass density. The effect of the decreased mass density according to the concentration of the cotton husks, directly reflects on the mechanical properties.

Usually, for a higher mass density, the mechanical properties should be significant. However, this is not always valid as in certain cases, it could be important to reduce the density of the composite, as in the case of transportation or packaging. In the latter case, we are interested only in the specific mass density, i.e. ρ_s with $\rho_s = \rho/m$.

Results of the mechanical tests

Tensile strength

Tensile modulus

Figure 10 shows the values of the tensile modulus for each cotton hull concentration in the three composites prepared.

The tensile modulus increases with the adding of cotton husks. So, the cotton husks help the polymer matrix to resist tensile stress. The improvement of the mechanical properties is less significant, as for a value of 20% of husks, the modulus increases only by 5 MPa. This means that the cotton husks, like the fibers, have a higher tensile strength than polymers. However, one observes that the tensile modulus does not vary significantly with an increased content in cotton husks

(30 MPa for 10% to 30,67 MPa for 20%). Also, one observes that the adding of cotton husks to the polymer increases the tensile module from 27.58 MPa for 0% of cotton husks to 30.67 MPa for 20% of cotton husks, representing an increase of about 3 MPa.

Highest tensile stresses

Figure 11 shows the values of the highest tensile stresses for each cotton hull concentration in the three composites prepared.

Like the tensile and flexural modulus, the value for the highest stress increases with increased fiber concentration. This is due to the fact it is the fiber (cotton husks) that has better resistance and communicates this property to the composite. For this reason, the composite has higher tensile stress compared to polymer alone. This theory is proven as the highest tensile stress for recycled polystyrene is 4.439 MPa, while that of cotton fiber is approximately 18 MPa. Adding 20% of cotton husks to the polymer increases the resistance from 4 to 18 MPa, i.e. 14 MPa. One notices that the highest stress does not vary significantly with the increased content in cotton husks (16 MPa for 10% to 18 MPa for 20%).

Elongation at break

Figure 12 shows the elongation at break for each concentration of cotton hulls in the composites

Similar to the mass density, the value of the elongation at break decreases drastically when the fiber is introduced into the polymer. This is explained in the same way as the mass density. Indeed, polymer has the property of aligning molecules in the direction of the stress and can stretch significantly depending on its relaxation. The fiber, when introduced into the polymer, disturbs the alignment of the molecules and breaks faster. For this reason, the values increase from about 25.52% for 0% of husks to 3.318% for 10% of husks and to 2.133% for 20% of husks on the stress/deformation curve in figure 13.

Flexion 3 points (NF EN ISO 178 NORM)

Flexural elastic modulus

Figure 14 presents the flexural modulus for each cotton hulls concentration in the composites.

Like the tensile modulus, the value of the flexural modulus increases when cotton husks (fibers) are added. The fiber helps the polymer matrix to resist flexural stress. There is significant improvement of the mechanical properties as for a value of 20% of husks, the modulus increases by approximately 960 MPa.

Indeed, fibers are reputed to have better flexural resistance than polymers. One notices that the flexural modulus does not vary significantly with increased fiber (cotton husks) concentration: it is 1770.572 MPa for 10%, 1771.352 MPa for 15% and 1771.482 MPa for 20%. One also observes that adding fibers to the polymer increases the flexural modulus of the latter from 805 MPa to 1771.482 MPa for 20% of cotton husks, representing an increase by 960 MPa.

Impact test (NF EN ISO 458-1 STANDARD)

Figure 15 presents the values of impact resistance for each cotton husks concentration in the composites. Unlike the previous mechanical properties, the value of the impact resistance is similar to the behaviour of the mass density. As a matter of fact, polymer alone has a good capacity to absorb energy without breaking. However, when the cotton husk (fiber) is added to polymer, the fiber causes a certain stiffness that helps the material to resist. The material becomes less resilient and more stiff.

Torsion test (NF EN ISO 458-1 STANDARD)

Figure 16 shows the values of the torsion test results according to the content of the composite in fiber. Like the tensile and flexural modulus, the value for the shear modulus or rigidity modulus increases with the adding of cotton husks (fibers). The fiber helps the polymer matrix to resist torque stress. The improvement of the mechanical properties is significant as for a value of 20% of husks, the module increases by approximately 130 MPa. One notices that the shear varies significantly with the increase in fiber concentration (cotton husks) : it amounts to 320 MPa for 10%, 390 MPa for 15% and 482 MPa for 20%.

Study of the influence of mass density on the mechanical properties

Figure 17 : Trend of the Young's modulus and of the tensile strength according to the mass density

The distribution of the cotton husks, which has not only the above-mentioned influence, but also a direct effect on the mechanical properties of the composite as well as on its anisotropy. Thus, good properties are achieved with low densities of the material because the specific resistance and the specific modulus are high.

DISCUSSIONS

Three sample materials were prepared with fiber rates of 10%, 15% and 20%.

The mechanical properties will individually for each mechanical property. Indeed, the effects were observed on the maximum elongation will not be the same as the flexural modulus, for example. However, there will be no analyzing for the density since it has no direct impact on the classification of composites. Sometimes you can find a lightweight material, while in other cases, a heavier had more durable, the complement of composite could be desired (Joshi SV, Drzal, LT, Mohanty, AK, Arora, S. 2003).

In general, the objective of bio composite to obtain good mechanical properties with significantly reducing the cost of this composite, usually the costs of natural fibers are much less expensive than the polymer. This is why the choice will be made mostly for the composites of fibers highest concentration allowed by the process.

Analysis of the mechanical properties

The analysis of the mechanical properties will be done individually for each mechanical property. Indeed, the effects observed on the maximum elongation will not be the same as the flexural modulus for instance. Nevertheless, there will be no analysis of the mass density as it has no direct impact on the classification of composites. Sometimes, one may look for a lightweight material, whereas in some cases, a heavier and more resistant material could be desired (Joshi, S.V., Drzal, L.T., Mohanty, A.K., Arora, S. 2003).

By and large, one of the objectives of adding fibers is to obtain good mechanical properties while reducing considerably the cost of the composite since the natural fiber is usually much cheaper than polymer. That is why composites with high content in fiber accommodated by the process will be selected.

Flexion

First of all, one notices that the fibers are probably not long for good resistance, whereas with 20% concentration, there seems to be enough fibers to resist flexion. This result is in line with that of Mechraoui and coll. (Mechraoui et al., 2007) where the size of the fibers was varied and the shorter and smaller fibers had lower mechanical properties. As mentioned above, it is advisable to work towards higher fiber concentration in order to reduce the cost to a minimum. However, these

results remain valid only under the conditions used.

Impact

As far as the impact properties are concerned, the analysis is slightly more complex. The issue is not just about having an increased resistance of this composite to that stress ; there should be a compromise between tiffness and ductility (Yuanjian et al., 2007). As a matter of fact, the virgin polymer has good energy absorbing capacity. Composites that are too stiff will not have good impact resistance capacity since they are fragile. Just as in the case of flexion, the results remain valid only under the conditions used. These results could differ outside these value ranges.

Tension

For the tensile properties of the composite, we chose two different methods of analyzing the results. The first method concerns the modulus and the second the maximum tensile strength and maximum elongation at break. In the case of the modulus, the adding of fibers should, theoretically, increase this resistance (Yamamoto et al., 2005), whereas for the other two properties, it is rather the plastic nature of the composite that is predominant. By adding fibers to the composite, the maximum elongation and strength decrease (Wambua et al., 2003).

In all, the best material in tension is undoubtedly the one prepared with a 20% fiber content. Once again, like the flexion and impact tests, the results are valid only under the conditions used.

One notices that the elasticity modulus increases with the proportion of fibers in the material. The value E is 1770,30 MPa, 1771,352 MPa and 1771,487 MPa, respectively for 10%, 15% and 20% of cotton husks during the flexural test. Similarly, one notices that breaking stresses (R_r) increase with the proportion of fibers in the material. They include 17.028 MPa, 18.058 MPa and 18.309 MPa, respectively for 10%, 15% and 20% of cotton husks. However, the elongation of the material decreases when the proportion of fibers increases with deformation ϵ values of 3.7%, 2.6% and 1.9%, respectively.

Furthermore, there is very good correlation of the various tensile stress/deformation curves of the material, mainly in the elastic zone. The elasticity modulus of the material ($E=1771.34$ Mpa) exceeds that of the recycled polystyrene ($E=805$ Mpa), which was also determined under the same conditions by the flexural test. This reflects an improvement in the rigidity of the material. The mechanical tensile strength is also improved ($R_r = 18.309$ MPa for the material with 20% against 17.028 MPa for the Polystyrene alone) and this equally reflects

an improvement in the strength of the material. So, one can conclude that the fact of adding cotton husks has improved the mechanical properties of the material. In the plastic range, the elongation percent is reduced : it is 1.9% for the material prepared with 20% of cotton husks against 25.52% for the recycled polystyrene.

Moreover, one notices that the elasticity modulus of the material does not vary significantly when the proportion of fibers in the material increases, which means that the elastic modulus is not based on the material content in fibers, whereas the maximum stress in the material increases with the proportion of fibers.

This behaviour of the material reflects the presence of fibers in the material, which help improve certain mechanical properties of the original material, such as the maximum strength, and the elasticity modulus ; however, one observes a degradation of others such as the elongation percent after breaking and the mass density and the resilience. The plastic range of the material is also reduced. Thus, the composite produced has no more a plastic behaviour like the original material (recycled polystyrene).

CONCLUSION

The objectif of the study was to develop, first of all, a bio-sourced material from recycled polystyrene plastics and cotton husks, and to determine its physical properties including the mass density, the elasticity modulus (flexural, tensile and torque), the tensile stresses at break and the impact resistance for various applications such as the manufacturing of thermal insulation parts, interior fittings of vehicles, casings for cell phones and computers.

At the end of the study, three control composite materials were produced by plastic injection after compounding and their physical and mechanical properties, determined. These include:

- samples developed with 10% of cotton husks and 90% of recycled polystyrene
- samples developed with 15% of cotton husks and 85% of recycled polystyrene
- samples developed with 20% of cotton husks and 80% of recycled polystyrene

The experimental results on manufacturing devices (mainly the extruder) limited the ratio of cotton husks in the material to 20% to develop a good faulty-free material. The rates of fibers (10% and 15%) were adopted for economic and technical reasons as they allow developing lightweight parts which could be used, for instance, as interior trim parts in the automotive field.

Then, we improved the mechanical properties of the recycled polystyrene by mainstreaming cotton husks, thus providing a second life to these two materials at end-of-life with no market value.

Moreover, considering the results in the following table 8 and by comparing the properties of the eco-composite produced with those of the shock PS and the standard PS and in view of the current areas of application of the last two materials, we can conclude that the new eco-materiel developed may be used in the following applications either as an alternative or complementary to these two materials:

✓ Food and related packaging: for dairy products such as: (tubs of yogurt) ; various packaging such egg-boxes, single-use dishes (disposable cups and plates, cutlery...).

✓ Household appliances: manufacturing of the external parts of washing machines, various kitchen appliances.

✓ Consumer electronic equipment: box sets and housing for TV, photocopiers, printers, iphone covers...

REFERENCES

- Andersen PJ, et Hodson SK (2001). Thermoplastic starch compositions incorporating aparticulate filler component. (2001), US 6,231,970
- Averous, L. et Boquillon, N. "Biocomposites based on plasticized starch: thermal and mechanical behaviours." *Carbohydrate Polymers* (2004) 56: 111-122.
- Baganz K, Lang H, et Meissner G (1980). "Industrial use of oilseed meal: a reasonable injection moulding compound." *Fett / Lipid* (1999) 101(8): 306-307.
- Duprat F, Gallant D, Guilbot A, Mercier C, et Robin JP (1980). *L'amidon, les polymères Végétaux : polymères pariétaux et alimentaires non azotés*. B. Monties. Paris, Gauthier-Villars Bordas. (1980). 176-231
- Joshi SV, Drzal LT, Mohanty AK, Arora S (2003). Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites Part A: Appl. Sci. Manuf*, 35, 371-376.
- Mechraoui A, Riedl B, Rodrigue D (2007). The effect of fibre and coupling agent content on the mechanical properties of hemp/polypropylene composites, *Comp. Interfi*, 14(7-9), 837-848.
- Wambua P, Iven J, and Verpoest I (2003). "Natural fibers : Can They replace glass in reinforced plastics " *Composite Science and Technology* (2003) 63: 1259-1264 .
- Yuanjian T, Isaac DH (2007). Impact and fatigue behaviour of hemp fibre composites, *Comp. Sci. Tech.*, 67, 3300-3307.
- Yamamoto T, Medina L, Schledjewski R (2005). Tensile properties of natural fibre reinforced thermoset composites, *Adv. Comp. Lett.*, 14(1), 29-34.