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Polyethylene Low and High Density-Polyethylene Terephthalate and Polypropylene Blend as Matrices for Wood Flour - Plastic Composites

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Abstract: ***This study present a composite material made of four thermoplastic polymers and wood sawdust. The wood sawdust of size 630, 315, 160 µm and plastic waste containing 3,91% of polyethylene terephthalate (PET), 87,62% of High-density polyethylene (HDPE), 7,23% of Low-density polyethylene (LDPE) and 1.21% of Polypropylene (PP) have been transformed in composites wood/polymer by extrusion. The mechanical and thermal properties have been studied through tensile test and a thermogravimetric analysis. The weight ratio of the cellulosic materials to polymer matrix was 25:75(w:w). Morphological study was done on the rupture surface on samples to appreciate the adherence of wood sawdust/matrix. The study shows that the presence of the wood sawdust increases the modulus of elasticity (MOE) of the composite by conferring a better rigidity. Also, we see that wood sawdust increases the thermal stability of the composite.***

Keywords: Tensile test, Composite wood polymer, Wood sawdust, Thermogravimetric analysis

1. Introduction

The environment protection and optimal management of natural resources for a sustainable development are most important concerns today. In Africa the management of plastic waste and wood sawdust is a real concern for the municipalities. Indeed the inexistence of management policy exposes the urban populations to garbage dumps containing plastics and wood chips. This situation creates a public health issues. The survival of human being is affected by this situation [1] [2] [3]. A study made in Benin Republic has shown that 86% of plastic users throw them in the street after usage, 5.5% incinerate them, 5.5% use them as combustible, and 2.75% for other usages [4]. In 2012, the total amount of plastic waste produced was 12,026 tons [4]. The waste management is a real challenge for local authorities and researchers [5] [6] [7] [8] [9] [10].

The household wastes of the cotonou city (Benin) contain 3.8% of PET,84.99% of HDPE,7.0% of LDPE,1.18% of PP and 3.01% of PUR [4].Analysis of these polymers showed that different types of Polymers find themselves on the same heap [4]. Indeed for a recycling purpose of these polymers it is technically difficult and expensive to separate these mixtures of plastic [11] [12]. The performances of these mixtures are usually much lower than the single elements because the polymers are immiscible [13].

The specificity of this work consists in realizing a composite wood / polymers material by using PET / HDPE / LDPE / PP / wood sawdust. The goal of this study is to find some mechanical properties that are close to the literature. Indeed many published works on the Wood Polymer Composite (WPC) present some values in the range of 1000-2000MPa for the elasticity modulus and 20-30MPa for the tensile rupture modulus in for the wood flour in the range of 20%-25% [12, 14, 15, 16, 17, 18, 19, 20].

2. Materials and Methods

2.1. Materials

2.1.1. The matrix

The polymer matrix used is a mixture of PP, HDPE, LDPE and PET. These different polymers come from recycling and come from good fellow certified ISO 9001 in France. The physical characteristics of these polymers are shown in

Table 1.

Table 1: Physical and mechanical characteristics of some thermoplastic polymers **[21]**

Polymers	Density ($g.cm^3$)	$\sigma_{tensile}$ (MPa)	MOE (GPa)
PP	0,9	25-40	0,9-1,5
HDPE	0,95	15-40	0,5-1,2
LDPE	0,92	5-25	0,1-0,3
PET	1,3-1,4	80	2-4
PS	1,05	30-100	2,3-4,1

2.1.2. The wood flour

The essence of the wood flour that was used in our study is abzeria essence (afzélia Africana). the wood flour was collected in sawmills and was sieved to separate the material into several granular classes. Finely ground wood flour comes from woody material recovered as a result of planning and sawing operations. The physical properties (Table 2) of wood flour: absolute density, apparent density and humidity level vary relatively for the same gasoline and depending on the place of collection. At the end of the sieving, we separated the sawdust by diameter. Thus, three diameters of sawdust and two granular mixtures were studied. We have therefore used the diameters 0.315mm-0.160mm-0.08mm (Figure 1.)

Table 2: Physical properties of wood flour by size.

Size of wood flour(mm)	Absolute density (g/cm^3)	Apparent density (g/cm^3)	Humidity level (%)
0,630 mm	0,270±0,0082	0,126±0,005	10,79±1,16
0,315 mm	0,278±0,0072	0,161±0,008	11,51±1,12
0,160 mm	0,294±0,0078	0,171±0,002	0,07±0,87

Figure 1 : Wood flour by size

2.2. Composite preparation

The extruder used for the manufacture of the wood polymers composite (CBP) allows the introduction of a limited quantity of wood sawdust to facilitate it's mechanical running. Therefore it turns out that many authors use the wood fibre between 10 and 35% [22] [23] [24].all the composite were made from 25% sawdust and 75% thermoplastic matrix to facilitate the enrobing of the wood particles by the plastic matrix. The different polymers have been mixed with wood flour. It is important that the mixture is homogeneous before being introduced into the extruder. The consequence would be highly heterogeneous material with regard to the sawdust and polymer repartition. The extruder was controlled at 175°C, 185°C, 195°C and 200°C for zones 1, 2, 3 and 4 respectively, while the temperature of the die was held at 200 °C. The melt temperature was kept 200 °C to prevent wood degradation .The extruded mixture is put under pressure in a moule preheated at 170°C and screwed at the output of the extruder. The demolding is done 3 hours later

2.3. Tensile test

The tensile test have been done at ambient temperature by using a INSTRION 4467 model which is a tensile test machine with respect to the norm NF EN ISO 527-1 and NF EN ISO 527-2 on wood/polymer samples

2.4. Thermogravimetric test

The thermogravimetric analysis has been done by using the SETRAN thermal analyser at a heating speed of 2K per minute under azoth atmosphere of 20ml/min. A sample made of 80 mg composite material and a sample made of 70 mg wood sawdust is used for the present analysis.

2.5. Morphological study

The morphological properties of samples have been analysed by using the HITACHI TM-3000 electronic microscope. After the tensile test, the rupture surface of the samples is taken and observed under the electronic microscope.

3. Results and Discussion

3.1. Tensile properties

The plastic matrix of reference E-CTN is made of 87.62% of HDPE and the polymers listed in

Table 3. The tensile resistance is 24.48 MPa and the elasticity modulus 975.2MPa (see

By considering the MOR in tensile test it turns out that for wood flour of 630, 315 and 160 µm diameters the MOR lowly vary. One can therefore notice that the MOR rises when the size of the wood sawdust decrease [27]. One can also notice a slight decreasing of the MOR of the composite with respect the MOR of the matrix. When the form factor is lower than 10, the fibres behave like loads [28] [29]. In addition, the presence of cellulosic elements improves the tensile MOE. The CBP are then more rigid than the polymer matrix [30]. The observed values of the MOE are close to the one obtained by Klason et al [31] for a composite with a HDPE matrix.

Table 3). These results are close to the tensile resistance of HDPE used. Osso researches conducted by Bailon and Morin [25] [26] gives a elasticity modulus (MOE) of approximately 1000MPa and a rupture modulus (MOR) between 21 and 38 MPa. It turns out that the combination of the different polymers that leads to the E-CTN do not have significant influence on the MOE, MOR and HDPE in tensile test although the polymers are immiscible.

Table 3: Mechanical results of wood / polymer composites and thermoplastic matrix

CODE	HDPE %	LDPE %	PET %	PP %	Fiber µm	MOR(MPa)	MOE(MPa)
Matrix							
E-CTN	87,62	7,23	3,91	1,21	0	24,48±0,34	975,20±20,2
Composite							
3E-CTN630	87,62	7,23	3,91	1,21	630	21,79±0,99	1341,85±81,82
3E-CTN315	87,62	7,23	3,91	1,21	315	21,86±0,73	1391,19±90,59
3E-CTN160	87,62	7,23	3,91	1,21	160	22,40±0,58	1578,80±67,23

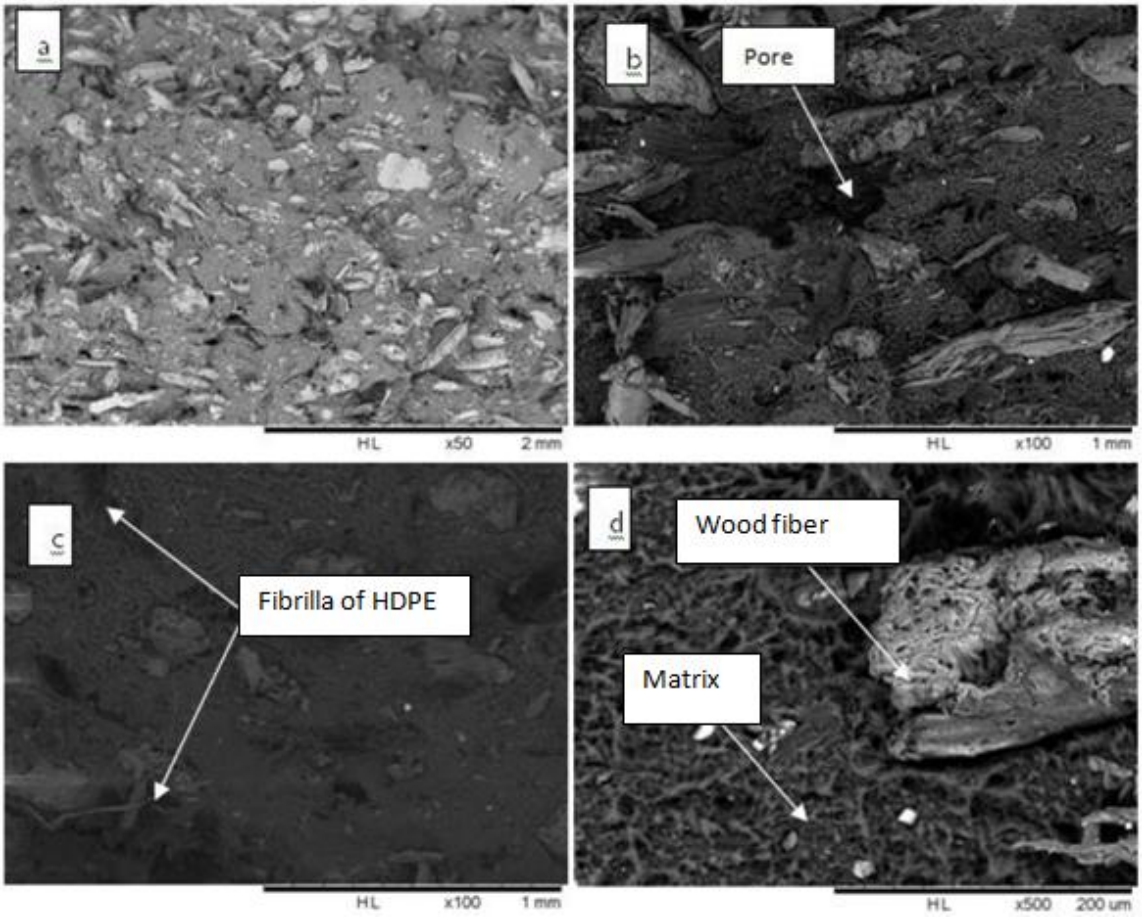

Figure 2 : SEM micrographs of fracture surfaces of the composites

3.2. Morphological properties

The SEM image of Fig. 3. represents the microstructure of the specimen on a rupture facies at the end of a one-axial tensile test. Although the matrix is obtained from several polymers, coherence at the level of the molecules constituting it is generally observed (Fig.3.a) This uniformity observed at the level of the matrix is confirmed on a larger scale x100 on the images Fig.3.b and Fig. 3.c. After fracture, we see in the image c what could be HDPE fibrils that correspond to stretched macromolecules that connect small crystal blocks to strong deformations [32]. The fibrils are conventionally observed in this kind of HDPE-based composite, are randomly oriented in the three directions of the space and have an average size of the order of one micron. In addition, this microstructure reveals broken wood fibers. The presence of these broken wood fibers indicates a break in the wood and not at the wood-matrix interface. This observation confirms the good mechanical strength of the wood-resin interface according to the observations usually encountered in wood-plastic composites [33]. In the image a the wood fibers are not oriented in the direction of traction; Indicating good adhesion of the wood / matrix interface. However, in some places, the fibers of wood are loosened, leaving a hole in the fracture rupture.

3.3. Thermal Properties

The thermal stability of composites is a very important parameter for the processing and use of these materials. The making such composites require the mixing of the fibers and the matrix at high temperatures, so that the degradation of the cellulosic materials can produce adverse effects on

properties. The results of thermogravimetric analysis (TGA) are consistent with those of the literature [34]. There are three stages of degradation (Fig. 4):

1) The first is linked to the release of water [35] [36] [37]; - the second is related to the degradation of cellulosic substances, such as hemicellulose and cellulose [35];
2) The last step refers to the degradation of non-cellulosic substances at the highest temperatures [38].

The first loss of mass (9%) between 270 °C and 345 °C corresponds to water loss and moisture content in wood fibers. The second loss of mass is the main one. At this stage, the composite loses 80% of its mass between 345 °C and 480 °C. These include depolymerization of cellulose and breakage of glucosidic bonds, degradation of lignin and depolymerization of the matrix. There is also a slight displacement of about 25 ° C from the maximum degradation temperature to a higher temperature. The presence of the wood flour improves the thermal stability of the polymer matrix. The Fig. 5 shows that the TGA curves as a function of the size of the sawdust are superimposed. The size of the sawdust does not influence the thermal stability of the composite. Sawdust degrades from 200 °C. The sawdust / polymer mixture must therefore be extruded at a temperature of less than 200°C.

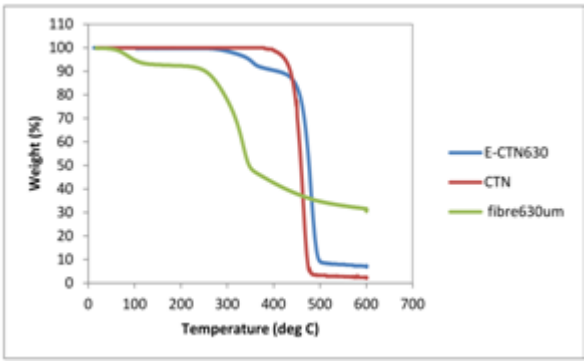

Figure 3 : TGA curves of the composites

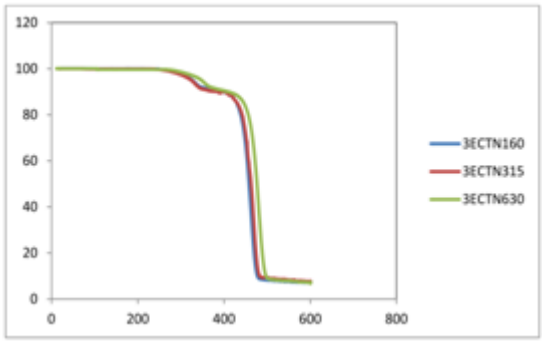

Figure 4 : TGA curves of the composites by wood flour size

4. Conclusion

The results of this work lead to the conclusion that:

1) The polymeric wood composite obtained from the E-CTN matrix has mechanical properties similar to those of other authors [31]and promoting its use for applications.
2) Wood flour improves the rigidity of the polymer wood composite and does not significantly reduce the modulus of rupture.
3) The SEM study also shows good interfacial adhesion between the fibers and the matrix.
4) The presence of the wood flour improves the thermal stability of the polymer matrix.

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