

Development of a Composite Material Based on Wood Waste Stabilized with Recycled Expanded Polystyrene

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Abstract

Environmental pollution is a whole world concern. One of the causes of that pollution is the proliferation of plastic waste. Among these wastes there is expanded polystyrene (EPS), mainly from packaging. This study aims to valorize EPS waste by developing a composite material from EPS waste and wood waste. For this purpose, a resin made of EPS has been elaborated by dissolving EPS in acetone. That resin was used as a binder in volume proportions of 15%, 20%, 25% and 30% to stabilize the samples. Some of them were thermoformed. The method of elaboration was based on a device consisting of an extruder for mixing the constituents, and a manual press for shaping and compacting the samples. Analyses show that the drying time depends on the composition of the mixture. Increasing the resin content leads to reduce water absorption and porosity of the samples; it also contributes to homogenize the internal structure of the samples. However, for the same resin contents, the thermoformed samples are less porous; they have more homogeneous internal structure; and absorb less water than non-thermoformed samples.

Keywords

Expanded Polystyrene, Wood Waste, Resin, Composite Material, Thermoforming

1. Introduction

Since its discovery, the use of plastic by population increases day by day. Today, many traditional materials such as wood, metal, earthenware, glass and natural fibers can be replaced by plastics. In addition, a long series of new functions can only be fulfilled by them [1]. Packaging represents most of their uses [2] and that has been accelerated by generalization of single-use packaging [3]. Beyond their

advantages, plastic products, after their consumption, generate voluminous waste and often with high dissemination, because of their low density, they are easily transported by wind and water [4]. Among these plastic wastes, expanded polystyrene has a significant negative impact on environment due to its large use (as shockproof for electronic devices) and its low recycling rate. Indeed, few companies are interested in recycling this material as its very low density makes collection and transport unprofitable [5]. Moreover no recycling system for expanded polystyrene currently exists in Côte d'Ivoire, while the quantity released into the environment continues to grow with the economic and social development of this country. This poses a major environmental problem in managing this waste.

Otherwise, tropical countries like Côte d'Ivoire have forests with wood used in many fields of activity such as cabinetmaking, furniture, shipbuilding ... for their remarkable properties. In order to reduce abusive exploitation of forests and control the timber industry which has become almost informal, and to bring also added value for exploitation of this resource, the Ivorian government has prohibited the export of wood in the form of logs (Decree No. 95-682 of 6 September 1995) [6]. This ban has led to increased local processing of wood through numerous sawmills. The activities of these units generally located near urban centers, generate important quantity of waste. Most part of this waste is incinerated (release of CO_2), or, left on site. In this case, they form huge heaps and often in the city. It degrades the living environment.

Recovering these two particularly bulky industrial wastes is the objective of this study. It aims to determine a method of developing composite. This method will not only solve the environmental problem that this waste poses, but will also provide a material that can be used as a substitute for certain sawing products and help to save forests. This study is based on an easy methodology, reproductive and energy efficient, therefore less expensive. The properties of the obtained composite will be determined.

2. Material and Methods

2.1. Raw Material

The raw material used in this work consists of EPS wastes, wood wastes and acetone.

2.1.1. Wood Wastes

Wood is one of the most used materials. However, lot of waste is generated, from its primary transformation to the end product. It is part of this waste (wood chips) that is used in this work. These are wood chips, which are woodworking waste in carpentry units.

The chips used are in the form of coverslip. To avoid the large size dispersion and to remove any pieces of wood, the chips were sieved using a 5 mm mesh sieve. The passing was used in this work (**Figure 1**). These chips were taken in carpentry units in Koumassi (Abidjan).



Figure 1. Wood waste.

2.1.2. Expanded Polystyrene (EPS) Waste

The EPS used is mainly from the packaging of household appliances and electrical appliances. After unpacking these devices, the EPS that served as a buffer for transport is discarded to nature as waste (**Figure 2**).

2.1.3. Acetone

Acetone is widely used in the laboratory because of its ability to dissolve many organic compounds, and some plastics [7]. For this work, the acetone used is commercial acetone. It served to dissolve the EPS.

2.2. Methods

2.2.1. Preparation of Binder

The resin is obtained by dissolution of EPS in acetone. This reduces the EPS volume by 98.4% and optimizes the recycling of this material [8]. In this study, to facilitate mixing, the ratio EPS mass/volume of acetone is set at 0.7 (kg/L).

2.2.2. Samples Elaboration

The sample elaboration was done in several steps summarized into the diagram of **Figure 3**. The resin is poured on the wood chips and manually mixed, obtained mixture is introduced into a counter-rotating twin-screw extruder for homogenization. After that, a quantity of this mixture is compacted in a manual press to extract samples of size $20 \times 10 \times 3$ cm³. Different samples were made by varying the proportion (volume) of resin by 15%; 20%; 25% and 30%.

After drying, some samples were thermoformed. To do this, the sample is placed between two metal plates and heated at 150°C for 50 minutes. And all is hot compacted with a manual press. So two types of samples were made: samples thermoformed samples and non-thermoformed sample.

2.2.3. Samples Characterization

Samples have been submitted to various characterization tests in order to know their properties.



Figure 2. Expanded polystyrene waste (EPS).



Wood waste

Figure 3. Method of sample elaboration.

1) Evaporation Test

During drying, solvent contained in the material evaporates and causes a mass loss of the sample. This evaporation can also be responsible for the formation of open pores. These mass variations were measured to understand their consequences on the properties of the composites, and to determine the drying duration of the samples.

The solvent evaporation rate (ΔE) is given by formula (1):

$$\Delta E(\%) = \frac{m_j - m_f}{m_f} \times 100 \tag{1}$$

with ΔE (%) the solvent evaporation rate in percentage, m_j the mass of the sample at the day "j", and m_f the mass of the sample at constant mass (at the end of drying).

2) Water absorption test

The samples are oven-dried at 60°C until constant mass (m_0) . Then they are immersed into water. The masses (m_j) are determined every 24 hours for 8 days of immersion (until saturation). Water absorption rate (*H*) was calculated for each sample by the formula (2) [9].

$$H(\%) = \frac{m_j - m_0}{m_0} \times 100$$
 (2)

3) Samples porosity measurement

Porosity was determined by the hydrostatic weighing method. For this, each sample was put into an oven at 60°C until constant mass and its dry mass (m_1) was determined. After that, sample was immersed into water until saturation. The soaked sample was weighed in immersion (m_2) and then in air (m_3) . Porosity (Π) was determined by the formula below [10].

$$\Pi(\%) = \frac{m_3 - m_1}{m_3 - m_2} \times 100 \tag{3}$$

4) Optical microscope observation

The observations were focused on the physical aspect of samples. Homogeneity of internal structure (distribution of the resin into the composites), size and distribution of pores have been observed.

For this, sections were made in the samples. Observations are made on these sections.

3. Results and Discussion

3.1. Evaporation Test

Figure 4 shows variation of evaporation rate according to drying time.

This evaporation depends on drying time and also on composition of the mixture used to make the samples.

These curves have the same appearance for all contents. They can be divided into three parts:

• The first part (P1) is rectilinear with a steep slope and occurs during the first 24 hours of drying for all composites. This part corresponds to a high evaporation rate of acetone.



Figure 4. Curve of variation of solvent evaporation rate during drying.

- The second part (P2) is concave. Its extent depends on the resin content: it increases with the resin content. The rate of evaporation of acetone gradually decreases.
- The third part (P3) seems horizontal; there is no evaporation of acetone, so the composites are dry.

These kinds of evaporation curve during drying time have been observed by several authors such as [11] and [12].

The evaporation rate decreases with the drying time because the acetone gradually evaporates. However, evaporation is faster for samples with low resin content than those of high resin content.

Indeed, at low content, the resin is not sufficient to coat all of the wood chips. So the samples contain more pores through which the solvent quickly evaporates. As the resin content increases, the coating of the wood chips improves more and more and samples become less and less porous then the solvent evaporates more slowly.

A similar observation was made by [5] during the drying study of a mixture of polystyrene resin and hemp seed. Thus it takes 3 days of drying for samples at 15% resin, 9 days for samples at 20%, 14 days for those at 25% resin and 21 days for those at 30% resin.

3.2. Water Absorption by Samples

The results of water absorption study are shown in Figure 5 below.

The curves show that the rate of water absorption increases with the duration of immersion. However, the absorption speed for each sample decreases during immersion and the curves can be divided into three parts.





- The first part (PI) is rectilinear with a steep slope synonymous with a high rate of water absorption. It takes the first 24 hours for all samples. However, this speed is high for low resin contents and decreases when the binder content increases; samples at 15% of resin absorb about 60% of their mass during this period, samples at 20% absorb 40% and those at 25% and 30% absorb around 10% respectively.
- The second part (PII) is curved indicating a gradual decrease in the absorption rate. It corresponds to moderate absorption range of the samples. The importance of this area is depends on binder content; it takes 2 days for 15% resin samples, 3 days for 20% samples and 4 days for 25% and 30% resin samples.
- The third part (PIII) is straight with an almost zero slope, which means zero water absorption speed. It therefore represents the water saturation zone of the composites.

Furthermore, the amount of water absorbed depends on the resin content; it is generally high for low resin levels. Thus, the samples at 15% of resin absorb approximately 80% of their dry mass; those at 20% of resin absorb approximately 60%, and those at 25% and 30% respectively 30%.

The water absorption of samples, after immersion, can be explained by infiltration of water into pores of the samples and their fixation by wood chips because of their hydrophilic nature [13]. This absorption is higher for sample of low resin content and tends to cancel out after three days of immersion. When the resin content is more than 20%, it reduces the absorption capacity of the samples. Indeed, it occupies the pores inside the composites; it gradually impregnates and waterproofs the surface of the wood particles. This has been also observed by [9] in her work.

3.3. Samples Porosity

The porosity measurement was carried out on thermoformed samples and non-thermoformed samples. The results are shown in **Figure 6** below.

The histograms show that the porosity of the samples (thermoformed or not) decreases when the content of binder increases. For thermoformed samples (in black), it goes from 23% for samples at 15% of binder to 12% for those at 30%. For non-thermoformed samples, their porosity goes from 31% for samples at 15% of binder to 16% for samples at 30%.

It can be noticed that for a same binder content, the porosity of the thermoformed samples is lower than that of the non-thermoformed samples. The reduction rate is about 25%.

According to [14]; there are three kinds of pores in the samples:

- intra-chip pores: caused by microscopic voids left by necrotic wood cells. Their proportion changes with that of the wood chips in the sample and are not influenced by the binder content [5];
- inter-chip pores: caused by poor impregnation of wood chips by the resin during mixing. They are numerous and large into samples with low binder content; their quantity and size decrease as the binder content increases;



Figure 6. Histogram showing the porosity rate of samples.

• pores in the matrix: caused by evaporation of acetone out of the resin. They are observed in samples with a high content of binder precisely from 25% of PSE.

When the binder content is low in the mixture, it has poor impregnation of the wood chips; so existence of many inter-chip pores. However, when the binder gradually increases in the mixture, the impregnation of the wood chips improves more and more and gradually inter-chip pores are filled, it leads reduce their amount.

At high content of binder in the mixture, there are more thick coating around wood chips and more binder into the matrix. Evaporation of acetone generates air bubbles into the matrix.

During thermoforming, there is an internal structure reorganization of samples under combined effects of heat and pressure [5]. Indeed, the thermoplastic matrix (PSE) of the samples softens when the heating temperature reaches 150°C. When the pressure is applied during compaction on the hot and softened samples, they become denser [15]. This densification reduces the porosity of the samples. That's the reason why the porosity of thermoformed samples is lower than that of non-thermoformed samples.

3.4. Observation with Optical Microscope

The optical microscope images show the distribution of the binder into the composites.

With a low content of binder (15% and 20% of EPS), the distribution is not homogeneous; and wood chips are not completely coated with the binder. So many wood chip-wood chip contacts are formed with numerous inter-wood chip pores (Figures 7(a)-(d)).



Figure 7. Microstructure of samples observed with optical microscope.

For composites at 25% and 30% of EPS resin, distribution of the binder becomes homogeneous. The wood chips are well coated with the binder. Contacts between wood chips and the inter-wood chip pores are no longer observed. However, pores are only observed into the matrix formed by the binder (Figures 7(e)-(h)).

For each binder contents, the distribution of binder into thermoformed sam-

ples is more homogeneous than that into non-thermoformed samples. The quantity and size of pores into the composite were reduced by thermoforming process.

4. Conclusions

The recycling methodology proposed in this work can be an alternative for the management of EPS and wood waste according to results obtained.

The study of the samples shows that the drying time depends on their binder content; but it does not exceed 21 days.

The open porosity and the absorption of water by the samples decrease as the binder content increases. An improvement in these properties can be obtained by thermoforming. In fact, for the same binder content, thermoforming reduces porosity by around 25% while improving the internal structure of the samples.

This way for recycling these wastes can have applications in many fields such as cabinetmaking for furniture making and the building as prefabricated structures.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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