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Elaboration and Characterization of a Material Based on Recycled Bottle Shards and Polystyrene: Effects of Polystyrene Resin on Strengths

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Abstract

This study consists of proposing a method of recycling polystyrene and glass bottle waste, by making construction materials. With a view to valorization its waste, this study was carried out and consisted of the development of materials based on expanded polystyrene (EPS) and bottle shards. The samples were developed with PSE rate varying from 20% to 85% with an increment of 5, followed by tests to determine their physical properties (density and absorption) and their mechanical properties (wear strength and three-point flexural strength). The results obtained show that the density of the materials decreases from 2.11 g/cm^3 to 1.06 g/cm^3 with an increase in the PSE rate. Likewise, absorption decreases from 4.45 to 0.33 with an increase in the PSE rate. Wear resistance also drops from 1.36 g/cm^2 to 0.0 g/cm^2 when going from 20 to 85% EPS. At last, the three-point flexural strength increases from 9.35 MPa to 23.19 MPa when going from 20 to 85% EPS. The use of EPS as a binder in materials gives it encouraging physical and mechanical properties. EPS and bottle shards waste considered as a new raw material resource in the manufacture of materials therefore constitutes a valorization way for this packaging waste.

Keywords

Bottle Shards, Expanded Polystyrene, Valorization, Waste, Resin

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1. Introduction

One of the possible ways to reduce the amount of non-biodegradable waste is valorization. Thus, this waste shouldn't be considered as a problem for our environment but rather as new sources of raw material for the production of materials. In addition, the valorization of this waste could constitute an attractive environmental and economic alternative, allowing the elimination of bulky and polluting landfills. However, the actual entry of the materials obtained into the range of construction products will depend on their physical and mechanical properties. This work then aims to develop materials based on expanded polystyrene (EPS) as a binder and bottle shards as reinforcement, then to determine some physical and mechanical properties.

2. Materials and Method

2.1. Raw Materials

2.1.1. Expanded Polystyrene

The polymer used for the material matrix is an expanded polystyrene (EPS) at the end of its life. It comes from the recovery of packaging material and other plastic products collected throughout the city of Abidjan (Figure 1). The recovered polystyrene is dissolved in a solvent which is acetone. This dissolution reduces its volume by 98% [1] and

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thus makes its collection profitable. This results in a resin (EPS) which will serve as a binder for the making of materials. The use of EPS resin as a binder has already been the subject of numerous studies [2-4].

Figure 1. Recycled expanded polystyrene.

2.1.2. Bottle Shards

The shards of bottles used in this study are obtained from glass bottles recovered from the garbage cans and streets of Abidjan and which represent on average around 2% of urban waste [5]. The bottles thus recovered are washed, dried, crushed with a ball mill and sieved. The shards used in this study are the passers-by of the 500 µm sieve (Figure 2).

Figure 2. Shards of glass.

2.2. Experimental Methods

The shards of the bottle and the EPS resin are first mixed in a container so as to obtain a homogeneous mixture. Then, the mixture is flowed into a mold and demolded 24 hours later. After demoulding, the sample is dried for 24 hours in a ventilated room under ambient conditions where the temperature is between 25°C and 30°C. The samples are produced by varying the EPS rate from 20% to 85% with an increment of 5. After drying, the samples are submitted to thermoforming. Thermoforming consists in softening the sample by introducing it into an electric oven at a temperature of 230°C for 30 minutes. Then the sample is compressed using a manual press. The elaboration procedure is summarized in Figure 3

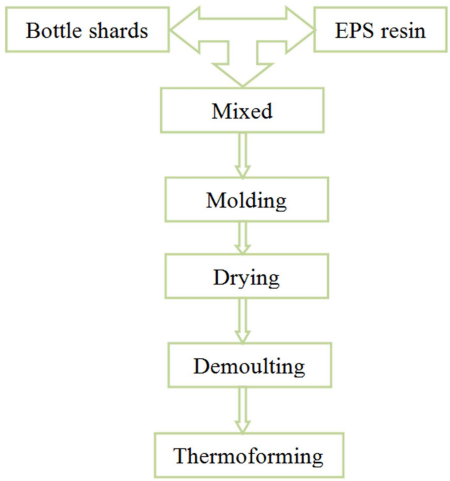

Figure 3. Diagram of the sample elaboration procedure.

The samples obtained are shown in Figure 4.

Figure 4. Image of the samples obtained.

2.3. Characterization of Samples

2.3.1. Physical Characterizations

(i) Density

After thermoforming, the samples are weighed with the 0.1 g precision balance.. Then the dimensions are measured using a precision 0.02 mm caliper. From the dimensions (length, width and thickness), the volume of the blocks is determined. The density is then calculated using formula 1:

$$\rho = \frac{M}{V} \quad (1)$$

Where ρ is the density (g/cm^3), M (g) is the weigth of the sample and V (cm^3) its volume.

(ii) Absorption Test

The absorption test of materials allows us to know their behavior in the presence of water. It is a fundamental property of a material that influences its durability. The penetration of water into a material occurs by absorption. This absorption is accountable for many damages. There are several types of absorption tests. The immersion absorption test carried out during our study was determined according to the guidelines of standard NBN B 15-215: 1989 [6]. After thermoforming the samples are weighed, the dry wegth (ws) is obtained. Then the samples are immersed in water for 24

hours and the new acquired weigth (mh) is obtained. The water absorption by immersion is expressed as a percentage and is calculated according to the following relation (2):

$$Abs = \frac{w_h - w_s}{w_s} * 100 \quad (2)$$

Where: w_h is the wet weight after immersion; w_s is the dry weight.

2.3.2. Mechanical Characterizations

(i) Wear Test

The wear test characterizes the abrasion strength of the faces of the materials. Samples having different contents of EPS resin and bottle shards are subjected to mechanical erosion by friction using a wire brush. For the measurement of wear, we used the device (Figure 5) produced by Kouakou [7]. The device consists of a small cart resting on four wheels, below which is attached a metallic brush. The trolley is mounted on two rails which fit together at both ends. The device is fixed to the support through the metal rods. The wheels have a translational movement along the metal rods. The trolley is loaded with a weight of 3 kg. A wrist is used to pull the cart which moves on the wheels.

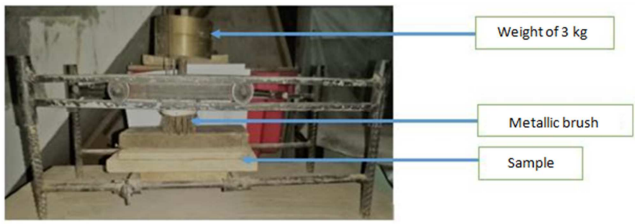

Figure 5. Wear measuring device.

The wear of the material is characterized by the loss of mass after 25 application cycles on the face of the composite. The wear is given by formula 3:

$$U = \frac{w_1 - w_2}{S} * 100 \quad (3)$$

Where w1 (g) is the weight before brushing, w2 (g) is the weight after brushing and S (cm^2) is the brushed surface.

(ii) Flexual Test

The samples are put on two (2) single supports at a distance of "L". A third support is placed on the upper face at mid-distance from the support supports. Then a gradual loading is exerted on the sample using the press until it breaks. The load at break "F" is noted. The three (3) point flexural strength expressed in MPa and is given by formula 4:

$$R_f = \frac{3FL}{2be^2} \quad (4)$$

Where F: the load measured at failure, L: distance between the two support points, b: width of the sample, e: thickness of the sample.

3. Results and Discussion

3.1. Influence of the EPS Content on the Density of the Samples

The results of the test are shown in Figure 6.

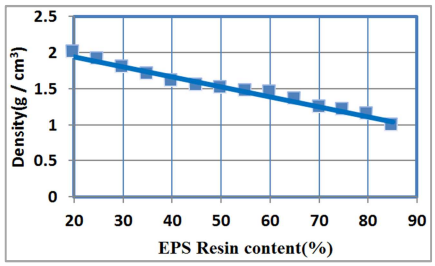

Figure 6. Density as a function of the EPS resin content.

This figure shows that the density of the materials gradually decreases from 2.11 to 1.06 g/cm^3 when the EPS resin content increases from 20 to 85%.

This decrease is due to an increase in the resin content relative to the amount of shards bottles in the material. In fact, the density of the shards (2.4 g/cm^3) is greater than that of the PSE resin (0.77 g/cm^3).

An increase in the content of resin having a low density will then lead to a decrease in the density of the material.

These results are confirmed by some authors [8] in their work on the incorporation of glass fibers in expanded polystyrene. They have shown that the density of composites decreases with increasing EPS resin. These results are also confirmed by studies on composite materials based on high density polyethylene (HDPE) and hemp fiber that the density decreases when the rate of the binder increases [9]. On the other hand, studies have shown that the density of these composites increases with the amount of EPS [10]. In fact, the author worked with particles of cotton hulls which have a density (0.66 g/cm^3) lower than that of EPS (0.79 g/cm^3).

3.2. Influence of the EPS Content on Water Absorption by Total Immersion

The results obtained during this experimental approach are presented in figure 7.

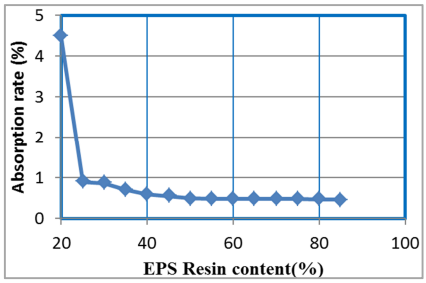

Figure 7. Variation of the absorption rate as a function of the EPS resin content.

This figure shows the variation of the absorption rate as a function of the EPS resin content. It shows that the absorption rate drops when the EPS resin content is between 20 and 25%. Thus, for contents of 20 to 25% EPS, the absorption rate drops from 4.45 to 0.88%, or about 80%. This confirms that the composite so much consolidates when going from 20 to 25%, with reduction of pores susceptible of absorbing water. Above 25% EPS resin, the absorption rate tends to stabilize from 0.88 to 0.33%. This stabilization could be linked to a significant reduction of the pores following an excessive supply of resin in the material. These results are in agreement with that obtained by Boussehel [11] who showed in his studies of stabilization of polystyrene-based composites that the absorption rate decreases with the increase of polystyrene in the material.

These results are also confirmed by Agred and Amokrane [12] who showed that the absorption decreases with the increase of PVC in the material and by Traore [13] who also shows that the absorption rate decreases with an increase in low density polyethylene (LDPE) in the material. This phenomenon can be explained by the fact that polymers being hydrophobic materials, they cannot absorb water. When they are introduced into the mixture, they occupy the place of the voids thus preventing water from filling them. When they are introduced into the mixture, they occupy the place of the voids thus preventing water from filling them. However, the results obtained during this study are lower than those obtained by some authors [14] who found that the absorption varies from 10% to 8%, when the coconut fiber content goes from 0.5% to 2% and when the latex content increases from 32% to 34%.

This can be explained by the fact that the reinforcements used are of a different nature. Indeed, the coconut fiber is hydrophilic while the shards bottles are hydrophobic.

3.3. Influence of the EPS Content on the Wear Resistance of the Samples

The results obtained during this test are given in figure 8.

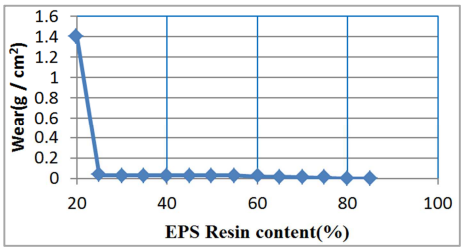

Figure 8. Variation of weight loss as a function of EPS resin content.

The figure shows the variation in materials wear as a function of the EPS resin content. It is observed that wear decreases when the EPS resin content evolved. In fact, for EPS resin a content varying from 20 to 25%, the wear drops very quickly and goes from 1.38 to 0.033 g/cm^2, while from 25 to 85%, the variation in wear is unimportant and goes from 0.033 to 0.0 g/cm^2. The sharp drop in wear between 20 and 25% can be explained by the fact that the EPS resin content becomes sufficient to strengthen the cohesion between the shards. When the EPS resin content increases (25 to 85%), the material is more resistant to wear because the shards are better coated and the cohesion between the shards is very strong. Thus, on brushing, the loss of weight of the material is negligible.

These results are similar to those of who obtained a reduction in the wear of the material by incorporating sand into the latex [15]. He finds that the loss of weight from brushing decreases as the latex content increases. From 10% latex to 22% it has a reduction in wear of the order of 0.01 g/cm^2. As for Djomo [16], he shows that the weight loss is negligible when the shards/cement ratio is between 0.7 and 1.5. Outside this interval the loss of weight is significant.

This is due to a disorganization of the structure linked to an excessive supply of bottles shards.

3.4. Influence of EPS on Flexural Strength

The results of the variation of the 3-point flexural strength are given in figure 9.

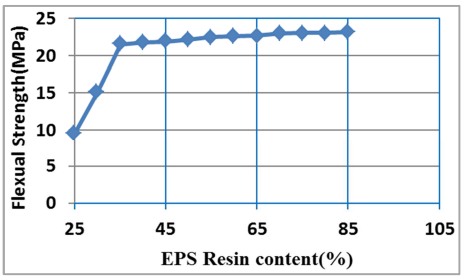

Figure 9. Variation of strength as a function of the EPS resin content.

Figure 9 indicates that the flexural strength evolve from 9.35 MPa to 21.56 MPa when the EPS resin content goes from 25% to 35%. Thus the flexural strength tends to stabilize between 35% and 85% EPS resin. This change in flexural strength is due to the addition of EPS resin to the material which reduces the areas of weakness between the shards. Outside this interval, the flexural strength tends to stabilize (it goes from 21.56 MPa to 23.19 MPa). This is due to a large supply of EPS resin having low flexural strength in the material. Therefore, the ideal rate for making materials is 35% EPS resin. These results are confirmed by some authors [8] in their work on the incorporation of glass fibers into expanded polystyrene as the strength evolve with the increase of EPS in material.

Similarly, some authors [17] have observed an increase in flexural strength with the level of EPS during their studies on

the stabilization of wood chips by EPS resin. As for Traore [13], he shows that the strength of materials based on LDPE and sand increases with a high plastic (LDPE) content. It goes from 13.69 MPa for the material with 15% LDPE to 28.94 MPa for the 50% LDPE material.

This growth is due to an improvement in the cohesion of the material with the increasing of LDPE. It reaches the maximum value for the rate of 50% LDPE. Beyond this rate, it drops and this is due to an excessive intake of plastic.

As for Djomo [16], he showed in his work on materials based on shards of glass and cement that the flexural strength increased from 2.6 MPa to 5.1 MPa when the ratio of shards to cement goes from 0 to 0.7%. This strength growth is due to the incorporation of the shards into the composite.

Outside this range, it drops from 5.1 MPa to 2.6 MPa.

This is due to the excess input of bottle shards which causes a drop in strength because there is not enough cement to hold the bottles shards together.

4. Conclusion

The objective of this study was to valorize polystyrene and glass waste by developing a material. The experimental results obtained through this study draw the following conclusions:

1) Increasing of the EPS content lightens the material

2) Increasing of the EPS rate improves the resistance to water absorption

3) Increasing of the EPS rate improves wear resistance;

4) Increasing of the EPS rate improves flexural strength

This method of materials elaboration is therefore proving to be a solution to the recycling of polystyrene and glass waste.

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