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Analysis of the Mechanical Behavior of Bricks Based on Iroko Sawdust Stabilized Using Recovered High-Density Polyethylene Resin

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Abstract

The work presented proposes, on the one hand, to develop a composite based on Iroko wood flour stabilized by high density polyethylene resin (Hdpe) and, on the other hand, to measure its mechanical characteristics. These are wood-plastic composites (CBP : composite bois-plastique (in French)). To do this, resin mass contents varying from 10 to 60% were mixed with the flour to obtain composites according to a well-defined method. We have studied the variation of these mechanical properties as a function of the proportions of the binder. The measurements carried out related to the behavior in compression, in traction and in flexion. It appears that the mechanical strengths increase for high levels of binder. In addition, for each resin content, the composite has an increasingly resistant behavior in compression than in traction and in flexion. For example, for 60% of Hdpe, the strengths are equal to 23.95 MPa in compression, 18.22 MPa in tension and 13,17 MPa in flexion. However, from 50%, the material adopts an increasingly stable behavior. In addition, it becomes more ductile and deformable as the binder content increases. From the point of view of mechanical resistance, these bricks can, for example, be used in construction for the establishment of non-load-bearing partitions.

***Keywords*:** Iroko wood flour, Resin, High Density Polyethylene, Mechanical Properties

Introduction

For more than a decade, synthetic polymers have started to replace natural materials in almost all fields [1] given the new functions they perform. However, their production generates a significant amount of waste. In fact, in 2016, more than 310 million tonnes of plastic waste were generated and a third of it ended up in nature, according to a report by WWF (World Wide Fund for Nature). The same source warns that the global production of this waste could increase by 4% by 2030, if nothing changes. In the specific case of Côte d'Ivoire, the Ministry of the Environment and Sustainable Development revealed in 2020 that the production of plastic waste exceeds 40,000 tonnes per year with more than 50% discharged into the streets. All of this constitutes an important source of pollution for the environment and represents a danger for ecosystems. Among this waste, Hdpe occupies a significant portion because, for example, of rigid plastics, opaque water bottles, and used plastic bags. As a result, the management of this waste has become one of the main concerns on a global scale due to its increasing quantity and the by-products which are becoming more and more numerous [2]. One of the preferred means is recycling for the development of new materials such as wood/polymer composites with interesting properties in sectors such as civil engineering, automotive and aeronautics.

Also, since time immemorial, wood has been one of the materials used by humans [3]. However, during the transformation of the tree, we observe a production of 40% of chips [4]. In addition, given the ban on the export of timber in the form of logs in Côte d'Ivoire [5] leading to the growth of the activities of local sawmills, this waste is increasingly on the increase. Usually incinerated causing the production of carbon dioxide and unsanitary conditions, this waste is unfortunately not recovered [6].

In order to make our contribution to the recovery of this waste, we have developed a composite based on Iroko wood flour and recovered Hdpe. Our approach consists in determining the effect of the Hdpe resin content on the mechanical behavior of these composites.

Materials and experiments

Materials

Collection and preparation of materials

The materials used in this study consist of Iroko sawdust and recycled high density polyethylene (Figure 1.).

Figure 1. (a) Iroko sawdust, (b) high density polyethylene waste

The Hdpe was collected from the large market, on the outskirts of the streets and from the pre-collette bins in the town of Daloa in the form of bottles and other plastic products. Among the waste that pollutes the urban environment of this city, it constitutes an increasingly important part. This polymer has a melting point of around 130 ^{o}C. Acetone is the best solvent with no health risks. In addition, it is very volatile; which makes it easy to evaporate [7]. Acetone does not break down polymer chains, it only changes the physical structure of Hdpe by diluting it [8]. The dissolution of Hdpe occurred at a ratio of approximately 0.60 per liter of acetone. This results in a resin which will serve as a binder for the preparation of the composites. In this study, the wood is used in the form of sieved sawdust. This sawdust was collected from carpentry units in the town of Daloa. They are made from Iroko, a hardwood species widely used in Ivory Cost. The sawdust was crushed and sieved to obtain a composition containing more than 90% fibers with diameters less than 0.70 mm. This flour is dried at 70 ^{o}C for 48 hours and then stored in glass bottles until the composites are developed. The residual moisture level was around 3% after 48 hours of drying.

Elaboration of composite

For sample preparation, wood flour and Hdpe resin are mixed manually in a container. Then, the mixture obtained is homogenized manually. A quantity is then taken and compacted in a mold using a manual press to obtain samples of dimensions 20x10x3 cm^3. We have developed different types of samples for mass contents of 10; 20; 30 ; 40; 50 and 60% of the Hdpe resin. They are respectively named CBP10, CBP20, CBP30, CBP40, CBP50 and CBP60. The composites are left to dry for 14 days in atmospheric conditions of relative humidity close to 77%, with a temperature varying between 25 and 27 ^{o}C. Then, they are subjected to thermoforming in a press between two plates at 100 ^{o}C for 2 hours [9]. The bricks are shown in Figure 2. In the end, the 6 samples underwent the various mechanical tests which are the compression, flexion and tensile tests.

Experiments

Compression test

Figure 2. Photos of the CBP samples

The aim of this test is to determine the compressive strength of the composite as a function of the content of Hdpe resin. Six types of prism samples of dimensions 10x5x3 cm^3, obtained from the basic composites, were tested. To do this, the block is placed on the 5x3 cm^2 facet to obtain a slenderness of 2 [9,10]. It is gradually charged until it breaks. The breaking load is raised. And the compressive strength expressed in mega pascal (MPa) is given by the formula:

$$\sigma_C = \frac{F}{A} \quad (1)$$

where σ_c (R_c) the compressive strength (MPa), F the force (N), and A the area of the loaded section (mm^2).

The value adopted is the average over three tests for each of the six types of samples. This remains valid for tensile tests.

Three-point flexion test

The behaviour at flexion was tested on samples of dimensions 20x10x3 cm^3 according to standard ASTMD 790-81 [11]. The composite was placed on two simple supports distant from (L). Another support is placed on the upper face equidistant from the first two supports. Then, gradual loading at a speed of 200N / s of the press is applied until failure. The breaking load is recorded and the flexural strength is calculated as follows:

$$\sigma_F = \frac{3FL}{2lh^2} \quad (2)$$

Where σ_F (R_F) the flexion strength (MPa), F the breaking load (N), L the distance between the supports (mm), b the width of the sample (mm) and h the thickness of the sample (mm).

Tensile test

The tensile test is a basic test in the mechanical characterization study. It makes it possible to determine Hooke's constitutive law in a given direction. The use of the force-displacement curve leads to the determination of the mechanical properties such as the Young's modulus (MPa), the tensile strength (MPa), the strain at break (%) and the elastic limit (MPa). After two weeks of storage, the tests were carried out in accordance with ASTM D5456 with a universal tensile machine with a 2.5 KN discharge cell for a loading speed of 3mm / min.

Results

Compression test

The results are shown in Figure 3. The curve shows that the compressive strength is an increasing function of the Hdpe content. Thus, for contents of 10 to 50% of binder, it goes from 11.20 MPa to 23.63 MPa, ie an increase rate of 1.11. However, this growth is more likely between 10 and 30% and is starting to moderate. Indeed, from 50% resin, the resistance varies slightly and would

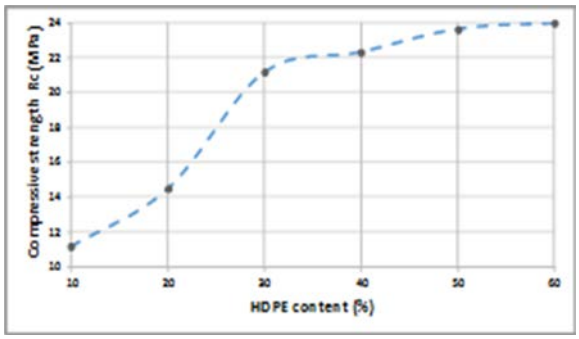

Figure 3. Variation of compressive strength as a function of Hdpe content

tend towards a limit value.

Three-point flexion test

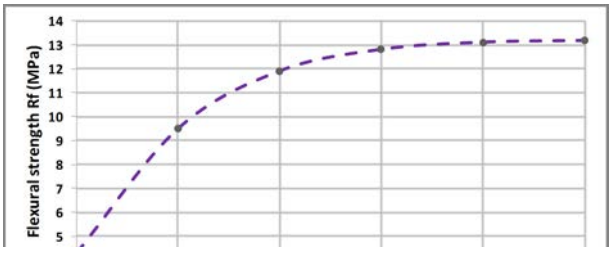

Figure 4. Variation of three-point flexural strength as a function of Hdpe content

The results obtained are shown schematically in Figure 4.

It can be seen that the flexural strength varies increasing logarithmically as the binder content increases. This growth is more remarkable between 10 and 50%. From this last content, there is a moderate horizontal asymptotic increase.

Thus, for a dosage ranging from 10 to 60% of Hdpe, the resistance goes from 4.3 MPa to 13.17 MPa, ie a growth rate of 2.09. We also note that for all binder contents, the compressive strength is greater than that in flexion. For example, at 60% Hdpe, the resistance values are respectively equal to 23.95 MPa and 13.17 MPa. Flexural strength is approximately 55% of compressive strength

Tensile test

The effect of the resin content on the tensile mechanical properties is illustrated in Figures 5, 6, 7 and 8.

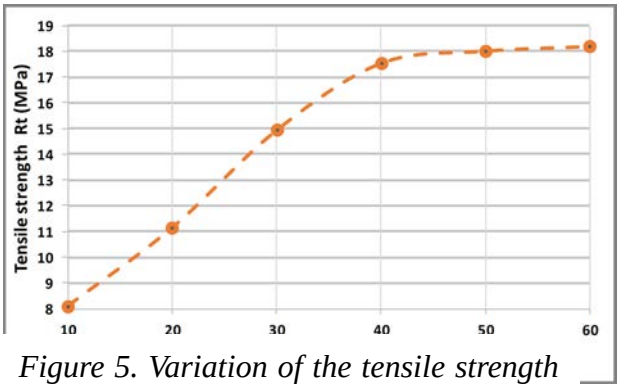

Figure 5. Variation of the tensile strength as a function of the content of Hdpe

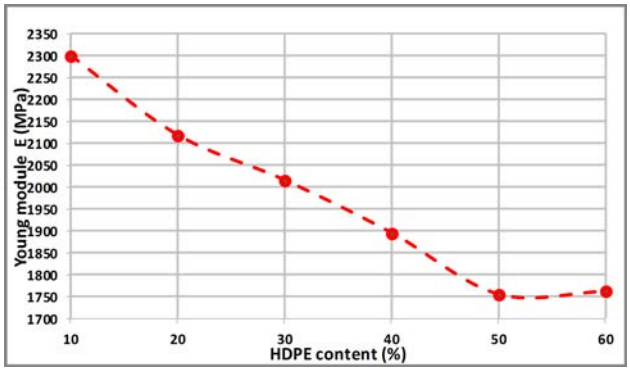

Figure 4. Variation of Young's modulus as a function of Hdpe content

Figure 6. Variation of Young Modulus as a function of the content of Hdpe

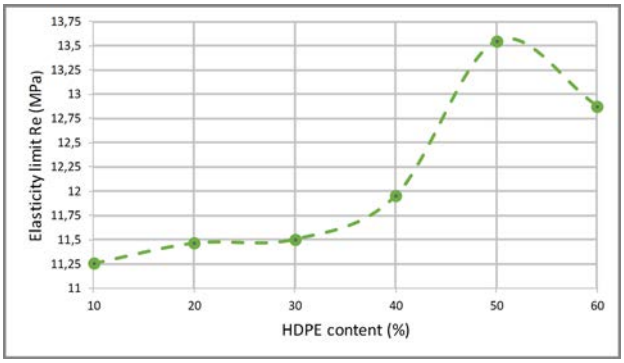

Figure 7. Variation of the elastic limit as a function of the content of Hdpe

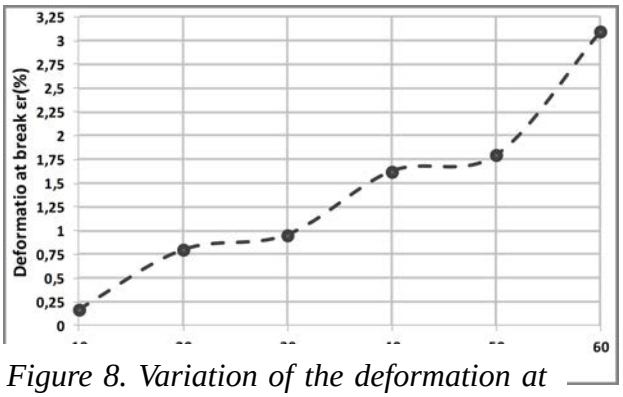

Figure 8. Variation of the deformation at break as a function of the content of Hdpe

The parameters measured are: tensile strength σ_T (MPa), Young's modulus E (MPa), the elastic limit σ_e (MPa) and the deformation at break (ε_r).

For the tensile strength (Figure 5), an increasing evolution is observed when the rate of binder increases. Thus, when the content varies from 10 to 60%, it goes from 8.1 MPa to 18.2 MPa. It is also noted that the resistance is respectively lower and higher than the compressive and flexural strengths. For a Hdpe content of 60%, the ratios σ_T/σ_C and σ_T/σ_F are respectively equal to 0.76 and 1.38. In Figure 6, it can be seen that the Young's modulus is a decreasing function of the binder content. The greatest rigidity is obtained in 60% of Hdpe [12]. From 10%, there is an almost linear continuous decrease before reaching a moderate growth phase from 50%.

For the elastic limit (Figure 7), the evolution can be subdivided into three phases: a first moderate decrease from 10 to 40%, an abrupt growth from 40 to 50% and a sudden and continuous decrease from 50 to 60% . We can therefore notice that the maximum value of 13.55 MPa of the elastic limit is reached in 50% before dropping to 12.88 MPa at 60%. Figure 8 shows an increase in the deformation at break for high resin levels. Thus, when the content varies from 10 to 60%, the deformation increases from 0.17 to 3.1%. We mainly observe two phases of evolution: moderate growth from 10 to 50% and abrupt growth from 50%.

Discussion

The increase in mechanical strengths in compression, flexion and tension when the Hdpe content increases could be explained by the improved interfaces between wood flour particles / Hdpe resin. This improvement could be due to the coexistence of two phenomena. The first is the effect of thermoforming [9]. Indeed, during this process, under the combined influence of heat and pressure, resin and particles reorganize [13]. Under the influence of heat, Hdpe softens to distribute itself under pressure between the wood particles in order to improve the bonds between the different phases [14]. Second, the increasing content of the binder promotes good impregnation and coating of the wood particles; which makes it possible to strengthen the contacts during drying [9]. In addition, the moderate variations in resistance from the proportion of 50% of binder is due to the saturation of the mixture in Hdpe. The material therefore adopts an increasingly stable resistant behavior. The same remark was made by B. Traoré [15] in his thesis work on sand pavers stabilized using low density polyethylene (Ldpe). For tensile strength, since composites are binary (Hdpe/wood or wood/Hdpe), we see similar results for this increase [16,17]. Also, the results show that composites have different behaviors depending on the type of stress. Indeed, its capacity to withstand stresses decreases from flexion to compression via traction. For example, for a content of 60% of Hdpe, the strengths are respectively equal to 13.17 MPa, 18.2 MPa and 23.95 MPa. In addition, composites become more elastic and therefore deformable in traction for high resin levels. This is confirmed by the Young's modulus which becomes weaker and weaker at high binder contents. This decrease in the modulus of elasticity is due to the plasticizing effect which caused a decrease in the stiffness of the composite. These results agree inversely with those of the work of S. Migneault [18] and other authors. Indeed, [16] found a value of 1680 MPa at 50%, [19] obtained moduli of around 2000 MPa at 60% while [17] found 1600 MPa at 50%. The increase in the

yield strength explains why the composite becomes more and more deformable as the resin content increases; which is in accordance with the evolution of Young's modulus. However, variations in this modulus and in the yield strength from 50% show that the material tends towards a more rigid behavior. The increase in deformation at break indicates that the composite becomes more ductile at high resin levels. This is corroborated by other studies [18,20]. This increase is justified throughout the literature with similar figures: from 1 to 5% for 50% in binder content [16,17,19].

Conclusions

This work made it possible to develop composites based on Iroko wood flour stabilized by high density polyethylene resin. The results showed us that the mechanical compressive strengths, three-point flexion and tensile strengths increase for high binder contents. These values start to stabilize from 50% of Hdpe. We retain therefore this value as the optimum content for producing the composite. In addition, this material becomes more and more deformable and ductile when the resin content increases. The use of the proposed method is an alternative for the management of the waste.

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