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Contribution to the Study of Water Behavior and Durability of Wood-Polymer Composite Bricks

Doumbia Ahmed[1], Traore Seydou[2]
[1]*Jean Lorougnon Guédé University, Earth Sciences Department, Faculty of Environment, Daloa, Côte d'Ivoire*
[2]*Félix Houphouët-Boigny University, Physics, Electronic and Telecommunication System Department, Faculty of Sciences of structures of Materials and Technology, Abidjan, Côte d'Ivoire*
Corresponding Author : Doumbia Ahmed

-----ABSTRACT-----
In our previous article, we developed a composite material from Iroko wood flour stabilized by High Density Polyethylene (HDPE) resin. The mechanical properties of these bricks were evaluated. They showed good behavior under traction, compression and bending. The aim of this work is to analyze the water behavior of these composites. The study focused on six samples due to the HDPE contents of 10%, 20%, 30%, 40%, 50%, 60% and 60%. To do this, we first evaluated the apparent and particle densities, and the porosities. Then, the water content was determined. Finally, the behavior of the different bricks was analyzed by immersion in liquid water, by capillarity and by exposure to different relative humidity of 72% and 98%. In each case, twelve measurements were taken and the standard deviations were calculated. In terms of results, the bricks have densities and porosities included in the intervals [691.22; 816.68kg/m3], [915; 991.67kg/m3] and [17.72; 24.45%]. They are close to those of CBP in general. We subsequently note that these values influence the water behavior of bricks exposed to the atmosphere, immersed in liquid water, and exposed to the phenomenon of capillarity. Indeed, like all the consequences linked to these phenomena, for example, the diffusion coefficient in the gas phase, swelling, sorptivity and the capillarity coefficient decrease when the HDPE content increases. The calculated standard deviations show good dispersion of the material and very good homogeneity of the composites. All this adds up to saying that the results obtained are convincing. The result is that these designed bricks have very good water behavior under usual conditions. They could be used in the construction sector
.***KEYWORDS;-*** *Iroko wood, HDPE, bricks, Water behavior, Durability*

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I. INTRODUCTION

The valorization of local materials in construction has currently become a necessary solution to the economic problems of countries, particularly developing countries [1]. However, in order to satisfy the need for secure and economical construction, waste recovery must target increasingly efficient materials [2]. CBPs are increasingly developing in construction [3]. These products require good durability against bad weather such as rain. Wood is a hydrophilic material unlike conventional semi-crystalline polyolefins. Thus, water absorption by these composites is an important factor to control in order to ensure the integrity of the CBP material over time [4].

The objective of this study is to analyze the water behavior of composites based on Iroko wood flour stabilized by recycled HDPE resin. To do this, we first carried out an experimental study relating to the determination of densities, porosities and water content. Then, for all the bricks, the water behavior by exposure to different relative humidity, by immersion in liquid water and by exposure to the phenomenon of capillarity. In all cases, twelve measurements were taken and standard deviations were calculated.

The results showed that these composites have very good water behavior under ordinary conditions of use. For example, the apparent and particle densities are respectively included in the intervals [691.22; 816.68kg/m3] and [915; 991.67kg/m3]. It appears, in accordance with these values, that the increase in HDPE content improves the water behavior of the bricks by exposure to the atmosphere, by immersion in liquid water and by capillarity. The standard deviations calculated on the measurements show very good homogeneity of the bricks produced.
This study convinced us that these elaborate bricks could be used in ordinary water conditions of use.

II. MATERIALS

The composite bricks covered by this study were developed during the work of our previous article. They are composed of Iroko type wood flour stabilized by high density polyethylene resin (PEHD). Wood flour is obtained from sawdust and carpentry waste. As for the resin, it comes from HDPE plastics recovered from trash cans and the streets around large stores such as markets and stores. The development process is specified in our previous work. Each brick is differentiated by the proportion of HDPE it contains. Figure 1 presents the different samples obtained (CBPx: Wood-Polymer composite stabilized at a content x of HDPE resin).

Figure 1. Photos of the CBP samples

Tableau 1. : Nomenclature of the different bricks manufactured

Percentage of HDPE (%)	10	20	30	40	50	60
Names of brick samples	CBP10	CBP20	CBP30	CBP40	CBP50	CBP60

III. MATERIEL ET METHODES

Measurements of density and porosity [5, 2, 6]

For the six samples, we determined the following three characteristics: particle density ρ_p, apparent density ρ_b and porosity p. Six test tubes were used per sample. The mass of the test pieces was determined using a Mettler AE 160 type digital balance with a precision of 0.0001 g.

The particle density expresses the ratio between the mass of a sample and the volume of the material which constitutes it. The volume of the constituent material represents the total volume of the sample minus the volume occupied by the pores. The volume of the constituent material was determined using a gas displacement pycnometer (helium), model AccuPyc II 1340, with a cell for a 10 cm3 test piece. These test pieces were previously dehumidified in a silica gel desiccator. 20 volume measurement cycles were carried out for each specimen.

The apparent density is the ratio of the mass of the sample to its envelope volume. This was determined by the double weighing method.

The porosity of a material expresses the proportion of voids it contains in relation to its total volume. It is therefore the relative difference in apparent and particle density. For each specimen, the porosity p (in percentage) was calculated according to the formula:

$$p(\%) = 100(\frac{\rho_p - \rho_b}{\rho_p}) \tag{1}$$

For each sample, the arithmetic mean and the standard deviation of the densities and porosities were calculated according to the equation:

$$\Delta p = p\left[(\frac{\Delta\rho_b}{\rho_b})^2 + (\frac{\rho_b \Delta\rho_p}{{\rho_p}^2})^2\right]^{1/2} \tag{2}$$

Water content

The water content is defined as the mass of water contained per unit mass of the sample. This value was determined according to the AOAC standard (1990) (Association of Official Analytical Chemists) [7]. The test being repeated six times, bricks of identical dimensions 20x10x3 cm^3 were used. They are dried in a vacuum oven at 70°C, over calcium chloride, until they reach a constant weight.

The water content is given by:

$$TE = \frac{M_{Ech} - M_{Finale}}{M_{Ech}} \times 100 \qquad (3)$$

where M_{Ec}h and M_{Finale} are the masses of the sample respectively before and after evaporation of water in g. The reported result represents the average over six samples with standard deviations included.

Isothermal diffusion of humidity in bricks

The bricks measuring 20x10x3cm^3 are cut and are each exposed to a constant temperature equal to 20°C ±1°C according to the ASTM Dl037 standard for the humidity test. For each sample, two tests are carried out at different relative humidity RH: 72% and 98%. Each test piece is then removed at time intervals t to be weighed; we obtain for each time, a mass M_t. The water absorption rate has the expression :

$$TA = \frac{M_t - M_i}{M_i} \times 100 \qquad (4)$$

The mass of water absorbed at time t, $M_f - M_i$, can be calculated as follows [8-9]:

$$\frac{M_t - M_i}{M_\infty} = \frac{2}{L}\left(\frac{D}{\pi}\right)^{1/2} t^{1/2} \qquad (5)$$

where M∞ is the equilibrium mass in g, M_t is the equilibrium mass at time t in g, L is half the thickness of the brick in mm, π is the angle made by the diffusion half-sphere, D the diffusion coefficient and n the number of samples having undergone the test. The representation of the absorption rate as a function of time makes it possible to determine the absorption coefficient. On the other hand, from equation (3) we obtain the expression for the diffusion coefficient:

$$D = \frac{\pi L^2}{4t}\left(\frac{M_t - M_s}{M_\infty}\right)^2 \qquad (6)$$

The methods presented in one of our articles [10] make it possible to determine the values of D.

Water absorption by immersion in liquid phase

The absorption and swelling tests consist of weighing the samples and drying them in an oven at 37°C until a constant loss of mass is obtained. Then, absorption is carried out in tanks filled with water. The water level in the tank is checked regularly and adjusted if necessary. At 23°C, the container is stored in a temperature-controlled room and at 37°C, in an oven. The temperature of 37°C was selected since it can be observed during hot periods in Ivory Coast on the facades of buildings. Mass and volume measurements were carried out at regular time intervals with a precision balance on three replicates [3-4]

The water absorption rate of each specimen is calculated as the mass of water absorbed at the instant of measurement (M_t-M_s) divided by the dry weight M_s using, in the lic phase, equation (4).

The swelling rate, at time t, is given by:

$$Gfm = \frac{C_t - C_0}{C_0} \times 100 \; c_t : \qquad (7)$$

Gfm : dimension of the submerged test piece, at a date t; C_0: dimension of the test piece in the anhydrous state.

Capillary absorption

Sorptivity, capillarity coefficient

In the presence of negligible hydraulic load, capillarity phenomena can become significant. If the phenomena of capillary absorption results in the absorption of water through the definition of sorptivity, which reflects the exchange at the water-material interface without taking into account the depth of penetration of the water [11 - 12]. The sorptivity is determined by smoothing the first experimental points by a linear function of type:

$$i(t) = i_o + St^{1/2} \qquad (8)$$

Where i(t): the quantity of water absorbed per unit area (mm), S: the sorptivity $(mm.h^{1/2})$ and io is the absorption rate (mm) at t =0.

The water penetration front by capillary action also follows a root law of time [13-14] which can be formulated as follows:

$$h(t) = h_o + kt^{1/2} \qquad (9)$$

Where h(t): the height of the water front (mm), k: the capillarity coefficient $(mm.h^{1/2})$ and h_o: the rate of rise of the water front (mm) at t=0 .

Thus, the relationship between sorptivity and capillarity is generally given by the coefficient C [15-16]:

$$C = \frac{k}{S} \qquad (10)$$

Operating mode [17]

Capillary absorption was studied experimentally from the dry state; as well as water diffusivity in an unsaturated medium. The capillary imbibition tests were carried out, at room temperature, on test pieces measuring 40 x 40 x 160 mm, previously dried to constant mass. In order to ensure one-dimensional flow and to avoid any exchange of humidity with the surrounding air, the side faces were waterproofed using a heat-shrinkable plastic film. The supply of liquid water is ensured by placing one of the cross sections in contact with the water contained in a tank.

The sorptivity coefficient is determined from monitoring the evolution of the volume of water absorbed i(t) by the sample, related to the contact surface (40 x 40 mm) as a function of the square root of time. The quantity of water absorbed is measured regularly over time, by weighing using a scale precise to mg. The evolution curve obtained, which is generally a straight line in the first absorption phase, makes it possible to calculate the sorptivity S of the material according to expression (3)

The penetration front h is measured at each moment of weighing the quantity of water absorbed. We obtain the curve of equation (4). The capillarity coefficient k is determined by smoothing the first experimental points by a linear function.

IV. RESULTS AND DISCUSSION

Densities and porosities

Table 2 presents the results of the determination of the apparent and particle densities of the six samples. It is observed that the densities are influenced by the HDPE content. In other words, the different bricks developed in this study have different densities.

The particle density (Figure 2.) increases when the HDPE content increases. This regular increase is observed for all samples for values ranging from 915 kg/m^3 to 992.67 k/m^3. This is explained by the fact that the density becomes higher and higher as it approaches that of HDPE which is 0.965. In addition, we note a very large dispersion taking into account the calculated values of the standard deviations of 0.01 to 0.46%. This means that the composite bricks are very homogeneous.

Figure 2 also shows the evolution of the apparent density of the different bricks when the proportion of plastic increases. The standard deviations measured, from 0.05 to 0.92, indicate, as expected, very good homogeneity of the material. For a proportion of wood equal to 40% [2021] finds different and lower values equal to 712 kg/m^3 for a grain size varying between 0.63 and 1.25 mm. While in this present work we find a value of 816.68 kg/m^3 for a grain size approximately equal to 0.7 mm. This difference is due to four parameters which may or may not coexist: the botanical nature of the wood, the grain size, the nature of the solvent and the stabilizer used by each author.

The porosity values are summarized in Table 2 and shown in Figure 3. They vary from 17.72 to 24.45% for a standard deviation ranging from 0.05 to 0.82%. The values are considerably different from one sample to another. This very low dispersion was predictable due to the relationships between it and the different densities.

Table 2.: Density and porosity values of the six samples

Samples	Number of measures	Ap. vol. mas (kg/m^3)		Par. vol. mas. (kg/m^3)		Porosity (%)	
		Av. val.	St. d.	Av. val.	St. d.	Av. val.	St. d.
CBP10	12	691.23	0.11	915.00	0.01	24.45	0.12
CBP20	12	709.11	0.05	930.00	0.34	23.82	0.43
CBP30	12	721.91	0.08	942.79	0.46	23.42	0.14
CBP40	12	741,20	0.45	960.38	0.27	22.82	0.05
CBP50	12	766.97	0.37	978.59	0.06	21.62	0.82
CBP60	12	816.68	0.92	992.67	0.20	17.72	0.65

Ap. vol. mas : apparent volumetric mass ; Par. vol. : Particulate volumetric mass
Av. Val. : average value; St. d. : standard deviation

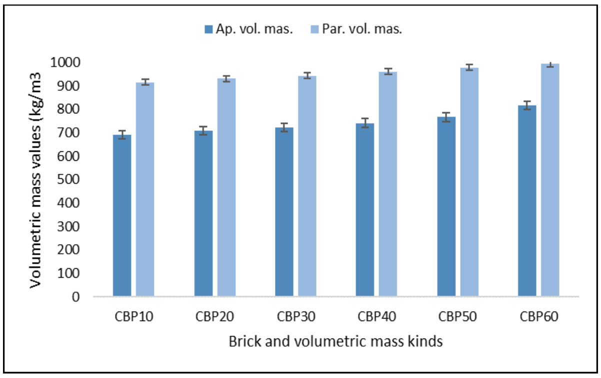

Figure 2 : Densities of the bricks

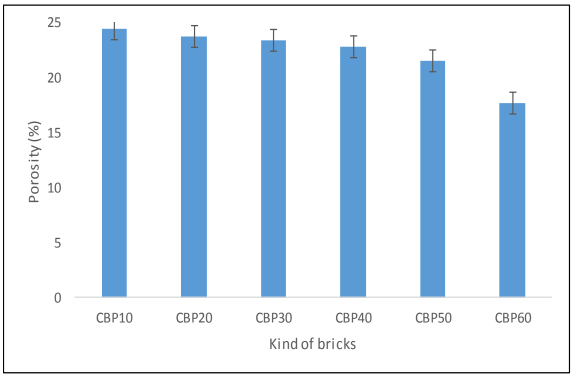

Figure 3 : Porosities of the bricks

Water content

Figure 4 shows the evolution of the mass loss of the different bricks. We observe a decrease as a function of time. Furthermore, this loss increases when the HDPE content decreases. Overall, it varies from 11.1 to 12%. This quantifies the desired water content (Figure 5.) for all the bricks taken on a case-by-case basis. We observe a decrease in water content when the proportion of HDPE increases. This is due to the fact that the number of pores in the composites depends on the presence of the plastic resin. Water retention interfaces are therefore reduced; This result therefore confirms the direction of variation of the densities, in this case the particle density.

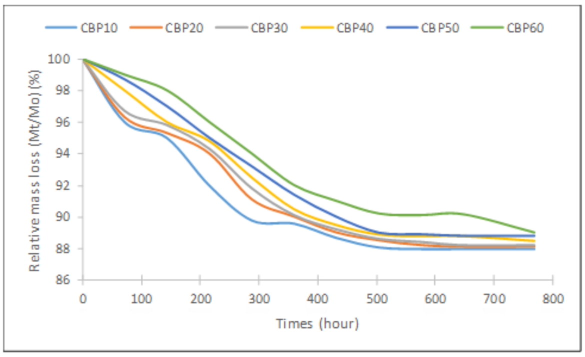

Figure 4.: Mass variation rate of bricks

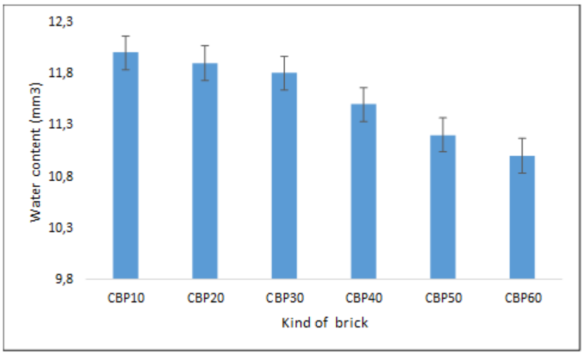

Figure 5.: Water content of the bricks

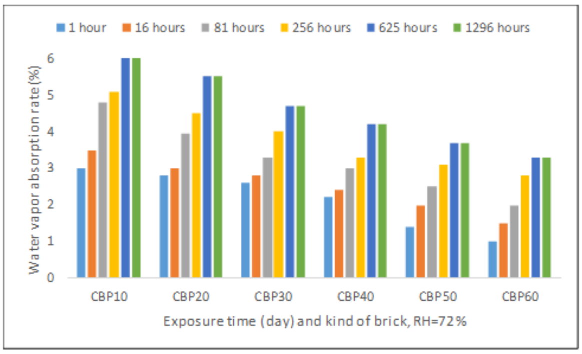

Figure 6: Water vapor absorption rate, RH=72%

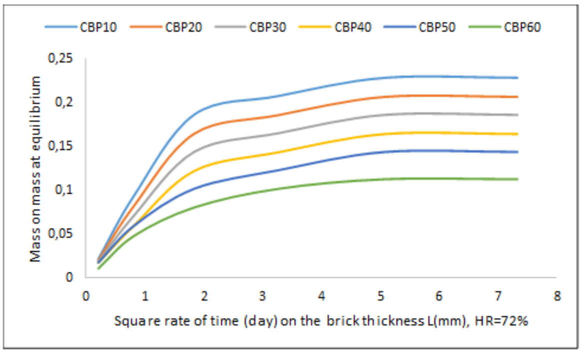

Figure 7: Water content of the bricks, HR= 72%

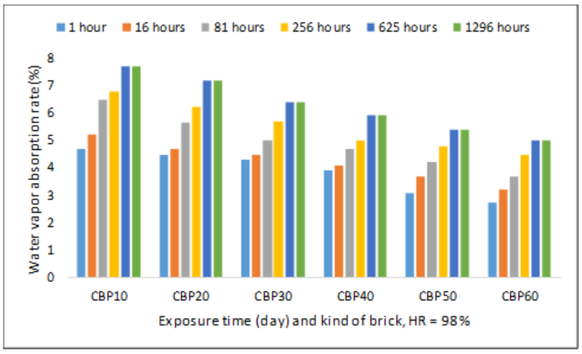

Figure 8: Water vapor absorption rate,, HR=98%

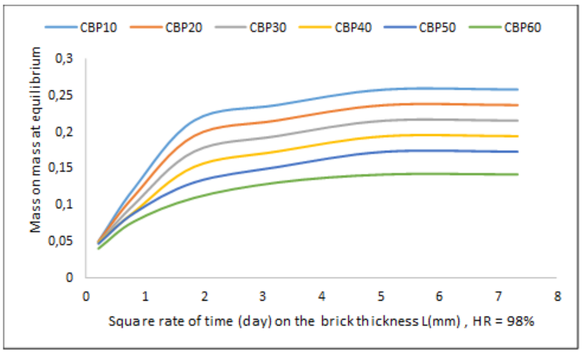

Figure 9: Water content of the bricks, HR=98%

Isothermal diffusion of humidity in bricks

Figures 6. and 8. (respectively Figures 7. and 9.) present the evolution of the absorption rate (TA) (respectively the content) of water vapor as a function of time and relative humidity levels (RH) of 72% and 98% respectively for all the bricks.

Firstly, the maximum quantity of water vapor that can be absorbed by each sample without its mechanical properties being degraded by contact with the atmosphere of actual exposure to use is determined. We notice that the absorption rate increases with time and relative humidity. After 1296 hours of exposure, the TA becomes constant for all bricks and for all HRs. In the two cases of HR, the highest TA is obtained for the CBP10 brick and the lowest for CBP60. This is again explained by the porosity determined previously. The more the porosity decreases, the more difficult it is for water vapor to infiltrate the composite. The diffusivity or diffusion coefficient in each brick was estimated by using the graphs in Figures 7. and 9. respectively for 72% and 98%. The values obtained are summarized in Table 3 and shown in Figure 10. Note that the diffusion coefficient varies as a function of time and the HDPE content. It is greater for the HR of 98%. In addition, it becomes smaller and smaller when the proportion of plastic increases. This is indeed an expected result after the study of porosity.

Table 3.: Variation of the diffusion coefficient as a function of relative humidity

		CBP10	CBP20	CBP30	CBP40	CBP50	CBP60
Diffusion coefficient (mm^2/J).10^{-3}	HR=72%	0.1627	0.1603	0.1541	0.1411	0.1310	0.1270
	HR=98%	0.1789	0.1731	0.1700	0.1630	0.1574	0.1500

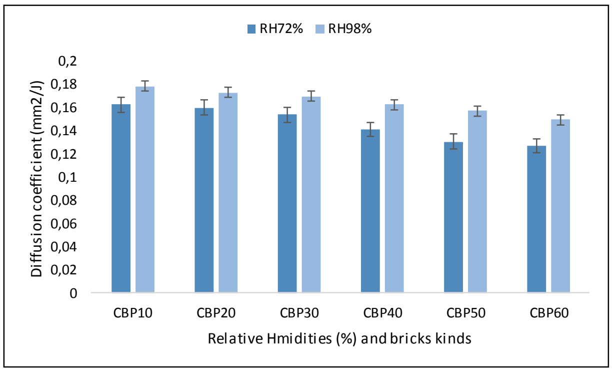

Figure 10. : Variation of diffusion coefficient,
HR = 72% et HR=98%

Water absorption by immersion in liquid phase

The values of the absorption rate in the liquid phase are given in Table 4. and represented in Figure 11. And Figure 12. is the graphic representation. Measurements are taken after 2 hours and 24 hours. On the one hand, we notice that the TA increases over time. For example, for the CBP10 brick, we have the values 9.17%

and 14.80% respectively. On the other hand, it decreases when the HDPE content increases. Generally speaking, absorption in the gas phase is smaller than that in the liquid phase.

Table 4 also provides the experimental values for the swelling of the thickness of each brick after 2 hours and 24 hours. We make the same observations as previously regarding its variation with respect to time and the HDPE resin content. Indeed, this swelling decreases when the proportion of plastic increases and increases when the RH increases. There is no significant difference in thickness swelling due to variation in HDPE content. On the other hand, after 2 hours of immersion, we observed that it increased. Its reduction and that of the TA are due to the fact that it is a consequence of it, on the one hand, and that these two properties are linked to porosity, on the other hand.[5]. We also note that after 2 hours of exposure, the TA of the bricks is low (less than 16%), lower than the saturation point of Iroko wood fibers (23% on average). The swelling in thickness is good negligible, less than 2.3%, i.e. a lower value than the transverse swelling of Iroko wood which is 5.4% on average with an average volumetric swelling equal to 44%. The calculated standard deviations show very good homogeneity of the composts produced. For comparison, the volumetric swellings of polypropylene-wood flour CBP (fir-spruce mixture) are 0.4%, 2%, 5.6%, 8%, 10.8%, for respective rates of 10%, 20%, 30%, 40%, 50% and 60% [5].

Table 4.: Absorption and swelling in liquid phase

Samples	Number of measures	Absorption (%)				Swelling (%)			
		After 2 H	St. d.	After 24 H	St. d.	After 2 H	St. d.	After 24 H	St. d.
CBP10	12	9.17	0.04	14.80	0.05	1.21	0.10	2.30	0.03
CBP20	12	8.70	0.08	14.10	0.02	1.16	0.08	2.23	0.08
CBP30	12	6.10	0.10	13.40	0.09	1.09	0.01	2.01	0.09
CBP40	12	4.12	0.04	11.93	0.03	0.97	0.05	1.87	0.07
CBP50	12	3.90	0.07	11.11	0.12	0.92	0.06	1.81	0.05
CBP60	12	3.78	0.02	10.00	0.07	0.79	0.03	1.76	0.01

Capillary absorption

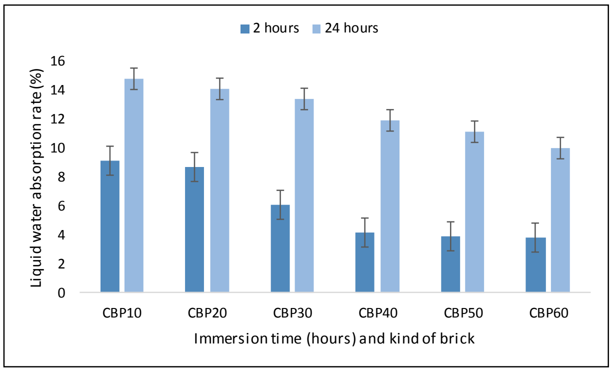

Figure 11. : Absorption of liquid water as a function of time and type of brick

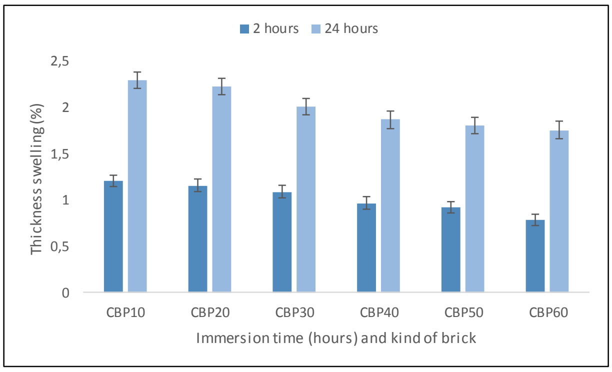

Figure 12. : Swelling of thickness in liquid water depending on time and type of bricks

Sorptivity and capillarity coefficient were measured for the six bricks. The results are shown in Table 5 and graphically represented in Figure 13.

Figure 14 illustrates an example of monitoring the absorption and rise of the water front from the test carried out on the CBP10 specimen. These graphs made it possible to determine the different coefficients sought. These results highlight relatively different values for all the parameters evaluated depending on the type of brick. For comparison, the sorptivity of ordinary concrete is between 0.8 and 1 $mm.h^{1/2}$ [6], and it is around 1.3 $mm.h^{1/2}$ for porous concrete. Whereas in our study, we find, for all the bricks, values varying from 0.36 to 1.71 mm.h1/2. This tendency is illustrated in Figure 13, which reflects the increasing evolution of sorptivity with the increase in the HDPE content. This is linked to porosity.

Table 5 also presents the capillarity coefficients of the different test pieces. We note that the specific behavior of the bricks during sorption has repercussions on capillarity. This decreases as the level of plastic resin increases. This variation appears regular. For all bricks, we have values less than 9 $mm.h^{1/2}$. The small values of the standard deviation once again specify that the bricks are very homogeneous.

Table 5.: Sorptivity and capillarity coefficients

Samples	Number of measures	S ($mmh^{1/2}$)		k ($mmh^{1/2}$)	
		Av. val.	St. d.	Av. val.	St. d.
CBP10	12	1.71	0.06	8.92	0.05
CBP20	12	1.52	0.08	7.11	0.14
CBP30	12	1.20	0.11	6.53	0.06
CBP40	12	0.57	0.07	2.99	0.09
CBP50	12	0.41	0.13	2.13	0.12
CBP60	12	0.36	0.03	1.99	0.03

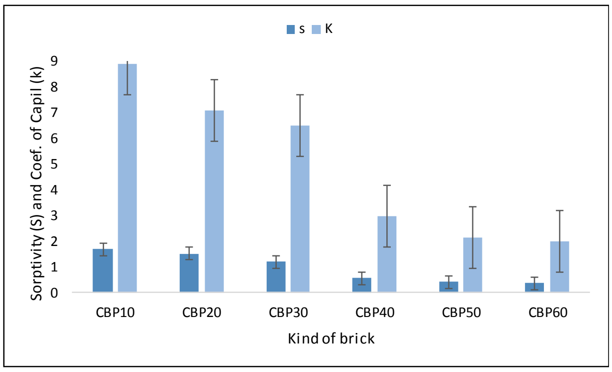

Figure 13. : Sorptivity and capillarity coefficient depending on the type of bricks

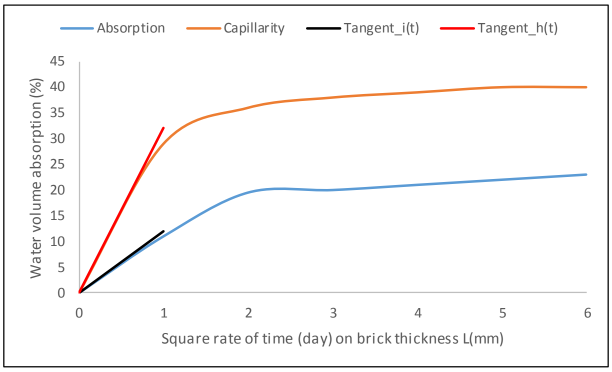

Figure 14. : Example of monitoring absorption and rise of the water front, case CBP10.

V. CONCLUSION

The use of CBP is in perfect progress taking into account various interests such as the valorization of local resources in the form of waste or not, the availability of agroresources and the reduction in weight specific to use compared to concrete and metals. It is therefore important to control their properties in accordance with the conditions of use. This study aimed to evaluate the water behavior of composites based on Iroko wood flour stabilized by HDPE resin. The tests focused on properties such as absorption by immersion in liquid water, exposure to different RHs, and capillarity. They gave convincing results. We note that the water properties of the manufactured bricks improved with the increase in the resin content. The composites behave well under normal hygrometric conditions.

In order to better understand their behavior, our next article will focus on the analysis of the thermal degradation of the present composites.

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