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RESEARCH ARTICLE

INFLUENCE OF VEGETABLE FIBERS ON DRYING PROCESS AND STABILITY IN WATER OF CLAY-SAWDUST WOOD BRICK

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ABSTRACT

The composite subjected to our study is obtained by mixing the clay and the sawdust. The sawdust has an important intrinsic porosity, because of presence of capillaries. Clay is a fine mineral, used as binder. The mixture of these components of nature with very different characteristics, led to a material which properties will be variable according to the voluminal concentrations of each component. Clay is used in the form of fine, with a granulometric size overall lower than 1 mm. It is a clay of the type kaolinic, plastic, containing illite and quartz. The sawdust, being used as reinforcement material, is used in its natural form (without treatment). It is presented mainly in granular and powdery forms, but it also contains short fibers. The results of the study show the water absorption coefficient of bricks drops when one of them incorporates 5 to 15% sawdust; it increases beyond 15%. These results also show that the bricks containing the clay and the sawdust have evaporation rates and withdrawal lower than those of bricks without sawdust. Moreover, after 4 days of total immersion of bricks, the results show that the composites clay-sawdust of wood is more resistant to water compared to the bricks without sawdust which dissolve completely. All these results make it possible to conclude that the sawdust influences indeed absorption rate, drying process and the conduct in the water of compressed ground bricks reinforced with the sawdust.

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INTRODUCTION

The drying process of building materials involves two complex and combined phenomena which are evaporation and the dimensional withdrawal. Evaporation is the departure of mixing water from material; therefore it corresponds to a loss of mass of material. The withdrawal represents the induced dimensional variations by the departure of this water, it thus brings back to a loss of volume of material. Improper drying can cause the the default appearance such as cracks, distortions, etc. If the drying process is not controlled, it could cause the deterioration of the mechanical and physical properties of building materials. It is important then, with an aim of controlling the drying of our composites clay-sawdust of wood, to study the interactions between the evaporation and the withdrawal.

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We thus recorded, during 28 days, the masses and dimensions (length, width and thickness) of the elaborated composites. Drying was done in a room, with an average temperature of approximately 30°C and a hygroscopy ranging between 50 and 70%.

MATERIAL AND METHODS

Raw material used

The raw materials used in this study are the clay and the sawdust. This clay is plastic and composed mainly of kaolinite and illite as clay minerals, which is associated quartz (Kouakou, 2005). The sawdust is not subject to particular preparation. It is used such as it is produced in the sawmills. The sawdust used is that of the wood of *framiré* (generic name). It is also called *Terminalia ivorensis* (scientific name). Before using this matérial, all the massive pieces of wood as of all the impurities which it contains are removed from it. It is used in the form of a mixture of powder, granules and short fibers. Its essential characteristics were studied by Gerard *and*

Al., (1998). The sawdust of *framiré* has a dry density which varies between 450 and 600 kg/m^3.

Method of development of CGB

Samples are made from the mixture of clay and sawdust, to which water is added for mixing. The raw materials are mixed dry in order to obtain a homogeneous mixture. The sample preparation scheme in shown below (Figure 1).

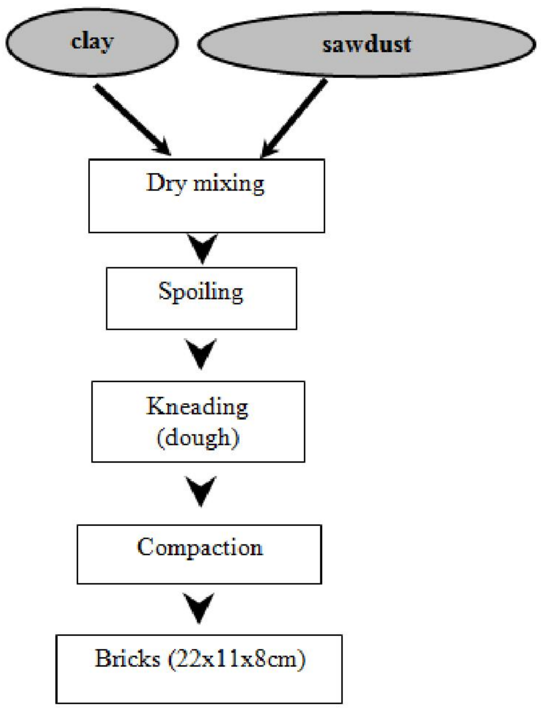

Figure 1. Chart of CGB elaboration process (Modified according to Kouadio, 2010)

After mixing the raw materials, mixing and kneading properly, paste volume needed to fill the mold was determined. This volume is closely linked to the size of the press mold. The chosen volume is the one for which the elaborate bricks present the best Ouattara (2013) compression resistances. For this study, a volume of 5530 cm3 is introduced into the mold to be compacted. The compaction was made by means of a mechanical TERSTARAM crank press.

Method of characterization of wood clay-sawdust bricks

Any ground material in the fresh state contains a proportion of water, related to the mixing of the raw material. Part of this one is used by the natural or hydraulic binders. Remaining water evaporates gradually from the external middle, which constitutes the drying process. The study of the drying of bricks is composed of the evaporation of mixing water and the drying shrinkage or dimensional variation. The brick characterization begins by the determining their absorption coefficient.

Test of absorption of water

The infiltration of water through a material is done by absorption. Absorptive water is responsible for many damages: molds, tasks, peeling wallpapers etc. To make the study of absorption of water, the bricks are partially immersed, in a plate, at 5 mm height. After 10 minutes of immersion, one determines the mass of bricks. The formula below makes it possible to calculate the absorption coefficient (CDE *and al.,* 2000); (Figure 2). The instrument used to weigh bricks is an electronic balance of precision 0.1 g.

Figure 2. Testing device of absorption by capillarity photographs

The absorption coefficient is calculed by the formula below:

$$C_b = \frac{(M_h - M_s) \times 100}{S \times \sqrt{t}} \qquad \text{......................(1)}$$

Where:

- C_b is the absorption coefficient of water per unit of area (g.cm^{-2}.min$^{-1/2}$);
- M_h is the mass of brick after 10 min, it is expressed in gram;
- M_s is the mass of dry brick; in gram;
- (M_h-M_s) is the absorptive water mass, in gram during *t* time;
- S is the surface of the submerged part, in square centimeter;
- t is time in minute.

Test of evaporation

During the drying process, part of the water contained in wet material evaporates. The departure of this water determines the dimensional withdrawal and the consequences which are attributable to it. To control the water evaporation from bricks and understand the influence of sawdust on the drying kinetics, we determined daily variations in the the mass of bricks. The measurements are made with electronic instruments with precision 0.1 g.

Evaporation is calculated by the formula:

$$H\,(\%) = \frac{(M_i - M_t)}{M_{28}} \times 100 \qquad \text{.........................(2)}$$

Where:

- H is evaporation expressed as a percentage;
- M_i mass at the 1st day, in gram;
- M_t mass withing *t* days, in gram;
- M_{28} mass at the 28th day, in gram.

Free shrinkage test

During the drying process, the wet argillaceous items have the ability to contract; this contraction can cause deformations and cracks in these items. To measure the free withdrawal on in order to assess the influence of sawdust on their dimensional stability, we measured during the drying process, the daily variations in the volume of bricks. The volume is calculated based on measurements of length, width and height of the brick. The measurements is carried out with a slide caliper of precision 0.01 mm (Figure 3).

Figure 3. Photographs showing the dimensional variations measurement device

The withdrawal is calculated based on the formula below:

$$R\,(\%) = \frac{(V_i - V_t)}{V_{28}} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

Where,

R is the withdrawal expressed as a percentage;
V_i is volume at the 1st day, in mm^3;
V_t is volume at the t day, in mm^3;
V_{28} is volume at the 28th day, in mm^3.

Test of the behavior of bricks in water

The behavior in the water of a material consists of the appreciation of its stability in water. Indeed, when certain materials are immersed in water, they dissolve or degrade. This test will enable us to understand the behavior of clay bricks compressed and reinforced with the sawdust once immersed in water. For its realization, the samples are completely immersed in water after 28 days of drying. Their behavior and their surface condition are observed during 96 hours of immersion (4 days). Then, after a 72 hours drying, their surface condition is observed again.

RESULTS

Influence of sawdust on the water absorption coefficient of clay-wood sawdust brick

Figure 4 presents the variation of the absorption coefficient according to the content of sawdust. This figure shows that the absorption coefficient drops between 5 and 15% of sawdust then increase between 15 and 25% of sawdust. It passes from 2.34 to 2.02 $kg.m^{-2}.min^{-1/2}$ on the one hand, then to 2.89 $kg.m^{-2}.min^{-1/2}$ on the other hand\; respectively for 0%, 15% and 25% of sawdust. The absorption coefficient for reference brick (sawdust 0%) is not measurable because the brick starts its dissolution as soon as it is in contact with water (Kouakou, 2005; Kouadio, 2010); this behavior changes with the incorporation of the sawdust (figure 5a). The absorption coefficient passes from 2.33 to 2.01 $kg.m^{-2}.min^{-1/2}$ respectively for 5 and 15% of sawdust. Such fall of the absorption coefficient between 5 and 15% would be related to the fact that the sawdust absorbs part of water and increases volume. This increase in volume of the sawdust will tighten a little more the argillaceous particles and will avoid their dispersion.

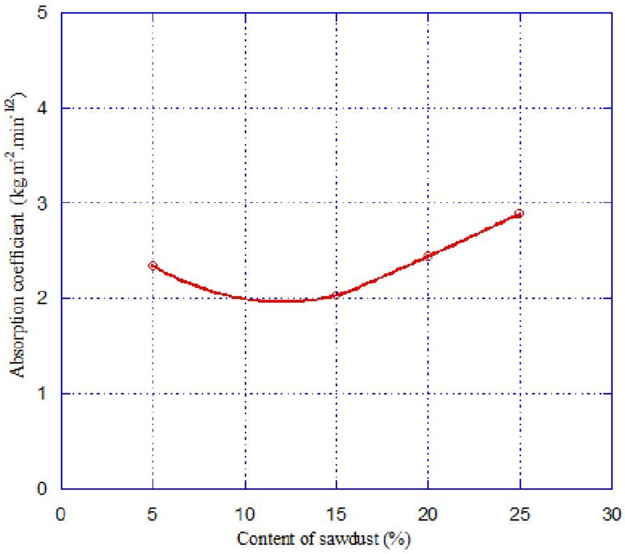

Figure 4. Variation of the water absorption coefficient of the composites

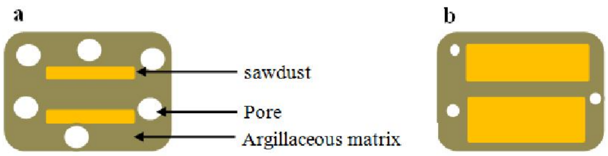

Figure 5. Diagram showing the behavior of the sawdust in the argillaceous matrix during the test of absorption with a = brick before immersion and b = brick after immersion

Influence of the incorporation of the sawdust on evaporation of water from the mixed composite during the drying process

The results of evaporation are presented though figure 6. This figure presents the variation of the evaporation of the water of bricks according to the duration of drying process. It shows that the rate of evaporation varies with time but also with the sawdust content of the bricks. With time, the increase in the water rate evaporated, which translates actually a loss of mass of bricks, is related to the progressive departure of the water of the composites during their drying.

Figure 6 Shows that the curve of water evaporation of brick without sawdust (reference brick, red curve) presents three portions:

- a first part ranging between 1st and the 8th day, it lasts 8 days. Here, the curve takes the increasing line form with a strong slope (2.9 %), synonymous with a high evaporation rate;
- a second part going from the 8th to the 16th day, it also lasts 8 days. It corresponds to the concave part of the curve where evaporation decreases gradually. The

speed of evaporation drops with time. The slope of the curve is lower than the previous one (0.4 %)

- a third part going from the 16th to the 28th day. It lasts 12 days and corresponds to an almost horizontal line of near zero slope (0.1 %). The speed of evaporation of this part is thus quasi constant.

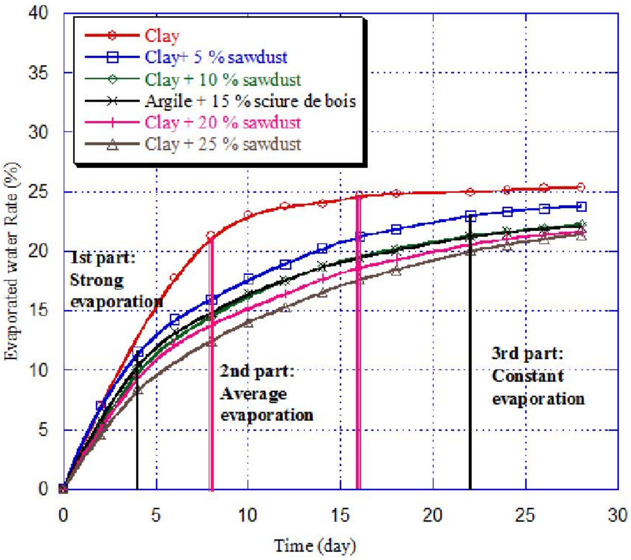

Figure 6. Curves of evaporation of the water from bricks during the drying process

In the presence of sawdust, the three parts are also observed but with different durations:

- a first part ranging between the 1st and the 4th day. It lasts 4 days. Here the slopes are virtually identical to that in the reference brick (2.5 %) but shorter in duration. This first part corresponds to the evaporation of water contained in the brick pores;
- a second part going from 4th to the 22nd day, it lasts 18 days and corresponds to the concave part of the curve where evaporation decreases gradually with a slope 0.6 %. The evaporation rate decreases with time. We note that this phase is longer for bricks with sawdust compared to brick of reference brick. It corresponds to the beginning of capillary water departure from the bricks. It is longer for composites clay-sawdust because sawdust, due to its high hydrophilicity, retains part of the water that gradually restore the external environment during the drying of the composites;
- a third part going from 22nd to the 28th day (6 days) corresponding to a substantially horizontal line. The curves have low slopes (0.1 %). As in the case of the bricks without sawdust, the evaporation rate in this part is almost constant.

We note that in presence as in absence of sawdust, the curves of evaporation present three phases having different durations depending on the composite of the mixture. For a better understanding of evaporation, we will examine the withdrawal that results from it.

Influence of the sawdust incorporation on the composites dimensional shrinkage during the drying process

Figure 7 presents the result of the shrinkage obtained on bricks. This figure presents the variation of the withdrawal of the composites depending on the duration of the drying process. The curves show that the shrinkage increases with time but decreases with the increase in the content of sawdust in the composites. Moreover, it will decrease the porosity of material (Figure 5b). This could substantiate the fall of the absorption coefficient with the increase of the sawdust content between 5 and 15%. Beyond certain quantity of sawdust (15%), the sawdust becomes too high in the structure of the composite (for a small quantity of clay), automatically increasing the porosity of the material; the absorption coefficient passes then to 2.44 and 2.89 $kg.m^{-2}.min^{-1/2}$ respectively for 20 and 25% of sawdust. This study therefore shows that the incorporation of the sawdust to reinforce the clay matrix, below 15%, reduces the absorption coefficient of compressed clay bricks.

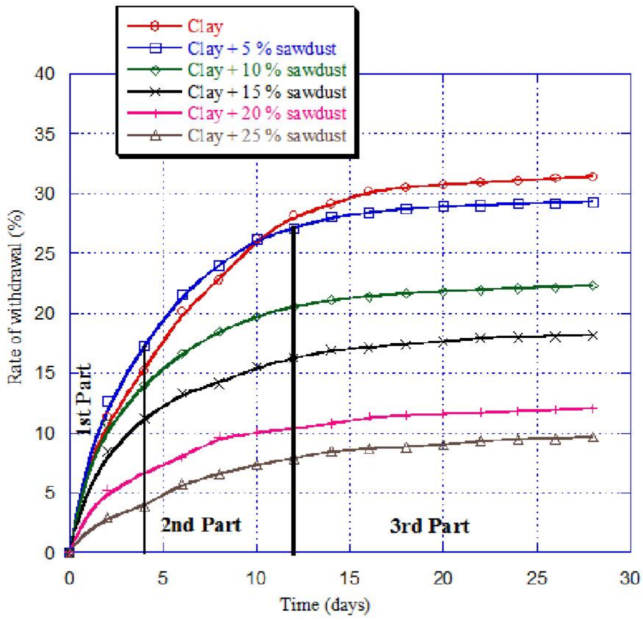

Figure 7. Curves of dimensional shrinking of bricks during the drying process

Figure 7 shows that the curve of shrinkage for brick without sawdust (brick of reference) can be subdivided in three parts:

- The first part goes from day 1 to day 6: there is an increasing curve slope of 2.20 %; in this part the speed of the shrinkage is strong;
- The second part is between 6th and the 16th day. This zone corresponds to the concave part of the curve. In this part which has a slope of 0.4 %, the speed of shrinkage decreases with time;
- The third part goes from the 16th day to until the 28th day of drying. It is the quasi constant part of the curve. The speed of shrinkage is constant (slope 0.1 %) and dimensions of bricks do not vary practically any more.

This figure also shows that the shrinking of bricks containing the sawdust presents three parts as well:

- a first part which lasts the first four days of drying and which corresponds almost to a line. Here, the speed of shrinkage depends on the content of sawdust in the composites. The slopes vary between 0.7 (sawdust 25 %) and 2.2 (sawdust 5 %). This part corresponds to the first part of the curve with sawdust 0%;

- the second part goes from the 4th to the 12th day. She corresponds to the concave part of the curves where the speed of shrinkage decreases with time. The slopes vary between 0,4% (sawdust 25%) and 0.9 (sawdust 5%) ;
- the third part extends between the 12th and the 28th day. It corresponds to the part of the curves where the speed of the shrinkage is practically constant with a slope of 0.1%.

In the presence of sawdust, the speeds of the shrinkage of bricks with sawdust, materialized by the slopes of the curves, are lower than those of the curve of the reference brick. Indeed, the structure of wood is very porous. These pores are the seat of wood components including hemicellulose which proves to be the most hydrophilic component of wood. During the mixture and shaping of the raw materials (clay + sawdust), part of clay penetrates the pores of wood. The compaction is responsible part of the dough into the pore oh the wood prior to covering its entire surface. We are witnessing a coating effect of wood by clay particles (Figure 8). The extent and the effectiveness of this coating depend on the composition of the mixtures. When the sawdust content is high, the clay film coating the wood particles is thinner. The clay particles of the rate of contraction will be small, hence the low shrinkage observed for high levels of sawdust.

Table 1. Behavior in the water of wood clay-sawdust bricks

Content of sawdust (%)	Physical status of bricks
0	Dissolution (45 mn)
5	Partially dissolved brick
10	Stable brick
15	Stable brick
20	Stable brick
25	Stable brick

Influence of the incorporation of sawdust on the water stability in the clay-sawdust bricks

The bricks were completely immersed in water during 4 days in order to study their behavior. The results are consigned in the table below. This table shows that at sawdust 0%, the bricks dissolve completely. At 5%, the bricks are partially damaged whereas from sawdust 10%, one notes a stability of bricks in water. We note that the immersion is followed by release of air bubbles at the surface of water. When the content of sawdust increases, the number of released bubbles increases too. From sawdust 10%, the release of the bubbles is done as of the immersion of bricks; however, between 0 and 5%, it appears after at least 1 to 2 minutes of immersion. In bricks, the pores or vacuums are occupied by the air\; the release of the bubbles is due to the entry of water in these pores.

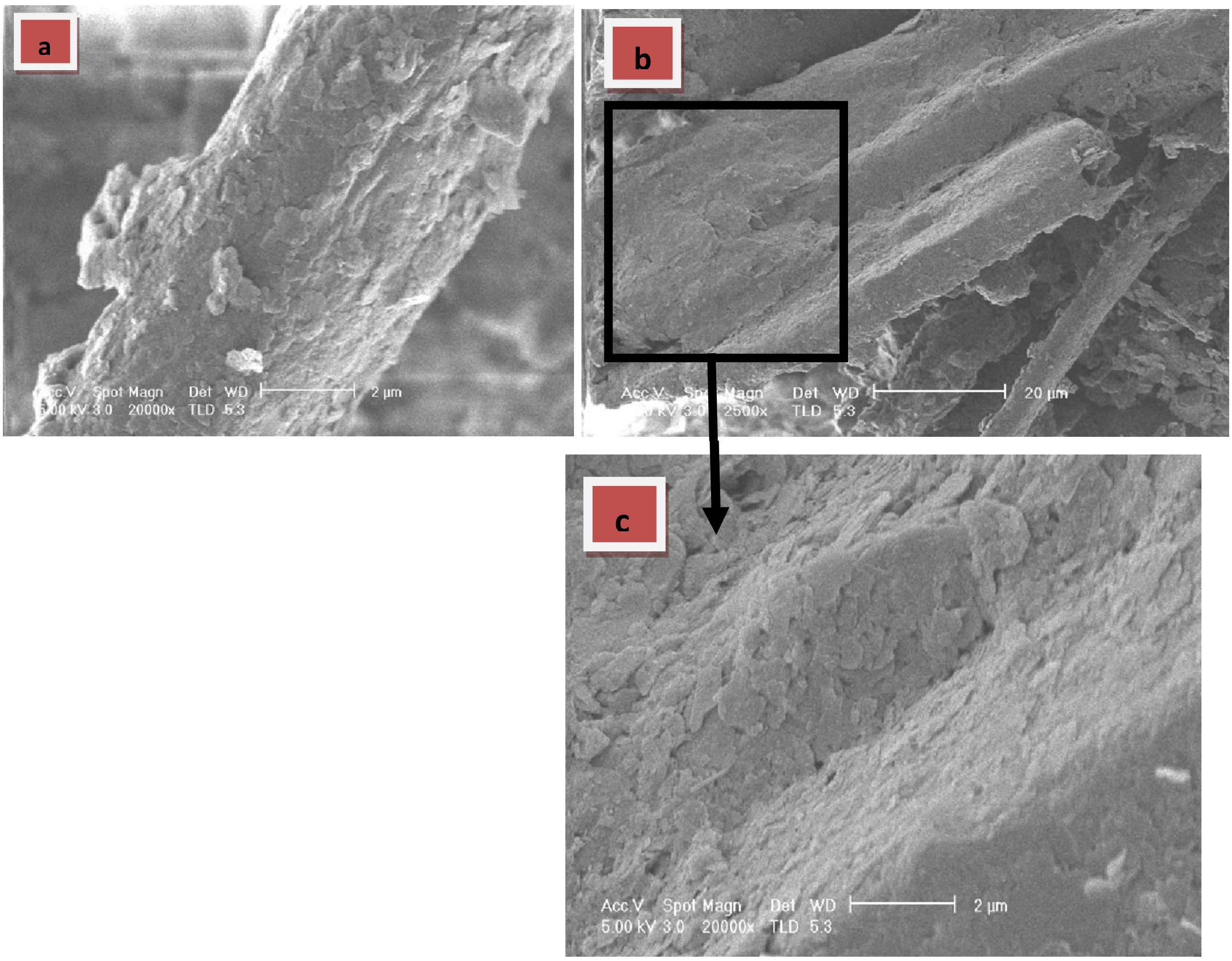

Figure 8. Micrographs showing the coating of the particles of clay
a)Wood fiber entirely covered by the clay platelets
b)Surface of a wood fiber coated by the clay
c)Detail of portion of the fiber shown in b

The number of released bubbles increases with the increase in the content of sawdust. It shows that the incorporation of the sawdust cause an increase in porosity in the bricks. We also note that the speed of dissolution of bricks decreases when the content of sawdust increases. The physical status of bricks that have resisted or partly resisted to the action of water after their immersion is presented on Figure 9.

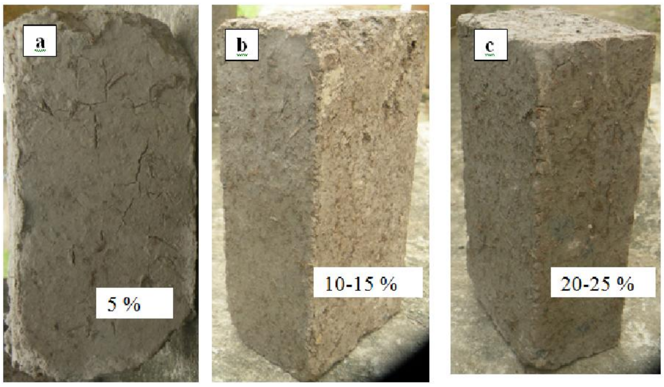

Figure 9. Photographs showing the aspect of bricks after four days of total immersion with: a = brick containing 5% of sawdust; b = brick containing 10 to 15% of sawdust and c = brick containing 20 to 25% sawdust

For bricks with low sawdust content (0 to 5%), water causes a loss of material which explains its angles blunted (figure 9a). From 10%, the sawdust creates more interconnected pores in material, which facilitates the flow of water. Moreover, sawdust (very hydrophilic) will cause certain water retention in brick. It is then inflated and tightens the clay particles together, thus reducing the speed of dislocation of the bricks. This is why, after four days of immersion, the bricks still remain intact as evidenced in the figures 9b and 9c. We can say that the sawdust acts as a brake to the dispersion of clay in the presence of water particles and at the same time it increases the porosity of the material.

DISCUSSION

The studies carried out on the drying process of bricks show that this one is influenced by the presence of the sawdust. According to the mix design, two scenarios arise:

1st case: content of weak sawdust (≤ 5 %)

Here, the quantity of clay in brick is very high. The wood particles are entirely imprisoned in the argillaceous matrix. The thickness of argillaceous film between two wood particles is important; thus, the clay controls the drying processof these bricks. It will lose very quickly the water (strong evaporation) and will very strongly contract following the evaporation of this water (strong shrinkage).

2nd case: content of sawdust average and content of high sawdust (5 à 25 %)

When the level of sawdust increases, the quantity of clay drops in bricks. The increase in the rate of sawdust is accompanied by the appearance of porosity in the structure of the composites. This porosity creates in theory a preferential way for the evaporation of water; what should indeed facilitate the departure of mixing water, therefore increasing the speed of evaporation. This hypothesis was put forth by El Hachem (1990) in a study on the influence of amorphous cast iron fiber on shrinkage and creep of concrete. It was also confirmed by Abdou and Houari (2007) during a study on the influence of steel fibers on the sizes and weight changes in cement matrices. The similarity between these two studies is that the fibers used in both cases are inert with water. They do not consume, nor retain mixing water. However, in our case, it is rather the opposite which occurs. This is because increasing the sawdust content leads to an increase in the number of wood particles in the bricks. Thus, the sawdust retains part of mixing water, which cause a drop in the quantity of water evaporated with the increase in the content of sawdust. In addition, clay traps a part of this water into the pores of wood. All this water will be discharged to the outside of the brick slowly and gradually. This is what also explains the decrease in the rate of evaporation in these bricks. Since shrinkage is a function of evaporation, the decrease in the evaporation rate induces a lower shrinkage on one hand and on the other hand, increasing the number of wood particles in the composites cause the decrease of the thickness of the clay film between these particles, thereby decreasing the magnitude of the withdrawal. This result on the withdrawal is in conformity with that of (Abdou and Houari, 2007) which showed that the fiber mortars are stabilized more quickly than the pilot mortars (without fibers). Our result is also in conformity with those of (El Hachem Étude de l, 1990) and Houari (1993) which arrived at the same conclusion during their studies relating to the fiber concretes.

Conclusion

The results of this study support the conclusion that the addition of clay to sawdust for the preparation of bricks reduce the sensitivity of the latter to water. The composite absorption coefficient fall between 5 and 15% of sawdust. After 28 days of drying, the total evaporation is about 25% for the reference brick for a withdrawal rate of 31%. For composite with 5 and 25% of sawdust, water evaporation percentages are 24 and 21% respectively. Withdrawals in turn becomes 29 to 9%. After this work, we can say that sawdust does influence the evaporation of water and the dimensional shrinkage of compressed clay bricks. It helps to lower the evaporation and shrinkage rate and improves water of compressed clay bricks.

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