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Stabilization of Clay Blocks with Potash Extracted from Cocoa Pods for Eco-Friendly Construction

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Abstract

This study aims to design stable and high-performance bricks for construction by developing geopolymers based on clay and potash extracted from the ashes of dried cocoa pods. For this purpose, three potash solutions of 100 g/l, 150 g/l, and 200 g/l were prepared by dissolving different masses of pellets derived from cocoa pods in water. These solutions were mixed with clay primarily composed of kaolinite, illite, and quartz, and the resulting paste was shaped using a hydraulic press. After demolding and drying at room temperature until a constant mass was achieved, the blocks underwent thermal treatment at 60˚C, 80˚C, 100˚C, and 150˚C. The thermally treated blocks were subjected to compression tests, capillary absorption tests, and X-ray diffraction analysis. The compressive strengths increased with potash concentration and thermal treatment temperature. From 100˚C and a potash concentration greater than 100 g/l, the blocks were stable in water, with a water absorption capacity that decreased with increasing potash concentration. All these physical and chemical changes are due to the formation of new mineral phases between the particles. Starting from 80˚C for a potash concentration of 150 g/l and from 100˚C for 100 g/l, the blocks were stable in water with a compressive strength exceeding the prescribed value of 4 MPa for load-bearing walls. Therefore, they can be used in construction.

Keywords

Clay, Potash, Geopolymers, Cocoa Pods

1. Introduction

For more than two decades, the earth has suffered the harmful effects of the release of carbon dioxide into the atmosphere, resulting in global warming [1]. According to studies, the production of Portland cement is one of the essential causes of the release of CO_2. It is responsible for 5% of global emissions. Also, in order to preserve the planet and guarantee sustainable development, research efforts are being carried out to reduce the carbon footprint of the building industry.

Several authors [2] [3] have suggested the use of alternative cements to reduce the production and consumption of Portland cement. These cements were obtained by adding ash from agricultural waste (rice husk, sugar cane, oil palm hulls and pulp) or mineral materials (glass powder, volcanic ash) to the clinker. This method makes it possible to reduce the use of clinker by 5% to 30% by weight [4]. However, CO_2 production by the construction industry still remains high because global consumption of concrete continues to grow year after year. It was 11 billion cubic meters in 2010 and 25 billion cubic meters in 2022 [5] [6]. Clinker remains the main constituent of the different types of formulated cement. It is estimated that the production of one ton of clinker generates on average 0.8 to 1 ton of CO_2 during the decomposition of limestone.

In addition, a total substitution of cement with geopolymer binders has been carried out by other authors. Geopolymers are inorganic materials, generally manufactured by mixing aluminosilicate materials such as fly ash, slag, kaolin, and metakaolins with an alkaline activator, either sodium silicate solution and/or sodium hydroxide solution, potassium and/or potash silicate, or many other alkaline solutions [7] [8]. The chemical reaction between the aluminosilicate source and the activator leads to the formation of a solid three-dimensional network at room temperature or at low temperature (from 20˚C to 80˚C). Thus, the production of geopolymers generates a very low carbon footprint compared to that of Portland cement [9] [10].

The properties of geopolymers obtained by alkaline activation of clays are influenced by numerous parameters: the activation time, the maturation time, the alkaline concentration, the characteristics of the aluminosilicate material (the Si/Al ratio) [11], the particle size, the morphology of its particles and the presence and nature of impurities) and the ratio of alkaline and aluminosilicate solutions [12]. According to [13] [14], the compressive and flexural strengths are optimal when the soda (sodium hydroxide) concentration varies between 10 M and 16 M. The sodium hydroxide used has a purity of 99%. Likewise, [15] obtained with a pure potash solution at 99% concentration, resistances similar to those [13] [14]. Also, Geopolymer bricks have been shown to give a lot of environmental advantages over traditional fired clay bricks. A study by [16] led a life cycle assessment comparing the two materials and realized that clay-based geopolymer bricks can lower CO_2 emissions by up to 55% compared to their traditional counterparts.

These geopolymers obtained by transformation of kaolin into metakaolins are of growing interest for the construction industry due to their high mechanical strength [17], their resistance to heat and fire [18] and chemical durability [19]. However, the use of energy for cooking kaolin at more than 600˚C and the use of sodium hydroxide and/or pure potash constitute many factors which limit the popularization of this process. Also, this research aims to explore other avenues, such as the production of geopolymers from kaolin and alkaline ash extracted from agricultural by-products. The challenge is to obtain a material which is stable in water and capable of being used in construction, therefore respecting the standards which govern the construction of buildings.

This work aims to design blocks of clay stable in water using potash extracted from cocoa pods with a view to using them in building construction.

2. Materials and Methods

2.1. Raw Materials

2.1.1. Clay

The clay comes from the locality of Dabou (Côte d'Ivoire), from the Niéky site. It is a brown clay, with a composition dominated by 98% fine particles (diameter is less than 80 µm). It is made up of 24% clay (diameter less than 2 µm), 63% silt (diameter between 2 and 63 µm) and 13% fine sand (diameter between 63 and 200 µm). For this clay, the Atterberg limit values are 55% for the liquidity limit; 21% for the plasticity limit and 28% with regard to the plasticity index [20]. Mineralogical and thermal analyzes have shown that it essentially contains kaolinite, illite and quartz and moreover it is a kaolin clay.

This clay was dried, crushed and sifted through a 2 mm sieve. The resulting passer was used in the making of clay blocks.

2.1.2. Potash

The potash used in this study is extracted from dried cocoa pods, taken from a plantation located not far from the town of Méagui, at a distance of 372 km from Abidjan (Côte d'Ivoire). The pods are collected, stacked and cleared of any sand and possible debris, then processed to extract the potash following the method recommended by [21].

2.2. Methods for Making Clay Blocks

2.2.1. Preparation of the Potash Solution

To obtain the potash solution, masses of potash powder of 100 g, 150 g and 200 g are dissolved individually in one liter of water. This mass selection was made in order to study the influence of potash concentration. The solution is homogenized for 5 minutes and left to stand for 24 hours to allow total dissolution of all the potash crystals in the water. The blocks will be developed using the three S1 solutions; S2 and S3 at concentrations of 100 g/l; 150 g/l and 200 g/l, each having a respective pH of 12.7; 12.96 and 13.17. In the work of [22], they studied raw potash extracted from the kapok tree, with concentrations ranging from 160 g/L to 260 g/L. Thus, we wanted to work with lower concentrations, below 160 g/L, to observe the results.

2.2.2. Preparation of Clay Blocks

The development of the blocks was done in 3 steps:

- **Preparing the mixture**

The clay powder is mixed with the potash solution, representing 30%. of the clay powder mass then left to rest for 10 minutes to ensure its impregnation. Then mixing is carried out until a homogeneous paste is obtained.

- **Shaping of specimens**

The paste or dough resulting from the preparation is introduced into the mold of the static press; then subjected to pressure. Once unmolded, the samples are shaped into the dimensions 21 × 10 × 4 cm^3. They then undergo drying in the laboratory, at a temperature fluctuating between 25˚C and 27˚C, with a humidity between 76% and 80% until reaching a constant mass at the end. 48 hours.

- **Activation and maturation**

The activation or heat treatment was carried out using an ILUX brand oven. The activation cycle includes a temperature rise phase to the desired value lasting 1 hour. This phase is followed by a level at the desired temperature for 48 hours (2 days). The end of the cycles is marked by the phase of temperature drop over a period of 1 hour. The thermal levels adopted are 60˚C, 80˚C, 100˚C and 150˚C.

The samples taken out of the oven undergo a maturation period for 28 and 90 days at the ambient temperature of the laboratory, oscillating between 25˚C and 27˚C with a humidity of between 76% and 80%.

Table 1 provides the identifications of the various samples produced as well as the heat treatments they underwent.

Table 1. Summary of the production experiment.

Potash Solutions		S0	S1	S2	S3
Activation temperature	60˚C	T 60 S0	T 60 S1	T 60 S2	T 60 S3
	80˚C	T 80 S0	T 80 S1	T 80 S2	T 80 S3
	100˚C	T 100 S0	T 100 S1	T 100 S2	T 100 S3
	150˚C	T 150 S0	T 150 S1	T 150 S2	T 150 S3

T: Temperature; S0: Potash-free solution.

2.3. Characterization of Clay Blocks

2.3.1. Compressive Resistance of Blocks

The determination of the resistance of the blocks subjected to crushing was carried out using a hydraulic press, according to the ASTM C109/C 109 M standard. For this test the 21 × 10 × 4 cm^3 samples were sectioned in half lengthwise to obtain blocks 10.5 × 10 × 4 cm^3. The force is exerted on the section 10 × 4 cm^2. The compressive strength expressed in MPa or N/mm^2 is given by the following Relation (1):

$$Cs = \frac{F}{S} \tag{1}$$

With Cs: the compressive strength (MPa), F is the Maximum force applied to the material during the test (N); S the Cross-sectional area over which the force is applied (mm^2).

2.3.2. Absorption of Test Pieces

Two types of measurement methods were applied: Total immersion absorption (the saturation absorption test) and partial immersion absorption (the capillary absorption test).

- **Absorption by total immersion**

The total immersion absorption test makes it possible to determine the absorption capacity of the blocks, in accordance with the directives of the NBN B 15-215 standard.

The samples are totally immersed in water at 20˚C ± 2˚C for 7 days so that the driving force that attracts water into the samples is the pressure gradient.

Weighing is carried out every 24 hours, preceded by wiping the samples to eliminate surface water. Water absorption by immersion (ABS_{sat}) is expressed as a percentage and calculated by Relation (2):

$$ABS_{sat} = \frac{M_{wet} - M_{dry}}{M_{dry}} * 100 \tag{2}$$

With:

M_{wet}: the wet mass after immersion (g);

M_{dry}: dry mass (g).

- **Absorption by partial immersion**

Partial immersion absorption is an index of moisture transport of unsaturated samples. It makes it possible to determine the suction speed of the samples and gives an idea of the size of the capillary pores.

The samples, arranged lengthwise, are placed in a tank whose bottom is lined with coarse sand to prevent any direct contact with the bottom. Then, water is poured into the tank to a height of 2 cm, starting from the underside of the sample so that the water can easily penetrate through this side.

Mass measurements are taken every 30 minutes over a period of 6 hours. Before each weighing, the samples are wiped with a cloth to remove surface water. Absorption (ABS_{unsat}) is expressed as a percentage and is calculated by Relation (3).

$$ABS_{unt} = \frac{M_{wet\ t} - M_{dry}}{M_{dry}} * 100 \tag{3}$$

With:

$M_{wet\ t}$: Wet mass at time t (g);

M_{dry}: Mass of dry sample (g).

From the partial immersion absorption results, the initial capillary absorption rate (R_{unsat}) is calculated by Relation (4).

$$R_{unsat} = \frac{M_2 - M_1}{S * \rho} (\text{mm}) \tag{4}$$

With:

M_1 = Mass of dry sample (g);

M_2 = Mass of wet sample (g);

S = Surface in contact with water (cm^2);

ρ = Density of the liquid (water) (g/cm^3).

Then the variation curve of (R_{unsat}) or (T_{unsat}) in french versus the square root of time is plotted. It enables us to determine the sorptivity (S_{ab}) which corresponds to the slope of this curve. Sorptivity evaluates the absorption capacity of a material with respect to a fluid. The interest of sorptivity is to control humidity and to understand the interaction of material with its environment.

2.3.3. XRD

XRD makes it possible to determine the different mineral phases present in the samples. XRD analysis was carried out using a diffractometer Emma type GBC with intensity 35 mA, voltage 20 kV and power 1 kV using Kα radiation from copper (λ Kα_1 Cu = 1.5418 Å). This device is coupled to a computer allowing control of the goniometer and obtaining data. On the diffractograms obtained, the peaks are identified with the XRD Analysis Software.

3. Results and Discussion

3.1. Compressive Strength of Materials

There **Figure 1** illustrates the results obtained, highlighting the variation in the compressive strength of the blocks as a function of the treatment temperature for the different potash concentrations.

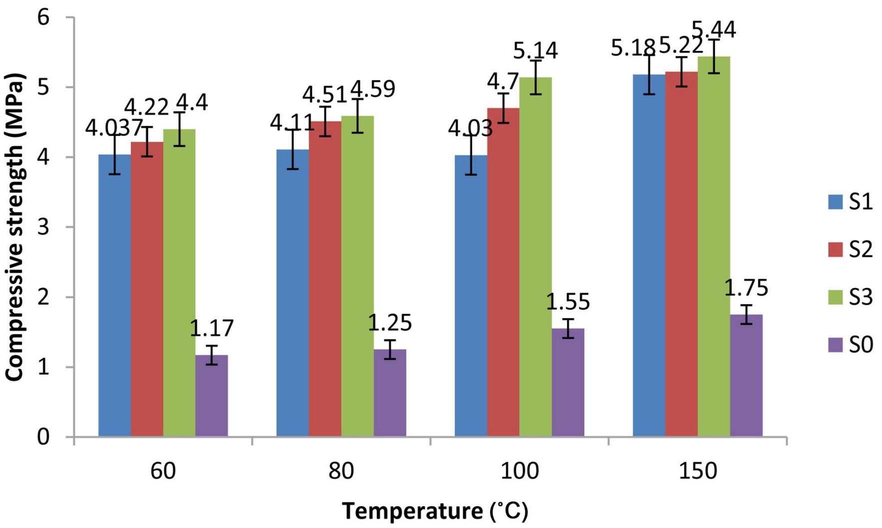

Figure 1. Compressive strength of blocks containing potash.

The analysis of **Figure 1** shows an increase in compressive strength with potash concentration independently of the activation temperature. For example, for blocks processed at 60˚C, the compressive strength varies from 1.17 MPa; 4.04 MPa; 4.22 MPa and 4.4 MPa with increases in potash concentration of 100 g/L, 150 g/L and 200 g/L respectively. The improvement in resistance is due to the establishment of bonds between the particles. These bonds are formed following thermal activation and their quantity increases with the potash concentration. Thus, an increase in the potash concentration leads to a hardening of the blocks after heat treatment and maturation due to the increase in the number of bonds between the particles.

Figure 1 also shows that, whatever the potash concentration, the compressive strength of the blocks increases with the activation temperature. For samples with a potash concentration of 100 g/L for example, the compressive strengths rise to 4.22 MPa; 4.51 MPa; 4.7 MPa to 5.22 MPa with processing temperatures of 60˚C, 80˚C, 100˚C and 150˚C respectively. The potash concentration being the same, the quantity of bonds formed is identical in the different blocks treated at different temperatures. Thus, the increase in resistance is explained by an increase in the quality of the connections. An increase in the activation temperature leads to blocks that are more resistant in compression through an improvement in the quality of the connections.

Neither tensile strength nor elasticity were measured.

3.2. Water Resistance of Designed Materials

The behavior of the blocks subjected to the water test is presented in **Table 2**.

Table 2. Variation in the stability of materials in water as a function of maturation time and temperature.

Raw [KOH] (g/l)	Maturation duration (days)	Processing temperature (˚C)			
		60	80	100	150
0	28	Quick dislocation	Quick dislocation	Quick dislocation	Quick dislocation
	90	Quick dislocation	Quick dislocation	Quick dislocation	Quick dislocation
100	28	Dislocation	Dislocation	Partial dislocation	Stable
	90	Dislocation within 30 min	Dislocation within 2 h 30 min	Stable	Stable
150	28	Dislocation	Dislocation	Tearing of brick parts	Stable
	90	Dislocation within 30 min	Stable	Stable	Stable
200	28	Dislocation	Tearing of brick parts	Stable	Stable
	90	Dislocation within 2 h 30 min	Stable	Stable	Stable

It shows a variation in the stability of the blocks in water depending on the potash concentration, the treatment temperature and the maturation time. This table shows that the stability of the blocks in water varies with the presence of potash whatever the activation temperature. Blocks without potash dissolve completely in water while the dissolution of blocks containing potash is either delayed, partial or absent. Dissolution occurs when water entering the blocks breaks the bonds between the particles. In the absence of potash, this rupture is rapid while it varies with the presence of potash. Potash influences the dissolution of blocks by establishing or strengthening the bonds between the particles. The potash therefore forms a bond between the particles which constitute the blocks.

The table further shows that for blocks containing potash, whatever the concentration of the latter, the behavior in water varies with the activation temperature. At a potash concentration of 100 g/l for example, after 90 days of maturation, the blocks dissolve after 30 minutes and 2 hours 30 minutes or are stable in water respectively at activation temperatures of 60˚C, 80˚C and 100˚C. The variation in the time taken by the blocks before their total dissolution or their stability in water over time is explained by the strengthening of the cohesions between the particles by thermal activation. In addition, increasing the activation temperature strengthens and multiplies the bonds between the particles constituting the different blocks, making them more stable in water.

The thermal activation of the blocks strengthens and multiplies the bonds between the particles which constitute them.

The blocks exhibit stability in water under the following conditions:

At 80˚C, after 90 days of maturation for potash concentrations of 150 g/l and 200 g/l.

At 100˚C, after 28 days of maturation for potash concentrations of 150 g/l and 200 g/l and after 90 days of maturation for the concentration of 100 g/l; 150 g/l and 200 g/l.

Finally, at 150˚C after 28 and 90 days of maturation for potash concentrations of 100 g/l; 150 g/l and 200 g/l.

The stability of blocks containing thermally activated potash in water depends on the potash concentration, the activation temperature and the maturation duration.

3.3. Absorption

3.3.1. Absorption by Total Immersion

Figure 2 shows the variation of the absorption of the blocks immersed in water as a function of time for the different activation temperatures.

The blocks T60S0, T80S0, T100S0, T150S0, T60S3, T60S1, T80S1, T60S2 and T60S3 are completely disintegrated in water and the particles form a suspension. The bonds between the particles are broken by water. For these potash concentrations and these activation temperatures, the modifications produced are not significant enough to resist the entry of water into the blocks. Thus, for an

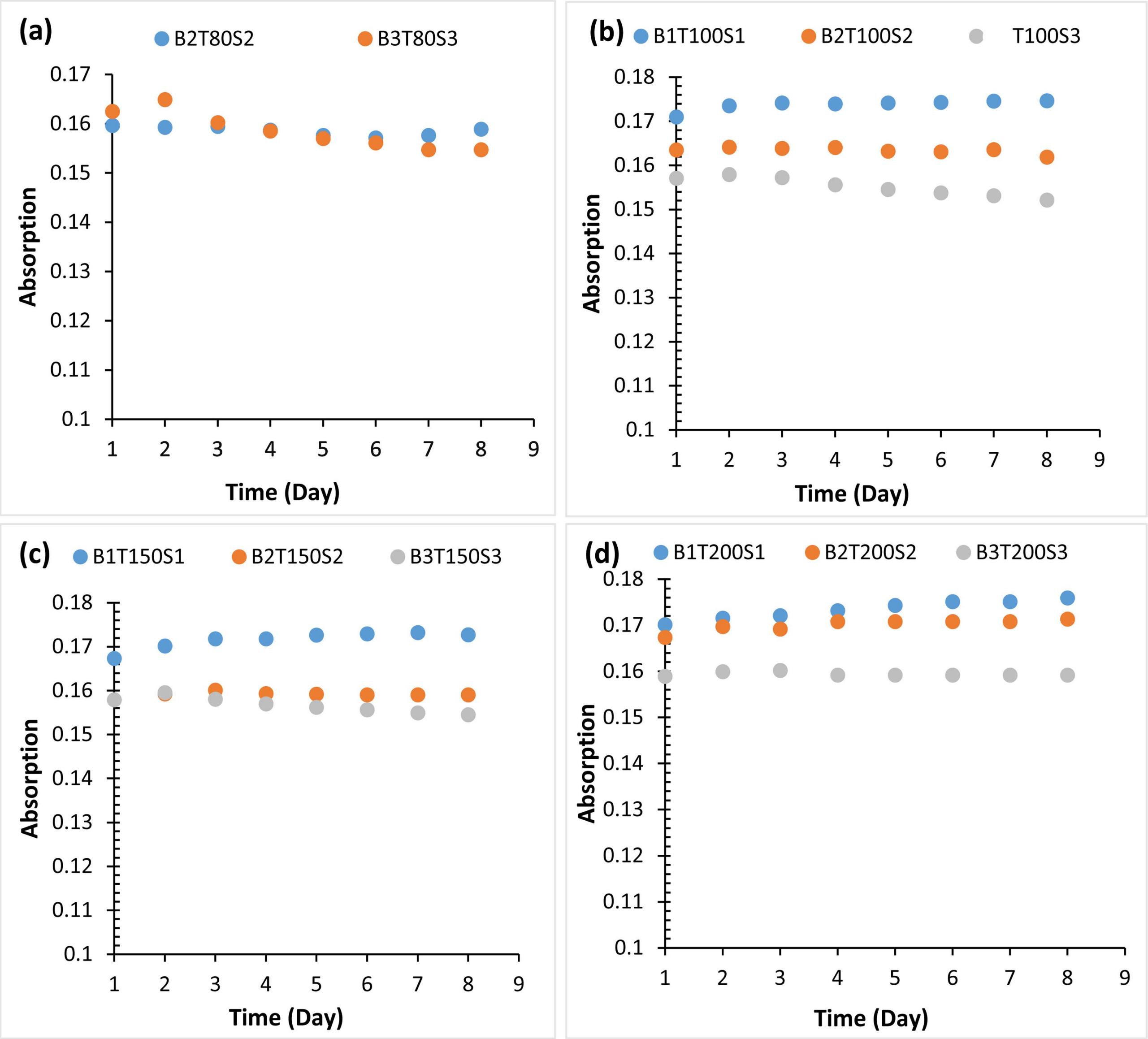

Figure 2. Absorption by total immersion of the blocks. (a) 80˚C; (b) 100˚C; (c) 150˚C and (d) 200˚C.

activation temperature less than or equal to 60˚C, whatever the potash concentration and for blocks containing a potash concentration of 100 g/L, activated at a temperature less than or equal to 80˚C, the modifications produced are partial or disparate. These results confirm those of water resistance.

Figure 2 also reveals that the absorption by immersion of the blocks is almost constant over time for all activation temperatures depending on the potash concentration. For blocks T100S1 and T150S1, the absorption is approximately 0.172, that of blocks (T80S2, T100S2, T150S2) is approximately 0.166 while blocks (T80S3, T100S3, T150S3) maintain an absorption of approximately 0.157. These constant values of the absorption of the blocks with the concentration of the potash solution whatever the activation temperature indicate that the potash content influences the volume of the voids accessible to water in the blocks. The more the potash concentration increases, the less accessible the pores are, hence the decrease in their volume. The increase in its concentration would lead to a decrease in open porosity.

3.3.2. Absorption by Capillary

Figure 3 shows the water absorption of the blocks as a function of time at different activation temperatures.

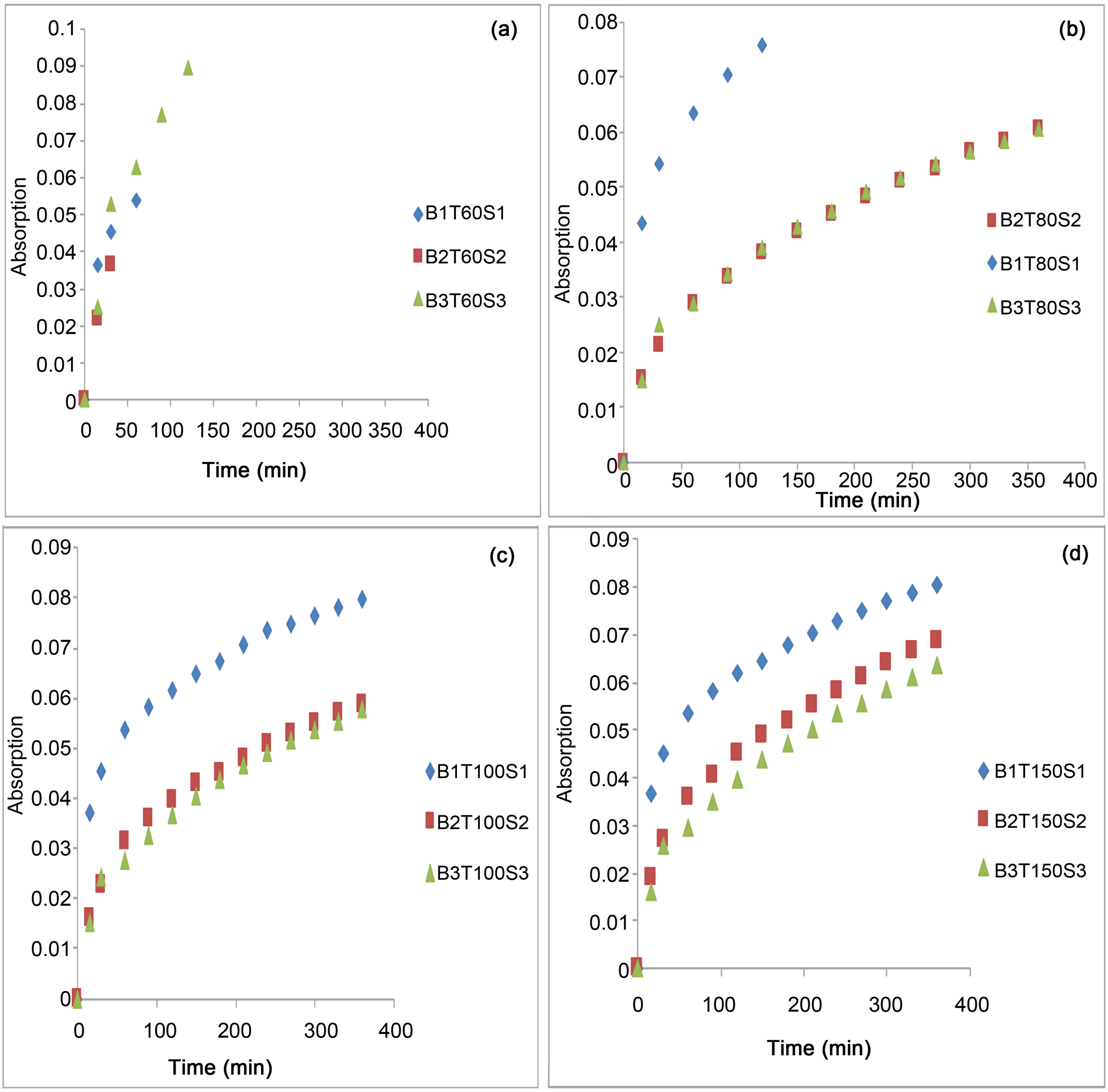

Figure 3. Variation of block absorption as a function of time for activation temperatures of: (a) 60˚C; (b) 80˚C; (c) 100˚C, (d) 150˚C.

The figure shows the increase in absorption of all blocks with time independent of activation temperature and potash concentration. Thus, for blocks containing

100 g/L of potash, activated at 100˚C for example, the absorption values increase from 0 to 0.08 when time goes from 0 to 360 min. This increase in absorption is due to the capillary rise of water in the blocks. Indeed, when the blocks are in water, at the water-pore interface, the capillary pressure; the difference between the pressure exerted by the air contained in the pores of the blocks and the pressure of the water will tend to attract water inside the porous network, hence the absorption of water by the blocks. Over time, water will gradually replace air, hence the increase in absorption over time. This increase will continue until the capillary pressure is zero, *i.e.* the pressure of the air in the pores becomes equal to that exerted by the water. This situation should be reflected on the curves at a certain moment by a constant absorption over time. This constant phase is not visible in Figure 3 because the tests were suspended after 360 min.

Figure 3 further shows that the absorption curves of the blocks activated at 60˚C and the 100 g/L blocks activated at 80˚C did not reach 6 hours. This is because the blocks dissolve in water after a while. This dissolution is explained by the degradation by water of the bonds which have been established.

Figure 3 also shows that, for the same activation temperature, the capillary absorption of the blocks decreases with the increase in the potash concentration except for the blocks activated at 60˚C. For blocks treated at 100˚C for example, whatever the duration of immersion in water, the absorption rates of blocks with a potash concentration of 100 g/L are more increased than those with a concentration of potash of S2 which are also higher than those of blocks with a potash concentration of S3. The reduction in the values of absorption by capillary action is due to the modification of the microstructure of the blocks, more precisely the porosity following the heat treatment. Indeed, the heat treatment of blocks of variable potash concentration would have favored the reduction of the pore volume. The activation of clay blocks containing potash concentrations greater than or equal to S1, at a temperature ≥80˚C leads to a modification of absorption and therefore of the porosity of the blocks. This decrease in water absorption is due to either the reduction in pore diameter or the decrease in the quantity of pores or both. To get an idea of the type of modification produced, let's analyze the initial capillary absorption rate and sorptivity.

At the temperature greater than or equal to 80˚C, the absorption of blocks containing potash concentrations of 150 g/l and 200 g/l is less than or equal to 8% after 6 hours of measurement. These blocks can therefore be used in construction in Ivory Coast, since long rainy episodes rarely last 6 hours.

1) Initial rate of capillary absorption

Figure 4 shows the variation in the mass of water absorbed per unit area as a function of the square root of time. It corresponds to the kinetics of water absorption of the blocks or to the initial rate of absorption of the blocks. This absorption kinetics generally follows a linear law with a determination coefficient $R^2 > 0.95$ for potash concentrations from S2 to S3 except for blocks made with a potash concentration of 100 g/L which have an R^2 between 0.7 and 0.89. The low value of the coefficient of determination is linked to the detachment of certain particles from the blocks with the duration of contact with water. [23] measured initial absorption rate values on geopolymers mixed with aggregates between 0 mm and 4.4 mm.

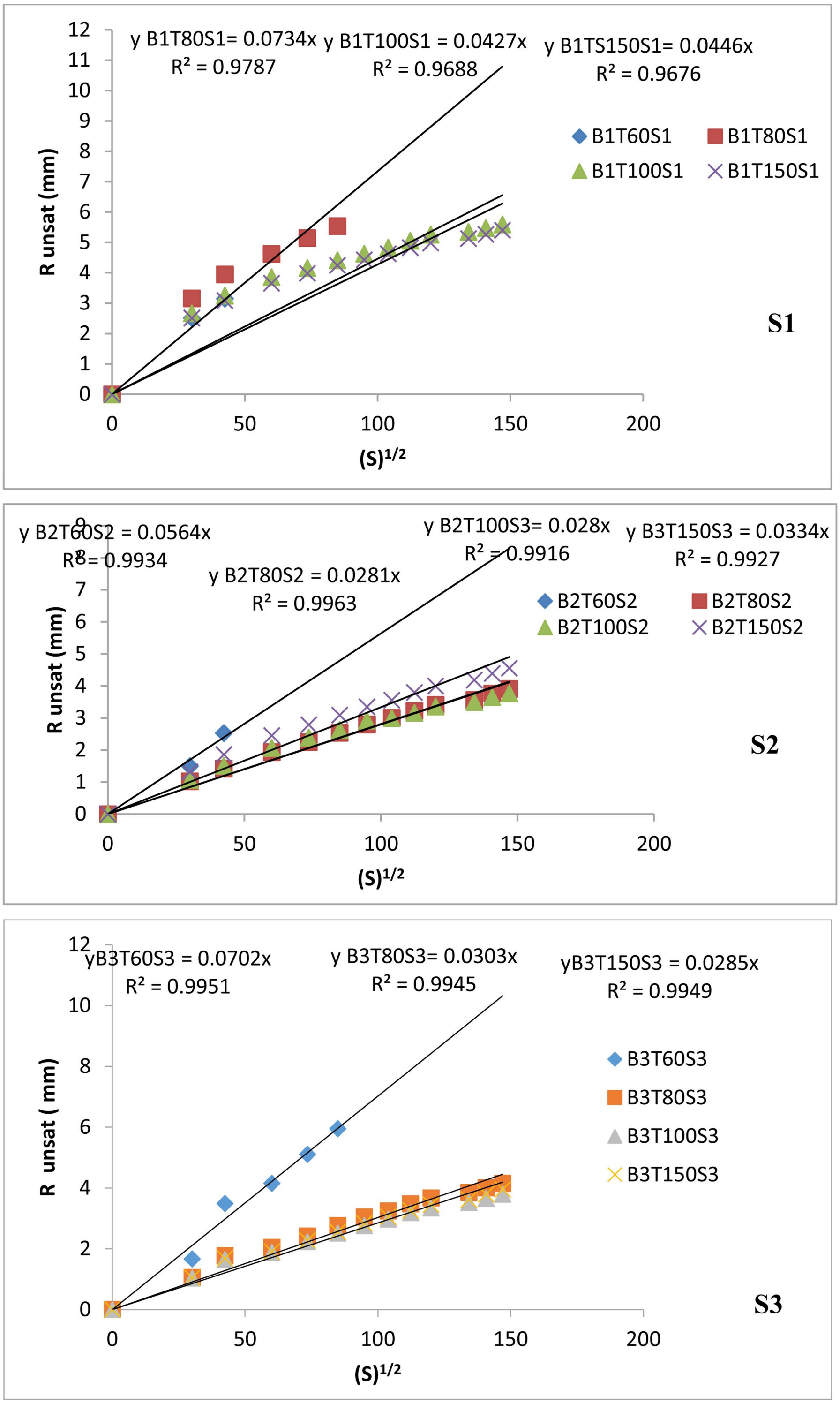

Figure 4. Initial absorption rate as a function of time for S1, S2 and S3.

The absorption kinetics equation is of the form $Y = S_{ab}x$.

S_{ab}; the slope of the absorption kinetics curves corresponds to Sorptivity [24]. The values of this Sorptivity as a function of the concentration and the activation temperature are given in **Table 3**.

2) Sorptivity

Table 3 illustrates the drop in the sorptivity of the different blocks with the increase in the treatment temperature for the same potash concentration on the one hand and with the increase in the potash concentration for the same activation temperature (processing) on the other hand. This variation in sorptivity is explained by a variation in the size of the pores. Indeed, according to Laplace's law, when an unsaturated porous material is brought into contact with liquid water, the phenomenon of capillary suction is the cause of water retention in the pores.

Table 3. Block sorptivity.

Block Index	Sorptivity (mm·s$^{-1/2}$)	Standard deviation
T60 S1	-	-
T80 S1	0.073	0.0025
T100 S1	0.044	0.00112
T150 S1	0.042	0.0033
T60 S2	0.056	0.0022
T80 S2	0.028	0.0019
T100 S2	0.028	0.0031
T150 S2	0.033	0.00171
T60 S3	0.07	0.0031
T80 S3	0.03	0.0015
T100 S3	0.027	0.0029
T150 S3	0.028	0.0012

Therefore, there is an attraction of water inside the porous network by capillary pressure. The latter depends on the diameter of the pores; the rise of water is faster when the pores are of smaller diameter. Thus, the increase in the activation temperature and the increase in the potash concentration in the blocks lead to a decrease in sorptivity and therefore an increase in the diameter of the pores.

The work of [23] on natural coarse aggregates and on 4 geopolymers based on recycled coarse aggregates, natural coarse aggregates and soda, gave sorptivity with values increasing between 0.0233 and 0.0331 when the rate of natural aggregates is replaced by recycled aggregates at 15%, 30% and 50%.

3.4. XRD

X-ray diffractometry of the samples processed at 80˚C and 150˚C and of the clay shows the different peaks obtained (**Figure 5**).

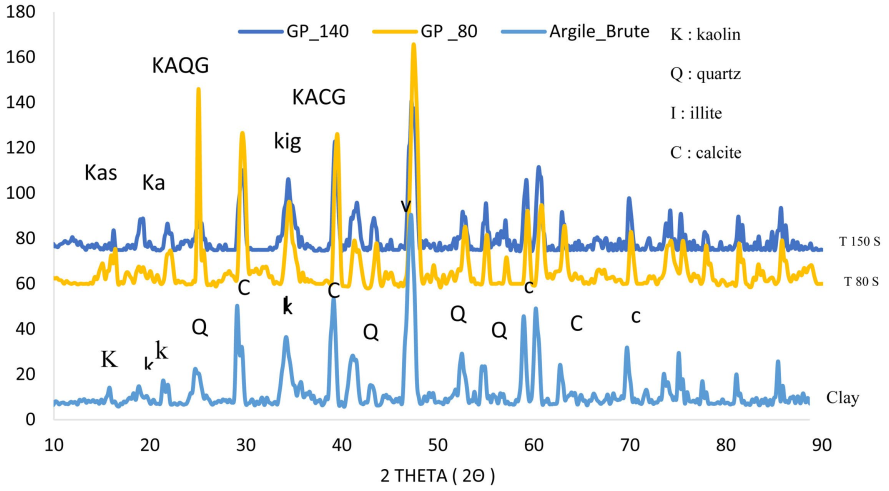

Figure 5. XRD of samples.

The characteristic peaks show minerals present in the different samples according to their diffraction angle. The figure also shows a transformation of minerals and a variation in angle and intensity from the raw clay sample to the potash-treated clay samples. But no change of minerals when going from sample processed from 80˚C to 150˚C.

Thus, the minerals of kaolin, quartz, illite, calcite, KAS, KA, KAQG, KIG and KACG were identified on the raw clay, T 80 S and T 150 S.

Kaolinite, illite, quartz and calcite minerals present in kaolin clay change to potassium aluminosilicate (KASH), respectively; Illite Aluminosilicate (KIG), Potash Activated Quartz Geopolymer (KAQG) and Potash Activated Calcite Geopolymer (KACG).

The XRD shows the action of potash on clay giving materials which are neither amorphous nor semi-amorphous taking into account the peaks which are not diffuse. On the contrary, they are crystallized.

This heat treatment of clay blocks containing potash leads to the formation of mineral phases between the particles. This mineral phase is responsible for modifying the porosity and hardening of the blocks. According to [25] the reaction responsible for this formation is geopolymerization.

The comparison of the designed blocks and the classification of compressed and stabilized earth blocks (CEB) according to the categories defined by the French standard (XP P 13-901, 2001) is illustrated in **Table 4**.

This table indicates that blocks with potash show strengths comparable to compressed earth bricks 40, thus making them suitable for construction applications. According to [26], the compressive strength values in the dry state in accordance with the standard (XPP 13-901) recommended in construction for compressed earth bricks are greater than or equal to 4 MPa. And are only reached by blocks containing potash after 28 days of maturation for an activation temperature exceeding 100˚C and a potash concentration of at least 150 g/L. Furthermore, the strength gain of blocks containing potash treated at 100˚C compared to those treated at 80˚C are 1.9%, 4.2% and 11.9% respectively for blocks containing 100 g/L, 150 g/L and 200 g/L of potash.

Table 4. Comparison of blocks containing potash to blocks filled with stabilized raw earth.

Index of blocks containing	CEB 20 Rc ≥ 2 Mpa	CEB 40 Rc ≥ 4 MPa	CEB 60 Rc ≥ 6 MPa
T60 S1	+	+	-
T80 S1	+	+	-
T100 S1	+	+	-
T150 S1	+	+	-
T60 S2	+	+	-
T80 S2	+	+	-
T100 S2	+	+	-
T150 S2	+	+	-
T60 S3	+	+	-
T80 S3	+	+	-
T100 S3	+	+	-
T150 S3	+	+	-

Cs: Dry compressive strength; T: Temperature; S: Solution; +: greater than; -: less than.

4. Conclusions

As part of the valorization of clay deposits and their stabilization, composites from the crude clay-potash mixture extracted from dry cocoa pods were manufactured. Water resistance tests have shown that composites made from a raw clay-potash mixture achieve better results and performances compared to those made with clay only. Composites resist when submerged, but clay that does not contain potash is dissolved. They are stable in water from 80˚C, with a crude potash concentration of 150 g/l. If we take compressive strength and temperatures into account, a concentration of 150 g/L would be required. Increasing the temperature accelerates the consolidation of samples containing crude potash.

Chemical analyzes of potash extracted from dried cocoa pods contained oxide elements and the largest proportion of these elements is held by potassium oxide with 42.62%. Given the high content of potassium oxide, the hydrogen potential of solutions is greater than 12 and therefore basic. After drying the blocks in the oven, the blocks are stable in water at 80˚C after 90 days of maturation for [KOH] of 150 g/l and 200 g/l; at 100˚C after 90 days of maturation for the concentration of 100 g/l; 150 g/l and 200 g/l and after 28 days of maturation for [KOH] of 150 and 200 g/l; at 150˚C after 28 and 90 days of maturation for [KOH] of 100 g/l; 150 g/l and 200 g/l and on the other hand the blocks disintegrate in the water completely after a few minutes or partially for all the others. Then two types of absorptions were carried out: absorption by capillarity and absorption by immersion.

The capillary absorption of all the blocks increases with time regardless of the activation temperature and the potash concentration on the one hand and the capillary absorption of the blocks decreases with the increase in the potash concentration except the activated blocks at 60˚C on the other hand. Absorption by immersion is almost constant over time for all activation temperatures depending on the potash concentration. For blocks T100S1 and T150S1, the absorption is approximately 0.172; that of blocks (T80S2, T100S2, T150S2) is approximately 0.166 while blocks (T80S3, T100S3 and T150S3) are 0.157; there is a decrease in capillary absorption as the concentration increases.

Finally, the compressive strength increases with the potash concentration independently of the activation temperature with values between 4 MPa and more than 5 MPa.

Research has shown that the purest potash solutions (99%) can increase compressive and flexural strength up to tenfold compared to impure potash. The purity of this potash solution is 42%, and it shows the best result in compressive strength. In similar results, the concentrations are assessed by molarity. To calculate the molarity (M) of a solution, we use the formula:

$$M = \frac{n}{V}$$

where

- M = molarity (moles per liter, mol/L);
- n = number of moles of solute (mol);
- V = volume of the solution (liters, L).

To determine the number of moles of solute (n), we use the formula:

$$n = \frac{\text{mass of solute}}{\text{molar mass of solute}}$$

Conflicts of Interest

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

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