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## Research Paper

### Improving the essential characteristics of Lake Chad diatomaceous earth for the ecological construction.

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#### ABSTRACT

In the Lake Chad region, diatomaceous earth is the type of soil that is easily accessible, but its use for construction presents challenges due to its specific characteristics. This study aims to characterize the physico-chemical and mechanical properties of these soils after adaptive treatment, consisting to add a small amount of lime. The X-ray diffraction reveals a composition of 73% quartz, 2.3% kyanite, 21% carbon and 1.58% of other minerals. The measured pH is 8.3, indicating this diatomite soil can be stabilize. Stabilized and Compressed Earth Blocks (SCEBs) were molded using six formulations (0% of lime added, 2%, 4%, 6%, 8% and 10%) and cured in three groups (groups of 7, 14 days and 30 days). The measure of their compressive strength denotes the SCEBs without lime, after 30 days of curing, show strength of 2 MPa and the SCEBs with 10% of lime exhibit a high compressive strength of 4.27 MPa, according to several standards of Compressed Earth Blocks. Thus, the addition of lime allow for the production of quality SCEB for construction. Regarding thermal properties, experiments on SCEBs show that thermal conductivity decrease with the addition of lime, from 0.194 W/m.°C to 0.370W/m.°K, and remain widely above 0.065 W/m.°K which is good value for thermal insulation. Finally, above 4% of lime, the mass loss (0.24%) is negligible.

## 1 Introduction

This work on the diatomite soil of Lake Chad, one of the soils most widely used as a building material in west and north of Chad, is to contribute to the promotion of local materials for habitat construction. This allows reducing the quantity of imported cement materials since some authors estimated that 50% of the world's cement consumption goes to under

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development countries [1] and furthermore the part of cement production in global CO<sub>2</sub> emissions is around 10% [2, 3]. So the development of new ecological materials capable of conserving energy is a solution for the reduction of excessive energy consumption [4] and protection of environment.

Building with sustainable materials in this region of Chad with its hot and dry climate, where over 85.7% [5] of the population lives under the poverty line with less than a dollar per day, is a challenge that must be met if the SDGs (Sustainable Development Goals) are to be achieved, both in terms of poverty reduction and environmental protection. Raw earth, a durable material, has been used for thousands of years to build homes around the world. However, unbaked clay is highly sensitive to atmospheric conditions and has stability problems on its own as a constituent of bricks and mortars [6].

The mechanical and physical qualities of bricks can be improved by incorporating a small quantity of mineral binders [7] like lime. Compression, as a manufacturing method using raw earth as the base material and without any type of stabilization, significantly improves the physical and mechanical characteristics of compressed earth bricks [8]. Several researchers have shown in their papers that compression combined with optimum stabilization gives compressed and/or stabilized earth bricks significantly better mechanical and physical characteristics.

As stated in the literature and echoed in Kipsanai's paper [9], the use of diatomaceous earth is one of the most effective ways of creating durable, insulating and lightweight building materials while minimising harmful economic and environmental effects. The diatomite from Lake Chad, a natural abundant raw material but complex to handle for the production of construction materials, are currently subject of in-depth studies. The goal is to master their physical-chemical and mechanical properties through lime stabilization and mechanical compression. This research aims to improve the availability and accessibility of sustainable and eco- friendly materials in this desert climate region, located at the crossroads of four countries: Chad, Cameroon, Niger and Nigeria.

## 2 Materials and Methods

### 2.1 Materials

The soil to be analysed was extracted from a quarry near the town of Bol, whose GPS coordinates are 13.593733°N and 14.557558°E. The town of Bol is characterized by a hot and dry climate, with an average temperature of 41°C and only 17.1 days of rainfall per year (not exceeding 1 mm). These conditions make it a particularly arid environment, where living conditions are challenging. This highlights the need to improve the properties of this soil to enable the construction of more comfortable habitats while also protecting the environment.

Researches on soil stabilization using lime have revealed the influence of four (4) essential mechanisms of lime (cation exchange, flocculation, agglomeration and pozzolanic reaction) on the finest particles of the mixture, particularly clays [10]. Lime is suitable for soils with a clay content of less than 20% [11], it is also important to emphasize that the incorporation of lime promotes significant water absorption, especially when it comes to quicklime.

All types of lime can be used to stabilize earth material intended for construction, but air lime is preferred to hydraulic lime. In these studies, quicklime sold on the markets in N'Djamena was used.

The water used in the mixtures is low in sulphate and has a temperature of  $20 \pm 1$  °C. Its quality complies with the requirements of standard NFP 18-404 [12].

### 2.2 Methods

#### 2.2.1 Characterization of soils

##### Mineralogical test

The mineralogical composition of this diatomaceous soil is analysed using X-ray Diffraction (XRD) with the Rigaku Miniflex 600 apparatus (see Fig.1 below), equipped with a 600W high-voltage power generator. The analysis is conducted using two software packages: Miniflex Guidance (for analysis) and PDXL2 (for processing). These tools are part of the resources at Abou Bakr Belkaid University in Tlemcen, Algeria, where the experimental work was performed.



**Fig. 1 - Rigaku Miniflex 600 apparatus, equipped**

#### Density test

The density of diatomite is determined using a water pycnometer in compliance with the NF P 94-054 standard [13].

#### Water absorption test

In accordance with the standard NF P 94 050 [14], the quantity of water present in a soil sample is determined by steaming. The sample is tared, weighed (wet mass  $M_h$ ) and placed in an oven to dry at 105°C for 24 hours. After drying, it is again weighed (dry mass  $M_s$ ) to deduce the mass of water  $M_w$  which allows the determination of the water content expressed by equation (1) below:

$$w(\%) = \frac{M_w}{M_s} \cdot 100, \text{ with } M_w = M_h - M_s \quad (1)$$

#### pH test

Measuring pH can provide valuable information about the predominance of advanced organic matter or carbonates. This prompted us to measure the pH of our study soil using an ADWA AD1030 pH meter, equipped with a combination electrode. After being calibrated with commercial KCl buffer solutions, this pH-meter can accurately determine the pH following this procedure:

Weigh 20g of dry raw soil at 40°C in a beaker. Add 50 ml of demineralised water solution and stir with a magnetic stirrer. Leave stand for 2 hours. Immerse the electrode in the supernatant liquid and take measurements at 5 minutes, 10 minutes and 15 minutes intervals until the values converge.

### 2.2.2 Experimental procedures

#### Production of samples

The diatomite is stored in the sun and subsequently sieved, with only the 5 mm bypass retained. For the quicklime, the 1.6 mm bypass is kept. These two materials (refer to Fig.2 below) are mixed in a dry state, and water is added afterward to complete the process.



**Fig. 2 - Mixture of diatomite and lime**

The Optimum Water Content (OWC), which corresponds to the maximum dry density (as described in [15]), is essential for the homogeneous fabrication of blocks. Once the mixture is prepared with the OWC, it is placed in a plastic bag for approximately 1 hour to ensure proper impregnation. The manual press (see Fi. 3 below), used to manufacture SCEB (Stabilized Compressed Earth Block) following the procedure of the “Centre pour le développement de l'Entreprise : CDE” [15], belongs to Building and Public Works Laboratory at the National High School of Public Work.

The mixture of materials is poured into the mould of this manual press. The lid is folded down and the lever is operated to compress the mixture, resulting in a regular SCEB measuring 29.5 x 15 x 8.5 cm after demoulding. Once formed, the bricks are weighed, labelled for identification and dried in the shade to ensure proper curing and stability.



**Fig. 3 - Manual press**

Six (6) different formulations are prepared, as detailed in table (1) below. The first formulation, made from 100% of diatomite and 0% of lime, produces the sample labeled 100D0C, the second, made from 98% of diatomite and 2% of lime, produces the sample labeled 98D2C, the third, made from 96% of diatomite and 4% of lime, produces the sample labeled 96D4C, the fourth made up of 94% diatomite and 6% lime to give the sample labeled 94D6C, the fifth made up of 92% diatomite and 8% lime to give the sample labeled 92D8C and the sixth and final formulation made up of 90% diatomite and 10% lime to give the sample labeled 90D10C.

**Table 1- Proportions of materials in each formulation of SCEB samples**

| Sample                                   | 100D0C | 98D2C | 96D4C | 94D6C | 92D8C | 90D10C |
|------------------------------------------|--------|-------|-------|-------|-------|--------|
| <b>Proportion of Diatomite (in gram)</b> | 5500   | 5390  | 5280  | 5170  | 5060  | 4950   |
| <b>Proportion of Diatomite (in %)</b>    | 100    | 98    | 96    | 94    | 92    | 90     |
| <b>Proportion of lime (in gram)</b>      | 0      | 110   | 220   | 330   | 440   | 550    |
| <b>Proportion of lime(in %)</b>          | 0      | 2     | 4     | 6     | 8     | 10     |

Each formulation is pressed to produce SCEB. After curing periods of 7 days, 14 days and 30 days, these bricks are subjected to series of mechanical, thermal and durability tests. While standards typically prescribe 28 days for curing period, we extended the treatment to 30 days to closely observe any additional effects in bricks properties. This extended period allows for a more thorough understanding of the bricks performance over time.

#### Compressive strength test

This test ensures an evaluation of bricks' mechanical strength, providing valuable data for assessing their performance in construction applications. For this, prismatic specimens ( $8.5 \times 15 \times 29$ ) cm<sup>3</sup> are cut from the SCEB for each type of formulation. These specimens are used to conduct compression tests in accordance with the standard XP 13-901 [16]. The tests are performed using the CONTROLAB compression machine (see Fig. 4 below), which has a maximum capacity of

250 kN, at the Building and Public Works Laboratory in N'Djamena, Chad. The compressive strength  $R_C$  (in MPa) is calculated as the ratio of the maximum load  $F_{max}$  (in kN) recorded on the CONTROLAB machine's dial, to the average surface area of the test faces  $S$  (in  $cm^2$ ). This is expressed by the formula (2).

$$R_C = 10 \times \frac{F_{max}}{S} \quad (2)$$



**Fig. 4 - The SCEB brick during the crushing test**

#### Heat test

The hot wire method [17] is used here to evaluate the thermal properties of  $5 \times 10 \times 16 \text{ cm}^3$  samples for each formulation. The following thermal parameters are measured: thermal conductivity ( $\lambda$ ) which indicates the material's ability to conduct heat and effusivity ( $e$ ) which reflects how quickly a material can be absorb and release heat. This method provides precise measurements, helping assess the insulating performance of SCEB.

The used device consists of a thermal shock probe, to be placed between two specimens of the material for characterization (symmetrical assembly, see Fig. 5 below), an electronic acquisition box and graphic interface software to control the tests and process the results.



**Fig. 5 - Thermal test device**

The shock probe operates by inducing a slight localized heating in the material and measuring the resulting temperature rise over a short period (a few minutes). This data is then processed mathematically using the provided software to determine the thermal conductivity of the material.

### Water durability test by immersion or water resistance test [16]

The measurements are carried out on three whole SCEB (see Fig. 6 below) which are dried in an oven ( $105^{\circ}\text{C} \pm 5$ ) for 24 hours after demoulding. Each sample, positioned and held vertically, is immersed to a depth of 10 cm in water for 10 minutes. The mass loss  $P$  (%) is determined using the formula (3) where  $M_1$  is the mass of the brick after immersion and  $M_2$  is the mass of the brick before immersion.

$$P = 100 \cdot \frac{M_1}{M_2} \quad (3)$$



**Fig. 6 - Samples for the immersion test**

## 3 Results and discussion

### 3.1 Characterization of soils

#### Mineralogical composition

The X-ray powder diffraction (XRD) analysis performed on the study of sample has provided valuable insights into its composition and the distribution of chemical elements (see Fig.7 below).

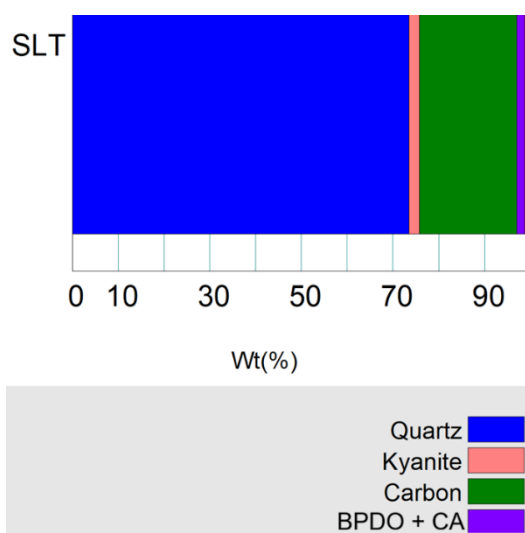


**Fig.7 - Distribution of the constituent elements of diatomite.**

The mineralogical analysis of the sample revealed a high quartz ( $\text{SiO}_2$ ) content of 73% as shown in this Fig.7. This high quartz percentage aligns with the geological context of the study area, as it is located on the same geological band as Faya-Largeau, a town situated approximately 1000 km to the north of the study site. The presence of quartz is consistent of diatomaceous earth, which has been studied in Faya Largeau [4]. Diatomaceous earth often contains high level of silica ( $\text{SiO}_2$ ), primarily in the form of quartz, due to its origin from the fossilized remains of diatoms. The percentages of other

elements found by this analysis are 21% of carbon (C), 2.3% of kyanite ( $\text{Al}_2\text{O}_5\text{Si}$ ), 1.7% of BPDO+CA( $\text{C}_{16}\text{H}_{14}\text{N}_8\text{O}_8$ ), 1% of 6-amino-1,3-dimethyluracil( $\text{C}_6\text{H}_9\text{N}_3\text{O}_2$ ) and 1% of ( $\text{C}_5\text{H}_6\text{N}_{10}\text{O}_4$ ).

### Density

The density of this soil is determined using standard NF P 94-054 [13] and a water pycnometer. For three samples, these followed values are obtained:  $\gamma_s1=1.56$ ,  $\gamma_s2=1.27$ , and  $\gamma_s3=1.21$ . So the mean density of the diatomaceous soil is  $\gamma_s=1.35$  which is a common value for well-structured soil and represents a medium to high density level, indicating that the soil is moderately compact.

### Water content

For knowing the quantity of water present in a soil sample, expressed by the water content  $w(\%)$ , wet-mass of three (3) samples are measured:  $M_h(1)=M_h(2)=M_h(3)=500\text{g}$ . After the steaming, dry masses obtained are  $M_s(1)=460\text{g}$ ,  $M_s(2)=431\text{g}$  and  $M_s(3)=432\text{g}$ . These masses are used to determine the water masses  $M_w(1)=40\text{g}$ ,  $M_w(2)=69\text{g}$  and  $M_w(3)=68\text{g}$  for samples 1, 2 and 3 respectively, and thus to calculate the water content  $w(\%)$  of these three samples using formula (1) above cited. With  $w(\%)1=8.7$ ,  $w(\%)2=16.01$  and  $w(\%)3=15.74$  as results, the water content in the first sample is evidently incorrect and is discarded. The water content in this study soil is 15.855 which indicates this fine soil is wet.

### Optimal water content

The value of water content is used in procedures described in [15] to obtain the optimum water content for the different types of SCEB formulations, as shown in Table 2 below.

**Table 2- OWC of different formulations**

| Formulation | 98D2C | 96D4C | 94D6C | 92D8C | 90D10C |
|-------------|-------|-------|-------|-------|--------|
| OWC (%)     | 52    | 56    | 60    | 64    | 68     |

Water content has a significant effect on the behaviour of materials. For all the materials tested, whether natural or reconstituted, especially when they are fine, a variation of 2 to 3 points around the static compaction optimum always results in a 30 to 50% drop in dry strength [18]. The water used in the mixtures is water containing little sulphate and having a temperature of  $20 \pm 1^\circ \text{C}$ . Its quality complies with the requirements of standard NF P 18-404 [12]. Note that the water requirement of the mixture increases with the quantity of lime added (see Table 2 above).

### pH measure

As shown on Fig.8 below, the pH of diatomaceous soil is 8.7, a suitable pH-value for stabilisation [19]. In general, soils with a high pH will have better resistance.

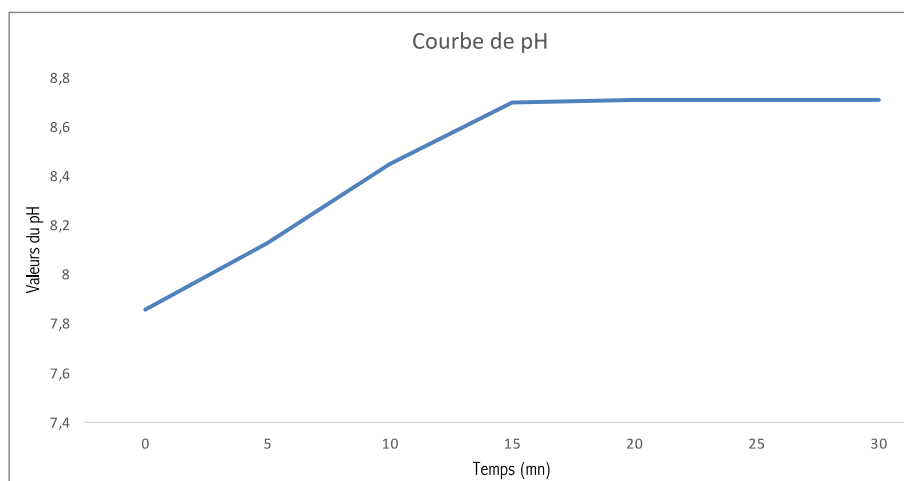


**Fig.8 - PH curve**

### 3.2 Mechanical compression tests [16]

Compressive strength values of all formulations, including periods of curing, are pooled in the following Table 3.

**Table 3: Compressive strength of SCEB according to formulation and curing time**

| Formulation          | $R_{C7}$ (MPa)<br><i>Compressive strenght at<br/>7 days of cure</i> | $R_{C14}$ (MPa)<br><i>Compressive strenght at<br/>14 days of cure</i> | $R_{C30}$ (MPa)<br><i>Compressive strenght at<br/>30 days of cure</i> |
|----------------------|---------------------------------------------------------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------|
| Sample <b>100D0C</b> | 0,23                                                                | 1,11                                                                  | 2,1                                                                   |
| Sample <b>98D2C</b>  | 0,32                                                                | 1,28                                                                  | 2,18                                                                  |
| Sample <b>96D4C</b>  | 0,37                                                                | 1,33                                                                  | 2,23                                                                  |
| Sample <b>94D6C</b>  | 0,44                                                                | 1,39                                                                  | 2,48                                                                  |
| Sample <b>92D8C</b>  | 0,47                                                                | 1,56                                                                  | 3,13                                                                  |
| Sample <b>90D10C</b> | 0,87                                                                | 1,86                                                                  | 4,27                                                                  |

Table 3 above shows the compressive strength of the sample labeled 100D0C (100% of diatomaceous soil) is low for a 14 days curing period. After 30 days of curing, the strength reaches the value of 2.1 MPa which is sufficient for the construction of infill walls as observed in Table 4 below giving the compressive strength values of Compressed Earth Block (CEB) in accordance with the standards of some countries.

**Table 4: Permissible compressive strength for CEB bricks according to standards**

|                     |            |                 |
|---------------------|------------|-----------------|
| New-Zeland Standard | NZS        | $R_c = 3.5$ MPa |
| Indian Standard     | IS-1725    | $R_c = 2$ MPa   |
| Brazilian Standard  | NBR        | $R_c = 2$ MPa   |
| Colombian Standard  | NTC532     | $R_c = 2$ MPa   |
| Kenyan Standard     | KS02-1070  | $R_c = 2.5$ MPa |
| Tunisian Standard   | NT         | $R_c = 2$ MPa   |
| French Standard     | XP P13-901 | $R_c = 2$ MPa   |
| Spanish Standard    | UNE 41410  | $R_c = 1.5$ MPa |

With values of compressive strengths in table 3, this following graph (Fig. 9) is shown for discussing

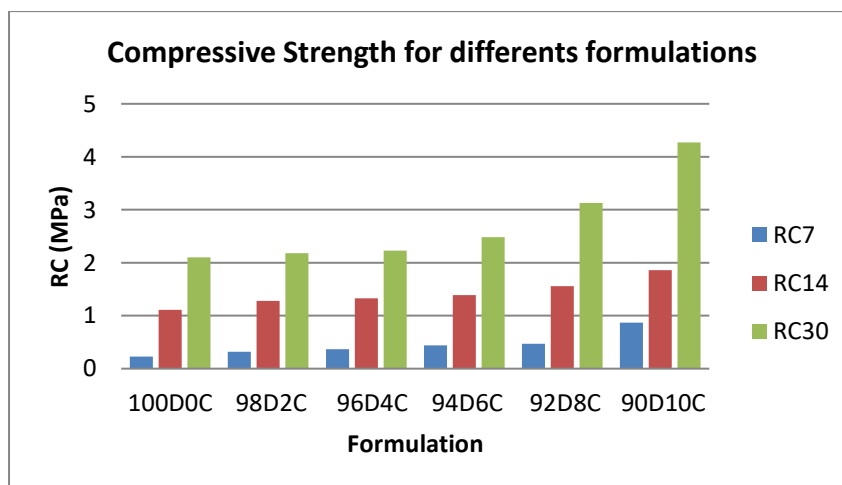


**Fig. 9 - Mechanical compressive strength**

Figure 9 shows compressive strengths that increase proportionally with lime dosages and curing times. For the control brick (100% diatomite compressed without stabilization), the compressive strength is just over 2 MPa after 30 days of curing. Depending on the lime incorporation rate and subsequent compression, there is a pronounced increase in compressive strength, sometimes approaching 90%. This can be further enhanced because stabilization with lime (3 to 7%) enables the formation of new minerals through a slow pozzolanic reaction at ordinary temperature. Several months may be required for the effects to be more fully realized [20].

It should be remembered that the formulations were stopped at 10% lime addition because, according to several authors and the study by Millogo and colleagues on lime-stabilized adobe bricks [21], the increase in strength for lime content below 10% is facilitated by the formation of a large quantity of CSH (Hydrated Calcium Silicate) in the presence of relatively small amounts of calcite and portlandite, whereas for contents above 10%, the formulation shifts toward substantial amounts of calcite and portlandite, leading to a reduction in strength. However, we note that the study bricks, made of diatomites stabilized with 10% lime and compressed 90D10C, exhibit a compressive strength of over 4 MPa (fig.9), which is low compared with conventional building materials but more than sufficient for construction according to Doat [11] and is expected to evolve over time in line with Le Roux [20]. Will the thermal characteristics of this SCEB brick earn it points for housing construction in the Lake region?

### 3.3 Heat test

The measurements of thermal conductivity  $\lambda$  in  $\text{W}/^\circ\text{K}^{-1}\cdot\text{m}^{-1}$  and effusivity  $e$  in  $\text{J}\cdot\text{m}^{-2}\cdot^\circ\text{K}^{-1}\cdot\text{s}^{-1/2}$  are summarised in Table 5 below for the different SCEB formulations studied.

**Table 5- Values of thermal conductivities and effusivities according to formulations**

| Formulation          | $\lambda$ ( $\text{W}\cdot\text{m}^{-1}\cdot^\circ\text{K}^{-1}$ )<br>Thermal Conductivity | $e$ ( $\text{J}\cdot\text{m}^{-2}\cdot^\circ\text{K}^{-1}\cdot\text{s}^{-1/2}$ )<br>Thermal Effusivity |
|----------------------|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| Sample <b>100D0C</b> | 0,194                                                                                      | 475                                                                                                    |
| Sample <b>98D2C</b>  | 0,197                                                                                      | 484                                                                                                    |
| Sample <b>96D4C</b>  | 0,211                                                                                      | 517                                                                                                    |
| Sample <b>94D6C</b>  | 0,231                                                                                      | 623                                                                                                    |
| Sample <b>92D8C</b>  | 0,245                                                                                      | 681                                                                                                    |
| Sample <b>90D10C</b> | 0,370                                                                                      | 940                                                                                                    |

The incorporation of lime into the SCEB formulation affects its main thermal characteristic, the conductivity. In this study, lime, employed as a stabilizer, exhibits a thermal conductivity ranging from 0.194 to 0.370  $\text{W}/\text{m}\cdot^\circ\text{K}$ . While diatomite is recognized in the literature as an excellent material in terms of thermal performance, the thermal efficiency of the combination diminishes with the addition of lime. Indeed, the thermal conductivity results obtained for the various formulations suggest that these materials are not insulating, as the thermal conductivity of an insulating material is typically less than  $0.065 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$  [22]. However, these SCEBs, particularly the 90D10C formulation, can still be utilized for modest comfort applications.

### 3.4 Water durability test by immersion or water resistance test [16]

The water durability test was carried out for the different SCEB formulations studied and the results are presented in Table 6. The mass loss of the unstabilised block is  $P=5.29\%$ . This result predicts low losses for stabilized blocks. And indeed, from 6% lime addition, the mass loss (0.24%) is negligible as referred in table 6 above. The appearance of the bricks (see Fig. 10), after the immersion test, confirm this little mass loss. Furthermore, Guettala et al [23] have demonstrated that laboratory durability tests for compressed earth bricks are conducted under conditions that are significantly more severe than natural climatic conditions. ARS [24] and Evans [25] highlight that soils with insufficient clay content, such as the material used in this study, exhibit low cohesion and, consequently, reduced structural stability. So, with increasing lime content, the percentage of mass loss gradually decreases, denoting stabilization.

**Table 6** Loss in mass according to the different formulations

| Formulation          | P (%) Loss in mass |
|----------------------|--------------------|
| Sample <b>100D0C</b> | 5,29194            |
| Sample <b>98D2C</b>  | 2,04               |
| Sample <b>96D4C</b>  | 1,28               |
| Sample <b>94D6C</b>  | 0,24               |
| Sample <b>92D8C</b>  | 0,0058             |
| Sample <b>90D10C</b> | 0,00035            |

**Fig.10** Appearance of SCEBs 100D0C (left) and 94D6C (right) bricks after immersion test

## 4 Conclusion

The results obtained for mechanical strength are conclusive and relevant for housing construction in the study area and its surroundings. The thermal conductivity and effusivity values diminish with the increasing of the lime incorporation rate. For the SCEB labelled 90D10C, formulated with 90% diatomaceous soil and 10% lime, which is recommended brick for construction in Lake Chad region, the thermal properties are somewhat limited in terms of insulation ( $\lambda=0.37\text{W.m}^{-1}.\text{K}^{-1}$ ,  $e=940\text{ J.m}^{-2}.\text{K}^{-1}.\text{s}^{-1/2}$ ) but it demonstrates good Compressive Strength (4,27 MPa) and an extremely low mass loss (0,035%).

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