Some Hydraulic, Mechanical, and Physical Characteristics of Three Types of Compressed Earth Blocks

R. Medjo Eko[1], Mamba Mpele[2], M. H. Dtawagap Doumtsop[3], L. Seba Minsili[4], and A.S. Wouatong[5]

1. Senior lecturer, Dept of Agric. Engineering, FASA, U. of Dschang, Cameroon
Dept. of Earth Sciences, Faculty of Science, U. of Yaounde I, Cameroon
rmedjo@yahoo.com
2. Senior lecturer, National Polytechnic Advanced School, University of Yaounde I, Cameroon
3. Graduate student, Department of Earth Sciences, Faculty of Science, University of Dschang, Cameroon
4. Lecturer, National Polytechnic Advanced School, University of Yaounde I, Cameroon
5. Senior lecturer, Department of Earth Sciences, Faculty of Science, University of Dschang, Cameroon

ABSTRACT

Three types of compressed earth blocks (CEB) were processed to carry out a comparative study on some of their hydraulic, mechanical, and physical characteristics. They were namely the unstabilized CEB, the partially stabilized CEB, and the fully stabilized CEB. The partial stabilization of the CEB was achieved by wrapping its unstabilized earthen inner part all around with a stabilized earthen crown. Soil stabilization was done using Portland cement. Levels of cement mixed with soil were 0, 6, 8, and 10%. Two wrapping crown thicknesses were tested: they were 0.75 cm and 2.25 cm. Mechanical tests consisted of running the compressive and the flexural strengths on CEBs. Physical and hydraulic properties evaluated were respectively their abrasion loss of matter and water absorption.

Results show that the fully stabilized CEB performed better in regard to all the tests. The two remaining types of CEB displayed similar mechanical characteristics. However, abrasion loss of matter of the partially stabilized CEB was lower than that of unstabilized CEB. In addition, unstabilized CEB did not sustain the water absorption test.

This investigation shows that the partially stabilized CEB with 2.25 cm crown thickness is mechanically safe and meets the requirements for earthen construction. Therefore it might be recommended to the earthen construction industry as an interesting alternative for the fully stabilized CEB since its processing requires a lesser amount of cement.

Keywords: CINVA-RAM press, compressed earth blocks, soil stabilization.

1. INTRODUCTION

In Cameroon, the traditional earth block processing method is the hand-molding technique. It is a very old technique which came into knowledge in Egypt (Africa) where its use dates back since 2900 B-C (Houben and Guillaud, 1995). Earth blocks processed this way in Cameroon are sun-dried as done in the past. Natural fibers are sometimes added to soil during processing to help hamper material cracking upon drying while increasing their flexural strength. Hand-molding earth blocks unfortunately yields unregular and low densified building materials. These shortcomings stem for its rejection in the country.

During the 70's, the introduction of the CINVA-RAM press in Cameroon helped drop the above shortcomings. In effect, it appeared that compacting the soil using a press improves the quality of the material. The higher density obtained thanks to compaction significantly increases the compressive strength of the blocks (Rigassi, 1995).Which enabled unstabilized CEB to be considered in very few private housing programmes. Unfortunately, its use in such programmes failed to convince the local builders because it poorly sustained erosion. As a consequence, it was kept out of the building industry mainstream for quite a long time. Today, thanks to some recipes developed by builders in addressing this limitation, it is being seriously considered again for construction.

When the improvement of unstabilized CEB is considered, using cement as a CEB stabilizer enhances its mechanical, physical, and hydraulic characteristics. The erosion resistance and the compressive strength of the building material are significantly increased.The higher the volume of the stabilizer, the greater the improvement of these characteristics. However, beyond a certain level of stabilizer, the building material is no more competitive. Many investigators quote this level at 8% by weight (Houben and Guillaud, 1995; Rigassi, 1995).

Today in Cameroon, the cost of cement is in rise. It already reaches inaccessible heights for the local builders. Stabilizing a CEB using this chemical is therefore more and more expensive. Hence, solutions need to be designed to lower the level of cement used in processing this building material, which would consequently help drop its cost.

An attempt to efficiently lower the level of cement used in processing a stabilized CEB was carried out in this investigation. It was done by first designing a partially stabilized CEB made up of unstabilized inner soil and crowned all around with cement stabilized soil. Its hydraulic, mechanical, and physical characteristics were then evaluated and compared to those of unstabilized CEB and fully stabilized CEB to evaluate its suitability for house construction.

2. MATERIALS AND METHODS

The materials consisted of lateritic soil, Portland cement, tap water, and a locally made CINVA-RAM press. The lateritic soil tested was collected at Odza, a location on the south outskirts of Yaounde, Cameroon. Laterite is a surface formation which is enriched in iron and aluminum and develops by intensive and long lasting weathering of the underlying parent rock in tropical areas (Mamba Mpele, 1997). The term laterite which is derived from the Latin word *later* means brickstone (Autret, 1983); the name was given to this soil because it is used for making bricks.

On the spot, the soil in the first 0.50 m depth was removed to get rid of the organic soil layer. Laterite was then taken from the A horizon whose thickness is approximately 3.5 m in the Yaounde area (Pellier, 1969). The grain size distribution of the tested soil is displayed in figure 1. It was carried out according to ASTM D 422-63. Atterberg limits done according to ASTM D 4318-05 yielded a liquid limit of 55.5 and a Plastic Index of 24.3. Interpretation made using AASHTO (American Association of State Highways and Transportation

Officials) soil classification led to the conclusion that the soil was a sandy clay. Compaction test carried out according to ASTM D 1557-02e1 showed that the soil optimum water content was 25% and its maximum dry density was 1680 kg/m^3 (figure 2).

Cement is the most active component of soil-cement and usually has the greatest unit cost; its selection and proper use are important in obtaining most economically the balance of properties desired for any particular soil-stabilizer mixture. Characteristics of Portland cement used in the tests are displayed in Table 1.

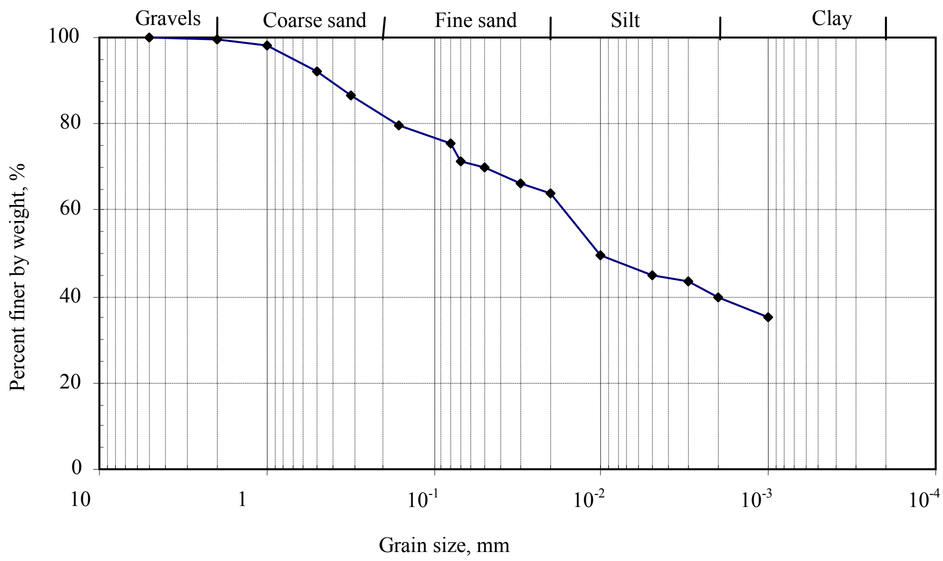

Figure 1: Grain size distribution of the tested soil

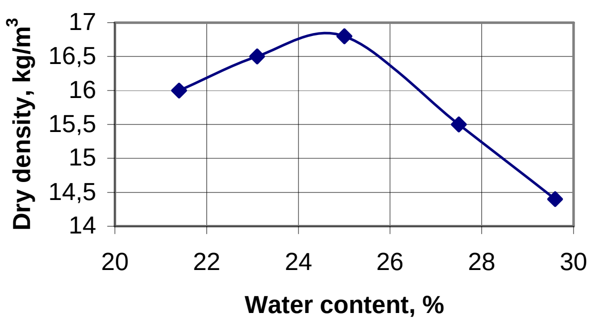

Figure 2: Proctor compaction curve of the tested soil

Table 1. Characteristics of Portland cement used

Cement type	Color	Specific gravity	Fineness	Setting time
CPJ35	Grey	3.10	3950 cm^{2}g^{-1}	2H30min

R. Medjo Eko, M. Mpele, M. Dtawagap Doumtsop, L. Seba Minsili, and A.S. Wouatong. "Some Hydraulic, Mechanical, and Physical Characteristics of Three Types of Compressed Earth Blocks". Agricultural Engineering International: the CIGR Ejournal. Manuscript BC 06 007, Vol. VIII, August, 2006.

The CINVA RAM press type used to compress the earth blocks is displayed in figure 3. Its characteristics are displayed in Table 2. Dimensions of earth blocks compressed using this machine were 21.5 x 10.5 x 5.50 cm^3 (length x depth x height). The casting pressure operated by the equipment was 0.35 bar; which was too low a pressure according to the standards. In effect, norms quote the lowest required casting pressure for compressing earth blocks used in the building industry to be 1-2 MPa (CDI and CRATerre-EAG, 1998)

Table 2**.** Characteristics of the manual press used

Arm of lever	Inner mold dimensions	Dimensions of blocks	Number of blocks	Applied Force	Compression mode	Compression category
180 cm	21.5 x 21.5 x 20 cm^3	21.5 x 10.5 x 5.5 cm^3	2	0.3 kN	Static	Very low

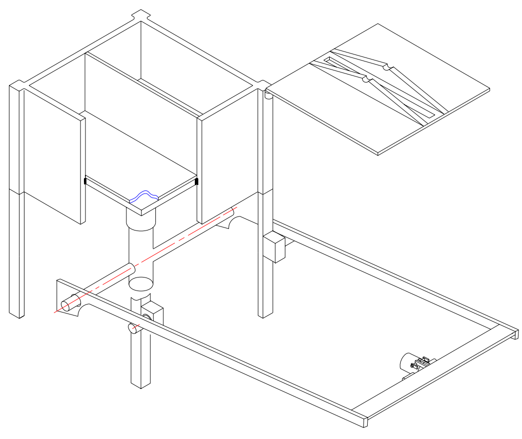

Figure 3. Manual press used for compressing the earth blocks

2.1 Processing of Compressed Earth Blocks

2.1.1 Soil Preparation

The soil planned to be used for earth block processing must not contain organic matter (Houben and Guillaud, 1995; Rigassi, 1995). To make sure the plain soil did not contain organic matter, a check of organic matter content was performed according to the procedure set by Mac Lean and Sherwood (1961). It is described elsewhere (Medjo and Riskowski, 2001). It was found that the tested soil did not contain organic matter.

The soil was dried in the oven for 48 hours at 40^{o}C to nullify its water content. It was then sieved to collect the less than 2 mm grain size. The collected soil was used as raw material for processing CEBs. Known weights of collected soil and Portland cement were homogeneously mixed using shovels. The mixing was done to ensure an even distribution of cement in the mixture. Water content up to the soil optimum water content was gradually added to the

mixture since it was planned to be compacted in the mold. The optimum water content is the water content which allows the highest dry density upon compaction of that soil using a given compactive energy. The dry density is the density of a dried soil packed in a given volume.
Three types of compressed earth blocks were processed. They were the following:

- the unstabilized earth block [CEB] in which the level of cement was zero percent ;
- the partially stabilized earth block. The partial stabilization of compressed earth block was achieved by wrapping all around an unstabilized earthen inner part with a fully stabilized earthen crown. Two crown thicknesses were tested : they were 0.75 cm [$CEB_{c0.75}$(m)] and 2.25 cm [$CEB_{c2.25}$(m)] where m was the level of cement in the crown mixture ;
- the fully stabilized earth block [CEB(m)] where m was the level of cement in the earth block mixture.

The various types of CEBs processed are reported in Table 3.

2.1.2 Processing of Unstabilized or Fully Stabilized CEBs

Two percent water content beyond the optimum was added to the soil for allowing the hydration of cement when stabilized soil was processed (ACI, 2000; Houben and Guillaud, 1995). Only optimum water content was added to the soil when unstabilized material was prepared. The levels of cement used in the various mixtures investigated were respectively 0, 6, 8, and 10%. The soil-cement mixture (used for fully stabilized CEB) or plain soil (used for unstabilized CEB) was poured into the press mold for compression. The casting pressure was 0.35 bar as previously stated. The compressed earth blocks were kept in conditions of relative humidity approaching 100% by covering them with waterproof plastic sheets for 7 days. From day 8 till day 28, the earth blocks were cured in a room open air.

2.1.3 Processing of Partially Stabilized CEB

The partially stabilized earth blocks were processed in 6 stages as follows:

- A known volume of stabilized earth was thrown and levelled at the bottom of the empty mold. Thickness of this earth block layer was $\lambda+\varepsilon$ cm (i.e. $\lambda+\varepsilon$ cm was the CEB crown thickness before compression);
- A second hollow mold was laid onto the levelled stabilized earth. It was placed within the original mold press at the center. The distance between its 4 vertical sides and the vertical sides of the original mold was $\lambda + \varepsilon$ each;
- The inner hollow mold was filled with unstabilized earth. Then the empty space between the inner mold and the original mold was filled with stabilized earth soil;
- The inner mold was withdrawn;
- A known volume of stabilized earth was laid over the nearly full original mold and was levelled. Thickness of this final earth block layer was also $\lambda + \varepsilon$;
- The mold cover was closed then the partially stabilized earth block was compressed. The CEB crown thickness after compression was λ cm.

The used plain soil and soil-cement mixtures were prepared as previously described. The partially stabilized CEB was then cured using the same procedure as described above. A section of the processed partially stabilized CEB is sketched in figure 4.

Table 3. Various types of CEBs processed

Designation	Description
CEB	Compressed Earth Block made of only plain soil.
CEB(m)	Fully Stabilized and Compressed Earth Block where soil was mixed with m cement level by weight.
$CEB_{c\lambda}(m)$	Partially Stabilized and Compressed Earth Block with outer crown thickness of λ cm ; its inner part was made of plain soil whereas its crown was made of soil-cement mixture with m cement level by weight

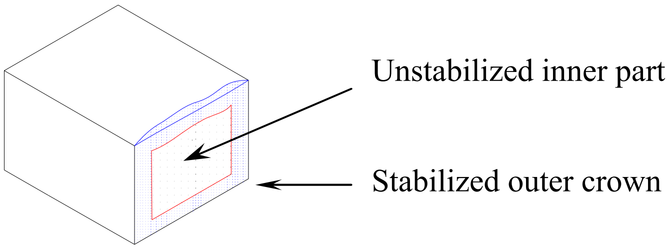

Figure 4. Section of the partially stabilized CEB

2.2 Experimental Program

Four tests were run on the processed earth blocks. They were namely the unconfined compressive strength, the flexural strength, the abrasion loss of matter and the water absorption tests. Unconfined compressive strength and flexural strength were evaluated respectively at the 7, 14, 21 and 28 curing day. Abrasion loss of matter and water absorption rate were performed only on the 28th curing day. Three replicates were processed for each test and each cement level.

2.2.1 Unconfined Compressive Strength

Compressed earth blocks were dry tested. The test procedure was the same as ASTM D 2166-00e1. The test was carried out as follows:

- specimen ends were sanded smooth; the specimen was laid on the steel bottom bearing plate of the testing machine (figure 5); the steel bottom bearing plate was covered with a hard paper cover;
- the steel top bearing plate was set on top of the specimen. That steel top bearing plate ensured a uniform pressure over the upper cross-section of the specimen;
- top and bottom bearing plates were identical; thickness was 6.0 cm while diameter was 32.4 cm;
- the specimen was loaded at the controlled rate of 0.5 bar/minute since a hydraulic machine was used;

- the load strain reading at failure F_r was recorded. It was the maximum load the specimen could carry in compression.

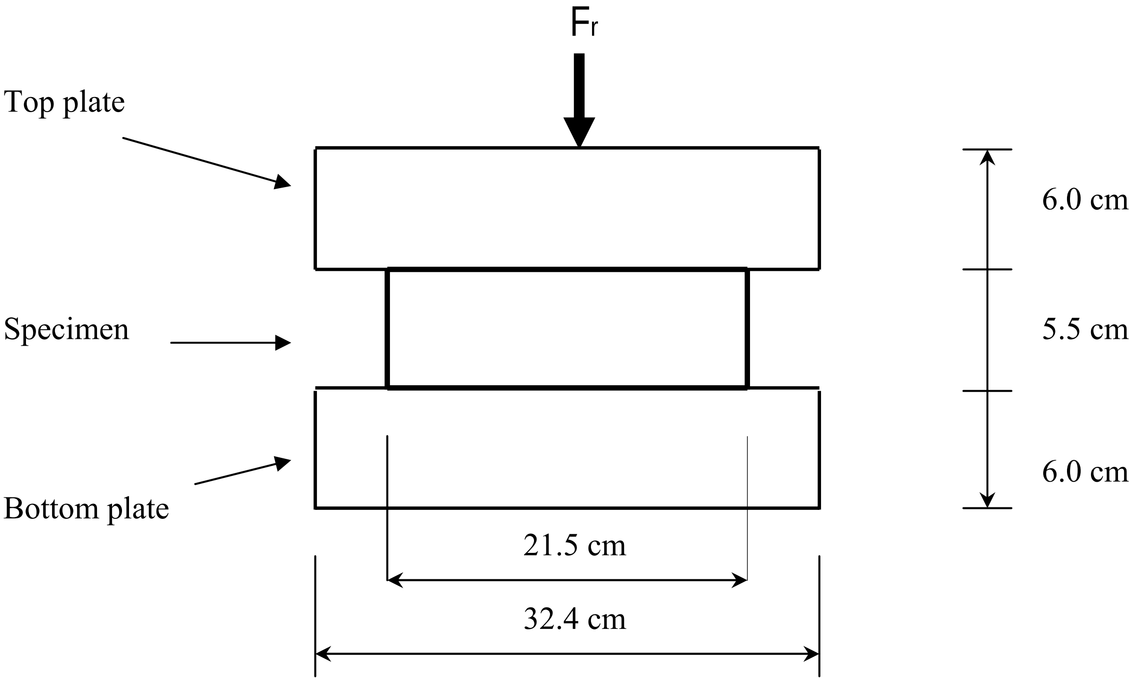

Figure 5. Set up used for testing the unconfined compressive strength

The unconfined compressive strength R_C of the earth block was given by the following relationship:

$$R_C = \frac{F_r}{S} \qquad (1)$$

where S was the section of the CEB.

2.2.2 Flexural Strength

The test was performed according to ASTM D 1635-00 procedure. It was carried out using a suitable apparatus mounted for this purpose (figure 6). The procedure run on dry specimens was as follows:

- two steel rollers were set at a distance of 16.50 cm apart on the bottom plate of a hydraulic machine. They were cylindrical, 10 cm long and had a diameter of 0.50 cm. Each bore a steel support plate whose length, width, and thickness were respectively 10 x 4 x 0.5 cm. The CEB was placed over the two steel support plates; which reduced the frictional forces between the rollers and the CEB. In other words, the steel rollers were free to rotate.
- Two loading steel rollers identical to the two described above were set on top of the CEB; each of them was laid on a steel support block whose length, width, and thickness were 10 x 4 x 0.5 cm. The loading rollers were separated by 5.5 cm. The horizontal distance between each loading roller and the nearest bottom steel roller was equal to

5.50 cm. Because the loading rollers laid on steel support plates in contact with the CEB, they were free to rotate; which reduced the frictional forces between the specimen and each loading roller.

- A 1.0 cm thick steel block was laid on the 2 steel rollers described above. It helped distribute the applied load evenly on the specimen.
- The load was applied via a steel roller identical to those described above. This latter laid directly onto the above steel block. The horizontal distance between this roller and the nearest one supporting the steel block was 2.75 cm.
- The loading rate was 2 mm/min as recommended by Singh et al. (1978).
- The maximum load at occurrence of the first crack was recorded as flexural strength F_{flex}. Upon crack occurrence, the strength decreased.

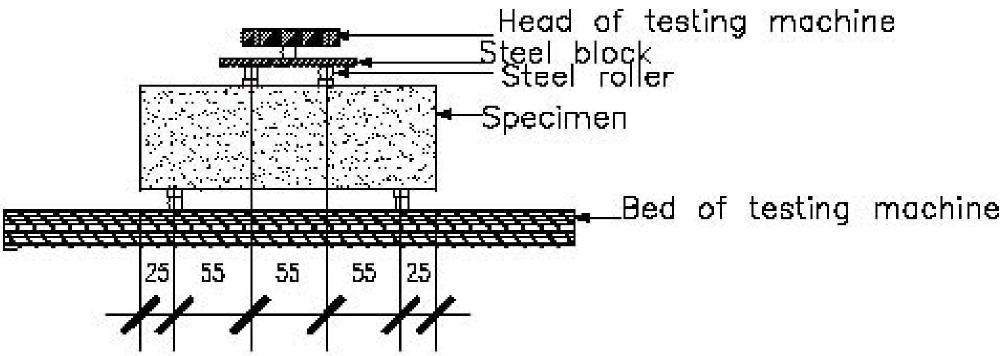

Fig 6: Setup used for testing the flexural strength

Key: dimensions are in mm

The flexural strength R_{flex} of the earth block is defined by the following relationship:

$$R_{flex} = \frac{3xF_{flex}xL}{h^2xa} \qquad (2)$$

where

F_{flex} = maximum applied load; l = span length

h =specimen height; a = specimen depth

2.2.3 Abrasion Loss of Matter

This test is used to determine the weight loss percentage of a CEB submitted to friction. The test was run on dry CEBs as follows:

R. Medjo Eko, M. Mpele, M. Dtawagap Doumtsop, L. Seba Minsili, and A.S. Wouatong. "Some Hydraulic, Mechanical, and Physical Characteristics of Three Types of Compressed Earth Blocks". Agricultural Engineering International: the CIGR Ejournal. Manuscript BC 06 007, Vol. VIII, August, 2006.

A conditioned specimen was first weighed and this weight M_0 was recorded. It was then held in a fixed position and supported by a steel plate. The specimen was abraded by rubbing one side back and forth with a 6 kg hammered metallic brush. Each back and forth operation was a cycle. After 50 cycles operation, the specimen weight M_F was recorded.
The abrasion loss of matter R_{abr} was evaluated using the following relationship:

$$R_{abr} = \frac{M_F}{M_0} x100 \qquad (3)$$

2.2.4 Water Absorption Rate

After 28 days curing, CEBs were totally immersed in water for 48 hours. They were then taken out, wiped with a cloth, and weighed. The weight of each specimen was recorded. This was the wet weight.

The specimen was then stored in the oven to dry up for 48 hours. Temperature in the oven was 40^oC during this period of time. After drying, the specimen was weighed once again and the weight was once again recorded. This was the dry weight. If M_H is the wet weight and M_s the dry weight, the soil water absorption T_W was given by the following relationship:

$$T_W = \frac{M_H - M_s}{M_S} x100 \qquad (4)$$

3. RESULTS AND DISCUSSION

3.1 Unconfined Compressive Strength

Dry compressive strengths of the CEBs increased over time (figure 7-9) except that of $CEB_{c0.75}$(6). The compressive strength of the latter first increased then decreased over time. This behavior was due to the fact that upon drying, the inner part of the material and the outer crown shrunk differently because they were naturally different (the inner part was made of plain soil while the crown was made of soil-cement). In addition the crown of $CEB_{c0.75}$ was not thick enough to nullify the detrimental effect of the above difference when both inner part and outer crown shrunk.

Increasing cement level from 8 to 10% induced high strength gains to fully stabilized CEBs while this increase of cement level had nearly no effect on partially stabilized CEBs. The low strength gains of partially stabilized CEBs in this range of cement levels was due to the fact that the beneficial effect of cement was confined to a very small area located at the outer edge of the material. In effect, the greater proportion of the partially stabilized CEB section was unstabilized and this fact induced negligible strength gain to the material over time. It therefore means that the inner part of the partially stabilized CEB controlled the major part of its compressive strength.

On the 28th day curing, compressive strength of fully stabilized CEB jumped from 2.7 to 3.48 MPa when cement level increased from 8 to 10 %. The increase was no significant when the cement level increased from 6 to 8% for the same material: the jump only shifted from 2.2 to 2.7 MPa. At 6% cement level, mixing cement with soil did not improve the soil mechanical behavior (figure 7). Mixing soil with cement level below 8% turned out to be ineffective. This finding is opposite to the observed mechanical behavior of CEB processed with soil-cement mixtures where cement levels are equal or greater than 4% (Rigassi, 1995; Houben and Guillaud, 1995). The fact observed in this investigation might be explained by the use of a low casting pressure. In effect, the beneficial effect of cement in soil-cement mixtures does not depend only on the amount of cement mixed with soil, but also on the casting pressure applied to the earth block. If the casting pressure is not high enough as was the case for this investigation, the tying of soil particles induced by $C_3S_2H_3$ compounds would not be as effective as it should be. As a consequence the beneficial effect of cement would rely only on its level in the soil-cement mixture. Which explains why only high cement contents induced noticeable strength gain to CEBs in this investigation. $C_3S_2H_3$ compounds result from the hydration of C_2S and C_3S compounds brought about by cement. $C_3S_2H_3$ are the compounds which tie the soil particles together in concrete or soil-cement (Mindess and Young, 1981).

Partially and fully stabilized CEB specimens whose ages were less than 14 days displayed compressive strengths lower than that of unstabilized CEB. This was due to the three following reasons:

- the $C_3S_2H_3$ compounds were not yet mature enough to tie soil particles together and induce substantial compressive strengths to the CEB matrix;
- their compaction took place at water content beyond the optimum while that of unstabilized CEBs were done at optimum water content; it is therefore expected that the early strength of the former CEBs be lower than that of unstabilized CEBs;
- soil compression was not effective enough to induce the tying of soil particles, which was detrimental for the stabilized CEBs that were compressed at a water content beyond the optimum.

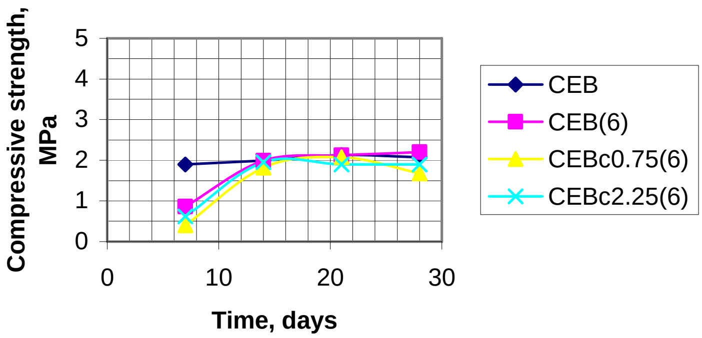

Figure 7. Compressive strength increase of CEBs over time (both fully and partially stabilized CEBs were processed using 6% cement level)

R. Medjo Eko, M. Mpele, M. Dtawagap Doumtsop, L. Seba Minsili, and A.S. Wouatong. "Some Hydraulic, Mechanical, and Physical Characteristics of Three Types of Compressed Earth Blocks". Agricultural Engineering International: the CIGR Ejournal. Manuscript BC 06 007, Vol. VIII, August, 2006.

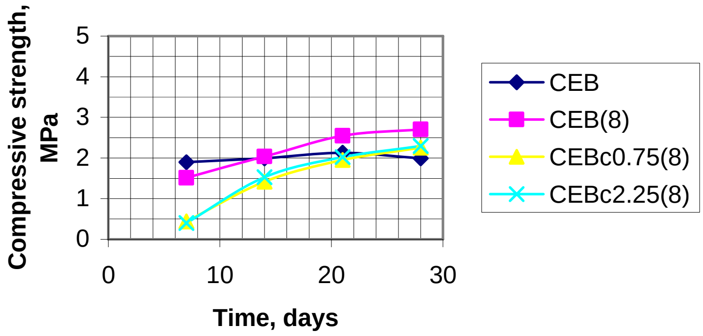

Figure 8. Compressive strength of CEBs over time (both fully and partially stabilized CEBs were processed using 8% cement level).

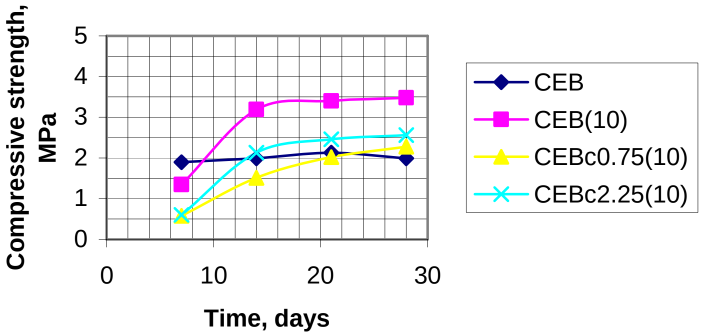

Figure 9. Compressive strength of CEBs over time (both fully and partially stabilized CEBs were processed using 10% cement level)

All the processed CEBs except the $CEB_{c0.75}(6)$ met the minimum requirements for their use in building one storey homes (CDI and CRATerre, 1998).

3.2 Flexural Strength

Flexural strength data (figures 10-12) show that strength gains of fully CEBs are significantly different from strength gains of partially stabilized or unstabilized CEBs when cement levels are greater than 8%. The reason why fully stabilized CEBs develop better strength gain than partially stabilized CEBs in compression also holds true in flexure. CEB, CEB(m) and $CEB_{c2.25}(m)$ flexural strengths increased with cement level over time. On the other hand, $CEB_{c0.75}(m)$ flexural strengths first increased then decreased over time whatever the cement level. The explanation of this behavior in flexure is the same as in compression.

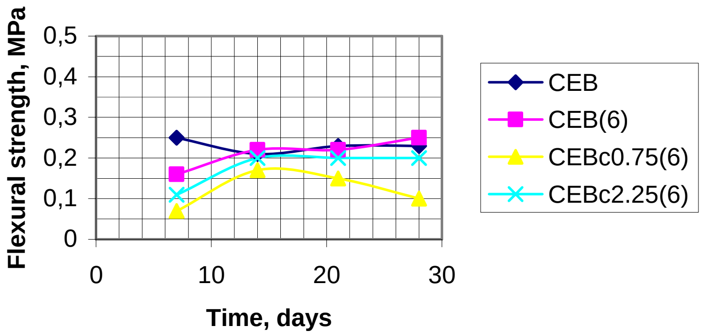

Figure 10. Flexural strength of CEBs over time (stabilized CEBs were processed using 6% cement level)

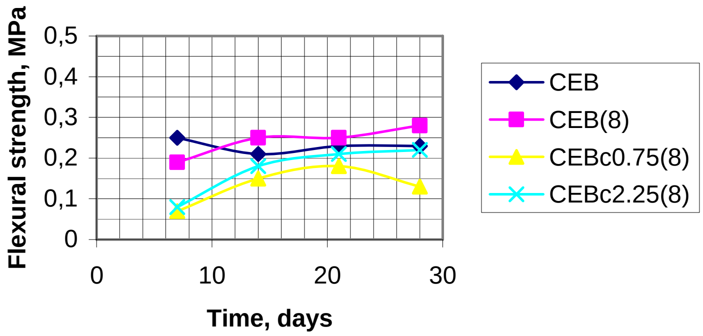

Figure 11. Flexural strength of CEBs over time (stabilized CEBs were processed using 8% cement level)

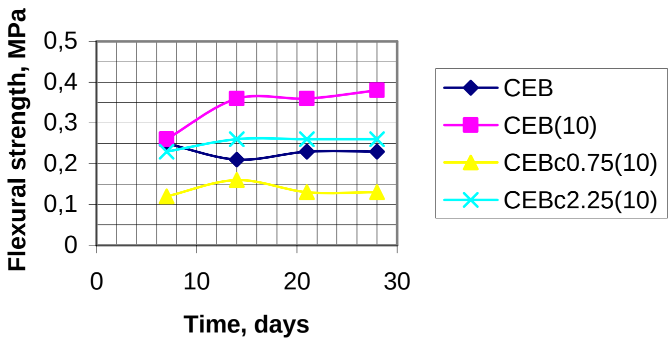

Figure 12. Flexural strength of CEBs over time (stabilized CEBs were processed using 10% cement level)

3.3 Abrasion Loss of Matter

Data pertaining to abrasion loss of matter are summarised in figure 13. They show that abrasion loss of matter decreased with increasing cement level whatever the stabilized CEB type (fully or partially stabilized). This happened because $C_3S_2H_3$ compounds held soil particles stronger and stronger as cement levels increased in the soil-cement mixtures. This

R. Medjo Eko, M. Mpele, M. Dtawagap Doumtsop, L. Seba Minsili, and A.S. Wouatong. "Some Hydraulic, Mechanical, and Physical Characteristics of Three Types of Compressed Earth Blocks". Agricultural Engineering International: the CIGR Ejournal. Manuscript BC 06 007, Vol. VIII, August, 2006.

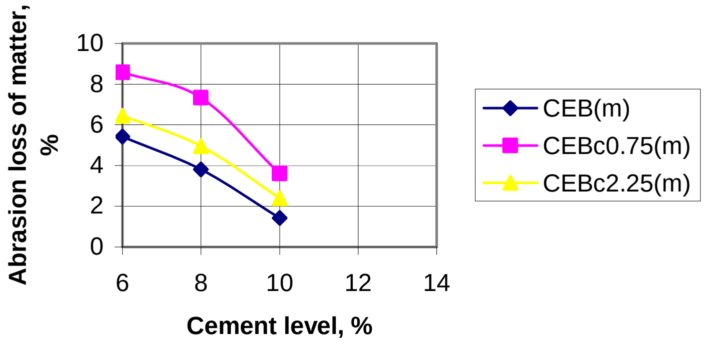

Figure 13. Effect of cement level on the abrasion loss of matter of CEBs

effect even increased with the increasing thickness of the earthen crown. After 50 cycles, the fully stabilized CEBs and the partially stabilized CEBs with 2.25 cm crown thickness displayed the lowest abrasion loss of matter.

3.4. Water Absorption Rate

Data related to CEBs water absorption are reported in figure 14. It is observed that water absorption decreased with cement level whatever the stabilized CEB type (fully or partially stabilized). This is due to the fact that as $C_3S_2H_3$ compounds held soil particles stronger and stronger because of increasing level of cement, the tortuosity of tiny channels in the soil-cement mixtures increased in the process. As a consequence, the permeability of the material decreased. It was noted that the fully stabilized CEBs displayed the lowest values of water absorption rate whereas the partially stabilized CEBs with 0.75 cm crown thickness performed very poorly (figure 14). Data of unstabilized CEBs are not displayed because those CEBs did not sustain the test: they were all disintegrated by the end of the test.

CDI and CRATerre (1995) requirements set the material water absorption in the 10-20% range. The gathered data show that all the processed CEBs (except the unstabilized material) were in the 10-20% water absorption range (figure 14). All the fully and partially stabilized materials therefore met the minimum requirements for their use in house construction in respect to this parameter.

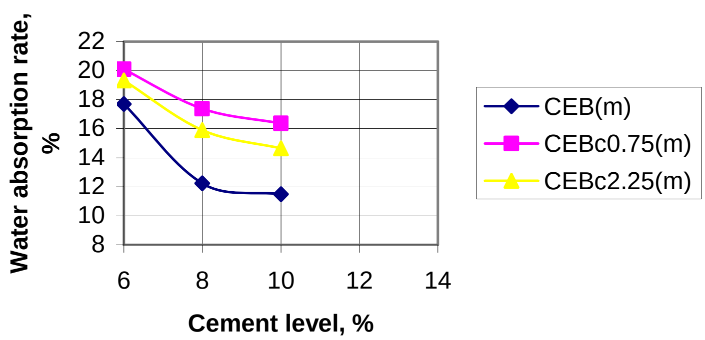

Figure 14. Effect of cement level on the water absorption rate of CEBs

4. CONCLUSION

A new partially stabilized CEB was developed in the search of an affordable solution to respond to the rise of cost of cement in Cameroon. Comparison of some of its hydraulic, mechanical, and physical characteristics with those of fully stabilized and unstabilized CEBs was also carried out to evaluate its suitability in local house construction. The investigation revealed that:

- The increasing cement level in the soil-cement mixtures improve the mechanical characteristics of the fully stabilized CEBs whereas their hydraulic and physical parameters decrease with cement level. The values of their investigated properties are beyond the minimum requirements for earth construction.
- The mechanical characteristics of partially stabilized CEBs with 0.75 cm crown thickness first increase then drop with time whatever the cement level. Partially stabilized CEBs are therefore unsafe for earth construction although they display a good resistance to abrasion loss of matter.
- If the crown thickness of partially stabilized CEBs is increased by 1.5 cm, their mechanical characteristics increase with time and cement level as do those of fully stabilized CEBs. Their hydraulic and physical characteristics similarly drop with cement level as do those of fully stabilized CEBs. This overall behavior of $CEB_{c2.25}$ is safe. It was observed that, using 8% cement by weight for processing stabilized earthen crowns enable the newly developed building material to reach the minimum requirements for earth construction.

In conclusion, processing partially stabilized CEB with 2.25 cm crown thickness and stabilizing it using 8% cement level by weight might be a good alternative for fully stabilized CEB since the engineering properties of the former meets the minimum requirements for earth construction and requires a lesser amount of cement when it is processed.

5. REFERENCES

ACI. 2000. *The State of the Art Report on Soil-Cement*. American Concrete Institute 20.1R-90, USA.

ASTM D 1635-00. 2006. Standard Test Method for Flexural Strength of Soil-Cement using Simple Beam with 3rd Point Loading, Vol. 04.02, American Society for Testing and Materials, West Conshohocken, Pennsylvania, PA 19428, USA

ASTM D 422-63. 2002. Standard Test Method for Particle Size Analysis of Soils, Vol. 04.08

ASTM D 1557-02e1. 2004. Standard Test Method for Laboratory Compaction Characteristics of Soils using Modified Effort (56,000ft-lb/ft^3(2,700 kN.m/m^3)), Vol. 04.08, American Society for Testing and Materials, West Conshohocken, Pennsylvania, PA 19428, USA

ASTM D 2166-00e1. 2004. Standard Test Method for Unconfined Compressive Strength of Cohesive Soils, Vol. 04.08, American Society for Testing and Materials, West Conshohocken, Pennsylvania, PA 19428, USA

ASTM D 4318-05. 2006. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, Vol. 04.08, American Society for Testing and Materials, West Conshohocken, Pennsylvania, PA 19428, USA

Autret, P. 1983. *Etude des Latérites et Graveleux Latéritiques*. Laboratoire Central des Ponts et Chaussées, Paris, France.

CDI and CRATerre-EAG. 1998. *Compressed Earth Blocks Standards*.ISBN 2-906901-18-0

Houben, H. and H. Guillaud. 1995. *Traité de Construction en Terre*. Editions Parenthèses, Marseille, France, ISBN 2-86364-041-0.

MacLean, D.J. and P.T Sherwood. 1961. Study of Occurrence and Effects of Organic Matter in Relation with the Stabilisation of Soils with Cement, *Proceedings Fifth International Conference on Soil Mechanics and Foundation Engineering*, *England , UK*

Mamba, Mpele.1997. Quelques Propriétés des Latérites du Cameroun et Critères à Appliquer aux Matières Premières pour la Fabrication des Blocs de Terre. *Cameroon Journal of Building Materials*, 1(2): 19-23.

Mamba, Mpele. 2003. Méthodologie d'Etalonnage d'une Presse Manuelle de Fabrication des Blocs de Terre Comprimée. Journées Universitaires des Sciences et Technologies de l'IUT de Douala, 4 au 9 Juillet 2003.

Medjo Eko, R. and Riskowski, G.L. 2001. A Procedure for Processing Mixtures of Soil, Cement, and Sugar Cane Bagasse. *Agricultural Engineering International: the CIGR E-journal*, Vol. III, Texas A&M University, USA

Mindess, S. and Young, F. 1981. *Concrete*, Prentice Hall Inc., Englewood Cliffs, New York, USA

Pellier, S .L, 1969. *Données Générales sur la Répartition des Principaux Types de Sols de la Région de Yaoundé*, ORSTOM, Yaoundé, 24 pp.

Rigassi, V. 1995. *Compressed Earth Blocks: Manual of Production.* ISBN 3-528-02079-2

Singh B., Walton P.L., and Stucke M.S. 1978. *Test Methods Used to Measure the Mechanical Properties of Fibre Cement Composites at the Building Research Establishment,* RILEM Symposium, University of Sheffield, England

R. Medjo Eko, M. Mpele, M. Dtawagap Doumtsop, L. Seba Minsili, and A.S. Wouatong. "Some Hydraulic, Mechanical, and Physical Characteristics of Three Types of Compressed Earth Blocks". Agricultural Engineering International: the CIGR Ejournal. Manuscript BC 06 007, Vol. VIII, August, 2006.