Influence of diatomite on the physico-mechanical properties of compressed earth blocks

ABSTRACT

Given the need for decent housing and respect for the environment, as well as the search for sustainable materials, in recent years researchers have begun to focus on local biodegradable and ecological materials. It should be noted that the use of building materials evolves in step with population growth. However, their production must have a clear positive impact on the environment and offer viable solutions for reducing energy consumption during use. However, these materials rarely meet the mechanical requirements for use in housing construction. The aim of this study is to investigate the potential use of diatomite in the manufacture of compressed earth bricks. Diatomite is used at between 5% and 50% in two clay soils to determine its physico-mechanical properties. The study focused on shrinkage and mass loss, density, porosity, flexural strength, compressive strength and splitting tensile strength of the composites. The results show that the incorporation of diatomite improves the linear shrinkage of CEBs and increases their porosities. The dry density of CEB decreased considerably with increasing percentages of diatomite, which also led to a reduction in mechanical strength. This reduction in mechanical strength is linked to the physicochemical characteristics of diatomite. According to a number of relevant standards and the literature, which set minimum permissible strengths at 2 MPa in simple compression and 0.1 MPa in bending and indirect tension, composites made from two clay soils and diatomite can be used in building construction.

Comment [H1]: CEBs abbreviations are used in the abstract. The researcher should say the full word once before to avoid confusion for readers.

Keywords: Clay soils, diatomite, physico-mechanical properties, CEB and eco-material

1. INTRODUCTION

The current housing crisis is forcing many researchers, especially in low-income countries, to focus more on the use of local, biodegradable and environmentally-friendly materials. Today, action on these building materials is becoming a necessity, even an "obligation", for a green transition that is synonymous with sustainable development [1]. Worldwide, it is estimated that over a third of all homes are built using raw earth [2]. Earth abounds in large quantities of clay raw materials that can be used to make bricks for housing construction. Its many virtues (its abundance, its high thermal inertia, etc.) have amply demonstrated its beneficial contribution to a home. However, its use as a raw material in construction brings with it a number of shortcomings, such as variation in volume (shrinkage and/or swelling) during drying and high sensitivity to water. The latter leads to numerous cracks, thus reducing mechanical performance (toughness, resistance to fracture and creep). These problems are generally dealt with in various ways, sometimes by adding stabilizers and/or additives to the clay. The most commonly used stabilizers are cement, lime and sand [3].

However, the production of these stabilizers requires considerable resources, and not everyone has access to them. What's more, their production pollutes the environment by releasing carbon dioxide into the atmosphere. Nowadays, however, natural adjuvants based on plant and animal waste have become a way of combating environmental pollution, and have been used to modify the properties of basic materials [4, 5]. In addition to these, there are other raw earth stabilizers with alternative mineral binders (sugarcane bagasse ash, coal ash, geopolymer ash) [6, 7] that have been shown to reduce block cracking, improve durability and mechanical strength, and reduce thermal conductivity [8]. However, at a certain percentage, these additives have negative effects on block properties [9]. It should be noted that the use of diatomite as an admixture to improve the mechanical and thermo-physical properties of building bricks has been the subject of a number of recent studies. The nature of the raw material, the proportion of admixture and the manufacturing process have a major influence on the properties of the building material. To the best of our knowledge, few scientific studies have been carried out on the physicomechanical properties of blocks made from clayey soils and diatomaceous earth (diatomite), which are nevertheless very important in understanding soil stabilization. In Chad, there is a strong presence of diatomite deposits in several provinces, but these have remained untapped until now. So, as part of a sustainable development approach to the promotion and valorization of local natural resources, particularly in the field of building construction, this material is used as an admixture in the clay matrix in various proportions. The main objective of this work is to stabilize clay soil blocks with diatomite in order to examine their physicomechanical properties for their use in eco-construction.

2. MATERIAL AND METHODS

2.1 Raw materials

The clay soils used in this study were taken from Toukra (latitude 12.00834 and longitude 15.15101) in the 9th arrondissement of the city of N'Djamena and Yeï (latitude 8.78543 and longitude 17.01523) in the Logone Oriental province in southern Chad. These two soils were subjected to various identification analyses and the results showed that the two soils studied are of different natures [10].

Diatomite ($SiO_2\_nH_2O$) or diatomaceous earth is a light-colored, porous, light siliceous rock composed mainly of frustules of diatoms (unicellular aquatic algae). It is composed mainly of fossilized diatom skeletons of various shapes and sizes [11], with structures containing up to 80-90% voids [12]. Thanks to its specific properties, diatomite provides a wide variety of uses in sustainable development and the environment. The diatomite used in this study comes from the Motto quarry in Mao, Kanem province, northern Chad. Figure 1 shows the clay soils and diatomite used in the manufacture of CEB, and Figure 2 shows the particle size curves of two clay samples studied.

Comment [H2]: According to the results of particle size in Figures 1 and 2, the particle sizes of clay and diatomaceous earth vary. Researchers should explain: The particle size in the content.

Figure 1: Clay soils [10] and diatomite samples

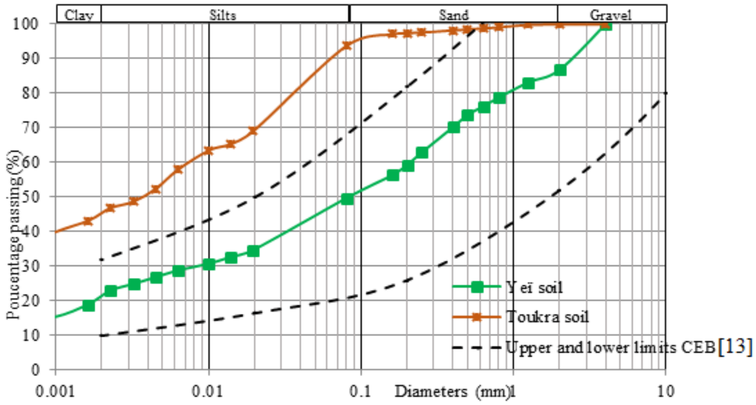


Figure 2: Complete particle size analysis curves for two soils and BTC spindles

2.2 Formulation and manufacture of diatomite-stabilized compressed earth blocks

The blocks were manufactured in the laboratory of the National School of Public Works in N'Djamena/Chad, using a diatomite stabilizer. The mass of the dry specimens was kept constant during the experimental phase. It is of the order of 500 g per specimen in compression, bending and absorption, and 2800 g per specimen in indirect tension (by splitting). One set of specimens is made with 100% clay soil (0% diatomite) and another set with eight different diatomite contents (5%, 10%, 15%, 20%, 25%, 30%, 40% and 50%) relative to the total dry mass of the specimens. Two types of specimen were used: prismatic specimens measuring 40x40x160 mm^3 for compression, flexural and absorption tests, and cylindrical specimens measuring 100x200 mm^2 for the splitting test, with a compaction force of 10 MPa. For each formulation carried out, four blocks were made per specimen in order to record the average value of each specimen in the various tests. Figure 3 shows the compressed earth block samples produced and laid out for drying in the laboratory.

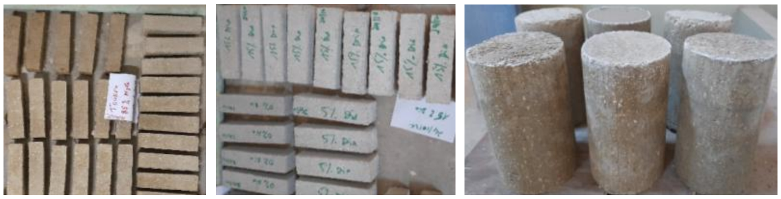


Figure 3: Prismatic and cylindrical specimens manufactured for testing

2.3 Experimental processes

The dry density, which is an index of block strength, and the optimum water content for specimen manufacture were determined using the normal Proctor test in accordance with standard NF P 94-093 [14].

Dimensional variations (linear shrinkage) and mass losses of specimens are determined using basic formulas (3) and (4) below.

$$R(\%) = \left(\frac{l_t - l}{l}\right).100 \quad (1)$$

$$P_m(\%) = \left(\frac{m_t - m}{m}\right).100 \quad (2)$$

With respectively, R and P_m: linear shrinkage and mass loss, l and m: length and mass of the specimen at demolding and l_t and m_t: length and mass of the specimen after drying time t.

Density is a key parameter for assessing the quality of manufactured blocks. The apparent density of bricks was measured using the hydrostatic weighing method in accordance with standard NF P 94-064 [15]. Knowledge of the hydrostatic apparent densities (ρ_a) and absolute densities (ρ_{ab}) measured with a pycnometer enables us to determine the closed porosities of the blocks. Porosity (η) expresses the proportions of voids in the specimens. It is determined by the following relationship.

$$\eta(\%) = \left(1 - \frac{\rho_a}{\rho_{ab}}\right).100 \qquad (3)$$

Three-point bending, simple compression and indirect tensile strength tests were carried out using a multifunction machine in the laboratory of the National School of Public Works. For all tests, five samples of each formulation were taken to determine the mean values of the measured quantities. Measurements were taken during four maturation periods (7, 14, 28 and 56 days).

2.2.1 Flexural strength test

The mechanical strengths obtained by testing prismatic specimens were carried out on the test configuration machine in accordance with NF EN 196-1 [16]. The maximum bending strength of the mortars was determined using relationship (4) by applying the load as represented by the device in figure 4.

$$R_f = \frac{3.F_f.L}{2.b^3} \qquad (4)$$

With Rf: bending strength, expressed in megapascals (MPa), F: maximum force applied in newtons (N), L: distance between the two supports in millimeters (mm), l: specimen width in millimeters (mm) and h: specimen height in millimeters (mm).

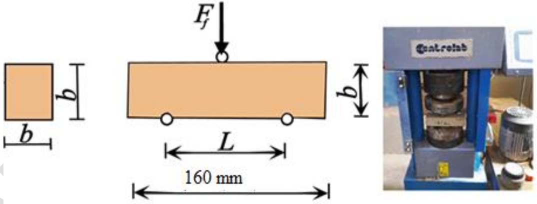


Figure 4: Testing the three-point bending strength of test specimens

2.2.2 Simple compressive strength test

Compressive strength was tested in accordance with EN 196-1 [16] on the half-sample obtained after flexural fracture. The mechanical strengths obtained from the test were also carried out on the specimen samples. The compressive strength of the mortars was then calculated from the maximum load using equation (5). Figure 5 illustrates the compressive strength device.

$$R_c = \frac{F_c}{b^2} \qquad (5)$$

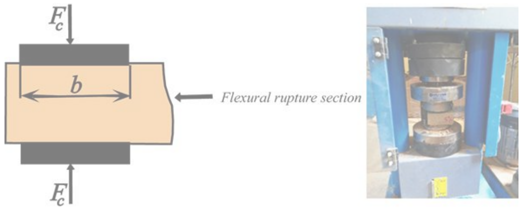


Figure 5: Testing the simple compressive strength of CEB specimens

2.2.3 Indirect tensile strength test

The tensile strength of specimens was estimated using the Brazilian test (NF EN 13286-42), also known as the split tensile test or indirect tensile test [17]. This test is frequently used on brittle materials. It involves splitting a cylindrical specimen of diameter D and length L, placed between two perfectly smooth, parallel plates and subjected to a compressive load F applied to two opposite generatrices (figure 5). Relation (6) is used to determine the indirect tensile strength of four specimens per formulation.

$$R_{ti} = \frac{2.F}{\pi.D.L}$$

(6)

Where, Rt is the indirect tensile strength, expressed in the specimen, expressed in newtons (N), D is the specimen diameter of the specimen, expressed in millimeters (mm).

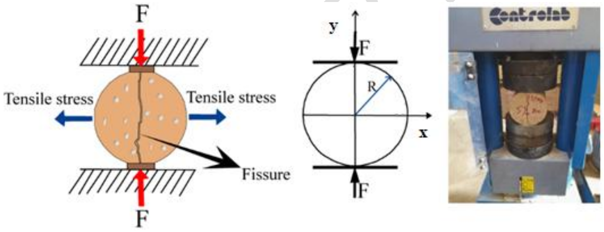


Figure 6. Indirect tensile strength test of specimens

3. RESULTS AND DISCUSSION

3.1 Water content and dry density

Figure 7 a and b show the results of tests to determine dry densities as a function of water content for each formulation. The different water content values are used to produce the compressed soil block samples. The water content of Toukra soil plus diatomite increased from 19.40% for the reference soil to 38.02% for the 50% diatomite composite, and from 21.00% to 42.53% for Yeï soil plus diatomite. This increase is attributed, on the one hand, to the low density of the diatomite and, on the other, to the voids in the matrix created by the introduction of diatomite during mixing. In both cases, dry densities decrease with increasing diatomite percentages, and the opposite is observed for water contents.

Comment [H3]: The test results for water content and dry density should be supplemented by other research. to support the results obtained from the research as well.

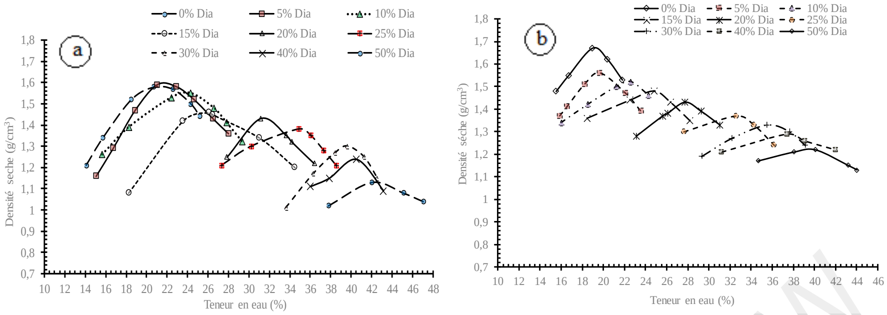


Figure 7. Density versus water content curves: a) Toukra composites and b) Yeï composites

The dry density and water content values of different composite formulations (two clay soils + diatomite) were used to wet each mixture for specimen production.

3.2 Linear shrinkage and mass loss

Linear shrinkage and mass loss were determined respectively by the length and mass ratios of 40x40x160 mm3 specimens after 28-day curing at a laboratory temperature of around 38°C. The effect of varying percentages of diatomite on the linear shrinkage and mass loss of the composites in the dry state, and their correlations, are shown in Figures 8, 9 and 10 for each composite.

For the different composites, shrinkage decreases from 1.52% for the Toukra reference block to 0.72% for the 50% diatomite composite, and from 1.42% for the Yeï reference mortar to 0.38% for the 50% diatomite composite. The high linear shrinkage of Toukra soil composites is due to the high presence of unstable minerals (feldspars, plagioclases, montmorillonite, etc.) [18]. On the other hand, the mass losses of composites increase with diatomite percentages. This increase in mass loss is linked to the significant departure of water during the manufacture of CEB. These increases were 27.90% for the Toukra composite and 32.33% for the Yeï composite. Compared with the use of fibers in the clay matrix to increase viscosity and reduce shrinkage [19], diatomite also plays the same role. A good correlation between dimensional variations and mass loss was observed for Yeï composites compared with Toukra.

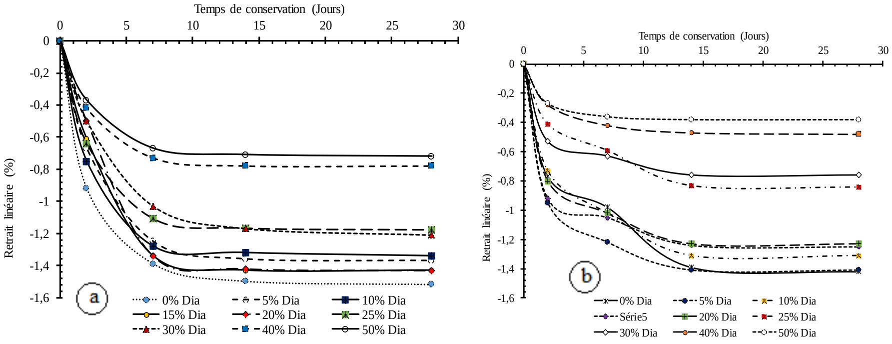


Figure 8. Linear shrinkage of BTC, a) Toukra composites and b) Yeï composites

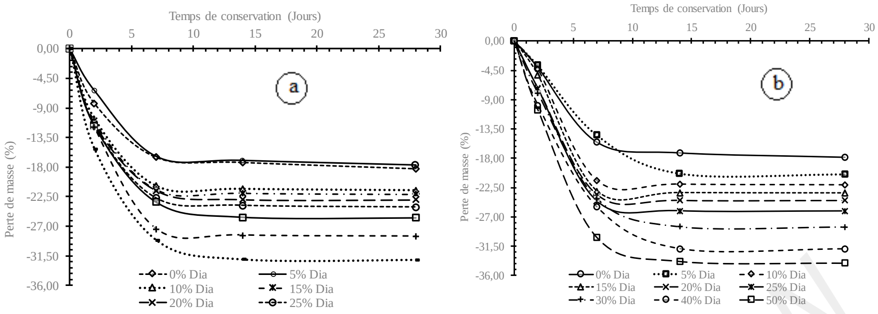


Figure 9. Mass losses of BTC, a) Toukra composites and b) Yeï composites

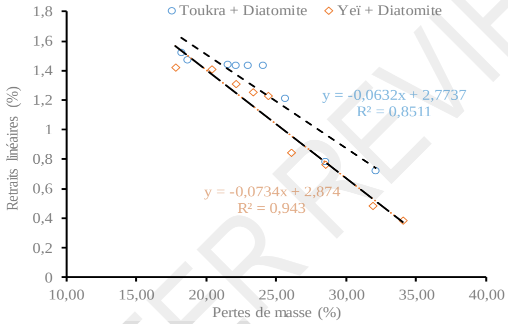


Figure 10. Correlations between linear shrinkage and BTC mass loss

3.3 Bulk densities and closed porosities

Figure 11 shows the results for bulk density and closed porosity of compressed earth blocks. Specimen densities decrease with increasing diatomite content, respectively from 1.25 to 1.14 g/cm3 for the Toukra composite and 1.29 to 1.09g/cm3 for the Yeï composite. This reduction in density is most pronounced for specimens from the Yeï composite, with a reduction of 15.50% compared with 8.81% for the Toukra composite. The curves show an increase in specific porosity with increasing diatomite content. They evolve in the opposite direction to those of density, and are most noticeable at 5% and 10% diatomite. Porosity values range from 49.90 to 54.56% and from 45.99 to 54.45% respectively for Toukra and Yeï composites. The dry density and porosity results for CEB corroborate some of the work reported in the literature [20, 21].

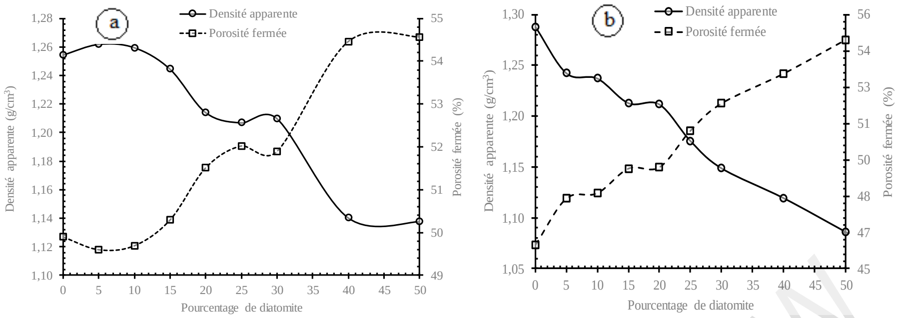


Figure 11. Densities and porosities of CEB a) Toukra composites and b) Yeï composites

3.4 Three-point flexural strength

Figures 12 a and 12 b respectively show the evolution of flexural strength as a function of diatomite content and curing time (7, 14, 28 and 56 days) for Toukra composites. For Yeï composites, Figures 13 a and 13 b also show flexural strengths. In both cases, the increase in diatomite content leads to a reduction in strength compared with the reference mortars. Flexural strengths also decrease on days 14 and 28 of curing, but increase on day 56 of curing in both cases.

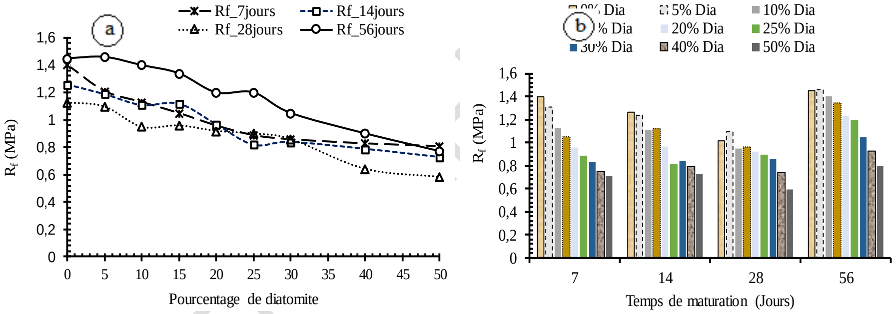
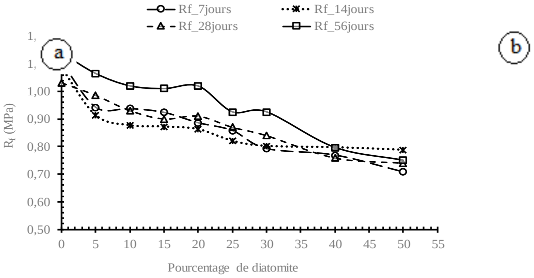


Figure 12. Flexural strengths of BTC as a function of: a) diatomite content, b) curing



time

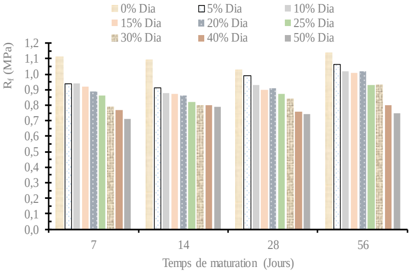


Figure 13. Flexural strengths of CEB as a function of: a) diatomite content, b) curing time

Flexural strength results for Toukra composites are significantly higher than those for Yeï. These differences in results can be explained by the different mineralogical composition of the two soils. The Toukra soil, with its high clay content, can act as a binder in the mixture.

3.5 Simple compressive strengths

Figures 14.a and 15.a show that the compressive strengths of general materials also decrease with increasing percentages of diatomite. The decrease in these strengths is attributed to the physicochemical and geometric properties of diatomite, which give rise to local brittleness in the composite matrix. The curing age of the samples also increases mechanical stress values during block drying, as shown in Figures 14.b and 15.b. Figures 14 and 15 illustrate Toukra and Yeï composites respectively.

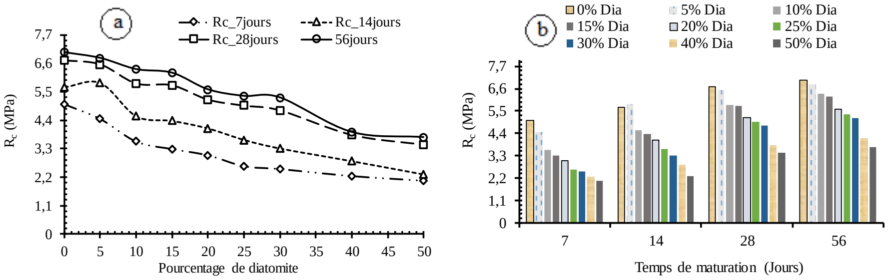


Figure 14. Compressive strengths of CEB as a function of: a) diatomite content, b) curing time

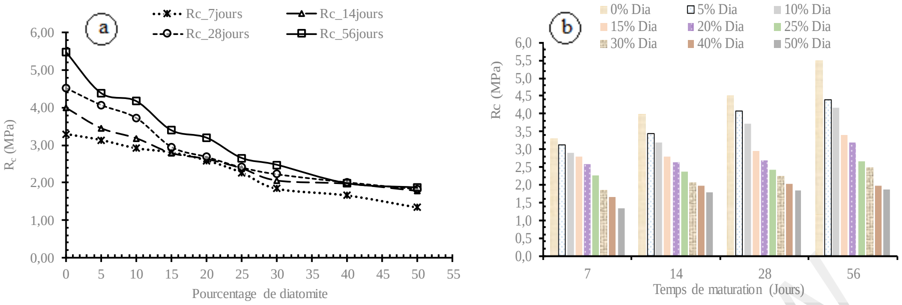


Figure 15. Compressive strengths of CEB as a function of: a) diatomite content, b) curing time

Compared with flexural strengths, we can see that simple compressive strength decreases are greater. For example, for composites of the same age containing 25% diatomite, a drop of around 1.19% in flexural strength and around 6.95% in simple compressive strength is observed.

3.6 Split tensile strength tests

Figures 16 a and 16 b respectively show the evolution of indirect tensile strength as a function of diatomite content and curing time for Toukra composites. Split tensile strength results for Yeï composites are shown in Figures 17 a and 17 b. In both cases, increasing the percentage of diatomite leads to a reduction in strength compared with the reference mortars.

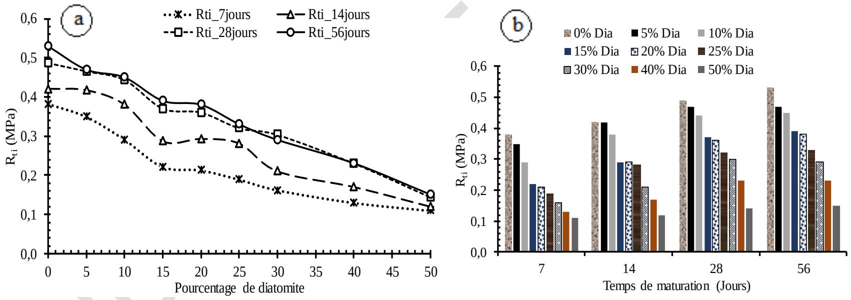


Figure 16. CEB splitting strengths as a function of: a) diatomite content, b) curing time

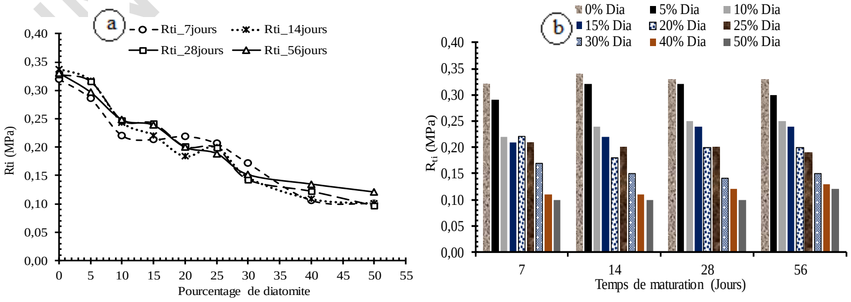


Figure 17. CEB splitting strengths as a function of: a) diatomite content, b) curing time

Changes in mechanical properties as a function of CEB density are shown in Figure 18. Previous studies have established relationships between dry density and mechanical strength [22, 23]. Their conclusions show that increasing the dry density of blocks also leads to an increase in their mechanical strength. In this study, mechanical strengths decreased with increasing dry densities of the samples, which is in line with literature data.

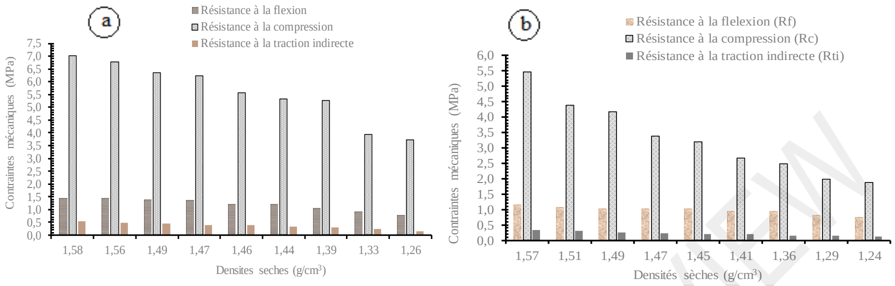


Figure 18. Evolution of all mechanical strengths as a function of CEB densities: a) Toukra and b) Yeï

Summaries of the mechanical strength results are presented in the table below, together with some reference data on compressed earth blocks.

Table 1: Summary of mechanical strength results and references

References	Bending strength R_f (MPa)	Compressive strength R_c (MPa)	Indirect tensile strength R_{ti} (MPa)
Bamboo fibers [24]	0.4 – 2,01	4.9 – 12.0	--
Lime-cement [25, 26]	0.1 – 0.5	--	0.1 – 0.5
Natural hydraulic lime [27]	--	4.5 – 5.5	--
Cow dung [28]	--	4.6 – 6.8	--
Cement [29]	--	1.6 – 6.4	--
Geopolymer (NaOH-activated metakaolin) [7]	--	1.4 – 8.9	--
Standards [30-32]	--	≥ 2	--
Diatomite	0.77 – 1.45	3.74 – 7.01	0.15 – 0.53
	0.75 – 1.14	1.87 – 5.48	0.12 – 0.33

The flexural strength results for CEB from two diatomite-admixed clay soils are high, given a compaction force of 10 MPa. The development of these strengths decreases with the diatomite content, which is the opposite of that of CEB made from plant fibers. In view of the brittle behavior of the material, several works in the literature have proposed minimum admissible values [26, 33]. All the values derived from this study are in line with their proposals.

With the exception of the composite (50% Yeï soil and 50% diatomite), which has a compressive strength of 1.87 MPa, the simple compressive strength values of the composites (CEB) are higher than the minimum required by the majority of specific standards at 2 MPa for CEB to be usable in construction [30-32]. According to the Spanish standard cited by [34], which sets the minimum compressive strength at 1.5 MPa, our composite (50% Yeï soil and 50% diatomite) can also be used in construction.

With regard to indirect tensile strengths, few of the research works found in the literature list values between 0.1 and 0.5 MPa derived from the splitting test for CEBs and Pisé [26]. For

some authors, the values generally range from 10 to 12% for simple compressive strength [33]. The indirect tensile strength results of this study are well in line with literature recommendations.
Overall, the results of this experimental study corroborate the literature data, despite the rapid decrease in mechanical strengths observed when increasing the amount of diatomite.

4. CONCLUSION

The work presented in this article concerns the study of the physicomechanical properties of compressed earth blocks reinforced with diatomite from Mao in northern Chad. This study of the compatibility between clay soils and diatomite showed that the addition of diatomaceous earth to the clay matrix generally reduces physicomechanical properties. Compared with reference mortars, CEBs made by substituting diatomite suffered decreases in physicomechanical parameters in line with increasing diatomite content. Composites require more water in their wet state. This excess water is often detrimental to the mechanical behavior of materials after drying. The physicomechanical characteristics obtained in simple compression and three-point bending, as well as in indirect tension, show that the use of these composites in building construction is perfectly feasible according to several current standards. However, at certain diatomite percentages, these composites are more suitable for secondary building elements such as thermal insulation panels and wall plaster. This study contributes to the search for local biodegradable and ecological building materials.

REFERENCES

1. Christophe Beslay and Marie-Christine Zelem. The paradox of the modern consumer: moderating energy consumption in an increasingly energy-intensive society. DOBRE M., JUAN S. Consuming differently. The ecological reform of lifestyles, Ed. L'Harmattan, 2009, 978-2-296-10232-3.
2. . Guillaud H. and Houben H. Treatise on earthen construction. (Vol. 2006).
3. Ouattara. Research into lightweight bricks: design and characterization of raw bricks based on clay and sawdust, stabilized with Portland cement. Félix Houphouët Boigny University thesis, (2013) p 160.
4. Benmansour N et al. Thermal and mechanical performance of natural mortar reinforced with date palm fibers for use as insulating materials in building Energy and Buildings 81, (2014) 98–104.
5. Diawara O.S., (2009). Geotechnical, chemical and mechanical characteristics of the clay materials used in the construction of the current city of Djenne: reinforcement tests, Thesis of the University of Bamako (Mali),
6. Alavéz-Ramírez, et al. (2012). The use of sugarcane bagasse ash and lime to improve the durability and mechanical properties of compacted soil blocks. construction Build. Mater. 34, 296–305. https://doi.org/10.1016/j.conbuildmat.2012.02.072
7. Sore, S., Messan, A., Prud'homme, E., Escadeillas, G., Tsobnang, F. Stabilization of compressed earth blocks (CEBs) by geopolymer binder based on local materials from Burkina Faso. construction Build. Mater. 165, (2018) 333–345. https://doi.org/10.1016/j.conbuildmat.2018.01.051
8. Richard Ntenga,. Multi-scale modeling and characterization of the elastic anisotropy of plant fibers for the reinforcement of composite materials. Plant's biology. United. Blaise Pascal - Clermont-Ferrand II; University of Yaoundé (2007).

9. Alsaeed T., B.F. Yousif and H.KU. The potential of using date palm fibers as reinforcement for polymeric composites, Mater. Des., 43, (2013) 177 - 184 p.
10. Togdjim J., Malloum S., Abderahman A. O., Abakar A., Alexis M. N., Danala S., Michel Q. Geotechnical, physicochemical and mineralogical characterizations of soil quarries in Chad with a view to their valorization in eco-construction, J Mater. Approximately. Sci., 14(2), (2023), 255-267.
11. Paschen, S. Diatomaceous earth extraction, processing and application. Erzmetall, 39: (1986) 158-161.
12. . Hossam E., Galal M., and Mohamed B. Diatomite: Its Characterization, Modifications and Applications. Asian Journal of Materials Science 2(3): 2010, 121-136
13. Rigasi. V. Compressed earth blocks. Volume I. Production Handbook, CRATerre-EAG, Friedrich Vieweg & Sohn, Braunschweig, Germany, (1995), p 104.
14. NF P 94-093. Normal Proctor, for the determination of dry density and water content according to the AFNOR standard, (1999).
15. NF P 94-064. Dry density of a rock element, hydrostatic soil weighing method, according to AFNOR standard, 1993.
16. NF EN 196-1. Methods of Testing Cements-Part 1: Determination of Strengths, 2016.
17. NF EN 13286-42. Unbound and hydraulically bound-Part 42: Test method for the determination for the indirect tensile strength of hydraulically bound mixtures, 2003.
18. Laibi A. B., M. Gomina, B. Sorgho, E. Sagbo, P Blanchart, M. Boutouil and D. Sohounhloule, Physico-chemical and geotechnical characterization of two clay sites in Benin with a view to their development in eco-construction , Int. J. Biol. Chem. Sci., 11 (2017), 499-514.
19. Meunier A. Clay Mineral Diversity and Abundance in Sedimentary Rocks of Gale Crater, March 2005. Ed. Springer, p 472.
20. Yetgin S., O. Cavdar, A. Cavdar, The effects of the fiber contents on the mechanical properties of the adobes, Construc. Build. Mater. 22(3) (2008) 222–227.
21. Jianzong Man, Wenyuan Gao, Shuang Yan, Guishan Liu, Hongshun Hao. Preparation of porous brick from diatomite and sugar filter mud at lower temperature. Construction and Building Materials 156 (2017) 1035–1042
22. Patcharapol Posi, Surasit Lertnimoolchai, Vanchai Sata, Prinya Chindaprasirt. Pressed lightweight concrete containing calcined diatomite aggregate. Construction and Building Materials 47 (2013) 896–901
23. Kouakou C. H. and Morel J. C. Strength and elastoplastic properties of non-industrial building materials manufactured with clay a natural binder. Applied clay no14, (2009) p 27-34.
24. Dieudonné A., Achille B. B., Didier F., B. M. G. Koungang and B. Nyouma Y. Effects of the length and content of bamboo fibers on the physicomechanical and hygroscopic properties of Compressed Earth Blocks (CEB) used in the construction. Africa SCIENCE 16(4) (2020) 13-22
25. Pirat, P.-E. and Filloux, R. Study of the scale effect on earth material. Research and Development Initiation Project, INSA Lyon, (2012).

26. Pkla, A., Mesbah, A., Rigassi, V. & Morel, J., Comparison of test methods for measuring the mechanical characteristics of earth mortars. Materials and Structures, 36(2), (2003) p. 108-117.
27. Seco, A., Urmeneta, P. , Prieto, E., Marcelino, S., García, B., Miqueleiz, L. Estimated and real durability of unfired clay bricks: Determining factors and representativeness of the laboratory tests. Constr. Build. Mater. 131, (2017) 600–605. https://doi.org/10.1016/j.conbuildmat.2016.11.107
28. Yalley, P.P.-K., Manu, D. Strength and Durability Properties of Cow Dung Stabilised Earth Brick. Civ. Environ. Res. 3, (2013) 117–125.
29. Bahar, R., Benazzoug, M., Kenai, S. Performance of compacted cement-stabilised soil. Cem. Concr. Compos. 26, (2004) 811–820. https://doi.org/10.1016/j.cemconcomp.2004.01.003
30. XP P13-901 - Blocs de terre comprimée pour murs et cloisons: définitions – Spécifications – Méthodes d’essais – Conditions de réception. La Plaine Saint-Denis: Éditions AFNOR (2001).
31. NZS 4298. (2015). Materials and workmanship for earth buildings. Wellington: Standards New Zealand.
32. ASTM. (2003). ASTM: D 559-96, Standard method of wetting and drying test of compacted soil cement mixture. Philadelphia: American Society for Testing and Materials.
33. Cid-Falceto, J., Mazarrón, F.R, Cañas, I. (2012). Assessment of compressed earth blocks made in Spain: International durability tests. Construction and Building Material, 37, 738-745, https://doi.org/10.1016/j.conbuildmat.2012.08.019.
34. Maniatidis, V. & Walker, P., (2003). Developing Rammed Earth for UK Housing. Natural Building Technology Group, University of Bath.