Research Article

Challenge to enhance the value of the Cameroonian coastal earth: physical tests and mechanical characterization of earth material

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Abstract

One of the main performances of earth material is the thermal regulation. The aim of this study is centered on the possibility of applying the grunge of the Cameroonian Coast for its suitable valorisation. Thus focusing on the parliamentary law so as to be capable of supplying, first, a material with a reduced polluting impact and secondly one with which the thermal comfort of the building would be amended; all these for the population of the Cameroonian Coast. The identification results assure the possibility of using the earth of the Cameroon coastal region for CEB with a grain size distribution even though the crater spindle contained shows a discontinuous tray type. Again, this study aims at showing the possibility of using this earth material for the manufacturing of porcelain, sanitary ware and tableware. As far as the characteristics are concerned, a convergence of the grading, mineralogical and chemical results show a medium-active kaolinite-type clay and a sandy loamy-clay earth. That's why for in-depth knowledge major elements and minerals have been identified by X-ray fluorescence and X-ray diffraction. The mechanical tests carried out on the clay show a sufficient plasticity in the wet state, even though it is also pointing out possibilities of improving these performances by using adequate stabilizers.

Keywords Cameroon coastal earth · Characterization · Earth identification · Earth classification · Mineralogy · Valorization

1 Introduction

Earth material is available and accessible all over the planet [1, 2]. This material known to be economical and doesn't require any transformation. Added to that, it is simple to use, adaptive to both hot and cold regions, and accessible to everyone [3–5]. With the new development policies, the African continent is at the heart of an unprecedented human dynamic growth. Its annual average growth rate is 5% over the last decade, Africa is becoming an increasingly important player on the world economic field. By 2050, it is expected that Africa will be having 1.5 billion inhabitants, 50% of whom shall be made up of urban dwellers [6]. It describes itself as an outstanding rush for building materials.

The production processes of a building material have a considerable impact on the environment. Researchers reviewed life cycle concepts and examined recent developments in cement and earth construction [7]. One of the cheapest and quickest construction solutions is the use of earth. All these activities are oriented to the optimization of the earth material production process [8–10]. For the Cameroonian context and particularly that of the city of Douala, on the coast, the light studies have demonstrated the quality and availability of land [11] for the constructions of compressed earth brick (CEB). Unfortunately, in

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spite of prospecting studies in your quarries, the population of Douala is focusing to date on valorizing only the sandy proportion of this earth resource. This is done by carrying out a separation through leaching process with sieves to reject the clayey proportion.

The purpose of this study is on one hand, to propose to construction engineers a material with known and adequate characteristics for earthen construction systems and on the other, offer an opportunity for its valorization. This material is the Douala earth of the Cameroonian coast which is still not valorized because of the absence of a deep and solid study which will guarantee the quality of the earth for multiple usage in this city and nationwide.

2 Materials and methods of experimentation

2.1 Raw materials

The main material of this study is earth. It comes from the city of Douala in Cameroon: 4°05, 9°74.

The earth is extracted from a depth of 0.5 m in accordance with the lithological structure of the site's soil (Fig. 1). To understand the behaviour of the material, it is necessary to study its clay fraction [2], which includes all particles smaller than 2 µm in size. These clays can be distinguished as a group made up of several crystals of various shapes. The stacking of the different crystal layers implies a different nature which may be mainly kaolinite, illite or smectite.

Once removed from the site, the soil is crushed to eliminate the lumps, followed by conditioning in a ventilated oven (Memmert brand) at a temperature of 105 °C. After 24H, there was a tendency of stability of the mass after successive weighing [12]. In this anhydrous state, the water content has been evaluated at 10%. This value will be considered as the initial water content of our soil sample at the beginning for all upcoming tests.

2.2 Experimentation method

2.2.1 pH analysis

This parameter enables us to determine the degree of salinity of a soil and thus to predict the different additives for designing a mix.

A quantity of ground earth, crushed and screened to 2 mm is suspended in the same quantity of distilled water (10 cm^3 soil/10 cm^3 water) in a beaker. The mixture is stirred and left to stand for 30 min, making sure it is stirred 6 times during this period, then the reading is taken when the pH value stabilizes on the pH meter display. This operation is carried out at a temperature of 21 °C [13].

2.2.2 Granulometric and sedimentometric analysis

Granulometric and sedimentometric analyses are used to determine the granularity of a soil [14]. These analyses make it possible to evaluate the reliability of the earth to be used with or without stabilizing agent. The estimation parameters are the clay proportion, the uniformity coefficients Cu (Eq. 1) and the conformity coefficients Cc (Eq. 2).

$$Cu = \frac{D_{60}}{D_{10}} \tag{1}$$

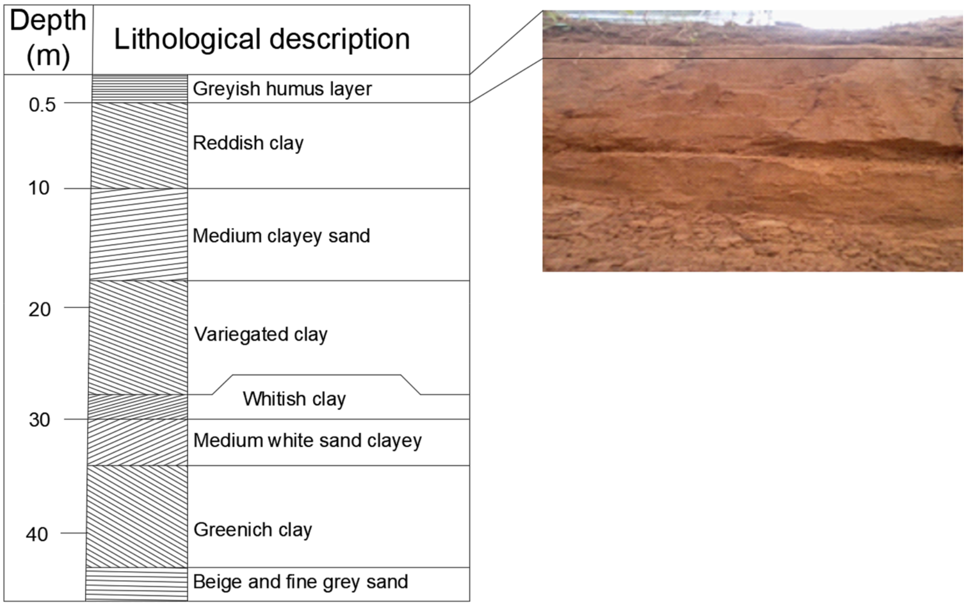


Fig. 1 Lithological structure of soil in the site

$$Cc = \frac{D_{30}^2}{D_{10}D_{60}} \tag{2}$$

With, D_i: particles passing to i µm for i equal to 10, 30 and 60.

2.2.3 Analysis of consistency states: earth's atterberg boundaries

The Atterberg boundaries define both an indicator qualifying the plasticity of a soil, but also the test that defines these indicators by quantification. Depending on the water content, a reworked soil has varying consistencies in which four states are distinguished: liquid, plastic, solid with shrinkage and solid without shrinkage. In reality, the soil passes from one state to another and the respective boundaries are not defined by the Atterberg boundaries [15, 16].

This analysis makes it possible for us to classify the soil. The following parameters are analysed as such: plastic index PI (Eq. 3), liquid index LI (Eq. 4), consistency index CI (Eq. 5), and the earth activity A_c (Eq. 6).

$$PI = \mathrm{LL} - \mathrm{PL} \tag{3}$$

$$\mathrm{LI} = \frac{w - PL}{\mathrm{PI}} \tag{4}$$

$$\mathrm{CI} = \frac{\mathrm{LL} - \mathrm{w}}{PI} \tag{5}$$

$$A_c = \frac{PI}{ta} = \frac{PI}{\frac{\mathrm{p}<2\mu m}{ps(<0{,}4\mu m)}} \tag{6}$$

where w: liquid limit in reference to 25 moves; weight of particles with a size less than 2 µm; dry weight of particles with a size less than 0.4 µm; ta: Clay content.

2.2.4 Methylene blue value analysis

The Methylene Blue (MB) test is used to determine the absorption property of a soil and the different types of clays. MB is preferentially adsorbed by montmorillonite clays (smectites) and organic materials. The other clays (illites and kaolinites) are not very sensitive to it. The test is carried out on a case-by-case basis and consists in the measurement (Eq. 7) of the quantity of dye: methylene blue value (MBV) fixed per 100 g of the granular fraction analysed [17].

$$MBV = \frac{V_1}{M_1} \times 10 \tag{7}$$

where V_1: total volume of the injected dye solution (mm); M_1: mass of methylene blue used (g).

2.2.5 Analysis of major minerals

The X-ray Diffractometry (XRD) technique has been used for analysing minerals contained in a soil, based on the diffraction of X-rays. The in-depth analysis of the clay fraction allows the nature of the clay contained in the earth sample to be precisely determined.

The sample analysed are of fine fraction (5–10 microns) in the form of a powder flattened in a cup. X-rays are sent in this sample using a Burker D8 Advance diffractometer, and a detector goes around the sample to measure the intensity of the x-rays in the direction. Topas (Burker) software was used to perform a qualitative and quantitative analysis of the sample. The data processing is governed by the Bragg's equation [18] (Eq. 8) which has made it possible to calculate the d-spacing of each mineral by knowing the angle of diffraction 2$\boldsymbol{\theta}$ (Fig. 2).

$$d = \frac{\lambda}{2sin\theta} \tag{8}$$

where d: interplaner spacing or d-spacing (in Å); Θ: peak position (in radians); λ wavelength of incident x-ray (1.5406).

2.2.6 Analysis of major chemical elements

X-ray Fluorescence Spectrometry (SFX or FX) is a chemical analysis technique using a physical property of the material to determine its major chemical components. X-ray has been used to characterise soil sample pressed into a boric acid pellet that ensures its mechanical strength. The X-ray spectrum emitted by the material is characteristic of the composition of the sample; by analysing this spectrum, the elementary composition is deduced with the associated concentrations. The machine used in this case is an ARL Perform'X Sequential XRF.

2.2.7 Chemical component analysis

First, the samples are crushed and then sieved; one milligram of the sample is then mixed with about three hundred milligrams of bromide. The mixture is homogenized with an

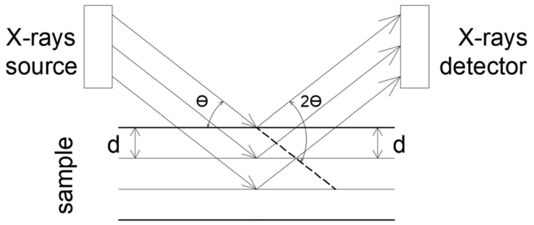


Fig. 2 X-rays diffraction method

electric vibrator and then compressed with a hydraulic press at a pressure of 10 t/cm^2 for three minutes. The spectra were recorded in the range of 4000 to 400 cm^{-1} at a velocity of 65 cm/min. Chemical components are detected by analysing the chemical bonds inside the material. These links are observed by optical spectroscopy to obtain information on the material from its interaction with infrared (IR) radiation for this study. The analysis performed is only qualitative with identification based on the spectral signature of the material. The samples are alkali metal halide pellets of the KBr type.

2.2.8 Thermogravimetric analysis

Thermogravimetric Analysis (TGA) makes it possible to characterize materials by directly measuring their mass as a function of temperature and time. The sample taken and placed in the ceramic crucible will be burned in a controlled argon atmosphere. A microbalance measures the mass variations of the sample on ~ 45 mg of the < 250 µm fraction of clay samples using a SETARAM equipment at a heating rate of 10 °C/min from ambient temperature to 1200 °C and up to 1450 °C.

2.2.9 Organic matter analysis

Organic Matter Content (OMC) is the ratio of the mass of organic matter (OM) present in the material to the total mass of solids. The conventional method for determining the mass of OM is to oxidize them with a mixture of concentrated sulphuric acid and boiling potassium dichromate: this is the sulfochromic method [19]. This method is used to determine the mass of organic carbon (OC) contained in the sample.

The calculation of the organic carbon content (OCC) on the basis of a dry sample is done using Eq. 9.

$$OCC = \frac{a}{m} * \frac{(100 + IWC)}{100} \tag{9}$$

where OCC: based on a dry sample (g/kg); a: mass of OC in the sample (g); m: mass of the sample (g); IWC: initial water content of the sample.

The OMC of the sample is calculated from the OCC using Eq. 10.

$$OMC = f * OCC \tag{10}$$

where f: conversion factor ranging from 1.7 to 2.5, conventionally f is 1.72 [20].

2.2.10 Analysis of calcium carbonate content (CCC)

Like OM, calcium carbonate ($CaCO_3$) is undesirable for earth constructions: it is important to limit $CaCO_3$ content. The CCC was determined in a representative elemental volume of the solid phase of a soil. The method used is the Bernard calcimeter volumetric method according to the chemical reactions (11) and (12).

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3 \tag{11}$$

$$H_2CO_3 \rightarrow H_2O + CO_{2gas} \tag{12}$$

The CCC of the soil is determined by attacking a certain amount of dry soil with hydrochloric acid (Eq. 10). The measurement of the amount of carbon dioxide (CO_2) released (Eq. 12) makes it possible to calculate the mass of dissolved $CaCO_3$ and therefore the CCC of the soil expressed as a percentage of the mass of the solid phase of the soil.

2.2.11 Analysis of the BET specific surface area of the fine fraction of the soil

The specific surface area is the actual surface area of an object as opposed to its apparent surface. This is of great importance for phenomena involving surfaces interactions [21], such as adsorption [21] or heat exchange.

In the case of this earth, the actual area is the sum of the grain surfaces. In general, for a given mass or volume, the finer the grains, the larger the specific surface area. The apparatus used is composed by device acquisition and control PC, gemini micromeritics, vacuum pumps, helium & nitrogen bottle.

2.2.12 Analysis of the optimal water content

The Proctor test is a geotechnical test that determines the moisture content required to obtain the maximum dry density of a soil by compaction at a fixed energy (lady's weight, number of strokes and standard dimensions). The values obtained by the test are noted Optimum Water Content (OWC) for the optimal moisture content, and ρ_{opt} for the optimal dry density [22].

2.2.13 Analysis of the wet failure mode in simple compression

This analysis is carried out by the "uni-axial" strength test on specimens of simple geometric shape: cylinder.

The previously conditioned soil as described above will be moistened with the OWC and then compacted in cylinders shown in Fig. 3c. The compaction with the manual hydraulic press (Fig. 3a) was carried out at 2.5 MPa. This is the approximate pressure which is deployed during the Proctor test.

At constant speed until failure, the specimens are loaded axially (Fig. 3b). To reduce the influence of circumferential and radial stresses at the bases (these forces induce a multi-axial stress state), the slenderness of the L/D core is greater than 2. The loading speed was static to minimize dynamic effects [23].

2.2.14 Thermal conductivity analysis

The measurement is carried out on dried aggregates compacted in a cylinder (h150mm and ø50mm), a known heat source is applied by a needle probe to the centre of the cylinder. The thermal conductivity of the dried sample which is packed inside the cylinder cup (h = 150 mm and Φ50 mm) is determined using thermocouples present in the probe. The acquisition is started after stabilization of the probe temperature and the absorbed current (mA) is recorded. This test is fully controlled on the acquisition device (Fig. 4) [24].

The measurements are interpreted to derive the thermal conductivity λ_t (W/mK) (Eq. 13):

$$\lambda_t = \frac{R * (I)^2}{4\pi * slope} \tag{13}$$

where R: Probe resistance (ohm/m); I: current intensity absorbed by the heating resistor (A).

3 Results and discussions

3.1 Identification results

The data resulting from the pH evaluation indicates a value of 5.52 for soil. This value characterizes an acidic soil [25].

The density of soil is 2.76 ± 0.03 g/cm^3. It is clearly higher than the density of sand aggregates [26]; the proportion of the fine clay fraction could be responsible for the increase

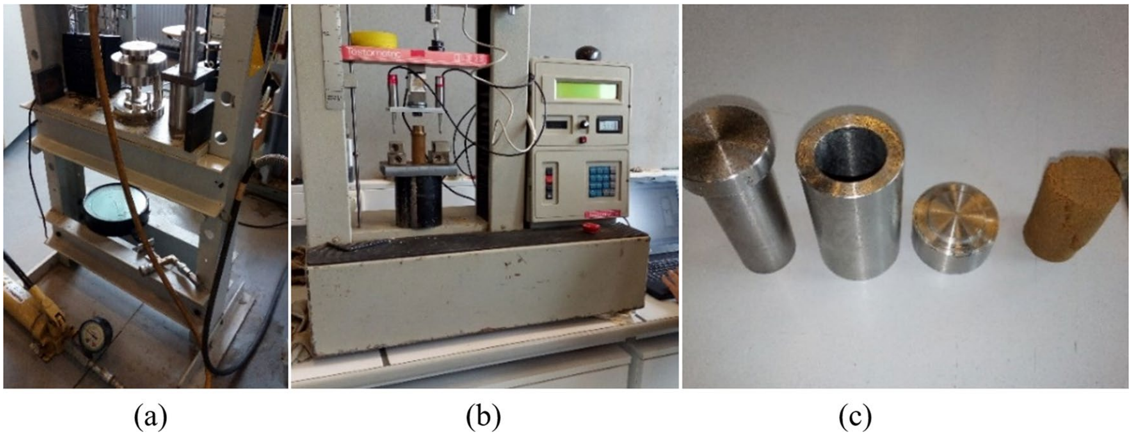


Fig. 3 Experiment earth compression test equipment: **a** Compaction machine **b** Compression test **c** Sample compression

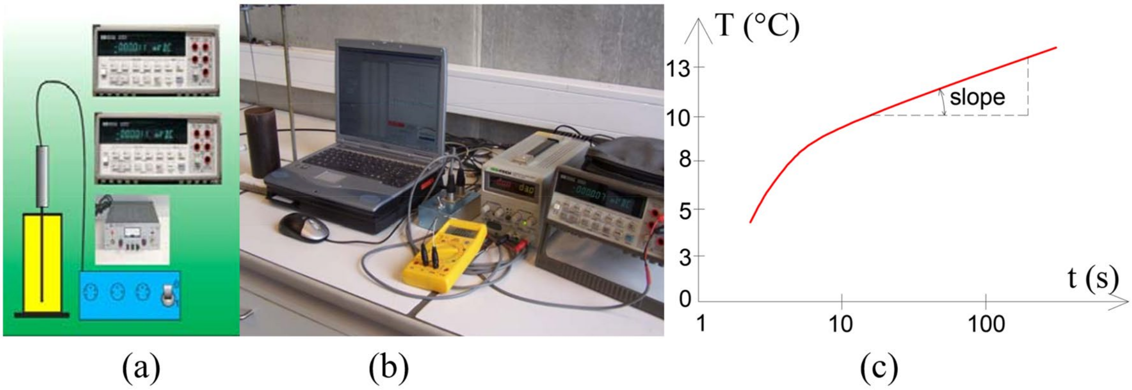
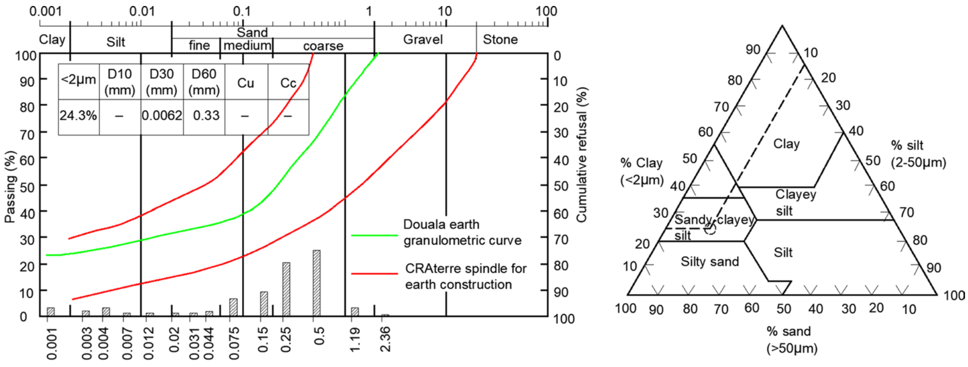


Fig. 4 Thermal test equipment: **a** Schematic diagram, **b** actual assembly: PC acquisition—thermal probe power supply (3 V, 1 A)—multimeter and ammeter, **c** acquisition model curve



(a) (b)

Fig. 5 Granular analysis: **a** Characteristic curve of the earth in the CRATerre spindle for the manufacture of earth construction; **b** triangular earth classification

Table 1 Earth identification results

	Clay	Silt (%)	Fine sand (%)	Medium sand (%)	Coarse sand (%)	Gravel (%)
Sedimento-granulometry	25	7	3	14	51	0
	w_L	w_P	IP	IWC	I_C	A_c
Consistency	40.64	21.45	19.18	10%	1.59	0.78
BET specific surface (m^2/g)	35.68 ± 0.19					
BMV	5.89 ± 0.11					
OWC	16.7%					
Major Minerals	Kaolinite					

of density. By verifying the adequacy with the ideal target for the earth raw material construction, it appears that it is possible to use as material construction.

The granulometric curve (Fig. 5a), although it contains in the recommended spindle for earth material construction: adobe, rammed earth, CEB; has a discontinuity depending on the granulometry of the sand: this is why it is impossible to evaluate Cu and Cc because of the zero D10 value.

The consistency tests resulted in LL, PL. The associated parameters are IP, CI. The IWC is evaluated around 10% which is specific for silty soils [27]. From the characterization data (Table 1), the earth under study is of the silt–clay-sand type, kaolinite clay with normal activity (medium). All these results, combined with triangular earth classification allowed to classify this earth as a sandy–clayey–silt soil (Fig. 5b).

Indeed, in the coastal zone of Cameroon, especially in Douala (prospecting area), there is a very advanced industrial development. So it is necessary to consider construction expressways. Although the representation of this land in the CRAterre abacus (Fig. 6) proposes tracks for the construction of adobe, CEB and rammed earth, the observation of its position at the border of adobe and rammed earth, supposes a motivated choice of the track of CEBs. It should also be clearly pointed out that CEBs offer a more flexible and robust brick format in terms of masonry that can be integrated into a column-beam structure as a filler as well as the main material in a load-bearing wall. The possibility of also establishing industrial production lines is envisaged both in the company and on the construction site.

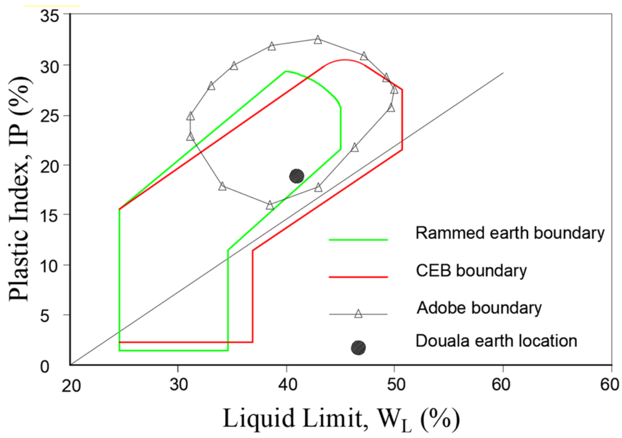


Fig. 6 Plasticity nomograms showing recommended areas of PI/LL of soils for adobe, compressed earth blocks or rammed earth [28]

3.2 Compressibility analysis by the simple earth compression test

The curve (Fig. 7) ρd = f(w) can be used to determine the maximum value of the dry density ρd i.e. the normal Proctor optimum.

The earth sample when moistened according to OPV value (16.7%), allows a transition from the solid phase to the plastic phase. The bladder is compressed to 1.7 bars. Under compression test piloted at 0.5 mm/min, diagonal deformations (Fig. 8) are observed, describing a type D failure with sliding. This confirms that the material has sufficient plasticity for CEB: the deformation in elastic zone is almost equal to that in plastic zone (Fig. 9).

As for the modulus of elasticity and the maximum stress, values of 0.17 MPa and 0.005 MPa respectively are obtained. It would therefore be wise to consider a stabilizer to improve these parameters. Knowing that the flanges remain straight before testing and the mode of rupture type D, this test guarantees workability according to the parameters obtained at the Proctor of this earth for bricks.

3.3 Mineral and chemical compositions

Each clay family is characterized by a plan value (001) [2, 29]. The main reflections (Fig. 10a) d(001) = 7.14 Å, d(001) = 3.34 Å, d(001) = 2.66 Å and d(001) = 1.89 Å, indicate the presence of kaolinite, quartz, hematite and anatase in earth, respectively.

The analysis of DRX data (Table 2) indicates a Kaolinite percentage at 22%, close to the value obtained in granulometric analysis which is 24.3%. In terms of this mineralogical composition (Kaolinite + quartz + mica < 95%), the most suitable industrial use is as a building material [30].

Using the data obtained from the MB and mineralogical tests, it emerged with convergence that the clay contained in the soil under study is of the kaolinite type. Only the proportion of sand (quartz/SiO) obtained in granulometry or diffractometry concludes from a soil composed of sand + slit and clay (kaolinite). The compositions of sandy clays are distinct from the specifications and it can be concluded that they are not suitable for the paper industry at the raw stage unless sand separation is carried out. Thus, by exploiting the clay separation way using either mechanical, chemical or magnetic methods, it would be possible to have two resources (sand and clay). The sand would be used in construction as filler and the clay with more open ways: paint formulation, pharmaceutical industries, cosmetic formulations or geopolymer [31]. It would thus be a big opportunity because 70% of these last products are totally imported in the country. These chemical results would be used in future work to select and rate the stabilizer and the type of adjuvant for the above applications.

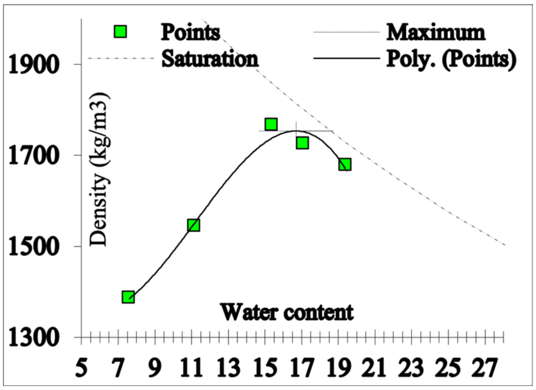


Fig. 7 Proctor curve of earth sample


(a) (b)

Fig. 8 Simple compression test: **a** sample during test, **b** sample after test

The presence of quartz can cause high abrasion to finished products such as bricks and tiles. Considering the OMC obtained (0.55) and the CCC (5.12), the soil under study is of a non-organic and non-calcareous type that is highly suitable for the manufacture of clay bricks with a thermal conductivity (0.319) which indicate the performance insulating material.

The analysis of the clay fraction (Fig. 10b), indicates the inactivity for treatment at 500 °C. On the other hand, a reaction for the ethylene glycol (EG) analysis and for the normal analysis to the scans of 7.2 and 3.55 respectively, is specific to kaolinite representatives. The clay fraction would therefore be very sensitive to temperature; it is important to consider the fact for any future valorization which is expose to temperature.

For FT-IR spectrum (Fig. 11), two absorption strips located between 3200–3800 cm^{-1} and 1600–1700 cm^{-1}.

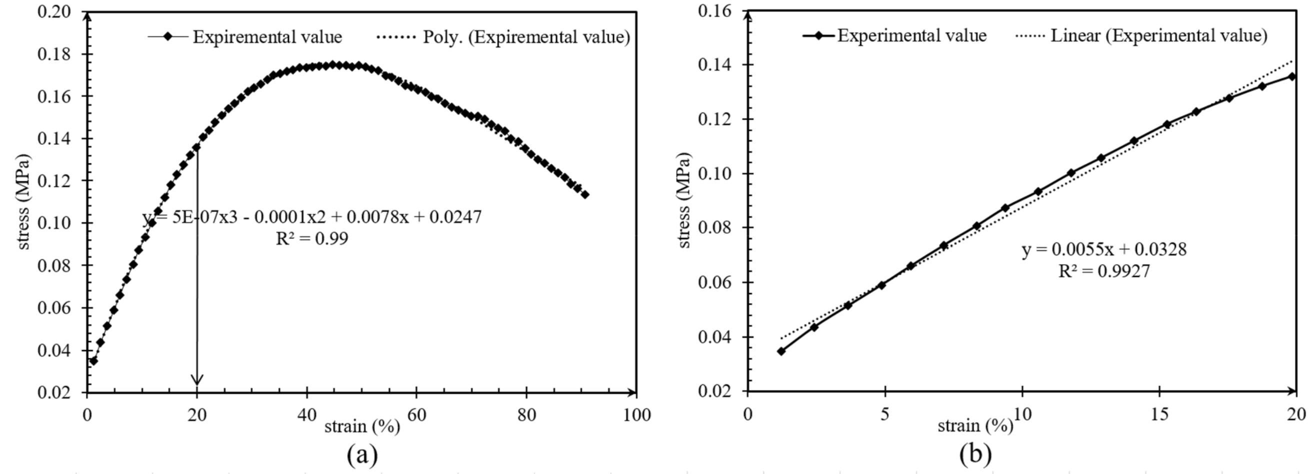


Fig. 9 Simple compression: **a** total stress/strain, **b** truncation 50% elastic zone

Fig. 10 Data graph in DRX: **a** DRX spectral composition; **b** spectrum of clay fraction

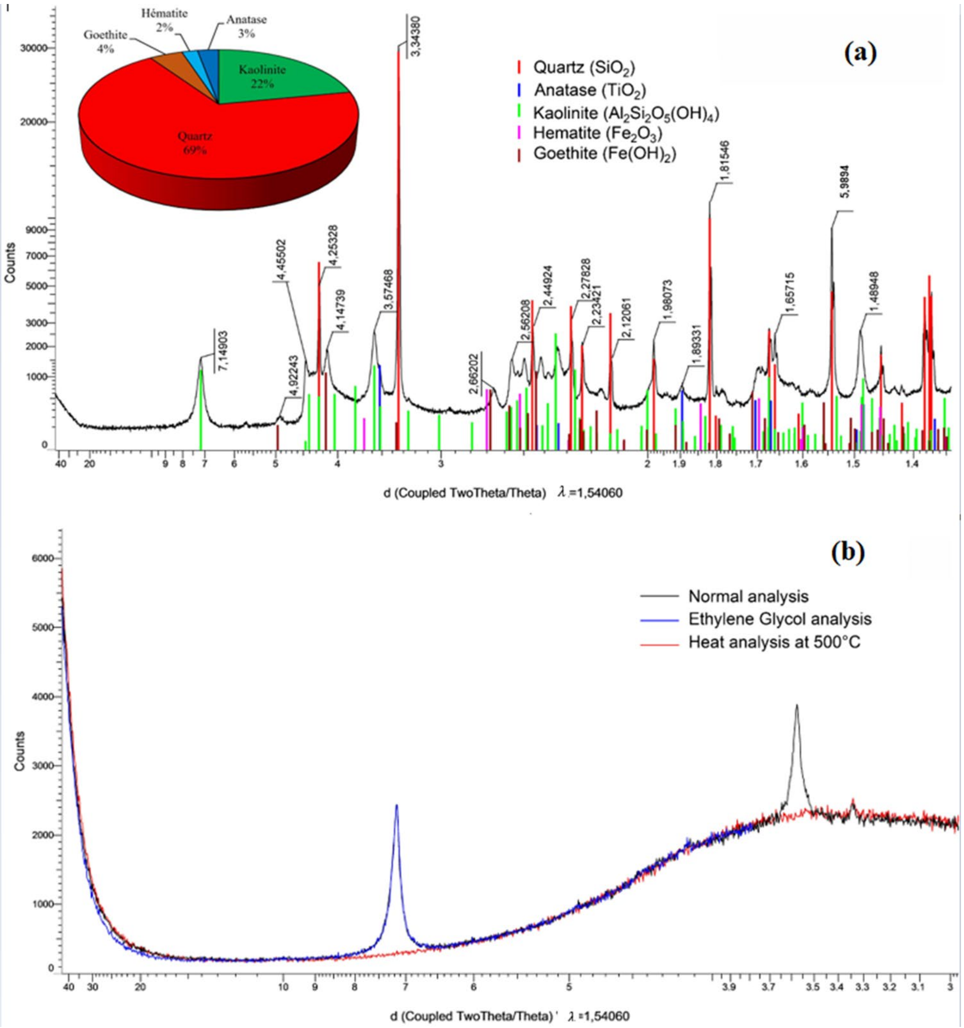


Table 2 Mineralogy

Constituent	Quartz	Kaolinite	Goethite	Hematite	Anatase
Mineral element					
Proportion (%)	69	22	4	2	3

Constituent	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	P_2O	LOI	Total
Oxide element										
Proportion (%)	77.30	1.29	11.49	4.07	0.01	0.09	0.07	0.12	5.38	99.90
Organic matter content (%)			Calcium carbonate content (%)				Thermal conductivity (W/mK)			
0.55			5.12				0.319			

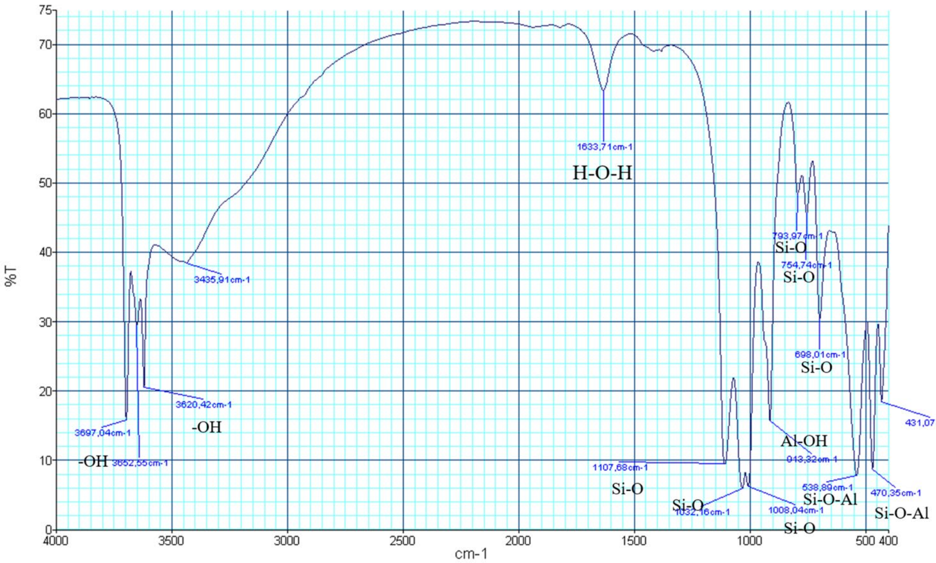
The main bonds observed were OH^- stretching, hydroxyl sheet at 3698 cm^{-1} and 3620 cm^{-1}. H_2O stretching was also found at 1633 cm^{-1}. Bands at 1107 cm^{-1}, 1033 cm^{-1} and 1008 cm^{-1} were assigned to Si–O bonds in the SiO_4 molecules [32]. The other band at 913 cm^{-1} was attributed to Al^{VI}–OH vibrations [33]. The bands at 793 cm^{-1} 754 cm^{-1} and 698 cm^{-1} were Si–O symmetric stretching [34]. Absorption at 538 cm^{-1} and 470 cm^{-1} were assigned as Si–O–Al^{VI}, where the Al is in octahedral coordination. By looking at this composition, this earth contains a specific lay which can be useful in environmental protection by immobilizing pollutants [35].

Figure 11 shows the thermograms of the TGA and its derived curve (TGD) for soil material conditioned at 60 °C.

The TGD curve (Fig. 12) shows three major endothermic phenomena that correspond to temperatures of 100, 361, 541 °C. The phenomenon observed at 100 °C corresponds to the elimination of hygroscopic water. At 361 °C, zeolitic water probably starts to flow, it would be the elimination of adsorbed water. The significant endothermic phenomenon at 541 °C corresponds to the elimination of the water of constitution of the residual kaolinite [36] contained in this product.

The clays consist mainly of SiO_2, Al_2O_3 and Fe_2O_3. The iron content is consistent with the observed thermal behaviour and colour of the clay under study. This clay cannot be recommended for the production of fine ceramics but can be considered as a raw material in structural ceramics such as paving bricks and some roof tiles [37]. The SiO_2/Al_2O_3 ratio of about 7 is related to the large amount of quartz (69%). The low total amount of alkaline elements (< 1.5%) suggests that clays are suitable for porcelain, sanitary ware and tableware [2]. The low alkali (CaO) proportion is the cause of an acid pH [38] and also conditions a medium activity of the Douala earth with a rather low BET specific surface compared to the values of the smectite (700–800 m^2/g) and illite (100–175 m^2/g) clays [39]. The low percentage of limestone explains the absence of vitreous phases at low firing temperatures observed in the thermodilatometric curves. The low LOI value (5.38%) compared to that of pure kaolinitic clays (14%) reflects

Fig. 11 FT-IR spectrum of Douala earth



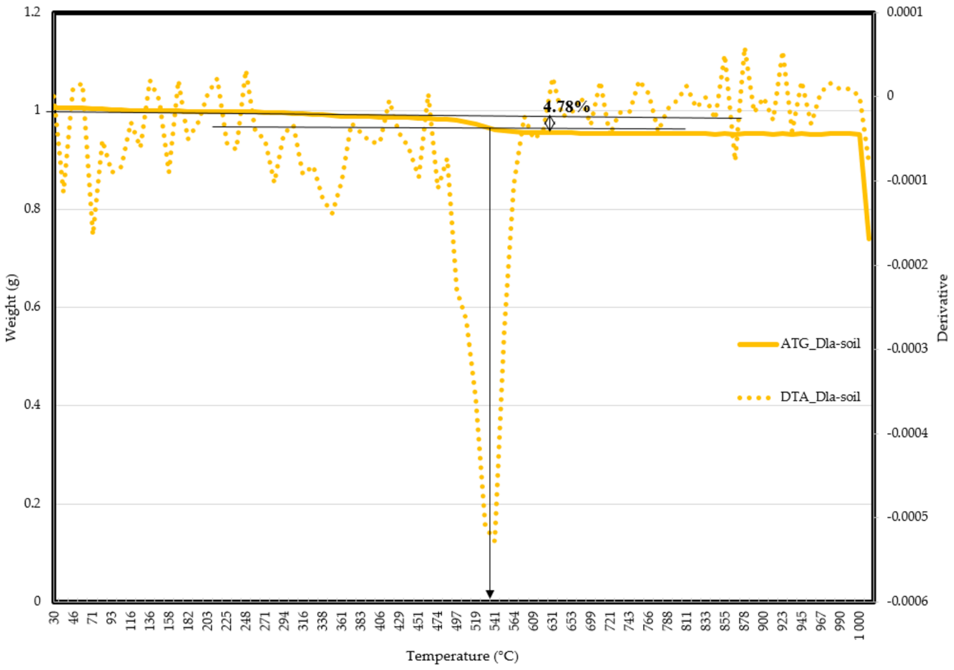


Fig. 12 TGA thermogram of Douala earth

the predominance of impurities such as quartz which can affect the surface aspect of the finished products as brick.

4 Conclusion

The purpose of this project was to examine the characteristics of the coastal soil in Cameroon in order to identify its potential in the manufacturing process of compressed earth bricks (CEB) for forthcoming constructions. A battery of characterization tests were conducted on this earth as well as covering chemical, physical, thermal and mechanical aspects. We, therefore, retain that the pH analysis indicates an acid soil, the mineralogical and diffractometric analysis presents major oxides of silicas conditioned by a strong presence of quartz; alumina and ferrite also responsible for the red tint and acid pH with a kaolinite clay type earth of medium activity. Also the TGA confirmed this type of clay by indicating a significant peak at 541° C corresponding to the destruction peak of kaolinite. These tests made it possible to classify this earth as a sandy loamy clayey type, non-organic and non-limestone. Furthermore, we came to know that its maximum compressive strength and its compression modulus remain low and require improvement. Added to that, its thermal conductivity is very low, which supports its possible contribution to the thermal comfort of the home. From the above, several ways of valorization have been issued, among which, the manufacturing of CEB by stabilization, using it for the manufacturing of porcelain, sanitary ware and tiles. Moreover, the study proved that by proposing a separation of the clay fraction, it would be possible to use the fine fraction not only in the formulation of paint, but also in the formulation of products in the pharmaceutical and cosmetics industries, as well as, for the use of sand fraction in construction as usual.

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Author's contribution BMGK: Conceptualization, Methodology, Writing-Original draft preparation Writing—review & editing; DN: Data curation, Validation, Writing-prereviewing; GT: Investigation, Methodology, Validation; AM: Visualization, Writing-prereviewing; EN: Validation, supervision; LC: Supervision, Methodology, Writing-prereviewing and Editing.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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