

Research

Geological and geotechnical characterization of clayey materials from Feutap (West Cameroon): suitability in ceramic industry

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Abstract

This study involves an extensive geological and geotechnical assessment of clayey materials from Feutap, West Cameroon, to establish their suitability for fire bricks. The field trip evaluated the thickness of each layer of clayey material along the profile; the structure and texture of the clayey materials were tested. The collected samples were then examined using X-ray diffraction (XRD); typical geotechnical tests were performed (grain size analysis, density, Atterberg limit, natural water content, porosity, and voice index); and bricks manufactured from this clayey material were sintered at 900, 1000, and 1100 °C, respectively. Water absorption, linear shrinkage, and flexural strength were the technological properties tested. The field trip indicated that the feutap clay is developed on the weathering profile level, with heights ranging from 02 to 28 m and a variety of hues. The structure ranges from angular to subangular polyhedral, and the texture is primarily clayey silt. The mineralogical examination revealed that kaolinite (25.8 to 90.71%), illite (5.5 to 29.42%), and montmorillonite (20 to 24.3%) were the most common clays minerals, with a few occurrences of goethite (3.8%), hematite (21.3 to 28.4%), calcite (24.8%), and magnetite (42.1 to 29.42%). The grain size study showed different proportions of fine sands (60% to 45%) and clays (40% to 57%). The plasticity index ranges from 35.73 and 72.47%. The density ranges between 2.49 and 2.87 g/cm³. The bulk density ranges from 0.89 to 1.11 g/cm³, while the voice index varies from 57.98 to 65.75%. International classifications such as HRB (High Research Board), LCPC (Central Civil Engineering Laboratory of Bridge and Highway), and GTR (Guide to Road Earthworks) all conclude that those clayey materials are silty soils. The empirical diagrams suggest that these clayey materials are suitable for ceramic applications. The firing brick test on five samples (F13; F14, F31, F32, F33) have shown that the water absorption decrease with the temperature of sintering (30.03 to 19.47%); the linear shrinkage range from 5 to 6.6% and the flexural strength increase with the temperature (1.75 to 7.7 Mpa). According to the lower limit of flexural strength recommendation, which is 5 Mpa, four clayey materials are suitable for producing bricks at temperatures above 1000 °C studied, while F31 requires correction to be suitable for firing brick at 1000 °C. In order to improve the properties of firing brick with those clays, crushing feldspar must be added to lower the sintering temperature and increase flexural strength.

Keywords Clayey materials · Feutap · Firing bricks · Mineralogy · Physicals properties

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1 Introduction

In tropical area, the rain is the main process of rock weathering specifically hydrolysis [1]. In Cameroon, 70% of the surface is covered by the natural resources come out of weathering process. Thirty percents of these resources are clays and clayey materials and identify in all regions [2–4]. Clayey materials have demonstrated the industrial potential in the domain of cosmetic, paints, plastics pharmaceutical and ceramic [5]. Under the climate change with the pressure to reduce energy consumption, environmental impact and demography increase with the lack of housing over the world, brick manufacturing is a key industry in the construction sector [6]. Fired bricks have significant advantages in building construction, including low production and maintenance costs, durability, thermal comfort, great load-bearing capability, and ease of installation [7].

Building materials are in high demand in most Cameroonian towns that is why in 2022, Cameroon imported 3021 tons of clay materials worldwide [8] due to the lack of industrial installation. Despite the presence of clay georesources, a potentially substantial market, and a legislative and institutional framework that encourages the development of natural resources, Cameroon clay products sector has remained underdeveloped due to the insuffisance data base. That is the reason what the new investigation remains the actuality to update the data base.

The use of the clayey materials in ceramics necessitates complete identification, beginning with in situ geological investigations (lithological description of the samples) and extending with laboratory studies (mineralogy, geotechnics, and testing of technological parameters such as strength, absorption rate, bulk density...) to validate industrial production [9]. Then, the geological study on the clay materials carried out in Yaoundé Cameroon [10] showed that they are made up of fine particles (55–60% clay and silt in the clay laterite, and over 70% clay and silt in the hydromorphic clay material). The average liquidity limits (44.56–91.58%) and plasticity limits (22.4–45.93%) show that hydromorphic clay materials have the greatest plasticity. However, the high iron content of clay laterite (between 11 and 12% Fe₂O₃) prevents it from being used effectively in the manufacture of ceramics.

The characterisation of clays from Nomayos (Cameroon) [11], have showed a density of 1.85–2.06 g/cm³, a water content of 29.1%, a porosity of 28.60%, a V_{bs} of 1.43 and a grain size characterised by a high percentage of clay (58.4%). The thermal analysis confirmed the presence of interstitial water, kaolinite, illite and quartz. Geochemical analysis also confirmed the presence of silane–CH₂ and amorphous silica –C–O, indicating its potential for construction and cladding.

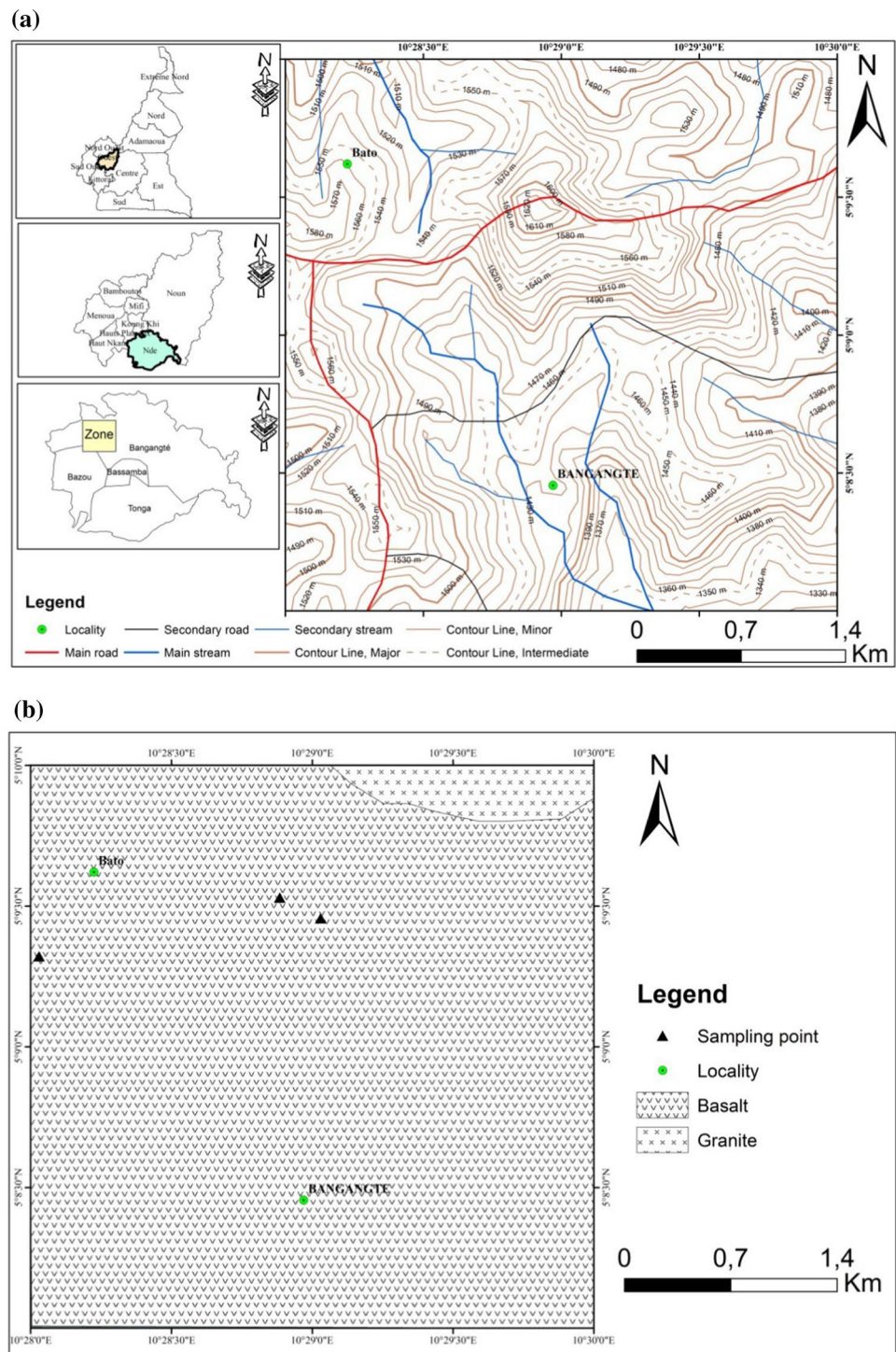
The characterisation of alluvial from Ngaye alluvial clays (Northern Cameroon) show the high presence of quartz and the low content of fusing agents such as Na₂O, K₂O, MgO and CaO. The results suggested that these alluvial clays could be used to make bricks, but would require an increase in fusing agents to improve the mechanical properties of the ceramic products [12].

However in Feutap, the large residual ore deposit clay materials have been discover with the thickness greater than 20 m showing by road embankments Bafang Bangangte. This ore deposit clay haven't been recognised or investigated, despite the fact that they are highly valued by the people for traditional pottery production. This article contributes to the database of clay materials used in ceramics. A geological research based on a lithological description of the clay facies, geotechnical characterisation, and burnt brick tests are planned to achieve this goal.

1.1 Geographical and geological location

The study area belongs to the Western Highlands of Cameroon (Fig. 1a) precisely on the western flank of Bangou Mountain (N 5°15'; E 10°25'). The Bangou Mount has the roughly elliptical form and covers an area of 210 km² and rises to 1924 m. It rests on a base of granitoids and gneisses, probably of Pan-African age. The lava flows were deposited mainly along the North–South, N40, East–West, N130 and N155 fractures in the pre-volcanic basement. The flows and dome falls are cut by dykes. The whole area is highly eroded, lateritic at all altitudes and covered by extensive vegetation [13, 14] The study area (Fig. 1b) is cover by the alkaline basalt (38 Ma) and granite (panafrican age) according to Fosso et al. [15].

Fig. 1 **a** Location of the study area; **b** Geology map section



1.2 Raw material sampling and experimental methodology

1.2.1 Raw material sampling

The geological field studies, defined by the discovery of outcrops, led to the selection of two road trenches covering approximately 6 kms. On these trenches, three profiles, each at least 1 m wide and covering the entire height, were renewed. The Feutap 1 profile (E10°29'01.8"; N05°09'27.4") is about 1.5 km from the Feutap chiefdom; the Feutap 2 profile (E10°28'53.1"; N05°09'31.8") is about 1 km from the first profile; and the Feutap 3 profile (E10°28'01.8";

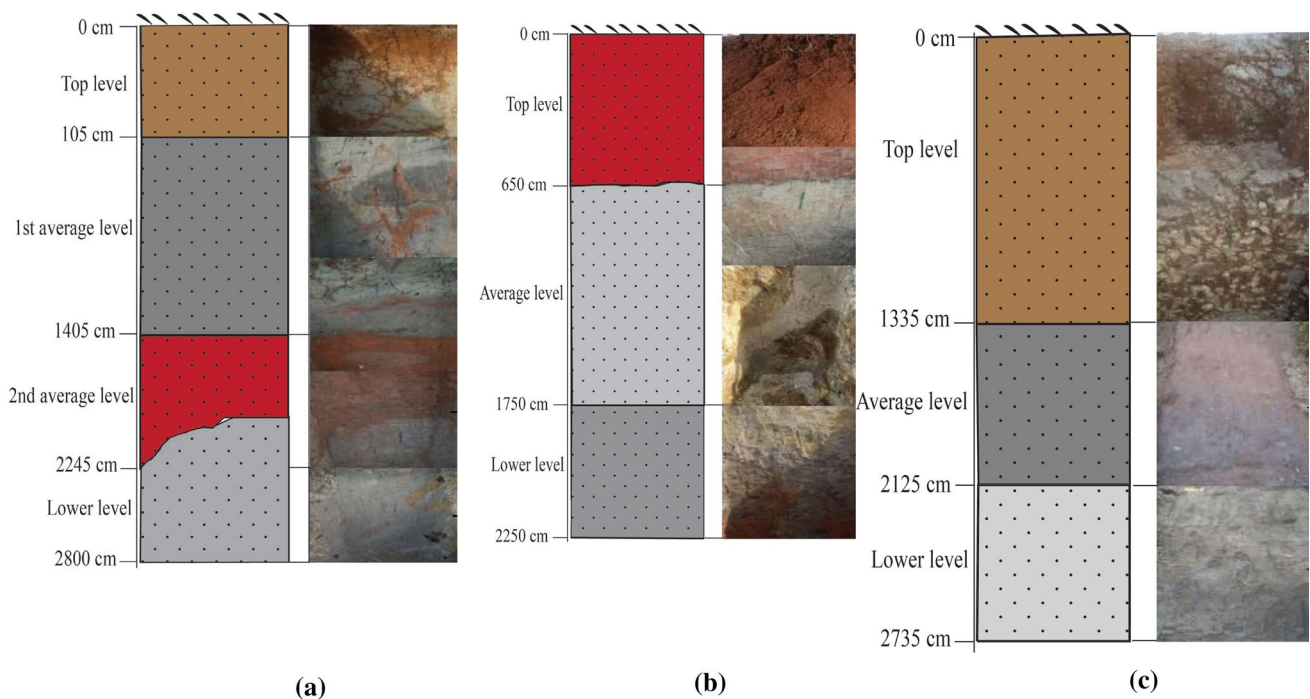


Fig. 2 **a** Profile Feutap 1; **b** profile Feutap 2; **c** Profile Feutap 3

N05°09'19.3") is about 3.5 km from the second profile. These three profiles are precisely described from bottom to top and have an average height of 21 m (Fig. 2).

The description has concerned the thickness of each layer measured with the decametre, the structure of the clay materials was visually assessed by the adhesion between the particles and the texture was assessed by the sticky or squeaky feeling when touched with the fingers under the action of a slight force and the end, the colours was appreciated by using munsel colour chart.

1.2.2 Sampling

Approximately 15 kg of material per sample was taken, stored in plastic bags and labelled according to the sampling levels. The total of ten samples was taken from the upper, intermediate and lower levels, taking into account the colour of the facies:

- Samples F11, F12, F13 and F14 were collected from the Feutap 1 profile;
- samples F21, F22 and F23 were collected from the Feutap 2 profile;
- samples F31, F32 and F33 were collected on Feutap 3 profile.

1.3 Experimental methodology

1.3.1 Geotechnical testing

Standard geotechnical tests were performed respectively state and natural parameters of the soils.

The states parameters of the sample have concerned water content; bulk density, reel density according to the French norm respectively **NF P 94-050** [16], **NF P 94-053** [17]. Void index and porosity have been obtained by mathematical calculation.

$$e = \frac{\rho_s}{\rho_d} - 1 \text{ and } n = \frac{e}{1+e}.$$

1.3.2 Grain size analysis

The particle size distribution of raw materials was obtained by sieving for sizes greater than 80 µm according to the NF P 94-056 [18] method and by sedimentation for sizes less than 80 µm following the NF P 94-057 5 [19] method.

1.3.3 Atterberg limits

Atterberg limits (liquid limit, plasticity limit) and plasticity index were measured according to the NF P 94-051 [20] standard at the promote mission material on Yaoundé.

1.3.4 Methylene blue test

Methylene blue adsorption experiments were performed according to the NF P94-068 [21].method. For 100 g of fine soil, the Methylene Blue Value (MBV) of the soil is given by the following Eq. (1).

$$\text{MBV (g /100g)} = \left[V_{cc} \text{ (mL)} 0.10 \text{ (g)} 0.100 \text{ (g)} \right] / \left[1000 \text{ (mL).} f' \text{ (g)} \right] \quad (1)$$

where V_{cc} = volume of the methylene blue solution injected into the soil solution, f' = dry weight of the specimen used.

1.4 Mineralogical analysis

Mineralogical analysis X-ray diffraction (XRD) was performed for mineralogical analysis. The XRD patterns were obtained by using a Bruker D8 Advance diffractometer (Department of Geology, AGEs, University of Liege, Belgium) at 40 kV and 25 mA, providing a CuK α 1 radiation ($\lambda = 1.5406 \text{ \AA}$). For the analysis of the total disoriented powder, the samples were first crushed in an agate mortar to obtain particle size fraction lower than 150 µm, then dried at 105 °C for 24 h. The powder was placed on a sample carrier.

The measurements were carried out in the 2θ range of 2° to 40° with an angular step of 0.01°/s. The relative abundance of minerals has been estimated from the height of diagnostic peak multiplied by correction factors defined by Boski et al. [22] Cook et al. [23].

1.5 Manufacture of firing brick specimen

For each raw material, eight test brick were manufactured using a laboratory hydraulic press. Those bricks are parallelepiped shapes (160 mm × 40 mm × 40 mm). Based on dry material, 20% water was added to achieve good workability. The parallelepiped samples were pressed at 10 MPa. Before sintering, bricks were dried on the home temperature during seven days and then for 24 h at 105 °C in an oven.

The dried samples were sintering at 900 °C, 1000 °C and 1100 °C for a period of 5 h at a heating rate of 5 °C/min in an electric furnace-type FP 34 G in promote mission of material laboratory in Yaoundé.

1.6 Ceramics properties

The ceramic properties like colour, tone, firing shrinkage, flexural strength, water absorption were evaluated using ASTM [24, 25] respectively.

1.7 Results and discussion

1.7.1 Morpho-structurale description of the profiles

Feutap area is covered by residual clay and the representative profiles are Feutap 1, 2 and 3 (Fig. 2).

1.7.2 Feutap 1 profile

It is located on the Bangangte-Bafang road trench with coordinates E010° 29' 01. 8" and N05° 09' 27.4". This very particular profile is formed by the succession of two sequences. The materials of two sequences seem to have been deposited at different times, hence the observed succession (Fig. 2a): a lower level, three intermediate levels, and an upper level.

1.7.2.1 Upper level It corresponds to the F11 material of the B horizon (105 cm thick); the colour here is dark reddish brown (2.5R:2.5/4); loose and crumbly with a fine to medium lumpy structure of 1 to 5 mm; porous with the presence of fine-cut roots and very sparse concretions.

1.7.2.2 Intermediate level 2 It forms a polychronous level of the B horizon and corresponds to the F13 material (840 cm thick); the colours here vary from dark red (10R: 3/4) to dark reddish-grey (10R: 4/1); it is compact with a medium and coarse angular polyhedral structure from 10 to 50 mm; it has a clayey silt texture as well as a steep and regular boundary with the ensemble that precedes it.

1.7.2.3 Intermediate level 1 It forms a polychronous level of the profile corresponding to the material F12 of the C horizon (1300 cm thick); the colours are greenish-grey (gley 2: 6/1), bluish-grey (gley 2: 6/1 and 5/1), dark bluish-grey (gley 2: 4/1), blackish blue (gley 2: 2.5/1), yellow (2.5Y: 7/8); there are fine to coarse rust spots that are not very abundant; it is compact with a medium to coarse angular polyhedral structure from 10 to 50 mm; it has a clayey silt texture as well as a progressive boundary with the upper set.

1.7.2.4 Lower level It forms a level of allotherite and polychronous alteration of the C horizon, corresponding to the F14 material (555 cm thick); the colours vary from bluish-grey (gley 2: 5/1) to yellow-brown (10YR: 6/8); there are very fine to coarse rust spots and very few in abundance; the material is compact with a medium and coarse angular polyhedral structure from 10 to 50 mm; it has a clayey silt texture as well as a steep and regular boundary with the ensemble that precedes it.

1.7.3 Feutap 2 profile

It has the coordinates E010° 28' 53.1" and N05° 09' 31.8" and has three layers (Fig. 2b).

1.7.3.1 Upper level It is polychronous and corresponds to the F21 and F22 materials of the B horizon over a thickness of 650 cm; the colours vary from red (10R: 5/8) to dark red (10R: 3/6) through a slightly less dark red (10R: 3/3); the concretions are very scarce; it is compact with a medium angular and subangular polyhedral structure combined with a lumpy structure; the material is porous in its upper part with the presence of thin to medium-sized roots; it has a clayey silt texture and a clear boundary with the intermediate level.

1.7.3.2 Intermediate level This level is 195 cm thick, it is polychromous: the various colours of white (gley1: 8/) mainly, light brown (10YR: 6/3), light olive brown (2.5YR: 5/6), bluish gray (gley 2: 3/1). There are fine rusty and dark spots that are abundant; it is compact on the whole with a medium and coarse angular, polyhedral structure; it has a clayey silt texture and has a diffuse, interrupted boundary with the lower level. The F23 material was sampled.

1.7.3.3 Lower level The level is 500 cm thick, it still has fragments of father rock in the process of alteration; it forms the isalteritic level of the polychromous C horizon; the colours vary from yellow (2.5YR: 7/8) to dark greenish grey (gley

2: 4/1); it is fresh; compact with medium and coarse angular polyhedral structure from 10 to 50 mm. It has a clayey silt texture.

1.7.4 Feutap 3 profile

Its coordinates are N05° 09' 19.3"; E 010° 28' 01.8" and presents three main subdivisions (Fig. 2c).

1.7.4.1 Upper level It forms the polychromous B horizon and corresponds to the F31 material (445 cm thick), the colours vary from dark brown (7.5YR:3/3) to dark red (2.5YR: 3/2); there are few rusty spots and about 50% of coarse elements of colour varying from yellowish red (5YR: 4/6) to pink (7.5YR: 8/3); it is loose and friable with a subangular polyhedral structure and medium lumpy; the material is not very porous with a few very fine roots; it has a clayey silty texture.

1.7.4.2 Intermediate level It forms the polychromous BC horizon corresponding to the F32 material (790 cm thick); the colours vary from light red (10R: 4/2 and 5/2) to dark reddish-grey (10R: 4/1); there is an abundance of whitish and rusty spots of fine to medium size; the material is compact with a medium angular and subangular polyhedral structure; it has a clayey loam texture as well as a diffuse, interrupted boundary with the upper level.

1.7.4.3 Lower level It is 610 cm thick and corresponds to the F33 material of the C horizon; it has a bluish-grey colour (Gley 2, 6/1); there is an abundance of whitish and rusty spots of medium to coarse size; the material is very compact with a medium and coarse angular polyhedral structure; it has a clayey silt texture as well as a diffuse and regular boundary with the middle level.

1.8 Mineralogical analysis of the raw clay material

The XRD data on the bulk samples from Feutap showed that the mineralogical composition was variable both under a qualitative and quantitative point of view (Table 3). The result mainly depicts the presence of clay minerals (kaolinite, montmorillonite), mica (illite), and oxide (goethite, hematite and magnetite). All samples show the similar XRD patterns (Fig. 3). The clay mineral found is kaolinite (25.8 to 90.71), illite (5.5 to 29.42%), montmorillonite (20 to 24.3%). The similar results of mineralogy have been obtained by Pialy et al. [26] on Lembo clays deposit developed on granite bedrock except the occurrence of quartz found supplementary.

The samples have a high concentration of kaolinite (25.8 to 90.71), illite (5.5 to 29.42%), montmorillonite (20 to 24.3%) and hematite (21.3 to 28.4%). Magnetite (42.1 and 29.42%) is founded on sample F21 and F32 respectively (Table 1 and Fig. 3). Carbonate represents 24.8% on sample F23 and goethite (3.8%) on sample F33. The genesis of montmorillonite may be related to the bisiallisation weathering mechanism favoured by hydrological and morphoclimatic conditions which concentrate the alkaline oxides bases (K₂O, Na₂O, CaO) and silica (SiO₂) according to [27]. This mineralogical composition characterised by the weak intensity of peaks (crystallisation) reveals that the local environmental conditions are not favourable for hydrolysis processes, and the studied weathering materials are outside of the lateritization field [28]. The high concentration of kaolinite in several samples (such as F21 and F33) indicates a high potential for quality bricks due to its fluidity and propensity to solidify during firing [29].

Illite and Montmorillonite in varying proportions will contribute to the plasticity of the materials during moulding [30]. Minerals such as hematite and magnetite will influence the colour and strength of the bricks once fired. For example, the presence of hematite will give bricks a reddish colour, which is often sought after in the construction industry [31].

The high proportion of carbonates (24.80%) in sample F23 predicts low-temperature maturation, as it promotes the vitrification reaction during firing, resulting in greater strength, durability and impermeability of the ceramic pieces [32].

1.9 Status parameter

The status parameters are shown in the Table 2. Analysis of the table shows that:

1.10 Density

True density values range from 2.49 to 2.87 g/cm³, while bulk densities range from 0.89 to 1.11 g/cm³. The Feutap 1 samples, such as F11 and F12, have high true density, which is favourable for the manufacture of resistant ceramics.

Fig. 3 Diffractograms of Feutap clayey materials. Kln: kaolinite, Il: illite, Mt: Montmorillonite, He: hematite, Goe: goethite, Ca: Carbonate, Mg: Magnetite

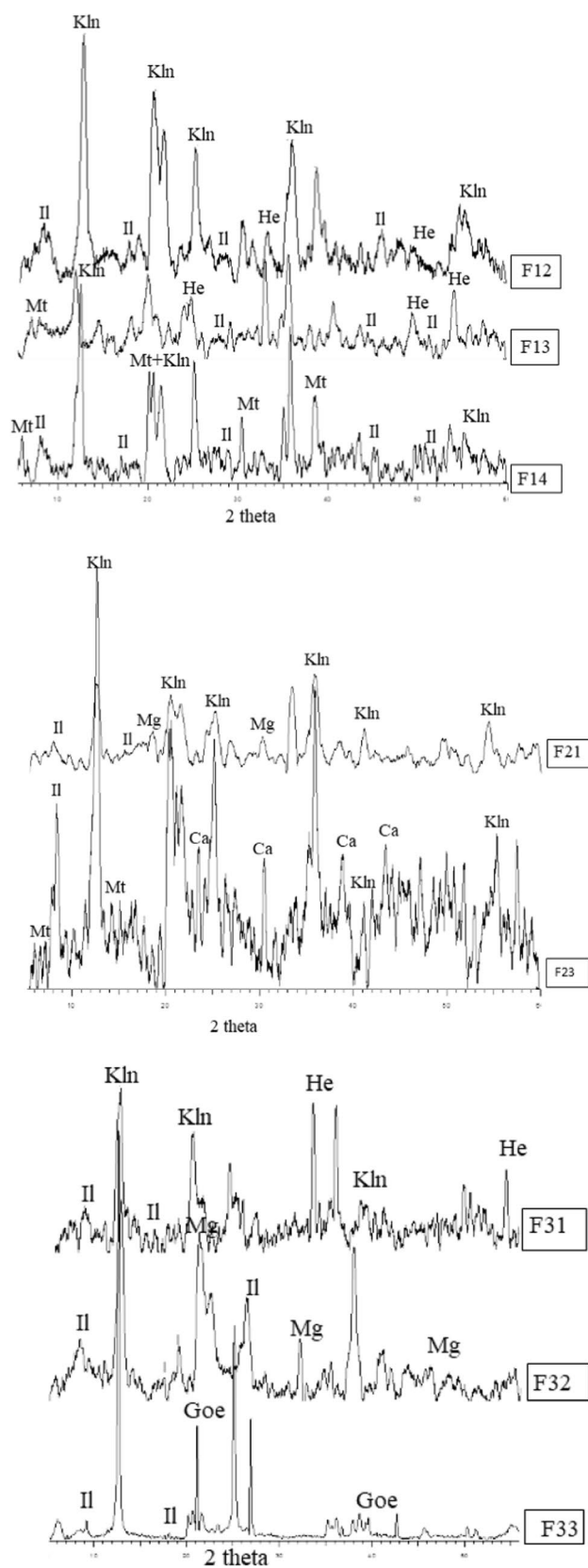


Table 1 Quantification of the mineral content of Feutap clayey materials

	Kaolinite	Illite	Montmorillonite	Hématite	Magnétite	Carbonates	Goethite
F12	34.19	23.41	21.07	21.31	–	–	–
F13	25.80	22.58	24.34	27.27	–	–	–
F14	31.13	21.69	20	27.16	–	–	–
F21	57.87	–	–	–	42.12	–	–
F23	31.67	21.75	21.75	–	–	24.80	–
F31	46.64	24.93	–	28.41	–	–	–
F32	41.14	29.42	–	–	29.42	–	–
F33	90.71	5.52	–	–	–	–	3.76

Table 2 Status parameters of the Feutap raw clayey material

Location	Id_sample	ρ	ρ_d	n	e	w
Profile 1	F11	2.59	0.89	65.63	1.91	46.15
	F12	2.78	0.95	65.75	1.92	43.90
	F13	2.63	1.08	58.84	1.43	34.31
	F14	2.65	1.11	57.98	1.38	34.65
Profile 2	F21	2.70	1.08	60	1.5	43.84
	F22	2.72	0.96	64.66	1.83	38.02
	F23	2.49	0.95	61.83	1.62	48.33
Profile 3	F31	2.68	1.05	60.78	1.55	38.10
	F32	2.87	1.11	61.24	1.58	41.30
	F33	2.71	1.03	61.97	1.63	35.85

Table 3 Proportion of grain size analysis of Feutap Clayey material

Feutap	Samples code	Gravels	Sands		Silts	Clays
			Coarse Sands	Fine Sands		
Profile 1	F11	5	2	24	17	52
	F12	0	0	44	40	16
	F13	0	0	24	29	47
	F14	0	0	57	25	18
Profile 2	F21	0	0	7	33	60
	F22	0	0	18	37	45
	F23	0	0	57	29	14
Profile 3	F31	14	2	39	27	18
	F32	0	0	48	37	15
	F33	0	1	45	32	22

In addition, this high density is due to the high content of kaolinite, whose density is between 2.5 and 2.6 g/cm³, as identified by the diffractograms of the samples analysed.

1.11 Porosity

Porosity values (n), which vary from 57.98% to 65.75%, are crucial for the water retention and mechanical strength properties of ceramics. High porosity (as observed in F11 and F12) can favour good firing and a better finish of ceramic products [30].

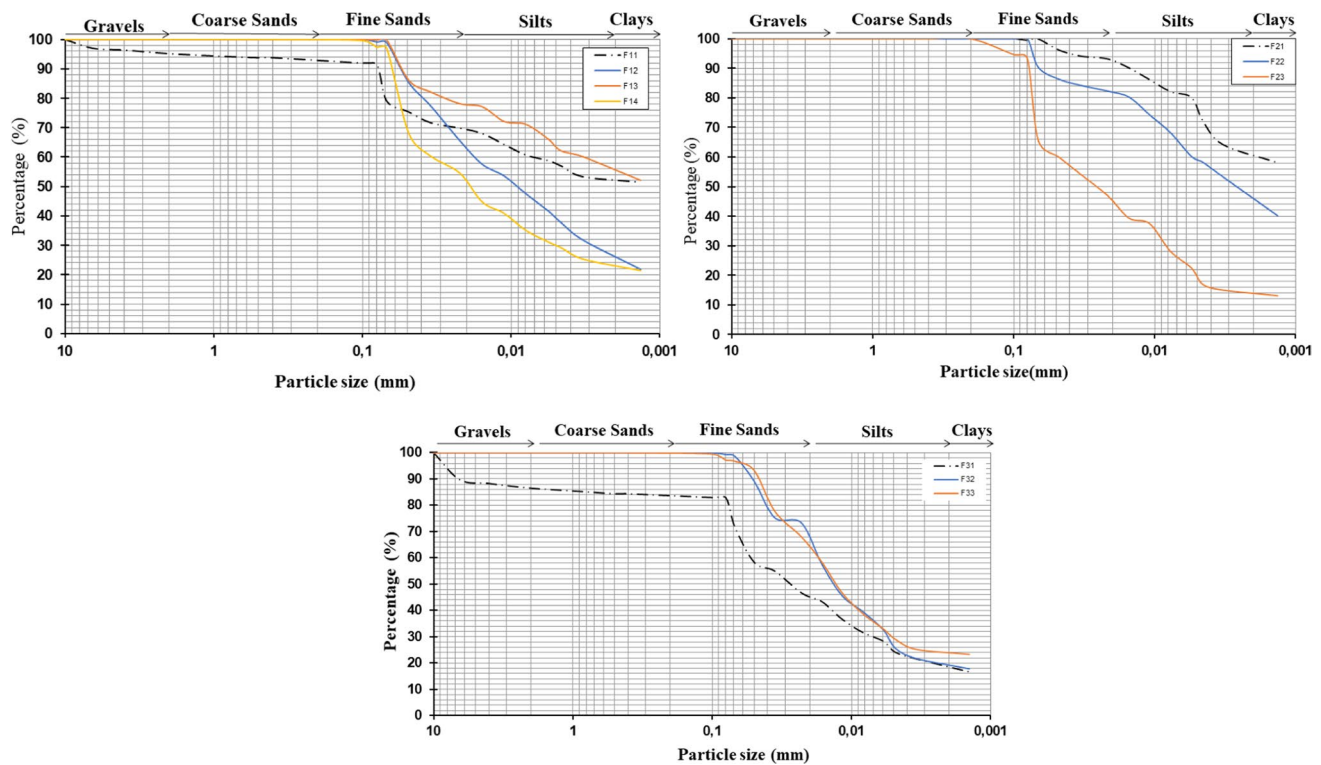


Fig. 4 Curve of the granulometry raw clayey materials analysis

Fig. 5 Belgian ternary diagram showing the textural classification of Feutap clayey material

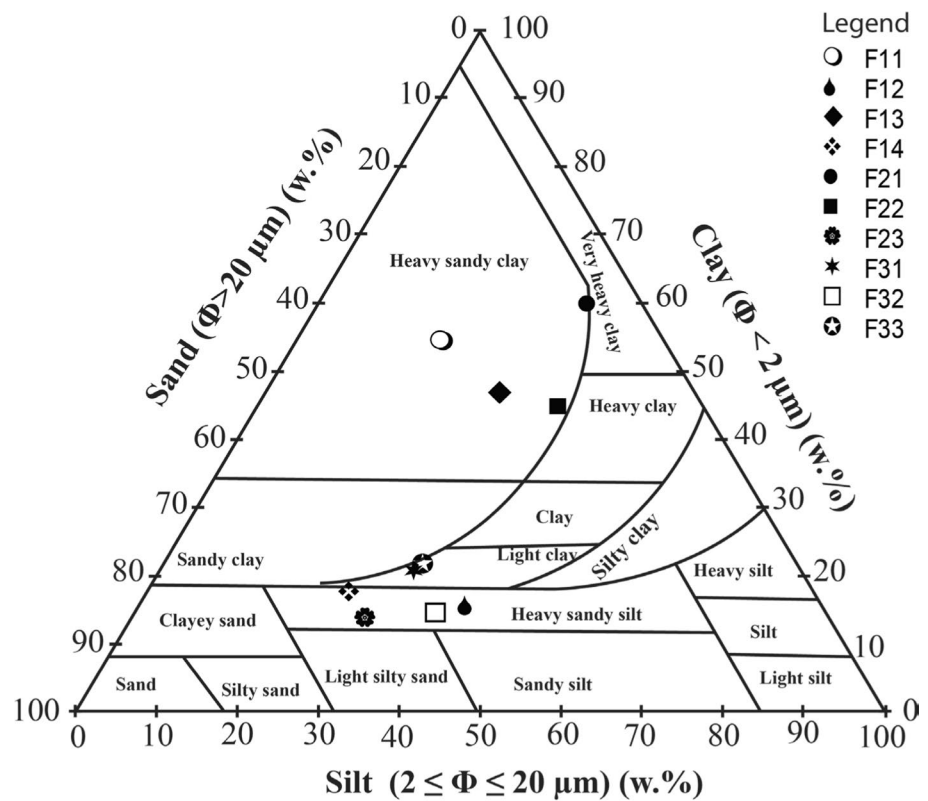


Fig. 6 Position of raw materials in the Winkler diagram. 1: common bricks; 2: vertically perforated bricks; 3: roofing tiles and masonry bricks; 4: hollow bricks

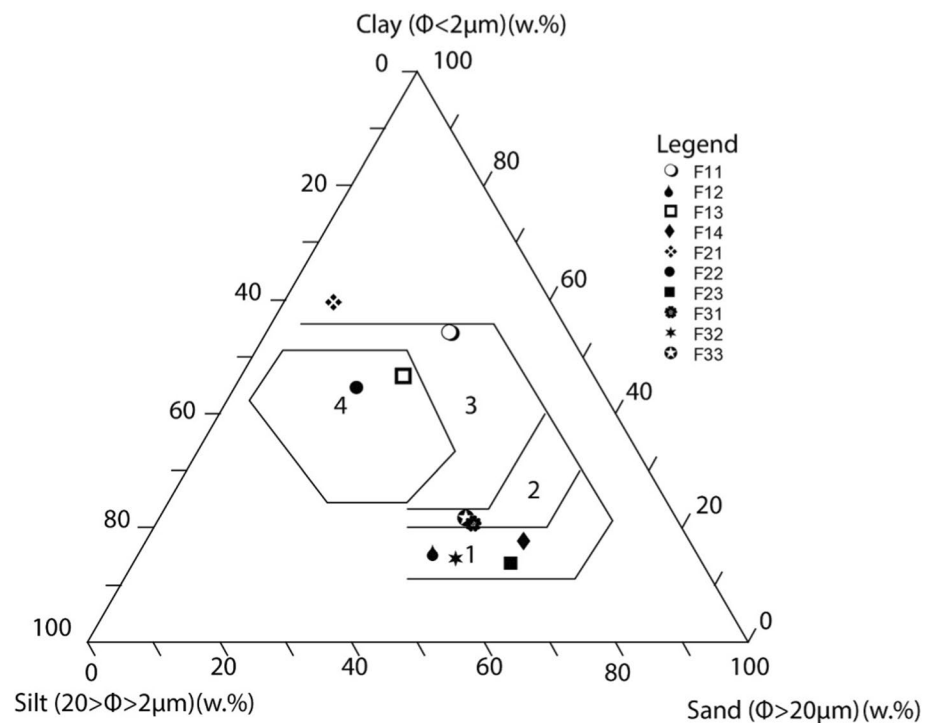


Table 4 Consistence properties of the raw material from Feutap

Profile	Samples	Wl (%)	Wp (%)	Pl (%)	Ic (%)	Ig (%)	MBV	Ac
Feutap 1	F11	72.47	34.87	37.60	0.7	20	1.33	0.72
	F12	68.63	32.91	35.73	0.69	20	1.60	2.23
	F13	41.53	20.32	21.21	0.34	12.79	1.66	0.45
	F14	40.45	19.35	21.09	0.27	12.52	1.73	1.17
Feutap 2	F21	57.31	27.95	29.36	0.46	19.20	1.80	0.49
	F22	54.40	26.57	27.83	0.6	18	1.33	0.62
	F23	64.42	31.54	32.88	0.5	20	0.93	2.35
Feutap 3	F31	24.48	11.69	12.61	−1.08	9	1.13	0.70
	F32	27.72	13.24	14.49	−0.937	9.79	1.13	0.97
	F33	40.87	19.66	21.21	0.23	12.65	0.93	0.96

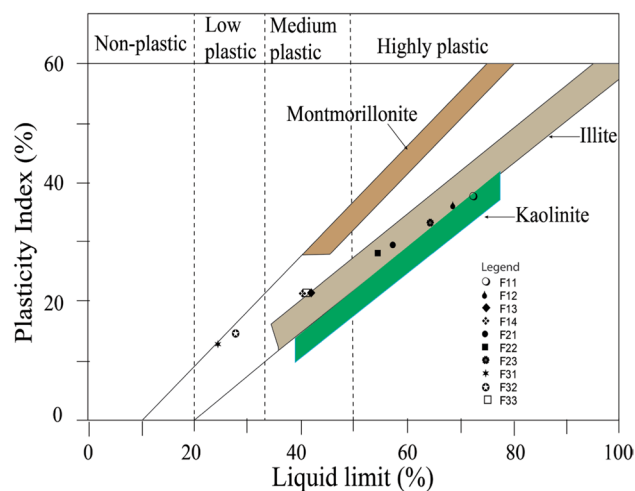
1.12 Void Index

The all samples have their void index (e) greater than 1. It is an indicator of water retention capacity. Those values prove the possibility of the sample to store significant amount of water, which is essential for shaping and drying ceramics [29].

1.13 Water content

The natural water content of the samples varies from 34.31% to 48.33%, which is surprising for a residual clay material. However, this high natural water content can be explained by the presence of swelling clays such as montmorillonite identified on the diffractogram.

Fig. 7 Position of Feutap clay materials in the plasticity diagram (Holtz and Kovacs, 1981)



1.14 Grain size analysis

The particle size analysis results (Table 3 and Fig. 4) demonstrate that, the samples have spread granulometry with varied quantities of gravel, sand, silt, and clay. Samples F12 and F14 contain a large percentage of clays (40% and 57%, respectively). The Belgian ternary diagram shows that these Feutap clayey materials are heavy sandy clay (F11, F13, F22, F21 and F23) heavy sandy silt (F14, F32, F12), and light clay (F31, F33) (Fig. 5).

This richness in clay is essential for applications such as the manufacture of bricks and other ceramic products, as clays confer plasticity and cohesion to the mix [29]. In addition, samples F21 and F22 show a high proportion of fine sands (60% and 45%). The latter may act as a degreaser and significantly reduce shrinkage during the firing of the bricks [33].

Most recommendations concerning the contents of the different soil fractions for brick manufacturing are 10–40% for clays, 10–30% for silt, 30–80% for sand, and 0–40% for gravel [34]. Considering these recommendations, studied raw materials have a richer content in clay than required. The projection of the particle size data in the Winkler diagram (Fig. 6) shows that these clay materials can be used in the manufacture of fired brick variants and roof tiles (F11), with the exception of sample F21, which requires particle size correction.

1.15 Consistency parameters

The results of the consistency tests are given in the Table 4. The limits of liquidity (LL) and plasticity (LP) are crucial in assessing the behaviour of soils during moulding. The Feutap 1 samples (e.g. F11 with 72.47% LL) show high plastic properties, which is favourable for ceramic working. Samples F11 and F12 have high plasticity indices (37.60 and 35.73 respectively), indicating a good ability to form without cracking. These values higher than 10% might be adequate for designing structural clay products by the extrusion process [35]. The projection in the plasticity diagram chart (Fig. 7) shows that, the variation of plasticity is due to the occurrence of kaolinite and illite [34].

The Consistency Index (CI) and Group Index (GI) measure soil cohesiveness and stability. Positive CI values, such as F11 and F12, indicate strong consistency, but Feutap 3 samples (such as F31) have negative values, implying potential instability.

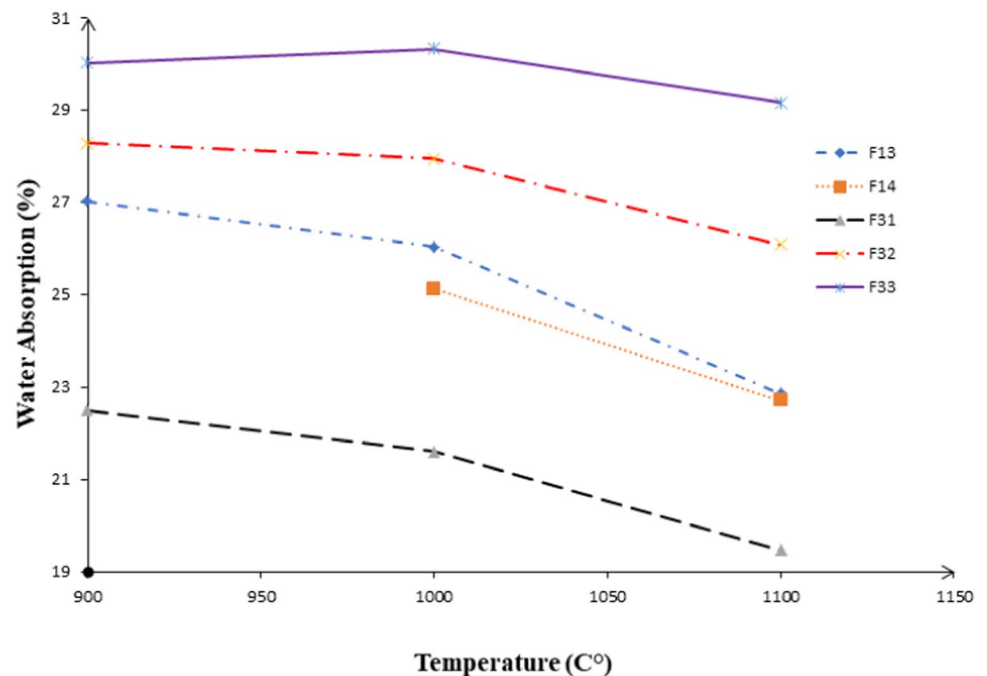
The proportion of fine (80 μ m) and the Atterberg limit value were allowed their classification according the Unified soil classification system (USCS) as SC (Clayey sands) for F12, F13, F14, F21, F22, F23, F32, F33 and sand-clay mixtures (F11; F31).

Methylene blue values (MBV) vary between 0.93 g/100 g (F23, F33) and 1.80 g/100 g (F21). According to Duplain et al. [36]. These materials belong to the class of silty soils. These low values of Methylene blue test show that the Feutap clay materials are not very sensitive to water due to the high kaolinite content. This is because kaolinite has low absorption and adsorption properties, which are directly linked to the low surface charge of the particle (10–30 m²/g) Murray [29].

The Skempton activity coefficient values shown in the Table 4 indicate substantial differences between the Feutap samples. Samples having an activity less than 0.75 (F11, F13, F21, F22, F31) are classed as inactive due to the presence

Table 5 preliminary properties of firing bricks (Sound and colours)

Id-Samples	Sounds			
	25°C	900°C	1000°C	1100°C
F13	No sound	Dull Sound	Metallic	Metallic
F14	No sound	Dull Sound	Slightly metallic	Slightly metallic
F23	No sound	Dull Sound	Slightly metallic	Slightly metallic
F31	No sound	Slightly metallic	Metallic	Metallic
F32	No sound	Dull Sound	Slightly metallic	Slightly metallic
F33	No sound	Dull Sound	Slightly metallic	Slightly metallic
Colours				
F13	Dark reddish-grey	Light red	Red	Red
F14	Bluish-grey	Gray	Yellow	Yellowish lighth
F23	Polychrome	Brown	Light brown	Brownish
F31	Dark brown	Light Red	Red	Red
F32	Dark reddish-grey	Light grey	Red	Red
F33	Bluish-grey	Gray	Gray	gray

Fig. 8 Water absorption of the firing bricks from Feutap Clayey material

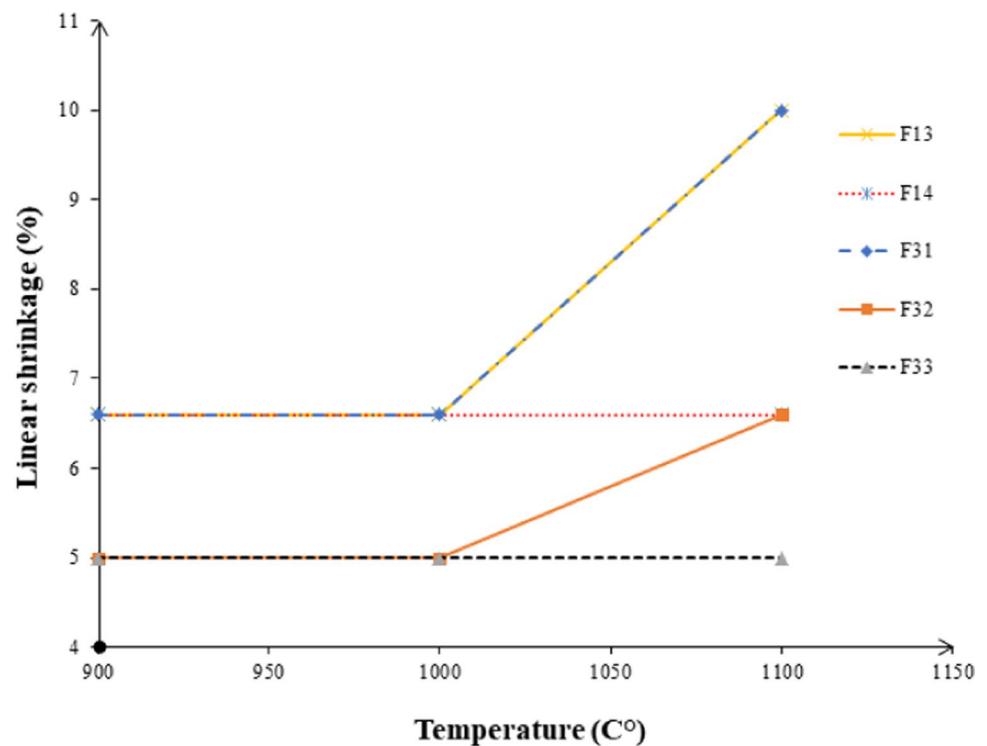
of kaolinite [9]. Furthermore, samples F12 and F23 had high activity values of 2.23 and 2.35, indicating a high water retention capacity (Wn: 43.9; 48.3%) and plasticity (IP: 35.7; 32.8%) due to the presence of montmorillonite (21.07 and 21.75%) detected by mineralogical analysis.

1.16 Technological properties of firing bricks

1.16.1 Colours of firing bricks

The colour of the fired bricks is recorded in Table 5. It appears that, the colour varies with the temperature of sintering. The yellowish and reddish colour of fired bricks is due to the presence of hematite (21.3 to 28.41%) which is transformed into goethite by dehydration during firing [37].

Fig. 9 Linear shrinkage of the firing bricks



1.16.2 Sound of firing bricks

The preliminary evaluation of the quality of firing brick, concern the metallic sound and red colour [30, 38]. Samples F13 and F31 (Table 5) have the metallic sound which reflect the maturity of the brick due to the high cohesion [30].

In addition, the metallic sound of the bricks illustrates the presence of iron, such as goethite, magnetite and hematite, which would have acted as a thermal conductor to promote the fusion of minerals and the formation of new mineralogical phases in the 900 and 1100 °C temperature ranges [2].

1.16.3 Water absorption of firing brick

The water absorption (Fig. 8) is related to microstructure and determines the open porosity level of the sintering product [27]. At 900 °C, absorption rates vary from 22.51% (F14) to 30.03% (F32). This indicates that F32 has a relatively higher porosity at this temperature, which may suggest that its internal structure is less dense or that it contains more voids.

At 1000 °C, the absorption rate for F33 reached 30.33%, the highest among the samples, while F31 had the lowest rate at 21.62%. The general trend shows a slight decrease in the absorption rates for most of the samples compared with 900 °C, which may indicate the start of vitrification and densification of the materials.

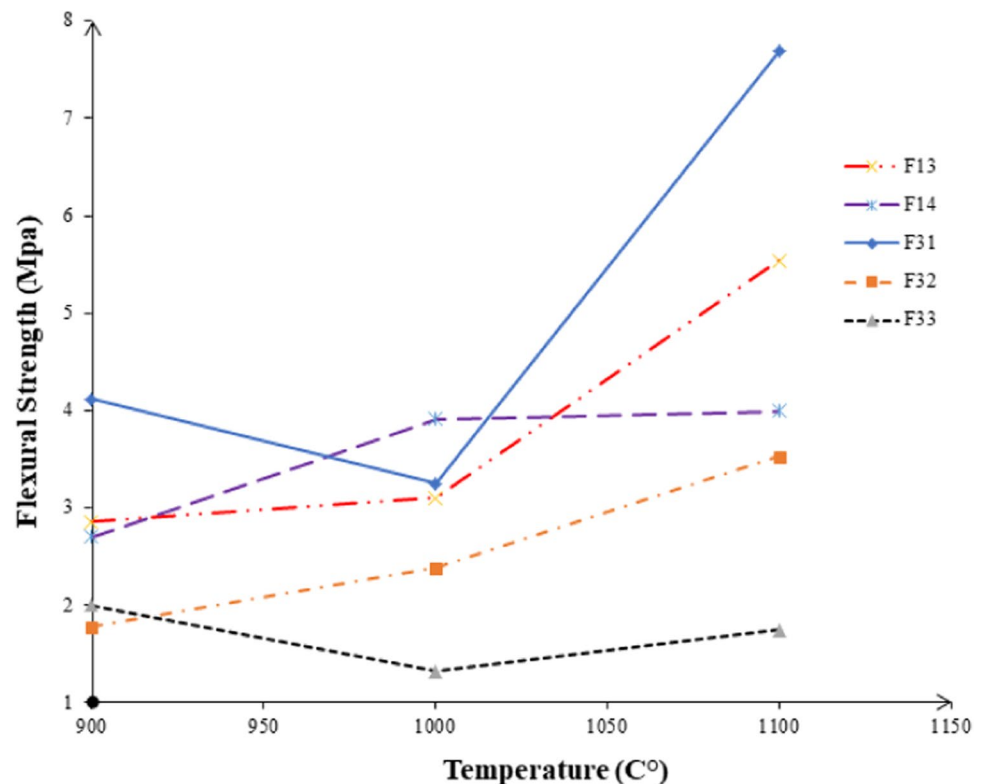
At 1100 °C, absorption rates continue to decrease, with F31 showing the lowest rate at 19.47% and F33 at 29.16%. This confirms that increasing the firing temperature promotes vitrification of the clays, reducing their porosity and absorption capacity [39].

The values of water absorption were less than 20%, which represents the recommended water absorption value of fired bricks in tropical countries [40], then only sample F31 can be used in fired bricks.

1.16.4 Linear shrinkage of firing brick

The linear shrinkage of fired bricks varies according to firing temperature (Fig. 9). At 900 °C: Samples F13, F14 and F31 show a constant linear shrinkage of 6.6%, while F32 and F33 show a lower shrinkage of 5%. This suggests that samples

Fig. 10 Flexural strength of firing brick from Feutap



F32 and F33 are less prone to shrinkage at this temperature, which may be attributed to a better mineral composition or a more stable clay structure [29].

At 1000 °C Shrinkage values remain the same as those observed at 900 °C for all samples, indicating dimensional stability at this temperature. This may mean that vitrification is not yet fully developed at 1000 °C, allowing some flexibility in the brick structure.

At 1100 °C a significant increase in shrinkage is observed, with F13 and F31 reaching 10%, while F14 and F32 remain at 6.6% and F33 at 5%. This may be explain by two hypothesis: (1) the occurrence of montmorillonite characterise by the high plastic index greater than the recommendation value for firing brick (PI: 15–22) founded in the sample; (2) the advanced vitrification phase, where the clays begin to melt and solidify, resulting in greater dimensional contraction [41].

1.16.5 Flexural strength of firing brick

Flexural strength, expressed in MPa, is essential for assessing the mechanical performance and suitability of the material in construction. The results obtained are given in Fig. 10. The flexural strength of fired bricks increases with the firing temperature (F13, F14, F32), with the exception of samples F33, which drop from 2 to 1.75 MPa in the 900 to 1100 °C temperature range. In addition, a similar behaviour is observed in the temperature range 900 to 1000 °C for sample F31 (4.12 – 3.25) before reaching the maximum strength of 7.7 MPa at 1100 °C.

2 Conclusion

The geological survey on three profile (lithostratigraphy description), geotechnical analysis on ten samples (density, voice index, porosity, grain-size and consistency limits) and ceramic properties of five representative raw clays materials from Feutap (west Cameroon) have been studied to evaluate their potential for firing brick. The field trip reveals that the clayey material developed on basaltic bedrock is wide spread with the thickness range from 2 to 28 m with the various colours. The structure ranges from angular to subangular polyhedral, and the texture is primarily clayey silt. Kaolinite (25.8 to 90.71%), illite (5.5 to 29.42%), montmorillonite (20 to 24.3%) of goethite (3.8%), hematite (21.3 to 28.4%), calcite (24.8%), and magnetite (42.1 to 29.42%) are the main mineral found in those clays. The grain size analysis showed the

occurrence of fine sands (60% to 45%) and clays (40% to 57%). The plasticity index ranges from 35.73 and 72.47%. The density ranges between 2.49 and 2.87 g/cm³. The bulk density ranges from 0.89 to 1.11 g/cm³, while the void index varies from 57.98 to 65.75%. Those clayey materials belong to silty soil on HRB, LCPC and GTR classification. The ceramic properties on firing brick illustrate the water absorption decrease with the increase temperature. The linear shrinkage is less than 7% and the flexural strength range from 1.75 to 7.7 Mpa. According to those result, 4 samples are suitable in ceramic brick with the sintering above 1000 °C and only F13 necessity the correction to fitting use in ceramic products. In view to obtain good ceramic product in low temperature, fluxing agent like feldspar shall be added.

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Data availability The datasets analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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