Suitability of Foumban Clays (West Cameroon) for Production of Bricks and Tiles

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Abstract

Particle size analysis, Atterberg limits, X-ray diffraction, X-ray fluorescence and firing tests were used to determine physico-chemical, mineralogical and technological characteristics of residual lateritic (K1M, Ma2) and alluvial (KB3, KG3) clays from Foumban (West-Cameroon). For technological properties, the samples were pressed and fired over a temperature range of 900°C - 1200°C to determine the open porosity, linear shrinkage, bulk density and compressive strength. Kaolinite (31% - 65%) and quartz (35% - 50%) are dominant in Foumban clays with accessory K-feldspar, plagioclase, illite, smectite, rutile, and goethite. But their proportion changes from one sample to another, having a significant effect on the behaviour of the clay materials: highest proportion of quartz (50%) in sample K1M; relative high feldspars (20%) and illite contents (10%) in KB3 and MA2; high smectite content in KG3 (up to 20%). Chemical analyses indicate high SiO_2 (49% - 77%) and low Al_2O_3 (14% - 23%) contents in the four samples, with comparatively low contents of iron oxides (4% - 7% in samples KB3 and KG3, 2.5% in MA2 and ~1.5% in sample K1M). The particle size distribution of the alluvial clays (KG3 and KB3) differs considerably: 7% to 37% of clay fraction, 20% to 78% of silt, and 15% to 58% of sand, while residual clays (K1M and MA2) present on average 12% of clay, 51% of silt and 37% of sand. Two raw clays (KB3 and MA2) can be used for bricks/tiles production without beneficiation or addition. K1M requires some flux addition to decrease the sintering temperature while KG3 presents poor properties due to the combined occurrence of smectite and a high clayey fraction (37%). Such mineralogical composition is responsible for very high plasticity (PI: 50), high shrinkage (LS: 5% - 16%), low porosity (OP: up to 21%) and high flexural strength (FS: 16 - 23 N/mm^2)

above 1050˚C. This last clay is therefore less appropriate for bricks and roofing tiles production since degreasers must be added to the raw material.

Keywords

Clay Materials, Ceramic Properties, Physical Characterization, Bricks, Tiles, Cameroon

1. Introduction

Clays have been used in a wide range of ceramic products as a major component in most ceramic bodies [1]. Clays are important raw material for construction such as bricks due to many specific characteristics before (mineralogy, plasticity and particle size distribution) and after firing (mineralogy, porosity, mechanical strength) [2]. The suitability of a clay for fired bricks depends on its behavior during shaping, drying and firing [2]. This behavior determines the final properties of bricks, especially their porosity and durability [1]. Thus, the characterization and quality control of clay is important for the technical performance of local products. Also, distinct layers associated with different clays can be found in a specific deposit; therefore, the mixture of various clays will permit to adjust the properties of both the unfired body and corresponding final product [3].

In Foumban (West Cameroon), clay raw materials display a widespread distribution and they have been exploited for the traditional production of small-scale ceramic products (pottery, bricks). In particular, clay materials from the localities of Marom and Koutaba, located eastern and southern Foumban respectively, are both residual and alluvial [4]. Residual lateritic clay material appears in yellowish to red color, and up to 15 m thick; alluvial clay materials appear in grey brown to grey green in color and less thick, 2 - 6 m thick. Mineralogical studies show that clay minerals (22% - 97%) and quartz (2% - 63%) are dominant in these two materials. Foumban clay is a primary material for local ceramic manufacturers but no detailed study of the properties of fired bricks has been made. A complete characterization of the precursor clays as a function of the firing temperature is needed. The aim of the present paper is to associate the mineralogical and chemical composition of clay materials to ceramic properties (linear shrinkage, open porosity, bulk density, and compressive strength) during firing in order to evaluate the applicability in fired bricks and tiles.

2. Material and Methods

2.1. Material

Foumban raw clays can be divided into two groups based on field observations: homogeneous clayey laterite in the upper part of a laterite cover on interfluves (e.g. at Marom and Koutaba) and heterogeneous hydromorphic clayey material

in the valley (e.g., at Koutaba) [4]. **Figure 1** shows coring localization on the geological map of the studied area. Koutaba and Marom clay deposits derive from the weathering of the Panafrican granite basement [5] [6]. Weathered granitic rocks are predominant sources, and, to certain extend, Eocene volcanic rocks. Four clay materials resulting from the homogenization of different clay varieties per profile were taken into consideration. The clay K1M represents the average profile of 11 Koutaba residual kaolin samples labelled (K1b1 toK1b11, **Table 1**). The clay KB3 (average of 5 samples labelled KB3a to KB3e, **Table 1**) and KG3 (average of 7 samples labelled KG3a to KG3g, **Table 1**) are the average profile of Koutaba grey-brown and grey-green alluvial clays. At Marom, the clay MA2 corresponds to the average profile of 5 layers (labelled MA2a to MA2e, **Table 1**).

2.2. Methods

The raw clay samples were dried in an oven at 40°C for 24 hours. They were characterized by XRD, chemical analyses (XRF), particles size distribution (PSD) and plasticity. Firing test including linear shrinkage, open porosity, dry bulk density and compressive strength were evaluated for fired press.

The X-ray diffraction (XRD) patterns were obtained with a Bruker D8-Avance Eco 1Kw diffractometer (Copper Ka radiance, a = 1.548 Å, V = 40 Kv, I = 25 mA)
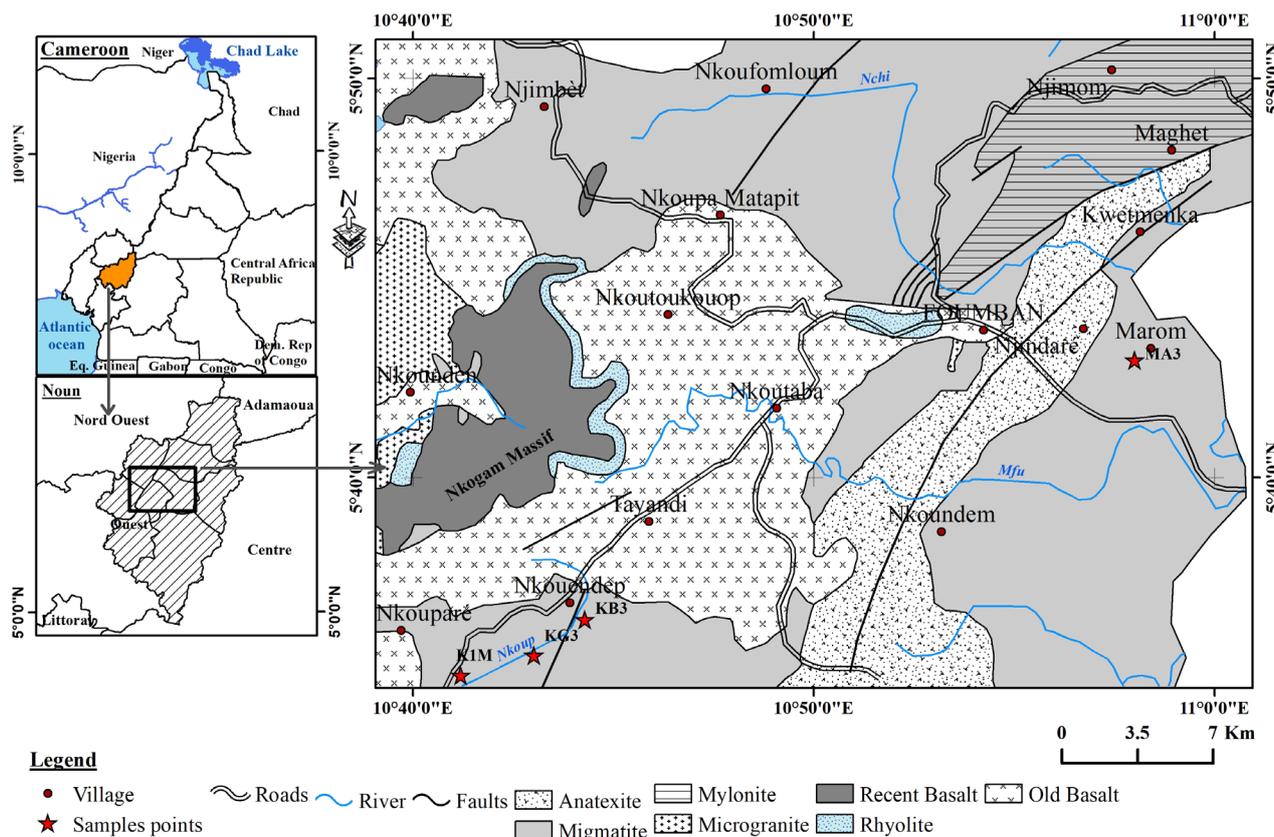

Figure 1. Location of the studied samples on the geological map of Foumban.

Table 1. Description of studied clay samples; depth (m) and mineralogical composition (%).

Sample	Depth	Clays	Quartz	K-F	Plag.	Rut.	Goe.	Kao.	Illite	Smec.
K1M	**3**	**44**	**50**	**-**	**-**	**-**	**6**	**32**	**12**	**-**
K1b1	0.1	44	56	-	-	-	-	44	28	-
K1b2	0.5	92	1	4	-	-	3	82	10	-
K1b3	1.2	42	54	4	-	-	-	32	13	-
K1b4	1.5	44	52	-	-	-	4	31	13	-
K1b5	1.6	44	55	-	-	-	1	32	12	-
K1b6	1.95	46	150	-	-	-	4	36	10	-
K1b7	2	41	57	-	2	-	-	30	10	-
K1b8	2.1	40	54	-	4	-	2	27	5	-
K1b9	2.4	20	75	-	-	-	5	14	16	-
K1b10	2.5	53	47	-	-	-	-	37	15	-
K1b11	2.8	46	54	-	-	-	-	31	28	-
MA2	**5.2**	**48**	**32**	**15**	**5**	**-**	**-**	**31**	**14**	**3**
MA21	0.4	60	15	11	13	-	-	45	12	3
MA22	0.6	45	33	20	3	-	-	24	17	4
MA23	2.5	28	50	19	3	-	-	16	11	1
MA24	0.6	26	44	26	4	-	-	16	8	2
MA25	0.4	63	26	7	4	-	-	39	21	3
KB3	**5**	**50**	**32**	**13**	**3**	**2**	**-**	**40**	**6**	**4**
KB31	0.9	47	42	7	4	-	-	33	10	3
KB32	1	56	39	5	-	2	-	45	10	
KB33	1	35	37	5	23	3	-	27	5	3
KB34	0.8	0	48	47	4	-	-	40	7	1
KB35	0.5	50	24	26	-	4	-	50	-	-
KB36	0.5	79	21	-	-	5	-	40	13	25
KG3	**5.2**	**75**	**20**	**2**	**-**	**1**	**2**	**50**	**5**	**20**
KG31	0.3	59	34	6	-	-	-	43	10	4
KG32	1.1	61	19	-	-	3	17	49	2	11
KG33	0.3	88	10	-	-	-	2	62	3	23
KG34	0.6	78	22	-	-	-	-			
KG35	1.3	86	11	3	-	-	-			
KG36	0.9	59	40	1	-	-	-	30	5	24
KG37	0.3	81	15	3	-	2	-	32	18	31

K-F = alkali feldspars; Plag = plagioclase; Rut = rutile; Goe = goethite; Kao = kaolinite; Sm = smectite.

with LynxeyeXe energy dispersive (one dimensional coupled $2\theta/\theta$ detector with 3.28) in the laboratory of "Argiles, Géochimie et Environnements sédimentaires (AGEs)" at the University of Liège, Belgium. The analyses were carried out on the non-oriented powder with grinded particles <250 µm (bulk material) and the oriented powder <2 µm (clay fraction) according to [7]. Eva software was used for the mineral phase analysis. The semi-quantitative relative abundance of minerals was estimated using the height of a diagnostic peak multiplied by a corrective factor [8] [9] [10] in combination with the 100% approach (the term 100% approach connotes that the sum of all phase quantities identified in a sample is 100%) [11] and an estimated uncertainty of ±5% - 10% [12]. The chemical analyses of major elements were carried out by X-ray Fluorescence Spectrometry ARL PERFORM-X 4200 (standard error < 1%) after Loss of Ignition (LOI) measurement at 1000˚C. The particle size distribution was determined by wet sieving for the ≥100 µm fraction and gravity sedimentation for <100 µm fraction. The Casagrande method helped to determine the Atterberg limits according to the ASTM D-422 and D-4318 norms respectively [13] [14].

For firing test, homogeneous mixture pieces (24 × 23 × 25 mm) were obtained by uniaxial pressing of a clay powder (20 g) at (45,73 Mpa) with a Graseby-Specac apparatus at the Belgian Ceramic Research Center (BCRC), Mons-Belgium. The firing stage took place at the temperature 900˚C - 1200˚C, at the intervals of 50˚C. The high pressing loads in dry process tends to increase the bending strength and reduce the shrinkage of fired bodies [15] [16]. The firing properties for all fired specimens were evaluated. The linear shrinkage $100\ (L_m - L_f)/L_m$ were obtained according to the relative variation length of the specimen, where L_m is the length of the mould and L_f that of the fired specimen. The compressive strength of fired clay bricks was measured according to the ASTM C377-88 standard [17]. Archimede's method based on ASTM C373-88 [18] helped to determine the open porosity and bulk density.

3. Results and Discussion

3.1. Mineralogical and Physico-Chemical Characterization

XRD patterns of the investigated clays are characterized by the peaks of quartz and kaolinite (Figure 2). This is the case for most clays resulting from the weathering of acid rocks such as granites [3] [19]. The characteristic peaks of K-feldspar, plagioclase, illite, smectite, rutile, and goethite are also identified, but they usually show small intensities (data in Table 1) except MA2 (for K-feldspar and plagioclase) and KG3 (for smectite). On the basis of semi-quantitative method, kaolinite (31% - 65%) and quartz (35% - 50%) are dominant in Foumban clays but their proportions vary from one sample to another. For example, the highest proportion of quartz (50%) is observed in the Koutaba residual clay sample (K1M), as indicated by the high SiO_2/Al_2O_3 ratio (5) and low LOI (5%, Table 2). Samples KB3 and MA2 are characterized by the relative high K-feldspar, plagioclase (20%) and illite contents (10%). Smectite content is high

in KG3 (up to 20%).

Chemical analyses allowed a rapid classification of the studied clays. The high SiO_2 (49% - 77%) and low Al_2O_3 (14% - 23%) contents, are in agreement with the proportion of kaolinite [3] [20]. This high proportion of SiO_2 observed in K1M may have a high abrasion effect on the applied finished products like bricks and tiles, therefore it should be reduced. Iron oxides (Fe_2O_3) account for the color of firing products [21]. The comparatively low content of iron oxides in samples KB3 and KG3 (4% - 7%, **Table 2**) is suitable for bricks production; their low content in sample K1M (~1.5%) inducing their white or whitish color after firing is in favor of porcelain, sanitary wares and/or tableware production [1]. In MA2 (2.5%), the iron oxide is likely more consistent with their use in roofing tiles and rustic floor tiles [2]. During firing, earth alkali oxides (CaO, MgO), al-kali oxides (K_2O) and iron oxides (FeO, Fe_2O_3) contents determine the firing temperature, the vitrification grade and the differentiation of ceramic dimensions [22]. The low amount (<3%) of these oxides in K1M explains the absence of vitreous phase at a low firing temperature (**Table 2**). In contrast, their relatively rich amount in MA2 and KG3 (>8%) is responsible for a rapid densification.

The grain-size distribution of raw materials for building clay products influences in particular the behavior of the material during the shaping and drying processes. Grain-size distribution also affects the microstructure and the mechanical properties of fired materials [23]. The particle size distribution of the alluvial clay (KG3 and KB3) is variable with 7% to 37% of clay fraction, 20% to
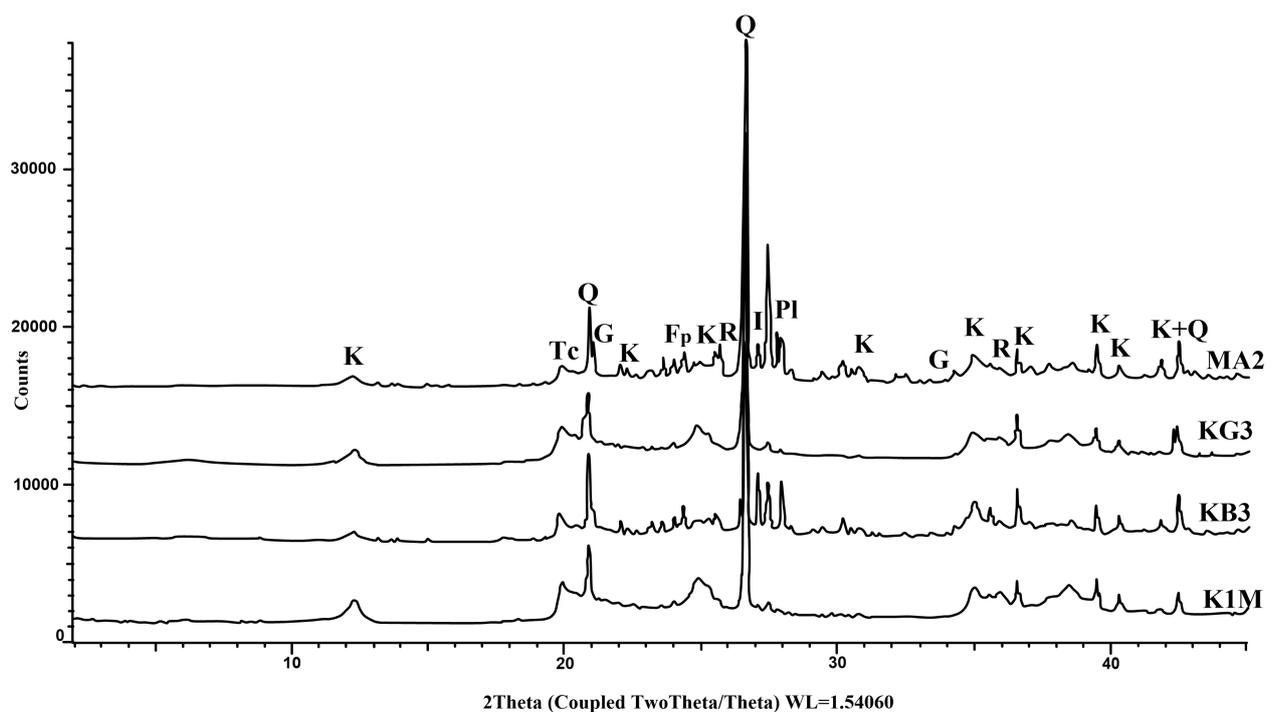

Figure 2. XRD of Bulk powder. K = Kaolinite; Tc = Total clay; Q = Quartz; Fp = Alkali-Feldspars; Pl = Plagioclase; I = Illite; G = Goethite; R = Rutile.

Table 2. Particle size distribution (PSD, %), Atterberg limits (%) and chemical composition (major oxides, wt%) of studied clay samples.

	Sample name			
	K1M	MA2	KB3	KG3
Physical properties (%)				
Clay	12	22	78	37
Silt	51	20	7	45
Sand	37	58	15	18
Wl	42	43.6	59	103.7
Wp	34	26.5	32	53. 2
Ip	8	17.1	27	50.5
Chemical composition (wt%)				
SiO_2	77.25	60.89	58.21	49.04
TiO_2	0.16	1.3	3.04	1.72
Al_2O_3	14.67	20.16	22.28	22.75
Fe_2O_3	1.4	2.59	3.97	6.92
MnO	0.01	0.01	0.02	0.02
MgO	0.08	0.39	0.13	0.53
CaO	0.06	0.63	0.18	0.46
Na_2O	nd	0.88	0	0
K_2O	1.08	4.64	1.29	0.74
P_2O_5	0.02	0.08	0.11	0.11
LOI	5.2	8.42	10.78	17.71
$(A + AT + Fe_2O_3)$	1.22	6.54	5.57	8.65

$A = K_2O + Na_2O$; $AT = CaO + MgO$.

78% of silt, and 15% to 58% of sand. The residual clays (K1M and MA2) present a less variable particle size distribution with on average 12% of clay, 51 of silt and 37% of sand. The raw clayey samples were plotted in the diagram of ideal particle size for bricks and tiles (Figure 3) as proposed by McNally [24]. The observed data distributions suggest that the samples K1M and MA2 would be applied to solid and performed bricks respectively. In contrary samples KG3 and KB3 are unsuitable for bricks manufacture: their high amount of fine fraction (>80% of fraction <20 microns) would account for excessive shrinking during firing.

The plasticity of clay materials depends to its particle size distribution and mineralogy composition [24]. In Table 3, clay materials characterized by a plasticity index (PI) 8% - 50% pertaining to the moderate (K1M), plastic (KB3 and MA2) and very high plastic group (KG3). They may be classified into the medium, plastic and very high plastic group [25]. The high plasticity of samples KB3 and KG3 (27% - 50%) is suitable for fine ceramic like pottery and sanitary

ware. The studied samples were further plotted using the clay workability chart [26]. Samples KB3 and MA2 are acceptable for moulding in brick-making (MA2) and pottery (KB3) (Figure 4). Samples KG3 and K1M are rather inappropriate for extrusion due to their plasticity parameters, very high for KG3, very low for K1M. For those two samples, the addition of degreaser (KG3) or greaser (K1M) are respectively requested to reach the adequate plasticity for the fabrication of solid or perforated bricks and roofing tiles. Note that sample KG3 could be used to amend K1M and sample K1M to degrease KG3.

3.2. Technological Properties of Fired Clays

The results of open porosity, linear shrinkage, density and compressive strength as a function the firing temperature are presented in Figure 5. Compressive strength, density and linear shrinkage of all raw clay samples increase while open porosity decreases. Sample KG3 which has the highest clay fraction (KG3) shows high linear shrinkage (5% - 16%), high compressive strength (16% - 23%) and low open porosity (up to 21%). The reverse trend is observed for sample K1M characterized by the lowest clay fraction. The relative high linear shrinkage in sample KG3 is in agreement with the occurrence of smectite and limits its application to produce bricks and tiles. Sample KG3 should rather be applied to amend non plastic clays like lateritic clays (e.g., K1M). The highest bulk density of sample KG3 (1496 - 2126, g/cm^3) explain its rapid densification as compared
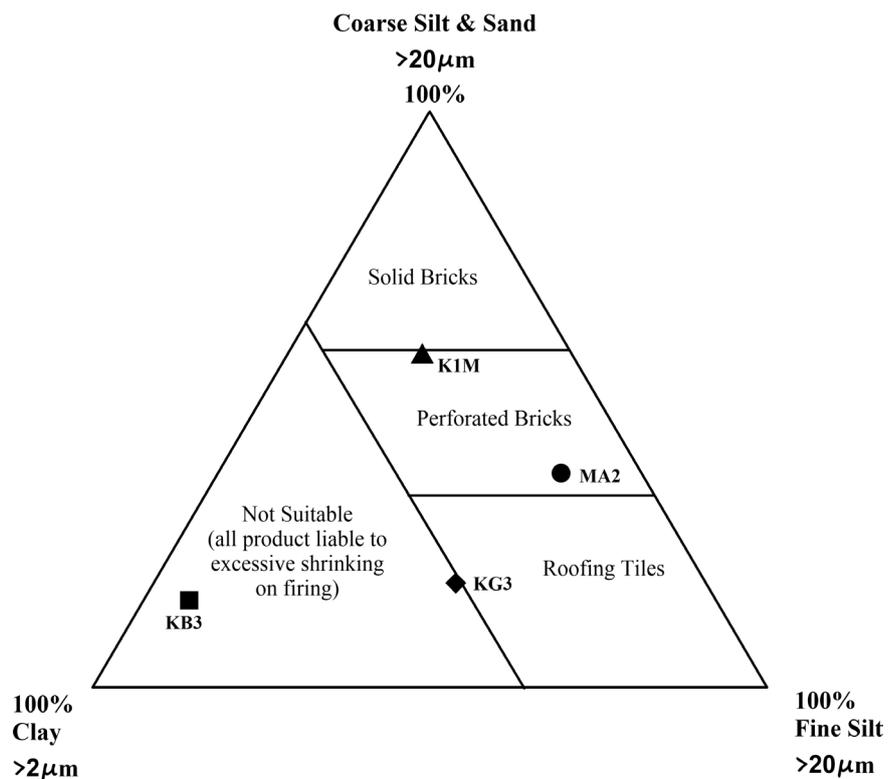

Figure 3. Evaluation of the suitability of raw material based on the diagram of the ideal particle size for bricks and tiles [1] [24].

Table 3. Physical and mechanical properties of fired products.

|		Sample name		
	K1M	MA2	KB3	KG3
Temperature (°C)		Linear shrinkage (%)		
900	1.6	1	2.8	12.1
950	2.3	1.1	4.3	8.2
1000	0.9	1.8	3.7	15.3
1050	0.7	4.2	3.6	17.1
1100	0.6	5.5	8.7	25
1150	0.6	10	12.6	37
1200	8	15.2	13.2	38.7
		Open porosity (%)		
900	41.4	40.2	40.1	40.8
950	41.3	40.95	40.1	42.8
1000	41.3	40.05	40.1	40.2
1050	41.6	38.4	40.4	41.2
1100	41.7	36.6	37.4	34.8
1150	41.7	33.9	33.4	21.9
1200	40.7	38.9	33.2	21
		ρ (g/cm³)		
900	1.523	1.562	1.593	1.496
950	1.531	1.543	1.602	1.421
1000	1.544	1.565	1.599	1.551
1050	1.543	1.568	1.585	1.576
1100	1.537	1.634	1.669	1.743
1150	1.563	1.714	1.76	2.076
1200	1.583	1.794	1.753	2.126
		σ (Mpa)		
900	2.7	3.7	6.2	9.3
950	3.8	2.7	9.2	9.8
1000	3.6	3.2	4.6	11.7
1050	4	1.5	5.3	11.5
1100	4.4	2.9	4.5	15.7
1150	6.1	5.4	4.5	22.7
1200	5.6	7.4	3.8	22.2
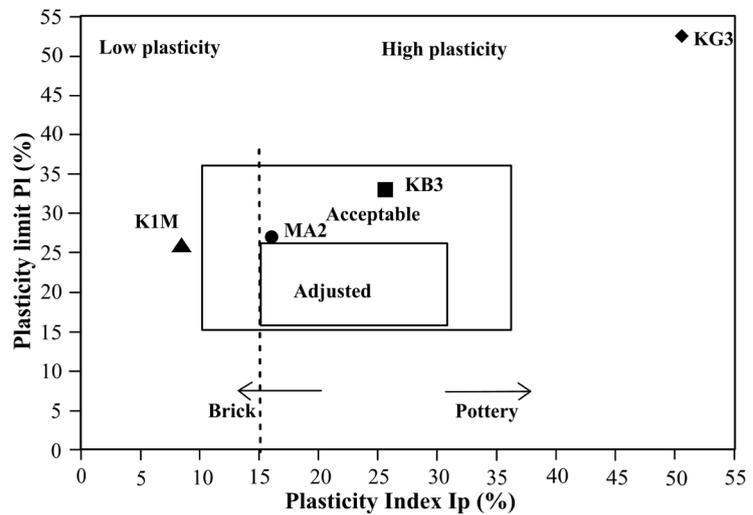
Figure 4. Evaluation of extrusion prognostic on the diagram of Bain and Highley [30]. Clay materials are suitable for pottery (KB3 and KG3) and brick making (K1M); samples KB3 and MA2 are acceptable for brick production by extrusion.
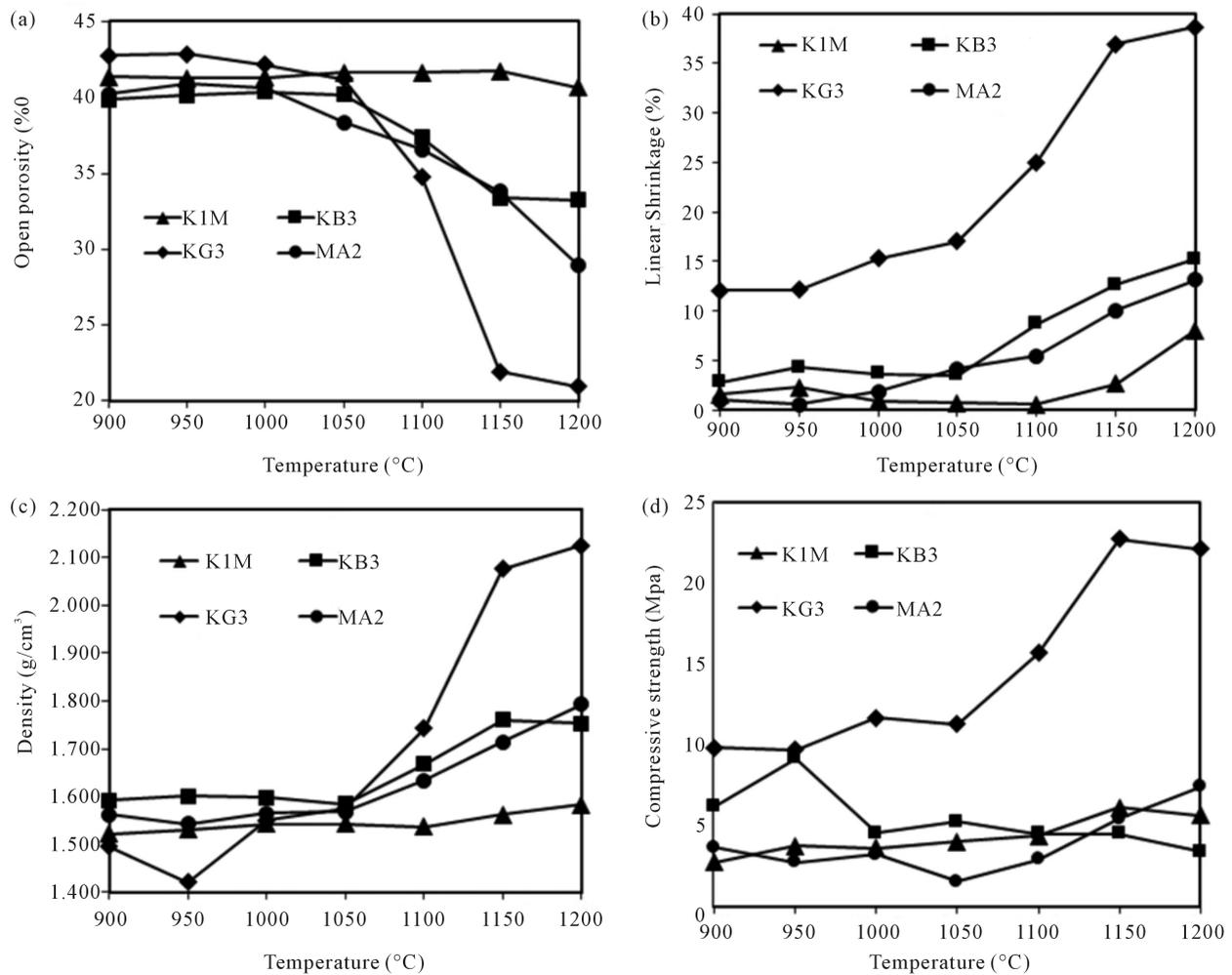

Figure 5. Evolution of physical and mechanical properties over 900°C to 1200°C heating: (a) Open porosity; (b) Linear shrinkage; (c) Density; (d) Compressive strength of the clays.

with the other samples. This different densification behavior is probably induced by their mineralogy due to the relative abundance of impurities [27]. Sample K1M presents only moderate values of bulk density in the fired properties at 900°C - 1150°C due to its refractory behavior. A significant change of bulk density observed above 1050°C of samples KB3, MA2 and KG3 is associated with the sintering mechanism that promotes the densification of these samples and reduces the porosity.

An open porosity is closely related to the densification of the clay matrix. The decrease of open porosity is associated with a considerable liquid phase formation, which penetrated and isolated the adjacent pores [28]. A significant increase of compressive strength occurring at 1050°C and 1150°C (KG3) reflects most probably the inception of a glassy phase formation, with the predominance of viscous flow sintering and increased the material densification [28] [29]. Sample K1M shows a low variation of the open porosity in the temperature 900°C - 1150°C (2 - 5 Mpa). This observation suggests a poor maturation of the firing products within this range of temperature [30]. Fluxing agents (feldspars and iron) were melted to reduce the temperature of vitrification and promote densification. The sintering temperature for sample K1M above 1150°C, agrees with its thermodilatometrical properties [4].

4. Conclusions

This study focuses on the composition and ceramic properties of four kaolinitic clays sampled from three deposits in Foumban (West Cameroon). The combination of mineralogical, physico-chemical and technological properties allow us to classify the raw clays according to their optimal application.

Technological properties of fired samples from both alluvial (KB3, KG3) and lateritic clays (K1M, MA2) are sufficient for bricks production. However, the addition of flux agent is recommended for sample K1M to decrease its sintering temperature. The low amount of fluxes, gives sample K1M a refractory firing behavior, which results in small variations in the properties above 1150°C. Samples K1M and KG3 display an extrusion behavior (low plastic and high plastic clay respectively) not acceptable for building ceramics. Those samples require a proper adjustment of their sand-silt-clay ratio to improve their workability (*i.e.*, addition of a plastic material for K1M and non-plastic material for KG3). The mineralogical composition of sample KG3 renders it inappropriate due to the high smectite content; this can be solved by some treatment or addition of quartz.

Further study of mineralogical transformations during firing can be carried out on Foumban raw clays (K1M, MA2 and KB3) to determine the influence of neoformation on the technological properties like porosity. They would provide valuable data regarding the choice of temperature, and the firing duration.

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