Journal of African Earth Sciences 124 (2016) 211–215

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Determination and adjustment of drying parameters of Tunisian ceramic bodies

Salah Mahmoudi [a, *], Ali Bennour [b], Ezzeddine Srasra [c], Fouad Zargouni [d]

[a] Department of Earth Sciences, Faculty of Sciences of Gabes, Zrig 6072, Tunisia
[b] Department of Geology, Faculty of Sciences of Bizerte, Zarzouna 7021, Tunisia
[c] Laboratory of Physicochemical of Minerals Materials and its Applications, National Centre of Research in Materials Sciences BP95, Hammam Lif, 2050, Tunisia
[d] Department of Geology, Faculty of Sciences of Tunis, 1060 Belvedere, Tunis, Tunisia

ARTICLE INFO

Article history:
Received 18 June 2014
Received in revised form
22 September 2016
Accepted 24 September 2016
Available online 25 September 2016

Keywords:
Drying parameters
Regression models
Physiochemical properties
Tunisia

ABSTRACT

This work deals with the mineralogical, physico-chemical and geotechnical analyses of representative Aptian clays in the north-east of Tunisia. X-ray diffraction reveals a predominance of illite (50–60 wt%) associated with kaolinite and interstratified illite/smectite. The accessory minerals detected in raw materials are quartz, calcite and Na–feldspar. The average amounts of silica, alumina and alkalis are 52, 20 and 3.5 wt%, respectively. The contents of lime and iron vary between 4 and 8 wt %. The plasticity test shows medium values of plasticity index (16–28 wt%). The linear drying shrinkage is weak (less than 0.99 wt%) which makes these clays suitable for fast drying. The firing shrinkage and expansion are limited. A lower firing and drying temperature allow significant energy savings. Currently, these clays are used in the industry for manufacturing earthenware tiles. For the optimum exploitation of the clay materials and improvement of production conditions, a mathematical formulationis established for the drying parameters. These models predict drying shrinkage (d), bending strength after drying (b) and residual moisture (r) from initial moisture (m) and pressing pressure (p).

1. Introduction

There are many studies of the characterization of clays used for the manufacture of ceramic products (e.g. Ibrahim et al., 2004; Monteiro and Vieira, 2004; Lisboa et al., 2007; Dondi et al., 2008; Mahmoudi et al., 2008; Meseguer et al., 2010; Diko et al., 2011; Mahmoudi et al., 2016). Researches on the transformations of clay materials by firing have shown that the reactions between phyllosilicates and accompanying minerals like quartz, feldspar and calcite are decisive in establishing the final properties of the ceramic bodies (e.g. Jordán et al., 1999; Carretero et al., 2002; Matteucci et al., 2002; Zanelli et al., 2003; Mao et al., 2006). The disappearance and neomineralisation of mineral components, such as the formation of wollastonite, gehlenite and anorthite is the subject of many works (e.g. Cultrone et al., 2001; Mansur and Mansur, 2003; Aras, 2004; Sousa and Holanda, 2005; Cultrone et al., 2005; Ferrari and Gualteri, 2006; Jordán et al., 2008, 2009; Mahmoudi et al., 2010; Pardo et al., 2011). The influence of heating rates on phase transformations and mullite formation is considered by Castelein et al. (2001), Tulyagunor et al. (2002), Sedmale et al. (2006) and Sahnoun et al. (2008) as decisive parameters for the quality of ceramic products.

It is clear that the firing stage is important and decisive in the manufacturing of ceramic bodies, but this step is preceded by a drying stage, which can influence and affect the later stages of production (Tarı and Ferreira 1998; Tarì et al., 1999). Few studies. The main steps in the drying process entail the evaporation of free-water, obtained from the green shaped bodies. With evaporation, the particles approach each other, causing shrinkage. The drying behaviour depends on the moisture content (m) and on the pressure (p) required for shaping (Carretero et al., 2002): it is characterized by three parameters: drying shrinkage (d), bending strength after drying (b) and residual moisture (r). In this paper our approach is to determine regression models of (d), (b) and (r) as functions of (p) and (m).

* Corresponding author. Tel.: +216 97 655 581; fax: +216 75 392 421.
E-mail address: Salah.Mahmoudi@fsg.rnu.tn (S. Mahmoudi).

http://dx.doi.org/10.1016/j.jafrearsci.2016.09.031
1464-343X/

2. Materials and methods

The measurements of drying shrinkage (d), bending strength after drying (b) and residual moisture (r) were determined under industry conditions. The raw materials were crushed (residue through a 425 μm sieve is less than 0.5 wt%), moistened (~8 wt%), mixed and sieved (Ø 2 mm) and then left to rest for 48 h to obtain homogeneous agglomerates. The paste was shaped by pressing and dried in an industrial fast horizontal roller drier (cycle = 12 min, T = 240 °C). Ten green specimens (300 mm × 75 mm × 7 mm) were collected to measure drying parameters for each according to the European Standard (ISO 10545). The linear drying shrinkage (d) was evaluated using the formula: $d = [(l_g - l_d)/l_g] \times 100$, where l_g and l_d are the measured length of green and dried samples (ISO 10545–2, 1995). The bending strength (b) was measured with a three-point flexural method according to the norm ISO 10545–4, 2004. The average values of bending strength were calculated by the equation: $b = 3FL/2yz^2$, where: F = breaking load (kg), L = distance between supports (L = 29.67 mm), y = sample width (mm), z = sample thickness (mm). After drying each green ceramic body was weighed (m_1) and dried at 105 °C until it reached a constant weight (m_2). The value of the residual moisture (r) was therefore: $r = [(m_1 - m_2)/m_2] \times 100$.

3. Results and discussion

Illite is the main mineral (50–60 wt%) but other minerals; quartz, kaolinite, interstratified illite/smectite, calcite and feldspar, are present in small quantities. In this study the average contents of SiO_2, K_2O, Fe_2O_3 and Al_2O_3 are 51.9, 3.4, 6 and 19.6 wt%, respectively. The CaO content of varied between 4 and 8 wt%. The grain size data indicate a silt-dominated assemblage. The value for the plasticity index ranges from 16 to 28 wt%. The firing shrinkage and expansion are limited.

According to Ferrari et al. (2006), who used illitic clays for traditional ceramics and showed that the high amount of illite is necessary in ceramic mixtures but causes a larger percentage of glass phase, lower water absorption and a higher linear shrinkage, thus the addition of a degreaser (sands, crushed glass, grogs, feldspars, pegmatite and chamotte; the latter is made up of brick debris and biscuit waste) is necessary to reduce the plasticity and the linear shrinkage, to improve water absorption and makes the clays easy to dry. To judge the quality of ceramic paste, the mixture used to produce the ceramic bodies is composed of 80% of Aptian clays and 20% of chamotte. From the measurements made (Table 1), regression models were derived for the drying parameters measured at different pressures (p) and moistures (m).

The mathematical equations (1) (2) and (3) are formulated as second–degree polynomials, to relate drying shrinkage (d), bending strength after drying (b) and residual moisture (r) with the moisture (m) and the pressure (p). The mathematic model is valid, when the error (difference between measured and calculated values) is uncorrelated and randomly distributed with a zero mean value and a common variance (Cornell, 2002; Myers and Montgomery, 2002; Correia et al., 2004).

$$d(m,p) = \sum_{i=0}^{n} \alpha_i m^i p^{n-1} \quad (1)$$

Table 1
The drying parameters: drying shrinkage (d), bending strength after drying (b), residual moisture (r) and pressure (p) applied upon the paste and moisture (m) of paste before drying.

Pieces	Pressure: p (Kg/cm^2)	Moisture: m (%)	Drying shrinkage: d (%)	Bending strength b: (N/mm^2)	Residual moisture: r (%)
1	185	5.4	0.99	1.28	0.10
2	190	5.6	0.86	1.43	0.13
3	195	5.8	0.78	1.58	0.20
4	200	6.0	0.66	1.73	0.37
5	205	6.2	0.61	1.76	0.42
6	207	6.2	0.41	1.98	0.44
7	207	6.3	0.52	1.88	0.40
8	210	6.3	0.33	1.94	0.46
9	210	6.4	0.51	1.99	0.48
10	215	6.6	0.40	2.05	0.60
11	220	6.8	0.38	2.10	0.71
12	225	7.0	0.35	2.15	0.92
13	230	7.2	0.31	2.18	1.01
14	235	7.4	0.36	2.22	1.07

Table 2
The errors between measured and calculated values.: drying shrinkage measured (d_m), drying shrinkage calculated (d_c), bending strength measured (b_m), bending strength calculatecd (b_c), residual moisture measured (r_m) and residual moisture calculated (r_c).

Pieces	d_m (%)	d_c (%)	Error $\lvert d_c - d_m \rvert$ (%)	b_m (N/mm^2)	b_c (N/mm^2)	Error $\lvert b_c - b_m \rvert$ (N/mm^2)	r_m (%)	r_c (%)	Error $\lvert b_c - b_m \rvert$ (%)
1	0.99	0.92	0.07	1.28	0.51	0.77	0.10	0.01	0.09
2	0.86	0.81	0.05	1.43	0.77	0.66	0.13	0.13	0.00
3	0.78	0.71	0.07	1.58	1.03	0.55	0.20	0.26	0.06
4	0.66	0.62	0.04	1.73	1.25	0.48	0.37	0.39	0.02
5	0.61	0.54	0.07	1.76	1.46	0.30	0.42	0.52	0.10
6	0.41	0.42	0.01	1.98	1.66	0.32	0.44	0.56	0.12
7	0.52	0.53	0.01	1.88	1.52	0.36	0.40	0.59	0.19
8	0.33	0.35	0.02	1.94	1.65	0.29	0.46	0.61	0.15
9	0.51	0.48	0.03	1.99	1.65	0.34	0.48	0.66	0.18
10	0.40	0.42	0.02	2.05	1.81	0.24	0.60	0.81	0.21
11	0.38	0.38	0.00	2.10	1.95	0.15	0.71	0.96	0.25
12	0.35	0.36	0.01	2.15	2.07	0.08	0.92	1.11	0.19
13	0.31	0.35	0.04	2.18	2.16	0.02	1.01	1.27	0.26
14	0.36	0.35	0.01	2.22	2.23	0.01	1.07	1.43	0.36