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Thermo-mechanical behaviour of the structures of tropical clays from Togo (West Africa) fired at 500 °C, 850 °C and 1060 °C

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ABSTRACT

This study aims to develop new environmentally friendly construction materials that compete with modern materials in civil engineering. The paper deals in particular with tropical clays in order to develop new processing of clay based construction materials such as bricks, roof and floor tiles, for building needs in developing countries. Physical and thermo-mechanical characterisations are carried out on six tropical clay varieties from Togo (West Africa). The mechanical resistance is carried out on clay structures fired at 500 °C, 850 °C and 1060 °C. Relationships between the physical properties and the mechanical characteristics of clay structures have been established.

1. Introduction

This study is part of a project that aims to develop ecological construction materials based on natural resources such as clays, in order to meet the increasing needs of housing in developing countries, in particular in West Africa. This project is born from a research program and academic cooperation between the laboratories SeT/UTBM/France (*Système et Transport/Université de Technologie de Belfort-Montbéliard*; *France*), the "Civil and Materials Engineering Department" of "Ecole Royale Militaire de Bruxelles/Belgium" and CCL/URMA/UL/Togo (*Centre de Construction du Logement/Unité de Recherche sur les Matériaux et les Agro-ressources/Université de Lomé; Togo*).

This paper presents a study on clay structures for clay based construction material processing. It presents the physical characterisation and the mechanical characterisation carried out on the structures of six tropical clay varieties (from Togo).

The physical characterisation concerns the determination of clay structures properties such as the porosity, the capillary water absorption, the density and shrinkage variation according to the firing temperatures. The clay structures have been fired to various temperatures in order to determine the minimal firing temperature susceptible to meet requirements of the standards on clay building materials and for a low cost manufacturing.

The mechanical characterisation concerns the compression tests carried out on structures to assess clays resistance at various temperatures and to define those that are adequate for tiles and bricks development. The compression test is also carried out on clay structures in a wet state in order to anticipate on their behaviour when wetted during natural elements (rain, flooding, etc.). The mechanical characterisation carried out on clay dry and wet structures is performed according to clay fired materials standards. A correlation of physical properties and mechanical properties will allow understanding the structures thermo-mechanical behaviour.

The experimental characterisation is performed on clay test-tubes that are obtained by compaction of clays structures at a predetermined pressure.

2. Physical characterisation of fired clay structures

2.1. Experimental protocol of the determination of physical properties of clay structures

2.1.1. Identification of minerals of studied clay raw materials by X-ray diffraction analysis

X-ray identification is suited to the recognition of structural varieties and structural groups of clays but it can allow identifying their mineralogical composition. Analysis performed by means of

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the diffractometer Bruker D8/Advance allow to identify the mineral elements contained in raw materials of studied clays: *white clay of Bangéli* (*ABB*); *red clay of Guérin-Kouka* (*ARG*); *black clay of Togblékopé* (*ANT*); *green clay of Kouvé* (*AVK*); *red clay of Kouvé* (*ARK*) *and red clay of Albi* (*ARA*). Table 1 gives the average contents values of these clays.

Those contain a large proportion of silica whose content varies from 62% to 70% according to clays. This variation in silica content will determine the thermo-mechanical behaviour of clay structures. Except the ABB clay, other clay varieties have approximately the same content of iron and aluminium oxides.

2.1.2. Test-tubes

To meet the manufacturing requirements in tiles industrial factories, the clay structure must be compressed to present a density of about 2 g/cm^3 [1,2]. So, the clay pastes previously moistened to a water content of 18% are shaped by compression at 8 MPa on a conventional traction and compression machine. Fig. 1 illustrates cylindrical test-tubes of six clay varieties studied in this paper. Physical characterisation is carried out on test-tubes fired at 500 °C, 850 °C, and at 1060 °C during 24 h.

2.1.3. Determination of the porosity of the structures by water soaking

Several techniques allow to determine the porosity of porous materials but the test by water soaking is chosen in this paper due to its lower cost and because it is simple to be achieved.

The dry mass m of the dry test-tube is measured and the test-tube is kept during 4 h in a vacuum box in which a vacuum of 1 bar is created by means of a vacuum pump. The test-tube is then immersed in water under vacuum and one measures the mass M_i of the sample when it is immersed in water and the mass M_h of the moistened test-tube when it is out of water. The sample porosity value is given by the relation [3–5]:

$$\psi = 100\frac{(M_h - m)}{(M_h - M_i)}(\%) \qquad (1)$$

2.1.4. Capillary absorption coefficient determination

The water absorption test is performed according to the specifications of European Committe for Standardisation (CEN) on clay masonry bricks, the standard EN 771-1 [6], and according to the French standard on fired materials NF P 10-305 [7]. Fig. 2 illustrates the test device and a clay test-tube during the water absorption test [8,9]. This device consists of a box containing a thin layer of sand that is feeds of water at the same level by a monitored tank. The test tube lies on the sand layer and the box is covered with a membrane to prevent the atmospheric pressure to disturb the capillary absorption. One measures the mass m of the water absorbed by the test-tube during a time t (≈10 min). The water absorption coefficient of the considered clay structure is given by the expression [6,7,10].

$$C = \frac{100\ \mathrm{m}}{S\sqrt{t}}(\mathrm{g\ cm^{-2}\ s^{-0.5}}) \qquad (2)$$

S is the surface in cm^2 of the absorption face of the test-tube, m is in grams and t in second.

2.1.5. Determination of the apparent density of the clay structures

The apparent density of structures is determined by hydrostatic weighing. The mass m of a dry test-tube is measured. The test-tube is coated with a thin layer of paraffin to prevent the clay structure to absorb water when immersed. The mass M_1 of the coating is measured and one immerseds the test-tube in a distilled water. One measures the hydrostatic mass M_2 of the test-tube when immersed. The apparent density of the dry clay structure of the considered test-tube is given by the expression [3]:

$$\rho_0 = \frac{m}{\frac{M_1 - M_2}{\rho_{\mathrm{water}}} - \frac{M_1 - m}{\rho_p}}(\mathrm{g/cm^3}) \qquad (3)$$

where ρ_p is the paraffin density (in g/cm^3) and ρ_{water} the distilled water density (ρ_{water} = 1 g/cm^3)

2.1.6. The firing shrinkage rate determination

Like drying, clay structures firing induces structures dimensions variation due to the shrinkage. The longitudinal firing shrinkage rate of clay structures is measured at 500 °C, 850 °C, 1060 °C.

2.2. Results and discussion

2.2.1. Physical properties of fired clay structures

For all the clay physical properties, the measurement is performed on 10 test-tubes of each clay variety and the average values are given in Table 2. The properties concern clay structures fired to 500 °C, 850 °C and 1060 °C. Results are discussed below.

2.2.2. Clay structures texture

An observation to the Scanning Electron Microscopy (SEM) of clay structures fired to 1060 °C makes it possible to establish the structures texture photos of Fig. 3.

2.2.3. Discussion

Referring to the results of Table 2, one can note that:

- the porosity of the clay structures decreases according to the firing temperature. During firing the structure pores closes progressively due to the clay matter melting. The porosity varies also according to the clay varieties. This is related to clay structures textures (Fig. 3),
- globally, the water absorption of clay structures increases with the firing temperature. The clay structure firing generates the progressive closing of small size pores whereas appear bigger size pores [5]. This increases the capillary water absorption of the clay structure. In other respects, the water absorption of some clays like the white clay of Bangeli (ABB clay) and the red clay of Guérin-Kouka (ARG clay) decreases considerably at 1060 °C. That is explained by the fact that the clay structure surface of these clays vitrifies and becomes watertight at 1060 °C.

Table 1
Mineral elements average contents of studied clays (in percent).

Clay variety	Silica (SiO_2)	Iron oxide (Fe_2O_3)	Aluminium oxide (Al_2O_3)	Calcium oxide (CaO)	Potassium oxide (K_2O)
ABB	69.8	–	22.8	–	7.4
ARG	62.1	10.6	20.6	–	6.8
ANT	66.8	10.1	20.9	2.3	–
AVK	64.4	10.0	20.4	–	7.0
ARK	65.0	10.1	20.9	2.4	6.8
ARA	64.8	10.6	20.6	–	–