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Research paper

Physical and mechanical properties improvement of a porous clay ceramic

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ABSTRACT

This work deals with the chemical, physical, thermal and mechanical analyses of porous clay and non-plastic clays mixtures from Tunisia. Five mixtures which are M1 (70 mass% clay + 30 mass% waste brick), M2 (70 mass % clay + 15 mass% waste brick + 15 mass% sand), M3 (70 mass% clay + 30 mass% sand), M4 (70 mass% clay + 30 mass% chamotte) and M5 (70 mass% clay + 15 mass% chamotte + 15 mass% sand) were sintered between 900 and 1100 °C and were evaluated for their possible ceramic applications. Thermal analysis (DTA/TG), dilatometry, X-ray diffraction (XRD), scanning electron microscopy (SEM) and physical-mechanical analyses (tensile strength, water absorption and bulk density) were used to assess the thermal behavior, phase evolution and microstructure of the fired mixtures. The formations of both the anorthite phase and the vitreous phase have improved the required ceramic product performance. M1 has the highest values of tensile strength and bulk density at 1100 °C. According to the European Norm EN 14411, all the mixtures belong to the BIII group which are suitable for the production of earthenware and unglazed stoneware.

1. Introduction

The valorization of natural clays of several applications, particularly in ceramics and earthenware industry, is fundamentally important for the development of raw material sector in Tunisia (Ben M'barek Jemai et al., 2015). Because of the challenges created by the opening of new markets and the increase of demands of national construction projects, the Tunisian clay industry has been one of the most dynamically developing businesses in Tunisia over the last decade (Boussen et al., 2016). The desired industrial application depended on the thermal behavior and the physicochemical characteristics as important properties for the industrial application extension of the studied materials (Ben M'barek Jemai et al., 2015). Numerous studies have been carried out on the clays or of raw materials used for traditional ceramic in Tunisia. Taking as an example, Bennour et al. (2015) studied the mineralogical, chemical and geotechnical characterizations, the firing behavior and the ceramic application of the Sejnéne clays (Northwest Tunisia). Mahmoudi et al. (2017) studied the mineralogical, chemical, physical and geotechnical properties carried out on cretaceous clays collected from the Zimlet El Beida in Gabes region in the southeast of Tunisia. Firing behavior and ceramic application are also conducted for these clay materials.

The study area includes Kasserine in Midwest Tunisia. The chemical and mineralogical compositions and the thermal behavior of this clay were carried out by Krichen et al. (Krichen et al., 2009). This study revealed that this clay raw materials contains 37 mass% in phyllosilicates, 25 mass% in quartz, 29 mass% in carbonates and 4 mass % in goethite and shows the presence of an important porosity even after firing for 4 h at 1100 °C. In order to obtain the required ceramic product performance and because of its lower bulk density value, this clay should be amended with non-plastic materials such as the sand, the chamotte and the waste brick.

The aim of this paper was to evaluate the ceramic properties of Tunisian clay from Kasserine region mixed with non-plastic minerals such as the sand, the waste brick and the chamotte in order to improve their physical and mechanical properties. The possible ceramic applications of five clay and non-plastic minerals mixtures (M1, M2, M3, M4 and M5) from Tunisia were investigated. A correlation between bulk density, tensile strength and water absorption of these mixtures according to the sintering temperature and the nature and the content of the non-plastic clay materials is examined in order to optimize the production process and enhance the quality of the final products.

2. Materials and analytical methods

2.1. Materials

2.1.1. Clay

The studied clay was selected from Kasserine (Midwest Tunisia). The chemical composition of the clay raw material (Table 1) shows that the major elements are SiO_2, CaO and Al_2O_3. The amounts of MgO, Fe_2O_3, K_2O and Na_2O are significant. From XRD analyses (Fig. 1), it is

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Table 1
Chemical composition (mass%) of the clay (Krichen et al., 2009) and the non-plastic clay.

Oxides	Al_2O_3	SiO_2	K_2O	MgO	CaO	Fe_2O_3	Na_2O	SO_2	P_2O_5	Cr_2O_3	Mn_2O_3	TiO_2	ZnO	L.O.I*	Total
Clay	9.87	41.70	2.87	4.94	16.46	3.84	1.04	–	–	0.01	0.06	0.39	0.13	18.60	99.91
Sand	0.93	94.58	0.29	–	–	–	3.81	–	–	–	–	–	–	0.36	99.97
Waste brick	12.79	59.36	4.03	1.15	4.79	12.87	1.41	0.48	1.10	–	–	–	–	2	99.98
Chamotte	34.65	62.53	1	–	–	–	0.68	0.35	0.32	–	–	–	–	0.43	99.96

L.O.I*: loss of ignition at 1200 °C.

found that this clay is mainly constituted of quartz, calcite, phlogopite, kaolinite and illite. Krichen et al. (2009) revealed that these clay raw materials is mainly contains illite (8 mass%), phlogopite (17 mass%), kaolinite (12 mass%), quartz (25 mass%), calcite (29 mass%) and goethite (7 mass%).

2.1.2. Non-plastic minerals

The non-plastic clay used is the sand, the waste brick and the chamotte. The chemical compositions, determined by ICP analysis, of the non-plastic clay are reported in Table 1. The major constituent present in the sand is SiO_2. The chemical composition of the waste brick shows that the major elements are SiO_2, Fe_2O_3 and Al_2O_3. The amounts of CaO and K_2O are higher than those of MgO, Na_2O and P_2O_5. The major elements present in the chamotte are Al_2O_3 and SiO_2. The XRD diagrams of the non-plastic constituents are represented in Fig. 1. The sand is constituted only of quartz phase, while the waste brick is mainly constituted of anorthite, hematite and quartz and the chamotte is made up of mullite, cristobalite and quartz.

2.2. Preparation of mixtures and ceramic products

Initially, the raw materials were homogenized, finely ground (< 63 μm) and heated for 2 h at 350 °C for the organic complete combustion. Five mixtures were prepared with the following composition: 70 mass% clay + 30 mass% of non-plastic mineral materials. The composition of the various samples is given in Table 2. After weighting, the mixtures were homogenized by humid way: firstly, the powders were dispersed in distilled water by mechanical agitation for 5 min. Secondly, the water was evaporated progressively under continuous agitation at 110 °C until getting a dough. Thirdly, the dough was dried at 110 °C during 24 h. Finally, the homogeneous mixture clods were finally ground using a mortar.

Table 2
Sample composition (mass%).

Sample label	Clay	Waste brick	Sand	Chamotte
M1	70	30	–	–
M2	70	15	15	–
M3	70	–	30	–
M4	70	–	–	30
M5	70	–	15	15

The obtained powders were dried pressed at 150 MPa. Cylindrical pellets were produced with dimensions suitable for the Brazilian test (20 mm diameter and 5 mm thickness). The specimens were then fired in an electric furnace between 900 and 1100 °C using heating and cooling rates of 10 °C/min and 12 min dwell time at maximum temperature.

2.3. Characterization techniques

The chemical analysis of major and trace elements in the samples were measured using a Perkin Elner 8300 DV ICP-AES plasma torch. The sample was previously dissolved within an acidic solution using a microwave device under appropriate pressure and temperature cycles.

The mineralogical analyses of powders were carried out by X-ray

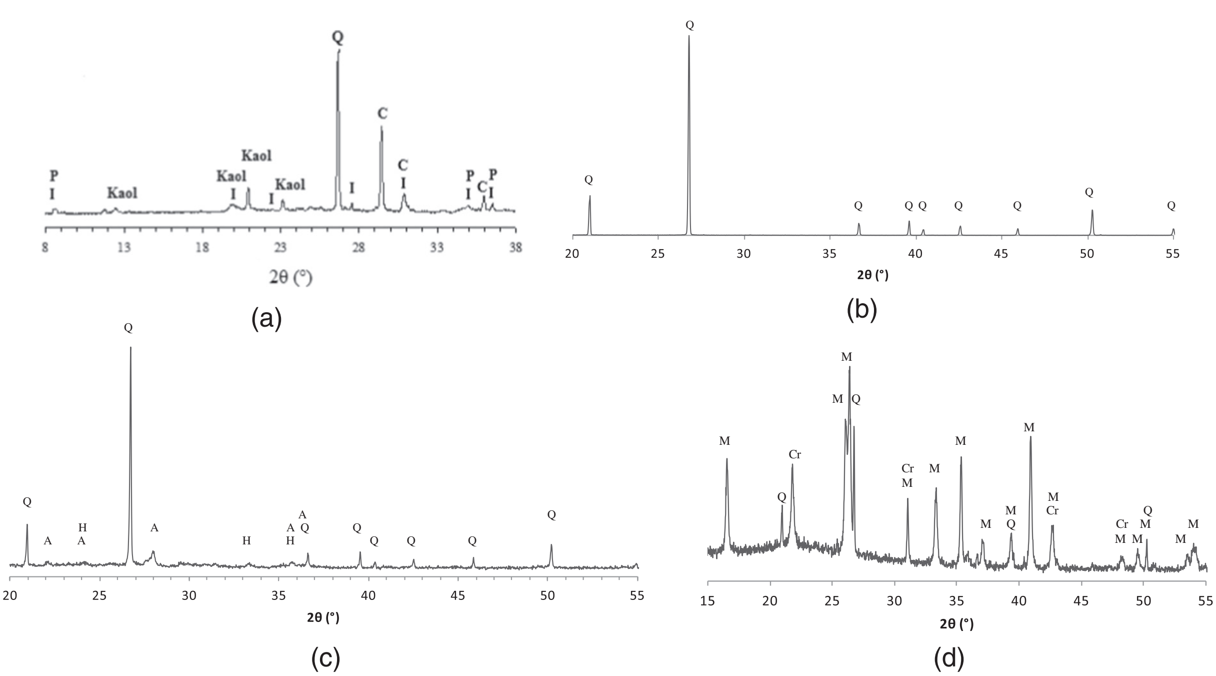

Fig. 1. XRD diffractograms of the clay (a) (Krichen et al., 2009), sand (b), the waste brick (c) and the chamotte (d). Legend: Kaol: kaolinite, I: illite, P: phlogopite, C: calcite, Q: quartz, A: anorthite, H: hematite, M: mullite and Cr: cristobalite.