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Suitability of soils and river deposits from Marrakech for the manufacturing of earthenware



Hicham El Boudour El Idrissi^{a,b,*}, Lahcen Daoudi^a, Meriam El Ouahabi^b, Achille Balo Madi^c, Frédéric Collin^d, Nathalie Fagel^b

^a Laboratoire de Géosciences et Environnement (LGSE), Département de Géologie, Faculté des Sciences et Techniques, Université Cadi Ayyad, BP 549 Marrakech, Morocco

^b UR Argile, Géochimie et Environnement sédimentaires (AGEs), Département de Géologie, Quartier Agora, Bâtiment B18, Allée du six Août, 14, Sart-Tilman, Université de Liège, B-4000, Belgium

^c Physico-chemistry of Mineral Materials Laboratory, University of Yaoundé I, and Local Materials Promotion Authority, MINRESI/MIPROMALO, PO Box 2396, Yaoundé, Cameroon

^d Laboratoire de Géotechnologies, Département ArGEnCo, B52, Sart-Tilman, Université de Liège, Liège B-4000, Belgium

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ABSTRACT

This paper investigates the suitability of clayey materials originating from semi-arid soil and river sediments, used by potters in the Agafay region for the manufacture of ceramic products. The clay samples were subjected to particle-size analysis, X-ray diffraction and X-ray fluorescence to investigate their physical, mineralogical and chemical characteristics respectively. The physical behaviour of the intermediate products was studied at the shaping and drying stages of the ceramics manufacturing process through the Atterberg limits and the plot of the Bigot curve respectively. The final product characteristics were determined through porosity tests, flexural and compressive strengths tests. Based on results obtained, the raw materials turn out to be suitable characteristics for the manufacture of earthenware products. The application of the suggested recommendations is worthy for the improvement of the products based on such raw materials.

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1. Introduction

The Marrakech area (central region of Morocco), is characterised by a semi arid climate, which renders difficult the practice of agriculture and necessitates the use of modern irrigation methods. But, due to economic reasons, these modern irrigation methods are within the reach of only a marginal part of the population. Thus, part of this land is used by an alternative income -generating activity- the production of earthenware. Many artisans are involved in ceramics production, but still persistent is the issue linked to the quality of the final products: cracks, lime blowing, melting of pieces and heterogeneous coloration. Moreover, no Moroccan standard yet exists for this activity. The selected site of Agafay (20 km south-west of Marrakech city, Fig. 1) is one of sites in the region with the most important artisanal ceramic manufacturing activity. With over 70 active workshops, the site is the main provider of the Marrakech region and other Moroccan cities with the traditional pottery dishes and bricks. This study aims to improve the quality of the final ceramic products, to assess the suitability and to supply new data for the use of raw materials from soil and river deposits in various ceramic applications. The results obtained

and recommendations suggested in this study can be applied to other neighbouring sites.

2. Material and methods

2.1. Material

The raw materials studied were collected from potters in their workshops and originate from soils of the Agafay village (Ag1, Ag2, Ag3 and Ag4) and from clayey deposits of N'Fis River (Nfs). These materials are relatively poor in organic matter due to their semi-arid climate area origin. Potters remove the upper part of the soil (up to a depth of approximately 30 cm) to reach the exploitable layer of about 50 cm thick. This clearance favours the decrease in organic matter and coarse particles contents in the material. The potters extract clayey material from the exploitable layer and thoroughly mix it with the required amount of water to obtain a homogeneous distribution with limited air-bubbles. The first category of raw materials (soil of Agafay village) is used to produce dishes locally called "Gasriyas", while the second (clayey deposits of N'Fis river) is used to produce traditional fired bricks and tiles.

2.2. Methods

The particle size distribution of the raw samples was determined by wet sieving for the fraction with grain diameter >40 µm. The fraction

* Corresponding author at: Université Cadi Ayyad, Département de Géologie, Faculté des Sciences et Techniques, 549 Marrakech, Morocco.

E-mail address: h.e.elidrissi@gmail.com (H. El Boudour El Idrissi).

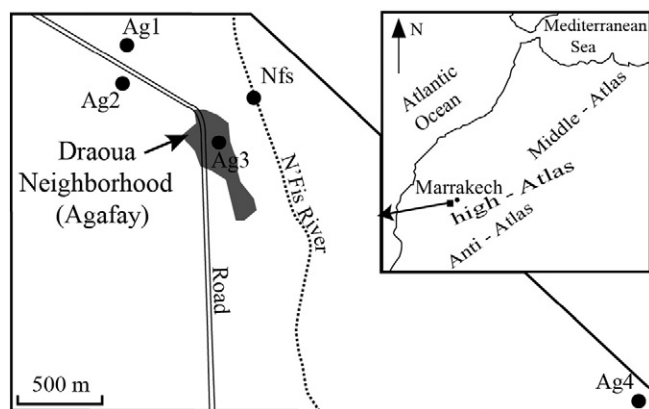


Fig. 1. Location map of the studied site and samples.

with grain diameter $<40\ \mu\text{m}$ was introduced for 24 h into a 100 ml deionized water tank, and was stirred from time to time before being analysed by a Horiba LA-300 laser diffraction analyser. The variation of linear drying shrinkage with water content was measured using the Bigot curve (Kornmann, 2006) on specimens (size: $16\ \text{cm} \times 4\ \text{cm} \times 1\ \text{cm}$) obtained by pressing the clay paste. The same specimens were used to determine the variation of linear firing shrinkage with respect to weight loss. The volatiles content (combined water, organic and inorganic matter) were determined by Loss-On-Ignition (LOI) measured on dried samples heated at $550\ ^\circ\text{C}$ for 4 h, then at $950\ ^\circ\text{C}$ for 2 h (Heiri et al., 2001).

The identification of the mineralogical phases of raw materials and neoformed phases of fired products was carried out by X-ray diffraction using a Bruker D8-Advance diffractometer with $\text{CuK}\alpha$ radiations (scan step size: 0.02° ; time/step: 0.6 s; anode: copper with $K\alpha = 1.5418\ \text{\AA}$). Qualitative identification was based on the method used by Moore and Reynolds (1997). Semi-quantitative identification have been described in Cook et al. (1975) and in Boski et al. (1998) for bulk sample, and in Fagel et al. (2003) for clay fraction. The latter was prepared from the fraction $<2\ \mu\text{m}$ of decarbonated sediments. After removing carbonates from the crushed rock with 0.2 N HCl, deflocculation of clays was done by successive washing with deionized water and centrifugation at 3000 rpm. The size-fraction $<2\ \text{mm}$ was separated by sedimentation following Stokes' law, and later placed on glass slides as oriented aggregates. The intensity of each peak was multiplied by a corrective factor. The intensity of the clay fraction was measured on ethylene glycol spectra. The porosity was determined by the absorption of water (Meyer et al., 1994) in specimens fired at different temperatures. Only the major elements (Si, Al, Ca, Fe, K; Mg, Mn, Na, Ti, P) were analysed by X-Ray Fluorescence (XRF) on lithium–borate fused glass (Duchesne and Bologne, 2009).

The plasticity indices were calculated after the determination of Atterberg limits (Casagrande, 1948). The flexural and compressive strength were also carried out on cylindrical and rectangular specimens fabricated respectively by rolling and pressing and then fired at $950\ ^\circ\text{C}$ and $1050\ ^\circ\text{C}$. The machines used are a "Testometric Micro350" for the flexural strength and a "compression machine made in University of Liege" (ArGenCo Laboratory) for the compressive strength, equipped with a worm gear motor NEFF and controlled by a Microstep Drive (Parker) and a compumotor PC23 adaptor.

Small fragment (3 mm long) of fired bricks were carbon-coated for electrical conductivity purpose and subjected to Scanning Electron Microscopy (SEM) coupled with EDX microanalysis in order to observe the texture of the specimens and to control the chemical composition of grains blowing.

Part of the experiments was carried out in University of Cadi Ayyad (particle size, linear shrinkage, and LOI) and the other part in University of Liege (mineralogical and chemical composition, plasticity indices, mechanical strength, and SEM-EDX).

The physical parameters were focused on samples Ag1, Ag2 and Nfs as they are the main ones used for ceramic manufacturing in the area.

3. Results and discussion

3.1. Composition and pastes behaviour

3.1.1. Particle-size distribution, mineralogical composition and plasticity

According to the particle size distribution (Table 1), Ag1 and Ag4 samples can be classified as silty clay, Nfs and Ag3 as sand-silt-clay, while Ag2 ranges between these two compositions. The contents in the different mineralogical phases of raw materials vary. These constituents range from clay minerals as plastic and binder components to siliceous sand as skeletal components and finally feldspars and fine carbonates as fluxing agents (Table 1).

The liquid and plastic limits of samples for the manufacturing of bricks (Nfs) are higher than those for the manufacturing of Gasriyas whereas they have close plasticity indices (16–17). The presence of organic matter (OM) provides various advantages during manufacturing. It acts as a binding agent providing more strength to the wet clay and greenwares (Skibo et al., 1989). OM also helps to improve the plasticity of the clayey material (Odell et al., 1960) after rotting in a moisturized clayey material for a few days (Husein Malkawi et al., 1999). However, a high organic matter content is disadvantageous (Skibo et al., 1989).

3.1.2. Drying behaviour

The Bigot curve (Kornmann, 2006) gives the shrinkage rate with respect to the mixing water content (Fig. 2A). Upon drying, the colloidal water (resulting from the difference between normal shaping water [FN] and interposition water [EI]) evaporates first. The interposition water then escapes later on leading to the appearance of intergranular pores.

From the Bigot curve we can determine the critical phase of the drying process at which cracks may appear. This phase requires a slow drying in damp and shadow conditions. The water content of this critical phase is stands between the moisture content of normal shaping and the interposition water, i.e. the beginning of drying process. Ag1 and Ag2 have the same behaviour on drying, except for the more abundant shaping water in Ag1 that increases the height of the curve (Fig. 2A). The shrinkage limit (Table 2) correlates with the smectite content of the paste (Table 1) due to the high absorption capacity of this mineral. The colloidal and the interposition waters play a key role in the drying process: the higher the colloidal water content, the more difficult the drying process; the higher the interposition water content, the less difficult the drying process (Kornmann, 2006). For the Nfs paste, the drying is more difficult at the beginning and becomes easier later on. The drying process must be conducted with caution, especially at its early stage, to avoid cracks.

The increase of shaping pressure facilitates the contact between the grains. This renders possible the reduction of the mixing water content, resulting in lower colloidal water, interposition water, end of linearity, shrinkage rate and porosity (Carretero et al., 2002). This hence shifts the curves closest to the shrinkage axis, as it is the case for sample Ag2. Lower mixing water content is used in Ag2 compared to Ag1 despite the slightly higher clay content in the former. The mixing water content was close to the plastic limit for Ag2. This required the application of a higher pressure during shaping to overcome the toughness of the paste.

3.2. Fired samples behaviour

3.2.1. Influence of chemical and mineralogical compositions

The predominant oxides (SiO_2 and Al_2O_3) are mainly associated with the clay minerals. The SiO_2 content is also associated with quartz particles. The content of iron oxide is sensitive to the firing conditions. It often produces unexpected results in the colour and texture of the fired clays (Molera et al., 1998; Ngun et al., 2011). All the studied

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