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5 authors, including:

Manuel Acosta-Alejandro
Universidad Juárez Autónoma de Tabasco

C.G Treviño-Palacios
Instituto Nacional de Astrofísica, Óptica y Elect…

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Microstructural Characterization of Fired Clay Bricks in the Chontalpa Region, Tabasco, Mexico

E. Custodio-García[1], M. Acosta-Alejandro[1], L. I. Acosta-Pérez[1], C. G. Treviño-Palacios[2], and D. Mendoza-Anaya[3]

[1]*Academic Division of Basic Sciences, Autonomous University Juárez of Tabasco, Tabasco, México*
[2]*National Institute of Astrophysics, Optics, and Electronics, Puebla, México*
[3]*Gerencia de Ciencias de Materiales, Instituto Nacional de Investigaciones Nucleares, D.F., Mexico*

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In the Mexican state of Tabasco, clay-like materials are of particular interest in the handcraft and construction industries. Combining both and due to the abundance of clay on this region, fired clay bricks are commonly used in construction. These are done in an artesian way without proper quality control. We present a chemical content analysis study for three particular areas in the Chontalpa region in Tabasco, where the mud used to produce the fired clay bricks is obtained. It is found that the mineralogical composition and firing temperature influence the brick porosity promoting textural and physical changes.

Keywords Aggressive environments; Building materials; Crystalline phases; Durability; Fired clay bricks; Firing temperature; Microstructural characterization; Mineralogical composition; Moisture; Pollution; Porosity; Radiation solar; Raw clay; Textural properties; Vitrification.

1. Introduction

An important objective in modern house building is the selection of the new materials to make a comfortable and durable building. The durability of building materials is strongly influenced by environmental conditions (e.g., solar radiation, moisture, and atmospheric pollution) [1–3]. Control of the microstructural properties, such as the porosity and the mineralogical composition, is considered a key parameter for the durability of different building materials [4–7]. New materials are studied and the durability parameters are determined, nevertheless there is an amount of wisdom on the traditional material selection in each region of the world. The variety of materials is the most abundant in the friendly climate for that particular region. In particular, in central Tabasco, Mexico, clay bricks have been used for a long time [1, 6]. These are made in an artisan way, without control of microstructural properties. The firing of clay bricks and the presence or absence of different minerals produce mineralogical, textural, and physical changes that influence porosity and pore distribution. For example carbonates in the raw clay brick promote the formation of fissures and pores when the bricks are fired between 800 and 1000°C [7]. Organic waste material increases porosity in a clay body, increasing the insulation capacity [8]. On the other hand, Tabasco is a region that presents an aggressive environment high in precipitations, monthly average relative humidity of 80%, monthly average temperatures of 30°C, and pollution emission sources due to petroleum exploration and exploitation [9]. Therefore, it is important for the local artisan brick-making industry to know the relationships AQ3
among the raw clay composition, firing temperature and porosity of solid bricks manufactured in Chontalpa region, using the microstructural analysis.

2. Materials and method

In order to observe the differences in the fired clay brick manufacturing procedure, a study was performed on clay samples obtained from different areas in Tabasco state, Mexico. The selected areas were three sites: Villahermosa, Cardenas, and Comalcalco. From each of the three sites, five clay solid bricks were prepared by hand, using a homogeneous mixture of clay (80%), sand (20%), and water to make the clay material, and placed in a wooden mould to shape the bricks with dimensions from $0.28 \times 0.13 \times 0.60$ m [1]. The pieces were subsequently sun-dried for two or three days, depending on the weather conditions. They were later fired in an electric oven with a 10°C/min heating ramp at a preset temperature which was maintained constant for 12 hours. The selected temperatures were 200°C, 400°C, 600°C, 800°C, and 1000°C. The texture and porosity evolution of the fired clay brick samples were studied by scanning electron microscopy (SEM), using a JEOL SEM model JSM 5900LV operating at 20 kV and 12 Pa pressure in the sample chamber and equipped with an EDAX solid-state energy-dispersive X-ray detector. The crystalline phase changes were determined by X-ray diffraction (XRD) using a diffractometer (Siemens model D5000) with copper target at 0.05° and 1 second integration in the 5° to 75° range on the 2θ scale.

3. Results and discussion

The fired clay bricks exhibit a range in color from orange (for low firing temperature) to dark red (for high firing temperature). For different samples, the texture and

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AQ2 Address correspondence to M. Acosta-Alejandro, División Académica de Ciencias Básicas, Universidad Juárez Autónoma de Tabasco, Carr. Cunduacán –Jalpa de Méndez, Km. 1.5, Tabasco, 86690 México; E-mail: manuel.acosta@dacb.ujat.mx

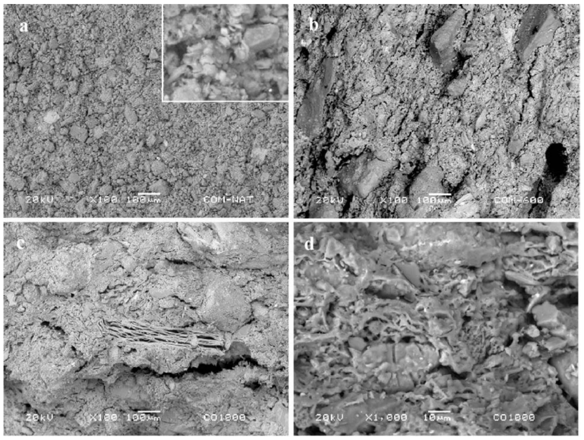

FIGURE 1.—SEM images for the Comalcalco site of the clay bricks: (a) in raw phase, (b) fired at 600°C, (c) fired at 1000°C, these were obtained to 100×, and (d) clay brick fired at 1000°C obtained to 1000×.

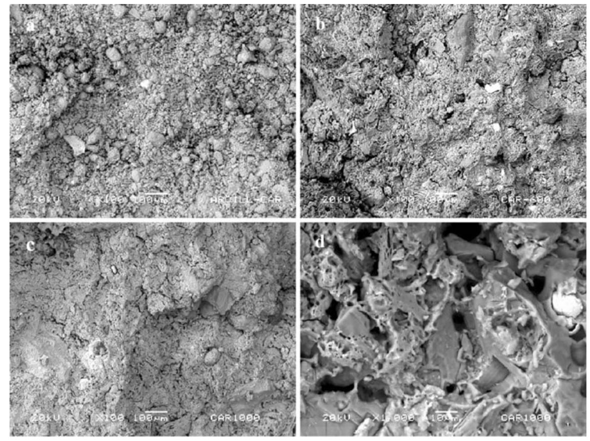

FIGURE 2.—SEM images for the Cardenas site of the clay bricks: (a) in raw phase, (b) fired at 600°C, (c) fired at 1000°C, these were obtained to 100×, and (d) clay brick fired at 1000°C obtained to 1000×.

crystalline evolution of the fired clay bricks were observed by SEM and XRD, respectively. A micrograph of the raw clay brick for Comalcalco shows a granular appearance with particle size ranging from 1 μm to 100 μm. However,
F1 higher magnification exhibits a faceted structure Fig. 1(a). In the first stages of firing, around 100°C, there is only loss of water, and we can recover the raw clay mixture adding some water. We can observe significant changes in the microstructure and physical properties of the clay bricks at T > 200°C. There is an apparent increase in particle size and some cracking at 600°C (Fig. 1b), and when the fired temperature exceeds 600°C, the brick acquires a reddish color and conglomeration of particles. At higher fired temperatures, between 800°C and 1000°C, the microstructure is further modified exhibiting vitrification and a dark red color. Vitrification can be clearly detected when the sample is fired at 1000°C Figs. 1(c) and (d). Similar behavior is present in the samples from Cardenas
F2 (Fig. 2) and Villahermosa (Fig. 3). Additionally, during the
F3 evaporation process, deformation and cracking are observed under the microscope.

The elemental composition of the raw clay bricks was
F4 obtained using EDAX (Fig. 4). We can observe that the main elements are oxygen (O), aluminum (Al), silicon (Si), iron (Fe), and in smaller quantities sodium (Na), magnesium (Mg), potassium (K), calcium (Ca), titanium (Ti), and
T1,T2,T3 fluorine (F). Tables 1, 2, and 3 show the crystalline phases present for raw and fired clay bricks at 200, 400, 600, 800, and 1000°C for Comalcalco, Cardenas, and Villahermosa sites, respectively. The tables show that the raw clay bricks have the albite, quartz, montmorillonite, biotite, and nacrite phases. When the clay bricks are baked, we observe the disappearance of some phases and the appearance of others. Similar results were observed for the Cardenas (Table 2) and Villahermosa (Table 3) sites. The crystalline phase evolution with respect to the baking temperature is similar for the three cases. At higher temperatures we have observed the disappearance of montmorillonite and biotite phases and the appearance of anorthoclase and hematite phases.

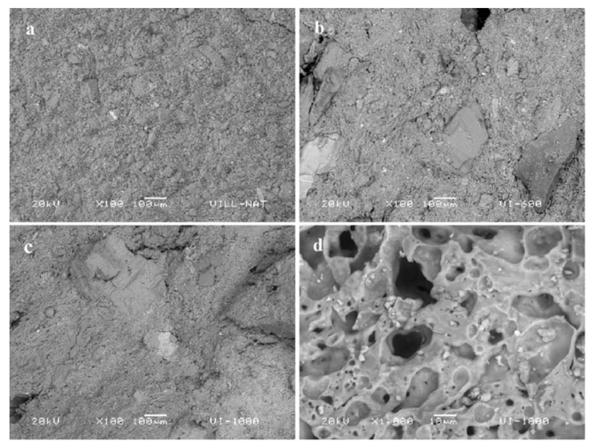

FIGURE 3.—SEM images for the Villahermosa site of the clay bricks: (a) in raw phase, (b) fired at 600°C, (c) fired at 1000°C, these were obtained to 100×, and (d) clay brick fired at 1000°C obtained to 1000×.

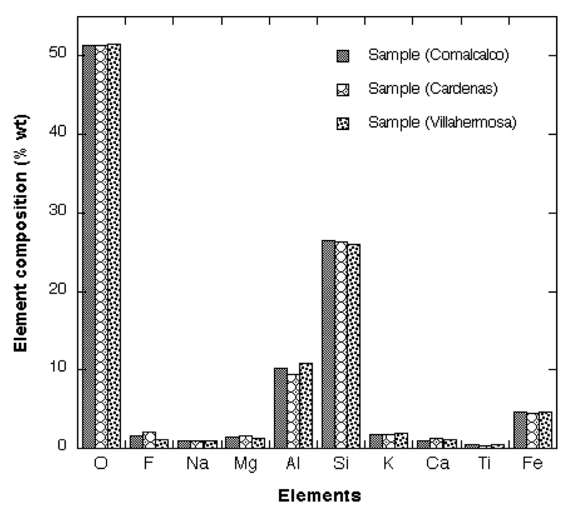

FIGURE 4.—Elemental composition (wt.%) of the raw clay for the three sites.

TABLE 1.—Main crystalline phases for raw and fired clay bricks at different temperatures for the Comalcalco site.

Crystalline phase	Raw	200°C	400°C	600°C	800°C	1000°C
Albite ($NaAlSi_3O_8$)	√	√	√	√	√	√
Quartz (SiO_2)	√	√	√	√	√	√
Montmorillonite [$CaO{\cdot}2(Al,Mg)_2Si_4O_{10}(OH)_2{\cdot}4H_2O$]	√	√	√	√		
Biotite [$K(Mg,Fe^{+2})3(Al,Fe^{+3})Si_3O_{10}(OH,F)_2$]	√	√	√	√	√	
Nacrite ($Al_2Si_2O_5(OH)_4$)	√	√	√			
Anorthoclase ($NaO{\cdot}71KO{\cdot}29AlSi_3O_8$)					√	
Hematite (Fe_2O_3)					√	√

TABLE 2.—Main crystalline phases for raw and fired clay bricks at different temperatures for the Cardenas site.

Crystalline phase	Raw	200°C	400°C	600°C	800°C	1000°C
Albite ($NaAlSi_3O_8$)	√	√	√	√	√	√
Quartz (SiO_2)	√	√	√	√	√	√
Montmorillonite [$CaO{\cdot}2(Al,Mg)_2Si_4O_{10}(OH)_2{\cdot}4H_2O$]	√	√	√	√	√	
Biotite [$K(Mg,Fe^{+2})3(Al,Fe^{+3})Si_3O_{10}(OH,F)_2$]	√	√	√	√		
Nacrite ($Al_2Si_2O_5(OH)_4$)	√	√	√			
Anorthoclase ($NaO{\cdot}71KO{\cdot}29AlSi_3O_8$)					√	√
Hematite (Fe_2O_3)					√	√

TABLE 3.—Main crystalline phases for raw and fired clay bricks at different temperatures for the Villahermosa site.

Crystalline phase	Raw	200°C	400°C	600°C	800°C	1000°C
Albite ($NaAlSi_3O_8$)	√	√	√	√	√	
Quartz (SiO_2)	√	√	√	√	√	√
Montmorillonite [$CaO{\cdot}2(Al,Mg)_2Si_4O_{10}(OH)_2{\cdot}4H_2O$]	√	√	√	√	√	
Biotite [$K(Mg,Fe^{+2})3(Al,Fe^{+3})Si_3O_{10}(OH,F)_2$]	√	√	√	√	√	
Nacrite ($Al_2Si_2O_5(OH)_4$)	√		√			
Anorthoclase ($Na0{\cdot}71K0{\cdot}29AlSi_3O_8$)		√	√	√	√	√
Hematite (Fe_2O_3)						√

4. CONCLUSIONS

1. SEM and XRD show that the firing temperature and mineralogical composition are relevant parameters for porosity and its evolution in clay bricks.
2. Relevant changes in the microstructural properties are observed between 800 and 1000°C. The reduction of porosity and vitrification occurring at these temperatures produces a material with higher quality.
3. Thus this study may have important implications in the artisan brick-making industry.

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