Influencia de la adición de un 2% de carbonato de calcio en el proceso de fabricación de los ladrillos de cerámica roja: etapas de secado y cocción

Influence of the addition of 2% calcium carbonate during the manufacturing process of red ceramic brick: drying and firing stage

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Fecha de Recepción: 02/05/2013

Fecha de Aceptación: 15/07/2013

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Resumen

El trabajo hace un estudio de la influencia de la adición del 2% de carbonato de calcio en la duración de la etapa de secado y la eficiencia de la etapa de cocción durante el proceso de fabricación de ladrillos de cerámica roja. Dicho estudio se realizó en una fábrica que produce ladrillos huecos con una capacidad instalada de 65000 ladrillos por cada quema. Los resultados del estudio realizado demostraron que la adición de un 2% de CaCO_3 a la pasta arcillosa disminuye el tiempo de secado en un 35% con respecto a los ladrillos elaborados sin adición y provoca una disminución del consumo de combustible del 27 % con respecto a quemas anteriores realizadas sin la adición de este fundente debido a la reducción del tiempo de cocción en los hornos.

Palabras Clave: Cocción, secado, eficiencia energética, fundentes, ladrillos de cerámica roja

Abstract

The work studies the influence of the addition of 2% calcium carbonate during the drying stage and the efficiency of the firing stage during the manufacturing process of red ceramic bricks. The study was conducted in a factory producing hollow bricks with an installed capacity of 65,000 bricks per burning. Results from the study showed that the addition of 2% CaCO_3 to the clay paste reduces the drying time by 35% compared with bricks made without addition, and causes a 27% reduction of the fuel consumption in relation to previous burnings without the addition of this flux, due to the reduction of the firing time in the ovens.

Keywords: Firing, drying, energy efficiency, fluxes, red ceramic bricks

1. Introduction

Usually, the manufacturing process of red ceramic bricks is composed of 5 stages: extraction of raw materials, preparation of ceramic pastes, molding, drying and firing. All of them require an effective quality control of the processes.

There is no doubt that compliance with the standards set for each manufacturing stage is important to achieve both their efficiency and the quality of the end product, but there are two key stages which fall within the so-called "thermal processing", which have a significant impact on the energy efficiency in the manufacturing of ceramic products in general: that is, drying and firing.

Although firing is considered the most important part of the manufacturing process of ceramic products, the drying process is of major importance. During this stage, there are several alterations in the dimensions and physical characteristics of the pieces, which can entail irreversible defects, such as cracking and deformation, if certain conditions are not met.

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Therefore, it is necessary to optimize the quality of this stage as much as possible (Sisti, 2002; Sisti, 2004a; Xavier, 2001; Berteli, 2005).

The water contained in the ceramic body can be found in the following ways:

- Interstitial water.
- Hygroscopic water.
- Crystallization and/or composition water.

Interstitial water is found among clay particles, weakly adhered to them and with migration possibilities from the body's interior towards the surface, due to a moisture gradient in the body. This water is eliminated from the body's surface, as a consequence of its dissolution in the air circulating around it; in other words, the drying speed is primarily controlled by the humidity conditions of the drying air (Sisti, 2002; Sisti, 2004a; Xavier, 2001; Berteli, 2005).

Therefore, residual water in ceramic pieces will depend on factors such as:

- Nature of the clays.
- Temperature of the system.
- Drying time.

As mentioned above, the nature of clays affects the drying time; bricks have to be made with sandy clay soils with a sand content of 25-30% in relation to the clay material content; if the soil does not have this sand percentage, it can be added directly in order to improve its properties. This particle size, either present or not, is usually called tempers, which are responsible for reducing clays' plasticity and their drying shrinkage, since they do not retain the water while reducing brusque mass shrinkage that lead to checking of the elements. Another function is to increase the strength of the pieces; these materials should be added in a finely ground manner so as not to reduce the homogeneity of the pastes (Xavier, 2001).

In the literature, the use of finely ground calcium carbonate is referred to as temper (Xavier, 2004; Sisti, 2004a; Juarez Badillo, 1972), stating that due to its physical and granulometric characteristics it acts as a natural temper that partially interferes in the reactions occurring inside the bricks; in a first phase, it regulates the drying time and then accelerates the reactions during firing (Xavier, 2004).

The use of finely ground calcium carbonate in very small doses (2-5% range) has also been reported (Betancourt, 2008), with the purpose of improving the energy efficiency of the firing process without affecting the properties of the baked red clay brick. It has been demonstrated that the addition of calcium carbonate quantities oscillating between 2% and 5% of the clay mass improves the bricks' compressive strength at temperatures close to 900°C, and sintering times of 1-3 hours.

This effect is attributed to the alterations of the clays' reactions during the thermal treatment by the presence of calcite mineral, which allows sintering at lower temperatures in the studied clays, in whose mineralogical composition the presence of kaolinite and montmorillonite is confirmed (Betancourt, 2008).

This paper is based on the principle of using small doses of calcium carbonate (2% in relation to the clay volume) as flux additive in the production of baked bricks, and its main purpose is studying the effect of this addition on the drying stage duration and the energy efficiency of the firing stage of red ceramic bricks.

2. Discussion and development

The experimental work was divided in two. In the first part, the possible effects on the drying stage of the 2% CaCO_3 addition, ground to a particle size of 150 μm , were studied. First, the changes during drying time were verified, associated to the material's moisture changes and the volumetric contraction of baked bricks in this stage of the manufacturing process.

The second stage of the experiment consisted in measuring fuel consumption, firing time and temperature in a discontinuous type of oven with capacity for 6,800 bricks per burning, with the aim of studying the influence of the 2% calcium carbonate addition on the energy efficiency of the firing stage. Both stages of the experimental work were performed in the Combinado de Cerámica Roja: "Sergio Soto" located in the township of Manicaragua, in the province of Villa Clara, Cuba.

2.1 Organization of the Experiment

In this research, clay material extracted from the Carranchola mineral deposit in La Moza was used, which is a large deposit located northwest of Manicaragua in the province of Villa Clara, containing kaolinite and montmorillonite clays, as shown in the X Ray Diffraction trials (XRD). (See Figure 1).

Figura 1. Resultados DRX de la comparación de fases en la roca arcillosa y la fracción arcillosa

Figure 1. XRD results for the phase comparison in the clay rock and the clay fraction

The calcium carbonate used as flux was extracted from the quarry of Palenque in the township of Remedios in the province of Villa Clara. The XRD analysis of the CaCO_3 (Figure 2) identified the main mineral phases as kaolinite, as well as the presence of dolomite [$(\text{CaMg}(\text{CO}_3)_2)$], which is very common, since both minerals can be found together in the nature.

Figura 2. Resultados DRX del carbonato de calcio procedente de la cantera de Palenque

Figura 2. XRD results for calcium carbonate extracted from the Palenque quarry

2.2 Brick Manufacturing

Bricks were manufactured with and without calcium carbonate addition in the study of both the drying and firing stages.

For the bricks with and without calcium carbonate addition, the mixing of raw materials was made in a pallet mill. With the purpose of obtaining the right dosing and homogenization of the clay material paste plus the flux additive for bricks manufactured with 2% CaCO_3 , the volume measurement of the added quantity considered the mixer's volume as reference volume. In order to add the calcium carbonate, a 0.01m^3 capacity container was used, with the aim of measuring the quantity of CaCO_3 to be added to the clay material accumulated in the mixer (0.7m^3), pouring 0.014m^3 of calcium carbonate per batch (see Figure 3).

Figura 3. Adición del CaCO_3 al material arcilloso, a) Adición del CaCO_3 b) Mezclado del material arcilloso con el CaCO_3

Figure 3. Addition of CaCO_3 to the clay material, a) Addition of CaCO_3 b) Mixing of the clay material with CaCO_3

The bricks were shaped and pressed in a vacuum extruder with a pressure of 7 MPa; after being shaped, they presented initial moisture between 15% and 17%, with established dimensions of 28cm long, 11cm wide and 7.5cm thick.

The drying process of the pieces with and without CaCO_3 addition was performed in the factory's covered bay, in the shade and in a natural way, with relative humidity of 90% and room temperature of 30°C.

During firing, the factory's small oven with intermittent operation and burner in the lower part was used, with capacity to process up to 6,800 units per burning. Two burnings were carried out: the first one denominated standard or control burning for bricks without CaCO_3 addition, and the second one for the same number of pieces with 2% added CaCO_3 . In both firing processes, temperature measurements were made at points located in the oven's doors. The temperature control was made by introducing a K-type temperature sensor of the brand METRA-202, placed in three holes (T_1 , T_2 , T_3), located in the oven doors (see Figure 4); measurements were made every hour.

Figura 4. Esquema del horno con capacidad para 6800 ladrillos

Figure 4. Oven model with capacity for 6,800 bricks

3. Discussion of Results

3.1 Influence of CaCO_3 in the drying process of red ceramic bricks

Figure 5 shows the evolution of the moisture percentage variation in relation to time, for the samples produced with and without CaCO_3 addition.

Figura 5. Gráfico de tendencia de Reducción del contenido de Humedad vs. Tiempo de secado de los ladrillos en la fábrica

Figura 5. Trend chart for moisture content reduction vs. drying time of the bricks at the factory

In the charts we can clearly observe that the moisture percentage eliminated by time unit is strongly related to the CaCO_3 content. The moisture % decreases from approximately 16% (extruder's outgoing moisture) to 5% (suitable moisture to enter the oven) in a 5-day timespan for the drying of bricks with CaCO_3 addition and 8 days for bricks without additive.

Based on this result, it is demonstrated that the performance reached during the drying process of the bricks with CaCO_3 addition is higher in more than 35% of the time in relation to the drying process of bricks without additive. According to the consulted authors (Xavier, 2004; Berteli, 2005; Juárez Badillo, 1972), this result could indicate an influence of non-plastic raw materials such as CaCO_3 on ceramic pastes, improving shaping and changing the structure of the capillary spaces towards the formation of pores with greater length and connectivity, facilitating the drying process and the elimination of the composition water during preheating in the bricks' firing stage, which favors a possible reduction of the energy consumption.

In order to verify the above statement in a simple way, mostly in relation to the capillary space phenomenon and the pore size, an "oedometer" test is carried out, also known as soil consolidation test, which is applied in soil samples with and without CaCO_3 addition. The test verifies the void ratio (e) under pressure (P) (see Figure 6), which makes it possible, when applying the physical equations related to the capillary space effects provoked by the surface tension (Juárez Badillo, 1972), to determine an equivalent pore diameter (D_0) for each sample with and without the CaCO_3 addition. The main results are shown below in Table 1.

Tabla 1. Relación de vacíos equivalente (e_0) en ladrillos

Tabla 1. Equivalent void ratio (e_0) in bricks

Relación de vacíos (e_0) ladrillos/ Brick Vaid Ratio (e_0)		
	0% de CaCO_3 /0% de CaCO_3	2% de CaCO_3 /2% de CaCO_3
Peso promedio húmedo W_s (g)/ Mean moist weight W_s (g)	3270	3180
Volumen promedio seco V (cm^3)/ Mean dry volume V (cm^3)	1940.08	1957.18
Peso específico del suelo $\delta_d = W_s/V$ (g/cm^3)/ Soil density $\delta_d = W_s/V$ (g/cm^3)	1.69	1.62
GS (g/cm^3)/ Specific Gravity SG (g/cm^3)	2.63	2.63
Relación de vacíos (e_0) $e_0 = (GS/\delta_d) - 1$ / Void ratio (e_0) $e_0 = (GS/\delta_d) - 1$	0.56	0.62

Table 1 shows the void ratio (e_0) obtained for each tested brick sample. When comparing both results, we observe that bricks with addition of 2% CaCO_3 show a slight increase in the void ratio (0.62), compared with the samples without additive (0.56). This evidences a porosity increase in the pieces produced with CaCO_3 addition.

The void ratios obtained from the bricks with and without CaCO_3 addition, together with the curves of the oedometer test (see Figure 6), allow determining the pressure to be applied to reach each one of the previously determined void ratios, which allows defining an equivalent pore diameter through the Terzaghi equations, as shown in Table 2.

Figura 6. Gráfico de relación de vacíos Vs Presión de compactación

Figure 6. Chart of void ratio vs. compaction pressure

Tabla 2. Diámetro equivalente (D_0) en ladrillos**Tabla 2.** Equivalent diameter (D_0) in bricks

Diámetro equivalente de poros (D_0)/ Equivalent pore diameter (D_0)		
	0% de CaCO_3 /0% of CaCO_3	2% de CaCO_3 /2% of CaCO_3
Tensión superficial (T_0) (g/cm)/ Surface tension (T_0) (g/cm)	0.074	0.074
Presión (P) (g/cm ³)/ Pressure (P) (g/cm ³)	4000.00	500.00
D_0 (cm) $D_0 = 4 \cdot T_0 / P$	0.000074	0.000592
D_0 (μm)	0.74	5.92

In the results' comparison, we observe that when adding CaCO_3 to the clay soil used for brick manufacturing, the capillary spaces facilitate the moisture flow from the inside to the outside, since they are more open in the samples containing 2% CaCO_3 ; thus, it provides a better elimination of the pore water, and this could be one of the reasons explaining the lesser drying time. These results have been obtained by a test which induces the pore diameter through compaction pressure (Juarez Badillo, 1972).

3.1.1 Influence of CaCO_3 on the contraction during the bricks' drying process

The above results are verified based on the relation between the variables of moisture %, volumetric contraction and the drawing of the Bigot curves (Tari, 1997), as shown in Figure 7. In the first place, even if the Bigot curves have a close relation with the clay material's granulometry (Fernández, 1990), these results showed a strong dependence due to the use of CaCO_3 as additive on the drying mechanism; in spite of working with the same type of drying, the relation of contraction versus moisture loss percentage variation follows different paths.

Figura 7. Gráfico de Pérdida de Humedad vs. % Contracción volumétrica (curva de Bigot)**Figure 7.** Chart of moisture loss vs. volumetric contraction % (Bigot curve)

Based on these curves, we can infer that to eliminate the same moisture percentage there is less contraction in the bricks made with calcium carbonate addition, compared with the bricks without addition, mostly in the moisture range between 6% and 13%, although both have a similar final contraction.

According to the consulted literature (Xavier, 2004; Fernández, 1990; Juárez Badillo, 1972; Cárdenas, 2009), these results could indicate a reformulation of the ceramic paste with the addition of CaCO_3 mineral that acts as a temper or non-plastic material, which reduces the plasticity of the paste and the contraction, mainly because tempers lose water without contracting (Xavier, 2004, Juárez Badillo, 1972). Therefore, a clay soil with higher temper content will present less contraction.

With the purpose of understanding the influence of CaCO_3 on plasticity and being able to clarify and/or confirm the above hypothesis, a plasticity test was carried out (Atterberg Limits) on clay soil samples with and without CaCO_3 addition. Results are shown in Table 3.

Tabla 3. Límites de plasticidad de muestras de suelo arcilloso con y sin CaCO_3

Table 3. Plastic limits of clay soil samples with and without CaCO_3

LIMITES/LIMITS	0% de CaCO_3 / 0% of CaCO_3	2% de CaCO_3 / 2% of CaCO_3
Límite líquido (%) / Liquid limit (%)	34,1	32.2
Límite plástico (%) / Plastic limit (%)	16.9	19.1
Índice de plasticidad (%) / Plasticity index	17.2	13.2

When comparing results, it was found that clay material samples mixed with 2% CaCO_3 showed a 23.3% drop of the plastic indexes, compared with the clay material samples without additive; therefore, when increasing the CaCO_3 content, there is less plasticity and contraction. This result is consistent with the consulted references on the matter (Juárez Badillo, 1972; Xavier, 2004; Sisti, 2004b).

3.2 Evaluation of the CaCO_3 influence on temperature, firing time and fuel consumption in the production of bricks

Figure 8 shows the evolution of the temperature-time ratio for the firing of bricks made with and without 2% CaCO_3 . This type of oven does not have reliable control systems for temperature and time; this difficulty was overcome with the personal effort of the authors, who controlled these basic parameters inside the oven by means of a thermocouple or K-type temperature sensor of the brand METRA-202, and the permanent monitoring of the operations, in which the know-how of the baker was a deciding factor.

Figura 8. Curvas de Temperatura de Cocción Vs. Tiempo de las quemas con y sin adición de CaCO_3

Figure 8. Curves of firing temperature vs. burning time with and without CaCO_3 addition

The charts show the existence of two well-defined zones with different interpretations for both firing processes. The first one corresponds to the preheating stage, mainly characterized by a gradual temperature increase (Segment A – B), and the second stage corresponds to the burning process defined by a constant temperature fluctuating between 800°C and 950°C (Segment B – C). Each one of the stages describes the firing process and they are associated to the elimination of crystallographic water (Segment A – B) and the formation of crystalline phases, which give hardness to the bricks (Segment B – C) (Xavier, 2001; Betancourt, 2008; Cultrone, 2004; Vidal, 2001).

As can be appreciated in the curves, there are differences in the duration of the firing process, which was considered finished using the main criterion of the bakers' experience. During firing of the bricks with calcium carbonate addition, time was reduced by 5 hours, compared with the burning of bricks without addition, which confirms the flux action of the CaCO_3 in the ceramic pastes when small doses are used.

Figure 9 shows the fuel consumption for each burning. A significant 27% reduction was observed in the fuel consumption for the firing of bricks with 2% addition of CaCO_3 , which means fuel savings in relation to the control burning or without additive of 951 fuel liters per burning. This result is consistent with the firing time reduction, but it is also influenced by the flux effect of the CaCO_3 in small doses, described in the literature (Betancourt, 2008).

Figura 9. Consumo de combustible

Figure 9. Fuel consumption

4. Conclusions

1. It is demonstrated that the addition of 2% CaCO_3 to the clay paste used in the manufacturing of bricks, significantly reduces the drying time by 35% in relation to the bricks made without addition.
2. The results of the contraction and plasticity tests indicated that the CaCO_3 acts as a temper in the ceramic pastes, regulating the contractions and contributing to the moisture loss.
3. The obtained results indicate that CaCO_3 addition to the clay soil used for brick manufacturing helps capillary spaces to facilitate the moisture flow from the inside to the outside, since they are more open in the samples containing 2% CaCO_3 ; thus, it provides a better elimination of the pore water, and this could be one of the reasons explaining the lesser drying time.
4. The CaCO_3 addition to the clay soil used in the manufacturing of baked bricks entailed a reduction of the firing time, which affects the resulting reduction of fuel consumption by 27%, compared with bricks baked without additive.

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