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Influence of the firing process on water absorption and compressive strength in ceramic samples

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Abstract. It presents the evaluation of water absorption and compressive and flexural strength in perforated blocks manufactured in a Hoffman-type kiln of brickworks Ocaña, Colombia. Combustion gases are reused in the firing process and the samples are directly exposed to fire. Standardized non-destructive quality control tests such as dimensional, initial absorption rate and 24-hour immersion, and destructive tests such as compressive strength and modulus of rupture were performed. The firing process with higher fire exposure on the samples showed values of compressive and flexural strength and water absorption percentage according to current regulations. The samples comply with the values established in the standard and allow their use as non-structural masonry products for interior or exterior use.

1. Introduction

Masonry clay units and ceramic bricks and blocks are used in the construction of civil works, for their low costs and their property of thermal insulation [1]; these acquire desired properties and characteristics set by the standards during the firing process [2]. The useful life of civil constructions depends on the action of vertical or horizontal loads that can generate fractures in masonry pieces [3]; if their quality is not adequate increases the seismic vulnerability [4,5].

In Ocaña, Colombia, the ceramic industry presents a technological backwardness and most of the brickworks carry out a completely handcrafted work. In spite of that, they generate a significant number of direct jobs, becoming one of the main development alternatives for the region. The national government proposes that by 2020, the ceramic industry should be the national and binational leader in the field of high-quality ceramic products [6]. To achieve this goal, the ceramic industry in the region must be technified and studies carried out should show the improvement in the quality of the products offered in order to achieve competitiveness to remain in the current market, complying with the regulations of government agencies. This research allows knowing the mechanical properties of the products manufactured in brickworks Ocaña, located in Ocaña, Norte de Santander, Colombia, following the guidelines of the standard. This serves for future research in order to optimize the manufacturing processes of ceramic materials and promote the proper exploitation of it.

2. Methodology

The study was carried out in the Hoffman kiln of the Ocaña brickworks, which is dedicated to the series production of hollow bricks for construction. The kiln has a monthly production of 611.320 units, is



circular cross section with internal diameter 2.12 meters and a height and wall thickness of 4.52 meters and 0.24 meters respectively, and is composed of 24 chambers or doors (12 on each side), in each door, 5 piles are introduced, of 620 bricks per pile approximately, separated 60 cm between them. The fuel used for the material firing is pulverized coal, which is injected through the holes located in the kiln dome by means of carbojet at a rate of 8 kg to 12 kg of coal per minute [7], with a consumption of 170 Tonnes/month [8]. The firing process of the samples is with direct exposition to the combustion gases.

2.1. Selection of samples

The selection of the samples in the kiln was carried out according to the methodology, selection processes and sample preparation established in the Colombian technical standard [9], using nondestructive and destructive standardized quality control tests of masonry bricks as initial rate of absorption, water absorption test, dimensions, compressive strength and flexural strength. For each test, 5 samples of bricks were selected according to the established by the standard, for a total of 20 samples.

The sample dimensions (length, width and thickness of the walls and partitions) were measured with the purpose of comparing them with the dimensions established in the standard [10], for which a Standard Gage digital caliper of 350 mm with tolerances of 0.1 μm . For the compressive strength and flexural strength tests, a Pinzuar PU-100 universal testing machine with a capacity of 1000 kN and the statistical software Statgraphics were used, belonging to the Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia.

2.2. Initial rate of absorption test

The test measures the amount of water absorbed by the brick in 1 minute; for this, the surface area of the sample in contact with the water, the dry mass of the sample and the final mass of the sample after the test were determined.

To perform the sample measurements and weights, we used a Standard Gage digital caliper of 350 mm and a Pinzuar PG89 digital electronic scale. The evaluation of the initial rate of absorption for each sample was determined with the following Equation (1), where TIA= initial rate of absorption ($\text{g}/\text{cm}^2/\text{min}$.), G = difference in grams between the initial dry mass and the final mass of the sample per minute (g/min) and A = sample net area in contact with water (cm^2).

$$\text{TIA} = \frac{G}{A} \quad (1)$$

2.3. Water absorption test

The test measures the amount of water absorbed by the brick in 24 hours. For the test, samples were dried for 24 hours in a Pinzuar muffle furnace at a temperature of 110 $^{\circ}\text{C}$, then placed in a cooling chamber during 4 hours at a temperature of 24 $^{\circ}\text{C} \pm 8$ $^{\circ}\text{C}$ and humidity between 30% and 70%; at that time, the dry masses of the samples were determined and then they were submerged in a tank with clean water for 24 hours at a temperature between 15 $^{\circ}\text{C}$ and 30 $^{\circ}\text{C}$. Finally, the final mass of the sample was determined after the test. The evaluation of the absorption during 24 hours for each sample was determined with the Equation (2), where % absorption = sample water absorption for 24 hours, W_{ss} = final mass of the sample after the test (g) and W_s = dry mass of the sample (g).

$$\% \text{ absorption} = \frac{(W_{ss} - W_s)}{W_s} * 100 \quad (2)$$

2.4. Compressive strength test

The compressive strength test consisted of taking the sample to the fault and record the rupture load to determine the maximum compressive stress [11,12]. For the test, the samples were dried for 24 hours in a Pinzuar muffle furnace at a temperature of 110 $^{\circ}\text{C}$, then placed in a cooling chamber for 4 hours at a temperature of 24 $^{\circ}\text{C} \pm 8$ $^{\circ}\text{C}$ and humidity between 30% and 70%; later, we applied a thin 3 mm-

thickness layer of supermold quick dry plaster on each of the faces opposite to the load application; finally, the samples were taken to a universal machine, to which a neoprene band was placed to ensure that the load applied by it is uniform over the entire surface to bring it to failure [13,14].

The compressive strength is used as quality control in the elaboration of masonry clay units, and ceramic bricks and blocks [12], and is determined using formulas that relate the sample properties [13]. The compressive strength for each sample was determined with the Equation (3), where f'_{cp} = resistance to compression of the sample (MPa), W = maximum breaking load (N) and A = average gross area of the upper and lower surfaces of the sample (mm^2).

$$f'_{cu} = \frac{W}{A} \quad (3)$$

2.5. Flexural strength test

The sample preparation in the flexural strength test is the same as in the compressive strength test. In this test, the sample is placed between two supports and subjected to a point load in the center of the light of the upper face of the sample, by means of a 6 mm-thick support steel plate, until the sample is brought to failure, registering the breaking load and thus determining the flexural modulus.

The modulus of rupture for each sample was determined with the Equation (4), where MR = modulus of rupture of the sample (Pa), W = maximum breaking load (N), L = distance between supports (mm), B = net width of the sample in the failure plane (mm), d = depth of the sample in the failure plane (mm) and X = average distance from the failure plane to the center of the piece, measured in the direction of the central line of the surface under tension (mm).

$$MR = \frac{3W * \left(\frac{L}{2} - X\right)}{b * d^2} \quad (4)$$

3. Results

3.1. Physical characterization of the samples

The length, width, height and thickness dimensions of walls and partitions of the samples are shown in Table 1. The sample dimensions do not present uniformity, the length depends on the cut made by the extruder, while the other dimensions depend on the mold, in addition the samples undergo contractions in the natural drying and in their firing. In the length of the samples, the values vary between 30.20 cm and 30.40 cm, with an average of 30.32 cm; in the width of the samples, the values vary between 19.66 cm and 19.99 cm, with an average of 19.83 cm; in the height of the samples, the values vary between 9.89 cm and 9.93 cm, with an average of 9.90 cm; in the thickness of the walls, the values vary between 15.00 mm and 16.50 mm, with an average of 15.45 mm; in the partition thickness, the values vary between 7.95 mm and 8.90 mm, with an average of 8.30 mm

Table 1. Dimensions of walls.

Samples	Large (cm)	Width (cm)	High (cm)	Wall thickness (cm)	Thickness of walls (cm)
1	30.4	19.6	9.89	0.8	0.15
2	30.4	19.7	9.87	0.9	0.15
3	30.2	19.9	9.93	0.7	0.15
4	30.4	20.1	9.9	0.7	0.15
5	30.2	20	9.91	0.8	0.15

3.2. Test analysis

The result obtained in the tests for the initial rate of absorption and the water absorption can be seen in Figure 1. The initial rate of absorption of water varies from 0.11 $\text{g/cm}^2/\text{min}$ and 0.19 $\text{g/cm}^2/\text{min}$, with an average of 0.16 $\text{g/cm}^2/\text{min}$.

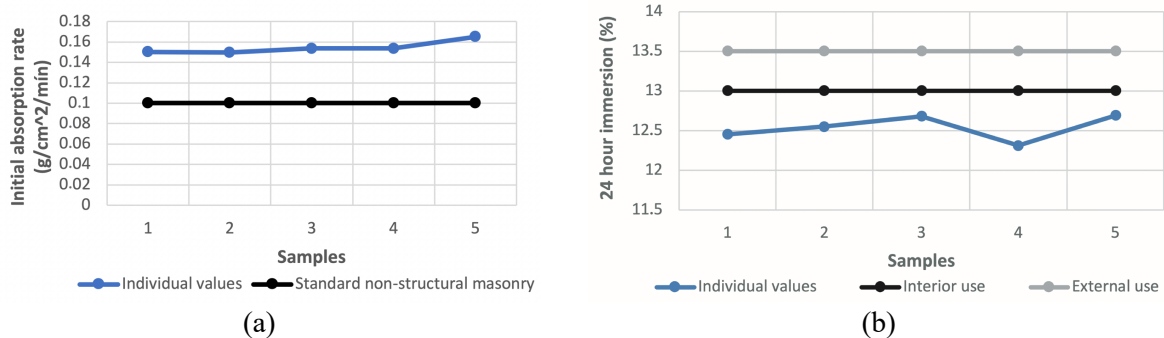


Figure 1. (a) Results of the initial rate of absorption test and (b) results of water absorption test.

According to the literature, in San José de Cúcuta, Norte de Santander department, Colombia, physical and mechanical properties studies have been carried out on two types of blocks [1], in which blocks with six and eight holes were considered.

The 24-hour immersion in the samples analyzed in this work varies between 12.31% and 12.69%, with an average of 12.54%; while in the samples from San José de Cúcuta, it ranges between 4.22% and 10.31%, with an average of 7.21%. The 24-hour absorption value in the study samples is 42.50% higher than the value in the samples from San José de Cúcuta, Colombia. The two samples comply with the standard and are below the maximum water absorption values, which must be 13.0% for interior use and 13.5% for exterior use. For this reason, this type of bricks can be used for interior and exterior use. The clays of Ocaña, Colombia, are of lower quality, because they will have more contraction and cracking, reducing the quality and stability of the finished product. The results obtained in the compressive strength and the flexural strength tests can be seen in Figure 2.

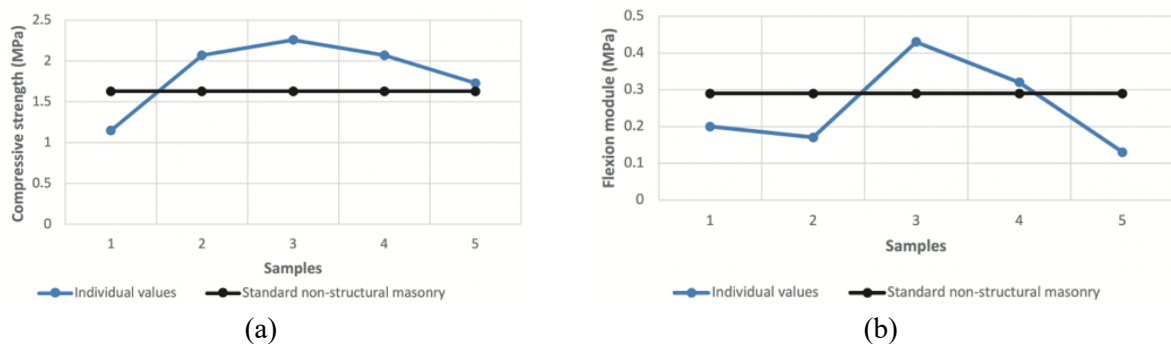


Figure 2. (a) Results of the compressive strength test and (b) Results of flexural strength test.

The average compressive strength for the samples analyzed in this work ranges from 1.15 MPa to 2.26 MPa with an average of 1.86 MPa; while in the samples from San José de Cúcuta ranges from 0.68 MPa to 6.82 MPa with an average of 3.19 MPa. The value for compressive strength in the samples from San José de Cúcuta is 266.67% higher than the value in the study samples. None of the two samples meets the standard of 14 MPa, indicating the high level of vulnerability to compression in solid brick walls used primarily in houses built using the earthquake-resistant confined masonry construction system; while the modulus of rupture fluctuates between 0.13 MPa and 0.43 MPa, with an average of 0.25 MPa.

4. Conclusions

The obtained results for the dimensions in the hollow bricks manufactured in the Ocaña, Colombia, brickworks must be standardized, since there is no uniformity among them, so the mold must be

designed taking into account the contractions and expansions suffered by the raw material of the samples in the drying and firing.

The average value in the wall thickness in the hollow bricks is 1.55 cm, above the minimum thickness established according to the standard of 1.00 cm for non-structural masonry, which complies with the established in the standard; while the average value in the partition thickness in the hollow bricks is 0.83 cm, above the minimum thickness established by the standard of 0.60 cm for non-structural masonry, complying with the standard.

According to the technification of the kiln used to fire the samples, an adequate distribution of the samples in the kiln, a proper fuel injection and the regulation of the air necessary for combustion, allowed the samples in the firing process to take greater advantage of the heat provided by the burning of coal, improving their behavior and meeting the requirements established in the standard.

The average value in the initial rate of absorption of water for hollow bricks is 0.16 g/cm²/min, so it complies with the established in the standard of 0.10 g/cm²/min. These high values could be due to a poor mix, poor process of artisanal grinding, poor firing process by the manufacturer, which generates the presence of surface pores allowing the brick to quickly absorb a large amount of water affecting the mortar adherence and consistency.

The average value in the water absorption test for hollow bricks is 12.54%, which is below the maximum water absorption values according to the standard, which must be 13.0% for indoor use and 13.5% for outdoor use, which is why this type of bricks can be used for indoor and outdoor use.

The average value in the compressive strength for hollow bricks is 1.86 MPa, being in the range between 1.63 MPa and 2.94 MPa established in the standard, so it complies with the mechanical resistance values established in the standard.

The average value in the modulus of rupture for hollow bricks is 0.25 MPa, being outside the range between 0.29 MPa and 0.884 MPa established in the standard, so it does not comply with the established values in the standard.

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