ANALYSIS OF THE PROCESS OF PRODUCTION AND THE COMPRESSIVE STRENGTH OF CERAMIC BLOCKS FOR NON STRUCTURAL MASONRY – CASE STUDY

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ABSTRACT

The manufacture of the red pottery in the State of Pernambuco (Brazil) is done in the empirical and conservative form. Thus it lacks technological control. The objective of this article is to contribute to the understanding of the current quality of the ceramic blocks used in the civil construction sites in the State of Pernambuco. This article shows an analysis of the composition from the raw material, the process of production and the final quality of the ceramic blocks and prisms from a ceramic specific industry. Visits to this ceramic industry located in the forest zone of Pernambuco gave us the opportunity for understanding the whole manufacturing process, seeing deposits of the raw material and observing its mixture and preparation. For the raw material, the results of granulometrie tests, limits of liquidity and plasticity, specific mass of the grains and moisture are presented. In the case of ceramic blocks and prisms, the tests of compressive strength, intended for non-structural masonry use, were performed.

KEYWORDS: Blocks and ceramic prisms, compressive strength, test of granulometry, limit of liquidity and plasticity, Winkler diagram.

INTRODUCTION

The non-structural horizontal hollow ceramic blocks have been widely used in the region for various constructive purposes, both in non-structural walls and in masonry buildings so-called “caixão”, with structural ends, see Figure 1. The abundance of clay mines in Pernambuco can be considered as the reason for the use of large ceramic blocks. The constant collapses of masonry buildings constructed with these ceramic blocks in the metropolitan region of Recife - Pernambuco motivated the development of this work.

OBJECTIVE

This article analyzes the efficiency of ceramic blocks such as their compressive strength, and gives the characteristics of the materials used in their production; both with the objective to show its weakness and inadequacy when used in structure of the building "caixão" in Pernambuco.

THE PRODUCTION PROCESS OF CERAMIC BLOCKS IN PERNAMBUCO

The production process of ceramic industry selected involves the following steps as explained by its manager of production:

1. mixture, in the proportion 1:3 (clay dark: clay red), implemented in the courtyard of the industry with a front loader, Figure 2;
2. the mixture is placed in the feeder room, passes by the clay grinder to crush the bulk clay, goes on to the mixer, where the water is put in small quantity (in the winter, water is dispensed);
3. the mixture is inserted in the laminator, where the clay is extruded and cut;
4. the ceramic blocks remain sheltered in a covered storage shed, opened in lateral direction, during a period of 24 to 72 hours;
5. after this period, the raw blocks pass by the furnace tunnel in wagons, at a temperature of approximately 400 ^{0}C, for 24 hours;
6. then, the blocks are led to the brick oven tunnel, also in wagons where they are burned for 24 hours. This oven is divided into ten cells, with a temperature of approximately 400 ^{0}C at the entrance cell, maximum temperature of 806 ^{0}C in the central cell, and decreasing temperature until the exit of the furnace;
7. the blocks return, after leaving the oven tunnel, to shed for cooling for 12 hours;
8. nowadays, the algaroba (scientific name: Prosopis Juliflora) is the wood used for the burning process of ceramic blocks at the furnace and at the oven. Both, the oven and the furnace are 100m long.

Figure 1: "Caixão" building: a) Building under construction; b) Typical building of four floors, in which non-structural ceramic blocks were used for structural ends.

Figure 2: Preparation of the mixture for the ceramic blocks manufacturing

As another option, there is also the continuous oven, in which the blocks remain for 72 hours and are placed manually. The burning process is done using the same type of wood, placed through openings in the upper furnace. When this oven is used, then the furnace is dispensed.

EXPERIMENTAL PROCEDURE

To assess the quality of the ceramic blocks and prisms experiments tests were carried out at the Catholic University of Pernambuco (UNICAP) and explained in this section.
The materials used in the manufacture of non structural ceramic blocks are red clay, extracted from the site, and the dark one, extracted from the banks of a river in a neighbor city. In the region of the factory, there is a large concentration of industrial ceramics. Table 1 shows the coordinates of the deposits, provided by GPS, and as a point of reference topography laboratory from UNICAP.

Table 1: coordinates provided by GPS

Location	Horizontal	Vertical	BRG	Distance (Km)	Date
Red clay deposit	25M 0258338	UTM 9125487	164^o	21,1	11-07-05
Dark clay deposit	25M 0252598	UTM 9145822	000^o	0,0	11-07-05
UNICAP	25L 0291985	UTM 9109197	133^o	53,8	11-07-05

CHARACTERIZATION OF MATERIALS OF CERAMIC BLOCK

Samples were collected at the site of both clays, the dark clay (sample 2) and red clay (sample 3), together with the mixture (sample 1) in a 1 (dark): 3 (red) rate, for analysis in the Geotechnic Laboratory of the Catholic University of Pernambuco.

The Winkler Diagram aims to give an appropriate granulometric composition, so the mass does not produce very high plasticity. When this occurs, there are difficulties in the manufacture of parts. With the right mix of grains, a mass with adequate properties and appropriate characteristics is obtained to support the process of manufacturing products. The diagram of Winkler [1] is shown in Figure 3 and represented in Table 2 [2].

Table 2: Adequate granulometric composition for products of red ceramic

Types of products	Granulometric composition (%)		
	≤ 2μm	2 a 20μm	≥20μm
A. Materials of quality difficult of producing	40 a 50	20 a 40	20 a 30
B. Barrel clay roof tile	30 a 40	20 a 50	20 a 40
C. Hollow ceramic blocks	20 a 30	20 a 55	20 a 50
D. Ceramic brick	15 a 20	20 a 55	25 a 55

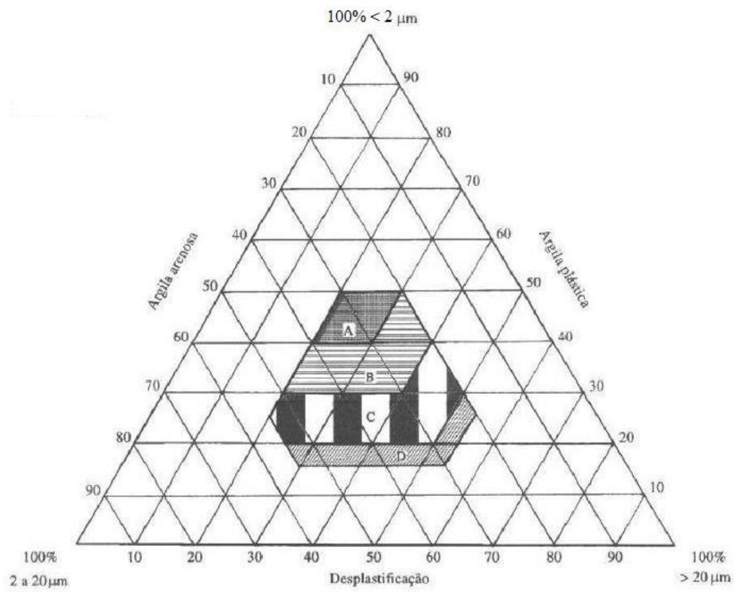

Figure 3: Granulometric diagram of Winkler (apud SANTANA e OLIVEIRA, 2007) [3]

SAMPLES PREPARATION

In this section the preparation of the blocks and prisms are explained.

BLOCK PREPARATION

The blocks preparation involves the following steps:

26 ceramic blocks were capped at both ends in a first stage of work (Figure 4), according to NBR standard 15270-3 (Ceramic components - Part 3: Ceramic blocks for structural and non structural masonry - test methods) [4]; after the hardening of the caps layer, the blocks were immersed into water for a period of 72 hours.

PRISM PREPARATION

The preparation involves 15 prisms, vertical layers or rows of masonry that bonded together by two ceramic blocks with dimensions 90 mm x 190 mm x 190 mm form the prism structure. The resting mortar of the ceramic elements was 1:1:6 proportions of cement, lime and sand, respectively. The cement used was type II PC - Z – 32 and the lime mortar was type CH 1 (layers or rows of masonry that, bonded together by two ceramic blocks, form the prism structure).

The ceramic prisms were cured in an environment, protected from the sun, during a minimum period of 28 days.

The capping process (Figure 5) was performed with cement paste, following the recommendations of NBR 15270-3 standard [4].

Figura 4: Ceramic blocks capped at both ends

Figura 5: Ceramic prisms capped at both ends

TESTS

In the second semester of 2005 tests were conducted to determine the compressive strength of the ceramic blocks and prisms to evaluate the current state of the quality of ceramic blocks used in construction works located in the State of Pernambuco.

DETERMINATION OF COMPRESSIVE STRENGTH OF CERAMIC BLOCK

For the determination of compressive strength, the ceramic blocks were numbered 1 to 26 (first stage) and theirs dimensions were measured. Then the compressive tests were conducted. The rupture stresses of the blocks were calculated using the following expressions:

$$\sigma_r = \frac{fc}{10.A_{base}} \quad (1)$$

Where:

σ_r - Ruputure stress in MPa (2)

fc - Load rupture in Kgf (3)

A_{base} - Área of the prism in cm^2 (4)

The Figures 6 and 7 show the sudden complete failure under load the of the ceramic blocks

Figure 6: Rupture of the ceramic block

Figure 7: Rupture of the ceramic block

DETERMINATION OF COMPRESSIVE STRENGTH OF CERAMIC PRISMS

For the determination of compressive strength, the prisms were numbered 1 to 15, and measured the width and length of blocks. Then, the ruptures were carried out, using a hydraulic press that meets the requirements of NBRNM-ISO7500-1: 2004 [5] obtaining the rupture loads in kgf. It was considered more 5.0 kgf, depending on the dead load of the press plate. Figure 8 shows a ruptured prism, forming a pile of superimposed layers of the block. The rupture stresses of the prism blocks were calculated using the expressions quoted in the previous item.

Figure 8: Ruptured prism

RESULTS

ANALYSIS OF CLAYS USED IN MANUFACTURE OF CERAMIC BLOCKS

The analysis results of clays used in the manufacture of ceramic blocks showed that the sample 3 bares no plasticity (see Table 3). The good plasticity of the mixture is due to the presence of dark clay (sample 2). Figures 9, 10, 11 show the graphs of the granulometry tests of red clay, dark and mixed at a ratio of 1:3, while figure 12 shows the results of the abacus of Winkler.

Table 3: results of the raw materials composition

	Samples		
	1	**2**	**3**
Compactation test			
Number of layers	3	3	3
Numbers of blows per layer	26	26	26
Results: maximum density (KN/m^3)	17,20	17,75	16,15
Optimum moisture content (%)	18,0	19,0	21,1
Tests for limit of liquidity and plasticity			
Liquid limit (%)	38,0	35,0	44,3
Plastic limit (%)	19,1	18,4	NP
Plasticity index (%)	18,9	16,6	NP
Determination of specific gravity of soil grains			
Average specific gravity of soil grains (KN/m^3)	$\gamma = 27,0$	$\Gamma = 25,7$	$\gamma = 27,0$
Granulometry test			
Clay (%)	32	24	11
Silt (%)	26	19	30
Sand (%)	41	57	55
Gravel (%)	1	0	4
Soil classification	Higlhly plastic	Higlhly plastic	-

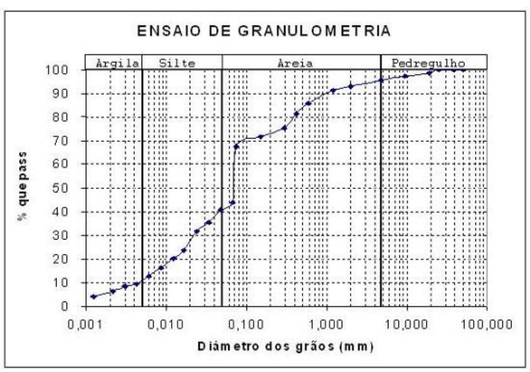

Figure 9: Granulometry test of red clay (sample 3)

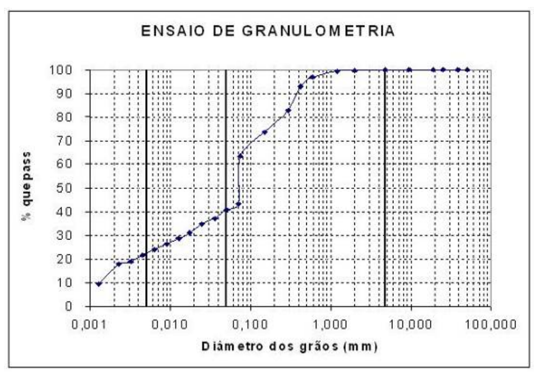

Figure 10: Granulometry test of dark clay (sample 2)

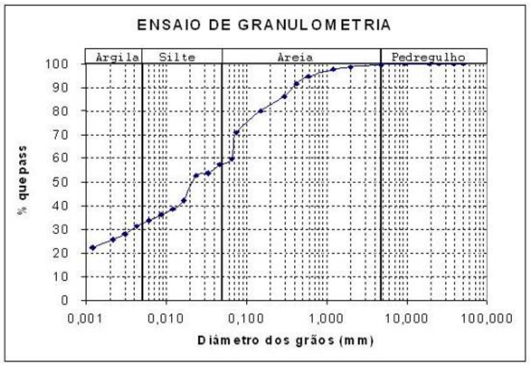

Figure 11: Granulometry test of mixture (rate 1:3) (sample 1)

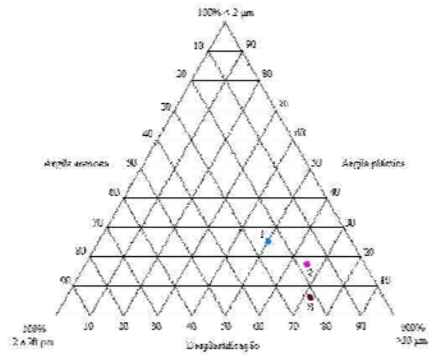

Figure 12: Granulometric diagram of Winkler of the samples 1, 2 and 3

COMPRESSIVE STRENGHT OF CERAMIC BLOCKS

Table 5 shows the results of compressive strength of the 26 ceramic blocks tested.

The arithmetic average of the resistance of the ceramic blocks was equal to 2.47 MPa. The standard deviation was equal to 0.485 MPa, which corresponds to the coefficient of variation (CV) of 19.6%. Sample 8 was not a representative one and was neglected because its result was too low.

Table 5: Compressive strength of the blocks

Block	Rupture load (Kgf)	Area of the Base (cm^2)	Resistance (Kgf/cm^2)	Resistance (MPa)
1	4493	9.0x19.4=174.60	25.73	2.573
2	5213	9.0x19.5=175.50	29.70	2.970
3	3780	9.0x19.3=173.70	21.76	2.176
4	3251	8.9x19.0=169.10	19.22	1.922
5	5336	8.9x19.2=170.88	31.23	3.123
6	4139	8.9x18.7=166.43	24.86	2.486
7	3723	9.1x19.1=173.81	21.42	2.142
8	1868	8.9x19.3=171.77	10.87	1.087
9	5606	8.9x19.3=171.77	32.64	3.264
10	4481	9.0x19.2=172.80	25.93	2.593
11	5602	8.9x19.0=169.10	33.13	3.313
12	4293	9.0x19.4=174.60	24.59	2.459
13	5633	9.0x19.3=173.70	32.43	3.243
14	4042	9.0x19.4=174.60	23.15	2.315
15	4303	9.0x19.0=171.00	25.16	2.516
16	4132	9.1x19.4=176.54	23.40	2.340
17	3797	9.1x19.4=176.54	21.51	2.151
18	3067	8.9x19.1=169.99	18.04	1.804
19	4426	9.0x19.3=173.70	25.48	2.548

20	3701	9.0x19.1=171.90	25.53	2.553
21	3874	9.2x19.0=174.80	22.16	2.216
22	3838	8.9x19.4=172.66	22.22	2.222
23	4621	9.2x18.9=173.88	26.57	2.657
24	4395	9.1x19.4=176.54	24.89	2.489
25	4646	8.9x19.3=171.77	27.04	2.704
26	4105	9.1x19.2=174.72	23.49	2.349

COMPRESSIVE STRENGHT OF CERAMIC PRISMS

Table 4 presents the results of compressive strenght of the 15 prisms. The arithmetic average of the resistance of prisms was equal to 1.642 MPa. The standard deviation was equal to 0.35 MPa. corresponding to the coefficient of variation of 21.3%.

Table 4: Compressive strenght of ceramic prisms

Prism	Rupture load (Kgf)	Area of the Base (cm^2)	Resistence (Kgf/cm^2)	Resistence (MPa)
1	1942	9.10x19.4=176.54	11.00	1.100
2	1767	9.3x19.4=180.42	9.79	0.979
3	3112	9.0x19.3=173.70	17.92	1.792
4	3423	9.0x19.3=173.70	19.71	1.971
5	3143	9.0x18.9=170.10	18.48	1.848
6	3289	8.9x19.2=170.88	19.25	1.925
7	2666	8.9x19.0=169.10	15.76	1.576
8	3538	9.0x19.0=171.00	20.69	2.069
9	3132	9.0x18.8=169.20	18.51	1.851
10	2184	9.0x19.0=171.00	12.77	1.277
11	2101	9.2x19.5=179.40	11.71	1.171
12	2921	9.1x18.9=171.99	16.98	1.698
13	3325	9.0x19.2=172.80	19.24	1.924
14	3271	9.0x19.3=173.70	18.83	1.883
15	2773	9.2x19.3=177.56	15.62	1.562

CONCLUSIONS

Considering the results obtained, we can conclude that the samples of the two types of clays are not suitable for use in the manufacture of products of red ceramic separately, because, both have greater granulometry in the range that corresponds to non-plastic material. It can be observed that the sample 1, as adopted by the manufacturer shows plasticity and granulometric composition in the proper range for hollow blocks in the granulometric diagram of Winkler [1], and can, therefore, be used in the manufacture of ceramic blocks. Thus, the empirical mixture, which has been used over generations, has proved suitable for the non-structural masonry usage.

All the blocks used had their dimension within the normative tolerances dimensions that set the width of 90 +5 mm and length of 190 +5 mm for the sole measurements. The blocks had: the minimum width of 89 mm and the maximum of 93 mm; the minimum length of 187 mm and the maximum of 195 mm.

The arithmetic average compressive strength of the blocks was equal to 2.47 MPa. This value is higher than the minimum resistance, recommended by NBR 15270-1 standard for non-structural masonry [6]. The blocks presented compressive strength within the range 1.80 MPa to 3.31 MPa. The coefficient of variation was 19.6% which shows low quality control of the production process. However, according to Brazilian standard NBR 15279-2 [7] these blocks did not attend the requirements for structural masonry.

The arithmetic average compressive strength of the ceramic prisms was equal to 1.64 MPa, corresponding to the efficiency coefficient of approximately 0.66 of the average compressive strength of ceramic blocks, proving to be of good efficiency for non-structural masonry. The blocks and prisms, tested without coating, had a sudden rupture forming a pile of superimposed layers.

The use of non-structural blocks for a different purpose of use might be one of the reasons for the collapses of many masonry buildings so-called "caixão" at the metropolitan area of the city of Recife (Pernambuco). These blocks should not be used for structural ends.

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