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INDUSTRIAL SCALE MANUFACTURING OF RED CERAMIC SEALING BLOCKS WITH ORNAMENTAL STONE WASTES

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ABSTRACT

Purpose: The objective of this work was to manufacture, on an industrial scale, sealing blocks, made in the red ceramic industry, incorporating ornamental stone wastes in percentages of 0%, 10% and 20% in the ceramic mass.

Theoretical framework: Red ceramics has an important paper in the construction industry. The sealing block is one of the most used products due to its thermal and acoustic insulation power. The state of Espírito Santo is one of the largest producers and exporters of ornamental stones in the country. The processing of these stones generate large amounts of fine waste. These wastes are deposited daily in ornamental stone landfills. Brazil generates around 2.5 million tons of fine waste per year, where the state of Espírito Santo is responsible for 2 million tons.

Method/design/approach: The sealing blocks were manufactured by extrusion in the size of 90x190x190 mm, without waste and with ornamental stone waste. After extrusion, the artifacts were dried in an oven for 7 days at 40°C. They were subsequently burned for 72 hours at a temperature of 900°C.

Results and conclusion: The results showed that the specimens manufactured with waste showed lower water absorption, which is a positive factor, they also met the geometric characteristics tests determined by the Brazilian standard for ceramic materials.

Research implications: Use ornamental stone waste that is deposited in millions of tons in landfills to manufacture red ceramic artifacts and thus contribute to reducing environmental impact.

Originality/value: Produce sealing blocks with ten holes in the red clay ceramic industry and certify their technological feasibility through tests established by Brazilian standards.

Keywords: Industrial Test, Sealing Block, Ceramic Artifacts, Ornamental Stones, Red Ceramic.

FABRICAÇÃO EM ESCALA INDUSTRIAL DE BLOCOS DE VEDAÇÃO DE CERÂMICA VERMELHA COM RESÍDUOS DE ROCHAS ORNAMENTAIS

RESUMO

Objetivo: O objetivo deste trabalho foi fabricar, em escala industrial, blocos de vedação, confeccionados em na indústria de cerâmica vermelha, incorporando resíduos de rochas ornamentais em percentuais de 0%, 10% e 20% na massa cerâmica.

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Referencial teórico: A cerâmica vermelha tem um papel importante na indústria da construção. O bloco de vedação é um dos produtos mais utilizados devido ao seu poder de isolamento térmico e acústico. O estado do Espírito Santo é um dos maiores produtores e exportadores de rochas ornamentais do país. O processamento dessas rochas gera grandes quantidades de resíduos finos. Esses resíduos são depositados diariamente em aterros de rochas ornamentais. O Brasil gera cerca de 2,5 milhões de toneladas de resíduos finos por ano, sendo o estado do Espírito Santo responsável por 2 milhões de toneladas.

Método/projeto/abordagem: Os blocos de vedação foram fabricados por extrusão no tamanho 90x190x190 mm, sem resíduos e com resíduos de rochas ornamentais. Após a extrusão, os artefatos foram secos em estufa por 7 dias a 40°C. Posteriormente, foram queimados durante 72 horas a uma temperatura de 900°C.

Resultados e conclusão: Os resultados mostraram que os corpos de prova fabricados com resíduos apresentaram menor absorção de água, o que é um fator positivo, também atenderam aos testes de características geométricas determinados pela norma brasileira para materiais cerâmicos.

Implicações da pesquisa: Utilizar resíduos de rochas ornamentais que são depositados em milhões de toneladas em aterros para fabricar artefatos de cerâmica vermelha e assim contribuir para a redução do impacto ambiental.

Originalidade/valor: Produzir blocos de vedação com dez furos na indústria de cerâmica vermelha e certificar sua viabilidade tecnológica por meio de testes estabelecidos pelas normas brasileiras.

Palavras-chave: Teste Industrial, Bloco de Vedação, Artefatos Cerâmicos, Rochas Ornamentais, Cerâmica Vermelha.

1 INTRODUCTION

Red ceramic products, bricks and sealing blocks, have evolved over the years and are applied in various sectors of civil construction, with greater use in masonry constructions, being, therefore, the largest Brazilian consumers of red ceramic (ANICER, 2023). The red ceramic industries, in the manufacture of ceramic artifacts, use natural clays contained in sedimentary deposits as their main raw material (Sant'Ana and Gadioli, 2018). According to the latest published data, it is estimated that in Brazil there are approximately 5,600 red ceramic industries (ANICER, 2023).

Brazil is the fifth largest producer of dimension stones in the world. The country exported US$ 1.34 billion and 2.40 million tons of ornamental stones in the year 2021 (ABIROCHAS, 2022). The state of Espírito Santo stands out in the Brazilian scenario, it is one of the largest producers and exporters of ornamental stones in the country, being responsible for 83% of the national production (ABIROCHAS, 2022). During the ornamental stone processing process, transforming the blocks into slabs, there is a great loss of material. Approximately 26% of a block of dimension stones, when processed, turns into fine waste (Silveira, Vidal, Souza, 2014). As the largest producer and exporter of ornamental stones, Espírito Santo is also the one that generates the most waste, approximately 2 million tons annually are discarded in landfills (Campos *et al.* 2014). Therefore, there are large amounts of waste that can be used.

Recent studies show that the wastes generated in the sawing of ornamental stone blocks with multiwire gangsaw are feasible to be incorporated in the manufacture of red ceramic artifacts. The fine wastes from the processing of ornamental stones are feasible for application and incorporation in the manufacture of red ceramic artifacts (Menezes, Neves, Ferreira, H. C, 2002). The incorporation of ornamental stone wastes in red ceramic artifacts helps to reduce the porosity of the material, which leads to an improvement in the technological properties (Aguiar, 2012). The use of 50% of these wastes in the mass of red ceramics, on a laboratory scale, can increase its mechanical resistance by up to 45%, which is why the incorporation of the waste is a viable alternative to reduce the environmental problems generated by their deposition (Sant'Ana and Gadioli, 2018). Using waste contributes to the circular economy, reducing environmental problems, sustainability and reducing disposal in landfills. Another preponderant factor is the decrease in the use of clay, which is a natural and non-renewable good.

To be used commercially, ceramic artifacts need to undergo normative technological tests. For this, they are submitted to the normative tests ABNT NBR 15270-1 Ceramic components — Blocks and bricks for masonry, part 1: requirements and ABNT NBR 15270-2 Ceramic components — Blocks and bricks for masonry, part 2: test methods (ABNT NBR 15270-1, 2017) e (ABNT NBR 15270-2, 2017). Ceramic artifacts, sealing blocks and bricks need to consider the specifications of these standards to attest that the manufactured product is suitable for commercial use.

Therefore, the central idea of this work is to take advantage of the fine waste from the processing of ornamental stones and also to certify its use in a technical and normative way. For this, sealing blocks with 10 holes and dimensions of 90X190X190 mm were manufactured on an industrial scale, and ornamental stone wastes were incorporated in the percentages of 0%, 10% and 20% in their ceramic mass and, finally, the feasibility was analyzed technological and economical following the norm of ABNT NBR 15270-1 and 2.

2 THEORETICAL REFERENCE

According to the latest published data on the sector, Brazil has around 5,600 ceramic and pottery factories, which generates around 18 million in annual revenue, in addition to generating around 293 thousand direct jobs and 900 thousand indirect jobs (ANICER, 2023). Up to 1.3 billion tiles and 4 billion sealing and structural blocks are produced per month. Products made from red ceramic are: sealing blocks, structural blocks, tiles, flagstones, shackles, pipes, bricks and household items such as filters and clay pots. The production of these products can occur with the most varied types of clay and processing techniques, therefore, the most varied properties can be expected (Pereira *et al*., 2011).

There are several types of red ceramic artifacts, including: tiles, solid bricks, sealing blocks, adoquim, ceramic shackles and other products. The most common in the construction industry are tiles and sealing blocks. All ceramic mass processing is almost always carried out using the same equipment in industrial plants. The process begins in the deposits. The clays used in the manufacture of ceramic artifacts are extracted close to the industries to reduce transport costs. After extraction, they are stored in piles in the ceramics yard for the seasoning process over a set period of time, which can be more than two years. This process aims to reduce the excess of organic materials and unwanted salts contained in clays and also promotes greater homogeneity, therefore contributing to higher quality of the final product (Gaidzinski *et al*., 2005).

The next stage is the formulation of ceramic masses to compose the artifacts. Most companies use more than one clay, which is why they are mixed according to the industry's formulation in pre-defined proportions. This initial mixing is carried out by wheel loaders in the ceramics yard itself. After this process, the ceramic mass goes to make the artifacts. The stages of homogenization, conformation, drying and firing of the ceramic pieces follow in sequence (Vidal *et al*., 2021). Some equipment changes its order sequence depending on the industrial plant of each ceramic industry.

The fifth most exported mineral-based product in Brazil is ornamental stones. The sector moves large quantities of materials, in the form of blocks, polished sheets and cut pieces such as tiles, countertops, sinks, finishes, among others (ABIROCHAS, 2022). Brazil is a country recognized worldwide for its great potential in the production of ornamental stones. It is in fifth place in the international ranking of the sector. In 2021, the country exported US$1.34 billion and 2.40 million tons of ornamental stones (ABIROCHAS, 2022).

The high production of ornamental stones results in the large generation of waste. They are divided into two main categories: coarse waste from the extraction/mining stage in quarries, and fine waste from processing plants. Processing waste can be divided into sawmill and polishing waste. Throughout the production chain, raw material losses of around 83% occur (Campos *et al*., 2014). Only 74% of a block becomes sheet when processed, the remainder is transformed into fine waste (Silveira, Vidal, Souza, 2014). Due to this, large amounts of waste are generated.

Adopting preventive environmental public policies means minimizing behaviors that negatively impact the environment and public health. With this in mind, on August 2, 2010, law Nº. 12,305 of the National Solid Waste Policy was implemented (BRASIL, 2010). establishes an order of priority in relation to waste generation. They are: non-generation, reduction, reuse, recycling, treatment and final disposal. Following this approach, the use of wastes from the processing of ornamental stones in ceramic mass for the manufacture of artifacts would be included in the reuse segment, a by-product. Therefore, its application would be a new use. Thus, it helps to reduce its final destination in landfills. According to Martínez (2022), investing in sustainability contributes to the company's growth and helps with long-term improvements. Socio-environmental practices can generate benefits, as they improve employee goodwill, along with morale and productivity (Mota and Pimentel, 2021).

Since the 1990s, ornamental stone waste has been studied for possible applications. Due to the large production of ornamental stones and, consequently, the enormous amount of waste generated, the scientific community began to research and analyze its possible applications in ceramic artifacts and other materials. Calmon *et al*. (1998) mention the incorporation of fine waste from ornamental stones in the manufacture of soil-cement bricks. These bricks were created from a mixture of clay, cement and stone waste to create ceramic artifacts. More current work also shows the possibility of using the waste of ornamental stones in red ceramic artifacts. Aguiar and Gadioli (2020) carried out laboratory tests incorporating ornamental stone wastes into ceramic masses in proportions of 20% and 40%, fired at temperatures of 850°C and 950°C. Therefore, these studies prove that there is the possibility of applying the waste of ornamental stones in ceramic artifacts.

3 METHODOLOGY

The ceramic mass composed of two clays and the fine waste from the processing of ornamental stones was used to carry out the industrial manufacturing of the red ceramic sealing blocks. The waste was collected in an ornamental stone processing industry in the municipality of Cachoeiro de Itapemirim-ES.

3.1 Characterization of Raw Materials

The chemical characterization of the raw materials was performed using X-ray fluorescence. The levels shown, expressed in percentage (%), are averages of 3 readings and were determined by semiquantitative analysis (standardless) in an X-ray fluorescence spectrometer (WDS-1), AxiosMax model (Panalytical). The determination of the loss by calcination (LOI) of the samples was carried out in Muffle. Aliquots of each sample were separated, placed in the muffle at 1000°C for 16 hours and after cooling were weighed to verify the loss by calcination.

Mineralogical characterization was performed by X-ray diffraction using the powder method. Data were collected in a Bruker-D4 Endeavor equipment, under the following operating conditions: Co Kα radiation (35 kV/40 mA); goniometer speed of 0.02° 2θ per step with a count time of 1 second per step and collected from 5 to 80° 2θ. Qualitative spectrum interpretations were performed by comparison with standards contained in the PDF02 database (ICDD, 2006) in Bruker AXS "Diffrac.Plus" software.

The particle size distribution of the ceramic mass composed of clays was obtained using a combined method of sieving and sedimentation by gravimetry, in accordance with the technical standard of ABNT NBR 7181 (ABNT NBR 7181, 2018). The equivalent spherical diameter of the sample particles is calculated using the law of Stokes, in which the determining sedimentation velocity depends on particle size and fluid viscosity.

The particle size distribution of the fine waste from the processing of ornamental stones was obtained in the Malvern Mastersizer equipment using the low angle laser light scattering technique, known generically as "light scattering".

3.2 Industrial Manufacturing of Sealing Blocks

The industrial manufacture was carried out in a ceramic company, located in the municipality of Itapemirim - ES. It made its facilities available for carrying out the work.

The ceramic artifact manufactured was the sealing block with 10 holes and dimensions 90x190x190 mm. This material is widely used in masonry works due to its thermal and acoustic insulation properties. Compositions were prepared with the ceramic mass incorporating the fine waste of ornamental stones in the percentages of 0%, 10% and 20%, for the manufacture of red ceramic sealing blocks. The control sample, with 0% waste, was prepared for comparison with which wastes were incorporated. Figure 1 shows the flowchart of the industrial plant for the manufacture of red ceramic sealing blocks with the incorporation of waste.

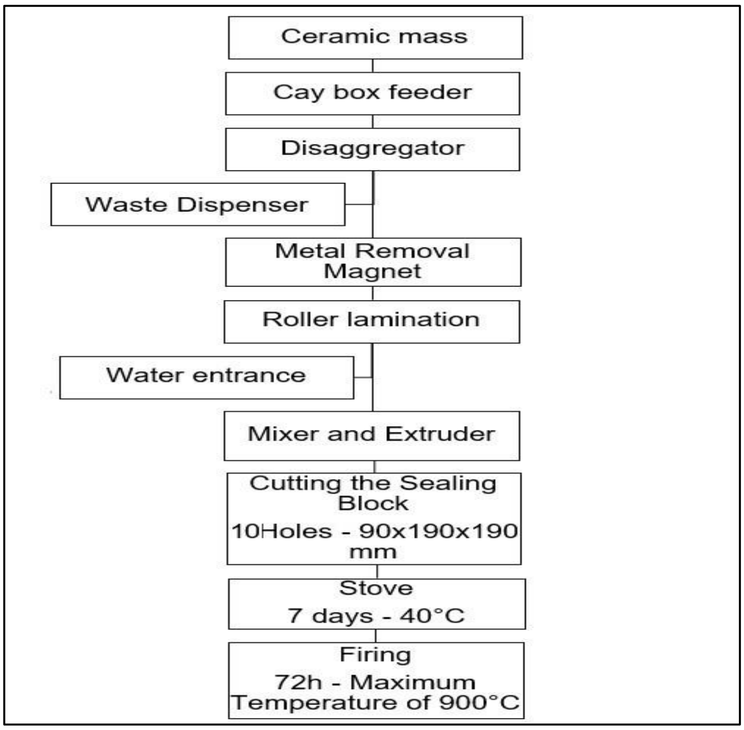

Figure 1. Flowchart of the industrial plant for the manufacture of red ceramic sealing blocks.
Source: Prepared by the authors.

After making, the sealing blocks underwent drying in a natural oven for 7 days at 40°C. After this process, they were subjected to firing. It was carried out in a model oven (Paulistinha) in 72 hours with a maximum temperature of 900°C. After burning, the materials were collected for normative tests. Figure 2 below shows, from left to right, the sealing blocks made with percentages of 0%, 10% and 20% of ornamental stone waste.

Figure 2. Sealing blocks with incorporation of 0%, 10% and 20% of wastes.
Source: Prepared by the authors.

3.3 Normative Tests

Normative tests were carried out to certify the technological viability of the manufactured ceramic artifacts. The standard used was ABNT NBR 15270-1 Ceramic components - Blocks and bricks for masonry, part 1 requirements and ABNT NBR 15270-2 Ceramic components - Blocks and bricks for masonry, part 2 test methods (ABNT NBR 15270-1, 2017) e (ABNT NBR 15270-2, 2017).

According to the standard, the following tests were applied:

Determination of the water absorption index in structural and sealing ceramic blocks and bricks. The equipment used for the test was a scale with a resolution of up to 5 g and an oven with an adjustable temperature of (105 ± 5) °C. The specimens were dried in an oven, after which they were weighed to obtain the dry mass value. For the wet mass, the specimens were submerged in water at room temperature over a period of 24 hours, after which they were weighed again. Finally, the water absorption index is determined, so the following equation is applied:

Where:

$$AA(\%)=\frac{m_u - m_s}{m_s} X100$$

Mu and Ms represent the wet mass and dry mass of each specimen, respectively, expressed in grams (g). Six specimens were used to carry out the tests, this value refers to what the current standard determines.

Determining the geometric characteristics of structural and sealing ceramic blocks and bricks (determining the measurements of the faces, determining the thickness of the external walls and septum, determining the deviation from the square and flatness of the faces). To carry out this test, the following equipment was used: caliper, metal ruler, deflectometer with dial indicator, metal square and scale with a resolution of 10g or less. They were responsible for carrying out measurements of the dimensions of the red ceramic artifacts. The specimens tested were related to the values requested by the standard, 13 in total.

4 RESULTS AND DISCUSSION

The following topics show the results of the clay and waste characterization and the normative test for manufacturing a red ceramic sealing block manufactured with ornamental stone waste.

4.1 Chemical Characterization

Table 1 shows the chemical characterization of the ceramic mass and the ornamental stone waste.

The major composition of the ceramic mass is SiO_2 and Al_2O_3, these elements form the aluminosilicate minerals, such as kaolinite. Kaolinite clays are responsible for a slow formation of the liquid phase in ceramics, because they do not have a large amount of flux oxides.

The ornamental stone waste showed a high SiO_2 content. It also has a higher content of flux oxides than ceramic mass, (Na_2O and K_2O) alkaline and (CaO and MgO) alkaline-earth. The greater the amount of flux oxides, the better the formation of the liquid phase during firing, which generates a reduction in porosity, consequently reducing the water absorption of the sealing block, therefore improving its technological characteristics.

The reddish coloration of the sealing blocks is due to the Fe_2O_3 content present in its composition.

Table 1. Chemical composition

	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	TiO_2	Na_2O	CaO	SO_3	LOI
Ceramic mass	48.60	28.50	6.07	2.13	1.71	1.19	-	0.48	0.15	10.60
Waste	60.70	19.60	4.46	1.79	2.47	0.76	0.96	1.61	0.11	7.05

Source: Prepared by the authors.

4.2 Mineralogical Characterization

Figure 3 shows the X-ray diffraction of the ceramic mass. Note peaks corresponding to kaolinite ($Al_2Si_2O_5(OH)_4$), quartz (SiO_2), gibbysite ($Al_2O_3.3H_2O$), microcline ($KAlSi_3O_8$), muscovite ($K_2O.3Al_2O_3.6SiO_2.2H_2O$), e montmorillonite ($Ca_{0,2}$(Al, Mg) 2 $Si_4O_{10}(OH)_2$. XH_2O), sepiolite ($Mg_4Si_6O_{15}$ $(OH)_6$ · $6H_2O$) and vermiculite (MgFe, $Al)_3$(Al, $Si)_4O_{10}(OH)_2.4H_2O$).

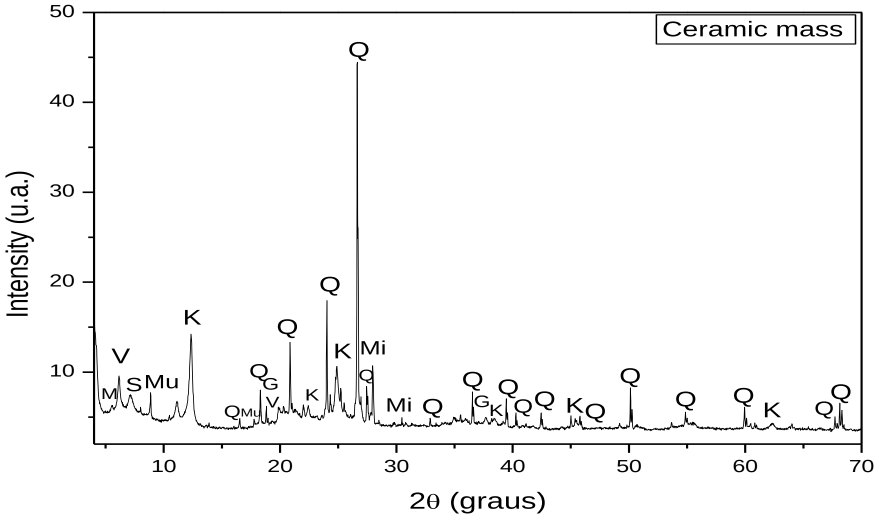

Figure 3. X-ray diffractogram of the ceramic mass. Q = Quartz, K = Kaolinite, M = Montmorillonite, G = Gibbysite, Mi = Microcline, Mu = Muscovite, S = Sepiolite, V = Vermiculite.
Source: Prepared by the authors.

Figure 4 shows the X-ray diffraction of ornamental rock waste. Note peaks corresponding to kaolinite ($Al_2Si_2O_5(OH)_4$), quartz (SiO_2), gibbysite ($Al_2O_3.3H_2O$), microcline ($KAlSi_3O_8$), muscovite ($K_2O.3Al_2O_3.6SiO_2.2H_2O$), sepiolite ($Mg_4Si_6O_{15}$ $(OH)_6$ · $6H_2O$) and vermiculite ($(MgFe, Al)_3(Al, Si)_4O_{10}(OH)_2.4H_2O$).

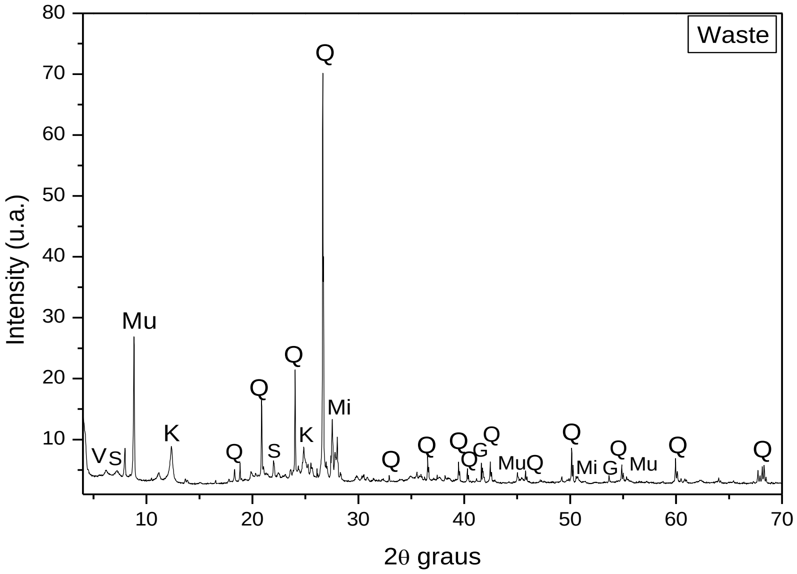

Figure 4. X-ray diffractogram of the waste. Q = Quartz, K = Kaolinite, G = Gibbysite, Mi = Microcline, Mu = Muscovite, S = Sepiolite, V = Vermiculite.
Source: Prepared by the authors.

Kaolinite is a clay mineral present in clays. Montimorilonite is also a clay mineral, however, it is highly plastic and has a great tendency to rehydrate, which can lead to processing problems. Quartz is the main impurity present in clays, acting as a non-plastic and inert raw material during firing. The microclimate found in clay and waste is beneficial for ceramic processing, as it can behave as a flux during the firing stage. Muscovite with reduced particle size can act as a flux due to the presence of alkaline oxides.

It is possible to observe that in the waste there are minerals characteristic of the ceramic mass. During the industrial test, the waste was deposited in the industry yard to carry out the industrial test, this deposition was close to clay piles. Therefore, contamination may have occurred at the time of collection of material for testing. This justifies the amount of clay mineral in its composition and the high loss on ignition, presented in its chemical and mineralogical analysis.

4.3 Particle Size Analysis

Figure 5 shows the particle size distribution of ornamental stone waste. The clay fraction, <0.002 mm, consists of clay minerals, and they are mainly responsible for the development of the plasticity of a ceramic mass (Santos, 1989). In the granulometry of the waste, 10% of the particles are below 0.0024 mm, confirming that the material is not plastic, 50% below 0.016 mm and 90% are below 0.098 mm.

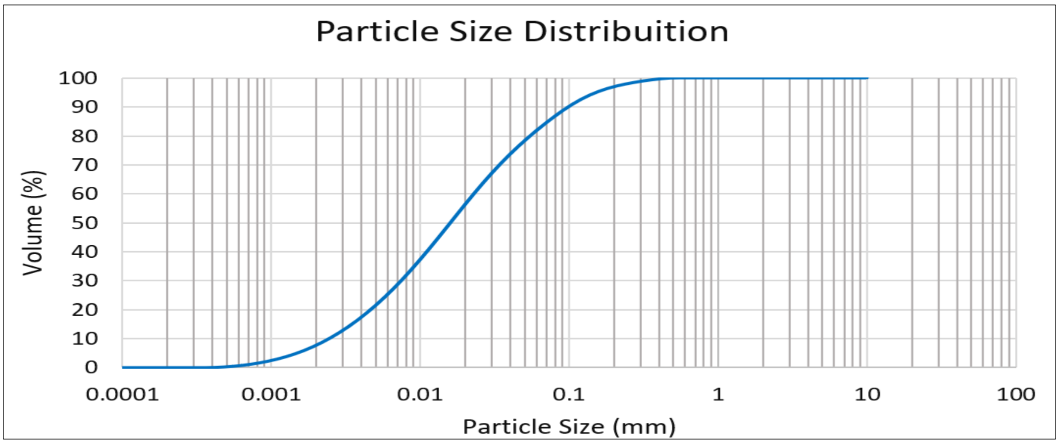

Figure 5. Ornamental stone waste particle size distribution (% by weight).
Source: Prepared by the authors.

Figure 6 shows the particle size distribution of the ceramic mass. Clay is comprised between fractions below 0.002 mm, silt between 0.002 mm and 0.06 mm, and above 0.06 mm to 2 mm is considered sand (ABNT NBR 6502, 2022). Therefore, in the graph shown, the clay mineral content called clay fraction is 33% by mass. A greater amount of clay makes the ceramic more plastic when it is mixed with water, which enables a better plastic consistency. The silt content shown is 40% and the sand content corresponds to 27%.

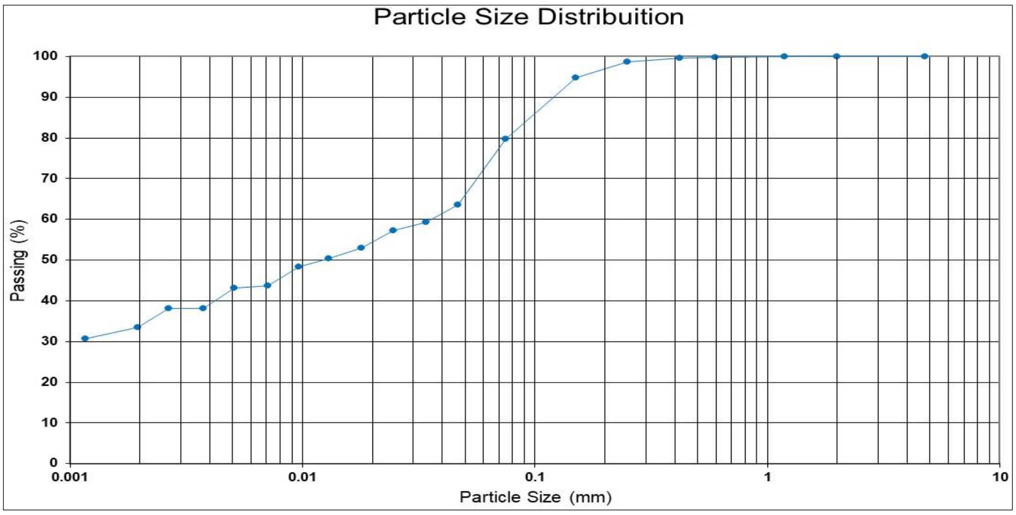

Figure 6. Ceramic mass particle size distribution.
Source: Prepared by the authors.

4.4 Water Absorption

Figure 7 shows the water absorption of the sealing blocks. It is noted that there is a slight tendency to reduce water absorption with the incorporation of ornamental stone waste for the manufacture of the sealing block. This fact can be justified by the raw materials used in the manufacture of the ceramic artifact, the processing and/or the temperature at which the pieces were fired were not enough for the melting action of the waste.

The use of ornamental stone waste in the ceramic material improves the packing of the particles. This occurs due to the fluxing action of the waste with the formation of a liquid phase, causing the porosity of the material to decrease and the material to become more sintered. The liquid-phase sintering process begins with the formation of a liquid, the spreading of this liquid around the particles leads to the rearrangement of the particles and the consolidation of the structure (German, 1985).

According to the NBR 15270-1 (2017) standard, the water absorption limit of sealing blocks must not be less than 8% nor greater than 25%[8.] Note that all sealing blocks manufactured in the industrial test did not exceed the values stipulated by the standard.

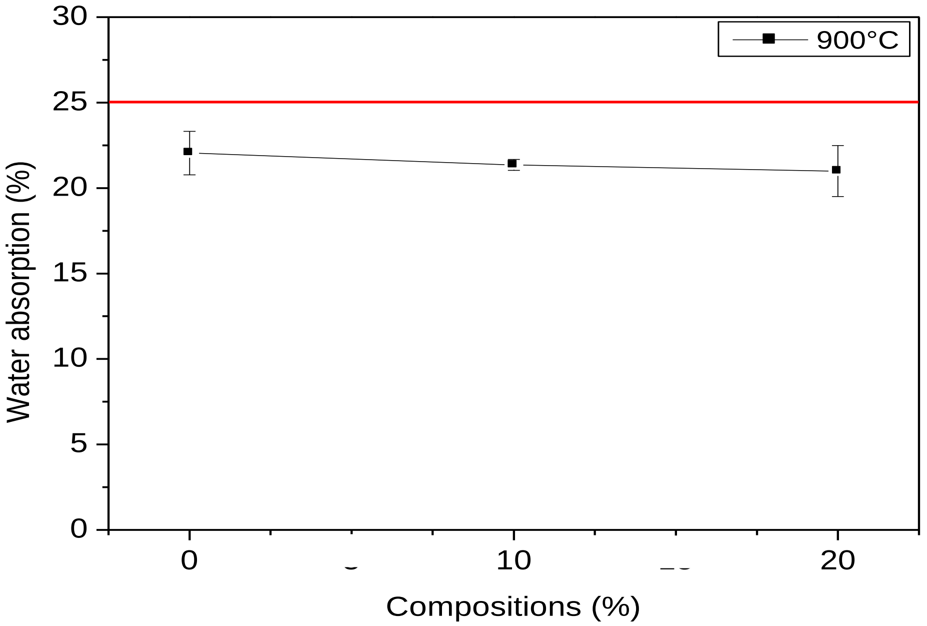

Figure 7. Water absorption of the ceramic artifact
Source: Prepared by the authors.

4.5 Geometric Characteristics

The sealing block with dimensions 90x190x190 mm must meet the following geometric characteristics according to NBR 15270-1 and 2 (2017) (ABNT NBR 15270-1, 2017) e (ABNT NBR 15270-2, 2017). The dimensional tolerance of the width, height and length values (L 90 mm, H 190 mm and L 190 mm) must be ± 5 mm for individual blocks and ± 3 mm for the average of the sampled blocks. The standard also defines that the sum of the thickness of the external walls must be equal to or greater than 20 mm. For the septum (internal wall), the sum of the dimensions must also be equal to or greater than 20 mm. Both have no minimum tolerance value for the sum. The deviation in relation to the square and also in relation to the flatness of the two faces must be a maximum of 3 mm. The rule determines that for a sample of 13 blocks the limit for acceptance of the lot is only 2 blocks, therefore only this quantity can present values outside the limits of the standard, above that the lot must be rejected.

Tables 2, 3 and 4 below present the data of the geometries of the specimens, in the respective percentages 0%, 10% and 20%.

Table 2. Geometric characteristics of the specimens with only the ceramic mass, 0% waste.

Number of pieces	Measurement of faces			Thickness of external walls (mm)	Thickness of septa (mm)	Deviation from the square (mm)	Flatness of face 1 (mm) Convex (+) Concave (-)	Flatness of face 2 (mm) Convex (+) Concave (-)
	L (mm)	H (mm)	C (mm)					
1	90.3	190.6	190.5	25.3	23.5	0.0	+ 0.1	+ 0.2
2	90.4	191.0	192.2	25.8	23.4	0.9	- 0.1	- 0.4
3	90.1	191.0	190.8	24.6	23.6	1.2	- 0.3	+ 1.4
4	90.0	190.8	190.6	26.1	23.4	0.6	+ 0.1	- 0.1
5	90.3	191.3	191.1	25.2	23.2	2.2	+ 0.2	- 0.4
6	90.5	190.6	190.7	25.2	23.2	0.8	- 0.1	- 0.1
7	90.2	190.8	190.7	25.9	22.8	1.3	- 1.1	+ 0.4
8	90.2	190.8	191.3	24.9	22.8	1.6	- 0.2	- 0.1
9	90.3	191.1	190.9	25.5	22.9	1.8	- 0.8	+ 0.5
10	90.6	191.5	191.9	26.0	24.3	1.7	- 0.7	+ 0.3
11	90.4	190.6	190.6	26.6	24.1	0.0	- 0.1	- 0.1
12	90.4	191.1	191.3	25.3	23.7	1.5	- 1.2	+ 0.5
13	90.5	190.5	190.9	25.9	23.5	0.7	- 0.7	+ 0.4
Average	90.3	190.9	191.0	-	-	-	-	-

Source: Prepared by the authors.

Table 3. Geometric characteristics of specimens with 10% waste.

Number of pieces	Measurement of faces			Thickness of external walls (mm)	Thickness of septa (mm)	Deviation from the square (mm)	Flatness of face 1 (mm) Convex (+) Concave (-)	Flatness of face 2 (mm) Convex (+) Concave (-)
	L (mm)	H (mm)	C (mm)					
1	90.6	191.6	191.2	25.6	24.8	2.3	- 0.3	+ 1.1
2	90.5	190.9	190.7	25.4	24.9	2.6	- 1.1	+ 0.8
3	90.5	191.2	190.9	25.4	24.6	2.9	- 0.4	+ 0.1
4	90.9	191.6	190.6	28.4	24.5	3.0	- 0.3	+ 0.7
5	90.5	191.3	190.9	25.7	24.3	3.0	- 0.2	+ 0.3
6	90.9	191.5	191.6	27.7	23.7	1.9	- 1.6	- 0.1
7	90.9	191.4	191.5	27.1	24.0	1.4	- 0.2	+ 0.2
8	89.4	191.2	191.1	24.6	24.8	1.7	- 0.2	+ 0.7
9	90.2	190.6	190.9	26.5	25.4	2.8	- 0.3	+ 1.2
10	90.8	191.1	190.6	26.5	25.3	3.0	- 0.8	+ 0.9
11	89.6	191.7	190.7	25.4	26.0	3.4	- 0.1	+ 2.1
12	89.7	191.1	191.2	27.9	25.5	3.2	- 1.1	+ 1.3
13	90.7	191.1	190.9	27.1	24.5	1.6	- 0.3	+ 0.2
Average	90.4	191.3	191.0	-	-	-	-	-

Source: Prepared by the authors.

Table 4. Geometric characteristics of specimens with 20% waste.

Number of pieces	Measurement of faces			Thickness of external walls (mm)	Thickness of septa (mm)	Deviation from the square (mm)	Flatness of face 1 (mm) Convex (+) Concave (-)	Flatness of face 1 (mm) Convex (+) Concave (-)
	L (mm)	H (mm)	C (mm)					
1	90.6	191.3	191.7	25.5	23.4	2.4	- 1.5	+ 0.4
2	91.1	192.5	191.9	24.6	23.1	2.0	- 0.6	- 0.1
3	90.8	191.2	191.4	26.0	24.0	2.9	- 1.2	+ 1.6
4	90.7	191.8	191.1	24.5	23.8	3.1	+ 0.3	+ 0.4
5	90.9	191.7	191.5	25.2	23.1	2.0	- 0.3	- 0.1
6	91.0	191.4	191.5	26.5	23.8	2.8	- 0.2	+ 0.2
7	90.7	191.1	191.5	24.0	24.6	1.8	- 1.2	+ 1.5
8	90.7	191.1	190.8	25.1	24.2	2.0	- 0.7	+ 0.7

9	90.6	191.2	190.8	24.3	23.9	2.1	- 0.9	+ 0.9
10	91.0	191.0	191.1	25.6	25.3	1.9	- 2.6	- 1.1
11	90.7	191.4	191.1	24.9	24.8	2.1	- 1.8	- 0.9
12	90.2	191.2	191.0	24.8	24.5	1.2	- 1.9	- 1.8
13	90.7	191.2	190.8	25.9	24.2	1.6	- 1.7	+ 0.1
Average	90.7	191.4	191.2	-	-	-	-	-

Source: Prepared by the authors.

According to the standard, the deviation from the square must be a maximum of 3 mm. The test with 10% of waste obtained two specimens, nº 11 and nº 12, above the stipulated value, and with 20%, the specimen of nº 4 was also above the allowed value. However, according to the norm, for the batch to be discarded, it must have more than two values above the allowed value, within the batch of 13 specimens. Therefore, in the study presented, it meets the requirement, and therefore the batch is within the limits allowed by the standard.

It can be observed in the tables that the specimens with 10% and 20% of waste had greater thicknesses of the septa when compared to those with 0%, ceramic mass without waste. The waste has a greater amount of silica and a smaller amount of clay minerals, the ceramic mass has a greater amount of clay minerals, this is proven by chemical and mineralogical analysis. Clay minerals, kaolinite specifically, lose mass when heated to high temperatures. The loss of mass of kaolinite is associated with its dehydroxylation, which occurs at temperatures above 480 °C. Therefore, after firing, the specimens with only clays, obtained smaller dimensions due to loss of mass (Aguiar, 2012).

5 CONCLUSION

The chemical and mineralogical characterization showed that the ceramic mass is, for the most part, composed of SiO_2 and Al_2O_3, therefore rich in aluminosilicate minerals such as kaolinite.

The ornamental stone waste used in the mixture showed a high SiO_2 content and flux oxides such as alkaline (Na_2O and K_2O) and alkaline earth (CaO and MgO). They help in the formation of the liquid phase during firing, which generates a reduction in porosity and consequently reduces the water absorption of the ceramic artifact. This is proven in the water absorption test. The sealing blocks with 10% and 20% of waste had less water absorption when compared with without waste.

When we compare the granulometric analysis of the waste and clay, we can find similarities between them. This observation shows that it does not interfere with the preparation of specimens.

The geometric characteristics test met the normative requirements, so the lot that was submitted to the test was approved. It can be observed that the septa of the specimens with wastes had larger sizes when compared to the one without waste, this can be explained by the loss of mass that the ceramic mass has when they have a high content of kaolinite in their composition.

Ornamental stone waste is technologically viable for use in red ceramic artifacts. The use of waste for the manufacture of new products contributes to reducing its deposition, which revolves around millions of tons, and collaborates with the circular economy, since this waste returns to the production cycle. The new product created with the waste becomes a sustainable and environmentally correct alternative.

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