Red Ceramics Produced with Primary Processing Fine Waste of Ornamental Stones According to the Circular Economy Model

Mariane Costalonga de Aguiar 1,*, Mônica Castoldi Borlini Gadioli 1,*, Maria Angelica Kramer Sant’Ana 1,*, Kayrone Marvila de Almeida 1,*, Francisco Wilson Hollanda Vidal 1 and Carlos Maurício Fontes Vieira 2

1 Centre for Mineral Technology-State of Espirito Santo Branch-CETEM/NRES, Cachoeiro de Itapemirim 29311-970, ES, Brazil
2 Advanced Materials Laboratory (LAMAV), State University of Northern Fluminense-UENF, Campos dos Goytacazes 28013-602, RJ, Brazil
* Correspondence: maguiar@cetem.gov.br (M.C.d.A.); mborlini@cetem.gov.br (M.C.B.G.)

Abstract: The ornamental stone industry is growing and has a large production in Brazil, mainly in Espírito Santo, where the largest production in the country is concentrated. Brazil is part of the group of countries that produce the most ornamental stones in the world; however, the generation of waste in this sector is very large. These ornamental stone wastes when used for the manufacture of new materials, such as red ceramics, contribute to the reduction in the raw material clay and to the reduction in the environmental impact. The objective of this work was to incorporate fine wastes from the processing of ornamental stones called FIBRO in red ceramics and later, to contribute to the standardization of the use of these wastes in the ceramic industry, contributing to the manufacture of more economical and sustainable products. Wastes were incorporated in the proportion of 0 to 50% by mass that were prepared by extrusion and fired at 900 °C, 950 °C, and 1000 °C. After firing, the physical and mechanical properties of the ceramic material were evaluated. Specific mass apparent, water absorption, porosity, and flexural strength by three points tests were carried out. The results showed that from 30% at the lowest temperature, tile is already fabricated within the values stipulated by the standards, thus saving energy. The analyzed waste is a material with excellent chemical characteristics to be used in the ceramic mass, in addition to having improved the technological properties of the material, such as less water absorption and greater flexural strength.

Keywords: sustainability; environmental impact; ornamental stone waste

1. Introduction

Brazil is internationally known for the wide variety of ornamental stones, due to its enormous geodiversity. The country is a reference in the sector, the ornamental stones produced serve several countries in the world [1,2]. Brazilian exports of natural stone materials totaled USD 1.34 billion and 2.40 million t in 2021, with a positive variation of 35.5% and 11.4%, respectively, compared with 2020 [1,2]. The sales figures and their annual variation surpassed the historical records registered in 2013 (USD 1.30 billion and 22.8%). The states of Espírito Santo and Minas Gerais are the main exporters of ornamental stones in Brazil [3]. With USD 1.10 billion and USD 132.8 million, respectively, they make up 93.2% of total Brazilian export earnings [1–3]. The main destinations for these stones are the US, China, Italy, Mexico, and the UK.

To produce ornamental stone cladding slabs it is necessary that the raw material is extracted and processed. The first stage of the process takes place in the mine, the block of ornamental stones is extracted from nature and sent to the second stage of the process [4]. The second stage is processing, in which the slabs are sawn and polished for sale. Sawing can be performed with a multiblade gangsaw using iron grit or a multiwire gangsaw using diamond wire. Approximately 26% of the block that passes through the beneficiated stage
becomes fine waste during the process [5]. Most of these wastes are deposited in landfills, which causes a negative environmental impact to the environment.

Waste in general, from all types of industries, is a growing concern for Brazilians. Its improper disposal can cause numerous environmental problems. Therefore, on 2 August 2010, Law No. 12305 of the National Solid Waste Policy was implemented in Brazil [6]. This is a federal law designed to solve the large amount of waste produced in the country. It establishes an order of priority in relation to waste generation, they are: non-generation, reduction, reuse, recycling, treatment, and final disposal.

Currently, the waste from the processing of ornamental stones receives only the treatment to remove moisture and then the final destination in landfills. Using this waste as an alternative would collaborate to reduce deposition in landfills, thus reducing negative environmental impacts. Its reuse would, therefore, be a possibility that meets the priority order of law No. 12305.

Brazil has a high demand in the civil construction sector. Most houses in the country are masonry, built with ceramic artifacts such as bricks and fence blocks. Therefore, the production of red ceramics is very important. The country has about 5600 red ceramic companies, which generates approximately 18 billion annual revenues, this creates 293 thousand direct jobs and 900 thousand indirect jobs [7], monthly producing approximately 1.3 billion tiles and 4 billion sealing and structural blocks [8].

The manufacture of red ceramics follows a standard processing sequence. The clays are deposited in a silo, then proceed to disaggregation and mixing, after passing through a rolling roll and then being shaped by an extrusion process, after which comes the most delicate stages of the process, drying and then firing of the product. Drying is the process that removes water slowly, which causes the ceramic piece to lose moisture in a homogeneous way, thus avoiding possible cracks [9]. This process can be carried out by industrial dryers or naturally in open air. The firing consists of sintering the ceramic artifact for union, particle growth and porosity reduction [10,11]. Sintering is a process that thickens solid clay particles, which causes pores to be reduced or eliminated due to heat treatment. This process cannot merge the material [9]. The ideal temperature for firing a ceramic piece depends on the composition and properties of the raw materials.

Since the 90s, ornamental stone waste has been studied for possible applications in the red ceramic industries. In 1995, the physical and chemical characteristics of the waste were studied and it was proven that it can be incorporated into red ceramics and other possible products [12]. The incorporation of 10% of ornamental stone waste in red ceramic artifacts fired at a temperature of 900 °C increases the product’s resistance and reduces its water absorption [13]. In another study, the addition of 40% of ornamental stone waste at a temperature of 1050 °C improved water absorption and mechanical strength [14]. Recent studies show that ornamental stone wastes may contain in their composition the presence of microcline, anorthoclase, and biotite; these minerals form a liquid phase in the sintering during firing, which fills the voids of the ceramic piece and thus improves its performance flexural strength [15]. The application of the waste also contributes to reducing the water absorption of ceramic artifacts, this contributes to better resistance and reduces the possibility of cracks and cracks in ceramic pieces [16,17]. Therefore, it is essential to study even more about the incorporation of ornamental stone waste in red ceramic artifacts due to the fact that the properties of red ceramic can be improved. The use of this waste contributes significantly to the circular economy and to the tripod of sustainability, which are social, environmental, and economic factors.

The Fundação de Amparo à Pesquisa e Inovação do Espírito Santo (FAPES), together with the Centre for Mineral Technology - State of Espírito Santo Branch-CETEM/NRES, is developing a project to standardize the use of waste obtained from the processing of ornamental stones in red ceramic artifacts. Within the scope of the project is the use of waste, reduction in environmental impact, reduction in consumption of raw materials in the manufacture of ceramic artifacts, environmental education, cost reduction in the
production of red ceramic artifacts, and the possibility of sustainable development of the Brazilian sector of ornamental stones and civil construction.

In view of all the above, the work developed aims to analyze the physical and mechanical properties of the red ceramic specimens that were fabricated using in their masses the fine waste from the processing of ornamental stones from the multiwire gangsaw. The use of the waste contributes to the manufacture of more economical and sustainable ceramic artifacts.

The objective of this work was to evaluate how the replacement of fines of the ornamental stone processing (FIBRO) (granite) can influence the physical and mechanical properties of red ceramics. The clays and waste for the manufacture of the ceramic artifact came from the state of Espirito Santo. Thus, the aim of this study is to collaborate for the regulation of the use of these wastes and contribute to the development of the sector.

2. Materials and Methods

2.1. Materials

In the present work, the ceramic mass from the north of the state of Espirito Santo and the fines of the ornamental stone processing, which were called FIBRO, from the multiwire gangsaw process, located in the municipality of Cachoeiro de Itapemirim, ES, were used as raw materials.

The Table 1 show the chemical composition of the raw materials studied.

|            | SiO₂ | Al₂O₃ | Fe₂O₃ | Na₂O | MgO | K₂O | P₂O₅ | CaO | TiO₂ | SO₃ | BaO |
|------------|------|-------|-------|------|-----|-----|------|-----|------|-----|-----|
| Ceramic Mass | 41.6 | 30.8  | 9.0   | 0.13 | 1.2 | 0.92| 0.17 | 0.16 | 1.3  | -   | -   |
| Waste      | 56.0 | 19.9  | 5.8   | 5.4  | 1.6 | 4.3 | 0.48 | 3.6 | 1.1  | 0.19| 0.59| 0.74|

* Loss on ignition.

Crystalline phases were also found in clay corresponding to: Quartz (SiO₂), kaolinite (2SiO₂·Al₂O₃·2H₂O), sepiolite (Mg₄Si₆O₁₅·(OH)₆·6H₂O), microcline (KAlSi₃O₈), gibbsite (Al(OH)₃), vermiculite (Mg₄Si₆O₁₅·(OH)₆·6H₂O), and muscovite (K₂O·3Al₂O₃·6SiO₂·2H₂O), and the waste corresponding to: quartz (SiO₂), albite (NaAlSi₃O₈), anorthite (CaAl₂Si₂O₇), microcline (KAlSi₃O₈), hornblende (Ca,Na)₂-3(Mg,Fe,Al)₅(Al,Si)₈O₂₂(OH,F)₂, and orthoclase (KAlSi₃O₈) [18].

2.2. Methods

2.2.1. Characterization of Raw Materials

The particle size distribution of the raw material, clay, was obtained using a combined method of sieving and sedimentation by gravimetry, according to the technical standard of ABNT NBR-7181 [19].

The Netzsch DIL 402 PC equipment from the Laboratory of Advanced Materials (LAMAV/UENF) was used to determine the dilatometry of the ceramic masses. The heating rate of 5 °C/min and final temperature of 1050 °C were used. For this test, 2 specimens of 2 g, in cylindrical shape, pressed with 1 t were fabricated. The specimens were fabricated with masses containing 0 and 50% of FIBRO. The accomplishment of this test was to verify the effect that the waste provoked in the behavior of burning of the mass.

2.2.2. Mass Preparation for Extrusion

Ceramic masses were prepared with clay and granite waste. Table 2 presents the percentage of raw materials in the compositions. The ceramic masses had nomenclature called M0-0%, M10-10% replacement of FIBRO, M20-20% of replacement of FIBRO, M30-30% of replacement of FIBRO, M40-40% of replacement of FIBRO and M50-50% replacement of FIBRO.
Table 2. Percentage of raw materials (%) of the compositions.

|        | Clay | Waste |
|--------|------|-------|
| M0     | 100  | 0     |
| M1     | 90   | 10    |
| M2     | 80   | 20    |
| M3     | 70   | 30    |
| M4     | 60   | 40    |
| M5     | 50   | 50    |

Ceramics Manufacture by Extrusion

In the Civil Engineering laboratory (UENF), the specimens measuring 120 x 30 x 18 mm were produced by vacuum extrusion in a Verdés extruder. After extrusion, drying was carried out at room temperature for a week, and then the specimens were dried in an oven at a temperature of 110 °C until reaching constant weight.

After the ceramics were manufactured by extrusion, the materials were measured and weighed and subsequently fired in a laboratory oven of the Maitec FL 1300 muffle type. The heating rate used for firing was 2 °C/min with a threshold temperature of 180 min. The specimens were fired at temperatures of 900 °C, 950 °C, and 1000 °C. Figure 1 shows the specimens after firing.

![Figure 1. Ceramic specimens fabricated from clay and ornamental stone waste.](image)

2.2.3. Physical and Mechanical Tests on Fired Ceramics

- ASTM C 373-72 [20] was used to determine the density of ceramic pieces;
- A Mitutoyo caliper (resolution ± 0.01 mm) was used to determine the linear shrinkage of the ceramic pieces;
- ABNT 15270-2 [21] was used to determine the water absorption of ceramic pieces;
- ASTM C373-88 [22] was used to determine the porosity of ceramic pieces;
- ASTM C674-77 [23] was used to assess the flexural strength (σ), which was determined by three points bending.

3. Results

3.1. Granulometry

Figure 2 shows the granulometric distribution of the ceramic mass. The granulometric ranges are associated with the classification of clay, silt, and sand fractions, where the clay fraction is associated with particles with an equivalent spherical diameter < 0.002 mm, the silt fraction corresponds to the range between 0.002 and 0.02 mm and the sand fraction...
corresponds to particles > 0.02 mm. Note that the clay mineral content or “clay fraction” is 61% by mass. The “clay fraction” provides the ceramic mass plasticity when mixed with water, thus enabling a plastic consistency. The silt content, particles with sizes between 0.002 and 0.02 mm, is 26%. The sand content, which corresponds to particles > 0.02 mm, is 13%.

The granulometry of the granite waste benefited by multiwire gang saw was also carried out. The results showed that the waste is a non-plastic material and that its fine particles contribute to better packaging and to the improvement of the final ceramic product [18].

Figure 2 shows the granulometric distribution of the ceramic mass. The granulometry of the granite waste benefited by multiwire gang saw was also carried out. The results showed that the waste is a non-plastic material and that its fine particles contribute to better packaging and to the improvement of the final ceramic product [18].

3.2. Dilatometry

Figure 3 shows the dilatometry of the ceramic masses without waste (0%) and with waste (50%).

According to Callister, when clay-based materials are heated to high temperatures, reactions occur where one of these reactions is vitrification. The temperature at which the liquid phase forms is reduced by the addition of fluxing agents, such as feldspar, for example, which is found in granite waste. This fluid phase flows around the unfused particles that remain in the medium and fill the pores. Upon cooling, this molten phase forms a glassy matrix that results in a dense and resistant body [24].

Note in Figure 3 that the curves remain stabilized up to 500 °C, where there is a slope in the curve originating from the transformation of kaolinite to metakaolinite, increasing the density of the particles formed with this change.

Note that for the mass without addition of waste there is greater shrinkage. It is observed that around 600 °C there is a contraction referring to the presence of quartz in the clay.

In the ceramic mass with the substitution of 50% of ornamental stone waste, there is also a dilation in the angle of the curve referring to the presence of free quartz, also around 600 °C. It is noted that around 950 °C there is a sudden retraction, this is due to the formation of a more abundant liquid phase. This point indicates that the samples are partially melted and that the liquid flows into the interstices of the more refractory particles that have not yet merged. This causes the particles to approach, which results in a very significant shrinkage. This means that the waste enters a fresh state and starts to close the matrix pores.
significant shrinkage. This means that the waste enters a fresh state and starts to close the matrix pores.

Figure 3. Dilatometric curve of the masses containing 0 and 50% of waste.

3.3. Density

Figures 4–6 show the densities of the studied ceramics. The density depends on the granulometric distribution and the body of the grains. Granite waste improves particle packing. In the production of ceramics, this is beneficial as the increase in the contact area between the particles favors sintering. Comparing the green and dry density values, it is noted that the dry density obtained lower values. This occurs due to the loss of mass of the ceramic material. This loss of mass occurs in the water that is used during the processing of the specimen.

It is also noted that the higher the temperature and the higher the percentage of waste, the greater the density of the material, which indicates that the specimens showed better packing of the particles. This better packing can be beneficial, as it can contribute to a better consolidation of the particles in the firing stage, improving the technological properties.

Figure 4. Apparent specific density in green.
3.4. Linear Shrinkage

Figure 7 shows the linear shrinkage of the ceramics produced. Linear shrinkage occurs due to sintering, which tends to close the pores of the ceramic body. Due to sintering, the ceramic body tends to retract and the pore volume decreases, causing the structure to contract.

A significant increase in linear shrinkage can be observed with the increase in firing temperature and with the replacement of the FIBRO, this occurs due to the evolution of the densification of the material and consequent decrease in porosity. It can also be seen that at 1000 °C the increase in shrinkage is significant for all compositions. The increase in shrinkage makes the risk of heating cracks also greater.
3.5. Absorption

Figure 8 shows the water absorption of the manufactured ceramics. Water absorption is a parameter used to measure open porosity and assess material melting.

Note that there is a reduction in water absorption with increasing temperature and with the use of FIBRO. This is due to better packaging and reduced mass loss during firing.

Due to the reactions that occurred with sintering, water absorption and porosity decreased. The liquid phase sintering process starts with the formation of a liquid, spreading of this liquid around the particles leads to the rearrangement of the particles and the densification of the structure [25]. As can be seen in the graph, the higher temperature had lower absorption, that is, at the higher firing temperature there was greater formation of liquid phase.

According to the NBR 15270-1 (2017) standard, for the manufacture of sealing blocks, the water absorption must not exceed 25% [26]. According to the standard NBR 15310 (2009) for the manufacture of tiles, the water absorption must not exceed 20% [27].
3.6. Porosity

Figure 9 shows the porosity of the ceramics manufactured. Note that the replacement of FIBRO and firing temperature influence the porosity of ceramic pieces. A behavior similar to that observed in the absorption of water can be observed, which corroborates the open porosity of the ceramic pieces.

![Figure 9. Porosity of the studied compositions at temperatures of 900 °C, 950 °C, and 1000 °C.](image)

3.7. Flexural Strength

Figure 10 shows the flexural strength of fabricated ceramics. In strength testing, materials generally break or fracture when subjected to a load with a very high force, either tensile or compressive. Note that the flexural strength increases significantly with increasing temperature and with the replacement of FIBRO. This is due to sintering causing greater formation of liquid phase. With this, the particles are more consolidated, thus making the material more resistant.

An increase in the strength of ceramics fabricated from FIBRO was already to be expected, due to the decrease in absorption. Water absorption is associated with the open porosity of the ceramic and with the microstructure of the interior of the ceramic body. The evolution of the flexural strength results with the replacement of FIBRO shows that sintering occurred at the temperatures studied.

It can be observed that with the replacement of FIBRO there is an increase in the flexural strength. However, with the replacement of 40% and 50% it starts to decrease, but with superior resistance in ceramics fabricated only with clay. Another factor that must have significantly influenced this decrease was quartz, a mineral that composes the waste, which probably acted as an inert material and may have contributed to the formation of microcracks [18]. The flexural strength of ceramics is greatly influenced by the presence and shape of defects in their microstructures, such as grains and pores [28].

For sealing blocks, the strength limit according to the standard is 1.5 MPa [26]. For ceramic tiles, the minimum strength limit is 1300 newtons for roman tiles and 1000 newtons for other tiles [27]. All manufactured ceramics presented the force in newtons above the value considered by the standard.
The replacement of FIBRO in red ceramic artifacts has been studied for years. According to the authors, the waste may have the potential to be applied in other ceramic products; therefore, it is important to study the properties of materials and their mineral compounds and to evaluate their physical and mechanical behavior [29].

After the turn of the millennium and over the years, other researchers continued to study the topic. A general review was published showing the use of waste as an alternative raw material for the production of ceramics, with the objective of creating economically viable and ecologically correct artifacts [30].

In another research, it was verified that the quartzite waste, with replacement into the red ceramic in the percentages of 10%, 20%, and 30% and at a temperature of 800 °C, meets the normative technological criteria for the manufacture of solids bricks [31].

In more recent works, they proved that ornamental stone wastes can replace a percentage of clay in the manufacture of red ceramic artifacts, in addition to increasing strength [17]. In another research, it was shown that the application of granite wastes in red ceramic artifacts improves their physical and mechanical properties [18].

The use of these ornamental stone wastes for the manufacture of red ceramics contributes to the development of the circular economy, causing the waste to be inserted into the life cycle of new manufactured products. In addition to the advantages, it can offer in ceramic material. The use of this waste improves the physical and mechanical properties of the ceramic and contributes to energy savings as shown in the results, where ceramic materials manufactured at the lowest temperature of 900 °C and 950 °C from the composition of 30% waste, already fit the minimum limit stipulated by the standard for their manufacture.

The waste used in ceramics came from the beneficiation process using the multiwire gangsaw technology, where only water is used in sawing and diamond wires are used in processing. There is also waste from the processing of a multiblade gangsaw, and in this processing, steel blades, abrasive steel shots, mud, and lime are used. The use of abrasive steel shots can cause defects and black heart in the ceramic, due to the high presence of iron oxide in this waste. However, the use of ornamental stone waste from this technology would be a disadvantage in the manufacture of red ceramics.

![Figure 10. Flexural strength of the studied compositions at temperatures of 900°C, 950°C, and 1000°C.](image-url)
All these studies prove that the use of ornamental stone wastes is viable for the manufacture of red ceramic artifacts. Thus, FAPES together with CETEM, and other institutions, proposed to develop a normative instruction for the application of FIBRO in red ceramic artifacts. The project standard is in progress, and the results were satisfactory. The work presented here is part of this larger project of normative instruction that seeks to produce an economically viable and sustainable red ceramic.

5. Conclusions

In this work, the following conclusions were reached:

- From the characterization of the clay, it has a typically kaolinitic composition and is constituted, above all, by kaolinite, quartz, gibbsite, microcline, sepiolite, and vermiculite. The large amount of grains in the “clay” fraction is associated with the presence of clay minerals. The FIBRO is constituted by quartz, albite, anorthite, hornblende, microcline, muscovite, and orthoclase;
- In the dry density, there was an increase in the replacement masses with FIBRO, improving the packing of the particles. However, the compositions with the replacement of granite waste did not increase significantly with increasing replacement. However, this increase is beneficial so that the shrinkage is reduced and so the particles are more consolidated during burning;
- Regarding the firing behavior, in general, the higher temperature had a lower water absorption and greater flexural strength and the ceramics fabricated with FIBRO had lower absorption and greater flexural strength. For linear shrinkage, it can be concluded that the ceramic mass with the replacement of FIBRO in the highest percentages showed lower shrinkage values, due to its lower mass loss and better packaging;
- It is observed that the flexural strength increased with the use of FIBRO. This increase in resistance was due to the influence of clay and the fluxing action of the waste.

The use of these wastes, which are currently discarded in landfills, will contribute to the development of new ecological materials with the use of FIBRO and consequently will contribute to the reduction in the consumption of natural raw materials and the reduction in the environmental impact generated with the disposal of waste; moreover, it will include the sectors involved in the circular economy, contributing to the sustainable development of the Brazilian ornamental stone and civil construction sector.

Due to the relevance of the matter and the potential of granite waste to be used as a raw material in ceramics, other studies are being carried out using this waste in the production of other ceramic materials with high added value. Industrial tests are also being carried out using these wastes to manufacture red ceramics.

Author Contributions: Conceptualization, M.C.d.A., M.C.B.G. and F.W.H.V.; Data curation, M.C.d.A., M.A.K.S., K.M.d.A. and C.M.FV.; Formal analysis, M.C.d.A., M.C.B.G. and F.W.H.V.; Funding acquisition, M.C.B.G. and F.W.H.V.; Investigation, M.C.d.A., M.C.B.G., F.W.H.V. and C.M.FV.; Methodology, M.C.d.A., M.C.B.G. and F.W.H.V.; Project administration, M.C.B.G. and F.W.H.V.; Resources, M.C.B.G. and F.W.H.V.; Software, M.C.d.A., M.A.K.S. and K.M.d.A.; Supervision, M.C.B.G. and F.W.H.V.; Validation, M.C.d.A., M.C.B.G. and F.W.H.V.; Visualization, M.C.B.G. and F.W.H.V.; Writing—original draft, M.C.d.A., M.A.K.S. and K.M.d.A.; Writing—review and editing, M.C.d.A., M.C.B.G. and F.W.H.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Fundação de Amparo à Pesquisa e Inovação do Espírito Santo (FAPES), grant number 84323264.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Fundação de Amparo à Pesquisa e Inovação do Espírito Santo (FAPES), grant numbers 80857019 and 84323264 for the financial support, the ceramic industries for the clay, and the ornamental stone industries for the wastes.
Conflicts of Interest: The authors declare no conflict of interest.

References

1. ABIROCHAS—Associação Brasileira da Indústria de Rochas Ornamentais. Balanço das Exportações e Importações Brasileiras de Rochas Ornamentais em 2021; Informe 01/2022; ABIROCHAS: Brasília, Brazil, 2022.

2. COMEX STAT. Ministério da Indústria, Comércio Exterior e Serviços. Exportação e Importação Geral. Base de Dados 2021. 2022. Available online: http://comexstat.mdic.gov.br/pt/home (accessed on 16 September 2022).

3. SINDIROCHAS—Sindicato da Indústria de Rochas Ornamentais, Cal e Calcários do Espírito Santo. Relatório de Exportação de Rochas Ornamentais 2021. Available online: https://www.sindirochas.com/ (accessed on 16 September 2022).

4. Vidal, F.W.H.; Pinheiro, J.R.; Castro, N.F.; Caranassios, A. Lavra de rochas ornamentais. In Tecnologia de Rochas Ornamentais: Pesquisa, Lavra e Beneficiamento; CETEM/MCTI: Rio de Janeiro, Brazil, 2014; Chapter 4; pp. 155–257.

5. Silveira LL, L.; Vidal FW, H.; Souza, J.C. Beneficiamento de rochas ornamentais. In Tecnologia de Rochas Ornamentais: Pesquisa, Lavra e Beneficiamento; CETEM/MCTI: Rio de Janeiro, Brazil, 2014; Chapter 7; pp. 329–398.

6. BRASIL. Lei n. 12.305, de 02 de Agosto de 2010. Institui a Política Nacional da Indústria de Resíduos Sólidos. Diário Oficial [da] República Federativa do Brasil, Brasília, 02 Ago. 2010. Available online: http://www.planalto.gov.br/ccivil_03/_ato20072010/2010/lei/l12305.htm (accessed on 24 June 2022).

7. ANICER—Associação Nacional da Indústria Cerâmica. ANICER. Dados do Setor. Santa Gertrudes, Brazil, 19 September 2019. Available online: https://www.anicer.com.br/anicer/setor/ (accessed on 25 July 2021).

8. SEBRAE—Serviço Brasileiro de Apoio às Micro e Pequenas Empresas. Construção Civil. Cerâmica Vermelha. Panorama do Mercado no Brasil. 2015. Available online: http://www.bibliotecas.sebrae.com.br/chronus/arquivosChronus/bds/bds.nsf/b8779b3e87b8382594c886e5c39b3b4/ficheiro/5846.pdf (accessed on 14 September 2019).

9. Almeida, G.S. Simulação e Experimentação da Secagem de Cerâmica Vermelha em Sistemas Térmicos Industriais. Ph.D. Thesis, Portal da Universidade Federal de Campina Grande (UFCG), Campina Grande, Brazil, 2009; 209p.

10. Callister, W.D.; Rethwisch, D.G. Ciência e Engenharia de Materiais: Uma Introdução, 8th ed.; Springer: New York, NY, USA, 2012; 716p.

11. Batista, V.R.; Nascimento, J.J.S.; Lima, A.G.B. Secagem e queima de tijolos cerâmicos. In Conexões dos Materiais, UENF, Campos dos Goytacazes, Brazil, 2012; 100p.

12. Freire, A.S.; Motta, J.F.M. Potencialidades para o aproveitamento econômico do rejeito de serragem de granito. Rochas Qual. 1995, 16, 98–108.

13. Rodrigues, D.V.; Xavier, G.C.; Saboya, F.; Maia, P.C.; Alexandre, J. Durabilidade de peças cerâmicas vermelhas com adição de rejeito de rocha ornamental isenta de granalha. Cerâmica 2012, 58, 286–293. [CrossRef]

14. Aguair, M.C. Utilização de Resíduo de Serragem de Rocha Ornamental com Tecnologia de Fio Diamantado em Cerâmica Vermelha. Master’s Thesis, Centro de Ciência e Tecnologia, Departamento de Ciências dos Materiais, UENF, Campos dos Goytacazes, Brazil, 2012; 100p.

15. Moraes, M.S.; Xavier, G.C.; Alexandre, J.; Azvedo, A.R.G. Análise do comportamento de peças cerâmicas com e sem a incorporação de resíduo de rocha ornamental após ciclos de umedecimento e secagem. In Proceedings of the 64th Congresso Brasileiro de Cerâmica, Águas de Lindóia, Brazil, 7–10 December 2020.

16. Azvedo, A.C.; Marvila, M.T.; Delaqua GC, G.; Amaral, L.F.; Colorado, H.; Vieira, C.M.F. Economy analysis of the implementation of extruded tiles fabrication in a ceramic industry containing ornamental rock waste. Int. J. Appl. Ceram. Technol. 2021, 18, 1876–1890. [CrossRef]

17. Sant’ana, M.A.K.; Gadioli, M.C.B. Estudo da Viabilidade Técnica da Utilização de Resíduos de Rochas em Massas Cerâmicas; Série Tecnologia Ambiental; Centro de Tecnologia Mineral: Rio de Janeiro, Brazil, 2018.

18. Gadioli, M.C.B.; Aguair, M.C.; Vidal, F.W.H.; Sant’ana, M.A.K.; Almeida, K.M.; Giori, A.J.N. Incorporation of Ornamental Stone Waste in the Manufacturing of Red Ceramics. Materials 2022, 15, 5635. [CrossRef] [PubMed]

19. NBR 7181; Análise Granulométrica. ABNT—Associação Brasileira de Normas Técnicas: Rio de Janeiro, Brazil, 1984.

20. ASTM C373-72; Test Method for Water Absorption, Bulk Density, Apparent Porosity and Apparent Specific Gravity of Fired Whiteware Products. American Society for Testing and Materials: West Conshohocken, PA, USA, 1977.

21. ASTM C373-88; Test Method for Water Absorption, Bulk Density and Apparent Porosity. American Society for Testing and Materials: West Conshohocken, PA, USA, 1994.

22. NBR 15270-2; Componentes Cerâmicos—Blocos e Tijolos para Alvenaria. Parte 2: Métodos de Ensaios. ABNT—Associação Brasileira de Normas Técnicas: Rio de Janeiro, Brazil, 2017.

23. ASTM C674-77; Flexural Properties of Ceramic Whiteware Materials. American Society for Testing and Materials: West Conshohocke, PA, USA, 1977.

24. Callister, W.D. Ciência e Engenharia dos Materiais, uma Introdução, 7th ed.; LTC: Rio de Janeiro, Brazil, 2008.

25. German, R.M. Liquid Phase Sintering; Rensselaer Polytechnic Institute Troy: New York, NY, USA, 1985.

26. NBR 15270-1; Componentes Cerâmicos—Blocos e Tijolos para Alvenaria. Parte 1: Requisitos. ABNT—Associação Brasileira de Normas Técnicas: Rio de Janeiro, Brazil, 2017.

27. NBR 15330; Componentes Cerâmicos—Telhas—Terminologia, Requisitos e Métodos de Ensaios. ABNT—Associação Brasileira de Normas Técnicas: Rio de Janeiro, Brazil, 2009.
28. Cerqueira, N.A.; Souza, V.; Alexandre, J.; Xavier, G.C.; Fediuk, R.; Monteiro, S.N.; Barreto, M.N.; Azevedo, A.R.G. Mechanical Feasibility Study of Pressed and Burned Red Ceramic Blocks as Structural and Sealing Masonry. *Materials* **2022**, *15*, 5004. [CrossRef] [PubMed]

29. Vieira, M.T.; Catarino, L.; Oliveira, M.; Sousa, J.; Torralba, J.M.; Cambronero, L.E.G.; Victoria, A. Optimization of the sintering process of raw material wastes. *J. Mater. Process. Technol.* **1999**, *92*, 97–101. [CrossRef]

30. Menezes, R.R.; Neves, G.D.A.; Ferreira, H.C. O estado da arte sobre o uso de resíduos como matérias-primas cerâmicas alternativas. *Rev. Bras. Eng. Agrícola Ambient.* **2002**, *6*, 303–313. [CrossRef]

31. Ribeiro, W.S.; Babisk, M.P. Estudo da influência de adição de resíduos de quartzitos na resistência de cerâmica vermelha. In *Jornada de Iniciação Científica*; CETEM: Rio de Janeiro, Brazil, 2012.