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CLASSIFICATION OF THE ORNAMENTAL STONES PROCESSING WASTE ACCORDING TO THE STANDARD NBR 10004/2004

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Abstract: The processing of ornamental stones is responsible for generating a substantial amount of fine waste. Known as abrasive sludge, they present high fineness resulting from the intense comminution to which they are submitted and, consequently, their particles have a reduced surface area. This characteristic aids the release of elements previously fixed in the crystalline structure of the minerals. The abrasive sludge is commonly deposited in open-air settling ponds, a factor that poses a contamination risk to local ecosystems and human health. Aiming to minimize such impacts, leaching and solubilization represent one of the tools for controlling the effects of the environmental disposal of these residues. In this sense, the Brazilian legislation, through the norm NBR 10004/2004 of ABNT, establishes criteria for classifying waste based on its polluting potential when leached and/or solubilized. Thus, the objective of this work was to investigate the risk of contamination of the abrasive sludge generated by companies located in the city of Campina Grande - PB in relation to the local ecosystem. The methodology consisted of the characterization of the samples by XRD, XRF, TG, and DTA and particle size analysis. Afterward, it was submitted to leaching and solubilization processes, enabling the classification according to the parameters established by the standard in force. The results obtained showed a majority chemical composition of silica (49.47%) and alumina (14.39%) and mineral composition with quartz, anorthite, and biotite. The particle size analysis confirmed the prevalently fine constitution characteristic of this type of material, while the thermal analyses pointed to endothermic peaks related to the decomposition of calcite into CO_2, and the melting temperature of the abrasive slurry. Finally, the leached extract of the sample did not show any elements with concentrations above the allowed limits and was therefore classified as Non-Hazardous. The solubilized extract showed an aluminum concentration of 0.50 $mg.L^{-1}$ while the maximum value allowed by the standard is 0.20 mg.L-1 thus, it is a Non-Inert waste.

Keywords: Leaching; sludge; waste management

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INTRODUCTION

Civil construction is recognized as an important practice for economic and social development, besides being one of the fastest-growing sectors in the world (Halmeman et al., 2010). Paradoxically, it is an activity with great environmental impact for two reasons: high use of natural resources for the production of consumer goods and a substantial generation of solid waste (Lima and Cabral, 2013).

In this segment, the rock resources used in the form of blocks or slabs are extracted and processed from different rocks, such as granite, marble, gneiss, and slate. Known as ornamental stones, these resources are used especially in buildings, monuments, architecture, and sculptures. The sector of ornamental stones processing in Brazil presents a large and regular growth in such a way that the country is considered one of the largest producers and exporters in the world, a situation that directly impacts the generation of wealth and jobs (Duarte et al., 2021; Menezes et al., 2005).

Allied to this positive scenario, this activity has a great impact in environmental terms, whether in the extraction of blocks of rock, cutting or processing of the same, since the generation of waste is associated with any process of transformation or production of materials, as well as all mining activity (Aguiar et al., 2016; Careddu and Dino, 2016; Delgado et al., 2006).

The processing of ornamental rocks refers to the unfolding of raw materials extracted from quarries into blocks or slabs. The process begins with the sheet cutting process performed by looms and block cutters, then finishing and squaring up to the final dimension of interest. The most common looms use an abrasive slurry whose main objectives are lubricating and cooling the blades, preventing oxidation of the plates, serving as a vehicle for the abrasive (grit)m and cleaning the channels between the plates, being distributed by showers in the block by pumping (Torres et al., 2004).

The main residues generated by this type of processing are rock dust, rock fragments, and abrasive mud. The abrasive mud generated by the cutting process presents greater complexity due to its composition and final disposal. It is most commonly thrown into decantation ponds and landfills, causing, besides the direct contamination of surface aquifers, the disfiguring of the landscape and worrying the public authorities, health agencies, and the population located near the sawmills and extraction areas (Braga et al., 2010; Freitas et al., 2012; Santos et al., 2013).

The inadequate disposal of solid waste in the environment has become a worldwide concern since this problem also encompasses the environmental impact through the inadequate and untreated disposal of this waste, and not only the waste of resources. This way, the stone sector has an indispensable challenge to reconcile industrial development and sustainable development (Jabbour et al., 2014; Marchi, 2011; Theodoro et al., 2012).

The evaluation of the environmental impacts caused by solid waste is essential for the understanding of the consequences inherent to its management. The classification of waste is associated with the potential risks it poses to the environment and public health, so both handling and appropriate disposal can be better defined. The possibility of subsequent reuse of the waste also depends on this classification since its associated risks are a function of the physical and chemical or infectious properties it may present (John and Zordan, 2000; Manhães and Holanda, 2008).

Leaching and solubilization are processes that help to identify the way of dissolution of certain waste in the environment or in water. The classification is based on the behavior of the waste in contact with a solvent so that the degree of immobilization of contaminants is diagnosed. This perspective led to the enactment of the NBR 10004 of 2004 by the Brazilian Association of Technical Standards (ABNT), where the waste is classified according to its behavior when dissolved (ABNT, 2004a).

The investigation of the solid polluting residues is directly associated with the sizing and consequent improvement in the management of the environmental impacts caused by the ornamental stone processing sector. However, this subject is not often treated with the importance it deserves. Based on the above, the objective was to characterize the waste generated by ornamental stone processing companies, specifically the abrasive sludge, and subsequently classify them according to the environmental standards in force proposed by NBR 10004/04 in order to assess the dimension of the environmental impact caused by this activity in the region.

METHODOLOGY

The research was enabled by collecting samples through technical visits to granite sawing industries located in the city of Campina Grande – Paraíba state. The geological context is presented in **Fig. 1**, where it is evident that the region is located in a predominantly granitoid belt. The waste was collected according to the NBR 10007 (ABNT, 2004d) and then pulverized and sieved on a 0.074mm mesh for 2 minutes in order to achieve standardization. The following characterization techniques were employed: particle size analysis, X-ray fluorescence (XRF), X-ray diffraction (XRD), and thermal analysis.

Finally, the samples were submitted to solubilization and leaching tests for further characterization of these

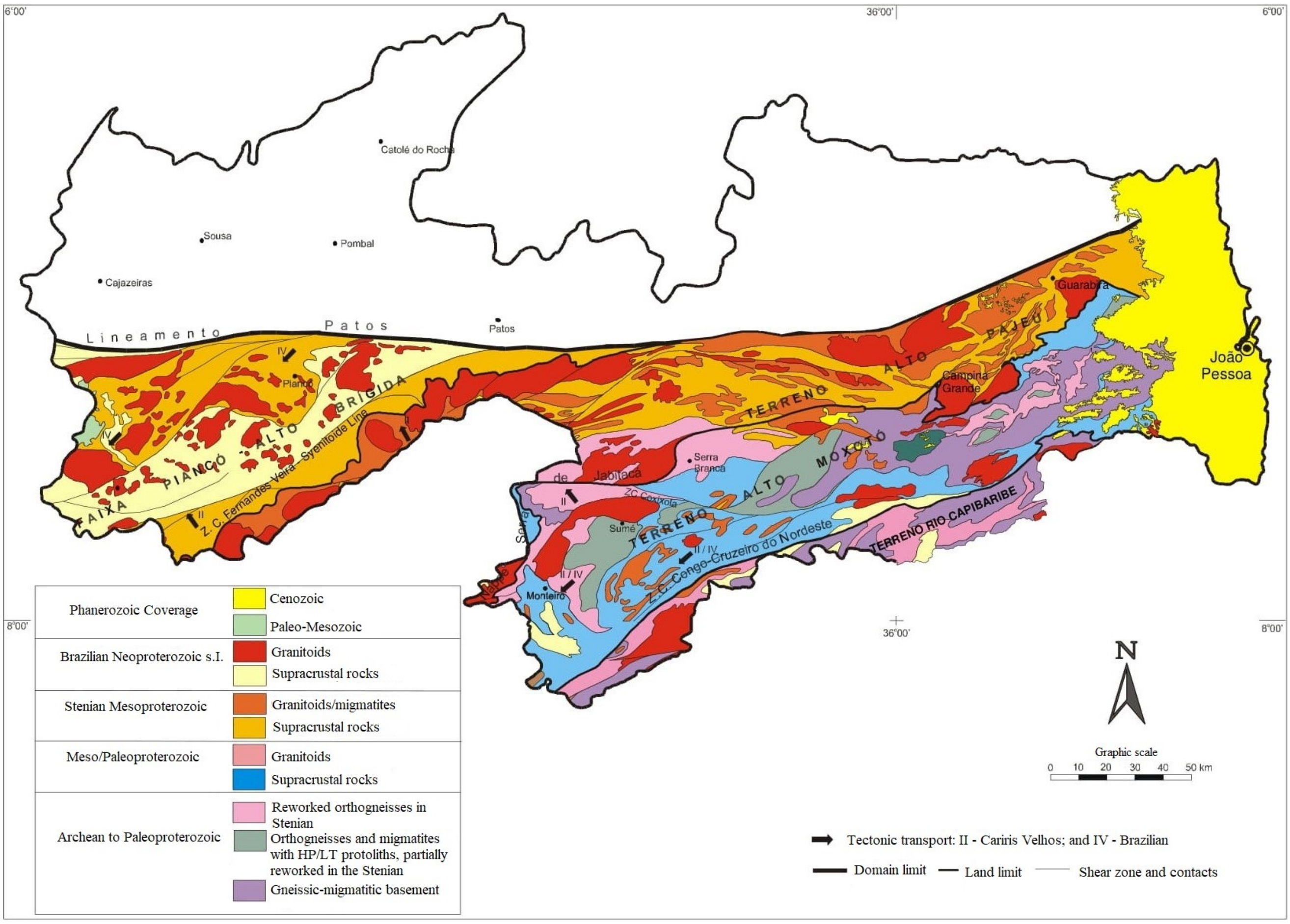

Fig. 1 Representation of the geological context of the sample collection site. Source: Adapted from CPRM (2002).

extracts in specialized laboratories following the standards in force.

Granulometric Evaluation

The particle size evaluation was performed by wet sieving using eight different mesh sizes: 300 mm, 180 mm, 150 mm, 106 mm, 75 mm, 53 mm, and 45 mm.

X-ray diffraction (XRD)

The identification of the mineralogy of the sample was achieved by X-ray diffraction analysis using SHIMADZU XRD 600 equipment. The identification of the phases was done by comparison between the results obtained with crystallographic maps registered in the ICDD (International Centre for Diffraction Data) database.

X-ray Fluorescence (XFR)

For the X-ray fluorescence chemical analysis**,** the SHIMADZU EDX 700 equipment was used to determine the elements present through the application of X-rays on the sample surface and subsequent analysis of the emitted fluorescence; the method of fundamental parameters with results normalized to 100% due to its limitation, only the elements between Na (11) and U (92) were analyzed.

Thermal Analysis

The samples were submitted to thermogravimetric analysis (TG) and differential thermal analysis (DTA). For TG, the SHIMADZU TGA 51H was used with a temperature range of ambient to 1000°C, a heating rate of 10°C/min in air, and a gas flow rate of 50 mL/min. While for DTA, the parameters were: SHIMADZU DTA 50H equipment, range of ambient temperature to 1000ºC with a heating rate of 10°C/min. The atmosphere was nitrogen (N2), and the gas flow rate was 50 mL/min.

Characterization of solubilized and leached extracts

The solid waste samples were sent to the SENAI-CIC laboratories to be tested for solubilization and leaching according to NBR 10006/04 (ABNT, 2004c) and 10005/04 (ABNT, 2004b), respectively. The subsequent classification was performed according to NBR 10004/04 (ABNT, 2004a).

RESULTS AND DISCUSSIONS

Granulometric Evaluation

Table 1 shows the percentages of the retained and passing sample obtained by wet sieving on sieves with different sizes. The values obtained with the granulometric evaluation showed the mostly fine granulometry of the abrasive sludge since a percentage higher than 50% of the sample behaved as passing in the smallest aperture investigated, i.e., 62.71% at 44 µm.

The particle size distribution of the sample represented in **Fig. 2** by the size distribution curve shows a loss of uniformity, which points to a variable distribution of the sample size. It is also observed a high content of particles above 50 µm; according to Manhães and Holanda (2008), it is a fraction rich in quartz in feldspars.

X-ray diffraction (XRD)

The identification of the mineralogy of the slurry waste sample (**Fig. 3**) studied showed its primary constitution of the minerals quartz SiO_2, anorthite $CaAl_2Si_2O_8$and biotite $K(Mg,Fe)_3(Al,Fe)Si_3O_{10}/(OH,F)_2$. The most expressive peak observed corresponds to the quartz, which has its presence due to the stone dust generated during the block sawing stage. The remaining peaks were associated with both anorthite and biotite. The former occurs in igneous and metamorphic rocks and presents due to sawing. While the second is a mineral from the mica group (present in the formation of granites) that contains in its composition potassium, magnesium, iron, and aluminum and is associated with the addition of iron grit during cutting. The verified phases agree with the recent literature, as can be observed in works such as those of Farias et al. (2018), Lozano-Lunar et al. (2020), Teixeira et al. (2018), and Santos and Galembeck (2016).

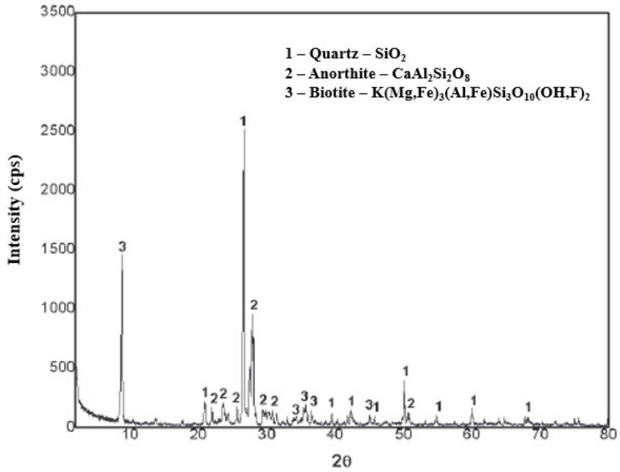

Fig. 3 Result of the XRD analysis of the slurry sample with the peaks indicated and related to the corresponding mineralogy.

Table 1. Results of particle size analysis identifying the percentages of retained and passing slurry sample at different apertures.

Aperture (µm)	Retained (%)	Passant (%)
297	9,95	90,05
177	16,02	83,98
149	19,37	80,63
105	24,53	75,47
74	30,02	69,98
53	35,60	64,40
44	37,29	62,71

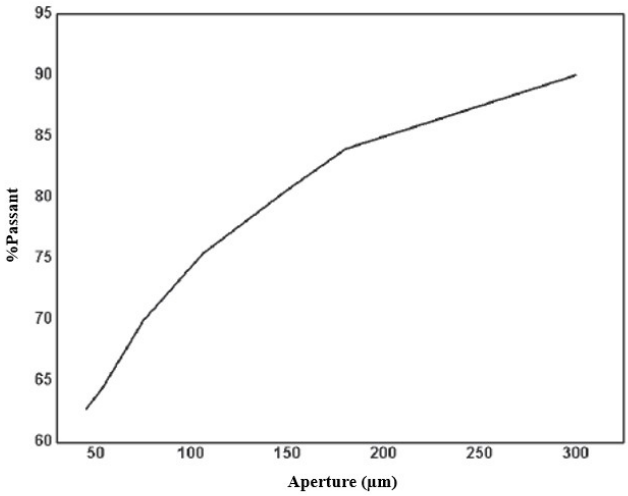

Fig. 2 Sieve size curve relating the percentage of abrasive sludge passing the sieve opening in µm.

X-ray Fluorescence (XFR)

The constitution of the abrasive slurry is shown in **Table 2**. It can be observed that it consists mostly of silicon dioxide (SiO2) and aluminum oxide (Al2O3). Their presence is commonly associated with feldspars, micas, and garnet. Iron oxide (Fe2O3), on the other hand, is associated with the leavening and polishing processes carried out during beneficiation; the same goes for CaO e K2O (Anthony et al., 2003). In this perspective, the XRF results ratify the mineralogical composition presented in **Fig. 3**. According to Teixeira et al. (2008), the low reactivity of the residues is indicated due to the well-defined crystalline peak of SiO2 and the absence of an amorphous halo in the diffractogram.

Thermogravimetric analysis

Figures 4–5 show the curves obtained in the thermogravimetric and thermo differential analyses of the slurry samples, respectively, where a small mass variation in the temperature range investigated in TG was demonstrated. The most striking mass loss occurs between 600°C and 730°C, where it is possible to observe an important endothermic peak at 710°C caused

Table 2. Chemical composition obtained by XRF of the abrasive sludge sample**.**

Analyte	Composition (%)
SiO_2	49.47
Al_2O_3	14.39
Fe_2O_3	11.76
CaO	8.79
K_2O	6.28
MgO	2.21
Na_2O	1.99
TiO_2	1.14
SnO_2	0.36
SO_3	0.18
MnO	0.17
P_2O_5	0.15
Nb_2O_5	0.12
SrO	0.08
ZrO_2	0.07
Cr_2O_3	0.06
NiO	0.03
ZnO	0.02
SUM	97.27

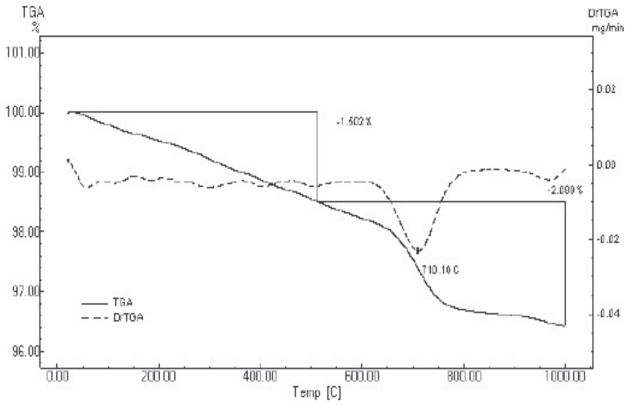

Fig. 4 TG and drTG curves from thermogravimetric analysis of the slurry sample.

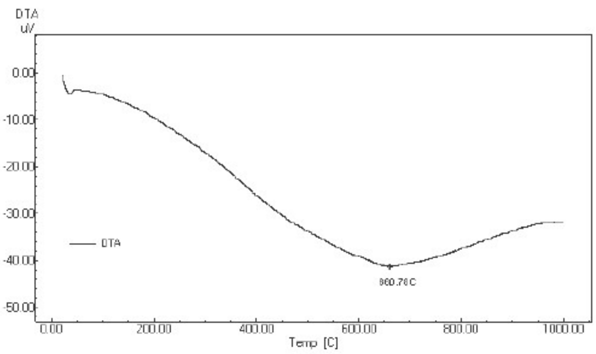

Fig. 5 DTA curve from the differential thermal analysis of the slurry sample.

probably by the decomposition of calcite into CO2 (Moreno-Maroto et al., 2017). While DTA allowed pointing to an endothermic peak above 1000ºC possibly associated with the melting temperature of the sample (Taguchi et al., 2012).

Extract characterization

The publication of NBR 10005 and NBR 10006 standards in 2004 stipulated the steps that comprise, respectively, the processes for obtaining leached and solubilized extracts from solid waste. The standards aim to ensure greater reliability of results through consistent standardization and to propose the requirements for obtaining extracts in order to classify them.

Thus, ABNT's NBR 10004/2004 categorizes waste into different classes. Class I (or Dangerous) groups the samples with one or more leachate parameters above the maximum values allowed by Annex F of NBR. For Class II A (Non-Inert), there are one or more parameters of the solubilized extract with values above the maximum allowed by Annex G of the standard. Finally, a waste sample will be in Class II B (Inert) when all the parameters of both the leaching and solubilization tests are below the maximum allowed values (Lima and Cabral, 2013).

Table 3 shows the results obtained for the leaching test of the abrasive sludge sample, as well as the upper limit allowed for each constituent according to Annex F of NBR 10004 (ABNT, 2004a). The leaching test indicates the presence of barium, cadmium, lead, and total chromium in the sludge, however, in concentrations below the maximum allowed limit, thus ruling out the possibility of this waste being classified as hazardous (Class I).

The results of the solubilization analysis and the respective limits established by Annex G of NBR 1004 (ABNT, 2004a) are presented in **Table 4.** The solubilized extract exhibited concentrations below the expected limit, the only exception being aluminum (0.50 mgL-1) which has a value of 0.20 mgL-1 as the maximum allowable concentration. Therefore, the abrasive sludge can be classified as Non-Inert or Class II A waste, i.e., they dissolve in water and are biodegradable, but are not inert (Lima and Cabral, 2013; Manhães and Holanda, 2008).

Table 3. Concentrations of the characterization parameters of the leached extract of the abrasive sludge sample and their limits.

Parameters	Leachate concentration (mgL^{-1})	Annex F - Upper limit (mgL^{-1})
Barium	0.65	70.00
Cadmium	< 0.10	0.50
Lead	< 0.50	1.00
Total chromium	0.07	5.00

Table 4. Concentrations of the characterization parameters of the solubilized extract of the abrasive sludge sample and their limits.

Parameters	Solubilized concentration (mgL^{-1})	Annex G - Upper limit (mgL^{-1})
Chlorides	12.50	250.00
Sulfate	16.58	250.00
Aluminium	0.50	0.20
Barium	0.50	0.70
Cadmium	< 0.0005	0.005
Lead	< 0.005	0.01
Copper	< 0.10	2.00
Total chromium	< 0.05	0.05
Iron	< 0.10	0.30
Manganese	< 0.10	0.10
Silver	< 0.05	0.05
Sodium	29.25	200.00
Zinc	< 0.10	5.00

The classification of the abrasive sludge corroborates with state of the art, since, according to Braga et al. (2010), 50% of the analyses performed on samples of waste from the processing of ornamental rocks classify it as Class II A for at least one of the following parameters: Al, F-, Pb, Hg, Cl-, Cr, Fe, Mn (Buzzi, 2006; Lorenzoni, 2005).

CONCLUSIONS

The abrasive sludge, the main residue generated in the processing of ornamental stones, was characterized as silicoaluminous with more than 60% of these elements in its composition. The presence of Fe2O3 was also observed, with a value of approximately 12%. The mineralogical constitution ratified the occurrence of these oxides since it basically comprises quartz, anorthite, and biotite from the type of rock processed. The granulometric analysis pointed to particles mostly fine and rich in feldspars, besides a considerable distribution variation. The thermal analyses allowed the identification of endothermic peaks possibly related to calcite decomposition and the melting temperature of the residue.

For classification purposes, according to ABNT's NBR 10004/2004, the leaching test allowed the identification of the abrasive sludge as Non Hazardous waste, i.e., it is not in Class I. The solubilization test, on the other hand, classified it as Class II A (Non-Inert), which indicates the possibility of detachment of these constituents in the natural environment, possibly causing contamination of soil or water resources.

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REFERENCES

ABNT. NBR 10004. (2004a). Resíduos sólidos – classificação. Associação Brasileira de Normas Técnicas.

ABNT. NBR 10005. (2004b). Procedimento para obtenção de extrato lixiviado de resíduos sólidos.

ABNT. NBR 10006. (2004c). Procedimento para obtenção de extrato solubilizado de resíduos sólidos.

Aguiar, L. L., Tonon, C. B., Nunes, E. T., Braga, A. C. A., Neves, M. A., & de Oliveira David, J. A. (2016). Mutagenic potential of fine wastes from dimension stone industry. *Ecotoxicology and Environmental Safety*, *125*, 116–120. https://doi.org/10.1016/j.ecoenv.2015.11.035

Anthony, J. W., Bideaux, R. A., Bladh, K. W., & Nichols., M. C. (2003). Handbook of Mineralogy. In *Mineralogical Society of America*.

Braga, F. dos S., Buzzi, D. C., Couto, M. C. L., & Lange, L. C. (2010). Environmental characterization of processing sludge of ornamental stones. *Engenharia Sanitaria e Ambiental*, *15*(3), 237–244. https://doi.org/10.1590/s1413-41522010000300006

Buzzi, D.C. Caracterização segundo a NBR 10004/2004 de resíduos gerados no beneficiamento de granitos. (2006). SIMPÓSIO ÍTALO BRASILEIRO DE ENGENHARIA SANITÁRIA E AMBIENTAL, 8, Fortaleza, Brasil.

Careddu, N., & Dino, G. A. (2016). Reuse of residual sludge from stone processing: differences and similarities between sludge coming from carbonate and silicate stones—Italian experiences. *Environmental Earth Sciences*, *75*(14), 1–9. https://doi.org/10.1007/s12665-016-5865-1

CPRM – Serviço Geológico do Brasil (2002). Geologia e Recursos Minerais do Estado da Paraíba. Companhia de Pesquisa de Recursos Minerais.

Delgado, J., Vázquez, A., Juncosa, R., & Barrientos, V. (2006). Geochemical assessment of the contaminant potential of granite fines produced during sawing and related processes associated to the dimension stone industry. *Journal of Geochemical Exploration*, *88*(1-3 SPEC. ISS.), 24–27. https://doi.org/10.1016/j.gexplo.2005.08.009

Duarte, E. B., Nascimento, A. P. da S., Gandine, S. M. da S., Carvalho, J. R. de, Burak, D. L., & Neves, M. A. (2021). Liberação de potássio e sódio a partir de resíduos do beneficiamento de rochas ornamentais. *Pesquisas Em Geociências*, *40*(1), e101373. https://doi.org/10.22456/1807-9806.101373

Farias, L.S., Ribeiro, J.M., & Souza, P.S.L. (2018). Análise da absorção do concreto reciclado com resíduo de corte de mármore e granito (RCMG) como adição. 60º Congresso Brasileiro do Concreto, Foz do Iguaçu, Brasil.

Freitas, J. J. G., Raymundo, V., & De Jesus, H. C. (2012). Características químicas dos resíduos de serragem segregados de rochas ornamentais do estado do Espírito Santo. *Revista Brasileira de Geociencias*, *42*(3), 615–624. https://doi.org/10.5327/Z0375-75362012000300014

Halmeman, M. C. R., Souza, P. C. De, & Casarin, A. N. (2010). Caracterização dos resíduos de construção e demolição na unidade de recebimento de resíduos sólidos no município de Campo Mourão-PR. *Revista Tecnológica*, *0*(0), 203–209. https://doi.org/10.4025/revtecnol.v0i0.8821

Jabbour, A. B. L. de S., Jabbour, C. J. C., Sarkis, J., & Govindan, K. (2014). Brazil's new national policy on solid waste: Challenges and opportunities. *Clean Technologies and Environmental Policy*, *16*(1), 7–9. https://doi.org/10.1007/s10098-013-0600-z

John, V. M., & Zordan, S. E. (2000). Research & Development methodology for recycling residues as building materials-A proposal. *Waste Management Series*, *1*(C), 513–524. https://doi.org/10.1016/S0713-2743(00)80062-8

Lima, A. S., & Cabral, A. E. B. (2013). Caracterização e classificação dos resíduos de construção civil da cidade de Fortaleza (CE). *Engenharia Sanitaria e Ambiental*, *18*(2), 169–176. https://doi.org/10.1590/S1413-41522013000200009

Lorenzoni, D.I. Tijolos prensados produzidos com resíduos sólidos industriais: uma caracterização segundo a NBR 10004/2004. (2005). Dissertação (Mestrado em Engenharia Ambiental), Universidade Federal do Espírito Santo, Vitória, Brasil.

Lozano-Lunar, A., Dubchenko, I., Bashynskyi, S., Rodero, A., Fernández, J. M., & Jiménez, J. R. (2020). Performance of self-compacting mortars with granite sludge as aggregate. *Construction and Building Materials*, *251*, 118998. https://doi.org/10.1016/j.conbuildmat.2020.118998

Manhães, J. P. V. T., & De Holanda, J. N. F. (2008). Characterization and classification of granitic rock powder solid waste produced by ornamental rock industry. *Quimica Nova*. https://doi.org/10.1590/S0100-40422008000600005

Marchi, C. M. D. F. (2011). Cenário mundial dos resíduos sólidos e o comporatamento corporativo brasileiro frente à logística reversa. *Perspectivas Em Gestão & Conhecimento*, *1*(2), 118–135.

Menezes, R. R., Ferreira, H. S., Neves, G. A., Lira, H. de L., & Ferreira, H. C. (2005). Use of granite sawing wastes in the production of ceramic bricks and tiles. *Journal of the European Ceramic Society*. https://doi.org/10.1016/j.jeurceramsoc.2004.04.020

Moreno-Maroto, J. M., González-Corrochano, B., Alonso-Azcárate, J., Rodríguez, L., & Acosta, A. (2017). Manufacturing of lightweight aggregates with carbon fiber and mineral wastes. *Cement and Concrete Composites*, *83*, 335–348. https://doi.org/10.1016/j.cemconcomp.2017.08.001

Santos, M. M. A., Destefani, A. Z., & Holanda, J. N. F. (2013). Caracterização de resíduos de rochas ornamentais provenientes de diferentes processos de corte e beneficiamento. *Revista Materia*, *18*(4), 1442–1450. https://doi.org/10.1590/S1517-70762013000400005

Santos, J., Galembeck, F.(2016). Caracterização de resíduos de rochas ornamentais: Aplicação de conceitos mecanoquímicos. 22º CBECiMat - Congresso Brasileiro de Engenharia e Ciência dos Materiais, Natal, Brasil.

Taguchi, S. P., Cunha, J. A., Cunha, N. A., Santos, F. A., & Silva, A. (2012). Produção de vidrado a partir de resíduo de rochas ornamentais. *20º CBECIMAT - Congresso Brasileiro de Engenharia e Ciência Dos Materiais*, (4220), 5–7.

Teixeira, F. R., Paliga, C. M., & Torres, A. S. (2018). Resistência à compressão e absorção de água em concretos produzidos com substituição parcial do cimento pelo resíduo do beneficiamento de rochas ornamentais. 60º Congresso Brasileiro do Concreto, Foz do Iguaçu, Brasil.

Theodoro, S. H., Tchouankoue, J. P., Gonçalves, A. O., Leonardos, O., & Harper, J. (2012). Revista Brasileira de Geografia Física. *Revista Brasileira de Geografia Física*, *06*(December 2012), 1390–1407.

Torres, P., Fernandes, H. R., Agathopoulos, S., Tulyaganov, D. U., & Ferreira, J. M. F. (2004). Incorporation of granite cutting sludge in industrial porcelain tile formulations. *Journal of the European Ceramic Society*. https://doi.org/10.1016/j.jeurceramsoc.2003.10.039