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Characterization of granite mining waste for geotechnical purposes

Caracterização de resíduo de lavra de granito para fins geotécnicos

Albert Jonatha Batista[1]; Maria Del Pilar Durante Ingunza[2]

[1] Federal University of Rio Grande do Norte (UFRN), Department of Civil Engineering, Natal/RN, Brazil. Email: albert.batista.064@ufrn.edu.br
ORCID: https://orcid.org/0000-0002-6873-0742

[2] Federal University of Rio Grande do Norte, (UFRN), Department of Civil Engineering, Natal/RN, Brazil. Email: maria.ingunza@ufrn.br
ORCID: https://orcid.org/0000-0001-6994-7559

Abstract: Waste generation is part of any production process. Among productive sectors, the mining industry stands out in environmentally sustainable models due to the large volume of waste produced. Crystalline rocks, particularly granites, are highlighted due to their high mechanical strength and esthetic characteristics. The aim of this study was to perform a geological/geotechnical characterization of granite mining waste for geotechnical purposes. Samples of granite mining waste were collected at different waste disposal points. The following characterizations were performed: physical (apparent specific gravity, apparent absorption and apparent porosity), optical and scanning electron microscopy and mechanical characterization (uniaxial compressive strength test). All the samples analyzed exhibited physical indices and average values compatible with those recommended by international standards. Textural aspects, such as random muscovite concentration, forming aggregates, can explain the mechanical behaviour of the samples. In addition, based on the results obtained, the waste collected can be used in the riprap of hydraulic and construction projects that cross water courses and roadways.

Keywords: Granite; Mining Waste; Geotechnical characterization.

Resumo: A geração de resíduos é parte de todo processo de produção. Entre os setores de produção, a indústria de mineração se destaca em modelos ambientais sustentáveis devido ao grande volume de resíduos produzidos. Rochas cristalinas, em particular granitos, se destacam devido à sua resistência mecânica e características estéticas. O objetivo deste estudo foi realizar uma caracterização geológica/geotécnica de resíduos de mineração de granito para fins geotécnicos. Amostras de resíduos de mineração de granito foram coletadas em diferentes pontos de disposição de resíduos. As seguintes caraterizações foram realizadas: física (massa específica aparente, absorção aparente e porosidade aparente), microscopia óptica e eletrônica de varredura e caracterização mecânica (ensaio de resistência à compressão uniaxial). Todas as amostras analisadas exibiram índices físicos e valores médios compatíveis com os recomendados pelas normas internacionais. Aspectos texturais, tais como concentrações aleatórias de moscovita, formando agregados, podem explicar o comportamento mecânico das amostras. Adicionalmente, com base nos resultados obtidos, os resíduos coletados podem ser usados no riprap de projetos hidráulicos e de construção que cruzam cursos de água e rodovias.

Palavras-chave: Rocha ornamental; Caracterização mecânica; Obras geotécnicas.

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1. Introduction

Waste generation is part of any production process. Among productive sectors, the mining industry stands out in environmentally sustainable models due to the large volume of waste produced.

Ornamental stone mining waste consists of solid (sterile) extraction waste normally composed of blocks or rock fragments. These are defined as natural rocky materials with an esthetic function (ABNT NBR 15012, 2013) and have different applications, mainly in the areas of architecture, construction and art. Among these stones, crystalline rocks, particularly granites, stand out due to their high mechanical strength and esthetic characteristics.

According to Montani (2020), in 2019 global production of granite as an ornamental stone was 89.5 million metric tons/year (57% of the total). In Brazil, the situation is no different. In recent years, the increasing demand for mineral inputs has led to a significant growth in mining activity, resulting in greater generation of mining waste. According to IBRAM (2021), Brazilian mining production in the first quarter of 2021 was US$70 billion, 95% higher than 2020.

Rio Grande do Norte state (Northeastern Brazil) produced 200,000 metric tons of ornamental stones in the crystalline rock category (primarily granites and marbles), ranking sixth among ornamental stone producers in the country (Chiodi Filho, 2021).

In civil construction, the growing demand for aggregates has raised environmental concerns (Akbulut and Gurer, 2007). In this respect, recent studies confirm the sustainable use of crystalline rock waste with geotechnical purposes (Gautam et al, 2018[a]; Akbulut and Gurer ,2007, Agyeman and Ampadu (2015), Deboucha et al. (2019) and Ahmed, Abdelhafez and Ahmed (2020) and Suliman and Alkherret, 2020). Notably, Bussière (2007) underscores the viability of using hard rock waste to improve the mechanical characteristics of tailings impoundments.

Thus, the aim of this study was to perform a geological/geotechnical characterization of granite mining waste for geotechnical purposes.

2. Methodology

The material used in the study was granite mining waste (Figures 1 and 2), obtained from a local mining company located in Northeastern Brazil. The region is known nationally for ornamental stone production. According to internal company reports, 14% of all the material extracted is reused and commercialized, and the rest discarded. The primary reasons to dispose of the material are not meeting the esthetic criteria required by the commercial sector and block cracking in the exploration stages.

Figure 1 – General overview of the granite mining waste área
Source: Authors (2021).

Figure 2 – Detail of the waste disposal deposit
Source: Authors (2021).

The study area is geologically located in the Borborema structural province, coinciding with the Região de Dobramentos Nordeste, developed during the Brazilian Cycle and constituting lithotypes from the Itaporanga Suite, the main Brazilian magmatic event in the region. It contains granite rocks with abundant potassium feldspar phenocrystals (CPRM, 2005).

The samples used in the study were collected at three different waste disposal points in a single deposit, called collection points 1, 2 and 3.

In order to reach the objectives proposed, the following characterizations were performed: physical, microscopic (optical microscopy and scanning electron microscopy) and mechanical characterization.

2.1. Physical characterization

Physical characterization consists of determining apparent specific gravity, apparent absorption and apparent porosity of the samples, according to ABNT NBR 15845-2, 2015.

It is important to underscore that ABNT NBR 15844 (2015) and ASTM C-615 (2003), which contain the requirements of granite coating, were used as comparative parameters, since the literature uses these standards with the same objective.

In this stage, eight test specimens were used for each collection point, totaling twenty-four specimens, denominated CP 01 to 08 for collection Point 1, CP 09 to 16 for collection point 2 and CP 17 to 24 for collection point 3.

2.2. Optical petrography characterization

Six thin sections were described (two for each collection point studied), according to ABNT NBR 15845-1 (2015), aimed at determining the degree of alteration in the rocks analyzed. The methodology described by Stoops et al. (1979) was applied to rock fragments, which proposes a series of alteration patterns to establish the degree of sample change based on the micromorphological description.

2.3. Scanning electron microscopy (SEM) characterization

A Hitachi TM-3000 scanning electron microscope (SEM) was used to confirm the information obtained in petrographic assessment, but specifically in morphostructural aspects.

2.4. Mechanical characterization

The test to determine the uniaxial compressive strength of the rocks (ABNT NBR 15845-5, 2015) according to the American guideline (ASTM C – 170, 2009), is one of the most widely used in ornamental rock characterization. The results obtained allow a good estimate of rock properties. For solid rock assessment, this guideline establishes a minimum of 10 cubic test specimens, with edges between 70 mm and 75 mm, or cylindrical, with diameter between 70 mm and 75 mm and a base/height ratio of 1:1. The test should be executed with the help of a hydraulic press (Figure 3) and force applied at a rate below 0.5 MPa/s, until the test specimen breaks.

Figure 3 – Hydraulic press used to determine the uniaxial compressive strength
Source: Authors (2021).

In order to obtain uniaxial compressive strength, the breaking force in Formula 1 is applied.

$$\sigma_c = \frac{P}{A} \tag{1}$$

Where σ_c is fracture stress under compression in megapascals (MPa), P the maximum breaking force in kilonewtons (kN) and A the area of the test specimen surface submitted to loading in square meters (m²).

The size of the samples collected in the field was reduced to produce the test specimens (Figure 4). Cubic test specimens were molded with 7 cm edges (Figure 5).

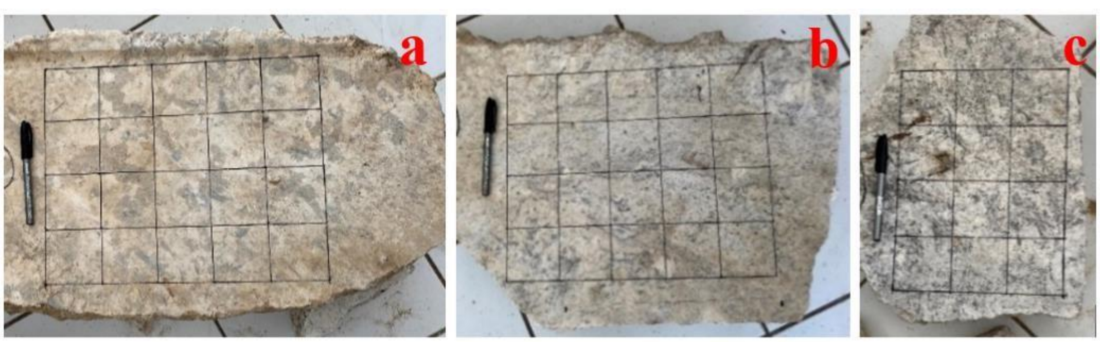

Figure 4 – Collected samples: (a) collection point 1 (b) collection point 2 e (c) collection point 3

Source: Authors (2021).

Figure 5 – Detail of cubic specimens, measuring 7 cm of edges to carry out the test resistance to uniaxial compression of rocks
Source: Authors (2021).

For each collection point 12 test specimens were molded, totaling thirty-six test specimens.

3. Results

3.1. Physical characterization

Figure 6 presents the apparent specific gravity values (g/cm³) of the test specimens. The average values obtained for the granite samples studied varied from 2.63g/cm³ to 2.64g/cm³. The minimum acceptable average apparent specific gravity of granites is 2.56 g/cm³ (ABNT NBR 15844) and 2.55 g/cm³ (ASTM C-615). Thus, all the samples obtained apparent specific gravity values in line with the guidelines.

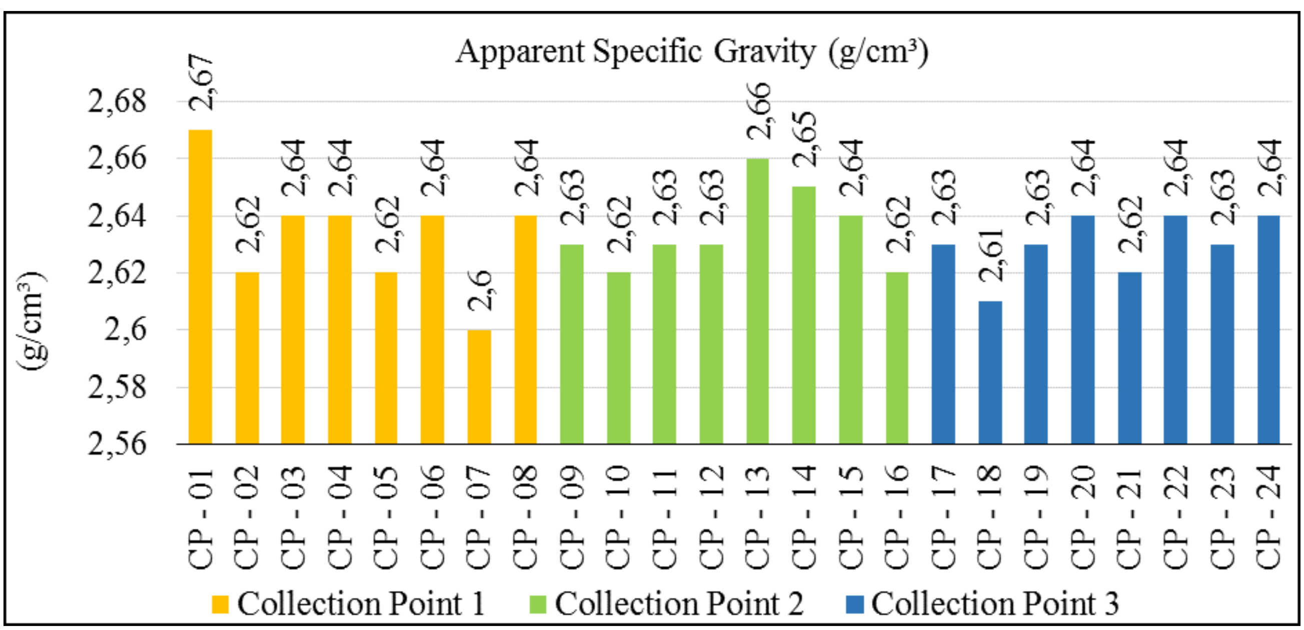

Figure 6 – Apparent specific gravity values (g/cm³) of the test specimens
Source: Authors (2021).

Figure 7 presents the water absorption values (%) of the test specimens. The average values obtained for the granite samples studied varied from 0.17 % to 0.24%. Given the average maximum acceptable water absorption value of 0.4% for granite (ABNT NBR 15844 and ASTM C-615), all the samples studied exhibited water absorption within the required values.

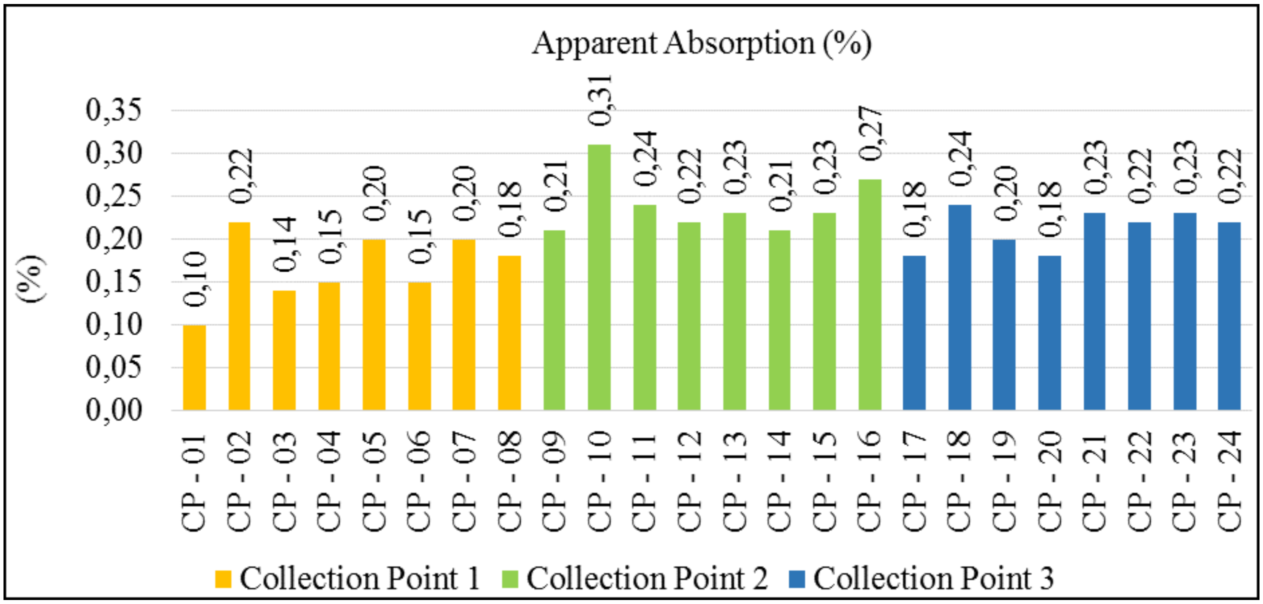

Figure 7 – Water absorption values (%) of the test specimens
Source: Authors (2021).

Figure 8 shows the apparent porosity values (%) of the test specimens. The average values obtained for the granite samples analyzed ranged from 0.44 % to 0.63%. According to the Brazilian guideline, the average maximum acceptable apparent porosity of granite is 1.0 %, meaning that the samples studied were within the established guidelines.

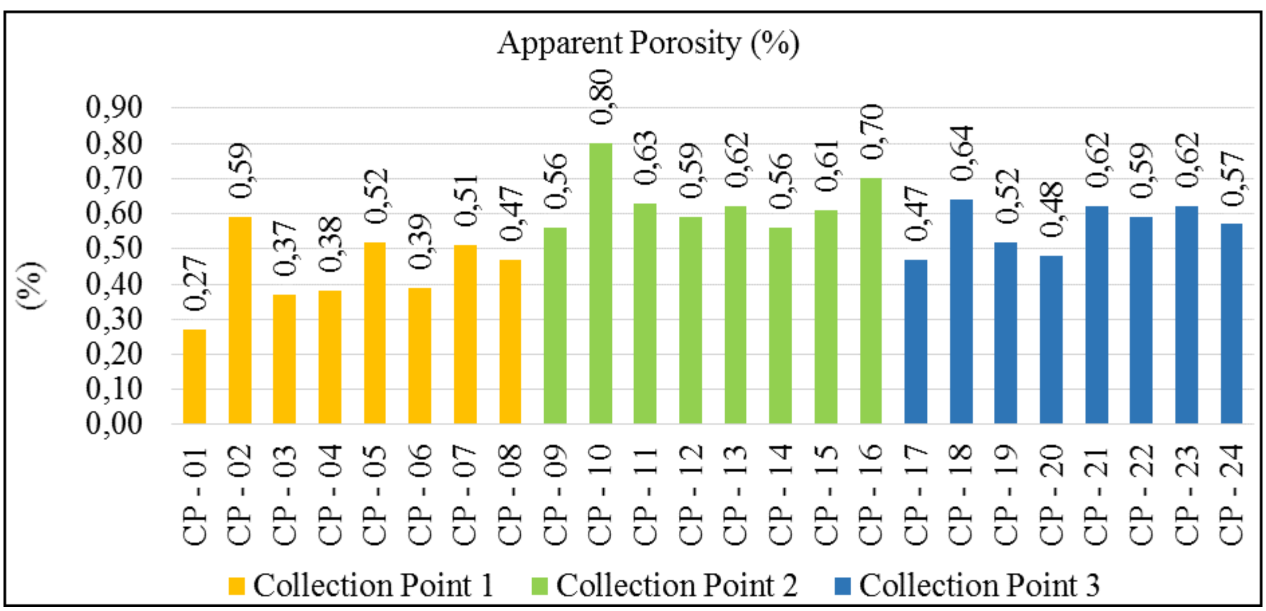

Figure 8 – Apparent porosity values (%) of the test specimens

Source: Authors (2021).

3.2. Mechanical characterization

Figure 9 presents the uniaxial compressive strength (MPa) of the test specimens. The average values obtained for the granite samples studied were 86 MPa, 132 MPa and 104 MPa, for collection points 1,2 and 3, respectively. The average minimum acceptable uniaxial compressive strength of granites is 100 MPa for the Brazilian guideline and 131 MPa for the American guideline. Thus, the collection point 1 result was below both values, collection Point 3 lower than the value established by ASTM C-615 (2003) and higher than that of ABNT NBR 15844 (2015), and collection Point 2 was higher than both.

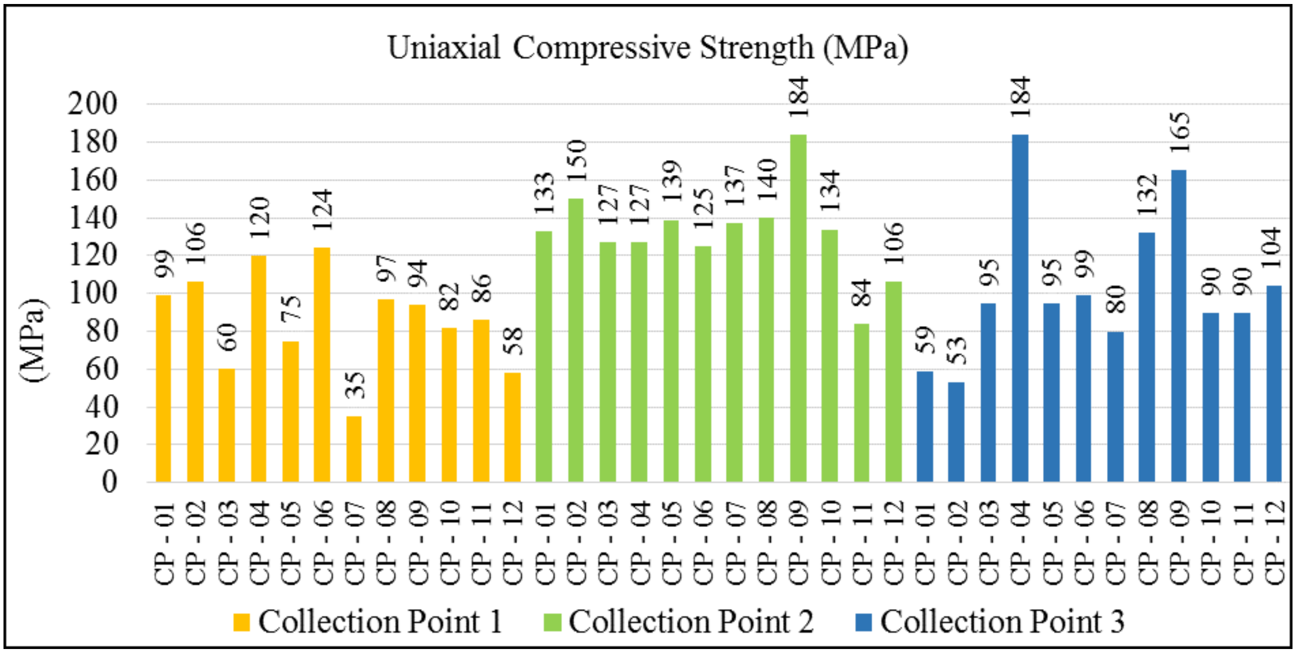

Figure 9 – Uniaxial compressive strength (MPa) of the test specimens
Source: Authors (2021).

3.3. Petrographic characterization

Petrographic analysis identified the samples as granite rocks with inequigranular medium to coarse particle size, with euhedral and subhedral crystals, exhibiting the following mineralogy: quartz, plagioclase feldspar, K-feldspar and muscovite mica (Figure 10). The primary accessories are apatite and green hornblende (Figure 11).

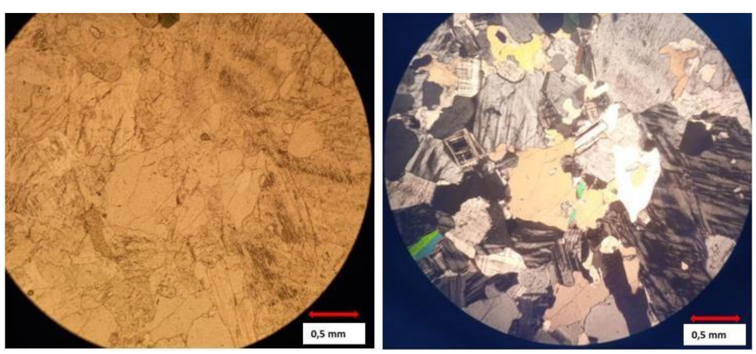

Figure 10 – Microphotographs. General view. Plane-polarized light (left) and crossed polars (right), showing the main mineralogy: quartz, plagioclase feldspar, K-feldspar and muscovite mica
Source: Authors (2021).

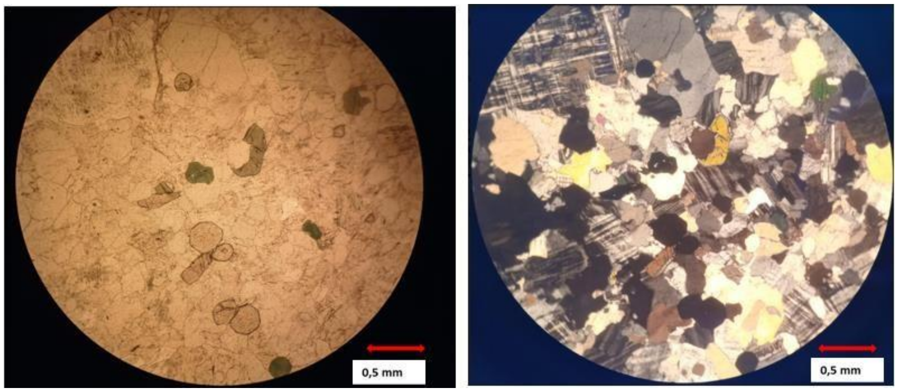

Figure 11 – Microphotographs. General view. Plane-polarized light (left) and crossed polars (right), showing the primary accessories: appatite, with isotropic basal sections, and green hornblende
Source: Authors (2021).

There is no preferred orientation of minerals, but muscovite crystal concentrations were distributed heterogeneously (Figure 12).

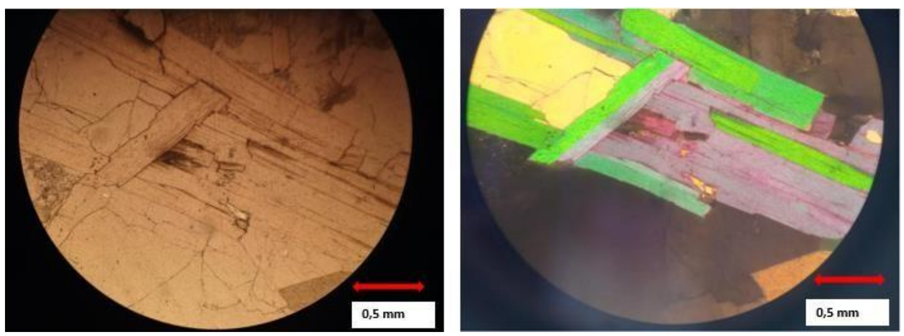

Figure 12 – Microphotographs. Plane-polarized light (left) and crossed polars (right), showing muscovite crystal concentrations heterogeneously distributed
Source: Authors (2021).

The degree of alteration is visible in plagioclase feldspars, primarily at the edges showing argillization processes. Some feldspar samples exhibited mica alteration due to sericitization (Figure 13).

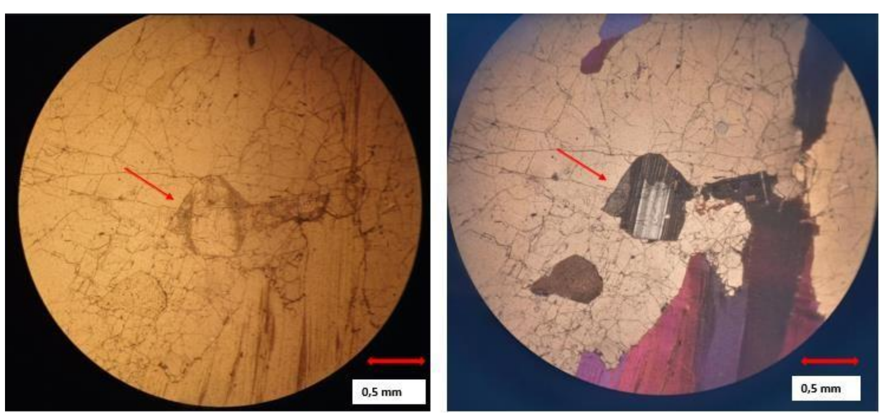

Figure 13 – Microphotographs. Alteration degree. Plane-polarized light (left) and crossed polars (right). Alteration in plagioclase feldspar crystal, primarily at the edges showing argillization processes

Source: Authors (2021).

According to the methodology proposed by Stoops et al. (1979), the degree of alteration in the samples is defined as incipient alteration (slightly altered) where between 2.5 and 25 % of the minerals (feldspars) are altered. The alteration processes are identified exclusively as argillization and sericitization. There are no alteration signs of fractures, cracks or secondary porosity. Furthermore, the alteration is identified by argillization and sericitization processes.

3.4. Scanning electron microscopy (SEM) characterization

The SEM images obtained (Figures 14 and 15) confirm the observations conducted in optical petrography. In general, a compact crystalline texture characteristic of the rocks studied is observed, highlighting fracture surfaces of the test specimens. There were no signs of structural changes such as secondary porosity or cracking. Microphotographs show different mica crystal distribution. Fig. 14 exhibits mica lamellae showing cleavage (14d). Fig. 15 shows the mica lamellae with cleavage planes perpendicular to the test specimen surface.

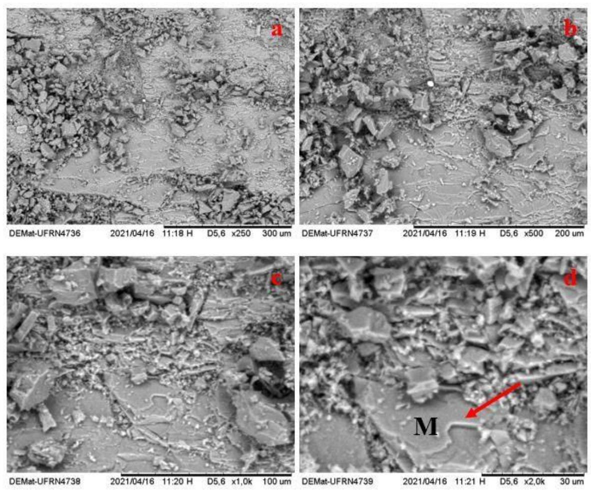

Figure 14 – SEM images. Collection point 1. Magnification: (a) x250, (b) x500, (c) x1000 e (d)x2000. Mica lamellae showing cleavage (14d)
Source: Authors (2021).

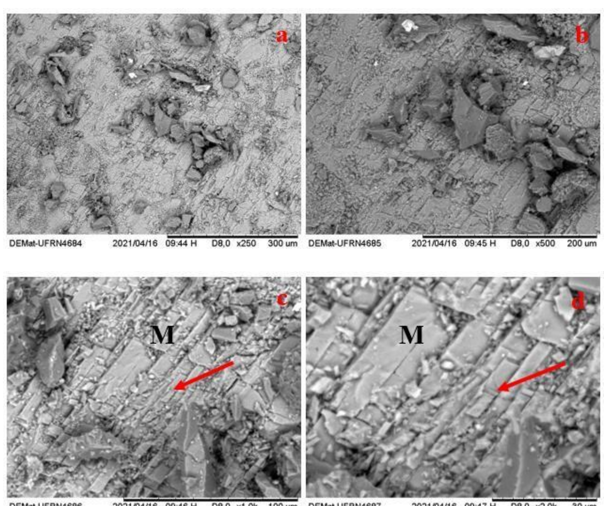

Figure 15 – SEM images. Collection point 2. Magnification: (a) x250, (b) x500, (c) x1000 e (d) x2000, showing the mica lamellae with perpendicular cleavage planes to the test specimen surface

Source: Authors (2021).

Mineralogy is the main factor explaining the results of mechanical behavior, more specifically the textural and structural features. Thus, due to the incipient degree, feldspar alteration does not seem significant, but the random muscovite concentration forming aggregates, displaying concentrations of up to 1cm thick in some samples, is an essential factor explaining this behavior (Figure 16). Furthermore, the orientation of the mica lamellae on the test specimens, demonstrating an important property in this type of silicate (cleavage), must have influenced the poorer mechanical performance of some test specimens, whereby in some test specimens with muscovite lamellae arranged perpendicularly to the force applied, compressive strength will be better than those with lamellae parallel to subparallel to the force applied.

Figura 16 – Specimen with Muscovite aggregates
Source: Authors (2021).

4. Conclusions

This study characterized granite mining waste according to its mineralogical and microstructural composition, physical indices and mechanical strength via unidirectional compression, for geotechnical purposes.

All the samples analyzed exhibited physical indices (apparent specific gravity and apparent porosity) and average values compatible with those recommended by Brazilian (ABNT NBR 15844) and American guidelines (ASTM C – 615).

With respect to the compressive strength values of the guidelines used, the samples from collection point 2 obtained higher average mechanical strength; those from collection point 1 lower average mechanical strength and point 3 samples higher mechanical strength than that suggested by the Brazilian guideline, but lower than that indicated by its American counterpart.

The samples studied demonstrated an incipient alteration in line with the methodology proposed by Stoops et al. (1979), which does not explain their mechanical performance variations. Thus, textural aspects, such as random muscovite concentration, forming aggregates, are essential to explaining this behavior. In addition, the arrangement of the mica aggregates in relation to the force received must have influenced the poorer mechanical performance of some test specimens, demonstrating the influence of structural characteristics, such as the cleavage of phyllosilicates.

Based on the results obtained, the waste collected can be used in the riprap of hydraulic and construction projects that cross water courses and roadways.

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