CHARACTERIZATION OF IRON ORE TAILINGS: POTENTIAL APPLICATION AS FOUNDRY SAND

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Submitted September 6, 2023 - Accepted December 1, 2023

DOI: 10.15628/holos.2023.14273

ABSTRACT

The use of tailings generated during the iron ore beneficiation process has been the subject of several studies aimed at finding economically viable solutions for managing the waste generated by the mining industry. In this context, this study was developed with the purpose of characterizing foundry sands manufactured from the waste material originating from the Andrade Mine in Minas Gerais, Brazil, with the aim of assessing the feasibility of using these sands as molding material for the casting process. Initially, the overall tailing sample underwent size classification to 150 µm, and the retained fraction was separated into two foundry sand samples, named Sand 01 (without additional treatment) and Sand 02 (subjected to magnetic separation). Studies were conducted on the chemical, physical, optical, and mineralogical characteristics of both the overall sample and the obtained sands. The results indicated that both sand samples were classified as medium sands based on the fineness modulus, an essential characteristic of materials used for casting molds. Sand 02, in particular, demonstrated characteristics closer to the standards recommended by the CEMP E-01 standard of ABIFA, highlighting the possibility of using this material as a co-product of iron ore beneficiation

KEYWORDS: iron ore tailings, foundry sand, magnetic separation, sustainability.

1 INTRODUCTION

Brazil, considered one of the world's largest mineral producers, stands out particularly in the extraction and export of iron ore. This activity plays a fundamental role in the country's economic development, generating both direct and indirect jobs in the communities where operations are established (Denes et al., 2022).

However, despite the positive aspects, mining is also responsible for significant environmental impacts (Lacaz et al., 2017). The increasing volume of waste generated during ore beneficiation and its disposal in tailings dams has raised concerns, especially due to the risk of collapse of these structures (Borges, 2018). According to data from the Brazilian Mining Institute (IBRAM) in 2022, iron ore, which accounts for a substantial part of Brazil's mineral production, has contributed to the growing need for dam storage capacity, with a significant increase in volume and height over the decades, as pointed out by Guedes and Schneider (2018)

In this scenario, many companies in the sector are adopting strategies aimed at waste management, with the goal of achieving "zero waste" production by transforming these materials into value-added byproducts. Recent research has confirmed the potential application of these materials in various areas, such as soil stabilization, manufacturing of interlocking concrete blocks, and incorporation into asphalt compositions (Oliveira, 2021). Other studies also highlight their utility in mortar production, the ceramics industry, and as materials for the pavement sector (Silva et al., 2023). An example of this trend is the mining company Vale, which recently started producing sand from iron ore tailings. This product has been directed towards the construction industry, meeting the requirements of industrial sand, including high chemical and granulometric uniformity (ABM Brasil, 2021).

However, the effective reuse of tailings for a specific application is directly related to their physical and chemical characteristics, making it essential to conduct studies to determine their specific properties (Andrade et al., 2017). The tailings from iron ore beneficiation typically consist of elements eliminated during the concentration phase, such as silica (SiO_2), hematite (Fe_2O_3), alumina (Al_2O_3), and other components in smaller percentages (Silva, 2014). The considerable silica content in this material positions it for comparison with industrial sands used in foundry processes (Aguiar et al., 2016). Industrial sands, known for their chemical and physical properties, including a high SiO_2 content (greater than 98%), have high economic value and are employed in various industries such as glass, foundry, ceramics, refractories, and cement (Luz & Lins, 2005; Ruiz, 2013).

In the context of foundry, sand plays a fundamental role as is frequently used in mold composition. The most commonly used molds are manufactured from a mixture of sand and different binders, such as cement, cold-curing resins, hot-curing resins, or sodium silicate. It is worth noting that the variety known as "green sand" prevails in this scenario due to its natural moisture, lower cost, and relatively simple manufacturing process. The term "green" refers to the natural moisture content of the mixture, composed of silica sand, binders, bentonite clays, and water (Mascarenhas, 2016; Moro & Auras, 2007).

Therefore, considering the need to address environmental issues associated with mining, this study was developed with the aim of characterizing foundry sands produced from the tailings of the iron ore concentration process at the ArcelorMittal Mina do Andrade in Minas Gerais, Brazil. The central proposal focused on evaluating the feasibility of using this tailings-based sand as a molding material in the foundry industry. If the results are positive, it opens up prospects for the continuation of casting tests using this type of sand as a co-product of iron ore beneficiation, which could represent a significant step towards sustainability in mining.

2 METHODOLOGY

For this study, a sample of tailings from the beneficiation plant of itabirite iron ore from the Andrade Mine, owned by ArcelorMittal, was used. The steps for the characterization of the overall sample are presented in the flowchart in Figure 1. Initially, a portion of the sample was reserved for moisture analysis, and then the material was subjected to drying in an oven at 100°C. After complete drying, the sample was homogenized and quartered, resulting in aliquots for particle size analysis, density analysis, as well as chemical analysis, mineralogical analysis, and determination of grain shape and structure.

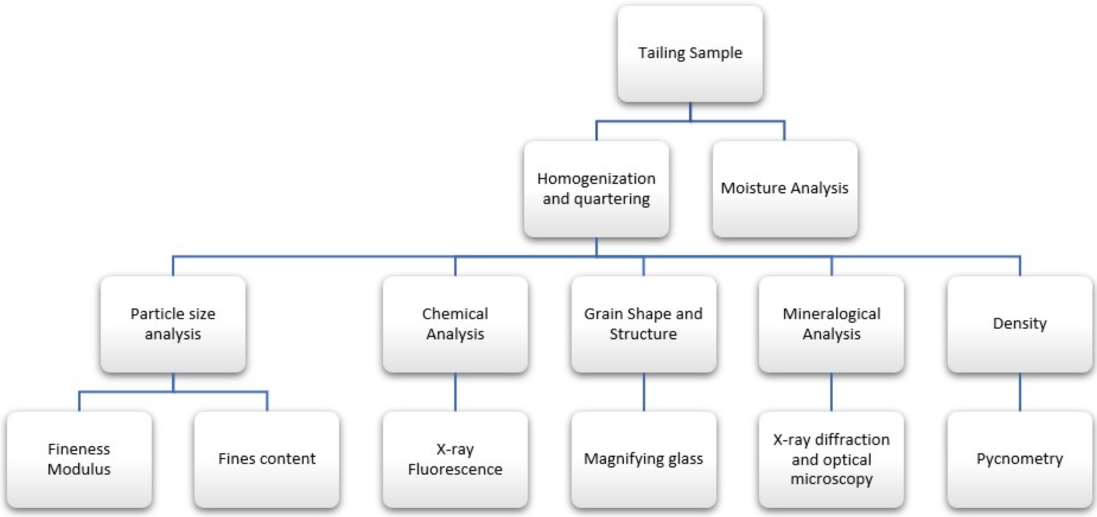

Figure 1: Flowchart of assays for characterization tailings.

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After the characterization phase, the global tailing sample was classified into 100# (150 µm) following the guidelines of the CEMP-081 standard (ABIFA, 2015). In the scope of this study, two types of foundry sands were produced: Sand 01 (without magnetic separation) and Sand 02 (after undergoing magnetic separation). Magnetic separation tests were conducted using a high-intensity magnetic separator from Carpco Inc, model WHIMS 3X4L, with serial number 210-97. The magnetic coil current was approximately 7A, and the magnetic coil voltage was maintained at 125 V. The magnetic separation process was conducted in a liquid medium, with a dilution of 3:1.

After magnetic separation, the two foundry sand samples were dried following the guidelines of the CEMP-105 standard (ABIFA, 2015) to determine the moisture content of the foundry sand. Immediately after drying, aliquots were taken for the characterization of the sands, as illustrated in the flowchart in Figure 2. The characterization of the foundry sands included chemical and mineralogical analyses, moisture measurements, density determinations, and loss on ignition measurements.

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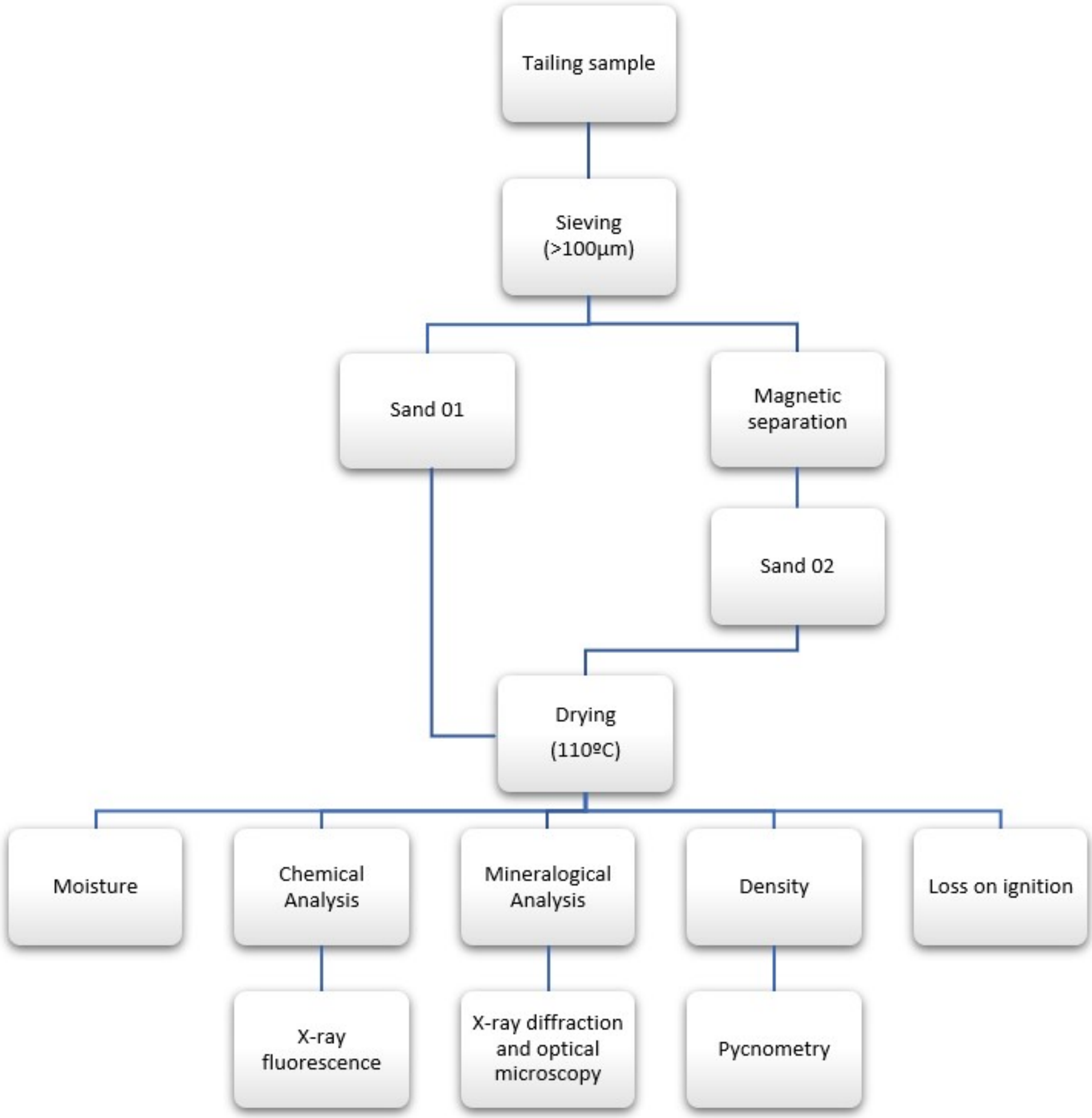


Figure 2: Flowchart of the production and characterization of the casting sands.

2.1 Chemical Analysis

The determination of the contents of elements and compounds Fe, SiO_2, Al_2O_3, Mn, P, CaO, MgO, TiO_2, Na_2O, K_2O, Cr_2O_3 present in the sample was performed using X-ray fluorescence (XRF) analysis. The analysis was conducted using a wavelength dispersive XRF spectrometer (WDXRF) from Panalytical, model Vulcan 6MA, Zetium. To minimize matrix effects and improve the reproducibility and precision of the analysis, the sample was pulverized in a pulverizing mill until 95% of the mass passed through a 100# (150 µm) mesh. For the fusion of the samples, lithium tetraborate was used with the Axios equipment. The determination of Loss on Ignition (LOI) was carried out following ASTM E1621 and ISO 11536/2015 standards. The sample was introduced into a muffle furnace and subjected to a calcination process at a temperature of 1000°C.

2.2 X-ray diffraction Mineralogical Analysis

Mineralogical analysis through X-ray diffraction was conducted using a Bruker D2 Phaser diffractometer. The samples were prepared by the powder method, and scans were performed between 2° and 70° with a step size of 0.018°. The experiment lasted approximately 20 minutes, with a data acquisition time of 1 second per point, and the sample holder rotation speed was set to 8 rotations per minute. The identification of crystalline phases was performed using the X'Pert High Score Plus 3.0 Panalytical softwar

2.3 Optical Microscopy Mineralogical Analysis

The mineralogical analysis was conducted using a reflected light optical microscope from Leica, equipped with 50x objective lenses. Samples were prepared by embedding them in epoxy resin, followed by grinding and polishing processes.

2.4 Grain shape and Structure

The determination of particle shape and structure was carried out using a magnifying glass from Leica, model EZ4W, with a 15x magnification.

3 RESULTS AND DISCUSSION

3.1 Particle Size characterization

The particle size distribution of the overall tailings sample and foundry sands 01 and 02 is depicted in the graph shown in Figure 3.

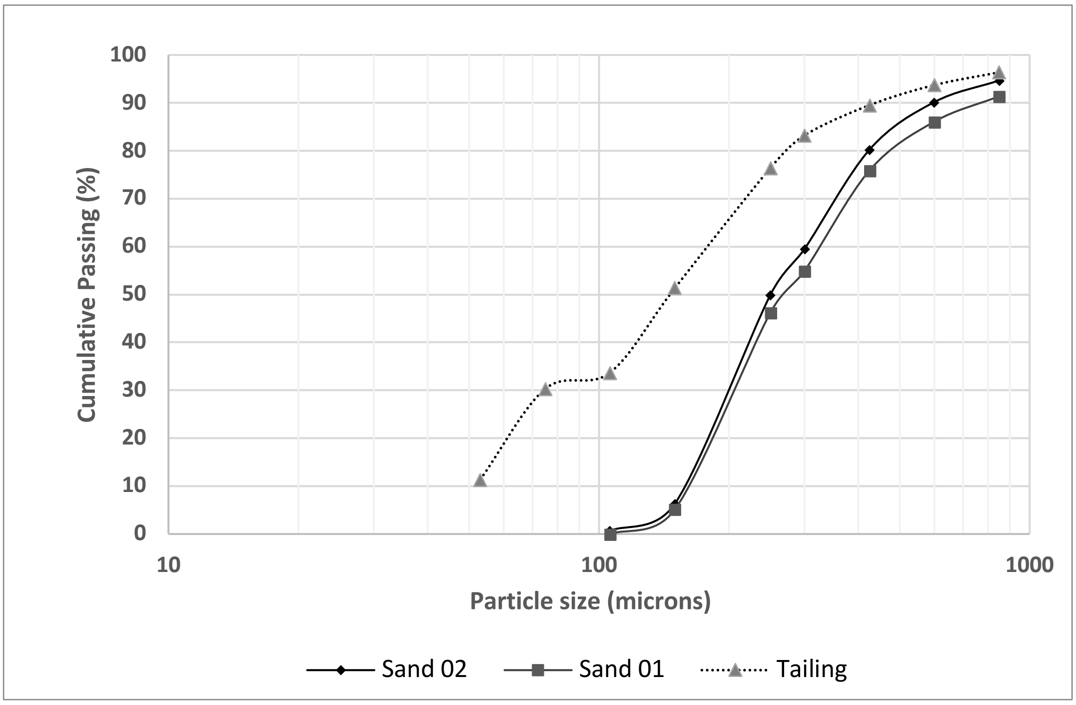


Figure 3: Particle Size Distribution of samples of Iron Ore tailing ,Sand 01, and Sand 02.

When analyzing the particle size distribution of the overall sample of tailings, it was observed that approximately 51% of the material passed through the 150 µm sieve, which is considered fine. The particle size distribution of Sands 01 and 02 appeared to be quite similar, with a significant amount of material retained on the 150 µm sieves, corroborating the assertion that the characteristic particle size of iron ore tailings is around 150 µm (Tolentino, 2010).

Table 1 presents the values of fineness modulus, fine content, and the classification of the tailings sample and foundry sands after the classification process on the 100# sieve (150 µm)

Table 1: Comparison between fineness modules, fine content and classification of tailings and sands.

Tests	Tailing	Sand 01(%)	Sand 02 (%)
Fineness Module	86.71	51.61	55.25
Fine Content (%)	0.39	0.05	0.06
Sand Classification	fine	medium	medium

According to the guidelines established in the CEMP – E01 recommendation from ABIFA, which defines specific criteria for standard foundry sand, the maximum allowable fine content is 0.1%. It was observed that the foundry sands produced met this standard. However, it is important to note that the initial tailings contained a significant amount of fines, which would make direct use of this material as a mold in foundry impractical due to the compromised permeability.

When comparing the results of the fineness modulus of Sand 01 and Sand 02 with the values established in the CEMP – 081 recommendation from ABIFA, it is found that Sand 02 complies with the norm's specifications. Furthermore, based on the classification proposed by Oliveira (2013), both fall within the range of medium sands (51-70). When analyzing the fineness modulus of the sands after granulometric cutting and comparing it with the classification made by ABIFA (CEMP – 081), a proximity is observed, as the norm establishes a value of 57.38 for the fineness modulus of foundry sand.

The tailing was classified as fine sand and had a fineness modulus above the limit specified by the recommendation. According to Oliveira (2013), fine sands provide superior finishes to castings but reduce mold permeability.Therefore, sands with a low fineness modulus are more recommended for casting ferrous alloys.

3.2 Chemical characterization

The results of the x-ray fluorescence analyses are presented in Table 2. As expected, the samples are primarily composed of silica and iron.

Table 2: Chemical analysis of samples.

	%Fe	%SiO_2	%Al_2O_3	%Mn	%P	%CaO	%MgO	%TiO_2	%Na_2O	%K_2O	%Cr_2O_3	PPC
Tailing	23.74	58.66	3.02	0.17	0.08	0.25	1.39	0.23	<0.01	0.15	<0.01	1.94
Sand 01	27.39	55.46	2.41	0.19	0.06	0.2	1.01	0.2	<0.01	0.16	<0.01	1.01
Sand 02	14.93	72.16	2.79	0.16	0.05	0.21	1.65	0.18	<0.01	0.24	<0.01	1.1

The iron content in the overall tailings sample was quantified at 23.74%. An increase in the iron content was observed for Sand 01, reaching 27.39%. This increase resulted from the preferential concentration of iron minerals in the coarser fractions after classification through the 150μm. On the other hand, the sample referred to as Sand 02, subjected to a magnetic separation process, showed a decrease in the iron content to 14.93%, while the silica content reached 72.16%.

According to the CEMP-E01 recommendation from ABIFA, the SiO_2 content for a standard foundry sand should be at least 99%. In this study, it was observed that, among the analyzed samples, Sand 02 had the highest content of this mineral, coming closer to the recommended level. This underscores the importance of improving the concentration techniques currently used to beneficiate the tailings.

Currently, only a small portion of iron ore tailings is utilized for the production of industrial sands used in the construction industry, which have a lower market value compared to silica sands. Increasing the ability to re-concentrate the useful minerals contained in the tailings can result in purer sands, ideal for use as molding material, with higher added value. It can also enable the recovery of a greater quantity of iron in the beneficiation circuits.

Considering the large annual volume of iron ore tailings, it is essential to continue studies with mechanical tests to assess the behavior of sands produced from these tailings in relation to the other requirements established by the standard. This is because among the additives added to foundry sands, iron oxides, particularly hematite, are the most commonly used, with levels ranging from 0.5% to 5%, depending on the desired effect, as indicated by Romanus (1991).

3.3 Mineralogical characterization by X-ray Diffraction

Based on the results of the mineralogical analysis, it is noteworthy that in all three samples, the mineral quartz (SiO_2) exhibited the most intense peak, indicating the abundance of silica in the tailings, which is consistent with the chemical characterization revealing a high content of this mineral. Regarding the iron mineral, hematite (Fe_2O_3) was identified in all three diffractograms.

Figure 4 shows the diffractogram of the overall sample of tailings, where it was possible to identify the presence of kaolinite ($Al_2Si_2O_5(OH)_4$) and biotite (Bt), in addition to quartz (Qz) and hematite (Hem).

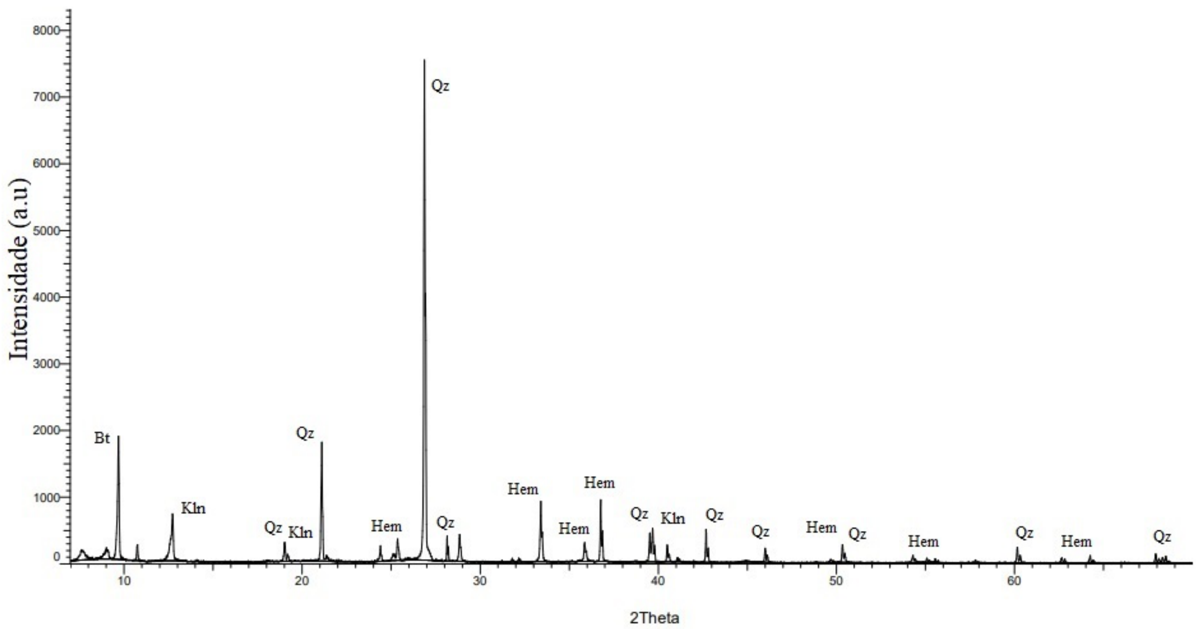


Figure 4: Difratogram of the global sample of tailings.
Legend: Qz - Quartz; Kln - Kaolinite; Hem - Hematite; Bt - Biotite.

In the diffractogram of the Sand 01 sample (Figure 5), a decrease in the intensity of the peaks related to the hematite phase was observed compared to the diffractogram of the overall sample of the tailings (Figure 4).

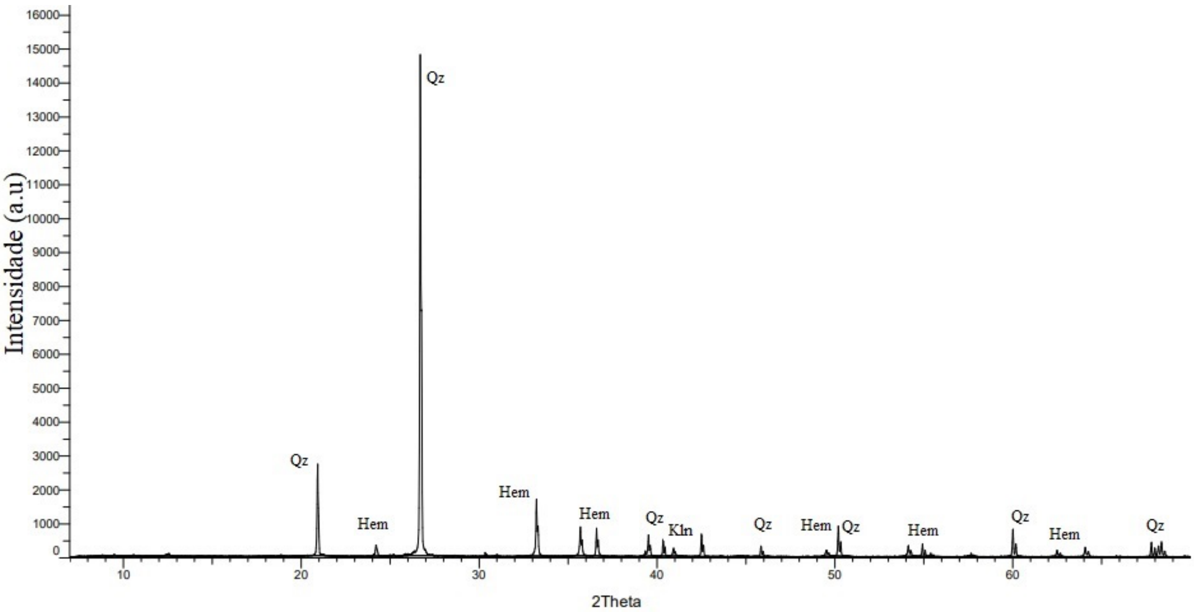


Figure 5: Difratogram of the Sand sample 01.
Legend: Qz - Quartz; Kln - Kaolinite; Hem - Hematite.

In the diffractogram of the sample from Sand 02 (Figure 6), the predominance of the mineral quartz and a smaller amount of hematite were evidenced. This pattern is particularly relevant when considering the sample's application as sand for use in casting processes.

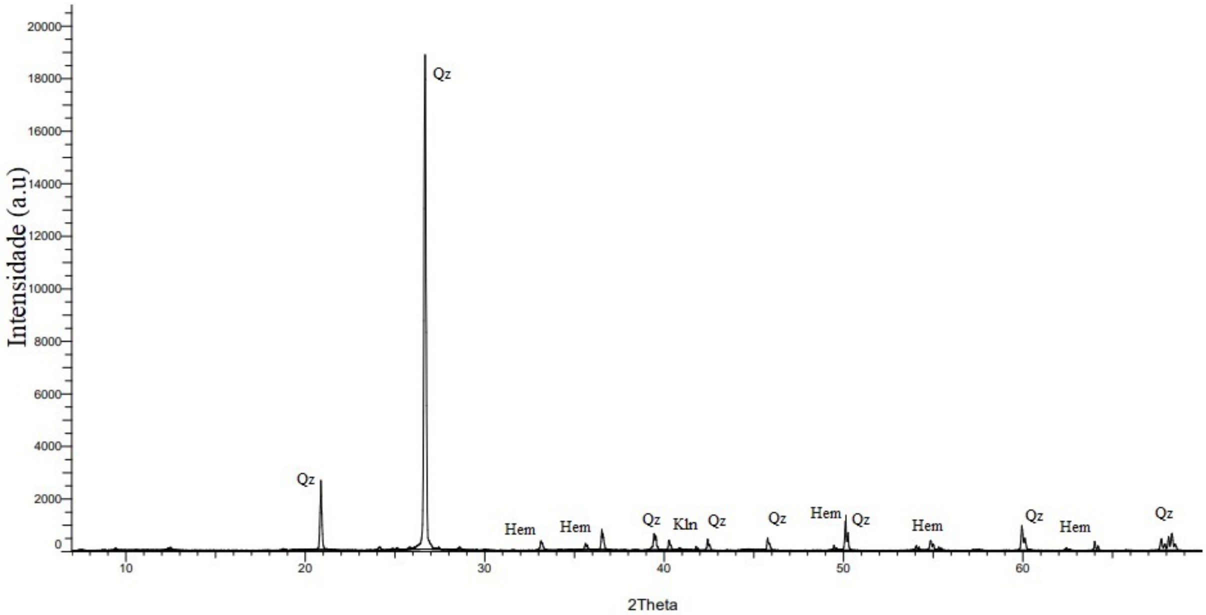
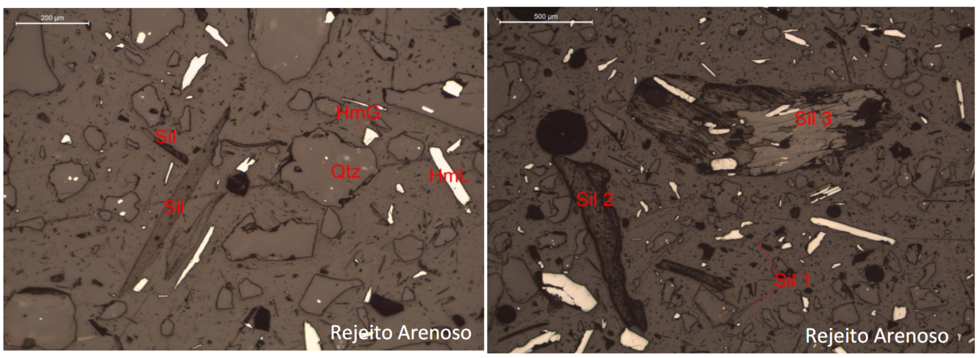


Figure 6: Difratogram of the Sand sample 02.
Legend: Qz - Quartz; Kln - Kaolinite; Hem - Hematite

3.4 Mineralogical characterization by optical microscopy

Through mineralogical characterization by optical microscopy, quantitative mineralogy of the samples was obtained. The images in Figure 7 depict the arrangement of different minerals and their individual forms. The graph in Figure 8 represents the percentage distribution of identified particles in each sample. The images on the left were captured at an approximation of 200 µm, while the images on the right were captured at 500 µm, resulting in more visible mineral contours in the later.



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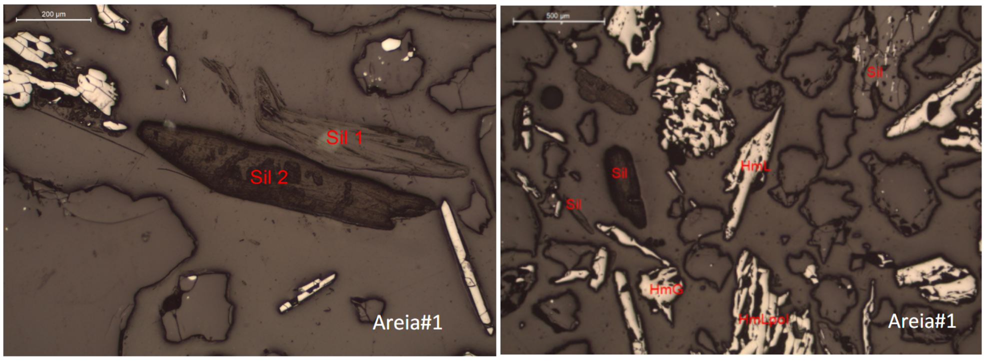

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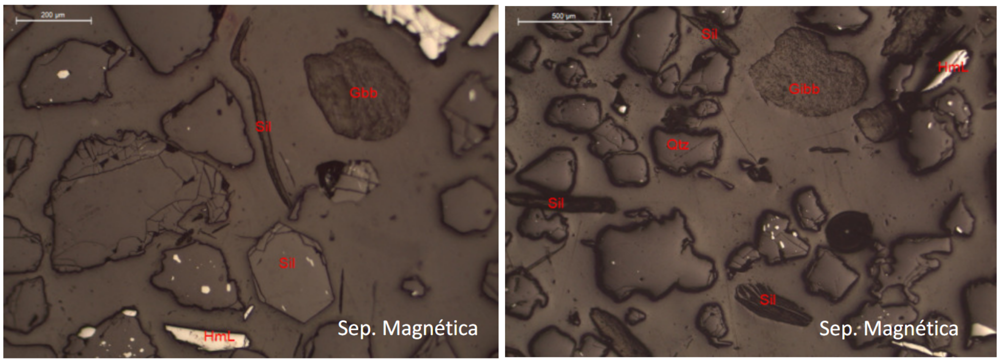

c)

Figure 7 - Quantitative minerography of the samples: a) overall sample of tailing; b) Sand 01; c) Sand 02.

The iron mineral present in the three analyzed images is lamellar monocrystalline hematite (LmH) with a metallic appearance. Dias, Lopes, and Braga (2021) state that the dominant texture in the hematite found in the Andrade Mine is lamellar with subhedral crystal shapes.

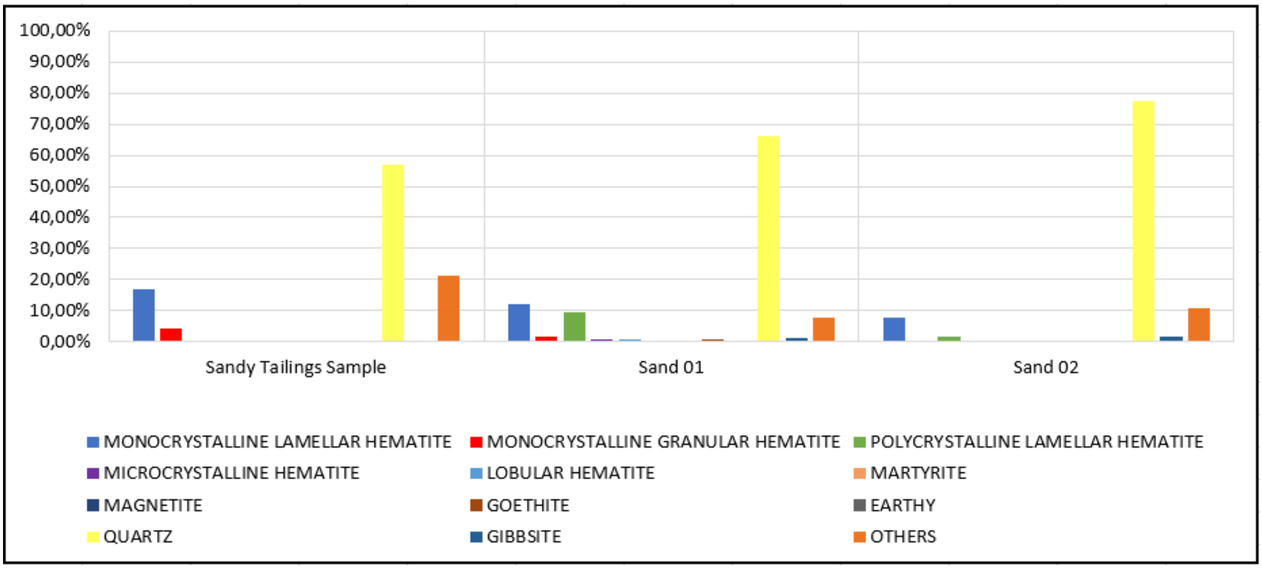

Figure 8: Total particles in tailing, Sand 01, and Sand 02 samples.

The results of the quantitative mineral analysis of the samples showed that the primary mineral found in the sample was quartz. In the overall tailing sample, approximately 21% of the minerals were classified as "others." Within this category, at least three types of silicates were identified, along with manganese and carbonate minerals. One of the silicates is more abundant, comprising about 97% of the silicates analyzed in this sample; this mineral has a tubular structure and appears to have low hardness. Manganese and carbonate, on the other hand, make up less than 1% of the total.

These same silicates are also present in the Sand 01 and Sand 02 samples, although in smaller proportions. In Sand 01, this mineral accounts for 50% of the minerals classified as "others," while in Sand 02, it reaches 71%. As for iron minerals, monoclinic lamellar hematite predominates in all three samples, with an additional highlight of polycrystalline lamellar hematite in the Sand 01 sample.

3.5 Moisture and Loss on ignition

Table 3 shows the results of moisture and Loss on ignition (LOI) tests for the samples.

Table 3: Moisture and Loss on Ignition Measurements.

Tests	Tailing	Sand 01	Sand 02
Moisture (%)	16.02	0.16	0.15
LOI(%)	-	0.79	0.89

The moisture test revealed that the tailing had a moisture content of 16%. However, samples from Sand 01 and Sand 02 recorded moisture contents of 0.16% and 0.15%, respectively, exceeding the moisture value allowed by the recommendation CEMP – E01 from ABIFA for foundry sand, which is 0.10%.

Regarding Loss on Ignition (LOI), the results for Sands 01 and 02 showed proximity, with both values being below 1%. LOI should be as low as possible, although values up to 2% are acceptable (Figueiredo, 2017; Carey, 1995).

3.6 Density of Samples

The density values were 3.14 g/cm³ ± 0.00089 for the tailing, 4.0 g/cm³ ± 0.01058 for Sand 01, and 3.85 g/cm³ ± 0.00251 for Sand 02. The significant difference in the density value observed in Sand 01 compared to the overall sample can be attributed to the concentration of iron minerals in the fraction above 150 µm (100#). As expected, Sand 02, with a lower iron content (14.93%) and a higher silica content (72.16%), exhibited a lower density compared to the other samples.

4 CONCLUSIONS

In this work, the characterization of the tailings from the Andrade Mine was carried out, as well as of two sands produced from these tailings. This analysis contributed to the understanding of the properties of this residue, paving the way for its potential use as a byproduct of iron ore beneficiation.

The chemical and mineralogical analyses of the tailings revealed the presence of high levels of quartz. The grain size analysis of the tailings showed that approximately 34% of the entire sample consists of fines. Regarding the moisture test, the material maintained high levels even after drying, not meeting the established recommendations for foundry sand.

For the sands produced from the tailings, the chemical and mineralogical analyses yielded similar results, except for the iron content, which was lower in the sand obtained from magnetic separation (Sand 02). This result indicates the feasibility of significantly reducing the presence of this metal, resulting in sand with a high quartz content, which is the main constituent of silica sands widely used in foundry. The sands were classified as medium based on the fineness modulus. Both exhibited low fines content, a highly relevant aspect for a material intended for foundry use. Sand 01 had higher density and a lower content of the mineral of interest (SiO_2) compared to Sand 02, due to the separation of the denser mineral (Fe_2O_3) during the magnetic separation process. As for the moisture test, both sands yielded results above the recommended standard.

From this study, it can be concluded that Sand 02 exhibited characteristics more closely aligned with the recommended standards for use as molding sand in foundry processes. Despite differences in iron content, both Sand 01 and Sand 02 showed similar characteristics to commercially available foundry sands

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ACKNOWLEDGMENT

This research was supported by Foundation of The State of Minas Gerais (FAPEMIG), State University of Minas Gerais (UEMG), PROPPG by researcher scholarship UEMG – PQ/UEMG, Federal University of Ouro Preto (UFOP) and Gorceix Foundation.

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COMO CITAR ESTE ARTIGO

Silva, F. L. (2023). CARACTERIZAÇÃO DE AREIAS SILICOSAS OBTIDAS ATRAVÉS DO REJEITO ARENOSO DA CONCENTRAÇÃO DO MINÉRIO DE FERRO . HOLOS, 4(39). Recuperado de https://www2.ifrn.edu.br/ojs/index.php/HOLOS/article/view/14273

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Editor Responsável: Franciolli Araújo

Submitted September 6, 2023
Accepted December 1, 2023
Published December 18, 2023