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TECHNOLOGICAL CHARACTERIZATION OF TALC ORE FROM CAÇAPAVA DO SUL, RS-BRAZIL FOR DEVELOPMENT OF A PROCESS ROUTE

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ABSTRACT

This paper provides technological characterization and preliminary studies for the concentration of talc ore from the municipality of Caçapava do Sul, RS - Brazil, for the purpose of defining its process route. The characterization was made by in bench channel sampling, preparation of the material by comminution, followed by homogenization, fractionation, and analyses of particle size, mineralogy, chemical composition, brightness, density and humidity of the sampled material. Afterwards, magnetic separation studies were carried out using Davis tube and leaching, in order to reduce the impurities, which consisted mainly of iron oxide contamination. After preparation of the sample, it

was possible to obtain a fine material of approximately 65 % passing 37 μm , with similar brightness values between all samples despite a variable distribution of Fe, Ca, Mg and Al contents. The best results of the study occurred for the sample with a granulometric cut of 100# subjected to a magnetic separation of 4050 G and later leaching at 80 °C for a time of 60 min. A maximum brightness of 72.3 % was achieved, with an increase in brightness of 10.3 % in relation to the initial brightness. This product could be applied to the paint, insecticide, textile and paper industries, requiring complementary characterization to fit further specifications.

KEYWORDS: talc; technological characterization; iron impurities; processing.

1. INTRODUCTION

Talc, a noble mineral for cosmetics, paints, and paper, may also be used for ceramics, rubber, insecticides and fertilizers. It occurs in very fine granulometry, in rocks of powdery texture and often has associations with impurities such as titanium, serpentine, dolomite, magnesite, limestone, manganese and iron oxides, sometimes in the form of gangue minerals, sometimes within its crystalline lattice. These impurities influence the variability of ore properties including whiteness, granulometry, texture, chemical composition and hydrophobicity (Pontes & Almeida, 2005).

According to data released in the Mineral Summary of 2015, by the National Department of Mineral Production (DNPM), the production of talc beneficiated in the year 2014 had an increase of 36.9 %. Compared to the previous year, this increase was 28.3 %, while imports grew 8.6 %.

Technological characterization is defined as a fundamental step to optimize the utilization of a mineral resource and allows for precise identification of inefficiencies and losses in processes, enabling an increase of the global yield and correct dimensioning of the beneficiation route (Neumann et al., 2004).

In this context, this work provides technological characterization and preliminary studies for the concentration of a talc ore, of a deposit located in Caçapava do Sul-RS, for the purpose of defining its process route.

2. BIBLIOGRAPHIC REVIEW

2.1. Talc

Pontes & Almeida (2005) describe talc as hydrated magnesium filosilicate of the chemical formula $\text{Mg}_3(\text{Si}_4\text{O}_{10})(\text{OH})_2$, with "tot" spatial arrangement represented by two tetrahedral sheets - t- linked by Van Der Waals bonds and formed by atoms of silicon and oxygen (siloxane sheet) that surround an octahedral sheet -o formed by magnesium and hydroxyl (brucite leaf).

According to Camara (2003), talc can occur in two different symmetries, monoclinic (more common) and triclinic, wherein the crystalline structure (Figure 1) presents a triple layer, being a sheet of magnesium hydroxide and two leaves composed of tetrahedra of SiO_4^{-4} . The external siliceous faces are apolar and oleophilic, hydrophobic, aerophilic and inert.

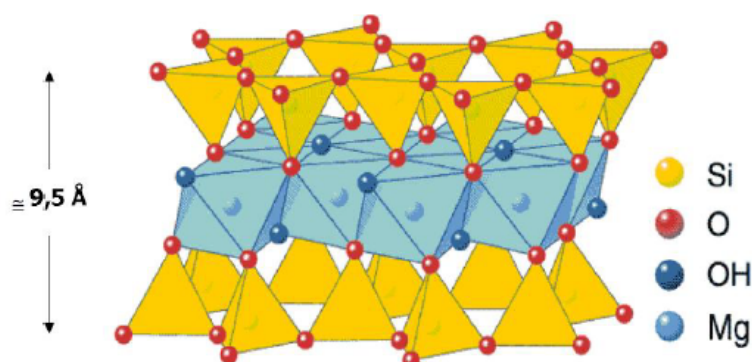


Figure 1: Crystal structure of talc ore (Camara, 2003).

Monte et al. (2003) considers that the physicochemical properties of talc products should vary according to the destination of the product as explained in Table 1, emphasizing the importance of characteristics such as granulometry, degree of purity and color of the product. The Table 1 shows some parameters required by different industries depending on the application of the talc ore.

Table 1: Industrial specifications.

Use	Size	Chemical composition	Brightness	Mineralogy	Properties	Others
Paint (Spreading)	100 % <200 # 96,5 % <325 #	SiO ₂ +MgO ≥75 % Al ₂ O ₃ ≤2 % H ₂ O+M.Vol. ≤1 % Loss on ignition ≤7 %	65 to 90	Lamellar particles.	Chemical inertia, Hydrophobicity, Brightness.	Density 2,8 a 2,9.
Paint (Pigment)	100 % <325 #	MgO: 24 to 32 % SiO ₂ : 50 to 65 % CaO ≤9 % MgO + SiO ₂ ≥88 % CO ₂ ≤1 % Al ₂ O ₃ +Fe ₂ O ₃ ≤6 % H ₂ O + MV ≤1 % Loss on ignition ≤7 %	80 to 90 GE	Fibrous particles (tremolite).	Brightness, Chemical inertia, Adsorption of oil 27 a 31 %.	Density 2,8 a 2,9.
Inseticide	90 % <325 #	pH 8	-----	-----	Chemical inertia.	Adsorption.
Textile	No sandy waste	-----	-----	No hard minerals.	Brightness	-----
Paper (Paper load)	95 % <400 #	-----	58 to 78 GE	-----	Chemical inertia, Hydrophobicity.	-----
Plastic (Load and support)	100 % <200 #	-----	≥ 77 GE	Talc or pyrophyllite.	Chemical inertia, Brightness.	No humidity.
Non-stick	100 % <325 #	-----	≥ 77 GE	Talc or pyrophyllite.	Chemical inertia, Brightness.	Low acidity.

GE = General Eletric Parameter

With respect to the use of talc ore in the manufacture of paints, it is used as charge and pigment in external uses of surfaces exposed to abrasion and low visibility paints. On the other hand, in the production of valve rubbers, talc is used as a spray to lubricate molds and prevent the surfaces from binding during the manufacture of the product. In the textile industry, after reaching very fine granulometry, talc gives weight and blemishes cotton fabrics, twines and yarns (Fabris, 2006), being this same bleaching function exercised in the paper industry, besides acting as a load when incorporated into the mass and to avoid reactions with other materials used in papermaking (Campos, 2011).

2.2. Geological Characterization

The talc ore from this deposit originates from hydrothermal alteration processes of magnesium minerals, mainly olivine and orthopyroxenes, but may also occur from a process of regional metamorphism or contact with magnesian calcareous or ultrabasic rocks. This occurrence is associated with minerals of biotite, chlorite, serpentine and carbonates (Machado, 2016).

As for the local geology, it was observed that the talc mineral is deposited either intercalated or sometimes on the amphibolite, evidenced by the outcrop on the west side of the bench. The amphibolite in this deposit is a metamorphic rock of basic igneous origin (Winge, 2016), relatively hard with a presence of quartz that accompanies the shale of the deposit.

To the west of the sampled basin, there are talc-filled fractures (Figure 2(a) and 2(b)) and quartz veins of ~ 0.5 cm (Figure 2(c)). To the east of the sampled basin, talc ore predominates with varying degrees of weathering from medium to high. Mineral occurrences in medium weathering zones include: dolomite minerals ($\text{CaMg}(\text{CO}_3)_2$), orthopyroxenes of the chemical formula $(\text{Mg}, \text{Fe})_2\text{Si}_2\text{O}_6$ (Figure 2(e)) and iron oxides (Fe_2O_3) with a content lower than that found in zones of high weathering. In high weathering zones, the presence of high levels of iron oxide occurs (Figure 2(d)), giving reddish coloration to the deposit, as observed by Walker (1967) when affirming that the coating of a great majority of the grains of these rocks by iron oxide films gives rise to the reddish color present in regions of the deposit. It should be noted that all such identifications were possible through X-Ray Fluorescence spectrometry analysis in samples taken from the deposit.

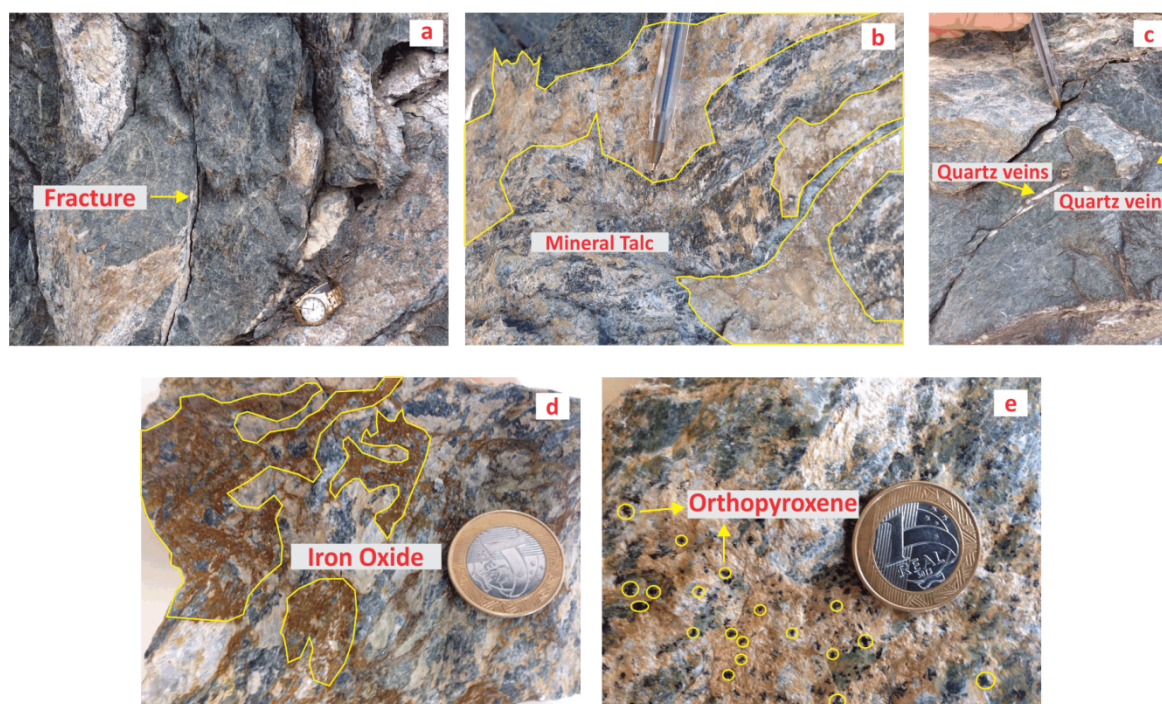


Figure 2: (a) Fracture; (b) mineral talc filling in the fractures; (c) quartz veins observed in the amphibolite; (d) iron oxide (Fe_2O_3) e (e) orthopyroxene ($(\text{Mg}, \text{Fe})_2\text{Si}_2\text{O}_6$) identified by X-Ray Fluorescence Spectroscopy.

2.3. Technological Characterization

Fontes (2013) defines the technological characterization of a specularite iron ore as the gathering of information such as density, magnetic properties and others, allowing knowledge of the chemical and physical properties of a given ore. Such characterization aims at stipulating a beneficiation process route based on ore and market needs, seeking greater efficiency in the possible changes of small properties during the process.

The successful separation of minerals of interest by concentration operations depends on 3 basic conditions (Fundação Cristiano Ottoni, 2016):

- i. liberation: where there is individualization of the species in order to make them free;
- ii. differentiability: existence of a property (natural or induced) capable of differentiating the mineral species from each other (Table 2);
- iii. dynamic separability: occurs when a compound force acts in the separation zone of the

equipment by promoting different trajectories to the particles in response to the different characteristics of the material.

Table 2: Treatment Method through differentiability of minerals.

Properties	Methods
Density	Liquid or dense medium
Texture and friability	Comminution, classification or screening
Magnetic Susceptibility	Magnetic Separation
Surface reactivity	Flotation

According to Neumann et al. (2010), the technological characterization of an ore varies according to the mineralogy and its inherent properties, as well as the scope and objectives of the characterization. Thus, the characterization has four main stages, independent of each other, defined as follows:

- i. fractionation of the sample: facilitates the identification of minerals, quantification of phases, and establishes some physical properties;
- ii. phase identification: for example, clear and easy-to-interpret signal of concentrated minerals in fractionation;
- iii. quantification of minerals;
- iv. liberation of the mineral of interest: related to the minerals of the gangue, it is verified in several ranges of particle size.

2.4. Leaching study

Dissolution of the mineral by water or aqueous solution of a leaching agent is termed leaching. The basic characteristic of leaching is the ability to treat ores with low grades, based on the specificity of the leaching agent used, while keeping the mineral of value in a solid state. When this process occurs for the purposes of removing impurities, it is called reverse leaching (Heck, 2016).

When processing talc ore to reduce iron concentration, Fabris (2006), who used 4 M hydrochloric acid (HCl), with an initial sample mass of 5 g for 30 min and at a temperature of 80 °C, obtained positive results for iron extraction, in the order of 78.7 %. In this same study, by exceeding the time (30 min) of exposure of the sample to the acid, the brightness of the product was maintained. In addition, it was observed that temperature and time are determining factors in the iron dissociation process, proving efficacy of the tests by subjecting samples up to 80 °C and 30 min, respectively.

Also, in order to reduce iron content within samples, Rodrigues (2010) carried out chemical attacks on flotation concentrate residues from soapstone handicrafts using HCl, starting with the flotation concentrate with a brightness of 70.8 % and obtaining a final product with maximum brightness of 86.5 % using the following reactions:



In the same work, Rodrigues (2010) when performing acid leaching in a crude sample of the fine (<74 μm) soapstone, with initial brightness of 51.8 %, obtained a brightness of 77.4 % in the product. To obtain these results, a solution of 4 M HCl, of temperature around 80 °C, was used for a time of 60 min.

The best brightness occurred in the higher reaction time (60 min), with temperature above 75 °C and HCl concentrations above 3.5 M.

2.5. Magnetic separation study

Magnetic separation is an important method of processing for concentration and purification of ores, which occurs due to different individual responses associated between mineralogical species and a magnetic field. This magnetic field is determined in function of the response of a property called magnetic susceptibility (Silva, 2012).

Rodrigues (2010) carried out magnetic separation studies with samples of soapstone, using 20 % solids and granulometry larger and smaller than 74 μm , in which magnetic fields (3000, 4300 and 4900 G) and currents (3, 5 and 7 A) were used.

The best results were obtained in the particle size fraction smaller than 74 μm , because with the fraction greater than 74 μm there were inclusions of oxidized iron particles in the talc beads due to the attraction generated by the magnetic field. The application of 4900 G promoted a 6 % increase in brightness.

Fontes (2013) applied low and high density magnetic fields to a specularite iron ore of 0.21 to 0.30 mm granulometry, in order to attract the particles and concentrate them. This concentration generated ferromagnetic material as a concentrated product in the order of 67 %, according to the distribution of the mass fractions of the material after magnetic separation.

Fontes (2013) states that low magnetic fields are applied to materials with high magnetic susceptibility, while high magnetic fields must be applied to paramagnetic materials, and considers the control of the feed rate to be important, that is, the speed and the flow with which the particles pass through the magnetic field, preferring a low velocity of the flow to prevent magnetic particles from being entrained with the non-magnetic particles.

3. METHODOLOGY

3.1. Channel sampling

The talc ore sample was collected by channel sampling along 47 m of the face of the bench, as seen in Figure 3, maintaining a constant average height between the base and the top of the channel with the following dimensions: width of 10 cm and depth of 4 cm, previously demarcated, totaling 440 kg of sampled material. This step was preceded by the cleaning of the face of the bench to remove the chemical alteration (surface oxidation) of the rock.

The channel was sampled using a geological hammer, tip, slit and mallet, and all material collected, meter by meter, was collected directly in a plastic tray, positioned just below the lower level of the sampled channel, and stored in clean, identified plastic bags.

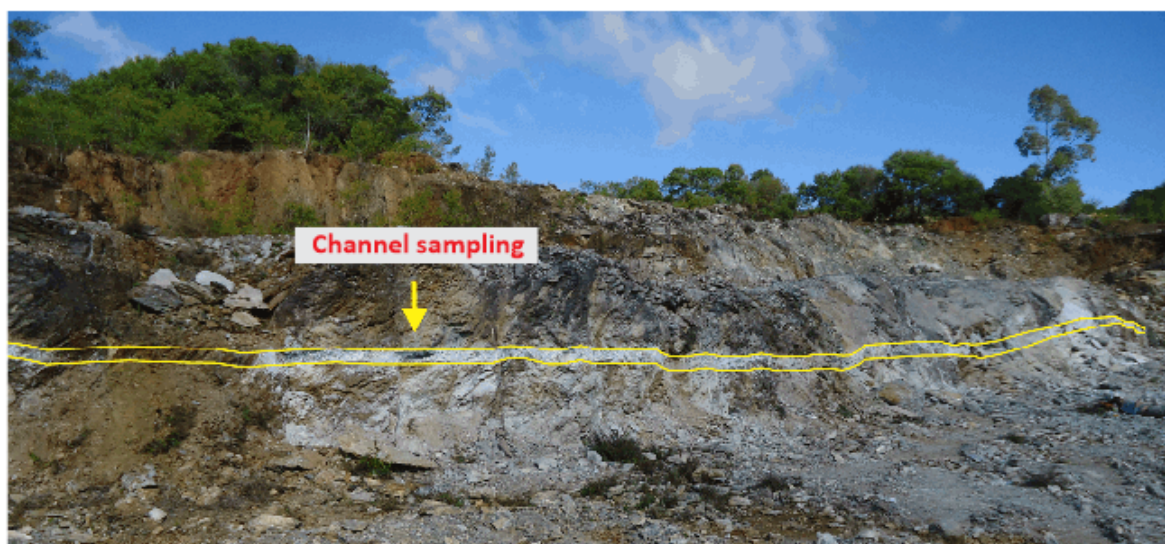


Figure 3: Channel sampling after collecting material.

3.2. Sample preparation

Sample preparation was performed by primary jaw crusher (Figure 4 (a)). Afterwards, the material was placed in a longitudinal pile mounted on a canvas for homogenization and fractionation (Góes et al., 2004), and stored in closed plastic containers to preserve the characteristics of the sample. An aliquot of ~100 kg was subjected to secondary crushing by roller crushers, and the material was screened and sieved in a 3.35 mm mesh. The material retained in the mesh returned to the roller crusher to obtain a 100 % <3.35 mm product (Figure 4 (b)).

Afterwards, all material was homogenized and fractionated by the longitudinal pile method and the aliquots obtained (~6 kg) were stored in plastic bags. Grinding tests were performed in ball mills and a ceramic jug with ~3 L volume. Aliquots of 336.7 g of the crushed sample were milled at various times for a determination of the feed size F80 (80 % passing) of 74 μm .

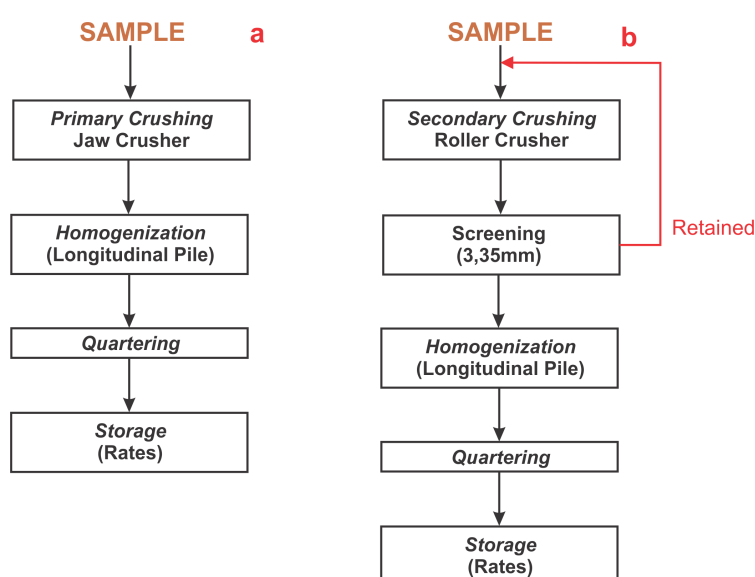


Figure 4: Sample preparation flowchart (a) primary crushing and (b) secondary crushing.

3.3. Particle size analysis

The granulometric distribution was tested by wet sieving, with aliquots of ~100 g of milled material in laboratory sieves of 20 cm diameter with the following meshes: 100 # (149 μm), 150 # (105 μm), 200 # (74 μm), 325 # (44 μm) and 400 # (37 μm). The fractions retained in the sieves were vacuum filtered, oven dried at 50 °C for 24 h, and weighed.

3.4. Density and humidity analyses

The determination of the density of the talc ore was performed in duplicate by the method of picnometry (Sampaio et al., 2007). For such, a sample weight of approximately 1 g of heavy ground talc ore was used, along with an analytical balance, a pycnometer and distilled / deionized water.

Moisture analysis was performed in duplicate with aliquots of 5 g of ground talc ore sample, weighed on analytical balance, and oven dried at 105 °C for 5 h. Then the whole was taken to the desiccator for cooling and subsequent weighing. The procedure was repeated until reaching constant weight or difference of at least 0.001 g.

3.5. Mineralogical analysis

The mineralogy of the talc ore was obtained by XRD analysis using a 20 g aliquot of material from the mill. This analysis was conducted by the Department of Physics/UFRGS using an X-ray diffractometer of the brand Siemens, model D-500, with curved graphite monochromator in the secondary beam and fixed anode tube of Cu, operating at 40 kV and 17.5 mA.

3.6. Chemical analysis

The sample and the granulometric fractions were analyzed for the following elements: Mg, Ca, Al and Fe, by the Atomic Flame Absorption Spectrometry method, at the Institute of Chemistry/UFRGS.

3.7. Brightness analysis

The whiteness analysis was performed according to ISO 2470 (ABNT, 2001), which assigns weight to reflectance in the range of 400 to 510 nm (Gonçalves, 2009). For this purpose, the aliquots were pulverized in an orbital disc mill, pressed for pellet formation and the reflectances obtained using a spectrophotometer previously calibrated with a white standard. The analyzes were carried out for the ground sample with and without a cut in the material passing 100 #, with the granulometric fractions, and with the products of the magnetic separation and the leaching.

3.8. Magnetic separation study

Magnetic separation studies were performed with a Davis Tube separator (Inbras brand, EDT model), following the procedure described in the manufacturer's manual. The separation tests were fed with two types of samples previously milled: one sample with no granulometric

cut and the other with a cut at 100 # (150 μ m). For these samples two magnetic fields of 3050 G (1.4 A) and 4050 G (2.0 A) were applied.

3.9. Leaching study

The leaching studies were performed with aliquots of 5 g of talc ore. To these samples 4 M HCl was added and the pulp (15 % w/w solids) from this mixture was stirred using a magnetic stirrer with rotation control and stirring (~ 1000 rpm). Tests were performed at room temperature (~ 22 °C) and heating ($\sim 80 \pm 5$ °C). The contact times were from 10 to 60 min.

Leaching tests were performed with the non - magnetic product from the magnetic separation test of the sample (100 #) and a field of 4050 G (2.0 A), and for the sample with a granulometric cut (100 #). For these leaching tests, heating at 80 ± 5 °C for 60 min was used.

4. RESULTS AND DISCUSSIONS

4.1. Characterization of the talc sample

Table 3 summarizes the characterization results of the ground talc ore sample. The relative density of 2.7 coincides with the value of silicate minerals. In addition, it presented natural humidity <1 % and brightness of ~ 60 %. The sample had high contents of the elements (Mg, Al, Fe and Ca).

Table 3: Summary of the ground talc sample characterization.

Relative Density	Humidity (%)	Brightness (%)	Fe (mg/g)	Ca (mg/g)	Mg (mg/g)	Al (mg/g)
2,7	0,9	59	34	17	200	147

Five crystalline phases were identified in the mineralogical analysis: antigorite (A), clinoclhor (C) and magnesite (M), constituents of the ore minerals, along with dolomite (D) and talc (E). The peak of the talc phase presents high intensity, which shows the excellent crystallization of this phase, however, causing the non-observation of phases near the baseline, such as ferromagnetic phases (Figure 5). Also, some phases overlap characterizing low symmetry, common in polycrystalline samples.

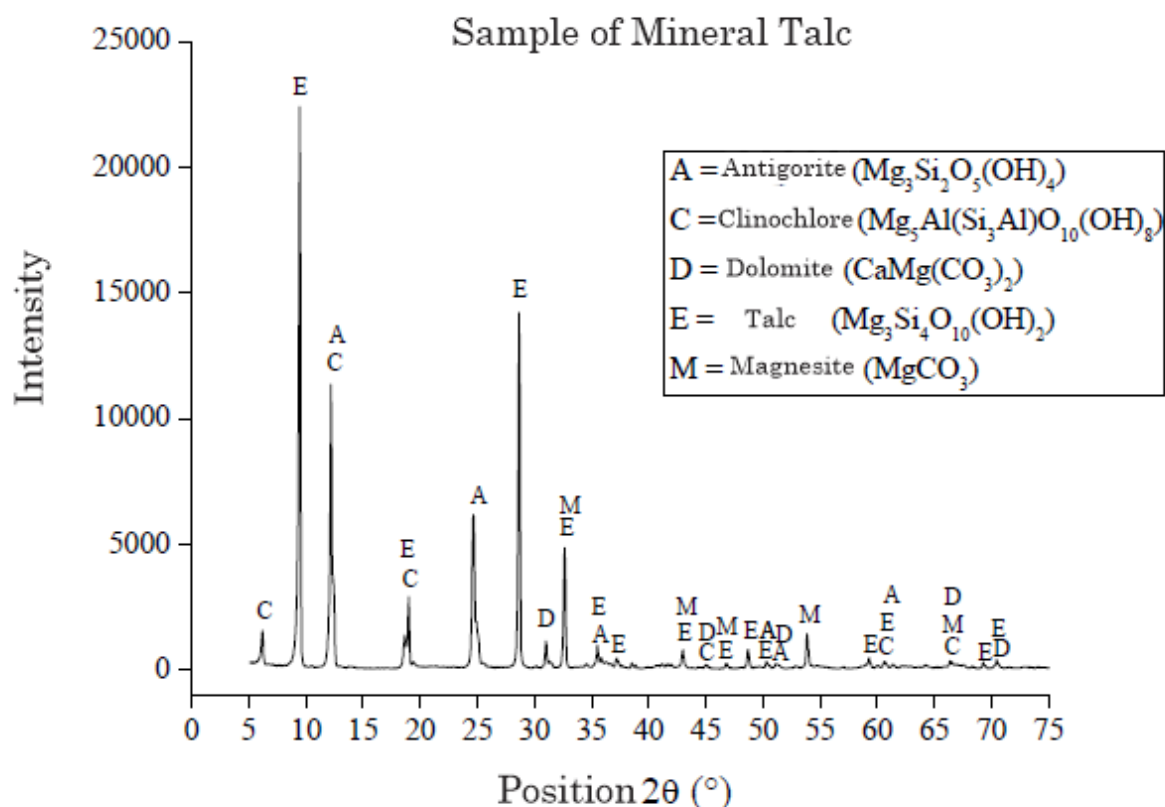


Figure 5: X – Ray Diffractogram of the ground talc sample.

The particle size distribution in the fraction $<37\ \mu\text{m}$ presented the highest value, and a maximum of approximately 10 % for all other fractions (Figure 6 (a)). The contents of Fe, Ca, Mg and Al, as a function of the granulometric bands, presented different behaviors and are shown in Figure 6 (b). The Fe content ($\sim 50\ \text{mg/g}$) is nearly evenly distributed in all particle size fractions. The maximum content of Ca ($\sim 50\ \text{mg/g}$) was observed in the fraction of $74\ \mu\text{m}$ and of Al in the finer fraction ($<37\ \mu\text{m}$). However, the Mg presented higher content in the fractions $<44\ \mu\text{m}$ and in the fractions $>74\ \mu\text{m}$, whereas the brightness presented similar behavior for all fractions with values greater than 50 %, except for the fraction retaining $37\ \mu\text{m}$ (Figure 6 (c)).

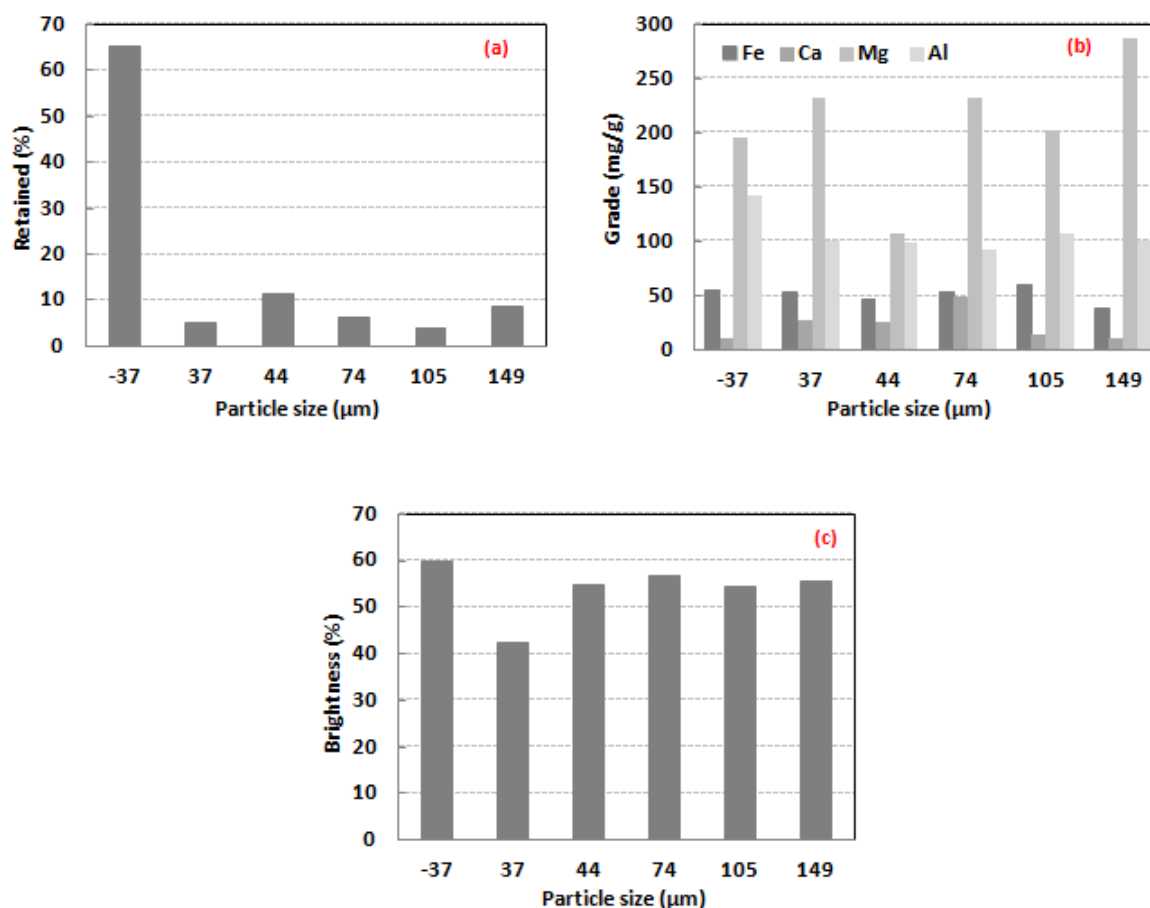


Figure 6: (a) Granulometric distribution of the ground talc sample, (b) grades and (c) brightness of each product retained.

4.2. Magnetic separation study

Considering the overall mass recovery, in which the losses of the granulometric cut and magnetic separation steps were evaluated, the results obtained for the cut samples (85 % and 86 %) were lower than those obtained for the samples without cutting (91 % and 94 %). The largest overall mass recovery was obtained after magnetic separation, without cutting, of the same sample (Table 4). The magnetic separation process resulted in an increase in brightness of about 5.7 % in the uncut sample when subjected to a 4050 G field and after separation the final brightness analysis showed very close results (~64 %).

Table 4: Magnetic separation test result.

Feed	Current (A) - Magnetic field (G)	Mass Recovery (%)	Global Recovery (%)	Brightness (%)	
				Start	End
Cut (100 #)	1,4 - 3050	94	85	61	64
Cut (100 #)	2,0 - 4050	94	86	61	63
No cut	1,4 - 3050	94	94	59	64
No cut	2,0 - 4050	91	91	59	65

4.3. Leaching study

Figure 7 (a) shows the mass recovery of the products from the leaching tests at $\sim 22^\circ\text{C}$ (room temperature) and at $\sim 80 \pm 5^\circ\text{C}$. When performing the studies at $80 \pm 5^\circ\text{C}$, the recovery decreased by approximately 10 % for the time interval between 10 and 60 min, stabilizing after 30 min. However, at room temperature this difference was only approximately 2 %, being practically constant over time, and showing that the use of temperature increases leaching kinetics. However, the difference in brightness between the products of the different temperatures was about 4 % (Figure 7 (b)). The maximum brightness (72 %) was obtained after the leaching test using the magnetic separation sample with 100 # cut, which also presented the largest increase (10 %) in relation to the initial brightness (Table 5) and the lowest overall mass recovery.

Table 5: Summary of the acid leaching in different samples (tests).

Feed	Mass Recovery (%)	Global Recovery (%)	Brightness (%)	
			Start	End
Ore	69	69	59	65
-100 #	68	62	61	65
Magnetic separation product (-100 #)	69	59	63	72

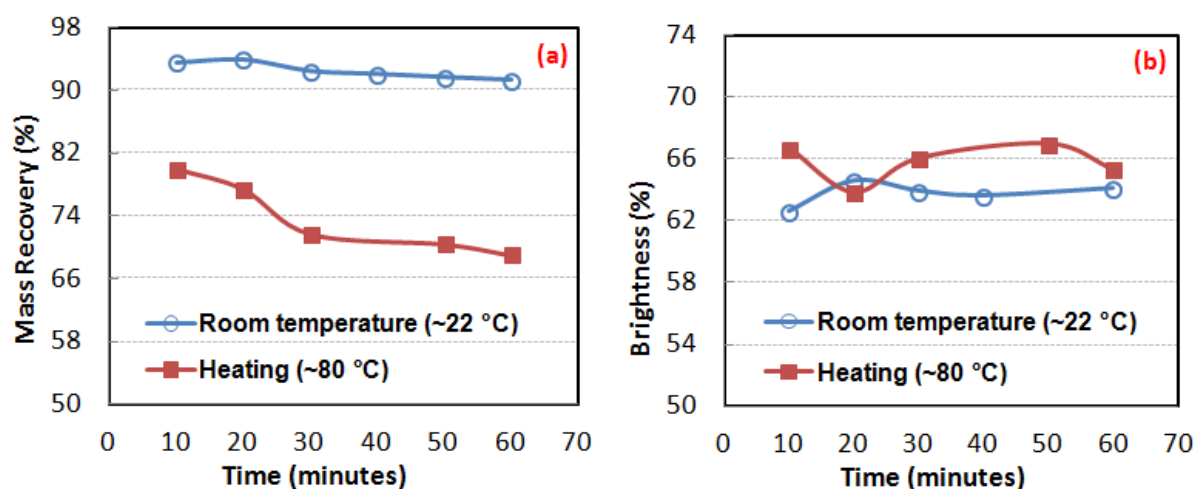


Figure 7: (a) Mass Recovery and (b) brightness of the leaching products in the ground talc sample.

5. CONCLUSIONS

A fine talc material ($\sim 65\%$) was obtained below $37\ \mu\text{m}$ after crushing and milling the sample. This granulometry must be adequate to market requirements. The distributions of Fe, Ca, Mg and Al contents of the analyzed elements presented different behaviors. The relative density of talc ore is characteristic of a silicate ore. However, the brightness showed a similarity between the values obtained for the talc ore sample, which meets the load requirements of the paper industry, although it has a high content of very reactive elements (Fe, Ca and Mg). Also, according to the data obtained by grain size, the cut of the material retained in 100 # did not influence the

final brightness of the feed. As for the mineralogical characterization, it was possible to identify the 5 main phases present in the talc ore (antigorite, clinochlore, magnesite, dolomite and talc), including ore and gangue minerals.

In all magnetic separation tests, a final brightness of the non-magnetic product of approximately 64 % was attained. This product could be applied in the paper industry pending a further examination of its constituent components.

The leaching studies, which involved heating, resulted in the greatest decrease of the mass recovery, which stabilized after 30 min of testing. When raising the temperature, a greater speed in the reaction of leaching was obtained, reducing the contact time between the ore and the leaching agent. These factors should be considered for future design of the leaching equipment and the need to apply heating in an industrial plant.

The best result of the study was obtained using the sample with a granulometric cut of 100 # that was submitted to the magnetic separation (4050 G) and later leached at 80 °C during the time of 60 min. For this test, a maximum brightness of 72 % was obtained, with an increase of 10 % over the initial brightness. This product could be applied, for example, to the paint, insecticide, textile and paper industry, requiring complementary characterization to fit each specification. The costs of implementation, operation and maintenance of the application of temperature to the process should be considered. Finally, future flotation studies are suggested to verify the applicability of the process.

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