Polymeric stabilization of iron ore tailings for disposal in piles

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ABSTRACT

More and more technologies are being sought in order to reduce the environmental impacts in mining processes and make them more efficient and safer, with dry stacking being one of the alternatives to the disposal of mining tailings in dams. However, the stages of filtration and disposal of materials need to be optimized, since they still require many processes to achieve the conditions of compaction of the piles, using auxiliary materials, such as lime and cement. On the other hand, there is the development of studies with new geotechnical materials, which, many times, in addition to being an alternative to the use of materials that cause greater damage to the environment, emitting toxic substances during their production, as is the case of cement, provide an increase in the mechanical, chemical and hydraulic resistance of the tailings. With this in mind, this article proposes the use of the polymer High Performance Agglomerate (HPA) in the stabilization of an iron ore tailings. Due to its formulation and absorption capacity, this material has great potential to improve the mechanical properties of tailings and act as a solidifier in tailings sludge filtration processes. For this purpose, characterization tests of the materials used and special tests were carried out, such as simple compressive strength and densification with different dosages of PAH. Although some of the results were inconclusive, some trends were observed regarding the potential of the material to be used in mining processes.

Keywords: Tailings, Stabilization, Composites, New geotechnical materials.

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INTRODUCTION

Mining activity is fundamental to Brazil's economy, having generated revenues of BRL 339.1 billion in 2021, according to data from the Brazilian Mining Institute (IBRAM). Minas Gerais, one of the country's main ore producing states, is responsible for about 50% of the national iron ore production, according to the National Department of Mineral Production (DNPM). Mining activity in Minas Gerais contributes significantly to the economy of the state and the country, generating direct and indirect jobs. However, it is important to highlight that mining also presents significant environmental challenges and impacts. To minimize these impacts and ensure the sustainability of mining activity, it is necessary to develop more efficient and sustainable technologies, as well as the adoption of responsible mining practices (IBRAM, 2021; DNPM, 2021).

One of the promising approaches to reducing the environmental impacts of mining activity is the dry stacking method of mining tailings. This process involves removing a portion of the moisture from the materials through different procedures, compacting and disposing of them in piles, avoiding storage in dams and reducing problems such as liquefaction. However, it is often necessary to use tailings stabilization techniques to improve their mechanical properties. Among the most widely used techniques is chemical stabilization with cement, which has been shown to be efficient in improving the mechanical properties of tailings, making them more resistant and durable (CONSOLI, 2019a).

Studies indicate that cement application can reduce permeability, increase compressive strength, and improve tailings stability (Zhu et al., 2021; Lee et al., 2019). Another common technique is stabilization with the addition of fly ash, which has also been shown to be efficient in reducing permeability and increasing tailings resistance (Liu et al., 2020). It is important to emphasize that the choice of stabilization technique must take into account the characteristics of the tailings and the environmental impact of the application of the techniques, and the adoption of responsible mining practices is essential.

However, the use of cement for tailings stabilization presents an environmental and sustainability problem due to the high emission of greenhouse gases during manufacturing. Brazilian studies have highlighted the need to seek alternatives to reduce cement consumption and minimize environmental impacts, proposing the use of organic additives (Oliveira et al., 2020) and pozzolanic materials (Reis et al., 2021). The use of coal ash is also pointed out as an alternative for the stabilization of iron ore tailings (Fernandes & Sales, 2018). Thus, it is essential to develop new stabilization techniques that reduce dependence on cement (Reis et al., 2021).

In addition, a new alternative to this problem consists in the addition of polymers capable of improving the mechanical capabilities of the tailings matrix. Studies such as those by Alelvan (2022) have already evaluated the use of organic polymers in mining tailings, obtaining positive results regarding the improvement of the mechanical properties of stabilized tailings and the possibility of reducing the effects of contamination.

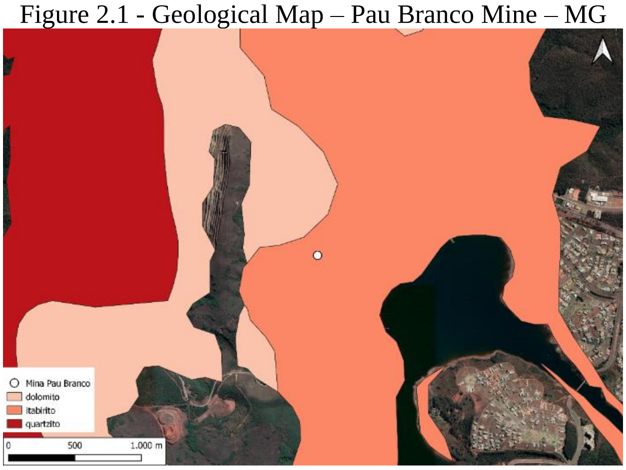
In this context, this work proposes the use of *the polymer High Performance Agglomerate* (HPA) for stabilization of an iron ore tailings. Characterization tests, simple compressive strength, scanning electron microscopy (SEM) and determination of the soil water retention curve with the contents of 1% and 3% of PAH were carried out at curing times of 7 and 28 days in order to verify the optimal dosage and ideal curing time. Subsequently, an analysis of the results was conducted to verify the stabilization of the iron ore tailings material for disposal in piles and other geotechnical structures.

MATERIALS AND METHODS

IRON ORE TAILINGS

The iron ore tailings used in this research come from the Pau Branco Mine, located in Nova Lima, Minas Gerais. As shown on the geological map of the Figure 2.1, the allofrant lithotypes are composed of itabirites in the eastern portion and phyllites in the western portion belonging to the Cauê Formation and Batatal Formation, respectively.

Figure 2.1 - Geological Map – Pau Branco Mine – MG



The pulp sample was collected in the final dewatering stage, according to Figure 2.2, with a field moisture content of 22.93%.

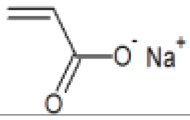
Figure 2.2 - Place of collection of samples.

HPA STABILIZER

The stabilizer used in this research is a type of solidifier called High Performance Agglomerate (HPA). It is a mixture of volcanic ash, composed mostly of silica and alumina, and an organic polymer of the sodium polyacrylate type. In this research, the composites were formed by mixtures of 20% volcanic ash (inorganic polymer) and 80% sodium polyacrylate (organic polymer).

The chemical composition (80%) of the organic polymer used in this research is presented in the Figure 2.3.

Figure 2.3 - Chemical composition of sodium acrylate

Acrilato de sódio		Sintético	Iônico (Aniônico)

The volcanic ash used in the mixture (20%) comes from the consolidation of magma from volcanoes and is extracted in the city of Kagoshima, Japan. The extraction process is very simple and initially consists of separating the material of interest with an excavator shovel. In Figure 2.4 The local active volcano is presented.

Figure 2.4 - Active Volcano in Kagoshima

Source: Fonntes Geotécnica, 2023

The extraction of the ashes is done by means of vertical cuts in the mountains of volcanic rocks, thus avoiding the accumulation of water and consequent landslides. The color of the ashes varies depending on the mountain on which they were extracted. The Figure 2.5 It presents one of the sites where the ashes were extracted.

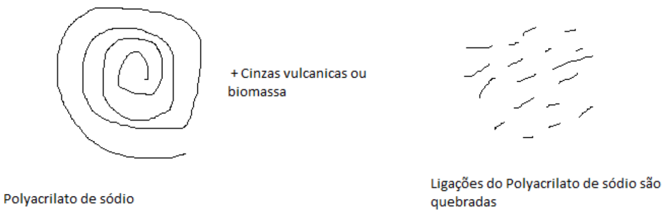
Figure 2.5 – Volcanic ash extraction site

Source: Fonntes Geotécnica, 2023

Then, a selection is made only of ashes that have a particle size of less than 590 micromillimeters. This process is carried out by passing the ashes through sieves immersed in water. Finally, the selected fraction of ash passes through a centrifuge and undergoes a drying process at temperatures between 400 and 500 °C.

The mixture, in the 80/20 ratio, which forms the HPA used in the tests, comes from the factory and no changes have been made to its composition. Polyacrylate has a surprisingly fast solidification when homogenized or under spraying of a tailings with a certain moisture. Volcanic ash, on the other hand, helps in cementation, which can alter the mechanical characteristics of the tailings. In addition, they have the function of breaking some polyacrylate bonds in the mixture and allowing the evaporation of water to be faster, since it prevents the polyacrylate from reabsorbing water after releasing it. The Figure 2.6 It contains a schematic that represents the action of volcanic ash on the behavior of sodium polyacrylate.

Figure 2.6 – Action of ash on sodium polyacrylate



Source: Fonntes Geotécnica, 2023

When HPA is introduced into an aqueous medium, the ionic units dissociate and generate charge density along the chain, resulting in electrostatic repulsion, which expands the gel and promotes swelling. In addition, a high concentration of ions is generated in the gel, which leads to a decrease in osmotic pressure due to dilution of the filler, i.e., swelling of the gel (KIATKAMJORNWONG, 2007).

This polymer is characterized by its high capacity for moisture absorption. According to Jensen (2011), the evaporation of the water retained by the HPA occurs only when under the sun and, after this evaporation, the product is able to absorb more water in the medium. The Figure 2.7 illustrates the reaction of PSA with water.

Figure 2.7 - Reaction of HPA in contact with water

Pacheco (2020) explains that this is due to the great affinity they have for water, absorbing it through the osmosis mechanism in an attempt to balance the concentration of sodium ions inside and outside the polymer. In engineering applications, most superabsorbent polymers are polyacrylates interconnected by covalent cross-bonds, or copolymerized polyacrylates/polyacrylamines (FRIEDRICH, 2012 apud CUNHA AND SANTOS, 2016). Superabsorbent polymers can have a water absorption of up to 5000 times their own weight, but in dilute saline solutions, their absorption capacity of commercial products is approximately 50 g/g (JENSEN AND HANSEN, 2001).

FORMATION OF COMPOSITES AND EXPERIMENTAL CAMPAIGN

The HPA polymer is added to the tailings matrix in its pure and dry state, and then water is added according to the optimum moisture obtained by the compaction test. At this stage of the study, 1% and 3% polymer were measured in relation to the mass of solids in the tailings matrix. The addition of the polymer aims to improve the properties of the tailings matrix, such as water holding capacity and mechanical strength. The dosage of the polymer is an important factor to consider, as a dosage that is too low may not have the desired effect, while a dosage that is too high can result in processing issues and can negatively affect the properties of the reject matrix.

The specimen molding process consists of collecting a representative sample of the tailings and polymer, preparing the composite solution, preparing a mold, and compacting the composite into successive layers using compaction equipment.

Specimens were molded for rupture in simple compression with the characteristics presented in the Table 2.1. The pure tailings were molded at the optimum moisture content (15%) and the composites at the optimum content for 1% (28%). The behavior of the composite in the wet branch, with a moisture content of 35%, was also evaluated to simulate the conditions of receiving the tailings in the field after the exit of the filter press.

Table 2.1 – Moulded composites for simple compression tests

Sample	Moisture content (%)	HPA Theory(%)	Curing time (days)
RP_15W_7D	15	0	7
RP_15W_28D	15	0	28
CP_28W_1%HPA_7D	28	1	7
CP_28W_1%HPA_28D	28	1	28
CP_28W_3%HPA_7D	28	3	7
CP_28W_3%HPA_28D	28	3	28
CP_35W_1%HPA_7D	35	1	7
CP_35W_1%HPA_28D	35	1	28

The molding process of the specimens initially consisted of performing the calculations through the specific mass found in the compaction test, for the preparation of the correct amount of soil, water and polymer, according to the volume of the mold used for the capsules. The mold is 3.5 cm in diameter and 8.8 cm in height, 9.62 cm^2 in area and 85.62 cm^3 in volume.

For the molding of the composite specimens (CP), the soil is de-disturbed in the mortar and then mixed to the indicated percentage of PAH until it becomes a homogeneous mixture, according to the Figure 2.8 and Figure 2.9 below. Finally, the percentage of water equivalent to the moisture content investigated was added – found through the compaction tests for each of the composites – and the correct homogenization and separation into 3 parts was made to take the material to the static compaction equipment, standardizing 7 strokes (turns) per layer.

Figure 2.8– Preparation of the composite for molding of the specimens.

Figure 2.9 – Manual compaction process of specimens.

For the molding of the pure tailings specimens, it was initially proposed that the simple compression tests be performed all at the same moisture content so that it would be possible to compare the stress x strain behavior of the composite and the pure tailings under the same percentage of water. However, during the molding of the specimens with pure tailings, it was noted that it was impossible to perform the molding with 35% water (wet branch) and 28% water (optimal moisture content of the composite). The Figure 2.10 It shows the molded specimens with 35% and 28% water, respectively.

Figure 2.10 – Molded pure tailings specimens with levels above the optimum: (a) 35%; (b) 28%.

(a) (b)

At first glance, it is possible to notice that the specimen molded with 35% water does not have enough consistency for the simple compression test, since, due to the excess of water, it was not possible to compact the RP. On the other hand, the specimen with 28% water was possible to be molded and compacted, however, still due to the excess of water, the body presented many cracks and fragility after 7 days of healing and, therefore, it was not possible to perform the simple compression rupture with these moistures.

Thus, the molding of the pure tailings specimens was carried out with the optimal moisture content of the tailings of 15.5%. This analysis is considered feasible, since at the optimum content the pure tailings must present the most stable structure, and consequently, greater resistance to be compared with the mechanical performance of the composites.

It is also important to point out that this situation demonstrated the problems faced in the field by mining companies, since with this moisture content the material does not allow adequate compaction. For this reason, there is a demand to seek solutions for drying the material for disposal in compacted dry stacks.

EXPERIMENTAL CAMPAIGN

The objective of the experimental campaign of geotechnical tests was the physical and mechanical characterization of a soil. The tests carried out were:

- Physical characterization, which involved the determination of particle size properties, plasticity index and bulk density;
- Normal Proctor compaction, which consisted of determining the soil compaction curve for different moisture contents;
- Simple compressive strength, performed in triplicate, which allowed the evaluation of the soil's capacity to withstand vertical loads;

Soil water retention curve, which allowed to determine the amount of water retained by the soil in different matrix potentials; and

- Mineralogical characterization by means of SEM imaging, which allowed to know the characteristics of the particles of the pure tailings and the composite.

The performance of these tests allowed to obtain important information about the characteristics of the soil under study, providing subsidies for the evaluation of its stability and potential for use in geotechnical works.

The tested composites will be analyzed using the "2k factorial" experiment methodology. This method evaluates the impact of k-factors on the response variable at two levels. Not all factors can affect you equally, and some may have no effect at all.

The number of experimental points grows geometrically with a ratio of 2. The "2k factorial" is useful for research to investigate in order to subsequently narrow down the investigation to the most relevant factors, with multiple replications per experimental point (MONTGOMERY, 2017). Studies such as those by Bruschi (2020) and Alelvan (2022) used the experimental methodology of the 2k factorial for similar tailings stabilization studies, investigating variables such as: curing time, specific mass, moisture content, and stabilizer dosage.

According to Alelvan (2022), among the advantages of using the 2k factorial experiment, it can be highlighted that it is an accurate estimate that requires less time and resources than other methods. In addition, the information obtained reflects the response of a larger experimental region, since each factorial effect is calculated considering all possible combinations of the levels of the other factors.

Based on this proposal, the following were adopted for this research:

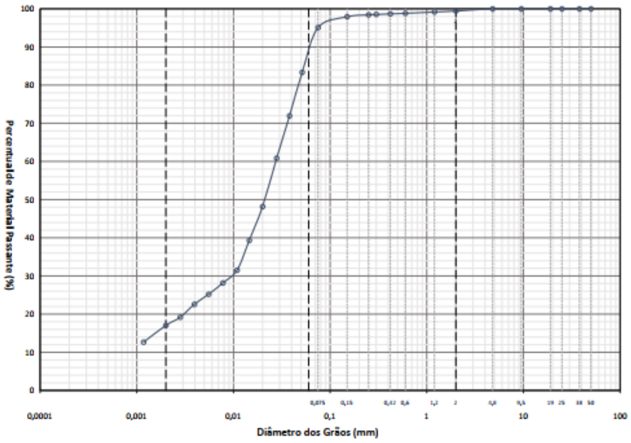
- Variables investigated: optimum moisture content of the composites; optimum moisture content of pure tailings.
- Fixed variables: type of tailings; type of stabilizer; polymeric contents (1% and 3%); curing time (7 and 28 days); strain rate in simple compression tests.
- Response variable: simple compressive strength (SCR).

TESTS AND RESULTS

CHARACTERIZATION TESTS

The particle size curve obtained for pure tailings is presented in the Figure 3.1. There was the presence of 16.1% of clay, 75.1% of silt, 8.4% of sand and 0.5% of gravel. Thus, the tailings were classified as clayey silt with little sand.

Figure 3.1 - Particle size curve.



ARGILA (%)	SILTE (%)	AREIA (%)			PEDREGULHO (%)
		FINA	MÉDIA	GROSSA	
17,0	70,6	10,6	0,7	0,6	0,6

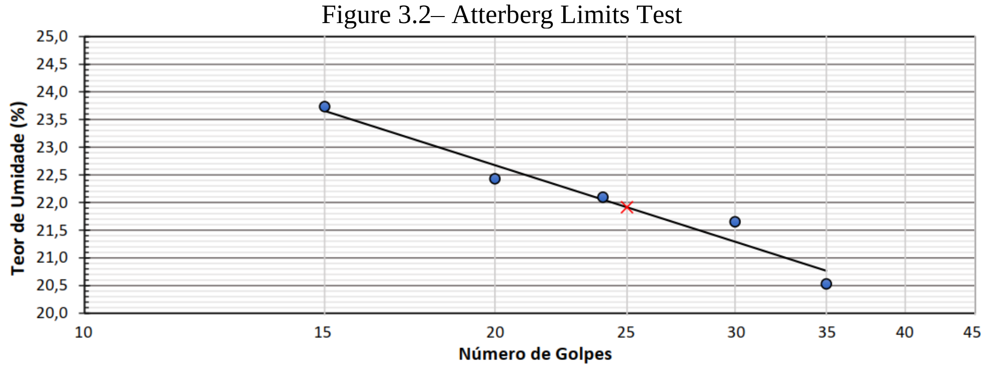
In the actual grain density test, performed only for pure tailings, the actual specific mass of the grains of the iron ore tailings resulted in 3.348 g/cm³. Regarding the moisture content, the contents of the samples collected from filter press 01, filter press 02 and filter press 03 were calculated. For this reason, a *Blend* of the tailings collected in the filters and, thus, the average humidity was calculated, as shown in the Table 3.1.

Table 3.1 - Moisture content per filter press

PRENSA FILTER	MOISTURE CONTENT
01	21,7
02	24,0
03	23,10
AVERAGE	22,93

Thus, the average natural moisture content of the virgin iron ore tailings sample presented in the laboratory tests was 22.93%. Finally, the consistency limit tests (Atterberg) showed the moisture contents from which there is a change in the physical state of the tailings, which are relevant for the understanding of the behavior of the material studied.

Figure 3.2– Atterberg Limits Test



The results of the liquidity limits and plasticity limit tests and the determination of the plasticity indices were 22%, 18% and 4%, respectively, for the pure tailings samples, which indicates, according to the classification of SOWERS (1965), presented in , that the tailings, with 4% of IP, are close to the behavior of a soil with a slightly plastic degree of plasticity.

Table 3.2 – Degree of soil plasticity

IP (%)	DESCRIPTION
0 – 3	Non-plastic
3 – 15	**Slightly plastic**
15 – 30	Low plasticity
> 30	High plasticity

Fonte: SOWERS (1965).

PROCTOR NORMAL COMPRESSION

The compaction test (Proctor Normal) was carried out according to the ABNT NBR 7182/1986 – Compaction Tests. Through the test, the maximum density of the tailings and the composite was obtained for different moisture contents. By means of this test, the optimum moisture content was also defined according to the maximum density obtained.

The test was performed for the pure tailings sample and for the composite samples with 1% and 3% PAH. The results are visible during the test and can be confirmed by means of the compaction curves presented in the Figure 3.3, Figure 3.4 and Figure 3.5.

Figure 3.3– Compaction curve - RP

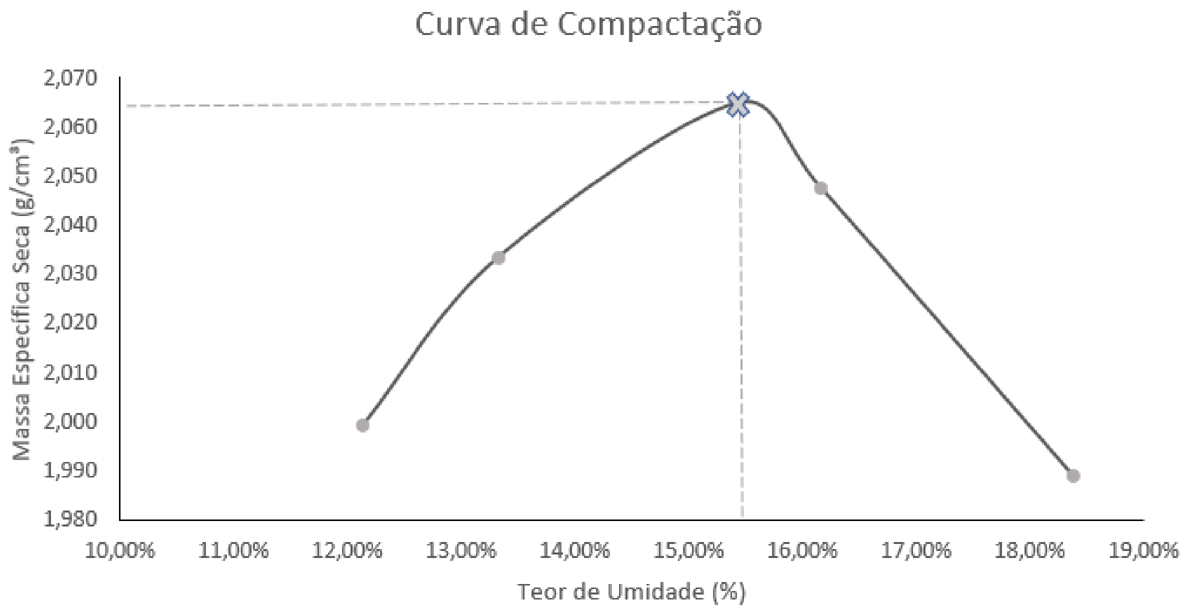


Figure 3.4– Compaction curve – CP_1%_HPA

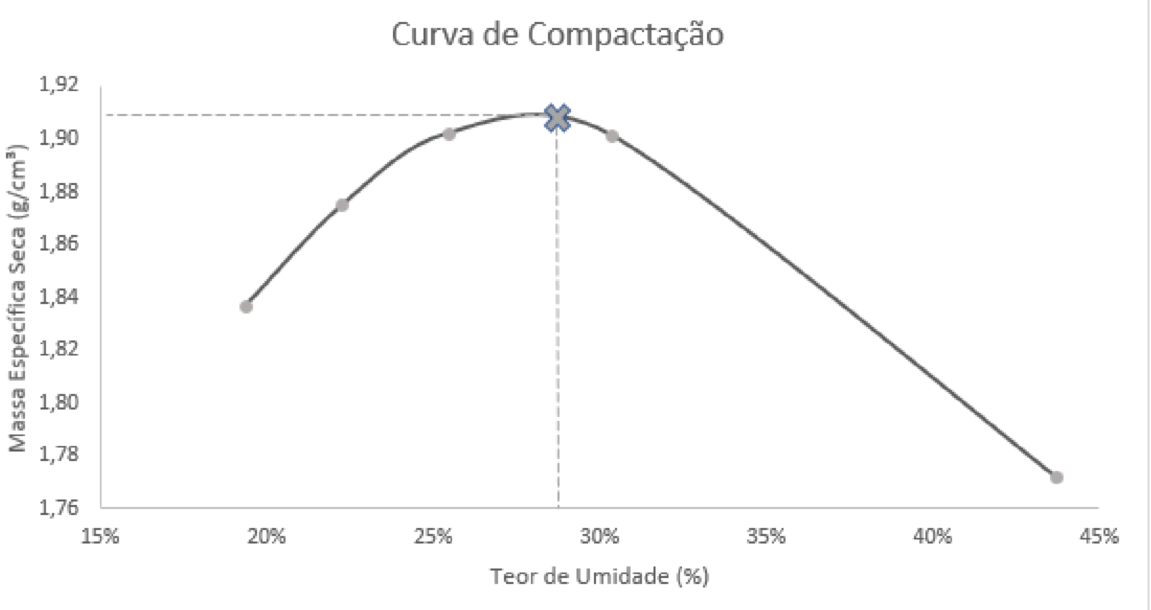
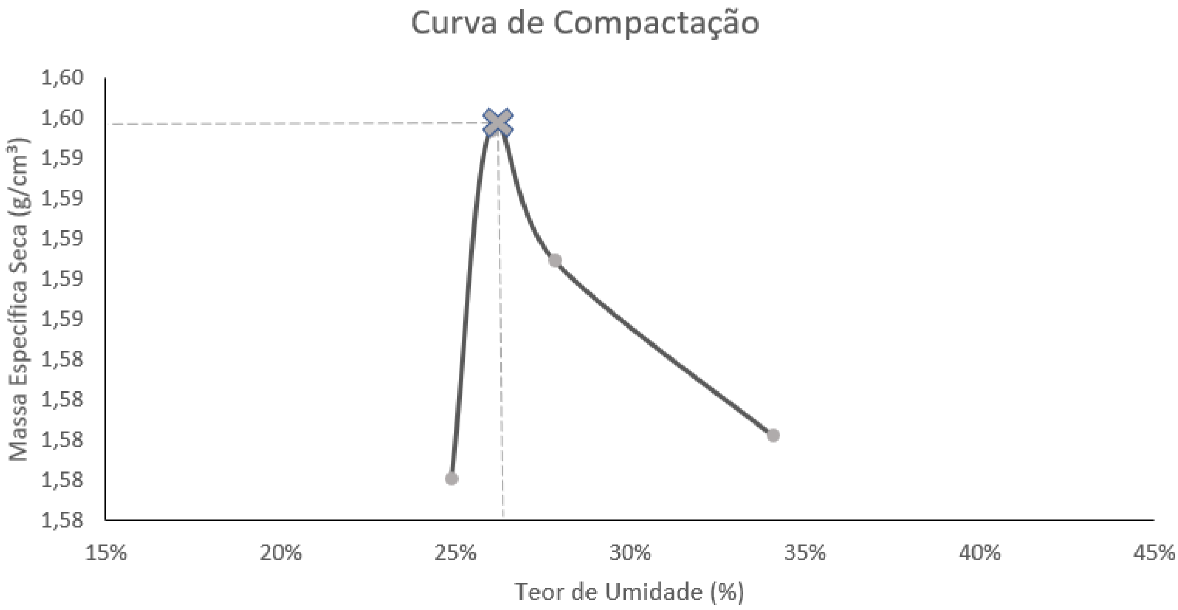


Figure 3.5 – Compaction curve – CP_1%_HPA



On Table 3.3 The optimum values of moisture content and specific dry mass for the three tests performed are presented.

Table 3.3 – Results of the compaction test

Sample	Optimum moisture content (%)	Optimum specific dry mass (g/cm³)
RP	15,5	2,065
CP_1%HPA	28,0	1,91
CP_3%HPA	26,0	1,60

It was observed that there was a change both in the optimal moisture content and in the optimal specific dry mass. This change can be observed as the test is performed, which, with the increase in the binding polymer content, there is an increase in the optimal moisture content and a decrease in the specific dry mass. It is understood that there is a relationship between the absorption of water by the action of PAH and the increase in the optimal moisture content.

On the other hand, a slight decrease in the optimal moisture content was observed for the sample with 3% PAH compared to the sample with 1% PAH. Even so, the optimal specific dry mass continued to decrease, as previously observed. The ratio of moisture content to this polymer content may be related to excess superabsorbent in the composite. The compaction test, specifically for RP_HPA3%, was difficult to perform, since as water was added to reach a certain moisture content, the polymer acted quickly, absorbing this water in hydrogel particles and leaving the composite with a very dry appearance. This made the test difficult in general, as it was necessary to start the first point of compaction with a very high percentage of water. It is understood, then, that the polymer content of 3% generated this agile superabsorption in the composite.

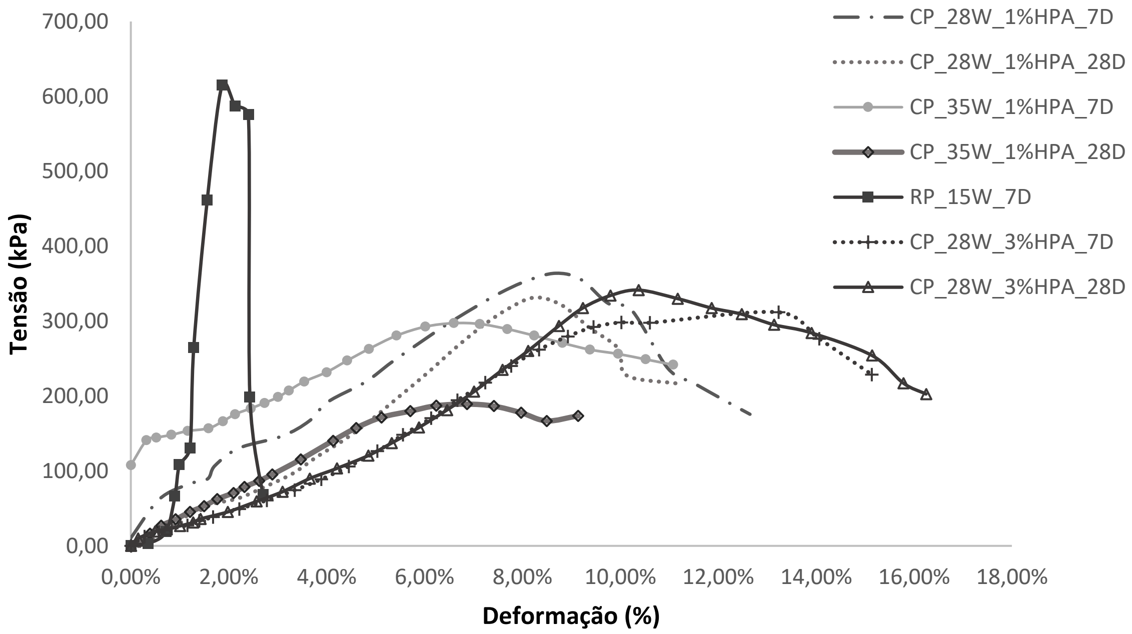
In general, the action of the superabsorbent polymer in the tailings + polymer composite causes the sensation, to the naked eye, of drying of the tailings. This drying forms hydrogels and increases the void index of the mixture, which can explain the behavior of increase in the optimal moisture content with the addition of polymer, since it shows that the material has a hydration time, in which it absorbs water to its full capacity and then, in the desorption process, releases this water to the tailings. leaving voids inside, as occurs in the cementitious media trials carried out by Mönnig (2009).

SIMPLE COMPRESSION

Simple compression tests were conducted varying moisture and solution contents. For the pure tailings, the optimum moisture content obtained in the compaction test was used, which was 15.5%. For the composites, the optimum moisture content of RP_HPA_1% was used. In addition, an assay was carried out with a content above the optimum humidity, which was 35% water.

The Figure 3.6 Shows the graph TESÃO x Deformation summary of the results for all scenarios analyzed in the simple compressive strength tests.

Figure 3.6 – Stress x Strain Graph – Simple Compressive Strength

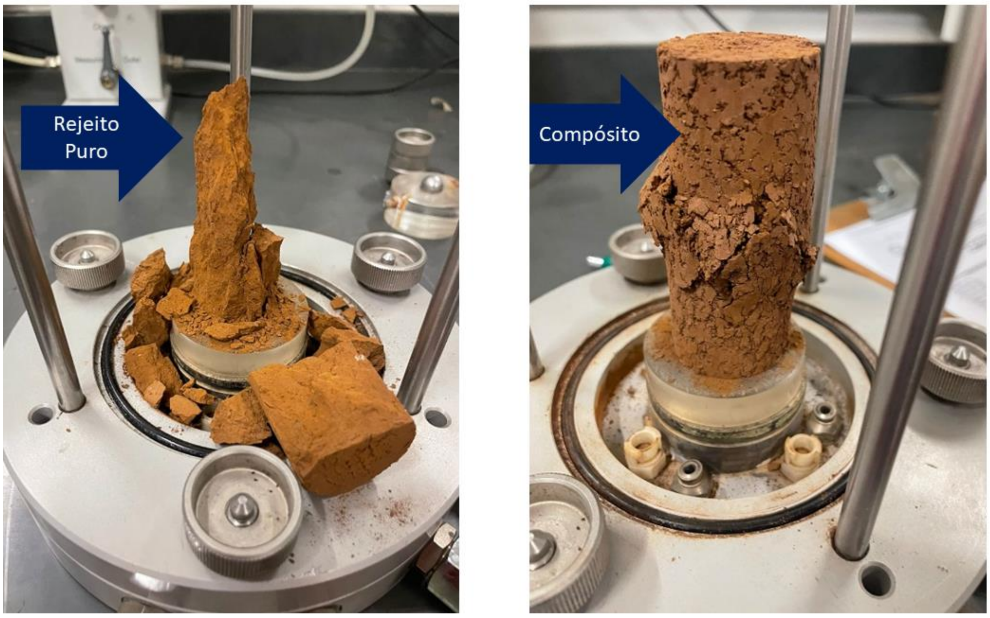


By comparing the stress x strain curves, it is possible to observe a standard behavior of loss of strength and gain of deformability with the increase of the polymer content in the composites. In addition, it can be noted that the samples with excess water (moisture content of 35%) in their composition did not show a favorable behavior to the composites, since the loss of strength is even more significant and the gain in deformability was less representative than in the other samples.

Therefore, it is considered that the appropriate condition for the strength of the composite is its optimum moisture content.

From the results, it is possible to verify that the polymer does not have efficiency for strength gain, however, it improves the deformability properties, ensuring an elastoplastic behavior for the polymer. In the curve of the pure tailings test, as well as during the compression process, it was possible to observe the brittle behavior of the tailings, characteristic of the material. As PAH is added, the workability of the composite improves and, with that, greater deformation capacities are ensured. In addition, in view of the graphical analyses, it was not possible to notice significant changes in behavior in relation to polymer content and curing time. The **Erro! Fonte de referência não encontrada.** Shows the pure tailings and composite specimens after test breakdown.

Figure 3.7 – Specimens in the simple compressive strength test



A Figure 3.7 It clearly shows the difference between pure tailings and composite specimens and their behavior under load compression. As mentioned, the pure tailings specimen has a notoriously more brittle behavior and less deformation capacity, since it breaks completely when loads are applied. On the other hand, the composite specimen, even after breaking, does not suffer as excessive deformations as pure tailings, which demonstrates the deformability that the polymer confers to the tailings. In addition, it is possible to observe a more porous aspect in the composite compared to pure tailings, due to the increase in void indices conferred by the binder. This also explains the decrease in the compressive strength of the composites.

STATISTICAL ANALYSIS

To evaluate the influence of the factors (polymer content and curing time) on the variables, a statistical analysis was performed in the RStudio software, based on the 2k factorial methodology, where the variables of solution content and curing time were fixed. This method evaluates the impact of k-factors on the response variable at two levels. Not all factors can affect you equally, and some may have no effect at all.

The number of experimental points grows geometrically with a ratio of 2. The "2k factorial" is useful for research to investigate in order to subsequently narrow down the investigation to the most relevant factors, with multiple replications per experimental point (MONTGOMERY, 2017). Studies such as those by Bruschi (2020) and Alelvan (2022) used the experimental methodology of the 2k factorial for similar tailings stabilization studies, investigating variables such as: curing time, specific mass, moisture content, and stabilizer dosage.

According to Alelvan (2022), among the advantages of using the 2k factorial experiment, it can be highlighted that it is an accurate estimate that requires less time and resources than other methods. In addition, the information obtained reflects the response of a larger experimental region, since each factorial effect is calculated considering all possible combinations of the levels of the other factors.

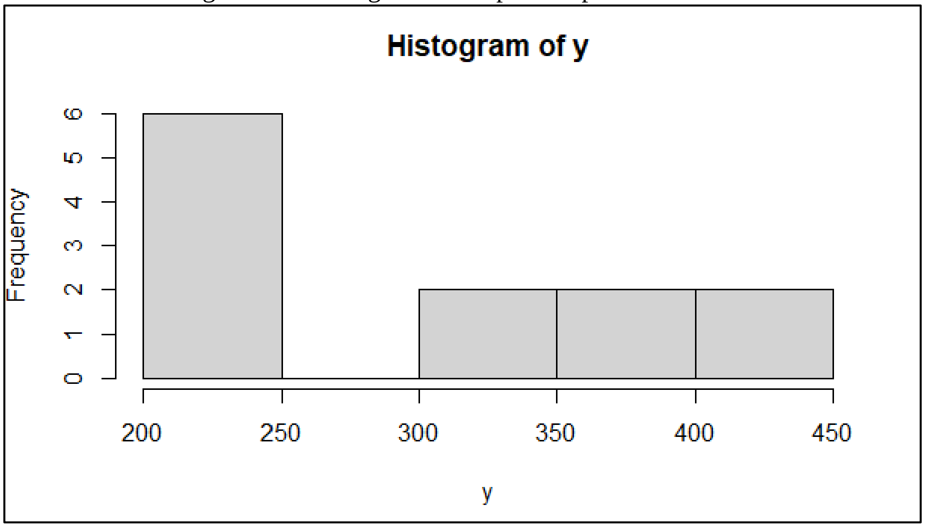
The statistical analysis took into account the variation of PAH contents of 1% and 3% for the cure times of 7 and 28 days. The data treatments used in the input matrix are presented in the Table 3.4.

Table 3.4 - Simple compression data for statistical treatment

Treatment	Polymer Theory (%)	Curing Time (days)	Simple Compressive Strength (kPa)	Average
1	1	7	347,79	326,99
	1	7	229,90	
	1	7	403,29	
2	1	28	239,06	230,92
	1	28	229,71	
	1	28	224,00	
3	3	7	242,18	336,42
	3	7	365,87	
	3	7	401,21	
4	3	28	238,44	307,11
	3	28	358,60	
	3	28	324,30	

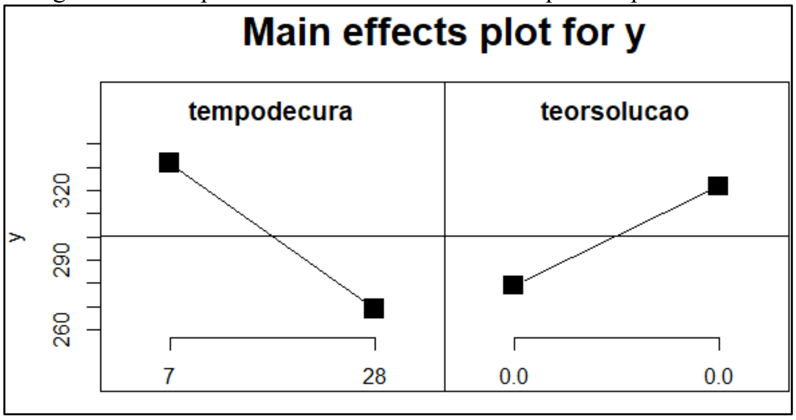
The response data from the statistical analyses are presented in the following figures (Figure 3.8, Figure 3.9 and Figure 3.10).

Figure 3.8– Histogram of simple compression results



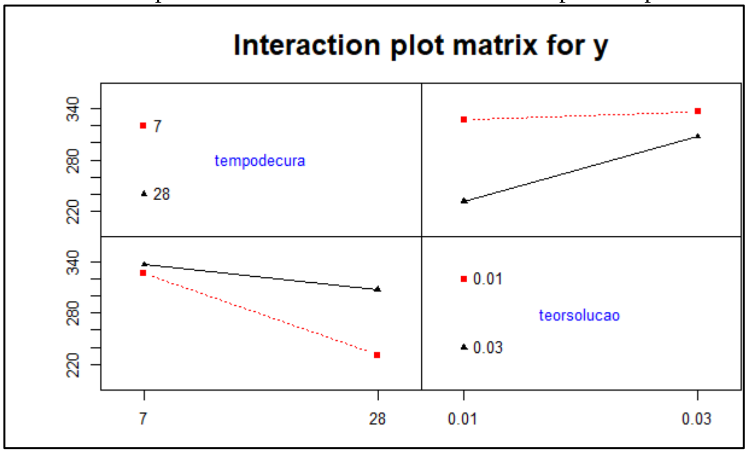
Source: Graph generated in RStudio.

Figure 3.9– Graph of the main effects of the simple compression test



Source: Graph generated in RStudio.

Figure 3.10 – Graph of the interaction matrix of the simple compression tests



Source: Graph generated in RStudio.

The statistical analyses showed that the matrix of results of the simple compressive strength tests varying polymer content (1% and 3%) and cure time (7 and 28 days) do not follow a normalized distribution. The result was expected in view of the behavior of the trials presented so far. The non-normalization of the statistical functions indicates, as already mentioned, that the variables used in the analysis do not influence the response variable of the simple compressive strength test. In other words, the polymer content and the curing time do not influence the strength gain of the composites.

COMPACTION TEST

The thickening test was conducted for the pure tailings and for the CP_1% sample_HPA with 7 days of curing. In Figure 3.11 and Figure 3.12 The curves that relate the void index and the densification stress are presented for the RP and CP_1%_HPA samples.

Figure 3.11 - Ratio of void index and densification stress – PR.

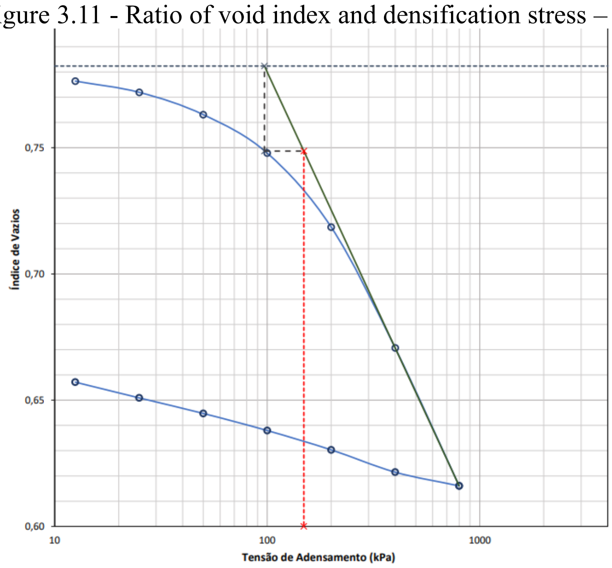
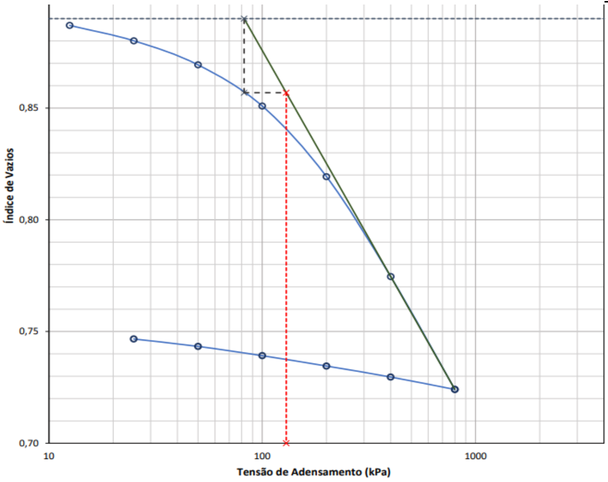


Figure 3.12 - Ratio of void index and densification stress – RP_HPA4



The results of the densification tests showed an increase in the void index in the polymer mixture. This information, coupled with the results of the compaction tests, shows that the material has a hydration time, in which it absorbs the water to its full capacity and then, in the desorption process, releases this water into the tailings, leaving voids inside, as observed by Mönnig (2009) in his studies on cementitious media.

SCANNING ELECTRON MICROSCOPY

Mineralogical characterization is a fundamental process for the study of geotechnical materials, especially when it comes to mining waste. In this context, the mineralogical characterization of the iron ore tailings was carried out to study the use of the binding HPA polymer as a stabilization and solidification technique by means of imaging through scanning electron microscopes.

Scanning electron microscopes (SEM) have a working principle based on the emission of a small diameter and high energy electron beam, exploring point by point the surface of the sample to be analyzed, which is subjected to vacuum.

The SEM provides morphology information and identifies chemical elements of a sample, being one of the most suitable instruments for analyzing the microstructural characteristics of solid objects. Another advantage of this test is the possibility of obtaining the three-dimensional characteristics of the studied samples (DEDAVID et al., 2007).

Electron microscope analyses were performed to detail the morphology and arrangement of the particles of the virgin tailings, treated tailings and the pure PAH sample. The samples were positioned in the cylinders and inserted into the vacuum microscope and the visualized images can be viewed from the Figure 3.13 until Figure 3.18.

Figure 3.13 – SEM – RP Sample - 50 µm

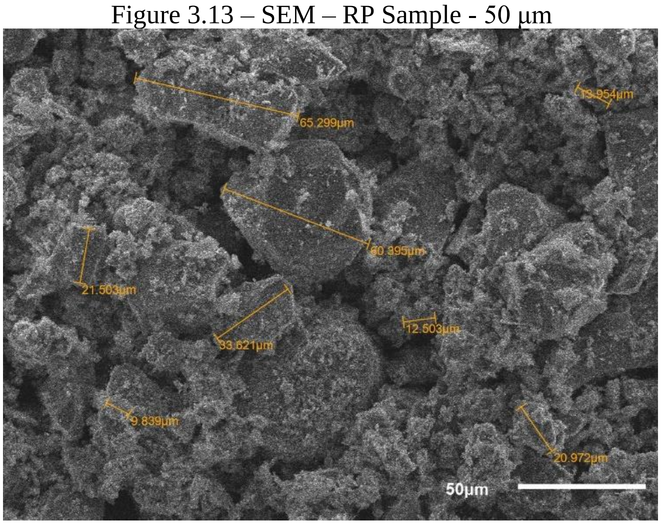


Figure 3.14 – SEM – HPA Sample - 200 µm

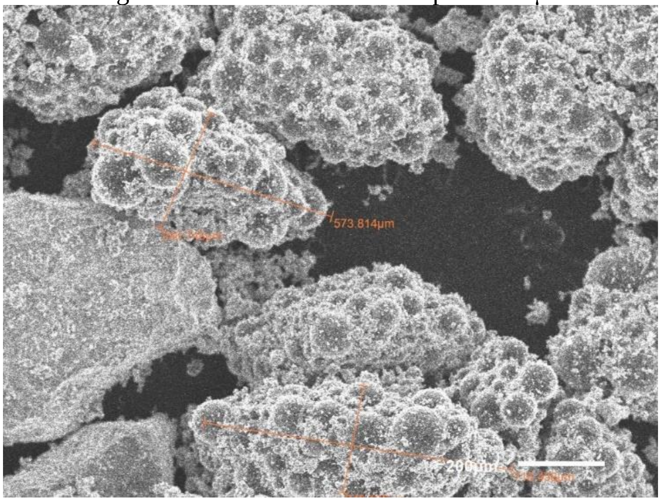


Figure 3.15 – MEXICANs RP_HPA 1% - 50 µm

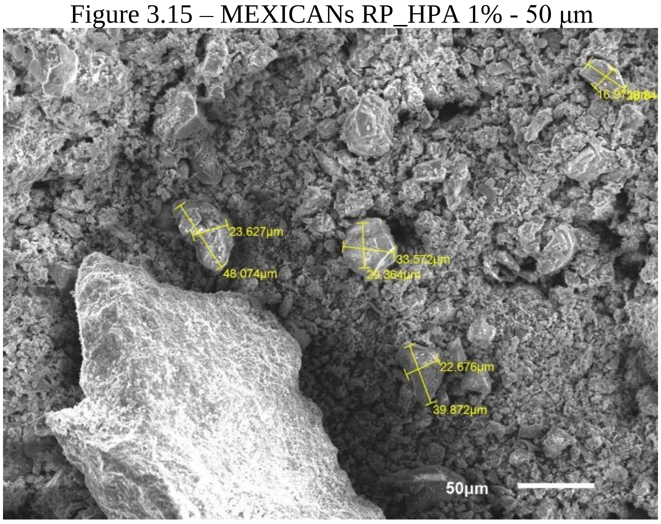


Figure 3.16 – MEXICAN - RP_HPA 1% - 200 µm

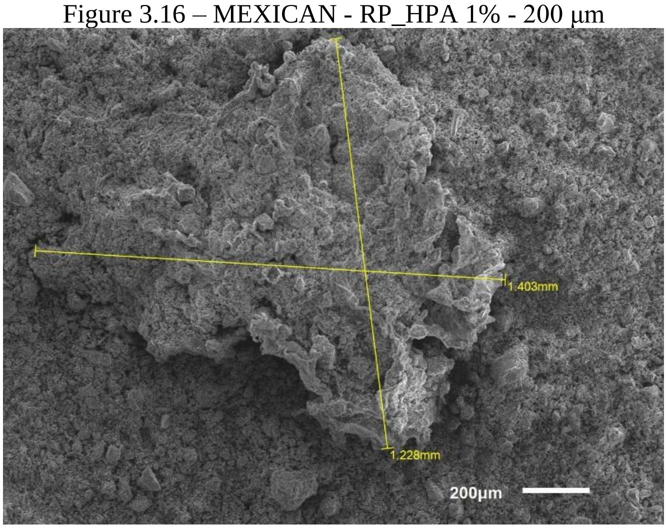


Figure 3.17 – MEXICAN - RP_HPA 3% - 50 µm

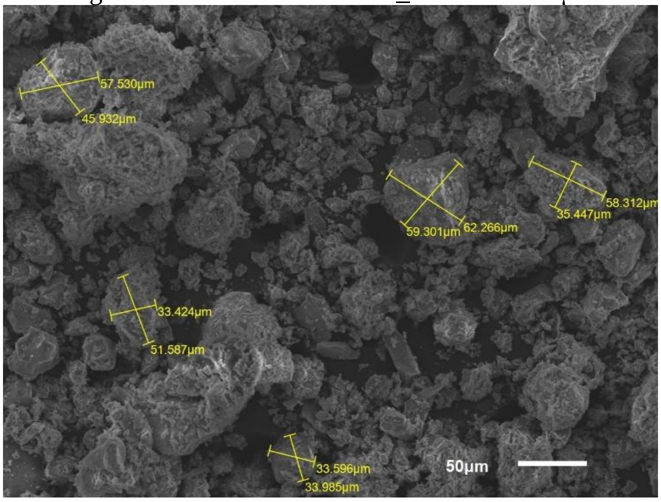
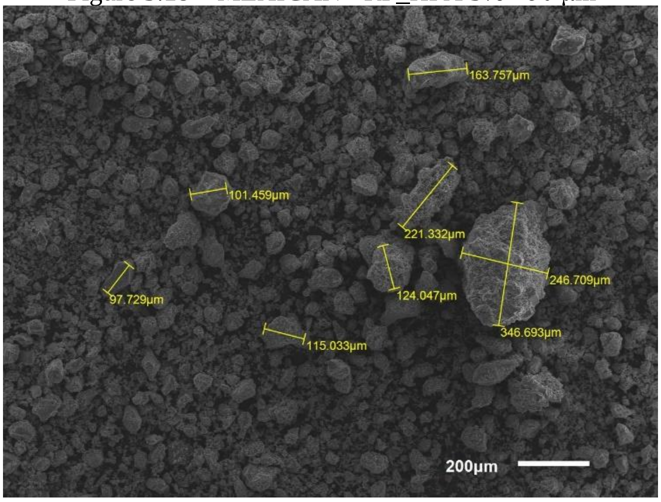


Figure 3.18 – MEXICAN - RP_HPA 3% - 50 µm



It is observed, by the imaging, that the tailings particles have a laminar structure, which is arranged according to a horizontal plane and does not tend to present high porosity and rounded spheres. This behavior indicates that the particle thickness of the iron ore tailings is small, which is confirmed by the **Erro! Fonte de referência não encontrada.**, which shows the size of the particles considering the 50 µm scale.

At first glance, it is possible to notice that the PAH particles are considerably larger than the particles of the tailings studied, but in fact, they may be agglomerations in the HPA, which, as observed by the particle size curves, may have adhered to the fine fraction of the tailings, forming larger particles. In addition, the structure of the grains is presented in a botrioidal texture, with its external shape composed of several rounded elements. This form is related to the growth of the mineral mainly from colloidal solutions. In this sense, it would be interesting to perform tests such as mass loss by immersion, in order to analyze the behavior of the treated samples when in contact with water.

CONCLUSIONS

In this work, the effects of chemical stabilization of an iron ore tailings using a superabsorbent polymer composed of 80% sodium polyacrylate and 20% volcanic ash were evaluated. The intention was to evaluate the effects of the mixture in terms of polymer content and curing time. For this purpose, composites with 1% and 3% polymer were formed for curing times of 7 and 28 days.

The iron ore tailings studied come from the Pau Branco Mine and, currently, the tailings come out of the filter press process with about 22% moisture content, which makes any type of disposal unfeasible without going through stabilization or drying processes. Thus, an alternative presented was the "drying" of the tailings with the absorbent polymer HPA (*High Performance Aglomerate*), which aims to improve the workability of the tailings for disposal.

In view of the needs presented, laboratory tests were carried out, both with the pure tailings and with the composites formed with the polymer contents, to compare the behaviors of the tailings and composite.

The laboratory results for the RP helped in the understanding of the soil type, demonstrating the feasibility of the proposed study. With the complete characterization tests, the following conclusions were obtained:

- The granulometry test showed that the material is classified as a clayey silt with little sand. Its consistency is thin and sticky due to the high portion of silt and clay, which makes it difficult to drain and compact the material, in addition to its high water retention capacity, which can affect stability and strength.
- The Atterberg Limits tests allowed the evaluation of the PR through its consistency properties, especially in relation to granulometry and compressibility. The results showed values of liquidity limits and plasticity limit and plasticity indices were 22%, 18% and 4%, respectively, which classifies the soil as non-plastic. This result, coupled with the particle size composition of the RP, shows that the material can be molded or deformed in a wet state, but can crack or shrink when dry.

The compaction test at normal proctor energy was performed for pure tailings and for composites at 1% and 3% levels, with the purpose of comparing and understanding the action of the superabsorbent polymer in the presence of water. The results showed that, with the addition of PAH, the tendency of the tailings is to become a visibly drier material, exerting a greater demand for water to reach the optimal compaction moisture. The same occurs with the specific dry mass that decreases with the addition of polymer.

In the mineralogical characterization of the materials of interest, SEM tests were carried out, with the purpose of glimpsing the particles, both of the tailings and composite, as well as of the pure HPA. At first glance, it is possible to notice that the PAH particles are considerably larger than the particles of the tailings studied, but in fact, they may be agglomerations in the HPA, which, as observed by the particle size curves, may have adhered to the fine fraction of the tailings, forming larger particles. In addition, the structure of the grains is presented in a botrioidal texture, with its external shape composed of several rounded elements. This form is related to the growth of the mineral mainly from colloidal solutions. In this sense, it would be interesting to perform tests such as mass loss by immersion, in order to analyze the behavior of the treated samples when in contact with water.

These behaviors in the compaction curves, both in relation to the optimal moisture content and the specific dry mass, occur because PAH is a polymer capable of absorbing and retaining large percentages of water in relation to its soil mass. The chemical structure of the HPA, in particular, forms bonds with water molecules that form hydrated hydrogels, which are the encapsulation of the water added to the mixture.

To understand the mechanical behavior of the samples, simple compressive strength tests were performed for pure tailings and composites. The initial purpose was to verify the possibility of strength gain for possible applications of tailings pile disposal. The change in the physical behavior of the composites, showing that they have better workability than the tailings in pure condition, demonstrates the possibility of this type of application for the material. However, the results of the simple compressive strength tests revealed the following conclusions:

- The pure tailings showed brittle behavior, visible both in the stress x strain curve and in the performance of the tests. The specimens ruptured in a short time, together with the rapid appearance of cracks and the crumbling of the specimen in the face of the application of low voltages;
- On the other hand, the composites showed significantly higher deformabilities. While the pure tailings specimens ruptured in 3 minutes of testing, the composites ruptured in an average of 25 minutes. In addition, even after the rupture, the specimen did not completely fall apart, keeping its structure still stable in some spots. Regarding the rupture deformation, while the PR presented values in the range of 2 to 3%, the composites presented this range in an average of 15 to 18%, increasing with the addition of PAH.
- Despite higher deformability, the composites presented lower tensile strength values than the RP samples. This trend may be related to the fact that, in general, the PAS, by absorbing the water present in the tailings, forming the hydrogel particles, cause the

attenuation of the cohesion between the particles, which have a lower capacity for interconnection.

Other conclusions regarding the simple compressive strength tests refer to the analysis of solution content and optimal curing time. To determine a range of values where the material showed better behaviors, a statistical analysis was performed using a language programmed through the RStudio software. This analysis used the experimental methodology of 2k factorial, where the variables of solution content and curing time were fixed.

Statistical analyses showed that the matrix of test results with these variables does not follow a normalized distribution. The result was expected in view of the behavior of the trials presented so far. The non-normalization of the statistical functions indicates, as already mentioned, that the variables used in the analysis are not an influence for the simple compressive strength test. In other words, the polymer content and the curing time do not influence the strength gain of the composites.

Finally, in view of the results obtained during the research, it is understood that the superabsorbent polymer with the addition of volcanic ash (PAH) has significant properties for use in an iron ore tailings. These applications can be made, linked to the appropriate dosages and humidity, in stability improvements, erosion control, compaction improvement and moisture reduction after the filter press process. However, it is worth mentioning that behaviors may vary depending on the characteristics of the iron ore tailings used. Thus, it is recommended to carry out studies and tests to evaluate the feasibility and benefits of composites in each case.

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