Mechanical behavior of iron tailings mine improved with organic polymer and polypropylene fibers

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ABSTRACT
The study on stabilization, whether soil or tailings, has been increasing. The lack of adequate material on site, the need to take advantage of existing materials and reduce environmental impact, has led to the use of soil improvement techniques. The minerals are mixed with different elements inside the rocks and can be removed by different mechanical and chemical processes intention to sell to several companies. The storage form of these tailings is determined by the type of material, site topography and existing environmental conditions. The addition of polymers and polypropylene fibers in stabilization of slopes increase the resistance parameters. When applied properly, becomes a strong stabilizer in unpaved roads, pavements base, slope protection. This study aims to analyze the characteristics of iron mine tailings, the influence of polymer content, and the mechanical behavior of the composites with polymer and fibers. Laboratory tests were performed to evaluate the effect of polymer and polypropylene fibers on the tailings mine. Through the analysis of the results, improvements were observed in the strength parameters with addition of polymers and fibers. After the fibers insertion, was an increase in the angle of friction and reduction in cohesion. The applicability of polymers and polypropylene fibers is an alternative to improve the behavior of the studied iron mining tailings for geotechnical applications.

1. INTRODUCTION

Mining tailings should be disposed of in locations that ensure safe environmental conditions. The best storage for these tailings is determined by the type of material, the site topography and the existing environmental conditions. There are several methods for storage, but by mainly economic criteria there is a reduction of choices to achieve efficiency and effectiveness in the disposal of tailings in a place that can contain them without compromising the environment and affecting the production speed of the mine.

The literature shows that soil improvement techniques are applicable, cost-effective and environmentally friendly. Furthermore, research shows that polymers can be used in various geotechnical engineering works as soil stabilizer on unpaved roads, parking floors, slope protection, as a sealant in dust control and erosion control and paving layers, and is also capable of increasing soil moisture resistance.

According to Xing et al. (2018), polymers are currently being increasingly used as a sandy soil stabilizer due to their stable chemical property and shorter cure time compared to traditional stabilizers such as lime cement, fly ash and bituminous materials, etc, which require a long healing time.

When applied correctly and at the proper dosage, the polymer application becomes a strong soil stabilizer on unpaved roads, parking floors, slope protection, and as a sealant in dust control and erosion control and paving layers. able to increase soil moisture resistance. It can be used in landfills with thin soils, as it prevents weathering erosion due to agglutination of the grains, improving the stability of the massif.

The longer the length, the greater the mechanical strength gain, to a limit (Gray and Ohashi, 1983; Heineck and Consoli, 2002) and the less likely they will be pulled out (Consoli, et al., 2007). For a given surface shear stress applied to the fiber, it will be more requested if its length is sufficiently capable of allowing the shear stress to develop a shear stress equal to its tensile strength.

The use of residues added to the soil, for the various geotechnical areas, has as its main objective to improve the mechanical properties of the materials / soils used in the works. Often the natural soil of a given region does not meet the specifications required for its use, requiring improvement or stabilization.

Barreto et al. (2018), Xing et al. (2018), Liu et al (2018), Mirzababaei et al (2017), Kolay et al. (2016) analyzed the application of polymers for soil improvement.

Sotomayor 2018 performed a conventional direct shear test on iron mining tailings with the addition of polypropylene fibers, the friction angle increased from 32.8º to 37.7º and the cohesive intercept with the addition of fibers showed a zero increment for 4.5 kPa. Concluding that the addition of fibers acts on the improvement of the tailings strength parameters

Aiming to improve the geotechnical characteristics of the tailings, the present work aims at the application of improvement techniques in the iron ore tailings with polymers and polypropylene fibers, to verify the behavior of the tailings with and without application of polymer and fiber.

2. MATERIALS AND METHODOLOGY

The iron ore tailings originate from the elevation dikes, thickened by the passage of the equipment, over a loan material dam.
The polymer used is an organic styrene acrylic copolymer obtained by random polymerization reactions through an anionic aqueous emulsion. According to the manufacturer, it has a density of 0.98–1.04 g / cm³, pH 8.0–9.0, and viscosity 3,000–10,000 cps.
The table 1 is presented as characteristics of polypropylene fibers. The product for commercial use is generally indicated for reinforcing concrete and mortar with good workability to generate homogeneous composites.

Table 1. Technical characteristics of polypropylene fibers.

Physical Properties	**Value**
Diameter (μm)	18
Length (mm)	24
Density (g/cm³)	0,91
Mechanical Properties	**Value**
Tensile Strength (MPa [N/mm²])	300
Young's Module (MPa)	3000

The characteristics of an ore tailings are related to the deposition of this material, location and age of the deposit, iron type, iron extraction process, weathering processes suffered by the rock. Therefore, when physically characterizing a tailings, it is always taken into consideration that it results from a succession of physical and chemical processes, and that there is not necessarily a correlation between the size distribution of solid particles and their mineralogical composition, as occurs in soils.
For the direct shear test, a square cross-section metal mold with sides of 60 mm and height equal to approximately 25 mm was used. Iron ore tailings were molded directly into the metal mold (Figure 1), the amount of material was calculated according to the mold volume.

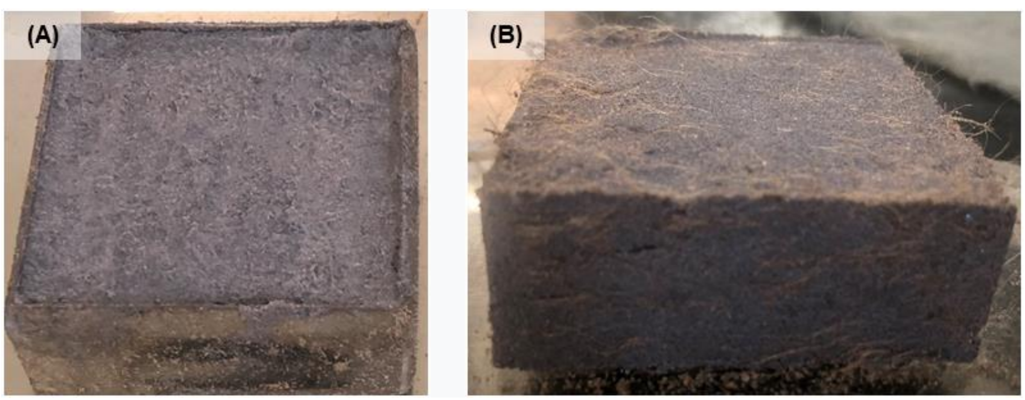

Figure 1. Iron mine tailings. (A) Iron mine tailings in the metallic mold; (B) Iron mine tailings with polymer and fibers

The application of the polymer in the tailings for all tests performed was the same. A solution containing 25% polymer and 75% water (1:4) by volume, following the manufacturer's use, after the solution became homogeneous, was mixed with the tailings and the specimens molded.
The polypropylene fibers were applied in the proportion of 0.5% in relation to the dry weight of the sample, value chosen according to studies carried out in previous researches. The sample preparation procedure consisted of first shredding the fibers loose, adding them to the tailings in a container and finally mixing the polymer solution (Figure 2).

Figure 2. (A) Materials used iron mine tailings, fiber and polymer; (B) iron mine tailings and fiber shredded; (C) iron mine tailings, fiber and polymer mixed; (D) molded specimen.

For the tests, the specimens were molded with near-optimum moisture content and maximum dry specific weight, verified by a Proctor Normal energy compaction test for the pure samples and with polymers and fibers, both in the densification step and in the shear stage and the tests were done in unsaturated condition.
The 14 days cure at room temperature, approximately 26º C, so that the mechanical behavior of the tailings and the influence of the additives could be analyzed.
The mechanical characterization of the studied material was performed by conventional direct shear tests, following the ASTM D3080 (2004) standard, in non-reinforced and reinforced samples. In both the thickening and shear stages, the specimens were maintained with moisture content close to the optimum moisture content of the compaction. The samples were thickened for the time required for 100% of the primary thickening to occur, and initial normal thickening stresses of 50 kPa, 100 kPa, 200 kPa and 400 kPa were applied to construct the Mohr-Coulomb envelope.
Based on the densification curves, it was possible to define the maximum shear velocity of the specimens. For the reinforced and unreinforced iron ore tailings, a shear velocity of 0.5 mm / min was adopted.
The confining stresses were the same employed in the densification step. The test procedure consisted of forcing the shear of the sample in a horizontal plane, recording the horizontal displacement, the vertical displacement and the applied shear load. The maximum horizontal displacement tested was 08 mm.

3. RESULTS AND DISCUSSION

The specific mass of mining tailings is generally higher than for most natural soils, because in the tailings there is a concentration of oxides whose specific mass is higher than that of the dominant minerals in natural soils such as quartz and kaolinite. Iron particles have a specific grain weight of approximately 5.25 g /cm³, while quartz grains are characterized by having a specific weight of around 2.65 g/cm³. Iron mine tailings, according to the x-ray diffraction test, are basically composed of quartz, hematite and other minerals in smaller proportions. Sotomayor (2018) performed the grain density test on the iron ore tailings studied, obtaining a value of 2.89. Through the Unified Soil Classification System (SUCS), iron ore tailings are classified as silty sand (SM). Through the liquidity and plasticity limit test, it was found that the iron ore tailings showed no plasticity.
The Proctor test performed at normal energy, using the usual procedure with water and the polymer solution, obtained a maximum dry weight of 1.79 g /cm³ and an optimal humidity of 14.08 % for the usual procedure and 1.83 g/cm³ and optimum humidity 12.23%.

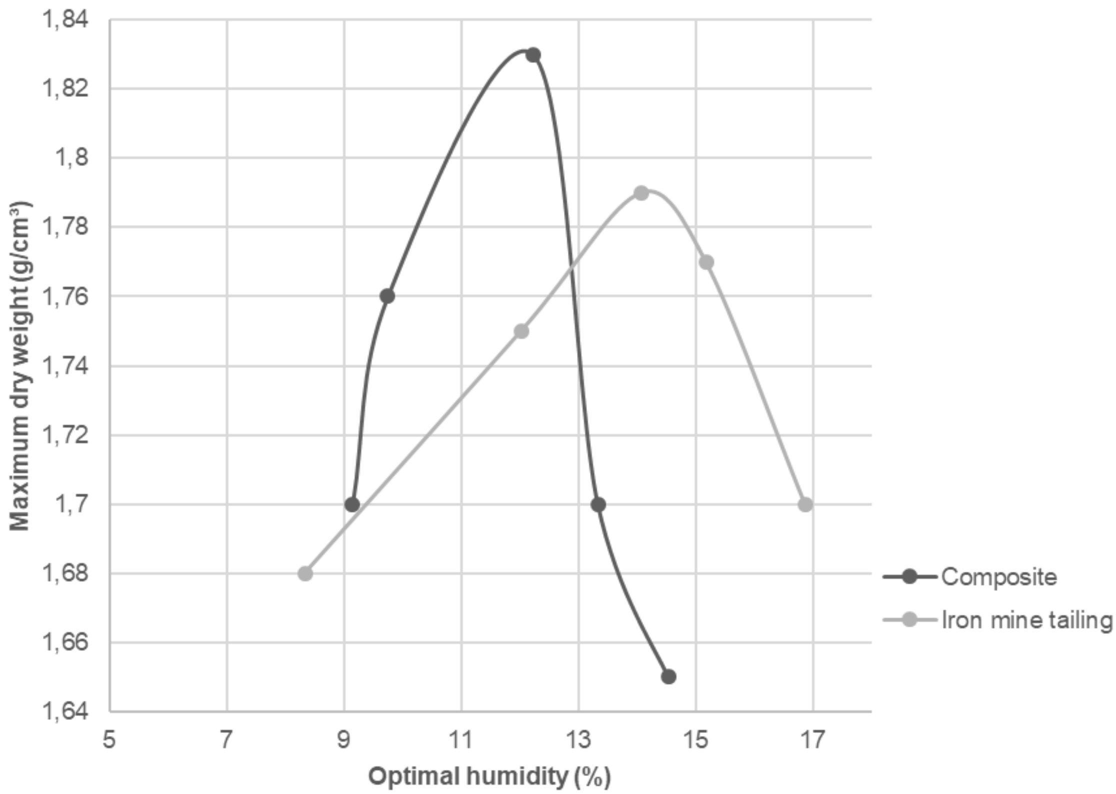

Figure 3. Proctor Normal compression curves

Synthetic polypropylene fibers were chosen to reinforce the mining tailings for their alkali and acid attack resistance. Given the tests to be performed, 24 mm long fibers were chosen, as shown in Figure 4, as they should be shorter than the diameter of the sample, to ensure a good distribution of the fibers.

Figure 4. Polypropylene fibers.

Shear tests were performed to describe the behavior of polymer-enhanced and fiber-reinforced mining tailings.
In Figure 4 can see the graph with comparative stress displacement regarding the behavior of materials when subjected to different confinement stresses.
It can be noted that after insertion of the polymer and polypropylene fibers, the curves showed an increasing behavior in relation to the resistance of the samples without additives, with no resistance drop. As the confinement stress increased, the strength of the composites increased. Samples without polymer and fiber insertion after shear, showed a decrease of post-peak strength and showed a residual behavior, being more accentuated with increase of the confinement stress.
The shear stresses considered for the construction of the resistance shells were determined for a horizontal displacement equal to 7 mm. The Figure 5 shows shear stress wraps vs. normal stress used to calculate the strength parameters of the direct shear, friction angle and cohesive intercept.

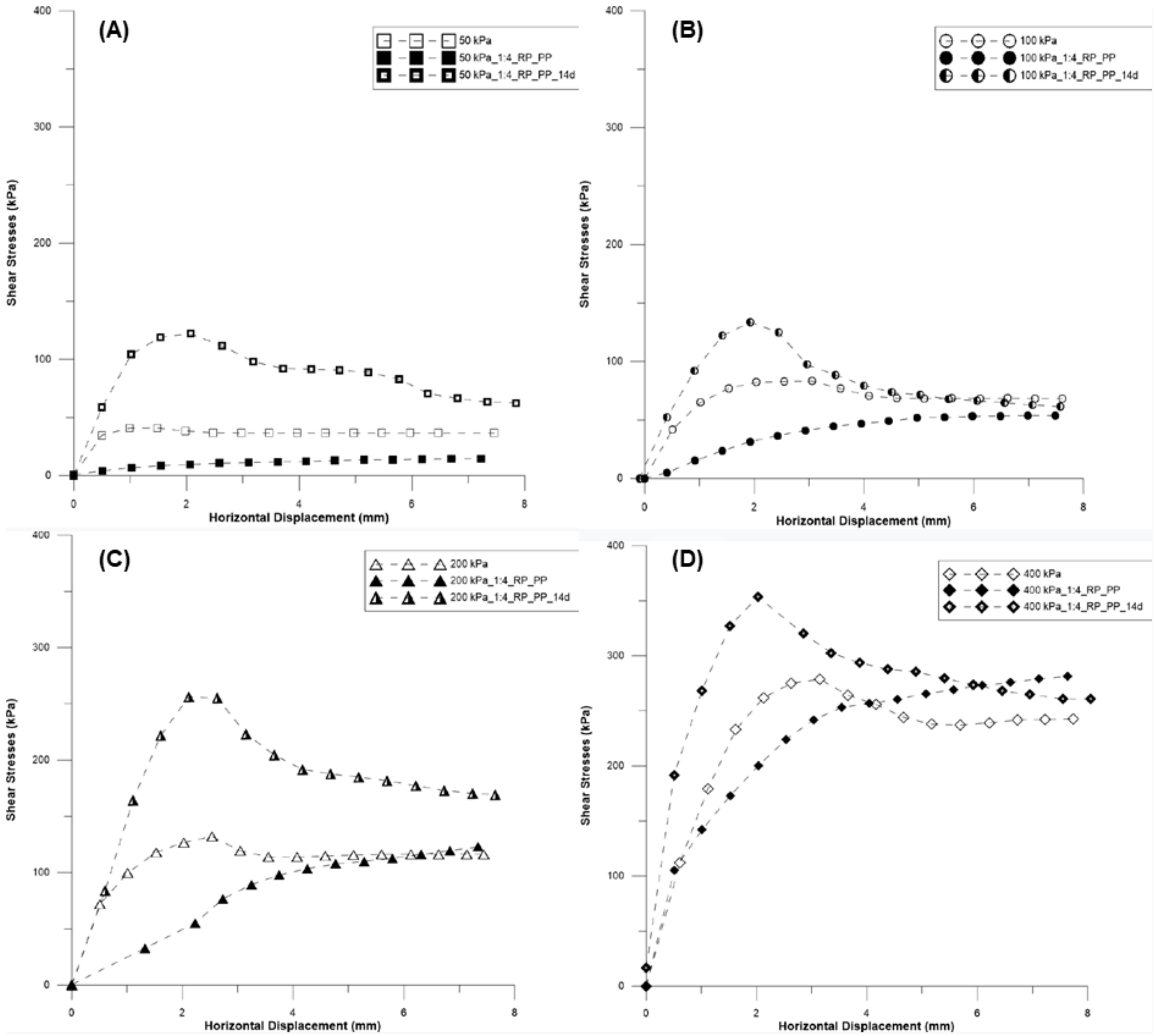

Figure 5. Relationship between shear stress and horizontal displacement from direct shear tests. (A) Confinement stress 50 kPa; B) Confinement stress 100 kPa; C) Confinement stress 200 kPa; D) Confinement stress 400 kPa. Where: R: iron mine tailings RP: iron mine tailings polymer; 1:4: solution ratio e PP: polypropylene fibers.

As expected, polymer and fiber insertion reduced the cohesion value. This is attributed to the fact that by adding the polymer solution, the composite becomes pasty. Adding to the addition of the fibers there is a greater lubrication between the elements, thus the tensile strength of the fibers that intersect the shear surface and around those of the wet grains, thus reducing the cohesive intercept. With the test with the dry and hard material there will be an increase in the effective friction angle and cohesive intercept due to water outlet and chemical reactions between substrate, polymer and fibers. The samples submitted to 14-day curing with polymer and fiber insertion, it can be observed that after the curing time there was a greater increase in the shear strength of the composite.
The Mohr failure line used to calculate the strength parameters of conventional direct shear tests (Figure 6).

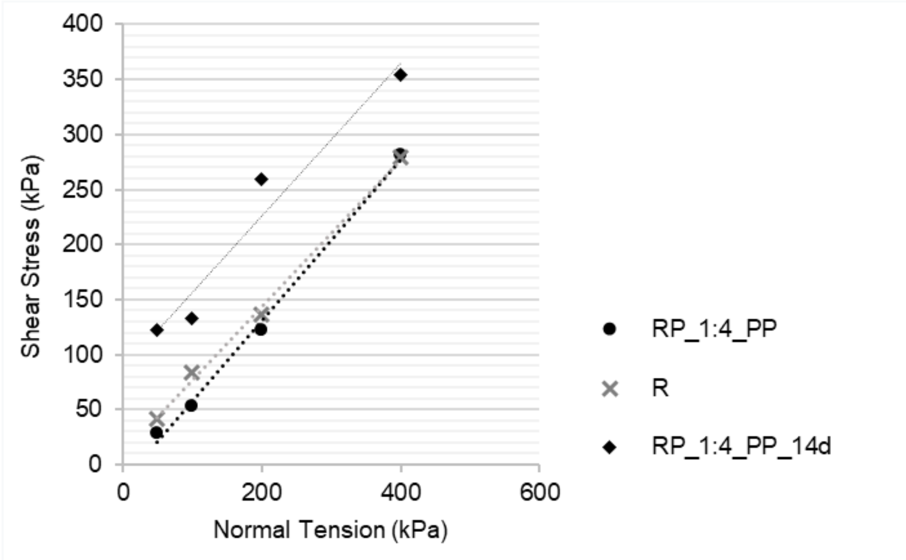

Figure 6. Relationship between shear stress and normal stress from direct shear test.

The Table 2 shows the strength parameters obtained by the direct shear. test of the iron ore tailings samples with and without polymer and fiber insertion.

Table 2. Resistance parameters table for iron.

	Friction Angle (º)	Cohesion (kPa)
R	33.7	9.4
R_1:4_PP	36.2	0
R_1:4_14d_PP	34.8	86.9

An increase in the value of the effective friction angle of the composite was observed, showing that the insertion of the fibers and polymer were positive in this resistance parameter. The curing time showed an increase in resistance parameters.

The Figure 7 through the use of a microscope with an increase of 10x, shows the arrangement of the iron grains and the new arrangement after the insertion of the polymer solution and polypropylene fibers. The polymer acts as a stabilizer, stiffening the grains and the fibers occupy the spaces between the grains, acting as reinforcement.

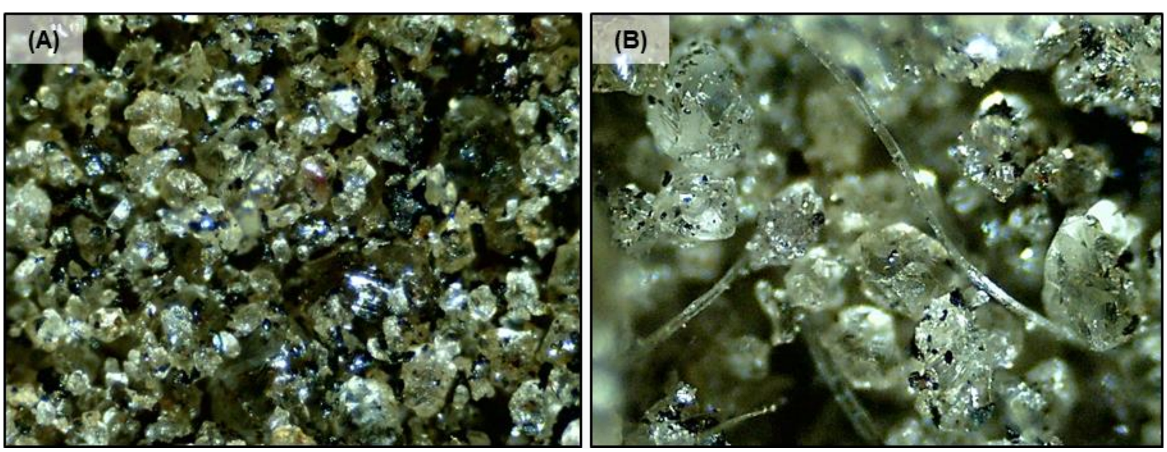

Figure 7. Microscopic image of iron mine tailings. (A) iron mine tailings; (B) iron mine tailings with polymer solution and polypropylene fibers.

4. CONCLUSION

The results obtained in the direct shear tests show that the polymer application and the polypropylene fiber insertion are advantageous improving the iron ore tailings strength. The polymer acted as a stabilizer and the fiber as reinforcement.
It was found that in pure samples without additive, the higher the confinement stress, the greater decrease in the post peak stage.
Even though there was a reduction in the cohesive intercept value, the effective friction angle increased showing that there was an improvement in the iron ore tailings resistance parameter.
With the obtained results, we concluded that the addition of polymer and polypropylene fibers proved to be advantageous and can be used to improve tailings strength parameters.
The curing time showed an increase in effective friction angle increased.

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