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Use of Quartz Mining Waste from Gouveia-MG-Brazil for Reinforcement of Subgrade and Subbase Used in Paving Layers

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Abstract. Considered a waste material by mining in Gouveia-MG-Brazil, the fine residue of quartz extraction is of great interest when applied to the soil, since it's expected to increase its resistive behavior. This research presents a study on the resistance variation of silt soils of the Gouveia-MG region, mixed with 5, 10, 15 and 25% of fine residues, for use in paving layers (sub-grade reinforcement). The residue studied in this research is a very fine material, generated in the extraction of quartz by a mining company. It was analyzed using Scanning Electron Microscopy with X-Ray Fluorescence Spectrometry, X-ray Diffraction and particle size distribution. For the analysis of the resistance of the incorporation of the fine material to the soil, the California Bearing Ratio test (CBR) was used. The results of the chemical characterization of the residue showed predominantly oxygen and aluminum, derived from phyllite, which was predicted for the quartz mines of that region considering the covering soil present in the mines. The soil was characterized as pink sandy silt. Mixtures of 5, 10, 15 and 25% of natural soil and residue were tested. Although the characterization results were consistent, the use of untreated residue decreased the resistance of the natural soil, with decreasing resistances with increased incorporation of the residue.. Due to this, the residue was washed in a # 200 sieve, reducing to almost zero the initial percentage of fines and again incorporated into the soil. The incorporation of the residue will not contaminate the soil. It also increases the puncture resistance when mixed soil contains more than 25% of residue, provided the mining company implements a treatment by sieving and washing the residue before the mixing with soil.

Keywords. Mining waste, soil reinforcement, paving.

1. Introduction

This research serves the need to reduce the environmental liabilities of a mining company located in the city of Gouveia-MG-Brazil by adding value to by-products of quartz extraction.

The mining company focuses on the exploration and storage of quartz in an area of 108,400,000 m^3. Extracted quartz is mainly used as a by-product in blast furnaces for

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the production of aluminum alloys, serving the internal and external market of the state of Minas Gerais, Brazil. In addition, part of the remaining quartz is sold in the form of gravel in different sizes for use in asphalt, road construction, and concrete plants, as well as in civil construction.

The fine residue produced by this mining has no economic value and is currently stored in piles within the mining area. Due to this, it is considered waste material and an environmental liability. In order to generate value from the fine residue, this research aims to use it as a soil reinforcement for paving in the region.

In general, the silt-clayey soil of Gouveia-MG-Brazil has low resistance to puncture, making it necessary to reinforce the sub-grade layer for highway paving, usually by using a mixture of natural soil with gravel.

The methodology of soil stabilization is a thousand-year old activity. Studies show that one of the first man-made ways to stabilize soils in paving was using mixtures of sand and clays, aiming to improve the roads used for transportation [1].

Soil stabilization can be accomplished through several techniques, divided basically into two groups. The first group uses mechanical means such as correction of particle size distribution by adding or subtracting certain amounts of the constituent fractions; the second uses chemical means such as organic or inorganic additives, including bituminous materials, resins, lime, cement and others [2].

In the specific case of this research, the stabilization of the soil will be done with the inclusion of the very fine material produced after a series of steps of the quartz extraction in the mining process. Mixtures with percentages of 5, 10, 15 and 25% of washed residue were tested in a common type of soil found in the region, which is usually used for the sub-grade layer of local highways.

Chemical and mineralogical tests were performed for the characterization of the fine mining waste. Soil characterization tests and California Bearing Ratio tests (CBR) were also conducted to obtain the resistance and expansion of the natural soil and the mixtures.

2. Materials

Two type of materials were used in this research: the natural soil (silt) and the quartz residue (mining waste).

The city of Gouveia-MG-Brazil is located in a geological area with predominant silty-clayey sediments. This soil has a high concentration of clay derived from the original rock formations found in the region. The soil used in this research was collected from the rural region of Gouveia-MG-Brazil and is already used in sub-grades and reinforcement of sub-grades in local highways.

The residue used in the research is a fine material, predominantly formed by quartz and with some percentage of phyllite, due to the geology of the exploration area. It was donated by the mining company to CEFET-MG with the purpose of finding an application that will add some economic value to it, thus reducing the volume of this material that is currently considered an environmental liability.

3. Method

Laboratory tests were performed to characterize the soil and the residue used in this research.

3.1. Mineralogical Characterization Tests

Mineralogical tests were conducted to analyze the fine residue.

They were performed by scanning electron microscopy (SEM) using Hitachi equipment with an energy dispersive X-ray spectrometer (SEM-EDS) and a SSX-550 Shimadzu that allows obtaining images by scanning the surface with a focused beam of electrons and the percentage of each element evidenced in the samples [3].

In addition, x-ray diffraction (XRD) tests using XDR-7000 Shimadzu equipment were done on samples of quartz and phyllite ground in a planetary ball mill equipment, with the purpose of defining the minerals in the samples.

3.2. Soil and Mixtures Characterization Tests

Using the results of the characterization tests, it is possible to find the parameters that identify the type of soil being used and its behavior. All the tests were performed following the recommendations of DNIT (Brazilian Department of National Transportation Infrastructure) [4][5].

In this research, the tests performed were: water content (natural and airdry) [6], particle size distribution [7], dry density [8], Atterberg limits (liquid [9] and plastic limits [10]), Proctor compaction with standard energy [11].

The California Bearing Ratio (CBR) test consists of determining the relationship between the pressure required to produce a piston penetration in a soil test body and the pressure required to produce the same penetration into a standard granulometric stabilized gravel mix. This ratio is expressed a percentage. In addition, the test predicts that soil expansion is measured for 96 hours. The result of this test allows the study of the soil for its application in paving. The test was performed according to DNIT procedure test method [12] and it was used to assess the variation in the puncture resistance and expansion of the natural soil and the mixtures.

3.3. Dosages

The residue used in this research is a material resulting from quartz grinding and washing. It contains fine particles of phyllite, the cover layer of the quartz vein in the mining area, in undisturbed areas of rock.

In the first phase of this research, the residue was used in the form it is produced in the mine. In analyzing the test results, it was noted that the incorporation of the fine residue in the soil decreased the puncture resistance -CBR- and increased the expansion. It is believed that the fine phyllite particles were responsible for this behavior. Therefore, it was decided to wash the residue in the sieve #200 (75μm) to remove the fine phyllite particles and only then incorporate the residue in the soil.

The study presented here is an initial phase of a bigger research project that aims to define the optimum soil-residue dosage. In this study, mixtures with 5, 10, 15 and 25% of residue incorporated to the soil were tested.

4. Results and Discussions

4.1. Mineralogical Tests

In this research, five crystals samples of clear quartz and of quartz with a little oxidation were used. Both were tested without polishing and without metallic coatings, as proved not necessary for this type of mineral [4].

Figures 1 and 2 show the results of the SEM tests. It is possible to see the striations that are typical of this material. Figure 3 shows the result of SEM-EDS for sample 2, which was representative for all samples. It demonstrates the presence of K, Si, Al, Fe, C and O.

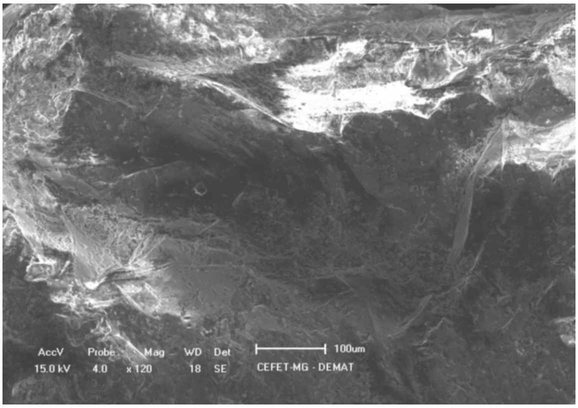

Figure 1. SEM of sample 5 – quartz with oxidation.

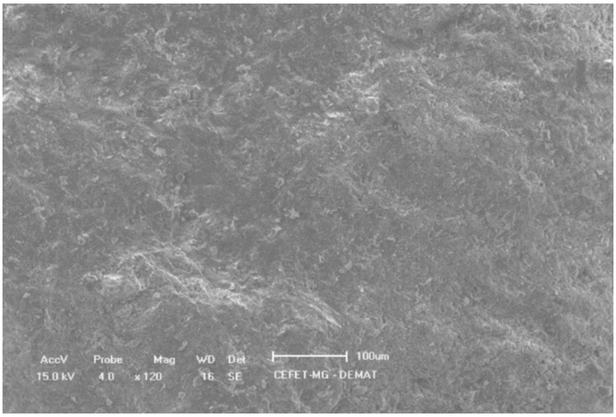

Figure 2. SEM of sample 3 – clear quartz.

The elements Al and Fe were abundant in the tested samples. Some of them could be representative from the oxide coatings on the surface of the quartz exposed in the pile, but in this region is very common to find Al and Fe as quartz structural impurities (charge balancing cations), because both elements can be substitutes for Si [4].

Table 1 shows a summary with the percentages of each element in each tested sample. It is possible to recognize the high percentage of oxygen in the samples tested.

This is justified by the quartz's tetrahedron structure and by the iron oxidation. The quartz in Gouveia generally has a dominant presence of Al and Fe, which can be seen clearly in samples 2, 4 and 5. The carbon concentration in the first two samples can be some residue of the carbon coating used in previous samples.

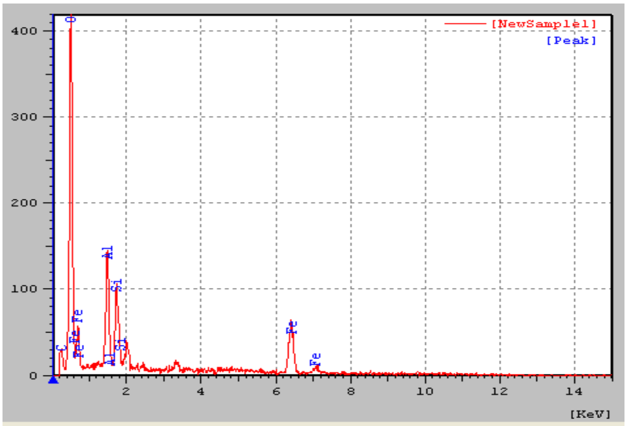

Figure 3. SEM-EDS of sample 2.

In Enokihara's research [4], quartz from hydrothermal vein of the Gouveia-MG-Brazil region showed absence of molecular H_2O and some percentage of Al. In addition, samples showed narrow peaks indicating the total absence of silanol (Si-OH).

Table 1. Summary of SEM-EDS tests' results.

Samples Elements	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
C	10.1	8.9	0.0	0.0	0.0
O	74.0	74.3	78.4	72.7	77.0
Al	5.8	2.4	2.0	5.0	6.8
Si	3.8	13.9	19.1	3.5	6.0
Fe	6.3	0.0	0.0	17.9	9.4
K	0.0	0.5	0.4	0.9	0.7

This result was confirmed with x-ray diffraction (XRD) tests, where it was identified that the samples are really quartz, as shown in Figure 4. It is important to notice that diffraction detects crystalline phase peaks with contents of 1 or 2% of the total amount.

Table 2. Summary of results – Soil Characterization.

Sample	Hygroscopic water content	Liquid Limit	Plastic Limit	Plasticity Index
A	0.54%	38.5%	24.5%	14.0%

4.2. Soil Characterization

The soil used in this research is a pink sandy-silt, well graded. Tables 2 and 3 show the summary of the laboratory characterizations test results of the soil and the mixtures. The nomenclature used was: Natural Soil (A), Soil + 5% of residue (B), Soil + 10% of residue (C), Soil + 15% of residue (D), Soil + 25% of residue (E).

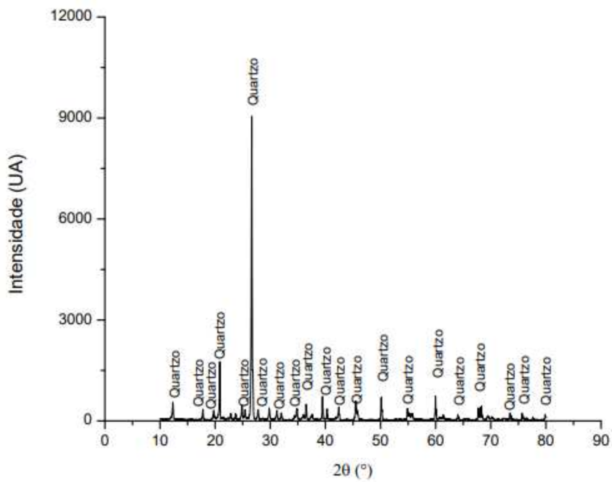

Figure 4. XRD results.

Table 3. Summary of results – Soil Characterization.

Characteristics	A	B	C	D	E
Dry density (g/cm³)	2.745	2.738	2.736	2.727	2.724
Gravel (>2,00 mm)	0.0%	37.6%	40.7%	54.5%	62.6%
Sand (0,06 - 2,00 mm)	9.0%	56.6%	51,4%	37.5%	29.4%
Silt (0,002 - 0,06 mm)	84.0%	4.0%	4.8%	4.8%	4.9%
Clay (<0,002 mm)	7.0%	1.8%	3.1%	3.2%	3.1%

The incorporation of residue in the soil decreases the percentage of fines and increases the percentage of gravel and sand (from the residue), which implies increasing puncture resistance and decreasing expansion.

4.3. Proctor compaction test

Table 4 shows the summary of results for each mixture. The maximum dry density increased and the optimum water content decreased with the increasing of residue in the mixtures, as expected.

Table 4. Summary of results – Compaction Test.

Compaction test	A	B	C	D	E
Maximum Dry density (g/cm³)	1.542	1.644	1.627	1.696	1.707
Optimum water content (%)	23.3	21.8	20.9	19.2	17.3

Table 5. Summary of results – CBR Test.

CBR test	A	B	C	D	E
Puncture resistance - CBR (%)	2.626	1.337	1.259	2.945	3.010
Expansion (%)	4.880	5.042	6.070	5.109	2.073

4.4. CBR and expansion

Figure 5 shows the curves obtained in CBR puncture test and Figure 6 shows the expansion curves. Table 5 presents a summary of the results in the optimum water content. All tests were performed according to the DNIT Brazilian Standards, allowing them to be reproduced at any time with the same procedure.

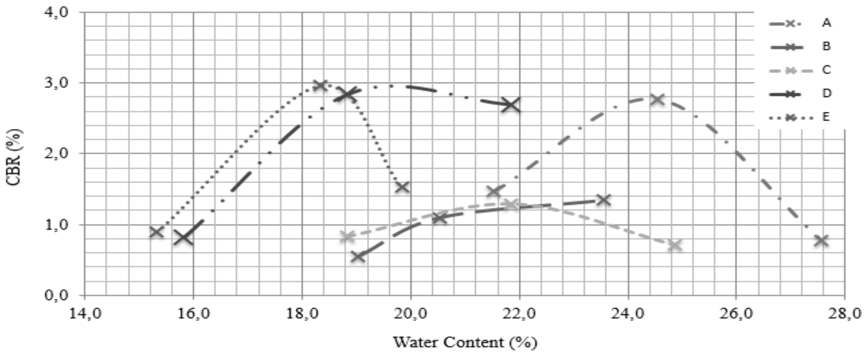

Figure 5. CBR curves.

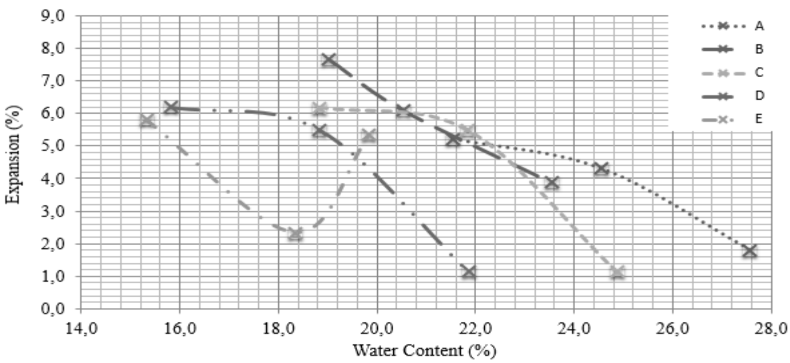

Figure 6. Expansion curves.

The results show that the addition of residue in the soil does not necessarily improve its resistance, as it can be seen in mixtures B and C. However, the increasing of CBR in mixtures D and E already allow them to be applied as sub-grade reinforcement (>2%). It is also possible to notice that the expansion in the material are still high for this application (>1%).

If the expansion is too high in the sub-grade soil, it can develop bigger settlements in the road. For long-term performance it is recommended soils with less than 1% expansion to avoid this problem. Considering the tropical soils existing in South America, it is hard to find a soil that has this property. Because of that, researches have been studying different mixtures [2] [5], different approaches to road design, such as deformation analysis [6], and using more specific tests (e.g. static and dynamic triaxial tests) [7] [8].

This research is an initial study that aims to perform more tests in different mixtures to find what is the best soil-residue dosage using the DNIT method and to perform shear tests and triaxial tests to assess the best dosage using the deformation analysis.

5. Conclusion

The fine residue used in this research is produced by a quartz mine located in Gouveia-MG-Brazil. It has no economic value and is stored in piles inside the mining area as waste material and an environmental liability. The main purpose of this research is to study one possibility to create commercial value for this residue using it as a soil reinforcement for paving.

Through the mineralogical tests, it was proved that this residue is inert and formed basically by quartz with Al and Fe. The soil used in this research is a pink sandy-silt, very common in Gouveia-MG region. The compaction tests showed that increasing the percentage of residue decreases the optimum water content and increases the maximum dry density.

Despite the characterization test results being consistent, the CBR result showed that the mix of soil and residue was only effective for 15% and 25%, which allows its application as a sub-grade reinforcement (CBR>2%). It is important to highlight that the expansions obtained are still high (>1%).

This study is the initial phase of a research where the main purpose is to define the optimum dosage soil-residue, testing different mixtures and analyzing their application as sub-grade reinforcement and sub-base of highways.

The results here shown indicate that the usage of the fine residue from the quartz mining is a possible alternative to improve physical and mechanical properties of silty soils. In addition, it will decrease the mining's environmental liability and it will allow the mining company eventually to explore the area below the residue pile.

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