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Granitic Mining Waste Feasibility for Liner Material Production

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Abstract - This work aims to characterize geotechnically and mechanically a granitic mine waste (MW), a clayey soil, and two mixtures of M:soil with 50% and 25% of (dry mass), looking to evaluate its feasibility for liner material production. Samples of MW, soil, M:soil(50:50%) M:soil(25:75%) were analysed in terms of specific gravity (G_S), coarse and fine portions granulometry distributions, Atterberg limits (W_L and W_P), Normal Proctor compaction parameters (w_{opt} and $\rho_{d,opt}$), oedometer compressibility test, consolidated undrained (CU) triaxial compression and hydraulic conductivity (k). MW showed finer granulometry, and higher plasticity than the soil, possibly showing filling properties for the mixtures, lower G_S and $\rho_{d,opt}$ indicating weight-reduction for a new liner material development. Furthermore, k values can reach the requirement for liner application of a minimum of 10^{-9} m/s, although it needs more investigation on leachability capacity, cation exchange capacity and chemical compatibility in case addition of chemicals are needed for improving mixtures properties for liner material.

***Keywords*:** mining waste – granite waste – geotechnical characterization– liner production – soil reinforcement – soil incorporation

1. Introduction

Mining tailings are generated from crushed rocks and the process of extracting the desired product from them by a mine processing plant, physic-chemical, mechanical, and hydraulic processes are used to extract the ore and it produces waste, usually as sludges called mining waste (MW). The characteristics of the tailings are in accordance with the extracted ore, but they can also undergo changes due to the chemical processes applied. The hydraulic conductivity of mine tailings has been studied by itself or mixed with other components to improve performance. [1] tested mixtures of waste and waste-dominated rocks, GeoWaste, which were created through waste rock particles act as inclusions in the tailing's matrix, the hydraulic conductivity of pure tailings varied between 10^{-8} and 10^{-10} m/s, while k of GeoWaste varied between 10^{-6} and 10^{-10} m/s, the water retention behavior of GeoWaste and pure tailings was dependent on the proportion of the mixture, in which mixtures with larger tailings fractions exhibited water retention in the soil more comparable to pure tailings. [2] investigated the feasibility of using bentonite paste waste (BPW) as a barrier material, basal and cover, for mine waste containment facilities, values around 1-4 x 10^{-9} m/s were obtained in 4-8% of bentonite in BPW, when compared to the conventional compacted clay-bentonite or sand-bentonite barrier, it reduced costs in 66%.

Soils are the raw material of various civil interventions that aims to improve urban infrastructure. However, the high variability of soils, as well as their geological conditions, are complex characteristics to be studied. Clay soils, depending on mineralogy and composition, may have high cation exchange capacity (CEC) associated with high volumetric variation, high plasticity, and low compressive strength, as well as low permeability. Landfills, slopes, roads, dams, ponds, canals, and sanitary landfills are some examples of earthworks that use clay layers in their construction. However, with its wide use, and still, great demand, such natural material is increasingly scarce and more expensive. Therefore, the valorization of MW as liner material for earth works applications emerges as a sustainable solution for avoiding its accumulation in the environment and can lead to new products within the scope of the circular economy.

The main properties of an ideal hydraulic barrier for earthworks application are low hydraulic conductivity, less than 1 x 10^{-9} m/s, enough strength to support the weigh above it, deformation during service without cracking or rupture and self-healing properties, chemical compatibilit, easy application, and low-cost material [3].

Therefore, properties such as compaction, compressibility and shear strength, chemical compatibility, and hydraulic conductivity, should be evaluated for the waste, soil and different mixtures waste:soil to evaluate the feasibility as soil or classical material (e.g. bentonites or geomembranes) substitutes. However, if the properties of the mixtures waste:soil are not enough for fulfilling liner material requirements, chemical addition may be necessary for their strengthen. In this case, solubilization and leaching tests are necessary for evaluating the potential of chemical transport into the soil and waters. Solubilization is a dissolution mechanism of a given material in water, and leaching is the potential transference of organic and inorganic substances through the material.

Therefore, understanding the geotechnical characteristics of MW with soils could provide a better understanding for their application in earthworks, such as liners materials, with the additional advantages of producing added-value product in the scope of circular economy [4]. According to literature reviewed, MW are a promising candidate for soil reinforcement [5], but there are no studies on their application for liner material production.

2. Material and Methods

The soil was collected at a construction site at Castelo Branco (Portugal) and MW was from João Tomé Saraiva construction company mine industry called “Pedreira da Devesa”, which is an extractive unit of rock, granite, located in Santana de Azinha, Guarda (Portugal). Two mixtures of granitic mining waste (MW) and soil were developed based on dried masses in temperatures of 60-65°C for 24h, with the following ratios: 50:50% (50% of MW and 50% of soil); and 25:75% (25% of MW and 75% of soil), they were characterized to evaluate their geotechnical characteristics following standards in Table 1.

Compaction characteristics are important due the energy to be considered and low compaction energy procedure was carried out using Normal Proctor. Hydraulic conductivity (k) can be determined by field and/or laboratory measurements mainly utilizing distilled water. According to [6] to determine leachate effect on the permeability of a soil, the hydraulic conductivity should be obtained with $CaSO_4$ or with tap water, due their representative salt concentration, in conformity with this, tap water was used in all laboratory tests. The sampling for oedometer, triaxial, and permeability tests was obtained through compaction in its humid phase, with water content (w) = w_{opt} + 2% and the extraction was crimped from Normal Proctor cylinder.

Permeability was determined through the falling head permeameter procedure is to insert the sample into a cylinder, the permeameter, with a cross section (A) and specimen height (L), this cylinder is connected through tubes to another graduated burette with a cross section (a), with 0.1cm^3 precision and maximum 100cm^3 volume, containing distilled water to a certain level. At a certain initial moment (t_1), there was a certain hydraulic load according to the height (h_1), at another moment (t_2) there was another hydraulic load (h_2). Thus, the hydraulic conductivity (k) was calculated according [9] for permeability evaluation. The following hypotheses were evaluated: water incompressibility; water in a saturated sample (i.e., the volume of water that enters is equal to the volume that leaves, so there is no water accumulation); water viscosity, which can change according to its temperature; and if Terzaghi's equation was valid.

Table 1: Characterization standards.

Tests	**Specific Gravity**	**Granulometry Distribution**	**Atterberg Limits**	**Normal Proctor**	**Oedometer**	**CU Triaxial**	**Hydraulic Conductivity**
Parameters	G_S	Curve	PI = W_L - W_P	w_{opt} $\rho_{d,opt}$	C_c C_r C_s	c’ φ’	k
Standards or equipments	ISO 17892-2 [7]	ISO 17892-4 [8]	ISO 17892-12 [9]	BS 1377-4 [10]	ISO 17892-5 [11]	ISO 17982-9 [12]	ISO 17982-11 [13]

2. Results and Discussion

2.1. Geotechnical characterization

Granulometry distributions of the analysed material are showed in Figure 1, and geotechnical parameters are summarized in Table 2.

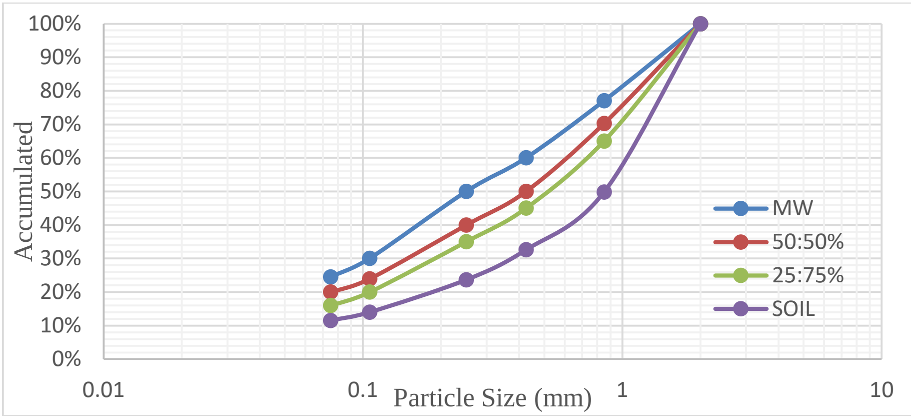

Fig. 1: Granulometry distribution.

Granulometry distribution shows that MW granulometry is a little finer than the soil, possibly indicating good filling properties, as it would decrease the number of voids within analysed mixtures, MW:Soil (50:50%) and MW:Soil (25:75%) granulometry curve were in between the MW and the soil, being finer with the increase of MW portion in the mixture.

Table 2: Geotechnical characterization results.

Material	G_S (-)	W_L (%)	W_P (%)	PI (%)	W_{opt} (%)	$\rho_{d,opt}$ (g/cm^3)	k (m/s)
SOIL	2.8	38	34	4	20	1.65	3×10^{-9}
MW	2.5	34	12	22	21	1.50	6×10^{-10}
MW:Soil (50:50%)	2.6	34	24	10	20	1.60	1×10^{-10}
MW:Soil (25:75%)	2.7	34	29	5	19	1.70	8×10^{-10}

Geotechnical parameters show that liquid limits of all material remain almost the same, between 34-38%, the plasticity change occurs principally on plastic limits, decreasing with more MW into the mixtures, consequently, there was an increase on PI (plastic index) when having more MW. For the soil, PI = 4%, 5% for (25:75%), 10% for (50:50%), and 22% for MW itself, which gives good information along workability for a liner paste development. An increasing of water content (w_{opt}) and decrease in dry density ($\rho_{d,opt}$) optimal compaction conditions were observed when MW was increased into the composites. Results suggest, however, that additional tests for mixtures as oedometer experiments and triaxial shear test for measuring of soil consolidation and compression properties.

The permeability clearly decreases with MW incorporation, that is a good behaviour when studying liner application while preventing ground and groundwater contamination, MW for itself already have very low permeability around 10^{-10} m/s, and even mixing it when the low permeability soil, k values decrease and can reach the minimum for hydraulic barriers.

Mechanical tests results are showed Table 3 and were performed only for MW, the soil, and the (50:50%) composite, looking to understand the small variance between the soil and MW, due to very similar results over oedometric and triaxial behaviour.

Oedometer tests results showed not a consistency difference for any of the studied materials, compressibility (C_c), recompression (C_r), and swelling (C_s) indexes have not chance much, C_c varied between 0.100-0.110, C_c between 0.016-0.030, and C_s among 0.015-0.020, characterizing all the samples as a low compressible material, achieving liner materials parameters. CU triaxial tests were conducted with a maximum axial strain of 23%, and the soil has low cohesion (c') of 10 kPa, and a friction angle (φ') of 25°, meanwhile, MW has no cohesion, 0 kPa, and a higher φ', reaching 30°, thus, (50:50%)

has less cohesion than the soil, and more than MW, occurring the opposite behaviour with friction angle, higher than the soil and lower than MW. These characteristics adequate the material as a possible stabilization and strengthening of soils.

For some soils, it may be necessary to add chemicals to improve the properties of the mixtures. In these cases, solubilization and leaching tests will be necessary to assess the eventual transport of chemicals to the soil and water.

In clayey soils, the MW mixture can lead to changes in the sorption properties of the soil, so it is advisable to carry out CEC tests.

Table 3: Mechanical characterization results.

Material	C_c (-)	C_r (-)	C_s (-)	c' (kPa)	φ' (°)
SOIL	0.100	0.016	0.015	10	25
MW	0.110	0.030	0.020	0	30
MW:SOIL (50:50%)	0.105	0.020	0.018	5	27

4. Conclusion

This research showed that the characterized materials had PI around 4-22%, indicating a plasticity reduction with MW incorporation, stabilizing clayey soils, but attending liners requirements. G_S around 2.5-2.7 and compaction $\rho_{d,opt,}$ lower than the soil's, showed a possible reduction in the weight of the final developed material, such as MW finer granulometry can indicate good filling properties within the soils. Compressibility indexes varied very little, and within triaxial results seems to reinforce the soil increasing friction angle, while decreasing cohesion and K values for MW, (50:50%), and (25:75%) composites are in accordance with liners requirement of 10^{-9} m/s and shall be a potential material for geological barrier utilization. Therefore, this MW can be considered a viable material to produce new liner material for earthworks application.

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