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Correction of the granulometric curve of fine soil using ash from the burning of sugarcane bagasse

Abstract

In road works, there are cases in which natural soils have inadequate characteristics for their intended use, especially clayey or fine ones, which leads to the need to find stabilization methods that allow the soil to present itself as a suitable material for its application. Thus, the ash, residue generated in the sugar and alcohol industry from the burning of sugarcane bagasse and which often does not have an adequate destination, becomes an attractive material due to its granulometry and chemical composition. Thus, the objective was to study the feasibility of correcting the granulometric curve of the fine soil from Maringá-PR with the addition of sugarcane bagasse ash, seeking to analyze the influence of this correction through granulometric analysis, particle density, limit of liquidity and plasticity, Unified Soil Classification System (USCS) and Highway Research Board Classification (HRB) and compaction curve. The results showed that the incorporation of ash in the fine soil remodeled the granulometric curve, making it similar to that of a sandy soil. According to the HRB and USCS classifications, the soil was shown as an A-7-5 soil or high compressibility silt and the mixture as an A-6 soil or clayey sand. There was also a reduction in the group index, in the limits of liquidity and plasticity, as well as in the optimal compaction moisture. Therefore, the addition of ash to the soil resulted in an increase in texture quality and plasticity. Since, for road applications, a correlation was found between the addition of ash and the increase in the quality of the mixture as a subgrade material.

Keywords: ash, granulometric stabilization, waste

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Introduction

In road works there are cases in which natural soils have characteristics that are unsuitable for their intended use. Thus, during the execution of the pavements, there is a need to replace, reinforce or stabilize this soil. Replacement or reinforcement generate high costs and environmental impacts, since they require abundant amounts of exploited natural resources, depend on the availability of materials and lack transport for the volume to be used. Stabilization, on the other hand, consists of improving the physical and mechanical properties of the natural soil through mixtures with other materials.[1]

The soil stabilization process can be obtained simply by the adequate distribution of the different portions of particle diameters, called granulometric stabilization. Thus, it is noted the importance of looking for alternative materials that offer low cost, small environmental impact and comprise the appropriate geotechnical characteristics. Allied to this, the growing generation of waste constitutes a major problem in sustainable development and an alternative to minimize it is the possible ability to incorporate this waste as raw material in the generation of new products, reducing the impact and/or environmental liability caused if these were discarded in the environment. In this context, the continuous concern with environmental preservation has encouraged the search for viable alternatives in the substitution and incorporation of natural materials in the field of paving, a sector responsible for a large part of this consumption.

The incorporation of waste in the use of alternative forms has shown satisfactory results according to the literature,[2–4] as in the case of the use of ash from sugarcane bagasse in the area of civil engineering, through additions and partial replacements of aggregates and binders, in asphalt, concrete, mortar, ceramic materials and soil.

In the stabilization of lateritic soils, the ash from the burning of sugarcane bagasse has shown good effectiveness, either in reducing the limits of liquidity and plasticity and consequent reduction in the plasticity index, or even in the reduction of optimal moisture content.[5–9]

Brazil as the world's largest sugarcane producer, with 657 millions of tons processed in the 2020/2021 harvest[10]. The energy sector derived from sugarcane is responsible for about 7% of the energy produced in Brazil and is the main source of biomass, representing 77% of the total. Together, the all the units generated 22.6 million MWh in 2020, with a forecast increase of 55% by 2030.[10]

It is estimated that 25% of the total mass of sugarcane is transformed into bagasse[11] and each ton of ground sugarcane produces 6.2 kg of ash,[12] which shows the alarming amount of waste generated annually. Most of the ashes are reused on the plantation and, although it is not a hazardous waste, it does not have the potential for fertilization.[13] The bottom ash is basically composed of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO and others.[2,4,11]

Materials

Soil

The fine soil used in this research is a lateritic soil, found at latitude 51°56'45.19"W and longitude 23°24'13.66"S, within the State University of Maringá (UEM). The material was collected manually, in the deformed form, after superficial cleaning of the terrain profile, at an average depth of between one and two meters (Figure 1). Afterwards, the sample was transported to the Laboratory of Soil Mechanics at UEM, dried at ambient temperature and in the shade, aiming to obtain its hygroscopic humidity. Then, the soil was homogenized and passed through a N°. 10 sieve (2.00 mm) (Figure 2). Finally, it was packed in a drum protected from moisture for further characterization.

Figure 1 Fine soil collection site.

Figure 2 Fine soil passed through a 2mm sieve.

Sugarcane bottom ash

The sugarcane bottom ash used comes from the Santa Terezinha Sugar Mill, located in the district of Iguatemi, in the city of Maringá-PR. The plant has two boilers, with a working temperature between 500 °C and 700 °C. The bottom ash (Figure 3) was transported to the Soil Laboratory at the State University of Maringá, dried at room temperature, until hygroscopic humidity, homogenized and passed through a Nº. 10 sieve (2 mm), in order to remove undesirable materials incorporated during storage, such as leaves and pieces bagasse with incomplete burning, resulting in the appearance shown in Figure 4. Afterwards, the ash was stored in a drum for further characterization.

Figure 3 Sugarcane ash used.

Figure 4 Sugarcane ash passed through a 2mm sieve.

Mixture

The mixture of soil and ash was carried out considering the granulometric curve of the two materials, in order to obtain the maximum possible density.

Methods

Particle density

The test to determine the particle densities of the materials was performed according to the ABNT NBR 6458:2016[14] and calculated using Equation 1, where ρ_s is the sample grain density (g/cm³), M_s is the dry sample mass (g), M_2 is the mass of the pycnometer + soil + water (g), M_3 is the mass of the pycnometer filled with water up to the reference mark, at the test temperature (g) and ρ_w is the density of the water (g/cm³).

$$\rho_s = \left(\frac{M_s}{M_s + M_3 - M_2} \right) . \rho_w \quad (1)$$

Granulometric analysis

The granulometric analysis of the soil and the ash was carried out according to ABNT NBR 7181: 2016,[15] using sieving and sedimentation.

Atterberg limits

The liquidity limit test is written by ABNT NBR 6459:2016,[16] while the plasticity limit follows ABNT NBR 7180:2016.[17] Through the results obtained, it is possible to determine the plasticity index, which is the result of the difference between the liquidity limit and the plasticity limit, and expresses the clayey character of the material.

Classification of materials

With the results of the characterization of the materials, the fine soil and the mixture were classified according to the Unified Soil Classification System (USCS)[18] and Highway Research Board Classification (HRB).

Maximum density and optimum moisture content

The methodology used for the compaction test is presented in ABNT NBR 7182: 2016,[19] in which the objective is to obtain the maximum compaction condition where the optimal moisture content and the maximum dry density are obtained. For this study, intermediate energy was used.

Results and discussion

Particle density

The particle density found for fine soil was 3.22 g/cm³ and for ash was 2.71 g/cm³, with respective moisture contents of 12.88% and 0.52%. The high value of soil density is due to iron oxides present in lateritic soils in the region. The mixture resulted in a particle density of 2.88 g/cm³ and a moisture content of 4.15%, which is a good indicator, since more stable soils have low hygroscopic humidity. Particle density, as expected, resulted in a decrease in value.

Granulometric analysis

With the results obtained in the granulometry, the granulometric curves of the soil and ash samples were traced, as well as the mixture, as shown in Figure 5.

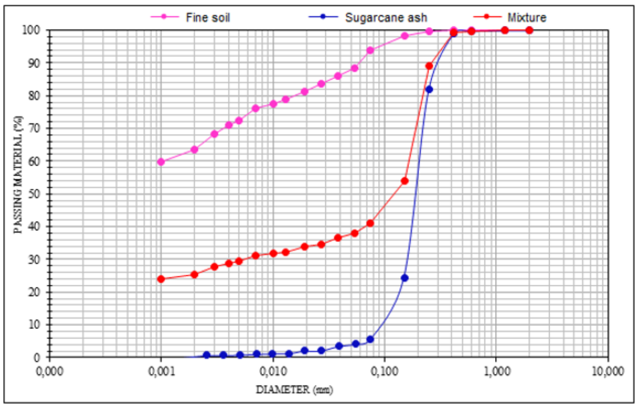

Figure 5 Granulometric curves.

In order to obtain the maximum density for the mixture and to create a granulometric curve that resembled a sandy soil, it was necessary to use 60% ash and 40% fine soil.

Atterberg limits

The Atterberg limits indicate the workability of the material and the results are shown in Table 1.

Table 1 Atterberg limits

Property	Fine soil	Mixture
Liquidity limit	58	36
Plasticity limit	42	22
Plasticity index	16	14

According to the results, it is possible to notice a considerable reduction in the values of the limits of liquidity and plasticity, as well as in the plasticity index, as observed in the literature[5,6], which indicates an improvement in the quality of the material resulting from the mixture.

Classification of materials

From the classification results, the mixture can be categorized into two classification systems, the Highway Classification System (HRB) and the Unified Soil Classification System (USCS), as shown in Table 2.

Table 2 Classification of materials

Sample	HRB	Group index	USCS
Fine soil	A-7-5	14	MH
Mixture	A-6	2.2	SC

It is observed, through Table 2, that the mixture is classified as clayey material by the HRB method, belonging to group A-6, still presenting weak behavior as a subgrade. However, the reference mixture provided a group index of 2.2, a lower value compared to the fine soil, highlighting the expectation of improved performance of the mixture when added with ash.

The mixture was classified in USCS as clayey sand (SC), presenting granular and well-graded particles, belonging to granular soils with a secondary characteristic belonging to fines, as plotted in the Casagrande plasticity chart, in Figure 6.

In general, the addition of ash to the soil resulted in an increase in texture quality and plasticity. Since, for road applications, a correlation was found between the addition of ash and the increase in the quality of the mixture as a subgrade material. Similar results were found in the literature.[9]

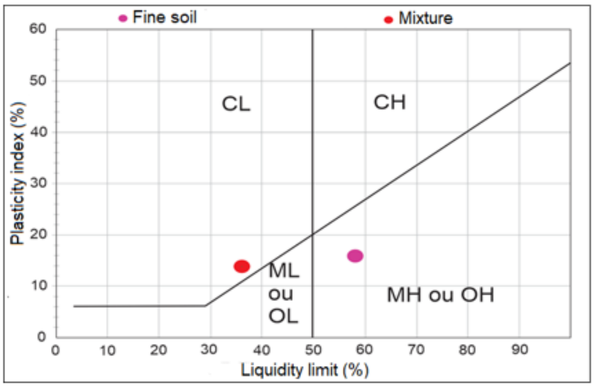

Figure 6 Unified soil classification system.

Maximum density and optimum moisture

The compaction curves to determine the maximum dry density and optimum moisture were carried out at intermediate energy for fine soil, for ash and for the mixture, and the results are shown in Figure 7.

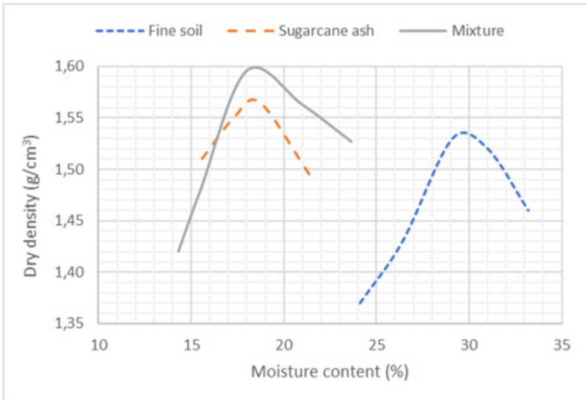

Figure 7 Compaction curves.

It is observed that the compaction of clayey soils occurs with higher moisture contents and results in lower specific masses compared to ash. In this sense, the addition of ash to the fine soil generated a granulometric curve that leads to the behavior of sandy soils, considered more efficient in paving works, corroborating the classification made in this research based on the samples and the reduction of fines content, as described in the literature.[7–9]

Regarding the dry density, the can be attributed to the filling of voids in the mixture, by adding ash to the soil, given that it tends to increase with the size of the solids.

Conclusion

The addition of ash to fine soil remodels the granulometry of the pure material. Thus, through the analysis of the granulometric curves, it can be seen that there was an increase in the sand fractions and a reduction in the clay and silt fraction content.

Still regarding the mixture and comparing it to fine soil, it was observed that there was a decrease in the liquidity and plasticity limits and the plasticity index of the material. It was also verified that, when the ash was inserted, the particle density decreased, as well as the moisture content, providing a lighter material than the fine soil, resembling a sandy soil.

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Through the Highway Classification System (HRB) and the Unified Soil Classification System, it was possible to understand that the mixture has better qualities as a subgrade layer compared to the fine soil.

In general, it was verified that the incorporation of sugarcane bagasse ash to the fine soil provided the generation of a new material with characteristics different from those of the original soil, providing better features. In this way, and supported by the presented laboratory results, it becomes evident the promising future for the use of sugarcane bottom ash as a stabilizing material in clayey soils, in addition, its low cost combined with compaction processes and appropriate final destination, encourage its use as a low-cost methodology for pavements.

For further researches on the insertion of sugarcane bagasse ash in the stabilization of lateritic soils, it is recommended to carry out tests of simple compressive strength and tensile strength to evaluate the mechanical behavior, as well as to verify the elastic response through tests to determine the resilience modulus and also to evaluate the expansion of this composite.

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Conflicts of interest

The author declared that there is no conflict of interest.

References

1. Firoozi AA, Olgun CG, Firoozi AA, et al. Fundamentals of soil stabilization. *International Journal of Geo-Engineering*. 2017.
2. Anupam AK, Kumar P, Ransinchung GDRN. Use of various agricultural and industrial waste materials in road construction. *Procedia - Social and Behavioral Sciences*. 2013;104:264–273.
3. Zainudin MZM, Khairuddin FH, Choy Peng NG, et al. Effect of sugarcane bagasse ash as filler in hot mix asphalt. *Materials Science Forum*. 2016.
4. Akshay MP, Tapase AB, Ghugal YM, et al. Investigation on the use of crumb rubber and bagasse ash in road construction. recent developments in pavement engineering. Proceedings of the 3rd GeoMEast *International* Congress and Exhibition, on Sustainable Civil Infrastructures, Egypt; 2020.
5. Muazu MA. Evaluation of plasticity and particle size distribution characteristics of bagasse ash on cement treated lateritic soil. *Leonardo Journal of Sciences*. 2007;10(1):137–152.
6. Amu OO, Ogunniyi SA, Oladeji OO. Geotechnical properties of lateritic soil stabilized with sugarcane straw ash. *American journal of Scientific and industrial Research*. 2011;2(2):323–331.
7. Yadav AK, Gaurav K, Kishor R, et al. Stabilization of alluvial soil for subgrade using rice husk ash, sugarcane bagasse ash and cow dung ash for rural roads. *International Journal of Pavement Research and Technology*. 2017;10(3):254–261.
8. Basack S, Goswami G, Khabbaz H, et al. A comparative study on soil stabilization relevant to transport infrastructure using bagasse ash and stone dust and cost effectiveness. *Civil Engineering Journal (Iran)*. 2021.
9. Ewa DE, Egbe EA, Ukpata JO, et al. Sustainable subgrade improvement using limestone dust and sugarcane bagasse ash. *Sustainable Technology and Entrepreneurship*. 2023;2(1):100028.
10. ÚNICA - Sugarcane industry union, 2021.
11. Frías M, Villar E, Savastano H. Brazilian sugar cane bagasse ashes from the cogeneration industry as active pozzolans for cement manufacture. *Cement and Concrete Composites*. 2011;33(4):490.
12. FIESP/CIESP. Expansion of energy supply through biomass. FIESP/CIESP; 2001.
13. Lima SA, Varum H, Sales A, et al. Analysis of the mechanical properties of compressed earth block masonry using the sugarcane bagasse ash. *Construction and Building Materials*. 2012;35:829–837.
14. Brazilian association of technical standards. ABNT NBR 6458: Gravel grains retained in the 4.8mm aperture sieve - Determination of apparent density and water absorption. Rio de Janeiro; 2016.
15. Brazilian association of technical standards. ABNT NBR 7181: Soil - Particle size analysis. Rio de Janeiro; 2016.
16. Brazilian association of technical standards. ABNT NBR 6459: Soil - Determination of the liquidity limit. Rio de Janeiro; 2016
17. Brazilian association of technical standards. ABNT NBR 7180: Soil - Determination of plasticity limit. Rio de Janeiro; 2016.
18. American society for testing and materials. Standard practice for classification of soils for engineering purposes (Unified Soil Classification System). ASTM D2487-17. PA, USA: West Conshohocken.
19. Brazilian association of technical standards. ABNT NBR 7182: Soil - Compaction test. Rio de Janeiro; 2016.