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Estabilização De Solo Com Rejeito Da Produção De Celulose

Soil Stabilization with Cellulose Production Residue

Estabilización de suelo con residuos de la producción de celulosa

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RESUMO

O presente artigo trata sobre o uso de lama de cal no solo com a finalidade de aplicação na pavimentação asfáltica com função de estabilizante de solo, tendo como objetivo estudar a estabilização física e mecânica dessa mistura, com teores de lama-cal em 10%, 20%, 30%, 40% e 50%. Foram analisadas cinco amostras para mini-Proctor de cada dosagem, realizando ensaios de caracterização, expansão e resistência à penetração, para obter a umidade ótima e o mini-CBR. Com base nos resultados do mini-CBR, foram conduzidos novamente os ensaios para o CBR padrão, utilizando duas amostras de cada teor de lama-cal na umidade ótima determinada em corpos-de-prova miniatura. A lama-cal é um resíduo do processo de industrialização do papel e celulose, utilizado como corretivo da acidez dos solos e agente aglomerante, responsável por reduzir a expansão e contração térmica do solo, resistindo às variações climáticas. No entanto, os estudos para a utilização dessa mistura para estabilização de solos são escassos, mas viáveis, o que contribui com a preservação do meio ambiente ao reduzir a quantidade de resíduos descartados em aterros. Com os resultados obtidos do mini-CBR e CBR padrão, é possível aplicar a lama-cal na pavimentação asfáltica na camada da sub-base e reforço do subleito, uma vez que todos os resultados estão em conformidade com as normativas atuais.

PALAVRAS-CHAVE: Lama-cal. Pavimentação Asfáltica. Estabilização de Solo.

ABSTRACT

The present article addresses the use of lime slurry in soil with the purpose of application in asphalt pavement as a soil stabilizer. The objective is to study the physical and mechanical stabilization of this mixture with lime slurry contents of 10%, 20%, 30%, 40%, and 50%. Five samples for mini-Proctor tests will be analysed for each dosage to determine characteristics, expansion, and penetration resistance, to obtain the optimum moisture content and mini-CBR values. Using the mini-CBR results, standard CBR tests were conducted again with two samples for each lime slurry content at the determined optimum moisture content in miniature specimens. Lime slurry is a residue from the paper and pulp industrialization process, used as a soil acidity corrector and binding agent, in addition to reducing soil thermal expansion and contraction while withstanding climatic variations. However, studies on its use for soil stabilization are scarce but feasible, contributing to environmental preservation by reducing the amount of waste deposited in landfills. Based on the results obtained from mini-CBR and standard CBR tests, it is possible to apply lime slurry in asphalt pavement in the sub-base and subgrade reinforcement layers, as all results comply with current regulations.

KEYWORDS: *Lime Slurry. Asphalt Pavement. Soil Stabilization.*

RESUMEN

El presente artículo aborda el uso de lodo de cal en el suelo con el propósito de su aplicación en pavimentos asfálticos como estabilizador de suelo. El objetivo es estudiar la estabilización física y mecánica de esta mezcla con contenidos de lodo de cal del 10%, 20%, 30%, 40% y 50%. Se analizarán cinco muestras para pruebas mini-Proctor en cada dosificación para determinar características, expansión y resistencia a la penetración, con el fin de obtener el contenido óptimo de humedad y valores de mini-CBR. Utilizando los resultados del mini-CBR, se realizaron nuevamente pruebas CBR estándar con dos muestras para cada contenido de lodo de cal al contenido óptimo de humedad determinado en especímenes en miniatura. El lodo de cal es un residuo del proceso de industrialización del papel y la pulpa, utilizado como corrector de la acidez del suelo y agente aglutinante, además de reducir la expansión térmica y contracción del suelo, resistiendo a las variaciones climáticas. Sin embargo, los estudios sobre su uso en la estabilización del suelo son escasos pero factibles, contribuyendo a la preservación del medio ambiente al reducir la cantidad de residuos depositados en vertederos. Basándonos en los resultados obtenidos de las pruebas mini-CBR y CBR estándar, es posible aplicar el lodo de cal en pavimentos asfálticos en las capas de sub-base y refuerzo del sublecho, ya que todos los resultados cumplen con las regulaciones actuales.

PALABRAS CLAVE: *Lodo de Cal. Pavimento Asfáltico. Estabilización de Suelo.*

1 INTRODUCTION

A material commonly used in road construction is soil, due to its availability and low cost. However, not all types of soil are suitable for paving purposes. The use of soil for such a function requires mechanical or chemical stabilization, with improvements to make its use viable. The search for elements that enhance the properties of soils, combined with the need to minimize environmental impact, sparks interest in researching ways to use them in mixtures.

Road paving plays a crucial role in transport infrastructure by providing vital connections for trade, mobility, and economic development. Increasingly, the search for sustainable and environmentally friendly solutions is highlighted. A promising approach to soil stabilization is the use of cellulose waste, derived from the paper and cellulose industry.

Cellulose waste is a fiber-rich byproduct obtained from wood processing. Generally, these materials are discarded in landfills, generating significant impacts, or are used for secondary purposes of low added value. According to the Brazilian Tree Industry (IBÁ, 2020), Brazil is the second largest producer of cellulose in the world, with an approximate production of 21 million tons per year, and the largest exporter of cellulose in the world, with an approximate export of 15.6 million tons per year.

Lime sludge, also known as lime-mud, is a residue from the industrialization process of paper and cellulose, regularly used in cultivation areas to correct soil acidity. It has a white color and is predominantly composed of calcium carbonate ($CaCO_3$) (IBÁ, 2020). However, few studies point to the viability of using lime-mud for soil stabilization for road paving.

Soil stabilization with cellulose waste offers several advantages. Among them is the action of these materials as binding agents, increasing the cohesion and resistance of the soil. In addition, it contributes to reducing the expansion and thermal contraction of the soil, minimizing the effects of climatic variations on the structure of the roads. Its use as a soil stabilizer reduces the need for extraction of natural resources, in addition to having low embodied energy compared to conventional materials.

However, lime-mud can release volatile organic compounds or leach harmful chemical substances into the environment. Investing in research to develop more efficient and effective technologies ensures better adaptation to the specific conditions of the roads and meets safety and performance requirements. Its use should be evaluated according to the type of soil used, which varies according to the region of each project. The adoption of this sustainable approach has the potential to benefit both the paper and cellulose industry and the infrastructure sector.

Until now, there is a scarcity of studies and research related to soil stabilization with cellulose waste for road paving. Therefore, the justification for approaching this topic lies in the need to seek innovative and sustainable solutions for soil stabilization, aiming to contribute to the preservation of the environment, the reduction of discarded waste, and the promotion of sustainable development in the context of road paving.

2 OBJECTIVE

With the aim of minimizing the disposal of tons of waste from cellulose production in nature and, consequently, mitigating environmental impacts, some studies are underway to propose different alternatives for the use of these materials. It is necessary to analyze the results obtained from lime-mud in the soil to assess its economic viability and establish clear guidelines for its use, in order to ensure the safety, efficiency, and sustainability of roads paved with soils stabilized with cellulose waste.

a) General Objective

The general objective of this research is to analyze the physical and mechanical stabilization of soil through the addition of lime-mud, aiming at its application in a layer of road pavements.

b) Specific Objectives

As specific objectives, the following stand out: analyze the mixture with contents of 10%, 20%, 30%, 40%, and 50% of cellulose waste in the soil, producing 5 samples of each content; investigate the expansion of the soil and its resistance to penetration to determine the optimum moisture content and evaluate the possible applicability of the soil with lime-mud at each content stipulated by the mini California Bearing Ratio (CBR).

With the optimum moisture of each content, perform the same tests planned for the standard size CBR, with the aim of verifying the results obtained with the mini-CBR.

3 METHODOLOGY

3.1 Materials and Equipament

The soil used as a reference in this work comes from a deposit located in Ilha Solteira-SP, named Torre. The lime-mud results from the production of cellulose, whose industry is installed in the same region. The stabilized mixtures were evaluated in controlled dosages of 10%, 20%, 30%, 40%, and 50% of lime-mud in the soil, without substitution.

The tests were carried out at the Civil Engineering Laboratory - FEIS/UNESP of Ilha Solteira and the main equipment used were:

- Sieves #10 and #30;
- Oven;
- Digital precision scale;
- Metallic cylindrical mold;
- Compactor with rammer;
- Extensometer;
- Penetration press.

3.2 Methods

In the context of road paving, no test methods defined in technical standards with the use of lime-mud were observed. Thus, conventional tests in the area of geotechnics were adopted to determine the classification and characterization parameters of the soil and the soil-lime-mud mixtures. The data from the soil in natura are used as a reference to evaluate the contribution of the residue in the mixtures.

The soil classification test observed the method proposed by the National Department of Transport Infrastructure (DNIT, 172/2016-ME). The compaction, CBR, and soil expansion tests and the mixtures were performed on miniature equipment, according to DNIT 228/2023-ME.

The mixtures were subjected to the compaction test to determine their optimal properties: maximum dry apparent specific mass and optimal moisture content. The energy employed was that of the normal Proctor. For the CBR and expansion tests, the optimal conditions and the DNIT 254/2023-ME standard were used.

Each sample was separated into individual plastic bags, in which the respective moisture contents were added. After homogenization, the samples were stored for at least 24 hours before compaction. This was carried out on test specimens with reduced dimensions and according to the DNIT standard (DNIT 228/2023-ME) with normal energy.

The compacted samples remained immersed in water for 24 hours, as part of the test for measuring expansion. After the immersion period, the test specimens were subjected to the mini-CBR penetration test. The CBR and expansion data are regularly adopted as references to indicate the potential use of materials in paving and in pavement layers.

In a second stage, the compaction, CBR, and expansion tests were repeated, however, this time, in larger cylinders. The respective standards adopted as references were: DNIT 164/2013-ME, DNIT 172/2016-ME, and Brazilian Association of Technical Standards (ABNT) NBR 9895 (2016). For each sample, 2 (two) repetitions were carried out, with the objective of observing and correcting possible variations in the procedures and data obtained.

4 RESULTS

4.1 **Compaction (mini-Proctor), mini-CBR, and Expansion**

Table 1 summarizes the results obtained in the compaction (mini-Proctor) and mini-CBR tests on test specimens with reduced dimensions and normal Proctor energy. The sample identified as 0% indicates the soil in natura. The other samples represent the different dosages of lime-mud added to the dry soil, without substitution, $\rho_{d\ max}$ (g/cm^3) corresponds to the maximum dry apparent specific mass, while W_{ot} (%) is equivalent to the optimum moisture content.

Table 1 – Results of compaction, mini-CBR, and expansion tests.

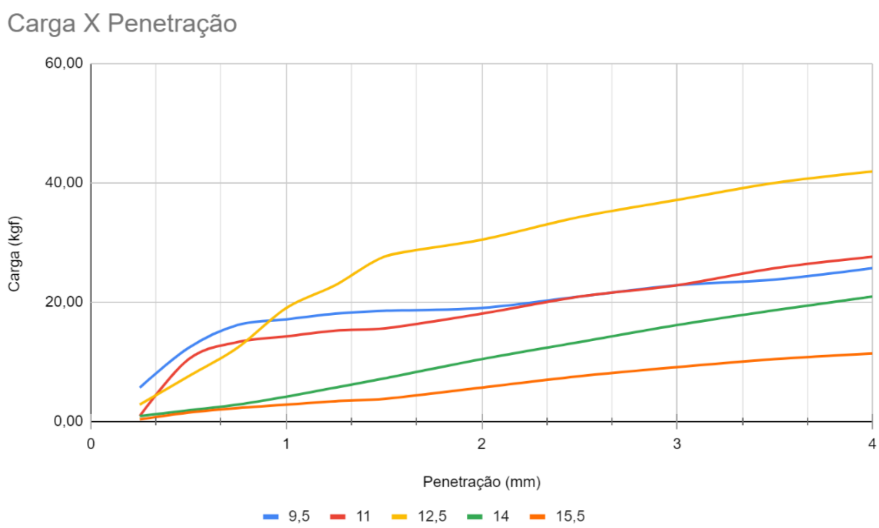
Sample soil + lime-mud	Optimal contents		Mini-CBR (%)	Expansion (%)
	$\rho_{d\ max}$ (g/cm³)	W_{ot} (%)		
0%	1,962	12,3%	29,3%	-
10%	1,945	12,5%	13,1%	0,079%
20%	1,825	13,0%	21,1%	0,000%
30%	1,739	14,0%	15,4%	0,000%
40%	1,710	17,5%	19,9%	0,059%
50%	1,650	17,5%	18,5%	0,100%

Source: Own Authorship, 2023.

It was observed that the use of lime-mud in the soil changes the color and odor of the water, in addition to causing oxidation in the parts used during immersion, even when greasing the accessories with Vaseline. Some samples showed shrinkage despite being immersed (did not expand), and all values below 1.0%. These results suggest that lime-mud does not negatively interfere with the soil's expansion property.

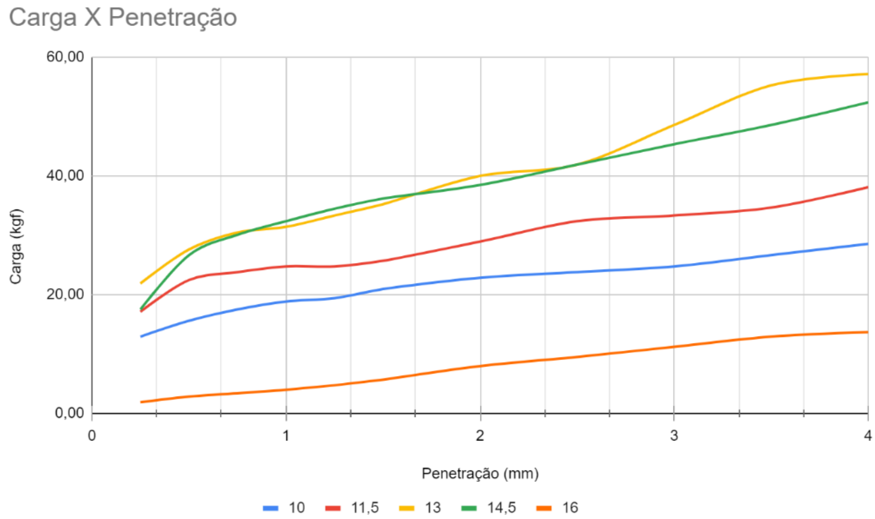
To evaluate the soil's resistance, the penetration test is essential. From the values obtained, it is possible to calculate the CBR value for the analyzed samples. Figures 1 to 5 display graphs of penetration versus corresponding load for each material used in this study, considering miniature size samples.

Figure 1 - Penetration Test – 10%.



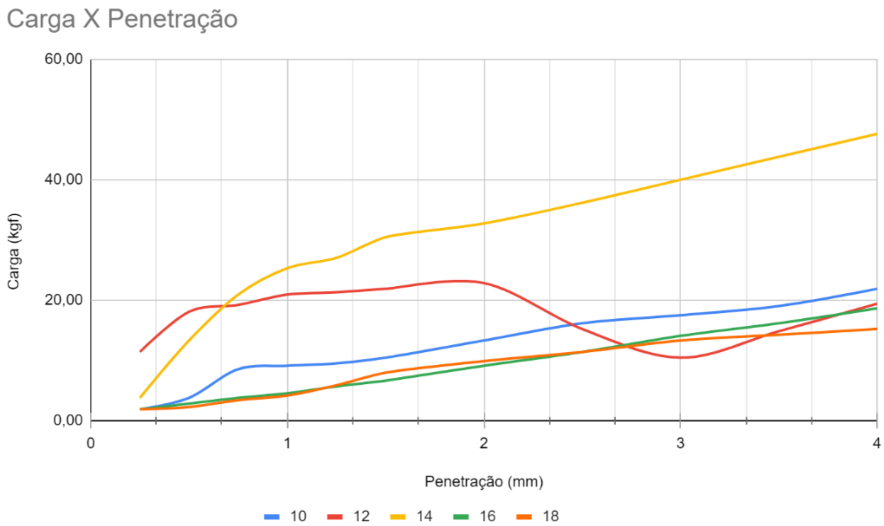
Source: Own Authorship, 2023.

Figure 2 - Penetration Test – 20%.



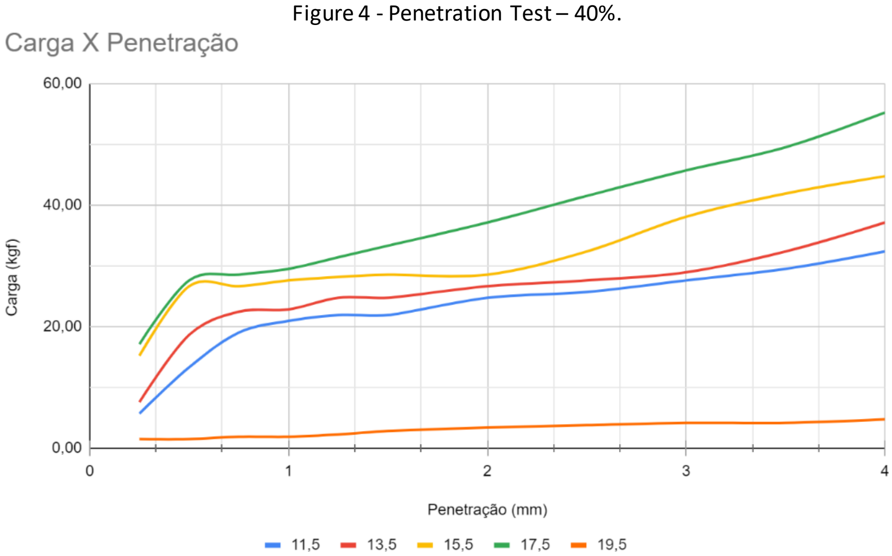
Source: Own Authorship, 2023.

Figure 3 - Penetration Test – 30%.



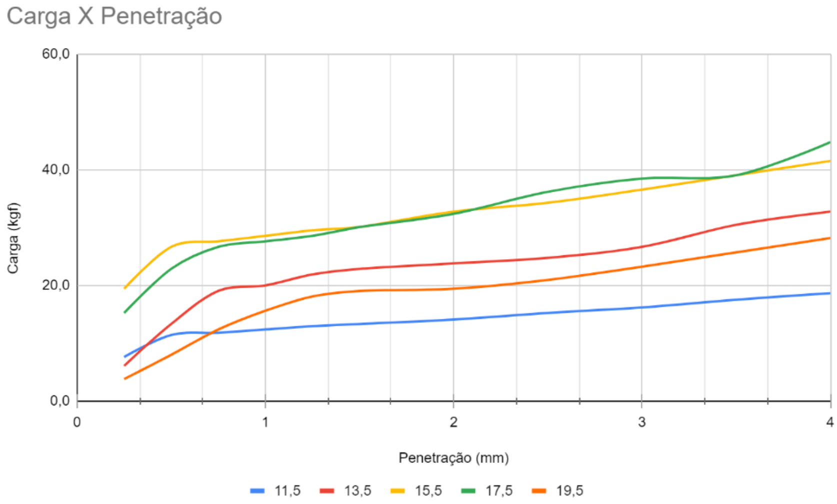
Source: Own Authorship, 2023.

Figure 4 - Penetration Test – 40%.



Source: Own Authorship, 2023.

Figure 5 - Penetration Test – 50%.



Source: Own Authorship, 2023.

All test specimens with soil-lime-mud mixtures presented lamellae. This type of behavior may be related to the distribution of energy and the effect of confinement on miniature size samples during compaction. For this reason, tests were carried out on test specimens with larger measurements (standard).

4.2 Compaction, CBR, and Expansion in Standard Test Specimens.

In this case, the same previous routines were adopted for the preparation of the samples and mixtures. Similarly, the compaction conditions (normal energy) and the optimum moisture content, determined in the mini-Proctor tests, were maintained. For each sample, two repetitions were carried out to correct any variations in the procedures. Table 2 summarizes the results for the optimal compaction, CBR, and expansion contents in standard test specimens.

Table 2 – CBR and expansion results for standard specimens.

Sample soil + lime-mud	Optimal contents		CBR (%)	Expansion (%)
	$\rho_{d\,max}$ (g/cm³)	W_{ot} (%)		
0%	1,876	12,3%	33,2%	-
10%	1,866	12,5%	16,4%	0,011%
10%	1,864	12,5%	16,1%	0,015%
20%	1,751	13,0%	27,5%	0,018%
20%	1,787	13,0%	20,3%	0,018%
30%	1,703	14,0%	20,0%	0,028%
30%	1,718	14,0%	25,8%	0,035%
40%	1,685	17,5%	4,4%	0,010%
40%	1,676	17,5%	14,4%	0,059%
50%	1,538	17,5%	21,3%	0,049%
50%	1,526	17,5%	17,6%	0,052%

Source: Own Authorship, 2023.

The soil is classified as lateritic 1 - 2 - 6 (4), silty with a group index equal to 4, and can be applied as a sub-base for asphalt paving. Regarding expansion, all the results of the analyzed samples were positive, remaining well below the value of 1% stipulated by the normatives.

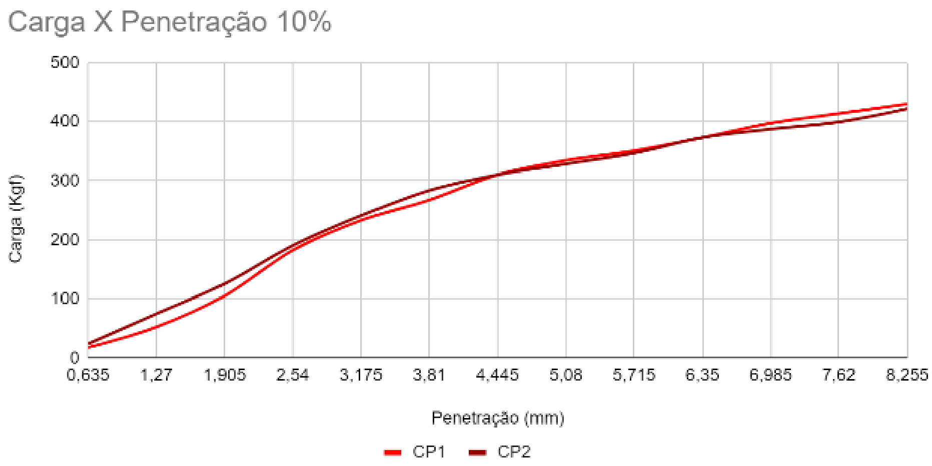
In relation to the maximum dry apparent specific mass, a decrease is observed as the content of lime-mud increases in the sample, without significant differences between the miniature test specimens and the standard size ones. The optimum moisture content also increases as the content of lime-mud becomes larger, with a large amount of fines the need for water also increases.

In relation to the CBR obtained, it can be noted that the results in miniature are close to those of the standard size samples, but there were discrepancies. The contents of 20% and 40% in miniature samples can be used as a sub-base, while in standard size the contents of 20% and 30% are presented as a sub-base. The other contents are suitable only for subgrade reinforcement.

In addition to the primary results measured in the tests, the penetration versus load curves in the CBR test can provide valuable information to explain properties and behaviors of the materials. In the case of soil-lime-mud stabilized mixtures, with a limited data collection, this information seems to be more relevant. In this sense, Figures 5 to 10 display the graphs of penetration versus corresponding load for each material used in this study in the standard size samples.

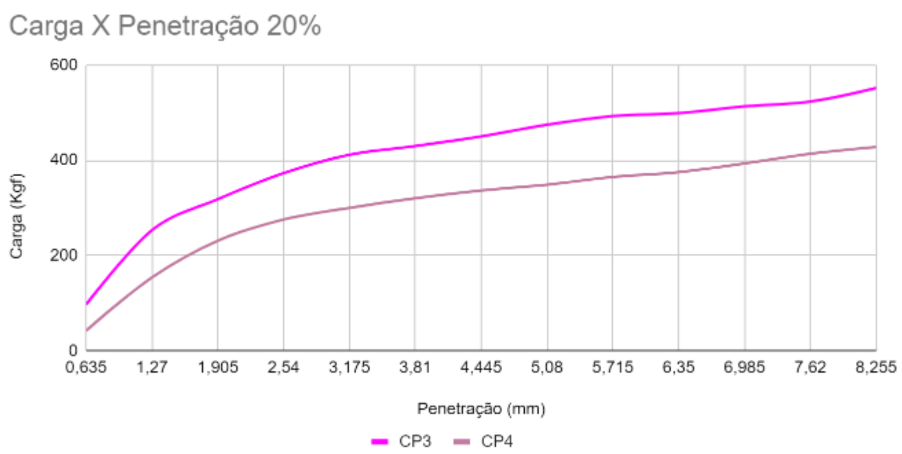
Just like in the miniature samples, lamellae were also identified in the deformed test specimens. The formation of these lamellae may be related to the amount of fines present in the mixtures, indicating, therefore, the need for complementary studies on this theme.

Figure 5 - Penetration Test – 10%.



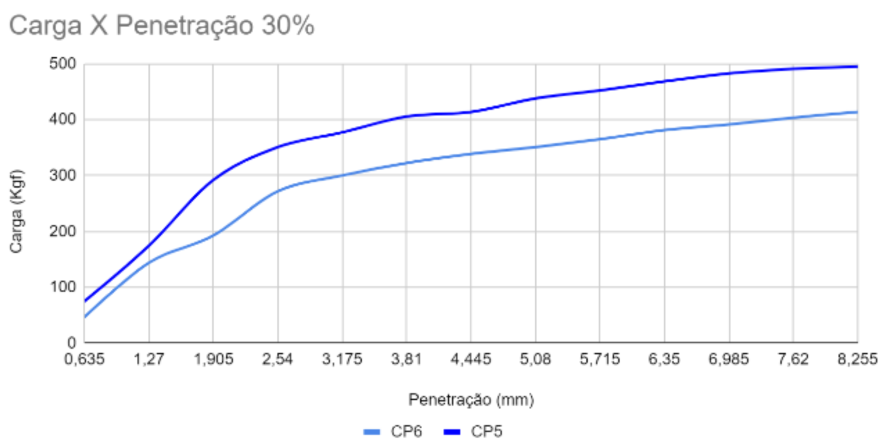
Source: Own Authorship, 2023.

Figure 6 - Penetration Test – 20%.



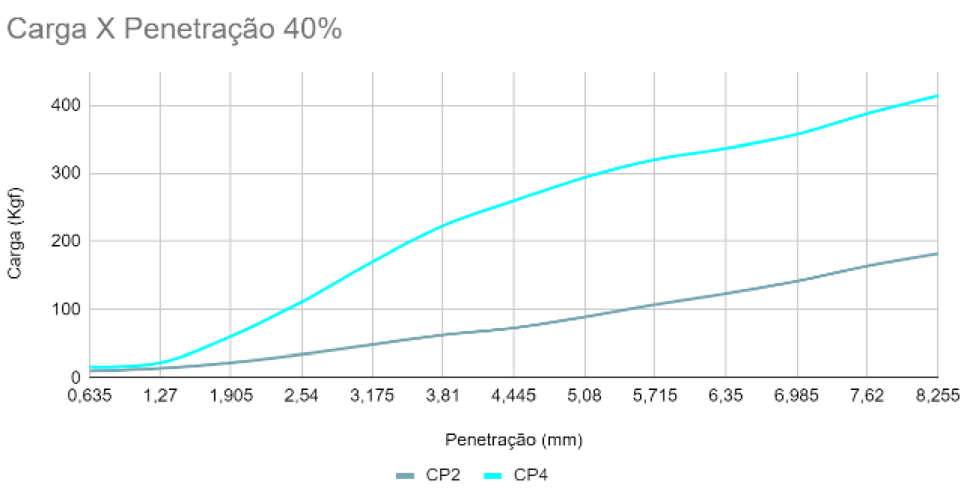
Source: Own Authorship, 2023.

Figure 7 - Penetration Test – 30%.



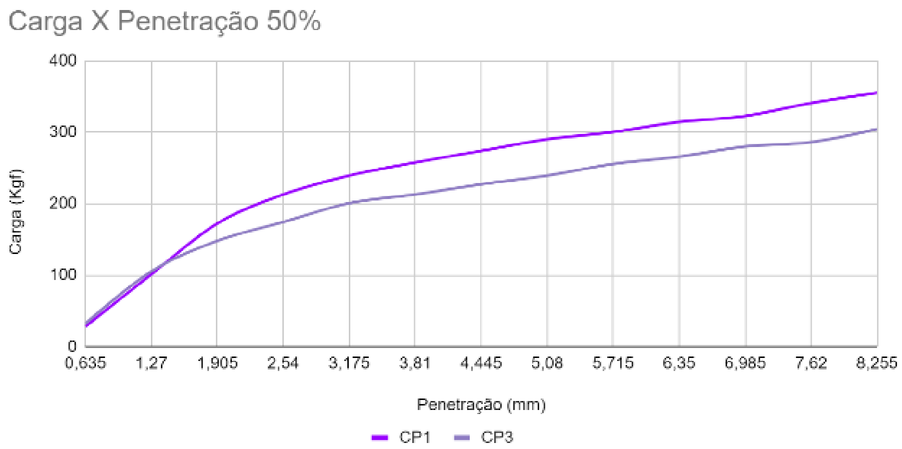
Source: Own Authorship, 2023.

Figure 9 - Penetration Test – 40%.



Source: Own Authorship, 2023.

Figure 10 - Penetration Test – 50%.



Source: Own Authorship, 2023.

The results obtained are very close to those of the mini-CBR, including the maximum dry apparent specific mass, with the CBR percentage between 13% and 27%. According to DNIT (2006), the paving manual presents characteristics of each soil layer, such as minimum thickness and maximum load supported. By obtaining the CBR of the soil, it is possible to determine in which layer the soil can be used. The flexible pavement is composed of subgrade, subgrade reinforcement, sub-base, base, and coating.

For the subgrade, the minimum thickness is 15 cm, the CBR must be greater than or equal to 2%, and the soil expansion cannot exceed 2%. In the subgrade reinforcement, the CBR must be higher than the subgrade value, however, the expansion cannot exceed 1%. As for the sub-base, the CBR must be greater than or equal to 20%, but its group index must be zero and the expansion cannot exceed 1%. As for the base, the CBR must be greater than or equal to 80%, and the expansion cannot exceed 0.5% (DNIT, 2006).

5 CONCLUSION

The soil used for the test is classified as lateritic, even though it is silty and has a large amount of fine material. For reference, the mini-Proctor test was performed, obtaining mini-CBR and CBR for standard size test specimens. With the results obtained, it is feasible to apply it as a sub-base for asphalt paving, as it presents mini-CBR and CBR above 20%.

When comparing the results of the maximum dry apparent specific mass of the soil in natura with the samples with lime-mud at 10%, 20%, 30%, 40%, and 50%, a decrease of 0.90%, 7.0%, 9.5%, 13.0%, and 18.0%, respectively, was observed. This reduction is attributed to the increase in fine material in the soil, since lime-mud also has a higher composition of fines. This resulted in a decrease in plasticity and compressive strength.

The immersion test did not reveal values above the limit recommended by the standard; all the analyzed samples expanded between 0.0% and 0.1%. Some showed shrinkage due to low moisture content, but those that were at optimum moisture did not show shrinkage.

The values obtained from the mini-CBR indicate the possibility of using the soil with lime-mud in the proportions of 20% and 40% as a sub-base of the flexible pavement. For the other contents analyzed, the mini-CBR is below 20%, and can be applied as subgrade reinforcement.

In relation to the standard size CBR, the samples with 20% and 30% of lime-mud can be used in the sub-base layer and the rest destined to reinforce the subgrade, in order to improve the pavement's support capacity.

There was a discrepancy in CBR values in the 30% and 40% samples when comparing the results of the miniature samples with the standard size ones, which indicates that the moisture used in the tests was not the most optimized for the tested contents, although the entire procedure was conducted under technical guidance and following current standards.

Soils with 40% and 50% lime-mud have a large amount of fine material, requiring a higher moisture content than the others. This makes it unfeasible to use this proportion for asphalt paving, since, in cases of rain, the soil would become unstable, acquiring characteristics similar to mud, which would harm the pavement.

During the tests, an unexpected incident occurred during the immersion of the test specimens, the mixture presented a corrosive character for metallic materials, causing oxidation in the cylindrical mold and the metallic support. Thus, the application of lime-mud in pavements would be limited, as it has a corrosive potential when in contact with water, which could damage the equipment and machinery used in road construction, in case of direct and prolonged contact.

Considering the unknown chemical properties of lime-mud, a more detailed study of the composition of this material could provide a more accurate understanding to improve its performance in asphalt paving.

In general, the addition of lime-mud can improve the quality of the soil, making it more cohesive and resistant. Its use in subgrade reinforcement can bring stabilization to soils that are expansive due to changes in moisture. With the reduction of plasticity caused by lime-mud, the soil becomes less prone to deformations and settlements, contributing to a longer durability of the pavement.

In addition, lime-mud also contributes to the increase in moisture resistance, making the soil less susceptible to water-induced damage, such as erosion and loss of support. However, it is crucial to highlight that the effectiveness of the addition of lime-mud depends on local conditions and specific characteristics of the soil, making it essential to carry out a detailed analysis of the mixture for each specific scenario.

Thus, for the soil analyzed, the most suitable content for application is 20% lime-mud, as it showed good results in the tests, being in accordance with existing standards and remaining constant in terms of mini CBR and CBR in standard size, recording results above 20% in the analyses performed.

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