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Physical-Mechanical Characterization of Soil-Aggregate Mixtures with Slate Waste for Application in Road Pavement Layers

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Abstract- The present paper presents the physical-mechanical characterization of soil-gravel mixtures of runner with aggregate from slate cutting of the region of Papagaios (city of Minas Gerais State in Brazil) aiming to evaluate the possibility of application in pavement's base and subbase layers. Seven mixing contents of runner of the slate waste (SW) with local clay-sandy soil. Physical-mechanical characterization tests were performed as well as verification of compliance with the normative for use as base and subbase of the pavement. Of the proportions 90/10, 80/20 and 70/30 for base only the first met the norm recommended, while all the proposed levels for subbase (75/25, 67/33, 60/40 and 50/50) were approved by the verification. It was also concluded that the addition of the residue provided an increase in the mechanical performance and reduced the expandability of the mixtures, besides providing the opportunity to use the SW, suggesting the performance of dynamic tests and resilient characterization in future studies with the mixtures.

Keywords- *Highway, Physical-Mechanical Characterization, Pavements, Slate Waste*

I. INTRODUCTION

We can observe recently in the construction industry the concern with economic-sustainable processes in view of the need for environmental conservation and the renewable nature of mineral reserves, as can be seen in the extractive field of rocks, particularly that of ornamental rocks. According to [1], Brazil is in the fourth position in the production of this branch, behind Italy, China and Spain, with almost 100,000 tons of slate being exported in 2014 according to [2]. As shown by [3], the state of Minas Gerais is the second largest mining center in the country, with the so-called Mineral Province in the region of the municipality of Papagaios.

In addition to the state's relevance in Brazilian production of slate exports and the shrinkage observed in recent years in the sector [4], the high generation of residues from the exploration of this mineral in blocks. According to [5], it considers in Brazil an average utilization rate of approximately 17% in mining and processing, whose generated residues are characterized by out-of-standard blocks, fragments of rock, while in the sawing and polishing steps a residue value generated of 40% of the volume of the block processed in the form of rock and mud powder is allowed.

A. *Use of slate waste*

Several studies have been presented in the literature on the use of residues from the slate waste (SW), of which we can mention the work of [6], which proposes to use as an addition to cement after thermal activation, [7] that deals with the behavior of concrete when it receives addition of slag from blast furnace with finely ground slate and [8] about the characterization of products generated in the thermal expansion process of slate tailings.

In this sense, the utilization of SW in paving layers (base and subbase) is presented as an alternative in the reduction of boot-off stocks as well as an opportunity to reduce the liabilities arising from the extraction and processing.

B. *Utilization of industrial waste in paving*

According to [9], the pavement of a highway is the superstructure consisting of a system of layers of finite thickness, defined on a space considered theoretically infinite, called natural subgrade.

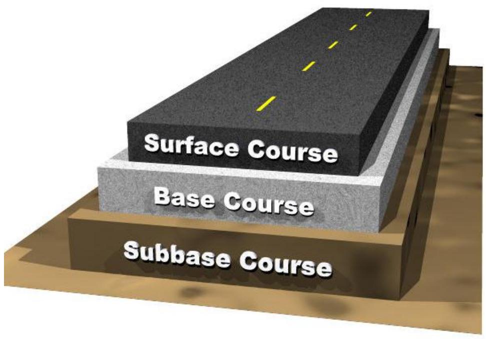

Figure 1. Pavement layers (Source: unknown author)

Many efforts have been made to reuse solid industrial waste in paving layers, such as blast furnace slag [10] and Construction and Demolition Waste (C&D), such as in [11] and [12], among others, the availability of materials and low acquisition cost, reduction of the disposal volume, reduction of extraction of primary materials from quarries [13]. Therefore, the use of SW in this context is the object of study of the present paper.

II. MATERIALS AND METHODS

The steps considered in this work were based on the following assumptions:

- Adaptation of the provisions of standard NBR 15116: 2004 [14] - recycled aggregates of solid construction waste - use in paving and preparation of concrete without structural function - requirements;
- DNIT paving manual (2006) [9];
- Manual of procedures for the elaboration of studies and projects of road engineering - Volume IV - Geological and geotechnical studies of DER/MG [15].

Considering the absence of specific regulations for the use of SW considering physical and mechanical behavior.

A. Collection and preparation of materials

The Papagaios region has a mineral reserve of various types of slate, the summarized description of which is presented in Table I. The material used, gray SW, comes from Pevex company and obtained through crushing in the form of crushed stone, aggregate with no defined grain size range, with 100% of the material passed through the opening sieve equal to 50.8 mm. The data in the table show that the predominant material in gray slate is white mica, followed by quartz.

TABLE I. MINERALOGICAL COMPOSITION OF THE SLATES

MINERALS (%)	BLACK	GRAY	GREEN
Quartz	25	28	31
White Mica	32	33	35
Chlorite	22	19	19
Feldspar	14	14	14
Carbonate	4	2	0,5
Iron oxide	2	2	2
Carbonaceous material	0,5	0,4	0,05

A sandy-clay site was also collected for SW-soil mixtures. After collection, the materials were sent to the laboratory of the Department of Highways of Minas Gerais (DER/MG) for the accomplishment of the (scattering and blocking - Figure 2 and 3), as recommended by DNER ME 041/94. Mixing contents were determined in SW-soil weight, with 3 (three) for study as base use and 4 (four) as subbase use.

Figure 2. Slate waste scattering (Source: Authors)

Figure 3. Clay soil scattering (Source: Authors)

B. Experimental campaing

For the physical-mechanical characterization, the tests described in Table II below for 9 (nine) samples, as recommended in the DER/MG manual [15]. Table III presents the compaction energies used for each mixture.

TABLE II. EXPERIMENTAL CAMPAING

TEST	STANDARD
Granulometric analysis by sieving	DNER-ME[a] 080/94 [16]
Atterberg Limits (Liquidity and Plasticity)	DNER-ME 122/94 [17] DNER-ME 082/94 [18]
Compression	DNER-ME 164/2013 [19]
California Bearing Ratio (CBR)	DNER-ME 049/94 [20]
Los Angeles Abrasion	DNER-ME 0035/98 [21]
Form index	DNER-ME 086/94 [22]

a. DNER-ME = Test Method of the National Highway Department.

TABLE III. COMPACTATION ENERGY

PAVEMENT LAYER	BASE			SUBBASE		
Proporcion Slate Waste / Clay soil	90/10	80/20	70/30	75/25	60/40	50/50
Compactation Energy	M	M	IM	IM	IM	I
M - Modified / IM - Intermodified / I - Intermediate						

III. RESULTS AND ANALYSYS

A. *Verification of the application of the mixtures as base layer*

According to [9] and [23], for this verification it is necessary that the studied material is analyzed according to some criteria:

- Fit into one of the standard particle size ranges;
- Presentation of Atterberg Indices lower than the admissible, which are: Liquidity Limit < 25.0% and Plasticity Index < 6.0%;
- CBR value > 80% for moderate to heavy traffic and CBR> 60% for light traffic, as defined by the traffic study.
- Expansion value less than 0.5%.

Analyzing Figure 4 and 5, can observe the grain size curves of the base and subbase mixtures, respectively. We can observe that, for the base, the mixtures approached the grain size range "D" which is one of the options provided in DNIT (2006) for approval of a given material for use as a base layer. For subbase there is no restriction as to the granulometric range for use.

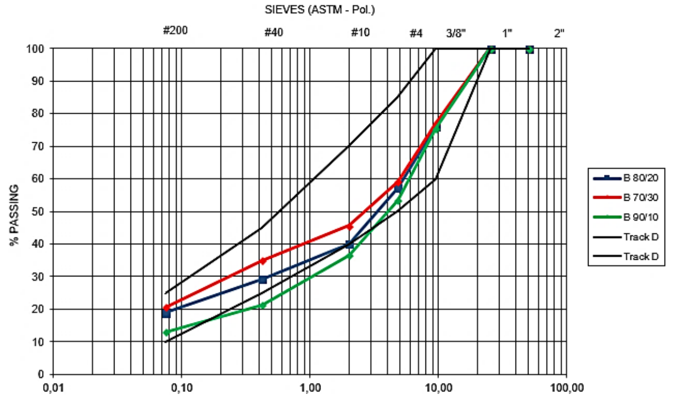

Figure 4. Framing of the mixtures in the grain size range D.

The results of the Atterberg limits tests are shown in Table IV. It is observed that the levels meet the limits.

TABLE IV. ATTERBERG LIMITS RESULTS

SAMPLE	LIQUIDITY LIMIT (%)	PLASTICITY INDEX (%)
B 90/10	20,7	4,1
B 80/20	21,5	5,8
B 70/30	23,1	7,4

The extract from the compaction tests is shown in Figures 5 to 7, below.

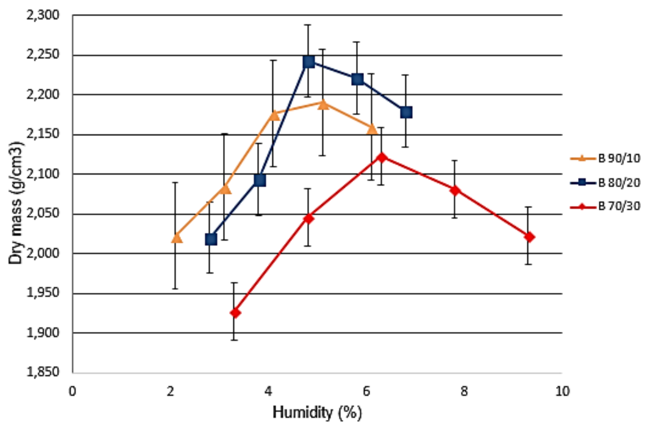

Figure 5. Humidity content x Dry mass.

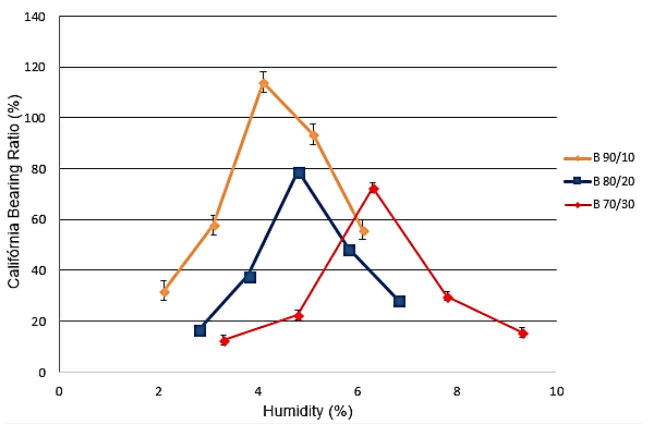

Figure 6. Humidity content x California Bearing Ratio.

When analyzing the results, taking into account the optimum point (optimal humidity x maximum specific apparent dry mass), an increase in the mechanical performance with the increase of the SW content is observed. However, only the 90/10 content met the minimum expected performance for pavement base subject to moderate to high traffic.

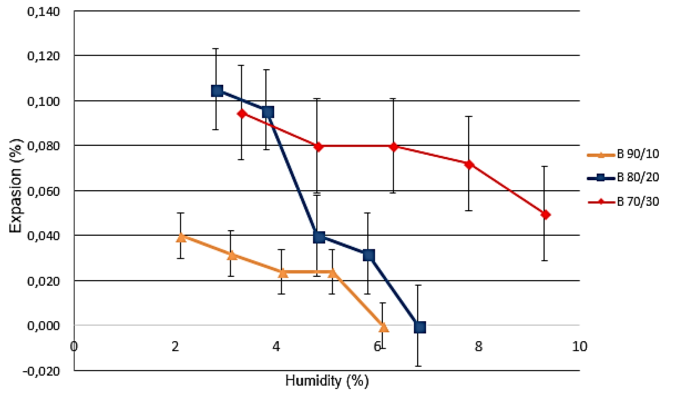

Figure 7. Humidity content x Expansion.

The same occurs in relation to the expandability, whose attendance occurred only to the highest of the SW levels proposed for use as a floor base.

B. Verification of the application of the mixtures as subbase layer

In the following, Figures 8 to 10 present the results of the compaction campaign for candidate content for use as a subbase.

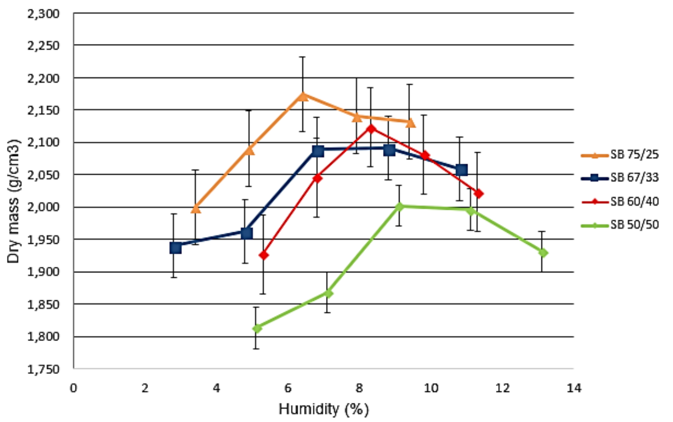

Figure 8. Humidity content x Dry mass.

Based on [24], considering that the restriction for use as a subbase layer is expansion less than 1.0% and California Support Index minimum of 20%, and taking as a reference the optimal point (optimum humidity x maximum specific apparent dry mass) it is observed that the contents met the recommended for use as subbase layer of road pavement.

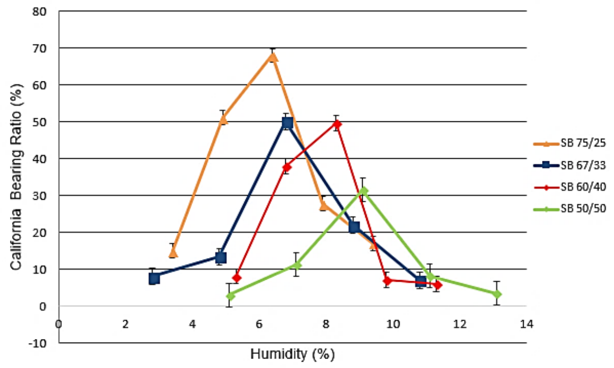

Figure 9. Humidity content x California Bearing Ratio.

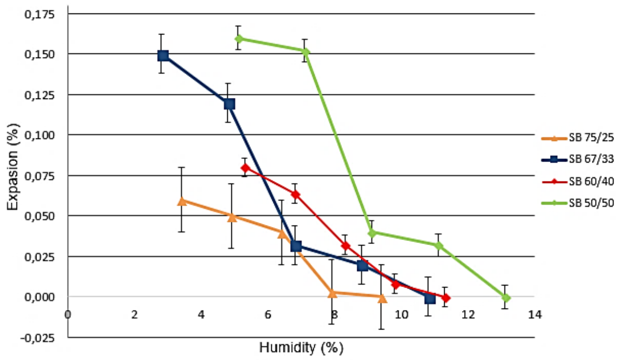

Figure 10. Humidity content x Expansion.

IV. CONCLUSION

The use of SW as the mixture with the soil for the application of base layers and subbase of pavements proved to be feasible according to the normative reference studied.

CBR values were obtained between 67.9% and 31.5% for subbase application, and between 114.0% and 72.5% for base. It is noted that CBR values increase as slate waste is added to the blend for a given compaction energy. For expansion, although it is not possible to relate the value of the same to the residue percentages of the mixtures, all the contents met the standards established by the DNIT for applications as subbase and base. Expansion values for the subbase were 0.018% and 0.040%, and for base were 0.024% and 0.079%.

This results in allowing the use of 90/10 for the base layer and, for subbase, 75/25 in case of greater amount of waste utilization. It is suggested the construction of future characterization studies by modules of resilient modulus for the same contents.

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