INDUSTRIAL SOLID WASTE (WHITEWASH MUD) USE IN FOREST ROAD PAVEMENTS[1]

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ABSTRACT – The objective of the present study was to evaluate the effects of industrial solid waste (whitewash mud) on geotechnical properties considering the following engineering parameters: California Bearing Ratio (CBR), Atterberg limits and Permeability test. Seven soil samples derived from Alagoinhas, Bahia - Brazil, were classified by the Transportation Research Board (TRB) system. Two were selected as having a great geotecnical potential classified as A-3 (0) and A-2-4 (0), whitewash mud contents 10%, 15%, 20% and 25% dry weight and medium compaction effort were studied in the laboratory testing program. The results indicated the soil denominated good gravel as being the most promising one, when stabilized with whitewash mud, reaching the best results with the dosage of 20 and 25% of whitewash mud.

Key Words: Forest road, industrial solid waste, whitewash mud, soil stabilization.

UTILIZAÇÃO DO RESÍDUO SÓLIDO INDUSTRIAL (LAMA-DE-CAL) EM PAVIMENTOS DE ESTRADAS FLORESTAIS

RESUMO – O objetivo do presente estudo foi avaliar os efeitos do resíduo sólido industrial (lama-de-cal) nas propriedades geotécnicas de amostras de solo da região de Alagoinhas, BA, Brasil. Das sete amostras coletadas, apenas duas foram selecionadas, por apresentar maior potencial geotécnico. Utilizaram-se ensaios de caracterização, CBR e permeabilidade, cujos resultados indicaram que a amostra de solo denominada good gravel quando estabilizada com lama-de-cal, na dosagem de 20 e 25%, foi a mais promissora.

Palavras-chave: Estrada florestal, resíduo sólido industrial, lama-de-cal, estabilização de solo.

1. INTRODUCTION

In many situations, soils in natural state do not present adequate geotechnical properties to be used as road service layers, therefore the importance of studying soil stabilization in order to adjust their geotechnical parameters to meet the requirements of technical specifications of the road construction industry. The problem in road supports is basically related to the type of soil to be used. When it is characterized as sand, it presents extreme conditions of the sandy soils, usually obtaining elevated support capacity under service conditions, if adequately confined laterally. On the other hand, the occurrence of unpaved road is generally associated with the presence of clay, clay-silty-sandy soils and even silty-clay soils, because they show substantial loss of superficial particles under traffic and local climatic factors.

Considering the Brazilian experience and the cost-benefit relation of road building contractors, the use of chemical stabilization and mechanical methods of soil stabilization for roads is common. Historically, cement and whitewash have been used in highways pavement, particularly in base and sub-base layers, usually 6-10% cement and 5-6% whitewash (BRASIL, 1996). DNER is actually DNIT (Brazilian Highway Department). However, in forest roads, the costs associated with the use of these techniques can be considered impracticable. Thus, a low cost technological solution for the forest road sector could be the application of waste generated in production processes, used as chemical additives to improve soil geotechnical characteristics. This would meet the road technical constructive requirements as well as guarantee the disposal of industrial waste, many times harmful to the environment, confining it in controlled conditions under the highway structure. Whitewash mud, a pulp and paper industry sub-product, has great potential for this kind of use.

The objective of this study was to analyze, in laboratory, the geotechnical performance of whitewash mud-soil mixtures in forest road pavements, considering the following engineering parameters: CBR, consistence limits and highway permeability tests.

2. MATERIAL AND METHODS

2.1. Soil samples

Seven soil samples, from Klabin-Bacell Company, Alagoinhas, Bahia, Brazil, have been characterized and classified geotechnically according to the system adopted by the Transportation Research Board (TRB). the most important samples had been identified in function of the collecting place as: a) Subgrade sand - samples collected under the forest road surface and; b) Good gravel - samples collected from a mine.

2.2. Whitewash mud

The potential of whitewash mud, derived from pulp and paper processing, was evaluated as chemical stabilizer for the soil samples, to be classified as a chemical stabilizer from a geotechnical point of view. Whitewash mud was used in its pure form, as the company disposes it of in the embankment.

2.3. Soil samples collection

The field procedures adopted for soil sample collection consisted in extraction, packing into plastic bags and transportation to the Geotechnical Laboratory of the Federal University of Viçosa. Then, the soil samples were dried to air, put through a 4,8 mm mesh sieve, determined the humidity, and stored in sealed up plastic bags. The preparation of deformed soil sample used in the geotechnical tests followed the recommendations of the Brazilian Association of Technical Standards (ABNT), according to procedure NBR 6457/86.

2.4. Whitewash mud dosages

The whitewash mud dosages were 10, 15, 20 and 25% of dry soil weight, chosen on the basis of preliminary tests.

2.5. Laboratory tests

The tests for soil sample characterization included the following determinations: sieve analysis (ABNT, 1984a), liquid limit (ABNT, 1984b), plastic limit (ABNT, 1984c) and soil particle specific mass determination (ABNT, 1984d). After this stage, a technical analysis of the results was carried out to define which soil samples could be considered representative to be used in stabilization processes and therefore in the determination of compaction, soil CBR, soil permeability and whitewash mud mixtures. The following indexes were determined for the selected samples: optimum compaction parameters (ABNT, 1986), in the medium energy effort AASHTO test; California Bearing Ratio - CBR (DNER, 1996); and permeability (HEAD, 1982). The sequence of execution for the compaction, CBR and permeability tests were: Soil as it is, dried to air humidity plus water - resting for 24 hours before compaction; Soil plus whitewash mud: addition of whitewash mud to the soil, with subsequent addition of water, and then sieving through a 4,8 mm mesh net, to reach homogenization of at least 80%, and finally, initiation of compaction.

3- RESULTS AND DISCUSSIONS

3.1. Classification and geotechnical characterization of soil

Table 1 presents a summary of the results for the geotechnical characterization tests, as well as the

respective classification of the soil samples from Alagoinhas, Bahia, Brazil, through the TRB process (BRASIL, 1996). Analyzing Table 1 according to the TRB recommendations, it is verified that the soil samples studied, except for the one called high subgrade collected at Klabin Farm, integrate the group of granular materials having potential for road building, foreseeing a good to excellent performance as material for subgrade in forest road pavement. The high subgrade sample fits the fine soil group of the related system of classification, showing a weak to poor performance as material for subgrade.

The analysis of the results presented in Table 1 also leads to the conclusion that the samples Subgrade sand and Good gravel, from the point of view of grain size and plasticity (NP for the first one, and IP equal to 6% for the second) can be considered representative of the set of soil tested and suitable to be used as component of the mixtures soil + whitewash mud. Figure 1 presents the grain size curves of these samples. It is observed in Table 1 that the grain sized fractions assigned as gravel, sand, silt and clay are related to the following diameters: 76 to 2 mm fraction gravel, 2 to 0,074 mm fraction sand, 0,074 to 0,005 mm fraction silt and under 0,005 mm fraction clay.

3.2. Compaction and CBR tests for soil and whitewash mud mixtures

Table 2 shows compaction, CBR and expansion measured in the CBR test of soil as it is and soil plus whitewash mud for the Subgrade sand and Good gravel samples. In the case of mixtures, it is noticed that there was a one-day cure period before performing the CBR test. The soil compaction parameters had little variation in optimum humidity and maximum specific mass in relation to the addition of different whitewash mud dosages. CBR values, for some whitewash mud contents, were superior to the ones of soil as it is, with the best results for Good gravel samples at the dosages of 20% and 25%, with gains respectively in the order of 14% and 46%.

However, it must be evidenced that the addition of whitewash to a soil is usually responsible for cationic exchange, flocculation and cementation as pozzolanic reactions. The first two are responsible for small immediate gains of mechanical resistance in the stabilized mixture, and the third for increasing mechanical resistance with time. Therefore, it must be considered the gain of soil-whitewash mixture resistance, separating mechanical resistance of cured mixture from mechanical resistance of uncured mixture. In this context, the parameters CBR and Expansion$_{CBR}$ presented in table 2 could be understood as corresponding to values for mechanical resistance of uncured mixture, foreseeing that there will be a trend of significant increase in CBR and decrease in Expansion$_{CBR}$ values with time.

Table 3 summarizes the technical requirements for dimensioning flexible pavements used by the Brasil (1996), which it is based on the results of soil characterization and CBR tests. In Alagoinhas, Bahia, Brazil, where there is a deficiency of road construction materials and the solicitation number for the standard axle (8.2 tons) can be estimated as equal or inferior to 5×10^6, it is known that the DNER recommends the use of base layers with CBR equal or below 60% and

Table 1 – Results for sieve analysis, Atterberg limits (LL, LP and IP) and TRB classification
Tabela 1 – *Resultados dos ensaios de caracterização e limites de Atterberg (LL, LP e IP)*

Sample Soil	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	LL (%)	LP (%)	IP (%)	Ydmax. (kN/m³)	Classification TRB
Farm KLB									
Subgrade sand-1	-	85	13	2	-	-	NP	26.5	A3 (0)
Subgrade sand-2	-	78	20	2	-	-	NP	26.0	A3 (0)
High Subgrade	-	59	16	25	27	17	10	26.5	A4 (0)
Good gravel	76	16	3	5	21	15	6	27.5	A-2-4 (0)
Poor gravel	50	26	10	14	34	22	11	27.0	A-2-6 (4)
Farm Matinha									
Subgrade	-	76	3	21	-	-	NP	26.0	A3 (0)
Gravel	32	24	21	23	20	14	6	27.0	A-2-4 (0)

Expansion$_{CBR}$ below 0.5%. Therefore, considering the data from Table 2, none of the tested mixtures met either requirement. That is why this material it is not recommended as base layer, even it has been verified significant gains of mechanical resistance in the mixtures Good gravel plus whitewash mud (20%:25%). It is worth mentioning that Sand subgrade and Good gravel, in natural state, meet the requirements for sub-base materials, since it presents CBR index above 20% (26,4 and 35,5%, respectively) and below 1% expansion.

3.3. Results of the permeability tests for soil and whitewash mud mixture

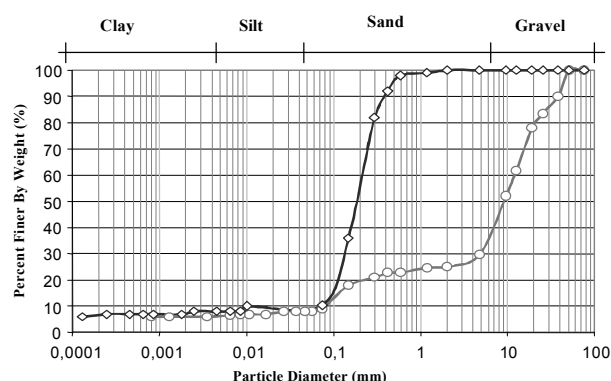Table 4 presents the values of hydraulic conductivity coefficients of the body-of-test molded soil, Subgrade sand, Good gravel, mixtures of Subgrade sand + 20% whitewash mud and Good gravel + 25% whitewash mud, compacted in American Association Highway and Transportation Officials (AASHTO) medium energy, 8.1% and 11.0% humidity contents respectively. It is observed in the case of Subgrade sand that there is no significant changes in the hydraulic conductivity values and the emptiness index of the soil samples when compared with soil stabilized with whitewash mud. However, it has occurred variation of 10% in the hydraulic conductivity and 63% in the emptiness index of Good gravel after the stabilization with whitewash mud. It is also noteworthy that the permeability coefficients of the soil studied fit into the characteristic fraction silt, by Pinto (2000).

Figure 1 – Particle size distribution of Subgrade sand and Good gravel.
Figura 1 – *Distribuição de tamanho de partícula de areia de Subgrade e pedregulho Bom.*

Table 3 – DNIT technical requirements to be used as layers of reinforcement, sub-base and base of flexible road floors
Tabela 3 – *Recomendações técnicas do DNIT para dimensionamento de pavimentos rodoviários flexíveis*

Pavement layer	Dimensioning Method of DNER (1996)
Reinforcement	CBR > CBR $_{SUBGRADE}$ Expansion ≤ 2%
Sub base	CBR ≥ 20% Expansion ≤ 1% Index Group (IG) = 0
Base	CBR* ≥ 80% Expansion ≤ 0,5%; LL≤25%; IP≤6% if LL>25% e IP>6% then Sand Equivalent (EA) ≥ 30%

* DNER (1971): in the case of N ≤ 5x 10^6 of the standard axle of 8.2 tones, it could be used material with CBR ≥ 60%.

Table 2 – Geotechnical parameters: moisture content (Wot), maximum specific dry gravity (Ydmax), CBR and expansion $_{CBR}$ (%), for the period of one-day cure before performing the CBR test
Tabela 2 – *Parâmetros geotécnicos: umidade, densidade máxima e expansão, no período de um dia de cura antes dos ensaios de CBR*

Soil Sample	W$_{ót}$ (%)	Y$_{dmáx}$ (kN/m³)	CBR (%)	Expansion$_{CBR}$ (%)
Subgrade sand	8.10	16.99	26.40	0.04
Subgrade sand+10% Whitewash Mud	8.20	16.30	12.50	0.10
Subgrade sand+15% Whitewash Mud	10.00	16.50	11.30	0.16
Subgrade sand+20% Whitewash Mud	11.40	17.40	27.30	0.26
Subgrade sand+25% Whitewash Mud	10.80	16.90	19.40	0.48
Good gravel	11.05	18.41	35.50	1.03
Good gravel+10% Whitewash Mud	10.40	16.60	23.00	0.21
Good gravel+15% Whitewash Mud	11.20	16.05	27.00	0.22
Good gravel+20% Whitewash Mud	11.40	18.30	40.50	0.88
Good gravel+25% Whitewash Mud	1080	18.45	52.00	0.92

Table 4 – Values of the hydraulic conductivity coefficient, K_{20} (cm/s) for Subgrade sand, Good gravel and Subgrade sand + 20% whitewash mud, and Good gravel + 25% of whitewash mud soil mixtures compacted in medium energy
Tabela 4 – *Valores dos coeficientes de condução hidráulica de amostras de solo e misturas solo-lama-de-cal a 25% compactada na energia intermediária*

Soil Sample	Hydraulic Conductivity Coefficient, K_{20} (cm/s)		Void Ratio (%)	
	Soil at it is	Soil-Whitewash Mud	Soil at it is	Soil-Whitewash Mud
Good gravel	2.6×10^{-4} cm/s	1.1×10^{-3} cm/s	0.27	0.44
Subgrade sand	4.2×10^{-4} cm/s	3.8×10^{-4} cm/s	0.56	0.50

4. CONCLUSIONS

The best effect of whitewash mud on soil mechanical characteristics occurred with 20% and 25% whitewash mud dosages for Good gravel, with CBR values of 40 and 53%, respectively. It is also observed the occurrence of small or insignificant variation in hydraulic conductivity coefficients of the mixtures in comparison with soils as they are. The present study on the whitewash mud addition "in natura" at maximum dosage of 25% demonstrated its potential to be used as chemical soil stabilizer, considering the one-day period of cure used in this work. Certainly, greater mechanical resistance gains can be expected for larger cure periods. It is therefore clear that better results can be obtained with a deeper study of the soil/whitewash mud reactivity, but taking into account the variable cure period for at least 7 and 28 days, and the possibility of product improvement by high temperature thermal treatments.

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