Characterization of stabilized soil with KR slag through determining the stabilization process

Isabella Madeira Bueno [a].

[a] Department of Civil Engineering, Federal University of Espírito Santo, Vitória, Brazil, isabueno2013@live.com.

Abstract. Due to the scarcity of natural resources that meet the minimum criteria for paving, new economical and sustainable alternatives are sought in the sector. As a result, the usage of byproducts such as steel slags has increased considerably during the last few years. These materials can be used for soil stabilization; a process that presents itself either in mechanical or chemical processes. Recent works have shown that the steel slag originated from the Kambara reactor (KR slag), a byproduct for paving applications used to improve the soil characteristics, and is showing promising results. Given the possibility of using KR slag in many paving solutions, this research paper aims at presenting and analyzing the behavior of a stabilized soil with KR slag based on the results obtained so far. The most recent work in the field showed that the slag improves the resilient modulus of the natural soil studied, although the resulting mixture still shows a granular behavior with low rigidity, classifying it as a mechanically stabilized material.

Keywords. Paving, KR slag, Soil stabilization, Resilient modulus.

1. Introduction

Due to the scarcity of natural resources that meet the minimum criteria for paving, it is sought to find new ways to improve the quality of existing soils. In this way, the stabilization process is used to promote the improvement of material properties when they do not meet the design requirements. Among the techniques used, there are two types of stabilization: (1) mechanical stabilization, a method that aims to correct grain distribution through mechanical compaction or addition of other materials followed by mechanical compaction, leaving the soil less permeable; (2) Chemical stabilization, a method that promotes the improvement of soil properties through the addition of cementitious and pozzolanic materials.

For economic and environmental reasons, the interest in using new materials, such as byproducts, in substitution of natural resources, has been increasing considerably. For instance, steel slag is a type of byproduct used for soil stabilization and obtained through the process of turning iron into steel. Its application for paving has gradually increased due to its important characteristics such as hardness, durability, mechanical resistance, and its high level of cementation when in contact with water [1].

Among the variety of slags, the KR slag is obtained through the process of removing excess sulfur from pig iron in reactors called Kambara [2]. Its use for paving application is still under study, but so far, it has shown promising results as a soil stabilizer.

Up to this moment, the stabilization mechanism promoted by the use of KR slag is still under investigation, however, other studies in the field carried out by [2], [3], and [4] show that the KR slag presents expansion levels in accordance to the limits defined by the Brazilian standard DNER - EM 262/94, as well as increasing in the bearing capacity of the soil, compressive strength, modulus of resilience and reducing the plasticity index of the mixture when used as a stabilizer.

2. Research objectives and scope

To contribute to future discussions on the use of KR slag for paving applications, this research paper aims to present and review the existing studies on the stabilization mechanism promoted by this byproduct.

For that matter, it is extremely necessary to analyze the mechanical characteristics and Resilient Modulus of the material or the mixture.

3. Methodology

The methodology of this research consists of the analysis of a test track built in Anchieta, Espírito Santo, as a part of a research project between the Federal University of Espirito Santo (LABGEO) and ECO101 Concessionária De Rodovias S.A. The track has four experimental lanes (Fig. 1), with different paving solutions. Lane 01, the scope of this study, presents a mixture of Soil and KR slag in the sub-base layer.

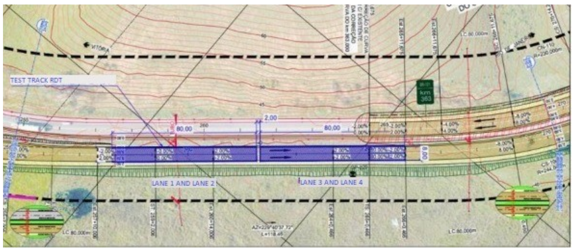


Fig. 1 - Test Track studied [4].

At first, the results of a preliminary characterization of the mechanical properties of the stabilized mixture, shown in [4], will be presented and discussed to verify its use for paving applications. Subsequently, complementary characteristics of the materials, such as Resilient Modulus, will be analyzed to determine its stabilization mechanism.

4. Development / Results

4.1 Preliminary characterization

The paving solution for Lane 01 (Fig. 2) presents a mixture of soil and KR slag in the sub-base layer. The soil S1 is mainly composed of clay, with a high liquid limit, very plastic, and with great volume variation. In that way, its use alone is not appropriate for paving, being necessary for its stabilization with the byproduct to improve its properties.

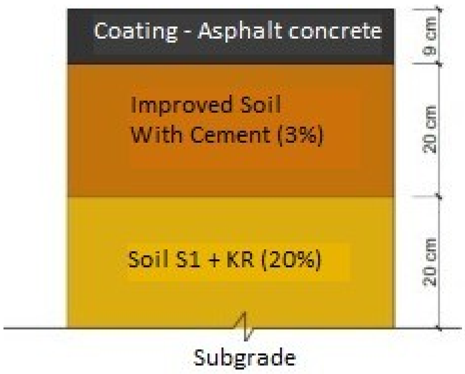


Fig. 2 - Paving Solution for Lane 1 [5].

All the characteristics of the natural soil, as well as of the mixture with KR, were determined by [4], including compaction, CBR, and expansion tests presented in Tables 1 and 2.

Table 1 - Mechanical characteristics of soil S1 and Soil S1+KR [4].

	S1	S1+20%KR
Specifig mass of the grains (g/cm³)	2,65	2,74
Liquidity limit (%)	49%	42,1%
Plastic limit (%)	24,8%	29,8%
Plasticity Index (%)	24,2%	12,3%

Table 2 - CBR, expansion, and mechanical compaction tests results [4]

	Energy	S1	S1+20%KR
Water absorption (%)	Intermediary	17,0	17,4
	Modified	16,3	15,5
Max. dry Dens. (g/cm³)	Intermediary	1,752	1,804
	Modified	1,808	1,853
Level of expansion (%)	Intermediary	0,02	0,01
	Modified	0,00	0,03
CBR (%)	Intermediary	22,7	81,2
	Modified	25,3	103,2

It is possible to notice that the use of the byproduct did not lead to any significant increases in the expansion values, which represents the main concern for using slags in paving solutions.

4.2 Determination of the stabilization mechanism

According to [6], mechanically stabilized materials are represented by their Resilient Modulus (RM), which is presented in a linear or constant form that is dependent on the deviator stress, Poisson's Coefficient, and Permanent Deformation parameters, not being evaluated for fatigue damage.

For chemically stabilized materials, the Modulus of Resilience decays every month, presenting a sigmoidal-like behavior, due to the accumulation and increase of fatigue damage, depending on the confining stress.

Therefore [7], in other to determine the stabilization mechanism promoted by the use of KR slag, performed tests using two different methods: (1) Method 1, according to DNIT 134/2018-ME standard for mechanically stabilized materials and soils; and (2) Method 2, according to DNIT 181/2018-ME, for chemically stabilized soils.

Firstly, considering the mixture as a mechanically stabilized material, the RM test was performed for different curing days (Charts. 1 and 2). In that way, [7] verified that the RM varies with time, as well as with the application of different stresses.

Chart 1 - RM x Deviator Stress [7].

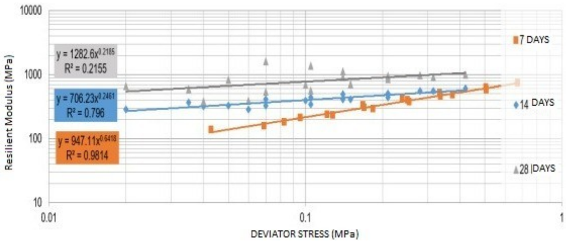
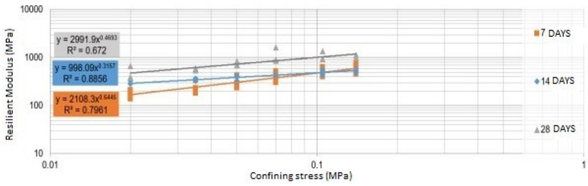


Chart 2 - RM x Confining Stress [7].



Although, there is a contradiction in the analysis of the obtained results, while, for different curing days, it is noticed a decrease in the dependence of the deviator stress, a common behavior of chemically stabilized materials. On the other hand, the highest RM value obtained (1.000 MPa for 28 days) is relatively low, a regular behavior of mechanically stabilized materials.

The results obtained by [7] of the RM using the standard test for chemically stabilized materials are shown in Table 3.

Table 3 - RM tests results [7].

Cicle	Axial Stress (MPa)	Resilient Displacement (mm)	Resilient Deformation	Resilient Modulus (MPa)
1	0,1	0,095	4,75E-04	224,169
2	0,2	0,143	7,13E-04	306,541
3	0,3	0,174	8,71E-04	377,003
4	0,4	0,202	1,01E-03	437,635
5	0,5	0,227	1,13E-03	490,174

It is possible to notice an increase in the resistance of the material for different stress levels, being the highest RM value still below the reference for chemically stabilized materials (10.000 MPa). Regarding the measured displacements, the values obtained are considerably higher than those allowed by the standard. In that way, the results show that the material is not rigid, relieving the stresses through high deformation.

Chemically Stabilized materials, due to their high modulus of resilience, relieve the stress through cracks. In this case, observing the high level of deformations, the material would crack due to fatigue, resulting in a reduction of the RM. However, the modulus tends to increase with the increment of deformations. Thus, [7] was able to conclude that the mixture is a mechanically stabilized material, relieving the stresses through permanent deformations.

This result contradicts the hypothesis [8] that the stabilization process occurs through the development of pozzolanic reactions, due to strength gain and cementation promoted by the material.

5. Conclusion

Analyzing the obtained results, it is noticed that the addition of KR slag to the S1 soil led to an increase in the Resilient Modulus of the mixture, confirming the results of previous studies. Furthermore, it is possible to confirm that the byproduct is suitable for paving applications since it promotes an increase in the California bearing ratio without significantly raising the expansion of the mixture, attending to the limits specified by the Brazilian standard.

Regarding the stabilization mechanism, it is concluded that KR slag promotes mechanical stabilization since the stabilized material presents high deformations when increasing its Resilient Modulus.

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