Availability of resilient modulus and permanent deformation laboratory tests of stabilized soil with municipal solid waste fly ash for pavements base

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ABSTRACT
This study presents the results of testing for resilient modulus and permanent deformation to evaluate the mechanical properties of a soil stabilized with fly ash from municipal solid waste incineration. The soil tested is a non-lateritic clayey soil, which is not suitable for use in pavement works. The addition of fly ash improved reduced its expansibility and modify their mechanical properties, these being dependent on the MSW fly ash content, moisture and number of load cycles. It was performed a paving project to assess their competitiveness as a base material for pavements. The results of this project showed that the soil stabilized with fly ash is competitive for low volume traffic roads, with the advantages of minimizing the environmental problems caused by solid waste disposal and waste incineration.

RÉSUMEN
Este estudio presenta los resultados de ensayos para módulo resiliente y deformación permanente para evaluar lãs propiedades mecánicas de un suelo estabilizado con ceniza volante de incineración de residuos sólidos municipales. El suelo testado es arcilloso no lateritico, el cual no es recomendable para su utilización en pavimentos. La adición de ceniza volante redujo su expansibilidad y modificó sus propiedades mecánicas, siendo estas dependientes del porcentaje de ceniza volante de RSM, humedad y número de ciclos de carga. Fue desarrollado un proyecto de pavimento para evaluar la competencia de este material como pavimento de bajo volumen de tráfico. Los resultados de este proyecto muestran que el suelo estabilizado con ceniza volante es competitivo para vías de bajo volumen de tráfico, con las ventajas de reducir los problemas ambientales causados por la disposición de residuos sólidos e incineración de residuos.

1 INTRODUCTION

The use of alternative materials is not common practice in geotechnical engineering. Recent research has been conducted, aimed at this goal. It is not always possible to find natural soils that meet the requirements of the specifications for the use of stabilized bases and sub-bases without granulometric mixture. The soil, when found, is located far from infrastructure, which increases the costs for transportation. An alternative to minimize the high costs is stabilizing the soil with waste. The proposition of this study should be preceded by a prior knowledge of the potential and limitations of the regional materials.

This study evaluates the application of fly ash obtained from incineration of Municipal Solid Waste (MSW) use in base layers of pavements, by mixing the ashes with a non-lateritic regional clay soil. The Usina Verde is a privately held company located in the Federal University of Rio de Janeiro, and aims to provide environmental solutions for the disposal of municipal solid waste, through incineration with energy co-generation. The Usina Verde receives, daily, 30 tons of MSW Company's Waste Disposal of Rio de Janeiro. In sorting, recyclable materials are segregated manually and with metal detectors, after this process, the composition of MSW is principally organic matter (88%), plastic (10%) and rubber (2%). Then the MSW is crushed and separate fine material and sent to drying. These wastes are sent to the incinerator, which operates at a temperature of 950ºC.

During the combustion process, two ashes are produced: bottom ash and fly ash. The bottom ash is deposited in the bottom of the chamber after combustion, referred to the storage tank and arranged into buckets. The hot gases and fly ash are exhausted chamber afterburner and inhaled into the recovery boiler, which is used to produce energy. Subsequently, the gases are neutralized in a set of washers and then the clean gases are extracted and discharged into the atmosphere. The wash solution is collected in settling tanks where the neutralization takes place with the ashes of the process and calcium hydroxide, which causes mineralization and this solution, is reused in the washing process. Then, the ash is sent to settling tanks where it is periodically removed and stored in buckets.

At the end of the incineration process are obtained fly ash and bottom ash, from 8 to 10% by volume of the two ashes, which represent about 80% of bottom ash and 20% of fly ash (Fontes, 2008).

2 OBJECTIVES

The objective of the investigations is to study the effect of MSW fly ash addition on the following:

- Deformability properties of soil with and without MSW fly ash
- Expansibility properties of soil with and without MSW fly ash
- Thickness layer pavements base of soil with and without MSW fly ash

3 EXPERIMENTAL INVESTIGATION

3.1 Materials and Properties

The non-lateritic clay soil in study came from a deposit located in the city of Campo Grande, Rio de Janeiro state (Figure 1). Fly ash comes from the burning of municipal solid waste (MSW) at Usina Verde, which is located on Rio de Janeiro / RJ (Figure 2). The tests performed at Pontifical Catholic University of Rio de Janeiro and Federal University of Rio de Janeiro, aiming to characterize and evaluate the soil and soil-MSW fly ash mixtures. Such as one does not have researches evidence previous on this theme, 20% and 40% as percentages of fly ash were utilized to adding a the soil. The symbols used in this study, which describe the materials and mixtures with percent in weight, are presented in Table 1.

Figure 1. Soil of Campo Grande's Field

Table 1. Material's Symbols

Material	% Soil	% MSW fly ash	Symbol
Soil	100	0	S
MSW fly ash	0	100	CV
Mixture 1	60	40	S60/CV40
Mixture 2	80	20	S80/CV20

Figure 2. MSW Fly Ash of the Usina Verde

3.2 Experimental Tests

3.2.1 Chemical and Physical characterization

Chemical characterization tests such as X-Ray Fluorescence, Organic Matter Content, Lixiviation and Solubilization; Physical characterization tests such as Granulometric Analysis and Atterberg's Limit, MCT Test and Proctor Compaction Test were conducted.

3.2.2 Mechanical characterization

3.2.2.1 Resilient Modulus Test.

The tests were performed according to standardized test in the Geotechnical Laboratory of UFRJ, into molds of 10 x 20 cm compacted at optimum moisture obtained in the compaction test. The composite model used in this study relates the resilient modulus of minor principal stress and deviator stress, as shown in Equation 1.

$$M_R = k_1 . \sigma_3^{k_2} \sigma_d^{k_3} \quad [1]$$

Where:

σ_3: minor principal stress;

σ_d: cyclic deviator stress ($\sigma 1 - \sigma 3$);

k_1, k_2 and k_3: correlation coefficients, derived from results of laboratory tests.

This model was chosen because it presents bigger correlation coefficients to the incorporating the minor principal stress and the deviator stress influence. The nonlinear least squares model estimation was utilized to obtain the correlation coefficients.

3.2.2.2 Permanent Deformation Test.

The tests were performed according to Guimarães (2009), into same molds used in the Resilient Modulus Test. Were applied 500,000 load cycles for each specimen.

Three tests were conducted in the Mixture S60/CV40, at stress levels shown in Table 2.

Table 2. Permanent Deformation Tests

Test Number	σ_3 (MPa)	σ_d (MPa)
1	0,098	0,294
2	0,118	0,353
3	0,098	0,392

3.2.2.3 CBR Test.

The tests were performed according to the Brazilian standard NBR 9895/1987 (ABNT, 1987), into molds of 152 x 178 mm compacted at optimum moisture obtained in the compaction test.

3.2.3 Pavement Design

It was assumed a pavement structure (Figure 3), with traffic data (Table 3), and Rio de Janeiro's weather, with the purpose of explore MSW fly ash addition effect in soil on pavement project one. The thickness and mechanical properties of the coated asphalt and subgrade stay constant, so that only we can change the thickness of the base, according to the parameters of resilience for each material. For the mechanistic-empirical analysis used the computer program SisPav (Franco, 2007). Bernucci (1995) indicates in order to Brazilian low traffic roads; N value of 10^4 to 10^6, in this study is assumed the N value of 10^5.

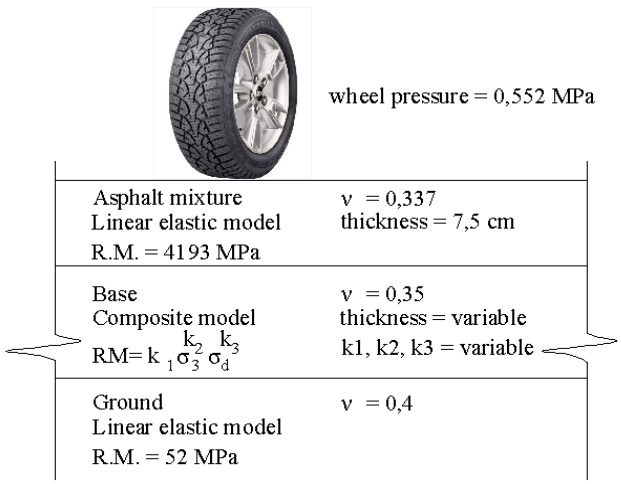

Figure 3. Pavement Structure adopted

4 RESULTS AND DISCUSSIONS

From the test conducted, the characteristics and effects of the addition of MSW Fly Ash into soil were studied.

4.1 Chemical characterization

The main chemical components of soil, which are normally found in residual soils, are SiO_2, Al_2O_3 and Fe_2O_3, such as showed in the Table 3, which participate actively in the process of chemical stabilization of soil (Rezende, 1999),. Lixiviation and Solubility tests performed according to Brazilian standards NBR 10005 and NBR 10006 for MSW fly ash and soil stabilized with 40% fly ash content. The mixture is classified non - dangerous and non-inert (Vizcarra, 2010).

Table 3. Soil, MSW Fly Ash Chemical Composition

	Concentration (%)	
Compost	Soil	MSW Fly Ash
SiO_2	36 - 43	13 - 21
Al_2O_3	35 - 38	12 - 15
Fe_2O_3	13 - 21	5 - 7
SO_3	0 - 1	5 - 10
CaO	-	32 - 45
TiO_2	0,9 - 1,7	3 - 4
K_2O	2 - 4	2 - 4
Cl	-	4 - 6
Organic Matter	0,1	0,7

4.2 Physical characterization

MSW fly ash and mixtures can be noted as follows: first, the limits of Atterberg for pure MSW fly ash could not be performed due to the behavior of granular material, which during the test did not show plastic characteristics to their achievement. Second, that the inclusion of MSW fly ash decreases the liquid limit and plasticity index, and increases the plastic limit of soil (Table 4).

Table 4. Atterberg's Limit vs. MSW Fly Ash Content

Material	MSW Fly Ash Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Soil (S)	0	60	24	36
S80/CV20	20	48	30	18
S60/CV40	40	39	32	7

According the classification MCT (Nogami & Villibor, 1995), which evaluates the behavior of tropical soils through special compaction and expansion laboratory tests, the soil is classified as NG' behavior "non-lateritic-clay." These soils when compacted under the conditions of optimum moisture content and density maximum energy normal characteristics of the traditional very plastic and expansive clays. The use of these soils is related to restrictions resulting from its high expansibility, plasticity, compressibility and contraction when subjected to drying, its use is not recommended for base pavements, and some of the worst soil for the purpose of paving, from the tropical soils (Nogami & Villibor, 1995).

From the curves of soil compaction and mixtures with fly ash obtained from the Modified Proctor tests, it can be stated that by increasing the level of ash in the mixture, the maximum dry density tends to decrease (Figure 4), which is consistent with research by Nicholson (2003), on the use of coal ash to stabilize tropical soils. It can be observed that the optimum moisture content decreases a level of 20% fly ash and grows to a maximum of 40%.

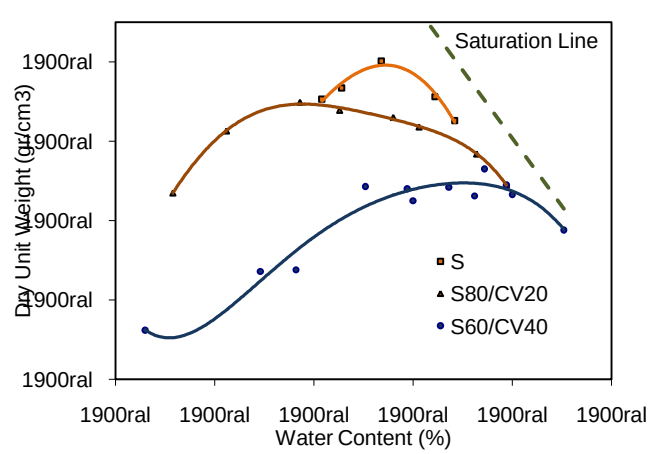

Figure 4. Compaction Curves of Soil and 20% - 40% Soil – Fly Ash Mixtures

4.3 Effect of MSW fly ash addition on mechanical properties of soil in study

4.3.1 Influence on deformability

4.3.1.1 Resilient Modulus

The results of Resilient Modulus tests (Figures 5 and 6) show that the Resilient Modulus of soil in study is dependent on the deviator stress and if the MSW fly ash is added, this behavior does not change. It is appreciated that the higher the deviator stress, the lower the value of resilient modulus.

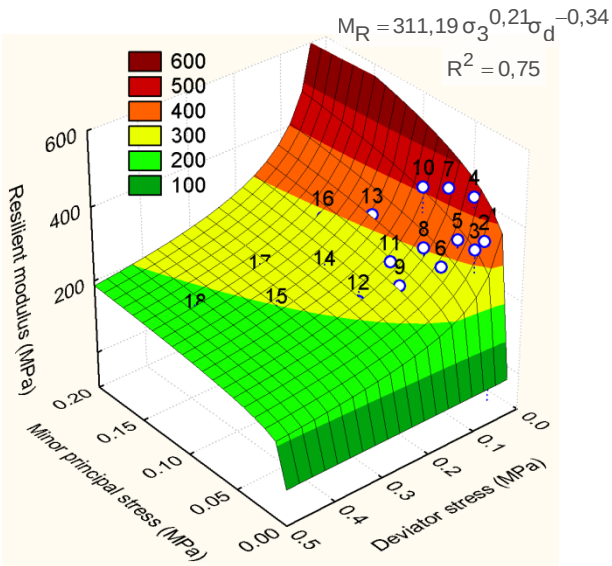

Figure 5. Soil Resilient Modulus vs. Stresses

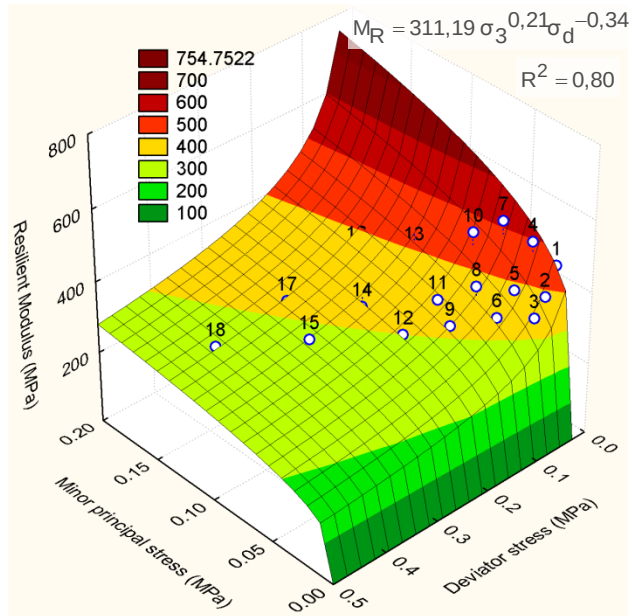

Figure 6. Soil with 40% MSW Fly Ash Resilient Modulus vs. Stresses (21 days of cure)

The mixture with 20% MSW fly ash improved the mechanical behavior of pure soil, the mixture with 40% MSW fly ash downgraded the mechanical behavior, but it improved with cure time (Figure 7). Another influence factor is the cycle number of cycling load (Figure 8). The resilient modulus improved with cycling loading.

The mixture with 20% MSW fly ash was assessed with several water content. The results indicated the resilient modulus increased as the water content decrease. (Figure 9).

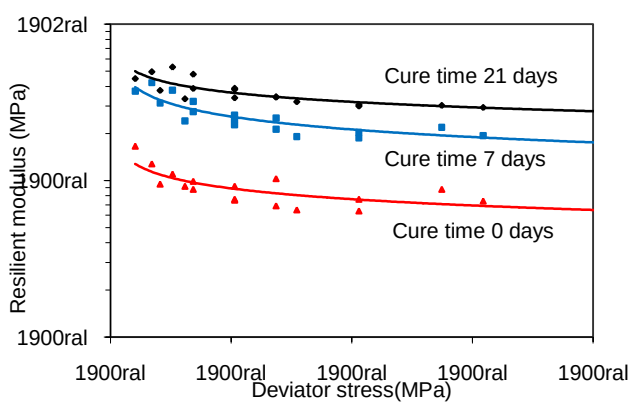

Figure 7. Resilient Modulus vs. Stress of Soil with 40% MSW Fly Ash – Cure Time Variation.

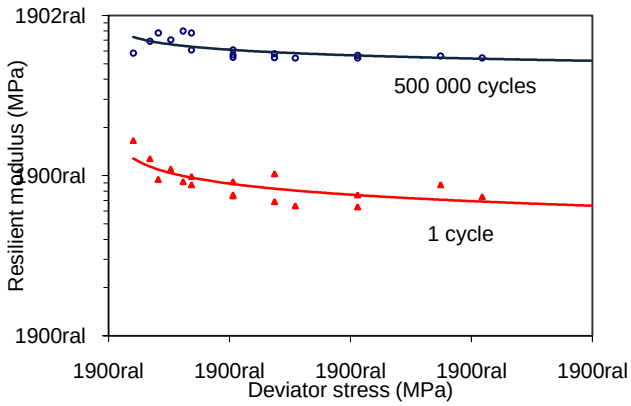

Figure 8. Resilient Modulus vs. Stress of Soil Stabilized with 40% MSW Fly Ash - Cycles Number Variation.

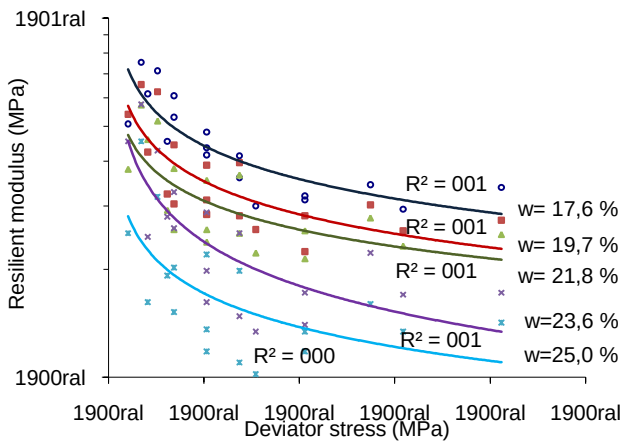

Figure 9. Resilient Modulus vs. Stress of Soil Stabilized with 20% MSW Fly Ash – Water Content (w) Variation.

4.3.1.2 Permanent Deformation

As shown in the Figure 10, the permanent deformation tends to stabilizes reaching a plateau, it´s observed that the Test 3 has a higher permanent deformation, this is due to increased tensions applied to the test.

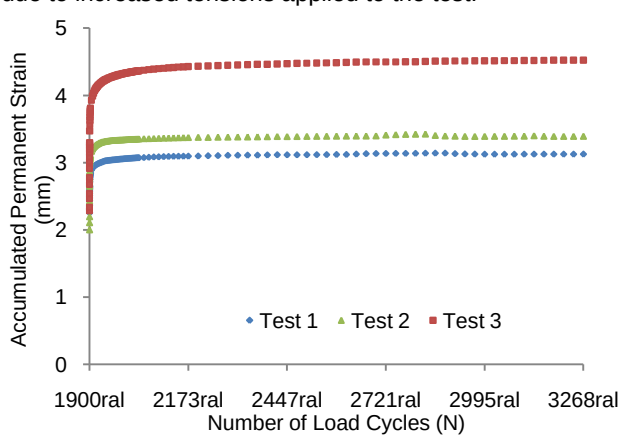

Figure 10. Accumulated Permanent Deformation Variation.

The resilient modulus is increased with the number of load cycles (Figure 11), this can be explained by the diminution of elastic strain (Figure 12).

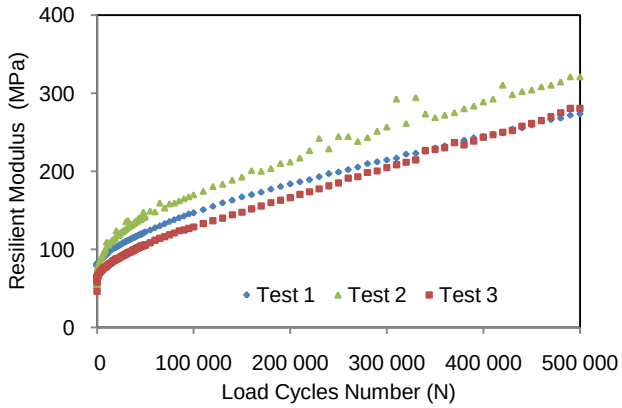

Figure 11. Resilient Modulus Variation.

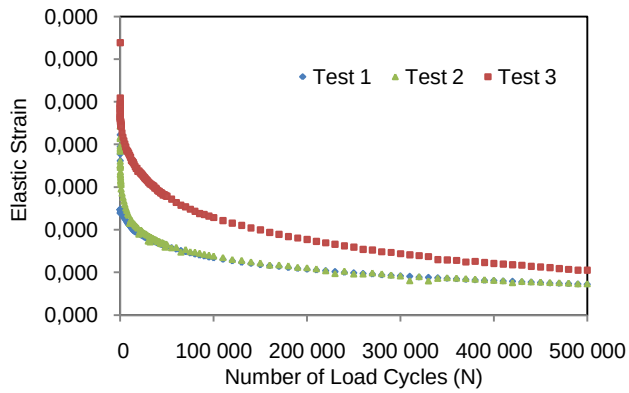

Figure 12. Elastic Strain Variation.

It was investigated the occurrence of the plastic accommodation (Shakedown) by using the behaviour model developed by Dawson and Wellner, cited by Werkmeister (2003). The test results of permanent deformation test for the MSW fly ash – soil mixture
According the graph model of Dawson and Wellner cited by Werkmeister (2003), search for the occurrence of Shakedown in this material, are presented in Figure 13.

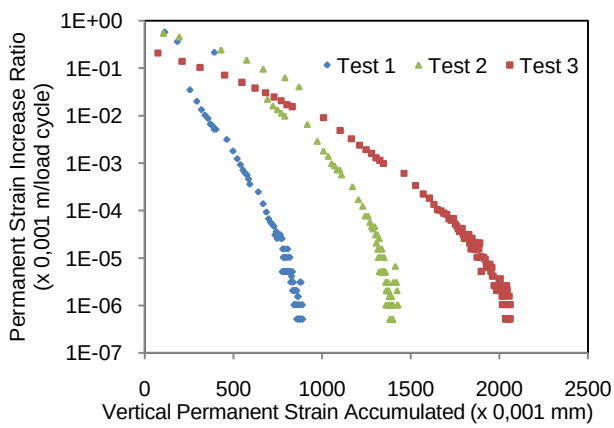

Figure 13. Shakedown's occurrence search.

The analysis of the Figure 13 it appears that all tests conducted with the MSW fly ash – soil mixture, showed a typical behaviour for level A, i.e. showed the plastic accommodation, depending on the model proposed by Werkmeister (2003). The characterization of the level A behaviour of both the shape of the curve, roughly parallel to the vertical axis, because when the rate of permanent deformation increase and have reached a magnitude of 10^{-7} (x 10^{-3} m/load cycle). I.e. at the final load cycles, the specimen´s permanent deformation increased by only 10 mm at each new cycle.

Uzan's Model (Uzan, 1982) was utilized for the foresight of permanent deformation, having as a result following equation.

$$\varepsilon_p/\varepsilon_r = 0{,}4268.N^{-0{,}2945} \quad (2)$$

The curve of correlation, together with the results of tests are in the Figure 14.

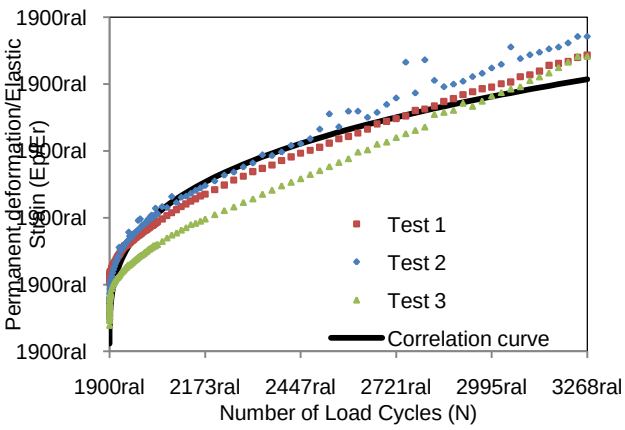

Figure 14. Uzan´s model correlation curve.

4.3.1.3 CBR

The CBR tests conducted revealed that the soil in this study has a CBR value of 2, which was improved with the addition of fly ash. The mixture S60/CV40's CBR reached a value equal to 33.

4.3.1.4 Expansibility

The MSW fly ash decreases the expansion of the soil in study, which had an expansion of 4%, but with the addition of fly ash, to 3,6% for 20% fly ash content and until it fell 0,4% to a level of 40% fly ash. However, high content of fly ash when can deteriorate the mechanical behavior, resulting in a thicker layer.

4.4 Effect of MSW fly ash addition in pavement base

The mixture with 20% fly ash improved the mechanical behavior of pure soil, which is revealed by the decrease in thickness of the base compared to pure soil, for the same loading level and same parameters (criteria) for sizing. The Figure 15 show the thickness of layers depending on the project period for each type of mixture, which was obtained by the computer program SisPav (Franco, 2007).

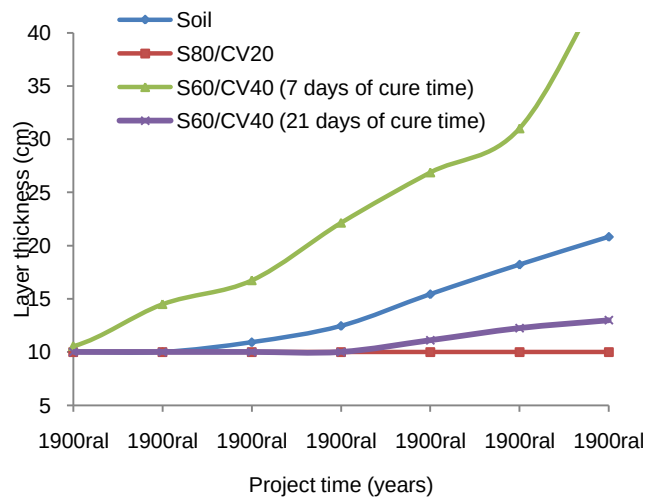

Figure 15. Layer Thickness according to Project Time

CONCLUSIONS

Mixtures with MSW ash inclusion had a mechanical behavior compatible with the requirements for a low traffic volume. The inclusion of 20% of fly ash on the non-lateritic clay soil improved the mechanical behavior and reduced the expansion of the soil. The soil mixed with a content of 40% of fly ash worsened the mechanical behavior compared to pure soil, with the consequent increase in thickness; however, it improved with cure time and cycle loading number, decrease significantly the expansion of the soil.

The results were satisfactory, being dependent on the ash content added, cure time and cycle loading number, highlighting the positive work of MSW fly ash for use in base layers of road pavements, eliminating the current problems of waste disposal in dumps and landfills, putting a noble application to this material.

ACKNOWLEDGEMENT

The authors thank CNPq (MCT/CNPq 14/2009 # 480748/2009-8 project) for the financial support, as well as Usina Verde S.A. for the Municipal Solid Waste ash supply.

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