Applicability of Municipal Solid Waste (MSW) Incineration Ash in Road Pavements Base

Utilisation de cendres d'incinération de déchets solides municipaux (MSW) dans la couche de base de chaussée

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ABSTRACT: This study presents the characteristics of Municipal Solid Waste (MSW) incineration ash, by-product obtained from electric energy generation power plant in Rio de Janeiro - Brazil, to evaluate its applicability in base road pavements layers through the ash mixture with a non-lateritic regional clay soil with very poor mechanical behavior. Chemical, physical, mechanical tests and the mechanistic-empirical design for a typical pavement structure were carried out on the pure soil and also in the soil mixtures with the addition of different ash content (20% and 40%). MSW fly ash reduced expansion of the material, showing increase in the resilient modulus value with time of cure, load cycle number and reduction of mixture water content. Permanent deformation tests showed mixture soil-MSW fly ash reached a state of plastic accommodation. A typical pavement design was carried out by comparing between pure soil and mixture soil-MSW fly ash; the results showed that it is feasible utilize it in low traffic road pavements, highlighting the positive work of MSW fly ash and its environmental advantages.

RÉSUMÉ: Cette étude présente les caractéristiques des cendres d'incinération des déchets solides municipaux (MSW), un sous-produit obtenu à partir d'une centrale de production d'électricité à Rio de Janeiro - Brésil, afin d'évaluer son applicabilité en tant que couche de base des chaussées en mélangeant la cendre avec un sol argileux non latéritique régional de comportement mécanique inacceptable à cet effet. Des essais chimiques, physiques, mécaniques,ainsi que la conception mécaniste-empirique d'une structure de chaussée typique ont été effectués sur le sol pur et aussi sur le mélange de sol avec addition de différentes concentrations de cendres volantes de MSW (20% et 40%). L'inclusion des cendres a réduit l'expansion du sol, indiquant une augmentation de la valeur du module résilient avec le temps de durcissement, le nombre de cycles de charge et la réduction de l'humidité du mélange. Des essais de déformation permanente ont montré que le mélange de sol-cendres volantes des déchets solides municipaux a atteint un stade de déformation plastique. La conception d'une chaussée typique a été réalisée pour comparer le sol pur et le mélange de sol-cendres volantes des déchets solides municipaux, les résultats ont montré que son utilisation est possible dans des chaussées de faible volume de trafic, mettant en évidence l'utilisation positive de ces cendres et ses avantages socio-économiques et environnementaux.

KEYWORDS: MSW fly ash, pavement, deformability properties, permanent deformation, resilient modulus.

1 INTRODUCTION.

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 along with the use of metal detectors; after this process, the composition of MSW is principally organic matter (88%), plastic (10%) and rubber (2%). The MSW is then crushed and separated as fine material and sent to drying. These wastes are sent to the incinerator, which operates at a temperature of 950ºC.

At the end of the incineration process are obtained fly ash and bottom ash, being 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 soil, evaluating deformability and expansibility properties, also 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. Fly ash comes from the burning of municipal solid waste (MSW) at Usina Verde, which is located on Rio de Janeiro / RJ. 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. Since there was no research evidence previous to this topic, 20% and 40% as percentages of fly ash were utilized to add to the soil. The symbols used in this study, which describe the materials and mixtures with percent in weight, are presented in Table 1.

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

3.2 *Experimental tests*

3.2.1 *Chemical and physical characterization*

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

3.2.2 *Resilient modulus test*

The tests were performed according to standardized test in the Geotechnical Laboratory of Federal University of Rio de Janeiro, into molds of 10 x 20 cm compacted at optimum moisture obtained in the compaction test.

In the cyclic load triaxial test, deviator stresses are applied in the sample top, always in the compression direction, furthering a load and unload, whereas the minor principal stress remains constant.

Each sample was subjected to eighteen stresses states were applied, with principal minor stress ranging from 0,021 to 0,137 MPa and deviator stress ranging from 0,021 to 0,412 MPa.

The Resilient Modulus (M_R) of soil is the relationship between the deviator stress (σ_d) applied repeatedly in a sample of soil in triaxial test and the corresponding specific recoverable or resilient strain (ε_r). As shown in Equation 1 (AASHTO TP46-94 1996).

$$M_R = \frac{\sigma_d}{\varepsilon_r} \tag{1}$$

Where:

M_R: resilient modulus;

σ_d: cyclic deviator stress (σ_1 - σ_3);

ε_r: resilient strain (vertical).

The composite model used in this study relates the resilient modulus of minor principal stress and deviator stress, as shown in Equation 2.

$$M_R = k_1.\sigma_3{}^{k_2}\,\sigma_d{}^{k_3} \tag{2}$$

Where:

σ_3: minor principal stress;

σ_d: cyclic deviator stress (σ_1 - σ_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.

In order to evaluate the influence of cure time, optimal water content samples were prepared and next rolled into hermetically closed plastic bags for 7 and 21 days. Soon afterwards, these were proceeded to the resilient modulus tests.

3.2.3 *Permanent deformation test*

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

Three tests were conducted in the Mixture S60/CV40, in the condition of maximum dry density, 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

3.2.4 *Pavement design*

A pavement structure was assumed (Figure 1) considering Rio de Janeiro's weather, with the purpose of exploring the effects of adding MSW fly ash in soil on pavement project one. The thickness and mechanical properties of the coated asphalt and subgrade remain constant, so that only the the thickness of the base may be modified, according to the parameters of resilience for each material. As for the mechanistic-empirical analysis, the computer program SisPav (Franco, 2007) was used. Bernucci (1995) indicates for Brazilian low traffic roads an N value of 10^4 to 10^6 should be used. Thus, in this study, N value of 10^5 was assumed.

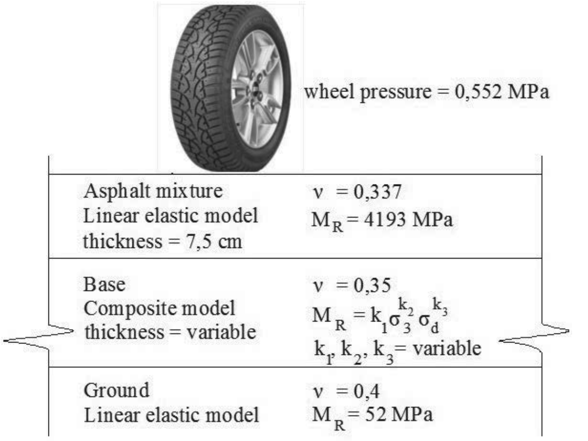

Figure 1. Pavement structure adopted.

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. 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).

4.2 *Physical characterization*

MSW fly ash and mixtures can be noted as follows: first, the Atterberg Limits 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, the inclusion of MSW fly ash decreases the liquid limit and plasticity index, and increases the plastic limit of soil.

According the classification MCT (Nogami & Villibor 1995), the soil is classified as NG' behavior "non-lateritic-clay." When compacted under the conditions of optimum moisture content and maximum dry unit weight for normal energy compaction, these soils present characteristics of traditional highly 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 2).

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

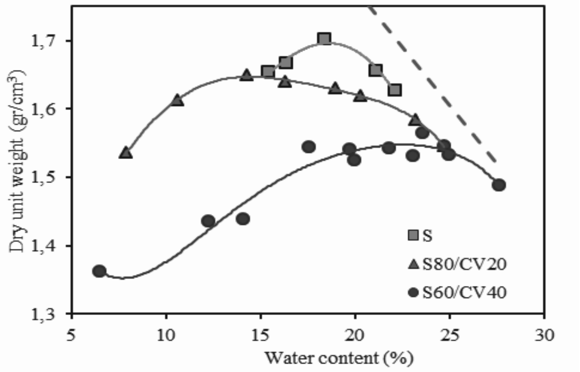

Figure 2. Compaction Curves of Soil and 20% - 40% Soil – Fly Ash Mixtures

4.3 *Effect of MSW fly ash addition on resilient modulus*

The results of Resilient Modulus tests (Figure 3) 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.

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 4).

The mixture with 20% MSW fly ash was assessed with several different water contents. The results indicated the resilient modulus increased as the water content decreased.

4.4 *Effect of MSW fly ash addition on permanent deformation*

As shown in the Figure 5, the permanent deformation tends to stabilize reaching a plateau, it´s observed that Test 3 has a higher permanent deformation, this is due to increased tensions applied to the test.

The resilient modulus is increased with the number of load cycles (Figure 6), this can be explained by the diminution of elastic strain. The occurrence of the plastic accommodation (i.e. Shakedown) was investigated by using the behavior model developed by Dawson and Wellner, cited by Werkmeister (2003). The test results of permanent deformation test for the MSW fly ash – soil mixture were obtained and are displayed by the graph model of Dawson and Wellner cited by Werkmeister (2003) in Figure 7.

By analysis of this Figure it appears that all tests conducted with the MSW fly ash – soil mixture show a typical behavior for level A, i.e., demonstrated plastic accommodation, depending on the model proposed by Werkmeister (2003). The characterization of the level A behavior 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.

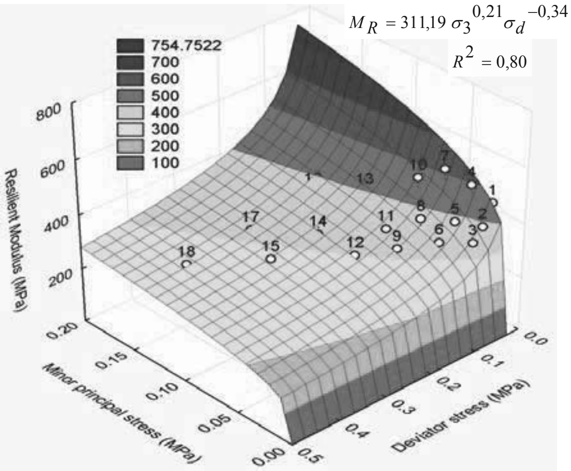

Figure 3. Soil with 40% MSW Fly Ash Resilient Modulus vs. Stresses (21 days of cure)

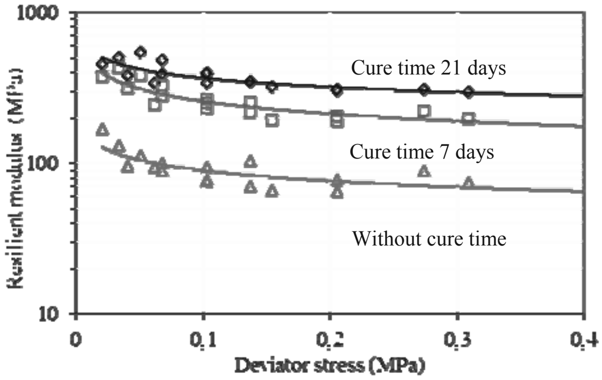

Figure 4. Resilient Modulus vs. Stress of Soil with 40% MSW Fly Ash – Cure Time Variation.

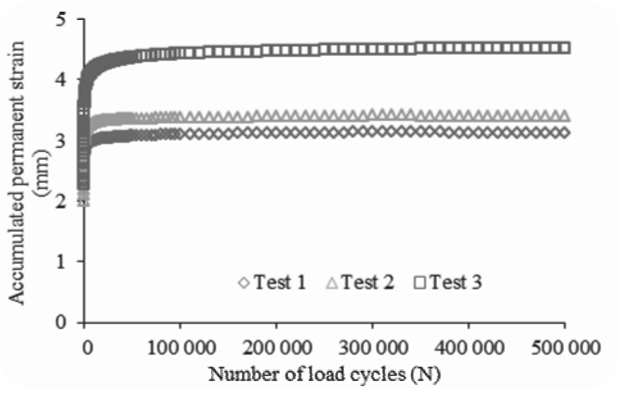

Figure 5. Accumulated Permanent Deformation Variation.

4.5 Effect of MSW fly ash addition on 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 reduced it to 3.6% for 20% fly ash content and fell to 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.

4.6 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. It is shown in Figure 8 the thickness of layers depending on the project period for each type of mixture, which was obtained by the computer program SisPav (Franco, 2007).

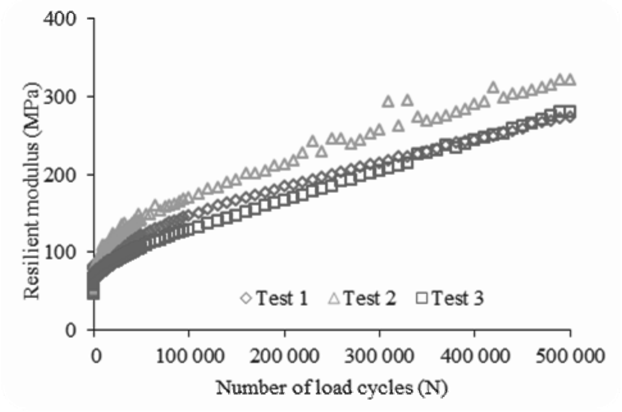

Figure 6. Resilient Modulus Variation.

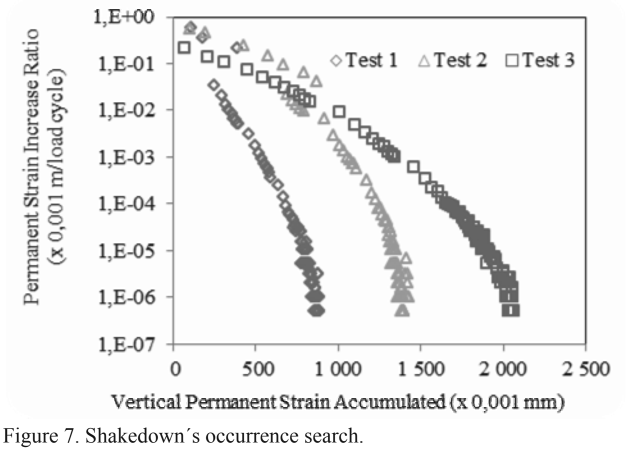

Figure 7. Shakedown´s occurrence search.

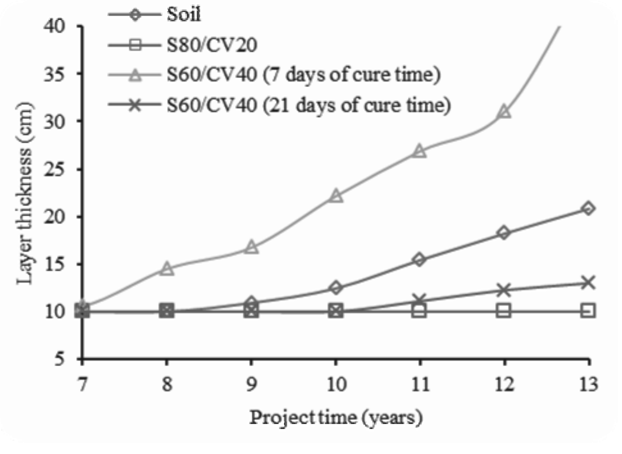

Figure 8. Layer Thickness according to Project Time

5 CONCLUSIONS

Mixtures with the inclusion of MSW fly ash had a mechanical behavior compatible with the requirements for a low traffic volume. The addition of 20% fly ash to 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 decrease the mechanical behavior compared to pure soil, with the consequent increase in thickness; however, it improved with cure time and cycle loading number, decreasing 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.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

AASHTO. 1996. TP46-94 - Standard Test Method for Determining the Resilient Modulus of Soils and Aggregate Materials. American Association of State Highway and Transportation Officials, Washington, D.C.

Bernucci, L. L. B. 1995. Considerations about pavement design using lateritic soils on low traffic volume roads. PhD Thesis. Polytechnic school of University of São Paulo, São Paulo, SP, Brazil (In Portuguese).

Brazilian Technical Standards Association ABNT. NBR 10005/04: *Procedure for obtention leaching extract of solid wastes*.

Brazilian Technical Standards Association ABNT. NBR 10006/04: *Procedure for obtention of solubilized extraction of solid wastes.*

Fontes, C. M. A. 2008. Utilization of the sewage sludge and urban solid waste ashes in high performance concrete. PhD Thesis. Federal University of Rio de Janeiro, Brazil (In Portuguese).

Franco, F. A. C. P. 2007. Mechanistical-empirical asphalt pavement design method - SisPAV. PhD Thesis. Federal University of Rio de Janeiro, Brazil (In Portuguese).

Guimaraes, A. C. R. 2009. A mechanistical empirical method to predict permanent deformation on tropical soils on pavements. PhD Thesis. Federal University of Rio de Janeiro, Brazil (In Portuguese).

Nogami, J. S., Villibor, D. F. 1995. *Pavimentos de Baixo Custo com Solos Lateríticos*, Editora Villibor, São Paulo. 240 p (In Portuguese).

Vizcarra, G.O.C. 2010. Aplicability of municipal solid waste for pavements base. M.Sc. Disssertation. Department of Civil Engineering, Pontifical Catholic University of Rio de Janeiro, Brazil (In Portuguese).

Werkmeister, S. 2003. Permanent Deformation Behavior of Unbound Granular Materials in Pavement Construction. These. Technical University of Dresden.