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Assessment of Soil – MSW Ash mixture mechanical behavior through laboratory testing

Évaluation du comportement mécanique du sol - mélange de cendres MSW par des tests en laboratoire

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ABSTRACT: Industrialization of developing countries has increased in the last years creating a high demand for energy supply. An alternative energy source is the Municipal Solid Waste (MSW) incineration which produces by-products as MSW ash; a regular practice is to dispose this material in landfills requiring appropriate areas. This study assesses the MSW ash applicability in embankments through the ash mixture with a non-lateritic regional clay soil. Chemical, physical and mechanical tests were carried out on the pure soil and in the soil mixture with the addition of different ash content. The addition of MSW fly ash reduced the expansion of the material and the results show that the resilient modulus of soil is dependent on the deviator stress, and the fly ash addition increases the value of resilient modulus. The results were satisfactory, being dependent on the ash content, highlighting the positive work of MSW fly ash usage in embankments.

RÉSUMÉ : L'industrialisation des pays en développement a augmenté ces dernières années, créant une forte demande d'approvisionnement énergétique. Une source d'énergie alternative est l'incinération des déchets solides municipaux (MSW) qui produit des sous-produits sous forme de cendres de MSW ; une pratique courante consiste à éliminer ce matériau dans des décharges nécessitant des zones appropriées. Cette étude évalue l'applicabilité des cendres MSW dans les remblais à travers le mélange de cendres avec un sol argileux régional non latéritique. Des tests chimiques, physiques et mécaniques ont été effectués sur le sol pur et dans le mélange de sol avec l'ajout de différentes teneurs en cendres. L'ajout de cendres volantes MSW a réduit l'expansion du matériau et les résultats montrent que le module d'élasticité du sol dépend de la contrainte du déviateur, et l'ajout de cendres volantes augmente la valeur du module d'élasticité. Les résultats ont été satisfaisants, dépendants de la teneur en cendres, soulignant le travail positif de l'utilisation des cendres volantes MSW dans les remblais.

KEYWORDS: MSW Fly Ash, deformability properties, triaxial testing, resilient modulus.

1 INTRODUCTION.

This study evaluates the mechanical behavior of fly ash obtained from incineration of Municipal Solid Waste (MSW), by mixing the ashes with a non-lateritic regional clay soil. The composition of MSW is primarily organic matter (88%), plastic (10%) and rubber (2%). The MSW is crushed and separated as fine material and sent to the power plant to dry. These wastes are delivered 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 on the bottom of the chamber after combustion. The hot gases and fly ash come out from the chamber after burning and inhaled into the recovery boiler, which is used to produce energy. Thereafter, 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 from the process and calcium hydroxide, which causes mineralization. The solution is reused in the washing process and then, the ash is sent to settling tanks where it is routinely removed and stored. At the end of the incineration process, fly ash and bottom ash are obtained. The volume of both ashes is 8 - 10% of the initial MSW volume, which represent about 80% of bottom ash and 20% of fly ash (Fontes, 2008).

2 OBJECTIVE

The objective of the investigation is to study the effect of MSW fly ash addition on the mechanical behavior of a clay soil.

3 EXPERIMENTAL INVESTIGATION

3.1 *Materials and properties*

The non-lateritic clay soil in this study came from a deposit located in the city of Campo Grande, Rio de Janeiro state in Brazil. The fly ash comes from the burning of municipal solid waste (MSW) at Usina Verde Powerplant, which is located at the same state. The tests were 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. The percentages of fly ash utilized to add to the soil were 20% and 40% respectively. The symbols used in this study, which describe the materials and mixtures with percent in weight, are presented in Table 1.

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.

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

3.2.2 *Resilient modulus test*

The tests were performed according to the standard test in the Geotechnical Laboratory of Federal University of Rio de Janeiro, into cylindrical specimens of 10 x 20 cm compacted at optimum moisture obtained in the Proctor Compaction Test.

In the cyclic load triaxial test, deviator stresses are applied in the sample top, which was always in the compression direction at a 1 Hz frequency, furthering a load and unload, whereas the minor principal stress remains constant.

Firstly, a sequence of loading stages was applied to eliminate initial permanent deformation. Each conditioning stage had 500 loading cycles. The Table 2 shows the stresses used for each stage.

Table 2. Conditioning stages

Stage	σ_3 (kPa)	σ_d (kPa)	q/p	Cycles number
1	70	70	0.75	500
2	70	210	1.5	500
3	105	315	1.5	500

After these stages, a set of eighteen stress states were tested progressively to obtain the resilient modulus (MR) for this material. The stresses levels are shown in the Figure 1.

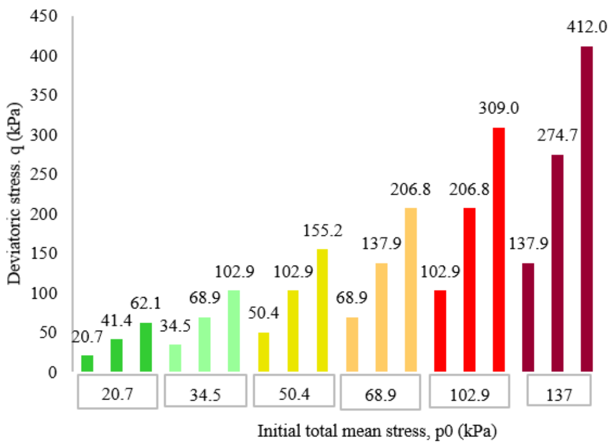

Figure 1. Stresses applied during Resilient Modulus test

The Figure 2 shows all stress paths for the resilient modulus test and the stress ratios (q/p) are indicated as dotted lines.

The Resilient Modulus (MR) of soil is the relationship between the deviator stress (σ_d) applied repeatedly in a soil sample in triaxial test and the corresponding specific recoverable or resilient strain (ε_r). As shown in Equation 1 (AASHTO T307, 2003).

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

Where:
M_R: resilient modulus;
σ_d: cyclic deviator stress (σ_1 - σ_3);
ε_r: resilient strain (vertical).

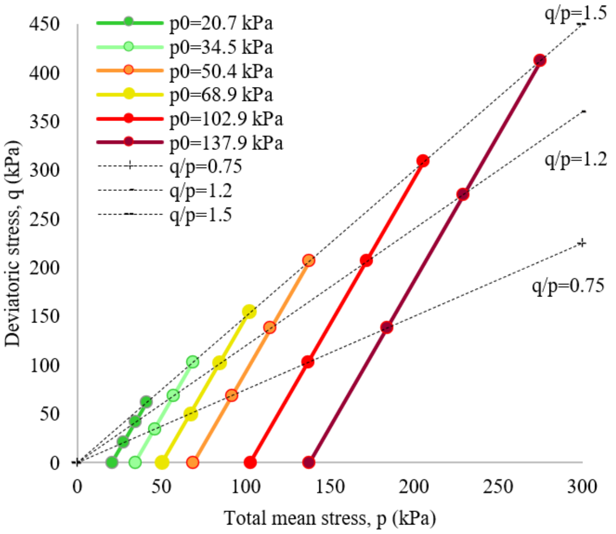

Figure 2. Stress paths applied during MR test in the p-q space

To evaluate the influence of cure time, optimal water content samples were prepared and 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 specimens 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 the Table 3.

Table 3. Permanent Deformation Tests

Test Number	σ_3 (kPa)	σ_d (kPa)	q/p	Cycles number
1	98	294	1.5	500 000
2	118	353	1.5	500 000
3	98	392	1.7	500 000

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 major chemical components of soil, which are normally found in residual soils, are SiO_2, Al_2O_3 and Fe_2O_3, such as shown in the Table 4. 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 as non - dangerous and non-inert (Vizcarra, 2010). The concentration of Calcium oxide (CaO) in MSW Fly Ash is high and could create cementitious bonds between soil particles.

Table 4. Soil, MSW Fly Ash Chemical Composition

Compost	Concentration (%) Soil	Concentration (%) 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*

The natural soil is classified as clay of high plasticity (CH) by the Unified Soil Classification System (USCS). After the addition of MSW fly ash in the soil, the mixture is classified as silty sand (SM). The effect of this inclusion is the decreasing of the liquid limit and plasticity index and the increasing of the plastic limit of soil.

According to the classification MCT (Nogami & Villibor, 1995) utilized for tropical soils in Brazil, the soil is classified as NG' behavior "non-lateritic-clay". These soils present characteristics of traditional highly plastic and expansive clays when they are compacted under the conditions of optimum moisture content and maximum dry unit weight for normal energy compaction.

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 it is one 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 (Table 5 & Figure 3).

Table 5. Soil and mixtures physical characterization

	S	S80/ CV20	S60/ CV40
Specific gravity of solids, Gs	2.709	2.691	2.678
Maximum dry unit weight, γd (kN/m^3)	16.848	16.181	15.249
Optimum water content, w (%)	18.5	14.3	22.5
Void ratio, e	0.58	0.63	0.72
Saturation degree, S (%)	87	61	83

4.3 *Effect of MSW fly ash addition on resilient modulus (MR) of soil in study*

The results of Resilient Modulus test on natural soil in study (Figure 4) show that the Resilient Modulus is dependent on the total mean stress, decreasing when the mean stress is increasing. The same behavior is observed when the stress ratio p/q increases. Higher values of resilient modulus occur at lower stress levels.

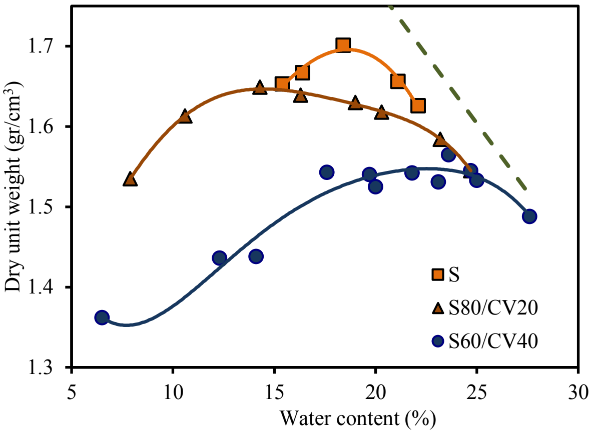

Figure 3. Compaction Curves of Soil and Mixtures.

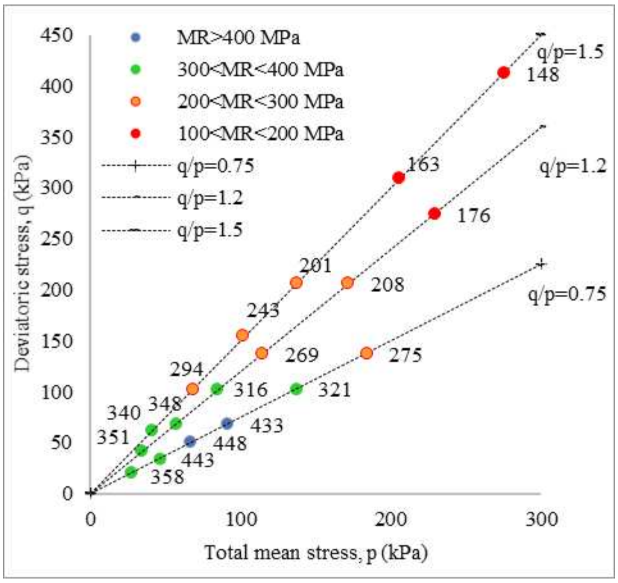

Figure 4. MR of the natural soil in the p-q space

The mixture with 40% MSW fly ash downgraded the mechanical behavior of pure soil (Figure 5), but it improved with cure time (Figure 6). The mixture S60/CV40 was tested immediately after the compaction and the elastic vertical strain for each stress level which is shown in the Figure 7, the strain is higher for high stress levels and stress ratio p/q. Another test conducted in the same mixture with seven days of cure after the compaction, showed a decreasing of the elastic vertical strain to approximately 40% (Figure 8).

The Figure 9 shows the influence of water content on the resilient modulus of the mixture S60/CV40. The resilient modulus decreases with an increase in the water content and total mean stress p. The Figure 10 depicts that the MR decrease in roughly 13 kPa for each increment of 1% in the water content for the stress ratio q/p=1.5; this trend was observed for other stress ratio tested.

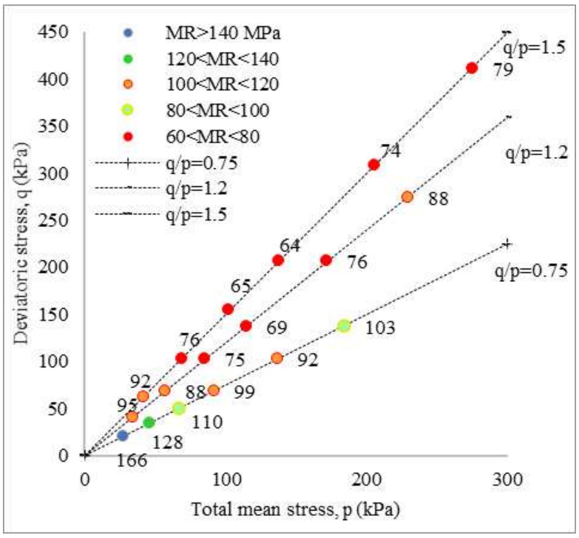

Figure 5. MR of the mixture S60/CV40 tested immediately after the compaction.

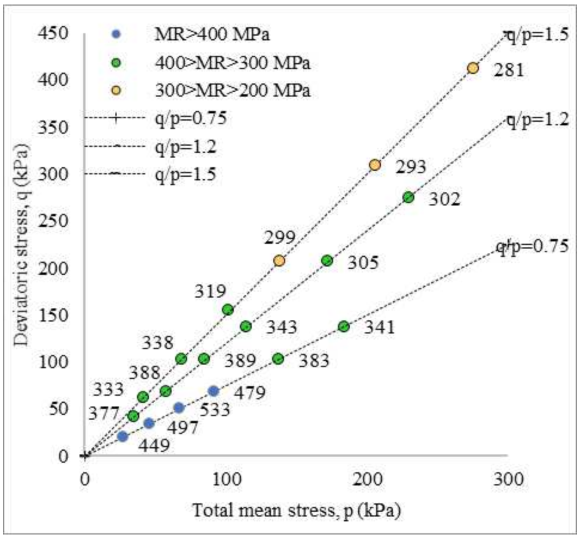

Figure 6. MR of the mixture S60/CV40 tested 21 days of cure after the compaction.

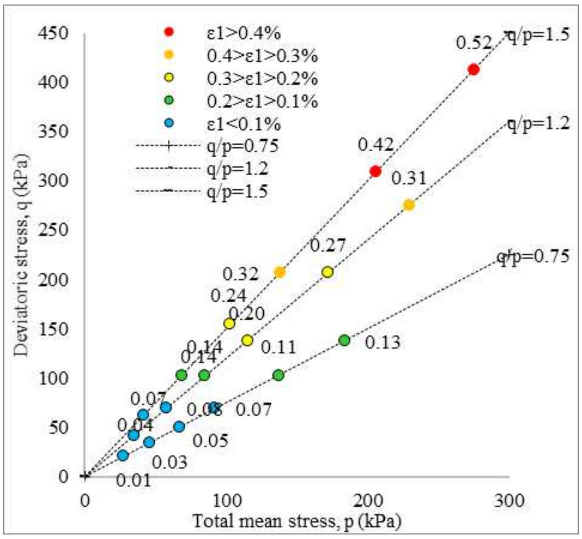

Figure 7. Elastic vertical strain of the mixture S60/CV40 tested immediately after the compaction.

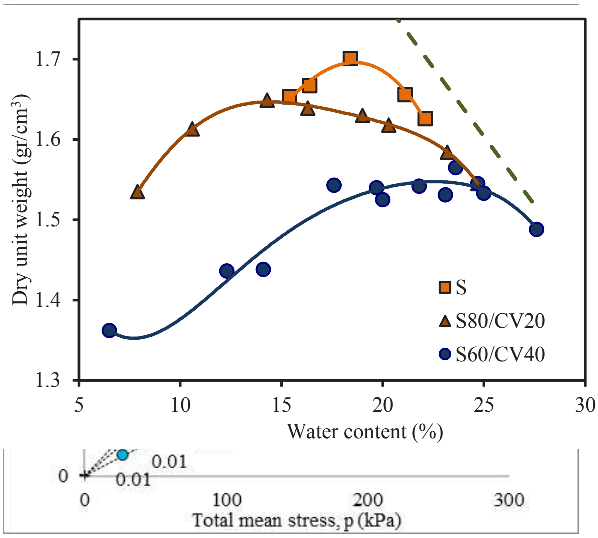

Figure 8. Elastic vertical strain of the mixture S60/CV40 tested after 7 days of cure after the compaction.

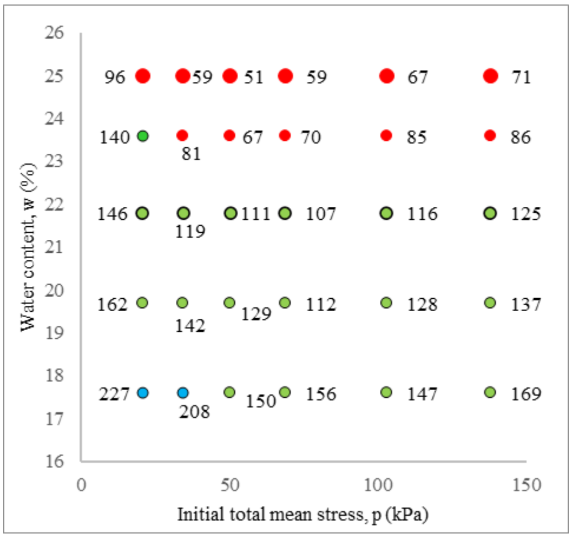

Figure 9. Resilient modulus in MPa of the mixture S60/CV40 tested immediately after the compaction. Legend: ● MR > 200 MPa; ● 200 MPa > MR > 100 MPa; ● MR < 100 MPa;

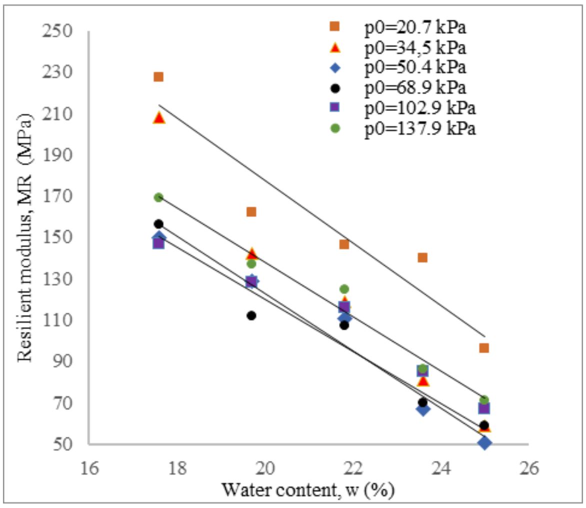

Figure 10. Resilient modulus of the mixture S60/CV40 tested immediately after the compaction vs water content (case: stress ratio q/p=1.5)

4.4 *Effect of MSW fly ash addition on permanent deformation of soil in study*

As shown in the Figure 11, the permanent deformation tends to stabilize reaching a plateau, it is observed that Test 3 has a higher permanent deformation, this is due to higher stress ratio tested.

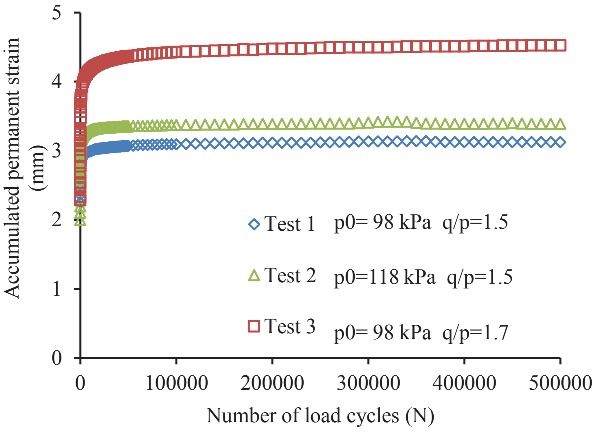

Figure 11. Accumulated Permanent deformation variation of the mixture S60/CV40.

The resilient modulus is increased with the number of load cycles (Figure 12), this can be explained by the diminution of elastic strain. In the range between 100 000 to 500 000 load cycles, the increase is roughly 38 MPa for each 100 000 load cycles for all three tests performed.

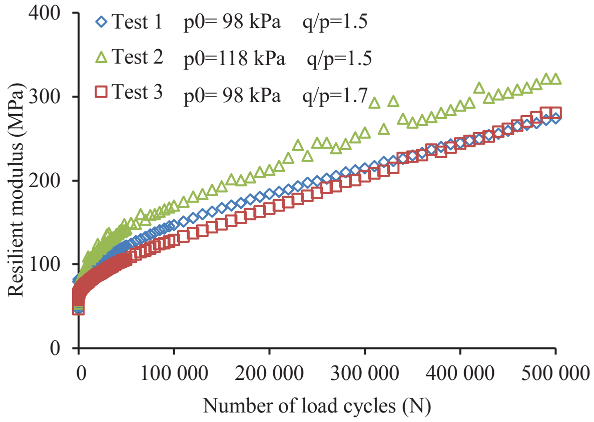

Figure 12. Resilient Modulus variation of the mixture S60/CV40

4.3.1.4 *Effect of MSW fly ash addition on expansibility of soil in study*

The MSW fly ash decreases the expansion of the soil in the 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 can deteriorate the mechanical behavior, resulting in a thicker layer.

5 CONCLUSIONS

The addition of fly ash to the non-lateritic clay soil improved the mechanical behavior after a period of cure time and reduced the expansion of the soil.

The water content is an important factor to evaluate the resilient modulus of the mixture; it was demonstrated that a high value of water content decreases the resilient modulus value. Another factor is the cure time that had a beneficial influence on improving the mechanical behavior which is likely due to high calcium oxide amount of the MSW fly ash.

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 embankments, providing an alternative solution to the waste disposal problem.

6 ACKNOWLEDGEMENTS

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