APPLICATION OF MUNICIPAL SOLID WASTE INCINERATION BOTTOM ASH IN ROAD CONSTRUCTION. A CASE STUDY

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ABSTRACT

The increased production of Municipal Solid Waste (MSW) in large cities, and the need for restricting the use of landfills to the so-called "ultimate waste" has led to a National and European strategy on recycling and energetic development of MSW, focusing on re-use and treatment operations. This fact, associated with the high energetic potential of MSW, led to the construction of an energetic development plant, located in S. João da Talha, Portugal. This plant is intended to incinerate municipal waste produced in the municipalities of the northern Lisbon area, which are managed by the company Valorsul S.A..

Given its responsibility for the incineration of MSW from the Lisbon area and for the subsequent re-use of the bottom ash deriving from the MSW Incineration (MSWI), that company promoted a research study conducted by National Laboratory of Civil Engineering (LNEC) about the possible application of MSWI bottom ash to road construction.

In a first stage, the study performed by LNEC included a wide range of laboratory tests aiming at the physical and chemical characterization of MSWI bottom ash (MSWIBA).

In a second stage, the execution of two experimental pavement sections with the application of MSWIBA on capping and sub-base courses was followed up. The main purpose of this second stage was to assess the site application conditions of MSWIBA, using normal construction procedures. Simultaneously, the aim was also to evaluate the structural performance of pavements built with these materials. *In situ* tests were performed to assess the mechanical performance and the compaction characteristics of layers made with MSWIBA.

All the materials used in sub-base courses and capping layers were also physically and chemically characterized, in laboratory, by LNEC.

This paper presents the main results obtained in the studies concerning the experimental sections and in the laboratory characterization of materials used, and presents recommendations for the application of treated MSWI bottom ash, in road construction.

Keywords: MSWI bottom ash, road construction, unbound pavement layers

1. INTRODUCTION

The production of MSW in large cities, and the need for reducing the use of landfills to the so-called “ultimate waste” has led to a National and European strategy on recycling and energetic development of MSW, focusing on re-use and treatment operations. This fact, associated with the high energetic potential of MSW, led to the construction of an energetic development plant, located in S. João da Talha. This plant is intended to incinerate municipal waste produced in the municipalities of the northern Lisbon area, which are managed by the company Valorsul S.A..

Given its responsibility for the incineration of MSW from the Lisbon area and for the re-use of the bottom ash deriving from the MSW Incineration, that company promoted a research study conducted by LNEC about the feasibility application of MSWI bottom ash to road construction. Concerns with environment preservation, namely with the search for alternatives to new quarries or alluvial aggregates exploitation increase the importance of promoting the application of alternative materials to road construction.

In the first stage, the study performed by LNEC included a wide range of laboratory tests aiming at the physical and chemical characterisation of MSWI bottom ash and comparison with established limits.

In the second stage, the execution of two experimental pavement sections with the application of MSWIBA in capping and sub-base courses was followed up. The main purpose of this second stage was to assess the site application conditions of MSWIBA, using usual construction procedures. Simultaneously, the aim was also to evaluate the structural performance of pavements built with these materials. In situ tests were performed to assess the mechanical response and the compaction characteristics of layers made with MSWI bottom ash.

The experimental pavements followed up by LNEC included re-paving works in Sta Iria da Azóia section, and construction works at the Organic Treatment and Development Plant (OTDP section) of Valorsul S.A., in Amadora.

All the materials used in sub-base courses and capping layers were also physically and chemically characterized, in the laboratory, by LNEC. Laboratory mechanical characteristics of applied materials are included in a third stage, in development. After the conclusion of the experimental sections, several test campaigns were performed with the Falling Weight Deflectometer (FWD) to evaluate the structural characteristics of the pavement layers.

The results obtained during the follow up of the experimental pavement sections construction made possible to evaluate the possibility of using traditional construction procedures for application of MSWI bottom ash in unbound layers construction.

2. LABORATORY CHARACTERISATION OF MUNICIPAL SOLID WASTE INCINERATION BOTTOM ASH

The laboratory characterisation of MSWIBA included the visual identification of its components, the determination of the chemical composition of both the MSWIBA and the leachate after leaching, as well as the physical characterisation using the properties normally used in road construction specifications.

Considering that MSWIBA are susceptible of grading alterations under the action of compaction equipment, grading analysis was conducted on samples collected before and after application.

2.1 Visual identification of components

Visual identification of MSWIBA samples composition was performed according to an internal laboratory procedure, on the material retained in sieve ASTM Nº. 4 (4.75 mm), which was obtained from samples collected in the two experimental pavement sections, before application.

Table 1 presents the results obtained. Figure 1 shows the four components of the MSWIBA, after separation.

From the results obtained, it can be concluded that glass is the prevailing component in the MSWIBA, followed by tile and brick. The results obtained are similar to other results previously obtained for this type of material (HADJADJI, T.; 2001).

Table 1: Components of MSWIBA samples – visual identification

MSWIBA components (% by the total mass of the sample)	Stª Iria section	OTDP section
Glass	50.2	51.4
Tile and brick	12.4	12.0
Metals	2.0	1.6

Figure 1 Components of the MSWIBA samples visually identified

2.2 Chemical characterisation

MSWIBA produced by Valorsul are being monitored through periodic tests in order to evaluate chemical concentrations of the leachate, after leaching, (HADJADJI, T.; 2001). Generally, it has been observed that these materials can be considered as “re-usable” for sub-base courses and capping layers, from an environmental point of view.

Within the framework of the present study, the chemical characterisation of both the MSWIBA (Table 2) and the leachate after leaching (Table 3) was performed on samples collected during the execution of the two experimental pavement sections.

The results obtained, when compared with those defined in Portuguese Decree-law 152/2002, which establishes the acceptance criteria for landfills for inert waste, (ESTEVES, A.M.,; MARTINS, I., 2005) (legal document in force at the date of execution of the study), demonstrate that these are within the limits defined in the above Decree-Law. These results are also acceptable when compared to the limits presented at the Council Decision of 19 December 2002 (2003/33/EC) that establishes criteria for landfills for non-hazardous waste.

Table 2: Chemical characterisation of MSWIBA (ESTEVES, A.M.,; MARTINS, I., 2005)

Sample	Element	Residue (mg/kg)	Portuguese Decree-law 152/2002* (mg/kg)
St[a] Iria Section	Cadmium	1,95	50
	Lead	1140	2000
	Copper	860	6000
	Chromium	66.5	3000
	Nickel	52.5	2000
	Zinc	3510	8000
	Loss at 105°C (%)	0.43	65
OTDP Section	Cadmium	1.20	50
	Lead	775	2000
	Copper	1140	6000
	Chromium	70.0	3000
	Nickel	57.5	2000
	Zinc	2010	8000
	Loss at 105°C (%)	0.37	65

* Limit values defined in Table 2 of Annex III of Portuguese Decree-law 152/2002 for the class of landfills for inert waste.

Table 3: Chemical characterisation of leachate after leaching of MSWIBA sample, (ESTEVES, A.M,; MARTINS, I., 2005)

Sample	Parameters	Leachate*	Portuguese Decree-law 152/2002****
St[a] Iria Section	pH	11.00	5.5<x<12
	Conductivity (mS/cm)	1.6	0<y<50
	Chlorides (mg/l)**	340	500
	Sulphates (mg/l)***	357	500
	Cadmium (mg/l)	$<62 \times 10^{-4}$	0,1
	Lead (mg/l)	1.7×10^{-2}	0.5
	Copper (mg/l)	1.0	2
	Chromium (mg/l)	2.7×10^{-2}	0.5
	Nickel (mg/l)	5.3×10^{-3}	0.5
	Zinc (mg/l)	2.4×10^{-2}	2
OTDP Section	pH	11.25	5.5<x<12
	Conductivity (mS/cm)	1.5	0<y<50
	Chlorides (mg/l)	270	500
	Sulphates (mg/l)	223	500
	Cadmium (mg/l)	$<62 \times 10^{-4}$	0.1
	Lead (mg/l)	1.8×10^{-2}	0.5
	Copper (mg/l)	7.5×10^{-1}	2
	Chromium (mg/l)	2.8×10^{-2}	0.5
	Nickel (mg/l)	3.1×10^{-3}	0.5
	Zinc (mg/l)	3.7×10^{-2}	2

* Leaching according DIN 38414 part 4

** Chloride concentration according NP 423

*** Sulphate concentration according NP 413

**** Limit values defined in Table 3 of Annex III of Portuguese Decree-law 152/2002 for the class of landfills for inert waste.

2.3 Physical characterisation

In order to physically characterise MSWIBA used on capping and sub-base courses of Sta Iria da Azóia and OTDP sections, the followed tests were performed:

1. Density and water absorption;
2. Determination of particle size distribution;
3. Atterberg limits;
4. Sand equivalent test;
5. Methylene blue test.

Wherever possible, tests were performed by two methods: a) using the applicable standard tests mentioned in the road construction specifications in Portugal; b) using Aggregate European Standards.

Table 4 summarises the results obtained in physical characterisation of samples collected on the two experimental pavement sections and established a comparison with the values defined by road construction specifications in Portugal, for sub-base courses (EP, E.P.E, 1998). Figure 2 presents the particle size distribution curves of tested samples, before and after application, as well as the particle size distribution bands established by road construction specifications in Portugal for sub-base layers. This figure also presents the average particle size distribution curves obtained in previous studies on MSWIBA (HADJADJI, T.; 2001).

Table 4: Physical characterisation of MSWIBA before application

Characteristics		Sta Iria section	OTDP section	Portugal specifications
Atterberg limits	NP 143-1969	NP (non-plastic)	NP (non-plastic)	NP (non-plastic)
Sand equivalent test	LNEC E199-1967	40%	44%	> 45%
	NP EN 933-8:2002	38%	40%	---
Methylene blue test	NP EN 933-9:2002	0.49 g/kg	0.50 g/kg	---

The results obtained for the physical characterisation of MSWIBA samples show that these materials do not comply with the Portuguese specifications for conventional materials applied in sub-base layers since the maximum particle size is smaller than the specified and the Equivalent Sand values are slightly lower than the minimum specified.

MSWIBA samples showed some degree of alteration in the particle size distribution after compaction. Therefore, their application should be preceded by the execution of experimental pavement sections, in order to adjust compaction methodology.

As concluded in previous studies, (HADJADJI, T.; 2001), MSWIBA are lighter materials than natural aggregates usually used in unbound granular layers, and have a higher absorption, particularly in the fine fraction. Therefore, the optimal water contents obtained in Proctor compaction tests are higher than values usually obtained for natural aggregates, being necessary some precautions during its application and compaction.

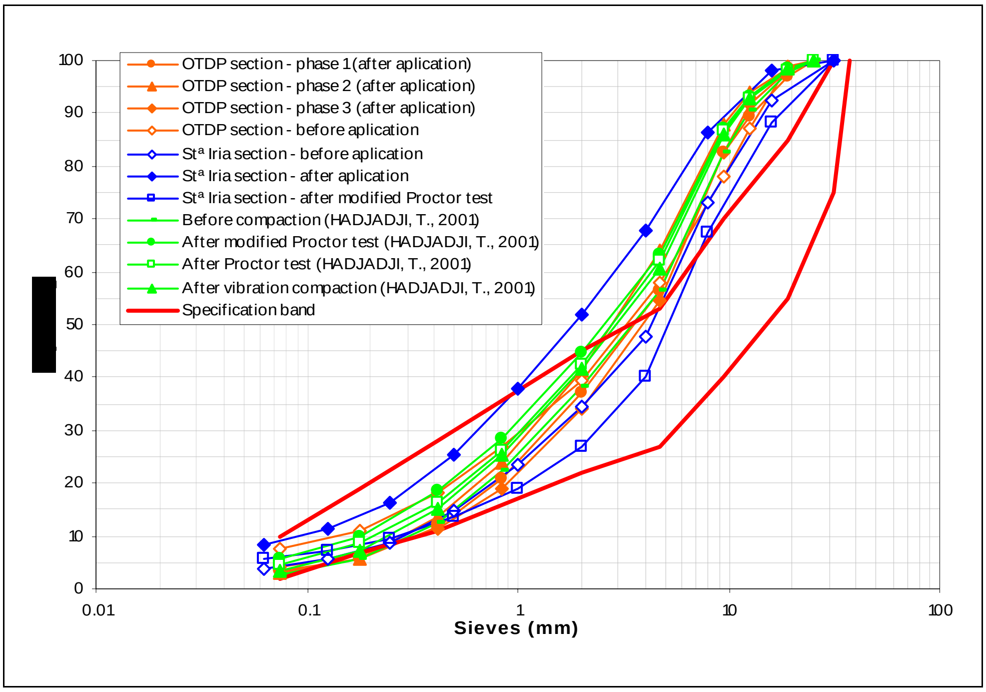

Figure 2 Particle size distribution curves of MSWIBA and of Portugal specifications

3. APPLICATION OF MSW IN EXPERIMENTAL PAVEMENT SECTIONS

3.1 Stª Iria section

The Stª Iria experimental section, with 150 m length and 3.5 width, has a flexible pavement, consisting of unbound granular base and sub-base layers (with natural crushed aggregates or MSWIBA), each layer having 150 mm thickness, as well asphalt binder and wearing courses with 40 mm and 50 mm thickness, respectively.

A reference section was built consisting on base and sub-base layers with conventional aggregate materials. Although assuming that MSWIBA may not be appropriate to be used in base layers, a decision was made to build a section with both base and sub-base layers made of MSWIBA to assess their performance.

Thus, three types of pavement structures were used in Stª Iria experimental pavement section (Figure 3).

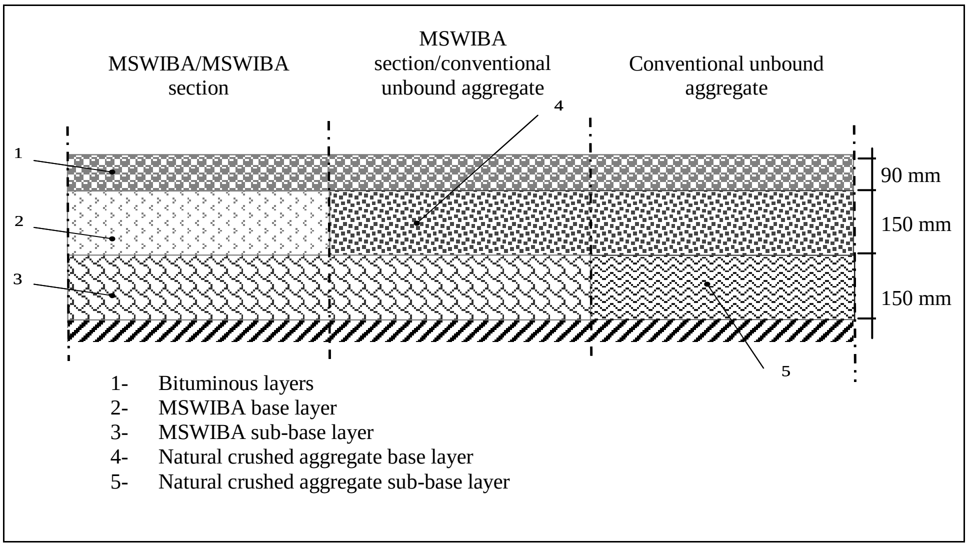

Figure 3 Stª Iria da Azóia experimental pavement section strucuture

The application of MSWIBA layers in Stª Iria experimental sections was made using standard road construction equipment. Granular layers were compacted with double drum vibratory rollers with 726 kg and 2503 kg weight. Paving works were negatively affected by various conditioning factors, due to the fact that pavement was open to traffic during construction.

In situ tests performed by LNEC on MSWIBA layers showed that these layers were compacted with moisture content generally below the optimum values, and that the water content was not homogeneous throughout the layer depth.

The compaction levels obtained in MSWIBA layers were, in some cases, considered insufficient. Lastly, it is observed that some difficulties have arisen during application of the tack coat on the MSWIBA layer, for the section in which it was used as the base layer, due to some alteration in the particle size distribution after compaction.

3.2 OTDP section

The general solution considered for the OTDP section is a flexible pavement, which consists of a MSWIBA sub-base layer and a base layer with crushed aggregate, each being 150 mm thick, an asphalt binder course with 40mm thickness and an asphalt layer wearing course 30 mm thick. The capping layer was also performed with MSWIBA applied on soils with CBR values of about 5% in excavation, and from 8 to 10% in fill. Pavement dimensioning has been done by assuming a deformability modulus of 80 MPa for the foundation (foundation class F2).

Experimental pavement section was divided into three experimental sections, which were designated as phase 1, 2 and 3. Figure 4 presents a schematic drawing of the cross-section adopted for the pavement. Each phase has about 200 m length and 3.5 m width.

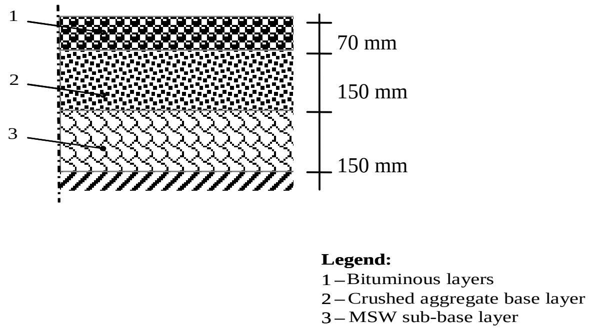

Figure 4 OTDP experimental pavemetn section strucuture

Similarly to St[a] Iria, the application of MSWIBA in capping layers and sub-base layers was performed with standard road equipment. From the results obtained in the tests performed by LNEC it was concluded that, generally, the minimum compaction levels established in the specifications were achieved for the MSWIBA layers.

Construction of the experimental pavement sections at the OTDS proved that the use of conventional procedures and equipment has not raised any difficulty for application of MSWIBA in pavement construction. Given the need to ensure a proper distribution of compaction water throughout the constructed layer, and in view of the possibility of alteration in the grain size of the MSWIBA as a result of the action of the compaction equipment, it is recommended that the application of these materials in pavement layers should always be preceded by the execution of an experimental section so as to optimize the construction procedure, defining the roller characteristics and the number of passes.

4. IN SITU LAYERS DEFORMABILITY CHARACTERISATION

Falling weight deflectometer tests (FWD) were performed for the mechanical characterisation of St[a] Iria and OTDP experimental pavement sections (COST 336, 1996). The results obtained were back-analysed for determination of layer moduli, based on multi-layered linear elastic model using ELSYM 5 software (KOPPERMAN, S. *et al*., 1985).

FWD tests were performed over the entire length of the experimental pavement sections, every 10 m, immediately after works conclusion and after a few months, in order to evaluate a possible evolution of the structural characteristics of the MSWIBA layers.

Figures 6 and 7 present the measured deflections obtained in the campaigns performed on St[a] Iria experimental pavement sections with conventional materials and with MSWIBA on the sub-base layer, respectively. Figure 8 presents the evolution of deflections obtained in the campaigns conducted in the OTDP experimental pavement section.

The results obtained in all sub-base experimental sections where MSWIBA was applied indicate a positive evolution of structural performance, represented by a reduction in the average values of deflections measured and by the corresponding variability. The magnitude of the values of the maximum deflections obtained for the OTDP sections is significantly less than the one obtained for Stª Iria experimental pavement section. As mentioned before the Stª Iria work was developed in adverse conditions.

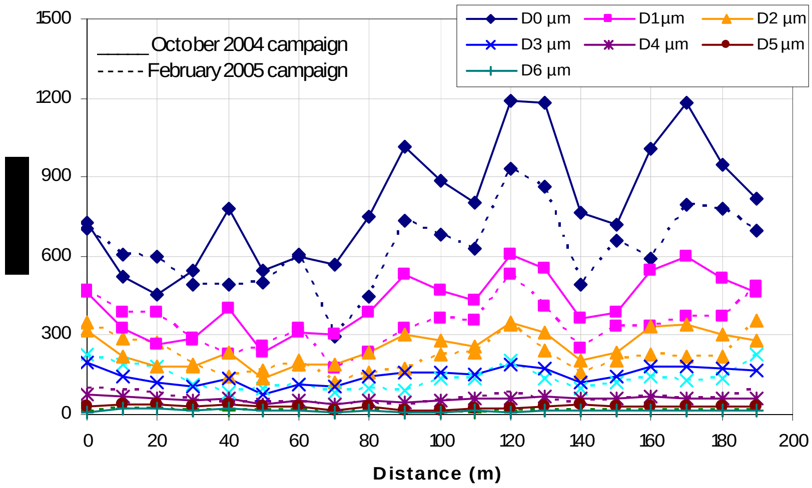

Figure 6 Stª Iria FWD deflections – MSWIBA/crushed aggregate section

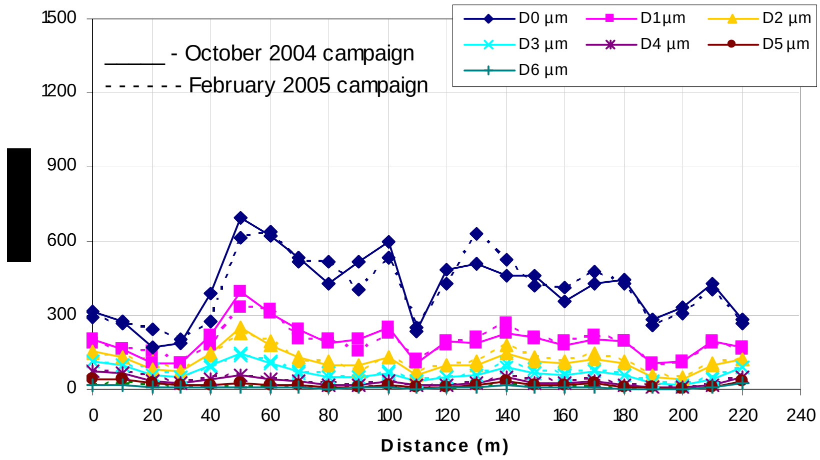

Figure 7 Stª Iria FWD deflections – crushed aggregate section

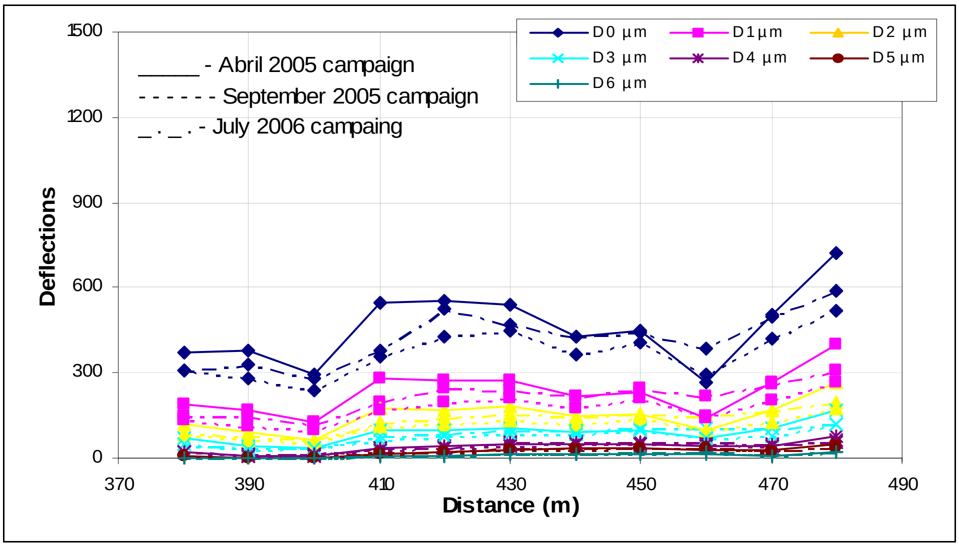

Figure 8 OTDP experimental pavement section strucuture – phase 2

Table 5 presents the results obtained for layer moduli in the OTDP section in May 2005 and in July 2006. The 15% percentile deflections were selected as representative of each of the test campaigns.

Table 5 shows that the E moduli of MSWIBA sub-base layers are of the magnitude generally obtained for granular layers with conventional materials.

Table 5 Models of structural performance established on the basis of the test campaigns performed on the OTDP – phase 2

Campaign	Asphalt layers		Base course		Sub-base course		Foundation(1)	
	H_B (m)	E_B (MPa)	H_{BC} (m)	E_{BC} (MPa)	H_{MSW} (m)	E_{MSW} (MPa)	H_{FS} (m)	E_{FS} (MPa)
April 2005	0.07	3800	0.15	320	0.15	200	1.20	100
July 2006	0.07	4400	0.15	370	0.15	250	1.20	110

LEGEND

(1) Upper subgrade layer (FS); lower semi-infinite subgrade layer with 1000 MPa modulus;
H Layer thickness;
E Layer modulus.

According to the results obtained in the tests performed up to now, it can be considered that even though MSWIBA do not fulfil the specifications for conventional materials applied in sub-base layers, it can be an interesting alternative as sub-base materials for low volume roads. In order to corroborate this conclusion, further studies should be done to assess the long-term performance of layers containing these materials by the long term monitoring up of experimental sections and by the execution of triaxial cycling tests, in order to assess their resistance to permanent deformation.

5. FINAL REMARKS

The results presented in this paper show that, although MSWIBA do not comply with the specifications for conventional granular materials for sub-base layers, they can be applied in sub-base layers for low volume roads, provided that good construction practices are used, after an adequate laboratory characterization.

It is recommended that an experimental section is always performed, for adjustment of construction procedures for this type of material, namely in order to define the roller characteristics and the number of passes.

FWD test results performed on pavement sections built with MSWIBA in the sub-base layer have shown that good mechanical characteristics can be obtained with these materials, even similar to those obtain with conventional materials. These characteristics seem to improve with time.

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