ASSESSMENT OF A FULL-SCALE TEST TRACK USING STABILIZED BOTTOM ASHES ON SUB-BASE AND BASE LAYERS FOR ROAD PAVEMENTS

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ABSTRACT

Stabilized Bottom Ashes (SBA) obtained as a by-product of Municipal Solid Waste Incinerators (MSWI) are considered hazardous waste which has a major environmental impact.

This paper reports the results of part of a comprehensive research project regarding the application of SBA as a granular aggregate for road pavements, in particular for granular, unbound and cement-treated layers. The focus of this paper is the analysis of results from laboratory optimization and a full-scale test track in order to study the structural performance of a granular sub-base and a cement-treated base layer made of SBAs. Sensitivity analysis carried out during the laboratory phase showed the optimum content to be 20% and 10% (weight BA/weight dry aggregates) for granular sub-base and cement-treated base respectively. The study also considered the environmental compatibility of both SBA and mixtures using leaching tests. A number of in-situ and laboratory tests were performed, with the aim of evaluating the volumetric characteristics and the mechanical behavior of the mixture used on the full-scale track, and to compare the obtained results with those from previous laboratory research.

The results obtained based on the performance of the test track in-situ as well as in laboratory phase, showed that SBA can be incorporated as aggregates in sub-base and cement-treated base, exhibiting a good performance for roadways with a low volume of traffic. As for the environmental tests, SBA fulfilled the requirements established by the Italian Ministerial Specifications.

Keywords: Stabilized bottom ashes, granular sub-base, cement-treated base, full scale test track, mechanical performance.

INTRODUCTION

Stabilized Bottom Ashes (SBAs) obtained as a by-product of Municipal Solid Waste Incinerators (MSWI) are considered hazardous waste with a major impact on the environment. Taking into account that thousands of millions of tons are produced every year around the world (ACAA, 2010), it is paramount to study possible and reliable alternative methods for managing this kind of refuse. Some applications for bottom ashes include its use as: filler material for structural applications and embankments, aggregates in road bases, sub-bases, and pavement, feed stock in the production of cement, aggregate in lightweight concrete products, and as a snow and ice traction control material (EPA, 2012). However, to incorporate bottom ashes on road base and sub-base is not an easy task, for the variability of its physical, chemical, and engineering characteristics (Forteza et al, 2004, Huang, 1990). The chemical composition of the BA depends on the type and source; normally they come from differentiated urban waste collection. A study of the composition shows that the primary elements are Si, Al, Fe, Mg, Ca, K, Na and Cl. In addition, SiO2, Al2O3, CaO, Fe2O3, Na2O, K2O are the common oxides found in ash, but SiO2 is the most abundant compound that exists in MSWI bottom ash (Charles et al, 2010, Kim et al, 2005, Huang 1990). Depending on the incinerator system, BA may have different characteristics: in some cases BA are characterized by having a highly porous surface, high absorption capacity and low density (Mostafa and Khalid 2010); in other cases, due to the incinerator vitrification process, BA may present low superficial porosity and high density (Toraldo et al., 2009). In addition, the literature reports the brittle and weak structure of the BA as a particular characteristic, with Los Angeles coefficient (LAC) ranging from 40% to 50% (Forteza et al., 2004, Toraldo et al., 2009, Huang., 1990, Nunes et al., 1996, Moulton., 1973).

Within the framework described above, and in order to evaluate the environmental and technical suitability for using BA in road pavement, a comprehensive research project was carried out at the Road Research Laboratory, Politecnico di Milano, Italy, funded by the Italian Ministry of Universities, Research and Education. The project comprised two phases: the preliminary phase, developed in the lab, focusing on the optimization of SBA content, and a second one involving the construction and evaluation of the performance on a full-scale test track.

The focus of this paper is to present a comparative analysis between the results obtained in the first phase (laboratory scale) and those of the second phase (real scale on the test track) concerning granular sub-base (GSB) and cement-treated base (CTB) materials with SBAs, with the aim of analyzing the mixing effects in a real scale and the performance in the constructive process. For this a number of lab and in-situ tests were performed, with the aim of evaluating the volumetric characteristics and the mechanical behavior of these mixtures. The study also considered the environmental compatibility of both SBA and mixtures by way of leaching tests.

EXPERIMENTAL PROGRAM, THE FULL-SCALE TEST TRACK AND MATERIALS

EXPERIMENTAL PROGRAM

The first part of the research was conducted in the laboratory with the purpose of optimizing the SBAs content in both GSB and CTB. For both material samples, three substitution quantities of SBAs were studied with respect of the percentage of lithic aggregates by weight (10%, 20%, and 30%), as well as a control sample without SBAs.

For GSB, the laboratory tests intended to determine the moisture content of the lithic aggregate without SBAs (w_{opt}=7%±0.5%) according to the Modified Proctor method (UNI EN 13286-2), the variations in both the Maximum Dry Density(MDD) with an increasing SBA content, and the Californian Bearing Ratio (CBR), according to UNI EN 10009.

The CTB test program focused on establishing the optimum cement content (3%, 4%, or 5% percentage in weight with respect of aggregates weight) by means of the Unconfined Compressive Strength Test UCS (EN 13286-41, Indirect Tensile Strength Test ITS (EN 13286-42) and the Elastic Stiffness Test (ES at 20°C and horizontal deformation of 100 kPa, rise time equal to 124 ms) at a number of curing times (7, 14 and 28 days). Because the aggregates for the CTB manufacture were the same as for GSB, the moisture content was 7%±0.5% as well.

In the second part of the research, the best-performing samples (GSB with 20% of SBAs and CTB with 10% of SBAs and 5% of cement) were selected for the construction of the full-scale test track. These optimized samples were then tested in the laboratory by repeating the test program carried out in the first phase for as long as in the full-scale test track, determining the Deflection Modulus (Md) in the range comprising from 0.15 to 0.25 MPa, by using a Static Plate Load Test (SPLT) (ASTM D1196-04) and the Dynamic Modulus (E_{LFWD}) by means of a Portable Falling Weight Deflectometer (CEN Workshop Agreement CWA 15846:2008) with 10 kg and 15 Kg falling weights.

THE FULL -SCALE TEST TRACK

The full-scale test track was constructed in the research facility field at the Road Research Laboratory, Politecnico di Milano, 20 m long and 3 m wide. The pavement structure comprised a subgrade created by mixing the excavated material and the existing subgrade, with the aim of providing a homogeneous foundation for the new structure. Above the subgrade layer, a GSB of 0.20 m thick was created containing 20% of SBA (percentage by weight with respect to both aggregate dry weight and SBAs weight), as obtained from the prior laboratory phase. As a base layer, a CTB 0.15 m thick with a 10% of SBA (percentage by weight with respect of both aggregate dry weight and SBA weight) and 5% of cement and 7% of moisture contents (percentage in weight with respect of the aggregate dry weight) was placed.

The test track construction lasted seven working days, spaced by the required technical periods (curing time) between each layer's placing. The subgrade was prepared by using natural excavation materials with a classification category of A-2, CBR of 16% (Wopt= 5%). The compaction process involved passing a Smooth-Drum Vibratory Roller ten times in order to to achieve the maximum density (2100 Kg/m^3). Between the conformed subgrade and the GSB a geotextil with a separation function was laid. The same compaction energy was applied for the GSB and CTB (see construction process of the test track Figure 1). The layout of the CTB was carried out with an Asphalt Paver at 5 m/min.

Figure 1. Test track construction

For each layer of the Full-Scale Test Track the above mentioned tests were carried out. To this aim, the Test Track was divided into 5 sections (2 sections: 2m long, and 3 sections: 4 m long) in order to adequately control all the performance variables (Figure 2).

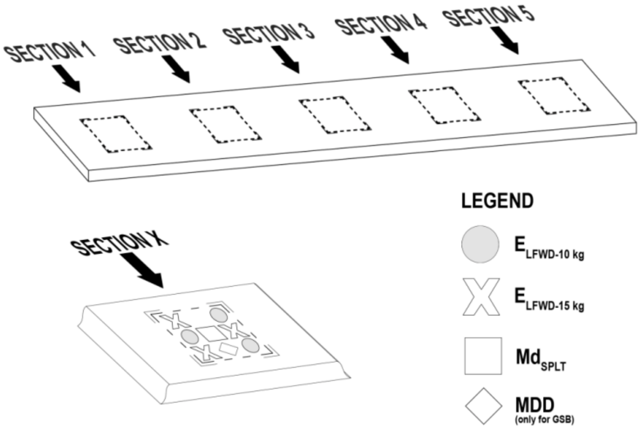

Figure 2. Test methods used to measure the materials' field performance

MATERIALS AND ENVIRONMENTAL CHARACTERISTICS

The SBA used in the research was from a Municipal Solid Waste Facility that process MSW in the south of Lombardy, in the area comprising the Provinces of Milan, Pavia and Lodi. The analysis of the virgin SBA required that larger elements (>30 mm) and elements of a longer dimension were manually removed (Figure 3). The SBA grain size distribution is also shown in Figure 3. Finally, after the extraction of the oversize particles, a grading between 0 – 30 mm was obtained, with a significant part (60%) comprising sand particles.

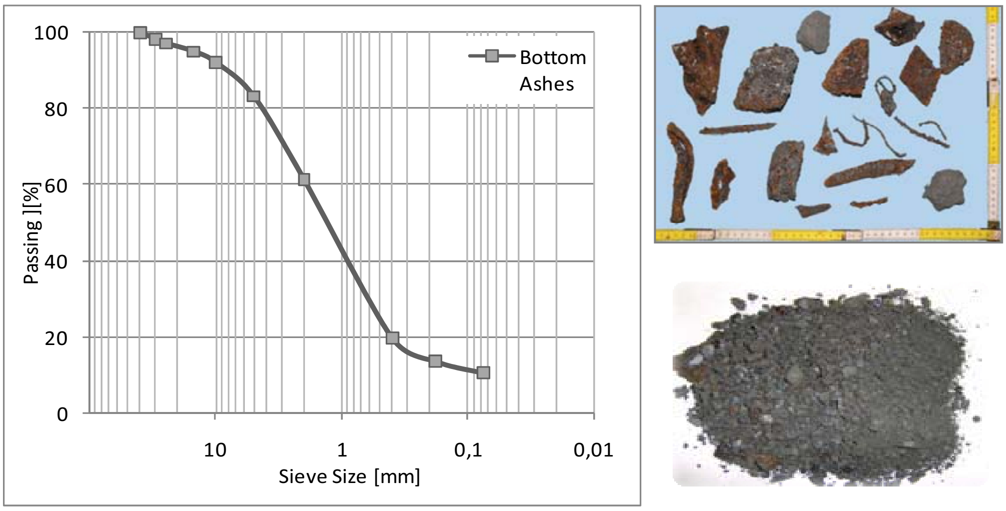

Figure 3. Particle size distribution of SBAs, removed pieces, SBAs used in the tests.

GSB compounded with lithic materials typical of quarries from the Lombardy region resulted in a grain size distribution ranging from 0 mm – 40 mm, Figure 4. The GSB was classified as A-1-a according to AASTHO soil classification system (Italian Standard UNI 10006). The material exhibited a LAC of 34%. For the CTB manufacture, a cement type II/B-LL Portland-limestone with strength Class 32.5 R (EN 196-1) was used. The grain size distribution used was the same as for the GSB.

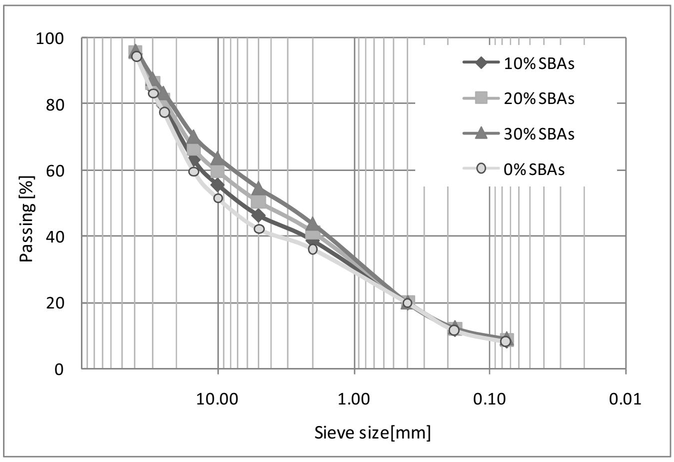

Figure 4. GSB and CTB grain size distribution

The environmental compatibility of the SBA was assessed by means of a leaching test according to the Ministerial Decree (DM) of April 5, 2006, nr. 186. This test, in accordance with the methodology reported in UNI EN 12457-2, consists of suspending and mixing the material sample with deionized water at a liquid to solid ratio of 10 lt/kg for 24 hours. At the end of the test, the solution is separated from the solid and analyzed to quantify the parameters of interest. Its concentration is then compared with the Concentration Limit (CL). The test was carried out on duplicate samples, resulting in concentration values below the CLs for all parameters (Table 1).

Table 1. Leaching test results

	Nitrates	Fluorides	SUlfates	Chlorides	Cyanides	Ba	Cu	Zn	Asbestos	COD	Be	Co	Ni	V	As	Cd	Total Cr	Pb	Se	Hg	pH
Unit	mg/l										µg/l										-
CL	50	1.5	250	100	50	1	0.05	3	30	30	10	250	10	250	50	5	50	50	10	1	5.5 - 12.0
DL	0.1	0.05	0.1	0.1	5	0.1	0.01	0.05	1	5	1	1	1	50	0.5	0.1	1	1	0.5	0.1	0.01
SBA	*	0.2	161	30	*	*	*	*	*	*	*	*	*	*	0.5	*	32	*	*	*	11.1
CTB	0.6	0.5	75	7.1	*	*	0.01	*	*	*	*	*	*	*	0.6	*	24	*	*	*	10.4
GSB	0.6	0.4	40	5.6	*	*	0.01	*	*	*	*	*	*	*	1.9	*	12	*	*	*	8.3

CL: Concentration Limit, DL: Analytical Detection Limit, * ≤ DL

RESULTS

GRANULAR SUB-BASE

Figure 5 shows the results concerning the volumetric and mechanic characteristics of GSB. The volumetric characterization is exhibited in Figure 5 (left), showing the trend of the MDD with respect to SBA contents, which were obtained in the first phase of the study. In addition, the figure shows the MDD measured in the laboratory for the granular material mixed in-situ with 20% of SBAs as well as the measurement of density in-situ.

It can be noticed from the figure that laboratory mixtures demonstrate a decrease in the MDD value with the increase in SBA content, moreover, it should be highlighted that the in-plant mixtures present an increase in MDD, both for in-plant mixtures compacted in the lab and in-plant mixtures laid in the field. This fact is a likely consequence of the more uniform homogeneity the in-plant mixing process.

It should be noted that in obtaining a compaction grade of 98%, compared to the value obtained in the laboratory, proves the suitability of the compaction method undertaken.

Bearing measurements, evaluated with the CBR index (Figure 5, right) for the laboratory mixtures, show that the higher the content of SBAs the greater the CBR index, whereas for the in-situ sample this index seems to be reduced.

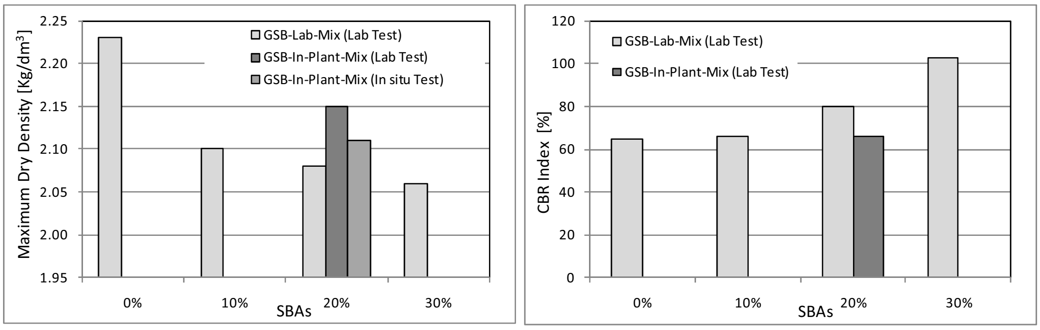

Figure 5. Maximum Dry Density and CBR value

Table 2, shows the modulus calculated from deflection measurements with the PLT and LFWD in the field.

The Moduli reported in the Table are the average value of 3 repeated tests taken on each point. Results were statistically analyzed to determine both standard deviation (SD) and coefficients of variation (CV). Overall for E_{PLT} as well as E_{LFWD} the SD and CV show a significant dispersion of the data. As a general trend lower moduli were measured after finishing the compaction phase (T=0 hours). However, after 24 hours, the GSB layer showed greater moduli, this fact is observed in the results obtained by means of the two test typologies PLT and LFWD. Furthermore, it should be noted that for the LFWD moduli, whichever load plate was used (10 and 15 kg), the recorded data were independent with respect to the load. One important characteristic observed after the comparative analysis is the fact of Md_{PLT} and E_{LFWD} show similar values after 24 hours. This may be indicative of two things; (1) firstly that LFWD is more suitable for quality control (QC) in terms of repeatability than PLT; (2) in the specific case of SBA layers, it could be recommendable to assess the compaction and QC activities within the first 24 hours of completion of the work, however, further research about this factor is required to properly understand this effect.

Table 3. In-situ mechanical performance of GSB.

Time [hours]	Md_{PLT} [Mpa]	SD [Mpa]	CV [%]	$E_{LFWD\ ,\ 10\ Kg}$ [MPa]	SD [MPa]	CV [%]	$E_{LFWD\ ,\ 15\ Kg}$ [MPa]	SD [MPa]	CV [%]
0	41,6	11,5	28,0	19,8	3,0	15,0	22,5	2,2	10,0
3	48,1	12,7	26,0	32,8	10,5	32,0	33,6	6,0	18,0
24	55,1	17,3	31,0	54,9	19,0	35,0	49,3	13,7	28,0

Note: SD=standard deviation, CV=coefficient of variation.

CEMENT-TREATED BASE

Figure 6, presents the results of the mechanical performance for the CTB laboratory and test track samples. The figure (left and central graphics) shows the UCS and ITS results of the CTB obtained with different cement and SBA contents after 7 days of curing time in the laboratory. It can be noticed that the performance of the sample decreases as the cement content decreases with an increase in the SBA level. Moreover is possible to observe that such a performance is considered acceptable for a road base layer with the specific condition of keeping a high cement content

(5%) and low SBA content (10%). For this reason the mentioned formulation was selected to be applied on the full-test track construction. The figures also report the same parameters (UCS and ITS) obtained from laboratory testing and samples prepared with the test track material from which it is observed that the test track mixture for UCS exhibits substantially the same performance as the corresponding laboratory mixture, while for the ITS test, a remarkable improvement in its performance can be observed.

The chart on the right of Figure 6 shows the CTB results concerning Elastic Stiffness (5% cement content) as well as the results for different curing times prepared in laboratory (0%, 10%, and 20% of SBAs) and for those taken from the field. It is possible to observe that mixture prepared in-situ demonstrates a better performance also when compared to the samples without SBAs. This may be explained by the fact that the in-plant mixing process allows a better homogenization of the components compared to the mixing process that can be accomplished in the laboratory with a small quantity of materials.

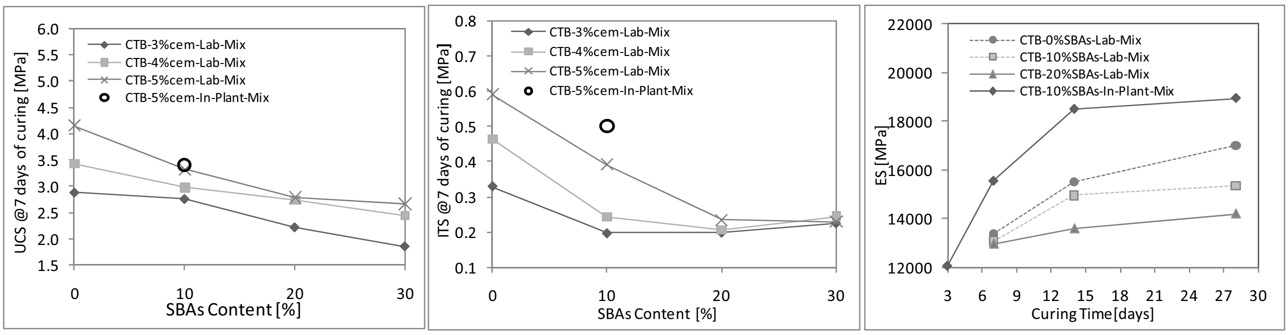

Figure 6. Results of CTB mechanical performance

A final assessment was undertaken on the test track in order to quantify the structural behavior of the whole layer set. A detailed survey was accomplished once the CTB laying process was finished with the additional aim of assessing the curing effects on the CTB bearing capacity. As such, SPLT and LFWD measurements were carried out, showing similar performances to those of GSB after compaction (Figure 7). The bearing capacity increased quickly as the cement curing process was carried out, reaching fourfold the initial bearing value (E-LFWD 10, E-LFWD 15 and Md-SPLT) after the first three days.

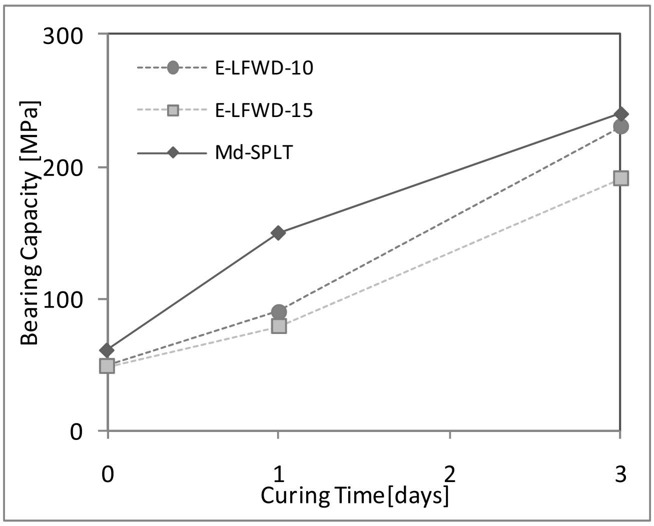

Figure 7. In situ mechanical test results on CTB

CONCLUSIONS

A comprehensive study was carried out involving the incorporation of SBA on granular Sub-base layers and Cement treated granular base. The research further analyzed the volumetric and mechanical performance of granular and cement treated mixtures. The environmental impact of the Bottom Ashes on these materials was also evaluated by means of leaching tests.

The assessment of the mixtures' performance included a number of laboratory and in-situ tests performed on both lab and in-plant mixed materials, also to evaluate the difference between lab and in-situ compaction effects.

The preliminary environmental analysis, carried out during the first phase of the investigation, supported the claim that stabilized bottom ashes can be used for road applications because they do not present an environmental risk because of the leachate chemical composition. These results were obtained for both the SBAs as a sole material and for all the mixtures tested.

The first phase of the investigation was also focused on the optimization of the composition of the materials from a road construction point of view. With regard to the GSB, the laboratory investigations reveal SBA content must be limited to 20% by weight. Exceeding this limit is not recommended, considering pavement's life cycle, as this could lead to a decrease in the mixture's performance due to a gradual weakening caused by SBA fragility.

Regarding CTB laboratory optimization, SBAs cause a fall in mechanical and volumetric performances, which must be balanced with an adequate cement dosage. Specifically, for the tested materials, a performance decrease linked to an increase of the SBA content was measured. As a consequence of that, an optimum SBA content of 10% by weight is suggested, which has to be used with an appropriate cement content (5%).

The field investigations regarding GSB and CTB confirmed that the mixtures optimized in the laboratory presented an adequate performance for use as foundation layers in highways. Furthermore, testing confirmed that the in-plant mixing process allowed for a better homogenization of materials, while the in-situ compaction demonstrated an acceptable performance according to the standard specifications for roadways construction.

Finally, it must be pointed out that limits in the use of SBAs in the road construction field highlighted in this experimental investigation relate both to the specific SBAs used and the peculiarity of the Italian lithic material. Therefore, it cannot be excluded that, in other contexts, these limits could be significantly different. Furthermore, the mechanical and volumetric requirements considered in this study refer to main roads. The optimal, stabilized bottom ash content could be increased for side roads following a project assessment, considering the specifics of individual projects.

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