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A road pavement full-scale test track containing stabilized bottom ashes

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This paper reports the results of a road pavement full-scale test track built by using stabilized bottom ash (SBA) from an Italian municipal solid waste incinerator as the aggregate in granular foundation, cement-bound mixes and asphalt concretes. The investigation focused on both the performance and the environmental compatibility of such mixes, especially with regard to the effects of mixing, laying and compaction. From the road construction point of view, the performance related to the effects of mixing, laying and compaction on constructability was assessed, as well as the volumetric and the mechanical properties. Environmental aspects were investigated by leaching tests. The results suggested that SBA meets the environmental Italian law for the reuse of non-hazardous waste and could be used as road material with the procedures, plants and equipment currently used for road construction.

Keywords: bottom ash; full-scale test track; leaching behaviour; performance tests; road construction

Introduction

Disposal of municipal solid waste (MSW) is a crucial aspect for proper management of both the environment and territory, especially for countries with high population density. In this context, incineration of MSW has proven to be strategic in the waste management process as it combines the advantages of potential energy production and volume reduction up to 90%.

Incineration products (bottom and fly ash) must be properly treated before landfilling to avoid health hazards and pollution due to heavy metal leaching.[1,2] Generally speaking, bottom ash (BA) and natural aggregates have similar composition and BA reuse is a common practice in civil engineering.[3–29] However, BA contains heavy metals and has variable mechanical properties, which hamper extensive reuse.[30–36]

In this context, the investigation herein described is part of a wider experimentation that focused on the use of stabilized bottom ashes (SBAs) for road constructions. In particular, a previous research at the laboratory scale was aimed at optimizing SBAs content in mixtures used as road materials.[37,38] This paper describes the results obtained when the mixtures (granular materials for foundations, cement-treated materials for subbase and asphalt concretes for base and binder courses) were used in a full-scale test track. The main goal of the research was to evaluate both the performance and the environmental compatibility of the mixes, especially with regard to the effects of mixing, laying and compaction.

Materials and methods

Materials

The SBAs were from a MSW facility in Lombardy (Italy). The production process and the chemical composition were described by Toraldo et al.[38]

SBAs had particle size up to 30 mm, 60% by weight being <2 mm, and Los Angeles coefficient (LAC) [39] of 48%.

Other materials involved in the experimentation were:

- natural excavation materials as subgrade, with California bearing ratio (CBR) [40] of 16% and optimal moisture content [41] of 5%, to provide a homogeneous support for the structure;
- granular material for foundation (GF) containing 20% SBAs [37,38] in addition to lithic aggregates, resulting in the sieve size distribution showed in Figure 1;
- cement-treated subbase (CTS) with 10% SBA [37,38] in addition to lithic aggregates (sieve size distribution in Figure 1), 5% cement CEM II/B-LL Portland Limestone of Strength Class 32.5R, based on EN 197-1,[42] and 7% moisture content (on dry aggregates weight basis);
- asphalt concretes for base and binder courses (hereafter named BaAC and BiAC, respectively), both with 10% SBA replacing by weight the sand fraction (Figure 1) and 4.0% of 50/70 pen unmodified bitumen, according to EN 12591.[43]

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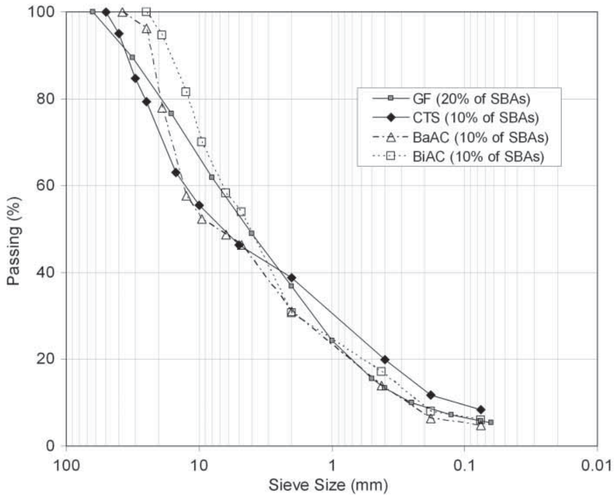

Figure 1. Particle size distribution of GF, CTS, BaAC and BiAC.

Table 1. Courses and thickness in the full-scale test track.

Course	Thickness (mm)
BiAC	60
BaAC	90
CTS	150
GF	200

Due to the high value of LAC, SBAs were not used for wearing courses.

Full-scale test track

The full-scale test track, constructed in the field research facility at the Road Research Laboratory, Politecnico di Milano, was 20 m long and 3 m wide. The courses' thickness is reported in Table 1.

The test track construction (Figure 2) lasted seven working days with technical periods (curing time) between layers placing. The subgrade was compacted by 10 passages of a Smooth-Drum Vibratory Roller (20 t) in order to achieve a density of 2100 kg/m^3. The CTS laying was carried out with an asphalt paver at 5 m/min. The compaction procedure applied to GF and CTS was as for the subgrade. A geotextile with a separation function was laid between the conformed subgrade and the GF. The in-plan mixing of asphalt concretes was performed at 160 $\pm$ 5 °C; laying was performed at 150 $\pm$ 5 °C by using an asphalt paver at 2 m/min; the compaction process involved 10 passages of a double steel Roller (10 t).

Experimental plan

The experimentation involved both road and environmental tests in order to compare the performance of the materials used in the construction of the full-scale test track with those obtained during previous lab investigations.[37,38]

Concerning road tests, samples prepared or measurements taken in the lab on materials from the full-scale test track are named TT Specimens or TT Cores, measurements taken in the field are named TT Field Test, the results of the previous lab investigation are named Lab Specimens.

As regards the GF, maximum dry density (MDD) tests, according to the Modified Proctor method,[44] and CBR tests, according to EN 13286-4,[40] were performed on GF samples taken during construction. Moreover, the *in situ* MDD was also measured, according to the Italian specifications.[45]

For the CTS, specimens were prepared in the lab by using both a Gyratory Compactor (GC, height to diameter ratio: 0.5) at 100 gyrations, 30 rpm, vertical pressure of 600 kPa, angle of gyration of 1.25°, and a Proctor Hammer (PH, height to diameter ratio: 2).[46] GC specimens were used to carry out elastic stiffness (ES) tests under dynamic conditions (pulse load at 2 Hz frequency and 100 kPa horizontal stress) and indirect tensile strength tests (ITS).[47] On PH specimens, unconfined compressive strength (UCS) tests [48] were carried out. The tests were performed at 20 °C after a curing period of 3, 7, 14 and 28 days in a climatic chamber (temperature of 20 °C and relative humidity of 95%).

Constructability, volumetric and mechanical tests were carried out on BaAC and BiAC layers. As regards constructability tests, both self-compaction (C_1) and workability (k) parameters were measured on specimens compacted in the lab by GC at 100 gyrations [49,50] using asphalt concretes taken from the mixing plant. Volumetric characteristics (voids content – V, voids in the mineral aggregates – VMA and voids filled with bitumen – VFB) of TT Specimens and TT Cores from the test track (TT Cores) were measured according to EN.[51]

The mechanical tests performed were ES [52] and ITS at failure.[53] Fatigue tests, in control stress mode (400 kPa), were performed on TT Specimens and TT Cores, resulting in the number of cycles at failure (CF). All tests were performed at temperature of 20 °C.

Tests on TT Specimens and TT Cores were repeated on samples previously soaked in water (15 days at 20 °C) or exposed to 10 freeze–thaw cycles (24 h freezing at -10 ± 2 °C and 24 h thawing at 20 $\pm$ 2 °C each freeze–thaw cycle), in order to investigate bitumen/SBA adhesion under water and ice aggression.[32,54,55]

The environmental compatibility of GF, BaAC and BiAC TT specimens was assessed in term of leaching behaviour. Leaching tests were performed according to the UNI EN 12457-2 method,[56] as required by the Italian regulation for reuse of not dangerous wastes.[57] The specimen (duplicate samples) was soaked in deionized water at

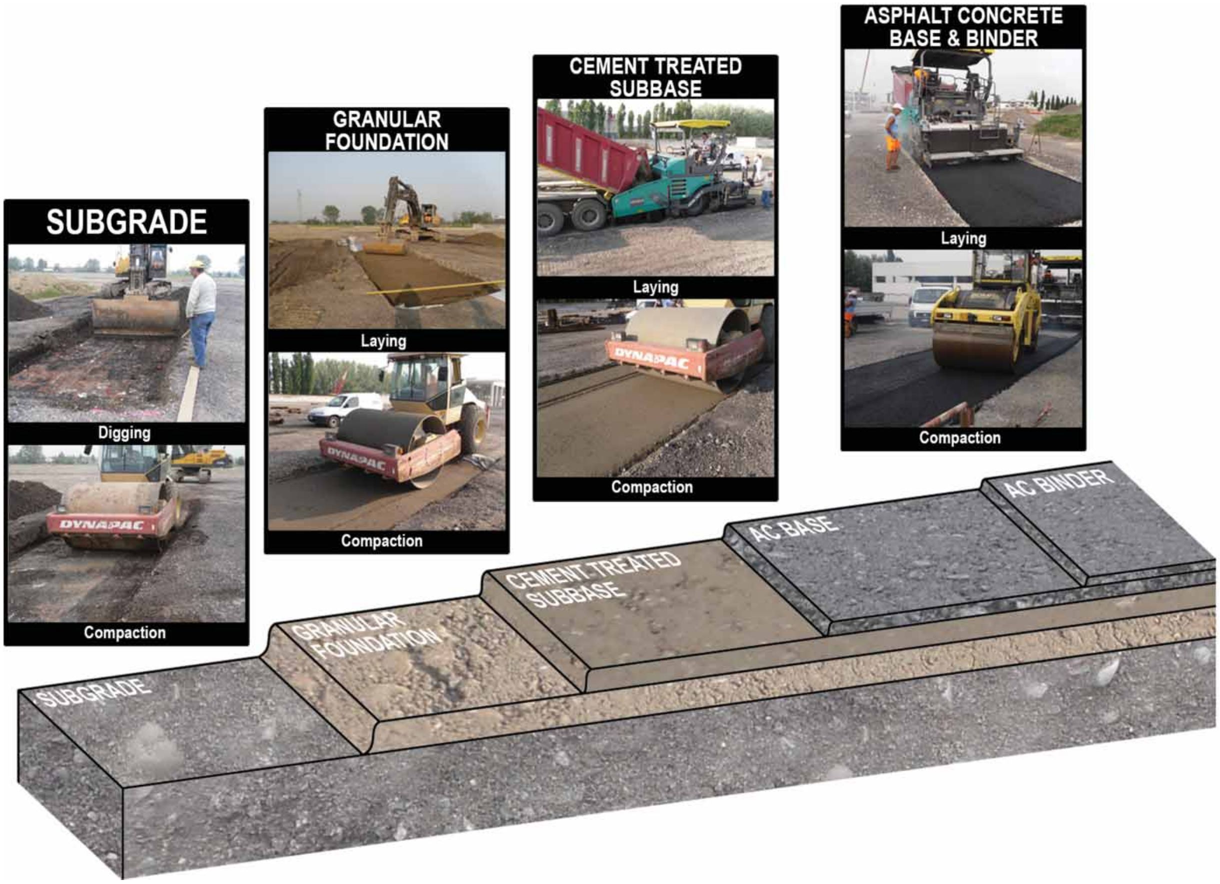

Figure 2. Test track construction.

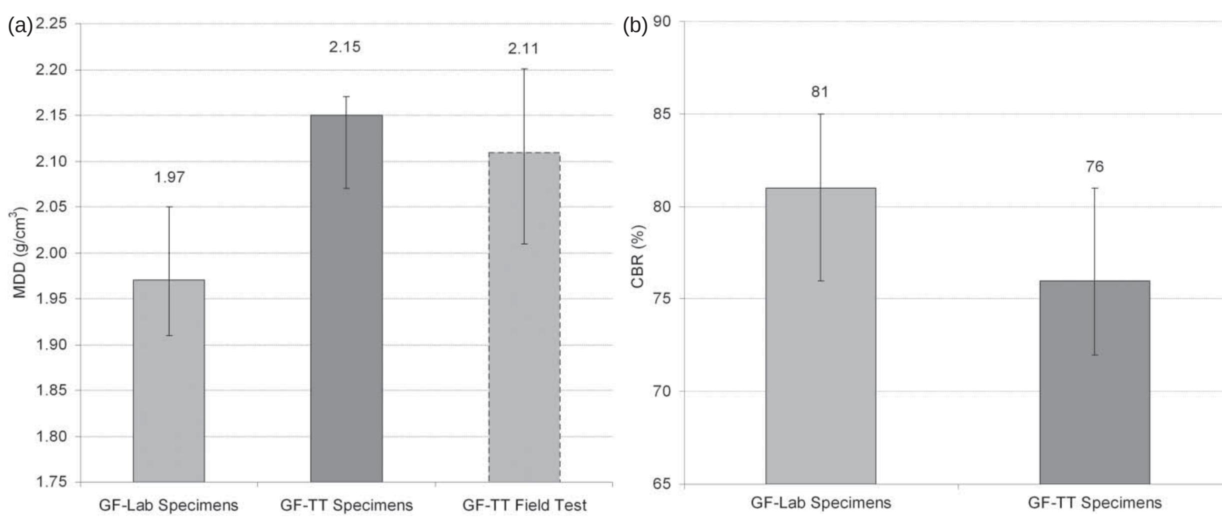

Figure 3. Test results (maximum dry density – MDD, California bearing ratio – CBR) on GF.

a liquid to solid ratio of 10 l/kg for 24 h. At the end of this period, the liquid solution was separated and analysed to quantify the parameters of concern. The concentrations were compared to the limits values (LVs) reported in the decree.[57]

Results and discussion

Granular foundation

Figure 3 shows the average results of tests on GF replicates of Lab Specimens and TT Volumetric properties (i.e.

MDD) are similar and the small differences between data are to be ascribed to heterogeneity in the tested materials. This is also confirmed by the mechanical properties' results (i.e. CBR) that show similar performance for both kinds of sample (lab or field).

Cement-treated subbase

Figure 4 shows the average results of tests on replicates of Lab Specimens and TT Specimens, as a function of the curing time, and the maximum and minimum values for each mixture as error bars. Both in the lab and in the field, mechanical performance (as ES, ITS and UCS) increased with the curing time. TT Specimens proved to be better (in the average) than Lab Specimens for all parameters, though the dispersion of ITS and UCS data was higher in the field test. Moreover, UCS and ITS results of both Lab Specimens and TT Specimens met the Italian Specifications,[58] which require an UCS value between 2.5 and 7.5 MPa and a minimum ITS value of 0.25 MPa, both obtained after seven days of curing.

Asphalt concretes

Figures 5–7 show the average results of constructability, volumetric and mechanical tests on asphalt concretes and

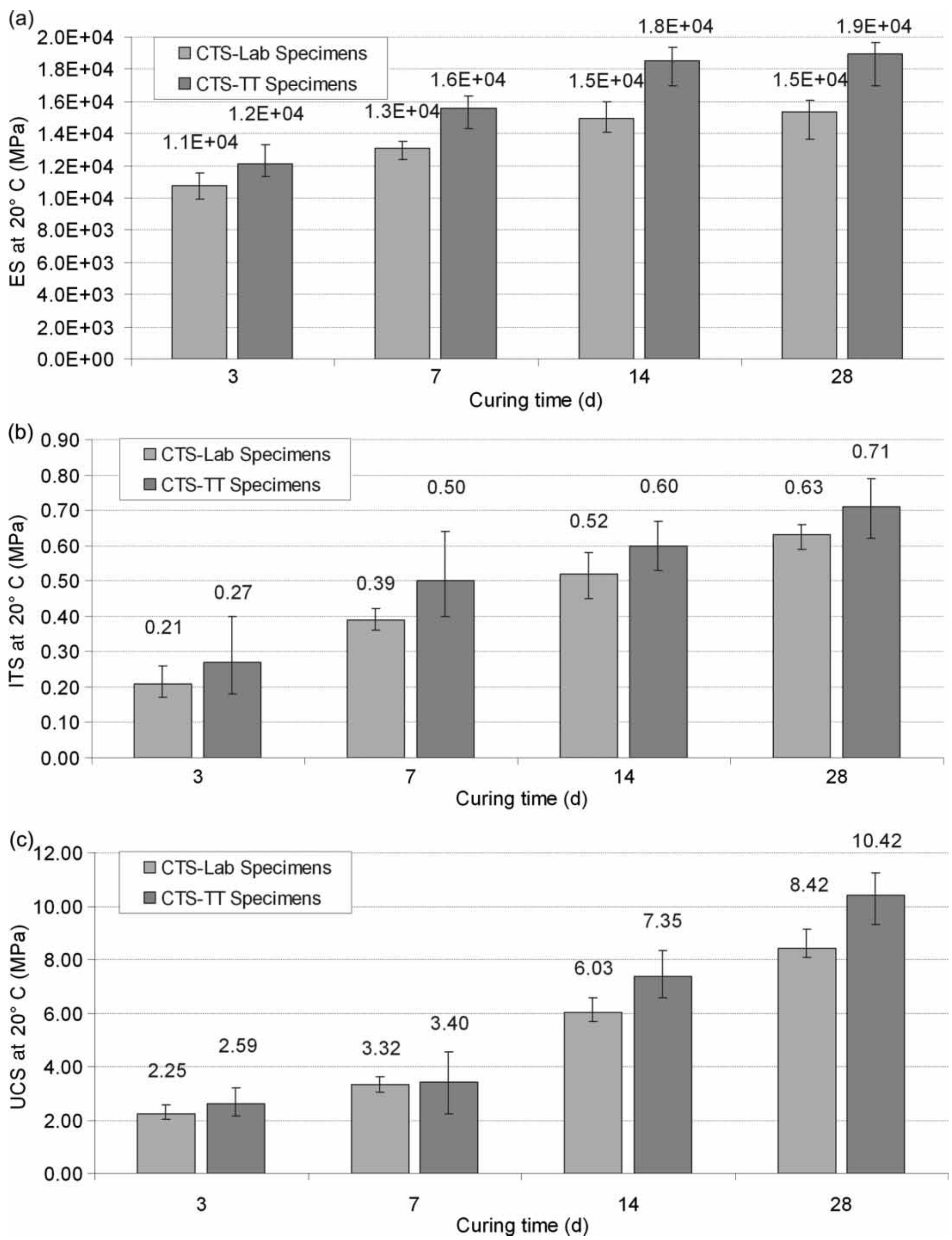

Figure 4. Test results (elastic stiffness – ES, indirect tensile strength – ITS, unconfined compressive strength – UCS) on CTS.

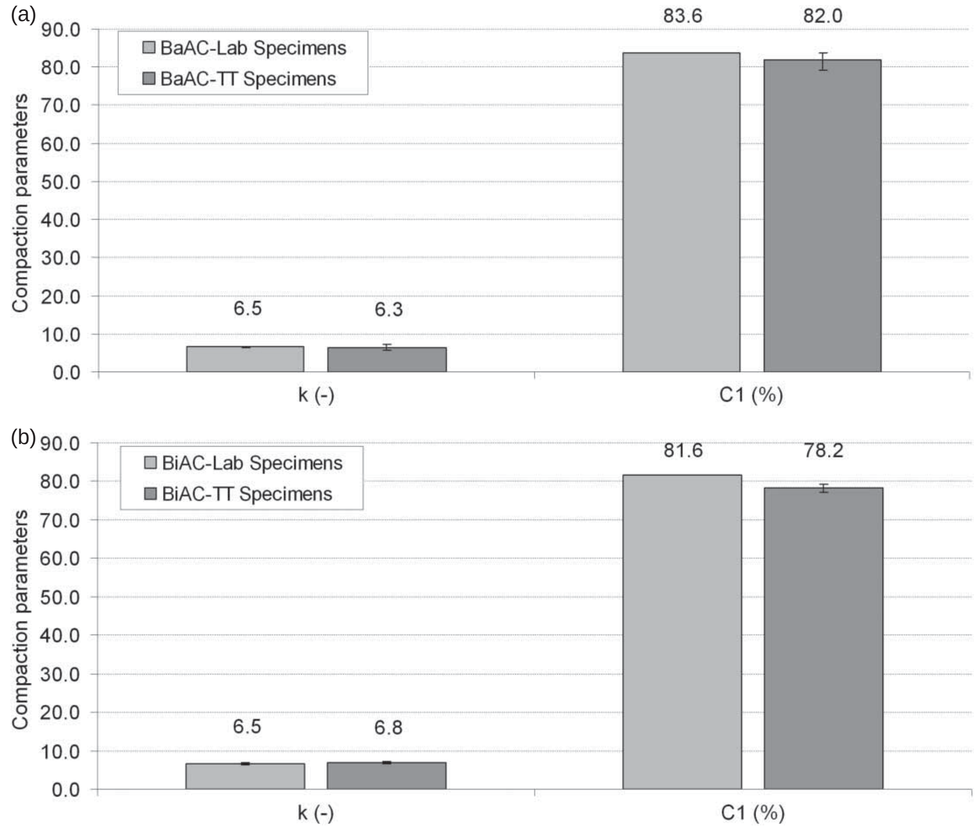

Figure 5. Constructability parameters (workability k, self-compaction C_1) of asphalt concretes.

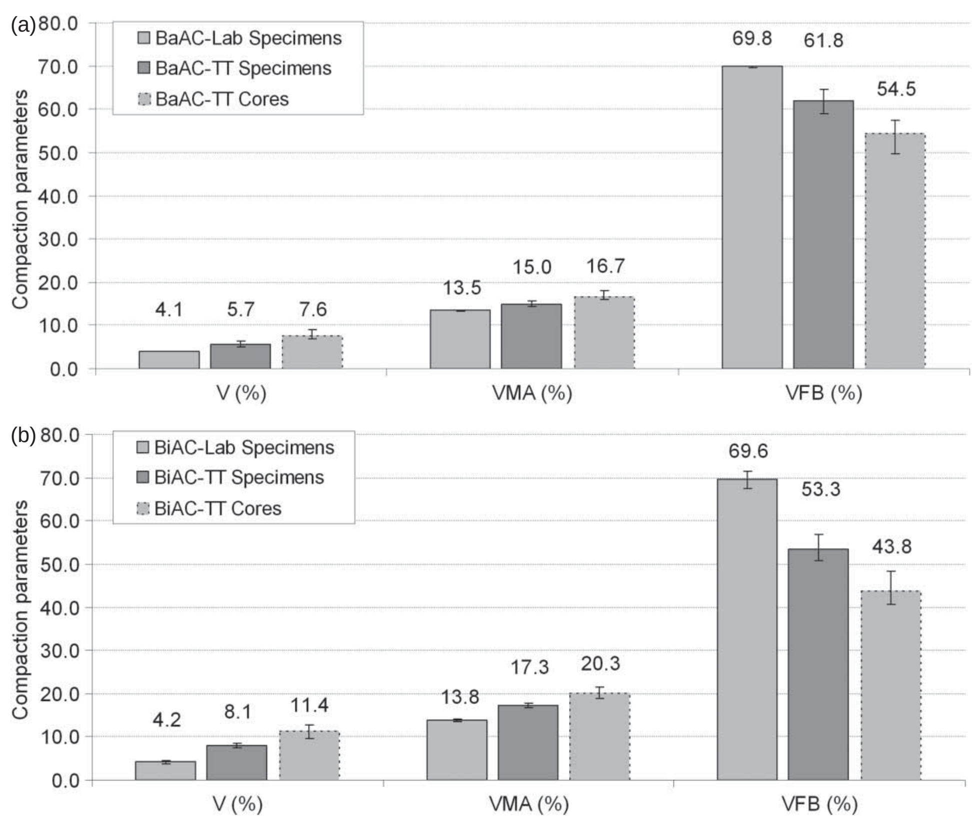

Figure 6. Volumetric properties (voids – V, voids in the mineral aggregates – VMA, voids filled with bitumen – VFB) of asphalt concretes.

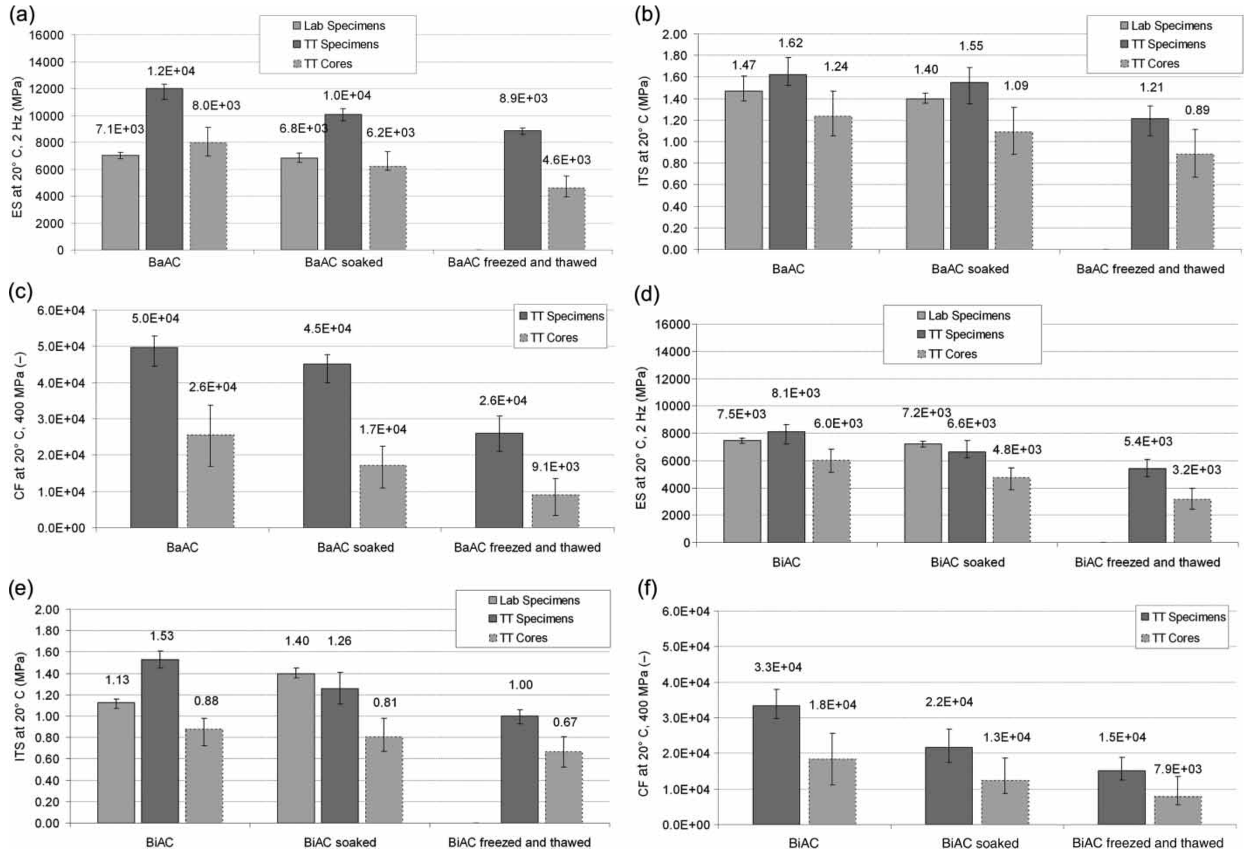

Figure 7. Mechanical performance (elastic stiffness – ES, indirect tensile strength – ITS, cycles to failure – CF) of asphalt concretes.

the maximum and minimum values for each mixture as error bars.

Constructability parameters (workability *k* and self-compaction C_1) of BaAC (Figure 5(a)) and BiAC (Figure 5(b)) on Lab Specimens and TT Specimens were quite similar, regardless of the origin of the samples, though self-compaction of BiAC in the field test was lower than in the lab. Again, the dispersion of data from the field test was higher than data from the lab.

As far as the volumetric tests are concerned (voids – V, voids in the mineral aggregates – VMA and voids filled with bitumen – VFB), the results of TT Cores, TT Specimens and Lab Specimens are shown in Figure 6(a) for BaAC and Figure 6(b) for BiAC. The best performance (low V and VMA, high VFB) was obtained at lab scale. TT cores exhibited the worst performance, particularly for BiAC mixture, probably caused by the working method used in the field, which was not able to guarantee a suitable compaction of the mixture containing SBAs.

Figure 7(a–c) and 7(d–f) shows, for BaAC and BiAC respectively, the average results of ES, ITS and CF measurements on asphalt concretes (also after soaking or freezing–thawing) and the maximum value and the minimum value for each mixture as error bars. TT Specimens had the best performance, because of the higher homogeneity attainable with the in-plant mixing. Confirming the volumetric results, TT Cores exhibited the worst performance, probably due to the compaction method used in the field. With regard to bitumen/SBA adhesion under water and ice aggression, the performance decreased especially after freezing–thawing cycles and particularly in TT Cores, characterized by a high void content. Finally, as the compaction methods currently adopted for road construction result in a decrease of both volumetric and mechanical performance, other compaction methods should be studied. At any rate, both the asphalt concretes and the compaction methods described in this paper could be used for low traffic roads.

Leaching behaviour

Leaching test results of TT specimens are reported in Table 2, as the maximum value of duplicate samples and, whenever possible, compared with those of the Lab Specimens.

For many parameters (cyanides, beryllium, cobalt, copper, mercury, nickel, selenium, vanadium, zinc and asbestos), the concentration in the leachate was below the analytical detection limit (DL) and far below the LV in all lab and field samples. For the other parameters (nitrates, fluorides, sulphates, chlorides, arsenic, barium, cadmium, total chromium, nickel, lead and chemical oxygen demand

Table 2. Leaching tests results (maximum values on duplicate samples).

		DL[a]	LV[b]	GF – TT specimens	BaAC – Lab specimens	BaAC – TT specimens	BiAC – Lab specimens	BiAC – TT specimens
Nitrates	mg/l	0.1	50	0.1	0.1	0.4	0.4	0.2
Fluorides	mg/l	0.05	1.5	0.17	0.34	0.09	0.13	0.06
Sulfates	mg/l	0.1	250	60	5.6	10	1.7	6.3
Chlorides	mg/l	0.1	100	10	0.9	0.9	0.9	0.9
Cyanides	μg/l	5	50	*	*	*	*	*
As	μg/l	0.5	50	4.4	*	2.7	*	4.0
Ba	mg/l	0.1	1	*	*	*	*	0.1
Be	μg/l	1	10	*	*	*	*	*
Cd	μg/l	0.1	5	0.1	*	*	*	*
Co	μg/l	1	250	*	*	*	*	*
Total Cr	μg/l	1	50	9	2	2	*	2
Cu	mg/l	0.01	0.05	*	*	*	*	*
Hg	μg/l	0.1	1	*	*	*	*	*
Ni	μg/l	1	10	*	*	4	*	*
Pb	μg/l	1	50	*	1	*	2	*
Se	μg/l	0.5	10	*	*	*	*	*
V	μg/l	50	250	*	*	*	*	*
Zn	mg/l	0.05	3	*	*	*	*	*
Asbestos	mg/l	1	30	*	*	*	*	*
COD	mg/l	5	30	*	5	*	*	*
pH	–	0.01	5.5–12	8.1	7.7	8.1	7.7	8.2

[a]Detection limit.
[b]Limit value.
* < DL.

– COD), results were above the DL in at least on sample, but however far below the LV. Arsenic was detected only in TT Specimens (GF, BaAC and BiAC). According to the Decree, the pH value was in the acceptable range.

Conclusions

In this study, the performance and the environmental compatibility of road materials containing SBA were reported and compared for lab and field scale tests.

As far as road tests are concerned, the experimental results showed that the investigated SBA can be used as road material with the procedures, plants and equipment currently used for road construction. Nevertheless, it is necessary to define carefully the compaction procedures, especially those involving bituminous layers. In fact, the results showed a decrease in both volumetric and mechanical performance using the compaction methods currently adopted for road construction; more weight and number of passages of roller compactors than those used in this research (10 t and 10 passages) are suggested.

As regards the environmental compatibility, the mixes fulfilled the Italian regulation limits for leaching behaviour, with concentrations in the leachate far below the limit values.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

References

[1] Sabbas T, Polettini A, Pomi R, Asprup T, Hjelmar O, Mostbauer P, Cappai G, Magel G, Salhofer S, Speiser C, Heuss-Assbichler S, Klein R, Lechner P. Management of municipal solid waste incineration residues. Waste Manage. 2003;23(1):61.
[2] Reijnders L. Disposal, uses and treatments of combustion ashes: a review. Resour Conserv Recy. 2005;43:313.
[3] Gress DL, Zhang X, Tarr S, Pazienza I, Eighmy TT. Municipal solid waste combustion ash as an aggregate substitute in asphaltic concrete. In: Goumans JJJM, van der Sloot HA, Aalbers TG, editors. Waste Materials in construction. Amsterdam: Elsevier; 1991. p. 161.
[4] Jackman TJ, Combotti RK, Roffmann HK. Eighty-fifth Annual Meeting of the Air & Waste Management Association, Kansas City, 1992.
[5] Eymael MMTh, de Wijs W, Mahadew D. The use of MSWI bottom ash in asphalt concrete. In: Goumans JJJM, van der Sloot HA, Aalbers TG, editors. Environmental aspect of construction with waste material. Amsterdam: Elsevier; 1994. p. 851.
[6] Alkemade MMC, Eymael MMTh, Mulder E, de Wijs W. How to prevent expansion of MSWI bottom ash in road constructions? In: Goumans JJJM, van der Sloot HA, Aalbers TG, editors. Environmental aspect of construction with waste material. Elsevier: Amsterdam; 1994, p. 863.

[7] McBath PJ, Mahooney PF, Hatmaker DM. 8th International Conference Municipal Solid Waste. Arlington: Combustor Utilization; 1995. p. 81.
[8] Roffman H, Roethel FJ, Barnes J. Ninetieth Annual Meeting of the Air Waste Management Association, Toronto, 1997.
[9] Ksaibati K, Stephen J. Utilization of bottom ash in asphalt mix. Research Report. Laramie: University of Wyoming; 1999.
[10] Reid JM, Evans RD, Holnsteiner R, Wimmer B, Gaggi W, Berg F, Phil KA, Milvang-Jensen O, Hjelmar O, Rathmeyer H, Francois D, Rimbault G, Johansson HG, Hakansson K, Nilsson U, Hungenor M. Report AEAT/ENV/R/0716. Oxford: National Environmental Technology Center; 2001.
[11] Filipponi P, Polettini A, Pomi R, Sirini P. Physical and mechanical properties of cement-based products containing incineration bottom ash. Waste Manage. 2003;23:145–156.
[12] Bertolini L, Carsana M, Cassago D, Quadrio Cursio A, Collepardi M. MSWI ashes as mineral additions in concrete. Cem Concr Res. 2004:34(10);1899.
[13] Cheeseman CR, Makinde A, Bethanis S. Properties of lightweight aggregate produced by rapid sintering of incinerator bottom ash. Resour Conserv Recy. 2005;43(2):147.
[14] Ma GF, Onitsuka K, Negami T. Utilizations of incineration ash from municipal solid waste as admixtures for road embankment materials. J South Asian Geotech Soc. 2007;38:87.
[15] Saikia N, Kato S, Kojima T. Production of cement clinkers from municipal solid waste incineration (MSWI) fly ash. Waste Manage. 2007;27:1178.
[16] Pan JR, Huang C, Kuo JJ, Lin SH. Recycling MSWI bottom and fly ash as raw materials for Portland cement. Waste Manage. 2008;28:1113.
[17] Francois D, Pierson K. Environmental assessment of a road site built with MSWI residue. Sci Total Environ. 2009;407:5949.
[18] Ginés O, Chimenosa JM, Vizcarroa A, Formosaa J, Rosell JR. Combined use of MSWI bottom ash and fly ash as aggregate in concrete formulation: environmental and mechanical considerations. J Hazard Mater. 2009;169:643.
[19] Siddique R. Use of municipal solid waste ash in concrete. Resour Conserv Rec. 2010;55:83–91.
[20] Hassan MM, Khalid H. Mechanical and environmental characteristics of bituminous mixtures with incinerator bottom ash aggregates. Int J Pavement Eng. 2010;11:83–94.
[21] Barbosa R, Lapa N, Lopes H, Gulyurtlu I, Mendes B. Stabilization/solidification of fly ashes and concrete production from bottom and circulating ashes produced in a power plant working under mono and co-combustion conditions. Waste Manage. 2011;31:2009.
[22] Cioffi R, Colangelo F, Montagnaro F, Santoro L. Manufacture of artificial aggregate using MSWI bottom ash. Waste Manage. 2011;31:281.
[23] De Windt L, Dabo D, Lidelöw S, Badreddine R, Lagerkvist A. MSWI bottom ash used as basement at two pilot-scale roads: Comparison of leachate chemistry and reactive transport modeling. Waste Manage. 2011;31:267.
[24] Sorlini S, Abbà A, Collivignarelli C. Recovery of MSWI and soil washing residues as concrete aggregates. Waste Manage. 2011;31:289–297.
[25] Chen JS, Kuo PH, Huang LS. Engineering and environmental characterization of municipal solid waste bottom ash applied to asphalt concrete. J Chin Inst Civil Hydraul Eng. 2012;24:25.
[26] Pasetto M, Baldo N. Laboratory investigation on foamed bitumen bound mixtures made with steel slag, foundry sand, bottom ash and reclaimed asphalt pavement. Road Mat Pavement. 2012;13:691–712.
[27] Zhang R, Hu Y. Feasibility of reutilizing municipal solid waste incineration residues as construction materials. Applied Mech Mat. 2012;164:289–292.
[28] del Valle-Zermeño R, Formosa J, Chimenos JM, Martínez M, Fernández AI. Aggregate material formulated with MSWI bottom ash and APC fly ash for use as secondary building material. Waste Manage. 2013;33:621–627.
[29] Gori M, Bergfeldt B, Reichelt J, Sirini P. Effect of natural ageing on volume stability of MSW and wood waste incineration residues. Waste Manage. 2013;33: 850–857.
[30] Lapa N, Barbosa R, Morais J, Mendes B, Mehu J, Santos Oliveira JF. Ecotoxicological assessment of leachates from MSWI bottom ashes. Waste Manage. 2002;22:583.
[31] Flyhammar P, Bendz D. Leaching of different elements from subbase layers of alternative aggregates in pavement constructions. J Hazard Mater. 2006;137(1):603.
[32] Bassani M, Santagata E, Baglieri O, Ferraris M, Salvo M, Ventrella A. Use of vitrified bottom ashes of municipal solid waste incinerators in bituminous mixtures in substitution of natural sands. Int J Adv App Ceram. 2009;108:3.
[33] Becquart F, Bernard F, Abriak NE, Zentar R. Monotonic aspects of the mechanical behaviour of bottom ash from municipal solid waste incineration and its potential use for road construction. Waste Manage. 2009;29:1320.
[34] Weng MC, Lin CL, Ho CI. Mechanical properties of incineration bottom ash: The influence of composite species. Waste Manage. 2010;30:1303.
[35] Shih HC, Ma HW. Assessing the health risk of reuse of bottom ash in road paving. Chemosphere. 2011;82: 1556.
[36] Chen C, Li Q, Shen L, Zhai J. Feasibility of manufacturing geopolymer bricks using circulating fluidized bed combustion bottom ash. Environ Technol. 2012;33: 1313.
[37] Toraldo E, Saponaro S. Laboratory investigation on the use of stabilized bottom ashes for road construction. International Rilem Conference Progress Recycling in the Built Environment. San Paolo; 2009.
[38] Toraldo E, Saponaro S, Careghini A, Mariani E. J Environ Manage. 2013;121:117–123.
[39] EN. EN 1097-2. European Committee for Standardization, Brussels; 2010.
[40] EN. EN 13286-47. European Committee for Standardization, Brussels; 2006.
[41] EN. EN 13286-2. European Committee for Standardization, Brussels; 2010.
[42] EN. EN 197-1. European Committee for Standardization, Brussels; 2011.
[43] EN. EN 12591. European Committee for Standardization, Brussels; 2009.
[44] EN. EN 13286-2. European Committee for Standardization, Brussels; 2005.
[45] CNR. CNR BU 22. Consiglio Nazionale delle Ricerche, Rome; 1972.
[46] EN. EN 13286-50. European Committee for Standardization, Brussels; 2005.
[47] EN. EN 13286-42. European Committee for Standardization, Brussels; 2006.
[48] EN. EN 13286-41. European Committee for Standardization, Brussels; 2006.
[49] Cominsky R, Leahy RB, Harringan ET. SHRP-A-408 Report. Washington: National Research Council; 1994.
[50] Bassani M, Santagata E. Third International Conference Bituminous Mixtures Pavements, Tessaloniki, 2002.
[51] EN. EN 12697-8. European Committee for Standardization, Brussels; 2003.

[52] EN. EN 12697-26. European Committee for Standardization, Brussels; 2007.
[53] EN. EN 12697-23. European Committee for Standardization, Brussels; 2006.
[54] Maupin GW. Final Report VTRC 98-R30. Transportation Research Council, Charlottesville; 1998.
[55] Christensen DW, Handojo T, Lee SW. Evaluation of recycled glass in bituminous concrete base course. The Pennsylvania State University, University Park; 1999.
[56] UNI EN. UNI EN 12457-2. Ente Italiano di Unificazione, Milano; 2004.
[57] Italian Ministry Decree. Decreto Ministeriale 5 aprile 2006, n. 186. Gazzetta Ufficiale 19 maggio 2006, n. 115, 2006.
[58] Italian Ministry of Infrastructures. Studio a carattere prenormativo delle norme tecniche di tipo prestazionale per capitolati speciali d'appalto (in Italian). 2001.