DURABILITY AND LEACHING PROPERTIES OF BITUMINOUS MIXTURES CONTAINING INCINERATOR BOTTOM ASH AGGREGATE

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ABSTRACT

Incinerator bottom ash (IBA) is a material removed from the grating at the bottom of energy from waste plants. This ash has traditionally been land-filled. However, this ash could be processes to produce incinerator bottom ash aggregate (IBAA). Due to the low density and high stiffness of IBAA, it has become widely used as a secondary aggregate material especially in road construction. It is chemically inert, with very low concentrations of soluble materials. Despite this increase in IBAA use, higher usage is still required. In addition, the mechanical and leaching properties of bituminous mixtures containing IBAA merit further exploration.

In this paper, an experimental investigation was performed to develop hot-applied mixtures containing high IBAA content. Three different mixtures were developed containing 30, 60 and 80% IBAA. A limestone blend, used as reference mix, was also included.

The sensitivity to moisture damage of the four mixtures was studied. The British Board of Agrément regime was adopted and used in this paper. In addition, an accelerated oven-ageing procedure was applied on samples to study the ageing effect on their stiffness. Finally, mixtures were tested for their leaching potential and the concentrations in their leachates were determined for compacted and loose blends.

Results showed that, generally, water ingress has a limited effect on IBAA bituminous mixtures' properties while ageing has a more significant effect. Most leachate components were found to be within allowable limits.
Keywords: IBAA, Moisturizing, Ageing, Leaching.

1. INTRODUCTION

Incinerator bottom ash (IBA) is the most significant residual by-product of burning municipal solid wastes in energy from waste plants. It is made up of 90% of the residues produced during combustion and it is equal approximately to 25% of the initial mass. It was not uncommon to use IBA for landfill. However, due to European Union restrictions on landfill sites, alternative usage has become necessary. One such alternative is using the incinerator bottom as aggregate (IBAA), resulting from processing IBA, in asphalt for roads.

Interest in IBAA started in the 1970s and declined in the 1980s then it picked up, again, from 1990 to be a common research field. Properties of IBAA have been studied mechanically, physically and environmentally. These properties considered IBAA to be similar to lightweight aggregates (Eighmy et al. 1992). Numerous successful trials were conducted to study IBAA as a road construction material. Nevertheless, higher usage still required. So far, up to 50% IBAA in a bituminous mixture was used in the USA (Zhang et al. 1999). Higher usage, especially in Europe, is envisaged to benefit both society and industry.

In this paper, usage of IBAA at high levels was investigated. Bituminous mixtures containing different levels of IBAA were designed. The influence of moisture ingress and ageing on the mechanical properties of these mixtures was studied. Finally, mixtures were tested for their leaching potential and the chemical element concentrations in the leachates were determined for compacted and loose blends.

2. BACKGROUND

Visual classification of IBAA fractions shows the presence of metals, slag, stone and ceramic, glass and organic materials. IBAA is a highly porous aggregate, which enhances its water absorption and subsequently bitumen absorption. IBAA was reported to have high modulus values when it is in a compacted state (Hartlen and Elander 1986). The unit weight, mean Proctor density and optimum moisture content values of IBAA confirm its classification as lightweight aggregates (Eighmy et al. 1992). Moreover, It has been shown that its use in road construction is safe environmentally (Bruder-Hubscher et al. 2001). As a result, use of IBAA in several road construction applications has been studied.

Regarding its use in bituminous mixtures, a few trials have been conducted. It was found that substitution of up to 20% IBAA for virgin aggregates yielded mixtures having aggregate structures that are well developed to resist compaction and rutting (Ogunro et al. 2004). A study by Vassiliadou and Amirkhanian (Vassiliadou and Amirkhanian 1999) showed that up to 30% substitution of natural aggregates with IBAA resulted in lower resilient modulus values. Moreover, using 32% IBAA has been suggested as satisfactory for a binder course in low quality surface applications (Garrick and Chan 1993). High IBAA replacement has been attempted with success in the US, where 50% was used in a binder course asphalt mixture on a major road trial (Zhang et al. 1999). The moisture susceptibility was investigated for 15% IBAA bituminous mixtures and it was found that the addition of IBAA did not reduce their resistance to moisture damage (Zeng and Kasibati 2003). Even so, the durability of bituminous mixtures containing high levels of IBAA requires more investigations.

IBAA leaching properties were studied (Eighmy et al. 1995) to investigate their diffusional leaching behaviour. Results suggested that the IBAA leaching behaviour is controlled by the binder. Moreover, it has been shown, in a field study, that the pH value of an IBAA construction layer, after 10 years, was significantly less than shortly after placement. The pH was close to neutral (Schreurs et al. 1997). The pH value was found to have a significant effect on the concentrations of toxic elements in IBAA leachates. These concentrations were showed to be greatest in the earliest stages of IBAA use or disposal while, the long-term leaching behaviour was likely to be reduced by the neutralisation of IBAA pH value (Meima and Comans 1997). In contrast, the heavy metals concentrations in an IBAA mix were recorded as limited (Cai et al. 2004). Despite this, the potential impact, of using high IBAA levels in bituminous mixtures, on the IBAA leaching properties, needs to be highlighted.

3. MATERIALS, BLENDS AND MIXTURES

3.1 Materials and Blends

Three different materials were used in this study: limestone, IBAA and bitumen. Limestone from North Wales, UK was chosen as the control aggregate in the bituminous mixtures. It was supplied in six sizes: 20, 14, 10, 6, 3 mm - dust and filler. IBAA from Teesside, UK was supplied in two sizes: 20-10 mm and 10 mm - down. The binder used was 100/150 Pen bitumen sourced from Venezuela.

A limestone control blend was first developed, which meets the BS 4987-1 (BSI 2003) grading envelop specifications for a 20mm binder course. Based on this blend, limestone was replaced by IBAA at different levels: 30, 60 and 80% by mass. The developed blends were then utilised to produce hot bituminous mixtures. As a result, four mixtures were manufactured. Details are shown in Table 1.

Table 1 Mixtures details

Mix reference	Limestone sizes content (%)						IBAA sizes content (%)	
	20 mm	14 mm	10 mm	6 mm	3 mm	Filler	20-10 mm	≤10 mm
OA	25	12	8	15	37	3	-	-
AA	13	6	4	8	37	3	24	6
BA	-	-	-	-	37	3	48	12
CA	-	-	-	-	17	3	48	32

3.2 Mix Design

Prior to mixing, the aggregates and bitumen were heated to a mixing temperature of 160 ^{0}C. Then the mixtures were laid in the moulds and compacted to slabs using a laboratory roller compactor. Cylindrical specimens of 100 mm diameter and 65 mm height were cored from the slabs. The specimens' volumetric properties were calculated, encompassing the compacted density of the mix (CDM), voids in mineral aggregate (VMA) and theoretical voids in mix (VIM). As can be seen from Fig 1, the IBAA mixtures are lighter than the control limestone material due to the difference in their respective specific gravities, which were 2.42 and 2.72. Subsequently, the indirect tensile stiffness modulus (ITSM) at 20 ^{0}C was measured in accordance with BS DD 213:1993 (BSI 1993).

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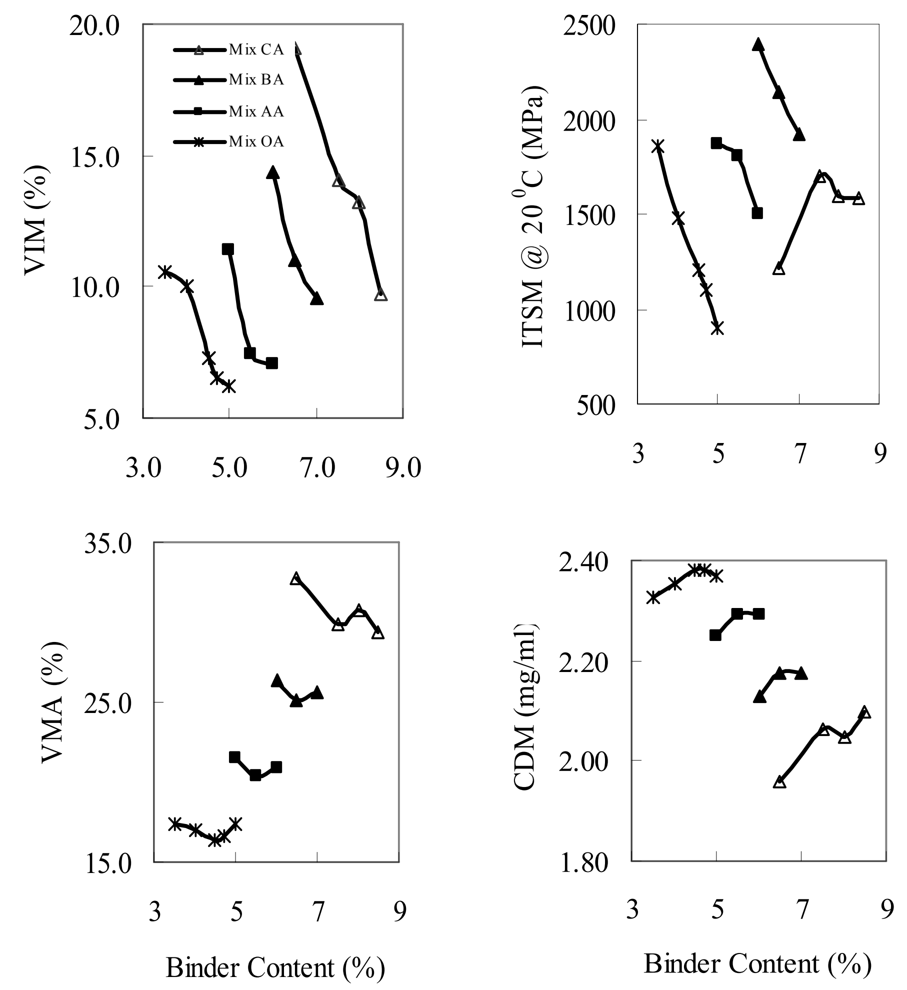

Figure 1 Mix design parameters

The design parameters in Fig 1 indicated that the VIM and ITSM values decreased with increase in binder content. The CDM reached its maximum values at 4.5, 5.5, 6.5, and 7.5% binder content for mixtures 0A, AA, BA, and CA respectively, while the VMA were at their lowest at the same binder contents. The volumetric approach, i.e. max. CDM and min. VMA values, was adopted to determine the optimum binder content (OBC). As a result, binder contents of 4.5, 5.5, 6.5, and 7.5% were chosen as OBCs for mixtures 0A, AA, BA, and CA respectively. At these OBCs the voids filled with bitumen (VFB) were found to be 55, 64, 56, and 53% which indicates the high absorption properties of the IBAA.

Mix design results show that mix AA, with 5.5% OBC and 7.4% voids content, is suitable for binder courses in flexible pavement according to the UK specifications, which allow up to 8% VIM. On the other hand, mixes BA and CA were found to have high OBC and voids content values, which render them uneconomical.

4. METHODOLOGIES

4.1 Moisture Immersion Regime

Bituminous mixtures should have an acceptable resistance to changes caused by the ingress of moisture. Water entry may result in loss of adhesion between bitumen and aggregates, which can lead to a reduction in the strength of the mixture. In most moisture sensitivity tests, coated aggregate is soaked in water under controlled conditions of time and temperature. Stiffness measurements are taken before and after immersion in order to assess the mixture susceptibility to water ingress. One of these regimes is that stipulated by the British Board of Agrément (British Board of Agrément 1998).

The test procedure used can be summarised as follows. Firstly, the stiffness of the unconditioned specimens was determined. The specimens were placed in a vacuum desiccator, shown in Fig 2 (a), at 20 ^{0}C, covered with distilled water and a partial vacuum of 510 mm Hg was applied for 30 minutes. The specimens were then moved from the desiccator and placed in a water bath, shown in Fig 2 (b and c), at 60 ^{0}C for 6 hours. After that, the specimens were immediately moved to a cold water bath at 5 ^{0}C for 16 hrs, and then placed in a moderate temperature bath at 20 ^{0}C for 2 hours. This thermal conditioning cycle, 6 hrs at 60 ^{0}C, 16 hrs at 5 ^{0}C and 2 hrs at 20 ^{0}C, was repeated three times one after the other immediately. During these steps, temperatures were monitored using a PC. At the end of the last cycle, the specimens were conditioned overnight at 20 ^{0}C and their stiffness was determined.

4.2 Ageing Procedure

A laboratory accelerated curing test was conducted with the aim of relating the in-service stiffness modulus of bituminous mixtures to their initial stiffness modulus measured soon after manufacturing. The protocol used was presented by the Highways Agency (Chaddock and Pledge 1994) in which the specimens are mounted in the percentage refusal density (PRD) moulds and then heated in a temperature controlled forced air draft oven at 60 ^{0}C for 48 hrs. Ordinary 100 mm diameter compaction moulds, which are similar to PRD moulds, were used in this study, as shown in Fig 3. The stiffness of the specimens was measured before and after curing to predict the stiffness after one year in service.

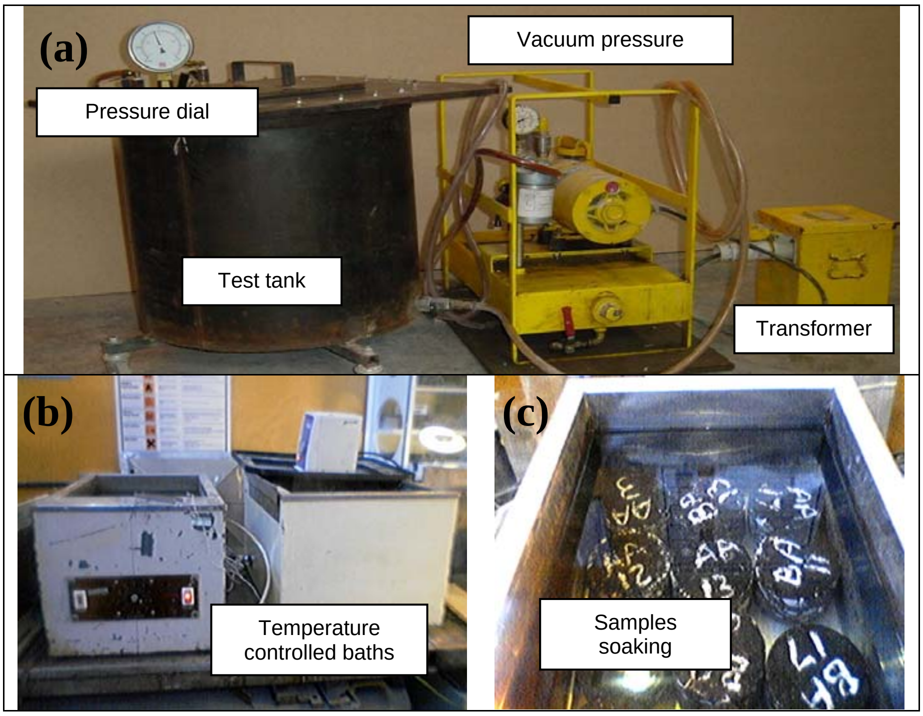

Figure 2 Moisturizing assembly

Figure 3 Samples in moulds during ageing

4.3 Leaching Test

The environmental compatibility of an aggregate is usually assessed on the basis of its leachability. It is known that leaching processes are very complex and depend on a number of different physical and chemical interactions. Laboratory tests can not simulate all possible practical conditions in a satisfactory way. Therefore it is necessary to make simplifications in order to conduct a quick and simple leaching test. Leaching tests were initially developed to study the short term environmental impact of waste disposal to landfill. In simple words, a leaching test involves bringing a tested material into contact with leachant under specific conditions. Then the resultant leachate should be analysed to indicate which elements are likely to dissolve.

In this paper, leachates were studied by running a national rivers authority (NRA) recommended leaching test, (Lewin et al. 1994), for mixtures AA, BA and CA. Three samples of each mixture were tested at three different binder contents, including the OBC. Leachates for the unbound loose blends, originally used to develop the bituminous mixtures, were also analysed to examine the effect of bitumen coating on IBAA leaching properties.

A leachate is prepared by adding 100 gm of sample to one litre of distilled, de-ionised water to obtain a liquid / solid ratio of 10:1 (L/S_{10}). This is then mechanically agitated, at 10 cycles per second, for 24 hrs. This duration is sufficient for the sample to reach the steady state or near equilibrium leaching conditions (Bialucha 2000). After equilibrium is achieved, leachates were filtered through 0.45 μm filter paper. The solution was then analysed for the determinants. The pH and the electrical conductivity were analysed using a calibrated electrode. In addition, metals were analysed using inductively coupled plasma - optical emission spectrometer (ICP-OES). The analysed metals were: Arsenic – Boron – Cadmium – Chromium – Copper – Iron – Mercury – Nickel – Lead - Zink.

Moreover, cyanides, sulphides and chlorides were analysed using liquid ion chromatography. Ammonia and chemical oxygen demand (COD) were analysed using colour-metric determinations. Phenol was analysed using gas chromatography.

5. RESULTS AND DISCUSSION

5.1 Moisture Effect

The retained stiffness results, shown in Fig 4, indicated that all mixtures suffer a loss in their stiffness values due to moisture effects. However, this retained stiffness ranged from 60 to 70% over a narrow range of binder contents. As a result, the IBAA could be considered as having a minor reduction effect on ITSM due to water ingress.

5.2 Ageing Effect

Fig 5 shows that mix AA, at its OBC, underwent least change in stiffness due to ageing, followed by mixes CA, OA and BA at their OBCs. This can be attributed to the fact that mix AA has the lowest voids, which aided in resisting ageing effects. Mix CA, although had highest voids, the binder film was thinnest as most of the binder was absorbed by the large proportion of IBAA in the blend. Thus, the effect of the binder was minimal. Mixes OA and BA showed commensurate ageing to their respective voids contents.

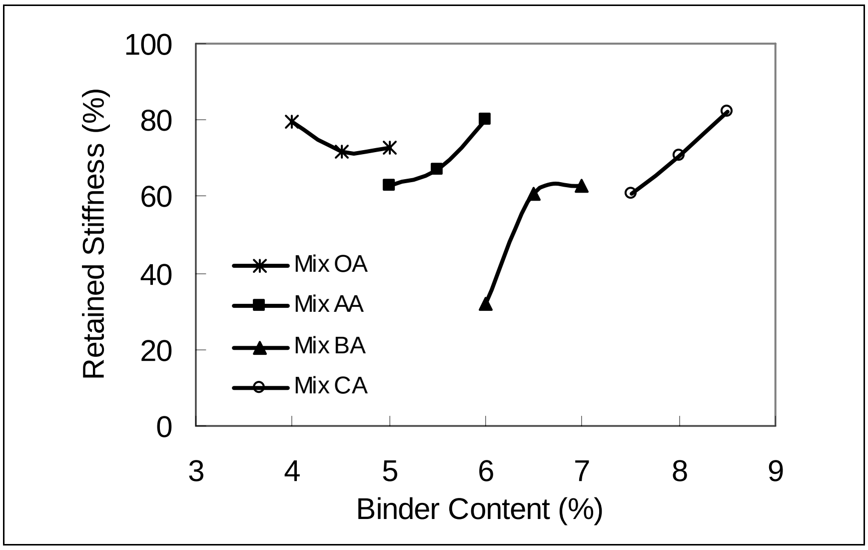

Figure 4 Retained ITSM values after moisturizing

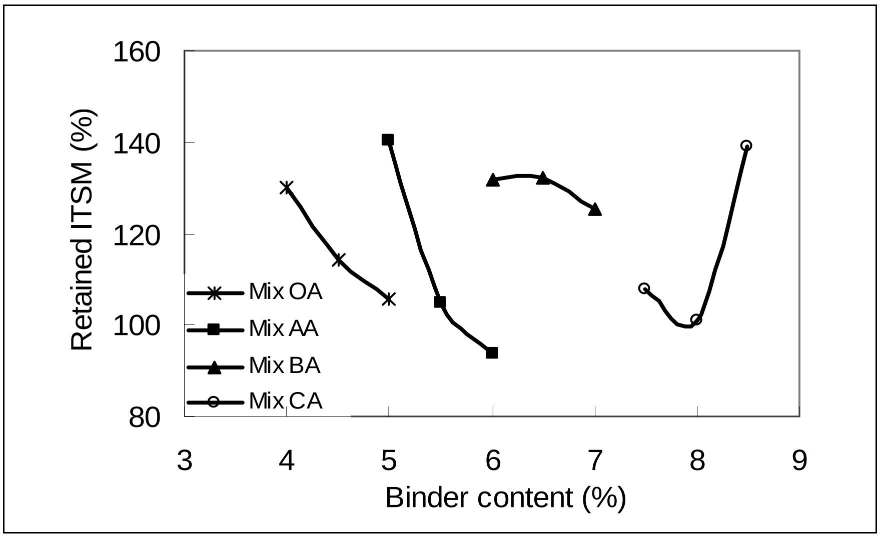

Figure 5 Retained ITSM values after ageing

The increase in ITSM was in the range of 5 to 15% for mixes OA, AA and CA, at their OBCs, which is good from the durability viewpoint. On the other hand, for mix

BA, the increase was about 30%, at its OBC, which is not good at low temperature conditions as the material may become more brittle and fracture can happen earlier. However, the rate of increase of the ITSM is expected to diminish after the first year of mixture production (Said 2005).

5.3 Leaching Properties

Elements found in the leachates from loose blends were compared to the corresponding environmental water quality standard / water quality standard (EQS/WQS) reference limits (National Rivers Authority 1994). Table 2 shows that the concentrations of the elements, found in the leachates, were at very low levels. This result highlighted that use of IBAA, added to limestone at high levels, gives an environmentally accepted material. Nevertheless, this fact needs to be emphasised by conducting a dynamic leaching test in which the leachant is continuously or intermittently renewed.

The other parameter investigated in this study was the effect of binder coating on the leaching properties of a bituminous mixture containing IBAA. Thus, the element concentrations found in the loose samples were compared to those found in the bituminous mixtures. Results indicated that coating IBAA with bitumen has a significant effect on its leaching properties. It was found that the pH and the electrical conductivity values for bituminous mixtures leachates were less than those for the loose blends. Moreover, most of the elements found in the leachates were found to decrease with increase in bitumen content. The only exception was the sulphate which had higher values in some bituminous mixtures compared with the loose blend. Table 3 shows a sample of results for mix BA. Due to lack of space the other mixture results are not shown here.

Table 2 Loose blends elements versus EQS/WQS standards

Species	Symbol	EQS/WQS (mg/l)	Mix AA (mg/l)	Mix BA (mg/l)	Mix CA (mg/l)
Arsenic	As	0.05	<0.01	<0.01	<0.01
Boron	B	2	<1	<1	<1
Cadmium	Cd	0.005	<0.001	<0.001	<0.001
Chromium	Cr	0.05	<0.05	<0.05	<0.05
Copper	Cu	3	<0.02	<0.02	<0.02
Iron	Fe	0.2	<0.1	<0.1	<0.1
Mercury	Hg	0.001	<0.001	<0.001	<0.001
Nickel	Ni	0.05	<0.02	<0.02	<0.02
Lead	Pb	0.05	<0.01	<0.01	<0.01
Zink	Zn	5	<0.1	<0.1	<0.1
Phenol	C_6H_5OH	0.0005	<0.0001	<0.0001	<0.0001
Cyanide	CN	0.05	<0.05	<0.05	<0.05
Sulphate	SO_4	250	14	42	25
Chloride	CL	400	10	95	47
COD	COD	200	10.5	76.8	48.4
Ammonia	NH_3	0.5	0.06	0.28	0.38

Table 3 Binder coating effect on IBAA mixtures leaching properties

Species		Loose blend	Mix BA	Mix BA	Mix BA
			6% binder	6.5% binder	7 % binder
pH value		12	9.1	9.8	10.1
Sulphate	mg/l	42	63	33	45
Chloride	mg/l	95	49	35	36
COD	mg/l	76.8	23.8	6.3	7.4
Electrical conductivity	μScm	1192	396	254	304

6. CONCLUSIONS

From the preceding sections, the following remarks can be made:

1. It is clear that the more IBAA was added, the higher the optimum binder content was and more voids resulted owing to the high absorption properties of IBAA.
2. Using IBAA at 30% content in bituminous mixtures is suitable for UK binder courses in UK flexible pavements. On the other hand, using 60 and 80% IBAA content produce uneconomical mixtures.
3. Addition of IBAA significantly improves the mixtures' ITSM values, excluding mix CA, at 80% IBAA.
4. The control mix retained stiffness, after a water immersion regime, was found to be 70%. Using IBAA led to a reduction in the retained stiffness of the mixtures. However, this reduction was less than 10% compared with the control mix.
5. IBAA mixtures' stiffness increased when subjected to an ageing protocol. This increase was significantly high at 60% IBAA, whereas the 0, 30 and 80% mixtures underwent insignificant changes to their stiffness values.
6. Most of the element concentrations found in the leachates of the IBAA-limestone loose blends were lower than the limits for EQS/WQS. These concentrations were found to decrease when tested in the IBAA bituminous mixtures. This indicates the safe use for IBAA in asphalt.
7. The pH and electrical conductivity values were found to decrease dramatically after coating with bitumen, whereas the sulphate was found to increase, with no known reason, in some mixtures.

REFERENCES

BIALUCHA R. (2000) - "Leaching standard for quality control of aggregates" - Waste Materials in Construction Conference, WASCON, UK.
BRITISH BOARD OF AGRÉMENT (1998) - "Guidelines document for the assessment and certification of thin surfacing systems for highway" - SG3/98/160, SG3, British Board of Agrément, Highway Authorities product approval scheme (BBA/HAPAS).
BRUDER-HUBSCHER V., F. LEROY, C. COUGHANOWR, AND F. ENGUEHARD (2001) - "Utilisation of bottom ash in road construction: Evaluation of the environmental impact" - Waste Management and Research, 19(6), pp. 545-556.
BSI (1993) - "Determination of the indirect tensile stiffness modulus of bituminous mixtures" - British Institution, DD 213:1993.
BSI (2003) - "Coated macadam (asphalt concrete) for roads and other paved areas: Specification for constituent materials and mixtures" - British Institution, BS 4987:2003 part 1.
CAI Z., D. BAGER, AND T. CHIRSTENSEN (2004) - "Leaching from solid waste incineration ashes used in cement treated base layers for pavements" - Waste Management, 24, pp. 603-612.
CHADDOCK B. AND A. PLEDGE (1994) - "Accelerated and field curing of bituminous roadbase" - Project report PR87, Transportation Research Laboratory.
EIGHMY T., D. CRIMI, S. HASSAN, X. ZHANG, AND D. GRESS (1995) - "Influence of void change, cracking, and bitumen aging on diffusional leaching behaviour of pavement monoliths constructed with MSW combustion bottom ash" - Transportation Research Record, 1486, pp. 42-48.
EIGHMY T., D. GREES, X. ZHANG, S. TARR, AND I. WHITEHEAD (1992) - "Bottom ash utilization evaluation for the Concord, New Hampshire waste-to-energy facility" - Environmental research interim report, Durham, University of New Hampshire, USA.
GARRICK W. AND K. CHAN (1993) - "Evaluation of domestic incinerator ash for use as aggregate in asphalt concrete" - Transportation Research Record, 1418, pp. 30-34.
HARTLEN J. AND P. ELANDER (1986) - "Residues from waste incineration - chemical and physical properties" - Report No. SGI VARIA 172, Swedish Geotechnical Institute, Linkoping, Sweden.
LEWIN K., K. BRADSHAW, N. C. BLAKEY, J. TURREL, S. M. HENNINGS AND R. J. FLAVIN (1994) - "Leaching tests for assessment of contaminated land" - Interim NRA guidance, National Rivers Authority, UK.
MEIMA J. AND A. R. COMANS (1997) - "Overview of geochemical processes controlling leaching characteristics of MSWI Bottom Ash" - Environmental and Technical Implications of Construction with Alternative Materials Conference, WASCON, Netherlands.
NATIONAL RIVERS AUTHORITY (1994) - "Water quality objectives" - Bristol, UK.
OGUNRO V., H. INYANG, D. YOUNG, AND A. OTURKAR (2004) - "Gradation control of bottom ash aggregate in Superpave bituminous mixes" - Journal of Materials in Civil Engineering, November/December 2004, pp. 604-613.
SAID S. (2005) - "Aging effect on mechanical characteristics of bituminous mixtures" - Transportation Research Record, 1901, pp. 1-9.

SCHREURS J., H. VAN-DEER. SLOOT, AND CH. HENDRIKS (1997) - "Verification of laboratory - field leaching behaviour of coal fly ash and MSWI bottom ash as a roadbase material" - Environmental and Technical Implications of Construction with Alternative Materials Conference, WASCON, Netherlands.

VASSILIADOU E. AND S. AMIRKHANIAN. (1999) - "Coal ash utilization in asphalt concrete mixtures" - Journal of Materials in Civil Engineering, November, pp. 295-301.

ZENG M. AND K. KASIBATI (2003) - "Evaluation of moisture susceptibility of asphalt mixtures containing bottom ash" - Transportation Research Record, 1832, pp. 25-33.

ZHANG X., D. GREES, S. KAPRINSKI, AND T. EIGHMY (1999) - "Utilization of municipal solid waste combustion bottom ash as a paving material" - Transportation Research Record, 1652, pp. 257-263.

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