HOT ASPHALT PAVEMENT MIXTURES INCORPORATING ALL WASTE MATERIALS

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Abstract
This paper describes the performances of asphalt hot mixtures incorporating all waste materials: crushed glass; steel slag; and coal ashes, i.e. fly ash and furnace bottom ash (FBA) into hot asphalt mixtures. The mixture properties evaluated were: volumetric properties, stiffness modulus (ITSM), dynamic creep, and creep stiffness. These properties were compared with conventional hot asphalt mixtures, i.e. not containing any waste/recycled materials. Porosity of 4 % and indirect tensile stiffness (ITSM) value of 2000 MPa was selected for low to medium trafficked road. Compared with other waste materials used, FBA has most significant potential to reduce stiffness; hence the main objective of the experiments was to evaluate the performance on the mixtures and to limit the incorporation of FBA for maintaining the stiffness (ITSM) of the mixtures. It was found that hot asphalt mixtures can incorporate all waste materials tried where a limited amount of FBA (up to 25 % of the fines aggregate components) can be used to maintain mix stiffness. The utilization of harder bitumen grades (minimum 50 pen.) is recommended.

Keywords:
hot asphalt mixtures, waste materials

INTRODUCTION

Increasing pressure on environment conservation leads to significant reduction of the amount of materials to be exploited from materials quarries. This matter coupled with limited availability of land filled site adds further needs to utilize waste materials for constructions including road asphalt pavement.

Within this investigation, some waste materials were used for producing asphalt mixtures, namely crushed glass, steel slag, and coal ashes, i.e. fly ash and furnace bottom ash (FBA). Hot bituminous mixes for roads / pavements provide an ideal opportunity to recycle these waste materials. Materials such as crushed glass, steel slag, coal fly ash, have previously been incorporated in hot mixes in the UK, except FBA. Furnace bottom ash is normally excluded because it is seen as a material of secondary quality, which is very porous, weak, and brittle. This material clearly cannot meet the aggregate quality specified in most specifications. The FBA consists of coarse and fine components. The coarse component can be as large as 75 mm in diameter and the fine ones can be of sand type particle sizes (Sear, 2001).

The incorporation of FBA into hot mixtures has the most significant potential to reduce the stiffness. However, *the aim of this investigation was* to evaluate the performance on the mixtures and to limit the incorporation of FBA for maintaining the stiffness (ITSM) of the mixtures. It was thought that only a limited amount of FBA can used as fine aggregate substitute in hot bituminous mixtures and that to maintain mix stiffness. The utilization of harder bitumen grades (minimum 50 pen.) is recommended.

The target compacted mix porosity was 4% and a minimum stiffness value (Indirect Tensile Stiffness Modulus - ITSM) of 2000 MPa was set which is suitable for low to medium trafficked road pavement (HAUC, 1992).

Coal ashes produces from coal fired electricity power station consist of around 20-25 % FBA, and 75-80 % fly ash. Traditionally, fly ashes have been used in a range of applications, namely: as fill materials, for grouting, and soil stabilization. Fly ash has also been used in road pavements: as road bases, sub bases, and as subgrade formations.

From a pavement engineering perspective, the most useful types of mixtures that utilize fly ashes for road pavements are fly ash bound mixtures (FABMs) and granular fly ashes (GFA). These mixtures rely on the pozzolanic properties of fly ash which can harden in the presence of water and lime and/or cement. Fly ash can also be used in cement bound mixtures (building blocks, concretes, etc). The FBA can be used as a capping layer for weak sub grades (sub grade formation), though it is mainly used in light weight concrete blocks (Sear, 2001).

The use of fly ash as fillers in Hot Rolled Asphalts (HRA's) had been tried in the UK. Since fly ash particles tend to be more spherical in shape when compared to limestone filler, laboratory investigations have shown that fly ashes can enhance the workability of the bituminous mixtures, which is of great benefit particularly during the compaction process (Cabrera and Zoorob, 1995).

The utilization of fly ash in the UK has remained stable for a number of years at around 50 % of production. The amount of fly ash available in stock, in addition to fresh production is estimated to have remained relatively constant at about 250,000,000 tones for a number of years (Sear, 2001).

Meanwhile, almost all FBA produced in the UK, has been used in the manufacture of light weight aggregate concrete blocks. However, outside the UK, all of the FBA produced is not yet fully utilized and there is some 56 % of the FBA produced were still disposed of or used as land reclamation (Sear, 2006).

The glass-manufacturing sector in the UK has a limited capacity to accept green and mixed colour glass. As glass collection increases (to meet the 2006 packaging targets of 60% an ‘excess’ (300,000 to 400,000 tonnes) of green glass is likely, for which alternative high value, high volume markets are required (WRAP, 2003). Glasphalt hot mixtures incorporating 30% crushed glass (using a 100 pen. bitumen), laid at a trial site in Milton Keynes by RMC Aggregates Ltd. showed an average ITSM value of 1900 MPa. Meanwhile, on the same trial, the control hot mixture (not containing crushed glass) gave 2200 MPa. The average porosity for the Glasphalt and the control mixtures on that trial were 4.9% and 4.7% respectively (Nichols and Lay, 2002).

Metallurgical slags (basic oxygen steel slag (BOS)) are secondary products of the refining of metals from metal ores. It has been used in pavement materials for a number of estate roads, including local distribution roads and bus routes. The material is hard, with a rough surface, angular shape, and reasonable water absorption. It therefore satisfies the requirements for road pavements. Steel slag is expansive by nature because of the presence of free calcium oxide and magnesium oxide and this expansion may cause premature deterioration (cracking) in bituminous mixtures. Hence in the UK it is weathered before use (HWD, 2001).

Aggregate Gradations for the Mixtures

The aggregate gradations of all the design mixtures used in this investigation were based on a modified Fuller’s curve (MFC) using a formula proposed by Cooper et al., 1985, as shown below:

$$P = \frac{(100 - F)(d^n - 0.075^n)}{D^n - 0.075^n} + F \ .... [1]$$

Where: P = % material passing sieve size d (mm), D = maximum aggregate size (mm), F = % filler (passing 0.075mm), n = an exponential value that dictates the concavity of the gradation line. The n value used was 0.45, which is an exponential factor that is widely accepted as producing very good aggregate packing. The value selected for F was equal to 4 %, which satisfies the allowable limits for filler content in Dense Bitumen Macadams (BS 4987, 2003).

The maximum aggregate size used was 14 mm. The gradation line (based on Cooper’s formula, i.e. Formula 1 as above) is shown in Figure 1 together with aggregate gradation limits of a typical BS 4987 Dense Bitumen Macadam mixture, for comparison.

To produce the 50pen. hot mixtures, the coarse aggregate fractions were sieved and batched individually, whilst the fine fraction was classified as all passing 2.36 mm.

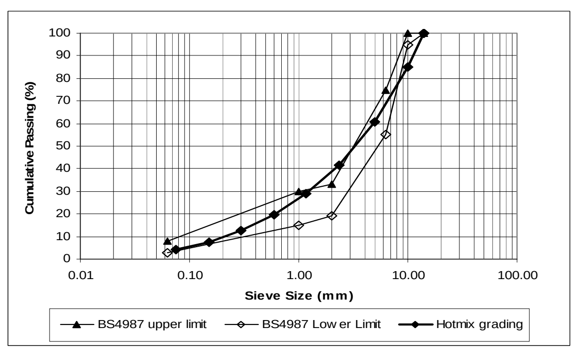

Figure 1. Aggregate Gradation

Porosity and compaction

Hot bituminous material mixtures for road pavement generally require 3, 4, and 5 % porosity values. These porosity values are typically specified for road pavements with low, medium, and heavy traffic loads, respectively. In this experiment, porosity values in the range of 4 % were targeted. To achieve this target, static compaction trials were carried out to compact the mixtures at 80-90 °C. It was found that a static compaction stress level of 50 MPa for 1 minute could result in the expected porosity.

The mechanical properties tested

In line with target performance, which was based on recommendation of the Highway Authority Utility Committee-HAUC, 1992, within this investigation the mechanical test used was the indirect tensile stiffness modulus (ITSM) at 20 °C (Figure 2), with ITSM min value targeted of 2000 MPa. The tests were done using a Universal Materials Testing Apparatus (MATTA). The ITSM tests were carried out in accordance with DD-213, (BS, 1993). For evaluation to resistance to deformation, dynamic creep test as shown in Figure 3 was applied to the samples.

The materials used

The materials used are shown in Table 1. The bitumen used was of 50 pens. Grade with density of 1.03 g/cm^3.

Table 1. The type of materials used

Materials	Density (g/cm^3)	Water Abs. (%)	Utilisation
Crushed glass	2.51	< 1	Coarse and fine aggregate
Steel Slag	3.39	1.9	Coarse aggregate
FBA (Ferrybridge PS)	1.60	13.9	Fine aggregate
Fly ash (Ferrybridge PS)	2.16	-	Filler

Note: PS = power station.

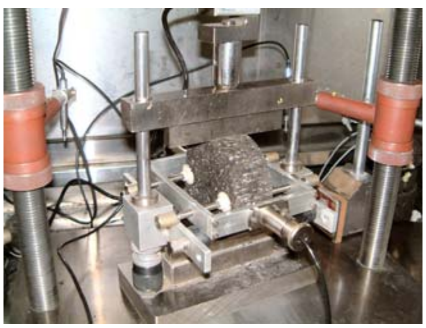

Figure 2. Indirect Tensile Stiffness Modulus (ITSM) Test

Figure 3. Dynamic Creep Test.

The FBA particles that were used as the fine aggregates were composed entirely of material passing 2.36 mm. The larger particles were discarded and were not re-crushed, as enough materials passing 2.36 mm available.

The type of materials used for optimum bitumen content determination

Initially, for the determination of optimum bitumen content (using 50 pen bitumen), the materials used for the mixtures were crushed glass coarse aggregates, crushed glass fine aggregates, and fly ash filler (without FBA component). The bitumen content was varied from 4 %, 4.5 %, 5%, 5.5 % and 6 %. With the type of materials used as above, it was found that *the optimum bitumen content was at 5 %*, with ITSM of 2050 MPa.

Trials on the effect of incorporating FBA

The materials used for these trials were the same as the materials for determining optimum bitumen content. It had been appreciated that FBA has the potential to reduce stiffness. In order to obtain the maximum amount of FBA that can be incorporated, the amount of FBA used *to substitute (by volume)* the fine aggregates (crushed glass passing 2.36 mm) was varied, i.e. 100 %, 75 %, 50 %, and 25 % of the fine aggregate (37.5 %) portion. As had been anticipated, the stiffness of the samples in line with the FBA content variation above, respectively reduces from 1100 MPa, 1540 MPa, 1860 MPa, and 2218 MPa.

As the FBA is a porous, brittle, and light type material with low density and high absorption properties (see Table 1). These properties in turn result in reduced strength. As the minimum target of ITSM was 2000 MPa, it was therefore the maximum FBA content of 25 % was selected (about 9% by weight of the total aggregate), which gave ITSM 2218 MPa.

Mixture Designation that contains 25 % FBA of the fine fraction

For further evaluation of the mixtures containing 25% FBA of the fine fraction, two type mixtures were produced as shown in Table 2.

Table 2. Type of Mixtures.

Mixture	Coarse aggregates * (58.5 %)	Fine Aggregates ** (37.5 %)	Filler (4%)
Glass Mix	100 % crushed glass	25 % FBA 75 % crushed glass	fly ash
Sslag Mix	100 % steel slag	25 % FBA 75 % crushed glass	fly ash

* The coarse aggregates were composed of the following fractions (14-10mm), (10-5mm), (5-2.36mm)

** The fine aggregates were composed of the fol lowing fraction (2.36-0.075mm).

Comparisons of with other conventional hot mixtures

The performances of the mixtures were also compared with a readily available test data. The mixtures chosen were a Hot Rolled Asphalt (a gap graded mix), and an Asphalt Concrete-AC (a continuously graded mix) both made with 50 pen. bitumen and both having a maximum aggregate size of 14mm. The optimum bitumen content of both mixtures was the same: 5 % by mass of total mixture. The materials used for the compared mixtures were limestone coarse aggregates, fine asphalt sand and ordinary Portland cement (OPC) as filler (Suparma, 2001).

Volumetric and stiffness properties

The volumetric and mechanical properties of the mixtures all at 5% optimum bitumen content are given in Table 3.

Table 3. Volumetric properties and ITSM of the mixtures.

Mixtures	Bitumen type	Density (g/cm^3)	Porosity (%)	ITSM (MPa) at 20 °C
Glass Mix	50pen.	2.159	4.3	2218
Sslag Mix	50pen.	2.602	4.1	2732
HRA *	50pen.	-	3.7	4564
A.C. *	50pen.	-	5.7	5683

* [Suparma, 2001], for comparison.

At 5% optimum bitumen content, both mixtures containing waste materials were evenly coated. As shown in Table 3, the ITSM values of the mixtures containing waste materials were in excess of 2000 MPa, which is the minimum, recommended ITSM value for medium to low trafficked roads (HAUC, 1992). The Glass Mix was weaker than the Sslag Mix. This is attributed to the fact that the coarse steel slag aggregates provide much better internal friction than the crushed glass.

The ITSM of the mixtures containing waste materials were approximately half the values obtained from conventional asphalt concrete (AC) and HRA hot mixtures. The continuously graded (better aggregate interlock) AC mix is slightly stiffer than the HRA mix, and hence has more resistance to creep deformations (see Figure 4), even though it has a higher porosity.

Creep Performance

Dynamic creep tests were carried out with the following test conditions: pulse width 1000 ms, pulse period 2000 ms, test termination Strain 100000 μs, terminal pulse count 3600 pulses, conditioning stress 10kPa, test loading stress 100 kPa, conditioning time 15 minutes, pre-load rest time 2 minutes, recovery time 2 minutes. The tests were carried out at 40 °C.

The creep performance of the samples (number of load cycles vs. cumulative strain) is shown in Figure 4. As is generally the case for creep behavior, the creep curve can be divided into three main regions; *the primary creep region* where the strain rate decreases with the number of load cycles applied; the *secondary creep region* where the strain rate is almost constant, otherwise known as the steady state strain rate; and the *tertiary creep region* where the strain rate increases rapidly up to failure. The steady state strain rates (secondary region), or creep slope values are shown in Table 4.

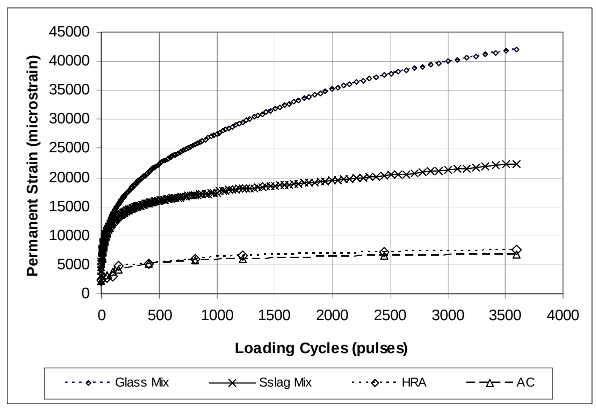

Figure 4. Dynamic Creep Test Results (strain vs. load cycles) at 40°C.

The results are compared with the available data from hot mixtures incorporating 50 pen. bitumen. Typical minimum acceptable creep slope values are given in Table 5.

Table 4. Dynamic Creep Slope data (Referring to Figure 4).

Mixture type	Test temp. (°C)	Linear Regression * Equations and R^2	Slope of Creep Curve (με / pulse)
Glass Mix	40	y= 4.2904x + 26770 R^2 = 0.9950	4.290
Sslag Mix	40	y= 1.8151x + 15852 R^2 = 0.9998	1.815
A.C.	40	y= 0.3378x + 5614.1 R^2 = 0.9841	0.338
HRA	40	y= 0.4229x + 6041.1 R^2 = 0.9565	0.423

* Equations applicable to the range from 1200 - 3600 pulses, on the steady state strain rates condition (see Figure 4).

Table 5. Typical laboratory determined minimum dynamic creep slope values *.

Average annual pavement temperature (ºC)	Heavy Traffic > 10^6 ESA	Medium Traffic 5×10^5 to 10^6 ESA	Light Traffic < 5×10^5 ESA
> 30	< 0.5	0.5 - 3	> 3 - 6
20 - 30	< 1	1 - 6	> 6 - 10
10 - 20	< 2	2 - 10	Not Applicable

* (Aderson, 1995).

Referring to the creep test results (Figures 4 and 5 and Tables 4 and 5), in general, the creep performance of the mixtures is directly related to their stiffness (ITSM) values. Naturally, a higher ITSM value results in higher creep stiffness value, which in turn leads to reduction of permanent deformations, and lower creep slope values.
Mineral aggregate substitution by lower quality materials, such as crushed glass and furnace bottom ash (FBA), reduces the stiffness properties (both ITSM and creep stiffness) of mixtures and hence there is a requirement for maximum levels of mineral aggregate substitution.

Creep Stiffness (S_{mix})

The S_{mix} value is an additional indicative of the resistance to permanent axial deformation and for bituminous specimens which is basically obtained from the ratio of applied stress (100 kPa) to the cumulative compressive strain at a defined temperature and time of loading, as can be seen in Figure 5. Mixtures with lower stiffness (ITSM) are common to undergo higher deformation, hence it is logical to have lower S_{mix} values. Data in Figure 5 are in line with those in Figure 4.

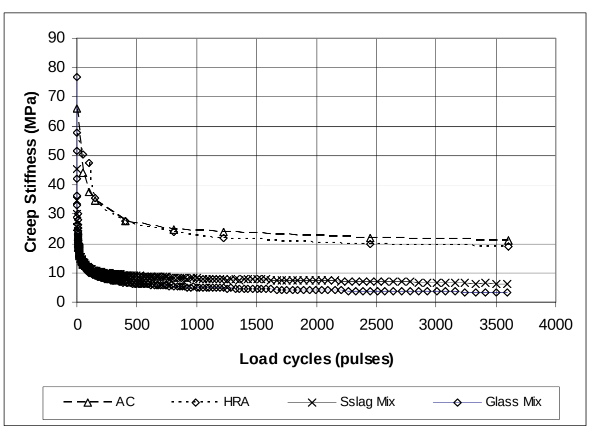

Figure 5. Creep Stiffness.

CONCLUSIONS

The main conclusions drawn from this investigation are as follows:

1. Hot asphalt mixtures in principle can incorporate all of the waste materials used, i.e. crushed glass, steel slag, fly ash, and furnace bottom ash (FBA).
2. A limited amount of furnace bottom ash (FBA), up to 25% by mass of the fine aggregate fraction (25% of 37.5%, see Table 1), i.e. equivalent to around 9% by mass of total aggregate, can maintain the targeted minimum stiffness (ITSM) value of 2000 MPa.
3. Utilization of aggregate materials, which is hard with angular shape and rough surface texture such as steel slag, increases the stiffness of the samples.
4. In order to maintain adequate stiffness (ITSM), hot asphalt mixtures incorporating FBA should use harder grade binders (recommended min penetration of 50 pen.), and are suitable for low to medium trafficked roads.

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