Aggregates Case Study

Ferrosilicate slag from zinc production as aggregates bound in bituminous mixes

Name: Trial Asphalt road at Britannia Zinc Limited (BZL)
Region: South West
Type of project: Demonstration (Research trial)
Date: September 2002
Background Information

History

Until early 2003 the BZL works was the UK’s only primary zinc smelter and had been at the site at Avonmouth, near the Severn Estuary, for 50 years. BZL was able to supply the zinc market with a range of grades and qualities through the development of the ‘Imperial Smelting Process’ to produce on average 90,000 tonnes of zinc and 35,000 tonnes of lead a year[1]. The zinc production process at BZL, Avonmouth, however, also produced 80,000 tonnes per year of ferro-silicate slag (Imperial Smelting Furnace slag, ISF slag) as a by-product. Ferro-silicate slag was produced and landfilled until March 2003 (when BZL ceased zinc production) and, at the time of writing, there are still significant quantities of this material (2 Mt stockpiled/landfilled) available at the Avonmouth site [1], Figure 1.

Figure 1    Zinc slag stockpile at BZL, Avonmouth

The project

A previous feasibility study undertaken by BRE [2] highlighted the potential use for ferro-silicate ISF slag from zinc production as aggregates bound in cement or bitumen. Additionally, laboratory studies at BRE showed the technical feasibility of using these waste streams in construction.

The BRE-led project described in this case study focused on development of asphalt mixes containing the ISF slag. The asphalt mix designs developed in the laboratory were then
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demonstrated in-situ through the construction of road sections on the Avonmouth site. The programme also included laboratory based leaching tests and on-going monitoring of the trial road sections on the Avonmouth site.

Specific issues associated with the use of ISF slag in construction investigated and addressed during this project are the potential for the slag to leach metals and long term durability.

Background to ISF slag

ISF slag is a by-product, generated during the primary smelting of zinc ore in a form of blast furnace. It is a granulated, glassy material and has the appearance of dark coloured sand. It typically has a particle size distribution between coarse and fine sand, but a higher specific gravity than sand due to its metal content (Figure 2). The typical chemical composition of ISF slag is shown in Table 1.

![Figure 2 Zinc slag](image)

### Table 1 Typical chemical analysis range of ISF slag (source Britannia Zinc Ltd)

<table>
<thead>
<tr>
<th>Name</th>
<th>Composition range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron oxide</td>
<td>37-40%</td>
</tr>
<tr>
<td>Silicon dioxide</td>
<td>19-20%</td>
</tr>
<tr>
<td>Calcium oxide</td>
<td>14-16%</td>
</tr>
<tr>
<td>Zinc</td>
<td>9-12%</td>
</tr>
<tr>
<td>Aluminium oxide</td>
<td>6-7%</td>
</tr>
<tr>
<td>Sulphur</td>
<td>1-3%</td>
</tr>
<tr>
<td>Lead</td>
<td>1-2%</td>
</tr>
<tr>
<td>Magnesium oxide</td>
<td>1-2%</td>
</tr>
<tr>
<td>Manganese oxide</td>
<td>1%</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0-5%</td>
</tr>
<tr>
<td>Copper</td>
<td>0-5%</td>
</tr>
</tbody>
</table>
ISF slag is inherently quite stable, retaining its physical characteristics over time. However, low level leaching of metals, in particular lead, typically occurs with prolonged exposure to water.

**Construction specification and related details**

**Specification**

A 28 mm nominal size Dense Bitumen Macadam (DBM) Binder Course [3] incorporating 50 pen bitumen was chosen as the target mixture for the asphalt road, since this is a widely used material for a range of pavement applications. Mixes were developed with and without ISF slag as a partial replacement for sand.

**Characterisation and Development of the mixes in the laboratory**

Through a process of mixture optimisation, a combination incorporating 30% ISF slag (replacing the sand completely in the original aggregate grading) and 70% limestone coarse aggregate was selected for use. The latter was sourced locally to the proposed demonstration site at Avonmouth.

In order to assess the suitability of ISF slag asphalt for use in pavement applications, a range of mixtures were manufactured and tested to assess mechanical and durability properties, which are known to be important for asphalt pavement life.

Four different mixture designs (to BS 4987-1, Tables 3 and 4), incorporating 30% ferrosilicate slag were produced. Test slabs were manufactured and a total of 20 number 100 mm diameter cores for each mixture design were tested as follows:

- stiffness [4], to assess load spreading ability
- deformation [5], to assess resistance to rutting
- fatigue [6], to assess resistance to cracking
- stiffness after ageing and water conditioning [7], to assess resistance to age and water related durability in service

The data in Table 2 indicated that the ISF slag asphalt mixtures are at least as good as asphalt mixtures manufactured with conventional aggregate with respect to stiffness and (age and water related) durability, but slightly inferior with respect to deformation and fatigue resistance. In practice, a 30% replacement of natural aggregate with ISF slag may be unrealistically high (due to the above effects on performance). It is anticipated that with lower levels of replacement (say 15%) more typical fatigue and deformation resistance properties could be achieved.

Mixture B in Table 2, which exhibited the best overall range of properties, was selected for the demonstration phase. This phase was carried out in the summer of 2003 in Avonmouth.
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Table 2  Key mechanical properties of different asphalt mixes

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Binder content (%)</th>
<th>Stiffness at 20°C (MPa)</th>
<th>Deformation (% Strain)</th>
<th>Fatigue (Life at 200 µε)</th>
<th>Ageing (% stiffness increase, aged/unaged)</th>
<th>Water Sensitivity (% retained stiffness, conditioned/unconditioned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.4</td>
<td>5080</td>
<td>2.3</td>
<td>10,000</td>
<td>34</td>
<td>90</td>
</tr>
<tr>
<td>B</td>
<td>4.0</td>
<td>3950</td>
<td>1.8</td>
<td>30,000</td>
<td>32</td>
<td>91</td>
</tr>
<tr>
<td>C</td>
<td>4.6</td>
<td>3320</td>
<td>2.9</td>
<td>40,000</td>
<td>6</td>
<td>104</td>
</tr>
<tr>
<td>D</td>
<td>4.0</td>
<td>4080</td>
<td>2.8</td>
<td>20,000</td>
<td>36</td>
<td>89</td>
</tr>
<tr>
<td>Typical Data</td>
<td>-</td>
<td>2380- 5060¹</td>
<td>&lt;2²</td>
<td>20,000-200,000³</td>
<td>&lt;100⁴</td>
<td>≥70%⁵</td>
</tr>
</tbody>
</table>

Notes:
1. Indirect Tensile Stiffness Modulus (ITSM) values for DBM50, from TRL Report 160 [8]
3. Indirect Tensile Fatigue Test (ITFT) data at 20°C, from SWPE database
4. From TRL Report 87 [10]

Construction process

A trial road was laid in Avonmouth on 21st July 2003. For the road trial, a DBM material comprising 30% ISF slag (% replacement of primary aggregate by volume) and 4.0% 50 penetration grade binder were used. The trial panel comprised two sections, the test and the control sections (with and without ISF slag respectively), which were manufactured, laid and compacted using full scale plant by Aggregate Industries under the direction of Scott Wilson Pavement Engineering (SWPE). The section of road containing the ISF slag proved easy to lay. These road sections, as with the trial concrete roadway laid previously, carry a significant amount of heavy industrial traffic and they have been visually monitored over a one year period with a final detailed assessment at 30 months.

Four site visits were carried out by SWPE: one a week after the road was laid (28 July 2003) with further interim inspections at three months (3 November 2003) and six months (19 February 2004) and at one year age (10 August 2004). A full assessment of site and laboratory tests was carried out at 17 months (17 December 2004).

A schematic of the trial sections is illustrated in Figure 3, and photos of the installation are shown in Figure 4.
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Figure 3  Trial Sections

Note: Numbers and circles denote number of cores removed from these sections (three full depth cores indicated by filled circles). Dimensions are in metres. The control section is nearest to the site entrance.
Figure 4 a) Laying the asphalt  b) Compacting of the asphalt road with a roller  
c) Asphalt roadway upon completion  d) Asphalt roadway at 30 months

Cost & environmental effectiveness

The quantities of these secondary materials produced may be considered small in relation to the volumes of aggregates consumed annually by the UK construction industry. However, the requirement to landfill these materials results in increased production costs and consumes valuable landfill sites. Equally, the comparatively small volumes can be readily consumed in the locality of production without affecting those parts of the local economy that rely on production of primary aggregates. This project offered a significant opportunity to not only demonstrate the technical feasibility of the consumption of these waste materials, but to also promote the use of small volumes of wastes in construction.

Slags from primary and secondary production of zinc (such as ISF slag) are classified as hazardous waste in the European waste catalogue. Due to the reclassification of landfill sites in July 2004 as part of The Landfill (England and Wales) Regulations 2004, costs of disposal of hazardous waste are expected to rise significantly.

Evidence from this project has provided re-assurance that contaminants in the ISF slag would be effectively immobilised in the matrix of an asphalt road structure in service, saving
the cost of its disposal to hazardous landfill and at the same time saving £1.60/t (aggregates Levy) for avoiding using a primary aggregate. At the end of its life, the road would be suitable for crushing to produce aggregate for new construction. One remaining concern could be disposal of the road material to landfill. Assessment of the crushed asphalt material (made with ISF slag) against landfill acceptance places the material in the “non-hazardous” category. Current charges for disposal of non-hazardous waste are £18/t under the landfill tax which aims to divert waste from landfill by charging for disposal. The landfill tax is expected to escalate yearly at £3/t until the charge reaches £35/t. It is most likely, however, that the material would be recycled.

Site assessment and lab work on cores from road

Initial assessment (at 1 week age)

The initial field monitoring involved coring, dynamic cone penetrometer (DCP) and falling weight deflectometer (FWD) testing, followed by an evaluation of the data and a comparison of the predicted pavement lives of the trial and control pavements for a hypothetical design traffic. The site evaluation has been carried out using FWD.

The results of the site and lab assessment are given in the final project report [2]. The conclusions drawn were broadly in line with those at 30 months.

Assessment of the road over time

The pavement assessments at 3, 6 and 12 months comprised a Detailed Visual Inspection (DVI) carried out in accordance with the UKPMS (United Kingdom Pavement Management System) Rules and Parameters Version 4 and the Visual Survey Manual.

At 12 months, the pavement surface appeared to be in good condition, with very little sign of distress. Localised surface aggregate loss was identified in a small area in the control section and localized permanent deformations, in the form of impressions from heavy tractor-type vehicle tyres, were identified in both sections, albeit more visible on the ISF Slag section surface.

Figure 5 shows that rutting values for both control and ISF slag sections are slightly greater or equal to those recorded during the previous inspections. However, the absolute magnitude of the recorded rutting remains low (6 mm max) (it would trigger "no action" in the structural assessment procedure detailed in Volume 7 of the Design Manual for Roads and Bridges) and there is no evidence of any significant difference in rutting between the control and ISF slag sections.
It should be emphasised that both the ISF slag and control sections comprised a DBM binder course type material that has been exposed to traffic. Under normal circumstances, a surface course would have been applied to the binder course before trafficking.

The inspections have demonstrated that an asphalt binder course material incorporating ISF slag sand, manufactured and laid with conventional plant, has performed satisfactorily for 12 months when subject to site trafficking with a mixture of light and heavy good vehicles. These results confirm those from the earlier laboratory investigation that ISF slag asphalt performs at least as well as comparable asphalt manufactured with conventional materials. There should therefore be no impediment to its immediate use.

**Assessment (at 17 months)**

The site evaluation was carried out using the FWD and DCP, whilst the laboratory testing was carried out on cores taken from site. The latter comprised determination of the stiffness, deformation resistance, fatigue resistance, water sensitivity, and composition analysis of the recovered asphalt cores and the determination of the calculated penetration and softening point values of binders recovered from the cored samples. The results obtained have been compared with those obtained during the initial monitoring, and are summarised below:

- The back-calculated in situ stiffness values for the Control and the ISF Slag materials were comparable. A shorter pavement life was calculated for the section overlaid with ISF Slag material; however, this was not attributed to the performance of the ISF Slag material, but a result of the lower stiffness and/or lower thickness of the pavement layers below.

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**Figure 5 Resume of the Rutting Measurements**

<table>
<thead>
<tr>
<th>ISF SLAG SECTION</th>
<th>CONTROL SECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>8m</td>
<td>8m</td>
</tr>
<tr>
<td>7m</td>
<td>(0) -&gt; (2)</td>
</tr>
<tr>
<td>6m</td>
<td>(2) -&gt; (1)</td>
</tr>
<tr>
<td>5m</td>
<td>(0) -&gt; (3)</td>
</tr>
<tr>
<td>4m</td>
<td>(1) -&gt; (4)</td>
</tr>
<tr>
<td>3m</td>
<td>(2) -&gt; (1)</td>
</tr>
<tr>
<td>2m</td>
<td>(0) -&gt; (2)</td>
</tr>
<tr>
<td>1m</td>
<td>(1) -&gt; (0)</td>
</tr>
</tbody>
</table>

Centre Line

www.aggregain.org.uk

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The Control and ISF Slag site samples showed an increase in the laboratory stiffness values (at 20°C) after more than one year in service (more significant for the Control samples). Overall, both locations presented good load spreading ability.

Both site mixtures presented good load spreading ability.

The fatigue lives of both site sections were considered to be comparable after more than one year in service. However, in comparison with the results from the initial field evaluation, the ISF Slag material showed a significant reduction in the fatigue resistance.

The water sensitivity testing indicated that all the studied mixtures would not be deemed susceptible to water related durability problems in service.

The recovered binder properties from each mix were satisfactory.

The laboratory test results highlighted that the control material has a slightly better resistance to permanent deformation, but higher air voids content, than the ISF Slag material. Load spreading ability, resistance to fatigue and water sensitivity of both site sections appeared to be comparable.

A reduction in fatigue resistance observed on both trial sections after over one year in service was not unexpected, since bituminous materials normally suffer from fatigue damage during their service lives. The fact that the DBM base materials were exposed directly to heavy traffic loading (i.e. instead of being overlaid by a surface course, as would be normal practice) might have exacerbated the level of reduction in the fatigue resistance of these trial materials.

**Leach tests**

SWPE completed laboratory leach testing of unbound ISF slag and bituminous mixes containing ISF slag using the LS2-10 [12] compliance test and aggregates tank leaching test [13]. This work has shown the following results:

- The quantities of constituents leaching from materials were all lower than the EQS/Water Quality Standards limits except for lead and nickel. Binding the ISF with bitumen significantly reduced the leached quantities.
- The quantities of materials leached from ISF bound by bitumen were similar to those leached from bound limestone and granite primary aggregates.
- The LS2-10 test for a sample of the ISF slag examined by SWPE gave values consistent with disposal to inert landfill.

Cores extracted from the ISF slag and Control asphalt road sections were crushed and subjected to the LS2-10 compliance test. The results were below the limits for inert landfill except for arsenic and levels were similar for both control and ISF samples. This implies that some contamination of the samples (due to materials present at the BZL site) has occurred.
probably during coring. However, levels of metals were all low. It appears that the asphalt road could be disposed of without difficulty associated with the use of ISF slag.

**Environmental/ regulatory issues**

Laboratory leach testing of high quality ISF slag asphalt with landfill acceptance tests has provided evidence that contaminants within the ISF slag are effectively bound up when the slag is used as an aggregate in asphalt. Furthermore, a properly designed and constructed road will minimise water ingress and percolation through its structure. Both these facts provide re-assurance that contaminants in the ISF slag would be effectively immobilised in the matrix of an asphalt road structure in service.

There are no reasons why the road should not be recycled at the end of its life. However, assessment of the crushed asphalt material (made with ISF slag) against landfill acceptance criteria for granular waste has indicated that levels of lead leached from crushed asphalt containing ISF slag exceeds the limits for inert waste, placing the material in the “non-hazardous” category.

Based on these results, there should not be any environmental barriers to the use of ISF slag in these applications.

**Lessons Learnt**

The objectives of the project were to:

- develop mix designs for asphalt containing ISF slag from zinc production
- demonstrate the use of the ferro-silicate slag through the construction of demonstration road sections.

These objectives have been met to a high degree. Asphalt mixes containing ISF slag aggregate have been successfully made and the roadway has been placed and assessed. The project has successfully demonstrated the feasibility of using ISF slag as a partial replacement for sand (up to 30% by volume) in DBM.

In conclusion, the laboratory and field work have confirmed that up to 30% ISF slag can be incorporated in typical coated macadam base/binder course mixtures without compromising environmental or mechanical performance. The field trials have confirmed that the slag asphalt can be easily laid with conventional equipment, and the in situ properties are similar to those of conventional mixtures.
References and Further Reading

Details of Parties

Client

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This case study was developed for WRAP by the Centre for Sustainability, a division of TRL

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