Creating markets for recycled resources

R&D Report: Aggregates

Added value of using new industrial waste streams as secondary aggregates in both concrete and asphalt

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Executive Summary

Introduction

One strategy to encourage the use of secondary aggregates[1] is to demonstrate applications where such materials offer a clear benefit or "added value" over primary alternatives. This study report identifies new industrial waste streams with potential uses as secondary aggregates in asphalt, concrete and concrete products. The work proves the technical feasibility of using the new materials identified in asphalt and concrete, demonstrates the nature of some of the "added value" effects and defines the market potential for the aggregates. The project was carried out under contract to DTI and WRAP (contract reference STBF/013/00015c). The major secondary aggregates covered by the Symonds report (Symonds, 2001) are specifically excluded from the study although many of these also have "added value" benefits.

A definition of "added value" proposed by BRE is one that encompasses materials that offer:

Improved technical performance relative to primary aggregate alternatives. This could include properties such as superior abrasion resistance, enhanced flow properties, beneficial effects on reinforcement corrosion, freeze thaw or other durability enhancements,

- Economies (for example, properties allowing use of less binder).
- Environmental enhancement eg aesthetic appearance, energy savings etc.

The project has included the following main activities:

- A desk study and market survey of selected materials identified through contact with industries
- A small experimental programme demonstrating the feasibility of use of manufactured plastic aggregates in asphalt and concrete and demonstrating some potential "added value" effects.
- Production of technical guidance on the waste streams and synthetic aggregates identified (Appendix A)

Project findings from the desk study

No major aggregate sources (in tonnage terms) were identified in addition to those already recorded in the Symonds report.

The following groups of waste streams, by-products and technologies have been considered:

- Waste plastics and plastics manufactured from a processed blend of quarry wastes and mixed plastics
- Synthetic aggregates produced from waste streams using an experimental technique known as accelerated carbonation technology (ACT)
- Wastes from non-ferrous metals production and recycling, incinerated sewage sludge ash, paper sludge and small volume wastes such as roofing felt.

"Added value" properties of plastic-based aggregates can include a combination of low density (the materials are classed as lightweight aggregates), stiffness, thermal insultation and improved workability.

Of the other materials considered, the most promising were incinerated sewage sludge ash and slags from non-ferrous metals production. However, with the exception of sewage sludge ash, the majority of these are produced in relatively small volumes. Added value effects can include savings on binder content, improved stiffness/abrasion resistance or control of cracking. Paper sludge is a significant resource but does not appear to have any beneficial effects without modification.

Project findings from the laboratory studies

Laboratory tests and previous work have provided some evidence that the replacement of expensive primary pumice aggregate with the manufactured plastic aggregate "Plasmega" lowers the thermal conductivity of lightweight concrete blocks with limited effect on density and compressive strength.

[1] Defined as aggregates from by products of other industrial processes and not previously used in construction.

For asphalt application as DBM base (20% replacement of primary aggregate), the added value properties of the Plasmega included:

- lower density compared with control mix;
- Mixture workability not dissimilar to that of conventional asphalt;
- Load spreading ability as good as conventional asphalt of similar type;
- Potential improvement in low temperature crack resistance compared with conventional asphalt;
- Better resistance to high temperature deformation (rutting) compared with conventional asphalt;
- Resistance to moisture damage comparable to that of conventional asphalt.

Market survey

The market potential of selected industrial waste streams and synthetic aggregates identified in the project have been assessed. The main materials considered are:

- Plastics from end of life vehicles and other sources
- Synthetic lightweight aggregates made from waste plastics and mineral wastes
- Drosses from aluminium production
- Incinerator sewage sludge ash
- Paper sludge
- Zinc (ISF) slag
- Other non ferrous slags
- Roofing felt

The main opportunities were identified for secondary aggregates in pre-cast concrete products and DBM base in asphalt. For concrete, utilization of secondary aggregates in concrete products presents a more accessible market than ready mixed concrete as the final concrete product has to meet a specification irrespective of its ingredients.

The most promising aggregate materials identified were waste plastics and synthetic aggregates manufactured from a combination of waste plastics and mineral wastes. Waste plastic materials are widely available and can be processed effectively. In 2002, the UK annual consumption of plastics was approx 3.5 m tonnes with approx. 0.2 m tonnes of post-consumer plastics being recycled per annum[2]. The plastics that are recycled are typically re-used in plastics manufacture. However, there are a range of mixed plastics and shredder wastes which are of lower value and provide potential sources for the production of plastic “aggregates”. However, producer responsibility (WEEE and ELV directives) is driving access to the material and it is expected that processing capacity will follow.

This report was prepared for DTI. The views expressed are those of the authors and not necessarily those of DTI.

[2] Source: British Plastics Federation and Enviros, 2003

Contents

1. Introduction

The disposal of wastes (including hazardous wastes) for industry is an increasing problem in the UK and throughout Europe. However, many of these wastes could be used as aggregates in concrete and asphalt. As bulk construction materials, concrete and asphalt have the potential to consume large volumes of these materials as aggregates. With an annual demand for asphalt of around 27 million tonnes, of which over 90% is aggregate, the scope for use of "added value" wastes is large, providing the waste stream is readily available at the point of need and any quality control issues can be addressed.

In order to enhance public perception of wastes and by-products as useful raw materials, create buoyant markets and therefore reduce disposal of industrial wastes to landfill, there is a need to demonstrate where these materials can offer real benefits over their primary alternatives, as aggregates for example. By emphasising the "added value" that a waste material may bring to asphalt or concrete, these materials may be placed in an advantageous market position. The work will also improve the image and perception of secondary materials and wastes as valuable resources with beneficial properties.

One strategy to encourage the use of secondary aggregates[3] is to demonstrate applications where such materials offer a clear benefit or "added value" over primary alternatives. This report demonstrates the feasibility of achieving some of these beneficial effects. The work will improve the "image" of secondary materials as useful resources and assist in moving such materials up the value chain.

This project has identified new industrial waste streams with potential uses as secondary aggregates in asphalt, concrete and concrete products. The work will prove the technical feasibility of using the new materials identified in asphalt and concrete, demonstrate the nature of the "added value" effects and define the market potential for the aggregates. The project was carried out under contract to DTI and WRAP (contract reference STBF/013/00015c).

The work has been undertaken by BRE (the lead partner) and Scott Wilson Pavement Engineering (SWPE). SWPE have focused on asphalt applications. BRE co-ordinated the project and undertook the activities relating to concrete. The National Industry Symbiosis Programme and Mini-Waste Faraday have provided support to identify potential waste streams and applications from among their member companies.

This report is intended to:

- Encourage potential users of waste streams as aggregates by demonstrating that there are advantages to be gained by using secondary aggregates in suitable end uses.
- Promote new small volume waste streams suitable for aggregate use
- Show that secondary aggregate materials can "add value" to concrete and asphalt
- Encourage the diversion of secondary materials from landfill and/or from low value to high value applications.

A definition of "added value" proposed by BRE is one that encompasses materials that offer:

- Improved technical performance relative to primary aggregate alternatives (eg: superior abrasion resistance, enhanced flow properties, beneficial effects on reinforcement corrosion, freeze thaw or other durability enhancements).
- Economies (eg: properties allowing use of less binder).
- Environmental enhancement (eg: aesthetic appearance, energy savings).

Secondary aggregates covered by the Symonds report (Symonds, 2001) are specifically excluded from the study. Thus, the mainstream secondary aggregate materials (blastfurnace and steel slags, china clay waste, colliery spoil, pfa, furnace bottom ash, spent railway ballast, slate waste, waste glass, incinerator bottom ash, waste tyres, fired ceramics and spent foundry sand) are excluded.

This report was prepared for DTI. The views expressed are those of the authors and not necessarily those of DTI.

[3] Defined as aggregates from by products of other industrial processes and not previously used in construction.

2. Description of the project

Our overall objectives in this work have been to:

- Identify industrial wastes with potential "added value" uses as secondary aggregates in both concrete and asphalt
- Prove the technical feasibility of using these new materials in both concrete and asphalt.
- Demonstrate the nature of the "added value" effects of the key aggregates.
- Define and identify the market potential of the new aggregates materials identified.
- Produce technical guidance on the feasibility of using the new industrial waste streams as secondary aggregates in both concrete and asphalt.
- Produce a study report to DTI and WRAP and a summary for publication identifying the new industrial waste streams as secondary aggregates.

Our approach to addressing these objectives has been first of all to carry out a desk study followed by a creative workshop (held in September 2004) drawing upon experts from waste producers and users of aggregates in concrete and asphalt products. The workshop produced a shortlist of key materials for further consideration. Additionally, discussions have been held with key individuals in the aggregates industry and WRAP.

We then examined and refined the shortlist (judged against relevant European standards for aggregates, concrete and asphalt) and made an assessment of the materials in terms of physical and chemical properties, quantities available, locations and level of processing required.

Having identified a series of key materials, a market analysis was undertaken. This assesses the market potential of the key selected new aggregate materials and also the potential market for aggregates in general which bring an "added value" to concrete and bitumen. We also set out "to prove technical feasibility" – through a small series of laboratory trials on one selected key aggregate material (a manufactured plastic aggregate) in concrete and asphalt respectively. The selection was made on the basis of the outcomes of the workshop and market analysis; a further requirement, "to demonstrate added value" has also been achieved through laboratory test evidence.

In the light of these findings we then make recommendations for further work to ensure that the work under this project has a positive effect on the utilisation of secondary materials.

This has been carried out through the following work programme:

- Project management (Task 1).
- Initial desk study to identify potential wastes which could potentially "add value" to concrete or asphalt products. A provisional list of potential wastes materials was put together by NISP in consultation with BRE and SWPE. A small 1 day workshop co-ordinated by NISP was held at BRE to gather industry's views on key materials and the type of "added value" properties that could be of use in concrete and asphalt products and also to identify existing commercial examples. (Task 2).
- Experimental programmes to prove the technical feasibility of using some of the materials selected in Task 2 in concrete and asphalt products and to demonstrate their "added value". Mixes were designed, asphalt specimens cast and concrete products tested/examined. The test data on early age "added value" properties obtained are reported in this final report (Task 3).
- Establish the market potential of the aggregates, selected for the experimental programme, both in concrete and asphalt products. The market potential of selected industrial waste streams, which have potentially high value applications as secondary aggregates, was also assessed (Task 4).

3. Summary of project findings

3.1. A summary of the current situation with the use of secondary aggregates in concrete and asphalt

3.1.1. Secondary aggregates from mineral sources

The majority of secondary aggregates are from inorganic sources. The traditional requirement for aggregates has been "clean, hard and durable" rather than source, and there has been a long history of use of slags (blastfurnace slag and steel slag) as well as natural aggregate in road construction. Steel slag is a high density, high strength material and the high polishing resistance of materials from the electric arc process has ensured a high demand for the material as an "added value" product in skid-resistant road surfacings. Both materials are identified in the Symonds report.

Manufactured concrete products may be specified by the product specification and not necessarily by specifications for the constituent materials. In some instances this may give manufacturers the option to use secondary aggregates, but mainly for applications with lower structural requirements. Precast concrete products prepared to BS 5328 could potentially use such materials.

Building blocks and bricks, cast stone, "reconstructed stone" masonry units and block paviours have their own product standards (respectively BS 6073, BS 1217 & BS 6717). These standards have traditionally relied on recipes for constituent materials and made no mention of recycled aggregate. However, the revision of BS 6717 which came out in September 2001 places no restriction on constituent materials and the requirements are based solely on performance tests.

This project has identified a range of secondary aggregates from mineral sources, including by-products from non-ferrous metals productions and construction industry. More details are given in section 3.2 and in the technical guidance report (Appendix A).

3.1.2. Manufactured plastic aggregates

In 2002, the UK annual consumption of plastics was approx 3.5 Mt with approx. 0.2 Mt of post-consumer plastics being recycled per annum[4]. The majority of plastics that are currently recycled are sorted to provide feedstocks for re-use in plastics manufacture. However, there are a range of mixed plastics and shredder wastes which are of lower value and provide potential sources for the production of plastic "aggregates". Shredded plastics from end of life vehicles (ELV) have been shown in earlier work to have beneficial effects on the density of concrete products and cohesion/stiffness of asphalt (TRL report/Hassan et al). A further lightweight aggregate, known under the trade name "Plasmega" is produced from thermal processing of a combination of mixed plastic wastes and fine mineral material such as china clay sand or quarry fines. This also has useful properties such as low density and stiffness. Plastics thus have the potential to provide a useful source of aggregates in addition to mineral aggregates. The relevant directives for end of life vehicles, electrical and electronic equipment which prescribe strict recycling targets, are likely to increase the supply of material available for aggregate use.

3.1.3. Other synthetic aggregates - Synthetic secondary aggregates from accelerated carbonation technology (ACT)

Laboratory work carried out at the University of Greenwich has shown that treatment of various wastes with carbon dioxide gas at ambient temperatures and pressures has a potential to produce secondary coarse aggregate pellets from fine grained wastes by rapid carbonate cementation (Padfield 2004). Using constituents such as pfa, ggbs, cement kiln dust and quarry waste fines, rounded to sub-rounded coarse aggregates with aggregate impact value (AIV) in the approximate range 14-17 and a loose bulk density of around 1,000 kg/m^3 have been produced. It is probable that fine industrial wastes other than quarry wastes could also be used. Although the production process has not been optimised, several of the aggregate recipes meet the density requirements for lightweight aggregates. BRE has not had the opportunity to assess the aggregate materials or construction products made with them. However, the published data suggests that these materials may be suitable for use as a lightweight aggregate for structural concrete, concrete block manufacture or highways applications if proved suitable through compliance with BS EN 13055: 2002.

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[4] Source: British Plastics Federation and Enviros, 2003

A relatively simple assessment of comparative costs by (Padfield et al., 2004) suggests that these aggregates could compete on price with lightweight alternatives such as pumice or expanded clay. The accelerated carbonation technique thus has the potential to "upgrade" fine wastes to produce higher value lightweight aggregate products which can attract a premium price compared with normal gravel aggregates.

3.2. Desk study

There are several examples of "added value" materials, including several materials listed by Symonds, which the project team have been associated. These are:

- Low grade waste plastics can be used to produce lightweight synthetic aggregates that could reduce the weight of concrete blocks or elements and could offer enhanced thermal and acoustic performance. Some plastics have been used as a decorative aggregate (Nasvik, 1991)
- There is some evidence for the successful use of fine hard materials (such as fine quartz or alumina) to control microcracking in concrete or enhance abrasion resistance.
- Based on BRE studies of some construction wastes (eg construction and demolition fines), some fine particle sizes waste streams (eg filter cake materials and other residues) could provide superior early age properties in foamed concrete or self compacting concrete (SCC). For SCC, such materials could provide technical benefits as well as providing alternatives to highly processed (and costly) primary materials.
- Non-ferrous slag from zinc production. This material when used as a partial sand replacement may reduce the amount of binder required in asphalt and could give beneficial effects on reinforcement corrosion (due to zinc content) in concrete.
- Various slag products have the potential to improve stiffness of asphalt (by virtue of their relatively high density), thus enabling reduced pavement thickness and/or improved pavement life. Examples of alternative slags include phosphoric slag.
- Suitably treated plastic may be used as a coarse aggregate replacement in asphalt to improve fatigue (or cracking resistance). Specific plastic products when ground may be used to modify a binder to improve its flexibility and provide superior fatigue resistance. Waste roofing felt may provide similar benefits.
- Glass cullet has shown potential as a decorative aggregate in some concrete products
- Electric arc furnace slag and basic oxygen steel (BOS) slag are well established as surface courses in the North East of England for their skid resistance and resistance to polishing.

The European standards relating to aggregates in concrete and asphalt were examined and the key properties required for the new materials were extracted. The findings are available in Appendix B.

3.2.1. Outcomes from the creative workshop

The workshop held at BRE was widely publicised to a range of industrial waste producers through NISP and MiniWaste Faraday's network of contacts. The workshop identified a range of materials and these were judged for their potential suitability as aggregates against the criteria set out in Tables 1, 2 and 3 Appendix B. The quantities of each material available and the level of processing available was also considered. Summary of the findings are given in Table 1 below:

Table 1: Materials identified during the creative workshop held at BRE on 16 September 2004.

Location	Quantity	Description of material produced	Comments	Application	Considered in study
Nationwide	Locally quite low	Roofing felt	Use of roofing felt in car park surfacing has been assessed, but separation process difficult. Need an incentive for producers	Asphalt	Market survey
North Scotland	1,000 - 100,000 t/year	Glass fibres of various length	Not an aggregate	Asphalt/ Concrete	
-	-	Dross powder waste from aluminium recycling (<1 mm), ~60% alumina content	Could be used in high alumina cement or sulfoaluminate cement. Could be used as aggregate to increase skid resistance.	Asphalt/ Concrete?	Market survey
-	Low	Light weight aggregate, <1 mm, alumino silicate	Produces gases when mixed with water	Probably unsuitable unless processed	
Reading, Essex, Birmingham	40,000 t from three locations	concrete block waste	Not a secondary aggregate: recycled aggregate.	Concrete	
N.E. Lincs	100,000 t	Gypsum: 65% solids (45% gypsum, 16% $Fe(OH)_3$) + 35% moisture	For cementitious applications: not aggregate	Blocks ?	
West Midlands	1,000 t	Fine thermoset powder	Possible use as a filler	Concrete	
Rotherham	100,000 t/ year	Secondary engineering steel slag waste/ mixed refractory bricks	Symonds material	Concrete	
Rugby (Warks) S. Ferriby (N. Lincs) Barrington (Cambs)	> 250,000 t/year	Cement kiln dust (alkaline dust from cement kiln manufacture)	May be suitable for manufacture of synthetic aggregates using ACT	-	Market Survey
Nationwide (near roads)	1 t/ 7 m road	Silt from drain (UK motorways network)	Could be suitable as aggregates for foamed concrete, no real added value demonstrated	Concrete	

Although a range of materials were identified from among NISP and MiniWaste members, none of the materials listed in Table 1 above were selected for the experimental study. The materials were either not suitable as aggregates (due to composition), were not available in large enough quantities for aggregate use, or are classified as recycled rather than secondary nmaterials. No major aggregate sources were identified in addition to those already recorded in the Symonds report. Roofing felt, drosses and cement kiln dust are, however, considered in the technical guidance and market survey.

3.2.2. The materials identified under the project and their potential “added value” uses

Following the workshop and a desk based study, the following materials were identified as having a significant potential “added value” as aggregates in concrete and asphalt products, see Table 2:

Table 2: List of materials considered for the project for their potential added value to concrete products.

	Improved physical properties (compressive strength/ stiffness)	Light weight	Control of micro cracking (fine materials only)	Enhanced thermal performance	Enhanced properties in self compacting concrete or foamed concrete
Mixed waste plastics from end of life vehicles (ELV)	√ (stiffness)	√	-	√	-
Synthetic aggregates from waste plastics and mineral waste	-	√	-	-	-
Black/white dross from aluminium production	√ (stiffness)	-	√	-	-
Incinerated sewage sludge ash	-	-	-	-	√
Paper Sludge	-	√	-	-	-
Synthetic aggregates made using: accelerated carbonation	-	-	-	-	-

The following initial assessment was made on the materials identified for use in concrete products:

- Mixed waste plastics from end of life vehicles (ELV) were studied during an earlier PII project and had been shown to be feasible in low strength concrete products (Hassan et al, 2004). Some beneficial effects on density and stiffness had been identified but no testing had been performed to demonstrate potential added value effects such as thermal performance.
- Synthetic aggregates from plastics and mineral waste (Plasmega) were also studied during the PII project. The work identified benefits to density whilst maintaining compressive strength. However, further tests, such as thermal performance, are needed to demonstrate possible good thermal insulation properties.
- Black/white dross from aluminium production have potential as filler aggregates in processed form (<700 µm). At present, there is no evidence of "added value" properties but the materials could improve abrasion resistance or control micro-cracking.
- Paper sludge has been shown to reduce density but also has a significant effect to reduce compressive strength (Goroyias et al., 2004), when used as an aggregate..
- Synthetic aggregates made using accelerated carbonation (ACT) have shown promising performance. Economic and market factors will need to be considered in assessing its feasibility.

Table 3: List of materials considered for the project for their potential added value to asphalt products.

	Improves skid resistance	Improves workability	Improves durability	Acts as additive	Reduces binder content	Improves deformation resistance	Improves stiffness
Mixed waste plastics from end of life vehicles (ELV)	-	√	-	-	-	-	√
Synthetic aggregates from waste plastics and mineral waste	-	√-	-	-	-	-	√
Zinc (ISF) slag	-	-	√	-	√	-	√
Other non-ferrous slags (black + white drosses from aluminium production and other metals production eg stainless steel)	√	-	-	-	-	-	-
Roofing felt	-	--	-	√	√	√	

The following initial assessment was made on the materials identified for use in asphalt products (Table 3):

- Mixed waste plastics from end of life vehicles (ELV) and the synthetic plastic aggregate "Plasmega": showed a potential to be used as aggregates in asphalt (Hassan et al, 2004). Some beneficial effects on workability and stiffness had been identified.
- Zinc (ISF) slag: Has been studied as part of a previous project and has been included in desk study. Potential effects include improved stiffness and saving on binder content (Dunster et al., 2003).
- Other non-ferrous slags (black + white drosses from aluminium production and other metals production eg stainless steel) have potential as filler aggregate in processed form (<700 micron). There is no evidence of "added value" properties but such materials could improve abrasion resistance or control micro-cracking.
- Roofing felt: A car park has been laid at BRE with asphalt containing roofing felt and a waste plastic synthetic aggregate. The car park might be assessed as part of this project.

3.3. Laboratory study on the use of manufactured plastic aggregates in concrete blocks: summary of findings

As part of a previous PII project that ended in April 04 (Hassan et al, 2004), Tarmac Ltd produced concrete blocks containing Plasmega aggregates. Tarmac tested the concrete blocks for compressive strength and density. The following conclusions were drawn:

- Plasmega aggregates cause only a slight loss in the compressive strength of concrete blocks when used to partially replace pumice lightweight aggregate.
- The bond between cement paste and Plasmega aggregates visually appears to be good.

The previous study by Tarmac stated that the use of Plasmega as aggregates could improve the thermal conductivity of the blocks. As part of the new experimental programme, BRE decided to test blocks for their thermal properties.

3.3.1. Concrete blocks

Sixteen concrete blocks provided by Tarmac were received at BRE in November 04, containing 0%, 25%, 50% and 100% replacement (by volume) of the lightweight Pumice aggregates by Plasmega. Tarmac had already tested concrete blocks from the same batches in the earlier project described above.

3.3.2. Thermal conductivity

Samples were sawn from concrete blocks and oven dried. The samples were sent to a testing laboratory and tested for thermal conductivity (according to ISO 8301/ BS 874). One sample was tested per mix. The samples tested were 100 mm thick. The results reflect a limited number of samples. However, they do provide some evidence that the higher replacement of primary pumice aggregate with Plasmega, the lower the thermal conductivity (see Figure 1).

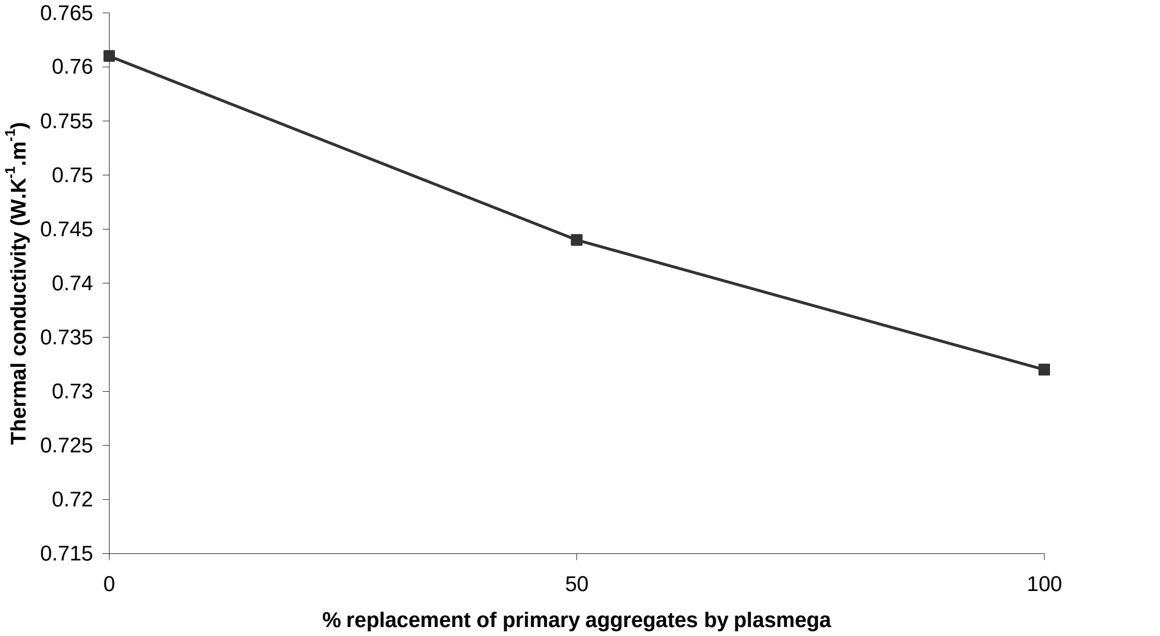

Figure 1: Relative thermal conductivity of concrete blocks versus % replacement of primary aggregates by Plasmega aggregates (by volume).

3.3.3. Density

The density of whole blocks (four blocks per mix) was determined by dimensional measurement and weighing. The results show that there are not large difference between the density of the blocks made with or without Plasmega, given the variation between different blocks from the same batch although there may be a trend (see Figure 2): as you add Plasmega in small quantities, the density decreases, but increases again when more are added. Pumice aggregates have a density of 500-900 kg/m^3 (Neville, 1995) and Plasmega have a density of about 600 kg/m^3 (Hassan et al., 2004). The variation in density might, therefore, be due to the grading and the water absorption of the aggregates (water absorption for Plasmega is significantly lower than for Pumice).

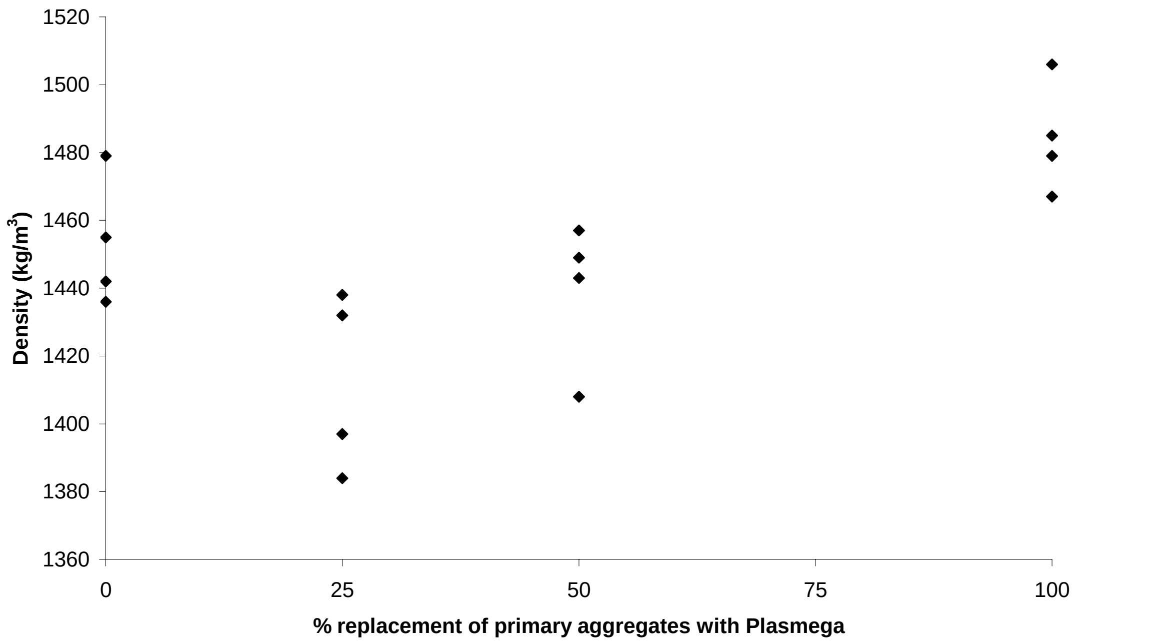

Figure 2: Density of concrete blocks versus % replacement of primary aggregates by Plasmega aggregates (by volume).

The results of both the Tarmac and the BRE studies indicate the potential to replace part of the expensive primary aggregate (Pumice) in the lightweight concrete blocks with Plasmega whilst maintaining adequate density and strength properties.

3.4. Laboratory study of the use of manufactured plastic aggregates in asphalt: summary of findings

Following the creative workshop at BRE (16 September 2004) and the desk based study, two sources of recycled aggregates that could potentially be investigated in laboratory tests were identified: Plasmega synthetic aggregates and End of Life Vehicle (ELV) plastics. However, the ELV plastics were not available within the required timescale of the project. Therefore, it was only possible to use Plasmega for this experimental study. Two types of asphalt containing Plasmega were evaluated during the project, an asphalt base and an asphalt surface course from an existing experimental car park surface at BRE. The work was undertaken by SWPE.

3.4.1. Mixture design for the asphalt base

An asphalt base course was manufactured in SWPE laboratory. A 0/32 mm size Dense Bitumen Macadam base (BS 4987-1, Tables 3 and 4) was selected as the target mixture design for the laboratory manufactured asphalt samples. The adopted asphalt base containing Plasmega are referred to here as DBM50P. The main properties of DBM50P asphalt base, which was expected to offer potential "added values", were assessed and compared against those typically expected for those using primary aggregates (denoted DBM50). These properties include stiffness, deformation resistance and durability.

An initial visual assessment of trial mixes was carried out and concluded that it was possible to incorporate 20% Plasmega into the target DBM50P mixture, and that 4.6% bitumen content would be sufficient in the mixture. Six slabs were manufactured using laboratory roller compactors, and cored to provide specimens for testing. The sample manufacturing process for the Plasmega mixes was similar to that normally used for conventional asphalt manufacturing with an exception that the primary aggregates were slightly superheated (to 180^{o}C) whilst the Plasmega was added cold. Visual observation of the workability of DBM50P was carried out during slab manufacturing. The material showed a degree of resilience during compaction. It is possible that this reaction was due to Plasmega's expansion while blended with bitumen; this phenomenon is commonly observed on materials containing recycled plastics or rubbers. Slab manufacturing was completed without any difficulty and the overall workability was comparable to that of conventional asphalt materials (such as DBM50).

3.4.2. Test methodology for asphalt base

The important mechanical properties of an asphalt material with respect to pavement life are:

- stiffness, related to load spreading ability (BS EN 12697-26, Annex C).
- deformation resistance, related to ability to resist rutting in service (BS DD 226).
- fatigue characteristics, related to crack resistance properties (not tested during this study).

Durability and mixture volumetrics are also important properties to measure. For asphalt,

- durability, related to the sensitivity of the asphalt mixtures to water, is assessed by measuring the stiffness before and after a water conditioning regime (BBA/HAPAS Protocol).
- Mixture volumetrics, the bulk density of a sample, is measured in accordance with Procedure C of BS EN 12697-6.

These properties are particularly important for the structural layers, but also contribute significantly to the performance of the surface course.
The bulk density of each sample was also tested. It was determined in accordance with Procedure C of BS EN 12697-6, using self-adhesive foil when weighing the specimen in water. The maximum density of selected samples from each mixture was determined in accordance with BS EN 12697-5. The bulk and maximum density data were used to calculate air voids content (BS EN 12697-8).

3.4.3. Tests results

The mechanical test results of the laboratory manufactured DBM50P were compared with other DBM50 materials manufactured with primary aggregates (DBM50). A summary of the results is presented in Table 4:

Table 4: Comparison of Materials Properties, Mean Values

Property	Unit	DBM50P	DBM50
Source*	**-**	***Lab*[1]**	***Site*[1]**
Density	Mg/m^3	2.027	2.341
Air Voids	%	7.5	9.5
Stiffness:			
10°C	MPa	6420	10020
20°C	MPa	3760	3590
30°C	MPa	2020	1060
Deformation Resistance (RLAT**):			
Permanent Strain	%	1.5	2.2
Strain Rate	%	0.5	1.5
Simulative Deformation Test (WTT) at 60°C:			
Rut Depth	mm	1.6	-
Rut Ratio	mm/hour	1.1	-
Durability (3rd Cycle Stiffness Ratio)	-	0.87	1.13

Note: [1]Denote laboratory (*Lab*) or site (*Site*) manufactured/compacted samples. DBM50 denote DBM50 materials containing 100% primary aggregates. The binder contents (by weight of total mixture) were slightly different: 4.6% for DBM50P and 4% For DBM50. [2]RLAT: Repeated Load Axial Test. [3]WTT: Wheel Track Test.

Table 4 shows that the bulk density value of DBM50P (with 20% Plasmega replacing the primary aggregate) was lower than that of DBM50 materials. In a sense, the "cost" for hauling and transporting the hot asphalt mix to the construction site could potentially be reduced due to its low density.

The relatively high air voids content (average 7.5% but predominantly between 5 – 10%) of DBM50P may be due in part to the low density and/or possible volume-expansion of Plasmega in the mix. A maximum average air void of either 9% or 8% is usually specified for each pair of core samples removed from base layer either with or without binder course respectively, (Clause 929 of the Specification for Highway Works (DETR)). In this case, the voidage of DBM50P is generally within the specification.

The 20°C mean stiffness value of DBM50P was comparable to that of DBM50 (i.e. within +/- 10%). This suggests no significant difference in load spreading ability of these materials at ambient service temperature. However, DBM50P shows lower stiffness at lower temperature, indicating a softer and more flexible material than DBM50, which is preferable for a better resistance to low temperature cracking.

The RLAT deformation resistance of DBM50P was considerably better than those of the control samples (DBM50). Similarly, higher stiffness at 30°C was shown by DBM50P data.

Simulative deformation testing under the wheel track test (WTT) at 60°C of DBM50P resulted in remarkably low deformation, well below the maximum values specified in the UK for very heavily stressed sites requiring very high deformation resistant materials, i.e. maximum rut depth and rut rate of 7 mm and 5 mm/hour respectively (Clause NG952 of the Specification for Highway Works (DETR)). It is worth noting here that the binder content in the DBM50P was slightly higher (i.e. 4.6%) than those in the other samples (i.e. 4%). Higher binder content would generally result in lower stiffness and greater deformation, but on the contrary, these were not evident from the DBM50P data.

In terms of durability, DBM50P appears to have resistance to water ingress at least comparable with DBM50. There is no unequivocal laboratory testing method for determining the susceptibility to water of in-service bituminous material. However, it has been known for some time that loss of cohesive bond within an asphalt mixture due to water damage appears to be more readily measured by tensile type tests (TRR843, 1982). A threshold value of retained "strength" of 70% has been suggested for deeming a mixture to be sensitive to water, by Lottman (Lottman, 1982) for tensile strength and stiffness tests, by Terrel and Al-Swailmi (Terrel et al., 1994) for triaxial resilient modulus tests, and by Scholz (Scholz, 1995) for indirect tensile stiffness modulus tests, all carried out pre and post conditioning; whilst the Strategic Highway Research Programme (SHRP) specification (Superpave, 1995) recommended a minimum tensile strength ratio of 80%. Scholz's work forms the basis for the BBA HAPAS procedure adopted here. In this case, DBM50P could be deemed as not susceptible to moisture damage.

Overall, Table 4 suggests that, when tested in the laboratory, asphalt containing Plasmega aggregates performed at least as well as the asphalt containing 100% primary aggregates.

3.4.4. Asphalt surface course from trial carpark

In June 2003, Aggregate Industries (AI) carried out field trials of asphalt surface courses containing Plasmega (referred to as Plasmatex) on a car-parking area at BRE.

Prior to the car park trial, an initial assessment of the mechanical properties of Plasmatex (Stone Mastic Asphalt (SMA) type asphalt containing 10% Plasmega) were carried out in laboratory by AI, and the findings were published in the recent Euroasphalt & Eurobitume congress (Philips et al., 2004). The asphalt materials laid in the car park were understood to be broadly similar to that of Plasmatex "Mix B", but with slightly lower percentages of added Plasmega (5% and 7.5%).

Since the initial assessment, however, performance monitoring of the car park has never been carried out. Consequently, the durability of these materials in situ was unknown. Therefore, it was considered useful to assess the long-term durability of the Plasmatex surfacing by removing core samples and subjecting them to laboratory assessment.

3.4.4.1. Materials received

A total of 20 number 150 mm cores from 4 rips of BRE car park (5 cores per rip) were taken in January 2005. Subsequently, the top layer (Plasmatex surface course) of each core was trimmed and subjected to further testing. However, only 12 samples were suitable for testing.
The compositions of the Plasmatex surface courses, together with that reported in (Philips et al., 2004), are presented in Table 5. These data were provided by AI.

Table 5: Composition of Plasmatex Surface Course

	Composition (% by weight)		
Mix Constituents	**Rip 1, Rip 4**	**Rip 2, Rip 3**	**Mix B***
Plastic Aggregate: 70% Cwm Nant Lleici dust, 30% MPWP (present as 20/10mm and 10/5mm, blended at 50/50)	5	7.5	10
Coarse Aggregate: 14mm Bardon Hill	69.7	67.2	64.7
Fine Aggregate: 50% Parr Sand (China Clay Waste), 50% Cwm Nant Lleici Dust	14	14	14
Filler: Greenwich reclaimed filler	5.3	5.3	5.3
Binder: BP 100/150 Pen	5.7	5.7	5.7
Fibres	0.3	0.3	0.3

Note: *Plasmatex Mix B which was a laboratory sample manufactured using gyratory compactor (Philips et al., 2004).

3.4.4.2. Test methodology

One of the important aspects of an asphalt surface course is durability, which could be represented by changes in materials stiffness during service. Reduction in stiffness may be an indication of sample deterioration; and the higher the rate of stiffness reduction the poorer the durability of the materials.
Consequently, assessment of stiffness of the surface courses was carried out using a methodology similar to that used for the asphalt base. For completeness, bulk density of these cores was also determined.

3.4.4.3. Results and Analysis

Table 6 presents the mean values of bulk density and stiffness modulus of the Plasmatex samples recovered from the car park (at 18 months age); detailed results are presented in Appendix C. The relevant mechanical test on similar material, but at a slightly higher proportion of Plasmega (10%), i.e. Plasmatex Mix B (Philips et al., 2004), which was carried out by the AI, is also reproduced in Table 6. It is understood that Plasmatex surface course is a member of Stone Mastic Asphalt (SMA) family (Philips et al., 2004). Consequently, the properties expected from an SMA surface course material are also presented in Table 6 for comparison purposes.

Table 6: Comparison of Materials Properties, Mean Values – 18 months of age

Sample	Plasmega (% by weight)	Density (Mg/m^3)	Stiffness (MPa)	Relative Stiffness*
Plasmatex Rip 1	5	2.205	2525	1.68
Plasmatex Rip 2	7.5	2.149	1707	1.30
Plasmatex Rip 3	7.5	2.165	2010	1.53
Plasmatex Rip 4	5	2.194	1530	1.17
Plasmatex Mix B	10	2.022	1270	0.96
10 mm SMAtex (100 pen)	0	n/a	1310	1.0

Note: Rip 1 – Rip 4 samples were roller compacted field cores. Plasmatex Mix B and 10mm SMAtex were laboratory samples manufactured using gyratory compactor (Philips et al., 2004). *Relative to the stiffness of 10mm SMAtex.

The AI Report (Philips et al., 2004) highlighted some added value potentials of plastic aggregates used in asphalt surfacing, including improving workability (compaction) whilst retaining stiffness characteristics.

Table 6 presents a trend of reducing mix density with increasing percentage of Plasmega, as shown by the following orders (higher to lower density:

Plasmatex Rip1/Rip 4 >, Plasmatex Rip 2/Rip 3, > Mix B

(for the 5%, 7.5% and 10% Plasmega contents respectively)

The mean stiffness values of the site samples were found to be higher than that of the Plasmatex Mix B and the 10.mm SMAtex. Asphalt materials are expected to have stiffness increases after several years in service due to age-hardening. High stiffness value normally indicates better load spreading ability, and high retained stiffness value could also indicate a good durability.

It should be noted here however that the level of stiffness increase for most of the site samples (assuming an initial value of around 1300 MPa) was not as much as would be expected for materials after over 1.5 years in service. This may indicate less stiff, relatively unaged but intact material, or some form of distress within the material. Possible reasons for this are, for example: resistance to age-hardening or stiffness loss due to poor durability; more detailed assessment or history data would be required to verify this issue. Nonetheless, this data suggests that the site cores (which contained 5 – 7.5% Plasmega) have comparable load spreading ability to that of unaged material of similar type but containing 100% primary aggregate.

3.4.5. Conclusions of the use of Plasmega in Asphalt surfacing and course

The assessment carried out on asphalt surfacing and base materials containing Plasmega recycled plastic aggregate showed a number of potential added values.

For application as DBM base, the added value properties include:

- Increase utilisation of recycled plastics, hence minimise the requirement for landfills and reduce cost to environment;
- Potential reduction of haulage and transport cost, due to its low density;
- Mixture workability not dissimilar to that of conventional asphalt;
- Load spreading ability as good as the conventional asphalt of similar type;
- Potential improvement in low temperature crack resistance compared with conventional asphalt;
- Better resistance to high temperature deformation (rutting) compared with conventional asphalt;
- Resistance to moisture damage comparable to that of conventional asphalt.

Plasmatex surfacing cores removed from the BRE car park, did not clearly show the degree of improvement in materials' stiffness; detailed assessment would be required to verify how durable the materials have been. At least, however, the stiffness values of the site cores were comparable to that of unaged materials of similar type containing 100% primary aggregate; suggesting comparable load spreading ability. In addition, improved workability of materials similar to those removed from the BRE car park was reported by the AI.

It should also be noted here however, that there are also some additional works/costs to be anticipated for using Plasmega, such as cost for processing the material to produce it at sizes suitable for construction use, increase consumption of bitumen and additional energy consumption to superheat the primary aggregate during asphalt production.

3.5. Outcome of the market survey: summary

The market potential of selected industrial waste streams and synthetic aggregates identified in the project which have potentially added value applications as secondary aggregates have been assessed. The main materials considered are:

- Plastics from end of life vehicles and other sources
- Synthetic lightweight aggregates made from waste plastics and mineral wastes
- Drosses from aluminium production
- Incinerator sewage sludge ash
- Paper sludge
- Zinc (ISF) slag
- Other non ferrous slags
- Roofing felt

The sales of aggregates in Great Britain was estimated at 209.3 MT in 2002 (DTI annual construction statistics, 2004). In England, currently, approx. 9.5 Mt of secondary materials are used as aggregates although more than 45 Mt of suitable material is thought to be available. There are therefore significant opportunities for secondary materials as aggregates in construction. A high proportion of such materials are currently used as fill and ballast, displacing low grade primary materials. There is scope to move secondary aggregates up the value chain and this could be assisted if "added value" applications can be identified/proven. The main opportunities were identified for secondary aggregates in pre-cast concrete products and DBM base in asphalt. For concrete, utilization of secondary aggregates in concrete products presents a more accessible market than ready mixed concrete as the final concrete product has to meet a specification irrespective of its ingredients.

The most promising aggregate materials identified were waste plastics and synthetic aggregates manufactured from a combination of waste plastics and mineral wastes. Waste plastic materials are widely available and can be processed effectively. In 2002, the UK annual consumption of plastics was approx 3.5 Mt with approx. 0.2 Mt of post-consumer plastics being recycled per annum[5]. The plastics that are recycled are typically sorted to provide relatively high value feedstocks for re-use in plastics manufacture. However, there are a range of mixed plastics and shredder wastes which are of lower value and provide potential sources for the production of plastic "aggregates". There may be inadequate re-processing and shredding capacity at present for wide aggregate use. However, producer responsibility (WEEE and ELV directives) is driving access to the material and it is expected that processing capacity will follow. "Added value" properties of plastic-based aggregates can include a combination of low density (materials are classed as lightweight aggregates), stiffness, thermal insulation, improved workability.

Of the other materials considered, the most promising were incinerated sewage sludge ash and slags from non-ferrous metals production. However, with the exception of sewage sludge ash, the majority of these are produced in relatively small volumes. Added value effects include savings on binder content, improved stiffness/abrasion resistance or control of cracking. Paper sludge is a significant resource but does not appear to have any beneficial effects without modification. Other than plastics, the project has not identified any aggregate resources other than the materials considered in the Symonds report (Symonds, 2001). These materials are outside the scope of the project. The full market survey is included in Appendix C.

[5] Source: British Plastics Federation and Enviros, 2003

4. Conclusions and recommendations

4.1. Conclusion

The most promising aggregate materials identified during the project were synthetic aggregates manufactured from a combination of shredded waste plastics and mineral wastes. There are likely to be a range of mixed plastics and shredder wastes of low value and in sufficient tonnages which are potential sources of plastic "aggregates". Traditional methods of plastic recycling will compete with these aggregates. However, given "added value" potential, it may be preferable to send to aggregate use rather than a recycling plant. This is mainly because the plastic can be used when mixed with other plastics, removing the need to segregate it.

"Added value" properties of plastic-based aggregates can include a combination of low density (the materials are classed as lightweight aggregates), stiffness, thermal insulation and improved workability. There were no obvious practical difficulties in their use in concrete and asphalt products.

There is evidence that the replacement of expensive primary pumice aggregate with the manufactured plastic aggregate "Plasmega" lowers the thermal conductivity of lightweight concrete blocks with limited effect on density and compressive strength.

For asphalt application as DBM base, the added value properties of the Plasmega include potential improvement in low temperature crack resistance compared with conventional asphalt and better resistance to high temperature deformation (rutting) compared with conventional asphalt.

Of the other materials considered, the most promising were incinerated sewage sludge ash and slags from non-ferrous metals production. However, with the exception of sewage sludge ash, the majority of these are produced in relatively small volumes. Added value effects can include savings on binder content, improved stiffness/abrasion resistance or control of cracking. Paper sludge is a significant resource but does not appear to have any beneficial effects without modification.

Accelerated carbonation technology (ACT) has shown promise for the production of aggregates from wastes on a laboratory scale.

No major aggregate sources (in tonnage terms) were identified in addition to those already recorded in the Symonds report.

4.2. Recommendations

In the light of these conclusions, we make the following recommendations:

- An intensive market study is recommended for those materials deemed potentially economically and environmentally viable, primarily plastic synthetics. There is also a need to acquire accurate information on geographical occurrences of all added value waste materials to calculate their viability on a regional basis. Economics of use and production of plastic aggregates needs to be re-examined.

- Technical case studies, illustrating technical benefits of using new aggregate materials (such as plastics) need to be developed.

- Sewage sludge ash: the economics of aggregates use and long term performance in construction products need to be re-examined.

- Examination of the feasibility of adapting, binding or modifying paper sludge or paper sludge ash for aggregate use is advisable.

- Synthetic aggregates made using accelerated carbonation are a good technique for encapsulation of hazardous materials and there is a potential for further study into using this to bind fine waste materials into aggregates. There is a need to assess the technical feasibility on pilot scale as well as the economic issues.

- Further investigation of the materials with potential added value properties is advised to determine durability performance in practical applications. Proving a materials use and value is the only way for it to be utilised in construction, the risks of using an unproven material are simply too great for contractors and clients alike to consider.

5. Reference

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Standards

BS EN 13055: 2002: Lightweight Aggregates
BS 1217:1997: Specification for cast stone
BS 6073-1:1981: Precast concrete masonry units. Specification for precast concrete masonry units
BS 6073-2:1981: Precast concrete masonry units. Method for specifying precast concrete masonry units
BS 1217:1997: Specification for cast stone
BS 5328:1981: Methods for specifying concrete, including ready-mixed concrete
BS 8500: 2002: Concrete. Complementary British Standard to BS EN 206-1.
BS EN 13055-1:2002: Lightweight aggregates. Lightweight aggregates for concrete, mortar and grout
BS EN 13055-2:2004: Lightweight aggregates. Lightweight aggregates for bituminous mixtures and surface treatments and for unbound and bound applications)
BS EN 12697-26: Bituminous mixtures – Test methods for hot mix asphalt. Part 26: Stiffness
BS DD 226:1996: Method for determining resistance to permanent deformation of bituminous mixtures subject to unconfined dynamic loading
BS EN 12697-5: 2002: Bituminous mixtures – Test methods for hot mix asphalt. Part 5: Determination of the maximum density.
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BS EN 12697-8: 2003: Bituminous mixtures – Test methods for hot mix asphalt. Part 8: Determination of void characteristics of bituminous specimens
BS 6717: 2001: Precast, unreinforced concrete paving blocks. Requirements and test methods.
BS 874-3.1: 1987: Methods for determining thermal insulating properties. Tests for thermal transmittance and conductance. Guarded hot-box method.

Appendix A – Added value of using new industrial by-products as secondary aggregates in both concrete and asphalt: technical guidance

Introduction

One strategy to enhance the value and use of secondary aggregates[6] is to demonstrate applications where such materials offer a clear benefit (or "added value") over primary alternatives (see definition below). This has the potential to improve the "image" of secondary or manufactured materials as useful aggregate resources and assist in moving such materials up the value chain.

This document provides technical guidance on the feasibility of using new industrial waste streams as secondary aggregates in both concrete and asphalt. Synthetic aggregates manufactured from industrial by-products are also included. Some examples of by-products are given in this technical guidance document.

The document firstly defines "added value" and considers the key properties that are required of all aggregates for use in concrete and asphalt. It then examines a range of potential aggregates; finally, it provides information on the properties and performance for selected materials and in particular aggregates produced from waste plastics.

Definition of "added value"

The definition of "added value", proposed by BRE and used here, is one that encompasses materials offering:

- Improved technical performance relative to primary aggregate alternatives (eg: superior abrasion resistance, enhanced flow properties, effects limiting reinforcement corrosion, freeze thaw or other durability enhancements. Improved resistance to deformation and/or cracking).
- Cost savings or increased profitability (eg: properties which allow use of less binder material for asphalt application).
- Environmental enhancement (eg: energy savings, reduced noise or dust emissions).
- Other considerations (eg: aesthetic appearance, reduced heath and safety risks0.

Aggregates for use in concrete and asphalt: General

The key properties for aggregates for concrete and asphalt (taken from the CEN aggregates standards) are reproduced below in Tables 1A (requirements for aggregates in concrete applications) and 2A (with requirements for lightweight aggregates for concrete applications) and in Table 3A (requirements for aggregates for asphalt applications).

Requirements for aggregates for concrete applications
The new CEN standards do not present a barrier to the use of by-products as aggregates since they do not discriminate between natural, secondary or recycled aggregates providing they meet the requirements of the standards. BS EN 12620 specifies the properties of aggregates and filler aggregates obtained by processing natural, manufactured or recycled materials and mixtures of these aggregates for use in concrete.

[6] Defined as aggregates from by products of other industrial processes and not previously used in construction.

Table 1A: Key properties for aggregates for concrete – (BS EN 12620 2002 and PD 6682-1, 2003)[7]

	Property	Limits/comments
Grading	Grading (coarse and fine aggregates)	see standard for details
	Filler aggregate	100% passing 2 mm sieve 85-100% passing 0.125 mm sieve 70-100% passing 0.063 mm sieve
Geometric requirements	Flakiness (coarse aggregate)	Limitations: Uncrushed gravel: FI_{50} Crushed rock and crushed gravel: FI_{35} Special circumstances, eg: pavement surface course: FI_{20}, FI_{15}
Physical requirements	Resistance to fragmentation (coarse aggregate)	Performance declared (when required) Los Angeles coefficient of 40 (max) recommended
	Particle density and water absorption	Performance declared (when required), EN 1097-6
	Freeze/thaw resistance of coarse aggregate	Performance declared (when required) EN 1097-3
Durability	Volume stability – drying shrinkage	< 0.75% (when required)
	Alkali-silica reactivity	An expansive reaction between alkali reactive aggregates and cement/ alkalis – Need to refer to regulations in place of use.
	Water soluble chloride	When (when required). Chloride can accelerate setting and promote corrosion of reinforcement
Chemical requirements	Acid soluble sulfate	< 0.2% (for aggregates other than blastfurnace slag) <= 1% for blastfurnace slag Sulfates can lead to expansive attack of cement in concrete
	Total sulfur	<= 1% S (for aggregates other than blastfurnace slag <= 2% for blastfurnace slag
	Constituents that affect rate of setting and hardening of concrete	Determine effects on setting time, eg: organics, lead, zinc salts
	Additional considerations	Eg: Iron pyrites and coal can mar surface

Full details of the requirement for lightweight aggregates are given in EN13055-1, 2002, some are given in Table 2A. All others are "when required". The list of properties that can be specified is similar to but not the same as Table 1A. The main differences in EN 13055-1 are as follows:

- The method for determination of flakiness is different for lightweight aggregates
- There is no requirement to test for resistance to fragmentation
- There is no volume stability/drying shrinkage requirement
- There are special test methods for the physical requirements of crushing resistance, percentage of crushed particles and resistance to disintegration that are specific to lightweight aggregates.

The requirement to test and declare the properties detailed in Table 1A and 2A is dependent on the particular end use, application or origin of the aggregate. For example, crushing resistance is not required for elastic materials such as plastics. Tests for properties such as loss on ignition (which would decompose plastics) and alkali-silica reactivity for concrete may also not be appropriate. However, synthetic aggregates which include mineral wastes or which are processed at high temperature may be ASR reactive.

[7] Issues associated with leaching from the material .may need to be considered.

Table 2A: Key properties for lightweight aggregates for concrete – limits and requirements (BS EN 13055-1, 2002)

	Property	Limits/comments
Physical requirements	Loose bulk density	Maximum 1200 ± 100 kg/m3
	Particle density	Maximum 2000 ± 150 kg/m3
Chemical requirements	Loss on ignition (for ashes)	Determined in accordance with EN 1744-1, clause 17 1998 and declared

Requirements for aggregates for asphalt applications

Table 3A: Key properties for aggregates for asphalt – (BS EN 13043:2002, PD 6682-2 & -9: 2003, MCHW1 Series 900 and HD 36/99)[8]

	Property	Limits/comments
Grading	Content of foreign materials in recycled aggregate (SHW Clauses 710 & 901)	< 1% by mass
	Coarse aggregate	Nominal size: 20/31.5, 14/20, 8/14, 6.3/10, 2/6.3, 2/4 Grading: Tables 3 & 4 of PD 6682-2
	Fine aggregate	Table 5 of PD 6682-2
	Filler aggregate (BS EN 13043 Clause 5.2.1)	100% passing 2 mm sieve 85-100% passing 0.125 mm sieve 70-100% passing 0.063 mm sieve
Cleanness	Fines quality (BS EN 13043 Clause 4.1.5)	See PD 6682-2 Clause 3.2.5
Geometric requirements	Flakiness of coarse aggregate (BS EN 13043 Clause 4.1.6)	FI_{35} (i.e. $\leq$ 35), except: FI_{25} (i.e. $\leq$ 25) for Stone Mastic Asphalt Binder Course (SHW Clause 937) FI_{20} (i.e. $\leq$ 20) for Chippings (SHW Clause 915) and Thin Surfacings (SHW Clause 942) FI_{15} (i.e. $\leq$ 15) for Porous Asphalt (SHW Clause 938)
Physical requirements	Resistance to fragmentation of coarse aggregate (BS EN 13043 Clause 4.2.2)	LA_{30} (i.e. $\leq$ 30) LA_{50} (i.e. $\leq$ 50) for blastfurnace slag
	Polished Stone Value ((BS EN 13043 Clause 4.2.3) – for surface course only	PSV_{44} (i.e. $\geq$ 44) for Hot Rolled Asphalt Surface Course (SHW Clauses 910/911/943) PSV_{50} (i.e. $\geq$ 50) for either aggregate in bituminous layer other than surface course, or as chipping in (temporary) surface dressing, when used as temporary running surface (SHW Clause 901) Otherwise: HD 36/99 minimum requirements (site specific)
	Aggregate Abrasion Value (BS EN 13043 Clause 4.2.4)	AAV_{12} (i.e. $\leq$ 12) for Porous Asphalt (SHW Clause 938) Otherwise: HD 36/99 maximum requirements (site specific)
	Particle density	Declared (when required)
	Loose bulk density in kerosene (for added filler), (BS EN 13043 Clause 5.5.5)	Declared (when required)
Durability	Freeze/thaw resistance (soundness) of coarse aggregate (BS EN 13043 Clause 4.2.9.2)	MS_{25} (i.e. $\leq$ 25% loss by mass)
	Water Absorption (BS EN 13043 Clause 4.2.9.1)	$WA_{24}2$ (i.e. $\leq$ 2% by mass) Soundness test required if $WA_{24}2$ > 2%
Chemical requirements	Dicalcium Silicate Disintegration (BS EN 13043 Clause 4.3.4.1)	free from dicalcium silicate disintegration – air cooled blastfurnace slag only
	Iron Disintegration (BS EN 13043 Clause 4.3.4.2)	free from iron disintegration – air cooled blastfurnace slag only
	Volume Stability (BS EN 13043 Clause 4.3.4.3)	V_{10} ($\leq$ 10%) - steel slag only

[8] Issues associated with leaching from the material .may need to be considered.

A review of the technical feasibility of the materials identified with potential "added value" as aggregates

Examples of industrial by-products with potential uses as secondary aggregates in asphalt, concrete and concrete products are given in Table 4A. These materials, which have been selected with reference to the properties in Tables 1A to 3A, are aggregate resources in addition to the more familiar materials considered in the Symonds report, "*a survey of arisings and use of secondary minerals*" (ODPM, 2001). A good example of one of the materials, reported by Symonds, with potential "added value" is glass aggregates, which can be used to produce decorative concrete block products (ConglassCrete).

Table 4A: Summary of the new by-products

Waste stream	Suitable in	Comment on the technical feasibility	Potential added value	Reference
Mixed waste plastics (eg: end of life vehicles (ELV), others)	Concrete	Can be used in concrete blocks if suitably processed	Thermal insulation, low density	(Hassan et al., 2004)
	Asphalt	Can be used in asphalt as coarse aggregates if suitably processed.	Stiffness Resistance to deformation & cracking	(Phillips and Richards, 2004) (Hassan et al., 2004)
Synthetic aggregates from waste plastics and mineral waste	Concrete	Can be use in concrete blocks and low grade concrete	Thermal insulation, low density	(Phillips and Richards, 2004) (Hassan et al., 2004)
	Asphalt	May be used as a coarse aggregate replacement	Improve fatigue (or cracking resistance).	(Phillips and Richards, 2004) (Hassan et al., 2004)
Non-ferrous slags and black + white drosses from production and recycling of aluminium and other metals e.g. stainless steel (excl. ISF slag)	Concrete	Processed drosses could be used as a filler aggregate if suitably re-processed	Processed drosses could give abrasion-resistant properties to floors	(Hooper et al., 2001)
	Asphalt	Examples of alternative slags for asphalt include phosphoric slag and lead slag. Have a relatively high density (disadvantage)	Could improve stiffness, thus could reduce pavement thickness. Improve skid resistance.	(FHWA, 1997) (Hosking, 1970) (Hosking, 1972) (Hooper et al., 2001)
Incinerated sewage sludge ash	Concrete	Can be used as ingredient in manufacture of synthetic aggregates for use in concrete blocks	Low density	(Gunn et al., 2004)
	Asphalt	As replacement fine or mineral filler	Lightweight Improved stability Improved durability	(FHWA, 1997)
ISF (Zinc) slag	Concrete	Effective as sand replacement in high grade concrete. However, effects on lead and zinc on setting needs to be considered	No evidence of added value	(Dunster and Elliott, 2003)
	Asphalt	Can be used as a sand aggregate replacement	Could save binder requirement in mixes due to low absorption	(Dunster and Elliott, 2003)
Roofing felt	Concrete	-	No evidence of added value	-
	Asphalt	May be used as a coarse aggregate replacement or finer size as binder modifier	Reduce binder content Anti-draindown additive Improved deformation resistance Improved stiffness	(De-Jonghe et al., 2004) (Carswell, 2004) (Kandhal, 1992) (FHWA, 1997)

A number of the by-products listed in Table 4A have already been used or demonstrated to have some degree of "added value" in concrete and asphalt. These include:

- Aggregate manufactured from waste plastics and mineral waste used in an industrial production trial (concrete blocks) (Hassan et al., 2004).
- ISF slag fine aggregate used for demonstration concrete and asphalt road sections at Avonmouth, Bristol (Dunster and Elliott, 2003).
- Shredded roofing felt used in an asphalt laying trial for a car park at BRE (unpublished).

Technical guidance on the use of plastic based aggregates in concrete and asphalt

Waste plastics are likely to become an increasingly available resource (WRAP) and consequently, more detailed technical guidance is provided in this document on plastic-based aggregates. In particular, two new directives from the EU relating to the compulsory recycling of electrical and electronic waste and road vehicles the Waste Electrical and Electronic equipment and End of Life Vehicle Directives (WEEE and the ELV Directives respectively) mean that quantities of mixed plastic material, unsuitable for recycling back into plastic, are likely to increase. Although they are not normally considered to be typical aggregate materials, significant tonnages of mixed waste plastics are available and there is already some experience of their use as aggregates in concrete and asphalt.

Waste plastics cover a range of materials, each with different properties and applications. Segregated waste plastics have a relatively high value as industrial feedstocks. Only mixed waste plastics are economically viable as construction aggregates as they are available at a cost that makes them more appropriate for aggregate use. Examples of use of mixed waste plastics are given below:

- Mixed waste plastics from processing of WEEE. Suitable shredded material can be used directly in concrete or asphalt.
- Mixed waste plastics from processing of ELV. Suitable shredded material can be used directly in concrete or asphalt.
- General mixed post-consumer plastic. This can be used as a feedstock for manufacturing synthetic aggregate.

Synthetic aggregates include products made by the partial melting of mixed waste plastics and then blending the plastics with fine mineral waste (such as china clay sand or quarry fines), and agglomerations of fine grained plastics. The improved technical performances, compared with conventional aggregates, associated with some plastic aggregates include:

- Improved thermal performance for concrete products.
- Improved flexibility, fatigue resistance and resistance to polishing (some synthetic plastic/mineral aggregates) in asphalt.

Materials properties for plastic aggregates

Plastic aggregates can be classified, according to BS EN 13055-1, as lightweight aggregates. The standard covers aggregates obtained by processing natural, manufactured or recycled materials with a particle density not exceeding 2000 kg/m3 or loose bulk density not exceeding 1200 kg/m3 (Table 2A).
BS EN 12620, 2002 covers only dense aggregates with an oven dry particle density greater than 2000 kg/m3 and is not relevant to plastic aggregates that have a specific gravity of approximately one third that of natural aggregates.

Indicative properties for a synthetic plastic aggregate (10-14 mm fraction) are given in Table 5A:

Table 5A: Indicative properties for a synthetic plastic aggregate.

	Limestone fines: mixed post consumer plastic waste 60:40	Limestone primary aggregate
Particle Density (SSD) Tonnes/m^3	1.49	2.71
Particle Density (OD) Tonnes/m^3	1.54	2.73
Water Absorption %	3.20	0.70
Bulk Density (Mg/m^3)	0.61	1.44

Note: SSD = saturated surface dry density, OD = oven dried density

Use of plastic aggregates in concrete and concrete products

Mixed waste plastics have the potential to produce lightweight aggregates or to improve the thermal insulation of concrete blocks and concrete products. Initial trials by a manufacturer (unpublished) have indicated that one synthetic plastic-based aggregate may reduce compressive strength of ready-mixed concrete, but that below a cement content of approximately 250 kg/m^3, the loss in strength is not significant provided only a relatively small amount of the synthetic aggregate is incorporated (around 15%).

The situation seems to be similar for other plastic aggregates. Tests on concrete made with shredded plastic indicated that replacement of 15% of the natural aggregate by shredded ELV plastic was appropriate for normal strength concrete with higher levels of replacement achievable with low strength concretes (Hassan et al., 2004).

At present, plastics are not specifically mentioned in BS EN 12620: 2002, which refers to aggregates from mineral sources. Plastic aggregates and combinations of plastic and natural aggregates to be used as aggregates in concrete should conform to the general requirements of BS EN 12620: 2002 and the guidance on the use of BS EN 12620: 2002 in BS PD 6682-1: 2003.

There is evidence that plastic aggregates can be used in pre-cast products such as blocks and bricks (BS 6073: 1981 and draft CEN Standards, (Hassan et al., 2004). The resistance to fire of the aggregates was not assessed in this project, but should be considered when using plastic aggregates.

Added value: lightweight aggregates, improved thermal insulation.

Use of plastic-based aggregates in asphalt and asphalt products

Lightweight asphalt products containing plastic-based aggregates could perform at least as well as their competitors, which use primary aggregates. These materials have been used in asphalt layers, from base to surface course. In addition, improved workability was also reported in these materials (Phillips and Richards, 2004). The aggregates should not be pre-heated in the asphalt plant but introduced directly into the mixer box with the remaining pre-mixed ingredients.

Significant improvement has been seen on the resistance to permanent deformation of an asphalt base containing plastic aggregates. In this case, the deformation was much lower than the maximum specified in Table NG9/33 of the Specification for Highway Works for a performance-specified asphalt base.

Recently, cores of asphalt surfacing containing plastic-based aggregates were removed from trial sections constructed 18 months ago at BRE; stiffness values of these cores were found to be at least comparable with that expected for unaged asphalt surfacing of similar type but containing 100% primary aggregate. This may indicate durability and relatively good load spreading material. However, long-term durability of these materials is not yet known.

Currently, there is no allowance in the Specification for Highway Works for using plastic-based aggregates in asphalt layers. However, due to the potential added values of asphalts containing plastic-based aggregates, there is no reason why an alternative route for certifying the use these aggregates as proprietary asphalt products could be initiated, such as through the British Board of Agrement (BBA).

Added value: good quality lightweight aggregate, improved workability, improved resistance to deformation, durable, good load spreading material.

Quality assurance

Minimum frequencies of test for concreting aggregates are given in BS 8500, relevant standards and in specifications for asphalt. It is not possible to provide general advice on frequencies of test. However, the critical quality properties are likely to include:
- Bulk density (for concrete & asphalt)
- Grading (for concrete & asphalt)
- Fines content (for concrete)
- Particle shape (for concrete)
- Water absorption (for concrete& asphalt)
- Flakiness index (for concrete& asphalt)
- Soundness test (for asphalt)
- Polished Stone Value (for asphalt surface course)
- Aggregate Abrasion Value (for asphalt surface course)
- Resistance to Fragmentation (for asphalt surface course)

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British and European Standards

BS EN 12620: 2002 - Aggregates for concrete
PD 6682-1: 2003 – Aggregates. Aggregates for concrete. Guidance on the use of BS EN 12620
BS EN 13043: 2002 - Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas
PD 6682-2: 2003 - Aggregates. Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas. Guidance on the use of BS EN 13043
EN 1744-1: 1998 - Tests for chemical properties of aggregates. Chemical analysis
EN 13055-1: 2002 - Lightweight aggregates. Lightweight aggregates for concrete, mortar and grout
BS 6073: 1981 - Precast concrete masonry units. Specification for precast concrete masonry units

Appendix B – Key Properties for aggregates

The European standards relating to aggregates in concrete and in asphalt were examined and the key properties of the new raw materials were extracted. These are given in Table 1A, 2A and 3A.

Table 1B: Key properties for aggregates for concrete – (BS EN 12620 2002 and PD 6682-1, 2003)[9]

	Property	Limits/comments
Grading	Grading (coarse and fine aggregates)	see standard for details
Grading	Filler aggregate	100% passing 2 mm sieve 85-100% passing 0.125 mm sieve 70-100% passing 0.063 mm sieve
Geometric requirements	Flakiness (coarse aggregate)	Limitations: Uncrushed gravel: FI_{50} Crushed rock and crushed gravel: FI_{35} Special circumstances, eg: pavement surface course: FI_{20}, FI_{15}
Physical requirements	Resistance to fragmentation (coarse aggregate)	Performance declared (when required) Los Angeles coefficient of 40 (max) recommended
Physical requirements	Particle density and water absorption	Performance declared (when required), EN 1097-6
Physical requirements	Freeze/thaw resistance of coarse aggregate	Performance declared (when required) EN 1097-3
Durability	Volume stability – drying shrinkage	< 0.75% (when required)
Durability	Alkali-silica reactivity	An expansive reaction between alkali reactive aggregates and cement/ alkalis – Need to refer to regulations in place of use.
Durability	Water soluble chloride	When (when required). Chloride can accelerate setting and promote corrosion of reinforcement
Chemical requirements	Acid soluble sulfate	< 0.2% (for aggregates other than blastfurnace slag) <= 1% for blastfurnace slag Sulfates can lead to expansive attack of cement in concrete
Chemical requirements	Total sulfur	<= 1% S (for aggregates other than blastfurnace slag <= 2% for blastfurnace slag
Chemical requirements	Constituents that affect rate of setting and hardening of concrete	Determine effects on setting time, eg: organics, lead, zinc salts
Chemical requirements	Additional considerations	Eg: Iron pyrites and coal can mar surface

Full details of the requirement for lightweight aggregates are given in EN13055-1, 2002, some are given in Table 2B. All others are "when required". The list of properties that can be specified is similar to but not the same as Table 1. The main differences in EN 13055-1 are as follows:

- The method for determination of flakiness is different for lightweight aggregates
- There is no requirement to test for resistance to fragmentation
- There is no volume stability/drying shrinkage requirement
- There are special test methods for the physical requirements of crushing resistance, percentage of crushed particles and resistance to disintegration that are specific to lightweight aggregates.

The requirement to test and declare the properties detailed in Table 1B and 2B is dependent on the particular end use, application or origin of the aggregate. For example, crushing resistance is not required for elastic materials such as plastics. Tests for properties such as loss on ignition (which would decompose plastics) and alkali-silica reactivity for concrete may also not be appropriate. However, synthetic aggregates which include mineral wastes or which are processed at high temperature may be ASR reactive.

[9] Issues associated with leaching from the material .may need to be considered.

Table 2B: Key properties for lightweight aggregates for concrete – (BS EN 13055-1, 2002)

	Property	Limits/comments
Physical requirements	Loose bulk density	Maximum 1200 ± 100 kg/m3
	Particle density	Maximum 2000 ± 150 kg/m3
Chemical requirements	Loss on ignition (for ashes)	Determined in accordance with EN 1744-1, clause 17 1998 and declared

Requirements for aggregates for asphalt applications:

Table 3B: Key properties for aggregates for asphalt – (BS EN 13043:2002, PD 6682-2 & -9: 2003, MCHW1 Series 900 and HD 36/99)[10]

	Property	Limits/comments
Grading	Content of foreign materials in recycled aggregate (SHW Clauses 710 & 901)	< 1% by mass
	Coarse aggregate	Nominal size: 20/31.5, 14/20, 8/14, 6.3/10, 2/6.3, 2/4 Grading: Tables 3 & 4 of PD 6682-2
	Fine aggregate	Table 5 of PD 6682-2
	Filler aggregate (BS EN 13043 Clause 5.2.1)	100% passing 2 mm sieve 85-100% passing 0.125 mm sieve 70-100% passing 0.063 mm sieve
Cleanness	Fines quality (BS EN 13043 Clause 4.1.5)	See PD 6682-2 Clause 3.2.5
Geometric requirements	Flakiness of coarse aggregate (BS EN 13043 Clause 4.1.6)	FI_{35} (i.e. $\leq$ 35), except: FI_{25} (i.e. $\leq$ 25) for Stone Mastic Asphalt Binder Course (SHW Clause 937) FI_{20} (i.e. $\leq$ 20) for Chippings (SHW Clause 915) and Thin Surfacings (SHW Clause 942) FI_{15} (i.e. $\leq$ 15) for Porous Asphalt (SHW Clause 938)
Physical requirements	Resistance to fragmentation of coarse aggregate (BS EN 13043 Clause 4.2.2)	LA_{30} (i.e. $\leq$ 30) LA_{50} (i.e. $\leq$ 50) for blastfurnace slag
	Polished Stone Value ((BS EN 13043 Clause 4.2.3) – for surface course only	PSV_{44} (i.e. $\geq$ 44) for Hot Rolled Asphalt Surface Course (SHW Clauses 910/911/943) PSV_{50} (i.e. $\geq$ 50) for either aggregate in bituminous layer other than surface course, or as chipping in (temporary) surface dressing, when used as temporary running surface (SHW Clause 901) Otherwise: HD 36/99 minimum requirements (site specific)
	Aggregate Abrasion Value (BS EN 13043 Clause 4.2.4)	AAV_{12} (i.e. $\leq$ 12) for Porous Asphalt (SHW Clause 938) Otherwise: HD 36/99 maximum requirements (site specific)
	Particle density	Declared (when required)
	Loose bulk density in kerosene (for added filler), (BS EN 13043 Clause 5.5.5)	Declared (when required)
Durability	Freeze/thaw resistance (soundness) of coarse aggregate (BS EN 13043 Clause 4.2.9.2)	MS_{25} (i.e. $\leq$ 25% loss by mass)
	Water Absorption (BS EN 13043 Clause 4.2.9.1)	$WA_{24}2$ (i.e. $\leq$ 2% by mass) Soundness test required if $WA_{24}2$ > 2%
Chemical requirements	Dicalcium Silicate Disintegration (BS EN 13043 Clause 4.3.4.1)	free from dicalcium silicate disintegration – air cooled blastfurnace slag only
	Iron Disintegration (BS EN 13043 Clause 4.3.4.2)	free from iron disintegration – air cooled blastfurnace slag only
	Volume Stability (BS EN 13043 Clause 4.3.4.3)	V_{10} ($\leq$ 10%) - steel slag only

[10] Issues associated with leaching from the material .may need to be considered.

Appendix C – Market Survey

Added value for the UK construction industry

Output in the UK construction industry increased from £41.4bn GVA[11] in 1999 to approximately £61bn GVA in 2003 [1] (Appx 5% of the total UK GDP). This trend seems set to continue with a predicted growth in the coming years. Currently the UK imports roughly twice the amount of materials it exports.

The utilisation of secondary or waste materials in construction applications is already established in the UK although often in low value applications (mainly the use of recycled and secondary aggregates). However, the underlying aim of the project is to change the perception of certain waste or by-product materials that have an intrinsic value so they are viewed as a resource rather than a waste.

The use of recycled and secondary aggregates reduces the pressure on raw materials, can be seen to respond to the Landfill Regulations as an alternative to disposal and avoids the Aggregates Levy and the Landfill Tax.

The concept of added value from the use of recycled or recovered waste materials is that they not only replace virgin materials but also have inherent qualities that enhance and improve the final product in some way. In this manner, utilisation of such materials may be considered a performance improving additive rather than a waste material replacement for virgin materials.

Recycling post-consumer and post-industrial materials in the UK is a trend the government is keen to promote and encourage. The government has set out its own series of targets and aspirations for different materials and different industries. One target is to increase the amount of aggregate recycling to 55 million tonnes in 2006 from 30 million tonnes (10% in 1989) [2].

Great Britain aggregates market

The sales of aggregates in Great Britain was estimated at 209.3 MT in 2002 [3], a breakdown of the main uses for this material can be seen in Figure 1C. The primary use for aggregate was in fill and concrete applications. A commonly acceptable substitute for some types of virgin aggregate used in sub-base applications is recycled aggregate and recycled concrete aggregate. Other recycled/reclaimed materials commonly used in concrete include pulverised fly ash (PFA) and glass cullet.

It is estimated that, in England, there is 43.07 MT/y of secondary materials suitable for aggregates. Currently only 9.36 MT is used as aggregates, 28.83 MT of material exists that could potentially be utilised [4].

[11] GVA or Gross Value Added = GDP minus tax including VAT plus product subsidies.

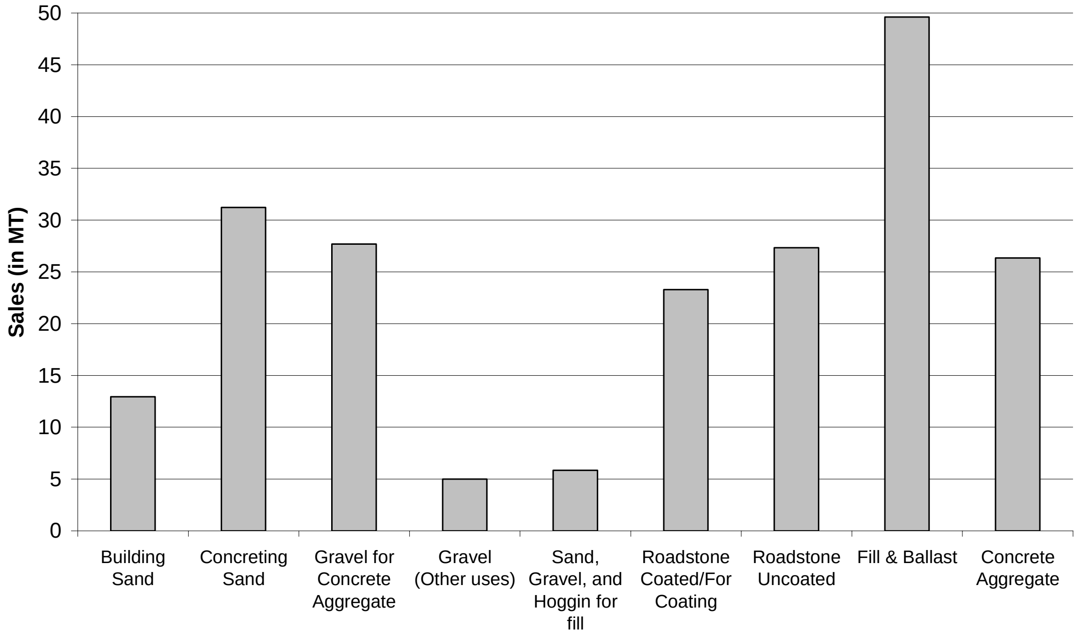

Figure 1C: Sales of aggregates by use in Great Britain (standard regions, Wales and Scotland, 2002) [3]

UK Asphalt Market

The main use for asphalt in the UK is primarily road surfacing and pavement construction. Currently the more common practices for waste material usage in asphalt includes glass cullet as secondary aggregates in road surfacing.

As can be seen from Figure 2C, the use of bitumen in the UK has greatly increased in general over the last 80 years, due to its use in asphalt and the improvement of the UK road system. The market trend for the use of bituminous materials in asphalt for road construction has moved from hot rolled asphalt over the last 5 years to thinner surfaces and cold lay applications.

Asphalt specifications set certain requirements for aggregates that limit particle size and shape, which must be complied with. This is a limiting factor in the utilisation of certain types of secondary materials in asphalt.

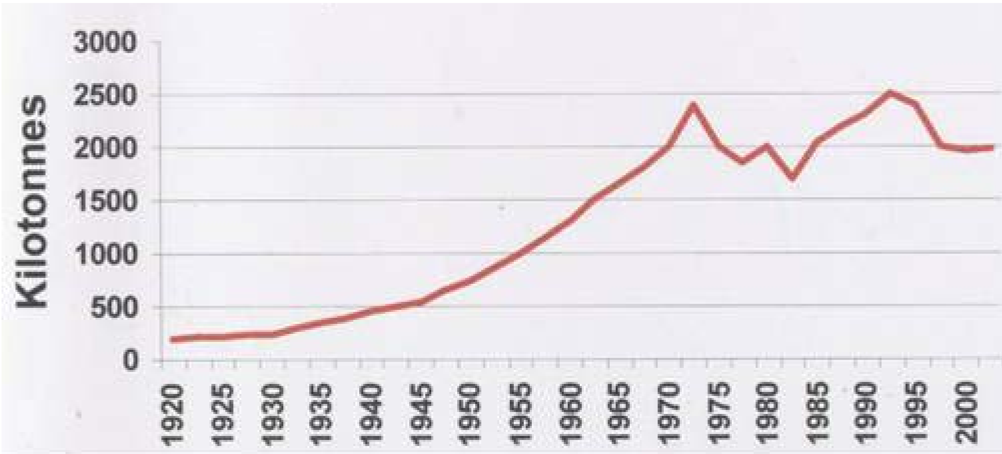

Figure 2C: UK annual bitumen consumption [5].

The UK's 25 asphalt producing companies (300 stationary plants and 10 mobile plants) annually produce 26 MT of asphalt mixture [6] (utilising over 6MT of bitumen per year, 4MT of this is imported [7]). The value of total import of asphalt materials is £8.6m as opposed to the £428,000 exported [4].

UK Concrete Market

Sales of aggregates and ready mixed concretes have remained largely constant since 1996 (Figure 3C). Export figures for 2002 for ready mixed concrete were valued at £3m (260,000 tonnes). Pre-cast concrete exports for 2002 exceeded imports by £6.9m [8].

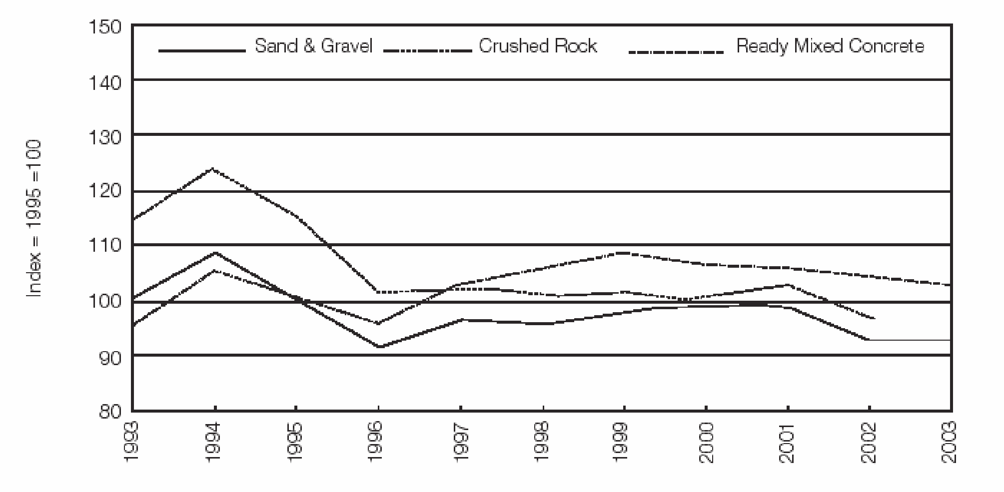

Figure 3C: Sales of aggregate and ready mixed concrete [3].

The application of materials as secondary aggregates in ready mixed concrete may be more limited as standards need to be met for the aggregates used in the mix. Utilising secondary aggregates in concrete products presents a much more accessible market as it is the product that has specifications rather than its component parts.

The price indices shown in Table C1 demonstrate the annual average price increase across the board in the UK construction industry for concrete products since 1994 based on 2000 figures. It is estimated that this growth trend will continue in the near future. With a confirmed growth in the purchase and value of pre-cast concrete products there is a clear market opportunity for the utilisation of secondary aggregates. Added value materials could theoretically be utilised to give a product a competitive edge in providing the product with marketable recycled content, plus an inherent added value.

Table 1C: Price indices of construction materials - Annual Averages (2000 (Baseline) = 100) [3].

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Cement	84.8	87.3	N/A	N/A	95.5	98.7	100.0	99.7	102.4	103.6
Pre-cast Concrete Products	82.3	85.2	N/A	N/A	92.9	97.6	100.0	103.4	108.1	113.1
Blocks, Bricks, Tiles & Flagstones	81.6	85.0	N/A	N/A	92.3	97.4	100.0	103.2	107.1	111.9
Concrete Blocks & Bricks	81.2	86.6	N/A	N/A	97.1	98.7	100.0	102.0	104.5	106.8
Concrete Roofing Tiles	77.1	77.5	N/A	N/A	88.4	97.1	100.0	101.1	103.6	104.3

Materials and products with potential added value applications in the construction industry

Materials chosen for this market survey were decided upon following feedback and input from the “Added Value of Using Industrial Waste Streams as Secondary Aggregates in Concrete & Asphalt” Workshop held at BRE (September 2004). Delegates feedback accompanied by industry professionals and consultants identified a series of materials that could present an added value when applied as replacement for virgin materials in construction products (See Table 2C and Table 3C). Commonly used materials such as glass cullet and other materials identified by the Symonds Report were not considered as these have already been studied in great depth and were not within the remit of this project.

Markets and potential markets for new waste streams require the consideration of several factors such as:

- Availability of the material
- Value of the material
- Cost of the primary material it can potentially replace
- Access to the material

The existing applications must also be considered as these will dictate both the current market value of that material and the actual potential for the material in alternative applications.

Table 2C: Evaluation of concrete applications for secondary materials identified in the project (Potential: High ●●● Some ●● Low ● None or unknown -)

	Lightweight aggregates	Ready mixed concrete	Aerated blocks	Non-aerated blocks	Concrete bricks	Concrete roof tiles	Other pre-cast concrete products[12]	Lightweight panels **	Pre-fabricated building components	Concrete pipes	hydraulically bound material (HBM)
Mixed waste plastics (eg: end of life vehicles (ELV))	●●●	-	-	●●	-	-	-	●●●	●●●	-	-
Synthetic aggregates from waste plastics and mineral waste	●	●● (low strength)	-	●●●	-	-	-	-	-	-	-
Black/white dross from aluminium production*	-	-	-	●● (filler)	●● (filler)	●● (filler)	-	-	-	-	-
Incinerated sewage sludge ash	●	-	-	-	-	-	-	●	-	-	-
Paper Sludge		-	-	●●	-	-	-	-	-	-	-
Synthetic aggregates made using: accelerated carbonation	●●●	●●		●●	-	-	●●	●●	●●	-	●●

* possible use as ingredient in synthetic aggregate
** Lightweight concrete panels incorporating low density plastics (such as polyester or expanded polystyrene)

Table 3C: Evaluation of asphalt applications for secondary materials identified in the project (Potential: High ● ● ● Some ● ● Low ● None or unknown -)

	DBM Base	Stone Mastic Asphalt Surfacing	Porous Asphalt	High Friction Course	Mastic Asphalt
Mixed waste plastics from end of life vehicles (ELV)	● ●	-	-	-	-
Synthetic aggregates from waste plastics and mineral waste	● ● ●	● ●	-	-	-
Zinc (ISF) slag	● ● ●	-	-	-	-
Other non-ferrous slags (black + white drosses from aluminium production and other metals production eg stainless steel)	-	-	-	●	-
Roofing felt	● ●	● ●	● ●	-	● ●

Table 4C: Market availability and information for new waste

	Waste Source	Produced Tonnages	Current Treatment / Disposal Methods	Current Disposal Costs	Reprocessing Requirements	Properties for Added Value (potential or actual)
Mixed waste plastics from end of life vehicles (ELV)	Motor vehicle components	In 1998: 121,000 t/y ELV landfilled 14,000 t/y ELV recycled [9].	Incineration, landfill disposal or recycling. ELV Directive, 80% recycled by 2006.	Landfill[13] Recycled (costs depends on distance) Incinerated for energy recovery	Material separation and size reduction	Low density Enhanced thermal performance
Synthetic aggregates from waste plastics and mineral waste	Plastics from electrical items and other post-consumer plastics	All plastics produced 2.5 Mt/y [10] WEEE: 201,300 t/y to landfill [33] ELV – see above	10-20% of plastic (in general) recycled WEEE recycling targets 4 kg/y/household by 2006.	Landfill[13] Recycled (costs depends on distance) Incinerated for energy recovery	Grading	Improved compressive strength/stiffness Low density Enhanced thermal performance
	Fines waste from inert material production, screening and washing	2 Mt/y china clay 4.8 Mt/y sand [12]. 0.9 Mt/y foundry sand [13] 23-51 Mt/y quarry fines [14].	Fines landfilled	Landfill[14]		
Black/white dross from aluminium recycling	Aluminium recycling	30,000 t/y in UK [23]	Landfill Reprocessed	£50 M/y (industry figures). Landfill figures dependant on the composition of the material (costs as per quote)	Remove chloride and metallic aluminium	Improved compressive strength/stiffness of concrete. Improved abrasion resistance/control of micro cracking
Incinerated sewage sludge ash	Sewage plants Potentially agricultural waste streams	100,000 t/y [16]	Landfilled Used as a soil conditioner	Landfill[13] Deep-fill landfill required if the material is very fine (increased cost and reduced choice of landfills).	None	Enhanced properties in self compacting concrete or foamed concrete
Paper Sludge	Pulping process	Over 1 Mt/y from recycling operations [16].	Energy recovery, anaerobic digestion, disposal	Landfilled[13] Energy recovery if free or may turn into a profit or be used to run the plant	Dewatering	Low density, but reduces concrete blocks strength

13 For non-hazardous wastes: landfill tax £15/tonne Gate fee: £17.50-£46.50 depending on geographical location
14 for inert wastes: Landfill tax £2/tonne.Gate fee's of £2-£46.50 depending on the utility of the material

Synthetic aggregates made using: accelerated carbonation technology	Quarry Operation Cement Kilns Incinerator Ashes	Quarry Fines [14] 23-51 MT/y cement kiln dust [18] 30 MT/y	Landfill	Landfilled[13]	None	Upgrade fine wastes into coarse aggregates with application as lightweight aggregates using PFA or GGBS
Zinc (ISF) slag	Imperial smelting Furnaces	Was 80,000 t/y [27] Now: 2 Mt stockpiled in Avonmouth	Landfill (limited)	Landfill costs £220,000/ y.		Asphalt applications: improves durability, stiffness & reduces binder content
Other metals slag production eg stainless steel	Steel furnace slag from smelting processes	Phosphorus slag: small volume waste Stainless Steel Slag [20] 1.9 Mt/y	Landfill or reprocessed			Stainless steel slag improves skid resistance of asphalt
Roofing felt	Roofing contractors and manufacturers	Difficult to estimate, produced in small quantities [21].	Landfilled, non-hazardous waste	Landfill non-hazardous or inert[13,14] Material usually mixed with other waste, so it is subject to disposal classification	Size reduction, possible contamination removal, sorting	Reduces binder content and improves deformation resistance

Opportunities for added value

Table 5 demonstrates the variables that dictate certain market factors for the selected materials. The most significant factor when considering a market is the principal concept of supply and demand. For a waste material to be considered suitable it must have a supply that matches the demand for any potential application. To this end the quantity of material available must first be ascertained (See Table 5C).

Table 5C: Summary of Table 4C 9Quantification of waste arisings for waste streams considered for added value (All references from Table 4C))

Material	Tonnages in UK
Mixed waste plastics from end of life vehicles (ELV)	In 1998: 121,000 t/y ELV landfilled 14,000 t/y ELV recycled
Ingredients for synthetic aggregates from waste plastics and mineral waste	2.5 Mt/y plastic waste 2 Mt/y china clay sand 0.9 Mt/y foundry sand 23-51 Mt/y quarry fines
Black/white dross from aluminium production	Est. 30,000 t/y UK.
Incinerated sewage sludge ash	100,000 t/y
Paper Sludge	>1 Mt/y
Ingredients for synthetic aggregates made using: accelerated carbonation technique	23-51 Mt/y quarry fines 30 Mt/y globally cement kiln dust (CKD)
Zinc (ISF) slag	80,000 t/y, not produced anymore. Now: 2Mt stockpiled
Other non-ferrous slags	1.9 Mt/y stainless steel slag N/A phosphorus slag
Roofing felt	Difficult to estimate, produced in small quantities locally

Once the amount of material has been identified, its suitability must be considered along with the materials' other potential uses and then compared economically to the current material supply for that application.

For all the chosen materials, potential uses were identified and assessed by industry professionals. Both concrete and asphalt applications were considered and a list of potential products was compiled for both concrete (Table 3) and asphalt (Table 4) in terms of their potential for added value.

Incinerated sewage sludge ash was identified as having low potential in lightweight aggregates and panels, but its potential supply is significant (100,000 tonnes pa currently, potential is 450,000 t/y if all sludge was incinerated) as to be worthy of inclusion.

ELV and other plastic wastes have potential for both concrete and asphalt applications plus can be considered as a potential material for the synthetic aggregates. This material is studied in detail later in this paper.

Added Value materials and recommendations

End of life vehicle plastic waste

It is estimated that 1.85 million vehicles will reach their end of life each year amounting to 2 million tonnes of waste. With the average lifespan of a car estimated at 13.5 years and car usage increasing annually, this equates to a steady stream of materials. The End of Life Vehicle (ELV) Directive states that by 2006 a minimum of 80% of vehicles must be recycled when they reach the end of their life.

An average vehicle is composed of 9% plastics (by weight) plastics which are currently a priority material for the industry. In modern vehicles, the plastics percentage can be as high as 11% and is expected to increase over the next few years.

Vehicle plastics types such as polypropylene account for approximately 41% of all car plastics (bumpers and dashboards mainly), and are easily recyclable as are polyethylene and polyurethane (commonly used in seat fill). Viable markets for these materials already exist outside of the motor recycling industry. The most likely recovery routes for ELV plastic waste are chemical feedstock recycling, energy from waste and materials recycling. Some low grade plastics are, however, likely to be available for aggregate use.

Another significant source of plastic waste material is from end life electrical devices driven by the WEEE directive, however at present it is difficult to acquire significant figures on the plastic waste available. Total plastic waste from electrical appliances in 1998 was thought to be approximately 200,000 tonnes. This material is a difficult waste to recycle in that it is very problematic to segregate the materials.

Recommendations:

ELV and WEEE plastic wastes are relatively new segregated waste stream driven by the relevant Directives which prescribe strict recycling targets. ELV material is readily recyclable if it can be segregated efficiently and economically. Given the number of plastic recycling facilities compared to the number of asphalt facilities it would appear that, generally speaking, traditional methods of plastic recycling may be preferable. However, given the added value potential for this material it may be preferable (if given a choice of recovery routes based on location of the material stockpile) to send this to asphalt reprocessing rather than a recycling plant. This is mainly because the plastic can be used when mixed with other plastics, removing the need to segregate it.

Synthetic aggregates from waste plastics and mineral waste

Synthetic aggregates can be produced from a composition of waste plastic (mainly plastic film and household waste plastic) and mineral wastes such as:

- *Foundry sand* is thought to be a declining waste material. Used mainly in ready-mix concrete and concrete block manufacture, 10-20% is used as aggregates (2003 figures). This material has potential for use as general fill, backfill or in trench reinstatements. This sand can be easily processed to be used as a sand for foamed concrete, cement manufacture or used in asphalt [22]. It may, however, contain leachable levels of heavy metals and other contaminants.
- *China Clay Waste* is a material much underutilised that has potential for use in the generation of synthetic aggregates. The main producer of this material targeted it as an aggregate and aimed to increase sales from 250 KT in 2003 to 5 MT by 2015. There is, however, lack of infrastructure in place to reprocess this material at present in large quantities. It may only be viable to use this material in South West UK where production of china clay and the waste stockpiles are located.
- *Quarry fines* are a by product of aggregate production and are already utilised in the construction industry as a secondary material in fill, concrete, ready-mix concrete, asphalt and pipe bedding. This material is subject to the Aggregates Levy, which may make it economically unviable compared to other waste materials.

Recommendations:

These synthetic aggregates require further study to confirm if the potential thermal enhancement of this material as an additive can be realised. It is not yet clear whether the lightweight properties that this material has may not alone be significant enough to justify this as an economically viable product.

Due to the nature of this product, the production requires there to be an available source of two materials. The value of the material it would potentially replace in concrete and asphalt is potentially another factor, although it has some promise as a substitute for imported pumice aggregate. The other consideration is that plastic materials already have alternative markets which may limit the availability of plastic feedstocks.

Black and white dross from aluminium production

Aluminium dross is a furnace by-product of the aluminium production process (after conventional recycling of waste metal has occurred). White dross is a fine powder from skimming the molten aluminium, this is usually reprocessed to extract the metals. Black dross has a higher salt content than white dross, it is usually in the form of large cast shapes or crushed lumps and is commonly reprocessed to recover the salt.

Most aluminium dross varies in composition between different production plants. This gives rise to an inherent problem in recycling this material in that its composition is usually unique to the plant generating the waste.

Current markets exist where the non-ferrous material can be separated out using an eddy current [23] and reclaimed for chemical reprocessing, however the majority of this material ends up in specialised landfills at a cost to the industry of £50m per annum.

Utilisation of this material in asphalt can improve stiffness if used as a filler aggregate (<700 micron in processed form). It is thought this material could improve abrasion resistance or control micro-cracking, however this is as yet unproven.

Recommendations:

Aluminium dross is a material with significant potential for use as a filler, however, further study is recommended as there is still no proven added value information for this material in concrete applications. Also there is a need to consolidate facts for the amount of this material produced annually in the UK.

Incinerated Sewage Sludge Ash

This ash can be mixed with PFA and clay and sintered for use as an aggregate in construction applications which has been pioneered by Anglian Water and others [24].

Drying the sludge by thermal methods produces a dry material suitable as a soil fertiliser and conditioner called Biogran. Pioneered by Wessex Water, this technology renders the material odourless and storable [24].

A gasification plant built by Northumbrian Water can use sewage sludge to generate electricity, an estimated 5 MW can be generated from 33,000 tonnes of material [24].

In application, this ash material can enhance the properties of self-compacting concrete or foamed concrete or provide an ingredient for synthetic aggregate.

Recommendations:

Incinerated sewage sludge ash has similar properties to PFA and is available in large quantities. The compaction properties of this material justifies it as a good choice for added value applications in concrete. The value of this material in other applications such as an untreated application as a soil enhancing material, may however outweigh its value as an additive or ingredient for construction materials.

Paper Sludge

Paper sludge has many waste management solutions as well as recovery potential.

The utilisation of paper sludge in construction applications such as insulation bricks is mainly limited by cost, research and low price of virgin materials. A recent WRAP study conducted by BRE showed that using paper sludge in concrete reduces the density and strength of the material [25]. Therefore the potential for this material in concrete products is thought to be low unless bound chemically to form and aggregate.

Recommendations:

Paper sludge is unsuitable at present due to its tendency to reduce material strength. Further study into adapting or modifying the material may be advisable.

Synthetic aggregates made using accelerated carbonation

Originally used as a rapid binding medium for encapsulation of hazardous wastes and contaminated land, its potential for use with non-hazardous materials is apparent. Accelerated carbonation has been used in construction as a lightweight fill for road embankments mixing PFA with silt dredgings and lime.

The process can be used to convert low value fines materials such as quarry waste fines into higher value lightweight coarse aggregates. This composite material is thought to be economically competitive with alternative aggregates such as pumice or expanded clay [26].

This composite material can be manufactured with properties comparable to virgin aggregates as a replacement for natural gravels in concrete, but this is a pilot scale study and is not yet commercially available.

Recommendations:

Synthetic aggregates made using accelerated carbonation is a good technique for encapsulation of hazardous materials and there is a potential for further study into using this to bind fine waste materials into concrete applications.

With the reduction in hazardous waste landfills in the UK caused by the Landfill Regulations, the cost of disposing of hazardous materials is expected to rise significantly in a short time frame. There is a need to carefully study the economic viability of this material before any judgement can be made.

Zinc ISF slag

Zinc Imperial Smelting Furnaces (ISF) produce a waste ferro-silicate slag which can contain traces of metals such as arsenic, lead and cadmium. Traditionally, the only recourse for this material is to send it to landfill.

The only company producing this material in the UK has now ceased production, but there is still a substantial stockpile of material.

This slag has been studied as part of a previous BRE study [27]. It's application in asphalt is thought to improve durability, reduce the binder content and improve stiffness.

Recommendations:

ISF slag has got good potential as aggregate in asphalt as it reduces the demand for the bonder content.

Roofing Felt

Recycling bitumen membranes into road mixes can improve the road's rut resistance amongst other benefits, but the material is only found in small volumes, is widely dispersed making transport an issue, is difficult to segregate and the waste material is very much a seasonal arising.

To fully realise flat roof recycling waste, there must be tangible benefits. Due to the associated problems, some form of incentive may be necessary to encourage contractors to segregate the materials or to subsidise customers to encourage them to use the materials. Another issue is transportation, utilising regional collection depots for existing materials may be an option, however the small amount of this material will still be an obstacle.

This material has potential for added value in asphalt as an additive it can improve the deformation resistance and reduces the binder content.

Recommendations:

Roofing felt cannot currently be considered a viable material for large scale recycling simply due to its lack of availability and, where it is available, the quantities are often too small.

Where this material arises in significantly large quantities it would be prudent to consider it for recycling into asphalt due to the significant added value it brings, but this is likely to be based on proximity, seasonal and sporadic factors.

Other materials for consideration identified at the industry workshop

Glass fibres:
- Estimated 1,000-100,000 tonnes per year of this material is produced.
- Material varies in length
- Potentially can be used as glass; is already used in asphalt and concrete applications

Cement kiln dust:
- Estimated over 250,000 tonnes per year generated
- Alkaline dust from cement kiln processes
- Potentially useful for manufacture of synthetic aggregates

Silt from UK motorway drains:

- Estimated 1 tonne per 7m of road
- Could be suitable for use in foamed concrete
- Seasonal availability, peak volumes during certain times of the year.

Plastic waste aggregates

This section of the report deals solely with plastic aggregates.
The report focuses in detail on plastic in aggregates as it is a large volume waste stream that presents promising added value in aggregate applications. The material is also driven by recent legislation such as the Waste Electronic and Electrical Directive (WEEE) and the End of Life Vehicle Directive (ELV).

International Experience

A US company (Conigliaro Industries Inc [28]) is producing lightweight aggregate from recycled plastics under licence from a New Zealand Company. They produce mixed ground plastics suitable for use as alternative lightweight aggregate. The material is made from various sources including shred and ground plastic computer and electronic housings, mixed flowerpots, and mixed consumer plastics. This plastic aggregate is used to produce "Plas-crete" wall blocks that use the ground plastics (50 percent by volume) in place of aggregate in the concrete mix. The blocks produced are approximately 20% lighter than comparable concrete blocks. A similar licensing agreement is in prospect in the UK.

Another company, Plasmega has set up a plant in the UK to produce similar type plastic aggregates. Plasmega is a product manufactured entirely from mixed waste plastic in combination with other materials such as incinerator ash, PFA, foundry sand, and quarry waste fines including fine secondary aggregates from china clay and the production of single sized stone for high polished stone value highway surfacing. The mixed waste products require no sorting, separation or cleansing to enable their use. The plastic is shredded into small chips usually with a maximum dimension of 50mm, this significantly reduces bulk and provides an attractive mixing media. Fine waste aggregate of less than 5mm grain size is used to improve the physical properties that can be achieved as well as acting as a bulking agent. The product can be used to make products such as paving slabs, piling sections, tiles, block paving and pipes. The patent holder believes that the polymer content creates a product with high crack and fatigue resistance due to improved tensile properties in comparison to concrete. The plastic aggregate has been trialled in the production of asphalt (Plasmatex) making up 10% of the mix. A ratio of 70/30 or 60/40 aggregate to mixed waste plastic is likely to be the most suitable. The properties of the plastic aggregate complement existing asphalt properties by improving compaction, superage, cohesion and elastic stiffness [29].

Lightweight concretes can be produced with unprocessed waste materials, such as expanded polystyrene granules [30, 31]. There are several patented lightweight construction systems, incorporating expanded polystyrene concrete panels, which are now more than ten years old. A good example is Stracke Ges m b H system in Vienna, Austria. Using a special concrete mixer, lightweight Portland cement concrete with polyester aggregate of between 300 and 350 kg/m^3 is formed into blocks or panels, which can be sawn, drilled and nailed. These are then used as a permanent formwork in buildings, providing excellent thermal and acoustic properties to a reinforced structure, cast with high workability concrete.

Raw Material Sources

There are a number of potential sources of mixed waste plastics which could be sourced for use as aggregate feedstock. Suitable material for use as aggregate will need to be a waste stream with zero or negative value and/or which currently has no recycling route (i.e. currently going to landfill and subject to landfill tax). They should also be in sufficient volumes to supply the aggregate application (i.e. millions of tonnes per year) [32].

Single polymer waste has a high value making them unviable for recycling into aggregates and they are more useful in making other plastic products. However, lower value mixed polymer plastic waste from municipal sources, the packaging industry, ELV which are not usually recycled provide the perfect feedstock for processing to become synthetic (plastic) aggregates [29].

Plas-crete uses municipal plastic waste from collection and drop-off programmes as well as waste from dismantlers of computers and electronics. The ground plastics are generally a mix of Specific Polymer identification (SPI) code 3-7 plastic (Polyvinyl chloride, low density polyethylene, polypropylene and polystyrene) [33].

Another potential source of plastic is from the recycling of old fridges, as required by legislation. Shredded rigid polyurethane (PU) foam obtained from the fridges has the potential to be added to concrete as a lightweight insulating filler.

Thermoset composite materials are another potential source of plastic material that could be used. This material contains fibre reinforcement, often in the form of glass fibres [25] which may provide additional reinforcement to concrete or asphalt. A RMCEF funded project run by BREWEB (the Building Research Establishment Waste and Environmental Body) [34] has been investigating this topic in partnership with the University of Ulster and Aggregate Industries. The project explored the possibility of developing a low-cost way of using the reinforcement potential of waste fibre reinforced polymer composites in road construction, particularly bituminous pavements.

ELV waste offers another potential source of material for plastic aggregate. Around 50,000 tonnes of heavy shredder waste resulting from vehicle shredding is generated by one UK company alone. It appears that the material contains high levels of rubber and plastics [25], but the material would need further investigation to determine its suitability and level of processing required to enable its use as an aggregate.

Waste Electrical & Electronic Equipment (WEEE) legislation requiring more responsible disposal of such equipment will see growing volumes of plastics that could be recovered from these products which may have the potential for use as an aggregate. However, this plastic waste stream will also need further investigation to determine its suitability. There are also a number of hazardous substances within electronic waste which may be contained in the plastic components, including brominated flame retardants, and cadmium and possibly lead in older equipment, which may be a barrier to recycling. Separating and recovering plastics from shredder residue on a commercial scale does not yet exist in the UK [35].

Raw Material Availability

The amount of plastic waste currently generated in the UK is about 2.5 million tonnes per annum. The British Plastics Federation figures indicate that the current recycling rate of post-use plastic waste generated by the domestic, commercial and industrial sectors is approximately only 5 % [10].

It is estimated that there will be around 15,000 tonnes of PU foam arising from fridge shredders in the UK each year [32].

The volumes of thermoset plastic waste available for use is unknown, but thought to be only in very small quantities in a large number of locations rather than the required large volume focused in one location [25].

Every year in Britain, around 1.85 million cars reach the end of their lives, either because of old age or because of a major accident. That equates to around 2 million tonnes of material to be recovered or disposed of. By volume, from bumper to bumper, cars today contain more plastics than traditional materials. Yet thanks to their light weight they account for, on average, only 9.3% (105 kg) of the total weight. Equivalent to 186,000 tonnes of plastic [35]. Around 50,000 tonnes of heavy shredder waste resulting from vehicle shredding is generated by one UK company alone [25].

In relation to WEEE, research undertaken by ICER has indicated that 915,000 tonnes of post consumer electronic equipment was discarded in 1998, of which 22% was found to be plastics. Almost half of the total tonnage went to recyclers, although metal was the only material recovered in large quantities. It can be difficult to recycle plastics from electrical and electronic equipment because of the many different polymer types [24].

Raw Material Reprocessing

The mixed plastics do not require sorting or cleaning, but do require some processing to obtain the desired particles size for the application. The particle size and shape of the plastic appear to be factors which affect strength gain in the desired application.

For the Plas-crete product, plastic particles (8 mm and 32 mm) appear to provide the highest strength, and can be used for “moderate-strength” lightweight concrete products. Whereas plastics, generally 3mm and 13mm, show potential for use as “low-density” (insulating) lightweight concrete [33].

The plastics may also require some other form of processing such as heating to enable binding with any other materials used such as with the Plasmega product. This uses mixed polymer waste plastic combined with fine aggregate in a patented process to produce a slurry suitable for casting into shapes for construction items. The process of manufacturing Plasmega involves a system of regulated high rate size reduction combined with controlled parameters of low temperature mixing and blending that alleviate noxious emissions [36]. The plastic is shredded into small chips usually with a maximum dimension of 50mm, this significantly reduces bulk and provides an attractive mixing media. The fine aggregate is heated and mixed with the plastic which melts and binds them together. The molten material is then capable of casting. The plastic becomes hard when it has cooled and the bulked material containing fine aggregate gives a strong low density material [29].

Legislation Issues

The main area of legislation affecting the use of plastics as aggregates is the waste management licensing regime and the current interpretation of waste licensing regulations. This requires that these alternative aggregates be subject to waste licensing until they are incorporated in a product. The new interpretation is that the material remains a waste until it has been recovered i.e. placed in construction materials, e.g. as aggregate in asphalt and concrete products. The issue of the definition of waste and the application of the waste management licensing regulations to secondary and recycled aggregates is probably the most important barrier to their greater use in construction, and needs to be addressed as a matter of urgency [29].The Wastes & Resources Action Programme (WRAP) have produced a quality protocol for inert wastes in an attempt to overcome these issues [37]. WRAP also have a programme and targets for increasing plastics recycling and a programme to promote sustainable aggregates in general.

Benefits of using plastics as aggregate

Plastics are not recommended for use as aggregates in hardcore or fill applications since they have the potential to be compressed. However, they have most potential to be used as a lightweight aggregate in concrete.

Standard concrete products such as wall blocks and kerbs are weighty and must be handled with heavy equipment during construction activities. This presents added costs, effort, safety concerns and inefficiencies during construction processes. By using waste plastic as a substitute for the comparatively heavy stone aggregate, such products can be produced which can be used for the same applications, but which are lighter and easier to handle. Therefore resulting in much more cost effective, safe and efficient construction [33].

The advantages of using plastic aggregates in concrete are associated with the lightweight and elastic properties of the materials. Aggregate occupies a large volume of concrete, more than 75%, and therefore the inclusion of higher volumes of plastic will contribute significantly to the lightweight and the thermal insulation properties of concrete. Also, the elastic properties of plastic, compared to mineral aggregates, improve the elasticity of concrete and the ability to withstand large deformations. Low-strength thermal insulating concrete could be the highest value application of plastic aggregates in the construction industry, as these requirements are not easily achieved with conventional natural aggregates. The defrayment of disposal costs means that these plastics are likely to be available at low prices compared to recycled single polymer plastics [32].

The use of plastic aggregates in concrete reduces the compressive strength but low density and elastic properties may make them more competitive in applications where lightweight, thermal insulation and shock absorbency are desirable. The highest value applications of plastic are probably in lightweight/thermal insulating concrete because these requirements are difficult to achieve with conventional natural aggregates.

Summary and Recommendations

An intensive market study is recommended for those materials deemed potentially economically and environmentally viable, primarily plastic synthetics. Also there is a need to clarify volumes of certain waste materials, such as aluminium dross and roofing felt. There is also a need to acquire accurate information on geographical occurrences of all added value waste materials to calculate their viability on a regional basis.

Further investigation and study for those materials with potential added value properties is also advised to determine solid figures for performance in practical applications. Proving a materials use and value is the only way for it to be utilised in construction, the risks of using an unproven material are simply too great for contractors and clients alike to consider.

Plastic aggregates were considered in detail due to the large tonnages available, the significant potential they have as additives to provide added value and the strong legislative drivers to recycle the material. Plastics have great potential, much more than the other materials considered, mainly as they can be used in a number of applications and their inherent properties are complimentary to both concrete and asphalt.

For the other materials considered:

- Sewage sludge ash has value in other applications in an untreated form that may be difficult to compete with, but it does have value as a concrete additive.
- Roofing felt has a very limited supply, although it does have a significant benefits in asphalt.
- Zinc ISF slag and aluminium dross have variable compositions and present potential handling hazards plus the material supply is limited for zinc ISF and low at present for dross.
- Paper sludge reduces the strength of concrete, so has low potential to be used in structural concrete applications but does have some potential for use as a filler.

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