Performance & benefits from using waste plastic-based aggregate in asphalts

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ABSTRACT: One strategy to encourage the use of secondary aggregates is to demonstrate applications where such materials offer at least equivalent performance or, preferably, clear benefits or "added value" over primary alternatives. This paper summarises findings from a project which was carried out by BRE in collaboration with SWPE for the Department of Trade and Industry (DTI)/Waste and Resources Action Programme (WRAP). The project aim was to identify and make industries aware of "added value" effects (such as improved technical performance) that secondary aggregates can offer relative to primary aggregates and to improve their 'image', so that they are perceived as more desirable commodities and thereby enhance their value. Specifically, the feasibility of using waste plastic-based aggregate in asphalt applications is presented in this paper. The use of plastic-based aggregate asphalt mixtures in base and surface course has been assessed. These mixtures have demonstrated performance at least as good as comparable materials using primary aggregates. The performance assessment includes workability, stiffness, resistance to deformation, moisture and ageing – both for laboratory-manufactured specimens and cores recovered from field trials after 18 months in situ.

1 INTRODUCTION

1.1 *Background*

The success of the Aggregates Levy on primary aggregates (currently £1.60 per tonne) introduced in 2002 has led in part to the United Kingdom (UK) becoming a leading user of recycled and secondary aggregates (RSA) in Europe. Recycled aggregates are derived from materials previously used in construction whilst secondary aggregates are by-products derived from industrial processes. 25% of the 275 million tonnes of aggregate annually consumed in the UK is either recycled or secondary aggregate (AggRegain 2005). However, the UK Government thinks the construction industry can achieve a lot more. One strategy to enhance the value and use of secondary aggregates is to demonstrate applications where such materials offer equivalent performance, cost savings and, preferably a clear benefit or "added value" over primary alternatives.

The Building Research Establishment (BRE), in collaboration with Scott Wilson Pavement Engineering (SWPE), led a recently completed research project on "Added value of using new industrial waste streams in concrete and asphalt", for the Department of Trade and Industry (DTI)/the Waste and Resources Action Programme (Dunster et al 2005). The aim was to make industries aware of some of the "added values" (benefits) associated with the use of industrial by-products as secondary aggregates. The project also aimed to improve the 'image' of RSA generally so they are perceived as desirable commodities and to therefore enhance their value. In this project, "added value" has been defined as one that encompasses materials offering:

1 Improved technical performance relative to primary aggregate alternatives;
2 Cost savings or increased profitability;
3 Environmental enhancement;
4 Other considerations, such as, aesthetic appearance, reduced heath and safety risks.

1.2 *Creative workshop*

As a part of this study, a creative workshop involving RSA users, producers, and regulators, was organised and held at the BRE. The workshop's main objective was to gather information on the potential use of new UK waste streams as construction aggregates. A list of materials with potential for application as secondary aggregates in concrete and asphalt was subsequently identified (Dunster et al 2005), specifically including:

- Mixed waste plastics (e.g. end of life vehicles)
- Synthetic aggregates from waste plastics and mineral waste
- Non-ferrous by-products, ashes and slags

The secondary materials already extensively covered as aggregates by WRAP's programmes (including glass and most high volume industrial by-products such as blastfurnace slag, steel slag and colliery spoil), were excluded from the scope of the project.

After the workshop, one of the materials selected for further assessment, based upon its immediate availability for the project and potential beneficial properties, was a manufactured plastic aggregate known as "Plasmega". This paper specifically presents the results from the mechanical assessment of this manufactured plastic aggregate which has been used in asphalt base and surface courses.

2 MATERIALS FOR TESTING

2.1 *Manufactured plastic aggregate*

The UK annual consumption of plastics in 2002 was approximately 3.5 Mt, with approximately 0.2 Mt of post-consumer plastics being recycled per annum (source: British Plastic Federation and Enviros, 2003). 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 light weight manufactured plastic "aggregates".

Plastics have the potential to provide a useful source of aggregates in addition to mineral aggregates. One manufactured plastic aggregate "Plasmega" and an earlier variant known as "Plasmatex" have been produced on a pilot scale from thermal processing of a combination of mixed plastic wastes and fine mineral material such as china clay sand or quarry fines. The particle density is typically around 1.60 Mg/m^3 and it may be crushed to a particle size of 5/20mm coarse aggregate (Phillips and Richards 2004).

2.2 *Asphalt mixtures - base*

0/32 mm size Coated Macadam base to British Standard (BS) 4987-1 Clause 5.2 was selected as the target mixture design for the laboratory manufactured asphalt samples. This specification accommodates 2 mixture designs: Dense Bitumen Macadam (DBM) and Heavy Duty Macadam (HDM); 40/60pen bitumen was used in the studied mixtures. It was decided that the target combined aggregate grading should fall within the grading envelopes of both DBM and HDM, to provide greater flexibility in terms of material's usage. Hereafter, the adopted asphalt bases containing 100% primary (limestone) aggregate and manufactured plastic aggregate were referred to as DBM50 and DBM50P respectively. The main properties of the RSA asphalt base, which were expected to offer potential "added value", were assessed and compared against those typically expected for this type of material.

Initial assessment was carried out by manufacturing DBM50P samples incorporating 10, 15, and 20% of the plastic aggregate (having a 5/20mm nominal aggregate size) at two different target binder contents, 4% and 4.6%, followed by a visual assessment of the coated asphalt samples. This visual assessment concluded that it is possible to incorporate 20% plastic aggregate into the target DBM50P mixture, and that 4.6% bitumen content would be sufficient to provide uniform coating of the aggregates in the mixture. Consequently, a target combined aggregate grading incorporating 20% plastic aggregate, and at 4.6% binder content, was adopted as summarised in Table 1.

Table 1. Combined aggregate grading and binder content.

BS Sieve Size (mm)	Cumulative Percentage Passing		
	BS 4987-1:2003 Clause 5.2 Grading Envelope		Target Grading
	DBM	HDM	
40	100	100	100
31.5	90 – 100	90 – 100	90 – 100
20	71 – 95	71 – 95	71 – 95
14	58 – 82	58 – 82	58 – 82
6.3	44 – 60	44 – 60	44 – 60
2	24 – 36	24 – 36	24 – 36
0.063	2 – 9	7 – 11	7 – 9
Binder content (%)	4.0 ± 0.6		4.0 (DBM50) (Control) 4.6 (DBM50P) (Plastic)

2.3 *Asphalt mixture – surface course*

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 the BRE site to the north of London, England. A summary of the composition of the Plasmatex surface course, together with that reported by Phillips et al (2004), is presented in Table 2.

Table 2. Composition of plasmatex surface course.

Mix Constituents	Composition (% by weight)		
	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 100/150 Pen	5.7	5.7	5.7
Fibres	0.3	0.3	0.3

Note: MPWP denotes Mixed Polymer Waste Plastic (‘Plasmatex’)

Prior to the car park trial, an initial assessment of the mechanical properties of Plasmatex (Stone Mastic Asphalt (SMA) type asphalt containing 10% Plasmega) was carried out in the laboratory by AI, and the findings were published elsewhere (Phillips and Richards, 2004). The asphalt materials laid in the car park were understood to be broadly similar to Plasmatex “Mix B”, but with slightly lower percentages of added Plasmega (5% and 7.5%).

The performance of the laid material after 18-months in service was subsequently assessed in the recent research project and the results are presented in this paper.

3 ASSESSMENT OF ASPHALT BASE

3.1 *Test methodology*

Following the above mixture design, 305mm x 305mm x 70mm asphalt slabs were manufactured by using a laboratory roller compactor; a number of 200mm diameter and 100mm diameter specimens of a suitable size for testing were then cored from each of these slabs. The adopted sample manufacturing process was not dissimilar to that normally used for conventional asphalt manufacturing, with the exception that for manufacturing the DBM50P specimens, the primary aggregates were superheated (to 180^{o}C) whilst the manufactured plastic aggregate was added cold.

The important mechanical properties of an asphalt material with respect to pavement life are its stiffness, deformation resistance and fatigue characteristics. The stiffness of a material relates to its load spreading ability, the deformation resistance relates to its ability to resist rutting in service, and the fatigue characteristics relate to its crack resistance properties. These properties are particularly important for the structural layers, but also contribute significantly to the performance of the surface course. The manufactured mixtures were assessed using the following methodology:

Bulk Density: The bulk density of each sample tested was determined in accordance with Procedure C of BS EN 12697-6, using self-adhesive foil when weighing the specimen in water.

Load Spreading Ability: In order to assess the variation of stiffness of the materials with temperature, the Indirect Tensile Stiffness Modulus (ITSM) test was carried out on six unaged samples for each mixture, at three different temperatures (10, 20 and 30°C). The ITSM testing was carried out under the standard conditions of 5 microns target horizontal deformation, an assumed Poisson's ratio of 0.35 and a rise time of 124 milliseconds (BS EN 12697-26, Annex C).

Deformation Resistance: The Repeated Load Axial Test (RLAT) was carried out on the asphalt mixture under the standard test conditions of a one second square load pulse of magnitude 100kPa, followed by a one second rest period, which have been suggested in the UK as being appropriate for most applications (BS DD 226). For each mixture, the RLAT was carried out on six samples of unaged material, to characterise each material's early age deformation resistance. For these tests, a total of 3600 load applications were made (or fewer if the specimen collapsed) and the permanent viscoplastic strain was recorded. The RLAT was carried out at 40°C because the susceptibility of bituminous material to deformation is greater at this temperature, and the effect of material constituents most obvious.

Resistance to Moisture Damage: The sensitivity to water (durability) of the asphalt mixtures was assessed by measuring the stiffness modulus (ITSM) before and after a water conditioning regime, in accordance with the BBA/HAPAS Protocol (Document SG3/05/234, Appendix A.2). The water conditioning was carried out by subjecting the specimens to a partial vacuum followed by three number conditioning cycles. For each cycle, the specimen was submerged in water for 6 ± 1 hours at 60 ± 1°C, then for 16 ± 1 hours at 5 ± 1°C, and followed by a minimum of 2 hours at 20 ± 0.5°C. Stiffness modulus values of the same specimens were determined initially (before being subjected the water conditioning cycles), after Cycle 1, after Cycle 2 and after Cycle 3; the stiffness ratio after each conditioning cycle was then compared against the initial value. This test was carried out on six unaged asphalt specimens for each mixture.

3.2 *Results and discussion*

The mechanical test results for the laboratory manufactured DBM50P (with plastic aggregate) and samples of DBM50 (control) are summarised in Table 3.

Table 3. Comparison of materials properties.

Property	DBM50	DBM50P
RSA Content & Type	Control	20% Manufactured plastic aggregate
Binder Content (by weight of mixture)	4.0%	4.6%
Density (Mg/m^3)	2.341	2.027
Stiffness, MPa at:		
10°C	10020	6420
20°C	3590	3760
30°C	1060	2020
Deformation Resistance:		
Permanent Strain (%)^	2.2	1.5
Strain Rate (με/cycle)^^	1.5	0.5
Resistance to Moisture Damage (3rd Cycle Stiffness Ratio)	1.13	0.87

Note: ^After 3600 cycles. ^^Between 2600 and 3600 cycles

Sample Manufacturing and Bulk Density: Table 3 shows that the bulk density value of the mix containing plastic aggregate (DBM50P) was lower than that of the Control DBM50. This may imply that the "cost" for hauling and transporting the hot DBM50P asphalt mix to a construction site could potentially be reduced due to its light weight (low density), e.g. less fuel consumption, lower emissions, and reduced damage to access roads.

During slab manufacturing in laboratory, the loose DBM50P was observed to show a degree of resilience during compaction. It is possible that this reaction was due to the plastic aggregate's particle size being expanded slightly when blended with bitumen; this phenomenon is commonly observed in materials containing recycled plastics or rubbers. At the end, slab manufacturing was completed without any difficulty and the overall workability was considered to be comparable to that of conventional asphalt materials (such as DBM50).

Load Spreading Ability: The 20°C mean stiffness value of DBM50P was considered to be comparable to that of DBM50 (control), i.e. within +/- 10% (Widyatmoko, 2002). This suggests there is no significant difference between the load spreading ability of these materials at ambient service temperature. However, DBM50P shows lower stiffness at lower temperature, indicating softer and more flexible material compared with DBM50, which is preferable for better resistance to low temperature cracking but higher stiffness at higher temperature, which is preferable for better load spreading ability.

Deformation Resistance: The RLAT deformation resistance of DBM50P was found to be better than that of DBM50. This is consistent with the higher stiffness, hence better load spreading ability, at 30°C shown by the DBM50P material. It is worth noting here that the binder content in the DBM50P was slightly higher (i.e. 4.6%) than that in DBM50 (i.e. 4.0%). Higher binder content would generally result in lower stiffness and greater deformation, but, on the contrary, these properties were not evident from the DBM50P data.

Resistance to Moisture Damage: 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 (TRR 843). A threshold value of retained “strength” of 70% has been suggested for deeming a mixture to be sensitive to water for: tensile strength (Lottman, 1982), triaxial resilient modulus (Terrel and Al-Swailmi, 1994), and indirect tensile stiffness modulus (Scholz, 1995), all carried out pre and post conditioning; whilst the Strategic Highway Research Programme (SHRP) specification recommended a minimum tensile strength of 80%. Scholz’s work forms the basis for the BBA HAPAS procedure adopted here. In this case, the laboratory manufactured DBM50P would be deemed as not susceptible to moisture damage since the mean cycle 3 stiffness for these materials exceeds the 80% threshold (i.e. exceeding both Lottman’s and SHRP’s threshold values).

4 ASSESSMENT OF ASPHALT SURFACE COURSE

4.1 *Test methodology*

A total of 20 number 150mm diameter cores from 4 paving rips of the BRE car park (5 cores per rip) were received by SWPE on 12 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.

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.

4.2 *Results and discussion*

Table 4 presents the mean values of bulk density and stiffness modulus of the Plasmatex samples recovered from the car park (at 18 months age). The relevant mechanical test on similar material, but at a slightly higher proportion of plastic aggregate (10%), i.e. Plasmatex Mix B (Philips et al., 2004) is also reproduced in Table 4. The properties expected from an SMA surface course material are also presented in Table 4 for comparison purposes.

Table 4. Comparison of materials properties

Sample	Plastic aggregate (% 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
10mm 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 the gyratory compactor. *Relative to the stiffness of 10mm SMAtex

Phillips et al (2004) highlighted some added value potential of a manufactured plastic aggregate used in asphalt surfacing, including improved workability (compaction) whilst retaining stiffness characteristics.

Table 4 shows a trend of reducing mix density as the percentage of plastic aggregate increases, as shown by the following ranking (higher to lower density): Plasmatex Rip1/Rip 4, Rip 2/Rip 3, and Mix B for the 5%, 7.5% and 10% plastic aggregate contents respectively. The mean stiffness values of the site samples were found to be higher than that of the Plasmatex Mix B and the 10mm SMAtex.

Asphalt materials are expected to experience stiffness increases after several years in service due to age-hardening, and stiffness after one year may be as much as twice the value of newly laid material. High stiffness values normally indicate better load spreading ability, and high retained stiffness values also indicate 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, i.e. most of the individual site samples had stiffness values less than 2000MPa, which are more comparable with those expected from unaged material of these types. This may indicate less stiff, relatively unaged but intact material, or some form of distress within the material. There are several possible reasons for this, including good resistance to age-hardening or, conversely, stiffness loss due to poor durability; more detailed assessment or historic data would be required to verify this. Nonetheless, the data suggest that the site cores (which contained 5 – 7.5% plastic aggregate) have comparable load spreading ability to that of unaged material of similar type, but containing 100% primary aggregate.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 *Conclusions*

The assessment carried out on asphalt surfacing and base materials containing recycled plastic aggregate showed potential added values in a number of areas. For application as DBM base, the added value properties (which in this context means similar or better than) include:

- Increased utilisation of recycled plastic, hence minimising the requirement for landfill and reduced cost to the environment;
- Potential reduction of haulage and transport cost, due to its light weight;
- Mixture workability not dissimilar to that of conventional asphalt;
- Load spreading ability as good as conventional asphalt of a similar type;
- Potential improvement in low temperature crack resistance;
- Better resistance to high temperature deformation (rutting);
- Resistance to moisture damage comparable to that of conventional asphalt.

For application as surface course material, the benefits of minimising the requirement for landfill and cost for haulage/transport still apply. However, the Plasmatex surfacing cores removed from the BRE car park did not clearly show the expected degree of improvement (increase) in stiffness. At least, however, the stiffness values of the site cores were comparable to those 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 Phillips et al (2004).

It should also be noted here, however, that there are also some additional works/costs to be anticipated when using plastic aggregate, including the cost for processing the material to produce it at sizes suitable for construction use, increased consumption of bitumen, a requirement for suitable space for stockpiling and additional energy consumption to superheat the primary aggregate during asphalt production. From a practical point of view, one of the UK major asphalt suppliers stated that the difference between asphalts containing recycled plastic aggregate and those containing 100% primary aggregate in relation to the overall manufacturing and producing cost (taking account of aggregate levy, land fill tax, gate fee and other processing costs) is relatively small (£1 – £2 per tonne); therefore, a strong business case for using recycled plastic aggregate in asphalts is feasible, provided that a sufficient tonnage of feedstock could be secured annually.

5.2 *Recommendations*

This report presents a feasibility study into the potentials for using waste materials, specifically recycled (manufactured) plastic aggregate in asphalt applications. Up to 10 and 20% plastic aggregate could potentially be used as aggregate replacement in SMA surface course and DBM50 base respectively. It is, however, feasible to increase the waste material contents to further exploit their usage; but subject to favourable findings in a more detailed investigation.

In the long run, there is a potential market for these materials, e.g. as proprietary asphalt products. Proprietary materials are usually judged based upon performance, certified by an independent body, and are sold under a manufacturer warranty. The Highway Authorities Product Approval Scheme (HAPAS), run by British Board of Agrément (BBA), issue certification for proprietary products, including those containing waste or reclaimed materials

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