Sub-Task 5: Best Practice for Recycling Asphalt Pavements

Task 1-111 Collaborative Research Project

Highways England, Mineral Product Association and Eurobitume UK

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Table of Contents

Figures

Tables

Executive Summary

This report is part of the Task 1-111 collaborative research project jointly commissioned to AECOM by Highways England, Mineral Products Association (MPA) and Eurobitume UK. The project is referenced: *"Task 1-111: Sub-Task 5: Review of Asphalt Recycling Practices"*. This report presents best practice guidelines for recycling asphalt into surface course.

This project is tasked with conducting a detailed review of recycling asphalt pavements into thin surfacings. The project reviews 'best practice' guidelines for recycling asphalt into thin surfacings and evaluates sites incorporating Reclaimed Asphalt (RA) on the SRN. This was undertaken to evaluate the performance of these mixtures to date (subject to available data). The role and influence of rejuvenators are discussed in this project with respect to making use of increased quantities of RA.

RA presents a beneficial alternative to the use of virgin aggregates. The use of RA can result in cost savings and environmental benefits. Recognising these economic and environmental benefits are important in the renewed interest and possibilities of incorporating increased quantities of RA in asphalt mixtures.

The methodology used for this project consists of a detailed literature review and web search study of papers and conference presentations focused on recycling asphalt planings into thin surface course systems. Discussions with MPA and Eurobitume UK members to establish best practice in the industry helped identify opportunities for improving current practices. The Web-based Departures Approval System (WebDAS) database which details all departures from standard was used in identifying sites on the Strategic Road Network (SRN) incorporating RA. These sites were evaluated with discussions on their performance.

This report was able to draw the following key points:

- The properties and performance of recycled asphalt mixtures are influenced by the level of ageing of the residual binder in the RA. The methods for compensating for the aged, stiff binder include the use of rejuvenators, softer virgin bitumen and increasing the total binder content in the mixture.
- The design and production of asphalt materials incorporating higher RA contents (i.e. >30%) should be optimised in order to achieve a successful mix design, production and performance of the produced asphalt mixture.
- The increased use of RA should be supported with a focus on their long-term performance.

1. Introduction

1.1 Background

This report is part of the Task 1-111 collaborative research project jointly commissioned to AECOM by Highways England, Mineral Products Association (MPA) and Eurobitume UK. The project is referenced: *"Task 1-111: Sub-Task 5: Review of Asphalt Recycling Practices"*. This report presents best practice guidelines for recycling asphalt. The report evaluates available information from sites incorporating Reclaimed Asphalt (RA) to assess performance.

Significant emphasis has been placed on the sustainable use of materials for the construction of roads in recent times. Incorporating suitable RA in the production of new thin surface course systems presents an interesting proposition for use as replacement materials for road construction in the industry as they contribute to sustainable development, help minimise environmental impact, optimise the use of natural resources and reduce the need for dumping waste materials into landfills.

The benefits of recycling asphalt materials are detailed below in Figure 1.

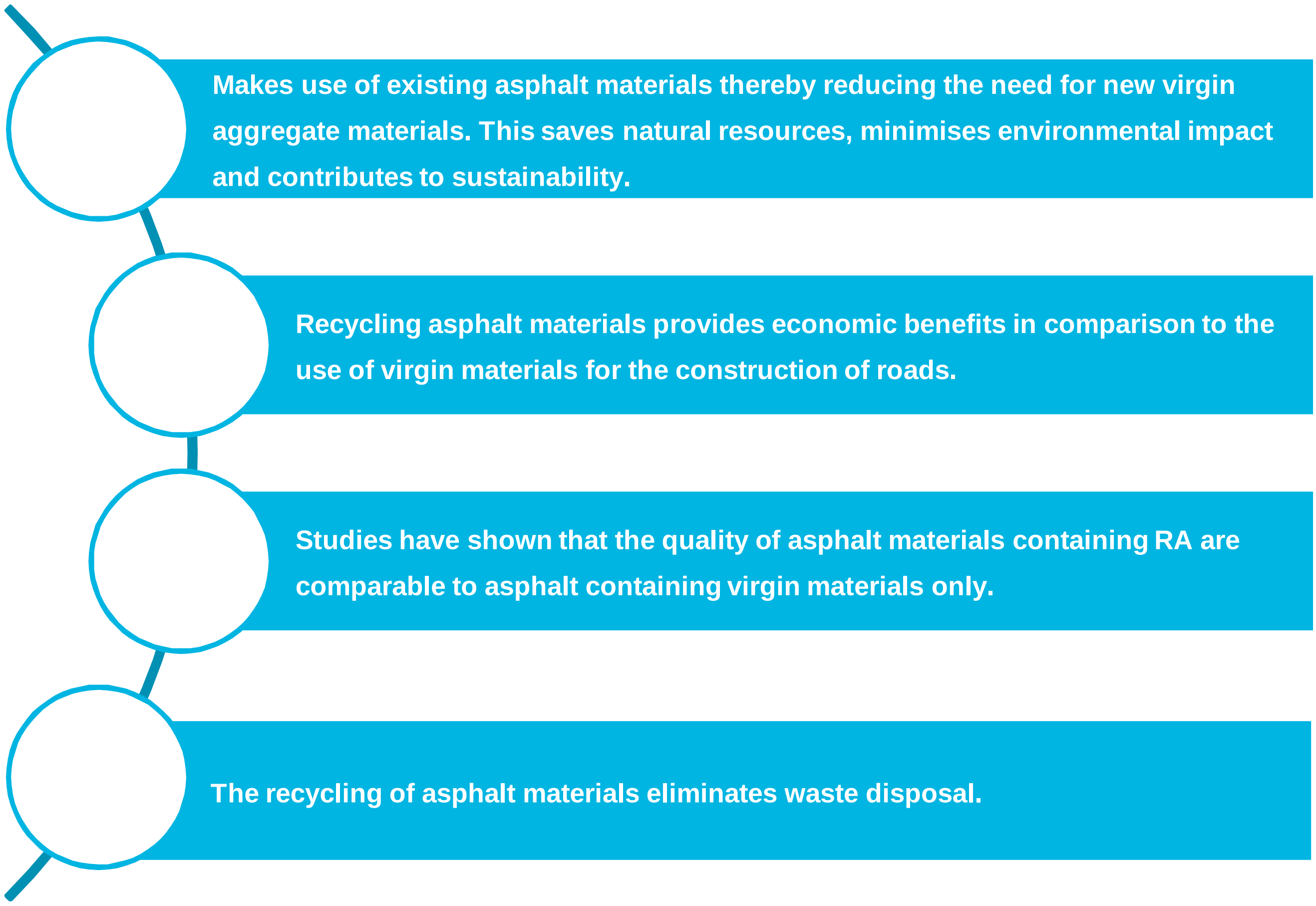

Figure 1: Benefits of Recycling Asphalt Pavements

1.2 Project Aim and Scope of Work

The primary aim of the project is tasked with evaluating asphalt materials incorporating RA in thin surface course systems on the Strategic Road Network (SRN). The specific tasks and objectives associated with this project are detailed below:

- A detailed literature review on recycling asphalt pavements.
- Evaluate the use of high RA content mixtures.
- The use and influence of rejuvenators.
- The mix design and durability of asphalt mixtures produced with RA.
- Evaluates sites in the UK that have incorporated RA (subject to available data).
- Best practice guidelines for recycling thin surfacings.

1.3 Methodology

The methodology used for this project comprised of the following key steps:

- Literature and web search study including a review of papers and conference presentations focused on RA into thin surface course systems.
- Engagement and discussions with MPA and Eurobitume UK members to ascertain best practice in the industry. Explore possible obstacles and identify opportunities for improving current practices.
- The Web-based Departures Approval System (WebDAS) database details all departures from standard and was used to identify RA sites on the SRN. This was used to provide discussions on performance.

2. Review of Recycling Asphalt Pavements

This section presents a literature review on recycling asphalt back into thin surface course systems. The literature study comprised of a web-based search of articles, technical reports, conference papers and presentations. The key findings and concepts are presented, taking into account experiences in the United Kingdom, Europe and the United States. The project details new applications, techniques and methodologies used in recycling asphalt materials.

2.1 Introduction

European Asphalt Pavement Association (EAPA, 2015) provided statistics showing that approximately 4.7 million kilometres of new roads are constructed with asphalt production exceeding 278.8 million tonnes of asphalt mixtures.

Roads are one of the most important transport infrastructures and an important contributor to the growth and development of national economies (World Highways, 2015). There is the need to improve resource efficiencies, reduce climate and environmental impacts by promoting recycling. This is a key component of the European Waste Framework Directive 2008/98/EC tasked with reducing disposal and incineration of waste materials (European Parliament, 2008).

The use of RA for thin surface course systems presents an interesting proposition to help reduce the need for the use of virgin materials, reduce disposal and incineration of waste materials in line with the European Waste Framework Directive 2008/98/EC. In addition to this, the use of RA provides economic and environmental benefits conserving natural resources and efficiently using recycled materials for the construction of optimally performing asphalt mixtures.

2.2 Key Factors for Consideration in Using RA

This section provides information on the key factors to be considered when using RA for recycling into thin surface course systems.

2.2.1 Method of Recycling

Milling is frequently used in rehabilitation projects for recycling into thin surface course systems. The milling process involves removing and replacing the upper layer of an existing asphalt material with new materials. This helps improve the mechanical and performance properties of the pavement.

RA obtained from a single source with the same asphalt material and composition usually has uniform properties which include similar: particle size distributions, residual binder contents and asphalt performance characteristics (Karlsson and Isacsson, 2006).

Asphalt recycling techniques can be divided into in-plant (ex-situ) or in-place (in-situ) both of which can be sub-divided and classified taking into account the temperature of the recycling process: Cold Mix: (<50 °C), Warm Mix: (70°C - 140 °C) and Hot Mix: (>140 °C) as presented in (Wayman et al., 2015).

Hot asphalt recycling in-place can be further classified into two categories called “Remix” and “Repave” (Karlsson and Isaacson, 2006). The “remix” process means that existing asphalt is pre-heated, scarified, mixed with new asphalt and spread out on the same road as one layer (Karlsson and Isaacson, 2006; Miliutenko et al., 2013). The “repave” process involves pre-heating the existing asphalt layer, scarifying and levelling the old asphalt mix. This is followed by the addition of a new asphalt mix, which usually results in an elevated surface of the virgin asphalt material on the surface of the pavement (Karlsson and Isaacson, 2006). Design Manual for Roads and Bridges (DMRB) HD 31/94 provides guidance on recycling of bituminous pavements using the “repaving” method.

The type of asphalt recycling technique used is known to provide different durability, mechanical and performance properties. Illustrating this, hot asphalt recycling in-plant and in-place can be used for most types of roads, while cold mix and warm mix asphalts are best suited for medium to low trafficked areas (Nicholls, 2017).

2.2.2 Ownership of RA

Planings are usually owned by the planing contractor. Certain contract terms split ownership of RA in a ratio of 50:50 between the client and the contractor. The ownership, type and quality of planings, the distance between site and asphalt plant are key factors to be considered in evaluating how the most value can be gained from the planings.

2.2.3 The Presence of Tar

The properties of the pavement materials should be evaluated to ascertain if the RA derived from it is suitable for use in the thin surface course. A key factor for consideration is identifying if tar is present in the material. Tar was widely used in the past as a binder as a by-product of the distillation of coal (Nicholls, 2017).

The use of tar has been discontinued due to high contents of Carcinogenic Polycyclic Aromatic Hydrocarbons (PAHs) and/or phenol (Blackburn et al., 1999). The likelihood that RA obtained from thin surface course systems on the SRN would contain tar is minimal due to environmental regulations. Nevertheless, RA still needs to be checked for the presence of tar (Widyatmoko, 2016). If RA contains tar, it is considered hazardous and hot recycling is not allowed (EAPA, 2004; Widyatmoko, 2016).

2.2.4 Ageing Characteristics of the Residual Binder in the RA

Age hardened bitumen experiences a loss in ductility of the residual binder. Severely aged RA could act as “black rock”. For optimum performance, the level of ageing must be evaluated to establish suitability for recycling into the thin surface course in line with the mix design as specified. This is a key factor for consideration to prevent cracking and ravelling of the produced asphalt (Zaumanis and Mallick, 2015).

2.2.5 RA Content

Current practice in the UK is to use up to 10% RA in thin surface courses as detailed in Specification for Highway Works (SHW) Series 900 and BSI PD 6691. It must be noted that job-specific designs may be required in projects that specify the use of RA greater than 10% produced with increased levels of control and performance testing.

The mix design for high RA contents should take into account the properties of the RA aggregate including variability in material properties especially when RA is obtained from different sources (Newcomb et al., 2007; Copeland, 2011). At low RA percentages, the effects may be minimal. When the aged binder from RA is combined with a new binder, it can have some effect on the resultant binder grade. At low RA percentages, the change in binder grade is negligible. At higher percentages, the effect of the RA becomes more significant (Al-Qadi et al., 2007).

In the United States, the Superpave method effectively limits RA content in HMA to 40% (Newcomb et al., 2007). It is advised that no more than 15 to 30% RA content should be included in a mix without additional specialised testing (Sullivan, 2010). Certain studies in the US have shown that high RA content mixtures up to 100% are achievable with the use of rejuvenators and the requirement to comply with specialist test requirements in the mix design (Mallick et al., 2009; Zaumanis et al., 2014). The specialised testing includes dynamic modulus and creep compliance testing. These tests were conducted to validate the performance of 100% RA asphalt mixtures in comparison with virgin or asphalt mixtures with low RA content (Sullivan, 2010; Zaumanis et al., 2014).

2.2.6 Production Process

Modifications to the plant in most cases are a key factor to be considered prior to integrating RA. Screening and crushing of RA might necessitate requirements for special storage facilities at the asphalt mixing plant (West, 2010). If quantities of RA exceed 10%, further modifications to the hot mixing asphalt plant might be required (West, 2010). The use of increased RA content requires some modifications to the asphalt plant. In most cases, multiple RA cold feed bins are required to add the different fractions of RA into the mix (Brock and Richmond 2007). High RA mixtures will most likely require additional storage tanks for specialist grade binders and rejuvenators (Zaumanis and Mallick, 2015).

2.2.7 Mix Design

TRL Road Note 43 as detailed by Carswell et al., (2010) provides key design factors for consideration when recycling asphalts into thin surfacings and recommendations for assessing the suitability of using RA. The design process is presented in Figure 2.

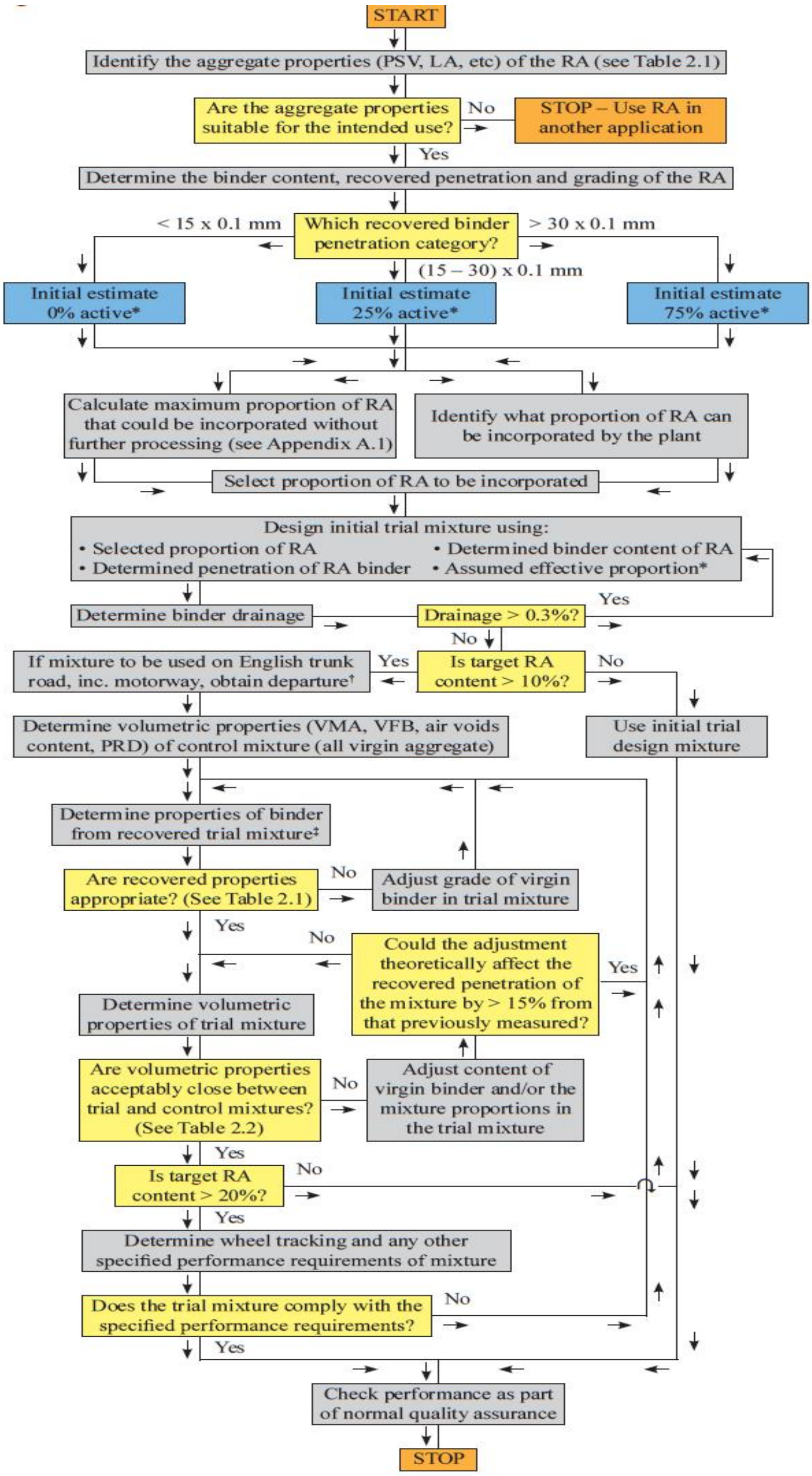

Figure 2: Design Factors for Incorporating RA (Carswell et al., 2010 - TRL Road Note 43)

The design factors highlight the following main considerations:

- If RA was obtained from the surface course with aggregate properties comparable to those required for the new recycled mixture, then it is generally assumed that there is little or no deterioration in the RA. The RA will generally be considered suitable for use, subject to assessment of PSV in relation to possible aggregate polishing.
- Consideration must be given to the potential contribution of the residual binder within the RA to the new recycled mixture. In this context, the percentage of "active" binder must be assessed based on the residual binder properties.
- The mixing plant must be able to process the specified percentage of RA.
- Considering the above factors, a mix design trial might be necessary to establish the maximum amount of virgin binder that can be added before risking binder drainage. Further to this, the optimised mix should be subjected to mechanical and performance tests (volumetrics, strength, moisture susceptibility and wheel tracking tests) to check compliance with specifications.

2.3 The Influence of Rejuvenators in RA

The level of ageing in the residual binder of the RA is a major factor that can adversely influence the properties of the produced asphalt mixture (Noferini, 2016). The methods for compensating for the aged binder and ensuring adequate performance include the use of rejuvenators, use of softer virgin binder grade and increasing the total binder content in the mixture (Zaumanis 2014).

Asphalt rejuvenators are used to revive and restore the rheological properties of the aged binder. Rejuvenators are usually derived from petroleum products (Boyer, 2000). In recent times, various organic oils have also been tested and trialled as rejuvenating agents to help improve the viscosity and elasticity of aged asphalt. Zaumanis et al., (2013) assessed the performance of nine rejuvenators. The findings from the research showed the viability of using refined tallow, organic blends and distilled tall oil to improve the cracking resistance of RA mixtures. Vegetable oils (both virgin and used) have been trialled in laboratory and field conditions as rejuvenators (Artamendi et al., 2011; Bailey and Zoorob, 2012).

Practical experiences that made use of rejuvenators in the UK include the A1 Mill Hill and A40 sites (discussed in sections 3.7 and 3.10 respectively). The A1 Mill Hill site made use of Arizona Chemical's SYLVAROAD with 50% RA. The A40 site made use of a workability/adhesion agent "Evoflex" produced by Ingevity designed to improve the contribution yield of the residual binder from the RA, rejuvenate the residual binder in the RA while maintaining flexibility and low temperature crack resistance for the recycled asphalt mixtures. Studies and practical experience show that the use of rejuvenators allows for increased amounts of RA, helps reduce the stiffness of the binder, minimises susceptibility to premature fatigue and low temperature cracking (Tran et al., 2012; Zaumanis et al., 2014).

2.4 Current Specifications and Guidelines

The current material specification for the classification of RA is detailed in BS EN 13108-8. The asphalt product standards: BS EN 13108-1 up to and including BS EN 13108-7 permits the use of RA with limitations on the amount allowed into the mix. The standards provide information on required properties of the RA and its constituent materials that must be declared and documented.

MCHW SHW Series 900 and BSI PD 6691 provide further guidance on the use of RA in bituminous bound materials. TRL Road Note 43 (Carswell et al., 2010) provides best practice guidelines for recycling into surface courses. Specification requirements and guideline documents are presented in Appendix A. The key points to note are summarised below:

1. All RA feedstock must be pre-treated to make sure they are homogeneously mixed and the maximum particle size does not exceed 32 mm.
2. 10% RA is allowed for use in the surface course. If RA > 10% is to be used, additional tests are required. This includes further sampling requirements per batch of feedstock. When using RA from mixtures in which a modified bitumen and/or a modified additive has been used, and/or the mixture itself contains a modified bitumen or a modifier, the amount of RA shall not, unless otherwise agreed between client and manufacturer, for surface courses exceed 10 % by the mass of the total mixture
3. The target composition of the mixture in terms of its constituent materials, the percentages passing the specified sieves, the binder content and where relevant the binder content from RA and/or natural asphalt and the percentage(s) of additive(s) shall be declared and documented.
4. Type testing procedures are required for samples incorporating RA. The tests are necessary to demonstrate that all constituent materials incorporating the RA conform to the appropriate requirements as detailed in Annex A of BS EN 13108-20. The tests for geometrical properties of the aggregate constituents, penetration/softening point/viscosity of the binder and grading, binder content and binder properties of RA shall be carried out on the constituents actually used in type testing.
5. Minimum inspection and test frequencies for RA, the range of testing and required properties of the RA are detailed in Table 7 and Table D.2 respectively of BS EN 13108-21.
6. The fresh bitumen added to the mixture shall not be more than two grades softer than the nominal grade for the mixture given in Table 12 of BSI PD 6691. Checks on the penetration of the binder recovered from the RA, together with a calculation of the properties of the combined binder, shall be carried out in accordance with the relevant parts of BS EN 13108.
7. When more than 10% of RA is incorporated in a mixture, tests on binder recovered from the mixture shall be carried out in accordance with BSI PD 6691 sub-clause 13.3.6.2. The results shall be within the limits set out in BSI PD 6691 sub-clause 13.3.6.2.
8. Application for departure from standards and review of BBA HAPAS certificates must be arranged where RA contents exceed 10%.

2.5 Summary

This review focused on recycling asphalts into thin surfacing systems by identifying key factors for consideration in using RA and the influence of rejuvenators in RA.

The use of RA for thin surface course systems presents a viable means to conserve virgin aggregate materials for road construction. The properties of the RA for use in the thin surface course needs to be evaluated. A key factor for consideration in using RA is identifying if tar is present in the material due to its high contents of Carcinogenic Polycyclic Aromatic Hydrocarbons (PAHs) and/or phenol.

Aged hardened asphalt reduces the elastic properties of the binder. The residual binder properties in the RA need to be evaluated to ascertain the level of ageing and suitability for used especially at high RA contents. This is a key factor for consideration in order to prevent cracking and ravelling. It must be noted that there are designs proposed for use in projects that specify the use of RA greater than 10%. These must be produced with increased levels of control and performance testing.

Modifications to the asphalt plant in most cases are a key factor to be considered prior to integrating RA. Screening and crushing of the RA might necessitate requirements for modifications to the asphalt mixing plant, special storage facilities for the RA and additional binder storage tanks for non-conventional grade binders or rejuvenators.

3. Existing Site Trials and Schemes

3.1 Introduction

This section summarises site trials and schemes that have recycled RA into thin surfacings in the UK. The performance of these sites is evaluated and reviewed based on available information to date.

3.2 Renishaw Pilot Scale Trials

The Renishaw pilot scale trial was installed on the access road to the Renishaw Asphalt Plant in South Yorkshire operated by Tarmac in 2002. The trial installation made use of RA from the A50 Doveridge site recycled into Stone Mastic Asphalt (SMA) thin surfacings.

The pilot scale trial at Renishaw installed three trial panels comprised of the following:

1. Control SMA without RA
2. SMA incorporating 15% RA
3. SMA incorporating 30% RA

Following installation of the trial sections, the site was subjected to heavy turning traffic. The visual assessment of the HA/TRL Inspection Panel 7 point scale ranked all three sections as "Moderate" as detailed in (Carswell et al., 2010). The site was monitored annually for penetration, softening point, viscosity and wheel tracking by TRL and Tarmac. The last survey as recorded was carried out in 2008, 75 months after construction. The test results are presented below (Figure 3 to Figure 6):

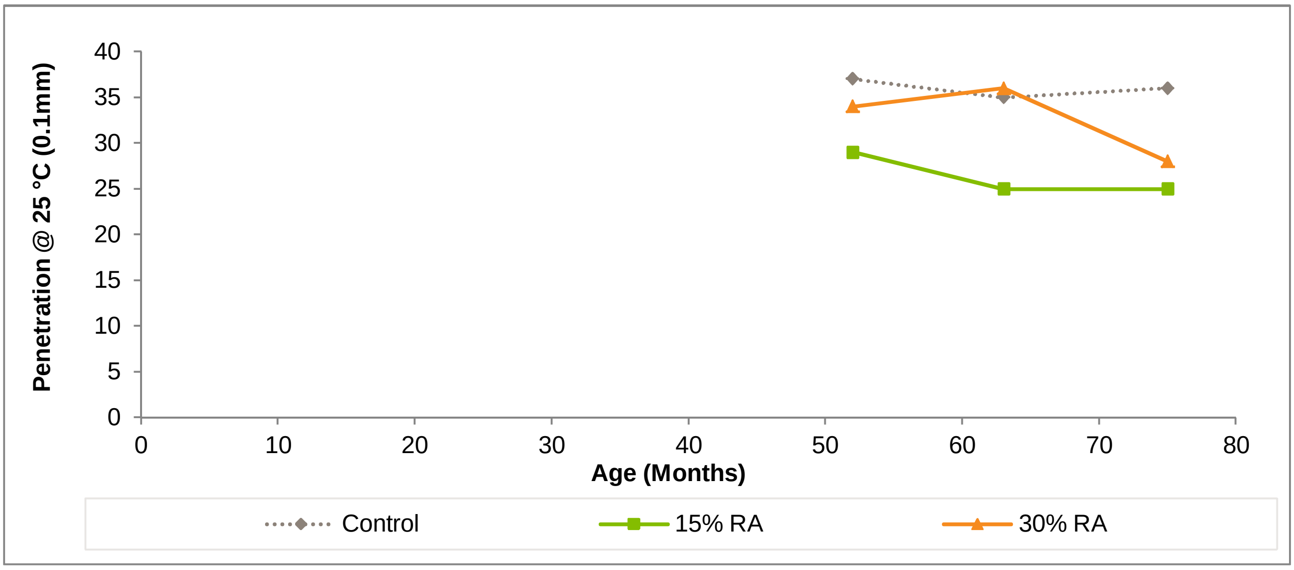

Figure 3: Penetration Test Results – Renishaw

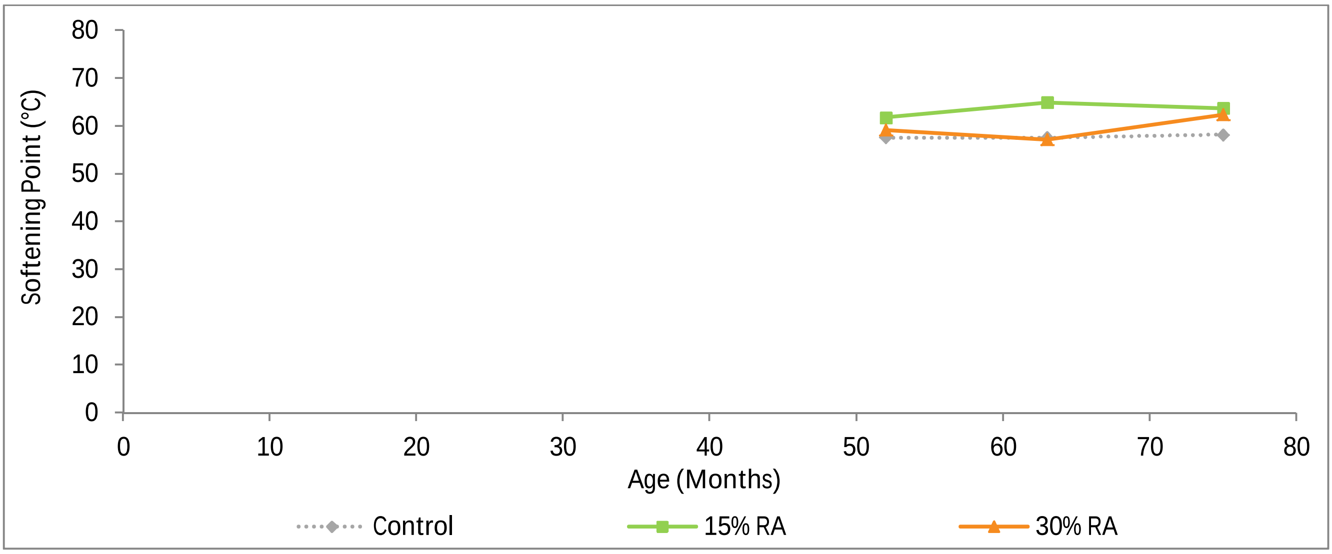

Figure 4: Softening Point - Renishaw

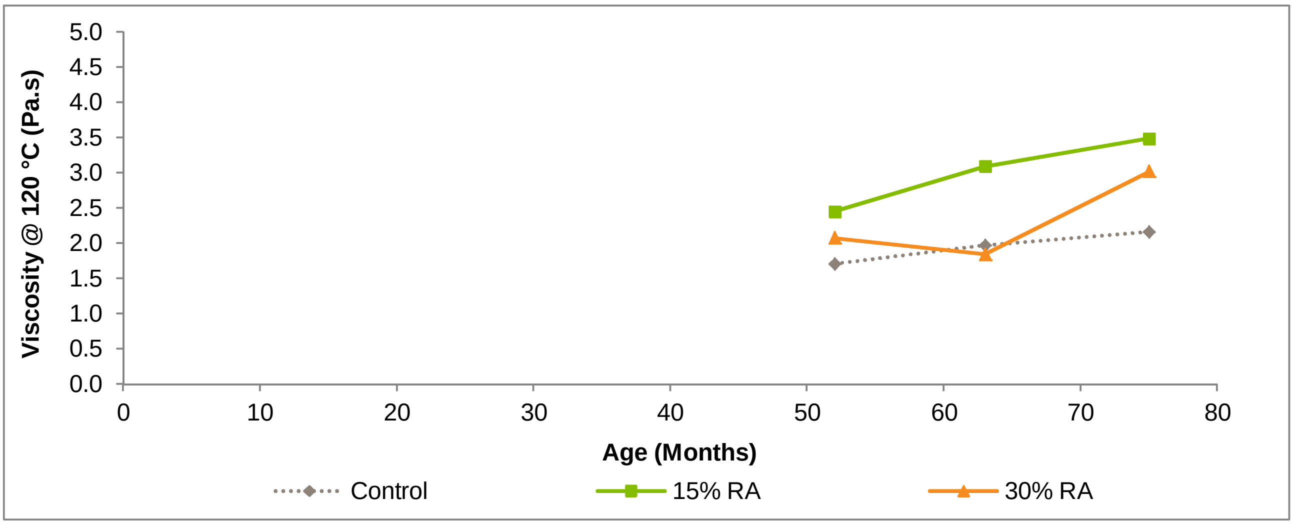

Figure 5: Viscosity - Renishaw

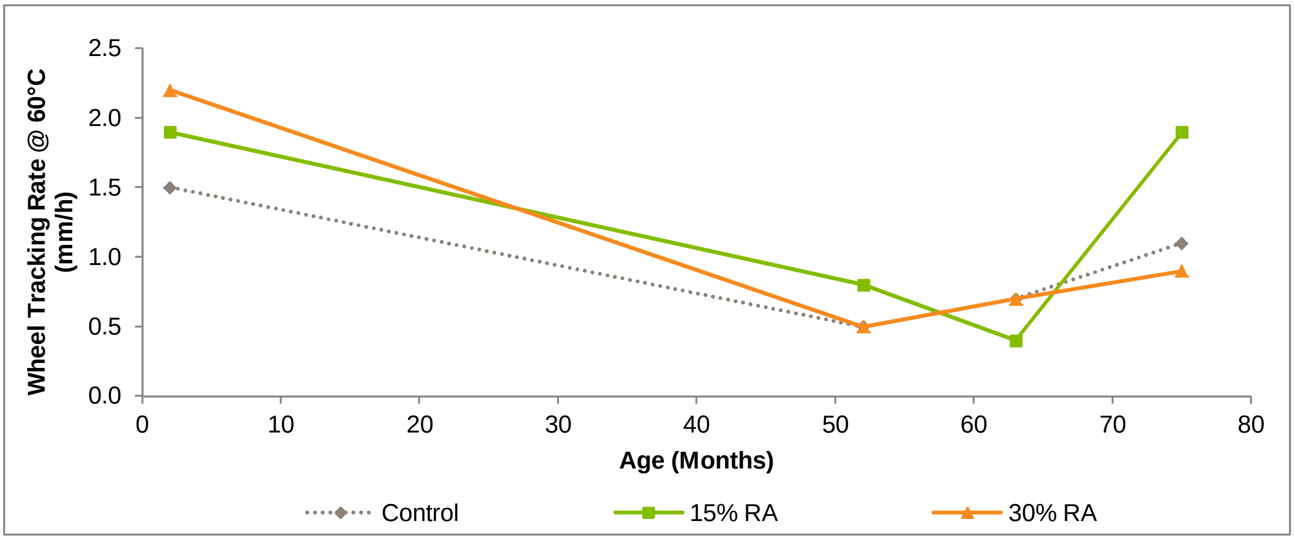

Figure 6: Wheel Tracking Tests - Renishaw

3.3 A1 (M) Hatfield

The trial was installed in 2004 on Lane 1 of the northbound carriageway of the A1 (M) in Hatfield consisting of four sections. The materials comprised of the following:

1. Two control sections without RA
2. Two sections with 10% RA.

The site has been monitored annually with TRL surveying the trial site on the A1 (M) Hatfield in August 2008, 55 months after construction. The test results are shown below (Figure 7 to Figure 11):

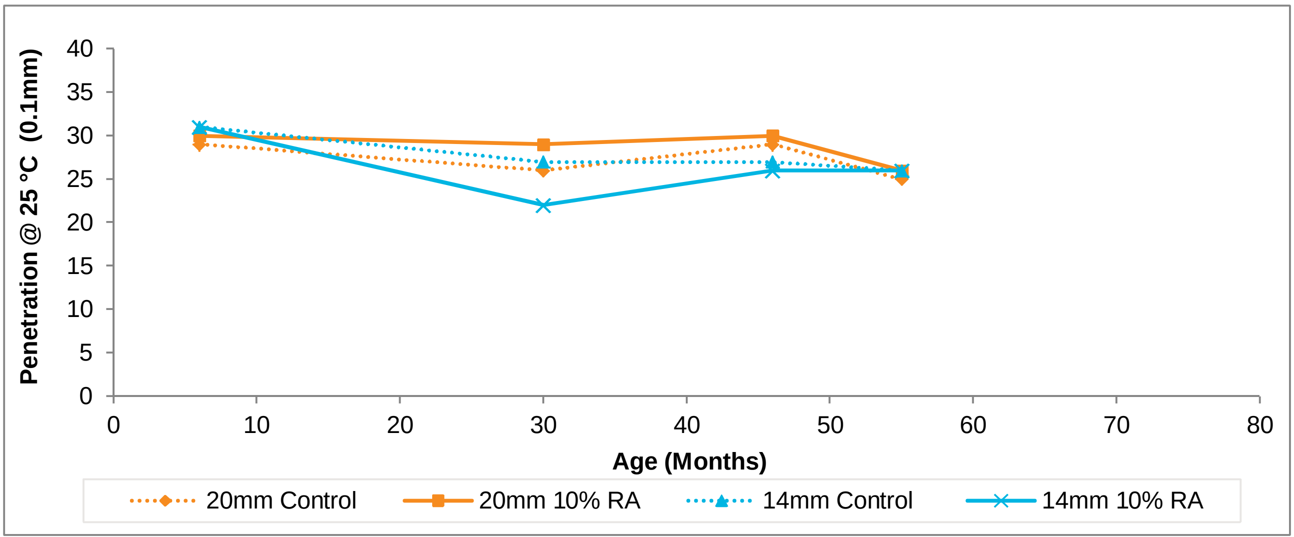

Figure 7: Penetration Test Results (TRL) – A1 (M) Hatfield

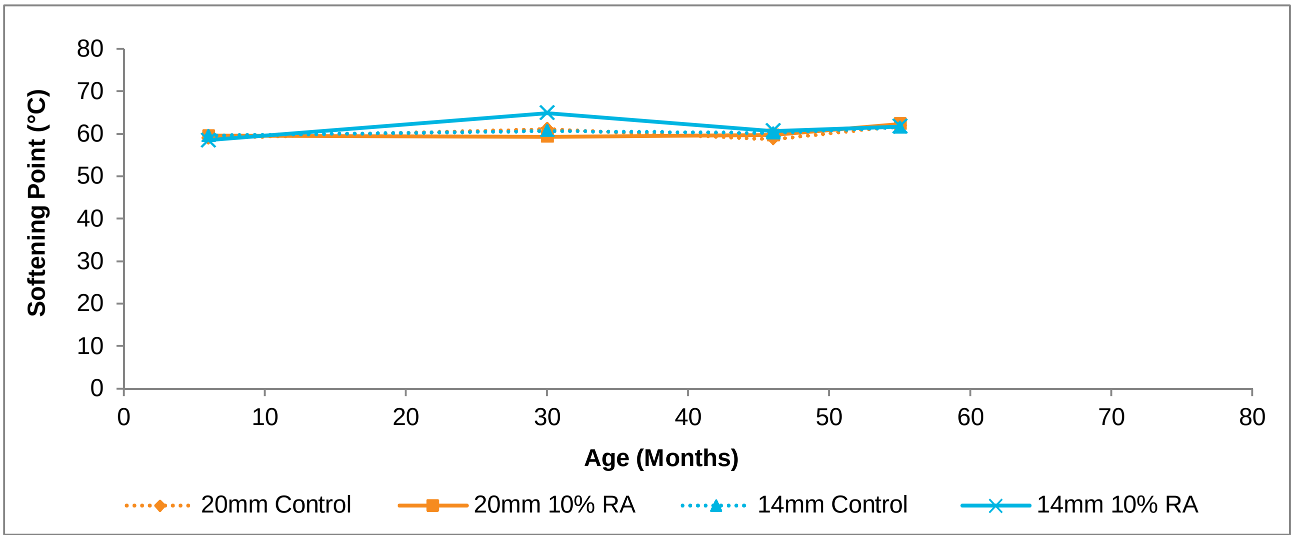

Figure 8: Softening Point Test Results (TRL) – A1 (M) Hatfield

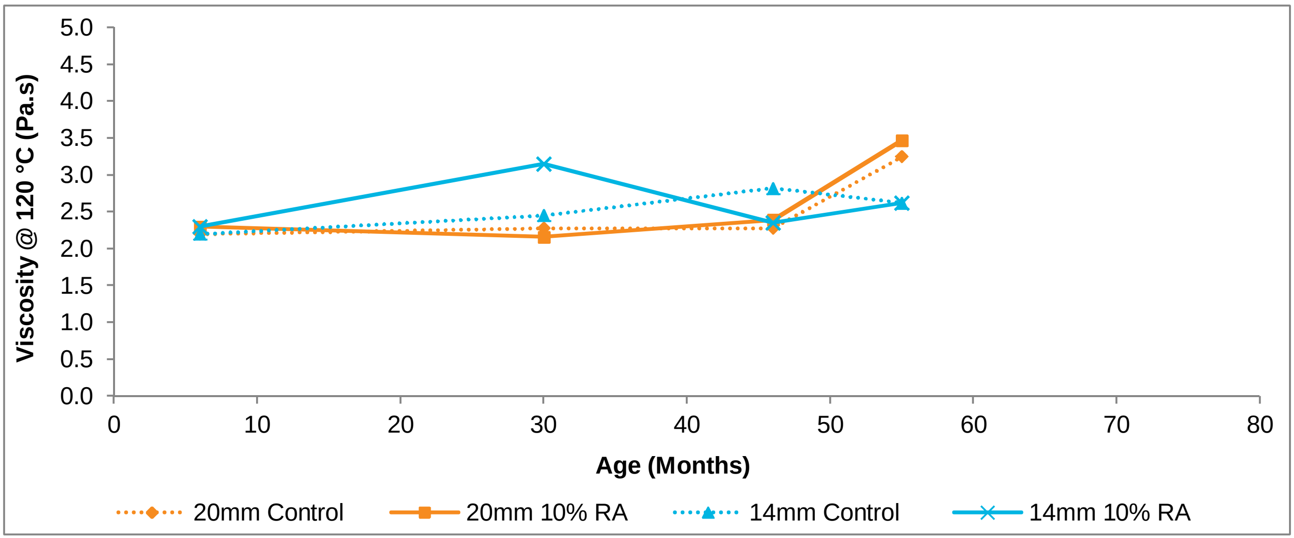

Figure 9: Viscosity - A1 (M) Hatfield

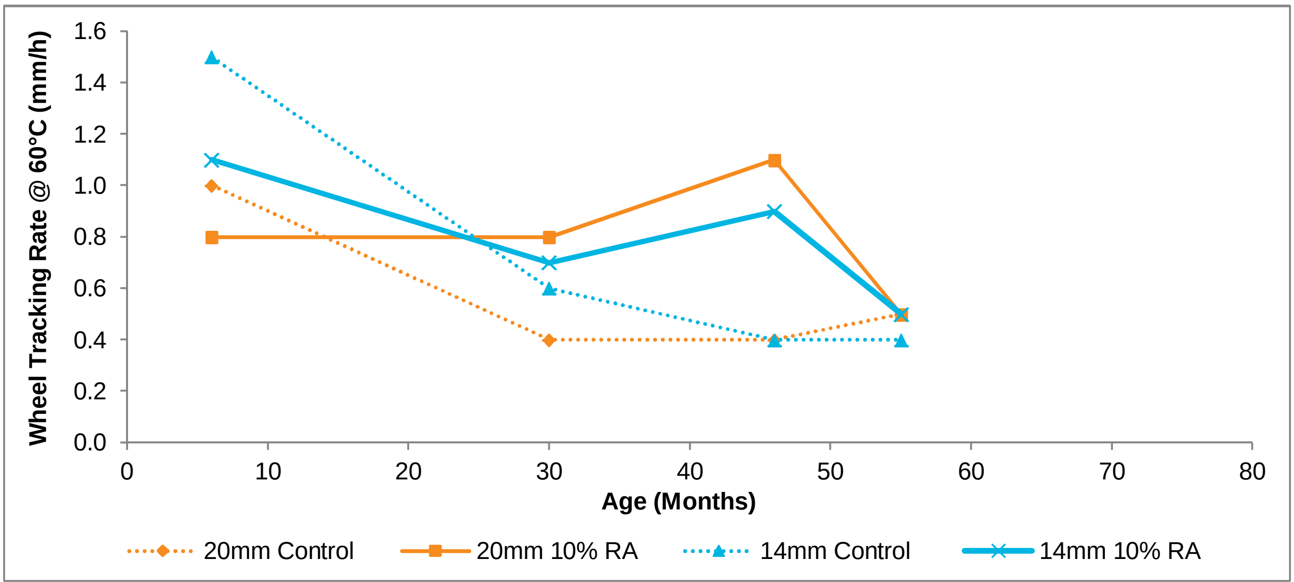

Figure 10: Wheel Tracking Tests - A1 (M) Hatfield

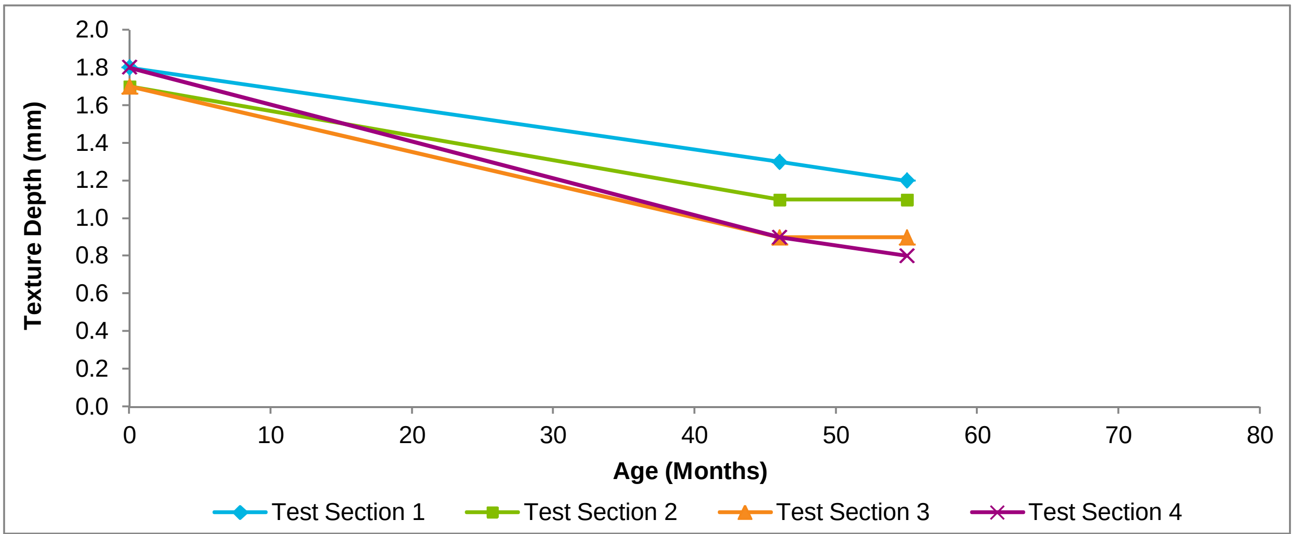

Figure 11: Texture Depths - A1 (M) Hatfield

There was little difference between the penetration, softening point and viscosity values from bitumen recovered from the control and 10% RA sections. The measured permanent deformation test results for both the control and 10% RA sections were comparable. The mean wheel tracking rates were in the range of 0.4 mm/h to 0.5 mm/h at 60 ºC. The visual assessment was "Good" for all sections, although the survey was undertaken during night-time working when there is limited visibility as reported by (Carswell et al., 2010). The texture depth results were consistent for all test sections tested.

3.4 A405 Bricket Wood

The installation on the A405 Bricket Wood was in Lane 1 of the northbound carriageway of the North Orbital Road between junction 6 of the M1 and junction 21a of the M25. The work was carried out in 2004 using polymer modified bitumen. Six trial sections were laid comprising of:

1. Thin Asphalt Concrete (TAC) control section without RA
2. Thin SMA (TSMA) control section without RA
3. TAC incorporating 10% RA
4. TAC incorporating 30% RA
5. TSMA incorporating 10% RA
6. TSMA incorporating 30% RA

Tests conducted on the site include penetration, softening point, viscosity, wheel tracking and texture depth. The results are presented below:

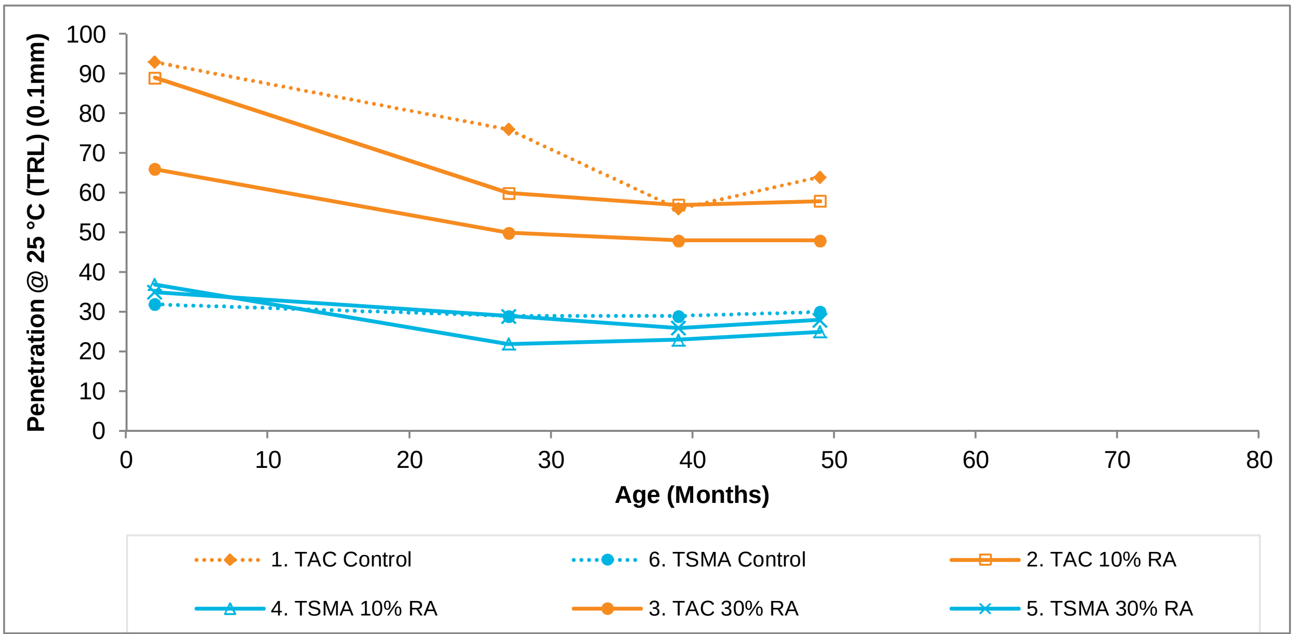

Figure 12: Penetration Test Results (TRL) – A405 Bricket Wood

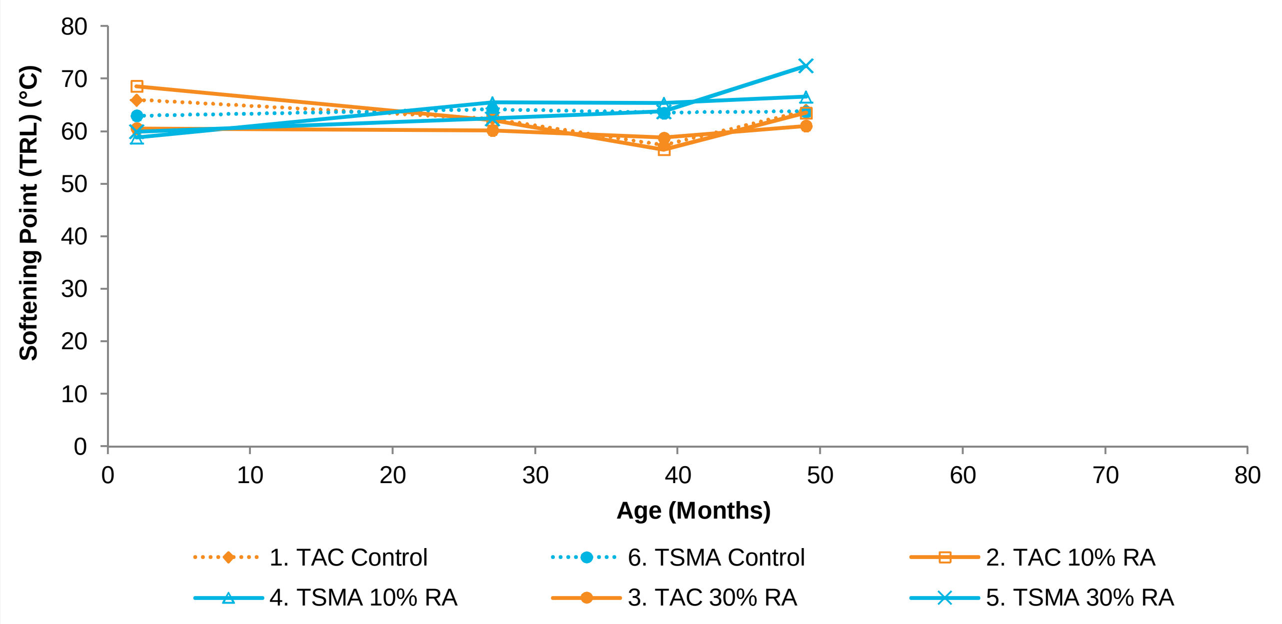

Figure 13: Softening Point Test Results (TRL) – A405 Bricket Wood

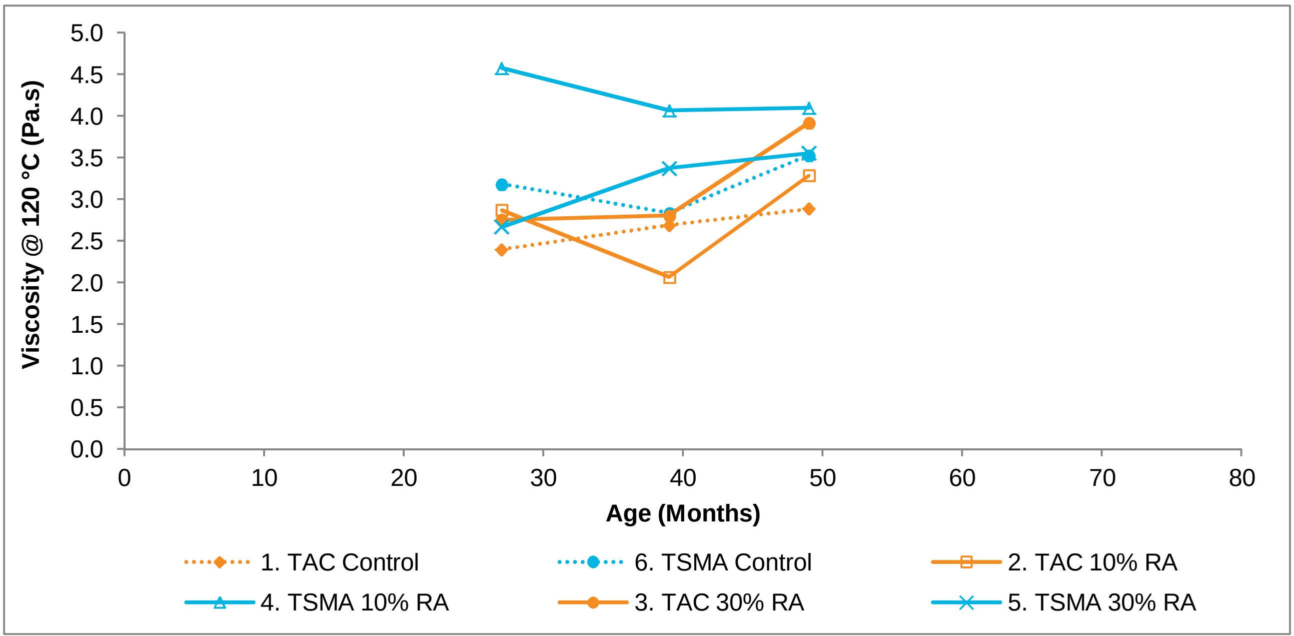

Figure 14: Viscosity Test Results - A405 Bricket Wood

As presented by Carswell et al., (2010), the recovered RA had binder produced with PMB. It was noted that the PMB used differed in both the TAC and TSMA sections. Properties of bitumen recovered showed the lowest penetration for the TSMA sections in comparison to the TAC sections. The TSMA samples appear more consistent through the years in comparison to the TAC samples. With respect to the TAC sections, the mixtures with the 30% RA had the lowest penetration followed by 10% RA. The softening point results depicted very similar test results. The viscosity results showed consistent test results.

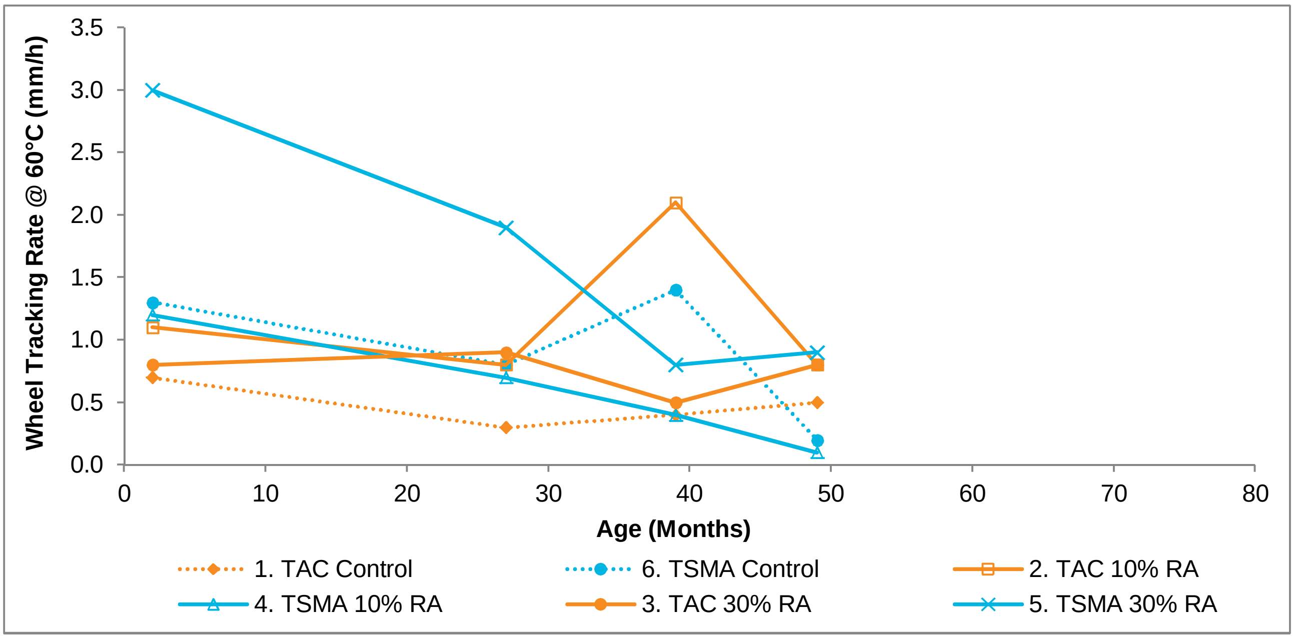

Figure 15: Wheel Tracking Test Results – A405 Bricket Wood

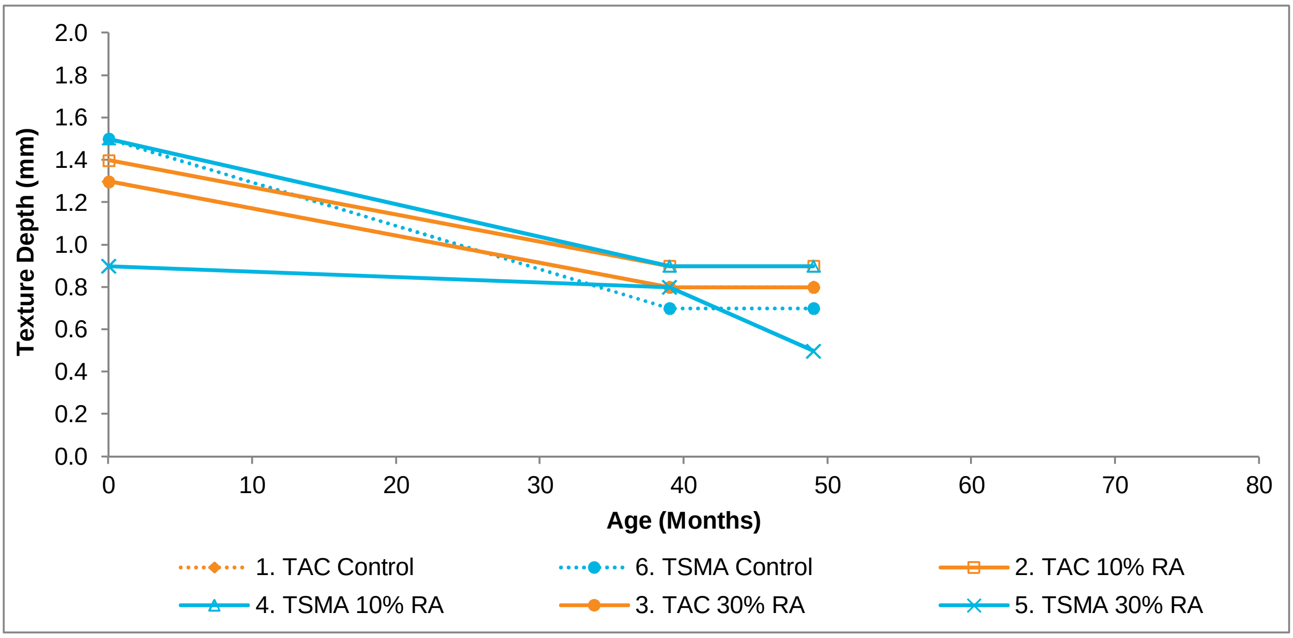

Figure 16: Texture Depth Test Results - A405 Bricket Wood

The permanent deformation characteristics showed variable test results with no identifiable clear trends. Visual surveys conducted by TRL showed comparable with “Good” or “Moderate” rating in the TAC sections. TSMA sections appeared more variable. This was attributed to possibly stripping effects in the binder course layer and the resulting aggregate loss in the surface. It was also noted that there were high moisture levels during construction. The texture depth results showed a decrease in values. After 49 months, the texture depth values ranged from 0.5 mm to 0.9 mm.

3.5 M4, Cardiff

The M4, Cardiff site had porous asphalts laid on 4.7 km of the motorway between junctions 32 and 33 in 1994. CEMEX Construction Services resurfaced this material in August 2006 with a requirement from the National Assembly for Wales to incorporate at least 25% of the reclaimed porous asphalt back into the new thin surfacing material (Carswell et al., 2010). Key points to note include the fact that the work was undertaken during night closures with the RA from one night being used after processing in producing the recycled asphalt for the following night. As such, the first night's production, with no RA, acted as a control section. The processing was to remove both the undersize (0/6 mm) and oversize (>18 mm) aggregate fractions, with these fractions being used on other jobs. The site has been monitored annually by the HE/TRL inspection panel, with both the control and main sections ratings downgraded from "Excellent" to "Good" in July 2008. However, it must be noted that the visibility was poor due to heavy rainfall during the survey (Carswell et al., 2010).

3.6 M25 Reigate

The M25 Reigate installation was found on the Highways England WebDAS database (Departure Numbers: 48012 and 55161). The M25 Reigate installation comprised of a couple of trials carried out by Tarmac in 2007 (Schiavi et al., 2008). The resurfacing works on the M25 Reigate project were carried out to replace the worn porous asphalt surface course with a thin surfacing in accordance with Clause 942. The first trial incorporated approximately 25% RA using a 14 mm, 65 PSV thin surface course system. The second trial incorporated 40% RA in a 20 mm thin surface course system. The binder for both trials made use of 40/60 binder grade and cellulose fibre mixes.

3.7 A1 Mill Hill

The A1 Mill Hill resurfacing scheme was carried out by FM Conway for Transport for London (TfL) in March 2016 on a non-event section comprising three lanes. The trial made use of 50% RA and Polymer Modified Bitumen (PMB). RA from TfL sites was identified as potentially containing a PSV of 65. Asphalt rejuvenators produced by Arizona Chemicals called SYLVAROAD was used to help improve the performance of the recycled asphalt mix to revive and restore the rheological properties of age-hardened asphalt binder taking into account the fact that 50% RA was recycled.

Pre-trial laboratory testing comprised of Polished Stone Value (PSV), Aggregate Abrasion Value (AAV), binder rheology, aggregate grading, water absorption, fatigue testing, stiffness (IT-CY), strength (ITSR), water sensitivity, wheel tracking at 60°C, binder drainage, air void content, binder volume calculations, penetration and softening point tests. Tests onsite were conducted in line with current BBA HAPAS guidelines. Post site tests including texture depths, visual surveys, SCRIM and binder tests have been carried out. The test results are detailed below:

The site had average texture depths of 1.3 mm following installation of the asphalt. The mean stiffness values for the samples were obtained as 4119 MPa in accordance with BS EN 12697-26. Samples tested following the installation showed that the mean rut depth of a set of six samples after 10,000 cycles at 60°C in accordance with BS EN 12697-22 was 2.2 mm which showed good performance of the asphalt mixture. Sensitivity to water damage was assessed on samples obtained from the site in line with BBA Specification Appendix A.2 having stiffness ratios of 107.6%.

3.8 M23

This trial site made use of 30% RA in 14 mm 60 PSV 40/60 grade thin surface course completed by Tarmac in June 2016. The trial has been SCRIM tested and is subject to routine SCRIM testing conducted every 6 months. The test results for this site were not available for this project.

3.9 A5 Grendon – Mancetter Warm Mix Trial

The demonstration site was located within a 1.1 km maintenance scheme on the A5 between Grendon and Mancetter in North Warwickshire, United Kingdom. A section of the westbound carriageway of the A5, approximately 220 m in length (Chainage: 2960-3180 m) was inlaid with 110 m length of WMA binder and surface courses and 110 m length of conventional HMA binder and surface courses acting as a control mixture.

The installation was carried out in 2014. The production and application of both binder and surface course layers were closely monitored and the laboratory properties of the asphalt mixtures tested to ascertain mechanical and performance properties (Wayman et al., 2014; PPR 742).

RA was incorporated in each of the asphalt mixtures. The proportions are detailed in Table 1 for the surface course mixtures as detailed in (Wayman et al., 2014; PPR 742).

Table 1: Reclaimed Asphalt Content for the A5 Project

Mixture No.	Type	Course	% Reclaimed Asphalt Mean	% Reclaimed Asphalt Range
1	WMA	Binder	25.9	24.4 – 27.2
2	WMA	Surface	15.6	14.9 – 17.1
3	HMA	Binder	5.9	0.0 – 13.0
4	HMA	Surface	15.6	15.2 – 16.4

Following review and evaluation of the site in 2017, observed defects include surface cracking, rutting, crazing and loss of aggregates (fretting). There was evidence of underlying issues (possible subsidence) in certain areas of the demonstration scheme. Considering issues with the substrates, it may not be advisable to draw weighty conclusions on the performance of the WMA on the basis of this demonstration site alone. It would be difficult to conclude that WMA (or HMA) incorporating recycled materials on this site performed "better (or worse)" or in excess of reasonable expectations. PPR 742 - Wayman et al., (2014) indicated challenges experienced in performing the trial which may have adversely influenced the general outcome of the installed material.

It is understood that maintenance of the trial site was undertaken in June 2017 to address the defects associated with underlying issues at the site. As such the trial site is no longer available for further monitoring.

3.10 A40 Site

The A40 westbound site was designated a “live” site comprising of three-lane sections in both east and westbound directions near the busy Westfield Shopping Centre. This project was carried out by FM Conway in September 2017 making use of 50% RA and PMB. The unique strategy for this project was the fact that the recycled asphalt mixture was laid at a depth of 70 mm. This was done to assess the time that could be saved on site by laying in a single layer rather than the traditional two layers. In addition to this, the mix temperatures were reduced from 180 - 190°C to 150-160°C. As part of this works, rolling techniques were modified to ensure that material was fully but not over compacted. This was monitored by both on-site density gauging and coring operations.

Testing for the A40 project was in line with the work completed on the A1 Mill Hill site. The test results for this site were not available for this project.

Table 2 below provides a summary of the detailed site trials and available data/test results.

Table 2: Site Trials and Schemes Incorporating RA

Site	Construction	Survey	Survey By	RA (%)	Material Type	Aggregate Size (mm)	Penetration	Softening Point	Viscosity	Wheel Tracking Rate	Texture	Visual Surveys	Energy Consumption
Renishaw	2002	2006 (after 52 months) 2007 (after 63 months) 2008 (after 75 months)	LA and TRL	15% and 30%	TSMA	0/14	ü	ü	ü	ü	û	ü	û
A1(M) Hatfield	2004	2005 (after 6 months) 2006 (after 30 months) 2007 (after 46 months) 2008 (after 55 months)	TRL and Shell	10%	TSMA	0/14 and 0/20	ü	ü	ü	ü	ü	ü	û
A405 Bricket Wood	2004	2004 (after 2 months) 2006 (after 27 months) 2007 (after 39 months) 2008 (after 49 months)	TRL and Shell	10% and 30%	TAC and TSMA	0/14	ü	ü	ü	ü	ü	ü	û
M4 Cardiff	2006	2007 & 2008	HA / TRL	25%	TAC	0/14 (6/18)	û	û	û	û	û	ü	û
M25 Reigate	2007/8	2007	HA / TRL	25%	TSMA	0/14	û	û	û	û	û	û	ü
				40%	TSMA	0/20	û	û	û	û	û	û	û
A1 Mill Hill	2016	-	TfL	50%	TAC	0/14	û	û	ü	ü	ü	ü	û
M23	2016	-	-	30%	TAC	0/14	û	û	û	û	û	û	û
A5 Grendon – Mancetter	2014	2017	AECOM	15%	WMA	0/14	ü	ü	û	ü	û	ü	û
A40 Westbound	2017	-	TfL	50%	AC	0/14	û	û	û	û	û	û	û

ü Tests conducted

û Test results/status not available

The Highways England WebDAS (Departures Approvals System) provides an electronic system designed to allow submission of new Departures and searching of existing Departures as shown in Table 3.

Table 3: WebDAS Information on Sites Incorporating RA

Departure	Contract	Road	Standard	Status	Date Achieved	Departure Summary
17895	DBFO	M40	0902 Reclaimed Bituminous Materials (RBM)	See Comments	22/09/1997	Testing of Bituminous Materials and Asphalt Kerbs
18199	DBFO	A6	0902 RBM	Draft not issued (DNI)	19/06/1997	Percentage of RA increased to: 20% in wearing course & 50% in base/road base.
18280	DBFO	A6	0902 RBM	DNI	19/06/1997	Percentage of reclaimed materials increased to: 20% in wearing course & 50% in base/road base.
18308	DBFO	A6	0902 RBM	DNI	19/06/1997	Percentage of reclaimed materials increased to: 20% in wearing course & 50% in base/road base.
18378	DBFO	A43	0902 RBM	DNI	19/06/1997	Percentage of reclaimed materials increased to: 20% in wearing course & 50% in base/road base.
18411	DBFO	A6	0902 RBM	DNI	19/06/1997	Percentage of reclaimed materials increased to: 20% in wearing course & 50% in base/road base.
18459	DBFO	A428	0902 RBM	DNI	19/06/1997	Percentage of reclaimed materials increased to: 20% in wearing course & 50% in base/road base.
18504	DBFO	A6	0902 RBM	DNI	19/06/1997	Percentage of reclaimed materials increased to: 20% in wearing course & 50% in base/road base.
18589	DBFO	A43	0902 RBM	DNI	19/06/1997	Percentage of reclaimed materials increased to: 20% in wearing course & 50% in base/road base.
18631	DBFO	A43	0902 RBM	DNI	19/06/1997	Percentage of reclaimed materials increased to: 20% in wearing course & 50% in base/road base.
18684	DBFO	A21	0902 RBM	Approved- Conditions	21/05/1997	Increase the % of reclaimed materials :- 20% in Wearing course, 50% in base/road base
18737	DBFO	A21	0902 RBM	Approved - Conditions	21/05/1997	Increase the % of reclaimed materials :- 20% in Wearing course, 50% in base/road base
18794	DBFO	A27	0902 RBM	Approved - Conditions	21/05/1997	Increase the % of reclaimed materials :- 20% in Wearing course, 50% in base/road base
18852	DBFO	A259	0902 RBM	Approved - Conditions	21/05/1997	Increase the % of reclaimed materials :- 20% in Wearing course, 50% in base/road base
18977	DBFO	A259	0902 RBM	Approved - Conditions	21/05/1997	Increase the % of reclaimed materials :- 20% in Wearing course, 50% in base/road base
19031	DBFO	A259	0902 RBM	Approved – Conditions	21/05/1997	Increase the % of reclaimed materials :- 20% in Wearing course, 50% in Base /road base
32958	ECC	M6	Additional Clause	Approved	30/05/2002	Departure required as the SHW does not address maintenance works
48012	Other	M25 (Reigate)	0902 RBM	Approved	06/08/2007	Application of proprietary thin surfacing except with the inclusion of up to 25% aggregate of the reclaimed porous asphalt from the existing surfacing. The reclaimed aggregate is a blend of three stone types from three different quarries with a polished stone value of 59, refer to attached test certificate dated 20/04/2007. Referring to DMRB Volume 7 HD 36/99 3.11 and table 3.1
55161	Other	M25 (Reigate)	0902 RBM	Approved with comments	19/06/2009	Application of proprietary thin surfacing except with the inclusion of up to 40% aggregate of the reclaimed porous asphalt from the existing surfacing. As this departure is based on a repeat of (48012) for the clockwise carriageway we have assumed the same PSV result on the basis that the material was all sources from the same quarries. The reclaimed aggregate is a blend of three stone types from three different quarries with a polished stone value of 68; refer to attached test certificate dated26/05/09. Referring to DMRB Volume 7 HD 36/99 3.11 and table 3.1

Limited information was obtained for most of these departures. The departures with status "draft not issued" were all withdrawn and not issued to the tenderer due to the cancellation of the schemes by the Government. Table 3 shows that the maximum RA content as detailed in the WebDAS was 40% for the M25 (Reigate) project with 20% RA widely proposed for use in the surface course.

3.11 Summary

Findings from the review of the existing sites incorporating RA show that it is feasible to incorporate up to 50% RA in thin surface course systems taking into account examples as shown in Table 2. Although, it must be stated that the use of rejuvenators might be necessary when using high RA contents in order to revive and restore the rheological properties of the residual binder in the RA as detailed in the A1 Mill Hill and A40 projects.

The source of the RA needs to be consistent and contain high PSV aggregates as required by the specification. Laboratory mix designs are required to ensure that the proposed mix meets specification requirements. If the residual binder in the RA contains PMB, laboratory trials and assessments are required to make certain that specified binder properties are obtainable. This is especially important for high RA contents.

It is important for departures to be inputted into the WebDAS database with all supporting information to allow for continuous review and help with the improvement of these material types over the long term. Continuous monitoring of sites incorporating RA is important in order to understand how these mixtures. This is essential for improving mix design procedures, improving the mechanical and performance properties of mixtures incorporating RA, provide best practice guidelines and advocate for effective policies on the recycling of asphalt pavements.

4. Best Practice Guidelines for Incorporating RA into Thin Surface Course Materials

4.1 Introduction

This section presents best practice guidelines for managing RA to include processing, storage and sampling of the RA materials. RA needs to be properly treated and processed in order to allow for increased flexibility in the mix design procedures.

4.2 Best Practice Guidelines

The best practice guidelines are detailed below:

- The choice of the milling equipment, depth and speed of the milling procedure needs to be properly selected as this could impact on the quality of the obtained RA.
- Adequate processing (sampling, screening, crushing and storage) of the RA is required. Special attention should be given to minimise fines content. Excessive water during the planing operation should be avoided as this could mean additional processing and drying of the RA.
- Stockpiled RA aggregate material is known to be able to hold water and not effectively drain over time in comparison to virgin aggregate stockpiles (Chesner et al., 1998). Stockpiles containing RA should be placed in a paved, sloped area covered by a roof. Tall conical stockpiles are preferred instead of flat horizontal piles for lower moisture accumulation.
- RA from different sources with different properties should ideally be stockpiled separately to increase consistency. In most cases due to the limited storage area, this is often impractical. In these cases, the RA can be blended to increase homogeneity before further processing.
- RA should be well characterised for the mechanical properties of the aggregates. This is taking into account the fact that most jobs require minimum PSV and AAV values. This is especially important when using high RA contents.
- RA material should be well characterised for mix design and quality control purposes. Properties including the binder content, moisture content, aggregate gradation and rheological properties of residual binder in the RA are key characteristic properties that provide useful analysis especially for mixtures containing high RA contents.
- The mixing of asphalt incorporating RA might require modifications to the asphalt plant. The costs need to be justifiable in economic and sustainability terms.
- The process of adding the RA with the virgin aggregates during mixing needs to be properly assessed and evaluated. RA can usually be added unheated through the cold feed on batch mixers although the virgin aggregates need to be superheated to drive off moisture within the RA. For larger proportions of RA, some RA may need to be added via a hot feed on batch mixers. For drum mix plants, the RA can be added through the recycled collar. Care must be taken to prevent excessive ageing of the residual binder in the RA.

- Quality control mechanisms and procedures are a key requirement when using RA. Produced mixtures incorporating RA require continuous monitoring and evaluation to assess mechanical and performance properties of the mixtures in order to provide best practice guidelines and advocate for effective policies on the use of RA.
- Thin surfacing system producers who have (Highways Authorities Product Approval Scheme (HAPAS)) certificates for their products should be encouraged to get certificates modified to permit the RA addition beyond 10% RA for approval by the nominated independent certification body. This is often facilitated with requirements for additional testing required such as listed in BS EN 13108-20 (type testing) and a review of the quality control for the recycled material and the production methods.
- Long-term monitoring of sections incorporating RA is required for continuous improvements in the mix design procedures, specification and evaluation of these mixtures. This could lead and have an influence on future policies promoting the use of RA.

4.3 Challenges

Rates of inclusion of RA > 10% are most feasible when the source of RA is consistent, the RA has not severely aged and the planings from the job does not have extensive repairs prior to being replaced. Usually, additional testing is required prior to the inclusion of RA as a surfacing material. This is necessary to ensure consistency of the mix and to make sure that the specifications as detailed in the mix design are achievable.

For jobs with RA content exceeding 10%, a HAPAS certificate is a prerequisite detailing the source of RA, aggregate gradation, aggregate properties, bitumen content and bitumen properties. In addition to this, the methodology for the mix design is required to be detailed in the HAPAS certificate. Trial sections are advised in order to ascertain mechanical and performance properties of the mixtures incorporating RA under typical and realistic scenarios to prevent premature failure of the produced mixtures. These challenges could add costs to the project that must be priced for. A means of mitigating this would be to standardise the use of RA, provide guidelines and specifications detailing the mechanical and performance properties required when incorporating RA into thin surfacing mixtures.

4.4 Summary

Currently, available RA technologies do allow high percentages of RA to be included in asphalt mixtures. This is a key component in reducing energy costs and facilitating a sustainable way of constructing pavements. Best practice guidelines for incorporating RA into thin surface course materials must be duly followed so as to have asphalt pavements that are durable, long-lasting and exceed performance requirements.

5. Industry Feedback

To capture industry best practice, feedback was requested from MPA and Eurobitume UK members via email and phone. Members were requested to provide information on best practice guidelines for incorporating RA into thin surfacings from an industry point of view.

The key findings are summarised and detailed anonymously below:

- Source of RA needs to be consistent and contain high PSV aggregates that are recoverable.
- The site to be planed should be cored so as to establish the actual thickness of the layer to be removed. Consideration needs to be given to the use of a planing technique that prevents contamination providing sufficient coarse high PSV aggregate materials.
- Adequate storage is required to quarantine and process the RA to prevent contamination.
- Processed planings should be stored in a manner to prevent ingress of moisture. This is very important as increased moisture content usually means a reduced amount of the RA can be included in the recycled asphalt mixtures.
- The properties of each batch of high PSV RA should be known before it is used.
- Extensive testing of RA is required to understand the grading of the RA, the actual PSV of aggregates recovered, binder content and grade of binder in the RA. This is required to ensure that the RA is consistent.
- Laboratory mix designs are required to make sure that the produced asphalt meets specification requirements.
- Things are more complicated if producing a PMB mix as generally the binder on the RA is not modified. Therefore some tailoring of the added PMB will be required to ensure that when blended with the binder, the resulting product has the required properties.
- The long-term monitoring and review of the produced asphalt incorporating RA are required to ascertain mechanical and performance properties for future design options.

6. Conclusion and Recommendation

The use of RA would help in preserving and responsibly using natural resources of premium quality virgin aggregate materials in a sustainable manner in order for future generations to be able to meet their needs. The use of RA provides the potential to gain energy savings leading to a decrease in energy consumption and congestion of roads, subject to haulage distance of planings. These benefits can be translated to a significant reduction in the emissions and carbon footprint for the industry.

In line with current practice in the UK, a maximum of 10% RA is usually specified for use in thin surface courses. Designs incorporating high quantities of RA need to have departures that must be entered into Highways England WebDAS database For thin surface course systems incorporating RA > 10%, these asphalt materials must be produced with high levels of control and performance testing.

The use of asphalt rejuvenators may help to revive and restore the rheological properties of age-hardened asphalt binder to a level where the binder can be considered comparable to a virgin material for asphalt mixtures, especially with high RA contents. The effectiveness of the rejuvenator and level of restoration taking into account the rheological properties of the RA binder should be evaluated to gain an understanding, ascertain performance levels and suitability for use.

Findings from the review of the existing site trials and schemes show that it is feasible to incorporate up to 50% RA in thin surface course systems. Pilot scale trials have been conducted making use of a range of RA proportions from 15% to 30% RA. The A1 (M) Hertfordshire in 2004 with 10% RA, the A405 Bricket Wood trial in 2004 with 10% and 30% RA, the A1 Mill Hill and A40 sites using 50% RA have shown good mechanical and performance properties indicating durability as specified in comparison to virgin aggregate variants.

The use of rejuvenators plays an important role when using high RA contents in order to revive and restore the rheological properties of the residual binder in the RA. The source of the RA needs to be consistent and contain high PSV aggregates as required by the specification. Laboratory mix designs are required to ensure that the proposed mix meets specification requirements. If the residual binder in the RA contains PMB, laboratory trials and assessments are required to make certain that specified binder properties are obtainable. This is especially important for high RA contents. Studies in the US have shown that high RA content mixtures up to 100% are achievable with good performance. This needs to be reviewed further in line with specifications and requirements for use on the SRN.

Moving forward, it is recommended that further research and development is required to include the long-term monitoring of the mechanical and performance properties of asphalt mixtures incorporating RA. This is important to understand the long-term performance capabilities of these materials and to help develop policies and guidance documents on their use. Continuous engagement with industry practitioners on all aspects of using RA is encouraged and continued using a structured and practical methodology.

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Bibliography

Arnold, C., Nolting, M., Riebensehl, G. and Denck, C., 2012, June. Unlocking the Full Potential of Reclaimed Asphalt Pavement (RAP): High-Quality Asphalt Courses Incorporating more than 90% RAP: A Case Study. In 5th Euroasphalt and Eurobitume Congress (pp. 13-15).

Bailey, H.K., 2010. Novel Uses of Vegetable Oil in Asphalt Mixtures. Doctoral dissertation at the University of East London.

Blackburn, G., Kriech, A., Kurek, J. and Osborn, L., 1999. Detection of Coal Tar Materials in Asphalt Pavements by using Chemical and Biological Methods. Transportation Research Record: Journal of the Transportation Research Board, (1661), pp.41-45, Washington DC.

Boyer, R.E. and Engineer, P.S.D., 2000. Asphalt Rejuvenators “Fact, or Fable”. Transportation systems, 58.

Carswell, I., Nicholls, J.C., Widyatmoko, I., Harris, J. and Taylor, R., 2010. Best Practice Guide for Recycling into Surface Course – TRL Road Note 43. IHS.

Chesner, W.H., Collins, R.J. and MacKay, M.H., 1998. User Guidelines for Waste and By-Product Materials in Pavement Construction (No. FHWA-RD-97-148), Washington DC.

Copeland, A., 2011. Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice. McLean, VA: Turner-Fairbank Highway Research Centre, Report Number FHWA-HRT-11-021 Washington DC.

European Asphalt Pavement Association (EAPA), 2004. Industry Statement on the Recycling of Asphalt Mixes and Use of Waste of Asphalt Pavements. EAPA, May Brussels.

European Asphalt Pavement Association (EAPA). 2015. Asphalt in Figures - 2015. [Online] Available at http://www.eapa.org/userfiles/2/Asphalt%20in%20Figures/2016/AIF_2015_v6.pdf. [Accessed: 6th September. 2017]

European Commission 2017. "Science for Environment Policy": European Commission DG Environment News Alert Service, edited by SCU, The University of the West of England, Bristol

HD 31/94 Design Manual for Roads and Bridges: Volume 7, Pavement Design and Maintenance: Section 4, Pavement Maintenance Methods: Part 1, Maintenance of Bituminous Roads

Karlsson, R. and Isacsson, U., 2006. Material-Related Aspects of Asphalt Recycling—State-of-the-Art. Journal of Materials in Civil Engineering, 18(1), pp.81-92 Miami.

Liu, S., Shukla, A. and Nandra, T., 2017. Technological, Environmental and Economic Aspects of Asphalt Recycling for Road Construction. Renewable and Sustainable Energy Reviews, 75, pp.879-893.

Mallick, R.B., Tao, M., O'Sullivan, K.A. and Frank, R., 2009. Use of 100% Reclaimed Asphalt Pavement (RAP) Material in Asphalt Pavement Construction. In Proceeding of the 89th Conference of International Society of Asphalt Pavement. Nagoya, Japan.

McDaniel, R.S., Soleymani, H., Anderson, R.M., Turner, P. and Peterson, R., 2000. Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method. NCHRP Web document, 30.

McGraw, J., Johnson, E., Johnson, G., Dai, S., Linell, D. and Watson, M., 2010. Incorporation of Recycled Asphalt Shingles in Hot-Mixed Asphalt Pavement Mixtures. Report Number MN/RC, 8.

Miliutenko, S., Björklund, A. and Carlsson, A., 2013. Opportunities for Environmentally Improved Asphalt Recycling: The Example of Sweden. Journal of Cleaner Production, 43, pp.156-165.

Newcomb, D., Brown, E., and Epps, J., 2007. Designing HMA Mixtures with High RAP Content: A Practical Guide. Lanham, MD: National Asphalt Pavement Association.

Nicholls, C., 2017. Asphalt Mixture Specification and Testing. CRC Press

Nikolaides, A. ed., 2015. Bituminous Mixtures and Pavements VI. CRC Press.

PD 6691:2015+A1:2016 Guidance on the use of BS EN 13108, Bituminous Mixtures. Material Specifications. British Standards Institution

Poulikakos, L.D., Papadaskalopoulou, C., Hofko, B., Gschösser, F., Falchetto, A.C., Bueno, M., Arraigada, M., Sousa, J., Ruiz, R., Petit, C. and Loizidou, M., 2017. Harvesting the unexplored potential of European waste materials for road construction. Resources, Conservation and Recycling, 116, pp.32-44.

Schiavi, I., Carswell, I. and Wayman, M., 2008. Recycled Asphalt in Surfacing Materials: A Case Study of Carbon Dioxide Emission Savings TRL PPR 304 Report. Crowthorne.

Tran, N.H., Taylor, A. and Willis, R., 2012. Effect of Rejuvenator on Performance Properties of HMA Mixtures with High RAP and RAS contents. NCAT Report, pp.12-05.

Wayman, M., Nicholls, J.C. and Carswell, I., 2015. Use of Lower Temperature Asphalt in Pavement Construction: Demonstration Site Construction, In-Service Performance and Specification (No. PPR 742) Crowthorne.

West, R., 2010. Reclaimed Asphalt Pavement Management: Best Practices. Auburn, AL: National Centre for Asphalt Technology, NCAT Draft Report, Auburn.

Widyatmoko, I. and Elliott, R., 2002, October. Asphalt Pavement Recycling for Hong Kong. In Proceedings of the Road Pavement Recycling Seminar, Organised by Polish Road and Bridge Research Institute & PIARC (pp. 10-11), Warsaw.

Widyatmoko, I., 2016. Sustainability of Bituminous Materials in Sustainability of Construction Materials, p.343. Elsevier

World Highways. 2015. The Importance of Road Maintenance. [Online] Available at http://www.worldhighways.com/categories/maintenance-utility/features/the-importance-of-road-maintenance/ [Accessed 6 Sep. 2017].

Zaumanis, M., Mallick, R. and Frank, R., 2013. Evaluation of Rejuvenator's Effectiveness with Conventional Mix Testing for 100% Reclaimed Asphalt Pavement Mixtures. Transportation Research Record: Journal of the Transportation Research Board, (2370), pp.17-25.

Zaumanis, M., Mallick, R.B. and Frank, R., 2014. 100% Recycled Hot Mix Asphalt: A Review and Analysis. Resources, Conservation and Recycling, 92, pp.230-245.

Zaumanis, M. and Mallick, R.B., 2015. Review of Very High-Content Reclaimed Asphalt Use In Plant-Produced Pavements: State of the Art. International Journal of Pavement Engineering, 16(1), pp.39-55.

Appendix A Current Specification Requirements

Specification	Clause	Requirement
BS EN 13108-8	Scope	Specifies requirements for the classification and description of reclaimed asphalt as a constituent material for asphalt mixtures.
BS EN 13108-8	5.4.4	When the reclaimed asphalt is intended for use only at addition percentages of less than 10 % in the surface course, the sampling frequency of once per 2 000 t and a single sample per batch of feedstock may be specified.
BS EN 13108-1 BS EN 13108-2 BS EN 13108-4 BS EN 13108-5	4.2.2.2 4.2.3 4.2.2.1 4.2.3	When using more than 10 % by mass of the total mixture of reclaimed asphalt from mixtures in which only paving grade bitumen has been used and when the binder added to the mixture is a paving grade bitumen and the grade of the bitumen is selected, the binder shall conform to the following requirements: - Penetration or the softening point of the binder in the resulting mixture, calculated from the penetrations or the softening points of the added binder and the recovered binder from the reclaimed asphalt, shall meet the penetration or softening point requirements of the selected grade. The calculation shall be executed according to Annex A. Either the penetration or the softening point requirement shall be selected.
BS EN 13108-1 BS EN 13108-4 BS EN 13108-5	4.4 4.4 4.4	The use and the amount of reclaimed asphalt, and the mixed group from which the reclaimed asphalt has been or will be derived shall be as specified. The properties of reclaimed asphalt declared in accordance with EN 13108-8 shall conform to specified requirements appropriate to the intended use. NOTE: The expression “appropriate to the intended use” means that the selection of the requirements and the particular category depends on a number of conditions. These conditions will include traffic density, climatic conditions, the construction of the course in which the mixture will be used, and economic considerations. The upper sieve size *D* of the aggregate in the reclaimed asphalt shall not exceed the upper sieve size *D* of the mixture. The aggregate properties of the reclaimed asphalt shall fulfil the requirements specified for the aggregate for the mixture.
BS EN 13108-1 BS EN 13108-4 BS EN 13108-5	5.3.1.2 5.1 5.1	When using reclaimed asphalt from mixtures in which a modified bitumen and/or a modifier additive has been used, and/or the mixture itself contains a modified bitumen or a modifier, the amount of reclaimed asphalt shall not, unless otherwise agreed between client and manufacturer, for surface courses exceed 10 % by the mass of the total mixture. Any agreement made between client and manufacturer shall not be in conflict with national regulatory requirements.
BS EN 13108-2	4.4	The use and the amount of reclaimed asphalt, and the mix group from which the reclaimed asphalt has been or will be derived shall be as specified. The properties of reclaimed asphalt declared in accordance with EN 13108-8 shall conform to specified requirements appropriate to the intended use. NOTE 1: The expression “appropriate to the intended use” means that the selection of the requirements and the particular category depends on a number of conditions. These conditions will include traffic density, climatic conditions, the construction of the course in which the mixture will be used, and economic considerations. The upper sieve size *D* of the aggregate in the reclaimed asphalt shall not exceed the upper sieve size *D* of the mixture. The aggregate properties of the reclaimed asphalt shall fulfil the requirements specified for the aggregate for the mixture. NOTE 2: In general the use of reclaimed asphalt will not be allowed due to the compulsory gap graded grading of the mixture, which is difficult to control with reclaimed asphalt.
BS EN 13108-2	5.1	The target composition of the mixture in terms of its constituent materials, the percentages passing the specified sieves, the binder content and where relevant the binder content from reclaimed asphalt and/or natural asphalt and the percentage(s) of additive(s) shall be declared and documented. At the target composition, the mixture shall conform to the specified requirements. When using reclaimed asphalt from mixtures in which a modified bitumen and/or a modifier additive has been used, and/or the mixture itself contains a modified bitumen or a modifier, the amount of reclaimed asphalt shall not exceed 10 % by mass of the total mixture.

Specification	Clause	Requirement
BS EN 13108-20	5	The Type Testing procedure shall include tests to demonstrate that all constituent materials, including any reclaimed asphalt addition, conform to the appropriate requirements. The requirements are detailed in Annex A. The tests for geometrical properties of the aggregate constituents, penetration/softening point/viscosity of the binder and grading, binder content and binder properties of reclaimed asphalt shall be carried out on the constituents actually used in Type Testing.
BS EN 13108-21	Table 7 Table D.2	Minimum inspection and test frequencies for reclaimed asphalt. The range of testing when using reclaimed asphalt and properties of the reclaimed binder.
PD6691	0.1	Gives guidance on a means of regulating the use of reclaimed asphalt.
PD6691	4.4.1	"The upper sieve size D of the aggregate in the reclaimed asphalt shall not exceed the upper sieve size (size D) of the mixture"; and "the aggregate in the reclaimed asphalt shall conform to the requirements for aggregate in the mixture specification." NOTE: BS EN 13108-8 does, however, allow for additional requirements to be defined and specified appropriately to the intended use. BS EN 13108‑8 is written as a means of classifying the properties of RA in a standard way in order to facilitate such specification.
PD6691	4.4.4	In line with current UK practice, the following limits normally apply: • surface courses, 10%; NOTE: There are designs which meet project outcomes were more than 10% reclaimed asphalt may be used in surface course mixtures and more than 50% in other mixtures, but these are subject to greater levels of control.
MCHW Series 900	901.3	Natural, recycled unbound and manufactured (artificial) aggregates shall be clean, hard and durable and shall comply with BS EN 13043. Where recycled coarse aggregate or recycled concrete aggregate is used in bituminous mixtures, it shall have been tested in accordance with Clause 710 and the content of other materials (Class X) including wood, plastic and metal shall not exceed 1% by mass. Reclaimed asphalt shall comply with Clause 902.
MCHW Series 900	902.2	Reclaimed asphalt may be used in the production of bituminous surface course, binder course, regulating course and base. Unless otherwise specified in Appendix 7/1, the use of reclaimed asphalt shall be in accordance with: (1) The relevant British Board of Agrément HAPAS Road and Bridges Certificate for surface course mixtures specified in Clause 942; (2) BSI PD 6691, B.2.4.4 for Asphalt Concrete mixtures (Macadam); (3) BSI PD 6691, C.2.3.4 for Hot Rolled Asphalt mixtures; (4) BSI PD 6691, D.2.2.3 for Stone Mastic Asphalt Mixtures.
MCHW Series 900	902.3	All reclaimed material shall be pre-treated before using such that it is homogeneously mixed and the maximum particle size does not exceed 32 mm.
MCHW Series 900	902.4	The fresh bitumen added to the mixture shall not be more than two grades softer than the nominal grade for the mixture given in Table 12 of BSI PD 6691. Checks on the penetration of the binder recovered from the reclaimed asphalt, together with a calculation of the properties of the combined binder, shall be carried out in accordance with the relevant parts of BS EN 13108. When more than 10% of reclaimed asphalt is incorporated in a mixture, tests on binder recovered from the mixture shall be carried out in accordance with BSI PD 6691 13.3.6.2. The results shall be within the limits set out in BSI PD 6691 13.3.6.2.

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