Specialist Professional and Technical Services (SPaTS) Framework
Lot 1

Task 1-583
Comprehensive review of asphalt recycling with a view to increasing recycled content in the medium-term

Subtask 1 – Establishing the Current Situation

January 2020

ATKINS
Member of the SNC-Lavalin Group

JACOBS

Reference Number: Subtask 1 – Establishing the Current Situation
Client Name: Highways England

This document has been issued and amended as follows:

Version	Date	Description	Created By	Verified By	Approved By
1.0	08/03/2019	Subtask 1 – Establishing the Current Situation	Dr. M.Wright, Dr. D.Bateman, Dr. W.Zuo, T.Lawrence & D.Lean.	Dr. B.Rahimzadeh & L. Taylor.	S.Pimperton
1.1	30/05/2019	Updated to include MPA (2019)	Dr. M.Wright, Dr. D.Bateman, Dr. W.Zuo, T.Lawrence & D.Lean.	Dr. B.Rahimzadeh & L. Taylor.	S.Pimperton
1.2	24/09/2019	Updated to include information obtain from Germany Visit.	Dr. M.Wright, Dr. D.Bateman, Dr. W.Zuo, T.Lawrence & D.Lean.	Dr. B.Rahimzadeh & L. Taylor.	S.Pimperton
1.3	14/01/2020	Final version for issue	Dr. M.Wright, Dr. D.Bateman, Dr. W.Zuo, T.Lawrence & D.Lean.	Dr. B.Rahimzadeh & L. Taylor.	S.Pimperton

The report is based on published technical standards and references current at the time of publication September 2019.

Table of Contents

Executive Summary....1
1. Introduction 4
2. Literature Review – Asphalt Recycling 5
3. Recycling Rates: Published Literature & National Data Analysis – Current Situation....26
4. Asphalt Recycling on the Strategic Road Network in England – Current Situation....36
5. UK Market Capabilities....48
6. International Comparisons – Recycling Rates & Recycling Plant Capabilities 52
7. Recycling Limitations....70
8. Conclusions....80
9. Recommendations 83

Executive Summary

The Atkins and Jacobs Joint Venture (AJJV) were appointed by Highways England in June 2018 through the SPaTS Framework to undertake a *Comprehensive review of asphalt recycling with a view to increasing recycled content in the medium-term*. This Report forms the deliverable for Sub-task 1 and provides the AJJV's assessment of the current status of asphalt recycling.

Techniques for recycling have been present in the Design Manual for Roads and Bridges (DMRB) for over twenty years (HD 31/94, Chapters 5-6) and the use of reclaimed asphalt and asphalt recycling techniques have long been specified in the MCHW and corresponding Notes for Guidance (see Clauses 902, 926, 947 and 948). The aim of this Sub-task 1 report is to understand the recycling rates and techniques currently used, understand the current market capacity and understand the key limitations preventing higher levels of recycling on the SRN.

To establish the current situation a range of primary and secondary data sources were identified and analysed. This analysis considers the current recycling rates specific to the SRN and from a national perspective. The report also compares current recycling rates on an internationally basis.

The review undertaken indicates that there is currently no central source of data that fully captures and monitors the use of reclaimed asphalt in bituminous materials for the Strategic and local road networks.

A range of data sources have been reviewed to gain a snapshot of current recycling levels including published literature, Highways England (HAMPS and Departures from Standard data) and industry consultation to understand the current recycling levels and techniques used on the SRN and nationally.

A review of published literature indicates that in the UK there was approximately 3,400,000T of reclaimed asphalt available in 2017 equating to 15% of total asphalt production. It is estimated that 80% is re-used in hot mix and warm mix applications, 5-15% of total RAP is cold recycled with the remainder used in other applications.

Consultation with industry and overseeing authorities indicates that 10% of reclaimed asphalt is now regularly incorporated into surface course materials on both the SRN and local road networks as permitted within current standards. A limited number of departures and associated trials on the SRN have been undertaken to date with reclaimed asphalt quantities approved ranging from 20% to 50%. The data indicates that requests for departures from standard in recent years has been severely limited and has not increased with time.

The level of reclaimed asphalt incorporated into binder and base course materials is variable. It is common practice to incorporate between 10 and 40% reclaimed asphalt into the lower pavement layers with up to 50% incorporated as permitted within standard where plant capabilities permit. No departures from standard have been submitted on the SRN for binder and base course materials in excess of 50% reclaimed asphalt, indicating that all recycling into these layers is within current standard and specification.

The levels of cold recycling using foamed bitumen on the SRN is limited with the equivalent of 184,017T installed over an 18-year period. The application of cold recycling using foamed bitumen installed on an annual basis has been highly variable with installation in 8 out of 18 years on the SRN. Since 2010 the use of cold recycling with foamed bitumen has been limited, however in recent the years the level of cold recycling using foamed bitumen has increased due to the application of the in-situ downcut technique. Ex-situ Cold Recycled Bitumen Bound Materials is a technique widely used by local authorities with an average annual production of 16,500T per authority. Highways England's records and responses from ADEPT members indicates asphalt waste containing coal tar is a key driver for the use of Cold Recycled Bitumen Bound Materials. Analysis of the Environment Agency, Waste Data Interrogator Tool indicates 88% of bitumen bound and tar bound asphalt wastes codes defined in the EWR are recovered.

Analysis of figures provided by EAPA (2017) indicates the percentage of asphalt plants that are equipped for hot or warm mix recycling in Great Britain (66%) is typical of other European countries. The values are significantly lower than a number of leading European countries such as Belgium, Denmark, Germany, Netherlands and Sweden.

In 2017 over 48,500,000T of reclaimed asphalt was available in Europe. Germany, Italy, France and the Netherlands. These are some of the of the leading countries in Europe in recycling asphalt in terms of total reclaimed asphalt available for recycling. Worldwide, the United States of America (USA) recycles the greatest quantity of reclaimed asphalt by far with over 76,200,000T recycled. The average estimated percentage of RAP used in asphalt mixtures has increased from 15.6% in 2009 to 20.1% in 2017. Recycled contents in Japan have also increased in recent years, with an average RAP content in asphalt mixtures increasing from 33% on average in 2000 to 47% on average in 2013.

All leading countries throughout Europe (such as Germany, Netherlands and Denmark) and worldwide (such as the USA and Japan) have invested heavily in recycling plant capabilities and processing of reclaimed asphalt. In contrast, the use of parallel drum systems and indirect heating systems to incorporate high levels of reclaimed asphalt in England is relatively limited.

The report identifies a range of complex factors are present that limit the rate of asphalt recycling on the SRN in terms of both the specific recycling method and the reclaimed asphalt content used within a particular material. The limitations cover a wide range of inter-related factors including but not limited to specification, economic, operational and material performance characteristics.

This report makes a number of recommendations to overcome the identified limitations and increasing recycled content in the medium-term.

The report recommends:

- The levels of reclaimed asphalt used on the SRN are monitored and regular reported.
- Testing protocols and systems are developed to improve the traceability of reclaimed asphalt planings.
- An assessment of the performance of existing installation sites where surface courses incorporating in excess of 10% reclaimed asphalt is undertaken and the need for further site trials.
- A review is undertaken to establish the end performance specification and certification requirements for surface course containing recycled contents above 10%.
- Further research is undertaken to consider the influence that reclaimed asphalt has on the skid resistance of the surface course.
- Technical reviews are undertaken regarding the impact that the reclaimed asphalt properties, processing of reclaimed asphalt and the application of rejuvenators have on the end performance.
- An assessment of RAP priority plants in Europe is undertaken to understand how the plants are being operated, the mix design process and any potential application for the UK.
- Any development to specifications considers the use of warm mix asphalt incorporating reclaimed asphalt.
- It is recommended that further research is undertaken in relation to the in-situ downcut recycling technique with appropriate design guidance and specifications produced. It is also recommended that appropriate ongoing monitoring of the sites installed to date is conducted.
- A full review of the performance of the cold recycling verification sites documented in TRL 611 and TRL 386 is undertaken with particular emphasis on the performance and traffic level (>30msa).
- Further research is undertaken to assess the relationship between the laboratory condition protocol with in-situ performance for cold recycled materials.
- The requirements defined in TRL 611 and SHW Clause 948 are aligned and the use of Class B4 materials is reviewed and appropriate application and design guidance provided.
- Further design guidance is produced for maintenance solutions using cold recycled materials.
- Analysis is undertaken to consider the use of Ex-Situ Cold Recycled Bitumen Bound Materials as a pavement foundation in any future revision of HD25.
- It is recommend that a review of current procurement methods is conducted to establish how recycling levels are considered.

- Scheme delivery processes are reviewed to ensure the incorporation of recycling solutions is considered by the client, designer and Contractor at the earliest possible stage in the design.

1. Introduction

This report forms part of SPaTS Task 1-583 *'Comprehensive review of asphalt recycling with a view to increasing recycled content in the medium-term'*, which Highways England have commissioned Atkins and Jacobs via the AJJV partnership to deliver.

The product of this project is to provide proposals for revising the following requirements in relation to asphalt recycling:

- Design Manual for Roads and Bridges (DMRB); and
- Specifications in the Manual of Contract Documents for Highway Works (MCHW).

The objective of the proposals is to increase the recycled content of asphalt laid on the Strategic Road Network (SRN), whilst maintaining or increasing the performance of these materials.

The project methodology has been defined as part of the agreed Work Package Scope, the AJJV Quality Submission (June 2018) and Project Inception Document.

This report is focused on Sub-task 1, which requires the current situation regarding asphalt recycling on the SRN in England to be established. The aim of this sub-task is to understand the recycling rates and techniques currently used, understand the current market capacity and understand the key limitations preventing higher levels of recycling.

To establish the current situation a range of primary and secondary data sources were identified and analysed. This analysis considers the current recycling rates specific to the SRN and from a national perspective. The report also compares current recycling rates on an international basis.

A detailed literature review was undertaken to understand the current situation, best practice and reported recycling rates. Extensive industry consultation has been undertaken through the creation of UK Pavement Liaison Group Working Group 9 (UKPLG WG9), consultation with various industry bodies (Mineral Products Association, Eurobtiume UK and ADEPT) and supporting companies (including but not limited to FM Conway, Tarmac and Wirtgen Group).

Analysis of data regarding the SRN was also conducted using data sources from the Highways Agency Pavement Management System (HAPMS) and Web-based Departures Approval System (WebDAS) database.

This Sub-task 1 report:

- Summarises the current bituminous bound recycling techniques, specifications and best practice;
- Analyses published literature and data sources regarding the current recycling rates on a national basis;
- Analyses the levels of recycling on the Strategic Road Network;
- Details the understanding of the current UK market capacity;
- Compares the UK recycling position with other international countries;
- Details the key limitations to increased recycling levels; and
- Outlines a number or recommendations to increasing recycling in the short-medium term.

2. Literature Review – Asphalt Recycling

2.1 Background

Asphalt can be reclaimed from expired bituminous-bound pavements as reclaimed asphalt planning (RAP). RAP is widely claimed to be 100% recyclable and can be added to fresh asphalt mixtures to reduce the requirement for virgin raw materials, both quarried stone and bitumen. Techniques for recycling have been present in the Design Manual for Roads and Bridges (DMRB) for over twenty years (HD 31/94, Chapters 5-6) and the use of reclaimed asphalt and asphalt recycling techniques have long been specified in the MCHW and corresponding Notes for Guidance (see Clauses 902, 926, 947 and 948).

Highways England are committed to sustainable development and their Sustainable Development Strategy includes objectives for promoting sustainability leadership, the circular economy and carbon management (amongst others). Increased use of reclaimed asphalt in road maintenance activities and new construction provides the following benefits:

- Increased sustainability in the road construction industry by reducing the impact on primary resources (less virgin bitumen and aggregate required), and reduces the volume of waste to be disposed;
- Promotes the use of secondary resources;
- Potential reduction in production costs due to less virgin bitumen and aggregates used, and reduced transport costs; and
- Reduces the energy use in the aggregate manufacturing sector and the overall UK carbon footprint, thereby reducing carbon emissions.

Integrating sustainable development into design enhances the performance of assets and infrastructure. Highways England's (2019) GG 103 together with the National Application Annexes, describes how sustainable development and good road design can be applied to the design of motorway and all-purpose trunk roads. It aligns with a range of global, European and national commitments on sustainable development and standards of design.

This section of the report presents a literature review of asphalt recycling. In particular, this section summarises; different recycling techniques that are currently used in the UK and internationally; specifications which govern recycling in the UK; and the integration of reclaimed asphalt in new construction and maintenance design.

2.2 Recycling Techniques

Asphalt recycling techniques can be divided into two main categories:

- In-place (in-situ) recycling; and
- In-plant (ex-situ) recycling.

Both categories can be sub-divided and classified taking into account the temperature of the recycling process (Wayman et al., 2015, Nicholls, 2017):

- Hot Mix recycling: Recycling process performed at temperatures >140 °C.
- Warm Mix recycling: Recycling process performed between 70-140 °C.
- Cold Mix recycling: Recycling process performed at temperatures <50 °C.

The following sections discuss hot mix and cold mix recycling. For the purposes of this report, the term in-plant will be used for hot mix recycling and ex-situ will be used for cold recycling. The term in-situ will be used for both hot and cold recycling.

2.3 Hot Mix Asphalt Recycling

2.3.1 Introduction

Hot mix recycling is where reclaimed asphalt is used as a bitumen coated aggregate in hot mix asphalt. In hot mix recycling, old asphalt pavement layers are removed, broken down and incorporated into new asphalt mixtures. The two methods for hot mix recycling are in-situ and in-plant recycling.

2.3.2 Hot In-situ recycling

Hot in-situ recycling is defined as "*a process to correct asphalt pavement surface distress by softening the existing surface with heat, mechanically removing the pavement surface, mixing the reclaimed asphalt with a recycling agent, possibly adding virgin asphalt and/or aggregate, and re-laying*" (Carswell et al., 2005).

Hot In-situ recycling typically involves various types of road construction equipment that are lined up one after another, as shown in Figure 2.1. The first stage involves planing out the material, which is then immediately processed and relayed on-site. In-situ hot mix recycling can be classified in two main categories; (i) Repave, and (ii) Remix (Karlsson and Isaacson, 2006).

(i) The "repave" process consists of pre-heating and scarifying the existing asphalt layer; mixing, laying and levelling the removed material; 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 (Carswell et al., 2005, Karlsson and Isaacson, 2006). The depth treated can vary from 25-50 mm. The heat from the Repave machine welds the new material to the remaining surface, therefore eliminating the need for a bond coat (Carswell et al., 2005).

(ii) The "remix" process is an adaption of the above process, whereby removed material is preheated, scarified, mixed with fresh asphalt material, before being re-laid as one layer (Carswell et al., 2005, Karlsson and Isaacson, 2006; Miliutenko et al., 2013).

Figure 2.1 - Example of hot mix asphalt recycling in operation (www.colas.co.uk)

Note that the American Asphalt Recycling and Reclaiming Association (ARRA) also recognises the above methods, and in addition use a "heater-scarification" process, which consists of heating, scarifying and rejuvenating the old material before levelling, reprofiling and compacting the recycled layer (Button et al., 1999, Carswell et al., 2005).

The benefits of this approach to in-plant recycling are the elimination of costs associated with stockpiling, processing, maintaining an inventory, and transportation. In-situ recycling also minimises the time required on site, therefore reducing exposure of workers to traffic and site-related risks, and less disruption to traffic. However, there is a high level of vehicle movements on site, which is a safety concern for site workers and road users. Furthermore, the level of quality control may not be as high as that of in-plant recycling.

2.3.3 In-plant recycling

Sources and Planning

In-plant recycling consists of processing reclaimed asphalt in an asphalt plant located off-site. The reclaimed asphalt is mixed with virgin materials in typical mixing blends. Traditionally, all layers of asphalt tend to be removed together. However, it is beneficial to plane the surface course separately from deeper layers, especially if the RAP is intended to be mixed in a surface course mixture, as indicated in Figure 2.2 to 2.4. Surface course planings need to be stockpiled separately with RAP from other layers when RAP is to be incorporated into surface course materials. (Carswell et al, 2010).

Road Note (RN) 43 (Carswell et al., 2010) recommends removing the surface treatment first before recycling the existing surface course. This is to avoid contamination of surface course RAP from surface treatment with different gradation and binder properties.

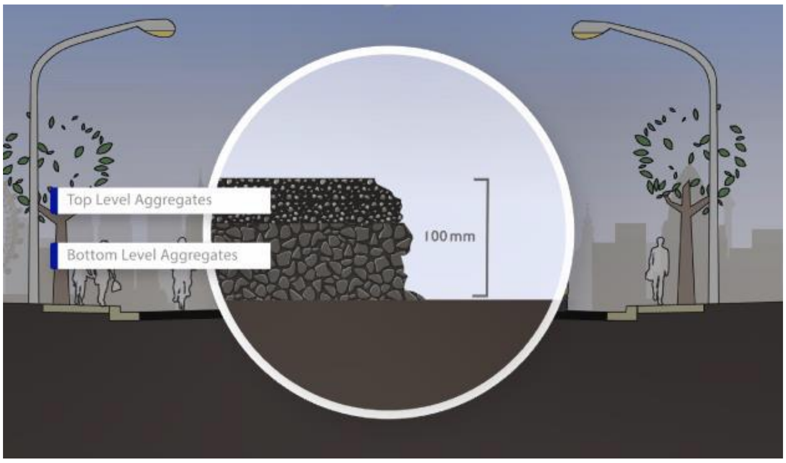


Figure 2.2 - Example of two asphalt mixtures with different aggregate sizes within an asphalt layer (Metcalf et. al. 2018)

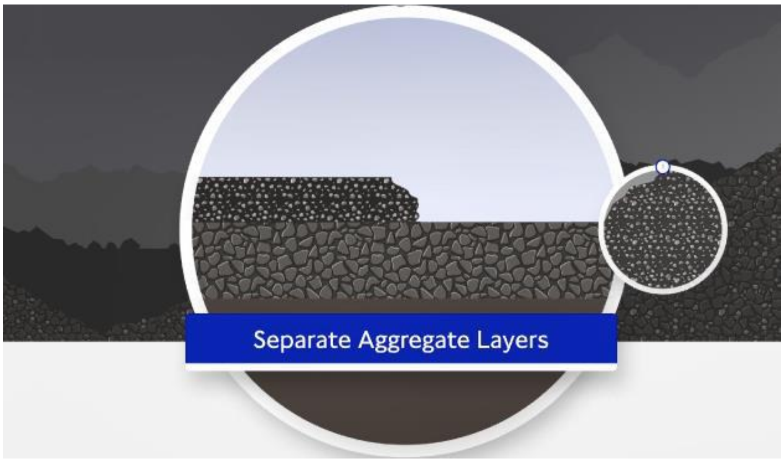


Figure 2.3 - Removal of top-level asphalt layer and stored in a stockpile (Metcalf et. al. 2018)

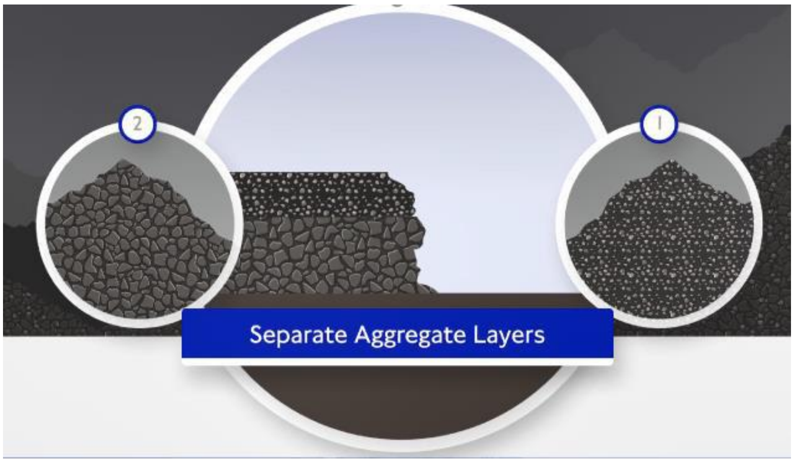


Figure 2.4 - Removal of bottom-level asphalt layer and stored in a separate stockpile (Metcalf et. al. 2018)

In addition, because of the high cost of the moisture removal during plant mixing, it is preferable not to introduce any more water than necessary during the planing operations.

Transportation

As a minimum, the Reclaimed Asphalt (RA) will have to be taken from the planing operation to the mixing plant for processing. For each journey, different categories of the RA are recommended to be kept separate to avoid additional cost to separate them later.

Processing and storage

Traditionally, RAP would be stored in a single pile, which might be adequate when the RA is intended to be used in a lower layer with low RA content. For high RA content mixes or when the RA is intended to be used in surface course, the RA shall ideally be stockpiled separately in accordance with the corresponding material characteristics.

It is desirable to screen or fractionate the RAP first to remove the over-sized particles or to separate the RAP into coarse and fine, as a minimum, to maximize the amount of RAP that can be used in a particular mixture (Copeland, 2011). In the USA, some Contractors prefer crushing the RAP to the top size of the design mixture. This can improve the consistency of the resulting planings, especially when they are from different sources. However, it should be noted that crushing to smaller top sizes will increase the dust content in the RAP, which can limit how much RAP can be used in the new mixture design (FHWA, 2011).

In recent years, alternative methods to crushing have been developed. This includes granulation, which is defined as the breaking of reclaimed asphalt down to a recyclable size without crushing/reducing the stone content or fabric. This enables the grading curve of the processed reclaimed asphalt to replicate the grading curve of the final asphalt product, which subsequently enables high levels of recycling. The influence of granulation compared to crushing of reclaimed asphalt is present in Figure 2.5.

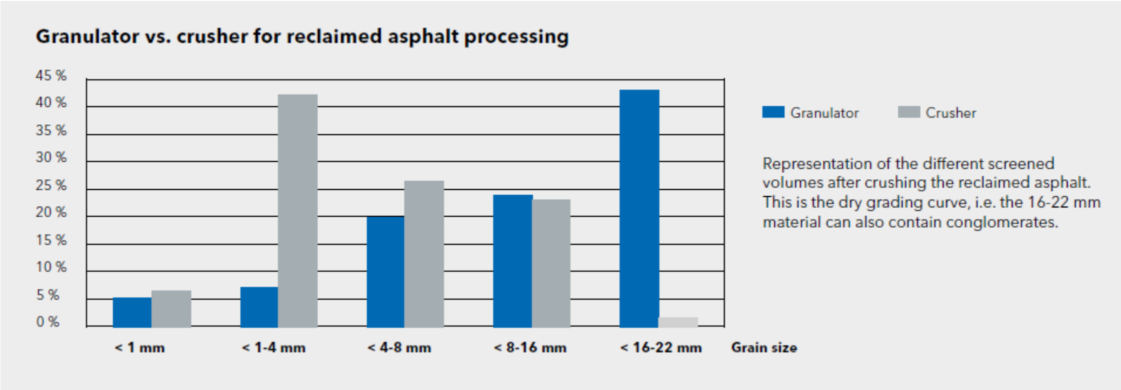


Figure 2.5 - Comparison of Granulation vs Crushing for Reclaimed Asphalt Processing (Benninghoven, 2018)

As stated previously, it is expensive to remove water from RA during the mixing process. Therefore, rather than wasting fuel in the mixing plants, it would be more beneficial to protect the RA stockpiles from rain with a fixed roof (Carswell et al, 2010).

Batch plant production

The plant consideration for the RAP mixture mainly depends on the content of RAP to be used in the asphalt mixture and the type of mixing plant (Shell, 2015).

For a RAP content typically less than 30%, the processed RAP can be cold fed into the mixing process. A range of technologies are available to cold feed reclaimed asphalt as shown in Figure 2.6. According to Benninghoven (2018) these include:

- Middle Ring Dosing System (25% RAP Content) – The material is introduced into the inside of the dryer drum via a belt and a ring elevator, mixed with aggregate and gently heated.
- Direct to Mixer Dosing System (30% RAP Content) – The RAP is conveyed from the feed hopper directly to the mixing tower via an inclined conveyor or RAP elevator. Dosing is carried out by belt scales.
- Multivariable Dosing System (40%) – The multivariable dosing system is similar to the direct to mixer system, however highly precise weight technology allows exact dosing. Time based additions prevents strong vapour shocks during the water expansion.

The most common technique is dosing direct into the mixer. The virgin aggregate needs be overheated first and then the RAP added to the mixer before the virgin bitumen is added. The superheated virgin aggregate will “dry out” and heat the RAP to activate the aged binder and allow the aggregate to blend as the virgin bitumen is introduced, as illustrated in Figure 2.7.

The benefits of Cold RAP additions are:

- The system can be retrofitted
- The equipment is relatively inexpensive
- The equipment is relatively low maintenance.

The incorporation of 25-40% of RAP using a cold feed is possible, depending on plant system, mix temperatures and moisture content (Benninghoven 2018). The key limitation for cold RAP additions, which prevents high RAP content is the moisture content and ability to remove moisture.

For a RAP content typically above 40%, it would not be cost efficient and environmentally friendly to superheat the virgin aggregate to warm the RAP in a cold RAP feed batch plant. Therefore, a hot RAP feed system with a parallel dryer for the reclaimed asphalt has been introduced, as illustrated in Figure 2.8. A parallel drum system can typically incorporate up to 70% RAP. The RAP is dried and heated on a separated dryer. The heated RAP, and activated residual binder, is then dropped directly into the mixing bin where it is blended with the virgin aggregate at the same time as the new bitumen is introduced. This process however, requires the batch plant to have a second drier located at the top.

For a RAP content more than 70%, an indirect heating system is generally required to heat the recycled material with hot air rather than directly with flames, see Figure 2.9. These systems are designed to heat the RAP up to the optimum processing temperature, while keeping emissions in the standard range and not burning the contained bitumen. It is claimed these systems are able to deal with 100% RAP mixture (Shell 2015, Zaumanis et al, 2014). In the USA, the indirect heating system has proven its ability for 100% RAP recycling in commercial use.

A number of RAP priority plants have been constructed in Germany. For example, a 40-year-old plant in Breisach, Germany (shown below) features new technology, increasing its range of recycling capabilities. Plant reconfiguration and the addition of a Benninghoven BA 4000 system, with a capacity of up to 320tonnes/hour, and equipped with a parallel counterflow drum, providing indirect heating of the RAP, as shown in Figure 2.10. This configuration ensures that the bitumen contained within the RAP is not damaged by direct heating. The new reconfiguration claims to generate RAP percentages as high as 90% (World Highways, 2017).

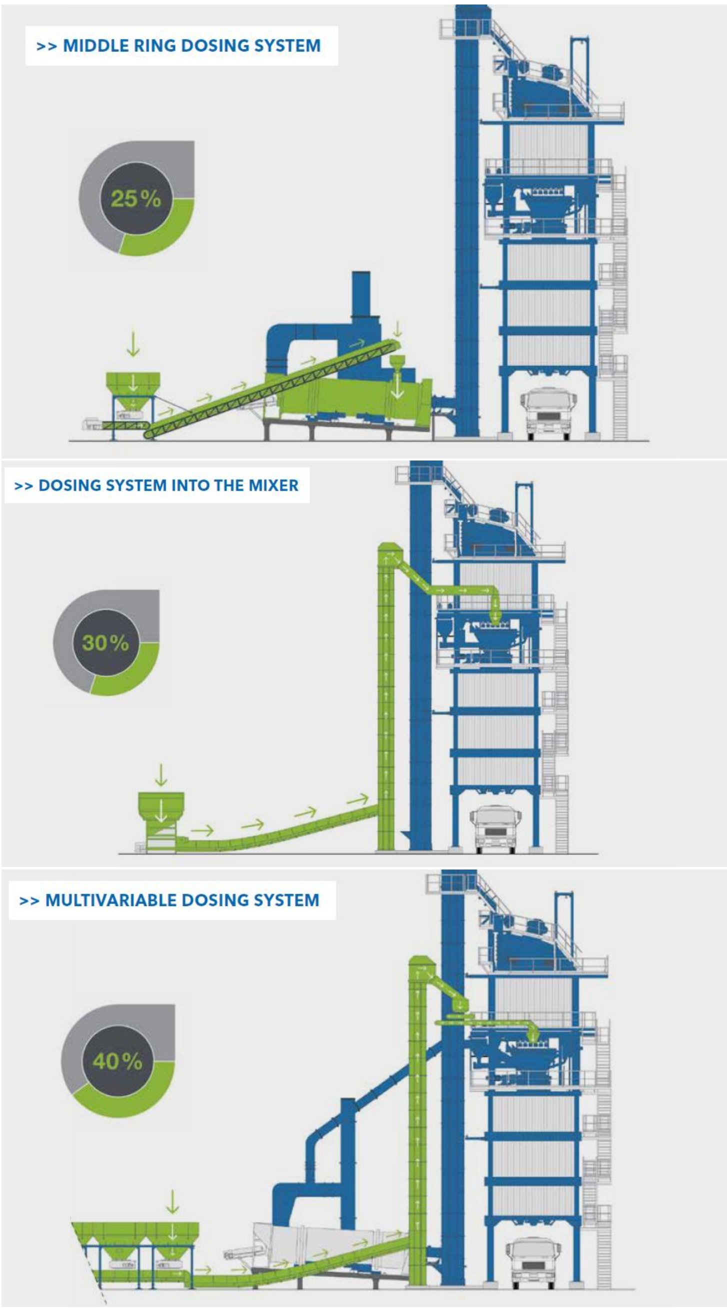


Figure 2.6 - Flow diagram for a Cold RAP additions (Benninghoven, 2018)

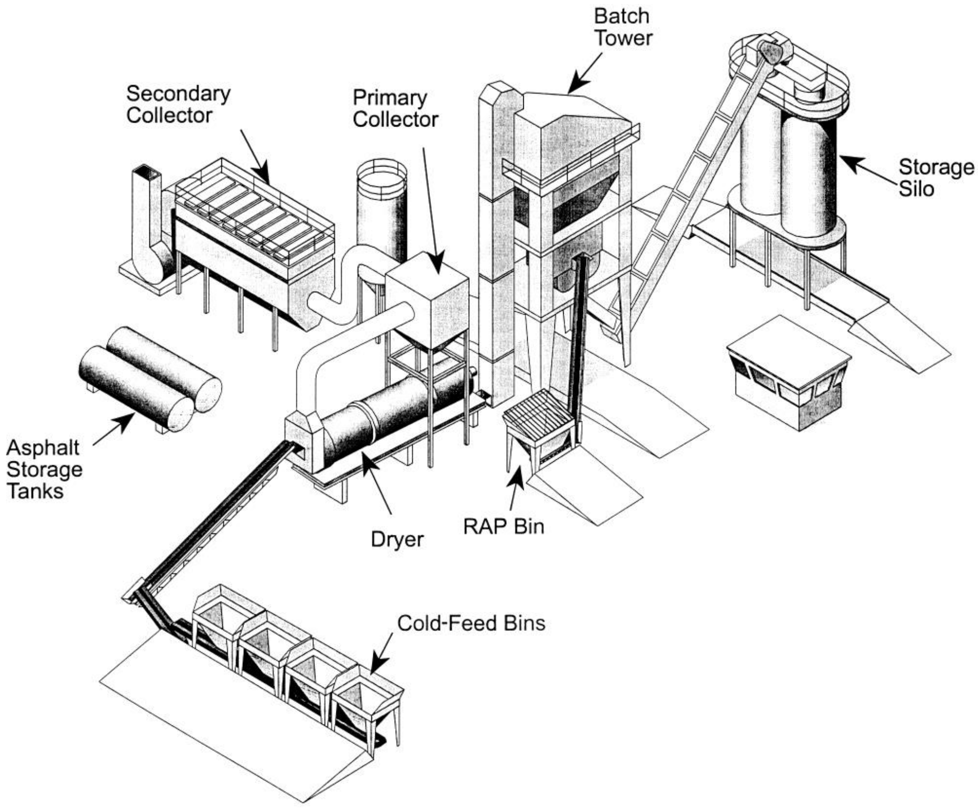


Figure 2.7 - Flow diagram for a cold RAP feed (USACE, 2000)

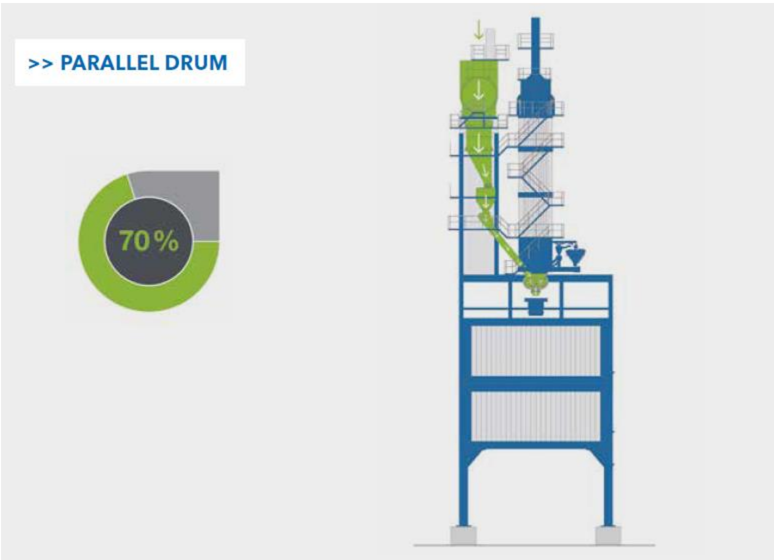


Figure 2.8 - Parallel Drum Plant Configuration (Benninghoven 2018)

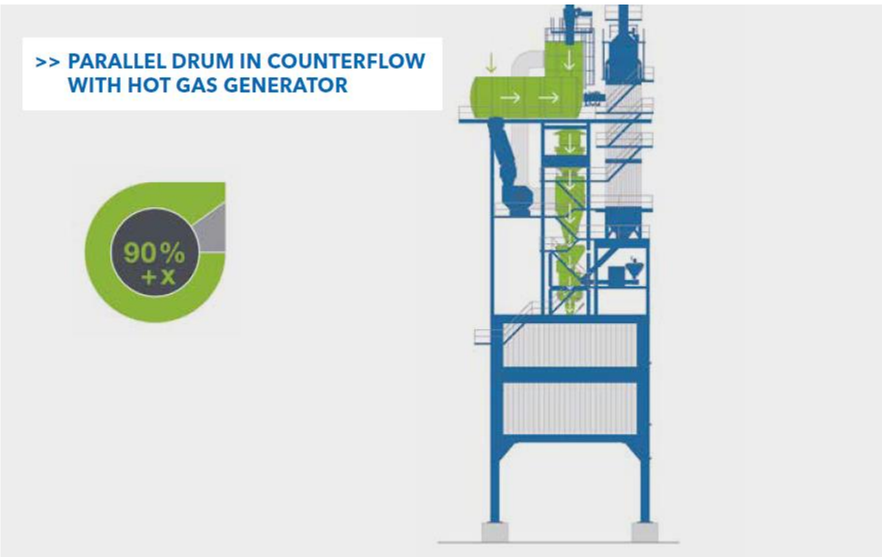


Figure 2.9 - Indirect Heating Configuration Plant Configuration (Benninghoven 2018)

Figure 2.10 - Benninghoven parallel drum in counterflow with a hot gas generator at asphalt plant in Breisach, Germany (Benninghoven, 2017)

2.3.4 RAP Mix Design Methods

Although recycling is now well established in the road construction industry, incorporating RA into new asphalt mixtures is not a simple process and needs specific consideration in order to obtain the optimal asphalt mix using the most appropriate RAP mix design method. This is consistent with Lo Presti et al. (2006) “. *obtaining good performance of high RA content asphalt concretes strongly depends on RA properties and mixture design. Special attention has to be paid to the mixture design due to the presence of the aged stiff binder*.”

There are a range of RAP mix design methods used worldwide. This section discusses some of the main considerations for incorporating RAP in new asphalt mixes in the UK, Europe, and internationally.

Properties of RA

Due to oxidation, the binder of the RAP is typically stiffer. For low RAP content (<10%), it is not necessary to check the properties of the aged binder, because of the insignificant influence on the properties of the mixed binder (West et al, 2013). For a higher RAP content, the hardened binder will have a noticeable effect and generally, a softer virgin binder and/or rejuvenator may be required to balance the stiffer aged RAP binder.

In the UK, according to RN 43 (Carswell et al, 2010), the aged binder shall be recovered in accordance with BS EN 12697-3, followed by the determination of the recovery tests, including penetration and softening point (see section 2.3.5).

A range of methods are documented in research reports across Europe and the United States to characterise reclaimed asphalt and undertake the mix design process. According to Lo Presti et al. (2006) “*In Europe, the standard EN 13108-8:2005 for reclaimed asphalt establishes that if RA content is higher than 10% for surface layers and 20% for base layers, a logarithmic blending law for penetration and a linear blending law for softening point should be applied to select the proper virgin binder to be used*”. The “log Pen” rule as below is used to determine the required penetration of the virgin binder to be added.

$$\boldsymbol{a} \times \log \boldsymbol{Pen_1} + \boldsymbol{b} \times \log \boldsymbol{Pen_2} = (\boldsymbol{a} + \boldsymbol{b}) \times \log \boldsymbol{Pen_{mix}} \qquad \text{(Equation 1)}$$

Where: a =volume percentage of the bitumen with Pen_1
b = volume percentage of the bitumen with Pen_2
Pen_{mix} = Penetration of the bitumen of the mixture.

The relationship is acceptable for low RA; however, research indicates that if the RA content increases to 40%, the softer virgin binder will rise to an unpractical high penetration requirement (Molenaar et al, 2014).

In the AASHTO design method M 323 R35, the virgin binder selection shall be based on the RAP content to be used in the mixture:

- When the RAP percentage is less than 15%, no change is required in binder selection.
- When the RAP percentage is between 15% and 25%, one Superpave PG grade softer than normal shall be used.
- When the RAP percentage is more than 25%, a blending chart analysis shall be conducted to select the proper binder.

Lo Presti (2006) explains “*In the United States of America, for high RA contents (>20%), NCHRP Report 452 (2001) described a particular procedure to obtain blending charts assessing high, intermediate and low critical temperatures of the blend of RA and virgin binder*”. The NCHRP report 452 (2001) introduced a simple linear blending chart for the virgin binder selection, which is based on the assumption that the mixed binder properties should be contributed from aged binder and virgin binder in proportion to their content.

In order to achieve a better prediction for the virgin binder in high RAP content, NCHRP report 752 (2013) adjusted the linear blending relationship with a new concept call RAP binder ratio (RAPBR), as shown below:

$$\boldsymbol{RAPBR} = \frac{(\boldsymbol{P}_{\boldsymbol{b(RAP)}} * \boldsymbol{P}_{\boldsymbol{RAP}})}{\boldsymbol{P}_{\boldsymbol{b(total)}}} \qquad \text{(Equation 2)}$$

Where $P_{\mathrm{b(total)}}$ is the total binder in the mix, $P_{\mathrm{b(RAP)}}$ is the recovered binder content of the RAP and the P_{RAP} is the percentage of RAP in the mix design. Then the critical temperature of the virgin asphalt binder $T_{\mathrm{crit(virgin)}}$, which is used in PG grade selection in AASHTO design, can be determined as below:

$$\boldsymbol{T}_{\boldsymbol{crit(virgin)}} = \frac{\boldsymbol{T}_{\boldsymbol{crit(need)}} - \boldsymbol{RAPBR} * \boldsymbol{T}_{\boldsymbol{crit(RAP\ binder)}}}{\boldsymbol{1 - RAPBR}} \qquad \text{(Equation 3)}$$

Where $T_{crit(need)}$ is the critical temperature needed for the climate and pavement layer, and $T_{crit(RAP\ binder)}$ is the critical temperature of the RAP binder determined from extraction, recovery, and PG grading.

This methodology should be completed to determine the appropriate high, intermediate and low temperature grades for the virgin binder.

Lo Presti (2006) proposed a methodology that allows predicting the binder's properties of the asphalt mixtures containing up to 100% RA. This methodology consists of the development of blending charts for conventional and performance-related binder properties, including the use of Replaced Virgin Binder (RVB) and Degree of Blending (DOB) concepts, it allows the use of rejuvenators and it is independent of the RA source.

Rejuvenators

Rejuvenators are additives and modifiers that can be used in hot (and cold) mix asphalt recycling to help regenerate the chemical and physical bitumen properties of RA that may have been reduced due to in-service aging. Rejuvenators can be produced from virgin raw materials or from recycled materials and are typically introduced with higher rates of recycling (>20% RA). There are numerous rejuvenators available, and there are studies which have demonstrated the successful application of rejuvenators to help increase the percentage of RA in asphalt mixes, such as the Asphalt Pavements for a Sustainable Environment, "APSE" project (Barrasa, 2017). In this study, a bio-flux agent, which is a plant-based additive, was added to the bitumen to increase the RA content of the binder course and base layer mixes to 30%. Accelerated pavement testing of experimental full-depth pavement sections which had both 'APSE' trial materials and conventional asphalt pavement materials showed similar performances in terms of rut resistance and fatigue resistance. Further laboratory testing on the cores post-trafficking revealed comparable air void contents for the APSE and conventional base-binder mixtures, inferring that the presence of RAP did not make the APSE materials less workable, likely due to the presence of the bio-flux agent (Barrasa, 2017 project). These mixtures were subsequently used in on-road trials in Poland and Spain in 2017. Initial results suggest that the trial sections are performing to a similar level as the control sections (Barrasa, 2017).

However, while the APSE project was successful in demonstrating the application of rejuvenators in asphalt mixtures, there is limited research on rejuvenators and there are generally no standards against which they can be assessed. Industry standards (EN 13108) require such constituent materials to be validated by "*demonstrable history of satisfactory use in asphalt*". Therefore, the potential use of rejuvenators to achieve a large proportion of RAP, requires the support of highways authorities, to help demonstrate a history of satisfactory use in asphalt.

2.3.5 Recycling into Surface Courses

Recycling RA into base and binder course mixtures has become almost routine, whilst the inclusion of RA in surface course has been much more limited. The use of RA into surface course provides significant economic and environmental benefits by efficiently using recycled materials in the optimal pavement layer. Recycling into surface courses makes best use of the high Polished Stone Value (PSV) aggregate in surfacing materials reducing demands on virgin PSV aggregate and the associated importing costs.

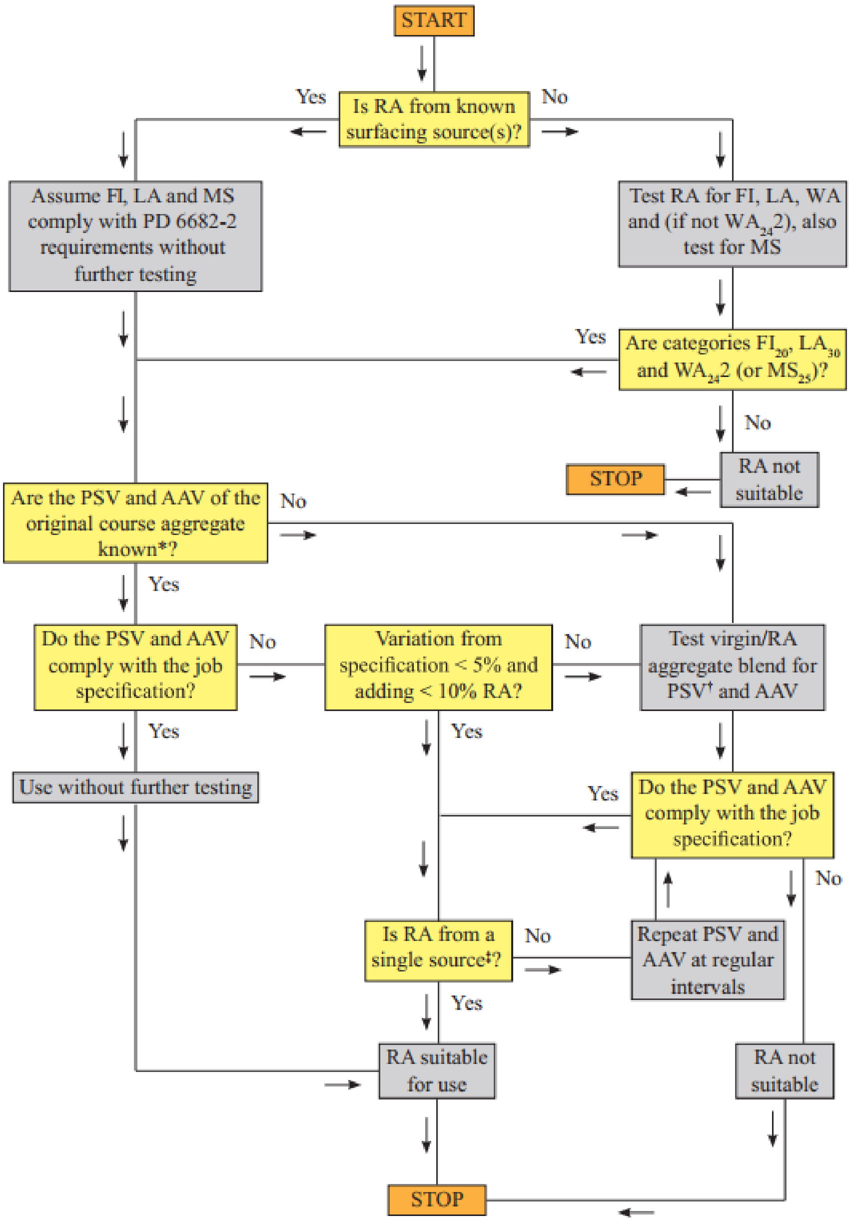
A study into recycling of thin asphalt surfacing's back into surface course layers established its feasibility (Carswell et al., 2005), and further research has led to the development of best practice guidance RN 43 (Carswell et al., 2010). Carswell et al, (2010) provides a detailed decision flow chart for the acceptable aggregate properties of RAP, as illustrated in Figure 2.11.

Chibuzor (2017) highlighted the main design factors for consideration:

- *"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".*

A range of trials have incorporated reclaimed asphalt into surface courses. As reported in TRL 645 (Carswell et al, 2005), trials of up to 30% RA have been monitored to demonstrate that it can produce satisfactory asphalt, in major contracts on the M4 and M25. In 2006, a scheme on the M4 near Cardiff used approximately 25% of the existing porous asphalt (Nicholls et al, 2007). Trials on the M25 were undertaken in 2007 (Schiavi, et al, 2007) and 2010 (Wayman and Carswell, 2010). The 2007 study was between Junctions 6 and 7 (clockwise carriageway) whereby 23% RA in the surface course was achieved. TRL PPR468 (Wayman and Carswell, 2010) trialled 40% RA in the surface course mix on the M25 between J6-7 (anticlockwise carriageway) using the old porous asphalt surfacing. TRL PPR742 trialled lower rates of RA (16%) in surface course mixes for both low temperature and hot mix asphalt, on a 1km stretch of the A5 between Grendon and Mancetter (Wayman et al, 2015).

Recently, trials of up to 50% RAP content design has been adopted on the A1 Mill Hill (Flint and Bailey 2018) and on the A40 by FM Conway in partnership with Transport for London in 2016 and 2017 respectively. The source of the RAP for the A1 Mill Hill trial was from the existing Stone Mastic Asphalt (SMA) surfacing. According to Flint and Bailey (2018) the trial comprised of FM Conway's 14mm SurePave incorporating 50% RAP, a polymer modified binder and Sylvaroad additive, which was compared against a control section of 14mm SurePave with no RAP.



* The mechanical properties of the aggregate in RA can be assumed to be at least comply with the limit set for the pavement from which it was taken.
†Chippings that have been recovered from bituminous materials may give misleading PSV results
‡A single source of RA is a road or roads know to have been laid with the same mixture, using the same component materials and laid at roughly the same time.
AAV=aggregate abrasion value; PSV= polished stone value; WA=water absorption; FI= flakiness index; LA=Los Angeles coefficient; MS=magnesium sulphate soundness

Figure 2.11 Flow chart for acceptable aggregate properties of RA (Carswell et al, 2010)

2.4 Current UK Specifications, Design Standards, and Published Guidance in Hot Mix In-situ and In-plant recycling

2.4.1 Introduction

In the UK, SHW clause 902 and PD6691 (2016) allows up to 10% of recycled asphalt to be mixed into the surface course and 50% in other materials without a departure from standard.

For asphalt recycling in roads, the relevant standards and guidance documents are as follows:

- BS EN 13108 (CEN, 2006);
- MCHW NG700 Series in the Specification for Highway Works (MCHW 2016);
- MCHW 900 Series in the Specification for Highway Works (MCHW 2018);
- PD 6691 (BSI, 2016); and
- HD 31 (DMRB, 1994).

BS EN 13108 is a European standard and it sets out the requirements and material specifications for RA in Parts 1 to 9 with particular focus on Part 8 (CEN, 2016). The national specification is in the MCHW NG700 Series (MCHW, 2016) and 900 Series (MCHW, 2018) in the Specification for Highway Works.

2.4.2 MCHW 900 Series in the Specification for Highway Works (MCHW 2018)

MCHW 900 has two clauses which specify the requirements for RA; Clause 902 – Reclaimed Asphalt and 926 - In-situ Recycling: The Repave Process.

Clause 902 states the following:

1. "*The requirements of this clause apply to all bituminous mixtures containing reclaimed asphalt.*
2. *Reclaimed asphalt may be used in the production of bituminous surface course, binder course, regulating course and base. Unless otherwise specified in contract specific Appendix 7/1, the use of reclaimed asphalt shall be in accordance with:*
   (i) Clause 942 for surface course mixtures specified in Clause 942;
   (ii) BSI PD 6691, B.2.4.4 for Asphalt Concrete mixtures (macadams);
   (iii) BSI PD 6691, C.2.3.4 for Hot Rolled Asphalt mixtures; and
   (iv) BSI PD 6691, D.2.2.3 for Stone Mastic Asphalt mixtures.
   Other recycled materials shall only be used in bituminous mixtures with the approval of the Overseeing Organisation. The mixed material shall comply with the requirements of all the relevant Clauses in this Series.
3. *Reclaimed Feedstock: All reclaimed material shall be pre-treated before use such that it is homogeneously mixed and the maximum particle size does not exceed 32 mm.*
4. *Properties of Binder: 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 following the example in BSI PD 6691 13.3.6.2. The results shall be within the limits set out in BSI PD 6691 13.3.6.2.*
5. *Mixed materials containing more than 25% reclaimed asphalt: When more than 25% of reclaimed asphalt is incorporated in a designed base or binder course mixture, cores taken to assess compliance with Clause 929.12 or Clause 930.14 shall also be tested for stiffness in accordance with BS EN 12697-26 (ITSM method 20°C). The frequency of testing shall be agreed with the Overseeing Organisation prior to the commencement of works and shall comply with the requirements of contract specific Appendices 1/5 and 1/6.*
6. *The stiffness of the mixture shall comply with the appropriate category from Table 9/1*."

2.4.3 MCHW NG700 Series in the Specification for Highway Works (MCHW 2016)

Series NG 700 includes a sample contract specific Appendix 7/5: Sample Contract Specific In-situ Recycling – The Remix and Repave Processes. This sample Appendix 7/5 provides an example of the details required by the designer to specify in-situ recycling within their design.

2.4.4 PD 6691 (BSI, 2016)

PD 6691 states the following:

"4.4.1 Requirements in BS EN 13108-8:2005 in relation to RA

There are only two definite requirements in BS EN 13108 in relation to the reclaimed asphalt:

- *The upper size of the reclaimed asphalt shall not exceed the upper size of the mixture; and*
- *The aggregate in the reclaimed asphalt shall conform to the requirements for aggregate in the mixture specification.*

BS EN 13108 does, however, allow for additional requirements to be defined and specified appropriate to the intended use. BS EN 13108-8 is written as a means of classifying the properties of reclaimed asphalt in a standard way in order to facilitate such specification.

Annex B, Annex C and Annex D of this Published Document indicate the preferred properties of reclaimed asphalt for use in UK mixtures.

4.4.2 Preferred Properties of Reclaimed Asphalts

For the purposes of specification, it is recommended that the following criteria are adopted in the UK:

- *foreign matter – category F5;*
- *binder properties – category P15.*

NOTE P15 is a general case, but reliable and consistent feedstocks of harder reclaimed materials might make them suitable for use, by agreement with the client.

4.4.4 Limiting the amount of reclaimed asphalt (RA)

BS EN 13108 also covers the possibility of limiting the amount of reclaimed asphalt permitted to be added to the mixture. In line with current UK practice it is recommended that the following limits normally apply:

- *surface courses 10%*
- *all other materials 50%*

However, it is envisaged that there will be situations where more than 10% reclaimed asphalt will be used in surface course mixtures and more than 50% in other mixtures, but these will be subject to greater levels of control.

4.4.5 Total binder in the mix

In cases where more than 10% for surface course mixtures, and 20% for other mixtures, by mass of the total mixture of reclaimed asphalt is added to the mixture, it is necessary to confirm that the properties of the total binder in the mixture, calculated from the combination of the properties of the fresh binder and the properties determined on the recovered binder from the reclaimed asphalt, conform to the grade specification for the mixture. BS EN 13108 gives the option of carrying out this calculation on either penetration or softening point. In line with current UK practice it is recommended that the penetration method is adopted.

NOTE Additional requirements are called up when the binder from the reclaimed asphalt or the binder for the mixture is modified."

2.4.5 HD 31 (DMRB, 1994)

HD 31 (DMRB, 1994). provides guidance on in-situ recycling of bituminous pavements using the "repaving" method.

2.5 Cold Recycling

2.5.1 Introduction

Cold Recycling is the "*term used for recovering and re-using material from an existing pavement, without the addition of heat*" Wirtgen (2016). The cold recycling process uses reclaimed asphalt obtained from pulverisation of all, or part an existing pavement, as an aggregate in a cold mix asphalt. In cold recycling, the reclaimed asphalt is combined with stabilising agents such as bitumen (foamed bitumen or bitumen emulsion), hydraulic binders or other admixtures/filler to form a new asphalt mixture. Cold recycling is typically used to rehabilitate the structural layers of the pavement.

2.6 Cold Recycling Methods

There are two main processes which can be used for cold recycling these are in-situ and ex-situ recycling. Both techniques have a number of similarities in terms of how they recycle the existing pavement but differ as in-situ recycling is recycled in place where as ex-situ recycling is produced in a fixed or mobile mixing plant. Each technique has varying advantages and disadvantages dependent upon the existing pavement construction/variation, rehabilitation needs, programming, economic and environmental constraints.

2.6.1 In-Situ Cold Recycling

In-situ cold recycling is performed on-site without removing the material away from the road. The process involves milling and pulverising the existing pavement which is collected in a mixing chamber where admixtures are added to create a recycled mix. Once produced the mix is placed using a paving screed and compacted.

In-situ recyclers have evolved over the years from modified milling machines and basic soil stabilisers into specialised recycling machines today. A wide range of in situ recycling machines and recycling train configurations are available depending on the project requirements. This can range from shallow recycling (typically 75mm) to deep structural recycling with depths ranging from 150-350mm. In the UK it is common practice to pre-mill the pavement surface prior to in-situ recycling to a typical depth between 150-180mm. However, a number of in situ recyclers can work to depths in excess of 300mm. The existing surface course is planed off and removed from site prior to recycling in order that satisfactory ride quality and existing levels can be maintained once a new surface has been installed.

Deep structural in-situ recycling in the UK is generally performed using two techniques, either cold recycling with up-cut process (Figure 2.12) or with downcut process (Figure 2.13). The two methods work in the same way with the main difference being the way the recycled material is processed. The recycled material in the up-cut process is spread across the entire working width by a spreading auger and placed true to line and level by the integrated paving screed. Whereas the recycled material during the downcut process is picked up by the loading conveyor and transferred into the material hopper of the asphalt paver which places it true to line and level. The downcut technique has a number of advantages in relation to level control, removal of baulking and the prevention of slabbing.

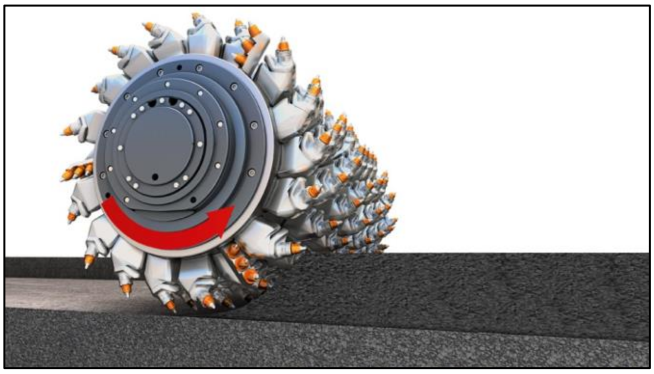


Figure 2.12: Cold Recycling with Upcut Process (Wirtgen 2018)

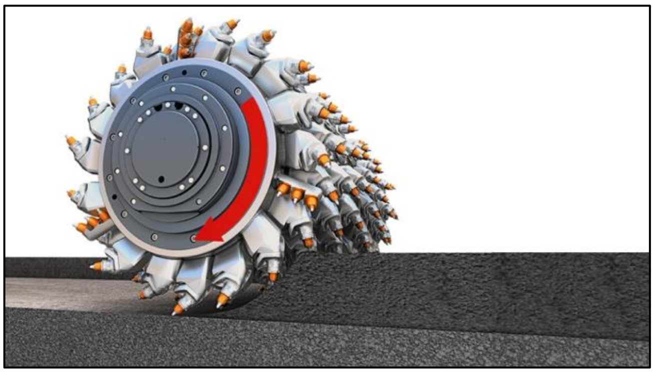


Figure 2.13: Cold Recycling with Downcut Process (Wirtgen 2018)

The degree to which layers of bound material (e.g. asphalt) are pulverised (the grading) is influenced mainly by the advance speed of the recycler, but also by the rotation speed of the drum. The faster the advance speed and the slower the speed of rotation, the coarser the product. Large lumps of material that are not pulverised in the process tend to be thrown to the bottom of the layer.

In order to consider an in-situ recycling process a full pavement investigation is required from the project onset. The existing pavement must have reasonably consistent types of existing flexible pavement materials which are at least as thick as the chosen depth of recycling.

The in-situ cold recycling processes has the advantage of being sustainable as there is very little waste material taken from site and the use of virgin materials and new asphalt is limited. Any materials containing tar in the pavement are immediately bound into the new pavement creating no hazardous waste nor any additional Environment Agency requirements as the tar is not moved from its original location. There are also significantly reduced lorry movements on the site compared with conventional planning and laying of new asphalt. The process is much quicker than conventional options leading to a reduced duration of traffic management.

2.6.2 Ex-Situ Cold Recycling

The key difference between cold in-situ and cold ex-situ recycling is that the mixing for ex-situ recycling is performed off site in a static or mobile mixing plant near to site. This process begins by planning out the existing pavement, transporting the reclaimed asphalt directly from the site to the mixing plant. The reclaimed asphalt is then processed, mixed with appropriate stabilising agents and transported back to the site. Images showing a typical ex-situ cold recycling setup are shown in Figures 2.14 and 2.15. The ex-situ cold recycling material is then laid using conventional pavers as a new pavement layer.

Figure 2.14: Ex-Situ Cold Recycling Setup (Wirtgen 2016)

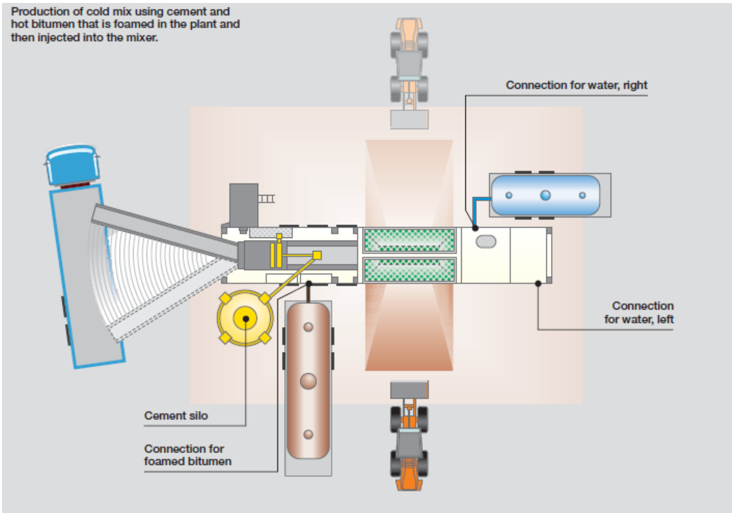


Figure 2.15 - Ex-Situ Cold Recycling KMA 200 Setup (Wirtgen 2008)

The main benefits of ex-situ recycling are described by Wirtgen (2016), which states *"In-plant recycling allows materials from an existing pavement to be selected and pre-treated, thereby increasing the level of confidence that can be achieved in the final product. The main benefits to accrue from in-plant compared to in-place treatment are:*

- *Control of input materials. Whereas in-place recycling allows no control over the type of material that is recovered from an existing pavement, a required end-product can be obtained by blending different aggregates in accurate proportions when mixing in-plant.*
- *Input materials can be selected, pre-treated (e.g. by crushing and screening), stockpiled and tested prior to mixing. The proportioning of various input materials can then by changed as and when required to obtain the required mix.*
- *Quality of mixing. An adjustment can be made to the mixer to vary the time the material is retained within the mixing chamber, thereby improving the quality of the mix.*
- *Stockpiling capabilities. Particularly with bitumen stabilised materials, the mixed product can be placed in stockpile and used when required, thereby removing the inter-dependency of the mixing and placing processes. Cognisance must, however, be taken of the strict time restrictions applicable to stockpiling mixes that include cement."*

2.7 Cold Recycled Mixtures

A typical mix for a recycled asphalt is made up of a primary aggregate and binder. The primary aggregate source is obtained by cold pulverisation of all, or part, of an existing pavement. The primary binder (stabilising agent) is typically a foamed bitumen, with cement or lime. Depending on the properties of the aggregate, the grading of it may be adjusted by the addition of a filler.

Several binder choices are available for cold recycled mixtures. The most common material families are described in TRL 611 by Merrill et. al. (2004) and include:

- Quick Hydraulic binder - using hydraulic binders only and including cement.
- Slow Hydraulic binders - using hydraulic binders only such as pulverised fuel ash/lime or granulated blast furnace slag/lime but excluding cement.
- Quick Visco-Elastic binder that uses bituminous binder as the main component but also includes portland cement.
- Slow Visco-Elastic binder that uses bituminous binder as the main component but excludes portland cement.

These are shown graphically in Figure 2.16.

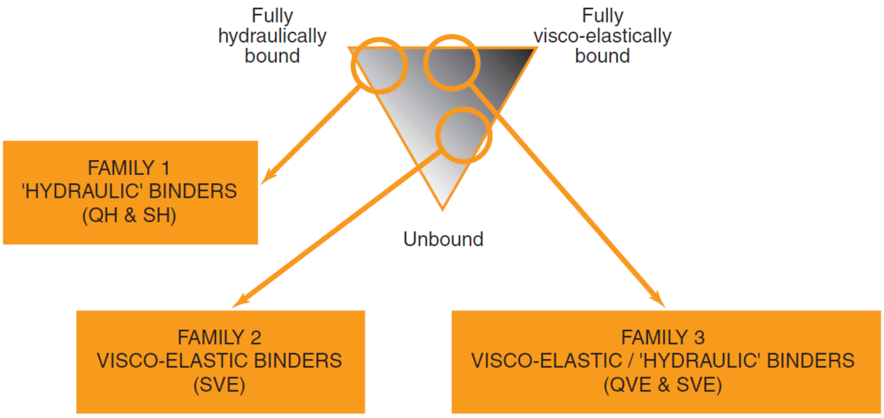


Figure 2.16 - Identification of Cold Recycling Material Families (Merrill et. al. (2004))

Most in-situ road recycling techniques used either Quick Hydraulic (QH), or Quick Visco-Elastic (QVE) binders. The most common type of ex-situ recycling is Quick Visco-Elastic.

2.8 Current UK – Cold Recycling Specification, Design Standards & Published Guidance

2.8.1 MCHW Volume 1, Series 900 - Road Pavements – Bituminous Bound Materials

Series 900 of Specification for Highway Works (SHW) has two clauses which specify the requirements for cold recycling of asphalt, Clause 947 and 948, In Situ Cold Recycled Bitumen Bound Material and Ex Situ Cold Recycled Bitumen Bound Material, respectively.

The clauses provide the specification requirements for the constituent materials, process control, mix design, end performance, testing and compliance requirements for the respective cold recycled material.

To supplement these clauses a draft Clause 949 is currently being considered for In-Situ Downcut Process Cold Recycled Bitumen Bound Materials. The draft Clause 949 would define the installation process, testing requirements, site control and quality assurance of the installed recycled material.

2.8.2 MCHW Volume 2, Series NG 700 – Road Pavements - General

Series NG 700 of SHW includes a sample contract specific Appendix 7/18: Site Specific Details and Requirements for Cold Recycled Bitumen Bound Material. This sample Appendix 7/18 provides an example of the details required by the designer to specify cold recycled bitumen bound material within their design.

2.8.3 HD 26/06 – Pavement Design

HD 26/06 provides the details of permitted materials and of thickness for the construction of pavements for new trunk roads. HD 26/06 states *"Pavement design guidance comprising cold recycled base material is presented in TRL Report 611 (2004). These designs require a 'Departure from Standard' from the Overseeing Organisation, with the exception of an ex situ stabilized Quick Visco-Elastic (QVE) base material comprising a minimum 3% bituminous binder and a minimum 1% cement, known as foamed asphalt, and classified as Zone B2 material, for a maximum cumulative design traffic up to 30msa."*

HD 26/06 also states "*For trunk roads up to 30 msa, it may be advantageous to use cold recycled materials and a design guide is available as part of TRL Report 611 (2004). These designs may also be suitable for nontrunk roads including those with design traffic less than 1 msa. For roads carrying less than 2.5 msa, using cement as the primary binder, the adjustments contained in Table 7.5 of TRL Report 611 (2004) have been reviewed. Experience indicates that such adjustment is unnecessary and that HBM based on the use of cement with strength classification H2 can be safely used for Type 4 roads and H3 for Type 3 roads. Further information is available from the Overseeing Organisation*."

2.8.4 TRL Report 611 - A guide to the use and specification of cold recycled materials for the maintenance of road pavements

TRL's report describes the pavement design and material specification to help facilitate the take-up of cold recycling. This covers the material design, site evaluation, pavement design and end product specification for both in-situ and ex-situ recycling methods.

The report provides information on various cold recycled mixtures and defines the material families based on the binders used. The report also provides specific advice on the site evaluation and the risk that needs to be considered.

The report provides pavement design charts for new pavement designs containing hydraulic bound (Zones H1-9) and bituminous bound mixtures (Class B1-B3) over a range of traffic conditions from lightly traffic roads up to 80msa. It is important to note that for heavier trafficked pavements the designs are based on the extrapolation of current knowledge and should be treated with caution. All pavement design charts allow for a 100mm conventional bituminous surfacing; however, guidance is provided on the minimum surfacing depth and adjustments. Methods for defining partial depth treatment are also presented.

The report provides a full list of the validation sites considered as part of the development of the methodology.

2.8.5 TRL Report 386, Design guide and specification for structural maintenance of highway pavements by cold in-situ recycling

This guidance document provides a design guide for in-situ cold recycling based on a three-year research programme reviewing in service performance of a recycled pavement. The document provides guidance on the whole recycling process from warranting whether the site is suitable for a recycled pavement to the design specification and overall performance requirements.

The report contains a flow chart which is designed to help engineers decide whether road recycling is a viable option for a site under consideration together with another flow chart which points the engineer in the direction of which binder to use.

2.8.6 HD 31/94 – Maintenance of Bituminous Road

HD 31/94 provides guidance on various recycling techniques. This includes cold in-situ recycling, which primarily relates to the Retread process. Limited guidance is also presented on cold ex-situ recycling.

2.8.7 RSTA/ADEPT, Code of practice for in-situ structural road recycling

The RSTA code of practice was prepared to provide a better understanding of in-situ road recycling and the cost saving benefits that can be realised through implementing it.

Recycling of RAP is acknowledged in the code of practise as being the preferred method of dealing with 'tar' in road construction. This best practice guide gives a detailed view of all the steps and processes required to carry out in-situ road recycling with references to TRL 386 and 611 and Clause 947 from Series 900.

3. Recycling Rates: Published Literature & National Data Analysis – Current Situation

3.1 Introduction

To understand the current situation regarding asphalt recycling at a national perspective a range of primary and secondary data sources were identified and analysed.

A detailed review of the European Asphalt Pavement Association (EAPA) – Asphalt in Figures 2010 - 2017 was undertaken to assess the current recycling rates in Great Britain.

Extensive industry consultation was also conducted through the creation of the UK Pavement Liaison Group Working Group 9 (UKPLG WG9). Consultations and specific surveys were also conducted with the following stakeholders:

- ADEPT (The Association of Directors of Environment, Economy, Planning and Transport) represents Place Directors from county, unitary and metropolitan authorities, along with Local Enterprise Partnerships and corporate partners drawn from key service sectors to understand the current situation for local authorities.
- Mineral Products Association (MPA), (the trade association for the aggregates, asphalt, cement, concrete, dimension stone, lime, mortar and silica sand industries) to understand the current situation nationally from a supply and production perspective.

Analysis of Environment Agency - Published Waste Data Interrogator Tool, HM Revenue and Customs, National Statistics Aggregates Levy Bulletin and Defra, Statistical data set ENV23 – UK statistics on waste – October 2018 was also undertaken, as recommended by UKPLG WG9 to understand if these data sources captured current levels of recycling of bituminous materials.

This Section of the report summarises the findings from each data source.

3.2 European Asphalt Pavement Association (EAPA) – Asphalt in Figures 2017

A study of asphalt production figures is reported by the European Asphalt Pavement Association (EAPA) on an annual basis. The study presents total asphalt production figures per European country and includes re-used and reclaimed asphalt. The EAPA findings for 2017 are presented in Table 3.1.

Table 3.1 – Re-use and recycling of reclaimed asphalt in 2017 (EAPA 2017)

Country	All available Reclaimed Asphalt in 2017 in tonnes	% of available reclaimed asphalt used in						Applied area in m2 of hot reuse of existing asphalt pavement material in-situ / on the road (Remixing, Repaving, Reshaping, Road Train etc.)	The amount of "only" reheated (reused) asphalt material insitu / on the road (Remixing, Repaving, Reshaping, RoadTrain etc.) in metric tonnes
		Hot and Warm Mix Asphalt Production	Half Warm Mix Asphalt Production	Cold Recycling**	Unbound Road Layers	Other Civil Engineering Applications	Put to Landfill / Other Applications/ Unknown		
Austria	1,650,000	60	No data	No data	No data	No data	No data	No data	No data
Belgium	1,030,000	95	No data	No data	No data	No data	No data	No data	No data
Czech Republic	2,600,000	14	0	30	20	10	26	381,280	418,000
Denmark	1,165,000	66	0	0	8	0	26	No data	No data
Finland	1,200,000	100	0	0	0	0	0	12,000,000	No data
France	6,400,000	70	No data	No data	No data	No data	No data	1,097,614	197,478
Germany	13,000,000	84	0	0	16	0	0	No data	No data
Great Britain	3,400,000	90 (Combined figure presented in 2017)			0	0	0	No data	No data
Hungary	120,000	95	0	0	0	4	1	No data	No data
Italy	9,000,000	23	No data	No data	No data	No data	No data	No data	No data
Netherlands	4,500,000	71	0	11	0	0	18	No data	No data
Norway	1,101,000	30	0	1	69	0	0	No data	No data
Slovakia	50,000	96	0	2	1	1	0	130,000	16,000
Slovenia	84,000	24	0	6	10	0	60	No data	No data
Spain	494,000	83	0	0	14	0	3	No data	No data
Turkey	2,570,589	9	0	6	85	0	0	No data	No data
USA	72,500,000	96	0	0	4	0	0	No data	No data

** Cold recycling includes stabilisation with bitumen emulsion, foamed bitumen and/or cement.

The data indicates that 3,400,000 Tonnes of reclaimed asphalt were available for use in the UK during 2017 which equates to 15% of the UK's total asphalt production. It is estimated that 80-90% of the available reclaimed asphalt is re-used in hot mix and warm mix applications based on EAPA (2016 and 2017) figures. No unique data was available regarding cold recycling or re-use of reclaimed asphalt in other applications in 2016 and 2017.

Analysis of historic records for Great Britain reported by EAPA between 2010 and 2017 are presented in Table 3.2.

Table 3.2 – EAPA figures for available reclaimed asphalt and percentage recycled for Great Britain (2010-2017)

EAPA Report Year	Total Production in tonnes	All Available Reclaimed Asphalt in tonnes	Percentage Reclaimed asphalt used in Hot and Warm mix production	Percentage Reclaimed asphalt used in Cold Recycling	Percentage used in unbound/other applications
2010	21,500,000	4,000,000	No Data	No Data	No Data
2011	22,400,000	4,500,000	No Data	No Data	No Data
2012	18,500,000	4,500,000	No Data	No Data	No Data
2013	19,200,000	4,000,000 – 5,000,000	No Data	No Data	No Data
2014	20,600,000	3,350,000	70%	5%	No Data
2015	21,900,000	3,500,000	85%	15%	No Data
2016	22,000,000	3,250,000	80%	No Data	No Data
2017	22,700,000	3,400,000	90% (Combined figure presented in 2017)		No Data

Analysis of the EAPA data between 2010 – 2017 indicates that the total asphalt production in Great Britain has fluctuated year on year with an average annual production of 21,100,00T. The average available reclaimed asphalt available per year between 2010 - 2017 is estimated at 3,785,714T representing 18% of total production.

The reclaimed asphalt available as a percentage of the total asphalt production between 2010 – 2017 is presented in Figure 3.1. The data indicates that the reclaimed asphalt available as a percentage of total production has ranged from 15% - 24% of total production. The percentage of available reclaimed asphalt peaked in 2012 at 24% and has subsequently reduced to approximately 15% in recent years. The reasons for this are not reported.

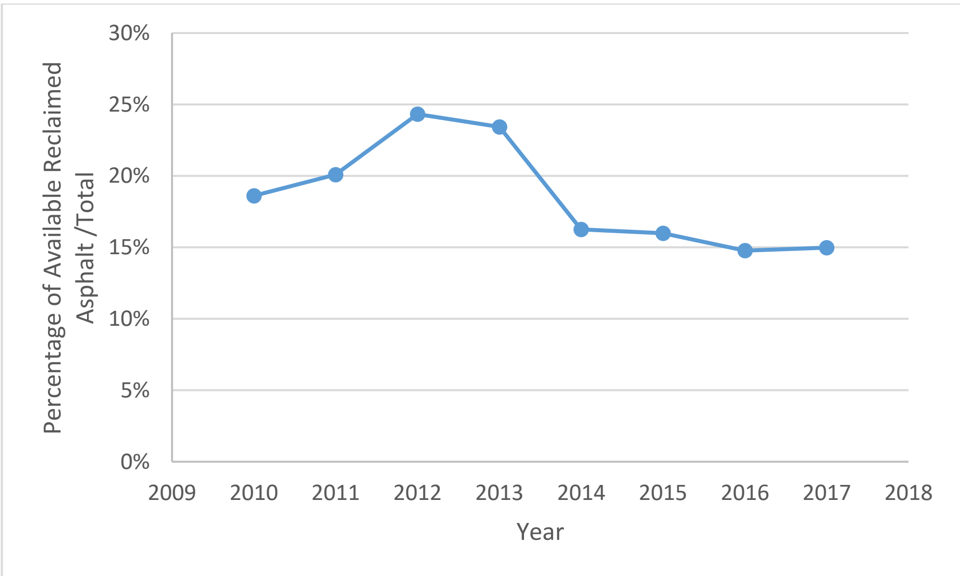


Figure 3.1 – Reclaimed asphalt available as a percentage of total asphalt production based on EAPA (2017) data

Based on the EAPA figures between 2014 – 2017. It is estimated that between 75-90% of all available RAP is used in the production of hot mix and warm mix. Generally, no data has been available for cold recycling, however when available the figures indicates this represents between 5-15% of total RAP used.

3.3 Mineral Products Association Survey

Discussions were undertaken with MPA in relation to surveying asphalt producers to understand the current situation nationally. The consultation with MPA highlighted that the information is considered to be highly commercially sensitive and no data could be made available to AJJV. This is consistent with the findings from WSP/PB (2014) as discussed in Section 4.2.

It was recommended that individual asphalt producers/suppliers are approached directly by Highways England in relation to all Highways England projects carried out in 2017 and 2018.

Direct consultation with industry has indicated that recycling into surface course is common practice and the level of recycling into binder and base courses is dependent on the individual plant capabilities.

Feedback from one supplier has indicated "*Currently all our CL942 surface course products have 10% RA in with the agreement of BBA HAPAS and dependent on the type/size of plant all Base and Binder products have up to 40% RA in but as above up to 50% is allowable*."

A copy of the MPA (2019) reported "*The Contribution of Recycled and Secondary Materials to Total Aggregates Supply in Great Britain" was provided by the MPA. The report concluded "In 2017, a total of 176 million tonnes of primary aggregates were produced by the industry in Great Britain, which, together with an estimated 72 million tonnes from recycled and secondary sources, supplied demand. Recycled and secondary materials accounted for 29% of the total aggregates supply, which has put Great Britain in a leading position internationally in the use of recycled and secondary aggregates for many years, well ahead of the European average.*"

The MPA (2019) report also considered asphalt planings separately and analysed data available by Ministry of Housing, Communities and Local Government. The MPA (2019) report concluded *"(DCLG, 2007b) report estimated that 8Mt of asphalt arisings were available in the UK in 2005, 70% of which occurred in England (5.6Mt). To obtain a GB total, MPA assumed an equal split of the difference between the UK and England to represent Scotland, Wales and Northern Ireland (0.8Mt each), meaning total arisings of 7.2Mt in GB in 2005.*"

The MPA (2019) study calculated the following reclaimed asphalt planings available between 2005 and 2017 as presented in Table 3.3.

Table 3.3 – Asphalt Planings in GB (million Tonnes) (MPA 2019)

	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
MPA Asphalt Sales		-11.2% (vs.0.5)	-17.5%	6.0%	4.2%	-16.9%	3.9%	8.8%	6.5%	3.5%	0.2%
Asphalt Planings (million tonnes)	7.2	6.4	5.3	5.6	5.8	4.8	5.0	5.5	5.8	6.0	6.1

The values reported indicate a high level of asphalt planings are available in the UK relative to the figures reported in EAPA (2017).

The MPA (2019) concluded "*No further direct sources of information on the size of the asphalt planings market at national level could be identified. As a result, from 2008 onward, MPA assumed total asphalt planings to follow the trend in MPA asphalt sales, a proxy for general road maintenance activity."*

3.4 ADEPT – Local Authority Survey

To understand the current situation regarding asphalt recycling within local authorities a survey questionnaire was prepared by AJJV. The survey was distributed to all ADEPT members via the ADEPT Soils and Materials Design and Specification Group on the 18th December 2018.

The survey comprised of a number of multiple choice and open questions in relation to current recycling rates. In total ten responses, were received from local authorities in England. This represents a relatively small sample of overseeing authorities and therefore the results should be treated with a degree of caution.

3.4.1 Average reclaimed asphalt content of surface course materials

Authorities were requested to provided the average reclaimed asphalt content of surface course materials installed on their network. The responses are summarised in Figure 3.2.

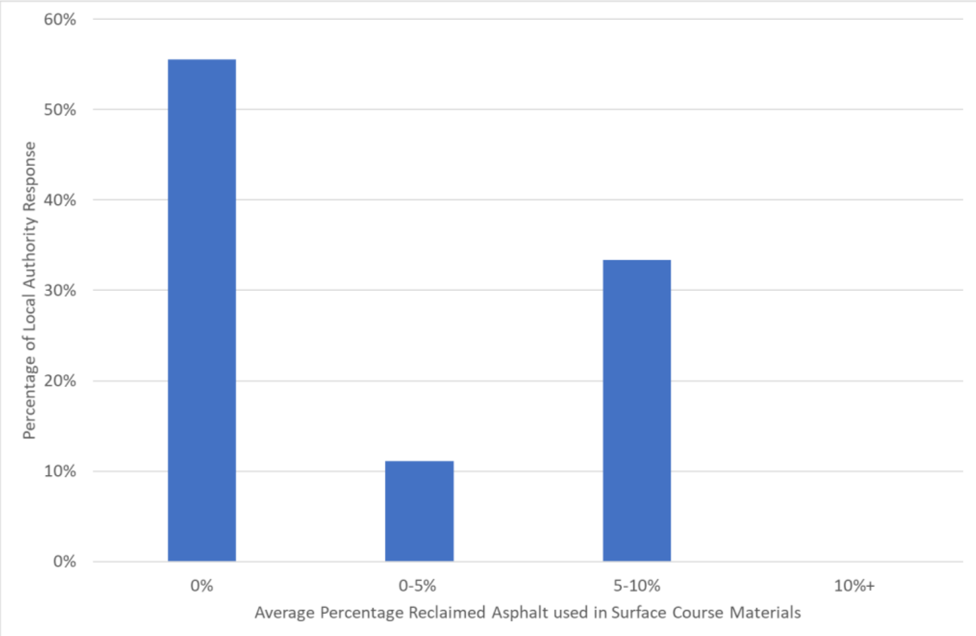


Figure 3.2 – Average reclaimed asphalt content of surface course used by local authorities

The data indicates that the majority of local authorities (56%) who responded to the survey do not incorporate recycled asphalt into surface materials. Approximately,44% reported that they incorporate up to 10% reclaimed asphalt into surface course materials.

For local authorities that incorporated reclaimed asphalt into surface course materials, 80% responded to confirm that RA used was from a known source. With the majority of local authorities stating the RA was primarily from their own network. 20% of local authorities reported that the source of RA was unknown.

3.4.2 Average reclaimed asphalt content used in bituminous binder and base course materials

Local authorities were requested to provide the average reclaimed asphalt content of binder and base course materials installed on their network. The responses are summarised in Figure 3.3.

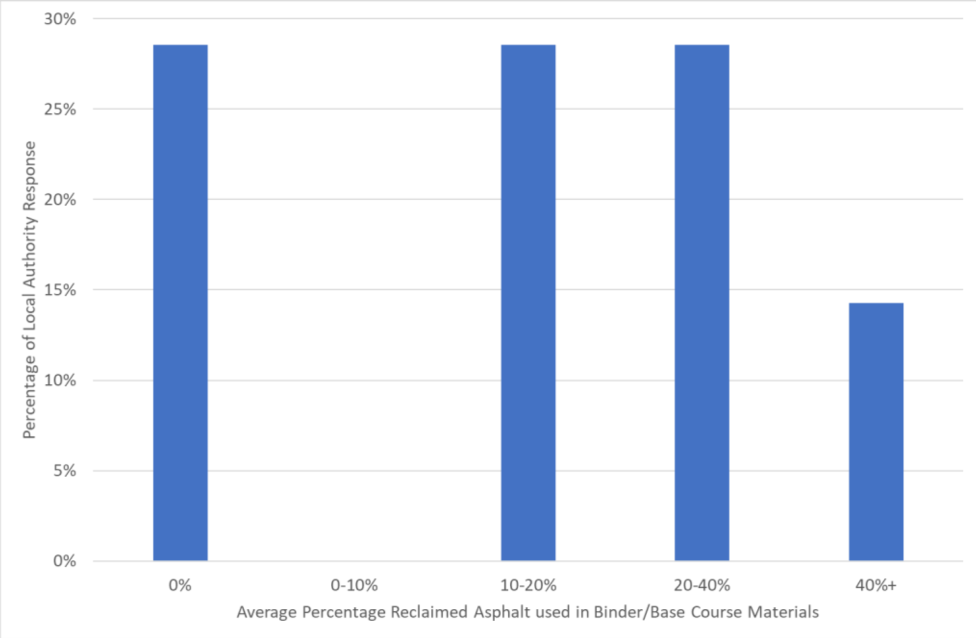


Figure 3.3 – Average reclaimed asphalt content of binder and base course used by local authorities

The data indicates the level of reclaimed asphalt in binder and base course supplied to local authorities is highly variable. 29% reported reclaimed asphalt is not used, 29% reported that between 10-20% is incorporated, 29% reported that between 20-40% is incorporated and 14% reported that in excess of 40% of reclaimed asphalt is incorporated.

3.4.3 Ex-situ Cold Recycled Bitumen Bound Materials

Local authorities were asked if they used Ex Situ Cold Recycled Bitumen Bound Materials on their networks. The responses are summarised in Figure 3.4.

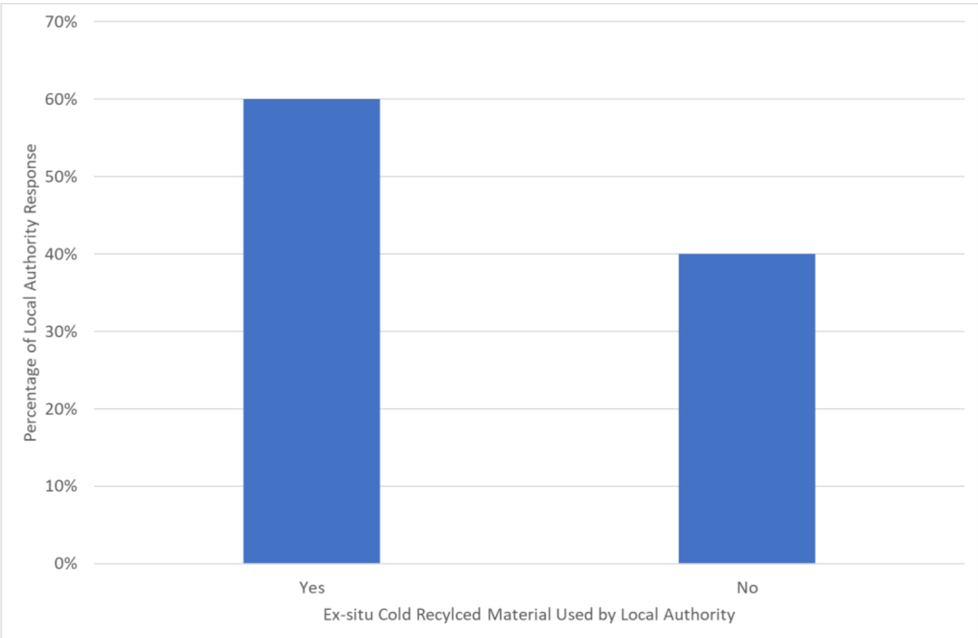


Figure 3.4 – Percentage of local authorities which use Ex-Situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 948

The data indicates that 60% of local authorities use Ex-situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 948. Where used, the typical annual production per local authorities ranged from 10,000T to 30,000T per year; with an average annual production of 16,500T.

All respondents using Ex-situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 948 reported using Quick Visco-Elast materials with either a Class B3 or Class B4 stiffness.

Based on the responses provided tar was identified as the key driver for the Ex-situ Cold Recycling programmes.

3.4.4 In-situ Cold Recycled Bitumen Bound Materials

Local authorities were asked if they used In-Situ Cold Recycled Bitumen Bound Materials on their networks. The responses are summarised in Figure 3.5.

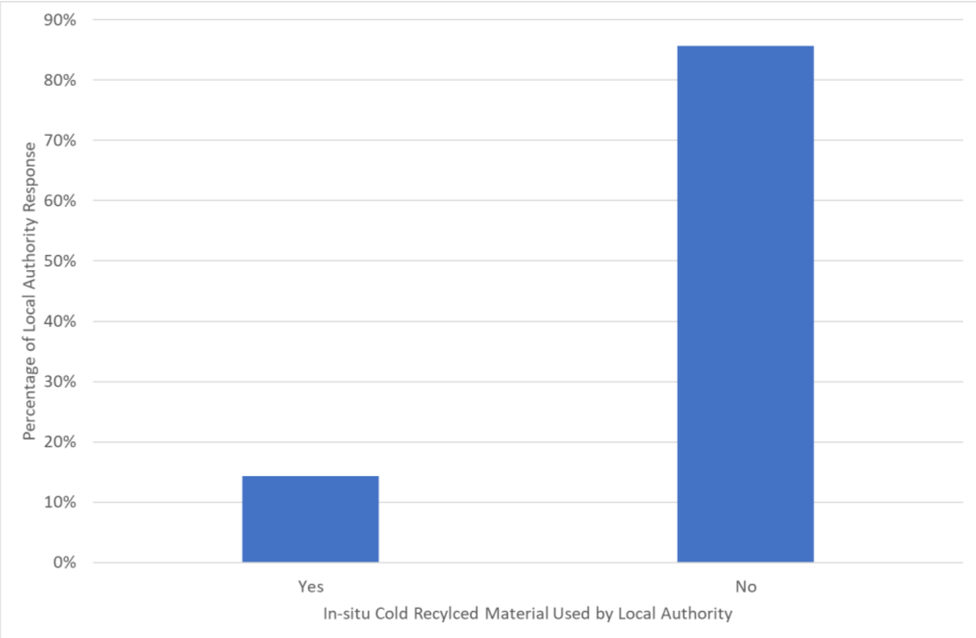


Figure 3.5 – Percentage of local authorities which use In-situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 947

The response indicates that the use of In-situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 947 by the local authorities that responded is limited. 14% of those who responded use In-situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 947. A number of authorities responded to state that they used In-Situ Cold Recycling but with hydraulic binders only.

3.5 Analysis of Environment Agency - Published Waste Data Interrogator Tool

Analysis of the Environment Agency, Waste Data Interrogator Tool was also conducted to assess the quantity of bitumen bound and tar bound asphalt wastes coded as 17-03-01 (bituminous mixtures containing coal tar), 17-03-02 (bituminous mixtures other than those mentioned in 17-03-01), and 17-03-03 (coal tar and tarred products) in the European Waste Catalogue (EWC). It is important to note that this data set represents operators of regulated waste management facilities in the UK and is not specific to Highways England or individual authorities. The analysis conducted indicates:

- 1.5 Mt of bituminous bound, tar bound, and tarred products were received as waste at permitted sites in 2014; and
- 0.3 Mt of bituminous bound, tar bound, and tarred products were removed as waste from permitted sites in 2014.

Assuming that the majority of these materials were subject to waste recovery processes (having already removed any waste allocated a disposal code from data set) the data indicates recovery rate of approximately 80% for bitumen bound and tar bound waste in 2014.

This trend is further continued in the subsequent Waste Data Interrogator Tool submissions:

- 2015: 1.7 Mt received, and 0.3 Mt removed; estimated recovery rate of 84%;
- 2016: 2.2 Mt received, and 0.3 Mt removed; estimated recovery rate of 85%; and
- 2017: 2.4 Mt received, and 0.3 Mt removed; estimated recovery rate of 88%.

This method assumes that the quantity of bitumen bound and tar bound waste beneficially recovered at permitted sites, within a given year, can be estimated through the total quantity of bitumen bound and tar bound waste received at permitted transfer, treatment and recovery sites (inputs) in the reporting year minus the total quantity of bitumen bound and tar bound waste leaving the permitted transfer, treatment and recovery sites (outputs) in the same reporting year.

As any bituminous bound and tar bound waste assigned with a disposal code were removed from the data set, it can be inferred that any bitumen bound and tar bound materials arriving as waste at a permitted transfer, treatment or recovery site, but not leaving a site as waste may have been used beneficially to replace primary materials which would otherwise have been used to fulfil a particular function (i.e. having achieved end of waste status, under the WRAP Quality Protocol 'Aggregates from Inert Waste: End of waste Criteria for the Production of Aggregates from Inert Waste' for example).

Alternatively, this material could have just been crushed and mixed with other non-hazardous mineral wastes before being reclassified. This method therefore does not account for any bitumen bound and tar bound waste that may have been received at a waste facility coded as wastes from Construction and Demolition (C&D) activities (EWC Chapter 17) and then reclassified as it passed through treatment and transfer station as waste from the mechanical treatment of waste at a waste management facility (EWC Chapter 19). This would include, for example, any bituminous waste that has been crushed and mixed with other similar mineral wastes from C&D and other Commercial & Industrial (C&I) activities.

This method also inevitably captures the recovery of asphalt waste in bituminous bound / hydraulically bound and unbound pavement applications, as well as non-highways uses

It is also worth noting that operator waste returns are public register information unless a claim for commercial confidentiality has been put forward by the waste operator and it accepted by the Environment Agency. It may therefore be the case that some waste returns for permitted asphalt recycling facilities may have been excluded from the data set on the grounds of substantiated confidentiality.

3.6 DEFRA Statistical data set ENV23 – UK statistics on waste – October 2018

A review of 'Statistical data set ENV23' was conducted. This data set covers the waste generation and management figures for the whole of the UK. These statistics are compiled to comply with EC Waste Framework Directive (2008/98/EC) and EC Waste Statistics Regulation (2150/2002/EC) reporting requirements.

The review has enabled the following high-level conclusions to be drawn for 2014, the most recent data available, covering 'Mineral Waste from Construction & Demolition (C&D)' activities:

- 53.7 Mt of 'Mineral Waste from C&D' was generated in England in 2014;
- 51.5 Mt (87.8%) of 'Mineral Waste from C&D' in England was sent for final treatment in 2014, split by the following methods of treatment:
  - Recovery other than energy recovery – Except backfilling: 48.3 Mt (93.7%);
  - Recovery other than energy recovery – Backfilling: 1.1 Mt (2.2%);
  - Deposit onto or into land: 2.1 Mt (4.1%).

The data confirms that the vast majority (93.7%) of 'Mineral Wastes from C&D' activities in England were subject to a recovery method (other than energy recovery, backfilling and deposit onto land) in 2014. Mineral Wastes from C&D activities are assigned a European Waste Classification for Statistics (EWC-STAT) code of 12.1. This code covers a wide range of mineral wastes including: concrete, bricks and gypsum waste; bituminous and tar bound road-surfacing waste; and certain mixed construction wastes streams.

No additional breakdown is provided in Statistical data set ENV23, as this is not required for the purposes of the Waste Statistics Regulation return for the European Commission, and it is therefore not possible based on the current methodology, to determine precisely what proportion of bituminous and tar bound road-surfacing materials are currently subject to waste recovery.

3.7 HM Revenue and Customs, National Statistics Aggregates Levy Bulletin

A review of the HM Revenue and Customs, National Statistics Aggregates Levy Bulletin was also conducted. The Aggregates Levy is defined by HMRC (2014) as "*a tax on the commercial exploitation in the UK of rock, sand and gravel, and is due from any business that quarries, dredges or imports these products*".

The data was considered to be of limited value in establishing the current rate of asphalt recycling as the data sources do not contain sector information.

3.8 Summary

A review of the current recycling rates nationally based on published literature and data analysis has demonstrated:

- It is estimated by EAPA (2017) that approximately 3,400,000 Tonnes of reclaimed asphalt was available in 2017 with 90% estimated to be re-used in hot mix, warm mix applications and cold recycled applications. This equates to 15% of total asphalt production.
- Estimates by MPA (2019) predicted that a great level of asphalt planings was available in Great Britain in 2017 with 6,100,000 Tonnes available.
- Based on published literature it appears that between 5-15% of total RAP is cold recycled.
- A survey of local authorities facilitated by ADEPT supports these findings with 56% of respondents reporting that they do not incorporate recycled asphalt into surface material and 44% reporting that they incorporate up to 10% reclaimed asphalt into surface course materials. No respondents reported that they regularly exceed 10% reclaimed asphalt although specific case study examples and trial sites have been reported.
- The survey responses from local authorities indicates the level of reclaimed asphalt incorporated in binder and base course supplied to local authorities is highly variable. Approximately 29% reported reclaimed asphalt is not used, 58% reported that reclaimed asphalt is used within standard with reclaimed asphalt contents between 10-40% and 14% reported that in excess of 40% of reclaimed asphalt is incorporated.
- Local authority responses regarding cold recycling was also variable. 60% of local authorities reported that they use Ex-situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 948 with an average annual production of 16,500T per authority.
- In contrast, the use of In-situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 947 was limited to only 14% of the local authorities who responded.
- Tar was reported as a key driver for the use of Cold Recycled Bitumen Bound Materials.
- Analysis of the Environment Agency, Waste Data Interrogator Tool indicates 88% of bitumen bound and tar bound asphalt wastes codes defined in the EWR are recovered.
- The review undertaken indicates that there is no central source of data that full captures the use of reclaimed asphalt in bituminous materials and the regional/overseeing authority variations. This is consistent with the findings from MPA (2019).

4. Asphalt Recycling on the Strategic Road Network in England – Current Situation

4.1 Introduction

Sub-task 1 requires the current situation regarding asphalt recycling on the Strategic Road Network (SRN) in England to be established. The aim of this sub-task is to understand the recycling rates and techniques currently used on the SRN.

A range of Highways England data sources were reviewed to understand the current recycling levels and techniques used on the SRN. These included:

- WSP/Parson Brinckerhoff (2014) - Sustainable Pavements: Materials Brokerage Service Study;
- Highways Agency Pavement Management System (HAPMS);
- Departure from Standard (WebDAS);
- Highways England Primary Data from Carbon Reporting;

The chapter summarises the findings from each data source.

4.2 WSP/Parson Brinckerhoff (2014) - Sustainable Pavements: Materials Brokerage Service Study

A market research study of sustainable pavement materials was conducted by WSP/ Parsons Brinckerhoff in 2014. The WSP/PB (2014) study was conducted on behalf of Highways Agency and comprised of a fact-finding questionnaire and direct interviews with leading asphalt Contractors regarding hot mix asphalt recycling.

The WSP/PB (2014) study concluded:

- *“Only about 10% of existing material is recycled back into the same layer on the Agency network.”*
- *“Currently on the HA network between 15 and 30% of asphalt planings are recycled into a lower asphalt layer, with the majority being sold off to other parties for uses other than asphalt.”*
- *“No planings are recycled into surface course layers”*

The WSP/PB (2014) study also examined the relationship between the generation of reclaimed asphalt and re-use on the Strategic Road Network. The study concluded:

- *“A general range of between 15-30% asphalt planning material taken into the supply chain’s own stockpile was considered as a true reflection of the industry. It can be assumed that most of this is recycled back through the asphalt plant.”*
- *“A broader range of between 35 -80% was sold on to other parties. The final usage of these products could not be determined, but it is considered unlikely that any of this ends up in new surface layers”.*
- *“No realistic numbers could be generated here, although it was estimated that between 10 and 20% of total planings handled came from HA sites. Smaller, more local plants have also been strategically set up to supply HA contracts and do report volumes up to 60%”.*

The study acknowledged that there was a low rate of returns to requests and concluded the “*issue of reuse of materials is indeed a sensitive subject in the marketplace.” ....” It was also noted that previous such questionnaire requests from the supply chain have yielded similar low returns”.*

4.3 Analysis of Highways Agency Pavement Management System (HAPMS) Data

4.3.1 Introduction

The Highways Agency Pavement Management System (HAPMS) provides a record of the pavement construction and condition data for the SRN.

Analysis of records contained within HAPMS was undertaken to provide a snapshot of:

- The quantities and locations/extents of recycled pavement layers on the SRN;
- Potential case studies for further investigation.

HAPMS data was considered to be beneficial for providing a snapshot of recycling rates because:

- The data source is readily available and is the standard method of recording the existing construction and treatments applied.
- The data covers the entire SRN.
- The data provides both historic and recent treatments.

It is important to note that there are a number of limitations associated with this data source:

- The data is dependent upon accurate records being provided by the supply chain and imported into HAPMS.
- The “Recycled Asphalt Layer” may not capture low-levels of asphalt recycling into standard materials and fully reflect the levels of recycling on the SRN.
- The source data may not differentiate between specific techniques.

4.3.2 Data Extraction & Analysis Methodology

HAPMS records were extracted by the Highways England HAPMS Data Team and provided to AJJV on the 4th September 2018. The records covered the full extent of the SRN.

Two recycled material types of interest to this study were identified from the reporting procedures defined in document SU159 – Bulk Loading of Construction Data Using “XML Import Elements” as shown in Table 4.1.

Table 4.1 - HAPMS Recycling Layer

Code	Description	Additional Attributes to be Extracted
RAL	• Recycled Asphalt Layer	• “recycled_asphalt_temperature” attribute containing a valid Recycled Asphalt Temperature code or description. • “recycled_asphalt_insitu” attribute containing a valid integer number between 0 and 100, being the percentage of material recycled from the existing road. • “recycled_asphalt_imported” attribute containing a valid integer number between 0 and 100, being the percentage of imported recycled material
RCYFB	• Recycled (Foamed Bitumen)	

The HAPMS data for the two material types was extracted for the full SRN, in addition to the inventory attributes and construction year.

4.3.3 Data Analysis & Conclusions - Cold Recycling

Analysis of the HAPMS construction data identified a number of records for Recycled (Foamed Bitumen). The notes associated with the HAPMS entry identified two further sub-categories:

- Recycled (Foamed Bitumen);
- Recycled (Foamed Bitumen with Tar Bound Material/Planings);
- Recycled Asphalt Layer (Cold)

The data was analysed per sub-category to establish the equivalent tonnage of cold recycled material installed on the SRN between 2000 and 2017. The data is presented in Figure 4.1 and Table 4.2.

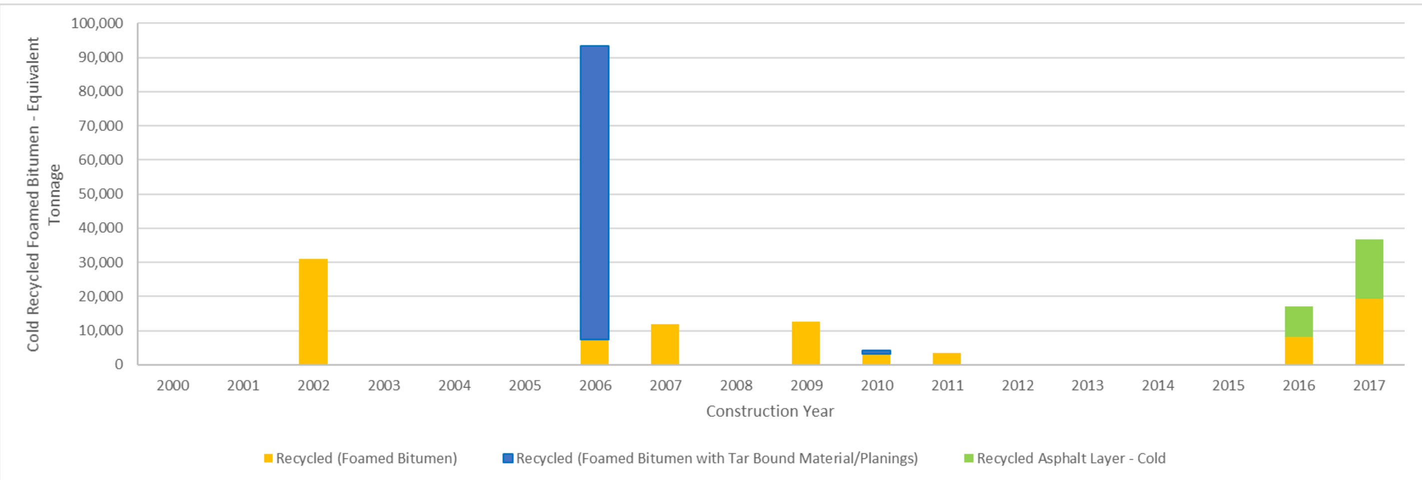


Figure 4.1 Cold Recycled Foamed Bitumen/Recycled Asphalt Layer Cold (equivalent tonnage) laid on the SRN from year 2000 based on HAPMS Records

Table 4.2 - Cold Recycled Foamed Bitumen/Recycled Asphalt Layer Cold (equivalent tonnage) laid on the SRN from year 2000 based on HAPMS Records

Material Type	Estimated Tonnage per Year																		
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Recycled (Foamed Concrete)	0	0	31,018	0	0	0	7,318	11,810	0	12,555	3,112	3,393	0	0	0	0	8,251	19,318	**96,775**
Recycled (Foamed Concrete with Tar Bound Material/Planings)	0	0	0	0	0	0	86,026	0	0	0	1,215	0	0	0	0	0	0	0	**87,242**
Recycled Asphalt Layer (Cold)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8,837	17,504	**26,341**

The analysis of the Recycled (Foamed Bitumen) and Recycled Asphalt Layer (Cold) data indicates:

- The levels of cold recycling on the SRN is limited with the equivalent of 210,357T installed over an 18-year period.
- The application of cold recycling has been highly variable with cold recycling only installed in 8 out of 18 years.
- The use of cold recycling peaked in 2006, comprising approximately 50% of all cold recycling using foamed bitumen installed on the SRN since 2000. The records indicate this is attributed to the reconstruction of the A38 in 2006. The records indicate the recycling of tar bound materials may have been a key driver for the recycling.
- Since 2010, the use of cold recycling has been limited. This may be associated with restriction on lane closures.
- In recent the years the level of cold recycling has increased. The HAPMS records indicates in 2016 and 2017 approximately 53,910T were installed on sites including the A21, A1, A1(M) and A66. This primarily appears consistent with an in-situ cold downcut recycling as assessed as part of the Departures from Standard discussed in Section 4.4.
- Based on the HAPMS data, the most significant programmes of cold recycling have taken place in Highways England Area 1 and Area 14. The use of cold recycled materials is also present in Areas 3, 4, 7 and 9.

4.3.4 Data Analysis & Conclusions – Recycled Asphalt Layer (Hot Lay)

Analysis of the HAPMS data for the material entry recycled asphalt layer (hot lay) was undertaken between 2000 and 2017. The analyse identified very limited entries and the data was not considered to be representative of the current levels of reclaimed asphalt being incorporated into hot mix materials. The data has therefore been excluded from this report and it was concluded that recycled contents of bituminous materials are not currently captured within HAPMS.

4.4 Analysis of Departures from Standard (WebDaS)

4.4.1 Introduction

Under the current standard and specifications, the following items require a departure from standard:

- MHW Clause 947 – In-situ Cold Recycled Bound Material & MCHW Clause 948 - Ex-situ Cold Recycled Bound Material - Departure from Standard are from the Overseeing Organisation for all cold recycled base mixtures apart from ex-situ stabilised Quick Visco-Elastic (QVE) base material comprising a minimum 3% bituminous binder and a minimum 1% cement, known as foamed asphalt, and classified as Zone B2 material, for a maximum cumulative design traffic up to 30msa. Departures from standard are also required for any technique that does not fully comply with the MCHW 947 requirements such as the downcut technique.

- Current practice in the UK is to permit up to 10% reclaimed asphalt (RA) in surface course mixes as detailed in the Specification for Highway Works (SHW) Series 902, BS EN 13108 and BSI PD 6691. Increasing the percentage of RA above 10% requires an increase in quality control and performance testing together with approval from the Overseeing Organisation.

The Highways England WebDAS (Departures Approvals System) provides an electronic system designed to allow submission of new departures and searching of existing departures.

Analysis of departures from standards from WebDaS was therefore conducted to provide a snapshot of current cold recycling rates and the level of hot mix recycling beyond existing specification limitations. The data source was also used to identify case studies of interest.

Departures from Standards were considered a suitable source of information as the data source is readily available, the data covers the entire SRN and specific details are provided on each technique used.

The main limitation of this approach is that the data source will not identify any recycling that is permitted within current standards and specifications. This includes the routine recycling reclaimed asphalt into hot bituminous materials and cold ex-situ recycling complying with Zone B2 or greater for design traffic levels up to 30msa.

4.4.2 Data Extraction & Methodology

A master list of departures approved in relation to the SHW Clauses shown in Table 4.3 was extracted from WebDAS by the Highways England – Departures from Standard team from 2001 to January 2019 and provided to AJJV. This period provided historic records and a snapshot of the Road Investment Strategy (RIS1 period). Additional supporting information (where available) was also extracted.

Table 4.3 – Departure from Standards Assessed in WebDAS

SHW Clause	Description
947	• In Situ Cold Recycled Bound Material
948	• Ex Situ Cold Recycled Bound Material
926	• In Situ Recycling: The Repave Process
902	• Reclaimed Asphalt

The data provided was analysed and a master list of departures and key sites of interest are summarised for cold recycling and hot mix recycling in sections 4.4.3 and 4.4.4, respectively.

For hot mix surface course recycling an earlier search was conducted as part of Highways England SPATS Task 1-111 (Chibuzor, 2017). The Departures from Standard extracted as part of Task 1-111 have been reproduced for completeness.

4.4.3 Data Analysis & Conclusions - Cold Recycling

A master list of all cold recycling departures from standard covering in-situ and ex-situ cold recycling for the period January 2009 to January 2019 is presented in Table 4.4. The data demonstrates twenty departures have been submitted over the last ten years in relation to cold recycling.

In total, eight departures have been approved by Highways England for the application of ex-situ cold recycling (SHW Clause 948). Twelve departures have been approved by Highways England for the application of in-situ cold recycling. The departures were in relation to SHW Clause 947.

A significant number of the cold recycling departures reference the use of the downcut technique as described in Chapter 2.6.1. This is consistent with the paper titled "*Highways England Way Forward – In-situ Downcut Recycling*", which states "*At least 7 departures have been granted for this process to be used on the SRN in the past two years. The first 3 schemes were concerned with learning about the* *process and how to specify the work. Originally a hot bitumen emulsion was used with a surface course. This evolved to become foamed bitumen with about 3.5% cement added.*

To safeguard the level of risk to Highways England a guide document was produced and recent departures require as a condition adherence to the guide. The main changes from the initial trials are the requirement for two-layer surfacing and the use of a bond coat if the base of the recycled layer is on a bound layer. There are also some discussion/requirements for appropriate site control measures to ensure a satisfactory product."

All the departures were designed based on a 20-year design life and most trial sites have a relatively low design traffic up to 30msa. Only two locations on the A1(M) are recorded with design traffic greater than 30msa (130.17msa) for an expected in 20 years' design life.

Table 4.4 - Summary of departure from standards approved in WebDaS for the application of cold recycling between 2009 and 2019.

DfS ID	Submitted	WebDAS	Contractor	Departure Specification	Road	Section Details	Design Life (Yrs)	Design Traffic (msa)	Treatment Depth	Tar reported in existing construction
52965	01/06/2009	Not Defined	Not Defined	Ex-situ Cold Recycling (SHW Cl. 948)	M25	J16 TO J23	N/A	min. 30 msa	Base layers of new hard shoulder	
53310	01/06/2009	Not Defined	Not Defined	Ex-situ Cold Recycling (SHW Cl. 948)	M25	J27 TO J30	N/A	min. 30 msa	Base layers of new hard shoulder	
56881	30/10/2009	Not Defined	Not Defined	Ex-situ Cold Recycling (SHW Cl. 948)	M25	J16 TO J23	N/A	min. 30 msa	Base layers of new hard shoulder	
69014	13/09/2013	Not Defined	Not Defined	Ex-situ Cold Recycling (SHW Cl. 948)	M1	J28 TO J31	N/A	N/A	Base layers of offside lane and central reserve	
69015	13/09/2013	Not Defined	Not Defined	Ex-situ Cold Recycling (SHW Cl. 948)	M1	J32 TO J35A	N/A	N/A	Base layers of offside lane and central reserve	
77427	18/01/2016	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A1	A1 WEST MOOR TO NEWTON ON THE MOOR	20	13.7	50-200	
77728	13/05/2016	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A1	A1 BROWNSIDE BYPASS RESURFACING SB	20	10.93	65-205	
80287	29/06/2017	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A1M	A1(M) DISHFORTH TO RIPON NB (RECYCLING)	20	130.17	80-230 (lanes 1&2) 50-100 (lane 3 and hard shoulder)	
80288	29/06/2017	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A1M	A1(M) DISHFORTH TO RIPON SB (RECYCLING)	20	130.17	80-230	
80335	30/06/2017	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A66	A66 ELTON TO LONG NEWTON WB	20	16.89	100-230 (lane 2 only)	

DfS ID	Submitted	WebDAS	Contractor	Departure Specification	Road	Section Details	Design Life (Yrs)	Design Traffic (msa)	Treatment Depth	Tar reported in existing construction
						(RECYCLING)				
80745	18/08/2017	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A1	A1 WANDYLAW TO WARRENFORD (COLD RECYCLING)	20	20	65-215	
81115	06/12/2017	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A66	A66 ELTON TO LONG NEWTON WB (RECYCLING)	20	16.89	100-300	
81659	19/03/2018	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A1	A1 BROWNIESIDE BY-PASS NB RECYCLING	20	20	80-200	
82301	27/06/2018	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A1M	A1(M) RIPON TO LEEMING NB	20	20	80-230	
73983	17/06/2015	Approved with comments	Tarmac	Ex-situ Cold Recycling (SHW Cl. 948)	A21	DEV A21 TONBRIDGE TO PEMBURY	20	up to 20.08	N/A	Yes
77078	24/02/2016	Approved with comments	Not Defined	In-situ Cold Recycling (SHW Cl. 947)	A11	A11 FIVEWAYS TO THETFORD	20	N/A	N/A	
80091	24/04/2017	Approved	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A63	A63 NRTCVE-WELTON PAVEMENT	20	13.7	40- up to 180	
80617	02/08/2017	Approved with comments	Not Defined	Ex-situ Cold Recycling (SHW Cl. 948)	A19	A19/A1058 COAST ROAD	N/A	up to 30	N/A	Yes
82351	28/06/2018	Approved with comments	Lane Rental	In-situ Cold Recycling (SHW Cl. 947)	A590	C001 A590 PIG WILLY WOOD TO JN 36	20	13.7	100-200	
83176	16/01/2019	TBC	TBC	Ex-situ Cold Recycling (SHW Cl. 948)	M6	J21A to J26	N/A	max. 30msa	Base layers in All Lane Running Lane 4 and central reserve.	

A plot of the number of departures submitted per year between 2009 and 2019 is shown in Figure 4.2. This indicates the number of departures submitted for cold recycling has been variable throughout this period. The number of the departures submitted in recent years has increased, which is associated with the use of the in-situ recycling downcut technique.

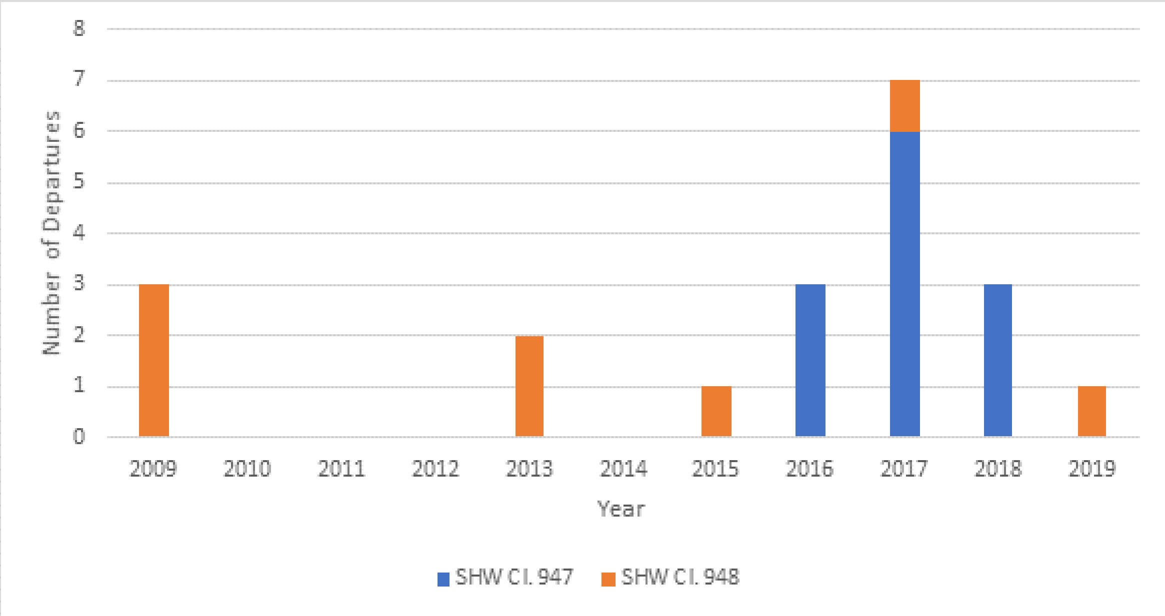


Figure 4.2 Number of departures submitted per year for cold recycling between 2009 and 2019

A comparison of the departures from standards with the HAPMS data sources was conducted to further understand how cold recycled materials are being recorded in HAMPS. The data indicates that of the twenty departures from standard submitted, the cold recycled layer could only be identified in the HAPMS construction records for four of these sites. All four sites related to the cold in-situ recycling using the downcut technique. With one site recorded as Recycled (Foamed Bitumen) and three sites recorded as Recycled Asphalt Layer (cold lay). The comparison between the data sources indicates that the actual tonnage of cold recycled material installed on the SRN may be higher than the estimated values from analysis of the HAPMS data.

4.4.4 Data Analysis & Conclusions – Hot Mix Recycling

To provide a better understanding of the quantity and frequency of RA material being used on the SRN within hot mix asphalt materials, an analysis of the relevant departures from standards was conducted.

The departures from standard since 1997 to 2009 has previously been reported by Chibuzor (2017) as part of Task 1-111 and is reproduced in Table 4.5 for completeness. The data shows there were nineteen departure records associated with hot mix surface course and binder/base recycling levels above current specification in this period.

A further list of all hot mix recycling departures from standard was extracted for the period 2009 to November 2018 and is presented in Table 4.6. This shows a further two departures were approved in this period, with one of these related to surface course recycling and the other associated with Roadmender patch repairs.

Overall, the analysis of the departures from standards indicates only a limited number of departures for hot mix surface courses containing reclaimed asphalt quantities in excess of 10% have been approved on the SRN. The reclaimed asphalt quantities approved range from 20% and 40%. It is important to note that the number of departures from standard submitted is relatively low with only twenty one departures from standard submitted over a total 21-year period. This indicates that the majority of reclaimed asphalt incorporated into surface course on the strategic road network is within standard.

No departures from standard have been submitted for binder and base course materials in excess of 50% indicating that all recycling into these layers are within current standard and specification.

Table 4.5 - Summary of departure from standards approved in WebDaS for hot mix surface course recycling from 1997 to 2009 (reproduced from Chibuzor 2017)

Departure	Contract	Road	Standard	Status	Date archived	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.

Departure	Contract	Road	Standard	Status	Date archived	Departure summary
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
329558	ECC	M6	Additional Clause	Approved	30/05/2002	Departure required as the SHW does not address maintenance works
48012	DBFO	M25	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	DBFO	M25	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 sourced 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

Table 4.6 - Summary of departure from standards approved in WebDaS for the application of hot mix surface course recycling between January 2016 and November 2018

Departure	Contract	Road	Standard	Status	Date archived	Departure summary
78030	DBFO	M20	Clause 942.5 - Thin Surface Course System Aggregate requirement	Approved with comments	27/06/2016	This Departure is proposed in order to carry out a trial using 30% recycled high PSV aggregate in Tarmac's 14mm Ultipave thin surfacing material on the M20 A carriageway between J2 and J3 in lane 2. The recycled aggregate comes from a known source and has been subject to Tarmac's Quality Plan for High PSV RAP into thin surfacing. The RAP is segregated from other recycled materials, tested for PSV and then used in a mix design for the 14mm Ultipave to demonstrate that the material is fully compliant with the performance requirements of SHW Cl942.
78739	ASC	ASC 9 PAVEMENT HOTBOX	HD 36/06 - DMRB Vol 07 Section 5	Approved with comments	10/01/2017	KIER Highways - Area 9 Wide Roadmender. To introduce the concept of a large hand lay hot patch (between 1 and 25 square metres per patch) as an alternative to a machine laid emergency scheme. The material will incorporate 30% recycled planings (from TSCS) and comply with the specification for HRA 55/10.

A plot of the number of departures submitted per year between 1999 and 2018 is shown in Figure 4.3. Considering the majority of these departures from standard were related to 1997, the data indicates that requests for departures from standard in recent years has been severely limited and has not increased with time. The majority of departures from standard have been submitted by Design, Build, Finance and Operate (DBFO) contracts including the recent departs from standard on the M25.

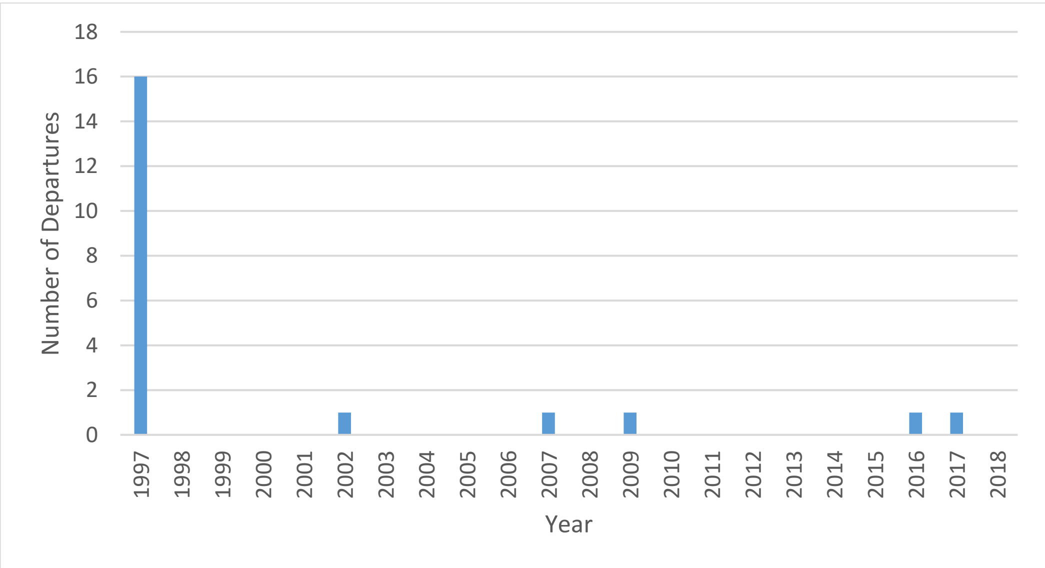


Figure 4.3 Number of departures submitted per year for reclaimed asphalt in hot mix surface course above permitted limits between 1997 and 2018

4.5 Highways England Primary Data from Sustainability/Carbon Reporting

A number of Highways England Area teams were consulted to understand if the use of reclaimed asphalt is recorded as part of carbon/sustainability report. The feedback received from a number of area teams is that data regarding the use of reclaimed asphalt is not readily available or could not be identified from the reporting statistics.

4.6 Summary

A range of Highways England data sources were reviewed to understand the current recycling levels and techniques used on the SRN including HAPMS, Departures from Standard and Carbon/Sustainability reporting. The reviewed consider both hot mix recycling and cold recycling.

The review of hot mix recycling on the SRN has indicated:

- A central source of data is not available to record and monitor the levels of reclaimed asphalt incorporated into hot mix bituminous material and installed on the SRN.
- Previous assessments by WSP/Parson Brinckerhoff (2014) have indicated the incorporation of reclaimed asphalt into surface courses is limited.
- The analysis of the departures from standards indicates only a limited number of departures for hot mix surface courses containing reclaimed asphalt quantities in excess of 10% have been approved. This indicates that the majority of reclaimed asphalt incorporated into surface course on the strategic road network is within standard.
- In total twenty one departures were submitted over a 21- year period. Considering the majority of these departures from standard were related to 1997, the data indicates that requests for departures from standard in recent years has been severely limited and has not increased with time.
- For the twenty one departures submitted, the reclaimed asphalt quantities approved ranged from 20% and 40%. The sites recorded through WebDaS present an opportunity to assess the performance of surface courses incorporating reclaimed asphalt above 10%.
- Previous assessments by WSP/Parson Brinckerhoff (2014) indicated between 15 and 30% of asphalt planings are recycled into the lower asphalt layers.
- No departures from standard have been submitted for binder and base course materials in excess of 50% indicating that all recycling into these layers is within current standard and specification.

The review of cold recycling on the SRN has indicated:

- The levels of cold recycling on the SRN is limited with the equivalent of 210,357T installed over an 18-year period.
- The application of cold recycling has been highly variable with cold recycling only installed in 8 out of 18 years.
- The use of cold recycling using foamed bitumen peaked 2006, comprising approximately 50% of all cold recycling using foamed bitumen laid on the SRN since 2000.
- Since 2010 the use of cold recycling has been limited, however in recent the years the level of cold recycling has increased due to the application of the in-situ downcut technique. Both the HAPMS data and departure from standard records indicates there has been a significant programme of in-situ cold recycling using the down cut technique.
- The data demonstrates twenty departures have been submitted over the last ten years in relation to cold recycling. At least seven departures from standard are associated with the in-situ downcut technique. This indicates that the majority of cold recycling is current being specified within standard, with the key exception of the in-situ downcut technique.
- The records indicate that the impact of asphalt waste containing coal tar has been a key factor in the application of the cold recycling on a number of schemes.

5. UK Market Capabilities

5.1 Hot mix and Warm mix Production

The EAPA (2017) indicates 165 (66%) out of a total of 250 plants in Great Britain had a recycling capability in 2016. The level of this capability is not defined in the EAPA (2017) figures.

Indicative figures reported by Carswell (2010) indicates:

- "*Between 10 – 20% of Asphalt Plants have the capability to recycle 10 – 15% of RAP.*
- *Up to 20% of Asphalt Plants have the capability to recycle over 30% RAP.*
- *Remaining could be able to accept up to 10% RAP".*

WSP/Parson Brinckerhoff (2014) reported *"A large capital investment is required by asphalt supply plants to allow the introduction of more than 25% planings into a new mix. Less than 5% of existing plants have made this investment".*

The EAPA (2017) figures indicate a significant proportion of asphalt plants in Great Britain have a recycling capability. The figures reported by Carswell (2010) and WSP/Parson Brinckerhoff (2014) suggests that the majority of asphalt plants have relatively low level of recycling capability with only a limited number of plants with high recycling capabilities.

It is understood through consultation with industry suppliers that the majority of UK asphalt plants which have the capability to add reclaimed asphalt in various proportions used cold feed technologies. Consultation with industry has identified the following seven asphalt plants in the Great Britain operate a parallel drum system:

Table 5.1 – Asphalt Plants in Great Britain Operating a Parallel Drum System

Company	Location
Eurovia	• Dagenham
Hansons	• West Drayton
Tarmac	• Ipswich
Tarmac	• Hayes
Tarmac	• Hillwood
FM Conway	• Erith
FM Conway	• Heathrow

It is understood that there are no RAP priority plants (see Section 2.3.3) in the UK.

WSP/Parson Brinckerhoff (2014) report that "*Most of the Supply Chain with their own stockpile sites operate some form of stockpile management, with weighbridges and screening facilities. None separate the materials by binder type, and only a fraction is stored by PSV value*."

It is understood through industry consultation that the most common processing of reclaimed asphalt is through crushing and screening. It is understood that only one granulator plant is operated in the UK by FM Conway.

5.2 Cold Recycling

Through consultation with the Wirtgen Group Limited, it is estimated that there are currently the following number of cold recycling machines in the UK:

- Ex-situ Cold Recycling Plant: 24 active plants.
- In-situ – Cold Recycling Machines (Bitumen Emulsion and Foamed Bitumen) – Upcut: 30 active machines.
- In-situ – Cold Recycling Machine (Bitumen Emulsion and Foamed Bitumen) – Downcut: 1 active machine.

Based on the above number of plants, it is estimated that in the UK there is the potential to produce over 4,000,000T of ex-situ cold recycled materials per year.

It is understood that there is one In-situ Recycling Machine with downcutting capability in UK operated by Lane Rentals (see Section 2.5.1 for details of site treated on the SRN). It is understood that this plant has the capability to recycle 1km per day or 60,000T per Summer. In contrast, it is understood that there are twelve in-situ recycling machines with downcutting capabilities in Europe.

5.3 Case Studies

5.3.1 Tarmac (Hayes)

The Tarmac plant in Hayes is one of the largest asphalt plants in the UK. In 2008, the plant was retro-fitted with a parallel dryer to allow the addition on recycled asphalt pavement (RAP) planings. The Hayes plant was the 2nd Tarmac plant to install a parallel drum for RAP processing, after the Hillwood plant.

The plant imports raw aggregates by rail, and all other materials and bitumen by road. RAP typically comes in the form of excavated pavement works, unused asphalt materials, and planings.

Tarmac can hold up to 4,000t of planings. The plant configuration means it is limited in the amount of storage space for recycled materials and the level of segregation prior to processing. Currently Tarmac hire a sub-contractor to process the planings.

Planings are passed through a crushing and screening process, before being stored in covered bays. Currently Tarmac have one area of covered RAP which is 10mm nominal size aggregate. When required, the stored planings are fed by a conveyor to a parallel heating drum. RAP is heated using a gas burning dryer with the burner at the entrance of the dryer. After drying the RAP drops down into two weighted hoppers which measure required volume, before being added to the mixer.

This process is capable of adding up to 85% recycled material into new mixes for use in the lower layers. Quality control of bitumen and asphalt products is monitored on site via an on-site laboratory.

Figure 5.1 - Conveyor Belt and Parallel Dryer at Tarmac Hayes plant

Figure 5.2 - Asphalt Loading Bays at Tarmac Hayes plant

Figure 5.3 - Aggregate Stockpile Storage at Tarmac Hayes plant

5.3.2 FM Conway (Heathrow)

The FM Conway 'Heathrow Asphalt' plant in Bulls Bridge, Hayes opened in 2014. The £10 million 'state-of-the-art Benninghoven BA5000 asphalt coating plant was designed with the emphasis on maximum recycling. The purpose-built plant represents one of the largest and most technically advanced asphalt production sites in the UK. The plant is strategically sited inside the M4–M25 motorway to service the growing west-London customer base for FM Conway. The asphalt plant produces batches of 5T and has an estimated annual production of up to 300,000T per annum.

The asphalt plant was designed around incorporating high reclaimed asphalt contents and is equipped with a high-level parallel hot recycling drum system. The 2.4m diameter x 11m long parallel-flow drum, which both dries and heats the recycled asphalt. The design of the drum internals ensures that the burner flame makes no direct contact with the moving reclaimed material inside the drum. The combustion zone of the drum is fitted with special heavy-duty, self-cleaning finger lifters that vibrate during the production process to prevent clogging of the material. The plant can deliver asphalt with up to 85% recycled asphalt pavement (RAP) content.

Significant emphasis is placed on the processing of the reclaimed asphalt to ensure the high-quality end product. FM Conway operate both a granulator and crushing and screening facilities to process the all reclaimed materials.

Reclaimed asphalt can be incorporated into mixes either using a cold feed direct into the mixer for lower reclaimed asphalt contents. For high reclaimed content the parallel drum system is used. Graded and tested reclaimed asphalt is fed to the recycling drum. Hot recycled material discharged from the drum is held in a 20-tonne electrically heated buffer silo prior to being discharged into a load-cell-mounted weigh hopper, where it is batch weighed before entering the mixing cycle. The hot recycled material then travels through a specially designed RAP chute which feeds it directly into the plant's paddle mixer.

Figure 5.4 – Processing of reclaimed asphalt using granulation

Figure 5.5 – Covered aggregate stockpile storage and cold feed system

Figure 5.6 – Heathrow Asphalt Plant

6. International Comparisons – Recycling Rates & Recycling Plant Capabilities

6.1 European Comparisons

6.1.1 Asphalt Plant Capabilities

The EAPA (2017) report on the number of asphalt plants per country as presented in Table 6.1. The EAPA provides the number of stationary and mobile plants and provides an estimation of the number of plants with hot and warm recycling capabilities.

Table 6.1 – Number of asphalt plants per country and recycling capabilities (EAPA 2017)

Country	Stationary Plants						Mobile plants						All plants that are fit for hot and warm recycling* ***					
	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017
Austria	112	113	114	113	114	115	1	1	1*	1*	1*	No data	80*	75	90	90*	90*	No data
Belgium	38	38	58	38	43	38	0	0	0	0	0	0	28	28	28	34	40	32
Croatia	52	55	55	52	53	53*	3	3	2	2	2	2*	5	6	10	13	14	14*
Czech Republic	105	101	101	103	105	104	2	2	2	2	2	2	70	70	70	72	75	75
Denmark	40	38	38	38	39	39	3	No data	No data	No data	0	0*	38	36	36	36	37	37
Estonia	10	9	9	10	10	5	13	11	10	10	11	16	11	13	13	14	14	12
Finland	52	59	50	35	47	No data	20	22	23	27	21	No data	55	62	62	42	54	No data
France **	438	434	430	423	423	423	67	62	57	46	46	46	>300	>300	>300	>300	>300	>350
Germany	635	630	615	612	597	589	No data	No data	No data	No data	No data	No data	610	605	600	610	590	580
Great Britain ***	250	240	245	245	250	250	No data	No data	No data	No data	No data	No data	No data	No data	130	150	165	No data
Greece ***	155	195	195*	195*	190*	190*	5	3	3*	3*	3*	3*	1	1	1*	1*	1*	No data
Hungary	84	85	87	86	86	83	5	5	6	6	5	2	40	42	48	50	52	50
Iceland ***	4	4	4	4	4*	4*	4	4	4	4	4*	4*	2	2	2	2	2*	2*
Ireland	37	37	37	38	38	39	No data	0	No data	0	1	1	3	2	No data	2	2	4
Italy	640	640	640*	640	640*	400	10	10	10*	10	10*	10	300	300	300*	350	350*	350*
Latvia	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
Lithuania	38	38*	38*	38	38	38*	3	3*	3*	1	1	1*	24	24*	24*	9	9	9*
Luxembourg	4	4	4	5	5*	4	0	0	0	0	0	0	2	4	4	3	3*	3
Netherlands	41	41	38	38	37	36	1	0	2	2	0	0	40	40	38	38	37	36
Norway	85	85	85	84	84	84	10	10	10	8	8	8	25	40	3	25	25	25
Poland	300	300	300*	300*	300*	300*	35	35	35*	35*	35*	35*	4	4	4*	4*	4*	4*
Portugal	25*	25*	25*	25*	25*	25*	25*	25*	25*	25*	25*	25*	15*	15*	15*	15*	15*	15*
Romania	8	49	50	50*	50*	50*	2	9	10	10*	10*	10*	8	8	10	10*	10*	10*
Serbia	No data	No data	31	31	31*	31*	No data	No data	2	2	2*	2*	No data	No data	15	15	15*	15*
Slovakia	54	51	46	49	47	44	0	0	0	1	1	4	22	No data	32	35	33	21

Country	Stationary Plants						Mobile plants						All plants that are fit for hot and warm recycling* ***					
	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017
Slovenia	13	18	16	16	16	17	1	1	No data	No data	1	1	8	8	No data	1	1	1
Spain	295	243	243	220	220	220	80	75	75	70	70	70	87	37	16	25	25	25
Sweden	87	87	87	87	87*	87*	10	8	8	10	10*	10*	80	90	90	90	90*	90*
Switzerland	142	147	142	142*	142*	142*	2	2	5	5*	5*	5*	78	83	80	80*	80*	80*
Turkey ***	225	176	104	117	112	119	437	462	449	449	535	535	10	10	12	12	15	15*
EU-28	>3.513	>3.530	>3.521	>3.456	> 3.460	3.149	>286	>275	>271	>261	> 255	238	> 1.751	> 1.770	> 1.921	>1.964	> 2.011	1.718
Europe	>3.969	>3.942	>3.887	>3.828	> 3.833	3.529	>739	>753	>741	>729	> 809	732	> 1.946	> 1.905	> 2.033	>2.098	> 2.148	1.855
Ontario - Canada	140	No data	114	132	145	145*	22	No data	5	3	5	5*	135	No data	100	125	100	100*
South Africa	28	33	29	29	29	30	23	25	24	25	26	26	32	31	34	35	36	37

** One or more plants are operated and owned by the road administration

*** One or more plants are operated and owned by the road administration and/or municipalities

**** Total of stationary and mobile plants

**** This can be all types, e.g. batch plants and/or drum mixer plants and/or plants with parallel drum.

An estimation of the number of plants with a hot and warm mix recycling capability as a percentage of total stationary and mobile plants is shown in Figure 6.1.

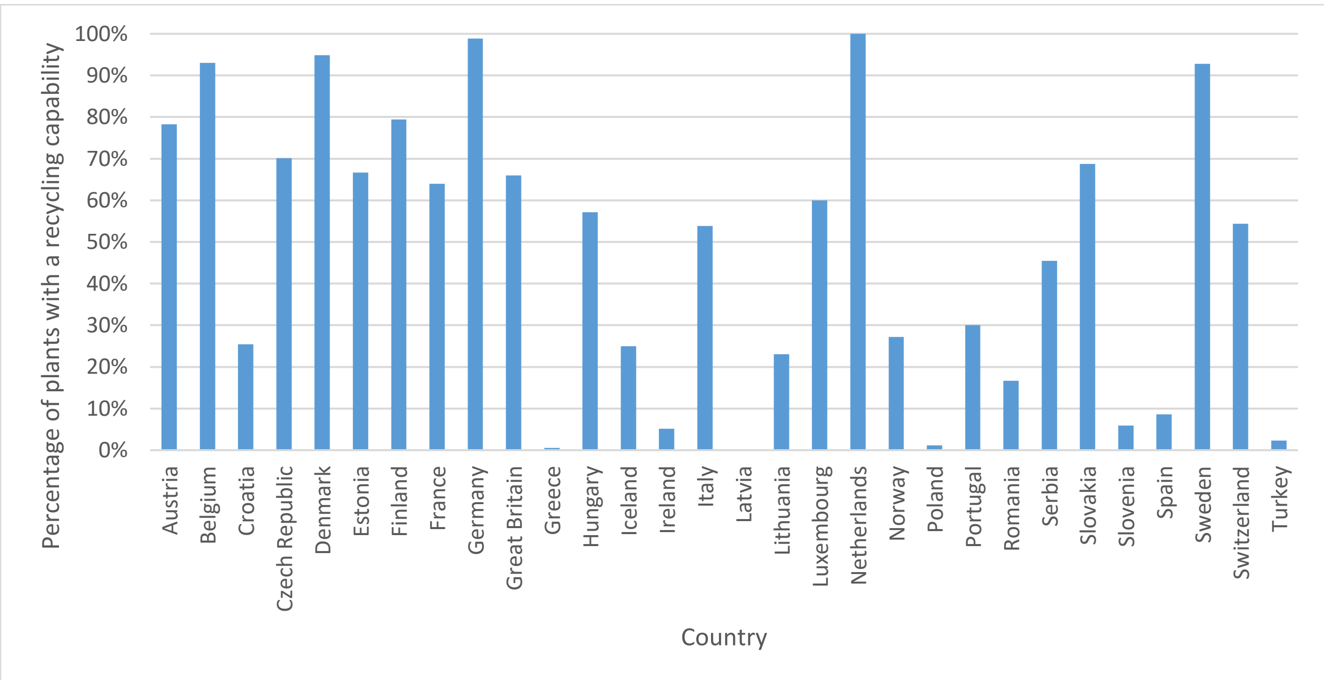


Figure 6.1 – Percentage of asphalt plants with a reported recycling capability in 2016 (EAPA 2017)

Based on the 2016 figures reported in EAPA (2017), it appears that the percentage of asphalt plants that are fit for hot or warm mix recycling in Great Britain (66%) is typical of other European countries and above the average of 47%. The values are significantly lower than a number of leading European countries with Belgium, Denmark, Germany, Netherlands and Sweden reporting levels indicating 93%, 95%, 99%, 100% and 93% plant recycling capabilities, respectively. Based on the data available it is not possible to establish the reason for this difference, however it may be linked to market demands, level of production, individual plant supply arrangements and age of plants. It is important to note that the EAPA (2017) does not consider the level of recycling capability.

Further details on plant capabilities throughout Europe is presented by Tušar et al. (2012). Tušar et al. (2012) reported:

- *“In Belgium, Denmark, Germany, Netherland and Sweden practically all asphalt plants are equipped to perform “mix in plant” recycling often applying a separating heating of RA and hot mix stone fractions”. With this technology content of reclaimed asphalt in a freshly produced asphalt mix is usually round 45% for batch plants and a bit more for drum mixer plants”.*
- *“In Demark and Germany asphalt plants were commonly equipped with a parallel drum dryer for heating the reclaimed asphalt, but nowadays some of the asphalt plant had recently been through a refitting which resulted in a new configuration so that the virgin drum dryer had been modified to with a high speed conveyor belt for throwing in the RA material into the last part of the drum dryer and the parallel drum dryer that formerly heated the RA for reaching high percentages of addition had been dismantled.”*
- *“In Portugal and Slovenia only some asphalt plants recycle only some asphalts are equipped with recycling capabilities. The asphalt plants that use reclaimed asphalt (RA) are not equipped with additional technology such as parallel drum enabling usage of no more than 30% RA in new asphalt mixtures.*

As part of this task, a visit to Germany was also undertaken by AJJV and Highways England on the 28 – 29th August 2019. The visit was facilitated by Retteinmeir and comprised of visits to Ingenieurgesellschaft PTM Dortmund, Bundesanstalt für Straßenwesen and the German Asphalt Pavement Association. The visit concluded the following in relation to asphalt plant capabilities:

- In Germany 25-30% of asphalt plants have parallel drum systems.
- 10% of these plants use indirect heating. It is estimated that approximately ten RAP priority plants, which use indirect heating are in operation in Germany and Austria.
- The relationship between the RA content and the plant capabilities is defined by a code of practice for the re-use of asphalt – M WA R2 “*Merkblatt fur die Wiederverwendung von Asphalt*”. The code of practice recommends the followings limits for batching plants:
    - Warming by the hot aggregates
        - Batch addition: 30 by wgt.-%
        - Continuous addition: 30 by wgt.-%
    - Warming together with the aggregates: 40 by wgt.-%
    - Warming in separate device (e.g. parallel drum): up to 100 by wgt.-%
    - For RA additions of 40%+ a parallel drum is recommended.
    - It was explained that higher addition rates above these limits are possible with corresponding positive experiences.
- The current trends in Germany included selective dosing with several cold bins, dry storage of RA and increased use of parallel drum systems/indirect heating.
- Granulation is becoming standard practice in Germany, which has the benefit of maintaining the particle size distribution and reducing the fines generated from crushing and screening.

Based on published literature supported by the findings of the visit to Germany, it appears that there is greater emphasis on heating reclaimed asphalt in a number of European Countries. There has been significant capital expenditure in countries such as Germany, Netherlands and Denmark with greater use of parallel drum systems and indirect heating relative to the UK. Consultation with industry has indicated in recent years significant investment has been made in RAP priority plants in Europe.

6.1.2 Reclaimed Asphalt and Recycling Levels

The use of reclaimed asphalt and recycling levels in Europe have been reported by a number of sources. EAPA (2017), Tušar et al. (2012) and Barrasa (2017).

EAPA (2017) provides statistics on the reclaimed asphalt available and use of reclaimed per country throughout Europe. Figure 6.2 presents the volume of reclaimed available (in millions of tonnes) in Europe.

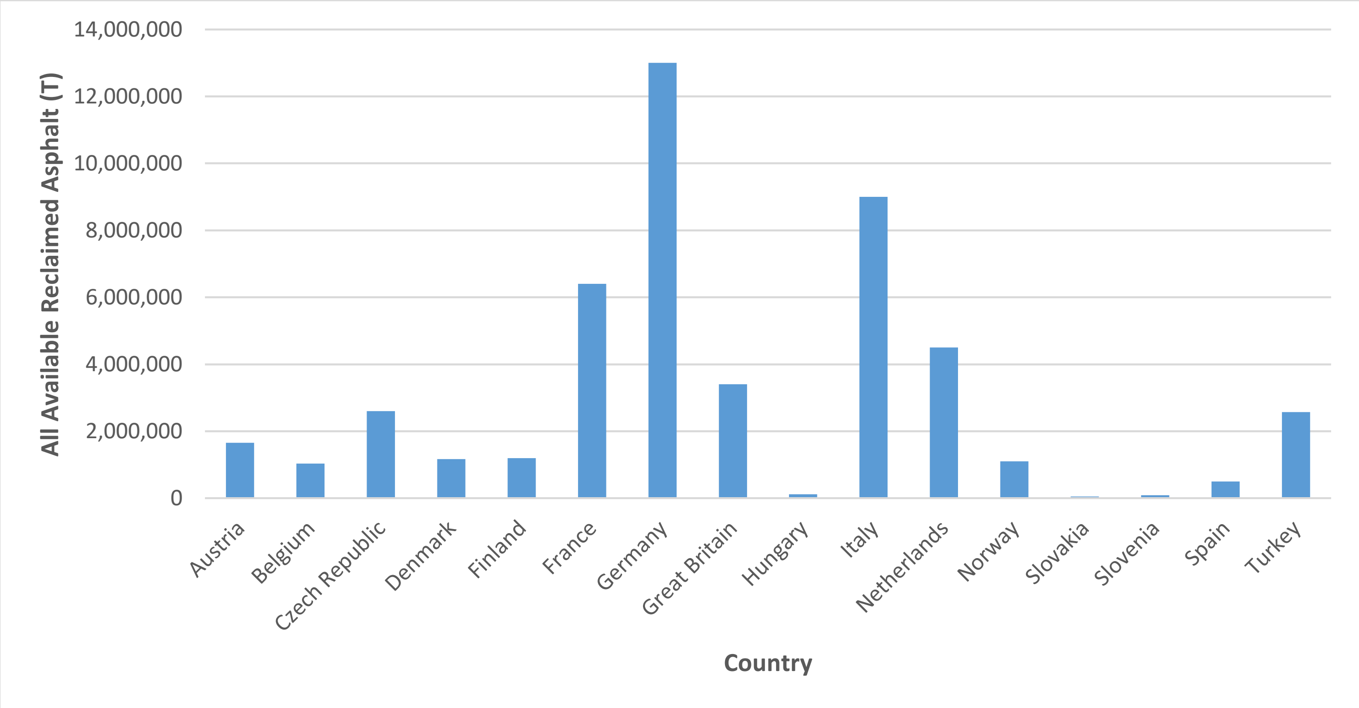


Figure 6.2 – Available Reclaimed Asphalt in million tonnes (EAPA, 2017)

The data presented in Figure 6.2 demonstrates that over 48,500,000T of reclaimed asphalt was available in Europe in 2017. Germany, Italy, France and the Netherlands are some of the of the leading countries in Europe in recycling asphalt in terms of total reclaimed asphalt available for recycling. Great Britain has the fifth highest reclaimed asphalt available for recycling in tonnage.

The data is also presented graphically as a percentage of the total annual production to account for the differences in total asphalt production in each country. The data demonstrates that in the Netherlands, Italy, Czech Republic and Germany reclaimed asphalt available for recycling forms a high percentage of total production with values of 56%, 40%, 35% and 31%, respectively. The percentage of reclaimed asphalt available for recycling of total production in Great Britain was 15%, which is just below the average value of 20% reported across all European Countries.

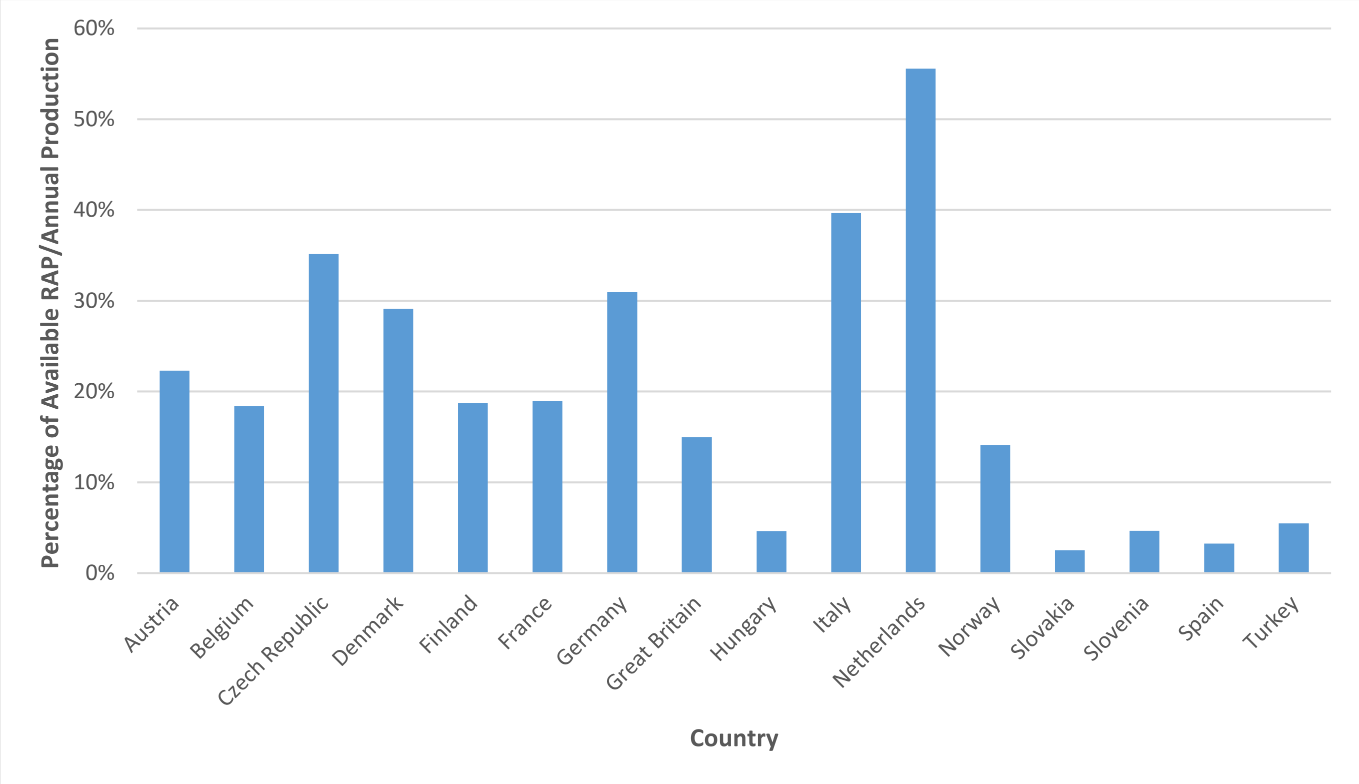


Figure 6.3 – Percentage of Reclaimed Asphalt Available compared to Annual Production per Country (EAPA, 2017)

The method of recycling and end use of the reclaimed asphalt is also assessed by EAPA (2017) as presented in Figure 6.4. The data demonstrates within Europe, some 62% of available RA is recycled to a bound application (hot mix, warm mix or cold recycled), with the remaining 38% (some 18 Mt) down cycled to a lower value application or discarded.

In Great Britain, 90% of available reclaimed asphalt is recycled in hot mix, warm mix or cold recycled. The data is not separated per technique but based on EAPA (2015 & 2016) it is estimated that 80% is re-used in hot mix and warm mix applications, 5-15% of total RAP is cold recycled with the remainder used in other applications. The data indicates that the reclaimed asphalt use in Great Britain is consistent with other European countries. It is important to note that the method for assessing unknown use/no data may be variable between individual European countries.

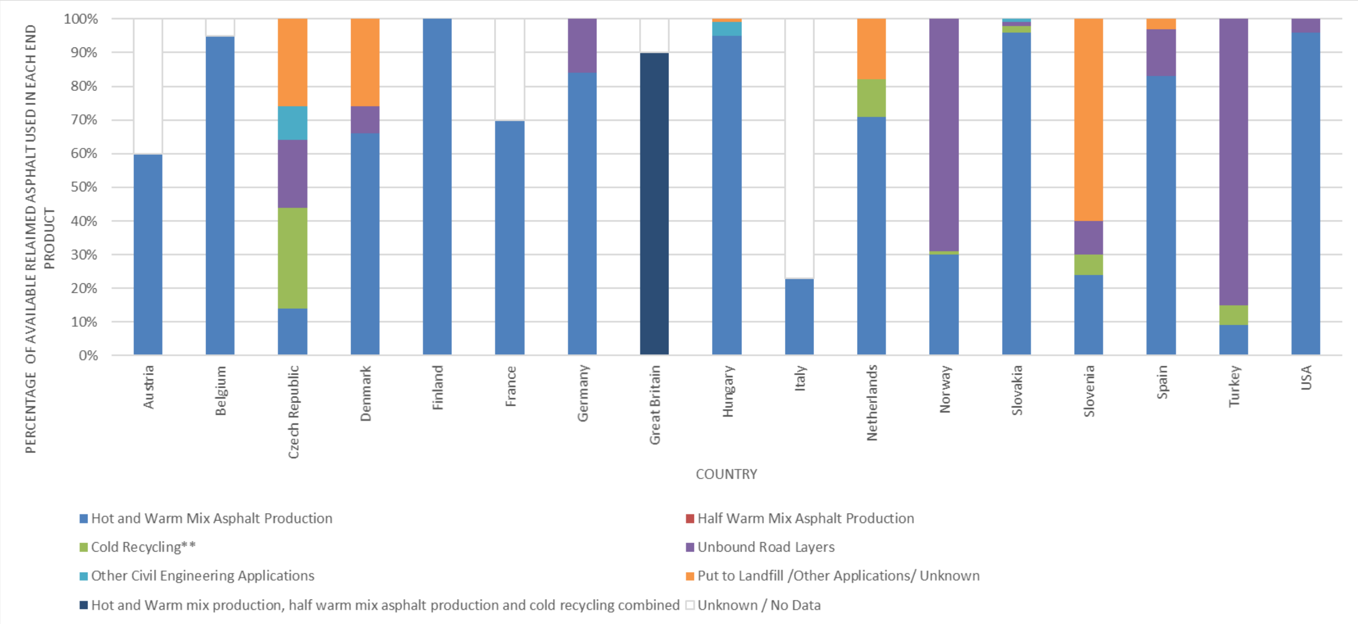


Figure 6.4 – Percentage of Reclaimed Asphalt Used in Each End Product per Country (EAPA, 2017)

The data presented in Figure 6.4 indicates the use of cold recycling is relatively limited. With Slovenia, Czech Republic, Netherlands, Turkey and Norway reporting varying degrees of cold recycling. An assessment of the cold bituminous mixture production is provided in the EAPA (2017) as presented in Table 6.2. The data is not specific to Cold Recycling, however indicates France and Turkey are the greatest producers of cold bituminous mixtures.

Table 6.2 – Cold Bituminous Mixtures (Below 50°C) From 2011 To 2017 (In Tonnes)

Country	2011	2012	2013	2014	2015	2016	2017
Austria	20,000	20,000	30,000	No data	No data	No data	No data
Belgium	33,000	27,000	30,000	No data	20,000	20,000	<10,000
Croatia	21,000	23,000	32,000	No data	No data	No data	No data
Czech Republic	9,907	4,421	9,570	40,000	5,400	5,000	4,000
France	1,600,000	1,460,000	1,550,000	1,418,000	1,808,000	1,858,000	1,977,000
Great Britain	No data	No data	No data	No data	<200,000	No data	No data
Hungary	40,000	15,400	58,800	40,000	60,000	30,000	50,000
Iceland	No data	No data	No data	10,000	10,000	No data	No data
Lithuania	No data	No data	No data	No data	No data	50,000	No data
Luxembourg	0	2,000	10,000,00	No data	10,000	No data	No data
Netherlands	No data	20,000	0	No data	No data	26,000	23,000
Norway	37,000	6,000	20,000	30,000	No data	No data	No data
Romania	13,000	2,000	2,625	No data	No data	No data	No data
Slovakia	3,000	0	No data	0	1,000	2,400	1,000
Slovenia	No data	No data	26,000	No data	No data	No data	No data
Spain	200,000	92,400	86,700	150,000	94,000	190,000	80,000
Sweden	60,000	90,000	90,000	100,000	100,000	No data	No data
Switzerland	740,000	710,000	830,000	25,000	No data	No data	No data
Turkey	1,020,000	1,818,000	1,050,000	938,000	783,000	543,446	1,048,000

Current recycling rates in Europe were also considered as part of the FEHR Re-Road Project "*RA optimization in asphalt plant mixin*g" (Tušar et al. 2012) and the Horizon 2020 EU funded project *"Asphalt Pavements for a Sustainable Environment, APSE*" (Barrasa, 2017).

Tušar et al. (2012) reported that "*due to different step technological development and public awareness asphalt plant recycling rate in Europe vary from 90% to less than 10%."* A similar finding from the APSE project whereby varying rates of asphalt recycling were reported across Europe, South Africa and in the USA (Barassa, 2017).

Table 6.3 presents maximum and optimal RA contents that can be incorporated in different pavement layers across Europe, as well as the capabilities of the plants in operation in selected EU countries.

Table 6.3 – Maximum RA Contents in Asphalt Road Mixtures in Selected EU Countries (Tušar et al. (2012))

Country	Surface Course	Binder/Base Course	Plant Capabilities and Comments
Belgium	Not referenced	Up to 50% (Optimal considered 40%. No maximum defined in tender specification – 50% considered maximum practical limit.	40No. Asphalt Plants are equipped to conduct "mix in plant" recycling applying a separate heating of RA (parallel black drum) and hot mix stone fractions. Approximately 5No. Asphalt Plants do not use RA. Majority of plants modified in 1990's. 37No. are Batch plants and 4No. are drum mixer plants. Mixing of RAP containing PMB and penetration grade is common to overcome challenges with PMB binders. Max. capacity is 300 tons/hour with RA
Denmark	Not referenced.	40%	Approximately 50No. Asphalt Plants in operation, majority of which are batch plants. Those with the greatest capacities are equipped to conducted "mix in plant" recycling, with potential for mixing RA in the drying drum.
Netherlands	25-30%	Up to 50% practical limit. Evidence of 70%.	Approx. 40No. Asphalt Plants are equipped to conducted "mix in plant" recycling using a parallel drum. Majority of plants modified in 1990's with further modifications since. 1No. Asphalt Plants was reported to not use RA. 35No. are batch mix plants. Max. capacity is 270 tons/hour with RA Mixing of RAP containing PMB is common although many SMA mixtures do not use PMB.
Germany	Not referenced.	Up to 50% considered practical limited. Evidence of 100%.	Asphalt Plants are equipped to conducted "mix in plant" recycling using a parallel drum. No reference to the ratio of batch plants or drum mixer plants in operation.
Portugal	Not referenced.	Up to 40%.	Up to 40% can be incorporated in regulating/binder courses successfully using drum mix plants with minor improvements in technology. Drum mix plants have estimated capacity of 320 tons/hour Studies show RA introduced halfway through the drum mixer, thereby avoiding direct contact with burner.
Slovenia	Limits not defined. Case Study	5-30%. Typically less than 10%.	Most common RA process is 'mix in plant'. No parallel black drums in operation in any plants. 50% RA in wearing courses using batch plant technology is possible, but

Country	Surface Course	Binder/Base Course	Plant Capabilities and Comments
	presented 40-45% RAP.		studies have shown it to be less profitable than conventional 20% RA incorporated.
Sweden	Maximum 20%	Maximum 30%. Examples of high RAP contents reported.	More than 20No. plants adapted for hot and cold recycling in 1990's. Asphalt Plants are equipped to conduct "mix in plant" recycling. Batch mixing plants are most common type of plant Drum mixing plants have capacity of 200-600 tons/hour. Recently built plants can incorporate up to 40% RA. Rejuvenation agents are not used in hot recycling in a central plant but have been used in the remixing. However, due to environmental reasons, it is not widely used. Cold recycling can incorporate up to 100% RA but typically includes 10-15% new aggregates. For cold mix recycling, drum mix plants are most common with capacities of 100-150 tons/hour.

The table shows that maximum (and optimal) RA contents that can be incorporated in the surface course, binder course, and base layers for different European countries. As expected, the majority of countries show a maximum RA content in the binder course and base layers, of 50%, with Belgium, the Netherlands, and Germany leading the way with maximum RA contents (in terms of practical limits). Examples from Belgium, Netherlands and Germany are reported with RAP contents in excess of 50%. As reported in Tušar et al. (2012), this is primarily due to the configuration of the mixing plants and the use of a separate 'black drums' and 'hot mix stone fractions' for drying the RA. Sweden, Portugal, and Denmark have the capability to incorporate 30%, 40% and 40% respectively in the lower asphalt layers, although having slightly different plant configurations.

RA contents in the surface course were not as well documented in Table 6.3. Of those countries identified, only the Netherlands and Sweden have reported RA contents (varying from 20% to 30%) in the surface course. A case study from an on-road trial in Slovenia shows 40-45% RA content in the surface course. Results from the study show that the RA mixture has a comparable performance with conventional surface course mixtures in terms of rut resistance after 12 months service (Tušar et al. 2012). A study from Sweden, which included on-road trials of 40% hot mix RA mixtures, showed better performances in terms of indirect tensile strength and water sensitivity when compared with conventional mixtures, even after ten years of trafficking (Tušar et al.2012).

The use of reclaimed asphalt and recycling levels in Germany were also discussed as part of the AJJV and Highways England visit on the 28 – 29th August 2019. The current levels of RA generated in Germany, and the levels of recycling are presented in Figures 6.5 and 6.6, respectively. The data presented in Figure 6.5 from the German Asphalt Pavement Association indicates approximately 10mT of RA was re-used compared to annual production of 40mT in 2017. The data presented in Figure 6.6 demonstrates that the RA re-used accounts for the majority of the RA generated with approximately 10mT of RA re-used compared to 13mT generated. A surplus of additional RA is generated each year currently.

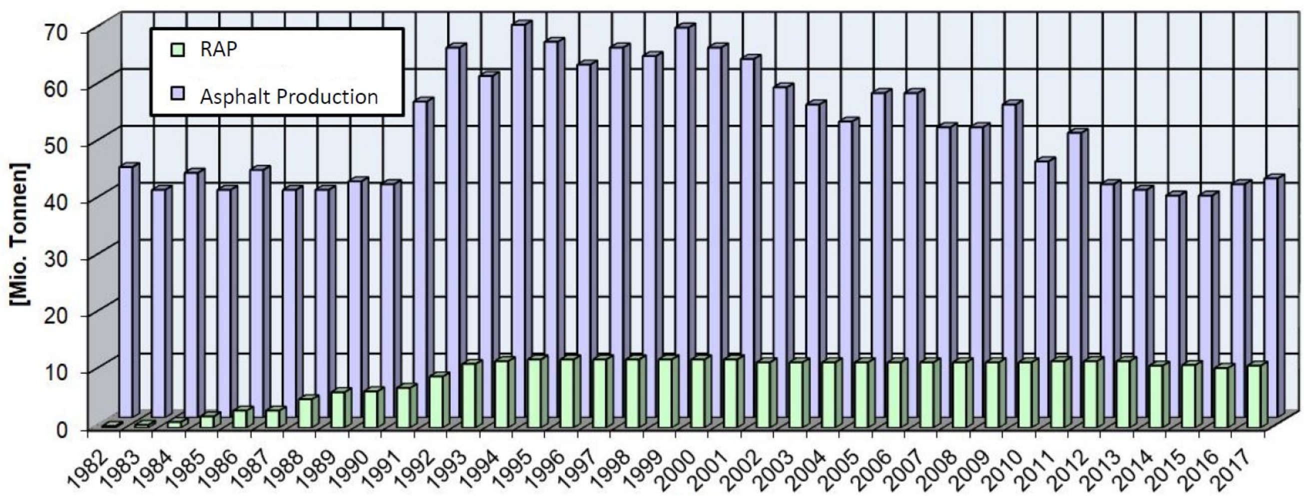


Figure 6.5 - Asphalt Production and RA Generated in Germany (Million Tons), 1982–2017 (German Asphalt Pavement Association 2019)

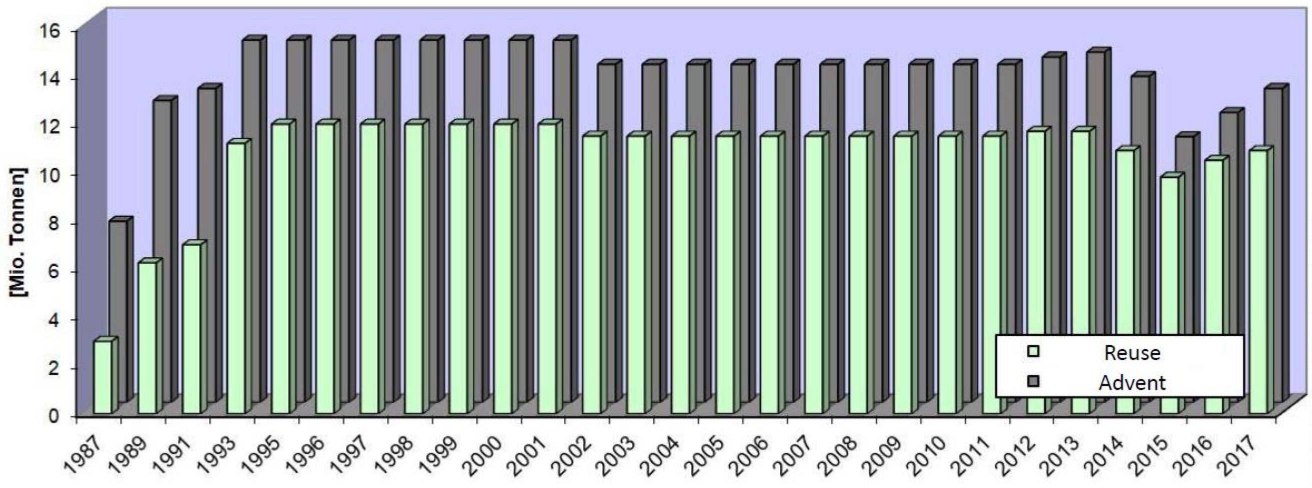


Figure 6.6 – Comparison of RA Generated and Re-used (Million Tons), 1982–2017 (German Asphalt Pavement Association 2019)

In Germany the network is split into 16 federal states. There are national standards that cover all federal states, however local revisions/additions can be specified leading to local variations.

A number of standards define the requirements for the re-use of RA in Germany. These are:

- ZTV Asphalt – StB 07/13 - Additional Technical Conditions of Contracts and Directives for the Construction of Road Asphalt Pavements, which defines the requirements and installation for asphalt layers.
- TL Asphalt – StB 07/13 - Technical Conditions of Delivery for Asphalt Mixtures for the Construction of Road Pavements. This standard defines the requirements for asphalt mixtures (Material specifications based on EN 1308 1-5,6, 7 & 9).
- TL AG – StB 09 – Technical Conditions for Asphalt Granulate. This standard defines the classification for RA (EN 13108-8).
- M WA R2 - Code of Practice for the Reuse of Asphalt, which provides additional recommendations on equipment.

The process for establishing the maximum permitted RA contents in accordance with the standards is presented in Figure 6.7.

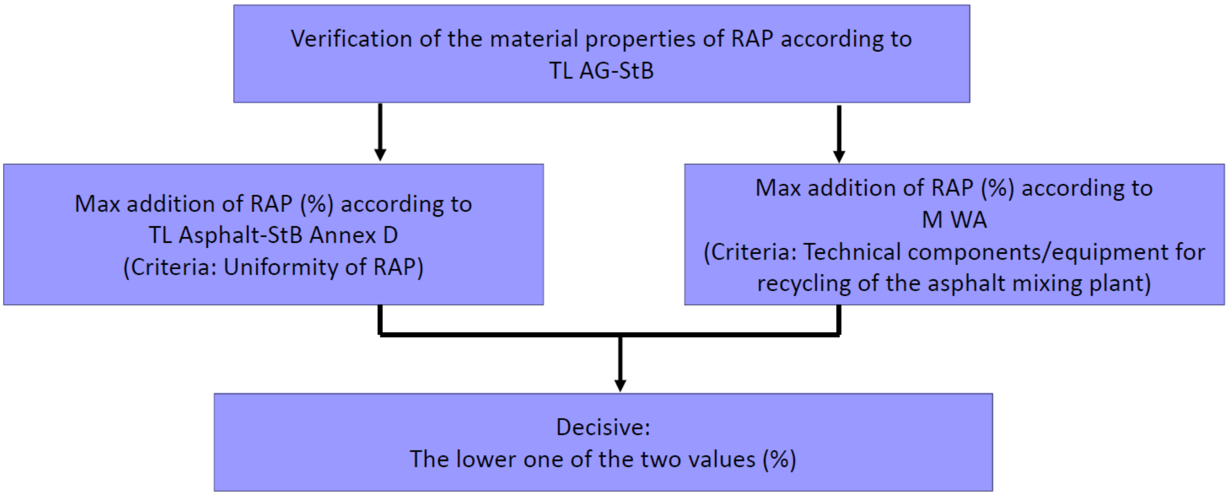


Figure 6.7 – Process for establishing the maximum permitted RA content in Germany (German Asphalt Pavement Association 2019)

The maximum permitted RA content is based on the uniformity of the RA in accordance with TL Asphalt – StB 07/13 and a check on the asphalt plant capabilities with the lowest of value selected.

In terms of uniformity, a nomograph is defined in the standards based on Softening Point, Binder Content and Grading (<63micron, 63micron – 2mm & >2mm) as shown in Figure 6.8. Each parameter is used to establish the permitted RA content and the lowest of each parameter is taken. This approach enables high RA contents to be used where the testing demonstrates the RA is homogenous.

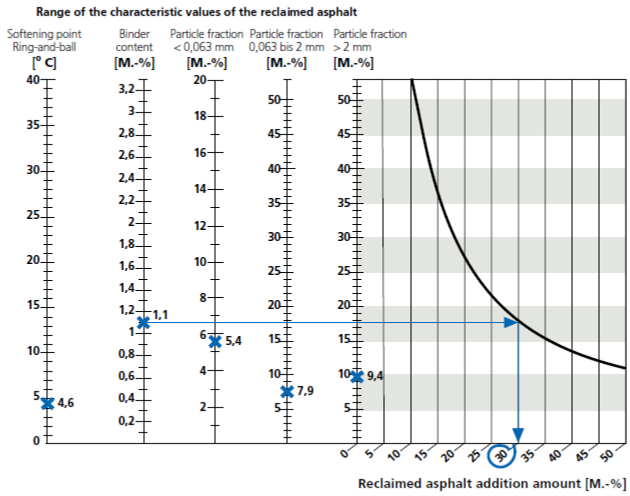


Figure 6.8 – Example of Nomograph for establishing maximum permitted RA content depending on RA uniformity (German Asphalt Pavement Association 2019)

For surface or binder course, one grade softer is allowed and the resulting binder has to be within grade. In terms of base layers, the binder shall be one grade softer and the resulting binder within grade or the required binder grade is added, and the results binder may be within one grade.

The bituminous mixtures where the inclusion RA is permitted is defined by M WA 09/13 depending on the RA source as presented in Figure 6.9. It is important to note each individual federal state may have different regulations.

Source of asphalt granulate	Addition possibility for				
	Mastic Asphalt	Asphalt Surface Course	Asphalt Binder Course	Asphalt Base Course	Asphalt ´´Base+ Surface´´ Course
Mastic Asphalt	++	O	O	+	O
Asphalt Surface Course	–	++[1)]	++	+	+
Asphalt Surface [2] & Binder Course	–	O[3)]	++	+	+
Asphalt Binder Course	–	O[3)]	++	+	+
Asphalt Base Course or Asphalt ´´Base+Surface´´ Course	–	–	–	++	O

++ Primary (horizontal recycling = RAP from old surf goes into new surf)
+ Possible, but without the full exploitation of technical features and economy
O Conditionally possible, after special lab testing
– Not possible
1) According to TL Asphalt-StB
2) Usually not from Mastic Asphalt
3) After separate treatment

Figure 6.9 – Bituminous mixtures RA permitted based on source (German Asphalt Pavement Association 2019 translated from M WA 09/13)

During the visit, it was reported that for SMA surface courses on the strategic network RA is generally not permitted, however specific federal states permit up to 40% RA. The inclusion of RA into SMA and porous asphalt is not standard practice.

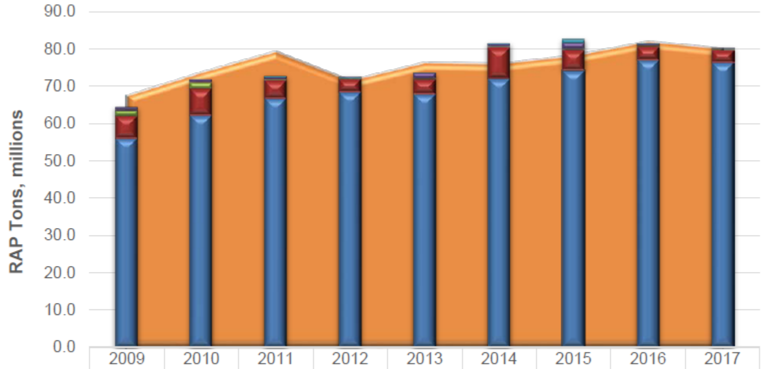
The majority of Federal states permit 30-40% in Asphalt Concrete layers including surface courses. The general view presented was that 30-40% is common in binder course layers with no limits in base layers. Studies have been undertaken with trials up to 90 - 100% RA into binder and base layers.

It was explained that it is standard practice to selective mill (the milling of individual layers separately), fractionate and segregate stockpiles. For example, in Hamburg selective milling is mandatory if the scheme is greater than 600m^2.

6.2 United States

The EAPA (2017) includes data produced from the United States of America (USA). The EAPA (2017) indicates that the USA recycled the greatest quantity of reclaimed asphalt by far in the world. EAPA (2017) reported in 2017, that 72,500,000T of reclaimed asphalt was available. This equates to 21% of total production. EAPA (2017) estimates that 96% of all reclaimed asphalt available is reused in hot and warm mix production with the remaining 4% reused in unbound layers.

Detailed analysis of the recycling rates in the USA have been established through a national asphalt pavement industry survey by the National Asphalt Pavement Association (NAPA) as reported by Williams and Copeland (2018). The estimated total tons of RAP used in asphalt mixtures, aggregate, cold-mix asphalt, and other uses, as well as the amount landfilled estimated from the (Williams and Copeland 2018) study is presented in Figure 6.10.



	2009	2010	2011	2012	2013	2014	2015	2016	2017
Accepted	67.2	73.5	79.1	71.3	76.1	75.8	78.0	81.8	79.9
Landfilled	0.1	0.0	0.3	0.2	0.1	0.2	1.0	0.1	0.0
Used in Other	0.7	0.8	0.7	0.2	1.5	0.6	1.6	0.4	0.2
Used in Cold Mix	1.5	1.6	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Used in Aggregate	6.2	7.3	4.9	3.6	4.0	8.5	5.5	3.7	3.4
Used in HMA/WMA	56.0	62.1	66.7	68.3	67.8	71.9	74.2	76.9	76.2

Figure 6.10 Comparison of Tons of RAP Accepted, and Tons of RAP Used or Landfilled (Million Tons), 2009–2017 (Williams and Copeland 2018)

(Williams and Copeland (2018) concluded "*The overwhelming majority of RAP is used in hot mix asphalt (HMA) or warm-mix asphalt (WMA) mixtures, which is the most optimal use of RAP. The tons used in cold-mix asphalt data may include some CCPR of RAP, but the survey does not specifically record the use of in-place recycling technologies".* In total 76,200,000T of RAP was recycled as hot mix and warm mix asphalt. Placement of RAP in construction and demolition landfills was limited.

Williams and Copeland (2018) also considered the average percentage RAP utilisation as presented in Figure 6.11. The study demonstrates the average percent RAP used by all sectors has seen variable growth from 2009 to 2017. The average estimated percentage of RAP used in asphalt mixtures has increased from 15.6% in 2009 to 20.1% in 2017.

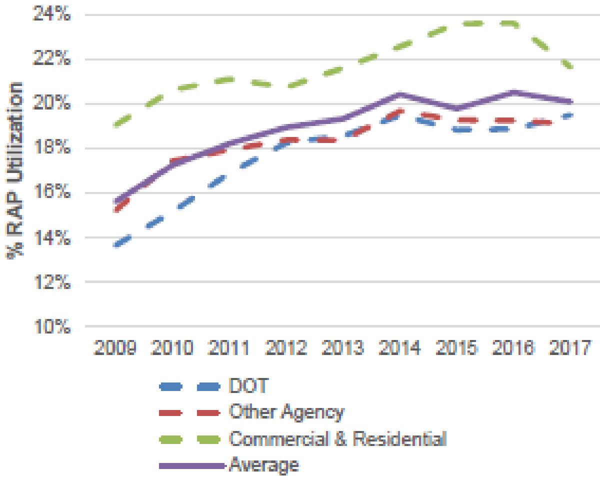


Figure 6.11: Average Percent RAP Used by Sector (Williams and Copeland 2018)

Figure 6.12 below presents the number of producers in each state reporting average RAP percentages at the various ranges by construction season from 2009 to 2017. The Williams and Copeland (2018) study concludes "*The number of states with producers reporting average RAP percentages 20 percent or greater has increased significantly, rising from 10 states in 2009 to 27 states in 2014; peaking at 29 states in 2016, and decreasing to 24 states in 2017. The number of states with producers reporting RAP percentages less than 15 percent has decreased from 23 states in 2009 to just two states in 2014 and then remained steady at 10 states in 2015 and 2016 and rising to 11 states in 2017".*

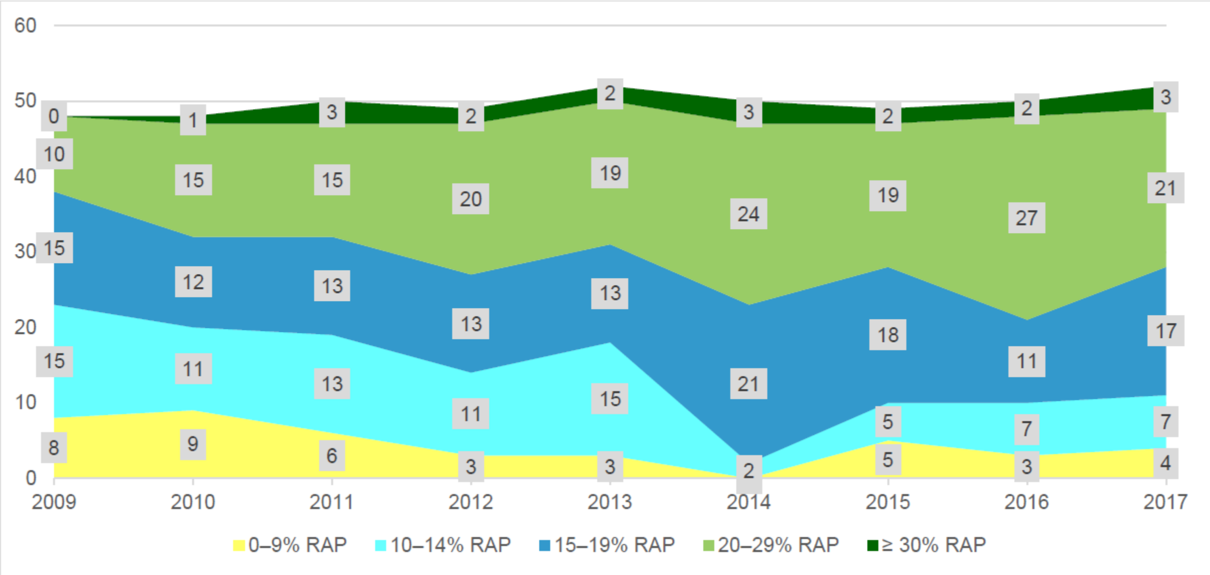


Figure 6.12: Number of States at Different Average RAP Percentages in HMA/WMA Mixtures, 2009–2017 (Williams and Copeland 2018)

The Williams and Copeland (2018) study also considered the level of RAP fractioning and binder correction using softer binders or recycling agents. Table 6.4 shows the average percentage of RAP fractionated into two or more sizes in each state, as reported by survey participants. The results show the level of fractioning is highly variable dependent on individual states. The study concluded that "*producers from 36 states reported fractionating RAP. Nationally, a reported 23 percent of RAP is fractionated*".

Table 6.4: Reported Percentage of RAP Fractionated, in Each State, 2016–2017 (Williams and Copeland 2018)

State	% Fractionated		State	% Fractionated		State	% Fractionated	
	2016	2017		2016	2017		2016	2017
Alabama	13%	29%	Kentucky	75%	53%	Ohio	6%	25%
Alaska	*	*	Louisiana	80%	75%	Oklahoma	50%	65%
American Samoa	NCR	*	Maine	0%	27%	Oregon	7%	3%
Arizona	0%	0%	Maryland	0%	0%	Pennsylvania	2%	5%
Arkansas	1%	0%	Massachusetts	4%	3%	Puerto Rico	NCR	NCR
California	31%	57%	Michigan	20%	24%	Rhode Island	*	*
Colorado	71%	22%	Minnesota	3%	10%	South Carolina	63%	50%
Connecticut	0%	0%	Mississippi	27%	25%	South Dakota	*	*
Delaware	*	*	Missouri	32%	10%	Tennessee	22%	55%
Dist. of Columbia	NCR	*	Montana	*	*	Texas	15%	39%
Florida	6%	28%	Nebraska	*	0%	Utah	13%	8%
Georgia	1%	8%	Nevada	0%	33%	Vermont	*	*
Hawaii	*	67%	New Hampshire	0%	0%	Virginia	34%	36%
Idaho	12%	17%	New Jersey	16%	12%	Washington	0%	14%
Illinois	89%	55%	New Mexico	52%	37%	West Virginia	15%	4%
Indiana	72%	43%	New York	12%	14%	Wisconsin	14%	4%
Iowa	3%	0%	North Carolina	39%	29%	Wyoming	0%	50%
Kansas	3%	5%	North Dakota	*	0%			
						Average, Where Used†	23%	23%

NCR No Companies Responding

* Fewer than 3 Companies Reporting

† Includes Values from States with Fewer than 3 Companies Reporting

The Williams and Copeland (2018) study also considered the use of softer binder and recycling agent as reported in Table 6.5. The study concluded "*While there is no strong relationship between the amount of RAP mixtures using softer binder or recycling agents and percentage of RAP used by the state, it should be noted that of the 23 states using more than 20 percent RAP, 18 of them report using softer binders and or recycling agents in a percentage of their RAP mixtures and five of these states reported no use of softer binders or recycling agents in RAP mixtures*".

Table 6.5: Percentage of RAP Mixes Using Softer Binder and/or Recycling Agents in Each State, 2017 (Williams and Copeland 2018)

State	Softer Binder	Recycling Agent	State	Softer Binder	Recycling Agent	State	Softer Binder	Recycling Agent
Alabama	0%	0%	Kentucky	8%	26%	Ohio	30%	0%
Alaska	*	*	Louisiana	12%	0%	Oklahoma	19%	0%
American Samoa	*	*	Maine	2%	0%	Oregon	0%	0%
Arizona	23%	0%	Maryland	29%	16%	Pennsylvania	3%	8%
Arkansas	0%	0%	Massachusetts	5%	0%	Puerto Rico	NCR	NCR
California	21%	38%	Michigan	24%	0%	Rhode Island	*	*
Colorado	0%	0%	Minnesota	10%	1%	South Carolina	0%	0%
Connecticut	0%	0%	Mississippi	3%	0%	South Dakota	*	*
Delaware	*	*	Missouri	39%	6%	Tennessee	0%	22%
Dist. of Columbia	*	*	Montana	*	*	Texas	31%	0%
Florida	83%	0%	Nebraska	0%	0%	Utah	48%	0%
Georgia	0%	0%	Nevada	17%	0%	Vermont	*	*
Hawaii	0%	0%	New Hampshire	0%	25%	Virginia	14%	4%
Idaho	79%	3%	New Jersey	0%	0%	Washington	16%	7%
Illinois	14%	1%	New Mexico	8%	0%	West Virginia	3%	0%
Indiana	22%	0%	New York	4%	9%	Wisconsin	19%	5%
Iowa	21%	0%	North Carolina	44%	0%	Wyoming	0%	0%
Kansas	65%	3%	North Dakota	3%	0%			
						Average, When Used†	18%	4%

NCR No Companies Responding for the State to the Survey

* Fewer than 3 Companies Reporting

† Includes Values from States with Fewer than 3 Companies Reporting

The limiting factors were also considered as part of the NAPA study as shown in Figure 6.13.

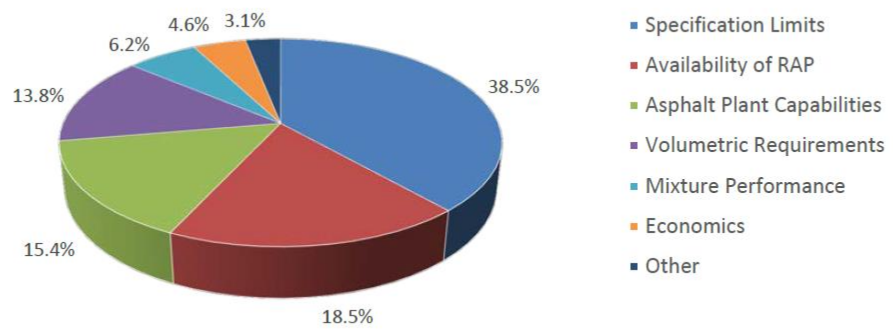


Figure 6.13: Reported Factors Limiting the Use of RAP, 2017 (Williams and Copeland 2018)

The Williams and Copeland (2018) study concluded “*specification limits (38.5 percent) was the most commonly cited limiting factor in increasing the use of RAP followed by RAP availability (18.5 percent) and asphalt plant capabilities (15.4 percent)*”.

6.3 Japan

A study of the actual situation of recycled asphalt mixtures in Japan was published by Hirama (2014). Hirama (2014) reported that "*In 2013, Japan produced approximately 50 million metric tonnes (55 million tons) of asphalt mixtures. Nearly 38 million metric tonnes (41.9 million tons) of asphalt mix contained RAP".*

Hirama (2014) assessed the production of virgin and recycled mixes in Japan. The findings are reproduced in Figure 6.14, which shows an increasing use of Reclaimed Asphalt over time. Hirama (2014) reports "*The average RAP content in Japan asphalt mixtures increased from 33% on average in 2000 to 47% on average in 2013."*

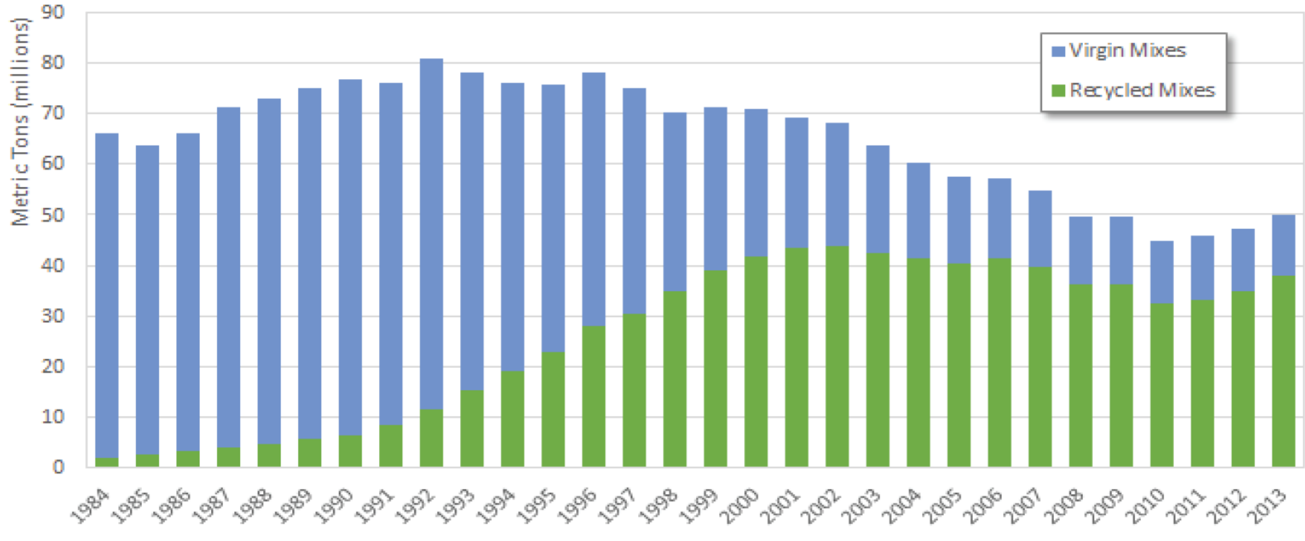


Figure 6.14: Production of Virgin and Recycled Mixes in Japan (Hirama 2014)

The National Asphalt Pavement Association (NAPA) (2015) produced a report on the "*High RAP Asphalt Pavements: Japan Practice – Lessons Learned*". The NAPA (2015) study reported *"The average RAP contents are similar in colder northern and warmer southern regions and vary from 20%–60% on average*."
The NAPA (2015) study explains "*Japan currently has 1,150 asphalt plants. All but 176 plants are capable of producing mixes with RAP. Of the Japanese plants with recycling capability, 17.7% utilize an indirect heating system, 68.8% use a parallel heating system, and 15.5% use a drum mix process.*"

The NAPA (2015) report explains that the Japanese attribute their successful use of high levels of RAP in HMA to three key points:

- *"1. A focus on quality (reducing variability), including processing RAP (i.e., fractionating) and covering stockpiles.*
- *2. Heating the RAP to drive out moisture and soften the RAP binder.*
- *3. Using a softening agent (and other mixing best practices) to achieve desired mix characteristics."*

According to NAPA (2015) key aspects of the Japanese asphalt recycling specification include:

- *"RAP is processed from multiple sources. No restrictions are made as to the origin of the RAP.*
- *RAP quality is judged by three criteria:*
  - *It must have a minimum asphalt content of 3.8%.*
  - *The recovered RAP binder must have a penetration greater than 20 or samples of the compacted RAP must have an IDT coefficient of less than 1.70 MPa/mm.*
  - *The processed RAP material may not contain more than 5% P200 fines.*
- *Fractionation of RAP is a contractor's choice, not a requirement. Most contractors choose to fractionate the RAP.*

- *Blending charts are used to determine ratios of virgin and recycled binders or dosage rates for recycling agents. Mix designers may use soft virgin asphalts or recycling agents to meet a target penetration value for the composite binder or a desired indirect tensile coefficient for the mixture.*
- *Mix designs use the Marshall Method and criteria with a simple supplemental performance test, the indirect tensile coefficient which limits mixes with very high stiffness (and low cracking resistance)."*

Key aspects of the Japanese method for high RAP mix production according to NAPA (2015) include:

- *"Drying and heating of RAP in a separate parallel dryer*
- *Use of thermal oxidizers to handle emissions from the RAP dryer*
- *Mixing a rejuvenator with the hot RAP and giving the material time to "activate and condition" the aged RAP binder.*
- *Low production rates, typically 100–180 metric tonnes per hour. The conditioning step noted above is likely the controlling process."*

6.4 South Africa

The use of reclaimed asphalt in the production of asphalt in South Africa is defined by the Sabita (2019) Manual 36 / TRH 21. Sabita (2019) provides guidelines for the asphalt recycling process, factors that influence the quality of reclaimed asphalt, investigation of reclaimed asphalt sources, mix design procedures, mix plant requirements and quality control requirements.

Sabita (2019) states "*The estimated annual production of asphalt in South Africa is reasonably constant at around 3.5 million tons. In 2014 it was estimated that the usage of RA was in the region of 10% of the annual asphalt production i.e. in the region of 350 000 tons. It has been stated by industry that, should the specifications permit higher proportions of RA in asphalt mixes, 95% of reclaimed material available at the various fixed asphalt plants can be utilised to this end.*

There would therefore appear to be considerable scope in South Africa, through the use of higher proportions of RA in asphalt, to effect significant financial savings through a decrease in virgin material input, as well as reducing the pressure on non-renewable resources and the carbon footprint of the asphalt industry. Since 2009 asphalt manufacturers have gained experience in the use of higher proportions (up to 40%) in asphalt mixes on major road contracts. With the expertise gained, the road industry is now in a position to exploit the benefits attached to the use of RA in new road layers."

6.5 Summary

A review of published literature and data relating to asphalt plant capabilities and current recycling rates in Europe and internationally (USA and Japan) has been conducted. The results have been compared against the current position in Great Britain. The review has concluded:

- Based on the 2016 figures reported in EAPA (2017), it appears that the percentage of asphalt plants that are fit for hot or warm mix recycling in Great Britain (66%) is typical of other European countries and above the average of 47%. The values are significantly lower than a number of leading countries leading European countries with Belgium, Denmark, Germany, Netherlands and Sweden.
- There has been significant capital expenditure in countries such as Germany, Netherlands and Denmark with greater use of parallel drum systems and indirect heating relative to the UK.
- In 2017 over 48,500,000T of reclaimed asphalt was available in Europe. Germany, Italy. France and the Netherlands are some of the of the leading countries in Europe in recycling asphalt in terms of total reclaimed asphalt available for recycling. Great Britain has the fifth highest reclaimed asphalt available for recycling in tonnage.
- As a percentage of total production Netherlands, Italy, Czech Republic and Germany have the highest reclaimed asphalt available. The percentage of reclaimed asphalt available for recycling of total production in Great Britain was 15%, which is just below the average value of 20% reported across all European Countries.

- The re-use of 90% of available reclaimed asphalt in hot mix, warm mix or cold recycled in Great Britain is above the average 62% of available RA into bound applications. This appears to indicate that where available reclaimed asphalt is used in the higher value applications rather than down cycled to a lower value application such as unbound layers.
- The USA recycles the greatest quantity of reclaimed asphalt by far in the world with over 76,200,000T recycled. The average estimated percentage of RAP used in asphalt mixtures has increased from 15.6% in 2009 to 20.1% in 2017.
- Recycled contents in Japan have also increased in recent years, with an average RAP content in Japan asphalt mixtures increased from 33% on average in 2000 to 47% on average in 2013. Of the Japanese plants with recycling capability, 17.7% utilise an indirect heating system, 68.8% use a parallel heating system, and 15.5% use a drum mix process.
- All leading countries throughout Europe (such as Germany, Netherlands and Denmark) and worldwide (such as the USA and Japan) have invested heavily in recycling plant capabilities and processing of reclaimed asphalt.

7. Recycling Limitations

7.1 Introduction

A range of complex factors are present that limit the rate of asphalt recycling on the SRN in terms of both the use of the specific recycling method and the reclaimed asphalt content. The limitations cover a wide range of inter-related factors including but not limited to technological, commercial and legislative/standards.

A Political, Economic, Social, Technological, Legislative and Environmental (PESTLE) analysis of each recycling method has therefore been undertaken to identify both primary and secondary issues hindering recycling rates. The PESTLE analysis was developed through a review of published literature and consultation with the industry. The limitations were reviewed as part of a UK Pavement Liaison Group Working Group 9 (UKPLG WG9) meeting held on the 29th October 2018, where industry representatives where requested to identify and rank limitations.

The finding of the PESTLE analysis is presented in Table 7.1 to 7.4 for each recycling technique. The following sections discuss the key limitations specific to each recycling technique. Common limitations across all recycling techniques are also discussed.

Table 7.1 – PESTLE Analysis for Hot mix Recycling into Surface Course

	Hot mix Recycling into Surface Course Limitations
Political	• Impact on network safety/skid resistance KPI's. • Perceptions - Durability and assumption that recycling must be cheaper. • Lack of marketing regarding the use of reclaimed asphalt in surface course materials. • Collaboration between client, designer and supplier. • Supply chain assurances regarding demand to warrant capital investment. • Collaboration between clients – Consistency between strategic and local authority requirements. It was reported that currently a number of authorities do not permit reclaimed asphalt in surface course materials.
Economic (Including Contractual)	• Segregation and Management of RAP. • Ownership of planings. • Scope of potential savings due to mix addition limitations. • Cost of additives (as required). • Availability of RAP drier/plant upgrades and associated capital investment costs. A large capital investment is required by asphalt supply plants to allow the introduction of more than 25% planings into a new mix. • Quality management/testing costs. • Impact upon and relationship with aggregate/bitumen supply/demand and market prices. • Risk ownership, risk sharing and reward incentives. • Procurement implications – sustainability submission/weighting in contracts, clients need to specify targets to provide incentives.
Social (Including People)	• Understanding/experience of use of technique/product on SRN. • Recycling needs to be considered at the point of design.
Technological	• Consistency and known source of RAP. • Impact upon durability. • Ability to correct binder properties. • Impact of RAP additions on skid resistance. • Ensuring homogeneity. • Impact of polymer modified binders. • Skid resistance related issues – A risk-based approach could be considered which utilises PSV testing, Friction after Polishing and in-situ testing.
Legal (Incorporating Technical/ Standards)	• PD6691 – Limitations to 10% of mix and/or departure from standard requirements. • Technical requirements for non-recycling standards e.g. skid resistance defined in HD28/15, HD36/06 and IAN 156. • Surface course certification/installation demonstration. • Durability – Ensuring durability is specified for increasing reclaimed asphalt contents. • There is no common definition of durability e.g. Measurement of PSV is by traffic count and durability is measured in years. Procurement implications – sustainability submission/weighting in contracts, clients need to specify targets to provide incentives. • Potential future impacts of the PSV from planings and segregations associated with CD236 and specification on a lane by lane basis.
Environmental	• EA regulatory position – Use of treated asphalt waste. • Update required to asPECT to demonstrate environmental benefits. • Availability of space to stockpile segregate planings e.g. storage of different PSV aggregates. • Location of planings and haulage.

Table 7.2 – PESTLE Analysis for Hot mix Recycling into Binder/Base Course Materials

	Hot mix Recycling into Binder/Base Course Materials Limitations
Political	• Output requirements need to be specified. • Lack of marketing regarding the use of reclaimed asphalt. • Collaboration between client, designer and supplier. • Supply chain assurances regarding demand to warrant capital investment.
Economic (Including Contractual)	• Segregation and Management of RAP • Ownership of planings. • Scope of potential savings due to mix addition limitations. • Cost of additives. • Availability of RAP drier/plant upgrades and associated capital investment costs. A large capital investment is required by asphalt supply plants to allow the introduction of more than 25% planings into a new mix. • Quality management/testing costs. • Impact upon and relationship with aggregate/bitumen supply/demand and market prices. • Risk ownership, risk sharing and reward incentives • Procurement implications – sustainability submission/weighting in contracts, clients need to specify targets to provide incentives.
Social (Including People)	• Understanding/experience of use of technique/product on SRN. • Recycling needs to be considered at the point of design.
Technological	• Consistency and known source of RAP. • Impact upon durability. • Ability to correct binder properties. • Ensuring homogeneity. • Impact of polymer modified binders.
Legal (Incorporating Technical/ Standards)	• PD6691 – Limitations to 50% of mix and/or departure from standard requirements.
Environmental	• EA regulatory position – Use of treated asphalt waste. • Update required to asPECT to demonstrate environmental benefits.

Table 7.3 – PESTLE Analysis for Cold Ex-situ Recycling

	Cold Ex-situ Recycling Limitations
Political	• Suitability of technique for Road Investment Strategy schemes. • Implications of the applicability to the SRN due to the majority of treatments focusing on re-surfacing rather than structural treatments. • Impact of curing times of network availability/road user delays KPI's. • Lack of marketing regarding the use of reclaimed asphalt.
Economic (Including Contractual)	• Mobilisation cost of plant. • Minimum production Tonnage requirements. • Increased thickness compared to conventional hot mix materials based on current TRL 611 design guidance. • Availability of mobile ex-situ plants. • Risk ownership, risk sharing and reward incentives. • Procurement implications – sustainability submission/weighting in contracts, clients need to specify targets to provide incentives.
Social (Including People)	• Increase traffic management time/road users delay due to product curing. • Understanding/experience of use of technique/product on SRN. • Recycling needs to be considered at the point of design.
Technological	• Product curing time. • Understanding of in-situ performance and relationship with Clause 948 end performance requirements • Treatment of structural pavement layers only. • Material performance characteristics compared to conventional hot mix materials. • A laboratory curing protocol is required to reflect in-service performance. • Fatigue standard for standard material is unknown so comparison with other materials is difficult. • Applicability to the heavy traffic roads.
Legal (Incorporating Technical/ Standards)	• Design standards typically limited to 30msa according to HD26/06 and TRL 611. • Departure from Standard required for above 30msa. • Inconsistency between standards and design guidance e.g. SHW contains Class B4 but this is not covered by TRL 611. • Knowledge regarding product performance. • Pavement design and maintenance guidance.
Environmental	• Product seasonal constraints. • EA regulatory position – Use of treated asphalt waste.

Table 7.4 – PESTLE Analysis for Cold In-situ Recycling

	Cold In-situ Recycling Limitations
Political	• Suitability of technique for Road Investment Strategy schemes. • Implications of the applicability to the SRN due to the majority of treatments focusing on re-surfacing rather than structural treatments. • Impact of curing times of network availability/road user delays KPI's. • Lack of marketing regarding the use of reclaimed asphalt.
Economic (Including Contractual)	• Mobilisation cost of plant. • Minimum output requirements. • Increased thickness compared to conventional hot mix materials based on current TRL 611 design guidance. • Availability of plants (e.g. downcut technique). • Risk ownership, risk sharing and reward incentives. • Procurement implications – sustainability submission/weighting in contracts, clients need to specify targets to provide incentives.
Social (Including People)	• Increase traffic management time/road users delay due to product curing. • Understanding/experience of use of technique/product on SRN. • Recycling needs to be considered at the point of design.
Technological	• Product curing time. • Understanding of in-situ performance • Treatment of structural pavement layers only. • Experience of specific techniques e.g. downcut process. • Material performance characteristics compared to conventional hot mix materials. • Consistency of existing pavement being recycled. • A laboratory curing protocol is required to reflect in-service performance. • Fatigue standard for standard material is unknown so comparison with other materials is difficult. • Applicability to the heavy traffic roads.
Legal (Incorporating Technical/ Standards)	• Design standards typically limited to 30msa. • Departure from Standard required. • Scope of standards. e.g SHW downcut process. • Knowledge regarding product performance. • Pavement design and maintenance guidance.
Environmental	• Product seasonal constraints.

7.2 Hot mix Recycling

7.2.1 Specification, Durability & Skid Resistance

Current specification limits were highlighted as a significant limitation. Current specifications are provided to ensure quality and safety, however the need for a departure from standard for increased recycled level and/or the application of specific recycling technique was considered to restrict increased recycling levels. The most significant limitation identified was the restriction of 10% reclaimed asphalt in surface course without the need for a departure from standard and the PSV value requirements.

Consultation with industry indicates concerns regarding long term durability and skid resistance of surface course containing reclaimed asphalt were a significant limitation with a number of local authorities not permitting the use of reclaimed asphalt and/or limiting the reclaimed asphalt content.

7.2.2 Thin Surface Course – Product Acceptance Certification

The specification requirements defined MCHW Clause 942 – Thin Surface Course Systems requires the "*The thin surface course mixture shall comply with BS EN 13108-1, BS EN 13108-2 or BS EN 13108-5. It shall be CE marked and the Contractor shall submit the declaration of performance for the material to the Overseeing Organisation. The declaration of performance shall demonstrate that the material meets the requirements of the specification*".

The specification also states "*The Contractor shall demonstrate that the 'as installed' thin surface course system can meet the requirements of the specification. This shall be demonstrated by the system meeting the stated material requirements and by having undergone a System Installation Performance Trial (SIPT) to cover the aspects of the installation not covered by the material's declaration of performance. The installed thin surface course system shall be assessed, tested and certified by a Certification Body using one or more trial areas of surfacing."*

Currently standards and certification permit the use of RA content up to 10% with appropriate controls on the feedstock and mixture design. Existing specification levels and the need for a departure from standard means that current certifications do not incorporate reclaimed asphalt levels above 10%. This is consistent with TRL 2010, which states *"On a job-specific basis when the client has requested the inclusion of more than 10%, the lack of a HAPAS certificate covering the thin surfacing may not be a problem. However, if such higher rates of inclusion were required on a regular basis, the product would probably require a specific certificate that would clarify the acceptable sources of RA and its subsequent processing."*

7.2.3 Capital Investment

Significant capital investment is required to upgrade asphalt plants in the UK to incorporate high levels of reclaimed asphalt. A review of the UK market has indicated that a large number of asphalt plants have a low level of recycling capability with only a limited number of plants have high recycling capabilities. This appears to be associated with the current UK specification, market demands, age of UK asphalt plants and the need to retro-fit recycling technologies.

The WSP/PB (2014) report concluded that:

- *"A large capital investment is required by asphalt supply plants to allow the introduction of more than 25% planings into a new mix. Less than 5% of existing plants have made this investment."*
- *"A fully modified batch plant able to process recycled planings with any formal control, is capital intensive and the supply chain would need assurance that the market would warrant this type of investment."*
- *"It was estimated that around £12million capital is required to establish a new asphalt plant capable of receiving recycled materials. Even then, new locations would probably not receive the planning approvals to allow for new plants to enter the industry. New plant is then most likely to replace existing batch plants which can impose asphalt supply shortages. Upgrades to existing plant is of the order of £8million, and is only possible provided there is sufficient space on the site."*

As part of the UK Pavement Liaison Group Working Group 9 (UKPLG WG9) discussions, it was highlighted that an increase in the permitted reclaimed asphalt content and procurement incentivisation would be required to support the business case for capital expenditure. It was also highlighted greater collaboration and a holistic view across all clients is required in a region to ensure local demands across all clients justified the need for the capital expenditure. This is consistent with the surveys undertaken which showed significant variations between local authority requirements regarding the use of reclaimed asphalt.

It was expressed that any increases in the permitted reclaimed asphalt content should be incremental to ensure a barrier to trade is not created.

7.2.4 Ownership, Segregating and Processing Planings

A key limitation identified for hot mix recycling is the consistency of the reclaimed asphalt and need to segregate and process planings.

Reclaimed asphalt is produced from various different sources with different binder contents, binder properties, aggregate gradation and aggregate properties. Individual contractual mechanisms are in place, which determine the ownership of planings, haulage arrangements and the subsequent end use.

The majority of planings have no documentation as to their source properties. Incoming planings with no source documentation require laboratory testing to understand the material properties prior to recycling. It is preferable to have all planings documented prior to arrival at the plant; thereby minimising preparation time and greater emphasis on planings processing, product production and delivery.

Operational and programme constraints can mean surface course planings are not planed separately/segregated from the lower pavement layers at the source of planing. The ownership of the planings, commercial arrangements, haulage efficiency and practically of segregating planings also have a limiting effect on the levels of recycling. The WSP/PB (2014) report concluded that *“The practicality of splitting stockpile sites into every parent possibility is enormous. Grading distinction is fairly easy, while PSV would require further type testing or original laying records (PSV is usually measured off fresh material at the quarry of source). Once two types of stone are mixed, it becomes ‘impossible’ to split them by PSV properties. Different binder types are not considered. (This would require testing or as built records). The presence of polymer modified binders in the planing aggregate is not considered as a desirable property for addition to recycled asphalt. A full management service would require a targeted planing operation at source, where different layers could be planned individually. Obviously, this would attract cost and time constraints on the current practices.”*

It was also highlighted by the working group that additional processing of reclaimed asphalt requires sufficient space at the production plant to process, segregate and store the reclaimed asphalt planings prior to re-use. It was highlighted that space is often limited, which influences the ability to process and segregate the reclaimed asphalt. This is consistent with the WSP/PB (2014) report, which concluded **“***Certain environmental or social constraints could also exist that prevent certain type of dust, noise or 24hr working operations”*.

Whilst space was considered to currently be a limiting factor at a number of asphalt plants, liaison with working group members indicated that if there was a business case for increased recycling then additional space could be purchased through capital investment.

7.3 Cold Recycling

A number of limitations have been identified in relation to cold recycling. The key limitations for cold in-situ and ex-situ recycling were generally consistent. The key limitations produced by the working group ranking are discussed in further detail below.

7.3.1 Application on the Strategic Road Network

It should be recognised that work on the SRN typically comprises re-surfacing rather than deeper structural treatments which reduces the opportunity to use cold recycling techniques.

Cold recycling requires longer curing times relative to conventional treatments. The working window on the SRN typically comprises of overnight lane closures. The need to re-open all lanes to traffic the next day is therefore prohibitive to cold recycling techniques. Seasonal constraints were considered to further limit the application of cold recycling.

It was identified that early consideration of cold recycling is required with buy-in from the client, designer and contractor to identify suitable schemes at the earliest opportunity with appropriate consideration of the traffic management.

7.3.2 Design Standards/Specifications

The current standards also bring several limitations. The most significant is considered to be the maximum design traffic required without a departure from standard. Currently HD 26/06 states "*Pavement design guidance comprising cold recycled base material is presented in TRL Report 611 (2004). These designs require a 'Departure from Standard' from the Overseeing Organisation, with the exception of an ex situ stabilized Quick Visco-Elastic (QVE) base material comprising a 3% bituminous binder and a minimum 1% cement, known as foamed asphalt, and classified as Zone B2 material, for a maximum cumulative design traffic up to 30msa*".

The limit of 30msa is understood to have been determined using a risk-based approach and current knowledge generated from monitoring sites at the time of publication of TRL 611 in 2004. This is consistent with TRL 611 which states "*This guide contains pavement design for sites with a design traffic carrying up to 80msa, although these designs are extrapolation of the current knowledge which exists for pavements up to 30 msa".*

Further guidance is required on maintenance design procedures using cold recycled materials to reflect the work undertaken on the SRN.

Due to the timing of publications, it was further identified that there are inconsistencies between the Specification of Highways Works – Series 900 and TRL 611. For example, it is identified that in SHW Clause 948 – Ex-situ Cold Recycled Bound Material, a Class B4 material is permitted with an end performance indirect tensile stiffness modulus requirement of 4700MPa. However, TRL 611, only includes design guidance for a Class B3 material with a minimum long-term stiffness of 3100MPa.

It was emphasised by the working group that a significant number of cold recycled sites have been installed since the publication of TRL 611 and views were expressed that the cold recycled materials had performed well. The need for an update of the design guidance and specification was highlighted by the working group and it was recommended that the original monitoring sites documented in TRL 611 and subsequent sites are revisited to evaluate how the recycled mixture has performed.

It was also stressed that in recent years specific cold recycling techniques have evolved such as the in-situ downcut recycling technique. The knowledge of this technique and subsequent design guidance and specification is considered to be a limitation.

7.3.3 Curing and Long-Term Material Characteristics/Performance

Material curing was cited as a key limitation in terms of opening to traffic (as discussed previously), the long-term material behaviour and how well laboratory curing protocols reflect in-service performance.

A range of laboratory curing procedures are defined in SHW Clause 947 and 948 depending on the material type. The curing of materials is critical to their long term performance. Replicating the actual in-service curing in the laboratory is complex due to the different material properties and variations in climatic conditions experienced.

Recent research undertaken by Transport Scotland "*The trialling of Cl.948 recycled material on Scottish trunk roads*" published in May 2018 indicates that the in-service stiffness values reported at 365 days do not appear to be consistent with the laboratory mix design. The results to date indicate "*Four sites along the M9 between junctions 4 and 3 were structurally improved using cold bound recycled material on the hard shoulder as a trial to better understand cold recycling. The design for the hard shoulder was specified as a class B4 material (Table 9/14 of Clause 948) which would be suitable for main carriageways. Testing at 365 days found the material to be non-compliant to the requirements of a Class B4 material as it was designed to be. From this, the report concludes that further development and understanding of Clause 948 material and the specification is required.*"

Concerns regarding curing were the most common limitation stated in response to the ADEPT surveys for cold recycled materials. In particular, the ability to close roads for long enough to enable strength build up as well as seasonal impactions were highlighted. The potential for cold recycled bound materials to be prematurely damaged if trafficked during the early life period prior to sufficient stiffness build-up was also identified.

For in-situ recycling, the responses also highlighted limitations in terms of the variability in the existing pavement construction and long-term performance concerns.

A number of parties highlighted that the mix is typically considered in terms of hot-mix equivalent with a focus predominantly on stiffness modulus. The material characteristics and behaviour is significantly different for cold recycled materials and a greater understanding of the fatigue performance, laboratory curing and in-service performance is required. It was also highlight that the specification of a minimum stiffness as the end performance requirement may not be the most effective approach for durability and may lead to overly stiff mixtures.

7.3.4 Commercial

A number of commercial considerations were identified to limit the application of cold recycling. The key factors considered are:

- An increased treatment thickness based on TRL 611 in relation to hot mix bituminous materials was cited as key factor for limiting the use of cold recycled bound material for ex-situ cold recycled bound design.
- Mobilisation costs and minimum treatment tonnage/output was also considered to be an important commercial factor. Early planning and a consistent programme of work was considered to be required to offset the mobilisation cost for cold recycling.
- The availability of sites for stockpiling and processing material within a suitable haul distance was also cited as a limiting factor for ex-situ cold recycled bound material. The impact of environmental legislation for the handling and stockpiling of asphalt waste containing coal tar was also identified.

The application of cold recycling techniques to mitigate the cost of disposing of asphalt waste containing coal tar was considered to be a key driver for cold recycling as shown by both the Highways England – Departures from Standard analysis and the ADEPT survey. In these instances, commercial and other limitations were significantly reduced as they were outweighed by the commercial implications of disposing of asphalt waste containing coal tar.

7.4 Limitations across all techniques

A number of limitations were identified through the working group that were common to all methods, in short these are generally related to:

- Client requirements, procurement and specifications were highlighted as a current limitation. Views were presented by the working group that the supply chain will provide what is specified by the client and that change to the procurement, specification and incentivisation is required to drive investment and increase recycling levels. Views were expressed that recycling targets could be implemented into contracts during procurement as a pre-qualifier i.e. a minimum ‘x’ amount of asphalt is recycled. Collaboration between client, designer and supplier was also deemed to be critical to increasing recycling. Recycling needs to be considered at the point of design, with significant early engagement required to deliver a number of recycling techniques.

- Risk ownership - The risk of performance and durability of the final laid product currently remains the responsibility of the supply contractor. It was highlighted that greater risk sharing is required to drive higher reclaimed asphalt contents.

- Cost & Perception – UKPLG WG9 emphasised that there is a perception that recycled products will always be cheaper without consideration of the additional processing cost. This was considered to be a limiting factor on schemes where there was no direct commercial benefit. It was also highlighted that there is a lack of marketing regarding the use of reclaimed asphalt across the industry with other types of recycling (e.g. recycled plastic) achieving significant press coverage and interest from stakeholders.

8. Conclusions

8.1 Current Recycling Levels

- The review undertaken indicates that there is currently no central source of data that fully captures and monitors the use of reclaimed asphalt in bituminous materials for the Strategic and local road networks.
- A range of data sources have been reviewed to gain a snapshot of current recycling levels including published literature, Highways England (HAMPS and Departures from Standard data) and industry consultation to understand the current recycling levels and techniques used on the SRN and nationally.
- A review of published literature indicates approximately 3,400,000T of reclaimed asphalt was available in 2017 equating to 15% of total asphalt production based on EAPA (2017). Estimates by MPA (2019) predicted that a great level of asphalt planings was available in Great Britain in 2017 with 6,100,000 Tonnes available.
- It is estimated by EAPA (2017) that 80% is re-used in hot mix and warm mix applications, 5-15% of total RAP is cold recycled with the remainder used in other applications.

8.2 Levels of Reclaimed Asphlat Incoporated into Surface Course Material

- Previous assessments by WSP/Parson Brinckerhoff (2014) have indicated the incorporation of reclaimed asphalt into surface courses is limited.
- Consultation with industry indicates that 10% of reclaimed asphalt is now regularly incorporated into surface course materials as permitted within current standards.
- The analysis of the departures from standards indicates only a limited number of departures for hot mix surface courses containing reclaimed asphalt quantities in excess of 10% have been approved. This shows that the majority of reclaimed asphalt incorporated into surface course on the strategic road network is within standard.
- In total twenty one departures were submitted for surface course materials over a 21-year period with reclaimed asphalt quantities approved ranging from 20% and 40%. These installation sites present an opportunity to assess the performance of surface courses incorporating reclaimed asphalt above 10%.
- Considering the majority of these departures from standard were related to 1997, the data indicates that requests for departures from standard in recent years has been severely limited and has not increased with time.
- A survey of local authorities facilitated by ADEPT indicates the current approach to recycling is variable. 56% of respondents do not incorporate recycled asphalt into surface material and 44% suggested that they incorporate up to 10% reclaimed asphalt into surface course materials. No respondents reported that they regularly exceed 10% reclaimed asphalt although specific case study examples have been highlighted.
- Overall, the data indicates that reclaimed contents of surface course materials used are typically up to 10% as permitted by the standards on both the SRN and local level.

8.3 Levels of Reclaimed Asphlat Incoporated into Binder and Base Course Material

- Previous assessments by WSP/Parson Brinckerhoff (2014) indicated between 15 and 30% of asphalt planings are recycled into the lower asphalt layers.
- No departures from standard have been submitted for binder and base course materials in excess of 50% on the SRN indicating that all recycling into these layers is within current standard and specification.
- A survey of local authorities facilitated by ADEPT indicates the current approach to recycling is variable. 29% reported reclaimed asphalt is not currently incorporated into binder and base course, 58% reported that reclaimed asphalt is used within standard with reclaimed asphalt contents between 10-40% and 14% reported that in excess of 40% of reclaimed asphalt is incorporated.

8.4 Cold Recycling Levels

- The levels of cold recycling on the SRN is limited with the equivalent of 210,357T installed over an 18-year period.
- The application of cold recycling has been highly variable with cold recycling only installed in 8 out of 18 years.
- The use of cold recycling peaked in 2006, comprising approximately 50% of all cold recycling using foamed bitumen installed on the SRN since 2000.
- Since 2010 the use of cold recycling with foamed bitumen has been limited, however in recent years the level of cold recycling using foamed bitumen has increased due to the application of the in-situ downcut technique. At least seven departures have been granted for this process to be used on the SRN in the past two years.
- Based on the HAPMS data, the most significant programmes of cold recycling have taken place in Highways England Area 1 and Area 14. The use of cold recycled materials is also present in Areas 3, 4, 7 and 9.
- 60% of local authorities reported that they use Ex-situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 948 with an average annual production of 16,500T per authority. In contrast, the use of In-situ Cold Recycled Bitumen Bound Materials in accordance with SHW Clause 947 was limited to only 14% of the local authorities who responded.
- Highways England records and responses from ADEPT members indicates asphalt waste containing coal tar is a key driver for the use of Cold Recycled Bitumen Bound Materials. Analysis of the Environment Agency, Waste Data Interrogator Tool indicates 88% of bitumen bound and tar bound asphalt wastes codes defined in the EWR are recovered.

8.5 UK Market Capacity

- EAPA (2016) figures indicate 165 out of the total 250 plants in Great Britain currently have a recycling capability.
- Figures reported by TRL (2009) and WSP/Parson Brinckerhoff (2014) indicate that the majority of asphalt plants have relatively low level of recycling capability (up to 30%) with only a limited number of plants with high recycling capabilities.
- It is understood through consultation with industry suppliers that most of plants in the UK use cold feed systems to incorporate reclaimed asphalt.
- The number of plants with high recycling capabilities is understood to be limited. In total only seven plants were identified as operating a parallel drum system as part of the consultation. It is understood that there are no RAP priority plants in the UK in comparison to approximately ten RAP priority plants in Germany and Austria.
- A significant number of cold recycling plants are present in the UK comprising approximately twenty four active ex-situ cold recycling plants, thirty active in-situ cold recycling machines (Bitumen Emulsion and Foamed Bitumen) using the up-cut approach and one in-situ cold recycling machine capable of the downcut technique.

8.6 International Comparisons

- Based on the 2016 figures reported in EAPA (2017), it appears that the percentage of asphalt plants that are equipped for hot or warm mix recycling in Great Britain (66%) is typical of other European countries and above the average of 47%. The values are significantly lower than the leading European countries Belgium, Denmark, Germany, Netherlands and Sweden.
- There has been significant capital expenditure in countries such as Germany, Netherlands and Denmark with greater use of parallel drum systems and indirect heating compared to the UK.
- In 2017 over 48,500,000T of reclaimed asphalt was available in Europe. Germany, Italy, France and the Netherlands are some of the of the leading countries in terms of total reclaimed asphalt available for recycling. Great Britain has the fifth highest reclaimed asphalt available for recycling in tonnage.
- As a percentage of total production Netherlands, Italy, Czech Republic and Germany has the highest reclaimed asphalt available. The percentage of reclaimed asphalt available for recycling in Great Britain was 15%, which is just below the average value of 20% reported across all

European Countries.

- The re-use of 90% of available reclaimed asphalt in hot mix, warm mix or cold recycled in Great Britain is above the average 62% of available RA into bound applications. This appears to indicate that where available reclaimed asphalt is used in the higher value applications rather than down cycled to a lower value application such as unbound layers.
- The United States of America (USA) recycles the greatest quantity of reclaimed asphalt by far in the world with over 76,200,000T recycled. The average estimated percentage of RAP used in asphalt mixtures has increased from 15.6% in 2009 to 20.1% in 2017.
- Recycled contents in Japan have also increased in recent years, with an average RAP content in Japan asphalt mixtures increased from 33% on average in 2000 to 47% on average in 2013. Of the Japanese plants with recycling capability, 17.7% utilise an indirect heating system, 68.8% use a parallel heating system, and 15.5% use a drum mix process.
- All leading countries throughout Europe (such as Germany, Netherlands and Denmark) and worldwide (such as the USA and Japan) have invested heavily in recycling plant capabilities and processing of reclaimed asphalt.

8.7 Key Limitations

- A range of complex factors are present that limit the rate of asphalt recycling on the SRN in terms of both the recycling method used and the reclaimed asphalt content used within a particular material. The limitations cover a wide range of inter-related factors.
- The key limitations for hot mix recycling are considered to be:
    - Specification limitations.
    - Ensuring durability and skid resistance for surface course materials.
    - Thin Surface Course certification for reclaimed asphalt contents above 10%.
    - The capital investment required to upgrade asphalt plants to incorporate high levels of reclaimed asphalt.
    - Business case for capital expenditure and collaboration/local demands across all clients justified the need for the capital expenditure.
    - Consistency and traceability of the reclaimed asphalt.
    - The ability to segregate planings due to commercial, operational and programme constraints.
- The key limitations for cold recycling are considered to be:
    - The applicability of cold recycling on the SRN was seen as limited due to the majority of treatment focusing on re-surfacing rather than structural treatments.
    - Curing constraints and available working window on the SRN was considered to be significant limiting factor.
    - The current standards also bring several limitations. The most significant limitation is considered to be the maximum design traffic of 30msa required without a departure from standard. Due to the timing of publications it has been identified that there are inconsistencies between the Specification of Highways Works – Series 900 and TRL 611.
    - It was also highlighted that in recent years specific cold recycling techniques have evolved such as the in-situ down recycling technique. The knowledge of this technique and subsequent design guidance and specification is considered to be a limitation.
    - A need to understand the relationship between laboratory and in-service curing characteristics and the impact on the long-term material performance was also considered to be a limiting factor in terms of technical knowledge and ensuring durability.
    - Commercial limitations were also identified due to the increased treatment thickness based on TRL 611 in relation to hot-mix bituminous materials and programme constraints to offset mobilisation costs and minimum tonnages/outputs.

9. Recommendations

The following recommendations are made to overcome the identified limitations and promote increased recycling levels in the medium-term:

9.1 Data Collection & Traceability

- Data Collection & Reporting – It is recommended that consideration is given to creating a central database that records the current level of recycling/reclaimed asphalt on the SRN. It is recommended that a review of HAPMS is undertaken to identify how HAPMS could be developed to store recycled information consistently to enable accurate records regarding recycling rates on the SRN to be automatically reported. It is recommended that any data collection is integrated with the carbon/sustainability reporting to regularly report on reclaimed asphalt use as per the approach taken by NAPA (2017). Future technologies and BIM integration could be considered for automatic reporting.
- Traceability of Reclaimed Asphalt - The source and traceability of reclaimed asphalt is a key consideration for recycling into surface course. Consultation with industry suppliers have indicated this will be a key factor to enable increases in surface course recycling and ensure durable materials. It is recommended that pavement investigation guidance considers the re-use of reclaimed asphalt and appropriate testing protocols are developed to assess the reclaimed asphalt properties and store this information. It is also recommended that future technologies (e.g. BIM, RFID…etc.) are considered for providing traceability from installation through to re-use.

9.2 Hot mix Recycling

- Assessment of Surface Course with RAP in excess of 10% - Surface course replacement represents a significant opportunity to increase recycling levels due to the re-surfacing work currently being undertaken on the SRN. Consultation with industry indicates the current level of recycling into surface course is limited by the specification. Industry have indicated that an increase in the specification limit to 20% would create a step change that could be achieved in the short-term. A number of limitations have been highlighted by various parties in relation to durability and skid resistance. This solution proposes to review the performance of the trials to date. A number of trials have been undertaken of surface courses with RAP contents in excess of 10%. A number of these trials were installed 10+years ago and have been monitored in detail after installation but have not been assessed in recent years. It is recommended an assessment of all available data and further investigation is undertaken.
- Review of Specification and Surface Course Certfiication - Current specifications limit the recycling content in surface courses. Consultation indicates that current specifications, certification requirements and the need for departures is preventing CAPEX investment. It is recommended that a review is undertaken to establish the end performance specification for surface course containing recycled contents above 10%.
- Skid Resistance – A key consideration for the incorporation of reclaimed asphalt into surface course materials is the influence that reclaimed asphalt has on skid resistance. It is recommended that a risk based approach is considered which studies the level of reclaimed asphalt incorporated and utilises PSV testing, Friction after Polishing testing and in-situ testing to mitigate any risks. It is recommended that further research is undertaken to consider the influence that reclaimed asphalt has on the skid resistance of the surface course.
- Full Scale Production Trials – It is recommended that further trials are undertaken to monitor the performance of surface courses in excess of 10% RAP limits. It is recommended that these site trials are representative of full-scale production and reclaimed asphalt source generated from the SRN. It is recommended that a long-term monitoring programme is developed for any trials.
- Segregating Planings – It is recommended that further work is undertaken to establish the feasibility of segregating surface course planings from other pavement layers on the SRN. It is

recommended that programming and operational impacts are assessed, and cost/benefit analysis conducted.

- Technical review of the processing of reclaimed asphalt and the influence on performance - The processing of reclaimed asphalt is of critical importance to the quality of the end product produced. The level of processing and quality control is proportional to the quantity of RAP incorporated. It is recommended that development in reclaimed asphalt processing such as granulation are assessed to determine the potential benefit on the end product performance.
- Technical study of binder properties from RAP and the application of rejuvenators - The use of asphalt rejuvenators has the potential to restore the rheological properties of aged binder and enable the introduction of higher reclaimed asphalt contents. It is recommended further research is undertaken to understand the benefits of incorporating various rejuvenators.
- Dedicated Highways England Reclaimed Asphalt Storage – It is recommended that further work is undertaken to establish the feasibility of creating dedicated reclaimed asphalt storage and processing facilities to promote a closed looped recycling of RAP on the SRN.
- RAP Priority Plants - In recent years a number of bespoke RAP priority plants have been developed which enable up to 100% hot mix recycling. It is recommended that an assessment of RAP priority plants in Germany and Austria is undertaken to understand how the plants are being operated, the mix design process and any potential application for the UK.
- Warm mix – Warm mix is considered to be a key solution for incorporating reclaimed asphalt. A number of warm mix additives are considered to work well with the incorporation of reclaimed asphalt (durability, water sensitivity, ageing resistance…etc.). It is recommended that any development to specifications consider the use of warm mix asphalt incorporating reclaimed asphalt.

9.3 Cold Recycling

- In-situ downcut recycling – It is recommended that further research is undertaken in relation to the in-situ downcut recycling technique in response to the increase in departures approved on the SRN in recent years. It is recommended that further research is undertaken to understand the performance of the seven installed in-situ downcut recycled sites installed to date. It is recommended that the application of the technique is documented, design guidance is produced, a specification clause in the SHW 900 series is produced and appropriate ongoing monitoring considered.
- Cold Recycling Pavement Design - The pavement designs specified in TRL 611/386 were verified by a number of documented sites. It was identified through consultation with the working group that the performance of these sites is unknown but are suspected to have performed well. It is therefore recommended that a full review of the performance of the verification sites is undertaken with particular emphasis on the performance and traffic level (>30msa).
- Curing - The in-situ curing for cold recycled materials is heavily dependent on the material conditions and climatic conditions. The current SHW Clause 948 protocol is designed to represent one year in service. The proposed curing protocol for Clause 948 is different to the proposed Clause 949. Experience indicates that the curing protocol significantly influences the ITSM results Research by Transport for Scotland indicates a significant difference between the laboratory mix design and in-situ performance. It is therefore recommended that further research is undertaken to assess the relationship between the laboratory condition protocol with in-situ performance.
- Cold Recycling SHW Clause 948/TRL 611 - Due to the timing of publications it has been identified that there are inconsistencies between the Specification of Highways Works – Series 900 and TRL 611. It is recommended that updates to both documents are considered to align TRL 611 and SHW Clause 948. In particular, it is recommended that the use of Class B4 materials is reviewed and appropriate application and design guidance provided.

- Maintenance Design Procedures – Current design guidance in TRL 611 is primarily focused on new construction with some guidance on partial depth recycling. The UKPLG WG9 identified that further design guidance is required for maintenance solutions in order to be representative of the work that was undertaken and design life expectations.
- Incoporating Ex-Situ Cold Recycled Bitumen Bound Materials into Pavement Foundations – Currently the application of ex-situ cold recycled bitumen bound material on the SRN is limited. There is the potential to incorporate ex-situ cold recycled bituminous bound materials as an alternative to HBM in a Class 3 or 4 Foundation Classes. It is recommended that analysis is undertaken to consider the use of Ex-Situ Cold Recycled Bitumen Bound Materials as a pavement foundation in any future revision of HD25.

9.4 Colloboration and Procurements

- Procurement Review – It is recommend that a review of current procurement methods is conducted to establish how recycling levels are considered. Potential options for introducing a minimum or target recycling level could be introduced for bituminous materials to promote recycling without creating a barrier to trade. It is recommended that procurement considers the ownership of planning and ensuring ownership is with the party that can ensure RA is reused in the highest value applications.
- Collaboration between client, contractor and designer - Collaboration between client, designer and supplier was also deemed to be critical to increasing recycling. It is recommended the scheme delivery process is reviewed to consider the incorporation of recycling solutions at the earliest possible stage in the design.

References

1. Barrasa (2017). APSE "Use of eco-friendly materials for a new concept of Asphalt Pavements for a Sustainable Environment. Project Final Report. Collaborative project. ENV.2013.6.3-2.
2. Benninghoven, (2017). Eco-friendly technology is a top priority. https://www.benninghoven.com/en/news-media/press-releases/magazin_11.135552.php [Accessed on 10/10/2018].
3. Benninghoven (2018). Granulator / Storage / Recycling Systems / Control Recycling. https://media.wirtgen-group.com/media/06_benninghoven/infomaterial_8/produkte/granulator/Finale_Screen_Prospekt_Recycling_EN.pdf. [Accessed on 23/02/2018].
4. BS EN 12697-3:2013+A1:2018. Bituminous mixtures. Test methods. Bitumen recovery: Rotary evaporator. Published June 2013.
5. Button, J.W., Estakhri C.K., and Little R.C. (1999). Overview of hot in-place recycling of bituminous pavements. Transportation Research Record No. 1684. Washington DC: National Academy Press.
6. Carswell, I. Nicholls, J.C., Elliott, R. C., Harris J. and Strickland, D., (2005). Feasibility of recycling thin surfacing back into thin surfacing systems, TRL Report 645, 2005.
7. Carswell, I., Nicholls, J.C., Widyatmoko, I., Harris, J. and Taylor R., (2010). Best Practice Guide for Recycling into Surface Course, TRL Road Note (RN) 43, 2010.
8. Chibuzor (2017). Sub-Task 5: Best Practice for Recycling Asphalt Pavements. Task 1-111 Collaborative Research Project. Highways England, Mineral Product, Association and Eurobitume UK. Project Number: 60523058, November 2017.
9. Copeland, A. (2011). Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice, FHWA report FHWA-HRT-11-021, 2011.
10. DEFRA (2018). Statistical data set ENV23 – UK statistics on waste. https://www.gov.uk/government/statistical-data-sets/env23-uk-waste-data-and-management. Accessed on 02 October 2018.
11. European Asphalt Pavement Association (EAPA), (2015) – Asphalt in Figures 2015, https://eapa.org/wp-content/uploads/2018/07/2015.pdf. [Accessed on 03/12/2018].
12. European Asphalt Pavement Association (EAPA), (2016). Asphalt in Figures 2016, https://eapa.org/wp-content/uploads/2018/07/2016.pdf Version 22-01-18.
13. European Asphalt Pavement Association (EAPA), (2017) – Asphalt in Figures 2017. https://eapa.org/wp-content/uploads/2018/12/AIF_2017.pdf [Accessed on 23/02/2018].
14. Environment Agency. Waster Data Interrogator 2017. https://data.gov.uk/dataset/c7c3c433-4656-44e9-9e1c-a4a565bf7b56/waste-data-interrogator-2016. [Accessed on 02/10/2018].
15. Flint, M and Bailey, H (2018). The Application of High Recycled Content Mixtures on Strategic Roads. The 16th Annual International Conference. 22nd – 23rd February 2017. Liverpool John Moores University, UK.
16. German Asphalt Pavement Association (2019). Asphalt Recycling in Germany – Short Overview Presentation. Meeting with Highways England. 29/08/2019.
17. HD 36/06 - Surfacing Materials for New and Maintenance Construction Design Manual For Roads and Bridges, Design Manual for Roads and Bridges, vol. 7, sect. 5, part 1, 2006
18. Highways England SU159 – Bulk Loading of Construction Data Using "XML Import Elements"
19. Highways England (2018). Highways England Way Forward: In-situ Downcut Recycling (Unpublished report).
20. Highways England (2018). Draft MCHW Recycling Clause 949: In Situ Downcut Process Cold Recycled Bitumen Bound Material (Unpublished).
21. Highways England, (2016). Road Pavements – General, Series NG 700, Manual of Contract Documents for Highway Works Vol 2: Notes for Guidance on the Specification for Highway Works. Stationery Office, London.
22. Highways England, (2018). Road Pavements – Bituminous Bound Materials, Series 900, Manual of Contract Documents for Highway Works Vol 1: Specification for Highway Works. Stationery Office, London.

23. Highways England, (2018). Road Pavements – Bituminous Bound Materials, Series NG 900, Manual of Contract Documents for Highway Works Vol 2: Notes for Guidance on the Specification for Highway Works. Stationery Office, London.
24. Hirama, A. (2014). The Actual Situation of Recycled Asphalt Mixture in Japan. Presentation at Seminar on Pavement Technology Exchange Between U.S.A. and Japan, 4 December 2014, Tokyo.HM Revenue and Customs, National Statistics Aggregates Levy Bulletin (2014).
25. 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.
26. Mineral Products Association, (2019). The Contribution of Recycled and Secondary Materials to Total Aggregates Supply in Great Britain.
27. Ministry of Housing, Communities & Local Government (DCLG), (2007a). Survey of Arisings and Use of Alternatives to Primary Aggregates in England - 2005 Construction, Demolition and Excavation Waste. Final Report.
28. Merrill, D, Nunn, M and Carswell, I, (2004)) A Guide to the Use and Specification of Cold Recycled Materials for the Maintenance of Road Pavements. Transport Research Laboratory, Crowthorne, UK.
29. Metcalf, T, Flint, M and Ikram M (2018). The Application of High Recycled Content Mixtures on the Strategic Road Network. IAT Presentation. 24th September 2018.
30. Molenaar, A.A.A., Mohajeri, M. and Van De Ven, M.F.C., (2014). Hot Recycling in the Netherlands, TRB Transportation Research Circular, no. E-C188, 2014, pp. 28-41
31. Milton LJ and Earland, M, (1999) Transport Research Laboratory (1999). Design Guide and Specification for Structural Maintenance of Highway Pavements by Cold In-situ Recycling. Transport Research Laboratory, Crowthorne, UK. 1999.
32. National Asphalt Pavement Association (NAPA), (2015). High RAP Asphalt Pavements. Japan Practice – Lessons Learned. Information Series 139. December 2015.
33. Williams, B.A. and Copeland, A., (2018). Asphalt Pavement Industry Survey on Recycled Materials and Warm Mix Asphalt Usage: 2017, NAPA Information Series 138 (8th edition), 2018.
34. Nicholls, J.C., Hannah, A., and Carroll, A. (2007). A practical example of recycling reclaimed asphalt back into the surface course. 6th International Conference on Sustainable Aggregates, Pavement Engineering AND Asphalt Technology, Liverpool John Moores University, February 2007. TRL Paper PA/INF/5687/06.
35. Nicholls, C., 2017. Asphalt Mixture Specification and Testing. CRC Press.
36. PD 6691: 2015+A1:2016 – Guidance on the Use of BS EN 13108, Bituminous Mixtures – Material Specifications, BSI Standards Publication, 2016.
37. Lo Presti D, Jiménez del Barco Carrión A, Airey G, Hajj E, Towards 100 % recycling of reclaimed asphalt in road surface courses: binder design methodology and case studies, Journal of Cleaner Production (2016)
38. RSTA/ADEPT (2012). Code of Practice for In-situ Structural Road Recycling. [Online] Available at: https://www.rsta-uk.org/downloads/RSTA-ADEPT-Code-of-Practice-for-In-situ-Structural-Road-Recycling-(2012).pdf [Accessed 08 Sept. 2018].
39. Sabita (2019). Use of Reclaimed Asphalt in the Production of Asphalt. MANUAL 36 / TRH 21.
40. Saeed, A., Hall, J. W. Jr. and Barker W., Performance-Related Tests of Aggregates for Use in Unbound Pavement Layers, TRB's NCHRP report 453, 2001.
41. Schiavi, I., Carswell, I., and Wayman, M. Recycled asphalt in surfacing materials: a case study on carbon dioxide emission savings. TRL Report PPR 304. 2007.
42. Shell (2015). The Shell Bitumen Handbook, London, UK, ICE Publishing, 2015.
43. Transport Scotland (2018). The Trialling of Cl.948 Recycled Material on Scottish Trunk Roads.
44. Tušar, M, Nielsen, E, Batista, F, Antunes, M, Mollenhauer, K, Vanstenkiste, S, Carswell, I, Kuttah D, Viman, L and Waldemarson, A (2012). Re-Road End of Life Strategies for Asphalt Pavements. Optimisation of Reclaimed Asphalt in Asphalt Plant Mixing. WP 4, DP 4.5, V3, 30/10/2012.
45. US Army Corps of Engineers (USACE), Hot Mix Asphalt Paving Handbook Part II: Hot Mix Asphalt Plant Operations, *AC 150/5370-14A*, Appendix 1, 2000.

46. Wayman, M. and Carswell, I. Enhanced levels of reclaimed asphalt in surfacing materials – a case study evaluating carbon dioxide emissions. TRL Report PPR 468, 2010.
47. Wayman, M., Nicholls, J.C., Carswell, I., Use of lower temperature asphalt in pavement construction, TRL Report PPR 742, 2015.
48. West, R., Wills, J. R. and Marasteanu, M., Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content, NCHRP report 752, 2013.
49. Wirtgen.com, (2008). A Mixing Plant that Comes to the Job Site: Mobile Cold Recycling Mixing Plant KMA 200. [online] Available at: http://media.wirtgen-group.com/media/02_wirtgen/infomaterial_1/kaltrecycler/mischanlage/kma_220/BR_KMA220_US.pdf [Accessed 10 Sept. 2018].
50. Wirtgen (2016). Cold Recycling: Wirtgen Cold Recycling Technology, http://media.wirtgen-group.com/media/02_wirtgen/infomaterial_1/kaltrecycler/kaltrecycling_technologie/kaltrecycling_handbuch/Cold_recycling_Manual_EN.pdf [Accessed on 23/02/2019].
51. Wirtgen (2018). Wirtgen Recycler 3800 CR: 100 miles – day and night. https://www.wirtgen-group.com/romania/ro/news-media/press-releases/wirtgen-group/press-releases-detail.138373.php [Accessed on 10/09/2018].
52. World Highways (2017). Upgrading a Benninghoven asphalt plant with new technology http://www.worldhighways.com/categories/materials-production-supply/products/upgrading-a-benninghoven-asphalt-plant-with-new-technology/ [Accessed on 23/02/2019].
53. WRAP (2010). Designing out Waste: A Design Team Guide for Civil Engineering, WRAP, 2010,
54. WRAP (2013). WRAP Quality Protocol ‘Aggregates. Aggregates from inert waste. End of waste criteria for the production of aggregates from inert waste’. October 2013.
55. WSP/PB (2014). Sustainable Pavement: Material Brokerage Service, Department for Transport Framework for Transport-Related Technical and Engineering Advice and Research, Ref: 240(4/45/12). WSP/PB, 2014.
56. Zaumanis, M., Mallick, R.B. and Frank, R. (2014) 100% Recycled Hot Mix Asphalt: A Review and Analysis, Resources, Conservation and Recycling, no. 92, 2014, pp. 230-245.
57. Highways England (2019). GG103 Introduction and general requirements for sustainable development and design. Revision 0. July 2019.