USE OF RECLAIMED ASPHALT IN THE PRODUCTION OF ASPHALT

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excellence in bituminous products

MANUAL 36 / TRH 21

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PREFACE

TECHNICAL RECOMMENDATIONS FOR HIGHWAYS (TRH) are written for practising engineers, technicians and technologists and describe current best practice in selected aspects of road engineering. The first draft of TRH 21: *Hot Mix Recycling* was produced in 1996 and updated as "TRH 21: 2009: *Hot mix Asphalt Recycling*". A copy of this version was placed on Sabita's website for a period of three months to encourage comment from local practitioners. It was then circulated to AAPA, NAPA and EAPA for peer review before the final document was published.

Since then there have been significant developments in asphalt recycling and this third edition of TRH 21: *The Use of Reclaimed Asphalt in the Production of Asphalt* incorporates these advances, based on experience in South Africa and information gathered from around the world in this field.

List of companion Sabita Manuals and DVDs

Manual 1	*Technical guidelines: Construction of bitumen rubber seals*
Manual 2	*Bituminous binders for road construction and maintenance*
Manual 3	*(Withdrawn)*
Manual 4	*(Withdrawn)*
Manual 5	*Guidelines for the manufacture and construction of hot mix asphalt*
Manual 6	*(Withdrawn)*
Manual 7	*SuperSurf – Economic warrants for surfacing roads*
Manual 8	*Guidelines for the safe and responsible handling of bituminous products*
Manual 9	*(Withdrawn)*
Manual 10	*Bituminous surfacing for low volume roads and temporary deviations*
Manual 11	*Labour enhanced construction for bituminous surfacings (This manual has been withdrawn and consolidated with Manual 12)*
Manual 12	*Labour Absorptive Methods in Road Construction using Bituminous Materials*
Manual 13	*LAMBs – The design and use of large aggregate mixes for bases*
Manual 14	*(Superseded by TG2)*
Manual 15	*(Withdrawn)*
Manual 16	*(Withdrawn)*
Manual 17	*Porous asphalt mixes: Design and use*
Manual 18	*Appropriate standards for the use of sand asphalt*
Manual 19	*Guidelines for the design, manufacture and construction of bitumen rubber asphalt wearing courses* (CD)
Manual 20	*Sealing of active cracks in road pavements*
Manual 21	*(Superseded by TG2)*
Manual 22	*Hot mix paving in adverse weather*
Manual 23	*Code of practice: Loading bitumen at refineries*
Manual 24	*(Withdrawn)*
Manual 25	*Code of practice: Transportation, off-loading and storage of bitumen and bituminous products* (CD)
Manual 26	*Interim guidelines for primes and stone pre-coating fluids*
Manual 27	*Guidelines for thin hot mix asphalt wearing courses on residential streets*
Manual 28	*Best practice for the design and construction of slurry seals*
Manual 29	*Guide to the safe use of solvents in a bituminous products laboratory*
Manual 30	*A guide to the selection of bituminous binders for road construction*
Manual 31	*Guidelines for calibrating a binder distributor to ensure satisfactory performance*
Manual 32	*Best practice guideline and specification for warm mix asphalt*
Manual 33	*Design procedure for high modulus asphalt (EME)*
Manual 34	(A) *Guidelines to the transportation of bitumen and* (B) *Bitumen spill protocol*
Manual 35/ TRH8	Design and use of Asphalt in Road Pavements

Technical guidelines

TG1	*The use of modified binders in road construction*
TG2	*Bitumen stabilised materials*
TG3	*Asphalt reinforcement for road condition*

DVDs

DVD100	*Test methods for bituminous products*
DVD200	*Training guide for the construction and repair of bituminous surfacings by hand*
DVD300	*Manufacture, paving and compaction of hot mix asphalt*
DVD410	*The safe handling of bitumen*
DVD420	*Treatment of bitumen burns*
DVD430	*Working safely with bitumen*
DVD440	*Firefighting in the bituminous products industry*
DVD450	*Safe loading and off-loading of bitumen*

Contents

1. Introduction

These guidelines cover all the main aspects of asphalt recycling, a process in which reclaimed asphalt is combined with new aggregate and new binder in a mixing plant to produce recycled asphalt. Experience gained in South Africa and internationally has been incorporated wherever possible.

1.1 Definition of Reclaimed Asphalt

In some countries – notably the USA – reclaimed asphalt is known as “RAP”; short for “reclaimed asphalt pavement” to differentiate it from reclaimed materials incorporating e.g. shingles for recycling. To avoid confusion with other recycling processes that may utilise material from other layers in the pavement besides the asphalt, the term “reclaimed asphalt – acronym RA” – is used here to describe fragments of asphalt that have been obtained from road pavements or plant returns and tailings.

For the purpose of this document reclaimed asphalt is defined as follows:

Reclaimed asphalt (RA) is obtained from milling or excavation of existing bituminous pavement layers or from stockpiles of asphalt production overruns and returned material. The material so obtained is crushed and screened to ensure an acceptable maximum size and grading. Following the crushing and fractionating process, RA is stockpiled and loaded in such a manner as will enhance the uniformity of the material.

RA should be free of foreign material such as unbound granular base, broken concrete or other contaminants. Asphalt containing coal tar shall not be used. A fundamental principle for producing asphalt containing RA is that the resulting product should deliver at least the same performance qualities as mixes containing new bituminous binder and aggregates. Most often the monetary value of this engineered product is worth more at the end of its design life then when it was first paved and the RA can be optimally re-used in the same product or application at the top of the recycling hierarchy and such use is eminently preferable to it being “down-cycled” as aggregate or bulk material for backfill, subgrade formations and trench reinstatement.

RA contains approximately 95% of high quality aggregate and 5% of aged bitumen, both valuable non-renewable resources. After many years of service the aged asphalt has most likely deformed or cracked as the aging process causes the binder to harden, making the asphalt brittle. However the aggregate quality will not have altered and the RA should be treated as a valuable public asset.

In the past, there was a tendency to associate the term “recycling” with inferior product, not of the same quality as a product manufactured from previously unused raw materials. This is certainly not the case; currently asphalt mixes containing RA are expected – with good cause – to perform at least as well as mixes using all new materials and are subject to the same quality and performance requirements.

Another source of RA, typically obtained from smaller works, such as trenching, removed pot-hole plugs and cycle paths, particularly in municipal areas, and in which a certain degree of contamination may occur, is still a viable stream of material. Such material can be used in low volume / lightly trafficked roads where a higher degree of variability can be accommodated compared to roads of a higher order.

Recycling asphalt pavements makes good sense from both economic and environmental points of view; the process enables petroleum and aggregate resources to be conserved, and saves landfill space that would otherwise have been taken up with the discarded asphalt. With the increasingly strong worldwide trend towards environmental issues, such as lifecycle inventories and carbon credits, the whole process of hot mix asphalt recycling not only makes good sense; there is an obligation on the part of the roads industry to encourage its use routinely.

1.2 PROPORTION OF RA IN A MIX

A significant deviation from previous issues of this document revolves around the terminology to define the proportion of RA in a mix, particularly as it influences decisions regarding the processing of RA as well as design routines and testing compliance.

A key element of the design of a mix containing RA is to take steps during the formal design procedure to ensure that the resultant binder, i.e. the blend of binder in the RA and new binder meets the quality standards required for the specific application. The proportion of binder in a particular RA fraction is significantly influenced by the aggregate size (or surface area) of that fraction. Consequently finer fractions will yield higher proportions of binder than the coarser fractions. It is therefore deemed appropriate to base designs on blends of binder and aggregate on *RA binder replacement* i.e. the amount of binder yielded by the RA as a proportion by mass of the total binder content of the mix – the binder in the RA plus the new binder – to meet the target binder content. The RA binder replacement would therefore determine the procedures to be followed in terms of processing / fractionating of RA, testing of recovered binder and design procedures.

1.3 DEFINITION OF RECYCLED ASPHALT

Recycled asphalt refers to asphalt in which the proportion of *RA binder replacement*, as defined in 1.2 above, exceeds 10%. In covering certain aspects of this material, reference is often made to *virgin materials*, e.g. virgin binder or virgin aggregate. In this context the term “virgin” implies that the specific material has not been used beforehand in any bituminous product application. Similarly a “virgin mix” refers to one which is composed wholly of materials not previously used in the manufacture of asphalt.

1.4 USAGE OF RA WORLD WIDE

The quantities of recycled hot mix asphalt have grown steadily in many countries around the world and it is true to say that using increasingly higher proportions of RA in the production of asphalt is now standard practice.

The use of RA in asphalt in the USA has increased since 2009. In 2014 the estimated usage of RA in asphalt produced in the USA was 72 million tons i.e. 20% of the total estimated quantity of asphalt produced in that year – 352 million tons. Discarding of RA in construction and demolition landfill is reported as “rare” – in the region of 0.2%. As for the proportion of RA used in asphalt, in 2009 only 23 states reported RA percentages of 15 – 30%; in 2014 37 states reported usage in this range, with 4 states reporting RA percentage of more than 30%.

Japan uses 99% of available RA in new mixes and, on average, uses between 47% and 51% RA in its asphalt pavements. Based on analyses and assessments of pavement performance these layers have performed as well as virgin mixes. It is likely that these high fractions of RA in asphalt will stimulate the utilisation of RA in mixes at higher proportions in other countries.

Figures published by EAPA in 2014 showed that on average 65% of the 39 million tons of RA available in Europe is used in asphalt production. Some countries, notably Germany, Finland, Slovakia and Spain reported using more than 80% of available RA in asphalt mixes.

1.5 USAGE IN SOUTH AFRICA

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.

2. LAYOUT OF THE DOCUMENT

The document is set out to cover the most important aspects of asphalt recycling in a logical sequence:

- The various types of recycling processes are described in chapter 3 - *Asphalt recycling processes* –with a note that this manual covers *hot in-plant recycling* only. In this chapter the principles of asphalt recycling is also set out.
- The process of asphalt recycling relies on sources of RA, mostly milled from existing road pavement bituminous layers. Factors that influence the availability and quality of this material are covered in Chapter 4 *Factors that influence the availability and quality of RA*. An overview of typical mix types and aggregate quality used in South Africa in the past is given, which should be taken into account when designing mixes with RA obtained from these.
- Chapter 5 *Investigation of RA sources* describes the methods and procedures for assessing the availability of suitable RA for a specific project, and the distribution of different mix types that will be a source of RA once milled from the road. Furthermore, it discusses the influence of components of these mixes on the quality of RA derived from these. Guidance is also given on the preliminary investigations to steer the mix design process.
- Chapter 6: *Reclaiming, processing and stockpiling RA* provides information on the process of reclaiming asphalt – mostly through milling operations – as well as the requisite processing which covers crushing, screening, fractionating and stockpiling techniques to optimise the use of the RA and to ensure a uniform, quality product.
- Once the RA has been prepared and stockpiled it is sampled and the laboratory mix design is carried out. This process is covered in Chapter 7: *Mix design procedures*. In this chapter the concept of *RA binder replacement* is explicitly defined as well as its influence on procedures to be followed in the materials testing, fractionating of RA and the need for the use of rejuvenating agents.
- The percentage of RA that can be used in an asphalt mix is dependent to a large extent on the design and configuration of the mixing plant. Chapter 8: *Mixing plant types and capabilities* focuses on the different types of mixing plants available, and gives guidelines regarding their capabilities to handle recycled mixes with respect to their RA content.
- Chapter 9: *Quality control of recycled asphalt* discusses measures, over and above those normally applied to the manufacture of asphalt, that are necessary to ensure the quality of recycled asphalt.
- Several environmental and economic factors drive the use of hot mix recycled asphalt. These are presented in Chapter 10: *Economic and environmental benefits* . Legislation covering the ownership of RA, that will impact on contract documentation is also presented here.
- Chapter 11 covers *Occupational health, safety and environmental considerations* concerning the production and use of recycled asphalt.
- Finally, Chapter 12 Contract documentation provides guidelines on the required information and pertinent considerations to facilitate efficient administration of contracts and to limit the potential for disputes.
- A Glossary of associated terminology is given in Chapter 12.

3. ASPHALT RECYCLING PROCESSES

Processes in general use that produce recycled asphalt include:

Cold in-place recycling

The road pavement is recycled in-place using specialised equipment. A bituminous binder, in the form of bitumen emulsion or foamed bitumen is added in predetermined quantities during the recycling process. The recycled layer is then shaped and compacted as a layer in the upper part of the pavement and overlaid with a bituminous wearing course.

Cold in-plant recycling

In this process the RA is transported to a specialised cold mixing plant where it is processed and mixed together with bitumen emulsion or foamed bitumen in a continuous mixing operation. The cold bituminous mix is paved, or spread with a motor grader, shaped and compacted. This process is also suited to labour intensive road construction methods within limited areas and applications. (Refer to Sabita Manual 12: *Labour Absorptive methods in road construction using bituminous materials.*) The recycled layer is then surfaced with a bituminous wearing course.

Hot in-place recycling

The asphalt surfacing layer in the existing pavement is heated in-place using specially designed radiant heaters. The heated asphalt is scarified, transferred into a continuous-mix pugmill and mixed with new aggregate, bitumen and rejuvenating agents. The mixture is then paved and compacted in the same way as conventional asphalt. As this method is more appropriate for fairly thick asphalt layers only, it has limited application in South Africa.

Hot in-plant recycling

In this process the RA is transported to a specially equipped and configured mixing plant where it is combined with new aggregate, new binder and, where appropriate, rejuvenating agents to produce recycled asphalt which satisfies the project specifications.

> ***NOTE:***
> ***This manual covers the last of the processes described above, i.e. hot in-plant recycling, employing the latest technology developed in this country as well as that currently used in other countries.***
>
> ***For more information on cold recycling processes the reader is referred to* TG 2: Technical Guideline: Bitumen Stabilised Materials – A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials, *published by the Asphalt Academy.***

3.1 PRINCIPLES OF ASPHALT RECYCLING

The process of asphalt recycling essentially includes:

- Obtaining RA, typically from the asphalt layers of existing pavements by means of milling machines, slabs excavated from asphalt pavement layers by means of full-depth layer removal as well as the reuse of returns and tailings at asphalt mixing plants;
- Transporting the RA to the mixing plant site;
- Crushing the RA, using an impact crusher;
- Screening into the various fractions and stockpiling the RA;
- Carrying out the design, based on the properties of both reclaimed and virgin aggregates and binder;
- Mixing the RA in prescribed proportions with new aggregates and bitumen in an asphalt mixing plant; and

- Transporting the recycled asphalt to site where it is paved.

Asphalt recycling is carried out using the two basic types of mixing plants – batch and continuous drum. The design of mixing plants used for recycling is covered in more detail later in Chapter 8, but in essence the plants should be capable of:

- Processing the required proportion of RA to meet the end product mix properties;
- Conforming to environmental regulations with regard to emissions, spillages, seepage and stockpiling;
- Minimising binder ageing during the manufacture of recycled asphalt;
- Operating at acceptable production levels and
- Switching readily from recycled asphalt to conventional asphalt mix production and vice versa.

An important aspect of asphalt recycling is the proportion of RA that is added to the mix. Factors that should be taken into account when taking decisions in this regard include:

- Type and configuration of the mixing plant;
- Layer in which the mix is to be used, i.e. wearing course, base.
- Type of asphalt mix that is to be produced, e.g. continuously graded mixes, high-modulus asphalt, ultra-thin friction courses or SMA;
- Number of stockpiles and grading of the fractions into which the RA is divided, which increases control and reduces variability;
- Whether the RA derives from a single source or multiple sources;
- Quality of the RA, i.e. aggregate properties, binder content and properties;
- Uniformity and consistency of the RA material which may require:
    - uniform milling speed to promote particle size consistency in the resulting RA;
    - split milling of intermediate and surface asphalt layers where one of these may contain impurities;
    - proper crushing of asphalt slabs from full-layer pavement removal.
- Moisture content of the RA;
- Possibility that the RA is contaminated with herbicides from crack sealing, coal tar, patching material or the underlying gravel layer;
- Need for the use of a rejuvenating agent.

NOTE:
If coal tar is present in the reclaimed material, it is not suitable for re-use, due to the carcinogenic effects of this substance. Such material should be disposed of in an approved waste site.

The basic steps that make up the asphalt recycling process are depicted in Figure 3.1.

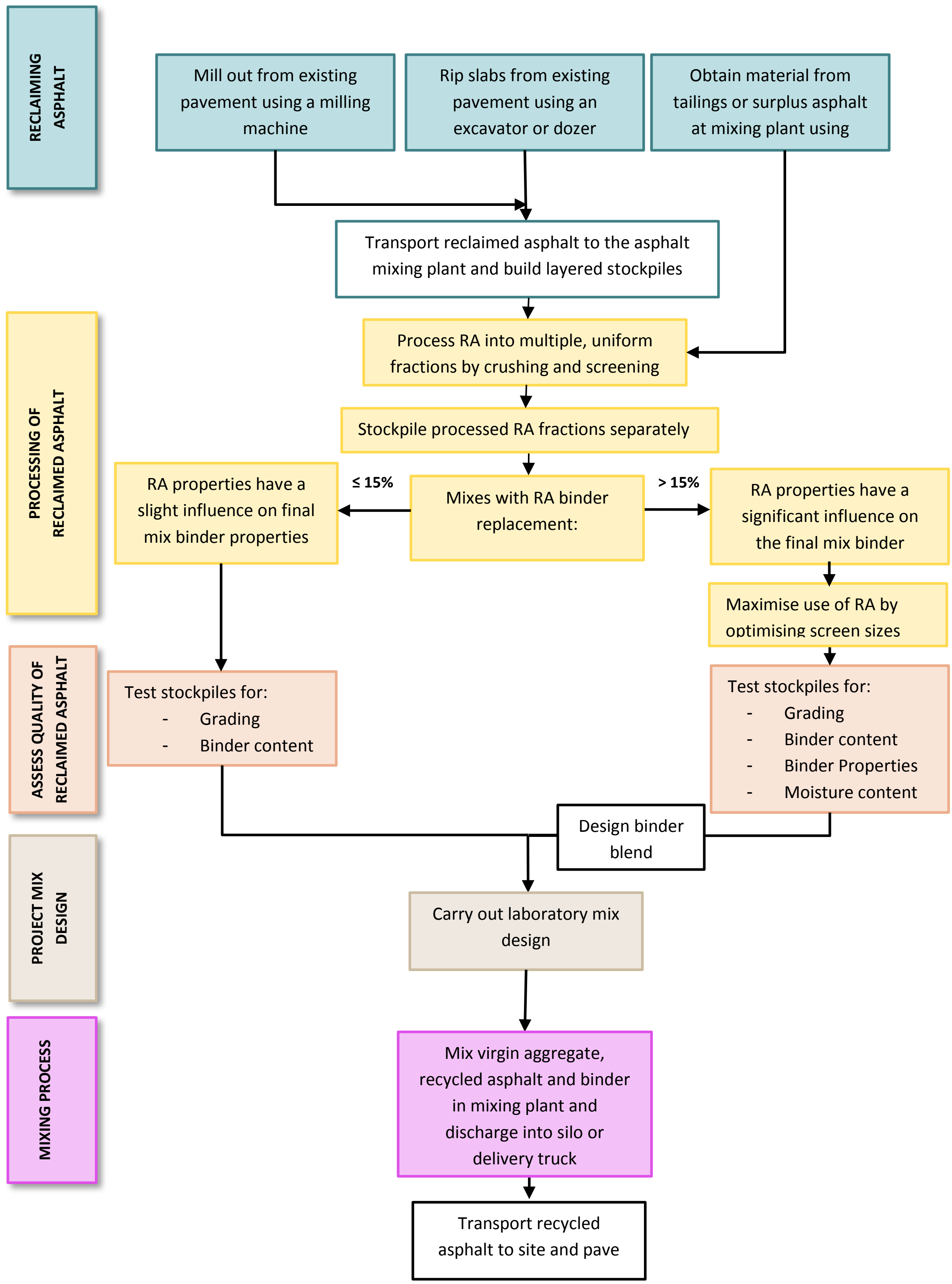

Figure 3.1 Basic steps of the asphalt recycling process

4. Factors that influence the availability and quality of RA

Engineering decisions on the use and proportions of RA in the production of recycled asphalt will be significantly influenced by availability of suitable sources in terms of their distribution and quality. Below is an overview of the geographic distribution of asphalt pavements in South Africa as well a description of mix types in general use that would influence their use in recycled asphalt.

4.1 Geographical distribution of asphalt pavements

The feasibility of in-plant asphalt recycling is closely related to the availability of RA that can be obtained from the asphalt layers found in road pavements. Obviously the close proximity of asphalt pavements which are able to yield RA impacts positively on the economics of in- plant asphalt recycling, and vice versa.

In large areas of South Africa, where the roads carry low to moderate volumes of traffic, the pavements consist of granular bases with thin surfacing spray seals, with asphalt typically only used on the bridge decks. In fact South Africa is renowned for its successful use of thin surfacings on highly engineered crushed stone bases, and the use of this type of pavement is widespread, particularly in the rural regions.

Pavements that include at least one asphalt layer are largely confined to the provincial main and trunk roads, sections of the national routes, as well as streets and motorways in the larger towns and cities. In addition, unlike the very thick asphalt pavements constructed in Europe and the USA, for economic reasons the asphalt pavement layers in South Africa are generally substantially thinner by comparison. Geographic information system (GIS) asset registers provide a convenient means of roughly estimating the quantities of asphalt in existing road networks.

While asphalt is 100% recyclable, the restricting factor for recycling high proportions of RA in-plant could be the limited availability of sufficient quantities of this material to suit a particular project at the required time. One way to overcome this problem is to ensure that no RA is wasted, but rather strategically stockpiled – thereby creating a consistent RA resource – even though there may not be a project immediately available where it can be utilised in producing recycled asphalt mixes. The stockpiled RA can then be earmarked for use on future projects. This strategy is especially relevant to metropolitan areas where thicker asphalt pavements are more prevalent, yielding opportunities to rehabilitate roads within the road network using in-plant asphalt recycling.

It is important to note that not all RA milled on site can be utilised for a particular project. During the milling procedure some crushing of aggregates occurs which generally leads to a finer graded RA compared to the originally paved material. Also, under normal construction operations, a minor loss of the RA material occurs during milling and transport.

Good practice dictates that RA requires processing which entails crushing and screening which ultimately produces different sized, or fractionated, RA stockpiles. The yield of each fractionated stockpile depends on several factors which include:

- the manner in which the RA was milled;
- the type of crusher used to break down the RA agglomerations; and
- the screen sizes used for the screening the material

It is highly unlikely that all fractions of RA on a particular project will be suitable for use in the recycled asphalt for that project; hence not all the RA that is obtained from a site can be recycled for a particular project.

In general there is not enough asphalt available in SA to recycle. Therefore, whenever there is a potential for RA to be used on a project, care must be taken to adopt correct procedures in the milling, processing and stockpiling of the RA as a valuable material resource. Furthermore, due to its limited availability, RA should, whenever feasible, be “up-cycled”, i.e. used as a bound layer through the asphalt recycling process.

4.2 CURRENT DISTRIBUTION OF MIX TYPES

During the past sixty years there have been, from time to time, several changes in the asphalt mix types used in South Africa’s road pavements. Most of the asphalt first used in South Africa consisted of continuously graded mixes. During the 60’s and early 70’s this mix type was largely superseded in some regions by gap-graded or semi-gap graded asphalt mixes, the former containing relatively high proportions of sand, based on the British BS 594 standard. For these mixes, the natural sand fraction had fairly stringent quality requirements, and therefore tended to be more durable and less permeable than the continuously graded mixes.

Over the years, as traffic loadings on the country’s roads increased, pavements with gap- graded asphalt mixes tended to rut and, in some areas, exhibited “top-down” cracking, a phenomenon not fully understood and attributed to factors such as high localised horizontal surface tensile stresses and age hardening of the asphalt binder in the upper zone.

These factors and an increasing shortage of suitable natural sand resulted in a shift back to continuously graded mixes in the early 90’s.

Around this time various modified asphalt mixes, including those containing bitumen-rubber, as well as polymers such as SBR and later SBS, were used fairly extensively. Sometimes the aggregate grading of the mixes, particularly those containing bitumen-rubber, were adjusted to make them more open graded, providing scope for binder contents of the mix to be increased.

The mid 90’s saw the introduction of stone mastic asphalt (SMA) mixes into South Africa. This gap-graded, stone-skeleton mix type frequently contains modified binder or cellulose fibres, or both, to prevent excessive drain-down of the binder during handling. SMA offers high resistance to rutting and good skid resistance and has gained popularity as a wearing course on major roads.

A specialised asphalt surfacing mix that first came into use on South Africa’s roads in 1999 is known as Ultra-Thin Friction Course (UTFC). This thin (typically 18 mm to 25 mm) functional wearing course contains a stiff modified binder and has superior riding quality and skid resistance properties.

EME (Enrobé à Module Élevé) was introduced in South Africa in 2011 as a high modulus asphalt base course. EME is a continuously graded mix which, containing a very hard unmodified binder that characteristically provides this material with superior load spreading capabilities due to its very high stiffness modulus. Additionally it provides high resistance to permanent deformation and fatigue resistance, the latter deriving from the high binder contents employed. Given the high strength and durability of EME, high modulus asphalt base courses may well become the preferred base type to use on major roads and bus routes in South Africa.

Within the last decade, the extent of asphalt recycling in South Africa has increased significantly as the industry gained experience and confidence in recycling increasingly higher proportions of RA. Recycling up of 40% RA content in-plant can at present be considered standard industry practise. As a result, many asphalt pavements that were constructed during this period may consist of significant proportions of RA. Cognisance should be taken when recycled asphalt mixes that contained relatively high proportions of RA in particular, are to be subsequently recycled to ensure that the binder in this type of RA is effectively rejuvenated.

The compositions of these various asphalt mix types clearly influences the aggregate grading, binder content and properties of asphalt that is reclaimed from South Africa's roads, and consequently must be taken into account when designing recycled asphalt mixes.

4.3 Other factors concerning RA quality

4.3.1 Presence of spray seals

It has been fairly common practice, and certainly this was the case before the introduction of UTFC, to apply a surfacing seal on top of the asphalt wearing course, as a maintenance measure or to improve surface friction. Modified binders, such as SBS, and occasionally bitumen-rubber, were quite frequently used in these seals. This makes it likely that many asphalt pavements will be found to contain at least one layer of spray seal, with the binder possibly being a modified bitumen. Experienced has shown that these particular types of seals can be effectively milled separately or together with asphalt layers directly below, processed and used in recycled asphalt.

4.3.2 Coal tar

Coal tar is no longer used in South Africa, however PVC modified tar was regularly used in surfacing seals in KwaZulu-Natal until the early 90's. The use of tar can usually be detected by its pungent smell, and its incorporation in recycled asphalt is strongly discouraged due to its carcinogenic nature.

4.3.3 Geosynthetic materials

Geosynthetic grids or fabrics are occasionally used in specific circumstances to retard crack propagation and improve the stability of pavements with asphalt layers. These materials may be found at the bottom of the asphalt layer or sandwiched between asphalt layers. Problems may occur with these materials as they may hinder milling operations, or contaminate RA stockpiles. The severity of the problems depends on factors such as the position of the geosynthetic material in the asphalt layers, as well as the type of geosynthetic material used. When these materials are detected during the investigation stage it is worthwhile carrying out a milling trial as this will indicate the severity of the problem so that a solution can be found. Generally it should be possible to screen out most of the geosynthetic fragments during the process of fractionating the RA.

4.3.4 Aggregates

Over the many years that asphalt has been used in South Africa, the coarse aggregates have generally been of a high standard, and problems caused by the intrinsic quality of crushed stone fractions in the mix are extremely rare. There is however, some evidence that aggregates deriving from basic igneous rock types, such as dolerite and basalt, can be prone to degradation over time. This has been known to occur in very isolated instances in the Free State Province, as well as in the Kingdom of Lesotho. When RA contains aggregates derived from these basic igneous rock types especially if there is some history of this problem in the area, testing of the intrinsic quality of the aggregates in the RA should be carried out to identify deleterious materials such as smectite.

In very isolated cases poor quality natural sands were used, and cognisance of this should be taken when considering reclaiming asphalt from old pavements, particularly where gap- or semi-gap graded asphalt mixes were used. The degree of rutting of such layers may be a useful indicator in this regard.

Stripping of the binder from the aggregate, caused by the poor adhesion between the bituminous binder and aggregate, is not often encountered, but it is worthwhile to take account of it when assessing the pavement during the investigation stage, especially in the wet regions of the country. In cases where an asphalt layer is surfaced with an impermeable seal, such as bitumen rubber, the potential for the binder to strip from the aggregate can be aggravated by the "pressure-cooking" effect of the seal. As this would affect the quality of the recycled asphalt, any signs of stripping should be recorded.

4.3.5 VARIABILITY OF RA

On sections of road that have been extensively repaired under routine road maintenance activities, e.g. pothole repairs and / or patching, the consistency of the RA milled from this section can easily become compromised in terms of the aggregate and binder properties. More attention must then be given when processing this type of material in order to reduce the variability. In general, the degree of variability is usually reduced after processing. However, if significant variability still exists in the reclaimed material after processing, the RA should only be recycled in low proportions or in low risk applications.

Split milling, whereby different layers of asphalt are separately milled off may be required in certain situations. For example, experience has shown that UTFC remains as rigid agglomerations after milling; these agglomerations are generally oversized and difficult to break down and therefore spilt milling would be recommended for UTFC. Furthermore, semi-gap graded and gap graded mixes have also been observed to require split milling.

5. INVESTIGATION OF RA SOURCES

5.1 DESK STUDY

When a project is earmarked for rehabilitation and it is intended to remove the asphalt layers in the existing pavement, there is potential to reuse the old asphalt in recycled asphalt mixes.

Investigations should be tailored around determining the following:

- potential quantity of the asphalt available for reclaiming;
- the haulage distance to the nearest asphalt mixing plant with recycling capability, or alternatively;
- locating a suitable area for stockpiling the RA to suit future recycling on other projects;
- basic asphalt mix types in the existing pavement;
- uniformity of the asphalt in the existing pavement layers;
- visual condition of the pavement;
- ownership of the RA

The process should start with a desk study of all available historical design– and as-built data that can provide information on:

- the specified and constructed thickness of the asphalt layer/s;
- descriptions of the mix type/s, such as "continuously graded" or "semi-gap graded";
- type and grade of the bituminous binder used;
- typical aggregate gradings;
- the recorded use and details of modifying agents and geosynthetic fabrics

The distance that the RA would have to be transported to the nearest asphalt mixing plant should be ascertained, as this will impact on the economics of the project.

In some situations where the rehabilitation of more than one project has to be considered, such as in a city environment where the rehabilitation of the road network is being programmed, it is necessary to carry out careful planning of the projects with respect to their respective locations, as well as sites where RA can be processed and stockpiled. Cognisance should be taken of the fact that pavements of city streets are quite likely to include layers of asphalt, which can be effectively utilised in recycled asphalt mixes.

Factors that may limit the use of RA include:

- extremely variable mixes, especially over short distances such as severely distressed roads with frequent repairs;
- asphalt that is contaminated with diesel or oil;
- the presence of modified binder in the asphalt;
- areas where the asphalt has a very high binder content; and
- asphalt containing coal tar – its use is prohibited for environmental and health reasons

Except for the presence of coal tar in the RA, these limiting factors can usually be overcome by increasing the number of fractions into which the RA is screened, so as to improve control at the mixing plant. Modified asphalt mixes, especially those containing bitumen-rubber, may limit the percentage of RA that can be added to the recycled mix. Identifying the presence of coal tar and the requisite arrangements and allowances for dealing with it should be addressed early in the pavement assessment phase.

5.2 FIELD INVESTIGATIONS

The potential quantity of asphalt that would be available as RA will depend on the extent and depth to which the asphalt is to be removed, as dictated by the rehabilitation design. Usually, unless the as-built data is available and is in great detail, it is necessary to check quantities by taking core samples and measuring the width of the pavement.

The frequency of the core sampling should be based on a comprehensive overview of all available information, but a minimum of six cores should be sampled. The cores should have a diameter of at least 150 mm.

The cores should be carefully examined to check:

- the thickness of each asphalt layer found in the core;
- asphalt mix types in single or multiple layers, for instance a layer of gap-graded asphalt overlain by a continuously graded asphalt;
- the presence of surfacing seals, particularly those containing highly modified binders;
- the presence of coal tar that can normally detected by its pungent odour;
- the presence of geosynthetic interlayers; and
- for signs of stripping of the binder from the aggregate

It is emphasised that these examinations should be carried out by experienced personnel.

Where significant variations are found in layer thickness and asphalt mix types, it is worthwhile to take intermediate cores to determine uniform sections of potential RA.

Once the cores have been measured and visually examined, samples should be selected for further testing, the complexity of which depends on the proportion and grading of the RA that it is intended to use in the recycled mix.

It is advisable to obtain binder characteristics such as the recovered binder content, penetration and softening point during the pavement assessment. These characteristics are useful during the design stage as well as during the contractor's tender stage as it enables maximisation of the RA in the intended asphalt.

The occurrence of spray seals as part of the proposed RA should not necessarily be viewed as problematic as the seals typically contain very good quality aggregate and binder which can be milled with the asphalt to form RA.

Where bitumen-rubber seals have been identified it should be brought to the attention of the tenderer as additional methods may be required to assess the suitability and proportions of such materials as well as means of obtaining the RA, which will have an influence on costs. It should also be kept in mind that the presence of crumbed rubber in the cores may influence the recovered binder content test results.

When RA is fractionated, the binder content of the finer fractions will be significantly higher than that of the coarser fractions. The use of finer graded RA fractions will therefore tend to influence the binder properties of the recycled mix to a greater extent than the coarser fractions. Consequently the recovered binder testing regimen will depend on the proportion of RA binder that will be used, as expressed in the *RA binder replacement* term. Guidance on this is presented in Chapter 7. Where the RA contains modified binder the influence thereof on the penetration values should be kept in mind.

When coarser fractions of RA are to be included in the mix, it is normally only necessary to take binder properties into account if the recycled mix entails more than 15% RA binder replacement.

In cases where more than one asphalt layer is found in the pavement, or where there are complications due to the presence of modified seals, the results of the core investigation will assist in deciding on the most appropriate milling strategy. For instance it can be decided whether to mill the asphalt layers separately, or to mill more than one layer at a time, in which case the RA from these layers will be mixed.

While it is not usually necessary to carry out a detailed visual inspection of the pavement as part of this particular assessment, a cursory visual inspection should be carried out to determine:

- general types and severity of pavement distress;
- frequency and type of patching;
- any signs of poor performance that could be related to aggregate / binder adhesion problems.

The outcome of this inspection will assist in deciding whether additional core sampling is required.

It should be noted that:

- A wide-ranging approach should be taken when considering the utilisation of RA from a particular project. It may not be feasible to use all the RA recovered from a particular project in the rehabilitation of that project. However, other projects where the RA can be used in the asphalt mix should be borne in mind. RA can thus be stockpiled awaiting its use in these projects.
- As discussed in more detail in Chapter 6, RA is crushed, screened, fractionated and stockpiled before it is incorporated in asphalt mixes. During these processes variations in quality tend to be evened out. If significant variations still remain after screening the RA to two fractions, it should be screened to three fractions. Thereafter, should significant variations and quality problems persist, further fractionating could be considered; alternatively the material could be set aside for use in such applications where the degree of variability would be acceptable, e.g. cycle tracks and sidewalks.
- RA sources should not be discarded due to the low penetration of recovered binder; instead it should be considered as “black aggregate” and used accordingly. However, once RA binder replacement exceeds 15%, it becomes necessary to check the properties of the recovered binder.
- Asphalt that inevitably accumulates at asphalt plants, including tailings and returns, should be considered for use in recycled mixes where good measures are in place to limit contamination.

On projects where it is decided to carry out a preliminary mix design, RA can be sampled using either a small milling machine or extracting cores of at least 150 mm diameter.

6. Reclaiming, processing and stockpiling RA

6.1 Milling RA

Most RA in South Africa is obtained through the use of milling machines – rather than by breaking out the asphalt in existing pavement layers using excavators or bulldozers – and then transporting this material to the crushing plant. An exception to the usual milling method would be the reuse of discarded or surplus asphalt that has been stockpiled at the asphalt mixing plant site for uniformity of binder and aggregate types.

The main advantages of using milling machines instead of ripping and crushing operation are that they:

- fragment the asphalt to achieve a fairly uniform grading;
- are able to remove the asphalt without disturbing the edges or underlying materials in the pavement;
- are able to remove the asphalt precisely to the prescribed thickness enabling selective milling to be carried out where this is found desirable during the design stage, such as when more than one type of asphalt is found in the pavement;
- greatly reduce the risk of contaminating the RA with material from the underlying layer works.

As RA is generally processed by crushing and screening before it is used in the recycled asphalt mix, there are no special restrictions on the milling process itself, such as milling speed, or milling drum and cutting tool configuration. Practical limitations regarding the milling process should however be taken into account, such as the likelihood of contaminating the RA with the underlying granular base when attempting to mill off asphalt surfacing with a thickness of less than 30 mm. An end-product specification, limiting the maximum size of the milled material to 37.5 mm, is advisable.

Split milling may be considered if asphalt varies significantly with respect to depth and mix type. Notwithstanding this, the preferred means of ensuring adequate uniformity is through processing, i.e. fractionating, screening and proper stockpiling.

It has been found that problems can be anticipated when bitumen rubber “SAM” or “SAMI” layers are milled together with the asphalt layer rather than being selectively milled off and discarded. The bitumen rubber seal tends to remain in large, resilient fragments which hinder the crushing and screening processes. Selective milling is therefore recommended when this material is encountered. Situations such as these highlight the need for proper screening and fractionating.

6.2 Stockpiling unprocessed RA

Stockpiles of *unprocessed* RA should be ramp shaped and lifted in layers. When flattening tipped material, care should be taken not to push material over the edge so as not to cause excessive segregation. Loading of stockpiled materials should be done with a loader proceeding from the front (high) face with the loading action starting at floor level and proceeding through the entire height of the face. This technique will ensure that loading will incorporate a number of layers, thereby ensuring improved uniformity. See Figure 6.1.

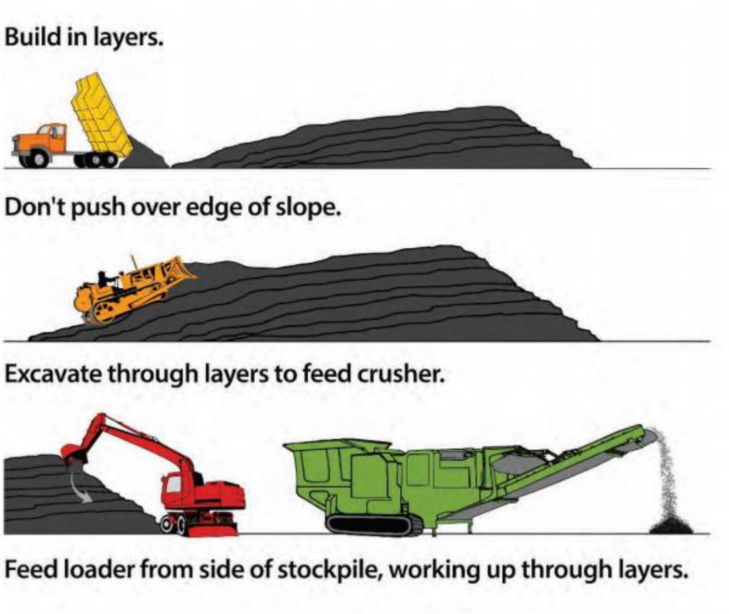

Figure 6.1: Stockpile building and loading (Acknowledgment: NAPA – QIS 29)

As indicated in section 6.6 a working stockpile, sufficient for at least a full day's production, is produced in front of the high face following the necessary testing.

6.3 Moisture in RA

An important issue concerning the asphalt recycling process is to limit and, if possible, reduce the moisture content of the RA before it is recycled. High moisture contents in the RA will result in a decrease in the rate of production and an increase in fuel energy costs, while the increased emissions and steam will tax the mixing plant's emission control systems. A one percent change in moisture content typically results in a ten percent change in the fuel consumption required to heat the RA.

High moisture contents in RA could also result in high moisture being present in the final recycled asphalt mix, which may lead to adhesion problems.

6.4 Stockpiling of processed RA

RA tends to retain moisture to a greater extent than aggregate and the following factors should be considered when stockpiling *processed* RA:

- stockpile base areas should be sloped (a six degree slope is ideal) so that they drain freely and ponding does not take place;
- the base of the stockpile area should be hardened so that water does not soak into the material under the stockpile. The hardening of the base will also reduce:
  - the likelihood of groundwater contamination;
  - loss of RA through contamination with the underlying soil;
- wherever possible, *processed* RA should be stockpiled in large conical shapes with steep sides. A crust will form on the surface of the stockpile, which will tend to shed water and help reduce consolidation of the rest of the stockpile;
- machines should be kept off stockpiles to avoid compaction of the processed RA;
- covering RA stockpiles with tarpaulins or plastic sheets tends to cause condensation which increases its moisture content, and should be avoided. An exception to this is when rain is imminent and the stockpiles can be temporarily covered to prevent the material getting wet. However, as soon as the rain has passed, the stockpiles should be uncovered again to reduce the effect of condensation moistening the RA;

- the best measure to prevent accumulation of moisture in RA is to stockpile processed RA in an open sided shed, which will allow moisture to escape while protecting the material from rain;
- the inevitable variability in grading (and hence binder content) that segregation causes when granular materials are stockpiled is reduced by fractionating the material into fairly similar sized particles; and
- it is advisable not to load the RA from one side of the stockpile to the other but rather in a staggered manner to produce more homogeneous RA

6.5 Processing RA prior to recycling: crushing, screening and fractionating

The processing of RA includes crushing, screening, and placing it in separate stockpiles. The aim is to produce a free-flowing material of uniform quality with a defined range of particle sizes in each stockpile. A general rule is that the need to implement these processes becomes increasingly important as larger proportions of RA are used in the recycled asphalt. Key factors governing the production of good quality recycled asphalt mixes include consistency and awareness of the properties of the aggregates and bitumen in the RA. It is recommended that contract documentation should provide for pay items in the schedule of quantities to cover the costs of the processing and handling of the RA.

It is strongly recommended that all RA destined for use in recycled asphalt should be fractionated to enhance the level of control at the mixing plant. However, in the case of low RA content recycled asphalt mixes – with RA binder replacement proportions of less than 15% – it is usually only necessary to remove oversize lumps by passing the RA over a scalping screen.

If the RA is not fractionated, and RA content close to this limit is required, consideration should be given to installing a roller crusher between the cold feed bin and the transfer conveyor. Once again billed items in contract documentation should provide for the handling and processing of RA.

When mixes are produced with RA binder replacement values above 15%, it is necessary to screen and fractionate the RA to ensure a consistent product that will not impair the quality of the recycled asphalt mix. It is common practice to crush the aggregate in the RA to a top sieve size of one sieve size smaller than that of the top size of the aggregate used in a particular mix.

The benefit of installing a crushing and screening system is that small quantities of RA can be processed to produce a consistent material that can be used straightaway, without the risk of it becoming wet from rain water. Ideally sufficient RA should be processed to meet the daily needs for the production of asphalt thereby reducing the effect of the RA consolidating during stockpiling. Two types of crushing plants are in general use, impact crushers and jaw/roller combination crushers.

6.6 Optimisation of the use of RA

As indicated previously, in selecting the fraction sizes, it should be borne in mind that coarser RA fractions will yield lower binder volumes than finer fractions due to the difference in aggregate surface area. As a quality control measure, the grading and binder content of the fractionated RA should be checked at intervals of not greater than 200 tons.

RA fraction screen sizes should be selected so as to tie in with the asphalt mix design for a particular project and to optimise the use and quality of RA.

Another factor that should be borne in mind when processing and stockpiling RA from a specific site is to keep it in demarcated stockpiles, as its characteristics are likely to be similar. Large quantities of RA from different sources should be kept separately for the same reason.

RA should be handled in three distinct stockpiling phases, as illustrated in Figure 6.2.

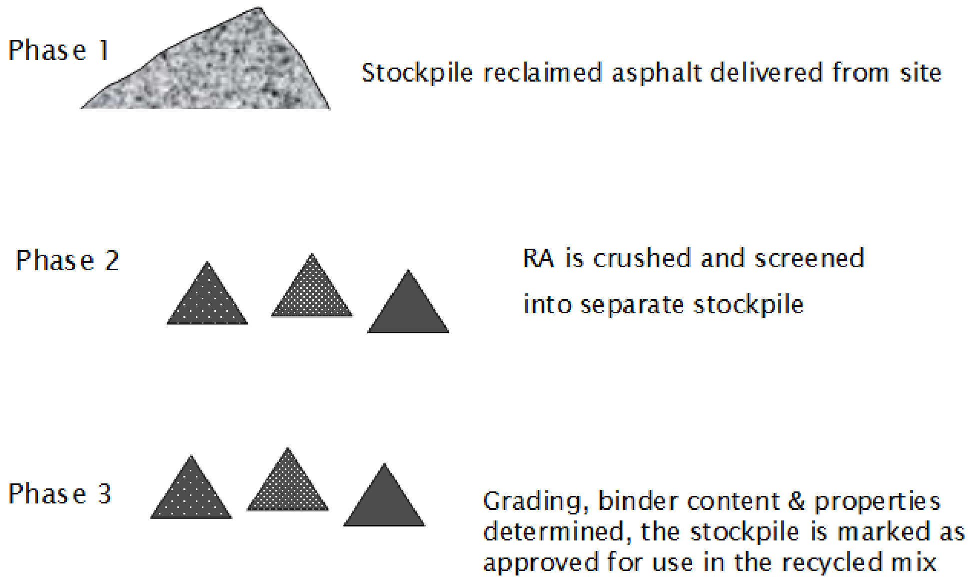

Figure 6.2: Phases of stockpiling RA

> ***NOTE:***
>
> ***The intention of the crushing is to break up the lumps of RA and not to crush the aggregates. The closed side setting of the crusher should be adjusted to the required maximum aggregate size of the mix. Impact crushers have been successfully used for this purpose.***

7. MIX DESIGN PROCEDURES

7.1 PROPORTION OF RA IN A RECYCLED MIX

The aim of the mix design is to determine the proportions of new aggregate, new binder and RA, as well as the total binder content that will fulfil the requirements of the asphalt specification. The RA content of a mix can be defined as the total mass of RA expressed as a percentage of the total mix mass. For example, a mix with a 20% RA content means that for every 1000kg of asphalt, about 200kg is RA and 800kg is new materials (i.e. aggregate, filler and binder). The RA content to be introduced should be determined by mix design characteristics and not by an asphalt plant's capability or by a road authority's preference e.g. to utilise all the milled material available on a specific project. The total RA content should be determined by limitations imposed by the amount binder in the RA as a proportion of the total binder content – the "RA binder replacement". These limitations will be determined by the virgin binder properties as well as the final binder requirements to meet performance criteria.

The RA binder replacement is calculated as follows:

Total RA binder in the mix, $B_{RA} = \sum_{i=1}^{n} \left(\frac{(RA\ content)_i}{100} \times \frac{(RA\ binder\ content)_i}{100} \times 100 \right)_{f_i}$

Where:

$n = total\ number\ of\ processed\ RA\ fractions\ used\ in\ the\ RA\ mix\ design$
$f_i = RA\ fraction\ number,\ e.g.\ f1,\ f2\ etc.$
$B_T = Target\ (optimum)\ binder\ content\ of\ the\ mix$
$i.e. the\ sum\ of\ RA\ binder\ and\ virgin\ binder$

RA binder replacement, $B_R = \frac{B_{RA}}{B_T} \times 100$

Virgin binder required in mix, $B_V = B_T - B_{RA}$

Example

Consider a mix that incorporates the following RA materials:

- A total RA content of 22%, made up of the following processed RA fractions screened on the A and B mm sieve sizes.
  - RA Fraction 1
    - Proportion used = 10%
    - size: -A + B mm
    - binder content = 4.0%
  - RA fraction 2
    - Proportion used = 12%
    - size: -B mm
    - binder content = 6%
- The target (optimum) binder content of the final mix, B_T, has been determined as 5.4%.

Hence:

$$B_{RA} = \left[\frac{10}{100} \times \frac{4.0}{100} \times 100\right] + \left[\frac{12}{100} \times \frac{6.0}{100} \times 100\right] = 1.1\%$$

RA Binder replacement, $B_R = \frac{1.1}{5.4} \times 100$

$$= 20.4\%$$

Virgin binder required:

$$B_V = 5.4\% - 1.1\% = 4.3\%$$

The binder content and aggregate grading of the RA are both a direct function of the processed RA fractions. In other words, the binder content and aggregate grading are expected to differ from one RA fraction to the next. The finer RA has more surface area than the coarser RA. Therefore a higher RA binder content is expected for a finer RA fraction, and vice versa. When considering the proportioning of the different RA fractions in a mix design, the RA binder replacement requirement may be satisfied by using a small content of fine RA; a large content of coarse RA, or a combination of the fine and coarse RA fractions.

For a particular RA, the binder properties, however, are considered to be independent of the processed RA fractions. In other words, the properties of the RA binder recovered from one fraction is expected to be the same as the RA binder properties recovered from another fraction or even the unprocessed RA.

In order to limit the variability of RA and improve the consistency of this raw material, it should always be processed (i.e. crushed and screened) into specific fractions. Sieve sizes for the different RA fractions should not be prescribed but rather left to the discretion of the asphalt manufacturer to allow for the mix to be optimised based on the RA binder replacement. However, to prevent the possible overuse of fine RA fractions in particular, Table 7.1 recommends the minimum number of processed RA fractions that should be included in an RA mix.

Table 7.1: Recommended minimum number of processed RA fractions

RA Binder Replacement in Mix	Number of processed RA fractions
≤ 15%	One
> 15%	Two

7.2 TESTING FOR RA QUALITY

The quality of the RA is a function of the properties of the aggregate in the RA and the binder in the RA. It is important to note that only the properties of the specific *processed RA fraction/s* to be used in a mix need to be evaluated for an RA mix design.

The proportion of the RA aggregate to the total aggregate in the mix is closely related to the *RA content*. Therefore the guideline for tests on the quality of aggregate recovered from each RA fraction is based on the *RA content* and is presented in Table 7.2

Table 7.2: Guideline for tests on quality of the recovered RA aggregate

RA content in mix	Recovered RA Aggregate Tests[1]
≤ 15%	• Check intrinsic aggregate properties[2] • Aggregate grading
> 15%	• Check intrinsic aggregate properties[2] • Aggregate grading • Aggregate Crushing Value (ACV) • 10% Fines Aggregate Crushing Value (10% FACT) • Flakiness Index

Notes

[1] *The recovery of aggregates from RA should be carried out in accordance with SANS 3001 AS-25 by solution of the binder; alternatively the method described in SANS 3001-AS21 using an ignition furnace can be used to burn off the bituminous binder.*

[2] *The intrinsic properties of the aggregate in the RA should be checked, especially if they consist of basic igneous rock types, such as dolerite or basalt (See below)*

The RA binder replacement, i.e. the proportion of the RA binder to the total binder in the mix is the basis for guideline for tests on the quality of binder recovered as presented in Table 7.3

Table 7.3: Guidelines for tests for quality of the recovered RA binder

RA binder replacement	Recovered RA Binder Tests[3]
≤ 15%	• Binder Content • Contaminants (presence of coal tar)
> 15%	• Binder Content • Contaminants (presence of coal tar) • Softening Point[4] • Penetration[4] • Performance grade parameters[4]: - G*, δ, Jnr, using the dynamic shear rheometer (DSR) - S and m value using the bending beam rheometer (BBR)

Notes

[3] *The method used for binder extraction and recovery shall be in accordance with SANS 3001-AS25: “Test method for the recovery and extraction of bitumen from an asphalt mix”.*
It is imperative to clearly state and agree upon the particular method used for both binder extraction and binder recovery as set out in SANS 3001-AS25.
The presence of coal tar and / or other contaminants should be checked for to determine the suitability or otherwise of the RA.

[4] *The recovered RA binder should be deemed to have already aged in service. Therefore for all recovered RA binder tests would reflect an RTFO and/or PAV aged binder as considered applicable.*

As mentioned in Chapter 4, the intrinsic properties of the aggregate in the RA should be checked, especially if they consist of basic igneous rock types, such as dolerite or basalt. If these aggregates are encountered they should be tested for the presence of deleterious components such as smectite. Additionally the presence of coal tar (and/or other suspected contaminants) in the RA binder should be checked for.

Binder content and grading tests should be carried out on each of the samples, and the results should be scrutinised for variations in the results. Where large variations are encountered, precautions to improve the uniformity of the mix should be taken, such as mixing the material with the front end loader before it is loaded into the cold feed hopper or by increasing the number of fractions into which the RA is screened. One of the main advantages of fractionating the RA is that a much higher level of uniformity can be expected.

As already stressed in this document, the moisture content of the RA should be kept as low as possible, and moisture content checks should be carried out on the various RA stockpiles as part of the mix design testing programme.

As the properties of the binder in the RA can have a significant influence on the final binder properties in the recycled mix, these guidelines should be regarded only as a starting point in the mix design process.

7.3 Preliminary Design

During the investigation and design stage a feasibility study should be conducted to determine the representative proportioning of the RA and new materials, to establish a nominal RA binder replacement value. This is an important step that will promote the development of realistic tender documents.

The feasibility study should firstly indicate if there will be enough processed RA available to recycle by analysing layer thicknesses and the average percentage yield of each processed RA fraction. For this purpose extracting 150 mm diameter cores is recommended. Where the type, quality and thickness of the asphalt, as found in the core samples, varies significantly along the project, further samples should be taken and evaluated to determine their influence on the use of the recycled mix.

Further analysis of the aggregate grading, binder content, binder properties and determination of the RA binder replacement should provide guidance on steps involved in the RA mix design procedure. The procedure for such a study is broadly as follows:

1. Mill the RA sample from the designated site (see comments below on sample size and milling procedure).
2. Process the RA into at least the minimum required fractions (full scale processing – at an asphalt plant).
3. Determine the average percentage yield of each processed RA fraction.
4. Conduct binder content tests on each RA fraction.
5. Conduct aggregate grading tests on each RA fraction.
6. Calculate the (nominal) RA binder replacement to be specified.
7. To allow the consultant to better understand the possible influence of the RA on the final binder specification, determine the following recovered RA binder properties:
    a. Softening Point
    b. Penetration
    c. PG Binder Tests (J_{NR}, G*, δ, etc.).

Representative samples of RA should be taken using a milling machine. A small milling machine should preferably be used for this purpose for economic reasons. This will closely simulate the full-scale process of reclaiming the asphalt. The milling should be carried out in accordance with the milling strategy covered in Chapter 6; the milling depth should be set so that the existing asphalt is milled to the required depth. Sufficient RA should be milled for the feasibility study (and/or for the laboratory mix design work). Generally, an RA sample size equivalent to a single filled 10m^3 tip truck would be deemed "sufficient" for the purpose of conducting a full scale crushing and screening exercise. This would then allow for the feasibility of the RA mix design to be established.

The milled RA must then be crushed, screened and fractioned by conducting a full scale processing exercise. Laboratory-scale processed RA samples are not recommended as they may not be truly representative of the full scale processing.

Generally, due to the milling process, some of the existing asphalt pavement is ground up and more fines are generated when compared to the original mix design of the existing pavement and as-built data. As a result, the finer fractions are expected to have the largest yields.

Since the binder content of the finer RA fractions is considered to be higher, due to the larger surface area compared to the coarser RA fractions, recovering enough RA binder for property testing from the finer RA fraction would result in fewer extraction cycles – saving time and money. Caution to this recommendation – careful filtering of the very fine RA aggregates is required during the extraction.

7.4 SAMPLING OF RA FOR THE MIX DESIGN

Generally the source of the RA to be used in a recycled asphalt mix will either come from a specific project site (i.e. usually mill and replace projects) or from an existing RA stockpile, or both. During the investigation of the RA sources, as discussed in Chapter 5, RA samples should be taken in the form of a series of 150 mm cores from a project site, or from an existing stockpile. A summary of tests conducted on this form of RA samples is as follows:

- RA aggregate grading – this should provide some indication of the possible RA fractions and percentage yields of the different fractions;
- RA binder content – this should provide an indication of how the binder content may vary with the different fractions; additionally it should also allow for the determination of a maximum RA binder replacement;
- Recovered RA binder properties – this should provide an early indication of the need to consider using a softer binder and/or a rejuvenator.

The client or his representative will generally specify the nominal mix proportions. For a recycled asphalt mix it is recommended that the specified nominal mix binder content, the RA binder content (as determined from field cores or RA stockpile samples) and a nominal RA content are used to determine a maximum RA binder replacement limit for specification purposes. The maximum RA binder replacement determines the minimum proportion of new binder that should be added to the recycled asphalt mix.

For the purpose of the mix design however, a more representative RA sample is required. When the RA is available in stockpiles, the yield of processed RA fractions, quality of the RA aggregate and binder, and other RA properties can be readily determined and this allows for the RA mix design to be conducted even before the project has commenced. However, when the RA is to be sourced from a project site, sufficient quantities of RA must first be milled, processed and stockpiled to provide samples for evaluation – which may cause a slight delay before the RA mix design can be conducted. In the latter case, the following recommendations are made to ensure a representative RA sample will be used in the mix design:

- It is advisable to conduct the recycled asphalt mix design after the RA has been milled and processed from site, as the milling and processing would be conducted as full-scale operations;
- Additionally, for economic reasons, this would prevent the cost of procuring milling and processing activities at an investigation level to produce the representative RA samples;
- Generally, an RA sample size equivalent to one laden $10m^3$ tip truck would be deemed sufficient for the purpose of conducting a full scale crushing and screening exercise;
- To ensure uniform quality of the processed RA, milling and processing operations should be consistent for the duration of the project;
- The processed RA stockpile/s should be sampled with the aid of a front end loader, following the method described in TMH5 Sampling Method MB1;
- ***In the case of mill-and-replace projects that require immediate paving of a new mix (e.g. temporary lane closures), an alternative approved mix design may be required initially until the RA mix design has been approved***.

7.5 Mix Design Procedure for Different Proportions of RA

Proportioning of the various sizes of aggregate and filler should be carried out in the same way as for mixes containing all new aggregates, using the results of the grading tests carried out on the RA. In the case of mixes with multiple RA fractions, blends should be carried out to find the most effective blend that can be used to produce the required grading of the intended mix. Once suitable proportions have been determined, the next step would be to design the binder to produce a blend that should conform to the end binder specification of an equivalent virgin asphalt mix. In order to do this, a softer binder and / or rejuvenator may be required.

When recycling RA there is inherently more risk attached to the RA binder than the RA aggregate. Therefore the procedure for recycling different proportions of RA has been based on the RA binder replacement. Recommendations on the procedure for the design of RA mixes are categorised by three tiers and are summarised in Table 7.4.

The laboratory mix design should only be conducted after the asphalt has been reclaimed from the site, crushed, screened and stockpiled in fractions. In order to best simulate the plant mix, only the processed RA fraction/s should be used in the laboratory mix.

Briquettes used to carry out volumetric and other tests, as well as other specialised tests should be manufactured using the method specified in SANS 3001-AS1:2009.

Table 7.4: Recommendations for the RA mix design procedure

RA Binder replacement	Minimum no. of processed RA fractions	Tests on processed RA fractions	Recommendations for achieving the end binder specification	Determine blended binder properties
≤ 15 %	One	Binder - binder content - contaminants Aggregate - Grading - intrinsic properties	• None	• Not required
15 – 30%	Two	Binder - binder content - contaminants - Softening point & penetration - G*, δ, J_{NR}, S & m Aggregate - Grading - intrinsic properties - ACV, 10% FACT - Flakiness index	• Use softer binder grade; • Use rejuvenator	• Use blending charts to determine appropriate softer binder grade • Use blending charts to determine appropriate rejuvenator dosage rate • Report blended binder properties
30 – 60%	Two		• Use Rejuvenator	• Use blending charts to determine appropriate rejuvenator dosage rate • Report blended binder property tests

In broad outline, the method relevant to mixes containing RA includes the following steps:

- The new aggregate is dried in an oven at a temperature of between 105°C and 110°C to a constant mass, preferably overnight.
- The RA is dried in an oven at a maximum temperature of 60°C to a constant mass, preferably overnight.
- The required number of portions of each fraction of new aggregate and RA are heated in an oven to 25°C above the required target mixing temperature.
- An appropriate mixing temperature is selected from a table, using the penetration that is achieved by blending the aged binder in the RA with the new binder. An example of a binder blending chart that can be used as a preliminary guideline is given in Table 7.6 and Table 7.7.
- The required percentage of new binder is added to the combined aggregate and RA and mixed thoroughly with a mechanical mixer for the period shown in Table 7.5.
- The appropriate compaction temperature is selected from a table, using the penetration that is achieved by blending the aged binder in the RA with the new binder. Examples of blending charts that can be used as a starting point are given in Table 7.6 and Table 7.7.
- Place the mixed material in an oven set at the required compaction temperature, cover and cure for a period of 60 minutes
- Transfer the material to heated Marshall moulds and compact as specified in SANS 3001-AS1.

Table 7.5; Laboratory mixing time for mixes containing various proportions of RA

RA Binder Replacement (%)	Mixing Time (min ± 5 sec)
< 15	5
15 – 30	7
30 – 50	8

Table 7.6: Typical binder blending chart for a 50/70 new binder

RA Binder Replacement (%)	Recovered RA Binder Penetration (dmm)						
	5	10	15	20	25	30	35
30	28	35	40	43	46	49	51
25	32	38	42	46	48	50	52
20	37	42	45	48	50	52	54
15	41	46	49	51	53	54	55
10	47	50	52	54	55	56	57
5	53	55	56	57	57	58	58
0	60	60	60	60	60	60	60
Resultant Pen of 50/70 Pen bitumen mixed with RA							

Example of the use of the blending charts

Consider an asphalt mix with a 20% RA binder replacement and the following details:

- New binder is 50/70 pen grade bitumen (assumed penetration is 60 dmm)
- RA binder penetration is 5 dmm
- The blended binder can be expected to have a resultant penetration in the region of 37 dmm.
- Therefore the mixing and compaction temperature should be based on a 35/50 pen grade binder (i.e. requiring higher mixing and compaction temperatures than a 50/70 pen grade).

NOTE:
In this example it is assumed that the end binder specification must fulfil 35/50 pen grade binder. If the final binder specification was intended to be a 50/70 pen grade binder, the use of a softer binder (e.g. 70/100) or a rejuvenator would be indicated.

Table 7.7: Typical binder blending chart for a 35/50 new binder

RA Binder Replacement (%)	Recovered RA Binder Penetration (dmm)						
	5	10	15	20	25	30	35
30	22	28	31	34	36	38	40
25	25	30	33	35	37	39	40
20	28	32	35	37	38	40	41
15	31	34	36	38	39	40	41
10	34	37	38	39	40	41	42
5	38	40	40	41	41	42	42
0	43	43	43	43	43	43	43
Resultant Pen of 35/50 Pen bitumen mixed with RA							

Example

For asphalt with a 20% RA binder replacement and the following details:

- New binder is 35/50 pen grade bitumen (assumed penetration is 43 dmm)
- RA binder penetration of 15 dmm
- The blended binder can be expected to have a resultant penetration in the region of 35 dmm.

Therefore the mixing and compaction temperature should be based on a 35/50 pen grade binder (i.e. expected stiffer binder can still be classified as a 35/50 pen grade and therefore the same mixing and compaction temperatures can be applied.

7.6 Use of Rejuvenators

Rejuvenators are products designed to restore (to some extent) the original properties of aged bituminous binders. They may either be applied by spraying onto an existing wearing course as a refurbishment, or by blending with a binder used in the manufacture of asphalt. Within the context of this document the term rejuvenator applies to the latter application only.

7.6.1 Purpose

The structure of a bituminous binder is often described as a complex colloid consisting of insoluble asphaltenes dispersed in soluble maltenes. When sufficient maltenes are present the asphaltene micelles, under stress, can move smoothly with the binder. As the bitumen ages due to oxidation, the maltenes are transformed into asphaltenes. This process upsets the balance of the ratio of the two components leading to a hardened, brittle asphalt mix, as is the case with RA binders.

7.6.2 Function

Briefly, the function of a rejuvenator for asphalt binder is to:

- restore the characteristics of the aged bitumen to a consistency appropriate for both construction purposes and performance of the mix through
  - dispersing the agglomeration of the asphaltene components that build up over the years which results in binder hardening
  - replenishing the lost maltene phase due to oxidation
- restore the aged binder to its optimal chemical characteristics for durability; and

- provide a sufficient quantity of additional, useful binder to coat aggregates and to meet design objectives

7.6.3 MECHANISM

The working mechanism or diffusion process of rejuvenation has been described by researches in four steps:

1. The rejuvenator forms a very low viscosity layer that surrounds the bitumen-coated aggregate where the binder layer is highly aged.
2. The rejuvenator begins to penetrate into the aged binder layer, decreasing the amount of raw rejuvenator that coats the particles and softening the aged binder.
3. No raw rejuvenator remains, and the penetration continues, decreasing the viscosity of the inner layer of binder film and gradually increasing the viscosity of the outer layer.
4. After a certain period, equilibrium is approached over the recycled binder film.

7.6.4 USE

Globally, over the years, many materials have been suggested as rejuvenators or recycling agents, ranging from aromatic oils, paraffinic oils, naphthenic oils, waste engine oils, waxes plus fatty acids and tall oils. Some of these, due to environmental and health concerns, should not be used in asphalt recycling. These concerns will be taken into account in the accreditation of products as being fit for purpose mentioned below.

A number of rejuvenating agents are available in South Africa, consisting of a variety of component materials – both mineral and organic. At the time of compiling this document, an industry group has been formed to propose a protocol for accreditation by Agrèment SA of rejuvenators for both surface application to aged surfacings and for use in recycled asphalt mixes. The aim of this accreditation is to facilitate the optimal selection of a specific rejuvenator for the conditions at hand and to protect workers against the use of toxic substances.

Softer binders and / or rejuvenators are used to obtain a binder blend that will conform to the final project requirement. As softer grades of new binder usually do not have enough co-mingling or diffusion capability when more that 15% RA binder replacement is employed the use of a rejuvenator is recommended; for RA binder replacement above 25% there may be no option but to use a rejuvenating agent. (See Table 7.4).

7.7 MIX DESIGN TESTING

The ultimate goal of the mix design process is for the recycled asphalt to meet the requirements of a specification of an equivalent asphalt mix composed of virgin materials, and thereby provide equal or better performance than the equivalent mix. Therefore the complete RA mix design should follow the guidelines set out in Sabita Manual 35 / TRH 8: *Design and use of Asphalt in Road Pavements*. Thus tests on the recycled asphalt mix should include the same tests as would routinely be carried out on asphalt mixes containing all new aggregate, including the usual volumetric and performance related tests. As is the general case, the testing programme should include tests to evaluate moisture sensitivity, such as the Modified Lottman test.

7.8 PLANT MIX TRIALS

Once the laboratory mix design process has been completed, trial mixes should be carried out by manufacturing small quantities in the mixing plant at three different binder contents, targeting the optimum binder content found in the laboratory mix, as well as at binder contents 0.5% above and below the optimum. The results of tests on these trial mixes should be examined, as there is often some shift between mixes produced in the laboratory and those manufactured full-scale, and final adjustments should be made accordingly. The moisture content of the final product should be checked again to ensure that the mix complies with maximum moisture requirements.

8. MIXING PLANT REQUIREMENTS

While the same basic types of mixing plants used to produce conventional hot mix asphalt are used to manufacture recycled asphalt mixes, some modifications are required to enable them to produce mixes of the same quality as those using all-virgin aggregates and binders. Standard plants should not be used to attempt to produce asphalt with high RA content and, in the case of drum mixer type plants, retrofitting should be carried out to protect the RA from naked flame. Additionally the mixing plants must be designed to comply with the same gas and particulate emissions standards when producing recycled mixes as they are for conventional asphalt mixes; they should comply with National Environment Management Air Quality Act (Act No 39 of 2004). Guidelines regarding the various types of mixing plants can be found in SABITA Manual 5, as well as in NAPA Information Series 123[10].

Asphalt mixing plant design has undergone significant development over the past ten years, particularly in the use of microprocessor systems that automate the cold feed and mixing operations. Two basic types of asphalt mixing plant are available; batch type and continuous drum mixer type plants. Both types of mixing plant have been adapted to enable RA to be added to the mix, and include systems to facilitate the venting of steam and the proper transfer of heat from the virgin material to the “cold” RA as it is being introduced into the mix.

Whatever the plant configuration, an abiding principle is that exposure of the RA to a naked flame in the heating process should be avoided or at least limited. Also, the throughput of the plant should be adjusted to allow for sufficient lag time in the mixer for heating the RA to a temperature that will enable proper co-mingling to be achieved.

8.1 MIXING PLANT TYPES AND CAPABILITIES

Whereas there are quite a number of plant options and plant technologies on the market that can be used to mix high quality asphalt containing RA, only the most common options are discussed in this document.

8.1.1 BATCH PLANTS

With batch type plants two broad options exist to introduce the RA into the asphalt mix:

Option 1 Pugmill recycling using a separate RA weigh hopper

The RA is fed and metered directly into the pugmill via a separate weigh hopper. The virgin aggregate has to be superheated to accommodate the “cold” RA. A slight adjustment may have to be made to the dry mix cycle to facilitate better heat transfer. Care is required when utilising this option to ensure that the steam, which is generated during the first few seconds after the RA has been fed into the pugmill, is properly vented into the dust extraction system. A mini explosion occurs as the moisture in the RA makes contact with the superheated aggregate. After this initial burst, the steam is being released relatively slowly – typically within a period of 30 seconds – by the vigorous mixing process in the pugmill.

It is possible to increase the RA contents of mixes using this process if the RA is dried prior to being introduced into the pugmill. Various drying systems exist in order to facilitate this. This system is illustrated in Figure 8.1.

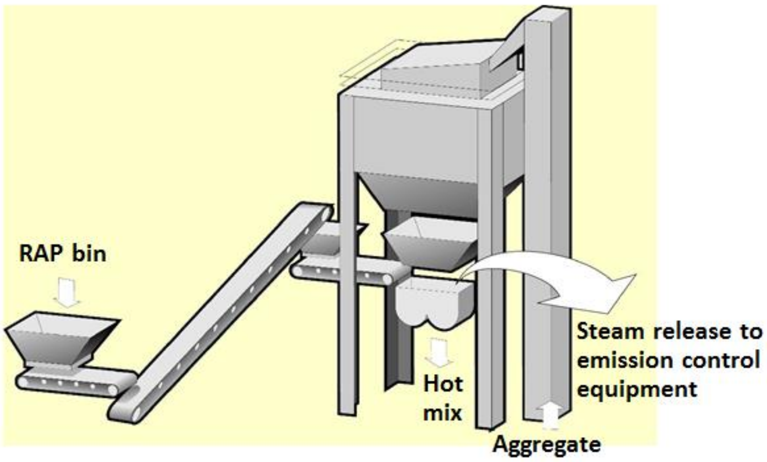

Figure 8.1: Pugmill recycling using a separate weigh hopper

Option 2 Introducing RA into the bucket elevator

RA is fed via a cold feed bin directly into the hot elevator at the point at which the heated virgin aggregate is discharged from the drying drum. The RA material mixes with the hot virgin aggregate in the bucket elevator, releasing steam more gradually as the material is lifted in the elevator to the screening deck. Thereafter the blend of RA and virgin aggregate is weighed off and falls into the pugmill where it is thoroughly mixed together with the new binder. This process facilitates good heat transfer from the virgin aggregate to the RA as the RA remains in contact with virgin aggregate for a relatively longer period. This eliminates the violent release of steam associated with the direct pugmill heat transfer method. This process is illustrated in Figure 8.2.

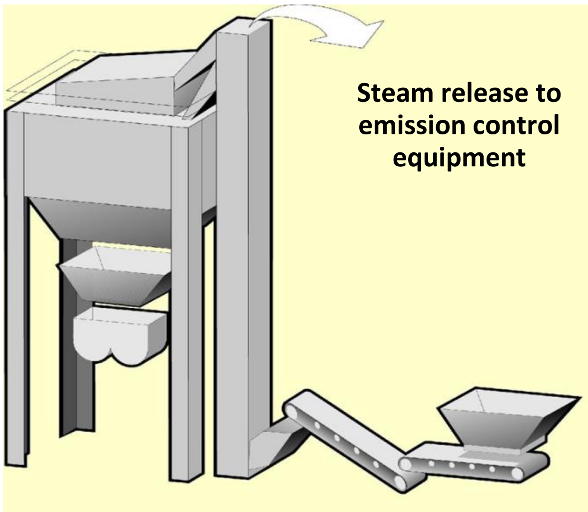

Figure 8.2: Introducing the RA into the bucket elevator

8.1.2 DRUM PLANTS

When it comes to continuous drum-type mixing plants, two basic configurations are available: parallel flow and counter flow. Feeding RA into a drum type plant is easier as the generation and venting of steam can be managed more easily through the drum, which has a larger volume. However, the possible risk of generating "blue smoke" is greater, as in some instances the burner flame makes direct contact with the RA as it is being fed into the drum.

The most basic parallel flow drum mixer utilises a cold feed bin for the metering of RA and then feeding it into the drum via an inclined belt, in the same way that virgin aggregate is fed into the drier drum. The former option, i.e. the use of the central ring, is the preferred option as the risk of “blue smoke” emissions is significantly reduced. Depending on the plant configuration the potential for blue smoke emissions may limit the proportion of RA that can be used in the mix to a maximum of 10%.

Parallel-flow drum mixers can be equipped with a centre RA ring. This mid-entry design system enables the RA to be kept away from the high temperatures at the burner end of the drum, thus reducing damage to the binder in the RA and reducing “blue smoke” emissions. The percentage of RA that can be used with this type of mixer is still limited by the level of emissions caused by the effect of high temperatures on the binder that is added during the recycling process. A maximum of 25% RA content is usually achievable with this type of plant.

The use of a separate rotating mixing drum or continuous pugmill, known as an “after-mixer” or “coater”, where the heated mixture of virgin aggregate and RA is mixed together with the binder, reduces emissions, as the hot gasses from the mixing drum do not come into direct contact with the binder and the RA content can consequently be increased to at least 30%. Limitations on the proportions of RA in relation to the configuration of this type of plant are thus:

- Parallel flow with RA ring – 25% max;
- Parallel flow with after-mixer/coater – 30% max;
- Parallel flow with RA ring and after-mixer/coater – 40% max.

The design of counter-flow drum mixers, where the burner is located at the opposite end of the drum to that into which the virgin aggregate is fed, enables excessively high process gas temperatures to be reduced by the cooler, moisture laden aggregate as the gasses evacuate the dryer. Steam is typically exhausted at the burner end of the dryer while hydrocarbons carried in the air stream are destroyed by the high temperatures that prevail in this part of the drum.

Various different types of counter-flow drum mixers exist:

- counter-flow drum with a RA ring. Mixing takes place in the drum on the burner side of the RA ring;
- counter-flow drum with an after-mixer (or coater) where mixing takes place;
- counter-flow drum with a RA ring and after mixer/coater as shown in Figure 8.3.
- twin drums, which consist basically of a counter-flow drum where drying and heating of the virgin material takes place, and a second drum (or in certain instances a barrel wrapped around the first drum) where mixing takes place. Typically, the percentage of RA that can be used is substantially higher when double/twin drum mixers are used, and mixes containing up to 70% RA can be produced successfully. The principle of the double-drum mixing system is illustrated in Figure 8.4.

Of primary concern, when any of the various type of mixing plants are used, is that the RA and the virgin aggregates and binder are properly blended; the blending process facilitates good heat transfer, ensures all moisture is driven off the RA and prevents both mechanical and thermal segregation.

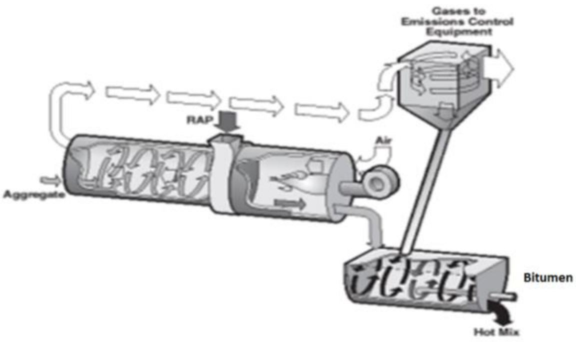

Figure 8.3: Counter-flow drum mixer with separate after-mixer

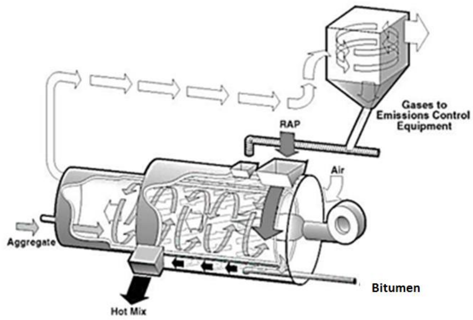

Figure 8.4: Double-drum type mixing plant

Table 8.1shows the maximum capabilities of the various types of mixing plants in terms of the percentage *cold, unheated* RA that they are typically able to handle subject to design considerations.

Table 8.1: Typical maximum RA capabilities of different types of mixing plant using unheated RA

Type of mixing plant	Maximum % RA[1]
Batch mix	
• Pugmill only	15
• Pugmill and hot elevator	30
Drum mix	
• Parallel flow feed with aggregate	10
• Parallel flow with centre ring	25
• Counter flow with RA ring	30
• Counter flow with after-mixer	30
• Counter flow with RA ring and after-mixer	40
Twin dryer drum	40
Double barrel drum	70

[1] These values are tentative and the limits would depend on the composition of the mix as well as the specific plant configuration

8.2 COLD FEED SYSTEMS

When the RA has been fractionated it is necessary to provide a separate cold feed bins for each fraction. To enable the RA to be added evenly, without the risk of blockages, the following aspects should be taken into account:

- the sides of the cold feed bins should be built steeper than those used for virgin aggregates;
- the openings of the cold feed bins onto the feed belts should be lengthened;
- longer feed belts are required;
- the RA should be trickle-fed into cold feed bin to prevent packing;
- the use of vibrators should be avoided;
- RA with a high binder content should not be left in the cold feed bins overnight; and
- the installation of sensors to detect blockages in the RA feed

The requirements of mixing plants, in relation to the proportion and processing of RA in recycled mixes are summarised in Table 8.2.

Table 8.2: Mixing plant requirements and factors that influence RA content

<table>
<tr><th rowspan="2">RA Content</th><th colspan="2">Mixing plant requirements</th><th rowspan="2">Binder adjustments</th></tr>
<tr><th>Cold feed</th><th>Mixing</th></tr>
<tr><td>Less than 15%</td><td>One cold feed bin is required for the RA</td><td>Batch plants with separate RA weight hoppers are suitable. Exhaust system modification required for mixes with >10% RA. Parallel-flow and counter-flow drum mixers with RA collars at mid-point of drier drum are suitable</td><td>Carry out mix design using normally specified bitumen grade. No change in bitumen grade is normally necessary, but could be changed after reviewing the mix properties</td></tr>
<tr><td>15% to 30%</td><td rowspan="2">Cold feed bin required for each RA fraction</td><td>Batch plant, with modified exhaust systems, are suitable up to 20% RA. Counter-flow drum mixers with RA collars at mid-point of drier drum are suitable.
Parallel-flow drum mixers require separate continuous mixer where the binder is added</td><td>Carry out mix design using one grade softer than normally specified bitumen grade.
Review binder grade based on the mix properties obtained in the design.</td></tr>
<tr><td>Greater than 30%</td><td>Parallel-flow mixers require a separate continuous mixer where the binder is added
Exhaust system to be modified.
Specialised plants, such as double drum or twin drum mixing plants are required when >40% RA is used in the mix</td><td>Ascertain properties of binder recovered from the RA. Carry out mix design with bitumen grade based on combined binder properties and, where applicable, rejuvenators</td></tr>
</table>

9. QUALITY CONTROL OF RECYCLED ASPHALT

The systematic quality control process of recycled asphalt is similar to that of conventional asphalt and must therefore be conducted in accordance with Chapter 7 of Sabita Manual 35 / TRH 8: *Design and Use of Asphalt in Road Pavements* or those specified in the COTO specifications or other project specifications. Items that require special attention are listed below.

9.1 RA STOCKPILES

RA should be treated as a controlled input component of any recycled asphalt mix. Consequently the following additional quality control aspects should be considered:

- Binder content of the RA;
- Gradation of the aggregate recovered from the RA;
- Moisture content of the RA;
- Bulk density of the RA aggregate;
- Agreed properties of the aggregate recovered from the RA; and
- RA binder properties (for mixes with RA binder replacement values of more than 15%).

In some cases, additional aggregate tests may be necessary. For example, if the RA is to be used in a wearing course layer, tests to evaluate the polishing or mineralogical composition of the RA aggregate may be required.

9.2 MOISTURE CONTENT

Good practice requires that moisture content (MC) of the RA be checked daily to ensure that MC in the mix does not exceed 0.5%. RA with MC's in excess of 0.5% can be problematic as not all asphalt mixing plants are capable of removing such high levels of moisture from the RA during the heating process. Should mixes with high binder replacement percentages (>15%) or large percentages of fine fractioned RA need to be used, special care and consideration should be taken when selecting the type of mixing plant to be used (Refer to Chapter 8) or conversions installed to render the mixing plant capable of pre-drying the RA. A large drop in temperature of the mix between the asphalt plant and paving site may be an indication of a high RA MC and could result in a non-homogeneous mix, poor workability and compaction problems.

The recycled *mix* should be checked for:

- MC at least once per day - anything in excess of 0.5% may be a problem as this is indicative that the moisture in the RA is not being completely removed via the heating process. Under extreme conditions, RA can be pre-dried through the asphalt plant the day before in order to reduce its moisture content. An unusually large drop in the temperature of the mix between the asphalt plant and the paving site may be indicative of high moisture content.
- Moisture susceptibility using tests such as the modified Lottman test or Immersion Index as a surrogate field test.

10. ECONOMIC AND ENVIRONMENTAL BENEFITS OF THE USE OF RA IN ASPHALT

10.1 GENERAL

The basis for the use of RA makes sense for environmental and economic reasons and the benefits are already being realised on an international and national level. The use of RA reduces the requirements for the use of virgin materials of a non-renewable nature, thereby upholding the first two principles of the National Environmental Management: Waste Act (Act 59 of 2008), reinforcing the waste hierarchy, as follows:

1. Minimising the consumption of natural resources; and
2. Avoiding and minimising the generation of waste.

A summary of the many overall benefits – in a socio-economic sense – of the recovery and recycling of asphalt can be briefly described as:

- Lower energy consumption and greenhouse gas emissions from transport, mining and the process;
- Recovery of a non-renewable raw material (bitumen) and aggregates;
- Reuse of aggregates;
- Cost savings:
  - by providing the same quality road layers at a lower cost; and
  - reducing the disposal costs
- By regarding RA as a valuable resource and not a waste material, the amount of waste produced by road construction is minimised as the industry's aim is to reclaim as much as possible for re-use; and
- Diversion of the waste stream from landfills, as RA can be stockpiled and used when and where required.

The presence of coal tar in the proposed RA will need to be identified routinely, as standard practice, during the testing and investigation process, i.e. prior to the milled asphalt being designated as RA and set aside for recycling. This identification procedure is of utmost importance, as it will ensure that asphalt contaminated with coal tar will never enter the recycling stream. The original motivation for this is that asphalt which contains coal tar cannot be incorporated and mixed with virgin asphalt and bitumen as the properties are completely different and, as such, it would compromise the integrity of the asphalt mix, which would subsequently not meet the required quality standards and specifications. This practicality has the knock-on effect of protecting the environment, as coal-tar contaminated asphalt cannot be re-used and will be disposed of as hazardous waste. In addition, there is an environmental benefit from a health and safety point of view, as the correct handling will manage and reduces the exposure of workers to coal tar.

Over and above the above benefits, supportive of sustainable practice, a key driver for using RA in new mixes is that it makes financial sense in terms of economic benefits across the full life-cycle of road building and maintenance. The economic and direct financial benefit is especially true in view of the frequent increases in bitumen and fuel costs.

RA is cheaper than virgin materials and its continued use will place less stress on, especially, quarries to produce the required volumes of virgin material required by industry.

The use of RA offers direct savings per ton of asphalt produced in terms of:

- Lower virgin aggregate consumption

    - The inclusion of RA reduces the quantity per ton of virgin aggregate required in the asphalt, provided haulage distances for the RA are not excessive, the cost per ton of RA is lower than that of virgin aggregate.
- Lower bitumen consumption
    - For every 10% of RA used in the mix, the bitumen content of the mix can be reduced by 0.3 - 0.5%. As a petroleum-based product, the price of bitumen is expected to increase over time, and hence a reduction in the quantity of virgin bitumen in the mix will become increasingly significant.
    - With the RA providing some of the binder for the mix, less new bitumen is required to optimise the mix's binder content. This results in less energy being required to heat the bitumen during mixing, storage and transport.
- Bitumen transport costs
    - A reduction in the quantity of bitumen in the mix also means that less bitumen has to be transported from the refinery to the asphalt mixing plant. However, the value of the RA is also influenced to a large extent by the distance it has to be transported from the work area to the asphalt plant. Long RA haulage distances obviously reduce the direct economic benefits of recycling.
- Disposal charges
    - Charges related to the disposal of asphalt at landfill sites are potentially eliminated or otherwise, greatly reduced by using the RA in new asphalt mixes.

The above cost savings obviously have to be offset against the additional costs incurred in handling and processing of the RA in the asphalt recycling process.

Key factors come into play when considering the economics of hot mix recycled asphalt, mainly around the proximity of the project to:

- Sources of RA;
- The value of the RA is influenced to a large extent by the distance it has to be transported from the jobsite to the asphalt mixing plant. Long RA haulage distances obviously reduce the direct economic benefits of recycling;
- Sources of suitable quality crushed stone;
- The haulage costs of virgin aggregates influence the economics of the recycled asphalt mixes in the same way;
- Sources of bitumen;
- The economic benefit resulting from the reduction in the quantity of bitumen required to produce recycled asphalt mixes is already covered in this chapter. Long haulage distances from refinery to asphalt mixing plant, which result in higher priced bitumen, increase the economic benefit of recycled asphalt mixes;
- Static or mobile asphalt plants with the capability to produce hot mix recycled asphalt mixes;
- The location of the nearest asphalt mixing plant in relation to the jobsite where the RA is available is an important factor in determining the cost-effectiveness of hot mix recycling.

10.2 OWNERSHIP AND DISPOSAL OF THE RA

In addition to the economic and environmental advantages of the use of RA, certain aspects relating to current legislation will impact on decisions related to the use and disposal of such material.

The ownership and disposal of assets of all state, i.e. national, provincial, municipal and state-owned-enterprises' assets are governed by enactments, including Section 19.6 of the Treasury Regulations 2005 promulgated in terms of Section 90 of the Public Finance Management Act No 1 of

1999 (PFMA), Section 90 of the PFMA and the Municipal Finance Management Act 2003 (MFMA) and Section 10 of Annexure A of the Standard for Infrastructure Procurement and Delivery Management 2015 (SIPDM) published by the National Treasury.

In terms of the above legislation and regulations, it can be accepted that ownership of RA, by default, vests with the road owner, who may transfer such ownership to another organ of state, or to the contractor in terms of the conditions of contract. The road owner should declare his intentions of transfer or disposal which should be ascertained and documented prior to going to tender.

Clearly RA has a value which must be reflected in any contract let by public tender and any arrangements regarding the transfer or disposal of the asset. Consequently, if the document requires that the contractor take ownership of the RA, a payment item must be included in the bill of quantities in which a saving to the contract is tendered.

In making decisions regarding the use, transfer or disposal of RA, the following considerations will need to be taken into account:

- Location of a project;
- Area required for temporary or permanent storage and stockpiling;
- Future use of stockpiled and excess processed RA, not required for the project;
- Responsibility for current and future handling an transport costs;
- Costs of securing the RA asset, e.g. fencing:
- Environmental requirement and obligations in terms of storage and disposal; an d
- Asset auditing obligations

11. OCCUPATIONAL HEALTH, SAFETY AND ENVIRONMENTAL CONSIDERATIONS

Recycling of asphalt has major environmental benefits and to optimise these benefits it is imperative that worker safety is not compromised and that due consideration is given to the environmental aspects during mixing operations.

11.1 GENERAL CONSIDERATIONS FOR BITUMEN HANDLING AND ASPHALT PRODUCTION

The general HSE considerations for bitumen handling and asphalt production are extensively covered in various SABITA publications and will not be repeated here. It is however considered prudent that the health and safety hazards and environmental aspects, as well as the associated control measures specific to recycled asphalt, be summarised and highlighted in this publication in the interests of completeness.

For more information refer to the following SABITA publications:

- SABITA Manual 8 *Guidelines for the safe and responsible handling of bituminous products*;
- SABITA Manual 25 Code of Practice: *Transportation, off-loading and storage of bitumen and bituminous products;*
- Best practice guide: *An industry best practice guide for the storage of reclaimed asphalt (RA) at asphalt plants;*
- Bitumen spill protocol – Version 1, August 2013: *An industry protocol for responding to bitumen spills on land and/or adjacent water environments;*

11.2 CONSIDERATIONS SPECIFIC TO RECYCLED ASPHALT

11.2.1 POTENTIAL HEALTH HAZARDS

Exposure to Coal Tar

Before milling commences the necessary steps must be taken to determine if any coal tar is present in the asphalt layer. In the past coal tar was used in surfacing seals, and, especially in the province of Kwazulu Natal, it is known to have been used as the binder in asphalt mixes in a few short sections of road. (It has been reported that white spray paint goes brown when in contact with coal tar and this method can be used as an indicator test for its presence.)

Coal tar is known to have carcinogenic properties and RA containing it should therefore be regarded as hazardous as it can present a health risk to workers if they are exposed to the fumes during paving of the new recycled asphalt.

Workers involved in reclaiming materials that contain tar should therefore be equipped with appropriate protective clothing and breathing apparatus, and the reclaimed material should be removed to a registered hazardous waste site.

If there is no tar present in the RA, it can be considered as being inert and can therefore be handled like virgin aggregate.

Exposure to dust

Care must be taken during milling operations when the RA is removed from the pavement. Workers must be protected against inhalation of dust that is generated during these operations. Ensure that suitable respiratory protection is provided and used.

Exposure to toxic vapours and fumes
In some instances aromatic oils may be used to rejuvenate the aged binder in the RA. Some of these aromatic oils contain high concentrations of harmful Polycyclic Aromatic Hydrocarbons (PAHs). Potentially hazardous concentrations of PAHs may be present in Bitumen fumes liberated when bitumen is heated and every precaution must be taken to reduce the exposure of workers to fumes or skin contact.

11.2.2 POTENTIAL SAFETY HAZARDS

Elevated temperatures
The most significant personal effect associated with bitumen is heat burns. Bitumen is normally handled at temperatures above 150°C and up to 210°C in the case of certain modified binders.

During the manufacture of the recycled asphalt, hot bitumen is mixed with heated aggregates at elevated temperatures which will cause severe burns where skin contact with liquid bitumen at these high temperatures occurs. This contact will cause severe burns and shock, which can be fatal. Contact with storage tanks and pipelines containing hot bitumen will also cause severe skin burns.

All workers involved with handling of the hot binder must be issued with appropriate Personal Protective Equipment (PPE) and its use must be strictly enforced.

Hazards arising from the combustible nature of bitumen
Paving grade bitumen is by definition not a "flammable" product. It is however combustible and under ideal conditions can ignite.[1] In asphalt blending operations ideal conditions for ignition may exist under the following circumstances:

- Elevated temperatures of bitumen increases volatility i.e. the ability of the bitumen to release flammable vapours. Bitumen and its derivatives contain hydrocarbons in various concentrations depending on composition. Small quantities of the vapours of hydrocarbons in air can form a flammable mixture. This flammable mixture can be ignited by a flame, hot surface or heating element, spark or other source of ignition, particularly in the vapour space of storage tanks, road tankers and other confined spaces where bitumen may be stored or handled.
- The bitumen is at a very high temperature above its flashpoint and contact with an ignition source (flame) can ignite the flammable vapour released from the surface of the bitumen;
- As the temperature of bitumen is usually above the boiling point of water, the presence of small quantities of water forms foam that will expand rapidly. This expansion may cause the tank to overflow. The expanding foam can quickly reach hot objects or burners, and cause the bitumen (flammable vapours) to ignite.

In practice there are some fundamental rules that can be applied to minimise the risk of ignition in bitumen operations:

- The first rule is to control the maximum temperature at which bitumen is stored and handled. *Bitumen should be stored and handled at the lowest temperature commensurate with efficient use.*
- The second rule is to control, and as far as is practicable, to *eliminate sources of ignition* in potentially dangerous atmospheres in the blending operations.

For more detailed information on fire prevention please refer to paragraph 4.6 of SABITA Manual 8**.**

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[1] It is recommended that the effect of the use of rejuvenator agents be considered in this respect.

11.2.3 POTENTIAL ENVIRONMENTAL ASPECTS

The main environmental aspects associated with bitumen are atmospheric discharges.

Excessive fume emissions during mixing

During the mixing of the asphalt excessive fuming can occur if the RA is exposed to the burner flame in the drum mixer. This contact should be avoided at all costs, even if it imposes a restriction in terms of the percentage of RA that can be recycled depending on the mixing plant configuration.

Baghouse emission control systems may not be adequate when high percentages of RA are used and supplementary or other types of emissions control systems may be necessary in these cases.

Spillage or leaching into the aquatic environment

Because of the viscous nature of paving grade bitumen, it is extremely unlikely that they could cause water pollution as a result of failure of storage systems.

Numerous studies conducted world-wide have concluded that the leaching behaviour of asphalt containing RA *(free of coal tar)* is not different from asphalt produced with virgin materials. For instance in Europe, Asphalt with or without RA**,** does meet the most onerous requirements with regard to leaching *(EAPA, 2008a).* However, any spillage into the environment is unacceptable and must be cleaned up as soon as possible.

Note: Recent changes in legislation and specifically the Waste Classification and Management Regulations which took effect in August 2013 have necessitated a review of storage practices.

For more detailed information on RA storage practices please refer to the SABITA best practice guide "An industry best practice guide for the storage of reclaimed asphalt (RA) at asphalt plants".

EAPA (2008a) *Arguments to stimulate the government to promote asphalt reuse and recycling*, Brussels, Belgium

12. CONTRACT DOCUMENTATION

Inappropriate, erroneous or incomplete tender information/specifications invariably lead to contractual disputes, with resultant administrative burdens to all parties and subsequent overruns in the total contract value and time. Depending on the specific Road Owners policies, asphalt recycling (and the specific percentages of RA contained therein) may be prescriptive or voluntary. Where it is voluntary, the client carries very little contractual risk as long as the final product satisfies all the specified properties.

Where, however, it is the client's policy to specify percentages of RA in a recycled asphalt mix, it is imperative that sufficient and appropriate information is provided in the contract documentation, at tender stage, to promote fair, competitive, transparent and fit-for-purpose procurement. This section provides guidelines as to the least information that should generally be provided, as well as other considerations that should be assessed, in order to minimise any possible contractual disputes.

12.1 MIX SELECTION

The primary objective of any pavement engineer should be to select an asphalt mix appropriate to the environmental conditions, expected traffic loading and functional demands. Any prescribed percentage of RA should thus be appropriate in terms of the inherent properties of the RA that is expected to be available. For example, it may be inappropriate to specify a 40% proportion of RA in a new SMA (stone skeleton) mix if the only RA available consists of an in-situ semi-gap asphalt (sand skeleton) mix.

12.2 MIXING PLANTS

It is probable that the major batching plants located in metropolitan areas are currently appropriately configured to produce asphalt containing high percentages of RA (40% and even higher).

The availability of suitable batching plants may, however, not be that evident on relatively remote project locations where the erection of temporary plants would most likely be required. It may also be the case that, on certain projects, the client's policy is to specifically promote the selection of emerging / new entrants into the market. In such instances it would be considered prudent to undertake a survey assess the availability of the number and types of mobile batching plants to ensure a competitive tendering process, prior to specifying any minimum RA content in the mix.

12.3 MILLING OF ASPHALT LAYERS

Existing asphalt layers within a pavement may often consist of different asphalt mix types, both vertically (overlays over time), or transversely (slow or fast lanes). In addition, it may be that the original asphalt surfacing has been regularly maintained by the application of single or multiple spray chip seals.

It is thus essential to carry out sufficient pre-tender investigations to identify – with certainty – all the various bituminous layers within the existing pavement as well as the estimated quantities of each. This may be done either by reviewing the various "As-Built" records (if available and considered accurate) or by carrying out an appropriate coring survey.

Where variable bituminous materials types have been identified, it would be prudent to provide for split (multiple) milling and stockpiling in the contract pricing schedule. This may be done by dividing the total estimated quantity into a number of Payment sub-items as may be dictated by the specific site conditions. This will permit the following:

- the designer can select the most appropriate RA stockpiles and fraction/s ratios in order to meet all the specified conditions/product properties;
- the client may dictate that any identified milled material that may be less suitable for recycling (due to e.g. ageing, variability, contamination) be used in other applications, as specified in the contract (together with any appropriate Payment Items).

In this manner changes can be made in order to maximise the inherent value of the various existing bituminous materials during construction without the need for negotiation of new rates, post-tender, with the associated administrative burden.

12.4 Utilisation of RA

It is generally acknowledged that RA has a significant asset value. The subsequent allocation, or reuse, of such a resource is highly dependent on the road owner's specific policies and/or the location of the project. However, the ultimate objective should always be to utilise this asset in a manner where its maximum inherent properties and value can be realised.

Irrespective of how much RA is to be used / specified, it is essential that the use or ownership of any residual RA be clearly defined in the Tender Document (COTO Standard Specifications and Project Specifications) as well as the Pricing Schedule and Site Information. In this regard various options may be available/required, but not limited to:

- The client specifies a minimum RA content, with any residual material becoming the property of the client for his future use. In such instances the Pricing Schedule shall include rates for processing (if required) all the residual RA as well as overhaul to the clients designated stockpile site.
- The client specifies a minimum RA content, with any residual material becoming the property of the contractor. In such instances the client only includes a quantity in the Schedule sufficient to meet the specific contract requirements. In addition, no overhaul rate should be included as the geographical location of the successful contractor is unknown at tender stage. In such a scenario the contractor, by taking ownership for use on other projects, essentially "purchases" the residual RA by means of discounting his unit rate for the final product in order to remain competitive.
- The client specifies a minimum RA content and schedules quantities and rates accordingly. It could be specified that all the residual RA be transported and utilised for any other application determined by the client, such as, pedestrian/cycle paths, access roads or inclusion as good quality "aggregate" within the supporting pavement layers. In such a scenario a quantity and rate for overhaul will be required to be scheduled in order to compensate for the transport of the residual RA to any final point of use.

12.5 Contract Information

For any project, it is essential that sufficient information is supplied at tender stage with respect to, amongst others, expected conditions and available materials sources. Any perceived, or otherwise, "unknowns" are invariably viewed by contractors as increasing their risk – with a consequent increase in any rates tendered.

At the investigation (pre-tender) stage it is considered essential that, as a minimum, the following information be supplied:

- The various mix/surfacing types, locations and quantities of the bituminous materials that can be reasonably expected;
- Aggregate type, grading and shape for each;
- Binder type, quantity and current recovered properties for each.

The above may either be determined by milling out selected areas or by extracting sufficient large diameter cores to provide sufficient sample sizes for the requisite testing.

12.6 Mix Design

The fundamental principle of recycling implies that recycled asphalt shall perform at least as well as an equivalent "virgin" mix. The current TRH8 provides for three levels of mix design, each considered appropriate for specific classes of road, expected traffic volumes as well as loading and structural support conditions. The mix design level, associated protocols and final mix properties selected should thus not differentiate between recycled and virgin mixes.

The major difference is that, where a specific percentage recycling has been prescribed, there will be:

- Changes to the standard nominal percentages listed in the COTO Standard Specifications, which will need to be adjusted accordingly to minimise any possible manipulation by contractors of the relevant Variation Rates
- Delays in obtaining the requisite RA component to permit the mix design process to commence. This may influence the envisaged construction programme, particularly if this work is on the critical path of the project, and thus exposed to any legitimate extensions of time.
- Different rejuvenators that may be the most appropriate for any specific conditions. It is thus strongly recommended that no specific type (and dosage) of rejuvenator be prescribed in any contract documentation, but that the contractor remains responsible for ensuring that the final asphaltic product satisfies all the specified mix properties.

There is currently an industry initiative to develop specifications and procurement protocols under the auspices of Agrèment SA for these products, with the ultimate objective of only specifying products that have been independently certified as being "fit for purpose".

12.7 Recycling and Construction Programme

As mentioned in "Mix Design" above, whether a mix contains RA or consists totally of virgin components, there are certain constraints with respect to the time and costs associated in undertaking the asphalt mix designs in accordance with the appropriate level specified. This would have a significant impact on the envisaged construction programme/time, particularly if the asphalt work is on the critical path of the project.

Current experience indicates the following periods that should be accommodated in any construction programme:

- Level I design: 4 – 6 weeks
- Level II design: 6 – 8 weeks
- Level III design: 8 – 12 weeks

Thus, if asphalt is a major component of a project and, particularly, if recycling has been prescribed, it is essential that sufficient time is allowed within the specified contract period to enable the contractor to undertake the full design process for acceptance, without incurring any unnecessary risks due to results being only partially available before commencing with the permanent works. This impact would also be exacerbated if multiple designs are required due to changes in the RA properties that may occur during the contract.

In existing commercial mixing facilities there would most likely be existing and / or residual stockpiles of RA which may be utilised to produce recycled asphalt soon after award of a contract. In rural situations however, or where the client has prescribed that only RA from his specific source be utilised, it would be prudent to allow for the inclusion of an appropriate quantity, and rate, of 100% virgin mix in the Pricing Schedule. This would permit work to commence as soon as possible, particularly in “mill and fill” situations whilst allowing sufficient time for adequate stockpiles of RA to be generated, processed and assessed, enabling the appropriate mix designs to be undertaken. Such an approach could significantly reduce the overall contract period.

12.8 Quality Assurance

Issues relating to quality are generally covered throughout this document. Recovery and assessment of reclaimed asphalt and its component properties is relatively expensive. It would thus be prudent in include an appropriate allowance in the contract Pricing Schedule, under a Provisional Sum, to cover the costs for any specialised testing that may be ordered by the client or his consulting engineer in order to verify, or add, to the information already supplied by the contractor.

13. GLOSSARY

Aggregate	A broad category of inert mineral matter used in asphalt and other pavement layers, including sand, gravel, crushed stone, slag, recycled concrete and geosynthetic aggregates. Aggregates are the most mined materials in the world
Asphalt	Asphalt as used in this document is in accord with European convention and refers to a mixture of bituminous binder and inert mineral aggregate in predetermined proportions designed for specific paving applications
Binder	A term describing bitumen that has been modified or that contains additives or fluxes to render it suitable for use in spray seals and the manufacture of asphalt mixes.
Bitumen	Bitumen which is obtained from crude petroleum by refining processes is a non-crystalline solid or viscous mixture of complex hydrocarbons that possesses characteristic agglomerating properties. It softens gradually when heated and is substantially soluble in trichloroethylene. In common parlance petroleum bitumen is often confused with tar.
Coal tar	By-product of the thermal processing of coal and means material that has or is reasonably suspected to contain volatile organic contaminants, such as water soluble phenols, harmful to biological systems, as well as other toxic materials such as polycyclic aromatic hydrocarbons (PAHs). Coal tars are classified by the International Agency for Research on Cancer as *carcinogenic to humans (Group 1)*
EAPA	European Asphalt Pavement Association, representing asphalt manufacturers in 18 countries in Europe
Fixed asphalt plant	A static or permanent asphalt plant which is a high production capacity asphalt plant operating from an authorized industrial zoned site and erected on a permanent foundation infrastructure serving multiple customers simultaneously.
Fractionating	A process increasingly used in which RA is screened into typically two or three sizes.
Gradation	Particle size distribution, normally expressed in cumulative quantities
Penetration value	A measure of the consistency of bitumen, determined as the depth to which a standard needle penetrates the sample under the conditions prescribed by EN 1426 or equivalent.
PVC	Polyvinyl chloride used to modify bituminous binders and, in the past, coal tar
RA	Reclaimed asphalt, obtained from milling or excavation of existing bituminous pavement layers or from stockpiles of asphalt production overruns and returned material. The material so obtained is crushed and screened to ensure an acceptable maximum size and grading. Following the crushing and fractionating process, RA is stockpiled and loaded in such a manner as will enhance the uniformity of the material.
RAP	Termed used in the USA for “reclaimed asphalt pavement” to differentiate it from reclaimed material incorporating typically shingles
Recovery	The controlled retrieval of any substance, material or object from other material or waste; In the process of recovering bitumen from asphalt, the bitumen extracted from asphalt by the use of a suitable solvent and is further processed to *recover* the bitumen from the solvent without significantly changing the asphalt’s properties
Recycle	A process where waste is reclaimed for further use, which process involves the separation of waste from a waste stream for further use and the processing of that separated material as a product or raw material
Recycled asphalt	An asphalt mixing containing RA in addition to virgin aggregates and binder and possibly rejuvenating agents

Re-use	The utilisation of the whole, a portion of or a specific part of any substance, material or object from the waste stream for a similar or different purpose without changing the form or properties of such substance, material or object
Sabita	Southern African Bitumen Association
SABS	South African Bureau of Standards
SAM	Stress absorbing membrane
SAMI	Stress absorbing membrane interlayer
SANS	South African National Standard
Temporary asphalt plant	an asphalt plant that is used for the sole purpose of supplying asphalt for a specific road paving contract not exceeding a period of 24 months

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