Information Series 136

NAPA
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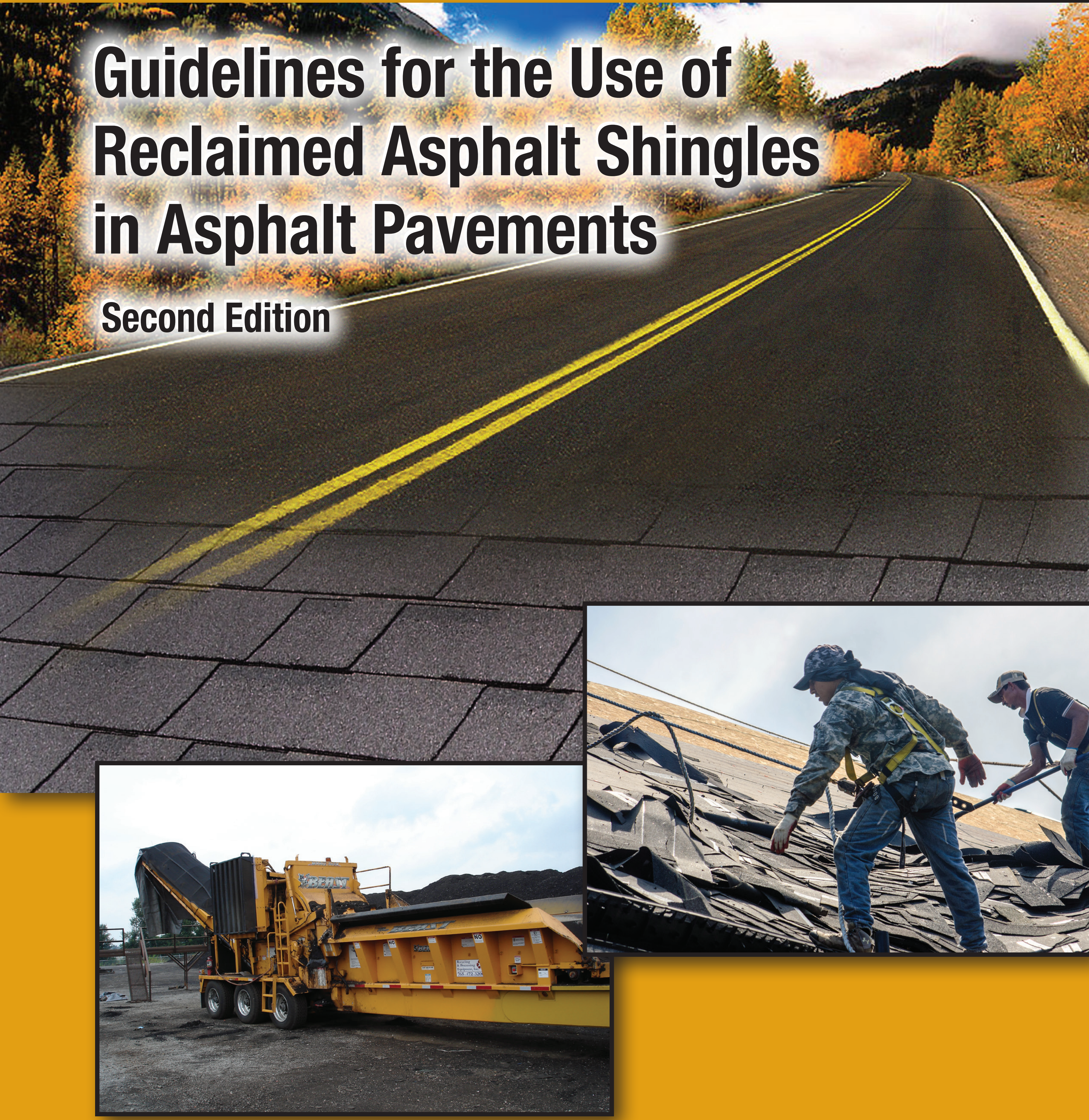
Guidelines for the Use of Reclaimed Asphalt Shingles in Asphalt Pavements

Second Edition



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Guidelines for the Use of Reclaimed Asphalt Shingles in Asphalt Pavements

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9. Abstract

Each year about 13.2 million tons of waste shingles are generated in the United States both from reroofing activities and manufacturing waste. The asphalt binder, aggregate, and fibers inherent in these shingles has the potential to be reused in new asphalt pavement mixtures, helping to offset the use of virgin materials and keeping the waste out of landfills.

While the use of RAS presents environmental and economic benefits, its use also presents challenges, and asphalt mixtures using this material must be properly designed, produced, and constructed to ensure long-term performance. To make the most of the opportunities offered by RAS, it is important to understand the properties of the shingle constituent materials and how they interact and perform when used in asphalt mixtures. To ensure the continued implementation of RAS in asphalt mixtures is successful, it is critical to follow quality-focused guidelines.

RAS use guidelines continue to evolve, and this document provides a comprehensive overview of current practices — from the sourcing of RAS through the construction of pavements with mixtures containing RAS. In addition to RAS usage guidelines, a life cycle assessment (LCA) and economic analysis are included to further illustrate the value and sustainability of this practice.

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CONTENTS

List of Abbreviations Used

AASHTO	American Association of State Highway and Transportation Officials
ACM	Asbestos-Containing Material
APA	Asphalt Pavement Analyzer
CDRA	Construction & Demolition Recycling Association
CMRA	Construction Materials Recycling Association
DEQ	Department of Environmental Quality
DNR	Department of Natural Resources
DOT	Department of Transportation
EAPA	European Asphalt Pavement Association
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FRT	French Rutting Tester
HMA	Hot-Mix Asphalt
LCA	Life Cycle Assessment
LCPC	Laboratoire Central des Ponts et Chaussées
MWAS	Manufacturing Waste Asphalt Shingles
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology at Auburn University
NCHRP	National Cooperative Highway Research Program
NESHAP	National Emissions Standards for Hazardous Air Pollutants
OGFC	Open-Graded Friction Course
PCAS	Post-Consumer Asphalt Shingles
PG	Performance Grade
RAP	Reclaimed Asphalt Pavement
RAS	Reclaimed (or Recycled) Asphalt Shingles
RBR	Reclaimed Binder Ratio
SMA	Stone-Matrix Asphalt
TSR	Tensile Strength Ratio
TSRST	Thermal Stress Restrained Specimen Test
VMA	Voids in Mineral Aggregate
WMA	Warm-Mix Asphalt

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Introduction

Historically, the asphalt pavement industry has embraced sustainability practices through operations that reduce energy use and emissions, eliminate waste, and improve community relations — all while reducing expenses. The continued use of recycled materials in asphalt mixtures, including reclaimed asphalt pavements (RAP) and reclaimed asphalt shingles (RAS), conserves raw materials, provides an economic benefit through material cost savings and improved material performance, and significantly reduces material being landfilled.

The National Asphalt Pavement Association (NAPA) in cooperation with the Federal Highway Administration (FHWA) has tracked the use of recycled materials and, more specifically RAS in asphalt mixtures since 2009. In 2009, it was estimated that 702,000 tons of RAS was utilized in asphalt mixtures. The use of RAS peaked in 2014 with 1,964,000 tons of RAS utilized. In 2017, the amount of RAS utilized in asphalt mixtures was estimated to be 944,000 tons, which equates to a 34.5% increase over 2009 usage, but a 52% decrease from the peak RAS usage in 2014 (Williams et al., 2018).

The annual NAPA–FHWA survey results clearly show the progression and fluctuation of RAS use since 2009. In 2009, asphalt producers in 22 states reported the use of RAS in asphalt mixtures. In 2017, asphalt producers in 29 states reported using RAS. At its highest point, in 2013, 38 states reported the use of RAS (Williams et al., 2018). The Asphalt Roofing Manufacturers Association (ARMA, 2015) reports that approximately 13.2 million tons of waste shingles are generated annually in the United States.[1] At the current utilization level, asphalt producers are only consuming about 9% of the available shingle waste stock. The level of implementation and rate of usage illustrate that continued implementation efforts can and should be made to further the sustainable practice of utilizing RAS in asphalt mixtures.

While the use of RAS presents several benefits, its use also presents challenges, and asphalt mixtures using this material must be properly designed, produced, and constructed to ensure long-term performance. To make the most of the opportunities offered by RAS, it is important to understand the properties of the shingle constituent materials and how they interact and perform when used in asphalt mixtures. To ensure the continued implementation of RAS in asphalt mixtures is successful, it is critical to follow quality-focused guidelines.

RAS use guidelines continue to evolve, and this document provides a comprehensive overview of current practices — from the sourcing of RAS through the construction of pavements with mixtures containing RAS. In addition to RAS usage guidelines, a life cycle assessment (LCA) and economic analysis are included to further illustrate the value and sustainability of this practice.

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[1] This is an increase from the commonly cited figure of 11 million tons (NAHB, 1998), reflecting changes in housing stock and the housing market since 1998.

Processed RAS should have the consistency and appearance of coffee grounds.

1

Asphalt Roofing Shingle Composition

The composition of asphalt roofing shingles varies depending upon the manufacturer, shingle age, product line, and roofing application, among other factors. The basic shingle composition is asphalt binder, filler, fine aggregate or granules, and fiberglass or organic felt. A typical cross-section diagram is provided in Figure 1 with the typical percentage range for each shingle component shown in Table 1.

The asphalt binder in RAS is significantly stiffer than standard paving grade asphalt binders and measures to account for the stiffer binder and the filler in the RAS are further discussed in Chapter 4: Mix Design & Material Properties.

The aggregate or mineral granules on the surface of the shingle are very durable and angular, which is desirable for incorporation in asphalt mixtures. In general, the properties of the surface aggregate in shingles can create additional voids in mineral aggregate (VMA) in the asphalt mixture. This could be helpful in cases where achieving minimum VMA requirements for a mix design is challenging.

Achieving proper VMA in asphalt mixtures is a key part of meeting the volumetric properties needed to help ensure a strong aggregate skeleton, the ideal amount of asphalt binder, and proper air void space to provide optimal performance against cracking, permanent deformation and aging. It is often challenging to meet minimum VMA requirements with less than ideal aggregate sources and more so when utilizing RAP.

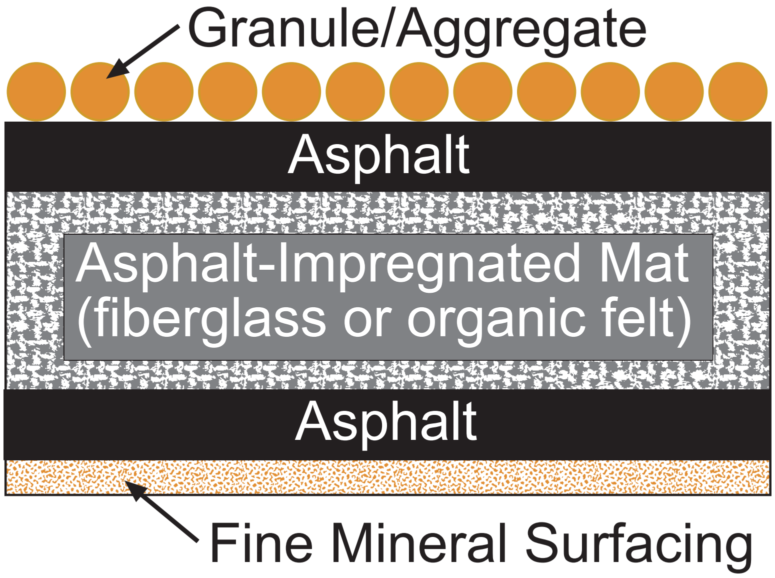

Figure 1. Typical Asphalt Shingle Composition

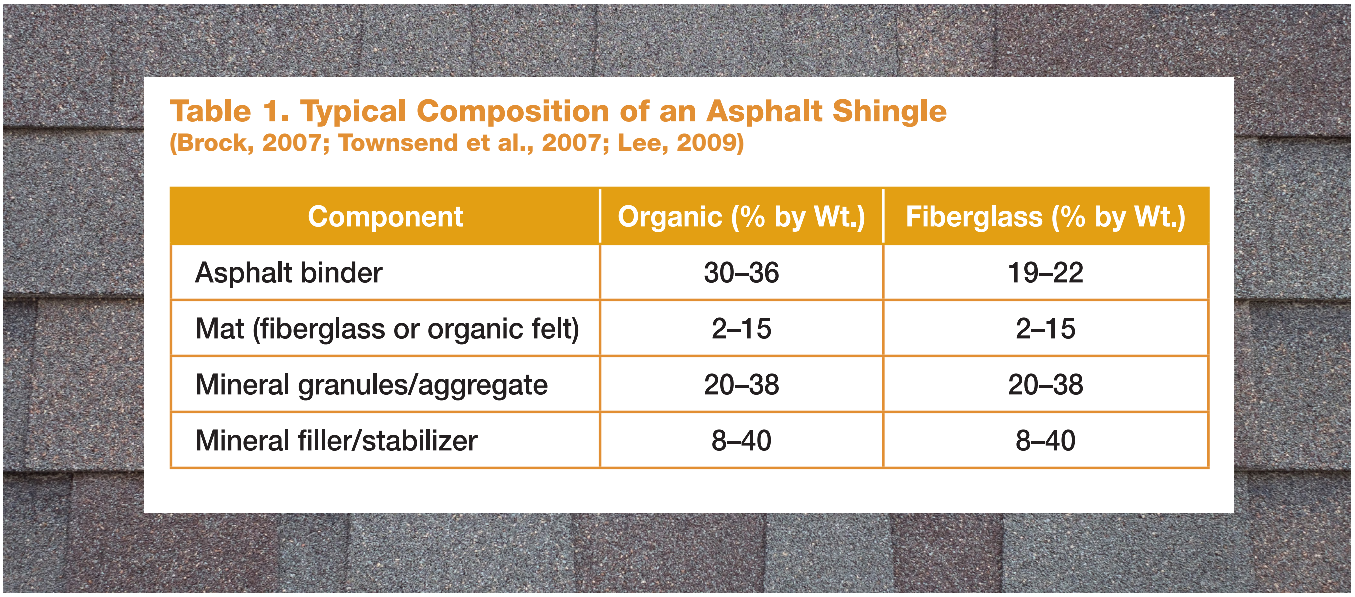

Table 1. Typical Composition of an Asphalt Shingle
(Brock, 2007; Townsend et al., 2007; Lee, 2009)

Component	Organic (% by Wt.)	Fiberglass (% by Wt.)
Asphalt binder	30–36	19–22
Mat (fiberglass or organic felt)	2–15	2–15
Mineral granules/aggregate	20–38	20–38
Mineral filler/stabilizer	8–40	8–40

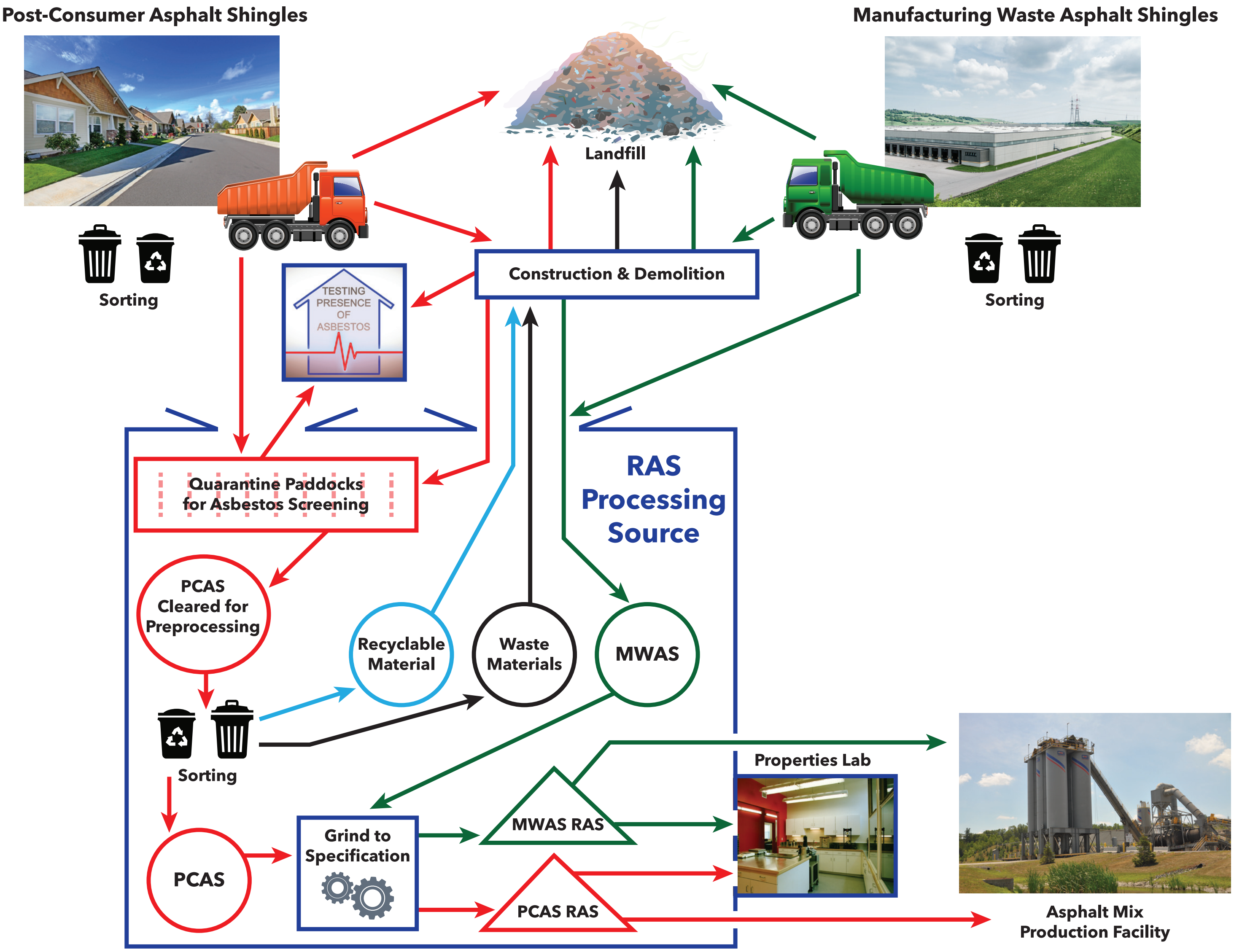

Figure 2. Reclaimed Asphalt Shingle Process (after Lippert & Brownlee, 2012)

2

Sources of Waste Roofing Shingles

A wide range of sources for waste shingles are available to asphalt mix producers. Categorically, waste shingles fall into two broad types: post-consumer asphalt shingles (PCAS) (also referred to as "tear-off shingles") or manufacturing waste asphalt shingles (MWAS). The sourcing and processing of asphalt shingles is illustrated in Figure 2.

Permitting and regulatory requirements for recycling shingles vary based on the condition of the shingles and are governed by local health, safety, and environmental regulations. Only processed waste shingles that meet the governing standard specifications or requirements are fed into the asphalt plant and incorporated in an asphalt mixture. A good resource for additional information on local regulatory agencies is the Construction & Demolition Recycling Association (CDRA) website *www.ShingleRecycling.org*; refer to the "State Experience & Contacts" section.

While many asphalt mix producers accept and process waste shingles directly, many also source RAS produced by shingle recyclers. Receiving and using this processed RAS often eliminates for asphalt mix producers many of the regulatory requirements associated with recycling shingles.

If waste shingle processors do not operate in a given area, then sources of unprocessed waste shingles will need to be identified. Shingle processors often prefer MWAS because they are free of most contaminants, such as nails, wood, and asbestos. An example of stockpiled MWAS prior to processing is shown in Figure 3.

MWAS is often generated when new shingles are trimmed to required size, as well as from material that does not meet manufacturer specifications, such as an incorrect color or aggregate coverage. Sources of MWAS are geographically more restricted than PCAS from reroofing activities, as shingle manufacturing facilities are not uniformly distributed across the country (Figure 4). Furthermore, the volume of PCAS generated from reroofing activities is about 10 times greater than the amount of MWAS generated by shingle manufacturers (ARMA, 2015).

Between the limited geographic availability and the significant waste volume differences, many asphalt producers may only have PCAS as an option. Obtaining a reliable supply of PCAS free of hazardous or harmful materials is very important as it affects the economics and sustainability of the use of shingles.

Figure 3. Stockpiled MWAS prior to processing

PCAS typically come from roofing companies who may have other options for disposing their waste shingles; however, they may be incentivized to recycle through reduced tipping fees, convenient location(s), less stringent requirements on non-hazardous contaminants, or other economic advantages. Depending upon local conditions, tipping fees from accepting RAS can be an additional minor revenue source for asphalt mixture producers.

Contaminants

PCAS will always have some minor quantities of contaminants. The shingle recycling operation must define what is acceptable, taking into account local, state, and federal requirements. However, in no case should PCAS include contaminants that are harmful to the health and safety of workers or the environment.

Asbestos-containing material (ACM), as defined under the U.S. EPA's rules for National Emissions Standards for Hazardous Air Pollutants (NESHAP), is prohibited (Krivit, 2007).

The basic modes for acceptance of PCAS are:

1. **Source separated** — This requires the roofing contractor to deliver only clean PCAS to the recycling facility. The shingles should be free of wood, plastics, large scrap metal, dirt, rocks, adhesives, solvents, petroleum contamination, other trash, and other substances deleterious to the shingle recycling processes. Deleterious materials are often defined in the specification along with standard testing protocols.
2. **Mixed roofing waste loads** — This requires sorting of the PCAS from the waste at the recycling facility. These can vary from simple "dump and pick" operations to more elaborate systems with screens, conveyor systems, and elevated picking stations to remove non-shingle materials. A shingle sorting operation is pictured in Figure 5.

Shingle recyclers should publish a written specification as to the types and quality of materials that are acceptable, as well as their criteria for rejecting loads (Krivit, 2007).

For more information on sorting options, refer to the Construction Materials Recycling Association (CMRA) *Recycling Tear-Off Shingles: Best Practices Guide* (Krivit, 2007).

Local specifications on allowable amounts of deleterious materials in processed reclaimed asphalt shingles can vary, however AASHTO MP 23-15 pro-

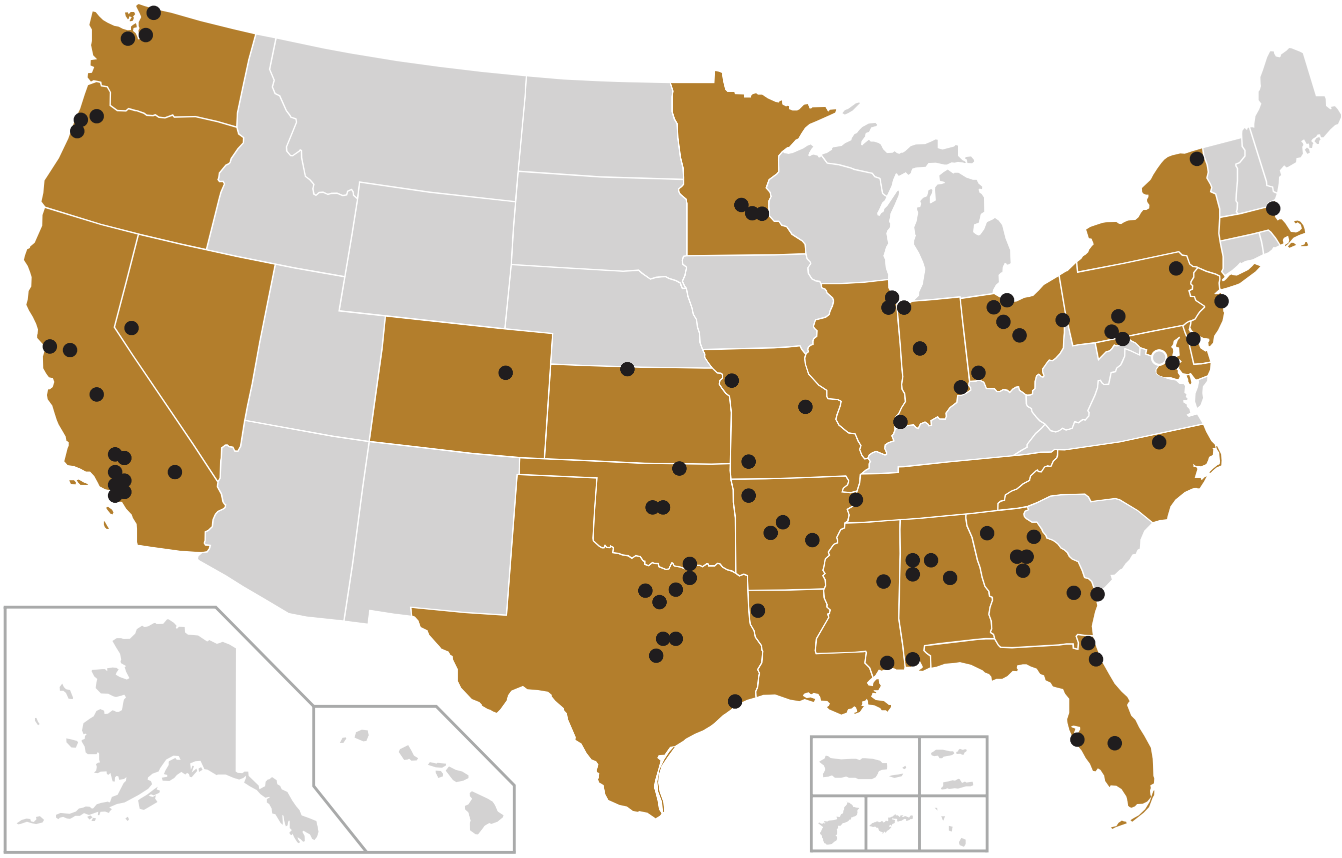

Figure 4. Approximate Location of U.S. Fiberglass and Organic Shingle Manufacturing Facilities (after 3M, 2016)

Figure 5. Shingle Sorting Operation (courtesy B.R. Amon & Sons Inc.)

vides guidance if no specifications are available. The AASHTO specification provides maximum limits for extraneous materials, such as metals, glass, rubber, soil, brick, paper, wood, and plastic. The RAS intended for use in asphalt mixtures must also be nail-free.

The current maximum limits are set based on a percent of the total mass retained on the No. 4 sieve for all extraneous material, and a separate maximum percent of the total mass retained on the No. 4 sieve for non-metallic extraneous material. The secondary maximum mass limit for non-metallic materials is used due to the discrepancy in mass between extraneous materials such as wood and metal.

Asbestos

One of the main concerns with PCAS is the potential for asbestos contamination. Although the use of asbestos in manufacturing asphalt roofing shingles was discontinued by the late 1970s (Wilson & Snodgrass, 2008), the potential for ACM to reach single recyclers remains a concern. PCAS with ACM are never utilized for producing asphalt mixtures.

Several studies have measured the occurrence of asbestos in PCAS tested samples. In a study conducted at the University of Massachusetts Lowell (Zickell, 2003), less than 1% of more than 11,000 PCAS samples tested contained asbestos. Townsend et al. (2007) conducted an extensive review of environmental issues associated with asphalt shingle recycling for CMRA, finding that of 27,000 test results from 10 shingle recycling facilities, only about 1.5% of samples contained asbestos and many of the asbestos detections were attributed to the presence of mastic and not the asphalt shingle itself. In a smaller study, only one of 191 samples taken from loads of asphalt shingles delivered to 27 randomly selected California landfills representing five regions of the state contained asbestos (Cascadia Consulting Group, 2009). The studies all indicate a low occurrence of ACM in PCAS samples analyzed.

The occurrence of ACM in PCAS is likely to continue to decline with time as the time since discontinuation of asbestos in shingles greatly exceeds the expected service life of asphalt shingles.

Regulations & Requirements

After sources of waste shingles are identified, the processing operation will need to obtain the necessary permits and licenses from local, state, and federal agencies. The permits and licenses vary from state to state and may include:

- Zoning, construction, and operation permits
- Solid waste and/or recycling facility licenses and permits

Regulations that may apply in addition to these permits and licenses include:

- State and federal worker health and safety regulations
- State and federal water quality protection
- State, regional, and federal air emissions regulations

When processing PCAS, local, state, and federal regulations on asbestos management, such as NESHAP Subpart M: National Emission Standard for Asbestos (40 CFR 61, Subpart M), will need to be reviewed.

A good overview of asbestos-related regulations can be found at *www.ShingleRecycling.org/content/regulatory-issues-regarding-asbestos*

Inspection & Testing Plan for PCAS

As part of the quality control and acceptance plan, shingle recycling operations need an inspection and testing plan for waste shingles delivered to the site. This plan should include:

- Acceptable shingle type and quality
- Criteria for rejecting loads
- Asbestos management plan (dependent upon state asbestos testing requirements)

In addition to ACM, the list of other prohibited materials for a PCAS recycler should include:

- Fiber cement shingles, shakes, and transite siding, which may contain ACM
- Any type of hazardous waste (e.g., mercury-containing devices, such as thermostats; paint; solvents or other volatile liquids; etc.)
- Other debris that are not asphalt shingles (e.g., plastic, paper, glass, wood, or metal)
- General trash

Personnel trained to visually detect possible ACM should inspect each load. ACM-identification training would ideally be part of a typical state-organized program. It is recommended that shingle recycling operators attend state-sponsored training courses to become licensed asbestos inspectors. This will help increase the awareness of potential ACM, as well as allow company personnel to provide accurate, timely and state-approved information and technical assistance to material suppliers and other customers. Shingle recycling operators should contact their state NESHAP office for technical assistance resources, including listing of organizations providing asbestos inspector training (Krivit, 2007).

There may be a need to develop an asbestos management plan for recycling PCAS. Federal NESHAP asbestos regulations are often administered and enforced by the state environmental agency. Contacts for most state NESHAP can be found on *ShingleRecycling.org* under “State Experience & Contacts.” PCAS can remain unregulated under NESHAP, even when the material is ground up for recycling. PCAS recyclers can work to reduce the chance of ACM reaching their recycling facility using the techniques described below. In some states, a combination of two or more of these techniques will be needed to meet the environmental regulations.

Regardless of the method used for avoiding known ACM evaluation and management, the roofing company and hauler should certify in writing that the used roofing materials are primarily asphalt shingles (such as three-tab shingles) and are free of prohibited materials.

It is recommended to pave areas where waste shingles are unloaded. This not only provides a cleaner facility, but will also make clean-up easier if any materials are found to contain asbestos.

When asbestos testing is required, it is best to separate untested loads from the main scrap stockpile until testing is complete. Once the material passes the test requirements, it may be moved to the main stockpile. Material that does not pass the required tests will need to be transported to an approved disposal area.

Each state environmental agency views processing PCAS differently. Some states will require continuous sampling for asbestos, while others require only intermittent sampling. Some state environmental agencies have posted fact sheets or other information about sampling PCAS for ACM. Although the rules are different in each state, review of the following examples of state requirements to process PCAS is prudent:

- Northeast Recycling Council with specifications and recommendations for Mid-Atlantic and Midwestern states (*https://nerc.org/documents/asphalt.pdf*)
- Oregon DEQ Fact Sheet (*www.oregon.gov/deq/FilterDocs/asb-AsphaltShingleFS.pdf*)
- Wisconsin DNR information (*https://dnr.wi.gov/topic/demo/shingles.html*)

3

Processing Waste Shingles

Shingle processing today consists of a wide variety of systems, equipment, and operational designs. Each processing facility has the following common elements (Krivit, 2007):

1. Feedstock quality assurance
2. Receiving and stockpiling of raw feedstock
3. Size reduction and screening
4. Final RAS product stockpiling
5. Final RAS product QA
6. Transport to end market

Figure 6 shows a simplified flow diagram for shingle processing. In this process, sorted shingles, which are free of extraneous material, are fed into a grinder or shredder to be processed into RAS. The ground or shredded shingles then pass through a screening process where material passing the specified size is stockpiled for use in asphalt pavement mixtures. Oversize material is typically returned to the grinder for further processing or may be sent to a separate stockpile for use in other purposes.

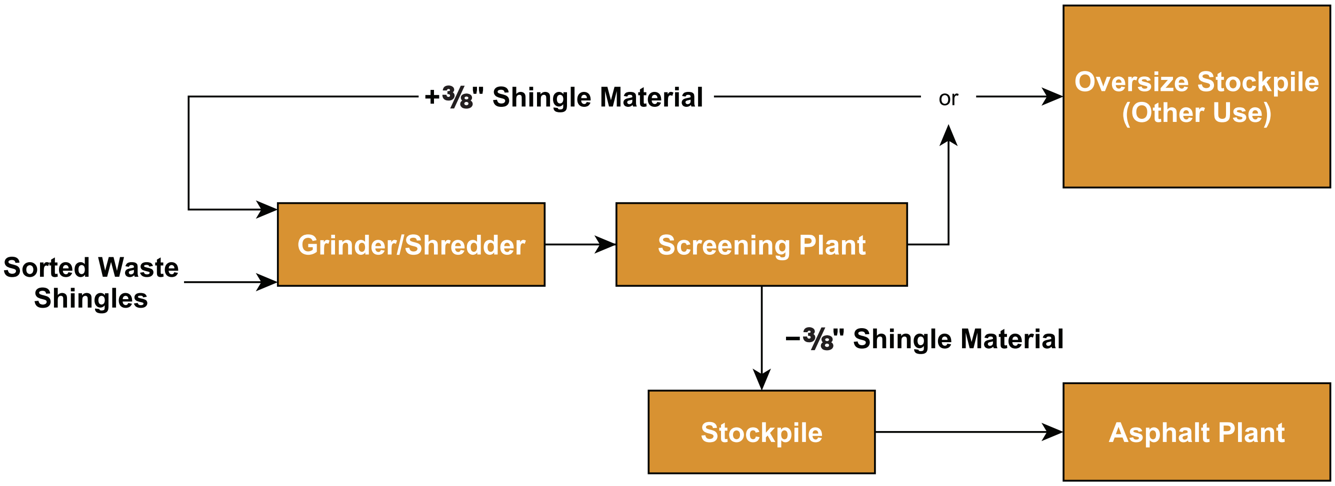

Figure 6. Simplified Shingle Processing Flow Diagram

A number of grinders or shredders may be used to process shingles. Each manufacturer uses its own combination of material-handling and size-reduction designs. The process and equipment are set up to achieve the specified gradation requirements at the production rate chosen by the recycler. Different agencies may have different sizing requirements for RAS, but AASHTO MP 23-15 specifies that reclaimed asphalt shingles for use in asphalt be processed so that the dry gradation prior to extraction be 100% passing the ⅜-inch sieve.

In general, the grinder will include a loading hopper, a feeding drum to move the shingles into the grinding chamber, a grinding chamber with cutting teeth, a sizing screen, and an exit conveyor. Figure 7 shows a mobile shingle grinder. Most often, a magnet head pulley at the end of the exit conveyor is standard equipment for removing nails and other ferrous metals, which is essential for processing PCAS. The final RAS product is stockpiled using a stacking conveyor or a front-end loader.

Shingles are very durable composite materials. Currently, most shingles are manufactured using fiberglass as the backing material, while older shingles were manufactured predominantly with an organic felt. One major difference between fiberglass and organic shingles is that the asphalt binder content is about 19–22% in most fiberglass shingles, compared to 30–36% in organic shingles.

In addition to the type of backing material used, another factor that may affect the quality of the RAS final product is the degree of aging of PCAS. The asphalt in PCAS is harder than that from MWAS due to oxidation that occurs during years of service on a rooftop.

The surface coloring granules and filler inside the shingle matrix are very hard, which makes them good materials for asphalt. The properties of the shingle will affect their processing. Aging of the PCAS embrittles the shingles and may make them easier to grind. However, the granules are very hard and abrasive and can accelerate wear and tear on processing equipment, especially the surfaces inside the grinding chamber. The shredding or grinding of shingles can also generate excessive heat, which is one reason why water is added to waste shingle material as it is fed into the grinding chamber (Krivit, 2007).

The clean asphalt shingles will also need to be sprayed with water on the feed system to the grinder to control fugitive dust and provide cooling for the grinder. In some cases, it may be necessary to add water to unprocessed shingle piles to control fugitive dust during loading. The amount of water used must be controlled to meet these goals without introducing excess water that will affect the production and energy efficiency of asphalt plants. Some shingle processors have installed dust-collection systems, which may include pneumatic systems capable of collecting fugitive dust and light extraneous material, such as plastic and paper. Both the pneumatic and water systems are designed to reduce potential exposure to fugitive dust and blowing litter.

For additional details on processing and managing RAS, consult the NAPA publication *Quality Improvement Series 129: Best Practices for RAP and RAS Management* (West, 2015).

Figure 7. Shingle Grinder

4

Mixture Design & Material Properties

Since the late 1980s, a number of laboratory studies have been conducted on asphalt mixtures containing RAS from MWAS and PCAS. Of particular interest has been the effect of RAS on asphalt binder grade, volumetric properties, performance properties, field production, construction, sustainability, and economics. These are discussed in this and the following chapters, along with a description of current AASHTO Standard Specifications and Standard Practices for using RAS in asphalt mixtures.

Asphalt Binder Grade

The asphalt binder contained in RAS is significantly stiffer than paving grade binders. This is because a stiffer binder is needed to prevent the material from creeping under its own weight when placed on sloped roofs. As with paving grade asphalt binders, roofing grade asphalt varies in stiffness according to climate, with stiffer asphalt used in warmer climates. Early studies evaluated recovered asphalt binder from RAS using penetration and viscosity measurements. More recent studies have evaluated the performance-graded (PG) binder properties recovered from laboratory and plant-produced mixtures that contained RAS.

A Minnesota Department of Transportation (MnDOT) research project (McGraw et al., 2007) compared the binder properties from dense-graded mixtures with 20% RAP (control), 15% RAP and 5% PCAS, and 15% RAP and 5% MWAS. The three mixes contained the same PG 58–28 virgin asphalt binder. The RAP and RAS were tested for percent asphalt binder, PG grading on recovered binder, gradation, percent glass fiber and paper content. An evaluation of the critical temperature (T_{cr}) of the mixes, obtained from direct tension testing, shows that the MWAS had no effect on T_{cr} and the PCAS only increased T_{cr} by a few degrees. In addition, the indirect tensile strengths were not significantly affected by the addition of shingles.

FHWA's TechBrief on asphalt mixtures with reclaimed binder content (FHWA, 2018) presented a table of binder grades from different mixtures con-

Table 2: RAS Binder Performance Grade (FHWA, 2018)

Reference	Material	High Temperature Grade	Low Temperature Grade
Standard	Virgin Binder	52°C to 76°C	–28°C to –16°C
NCAT (2014)	RAP	85°C to 95°C	–20°C to –5°C
	MWAS	125°C to 135°C	
	PCAS	150°C to 170°C	
Willis (2013)	MWAS	132°C to 154°C	–18°C to > 0°C
	PCAS	121°C to 175°C	–6.9°C to 41°C
Zhou et al. (2013)	MWAS	124°C to 138°C	
	PCAS	159°C to 214°C	
Bonaquist (2011)	RAS	110°C to 126°C	–10.1°C to 4.5°C
Willis & Turner (2016)	MWAS	126.6°C to 144.7°C	
	PCAS	144.4°C to 170.3°C	

taining RAP and RAS. Table 2 presents the recovered binder grades from several studies of asphalt mixtures that contained both MWAS and PCAS.

A study in Canada (Middleton & Forfylow, 2009) of plant-produced mixtures evaluated the effects of RAP and RAS from MWAS on various properties. The results showed that the addition of 15% RAP and 5% RAS shifted the binder temperature grade from PG 70–22 to PG 76–16 for the recovered binder. Interestingly, a mix containing 15% RAP had no effect on the temperature grade over that recovered from the virgin mix, and a mix containing 50% RAP only affected the low temperature grade. These results reinforce the conclusions from McGraw et al. (2007) in that the binder grade was more severely affected by the RAS binder than the RAP binder.

A study at the University of Nevada, Reno (Paulson et al., 1987) investigated the use of soft asphalt (AR-4000) and a recycling agent (RA-75) in laboratory mixtures containing RAS. It was found that for PCAS from Nevada, the recycling agent worked best for these mixtures, while the soft asphalt worked best for PCAS from New Jersey. It is suspected that, due to its climate, the Nevada PCAS contained a harder asphalt than the New Jersey PCAS. This highlights the critical need to 1) know the grade of the RAS binder, and 2) match the virgin binder with the RAS binder to yield a composite binder suitable for the end use application.

The studies illustrate that the binder contribution from RAS impacts asphalt mixtures differently than RAP and identifies the importance of accounting for RAS binder properties when incorporating RAS into an asphalt mixture design.

Mixture Volumetric & Performance Properties

Binder Ratio

The amount of available asphalt binder is the primary volumetric challenge in the use of roofing shingles in asphalt mixtures. As shown in Table 1, organic felt-backed shingles generally contain 30–36% binder by weight, and fiberglass shingles contain 19–22% by weight. The total asphalt binder content of PCAS is generally higher due to loss of granular material from the surface of the shingle during its service life.

Newcomb et al. (1993) found that the organic felt-backed shingles offered little reduction in the virgin asphalt content required to meet the mix design standards. The same study found that fiberglass PCAS allowed for virgin asphalt binder reductions ranging from 20–25% for dense-graded mixtures. Although this study did not find much binder reduction benefit in the use of felt-backed shingles, it is important to consider that the shingles were coarsely ground, significantly coarser than the ⅜-inch maximum size allowed in the AASHTO MP 23-15 specification, with a maximum size of 0.5 inches. When the shingles are ground finer, more of the RAS asphalt can be mobilized within the mixture.

Mallick et al. (2000) found that the virgin binder could be reduced about 0.2% for every 1% by weight of MWAS used in a mixture. Overall, Mallick et al. (2000) found that mixture volumetric properties were not appreciably different for RAS mixtures than regular asphalt mixtures. The findings illustrate how RAS can reduce the need for virgin binder in some asphalt mixtures.

Wu et al. (2016) found that the inclusion of low percentages (≤ 3%) of RAS had little effect on the PG grade of the recovered asphalt. The study examined material cored from a road project that included four test sections: two with 15% RAP and two with 15% RAP and 3% RAS. The binder testing showed that the mixtures with 3% RAS had properties indicating improved performance for both rutting and fatigue cracking, but also lower resistance to thermal cracking through reduced failure strains at 5°C.

Findings from these studies illustrate that 1% RAS asphalt binder will contribute less than 1% active binder to the asphalt mixture. The studies also shed light on some factors that can drive how much of the RAS binder is active in the asphalt mixture, including grind size, type of shingles, source of shingles and shingle age, among other factors.

To account for the varying binder content and properties in RAS sources that may impact binder grade, some agencies and researchers are using the concept of “reclaimed binder ratio” (RBR) to describe the amount of reclaimed binder to total binder in a mixture. RBR is calculated by multiplying the binder content of the RAS by the RAS percentage by weight in the mixture and then dividing by the total binder content of the mixture (FHWA, 2018).

Workability

RAS is generally utilized at between 3% and 5% in asphalt mixtures; therefore, asphalt mixtures containing RAS exhibit different workability characteristics based on other mixture properties. The RAS contains stiffer asphalt binder, fibers, and filler, as well as hard, durable, and angular aggregates, which could contribute to mixtures requiring increased production and placement temperatures and/or additional compactive effort during construction.

Research projects that involved asphalt mixtures containing RAS resulted in similar findings regarding workability. Newcomb et al. (1993) commented on the improved workability with the addition of shingles, leading to higher density for the same compaction effort; this has been supported by a number of observations (Lum, 2006; Ordorff, 2007). A possible explanation for this is that the RAS provides asphalt-rich fibers that can provide lubrication during the compaction process. In contrast, in 2011 it was noted that a mixture containing 5% RAS and a warm-mix asphalt (WMA) technology needed to be placed at 157°C to provide good workability, which was a substantially higher temperature than typical for WMA projects (Kopp, 2012).

Some producers report that RAS mixtures can be more challenging to achieve the same level of workmanship when compared to mixtures that do not contain RAS. The challenges reported range from difficulties with achieving density to undesirable aesthetics when completing hand work.

Cracking Resistance

A study conducted for MnDOT (Newcomb et al., 1993) found that up to 5% RAS could be incorporated into asphalt mixtures without negatively affecting the mixture properties. The mixture's cold temperature properties were investigated using the indirect tensile test. The evaluation considered the mixture tensile strength and the strain at peak stress.

Middleton & Forfylow (2009) compared the resilient modulus of a virgin asphalt mixture to mixtures with RAP and MWAS and reported an approximately 30% increase in the values obtained at both 5°C and 25°C test temperatures, which are considered the pavement service temperatures for Vancouver, British Columbia. Generally, such a difference is not considered significant for pavement design purposes. Figure 8 shows the modulus test results. Similar results were reported by Mallick et al. (2000) where they found the cold temperature properties of mixtures containing RAS were not that different from regular asphalt mixtures.

Baaj & Paradis (2008) studied the resistance to thermal cracking of a stone-matrix asphalt (SMA) mixture constructed using MWAS using Thermal Stress Restrained Specimen Test (TSRST). The loose asphalt mixture tested had been stored in boxes for about two

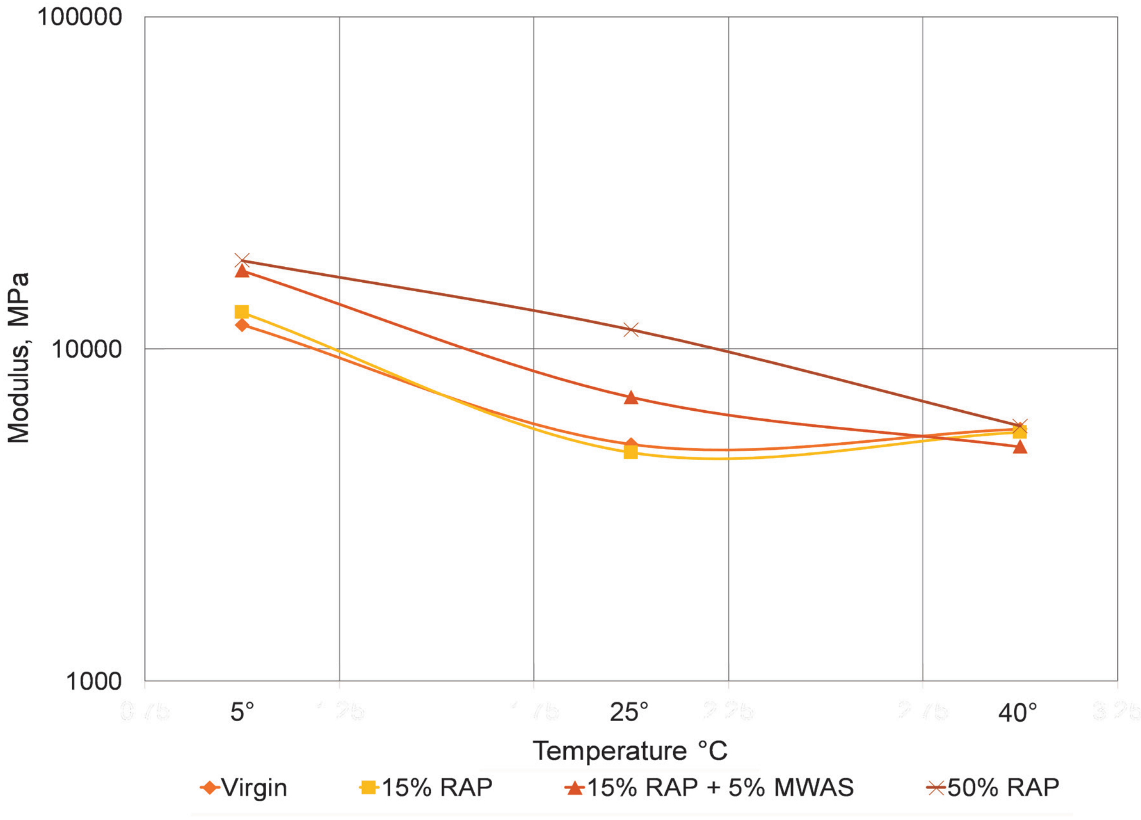

Figure 8. Summary of Modulus Test Results (Middleton & Forfylow, 2009)

years. They report, "The average failure temperature in all tests was –26°C. This temperature is quite good, because the bitumen used in the asphalt mixture was PG 58–28, and the slabs were made using boxed shingle asphalt mixture which promotes aging of the bitumen." After two years of service "the pavement shows no sign of thermal cracking."

Extracted binder testing was compared to mixture performance testing on cores obtained from four sections of a project (Wu et al., 2016). The sections included two asphalt mixtures containing 15% RAP and two sections with mixtures containing 3% RAS with 15% RAP. The study found that the asphalt mixtures containing 3% RAS showed a decreased resistance to thermal cracking when looking at the extracted binder, but the mixture performance testing, using the AASHTO T 322 Indirect Tensile Test method, showed no significant difference in expected thermal cracking resistance. The difference in thermal cracking resistance results between the binder testing and asphalt mixture testing was attributed to the benefits provided by the RAS fibers in the asphalt mixture.

Based on a review of these studies, it appears that while there is a stiffening in RAS asphalt mixtures at cold temperatures, it is usually not significant when utilized at 5% RAS or less.

Rutting Resistance

Middleton & Forfylow (2009) accounted for slow-moving, heavy traffic, using the Asphalt Pavement Analyzer (APA) test. The APA testing was conducted at 58°C, which is one PG grade higher than the base temperature grade of 52°C typically used in the Vancouver, British Columbia, region. In addition, APA testing was also conducted with the specimens submerged in water at 58°C to assess the effects of moisture damage.

Although the dry test results indicate a modest reduction in the APA rutting depth as the amount of incorporated reclaimed material (RAP and MWAS) increases, the magnitude of the difference is not considered significant. Wet testing indicated similar results. Figure 9 shows the results of the APA rut testing. Asphalt mixtures with less than 8 mm of rut depth are not considered susceptible to rutting.

Other studies have documented improvement in rut resistance for asphalt mixtures with RAS. Mallick et al. (2000) found rutting properties were significantly better for the asphalt mixtures using RAS. Newcomb et al. (1993) found that RAS asphalt mixtures containing fiberglass shingles were more resistant to permanent deformation than those containing cellulose fiber shingles.

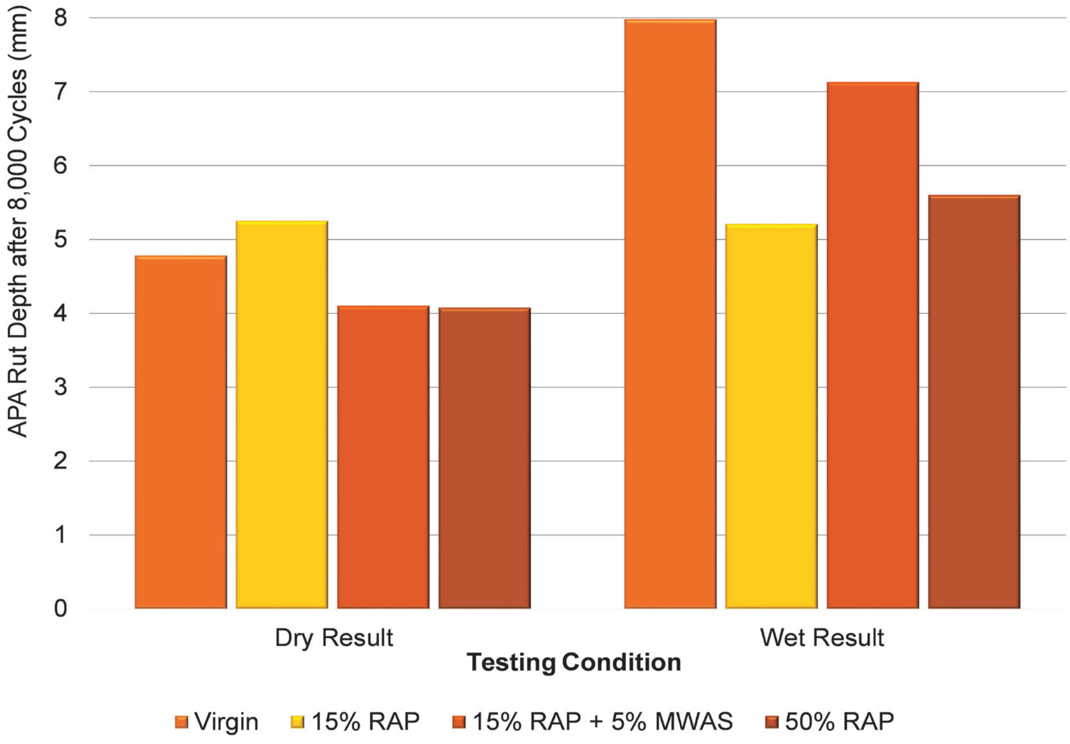

Figure 9. Summary of APA Laboratory Rut Testing (Middleton & Forfylow, 2009)

Table 3. Moisture Susceptibility Testing of Asphalt Mixtures (Middleton & Forfylow, 2009)

Asphalt Mixtures	Air Voids (%)	TSR (%)
Virgin	7.2	77.5
15% RAP	6.5	87.9
15% RAP + 5% RAS	6.8	83.1
50% RAP	7.2	96.4

Baaj & Paradis (2008) studied the rutting resistance of an SMA mixture constructed using MWAS and the Laboratoire Central des Ponts et Chaussées (LCPC) wheel tracker, also known as the French Rutting Tester (FRT). The rutting resistance was good, with measured rutting test results at slightly over half the maximum value specified for this asphalt mixture. They report that “after two years of service, this mix shows no signs of rutting on the pavement.”

Wu et al. (2016) found that asphalt mixtures containing RAS showed improved rutting resistance when evaluated with the Hamburg wheel tracking device. The study examined material cored from a Washington state road project that included four test sections: two with 15% RAP and two with 15% RAP and 3% RAS.

Payne & Dolan Inc., a Walbec Group Co., won a 2018 Green Quality in Construction Award for its repaving of U.S. 10 near the Village of Whilelaw, Wisconsin. The binder course for the project was a 19mm Superpave mix with 12% RAP and 4% RAS.

Moisture Susceptibility

While the earlier Minnesota study (Newcomb et al., 1993) was inconclusive regarding the effect of RAS on the moisture susceptibility of dense-graded asphalt mixtures, improvement in moisture resistance was noted for the SMA mixtures studied. This confirms the results shown by Middleton & Forfylow (2009) as illustrated in Figure 9 and Table 3.

A study of RAS use in open-graded friction course (OGFC) mixtures found that the addition of RAS did not have a significant impact on asphalt mixture moisture susceptibility (Wang et al., 2014). Asphalt mixture moisture susceptibility was evaluated with tensile strength ratio (TSR), where the non-RAS and RAS asphalt mixtures had average TSR values of 0.81 and 0.83, respectively.

Asphalt Mixture Design Standards

Designing asphalt mixtures using RAS follows a similar process as when using RAP. AASHTO MP 23-15, *Standard Specification for Reclaimed Asphalt Shingles for Use in Asphalt Mixtures*, provides specification requirements for RAS utilization (AASHTO, 2015). AASHTO PP 78-17, *Standard Practice for Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in Asphalt Mixtures*, provides information on asphalt mixture design considerations, determining shingle aggregate gradation, and binder considerations when designing asphalt mixtures that incorporate RAS (AASHTO, 2017).

A 2018 FHWA survey of its Division Offices (Aschenbrener, 2018) identified 31 state highway agencies that allow the use of RAS in asphalt mixes and have specifications and mixture design procedures for this purpose. Figure 10 shows those states with specifications and/or procedures for utilizing RAS in asphalt mixtures.

AASHTO PP 78-17 identifies and addresses three areas within the recommended practice of designing asphalt mixtures with RAS:

- Determining the shingle aggregate gradation and specific gravity
- Determining binder quantity requirement for effective asphalt

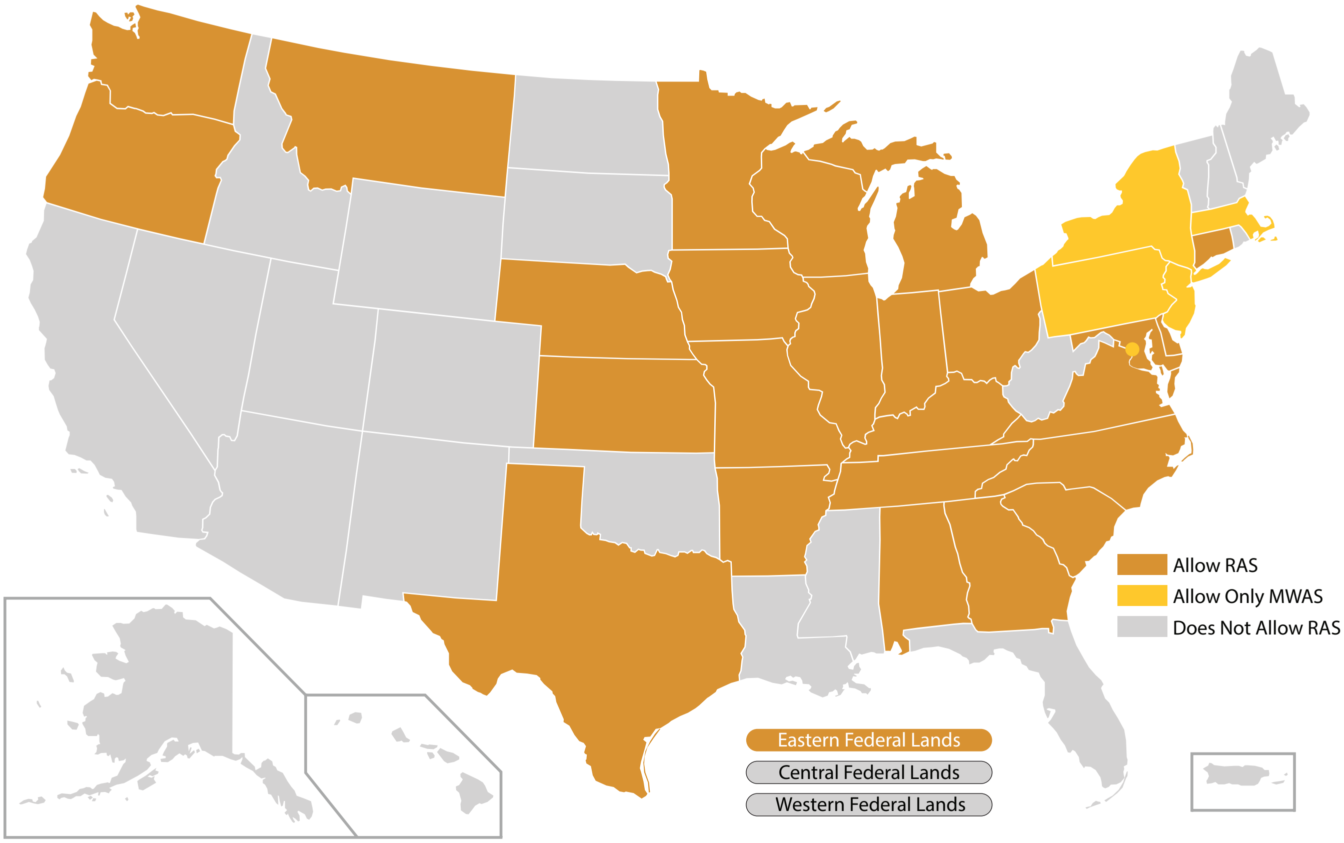

Figure 10. States and Agencies with Specifications or Procedures that Allow Use of Reclaimed Asphalt Shingles in Asphalt Pavements (Aschenbrener, 2018)

- Determining binder quality requirements for binder embrittlement

The RAS asphalt binder content can be determined by solvent extraction or by ignition furnace. Solvent extraction is necessary when the properties of the RAS binder are also required. Many state specifications only require such extracted binder testing when the percent of RAS or the RBR exceeds a certain threshold (15–30% RBR).

The extraction of all the asphalt from RAS will likely require more time than for asphalt mixtures. The ignition furnace may be used when only the asphalt binder content and gradation need to be determined. Solvent extraction is required for establishing a correction factor for the ignition furnace.

Safe operation of the ignition furnace will require smaller sample sizes when testing RAS due to the higher asphalt binder content in the shingles. Consult the ignition furnace operation manual or contact the manufacturer to ensure safe operation.

Some research has been conducted on the blending of the RAS asphalt binder and the virgin asphalt binder, as previously discussed (Newcomb et al., 1993; Mallick et al., 2000; Wu et al., 2016). AASHTO PP 78-17 addresses RAS effective asphalt content in which the minimum VMA requirement is increased 0.1% for every 1% of RAS. (RAS percentage is determined by the weight of total aggregate incorporated into the asphalt mixture.) Increasing the VMA requirement will increase the total and effective asphalt binder in the asphalt mixture.

This procedure was developed to account for RAS asphalt binder that does not become effective during the production. The asphalt binder in RAS does not fully liquefy during asphalt production, the effective portion is the asphalt binder that contributes to the binder adhering the mixture together.

The AASHTO MP 23-15 specification requires RAS be processed to 100% passing the ⅜-inch sieve to optimize blending. Variations in processed RAS gradations have resulted in a range of RAS asphalt binder effectiveness when mixing with new asphalt binders. Generally, finer RAS gradations lead to higher effective asphalt contents.

To address binder quality, AASHTO PP 78-17 has requirements for binder embrittlement in which the blended asphalt binder is evaluated using the Critical Low-Temperature Difference (ΔT_c).

The AASHTO standard practice notes that in lieu of blended asphalt binder testing for ΔT_c, an agency can implement a performance test for cracking. The ΔT_c criteria is presented with two allowable methodologies:

- An agency develops a statewide or regional RAS Binder Ratio (RASBR), or
- Allowable RAS usage is determined on a mixture-by-mixture basis

ΔT_c binder testing is conducted on aged samples, and the minimum ΔT_c is –5.0°C.

Binder Adjustments

In addition to the guidance provided by AASHTO, many producers have employed various engineering controls to help offset the age-hardened binder of RAS. Recently, agencies have specified that producers use softer virgin asphalt binders when using and/or exceeding certain percent binder ratios from recycled materials (e.g., the project asphalt binder grade is a PG 64–22; however, when using RAS, the virgin asphalt binder grade becomes a PG 58–28). Data from a FHWA study (Gibson et al., 2014) supports using a softer binder grade to reduce the overall stiffness of high recycled binder ratio mixes.

In addition, recycling agents and/or WMA technologies have been utilized in addition to or in replacement of softer asphalt binder grades when incorporating recycled binders. NCHRP Research Report 890 (West et al., 2018) found no detrimental effects from utilizing WMA technologies with asphalt mixtures containing RAS, and reported laboratory testing results indicating that asphalt mixtures containing RAS produced with WMA technologies showed improved cracking resistance when compared to the same mixes produced at hot-mix asphalt temperatures.

Several recycling agents are available; most aim to offset the age-hardened binder of the recycled materials in the asphalt mixture, while some also look to improve ΔT_c of the mixture's asphalt binder.

The European Asphalt Pavement Association (EAPA) has a position paper, *Recommendations for the Use of Rejuvenators in Hot and Warm Asphalt Production* (EAPA, 2018), which provides guidance to the asphalt industry for selecting rejuvenators with desired properties for the application.

For additional details on mix designs incorporating RAS, consult the NAPA publications *Quality Improvement Series 129: Best Practices for RAP and RAS Management* (West, 2015) and *Special Report 213: Use of RAP & RAS in High Binder Replacement Asphalt Mixtures: A Synthesis* (Newcomb et al., 2016).

Figure 11. Reverse Weigh Recycle Bin

5

Production & Construction Considerations

Production

Plant production of asphalt mixtures containing RAS is similar to producing RAP asphalt mixtures. RAS is fed into the plant through a recycle feed bin and into a recycle feed collar for drum-mix plants or any of the methods used to mix RAP with batch plants.

Although not required when using RAS, some producers have found that certain plant modifications helpful when incorporating RAS into asphalt mixtures. A few examples of these modifications follow.

RAS Feed Bins

The geometry of the RAS feed bin may be altered from the standard recycle feed bin. Steepening the bin sides helps prevent RAS material from bridging and can help ensure uniform material feed or flow.

A no flow, or zero flow alarm is also a common feature to allow plant operators an early indication of RAS material bridging and/or not being fed into the plant. Because of the low amount of shingles added to asphalt pavement mixtures, the RAS feed bin may also be outfitted with load cells to allow the feed rate to be controlled by weight depletion.

This type of feed rate control is also referred to as "reverse weigh" and can be an effective method when feeding materials at slower rates, which often is the case when a material being fed into the plant only represents a small percentage of the total mixture. Figure 11 shows a single recycle bin that has been outfitted with load cells to allow for reverse weigh feed control.

Software can also be used to automatically change the rate of the RAS feed bin belt, allowing the belt to speed up if any bridging does occur.

The allowance for feed error of recycled products may be defined in the owner agency specification or may be part of the asphalt mixture producers operating procedures.

Knowing the tolerances needed is important when working with asphalt plant suppliers in determining the proper equipment for feeding RAS.

RAS Storage

Agglomeration of ground shingles during stockpile storage must be addressed at the asphalt plant. Recycle feed bins should include a scalping screen to remove oversized materials or agglomerated particles.

There are several ways to minimize agglomeration of ground shingles, including:

- **Just-in-time grinding of shingles —** Shingles are ground and stockpiled to match expected production. The amount of time the processed shingles can tolerate stockpiling depends on the type of shingle and ambient temperature. Eliminating or reducing storage time will assist in minimizing agglomeration problems, but could affect RAS material availability for the plant if shingle processing is unexpectedly interrupted.
- **Covering stockpiles —** Stockpiling in a covered area or building shades the shingles from the sun and reduces exposure to additional moisture. Shading the material from sun and rain can help extend storage time and forestalling agglomeration. Figure 12 provides an example of a structure utilized for covering a RAS stockpile.
- **Blending with fine aggregate —** Processed shingles are blended with sand (often referred to as "carrier material") to reduce agglomeration. One method uses RAS from the screening unit fed onto a conveyor leading to an automatically controlled surge hopper, where the processed shingles are blended with sand in a pugmill. The pugmill then feeds the blended material to a stacker conveyor for stockpiling. Approximately 20% sand or screenings is recommended when blending to prevent RAS from sticking together. Older PCAS can often use less carrier material than newer MWAS. While blending fine aggregate with RAS can address agglomeration, it is critical that the blending process utilized provide a consistent blend that is not prone to segregation. If the blended product is not accurately

proportioned, product variability becomes a concern. Figure 13 shows a schematic of one system for mixing RAS with sand.

- **Blending with RAP —** A number of producers blend RAP with RAS. A typical system may consist of bins for metering RAP and RAS onto a conveyor, similar to what is done when metering aggregates into a drum. The combined RAP and RAS are then mixed in a pugmill or drum and transferred to a stockpile. This type of pre-blending may limit an asphalt producer's options when production changes need to be made.
- **Breaking the RAS in the asphalt plant feed system —** This system uses a lump breaker or grinder to break down agglomerated RAS prior to feeding it into the plant. Such a system should include a scalping screen to minimize excess size material. The lump breaker or grinder is incorporated into the recycle feed system with the scalping screen between the recycle feeder bins and the recycle material weigh bridge.
- **Blending with additives —** Producers have reported that blending RAS with products like zeolites during RAS production helps reduce agglomeration in the stockpile and helps the material flow better during the feeding process. This process adds cost to the finished RAS product, but in the case of zeolites may also provide some warm-mix characteristics to the finished asphalt mixture.

Drum Configuration

Asphalt plant drum configuration will determine the degree of mixing an asphalt mixture receives. Depending on the percentage of RAS in the blend, the producer may wish to consider how their drum configuration works with their RAS mixtures. Material dwell times can be lengthened in order to increase drying and mixing times, if needed (Brock, 2007).

Additional Best Management Practices

In addition to plant alterations and/or feedstock modifications, some additional best management practices may need to be employed during production to ensure that a quality asphalt mixture with RAS is produced.

- **RAS stockpile moisture monitoring —** RAS contains approximately 19–36% asphalt binder, of which a portion is assumed to be effective in the mixture. Therefore, entering an accurate moisture value into the plant computer is crucial. If not, added asphalt binder contents can be negatively affected by either over- or under-asphalting the mixture.
- **Increased mixture moisture monitoring —** In addition to the normal aggregate moisture and mixture moisture monitoring, there should be increased focus on drying when producing RAS mixtures. One way to monitor this is by measuring the temperature of the mixture in the back of the transport truck at the plant and again at the project site. Depending on the haul time and weather conditions, losses

Figure 12. Two examples of covered processed RAS. At left, the RAS is stored on a paved surface with the RAS feed system in the foreground.

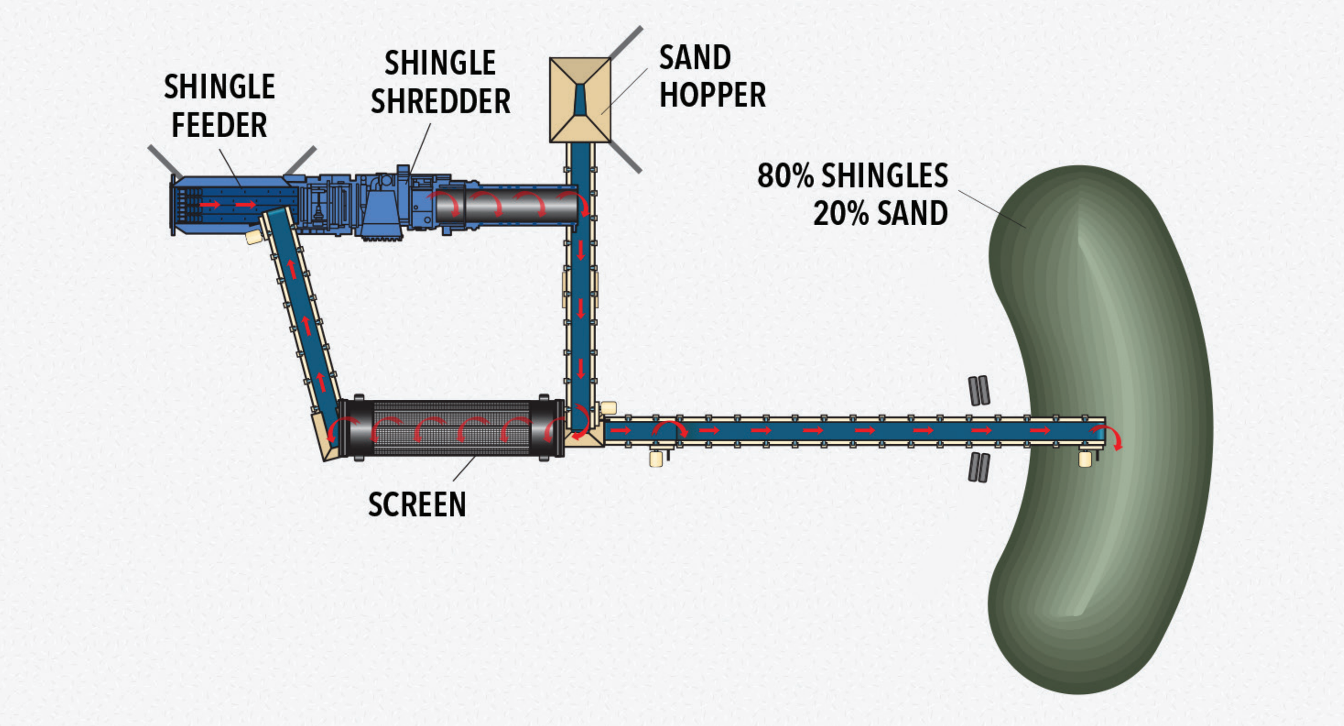

Figure 13. Schematic of RAS/Sand Blending System (Brock, 2007)

in temperature may indicate that the material needs additional drying time during production. Calibrated temperature probes should be used to measure the temperature to reduce the potential for erroneous readings.

- **RAS feeding —** Because RAS is relatively light, care should be taken to ensure it is not blown from the conveyor(s) during production. The feeding process may need to be configured such that the RAS is covered by a heavier product, like RAP, as soon as possible. More extensive measures may require the plant to cover the RAS conveyor(s) to prevent material loss during production, which could affect the resulting asphalt mixture.
- **RAS storage —** Several producers have noted that storage time of an asphalt mixture with RAS can affect the measured volumetric properties. Whether that storage takes place in the silo at the plant or in the transport truck on the way to the project, the producer should be aware of and understand how that time may affect the volumetrics of the mixture. If necessary, additional research may need to be conducted in order to ensure appropriate changes are made to meet whatever volumetrics specifications the project requires.

Construction

As with production, the construction of mixtures containing RAS is similar to constructing pavements with asphalt mixtures containing RAP. However, due to the increased stiffness of the asphalt binder in the RAS, the time that the asphalt mixture stays workable may be reduced. Therefore, production rates should be balanced with demand to make sure asphalt mixture does not sit in transport trucks for an extended period of time.

Rollers must stay within their temperature zone and complete their patterns in a timely manner to ensure proper compaction is achieved. As with any asphalt mixture, compacting the asphalt mixture in the most efficient manner possible gives the greatest potential for constructing a quality pavement.

For additional details on processing and managing RAS, consult the NAPA publication *Quality Improvement Series 129: Best Practices for RAP and RAS Management* (West, 2015).

S.T. Wooten won a 2018 Green Quality in Construction Award for its repaving of I-795 in Wayne County, North Carolina. For the project, the company produced and placed more than 19,000 tons of an OGFC surface mix that included 5% RAS.

6

RAS & Sustainability

Since RAS has been used as a substitute for some of the virgin asphalt binder and fine aggregate sources in asphalt mixtures, it is considered by many to be a resource responsible or sustainable material. When used in dosages of 3–5% of the asphalt mixture, RAS can reduce the virgin asphalt binder in a mixture by between 15% and 30%, depending on the asphalt content of the new mixture and RAS itself.

A limited LCA performed for the U.S. Environmental Protection Agency showed that using RAS in asphalt mixtures in conjunction with RAP further reduced the greenhouse gas emissions associated with mixture production (Booz Allen Hamilton, 2013).

A more detailed LCA case study was conducted by Willis (2014) on the Green Group Experimental mixtures at the National Center for Asphalt Technology at Auburn University Pavement Test Track. This experiment compared the environmental and field performance of virgin mixtures to mixtures containing RAP, ground tire rubber, and RAP+RAS. The LCA covered the material extraction, mixture production and construction phases of the experiment. In the LCA, Willis (2014) showed that the RAP+RAS mixture lowered the required production energy and released carbon dioxide (CO_2). Table 4 provides the savings for material extraction, mixture production, and material transportation. Similar construction efforts were used to place both mixtures and thus not reported; however, haul distances for materials between the mixtures varied as the RAP and RAS were acquired from a local source and thus required less transportation effort than the virgin aggregates.

These LCAs should be considered as partial LCAs because the entire life-cycle of the asphalt mixture is not considered. For example, if a RAS-containing mixture saved 19% in energy production but only had half the life of a virgin mixture, the energy savings would be eliminated due to the production of a new mixture to replace the poorly performing one. Asphalt mixtures with RAS must be designed, produced, and constructed to provide long-lasting performance in order to be truly sustainable.

Table 4. Energy and CO_2 Savings from the Use of RAP and RAS (Willis, 2014)

Test Section	Recycled Content by Weight of Mixture	Haul Distance (miles)	Virgin Material Extraction and Production Savings		Transportation Savings		Mixture Production Savings	
			Energy (%)	CO_2 (%)	Energy (%)	CO_2 (%)	Energy (%)	CO_2 (%)
Control/Virgin	0.0%	15.1	—	—	—	—	—	—
S6/RAP+RAS	25.7% (22.7% RAP + 3% RAS)	7.5	19	28	30	39	15	9

Note: Energy savings strongly correlate to fuel savings during each phase.

Table 5. Calculating the Savings When Using RAS

				Per Ton
A		*Savings from Asphalt Binder:* New Asphalt Binder Cost ($/ton) × Asphalt Binder % in RAS × Effective % of Asphalt Binder in RAS × % RAS in Asphalt Mixture		$
B		*Cost of Using Softer Binder (if used):*		$
	B_1	*Percent Virgin Binder in Asphalt Mixture:* % Total Asphalt Binder in Asphalt Mixture – [Asphalt Binder % in RAS × Effective % of Asphalt Binder in RAS × % RAS in Asphalt Mixture]	%	
	B_2	*Additional Cost per Ton for Softer Asphalt Binder:* Softer Asphalt Binder Cost ($/ton) – Standard Asphalt Binder Cost ($/ton)	$	
		Multiply B_1 by B_2 ($/ton)		
C		*Cost of Recycling Agent (if used):* Recycling Agent Cost ($/ton) × % Used in Asphalt Mixture		$
D		*Gross Savings per Ton for RAS Binder:* *If no modifications are made,* use A *If a softer binder is used,* Subtract B from A *If a recycling agent is used,* Subtract C from A *If both a softer binder and recycling agent are used,* Add B+C and Then Subtract from A		$
E		*Savings from Fine Aggregate:* New Fine Aggregate Cost ($/ton) × % Fine Aggregate in RAS × % RAS in Asphalt Mixture		$
F		*Revenue from Tipping Fee:* Tipping Fee ($/ton) × % RAS in Asphalt Mixture		$
G		*Total Gross Savings per Ton of Asphalt Mixture:* Add D+E+F		$
H		*Acquisition Cost of RAS (including trucking cost):* Acquisition Cost ($/ton) × % RAS in Asphalt Mixture		$
I		*Additional Processing/Crushing Cost:* Processing/Crushing Cost ($/ton) × % RAS in Asphalt Mixture		$
J		*Miscellaneous Costs/Savings (i.e., amortized capital costs for new equipment):* Miscellaneous Costs/Savings ($/ton) × % RAS in Asphalt Mixture		$
K		*Total Gross Cost Adjustment per Ton of Asphalt Mixture:* Add H+I+J		$
L		*Net Savings per Ton of Asphalt Mixture:* Subtract J From G		$

Note: Lines D and J may be either a Cost Savings or a Cost Addition.

7

Economics of RAS

Because liquid asphalt is typically the single-greatest cost input for each ton of asphalt pavement mixture, the ability to reuse asphalt binder inherent in asphalt roofing shingles creates a potential for cost savings. This can make the mixture more cost effective, allowing a contractor to pass savings along to customers through a lower bid price.

However, the additional costs involved in acquiring and processing RAS, as well as the cost of any additives or binder changes necessary to ensure a high-performing mix must also be considered.

Table 5 on the facing page shows a simple method for calculating the economic impact of reclaimed asphalt shingles in asphalt mixtures.

Table 6 illustrates the potential savings of using waste shingles in asphalt mixtures, using the following values and assumptions:

- New Asphalt Binder Cost = $350, $450, and $550/ton
  - ☞ *For this example, it is assumed that no recycling agents or softer binder are being used*
- % RAS in Asphalt Mixture = 5%
- Asphalt Binder % in RAS = 25%
  - ☞ Effective % of Asphalt Binder in RAS = 80%
- % Fine Aggregate in RAS = 30%
- New Fine Aggregate Cost = $10/ton
- Tipping Fee Revenue = $45/ton
- Acquisition Cost = $0/ton (assumes generator of waste pays this cost)
- Processing/Crushing Cost = $12/ton
- Miscellaneous Costs = $0 (unknown)

Items that are an additional cost in Table 5 are shown in red.

Applying these values to the formulas in Table 5, the savings in Table 6 are realized.

This clearly illustrates the value of waste asphalt shingle in asphalt mixtures, with a majority of the potential savings coming from replacing the asphalt binder. If all the 13.2 million tons of waste asphalt shingles generated annually (ARMA, 2015) were used in asphalt mixtures, the savings would be significant (approximately $63 million at $400/ton asphalt binder). This would also reduce the demand for new asphalt binder by about 2.6 million tons (14 million barrels).

If RAS is used in quantities that would require a

Table 6. Savings When Using RAS

	Asphalt Binder Cost Per Ton	$350	$450	$550
A	Savings from Asphalt Binder	$3.50	$4.50	$5.50
B	Cost of Using Softer Binder	$0	$0	$0
C	Cost of Recycling Agent	$0	$0	$0
D	*Gross Savings per Ton for RAS Binder*	$3.50	$4.50	$5.50
E	Savings from Fine Aggregate	$0.15	$0.15	$0.15
F	Revenue from Tipping Fee	$2.25	$2.25	$2.25
G	*Total Gross Savings per Ton of Asphalt Mixture*	$5.90	$6.90	$7.90
H	Acquisition Cost of RAS	$0	$0	$0
I	Additional Processing/Crushing Cost	$0.60	$0.60	$0.60
J	Miscellaneous Costs/Savings	$0	$0	$0
K	*Total Gross Cost Adjustment per Ton of Asphalt Mixture*	$0.60	$0.60	$0.60
L	*Net Savings per Ton of Asphalt Mixture*	$5.30	$6.30	$7.30

softer grade of binder and/or recycling agents (see the Binder Adjustments discussion in Chapter 4), then the Rows B and C in Table 5 must be used to account for the additional cost of the softer binder and/or recycling agents.

Table 7 illustrates the increased cost of softer binder and/or recycling agents when using waste shingles in asphalt mixtures, using the following values and assumptions:

- % Total Asphalt Binder in Asphalt Mixture = 6%
- % RAS in Asphalt Mixture = 5%
- Asphalt Binder % in RAS = 25%
  - ☞ Effective % of Asphalt Binder in RAS = 80%
- Softer Asphalt Binder Cost = $500/ton
- Recycling Agent Cost = 75¢/lb. ($1,500/ton)
  - ☞ % Recycling Agent in Asphalt Mixture = 0.2%
- Standard Asphalt Binder Cost = $450/ton

Items that are an additional cost in Table 7 are shown in red.

As seen in Table 7, the additional cost of recycling agents and/or using softer binders may negate some of the initial cost savings that otherwise would be realized from the use of RAS. However, as with the LCA benefits discussed in Chapter 6, if the use of a softer binder and/or recycling agents helps improve pavement performance and longevity, then the extra expense will be recouped in terms of the pavement's life-cycle costs.

Table 7. How Softer Binders and/or Recycling Agents Impact Savings When Using RAS

			RAS Alone	RAS With Softer Binder	RAS With Recycling Agent
A	Savings from Asphalt Binder		$4.50	$4.50	$4.50
B	Cost of Using Softer Binder		$0	$2.50	$0
	B$_1$ Percent Virgin Binder in Asphalt Mixture	5%			
	B$_2$ Additional Cost per Ton for Softer Asphalt Binder	$50			
C	Cost of Recycling Agent		$0	$0	$3.00
D	***Gross Savings per Ton for RAS Binder***		$4.50	$2.00	$1.50
E	Savings from Fine Aggregate		$0.15	$0.15	$0.15
F	Revenue from Tipping Fee		$2.25	$2.25	$2.25
G	***Total Gross Savings per Ton of Asphalt Mixture***		$6.90	$4.40	$3.90
H	Acquisition Cost of RAS		$0	$0	$0
I	Additional Processing/Crushing Cost		$0.60	$0.60	$0.60
J	Miscellaneous Costs/Savings		$0	$0	$0
K	***Total Gross Additional Costs per Ton of Asphalt Mixture***		$0.60	$0.60	$0.60
L	***Net Savings per Ton of Asphalt Mixture***		$6.30	$3.80	$3.30

8

Summary

The use of RAS from both MWAS and PCAS in asphalt mixture can be a win–win situation for owners, asphalt producers, and the environment. While the use of RAS provides economic, engineering, and environmental benefits, its use also presents challenges. Asphalt mixtures using this material must be properly designed, produced, and constructed to ensure long-term performance. With proper inspection and testing of PCAS materials, the potential risk of asbestos contamination is extremely low. Persons recycling PCAS will need to work with roofing companies and federal, state, and local agencies to develop a monitoring plan to ensure the process is safe for workers and the environment.

The high asphalt content of shingles enables a small percentage of RAS to replace significant quantities of new asphalt binder, saving materials and reducing costs. Thus RAS is typically used as a small percentage of the asphalt mixture, often 5% or less. The utilization of RAS in asphalt mixtures also prevents a significant amount of waste materials from being landfilled.

Research and experience shows that RAS can work in all asphalt mixture types, including dense-graded, SMA, and OGFC. Utilizing RAS in asphalt mixtures can improve a mixture's rutting performance and, if accounted for properly, maintain the low temperature properties of the asphalt mixture. When RAS is utilized at percentages where the amount of virgin binder in the asphalt mixture is 85% or greater of the total binder, no change in binder grade is normally required. If the percent reclaimed binder ratio exceeds 15%, the specifications may require a softer binder and/or recycling agents when using RAS.

APAC Kansas inc., Shears Division, a CRH Company, won a 2018 Green Quality in Construction Award for its overlay of U.S. 50 in Harvey County, Kansas. To restore performance to a deteriorating concrete pavement, the company used nearly 37,000 tons of a mix with 10% RAP and 5% RAS.

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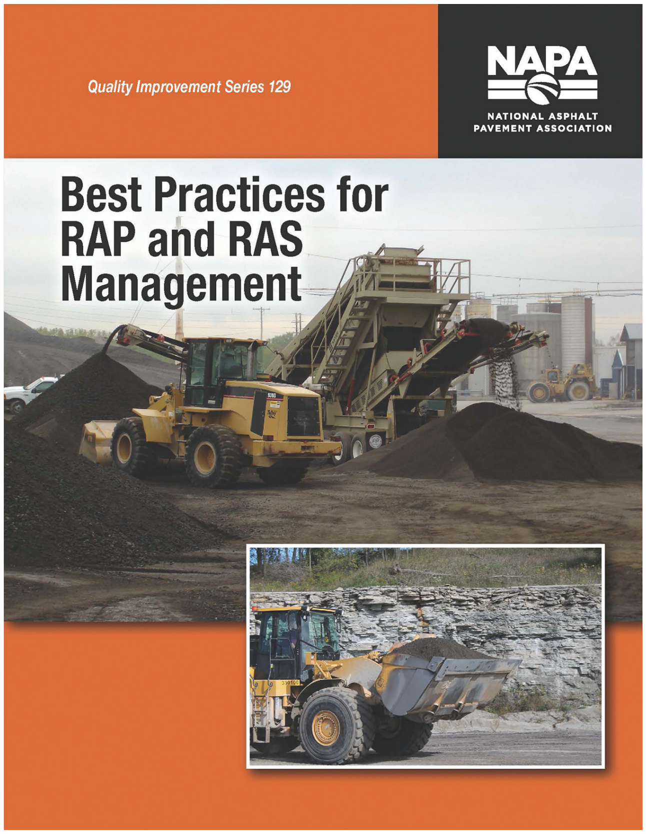
Further Reading



To help asphalt pavement mix producers, engineering consultants, and road owners make the most effective utilization of reclaimed asphalt shingles (RAS), the National Asphalt Pavement Association also offers the following publication:

- *Best Practices for RAP and RAS Management* (Quality Improvement Publication 129) by Randy C. West, Ph.D., P.E., covers pavement milling, inventory management, processing, sampling, and testing of RAP and recycled asphalt shingles (RAS), as well as a discussion of production concerns.

The publication was produced under NAPA's cooperative agreement with the Federal Highway Administration (FHWA) and is available as a high-quality PDF electronic document through the NAPA Online Store, along with many other technical publications, webinar archives, and additional helpful materials.

http://store.asphaltpavement.org

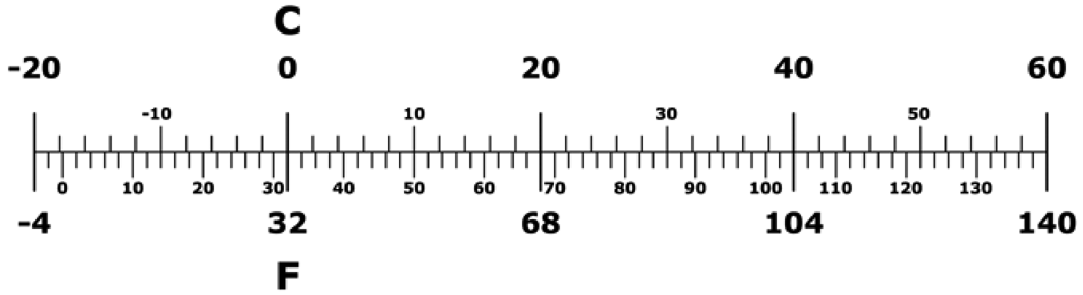
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSION TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	645.2	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L should be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lbs	pounds	0.454	kilograms	kg
T	short tons	0.907	megagrams	Mg
T	short tons	0.907	metric tonnes	t
NOTE: A short ton is equal to 2,000 lbs				
TEMPERATURE (exact)				
°F	Fahrenheit	$\frac{5\times(F-32)}{9}$	Celsius	°C

APPROXIMATE CONVERSION FROM SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lbs
Mg	megagrams	1.102	short tons	T
t	metric tonnes	1.102	short tons	T
NOTE: A short ton is equal to 2,000 lbs				
TEMPERATURE (exact)				
°C	Celsius	(1.8×C)+32	Fahrenheit	°F



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*SI is the symbol for the International System of Units

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