Quality Improvement Series 129

NAPA

NATIONAL ASPHALT PAVEMENT ASSOCIATION

Best Practices for RAP and RAS Management

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NATIONAL ASPHALT
PAVEMENT ASSOCIATION

NAPA Building ▪ 5100 Forbes Blvd. ▪ Lanham, MD 20706-4407
Tel: 301-731-4748 ▪ Fax: 301-731-4621 ▪ Toll free 1-888-468-6499
www.AsphaltPavement.org ▪ NAPA@AsphaltPavement.org

Mike Acott
President

T. Carter Ross
Vice President for Communications

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Quality Improvement Series 129

Printed 12/15

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Best Practices for RAP and RAS Management

By
Randy C. West, Ph.D., P.E.
Director
National Center for Asphalt Technology
Auburn University

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NATIONAL ASPHALT PAVEMENT ASSOCIATION

NAPA Building ■ 5100 Forbes Blvd. ■ Lanham, MD 20706-4407
Tel: 301-731-4748 ■ Fax: 301-731-4621 ■ Toll free 1-888-468-6499
www.AsphaltPavement.org ■ NAPA@AsphaltPavement.org

Technical Report Documentation Page

1. Report No. QIP 129	**2. Government Accession No.**	**3. Recipient's Catalog No.**	
4. Title and Subtitle Best Practices for RAP And RAS Management		**5. Report Date** December 2015	
		6. Performing Organization Code	
7. Author(s) Randy C. West, Ph.D., P.E.		**8. Performing Organization Report No.** QIP 129	
9. Performing Organization Name and Address National Asphalt Pavement Association 5100 Forbes Blvd. Lanham, MD 20706		**10. Work Unit No. (TRAIS)**	
		11. Contract or Grant No. DTFH61-13-H-00027	
12. Sponsoring Organization Name and Address Federal Highway Administration Office of Asset Management, Pavement and Construction 1200 New Jersey Ave. SE Washington, DC 20590		**13. Type of Report and Period Covered** Final Report	
		14. Sponsoring Agency Code FHWA-HIAP-20	
15. Supplementary Notes This project was funded under FHWA Cooperative Agreement DTFH61-13-H-00027 "Deployment of Innovative Asphalt Technologies."			
16. Abstract This document covers the current best practices for management of reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS) as of 2015. The goal of this guide is to facilitate the most effective utilization of RAP as a component in asphalt paving mixtures. This document provides guidance for management of RAP from the time of collection through processing, sampling and testing of RAP for mix design, and quality control practices during production of asphalt mixtures containing RAP. A brief section also presents best practices for management of RAS for use in asphalt paving mixtures. Good RAP and RAS management practices are important to ensure the greatest economic benefit of these materials and the highest quality asphalt mixtures.			
17. Key Words Reclaimed Asphalt Pavement, RAP, Reclaimed Asphalt Shingles, RAS, Asphalt Pavements, Quality Management		**18. Distribution Statement** No restrictions.	
19. Security Classification (of this report) Unclassified.	**20. Security Classification (of this page)** Unclassified.	**21. No. of Pages** 44	**22. Price** NA

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Introduction

Historical Perspective on Recycling

The asphalt paving industry has had great success with recycling asphalt pavements. Other recycled materials such as shingles, slag, ground tire rubber, glass, and cellulose fibers produced from recycled paper have also been used in numerous asphalt projects for decades. Recycling of asphalt pavements dates back to 1915 (Kandhal & Mallick, 1997), but it did not become a common practice until the early 1970s when asphalt binder prices skyrocketed as a result of the 1973 Arab Oil Embargo. The asphalt paving industry reacted to this situation by developing recycling technologies that helped reduce the demand on asphalt binder and thereby reduce the costs of asphalt paving mixtures. Many practices initially developed during that period are still in use today and have become part of routine operations for pavement construction and rehabilitation.

Motivations for recycling include economic savings and environmental benefits. Recycling reduces the demand for non-renewable natural resources (both asphalt and aggregates) and thereby also reduces the energy and emissions associated with the extraction and transportation of those raw virgin materials. Recycling also avoids landfilling of old pavement materials removed during rehabilitation. The economic benefit results from materials cost savings resulting from a replacement of a portion of virgin aggregates and binders. The asphalt and aggregate components of an asphalt mix represent the greatest proportion of the cost of pavement construction (Copeland, 2011).

For more than three decades, two guiding principles of asphalt recycling have been: 1) mixtures containing RAP should meet the same requirements as mixes with all virgin materials, and 2) mixes containing RAP should perform equal to or better than virgin mixtures.

Recent NAPA surveys of the asphalt pavement industry have reported that across the U.S., the average RAP content in new asphalt mixes has steadily increased in recent years with the national average RAP content now around 20%. However, the percentage of RAP used in new plant mix varies considerably by state (Hansen & Copeland, 2015).

Quality recycled mixes have been successfully designed and produced for many years. The proof is in performance: a recent study comparing the performance of recycled versus virgin mixes based on Long-Term Pavement Performance (LTPP) data from 16 U.S. states and two Canadian provinces shows that overlays containing at least 30% RAP performed equal to overlays using virgin mixtures (Carvalho et al., 2010; West et al., 2011). At the NCAT Test Track, test sections containing 50% RAP using standard Superpave mix design procedures for each layer outperformed companion test sections with all virgin materials in all pavement performance measures through five years of heavy loading (West et al., 2012; Timm et al., 2016).

Purpose of This Guide

The goal of this best management practices guide is to facilitate the most effective utilization of RAP as a component in an asphalt paving mixture. This document provides guidance for management of reclaimed asphalt pavement (RAP) materials from the time of collection through processing, mix design, and quality control practices during production of asphalt mixtures containing RAP. Good RAP management practices are important to ensure the greatest economic benefit for RAP and the highest quality of recycled asphalt mixtures.

This document is organized to follow the sequence of handling and evaluating RAP materials from the point of reclaiming RAP through quality control practices during production of asphalt mixtures containing RAP. Chapter 1 provides guidance on reclamation processes. Chapter 2 covers decisions and practices for processing and inventory management of RAP materials. Chapter 3 presents best practices for sampling and testing stockpiled RAP materials. Chapter 4 discusses production concerns for mixes containing RAP. Chapter 5 provides additional guidance on best practices for handling Reclaimed Asphalt Shingles (RAS).

This document represents the current best practices for RAP and RAS management as of 2015 and, as such, may need periodic revision. This document was prepared by the National Center for Asphalt Technology and reviewed by numerous agency and industry experts.

1 Managing the Reclaiming Process

RAP may be obtained from several sources. The most common method is through pavement milling operations, also known as cold planing. Two other common sources of RAP are full-depth pavement demolition and wasted asphalt plant mix. This chapter discusses these different types of RAP sources.

Milling

Milling is a beneficial part of pavement rehabilitation. Advantages of milling include the following:

- Removes distressed pavement layers, maintains clearances under bridges, and avoids buildup of pavement weight on bridges;
- Avoids filling up curbs and avoids drop-offs at drainage inlets in urban settings;
- Reduces the need for the costly addition of shoulder material along the edge of pavements on rural roadways;
- Restores pavement grades, cross-slopes, and profiles, which are important for smoothness;
- Leaves a rough texture on the remaining surface that creates a very good bond with an overlay; and
- Is an efficient removal process that can be done within a short lane-closure with the paving operations.

Figure 1-1. Milling machine removes asphalt pavement layers as part of pavement rehabilitation.
(Photo courtesy of Astec Industries)

Selecting the Milling Depth

Selection of the milling depth is a critical agency decision during planning of the rehabilitation of a pavement. Milling depth should be based on visual examination of cores to determine the depth of surface cracks and/or the location of weak layers or interfaces. Removal of these distressed or weak layers helps achieve long-term performance of the overlay. Cores should be taken at least once every lane mile on highways and one per lane per block on city streets. It is important to check the cross-section of pavement layers across lanes, since roads have often been widened in the past with a different buildup on the added roadway width.

Figure 1-2. Roadway cores showing distressed layers: top-down cracking on top; stripping damage on the bottom.

In cases where milling is also used to improve the roadway's profile (smoothness) and/or cross-slope, it must be realized that the milling depth will vary. Careful consideration must be given to how the variable thickness may affect the structural integrity of the remaining pavement as well as the uniformity of the milled material.

Inspecting the Milling Process

Milling processes should be closely examined to make sure the milled material is not contaminated with soil, base material, paving geotextiles, or other debris. This is particularly important for deep mills or milling on shoulders or widened roadways. Milled materials that become contaminated should be used only as shoulder material and should be stockpiled separately from RAP that will be used in asphalt mix. A recommended maximum limit of 1% deleterious material should be used to evaluate RAP contamination. This limit is consistent with requirements for virgin aggregates.

The milled surface should also be inspected for "scabbing" where thin, weakly bonded layers are left in place. Figure 1-3 shows an example of a milled pavement with scabbing. If this is observed, the milling depth should be adjusted to remove the scab layer. If such a weakly bonded layer is allowed to remain in place, the performance of the overlay will severely diminish.

Finally, the milled surface should be inspected for uniform texture. A non-uniform texture resulting from worn or broken tips on the milling drum can cause problems with compaction of thin overlays. It may also cause an unsafe surface for motorcycles if the milled surface is opened to traffic. Some agencies require a simple texture check and have a limit of ½-inch peak to valley on the milled surface.

Figure 1-3. Milled pavement surface with thin scab layer that will likely lead to premature failure of the overlay. *(Photo courtesy of Jim Scherocman)*

Aggregate Breakdown During Milling

Milling machines consume a lot of energy in removing pavement layers by impacting the pavement with milling teeth mounted on a drum rotating at about 200 rpm. The impacts break up the pavement by ripping through the mastic and aggregate particles. Crushing of aggregate particles causes the gradation of the millings to be much finer than the gradation of the pavement layers in place. In the past, pavement cores were obtained before milling and the layers to be milled were removed for extraction tests. Adjustment factors were then applied to the extracted gradation to estimate the gradation after milling. However, this technique is not reliable since the amount of aggregate degradation depends on the hardness and brittleness (impact resistance) of the aggregate, the stiffness of the asphalt (and, therefore, the temperature of the pavement at the time of milling), the speed of the milling machine, and the depth of the cut.

Milling for Removal of Specific Layers

In some cases, it may be advantageous to use special milling operations to remove specific pavement layers. One example is milling to remove an open-graded friction course layer or chip seal that is raveling. If the pavement will be resurfaced with a new OGFC or other type of very thin wearing course, it may be beneficial to remove only the existing OGFC surface without milling much into the underlying layer and produce a fine-textured milled surface on which the new surface course can be placed. In this case, a micro-milling drum, as shown in Figure 1-4, can provide a much smoother surface texture which is better suited for achieving the desired smoothness for the new surface layer. Using a normal milling drum may result in deep and/or irregular groves that can lead to dragging when a thin layer is placed on top.

Figure 1-4. Micro-milling drums have three times the number of teeth as a normal milling drum.

A special milling operation may also be beneficial when it is desirable to mill the surface layer in one pass and the underlying layer(s) in a second pass because the surface layer contains a high-value friction aggregate, a very high specific gravity aggregate, and/or a modified binder. Some contractors have found the two-pass milling operation to be economical when the cost of new friction aggregates is very high and the project specifications allow the surface-course RAP to be used in new surface layers. Other situations that may warrant milling the surface layer separately from the underlying layers include projects with surface layers containing steel slag or asphalt-rubber binder. High specific gravity steel slag can introduce significant variations in RAP stockpiles. Similarly, it may be challenging to recycle RAP with high rubber contents, so keeping that material separated from the other RAP may be a RAP management consideration.

Pavement Demolition

RAP may also be obtained from utility cuts in a roadway, removal of isolated areas for patching, or complete demolition of an existing pavement using a bulldozer or backhoe. Figure 1-5 shows an example of pavement rubble resulting from demolition of a roadway. This process is typically limited to small areas of pavement. This method of pavement removal is slow and results in large chunks of pavement rubble that may be more challenging to process into a usable recycled material. It is important that the quality of this type of material be closely monitored during unloading to avoid contamination and deleterious materials, particularly when it is received from another contractor. When pavement rubble is contaminated with underlying layers and soil, it is better for this material to be crushed and used as a shoulder or base material than used in an asphalt mixture.

Figure 1-5. Pavement rubble from full-depth demolition of a roadway.

Plant Waste

All asphalt plant operations generate some material waste during plant start-up, transition between mixes, and clean-out. Generally, start-up and shutdown plant wastes have very low asphalt contents. Another form of waste is mix rejected from a project due to incomplete coating or due to the mix temperature being too high or too low for the job. Other situations that may result in wasted mix include trucks loaded with too much mix to finish the job or mix that could not be placed due to inclement weather. These waste materials are often stockpiled for later processing into a recyclable material.

Because these waste mixes have not been subjected to environmental aging from years of service, the asphalt binder is less aged than RAP recovered from the road. Waste materials also have fewer fines than other sources of RAP as it was not milled or broken up during demolition. However, waste materials must be thoroughly mixed and processed to make them into uniform, recyclable materials. Waste materials are often combined with other sources of RAP in multiple-source stockpiles. Processing RAP from multiple sources is discussed in greater detail in Chapter 2.

Contamination

It is important that stockpiles be kept free of contaminants from the beginning. It is easy to understand how bad perceptions of RAP may form when there is dirt, rubbish, or vegetation in RAP stockpiles, or when trash is found in the mix when it shows up on the job site or pops out of the pavement a few days after paving. Treat RAP stockpiles as the most valuable material on the plant yard—because they are. Truck drivers bringing recyclable materials onto the plant yard must be clearly instructed where to dump loads of RAP or pavement rubble so that unwanted construction debris does not end up in the RAP stockpile. Drivers must also be instructed to clean the truck beds before hauling millings or usable RAP. The plant QC personnel and the loader operator should also regularly inspect unprocessed and processed RAP stockpiles to make sure they do not contain deleterious materials. If contaminants are found, dig them out immediately so that they are not covered up with other RAP brought onto the yard.

Figure 1-6. Multiple-source RAP pile with dirt contamination (circled in red).

2 Inventory Management and Processing RAP

Poor management of RAP stockpiles is commonly cited as a reason agencies are reluctant to increase allowable RAP contents in asphalt mixtures. This chapter provides guidance on inventory management of RAP materials and options for stockpiling, crushing, and screening RAP. Good materials management practices should always be a part of the quality control program for any asphalt mix production operation. For production of quality mixes with high RAP contents, excellent materials management practices are essential.

Inventory Analysis

RAP management should begin with a basic inventory analysis of available RAP and mix production. This analysis is important to establish realistic goals for how much RAP can be used at a particular plant. The analysis includes four simple steps:

1. An inventory of RAP on hand and RAP generated per year;
2. A summary of mixes produced per year by mix types and customers;
3. Determining the maximum amount of RAP that can be used; and
4. A comparison of the quantity of RAP available to the amount of RAP needed.

Note that in this context, "RAP contents" refer to the RAP material as a percentage of the total mixture. Some agencies now have specification limitations based on the percentage of RAP binder in the total binder content. Such specifications have merit when dealing with changing the grade of the virgin binder in the recycled mixture. However, for an inventory analysis, the more common expression of RAP content as a percentage of the total mixture is more appropriate.

Examples are the best way to illustrate the inventory analysis. Three cases are presented.

Case #1: Contractor A has an estimated 20,000 tons of RAP on a plant site and typically brings in about 30,000 tons per year from milling projects and other sources. The plant typically produces about 150,000 tons of HMA per year. Of that quantity, approximately 100,000 tons is produced for state projects, and the other 50,000 tons is produced for commercial work and local governments.

The contractor generally follows DOT specifications for designing mixes for local and commercial work. It is estimated that 80% of the mix produced is surface mix. The state specifications currently allow up to 20% RAP in surface mixes and up to 30% in base and binder layer mixes. Contractor A currently uses the maximum-allowable RAP by specification.

- *RAP Available = 20,000 tons + 30,000 tons = 50,000 tons*
- *Maximum RAP Needed = 150,000 tons × [(80% surface × 20% RAP) + (20% base/binder mix × 30% RAP)] = 33,000 tons of RAP*

Therefore, for Contractor A to increase RAP usage, they will have to either

1. Get the agency specifications changed;
2. Increase the plant's annual production; or
3. Increase RAP contents in local and commercial work.

If Contractor A does nothing different, they will have a large excess supply of RAP, which may become a storage problem.

Case #2: Contractor B has 10,000 tons of RAP on site and brings in about 25,000 tons of new RAP per year. The plant typically produces 200,000 tons of HMA per year of which 80% is surface mix and 20% is non-surface mix. Production of mix for the state agency is about 120,000 tons, and the remainder is for the city, county, and private business.

Contractor B currently uses 15% RAP in all DOT mixes even though the agency allows 20% RAP in surface mixes and 40% in base and leveling mixes. Mix designs are typically tweaked for local mixes to include 20% RAP although there is no provision on the maximum-allowable RAP content for these mixes.

- *RAP Available = 10,000 tons + 25,000 tons = 35,000 tons*
- *Maximum RAP Needed = 120,000 tons × [(80% surface × 20% RAP) + (20% nonsurface mix × 40% RAP)] + (80,000 tons × 20% RAP) = 44,800 tons of RAP*
- *RAP Currently Used = 120,000 tons × 15% RAP + 80,000 tons × 20% RAP = 34,000 tons of RAP*

Therefore, Contractor B has about enough RAP on hand for an average year using the plant's historical RAP percentages. This contractor could increase RAP usage, but will have to get more RAP. If the contractor begins to use higher RAP percentages but does not bring in additional RAP, they will run out of RAP before the year is over.

Case #3: Contractor C has 60,000 tons of unprocessed RAP in inventory and generates nearly 40,000 tons of RAP from milling and pavement demolition each year. The contractor recently replaced an old plant and expects annual tonnage to increase from about 170,000 tons per year to 200,000 tons per year. Historically, the contractor was able to use only about 15% RAP with the old plant, but the new plant was advertised to handle up to 50% RAP. Annual tonnage for the city work has been about 30,000 tons, commercial work has been about 30,000 tons, and state work about 110,000 tons. All sectors are expected to grow by about 10,000 tons each.

State DOT and city specs have recently changed to allow 30% RAP in surface mixes and 40% in base and binder mixes. Commercial work generally does not have limits on RAP percentages. Surface mixes generally are about 80% of the city and state mix production but only about 50% of the commercial work.

- *RAP Available = 60,000 tons + 40,000 tons = 100,000 tons*

Maximum RAP Needed:

- *City: 40,000 tons × [(80% surface × 30% RAP) + (20% base/binder mix × 40% RAP)] = 12,800 tons of RAP*
- *Commercial: 40,000 tons × [(50% surface × 50% RAP) + (50% base/binder mix × 50% RAP)] = 20,000 tons of RAP*
- *State: 120,000 tons × [(80% surface × 30% RAP) + (20% base/binder mix × 40% RAP)] = 38,400 tons of RAP*

  Total: *71,200 tons of RAP*

If Contractor C is able to use the maximum amount of RAP for each type of mix in all sectors, they will have enough RAP for the first year but will run out of RAP in the second year if new RAP continues to be brought in at the historic rate.

If Contractor C believes that 40,000 tons of new RAP is reasonable, then they may want to consider using 25% RAP in all mixes. That would consume 50,000 tons of RAP per year, which the facility would be able to sustain for six years.

In most cases, when a contractor has a limited supply of RAP, it is logical to try to use a relatively consistent amount of RAP in all mixes rather than to use a lot of RAP in some mixes and less in other mixes. For example, if a contractor has 40,000 tons of RAP and produces 200,000 tons of HMA per year, then it is better to run 40,000 ÷ 200,000 = 20% in all mixes. If 40% RAP is used in some mixes, then the contractor will have to use less than 20% in other mixes to keep the RAP supply in balance with the total RAP used.

Running higher RAP contents could be more competitive on certain jobs, but there may be additional costs associated with higher RAP contents, such as additional materials testing, higher RAP processing costs, plant modifications, and higher plant maintenance costs. Using a consistent percentage of RAP is likely to be easier on the plant, mix design and QC staff, and paving crews.

Single or Multiple Unprocessed RAP Stockpiles

One of the first decisions in inventory management of RAP should be whether or not to put all incoming RAP materials into a single pile or to create separate stockpiles for RAP obtained from different sources. The decision will likely depend on the following factors:

- Components in the RAP, such as special classes of aggregate, steel slag, or asphalt rubber, that warrant handling the material separately from other sources;
- Whether the state or primary local agency allows RAP from other sources in asphalt mixes produced for its agency specifications;
- Whether or not the state or other primary local agency requires captive stockpiles or allows continuous replenishment of stockpiles;
- The space available at the plant site for RAP processing and stockpiling;
- The target RAP percentages in the asphalt mixes to be produced; and
- How much RAP comes from a single project.

Some agencies' specifications allow only RAP from their projects to be used in their mixes. RAP from agency projects are often referred to as "classified RAP" as the origin of the materials are known. This limitation is used to assure that the aggregate and binder in the RAP were of satisfactory quality in the original pavement.

Most agencies allow the use of RAP from multiple sources, including "unclassified RAP," that has been combined and processed into a single uniform RAP stockpile. Agencies typically allow this practice with the stipulations that 1) the combined blend of RAP and virgin aggregates meet the appropriate Superpave consensus aggregate requirements and 2) the volumetric properties of the recycled mix design meet all of the standard asphalt mix specifications. When this approach is used, good processing practices of the multiple-source RAP material are necessary to create a uniform material.

Because many contractors report that a substantial amount of their RAP comes from non-DOT sources, this approach enables them to best utilize RAP from different sources in a wide range of mix designs and requires the least amount of testing and mix design work. In other words, using just one RAP stockpile in many different mix designs is efficient from a testing point of view. Specifications that prohibit the use of RAP processed from multiple source RAP can be unnecessarily restrictive. In many cases, it is not cost effective to perform all the necessary tests and perform mix designs for small quantities of RAP.

Captive or Continuously Replenishing RAP Stockpiles

Another requirement some agencies impose on RAP stockpiles is that no additional material can be added to a RAP stockpile once it is built and tested. This is referred to as a "captive" RAP stockpile. A few agencies take this same approach with virgin aggregate stockpiles. The opposite and more common approach is to allow stockpiles to be continuously replenished with new material. Most agencies use this approach for virgin aggregates because there are other controls on aggregate testing at the source. This is appropriate for RAP as well if consistency can be established through a RAP quality control plan.

The more conservative captive stockpile approach is based on the premise that the properties of the stockpile must be precisely known if it is to be used as a component in an asphalt paving mixture. However, some contractors have been able to develop RAP-processing practices using continuously replenished stockpiles that have very consistent gradations, aggregate properties, and asphalt contents over a long period of time.

Determining if the RAP processing provides a consistent material over time requires regular testing and analysis of the RAP to document the RAP stockpile variability. Guidelines for a RAP quality control plan are provided in Chapter 3.

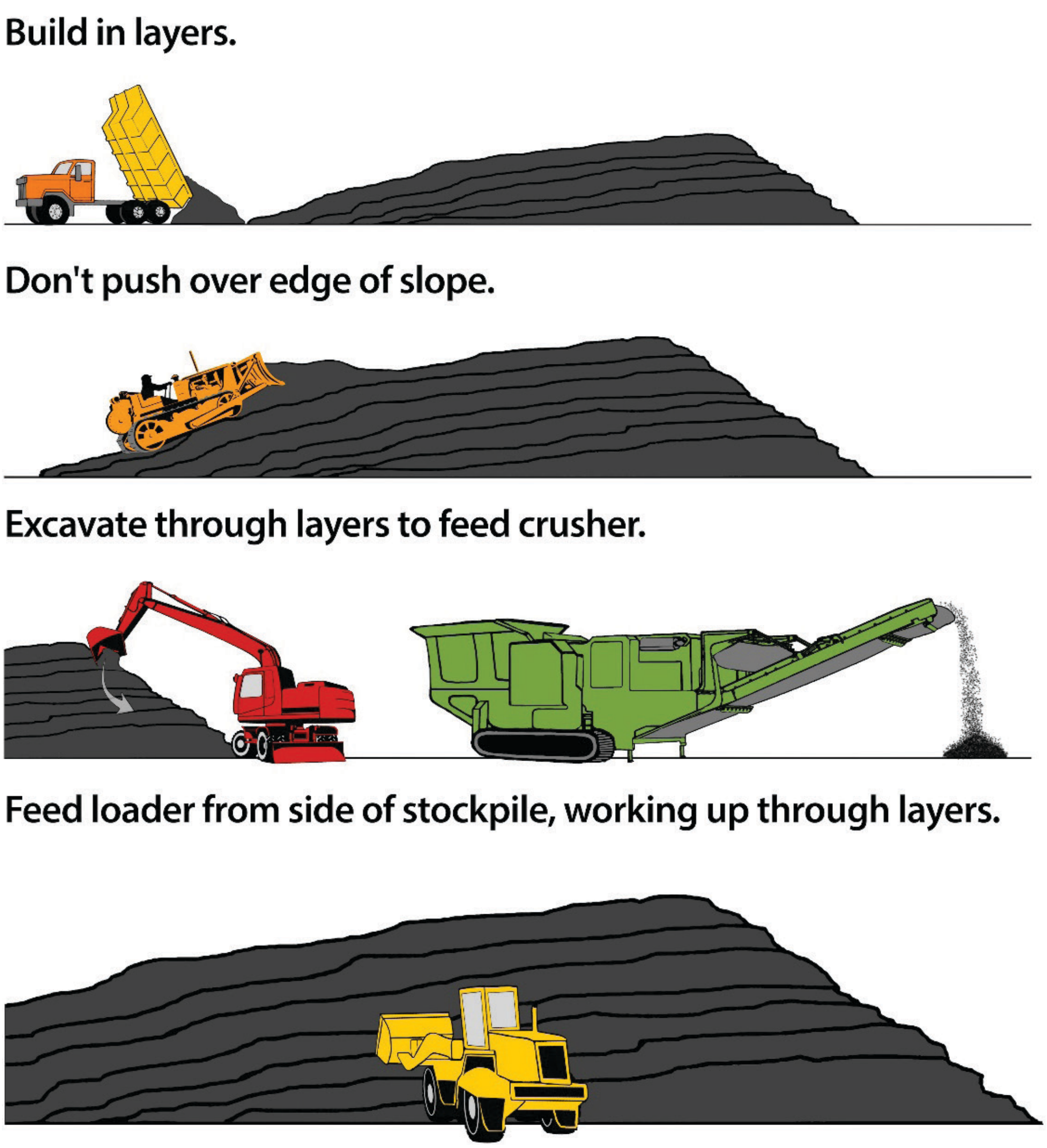
In some cases, limited stockpile space may constrain processing and stockpiling practices. Plant yards with limited space for stockpiles may not have sufficient room for multiple small RAP stockpiles. This can affect how some contractors use RAP.

Processing and Crushing RAP

Figure 2-1 illustrates important practices for stockpiling and processing RAP that will help provide consistent material. A small bulldozer should push the RAP onto the stockpile in layers, taking care not to push the material over the slopes as that will eliminate the layered effect and tend to cause the material to segregate as it cascades down the side. Only light dozers should drive on the stockpile to minimize compaction. If the stockpiled RAP is millings from a single project, the material may be consistent enough to feed directly into the plant. When this is the case, the loader should approach the stockpile from the side and dig up through material to charge the bucket with materials from numerous layers. Figure 2-2 shows the working face of a millings stockpile that was properly built in layers.

When the stockpiled material is from multiple

Figure 2-1. Illustration of recommended practices for RAP stockpiling.



sources, an excavator should dig through multiple layers to feed the processing unit so that the material exiting the unit is a composite of RAP from different layers from different sources.

The basic goals of processing RAP are to:

1. Create a uniform stockpile of material;
2. Separate or break apart large agglomerations of RAP particles to a size that can be efficiently dried, heated, and broken apart during mixing with the virgin aggregates;
3. Reduce the maximum aggregate particle size in the RAP so that the RAP can be used in surface mixes (or other small nominal maximum aggregate size mixtures); and
4. Minimize the generation of additional P_{200} (i.e., dust).

Figure 2-2. Working face of a stockpile of milled RAP. Layers of the materials are evident.

Processing Millings

Millings from a single project are usually very consistent in gradation, asphalt content, aggregate properties, and binder properties. Therefore, processing millings may only be necessary to achieve Goals #2 or #3. However, as noted previously, a common limitation to increasing RAP contents in asphalt mixtures is the dust content in the RAP. Because milled RAP already contains appreciable amounts of P_{200} (typically between 10% and 20%) due to the milling of the material from the roadway, it is best to minimize further crushing of milled RAP whenever possible. Therefore, when a contractor obtains a large quantity of millings from a single project, it is considered a best practice not to further crush this material, but rather to use it "as-is" in mix designs or to only screen the millings to remove larger particles.

Millings: Recommended Processing Options

1. Receive millings from project and stockpile the material in such a way to minimize segregation, effectively drain precipitation, and avoid contamination with underlying material or adjacent stockpiles.
2. Sample and test a few locations of the millings stockpile to determine the as-received gradation and check the maximum aggregate size.
3. If the maximum aggregate size of the as-received millings is small enough to use in the desired mix design(s), do not further process the millings. Sample and test the millings as described in Chapter 4.
4. If maximum particle size is too large for desired mix(es), then either:
   a) Fractionate the RAP over a screen equal to or smaller than the NMAS of desired mix(es). Stockpile the fine RAP (portion passing through the screen) and test for properties, as described in Chapter 3. Stockpile the coarse RAP fraction(s) into separate stockpile(s) for use in other, larger NMAS mixes; or
   b) Crush the millings so that they will pass the desired screen size. This is the least desirable option because it will result in more uncoated faces of RAP particles and generate additional dust, which can severely hamper how much of the crushed RAP can be used in mix designs. When a contractor wants to increase RAP contents but is often limited by VMA requirements or the dust-to-binder ratio during mix designs, Goal #4 — minimizing the generation of additional P_{200} — must become a primary consideration in the RAP-processing plan.

Processing RAP from Multiple Sources

RAP materials from multiple sources that have different compositions must be processed to create a uniform material suitable for use in a new asphalt mixture. Around the world, contractors have found that they can make uniform and high-quality RAP from a combination of pavement rubble, millings, and wasted mix. The key to achieving consistent RAP from multiple sources is careful blending as part of the processing operation. A bulldozer, excavator, or similar equipment should be used to blend materials from different locations in the multiple-source RAP stockpile as it is fed into the screening and crushing operation. Figure 2-3 shows an excavator feeding a RAP processing unit with material from different parts of a multiple source stockpile to “average-out” variations in the RAP from different sources.

Figure 2-3. Excavator feeding material into a RAP crushing and screening process.

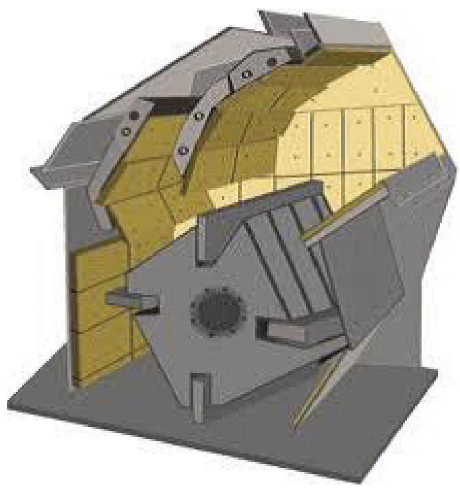
Screening RAP During Processing

Since crushing RAP will create more aggregate fines, it is best to set up the crushing operation so that the RAP is screened before it enters the crusher. This will allow the finer RAP particles that pass through the screen to bypass the crusher. Figure 2-4 shows a portable RAP crushing unit that is equipped with a screen deck in line before the crusher. Only the RAP particles retained on the screen will pass through the crusher.

Figure 2-4. RAP processing unit with a screen before the crusher.

Some RAP crushing units are set up so that all of the RAP is conveyed from the feeder bin into the crusher, followed by a recirculation circuit after the crusher. The recirculation circuit is designed to return larger particles that do not pass through the screen back to the crusher. However, because all the material must go through the crusher in the first pass, there is a good chance that breakdown will occur for some smaller particles that did not need to be reduced in size.

Figure 2-5. Illustration of a horizontal-shaft impact crusher.



Crusher Types

A variety of crusher types are used for crushing RAP. Many contractors have found that the best type of RAP crushers are horizontal-shaft impactors (HSI) as illustrated in Figure 2-5. Roller or mill-type breakers are also made specifically for processing RAP. These RAP crushers/breakers are designed to break up chunks of pavement or agglomerations of RAP rather than downsize the aggregate gradation. HSI crushers typically use a three-stage impact bar arrangement that can be set to size material according to the desired top-size. However, crushing to smaller top sizes will increase the percentage of material passing the No. 200 sieve, which often limits how much of the RAP can be used in mix designs while still meeting VMA and dust-to-binder ratio criteria. Further information on RAP crushing equipment can be found in the National Asphalt Pavement Association's *Information Series 123: Recycling Hot-Mix Asphalt Pavements* (Young, 2007).

Compression-type crushers such as jaw crushers and cone crushers tend to clog due to packing (caking) of RAP when the RAP is warm or wet. Hammermill crushers tend to generate more fines due to the retention of the material in the chamber. Hammermills can also be maintenance intensive when material jams between the hammers and the anvils. The speed and clearance of hammermill crushers can be adjusted to reduce aggregate crushing.

Some contractors have used milling machines to crush stockpiled RAP. This practice is not recommended as there may be a risk of the milling machine overturning because the stockpile is uneven and may not provide stable support for the top-heavy machine. No data are available regarding the effectiveness of this method of processing in terms of size reduction or consistency of the RAP.

Weather

Moisture and temperature can affect crushing and screening of RAP. When the RAP is wet and/or temperatures are hot, RAP will be stickier and tend to build up in feeders and crushers, blind screens, stick to belts, and accumulate under conveyors. Not only does this require more maintenance of RAP processing units and RAP feeder systems for mix production, it can also affect the gradation and asphalt content of the RAP.

Fractionating

Fractionating is a process gaining popularity in which RAP is screened into typically two or three sizes. The sizes are typically ¾" × ⅜", ⅜" × 3⁄16", and –3⁄16". In some cases, the +¾" size material is returned to a crusher, and the crushed material is then returned to the screening unit. The primary advantage of fractionating RAP is that having stockpiles of different RAP sizes provides more flexibility in meeting mix design requirements.

Figure 2-6. Samples of fractionated RAP.

Producers that can answer "yes" to the following seven questions should consider fractionating RAP.

1. Can your plant produce mixes containing 20% or more RAP without emissions problems?
2. Can your plant produce mixes containing 20% or more RAP without significant decline in production rate?
3. Does the market this plant supplies allow RAP contents above 20%?
4. Does your plant have an excess amount of RAP (i.e., the quantity of RAP stockpiled exceeds RAP usage per year)?
5. Does your plant site have at least 10,000 sq. ft. available in the stockpile area for a RAP fractionation unit?
6. Do you have difficulty meeting mix design requirements such as minimum VMA, dust proportion, or P_{200} content for mixes with more than 20% RAP?
7. Do you have trouble keeping RAP mixes within quality control and acceptance limits?

The decision of whether or not to fractionate RAP into different sizes should be the mix producer's choice and not a specification. Some agencies have recently begun to require RAP fractionation for higher RAP contents. This type of method specification is not recommended; a better approach to assure consistency of RAP is to set limits on the variability of the RAP stockpiles. This is discussed in further detail in Chapter 3.

Figure 2-7. Portable RAP fractionation unit. This unit screens RAP into three sizes: +¾" on right, –3⁄16" on left, and ¾" × 3⁄16" in back.

Moving the Processed RAP Stockpiles

In most cases, processed RAP will be moved from the location it is screened and/or crushed to another location more convenient to feed into the asphalt plant. This is another opportunity to remix the material and improve its consistency. Using the loader to dig into the RAP stockpile at the processing unit at different locations around the pile and remixing loads while building the stockpile at the final location can again be used to average out variations.

Stockpiling to Minimize Segregation

As with virgin aggregates, there is a potential for RAP materials to become segregated in stockpiles. This is a common problem when stockpiles are built using fixed conveyors that allow the RAP particles to drop long distances to the stockpile. Larger particles have more kinetic energy and will tend to roll down toward the bottom of the stockpile. This method of operation results in more coarse particles with a lower asphalt content at the base of the stockpile and finer higher asphalt content RAP in the top of the stockpile. This problem can be minimized by using indexing-type conveyors that extend and raise the end of the conveyor as the size of the stockpile increases. If segregation is evident, a front-end loader can be used to remix the stockpile.

Stockpiling to Minimize Moisture

Moisture content of aggregates and RAP is a primary factor affecting an asphalt plant's production rate and drying costs. Some contractors have implemented creative approaches to reducing moisture content in stockpiles. The best practice to minimize the accumulation of moisture in any stockpile is to cover the stockpile with a shelter or building to prevent precipitation from getting to the RAP. Second to that, it is a good practice to use conical stockpiles to naturally shed rain or snow and to place the stockpile on a paved and sloped surface to help water drain from the pile. Irregularly shaped stockpiles with surface depressions that will pond water should be corrected by shaping the pile as it is built with a small bulldozer or front-end loader. However, the use of heavy equipment on the top of RAP stockpiles should be minimized to avoid compaction of the RAP. Likewise, processed RAP and millings stockpiles should be limited to 30 feet in height to reduce the potential for self-consolidation of the stockpile.

Figure 2-8. Covered stockpile to minimize moisture in RAP.

In-line RAP Crushers or Crusher Circuits

RAP crushers or crushing circuits built into the asphalt plant's RAP feed line are used by some asphalt mix producers. An example of an in-line crusher is shown in Figure 2-9. The advantage of in-line RAP crushing circuits is elimination of the accumulation of oversized particles at the scalping screen. However, in-line crushers can change the gradation of the RAP material being fed into the mix. Gradation test results on the stockpiled RAP then become meaningless, and the quality control technician will have to make unnecessary, and probably substantial, mix adjustments to get the mix gradation and volumetric properties in specification during production start-up. In many cases, this could result in the technician reducing the RAP content in order to meet the quality control tolerances for the mix.

Therefore, when in-line RAP crushers are used, it is a recommended best practice to check extracted gradations before and after the crusher to make sure the RAP aggregate gradation is not changing. Some plant owners prefer to return the oversized particles from the RAP screen back to the initial processing point, finding that to be easier and more effective than adding an in-line crusher.

In-line roller crushers (also known as lump-breakers) and reduced-speed impact crushers are designed to break up agglomerations of RAP rather than change the gradation. Example roller crushers are shown in Figure 2-10. It is recommended that a simple extracted gradation check of RAP samples before and after the in-line crusher be conducted to determine if it is breaking down the RAP aggregate.

Figure 2-9. In-line crushing circuit added to a plant to process oversized material.

Figure 2-10. Roller crushers designed to break up agglomerations of RAP.

Advantages and Disadvantages of Different RAP Processing Options

Table 2-1 summarizes the advantages and disadvantages of various RAP processing options.

Table 2-1. Advantages and Disadvantages of RAP Processing Options.

Process	Possible Advantages	Possible Disadvantages
Use of Millings Without Further Processing	• Avoids further crushing of aggregate particles in RAP, which may allow for higher RAP contents in mixes. • Lowest cost RAP processing option. • Millings from large projects are likely to have a consistent gradation and asphalt content.	• Requires multiple RAP stockpiles at the plant. • Millings from individual projects are different; therefore, when a particular millings stockpile is depleted, new mix designs must be developed with other RAP.
Screening RAP Before Crushing	• Limits crushing of aggregate particles in RAP, which reduces dust generation.	• Few RAP crushing and screening units are set up to pre-screen RAP.
Crushing all RAP to a Single Size	• Allows the processed RAP to be used in many different mix types. • Generally provides good uniformity from RAP materials obtained from multiple sources.	• Increases the dust content of RAP stockpiles, which will tend to limit how much RAP can be used in mix designs.
Fractionating RAP	• Using different sized RAP stockpiles provides much greater flexibility in developing mix designs. Fine RAP fraction is ideal for Thinlay mixes. • Heat transfer to fine RAP may be more efficient during plant mixing.	• Requires the most space for multiple smaller stockpiles. • Most expensive processing option (cost of fractionation unit plus additional RAP feed bins). • Due to higher AC contents, fine fractionated RAP stockpiles tend to have agglomerations, which may not feed well through the plant.

3 Sampling and Testing of the RAP

This chapter provides guidance on the best methods and practices for sampling and testing RAP as part of a quality management program. A well-executed sampling and testing plan for RAP is necessary to assess the consistency of the RAP stockpiles and to obtain representative properties for use in mix designs.

RAP Variability

A common misconception exists that RAP stockpiles are highly variable and, thus, using higher RAP contents in new asphalt mixes will lead to more variability in the mixtures. However, well-managed RAP stockpiles have a more consistent gradation than virgin aggregates (Nady, 1997). That was the finding of a 1998 study by the International Center for Aggregate Research (Estakhri et al., 1998) and confirmed with recent data gathered by NCAT (West, 2009). Considering that RAP obtained from a single milling project in which the pavement was constructed of mixtures subject to high quality assurance standards, it is no surprise that the millings would have a consistent gradation, asphalt content, and binder properties. Although it may be unexpected, RAP processed from multiple sources can also be just as consistent in gradation and asphalt content as millings.

Sampling and Testing Frequency

Sampling at least one set of tests per 1,000 tons of RAP is considered a best practice. This is generally more frequent than is required for virgin aggregates, but is appropriate for a component that will comprise a large portion of an asphalt mixture. A minimum of 10 tests should be performed on a RAP stockpile to yield good statistics for consistency analyses. Some agencies allow for a reduced testing frequency after the consistency of the materials properties for the stockpile can be demonstrated.

Figure 3-1. Processed RAP with a uniform appearance.

Sampling Method

It is recommended that RAP stockpiles be sampled as they are being built at the location where they will be fed into the asphalt plant. Samples from the different locations around the stockpile should not be combined since the results from the different locations will be used to calculate variability statistics. Sampling at the time the stockpile is built will be easier and more representative of the stockpile compared to samples taken later, after a crust forms on the RAP stockpile. When a RAP stockpile has been in place for a while, it is generally difficult to dig into with a shovel. The best way to sample existing RAP stockpiles is with the assistance of a front-end loader, as described in Section X1.2 of AASHTO T 2 or ASTM D75-03. This method is described below and illustrated in the sequence of pictures 1 through 8 in Figure 3-2.

1. Use a front-end loader to dig into the ready-to-use RAP stockpile.
2. Empty the bucket on a clean surface to form a miniature sampling stockpile.
3. Use the loader to back blade across the top of the mini stockpile to create a flat surface.
4. Mini stockpile ready to be sampled.
5. Use a square-end shovel to obtain samples from the surface of the mini stockpile.
6. Sample from three locations over the surface of the mini stockpile.
7. Combine samples taken from the same mini stockpile. This sample will later be divided into test portions.
8. Repeat these steps to obtain samples at other locations around the RAP stockpile. Do not combine samples from different locations.

For projects that use portable asphalt plants set up on a temporary site adjacent to or near the project, typically the only RAP available is millings generated from that project. In these situations, the RAP is typically stockpiled at the plant site just after the plant is set up and continues at the same time as the paving operations. In order to prepare a mix design using the project millings, it is necessary to obtain RAP samples from the roadway about a month in advance of the plant set up.

Figure 3-2. Steps for the best method to sample RAP.

The preferred method of obtaining samples of RAP is to use a milling machine to mill small areas of the roadway at the project's planned milling depth at selected representative locations. This requires mobilization of a milling machine and other equipment to fill in the sampled areas, as well as traffic control for the temporary short lane closures.

This method of sampling is most likely to produce representative samples of RAP for the mix design. Using a skid steer with a small milling head attachment has been found to produce a different gradation than a full-size milling machine. Taking roadway cores and crushing them in the laboratory has also been found to not produce representative material for mix designs.

Test Methods

For mix designs using RAP, the data needed from tests on the RAP are

1. Asphalt binder content of the RAP;
2. Gradation of the aggregate recovered from the RAP;
3. Bulk specific gravity of the RAP aggregate;
4. Consensus properties of the aggregate recovered from the RAP; and
5. (For high RAP contents) the RAP asphalt binder properties.

In some cases, additional aggregate tests may be necessary. For example, if the RAP is to be used in a surface mix for high-speed traffic, some agencies may require tests to evaluate the polishing or mineralogical composition of the RAP aggregate. Typically, source properties such as L.A. abrasion and sulfate-soundness tests are not necessary as it is unlikely the coarse aggregates in the RAP would have come from sources not originally approved by the state agency.

A recent joint study by the University of Nevada Reno and NCAT (Hajj et al., 2012) examined several options for testing RAP to determine the best methods for determining many of the properties noted above. Three methods were used to determine asphalt contents and recover the aggregates for aggregate property tests: the ignition method, the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8

centrifuge extraction method, and the reflux extraction method. Trichloroethylene (C_2HCl_3) was used as the solvent in the centrifuge and reflux methods. The results of the study indicate that:

- The ignition method yielded the most accurate asphalt contents for the RAP and provided the lowest testing variability compared to solvent extraction methods.
- The centrifuge extraction method had the smallest effect on the gradations of the recovered aggregate.
- The combined bulk specific gravity of the aggregates recovered by the ignition method was closest to the original materials, except for the soft limestone aggregate. In that case, the aggregate recovered from the centrifuge extraction was closest to the original material.
- The sand-equivalent and fine-aggregate angularity values for aggregates recovered from all three methods were different from the original materials. No consistent biases were evident to warrant making adjustments to the tested results.
- L.A. abrasion values for aggregates recovered from the centrifuge extraction were closest to the original values.

Additional tests on the extracted and recovered asphalt binder from the RAP may be required for mix designs that will contain more than 25% RAP. Current best practices for determining RAP binder properties are described in Chapter 3 of *NCHRP Report 452* (McDaniel & Anderson, 2001).

Methods for Determining RAP Asphalt Contents and Recovering Aggregates for Characterization

Two options are recommended for determining RAP asphalt content and recovering aggregates: the ignition method and solvent extractions. Both methods have advantages and disadvantages as described below.

Ignition Method

The most popular method for determining RAP asphalt contents and recovering aggregates for other tests is the ignition method, AASHTO T 308 or ASTM D6307. Advantages of the ignition method include quick results, little testing time, and no need for solvents. One issue with this method is that in order to obtain an accurate asphalt content for a sample, it is necessary to know the aggregate-correction factor.

For virgin materials, the aggregate-correction factor is determined by testing samples with a known asphalt content. The difference between the known asphalt content and the test result for the prepared samples is the aggregate-correction factor. However, for RAP, it is not possible to have a sample with a known asphalt content and, therefore, not possible to determine the aggregate-correction factor.

Fortunately, aggregate-correction factors are typically consistent over time when the aggregate materials used at the location are from the same quarry or deposits. Therefore, a historical average aggregate-correction factor of the materials at a location can be used as the aggregate-correction factor for the RAP if there is a high level of confidence that the RAP contains aggregates from the same sources as current asphalt mixtures.

Note that ignition method correction factors may be unique to a specific unit and/or model, so caution must be taken when considering the use of correction factors from different labs. It is not advisable to use results from a few solvent extractions on the RAP to correct/calibrate the ignition method results for the same RAP as the solvent extraction method often has a greater bias (difference from the true AC content) than ignition method results.

RAP aggregates recovered from the ignition method can be used for gradation analysis and many other aggregate-property tests, but not all. Some aggregate types (e.g., dolomites) can have significant changes in mass when heated to 1,000°F in an ignition oven. Small natural variations in the mineralogy of these aggregates create large variations in aggregate-correction factors in the ignition oven (as high as 1% to 2%). Some agencies have altered the test to reduce the ignition oven temperature to minimize this problem. However, in some cases, agencies have elected simply to use other methods for determining asphalt contents and recovering aggregates for asphalt mixes in their jurisdiction. In these locations, the asphalt content for RAP samples should be determined using solvent extractions.

Solvent Extraction

Solvent extractions with trichloroethylene or other solvents have been used for many decades to determine asphalt contents of asphalt mixtures and as a method of recovering aggregates for additional tests. However, use of the method has declined due to health and environmental concerns with the chlorinated solvents. Normal-propyl bromide and some non-halogenated (terpene- or d-limonene-based) solvents were found to be acceptable alternative solvents and are permitted in AASHTO T 164, but some problems have been reported with the effectiveness of these solvents to remove polymer-modified asphalt binders.

However, some agencies and contractors continue to use solvent extractions due to problems with highly variable ignition furnace aggregate-correction factors or with the breakdown of certain aggregate types. Depending on aggregate absorption and texture, solvency power of the solvent, and hardness of the binder, solvent extractions may not remove all of the absorbed asphalt binder from the aggregate.

Based on the published precision information, the repeatability and reproducibility of the ignition method are more than four times better than the solvent extraction method. It is prudent for agencies and contractors to cooperate in establishing the best method for the materials in their region or jurisdiction.

Aggregate Bulk Specific Gravity

Aggregate specific gravity of the RAP aggregate is a critical property for mix design because it is used in calculating VMA. Since VMA is the primary mix design parameter to assure good durability, accurately determining the RAP aggregate G_{sb} is essential, especially for high RAP contents.

Previous studies have recommended several methods for determining the bulk specific gravity of the RAP aggregate:

1. Recovery of the RAP aggregate using the ignition method (AASHTO T 308) followed by conducting AASHTO T 84 and T 85 for specific gravity of the fine and coarse aggregate portions, respectively.
2. Recovery of the RAP aggregate using the solvent extraction method (AASHTO T 164) followed by conducting AASHTO T 84 and T 85 for specific gravity of the fine and coarse aggregate portions, respectively.
3. Estimating the RAP aggregate bulk specific gravity using the following process:
   a) Conduct the maximum theoretical specific gravity test (i.e., the Rice method) on samples of the RAP following AASHTO T 209 and determine the asphalt content of RAP samples using AASHTO T 308 or T 164. Samples for the G_{mm} and asphalt content should be obtained from the same locations in the stockpile.
   b) Calculate the effective specific gravity of the RAP aggregate from the asphalt content, G_{mm} of the RAP, and an assumed value for specific gravity of the binder, G_b.

$$G_{se(RAP)} = \frac{100 - P_{b(RAP)}}{\left(\frac{100}{G_{mm}}\right) - \left(\frac{P_{b(RAP)}}{G_b}\right)}$$

   c) Calculate the RAP aggregate bulk specific gravity using the formula:

$$G_{sb(RAP)} = \frac{G_{se(RAP)}}{\left(\frac{P_{ba} \times G_{se(RAP)}}{100 \times G_b} + 1\right)}$$

   where P_{ba} (asphalt absorption) also has to be assumed based on historical records of mixes with the same raw materials.

These three methods were evaluated in a study by the University of Nevada-Reno and NCAT (Hajj et al., 2012) and in NCHRP 9-46 (West et al., 2013). These studies found that the accuracy of Method 3 was highly dependent on how well the percentage of absorbed asphalt could be estimated. Even small errors in the assumed asphalt absorption value caused significant errors in VMA for the mix designs. Therefore, the author does not recommend Method 3.

The flowchart (Figure 3-3) on the following page outlines the recommended process for sampling and testing RAP.

All test results should be recorded in a spreadsheet or software program to organize and summa-

Table 3-1. Variability Guidelines for RAP Stockpiles.

RAP Property	Maximum Std. Dev. (%)
Asphalt Content	0.5
% Passing Median Sieve	5.0
% Passing 0.075 mm Sieve	1.5

rize the data. The database should include stockpile name/description, date of samples, and for each sample, the results for asphalt content, gradation of recovered aggregate, and bulk specific gravity (G_{sb}) of the RAP aggregate. The spreadsheet should calculate the average and standard deviation of each property. An example spreadsheet is shown in Figure 3-4. It is necessary to collect and analyze test results of at least 10 RAP samples to estimate the statistics for the stockpile.

If more RAP is added to the stockpile, sampling and testing should continue at a frequency of one set of tests per 1,000 tons of RAP. Table 3-1 shows guidelines for standard deviations of key properties of RAP. The standard deviation statistic is a basic measure of variability. The median sieve is the sieve closest to having an average of 50% passing. Typically, this is the sieve with the largest standard deviation. In the example spreadsheet below (Figure 3-4), the median sieve is the 2.36 mm sieve.

These values are based on data gathered from contractors using many of the best practices in this document. Although excellent RAP-management practices are necessary to have standard deviations within these limits, published reports and recent surveys indicate that they are attainable. If the variability of one or more properties exceeds the values in Table 3-1, the stockpile management guidelines in this document may be helpful in reducing the standard deviations. Also keep in mind that sampling practices can have a significant effect on variability results.

Figure 3-3. Recommended process for sampling and testing RAP samples.

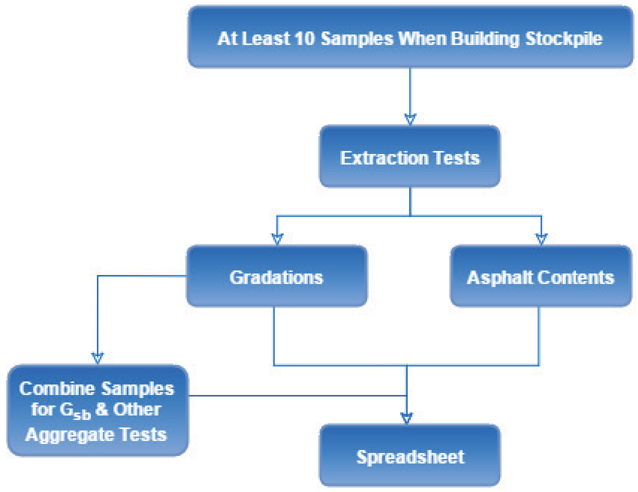

Figure 3-4. Example spreadsheet used for organizing and analyzing RAP stockpile test results.

Example Data - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Developer Acrobat

E48

RAP STOCKPILE ANALYSIS

PLANT: Madison | MATERIA Crushed RAP | SOURCE Multiple Source

Sample	Date	Gsb	Pb %	19.0	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
1	10/09/09	2.626	5.32	100	99	94	75	58	47	39	29	14	7.9
2	10/09/09	2.641	5.55	100	100	95	78	62	51	42	32	15	8.3
3	10/10/09	2.606	5.10	100	98	91	69	52	41	34	26	14	7.6
4	10/10/09	2.608	4.81	100	99	92	67	49	40	33	25	13	6.9
5	10/13/09	2.611	4.90	100	100	93	66	50	40	34	27	16	11.4
6	10/14/09	2.628	4.98	100	99	91	65	48	38	31	24	13	7.3
7	10/15/09	2.614	5.04	100	99	92	68	51	40	32	25	13	7.1
8	10/16/09		5.05	100	99	91	69	54	44	36	28	15	8.3
9	10/17/09	2.635	5.39	100	100	96	78	63	52	43	32	16	8.6
10	10/17/08		6.23	100	99	94	73	57	46	38	29	14	8.8
11													
12													
Avg.		2.621	5.24	100.0	99.2	92.9	70.8	54.4	43.9	36.2	27.7	14.3	8.22
Std. Dev.		0.013	0.42		0.6	1.8	4.8	5.4	4.9	4.2	2.8	1.2	1.29

4 Production Concerns for Mixes Containing RAP

Some of the important considerations for the production of asphalt paving mixes containing RAP have been mentioned in previous chapters. These concerns include minimizing moisture in RAP stockpiles and checking the uniformity of RAP fed into the plant.

RAP feed bins and conveyors are similar to their aggregate counterparts, however, RAP feed bins typically have steeper sides than aggregate feed bins to avoid bridging of the RAP at the bottom of the bin, which can stop or restrict flow of the RAP onto the conveyor belt. If a mix design uses more than one size of fractionated RAP, then the plant must be equipped with the same number of RAP feeder bins.

In the U.S., RAP is typically added to the plant at some point after the burner combustion zone so that the RAP does not come in contact with the flame or

Figure 4-1. Steep-sided RAP cold feed bin.

extremely hot gases. If the RAP is exposed to the hot gases of combustion, the RAP binder will smoke and can be severely damaged. Most modern plants are designed to handle higher percentages of RAP by adding the RAP downstream of the burner in a counter-flow dryer arrangement. Plants designed for higher RAP contents also typically provide longer mixing times for the aggregate, RAP, and virgin binder.

The approach to drying and heating RAP in the U.S. is to use excess heat from the virgin aggregate to dry and raise the temperature of the RAP. That is, the virgin aggregate is "superheated" well above the mixing temperature so the excess heat can be transferred to the RAP during mixing. Therefore, when more RAP is used, the virgin aggregate must be heated to much higher temperatures. This can create the potential for a fire in the mixer, or in the mixer section of the drum, if the feed of the RAP is disrupted due to a clogged gate, broken belt, or clogged dryer entry and the virgin asphalt contacts superheated aggregate.

As previously noted, RAP moisture content also has a big impact on the temperature to which the virgin aggregate must be superheated. Considerable energy (heat) is required to convert moisture in the RAP to steam before the temperature of RAP particles will increase above the boiling point of water. Guidelines for aggregate superheating temperatures are provided by plant manufacturers. Superheated virgin aggregate does not damage the liquid asphalt on the RAP, because it is protected by the steam formed in drying the RAP. The steam displaces oxygen thereby preventing oxidation of the asphalt.

As with virgin aggregate, an incorrect moisture content for RAP input into the plant controls will result in an incorrect amount of virgin asphalt being added to the mix. Variations in moisture contents of virgin aggregate and/or RAP through the day will also lead to variations in the asphalt content of the mix produced.

Higher RAP contents may also require using a softer grade of virgin binder, a recycling agent, or rejuvenator. This would require additional tanks and possibly additional pumps and meters for these materials. Mix design guidelines for RAP mixes are beyond the scope of this document. Readers interested in more information about mix designs with high RAP contents are encouraged consult NAPA publication *Quality Improvement Series 124: Designing HMA Mixtures With High RAP Content* (Newcomb et al., 2007), NCHRP Report 752 (West et al., 2013), or to find training classes offered by organizations with this expertise.

5 Management of Recycled Asphalt Shingles

Background

Although a few contractors began using recycled asphalt shingles (RAS) in asphalt paving mixtures as early as the 1980s, it was a limited practice for several decades. However, based on annual NAPA surveys, the use of RAS increased significantly between 2009 and 2014 (Hansen & Copeland, 2015); an estimated 1.9 million tons of RAS were recycled into asphalt mixes in 2014 (Hansen & Copeland, 2015). During 2014, 19 state DOTs allowed RAS in asphalt mixes; contractors in another 15 states reported using RAS in commercial work or in paving projects for other government agencies. Since 2009, contractors in 42 states report having used some amount of RAS in asphalt pavement mixes (Hansen & Copeland, 2015).

Some contractors that use RAS combine the processed RAS with RAP, a fine aggregate, or synthetic zeolite to facilitate feeding into the asphalt plant. Most of the best practices for handling RAP described earlier are also appropriate and necessary for RAS and/or RAS combined with other materials. This chapter covers unique aspects of RAS management that are important to highlight. Other useful references include NAPA publication *Information Series 136: Guidelines for the Use of Reclaimed Asphalt Shingles in Asphalt Pavements* (Hansen, 2009), and the Construction Materials Recycling Association's (CMRA) *Recycling Tear-Off Shingles: Best Practices Guide* (Krivit, 2007).

Establishing a quality control plan for handling, testing, processing, and storing RAS is an important first step to assure that all requirements are met and a quality product will result.

Although a growing body of research about mixes containing RAS has been published in the past few years, most of the reports have focused on laboratory testing and very little information is available regarding field performance. Therefore, the state of knowledge concerning the use of RAS in asphalt pavements will likely continue to develop in the coming years.

Composition and Types of RAS

Roofing shingles are composed of a hard asphalt, a fiberglass or organic felt mat, mineral filler, and mineral granules. Waste shingles can be obtained from two sources: shingle manufacturer waste (MW) and used shingles removed from residential and/or commercial buildings (i.e., tear-offs), also commonly referred to as post-consumer waste (PC). It is estimated that approximately 1.2 million tons of manufacturer waste shingles and 12 million tons of post-consumer shingles are generated each year (Hansen & Copeland, 2015).

There are a number of important distinctions between MW shingles and PC shingles, including stiffness of the asphalt, asphalt content, and potential for deleterious and/or hazardous materials. The asphalt in new roofing shingles is air blown to make it much stiffer than paving grade asphalt. Exposure to weather and sunlight over time further oxidizes the shingle asphalt, causing it to become even harder and more brittle. Therefore, the asphalt in PC RAS is typically much stiffer than MW RAS asphalt. PC RAS typically has a higher asphalt content than MW RAS partly due to the mineral granules wearing off. As shingle manufacturers changed from organic felt mats to fiberglass over the last quarter of the 20th century, the asphalt content of the shingles also decreased (Dixon, 2013).

PC RAS is also much more likely to contain deleterious materials, such as roofing nails and other debris from reroofing houses and buildings. Since asbestos was used in the manufacture of some asphalt shingles until the late 1970s, there is also the potential for older tear-off shingles to contain this hazardous material. Federal law prohibits recycling of shingles containing more than 1% asbestos. It should be noted that it has been extremely rare for any asbestos to be detected in shingle recycling operation testing programs (Towsend et al., 2007). Some state highway agencies only allow MW RAS to be used in asphalt mixtures due to concerns with asbestos, deleterious materials, and the brittleness of PC RAS.

Specifications

Most DOTs that permit RAS in asphalt mixtures currently limit the amount of RAS to 5% or less by weight of the aggregate (or by weight of the mix). Many highway agencies that allow RAS have recently added a maximum ratio or percentage of recycled binder to total binder (aka binder replacement) or now use this approach as the primary way to limit RAS contents. For highway agencies that allow RAP and RAS together in mixes, it is advisable to have control parameters on both components because RAP binders and RAS binders have large differences in properties. Generally, RAS specifications will state if RAS is permitted only from shingle manufacturer waste or if both MW RAS and PC RAS can be used. Specifications also typically set limits on deleterious materials and the maximum RAS particle size, also referred to as the grind size.

AASHTO standard specification MP 23-14 *Reclaimed Asphalt Shingles for Use in Asphalt Mixtures* is a general specification for RAS. This standard sets the maximum amount of +No. 4 deleterious material at 1.5% and the non-metallic extraneous material (e.g., paper, wood, and plastic) shall not exceed 0.5%. The standard also sets the RAS grind size to 100% passing the 9.5 mm sieve. It is believed that smaller grind sizes provide more complete activation of the RAS asphalt binder in mixes.

Processing RAS

Shingle recycling operations must conform to all federal, state and local regulations. The CMRA *Recycling Tear-Off Shingles: Best Practices Guide* is a useful resource on pertinent regulations and the agencies that issue permits and approvals. The RAS processor's quality control program should ensure that the operation meets all regulations.

Prior to grinding RAS, it is necessary to remove as much deleterious materials as possible. There are different approaches to getting clean RAS. One approach is to avoid contaminants at the source. In the case of PC tear-off shingles, from which contaminants are more likely to originate, it is preferred to have roofing contractors separate shingles from other roofing debris and trash at the source. Alternatively, the shingle waste has to be manually separated at the processing location or at a separate transfer station. Some processors have different tipping fees for waste shingles that are essentially free of contaminants versus shingle waste that is contaminated with other materials.

Shingle grinders are now a specialty type of recycled material grinder. Some water may be added during the grinding process to keep the RAS from heating up to the point where it starts to clump together and gum up the grinder. Water may also be added to the RAS exiting the grinder to control dust and keep fibers from becoming airborne as the RAS is conveyed to the stockpile or screening unit. The amount of water used in processing should be no more than is necessary to facilitate grinding and control fugitive dust and fibers. Some processing units screen the RAS over a high-frequency inclined screen or a Trommel screen to catch oversized RAS particles (e.g., +⅜") that are then conveyed back to the grinder.

Figure 5-1. Shingle grinder (left) and rotating Trommel screen (right) used for RAS processing.

Stockpiling

RAS stockpiles tend to hold the water added during grinding and will soak up additional water from precipitation. Since high water contents are detrimental to drying and heating the RAS during asphalt mix production, many contractors cover RAS stockpiles. Covering the stockpiles shades the material from sunlight, reducing the potential for the material to clump. It is also considered a best practice to process the RAS just before it will be used to avoid making large stockpiles that may compact under their own weight.

is to feed both materials through calibrated bin gate openings to achieve the desired proportions. Using a loader to blend two stockpiles is not recommended.

Sampling and Testing

To determine RAS properties for mix design, it should be sampled from a stockpile after grinding and screening but before it is blended with other materials. Testing of the RAS should include determination of asphalt content, gradation, deleterious content, and aggregate specific gravity. Some agencies may also require recovery and grading of the RAS asphalt or conducting a test to determine its softening point. An average of at least three results is recommended for asphalt content, gradation, deleterious content, and aggregate specific gravity for use in mix designs.

The preferred method for determining RAS asphalt content is a solvent extraction using AASHTO T 64, Method A using trichloroethylene, normal-propyl bromide, or methylene chloride (CH_2Cl_2). Using the ignition method, AASHTO T 308, to determine asphalt content of RAS materials may be used only if correction factors can be established by first determining the asphalt content for the stockpile using a solvent extraction.

Figure 5-2. Covered RAS stockpile.

Blending RAS with Other Materials

As previously noted, some contractors also blend the RAS with a fine aggregate, RAP, or a synthetic zeolite to minimize agglomerations and improve its ability to feed through cold feed bins at low rates. Blending RAS and RAP, however, is not permitted by some DOTs because it is difficult to verify the amount of RAS, or more specifically the amount of RAS binder being used in the mix.

When blending RAS with another material, it is critical that blending be done such that the stockpile is uniform throughout to avoid fluctuations in asphalt contents and gradations during production. The best way to achieve a uniformly blended stockpile

After the solvent extraction, the recovered aggregate should be tested in the ignition method to burn off any organic fibers and determine if the mineral matter will lose additional mass when subjected to ignition method temperatures. Gradation of the RAS aggregate can be determined following a solvent extraction or the ignition method in the same way as aggregate recovered from an asphalt mix or RAP.

Although AASHTO MP 23-14 gives limits for deleterious materials in RAS, there is currently no national standard method for determining deleterious content. Testing of deleterious materials is typically conducted by manually separating out contaminants from a 500 to 700 gram sample of RAS retained on the No. 4 sieve. Deleterious content can be calculated using this equation:

$$P = \frac{M_D}{M_T} \times 100$$

where P = deleterious content, percent
M_D = mass of deleterious materials, g
M_T = total mass of sample, g.

The recommended method for estimating the RAS aggregate specific gravity is the approach described as Method 3 for RAP in Chapter 3, except there is no need to use Step C as it may be assumed that the RAS aggregate is non-absorptive. Note that shingle manufacturers treat the aggregate granules used on shingles with a color coating that makes them impermeable. Therefore, the estimated G_{se} from Step B can be used as the G_{sb} for the RAS aggregate.

For quality control, RAS stockpiles (or RAS blended with other materials) should be tested to check consistency of the above characteristics at a frequency of one test for every 100 tons of RAS.

Mix Production

One of the challenges with using RAS in asphalt mixes is to feed a consistent amount into the asphalt plant. Cold feed bins for RAS are typically steep-sided with gates designed to provide a consistent feed at low rates. Given that RAS is typically only about 5% of the mix, the load cell used in the belt scale must be able to accurately measure low feed rates. For PC RAS, it is a good practice to use a large magnet over the RAS feed belt to remove roofing nails not removed during RAS processing.

Figure 5-3. Magnet used to remove nails from RAS feed to the asphalt plant.

The primary challenge with producing a mix containing RAS is to activate or mobilize as much of the RAS asphalt as possible. Activation of RAS binder is believed to be affected by grind size, RAS moisture content, mixing temperature, mixing time, and hot storage time. Smaller grind size is expected to increase activation due to the larger surface area available to contact with the virgin binder and/or rejuvenator.

Lower moisture contents for RAS should also improve activation by allowing the RAS temperature to more quickly increase to the melting point of the RAS asphalt. Activation should also increase for longer mixing times and higher mixing temperatures. Some continuous-mix asphalt plants have been designed to have longer mixing zones, which may be very beneficial for thorough activation of RAS binder.

There has been some concern about the degree to which RAS binders are activated when the asphalt mix is produced at lower temperatures using some warm-mix technologies. Research is still underway to address this question. Lastly, it is suspected that storage of the mix at normal mix temperatures also gives more opportunity for the RAS binder to be activated and become an integral part of the total binder.

Presently, these are just logical theories of the probable factors that may affect RAS binder activation as research has yet to demonstrate an effective means for quantifying the degree of activation.

6 Summary and Conclusions

A disciplined approach to RAP and RAS management — one based on data to manage inventory, processing, uniformity, and quality — will maximize the return on investment in materials, equipment, and people.

Good management of RAP and RAS begins with collecting or accepting the materials in ways that ensure the materials are not contaminated. Most RAP is obtained through roadway milling operations. Milling is beneficial to roadway maintenance because it removes distressed layers, helps restore the roadway profile and cross slope, and aids in creating a strong bond with the overlay. An important decision by the highway agency is determining the appropriate milling depth. Leaving a poorly bonded interface or a moisture damaged layer in the pavement structure is a sure way to a short life for the rehabilitation.

Millings from a single project are typically very consistent in properties such as asphalt content, gradation, specific gravity, and binder characteristics. When a significant quantity of RAP is obtained from a single project, it is a best practice to stockpile this material separately and minimize further processing that will increase the P_{200} content.

RAP from multiple sources can be made into a very consistent material with good stockpiling and processing techniques. An inventory analysis is very helpful to make the best decisions on when and how to process. Good stockpiling practices include building in layers to help average out variations, avoiding trucks on top of the stockpiles to minimize compaction, and avoiding pushing material over the edge of the stockpile to minimize segregation.

The goal of processing RAP is to make a uniform material that meets the needs of mix designs that will use RAP as a component. A decision about processing includes setting the crusher top size to balance the need to utilize the material in a range of mix types versus the generation of additional fines. Fractionating RAP should be a contractor's choice, not a specification requirement. Fractionating RAP can be beneficial when the RAP supply exceeds the current rate of usage and the plant is capable of producing higher RAP contents, but mixes are unable to meet volumetric or gradation requirements during mix design or quality assurance testing.

Sampling, testing, and analysis of the RAP are vital to good management of this valuable material. The testing data is not only necessary for use in mix designs, it is also essential for assessing uniformity of the RAP. Uniformity guidelines are provided in Chapter 3. If the variability of the test data exceeds these guidelines, then stockpiling and processing practices should be carefully reevaluated. More consistent RAP is important to producing consistent mixes, especially as RAP contents increase.

Currently, there is no single method for determining G_{sb} of RAP aggregate that works well for all materials across the U.S. Therefore, research is needed at the state or local level to determine which method is best suited for the aggregate types used in that jurisdiction. The use of G_{se} for the RAP is not recommended as this will result in a lower asphalt content for mix designs.

Many of the concepts for proper management of RAP also apply to RAS. However, RAS has some unique characteristics that demand special attention at each step. RAS binders are much harder than RAP binder and tend to stiffen mixes much more than mixes with an equivalent percentage of RAP binder. Post-consumer RAS is more likely to contain deleterious materials, so these PC materials must be closely inspected upon receipt before stockpiling.

Processing RAS to a smaller grind size has been found to be beneficial. RAS processing should also minimize the amount of water used because moisture in the RAS has a substantial impact on mix production efficiency and quality. Covering processed RAS stockpiles is also a best practice to avoid precipitation and to shade the material from sunlight, which tends to cause the RAS to clump together.

Another challenge with producing mixes that contain RAS deals with feeding a low percentage of RAS at a consistent rate into the plant. Feeders designed specifically for RAS are recommended.

Plants with longer mixing times are able to better handle high moisture contents in RAS and heat the RAS sufficiently to allow RAS particles to break up and become integrated in the mix.

Over a long-term view, the economic and environmental benefits of using recycled materials are only valid when the product containing the recycled material performs equal to or better than the product without the recycled material. Following best practices for management of RAP and RAS are essential to producing a high-quality long-lasting pavement.

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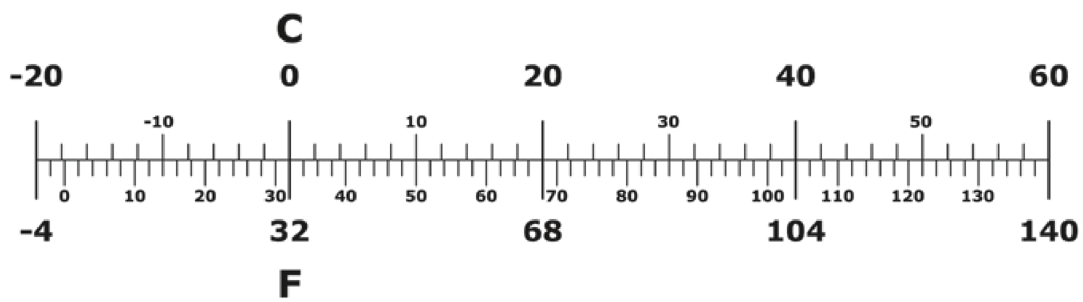
SI* (MODERN METRIC) CONVERSION FACTORS

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	$\frac{5(F-32)}{9}$	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



*SI is the symbol for the International System of Units

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National Asphalt Pavement Association
NAPA Building
5100 Forbes Blvd.
Lanham, Maryland 20706-4407
www.AsphaltPavement.org
NAPA@AsphaltPavement.org
Tel: 301-731-4748
Fax: 301-731-4621
Toll Free: 1-888-468-6499

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