RECLAIMED ASPHALT PAVEMENT MANAGEMENT: BEST PRACTICES

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I. PURPOSE OF THE GUIDE

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. This document is intended primarily as a guide for contractors, but contains some useful information for street and highway agencies. However, this guide is not intended to be used as a specification.

This document represents the current best practices for RAP management as of 2010 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. Feedback on this document should be addressed to the authors at the NCAT website: www.NCAT.us.

The goal of this best management practices guide is to facilitate the most effective utilization of RAP. Good RAP management practices are important to ensure the greatest economic benefit for RAP and the highest quality of recycled asphalt mixtures.

Historical Perspective on Recycling

The asphalt paving industry has had great success with recycling asphalt pavements and other recycled materials such as shingles, glass, and ground tire rubber. Recycling of asphalt pavements dates back to 1915 (*1*), but it did not become a common practice until the early 1970s when asphalt binder prices skyrocketed as a result of the Arab oil embargo. Asphalt paving technologists reacted to this situation by developing recycling methods to reduce the demand on asphalt binder and, thereby, reduce the costs of asphalt paving mixtures. Many practices that were 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. Environmental benefits include reduced emissions and fuel usage due to reduced extraction and transportation of virgin materials, reduced demands on non-renewable resources, and reduced landfill space for disposal of used pavements. Economic benefits include materials cost savings from replacing a portion of virgin aggregates and binders with RAP as well as reduced costs associated with transporting virgin materials to a site.

For over 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 surveys have reported that across the U.S., the average RAP content in new asphalt mixes is around 12% to 15%. A goal established by the National Asphalt Pavement Association (NAPA) is to increase the average RAP content to 25% by the end of 2013.

Although a few people in the pavement community have a negative perception about using reclaimed asphalt pavement materials in new asphalt mixes, mixes with moderate to high RAP contents are not inferior paving products. 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 18 U.S. states and Canadian provinces shows that mixes containing at least 30% RAP are equal to virgin mixtures in all measures of pavement performance.

Overview of Document

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. Section II provides guidance on the reclaiming processes. Section III covers decisions and practices for processing and inventory management of RAP materials. Section IV presents best practices for sampling and testing stockpiled RAP materials.

II. MANAGING THE RECLAIMING PROCESS

RAP may be obtained from several sources. The most common method is through milling operations, also known as cold planning. Two other common sources of RAP are full-depth pavement demolition and asphalt plant waste. This section discusses the 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 bridge decks,
- avoids filling up curbs and avoids drop-offs at drainage inlets and pavement edges,
- restores pavement grades 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. 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 in planning the rehabilitation of a pavement. Often, a milling depth is 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 in areas where the pavement is distressed and not distressed with at least one core 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. The cores should be carefully inspected for crack depths, weak interfaces, and layers damaged by stripping.

Figure 2. Roadway cores showing distressed layers: top-down cracking on left, stripping damage on the right.

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 to 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. 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, performance of the overlay will be severely diminished.

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 3. Milled pavement surface with thin scab layer which will likely lead to premature failure of the overlay

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 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 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 4, can provide a much smoother surface texture, which is better suited for achieving the desired smoothness with 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 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-course millings contain a high-value friction aggregate and/or a modified binder. Some contractors have found this type of 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.

Pavement Demolition

RAP may also be obtained from complete demolition of an existing pavement using a bulldozer or backhoe. This process is typically limited to small areas of pavement. It is slow and results in large chunks of pavement that may be more challenging to process into a useable recycled material. 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 5 Pavement rubble from full-depth demolition of a roadway.

Plant Waste

All asphalt plant operations generate some waste during plant start-up, transition between mixes, and clean-out. Generally, start-up and shut-down 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. Since these waste mixes have not been subjected to environmental aging from years of service, the asphalt binder is less aged than RAP recovered from a road. Waste materials also have fewer fines than other sources of RAP since 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 the next section.

Contamination

It is important that stockpiles be kept free of contaminants from the beginning. It easy to understand how bad perceptions of RAP 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 materials onto the plant yard must be clearly instructed where to dump their loads so that unwanted construction debris does not end up in the RAP stockpile and instructed that they should clean the truck beds before hauling millings or useable RAP. The plant QC personnel and the loader operator should also continuously monitor 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 6 Multiple-source RAP pile with dirt contamination on the right side of the photo.

III. INVENTORY MANAGEMENT AND PROCESSING RAP

Poor management of RAP stockpiles is commonly cited as one reason agencies are reluctant to increase allowable RAP contents in asphalt mixtures. This section 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 mix 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 his 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. However, 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 his RAP usage, she/he 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, she/he will have a large excess 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. His plant typically produces 200,000 tons of HMA per year of which 80% is surface mix and 20% is non-surface mix. His 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% non-surface 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 his historical RAP percentages. This contractor could increase his 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, he 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 his old plant and expects his 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 his old plant, but the new plant was advertised to handle up to 50% RAP. His 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, he will have enough RAP for the first year but will run out of RAP in the second year if he continues to bring in the same amount of new RAP.

If Contractor C believes that 40,000 tons of new RAP is reasonable, then he may want to consider using 25% RAP in all mixes. That would consume 50,000 tons of RAP per year, which he 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 he uses 40% RAP in some mixes, then he will have to use less than 20% other mixes to keep his 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.

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:

- 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,
- whether or not an incoming material is likely to have contaminants,
- 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" since 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 the combined blend of RAP and virgin aggregates meet the appropriate Superpave consensus aggregate requirements and 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. Since 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. Agencies that prohibit the use of RAP processed from multiple sources will suppress the use of RAP. 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 stockpiles 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 hot-mix asphalt. However, some contractors have been able to develop RAP-processing practices using continuously replenished stockpiles that have very consistent gradations 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 Section 4.

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 has been one factor that affects how some contractors use RAP.

Processing and Crushing RAP

The basic goals of processing RAP are to

1) create a uniform stockpile of material from a collection of different RAP materials from various sources,
2) separate or break apart large agglomerations of RAP particles to a size that can be efficiently 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).

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. Since milled RAPs already contain 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 <u>not</u> to further crush this material, but rather to use it "as-is" in mix designs or to screen the millings to remove larger particles.

Millings: Recommended Processing Options

1. Receive millings from project.
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 Section IV.
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 Section 4. 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 must become a primary consideration in his 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. All around the world, contractors have found that they can make a very uniform and high quality RAP from a combination of pavement rubble, millings, and wasted mix. The key to achieving a consistent RAP from multiple sources is careful bending as part of the processing operations. 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. This will tend to “average-out” variations in the RAP from different sources.

Figure 7 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 8 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 8. 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, since all of 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.

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) and roller- or mill-type breakers made specifically for processing RAP. These RAP crushers/breakers are designed to break up chucks of pavement or agglomerations of RAP rather than downsize the aggregate gradation. Further information on RAP crushing equipment can be found in the National Asphalt Pavement Association's Information Series 123, Recycling Hot-Mix Asphalt Pavements (*2*).

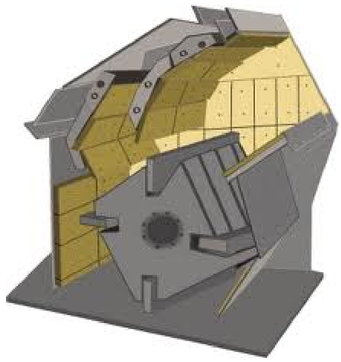

Figure 9. Illustration of HSI crusher

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. The speed and clearance of hammermill crushers can be adjusted to reduce aggregate crushing.

Some contractors have used milling machines to crush stockpiled RAP. There may be a risk of the milling machine overturning since the stockpile is uneven and may not provide stable support for the 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, and RAP fines will 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 3/4” x 3/8”, 3/8” x 3/16”, and minus 3/16”. In some cases, the plus 3/4” 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.

Figure10. Samples of fractionated RAP.

Producers that can answer “yes” to the following six questions should consider fractionating RAP.

1) Can your plant produce mixes containing 20% or more RAP without emissions problems or significant decline in production rate?
2) Does the market this plant supplies allow RAP contents above 20%? (probably should be specific with a quantity of mix per year)
3) Does your plant have an excess amount of RAP (i.e., the quantity of RAP stockpiled exceeds RAP usage per year)?
4) Does your plant site have at least 10,000 sq. ft. available in the stockpile area for a RAP fractionation plant?
5) Do you have difficulty meeting mix design requirements such as minimum VMA, dust proportion, or P0.075 content for mixes with over 20% RAP?
6) Do you have trouble keeping RAP mixes within quality control and acceptance limits?

Figure 11. Portable RAP fractionation unit. This unit screens RAP into three sizes: +3/4” on right, -3/16” on left, and 3/4” x 3/16” in back.

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 appropriate; 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 Section IV.

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 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 stockpiles 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. Irregular-shaped stockpiles with surface depressions that will pond water should be corrected by shaping the pile as it is being built with the front-end loader or a small dozer. However, the use of heavy equipment on the top of RAP stockpiles should be minimized to avoid compaction of the RAP. Likewise, it is also recommended that RAP stockpiles be limited to 20 feet in height to reduce the potential for self-consolidation of the stockpile.

Figure12 . Covered stockpile to minimize moisture in RAP.

In-line RAP Crushers or Crusher Circuits

RAP crushers or crushing circuits that are built into the asphalt plant's RAP feed line 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 personnel 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 require a reduction in the RAP content in order to meet the quality control tolerances for the mix.

In-line roller crushers (also known as lump-breakers) and reduced-speed impact crushers designed to break up agglomerations of RAP rather than change the gradation are used by some contractors. It is recommended to conduct a simple extracted gradation check of RAP samples before and after the in-line crusher to determine if it is breaking down the RAP aggregate.

Figure 13. When using In-line RAP crushers, check extracted gradations before and after the crusher to make sure the RAP aggregate gradation is not changing.

Advantages and Disadvantages of Different RAP Processing Options

Table 1 lists possible advantages and disadvantages of different RAP processing options.

Table 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 higher RAP contents in mixes • Lowest cost of RAP processing options • 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 • Large RAP stockpiles can be generated for annual production	• Tends to increase the dust content of RAP stockpiles, which may limit how much RAP can be used in mix designs
Fractionating RAP	• Using different sized RAP stockpiles provides greater flexibility in developing mix designs	• Requires the most space for multiple smaller stockpiles • Most expensive processing option (cost of fractionation unit plus additional RAP cold feed bin) • May generate an excess of a RAP size if the mix designs are not balanced to the RAP feed

IV. SAMPLING AND TESTING THE RAP

This section 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 (*3*). That was the finding of a 1988 study by the International Center for Aggregate Research (*4*) and confirmed with recent data gathered by NCAT (*5*). 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. Less expected is how consistent RAP processed from multiple sources can also be just as consistent in gradation and asphalt content as millings.

Figure 14. Processed RAP with a uniform appearance.

Sampling and Testing Frequency

Sampling for 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.

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 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 T2 or ASTM D 75-03. This method is described and illustrated below.

1. Use a front end loader to dig into to the ready to use RAP stockpile.

2. Empty the bucket on a clean surface to form 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 this process to obtain samples at other locations around the RAP stockpile. Do not combine samples from different locations.

Figure 15. Steps for the best method to sample RAP

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 LA abrasion and sulfate-soundness tests are not necessary since it is unlikely that 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 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 centrifuge extraction method, and the reflux extraction method. Trichloroethylene 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 the solvent extraction methods.
- The centrifuge extraction method had the smallest affect 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.
- LA 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 (*6*). Several research studies are currently in progress to develop alternative procedures for determining RAP binder properties and methods for selecting the grade of the virgin binder for high RAP content mixtures.

Methods for Determining RAP Asphalt Contents and Recovering Aggregates

Two options are recommended for determining RAP asphalt content and recovering aggregates: the ignition method and solvent extractions. Both methods have advantages and disadvantages. The following sections discuss the associated advantages and disadvantages of these methods.

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 D 6307. Advantages of the ignition method include quick results, little testing time, and no solvents are needed. 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.

RAP aggregates recovered from the ignition method can be used for gradation analysis and some other aggregate-property tests, but not all. Some aggregate types (e.g., dolomites) can have significant changes in mass when heated to 1000°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-propylene 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 were 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 characteristics, 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.

Aggregate Bulk Specific Gravity

An alternate approach to estimating the bulk specific gravity of the RAP aggregate discussed in NCHRP Report 452 (*6*) was also evaluated in the UNR-NCAT study. This approach begins with conducting the maximum theoretical specific gravity tests (i.e., the Rice method) on samples of the RAP following AASHTO T 209. The effective specific gravity of the RAP aggregate is then calculated from the asphalt content and G_{mm} values determined from tests on the samples as follows.

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

The final step is to calculate the RAP aggregate bulk specific gravity using the formula:

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

where P_{ba} (asphalt absorption) and G_b (binder specific gravity) have to be assumed. Historical values for P_{ba} and G_b for the materials used at each plant location should be reviewed to determine if they have been consistent over time. Advantages of this approach are that no solvent is needed (if the ignition method is used to determine the RAP binder content), and the method is much faster than recovering the RAP aggregate from the solvent extraction or ignition method and testing the aggregate specific gravities using AASHTO T84 and T85, like any other aggregate. However, the accuracy of this method is highly dependent on how well the percentage of absorbed asphalt can be estimated.

Due to the advantages, disadvantages, and limitations of the different methods for determining asphalt contents, recovering RAP aggregates, and determining their properties, it is necessary to have a couple options for testing. It is prudent for agencies and contractors to cooperate in establishing the best methods for the materials in their region or jurisdiction. The following flow charts present two reasonable approaches.

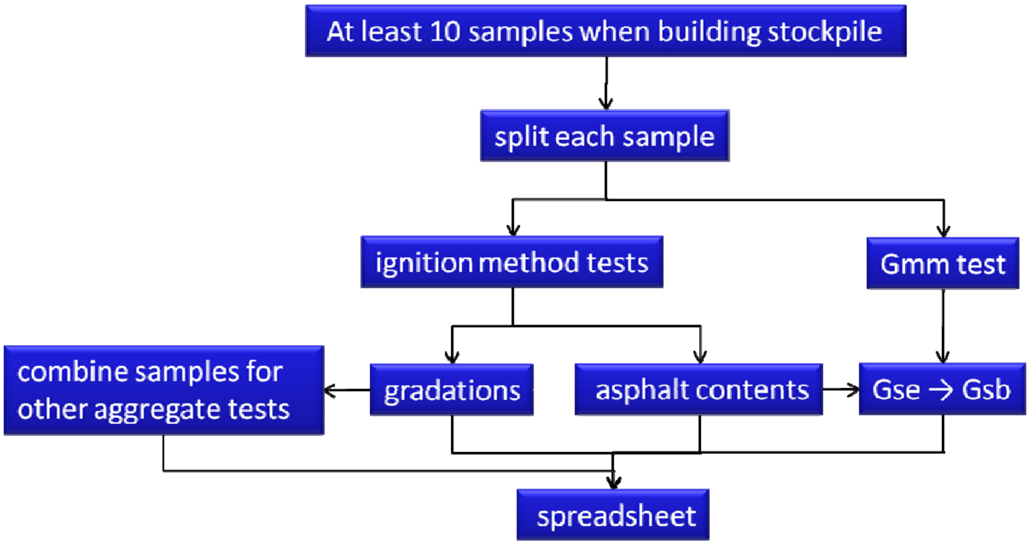

Figure 16. Option 1 for Sampling and Testing RAP Samples.

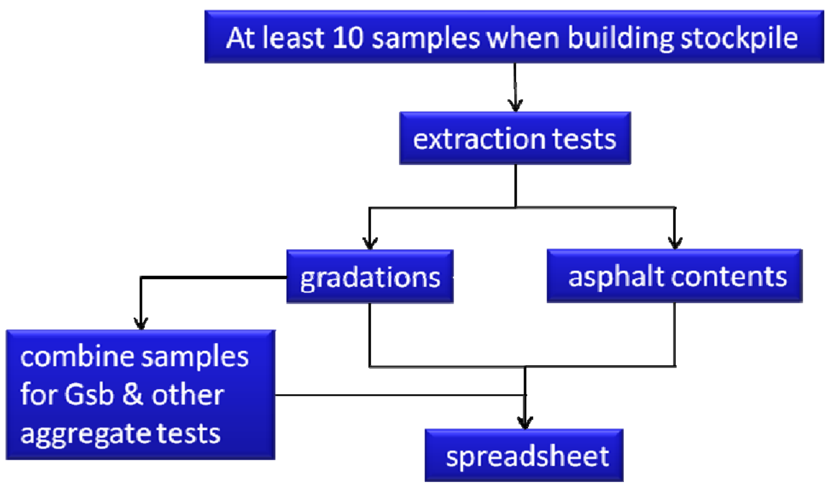

Figure 17. Option 2 for Sampling and Testing RAP Samples.

All test results should be recorded in a spreadsheet or software program to organize and summarize 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 of the RAP aggregate. The spreadsheet should calculate the average and standard deviation of each property. An example spreadsheet is shown in Figure 15. It is necessary to collect and analyze test results of at least 10 RAP samples to estimate the statistics for the stockpile.

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

Figure 18. Example Spreadsheet Used for Organizing and Analyzing RAP Stockpile Test Results

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 2 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 above, the median sieve is the 2.36 mm sieve.

~~Figure 15. Example Spreadsheet Used for Organizing and Analyzing RAP Stockpile Test Results~~

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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 show indicate that they are attainable. If the variability of one or more properties exceeds the values in Table 2, 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.

Table 2. Variability Guidelines for RAP Stockpiles

RAP property	Maximum Std. Dev. (%)
Asphalt Content	0.5
% Passing Median Sieve	5.0
% Passing 0.075 mm Sieve	1.0

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