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DEPARTMENT OF TRANSPORTATION

# Best Practices for the Design, Evaluation and Quality Control of High Percentage RAP Mixes

FINAL REPORT

December 1, 2015

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**16. Abstract**

Placing reclaimed asphalt pavement (RAP) back on the roadway is a common and popular technique in the paving industry. There are always challenges associated with this type of recycling, especially when the RAP content in the newly paved asphalt mix exceeds 20 to 30 percent by mass of the total mix. The Federal Highway Administration (FHWA) and many state highway agencies have been pursuing usage of high RAP content in asphalt mixes. There are concerns about uniformity of the stockpiled RAP and the brittleness of the RAP aged binder. When using high RAP content in asphalt mixes, high quality can only be achieved through best practices in design, RAP stockpile management, and construction. The Pennsylvania Department of Transportation (PennDOT) has been an advocate of using RAP in asphalt pavements. Under a PennDOT-sponsored project, Penn State was charged with reviewing and revising PennDOT publications based on the most recent research findings in regard to RAP usage. The PennDOT documents that were affected by these practices were Publication 27, Specification 408, and Publication 2 (POM). Most of the changes incorporated into PennDOT publications were applicable to the RAP usage. However, the changes also covered usage of recycled asphalt shingles (RAS). The overall goal of this work was the adaptation and implementation of accepted best practices for mix design procedures and performance evaluation of higher percentage RAP mixes. The main objective of this work was to make necessary changes to PennDOT publications affected by recently proposed practices by NCHRP 752 and its accompanying report on the best RAP management practices.

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# INTRODUCTION

Placing reclaimed asphalt pavement (RAP) back on the roadway is a common and popular technique in the paving industry. There are always challenges associated with this type of recycling, especially when the RAP content in the newly paved asphalt mix exceeds 20 to 30 percent by mass of the total mix. The Federal Highway Administration (FHWA) and many state highway agencies have been pursuing usage of high RAP content in asphalt mixes. There are concerns about uniformity of the stockpiled RAP and the brittleness of the RAP aged binder. When using high RAP content in asphalt mixes, high quality can only be achieved through best practices in design, RAP stockpile management, and construction. Such practices have been covered in a series of recent documents (*1, 2*).

The Pennsylvania Department of Transportation (PennDOT) has been an advocate of using RAP in asphalt pavements. The design of mixes containing RAP and relevant specifications are covered in PennDOT Publication 27 (*3*). Appendix H of this publication (Bulletin 27) is allocated to asphalt mix design containing RAP. Specifications relevant to construction of asphalt mixes with RAP is covered in section 409 of Publication 408 (*4*). Finally, Part B of Section 7 of the PennDOT Project Office Manual (POM), which contains minimum quality control/assurance requirements for bituminous mixes, covers requirements on RAP stockpiling and quality control (*5*). In the introduction part of POM, it is stated that "The Project Office Manual is a compilation of Department policies and procedures relating to field administration and inspection of construction contracts. The purpose of the POM is to act as a reference for the appropriate District staffs so they may perform their duties in accordance with Department policies and procedures."

Under a PennDOT-sponsored project, Penn State was charged with reviewing and revising PennDOT publications based on the most recent research findings in regard to RAP usage. The PennDOT documents that were affected by these practices were Publication 27, Specification 408, and Publication 2 (POM). Most of the changes incorporated into PennDOT publications were applicable to the RAP usage. However, the changes also covered usage of recycled asphalt shingles (RAS).

## OBJECTIVE

The overall goal of this work was the adaptation and implementation of accepted best practices for mix design procedures and performance evaluation of higher percentage RAP mixes. The main objective of this work was to make necessary changes to PennDOT publications affected by recently proposed practices by NCHRP 752 and its accompanying report on the best RAP management practices.

## TASKS

The work was carried out in five main tasks. The first task covered review of PennDOT publications. The second task covered literature review, review of NCHRP 752 report, and review of other relevant national documents on high RAP usage. Task three covered modifications to PennDOT publications based on results from Tasks 1 and 2. Task 4 was finalizing the changes. Finally, under Task 5 an implementation plan was developed for taking the changes into practice.

At the time of this writing, revisions to publications have been made at three different times. The first revisions were made, under Task 3, based on the review of literature and publications on RAP usage best practices. The second and third rounds of revisions were made after the Task 3 revised publications were sent out for comments under the PennDOT clearance transmittal package. The most recent revisions in publications reflect the comments received from these two rounds of distribution under clearance transmittal package. It is anticipated that further changes will be applied to these publications as further comments are provided beyond this research contract.

### *Task 1: Review Current PennDOT Practices and Specification of RAP Usage*

The research team determined, with the collaboration of the PennDOT technical advisor, the PennDOT publications that would be affected by the recent practices on RAP mixes. For each PennDOT publication, the sections that contained information on RAP were identified and highlighted. Specifically, the documents that were reviewed included PennDOT Bulletin 27, Specification 408 (Section 409), and Publication 2 (POM). The review included documenting

existing mix design procedures for mixes containing RAP, sampling and testing, and existing quality control (QC) measures utilized by producers in managing the RAP, along with currently minimum QC requirements that the producer must follow, as stated in POM. The results of this investigation were summarized in three lists. The lists, one for each document, indicated page numbers, relevant sections, and the technical aspect of RAP usage addressed in each document. All three lists, which were shared with PennDOT in August 2014, are provided in Appendix A to this report.

***Task 2: Review and Select Nationally Developed Practices for High RAP***

Parallel to Task 1, a review was made of NCHRP Report 752 (*6*). This report was the result of research conducted by the National Center for Asphalt Technology (NCAT) under National Cooperative Highway Research Program Project 9-46. The report covers mix design practices, RAP characterization, and RAP stockpile management. This report had the largest impact on the changes made in PennDOT publications under current research.

Simultaneously, most recent documents related to RAP mix design and best management practices were reviewed and evaluated. These included parts of the mix design manual that was developed in 2002 (*7*), the National Asphalt Pavement Association (NAPA) practical guide on high RAP (*1*), and the best practices developed by the Texas Transportation Institute (*2*). Upon completion of the review, a point-by-point analysis of the best management practices was conducted, and a set of summary documents, which contained important items affecting PennDOT publications, was developed and submitted to PennDOT in October 2014. As a result of discussions with the PennDOT technical advisor, improvements were made to the submitted documents and a revised set was submitted in December 2014. The summary documents developed under Task 2 are provided in Appendix B to this report.

***Task 3: Incorporate the Changes into PennDOT Publications and Minimum QC Requirements***

PennDOT publications that were reviewed under Task 1 were revisited for any changes needed based on findings from Task 2. The list of items affecting the publications, as developed under Task 2, were the basis for making any recommended changes. The changes affected all three documents: Bulletin 27, Specification 409, and Publication 2. Revisions were made to these

documents in tracked form and submitted to PennDOT in April 2015. As a result of a series of meetings and discussion sessions with the project technical advisor, these revisions were expanded and improved several times and a final copy of the revised version of the publications under Task 3 was provided to PennDOT in July 2015. The major changes applied to these publications included:

- Replace requirements on RAP content with requirements on reclaimed asphalt binder ratio (RBR).
- Change the number of design levels from 2 to 3. Design levels were established based on RBR.
- Provide alternatives for determination of RAP aggregate bulk specific gravity.
- Include performance testing as part of design procedure under Level 3 design.
- Establish standard deviation on asphalt content and gradation for RAP stockpile to control variability.
- Distinguish between the wearing/binder layer and base layer in deciding design levels.
- Provide guidance on RAP stockpile management.
- Address sampling procedures from RAP stockpile.
- Include a procedure for determination of RAS binder grade.

In addition to the information given in NCHRP report 752, several other documents (*2, 7, 8*) that had discussed RAP variability were considered in establishing standard deviation levels.

***Task 4: Finalize the Changes in PennDOT Publications***

PennDOT publications that were revised under Task 3 were circulated by PennDOT for internal review in a clearance transmittal (CT) package in June 2015. Comments received from this round of CT were addressed by Penn State team researchers. Some of the comments resulted in further changes to the publications. Furthermore, several discussions took place with the project technical advisor as a result of these comments. Results of CT comments and technical discussions were reflected in a set of newly revised documents that were submitted to PennDOT in August 2015. PennDOT circulated these revised documents for the second round of CT in September 2015. Both internal and external reviewers were included in this second round of CT. Further comments and feedback were provided from this review. The comments from industry resulted in a face-to-face meeting in the Harrisburg PennDOT Lab, where the comments were discussed. The meeting took place in November 2015. The results of the second round of CT and the meeting with industry representatives resulted in further revisions

to the publications. It is anticipated that further changes will be made to the publications as new comments are received. Addressing new comments will be beyond the scope and allocated time for this project, and will be addressed by PennDOT.

***Task 5: Develop an Implementation Plan***

Upon finalizing the changes in the PennDOT publications, the research team developed an implementation plan and a roadmap to guide the implementation. The idea behind development of such a plan was to ensure a smooth transition of the changes to mix designers, asphalt producers, and contractors. The plan is reported in Appendix C to this report.

## SUMMARY

Through a PennDOT-sponsored project, the Penn State research team was charged with revising three PennDOT publications, namely Bulletin 27, Specification 409, and Publication 2. It was expected that the changes would be made based on the most recent developments dealing with the usage of high percent of RAP in asphalt mixes. Several documents dealing with high RAP mixes were reviewed for this purpose. Specifically, NCHRP Report 752 was the core of this investigation. The results of these reviews resulted in a series of changes in the preceding PennDOT publications.

The most important change was to consider the amount of RAP binder in the mix as a measure of RAP effect on the mix rather than considering the amount of RAP itself. This change has been discussed and promoted at the national level within the last several years, and was the major recommendation of NCHRP Report 752. This change was incorporated into the PennDOT publications. The term reclaimed asphalt binder ratio (RBR) was introduced into the publications to reflect this change.

Several other important changes were incorporated into the PennDOT publications. The number of design tiers including RAP was established at three rather than the existing system, which includes two. Design tiers were based on RBR. For base course mixes with nominal maximum aggregate size $\geq$ 25 mm, higher RBR levels were considered compared with wearing course and binder course mixes, to separate different design levels. Controlling

stockpile variability was established through sampling and statistical measurement of asphalt content and gradation. Recommendations were provided for RAP stockpile management based on existing best practices. Fractioning RAP stockpiles was included in Publication 2 as a best practice recommended procedure when RAP content in the mix is high. Fractionating RAP stockpile into at least two piles of coarse and fine RAP is promoted by several publications when RAP content is high (*1, 2, 6, 7, 9*).

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3. Pennsylvania Department of Transportation, Publication 27, "*Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixes.*"

4. Pennsylvania Department of Transportation, Specifications, Publication 408/2011.

5. Pennsylvania Department of Transportation, Publication 2, the Project Office Manual.

6. West, R., J. R. Willis, and M. Marasteanu, 2013: *Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content*, NCHRP 752, National Cooperative Highway Research Program, Report No. 673, Washington D.C.

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9. Shannon C. P., 2012: *Fractionation of Recycled Asphalt Pavement Materials: Improvement of Volumetric Mix Design Criteria for High-RAP Content Surface Mixtures*, Dissertation, University of Iowa.

# APPENDIX A

**WO#10**

**Deliverable for Task 1**

**Summary of Results from Reviewing PennDOT Publications**

| BITUMINOUS CONCRETE MIXTURES, DESIGN PROCEDURES, AND SPECIFICATIONS FOR SPECIAL BITUMINOUS MIXTURES | |
|---|---|
| ***PUBLICATION 27 JANUARY 2003 EDITION CHANGE 5*** | |
| CHAPTER1<br>Title Department Specifications for Bituminous Mixing Plants for Hot-Mixed, Hot-Laid Paving Mixtures | |
| **Page Number** | **Content** |
| | **2. General Requirements for All Plants** |
| 1 | **2.1 Uniformity and Control of Completed Mixtures.** The plant shall be designed, operated and maintained such that it is capable of combining and mixing any required sizes of heated aggregate and reclaimed asphalt pavement (RAP) and/or recycled asphalt shingles (RAS), when required, from stockpiles or bins with asphalt binder (bituminous material); to produce mixtures within PENNDOT Publication 408 Specifications or within applicable Standard Special Provisions. |
| 6 | **2.4 Cold Aggregate Feed System**<br><br>**2.4.3 Cold Aggregate Feeder.** The plant shall be provided with mechanical means for uniformly feeding the aggregates into the dryer so that uniform production and temperature may be assured. When aggregates must be blended from two or more bins at the cold feed to meet the requirements of PENNDOT Publication 408 specifications, a synchronized proportioning method shall be provided. When recycling capability is selected, the plant shall be equipped with mechanical means for feeding the desired weight of RAP into the mix. Facilities shall be provided for obtaining samples of the RAP. |
| 8 | **2.10 Surge Silo or Storage Systems and Approval**<br><br>The mixture as delivered for the work shall comply with all specified requirements. Since the asphalt binder on larger stone, lower asphalt content, base mixes may oxidize more rapidly than smaller stone, dense-graded wearing course type mixes, a silo storage system approved for base mix is approved for all other types of dense-graded (ID & Superpave) HMA, with the following exceptions. When PG-Binder is modified, or RAP and/or RAS or any other modifier or additive that its properties may be altered by the extended elevated temperatures, is included in the mix, extended storage time will be approved on a mix-by-mix basis. The approval of the storage system may be withdrawn whenever material processed through or held therein does not comply with the specification or when the Engineer visually determines the mixture to be lumpy or segregated or non-uniform due to drain down or excessive hardening. When recycled materials or heat sensitive modifiers or additives are included in the mix, additional requirements as deemed appropriate during the evaluation by the MTD may be utilized. Typically, additional criteria may include a maximum $G^*/\sin\delta$ or maximum ratio of change ($\geq$ 4 times) based on zero storage time and initial recovery. Also, mixture volumetric properties may be evaluated relative to storage time by MTD request. |
| 16 | **4. Requirements for Drum-Mix Plants.**<br><br>**4.5 Plant Tolerances.** All bituminous drum plants shall be capable of consistently delivering materials within the following tolerances:<br><br>Bituminous Material +/- 0.5%<br>Recycled Material +/- 0.5%<br>Individual Aggregate Feed +/- 1.0%<br>Total Aggregate Feed +/- 1.0% |

| Page Number | Content |
|---|---|
| 1 | **2. General Requirements**<br><br>**2.1 Uniformity and Control of Completed Mixtures.** The plant shall be designed and operated such that it is capable of combining and mixing aggregate, asphalt binder, and RAP (if specified) to produce mixtures meeting the JMF and within Publication 408 specifications. The plant shall be capable of mixing materials to obtain a uniform coating of particles and a thorough distribution of bituminous material throughout the aggregate. |

| Page Number | Content |
|---|---|
| 14 | **5. HOT-MIX RECYCLING DESIGN PROCESS**<br>**STEP 1** - Obtain ten representative samples of the reclaimed asphalt pavement (RAP) material or milled material from different locations in the stockpile. Remove at least 150 mm (six inches) of the material from the surface of the stockpile before obtaining the sample to minimize segregation effects. Scalp off and discard the material retained on 50 mm (2 inch) sieve. Sample size at least 5 kg (10 lbs.) each after scalping. Split each sample into two portions. Identify the samples (No. 1 thru 10). Save ten split samples [at least 2.5 kg (5 lbs.) each] for sending to the Materials and Testing Division (Step 4). Retain the other ten split samples at the plant for testing and designing the recycled mix.<br><br>**STEP 2** - Run extraction on the retained ten samples of the RAP. Use 1.02 as the specific gravity of the aged asphalt. Report the extraction results on Table 1. Save the remaining portions of the retained samples for subsequent mix designs at the plant (Step 6).<br><br>**STEP 3** - Select the percentage of RAP to be recycled, and determine the percentages of virgin aggregate(s) to meet the specification requirements. Determine typical properties of all virgin asphalt cements (PG 58-28, PG 64-22, etc.) from the asphalt supplier. Fill out Tables 2 and 3. |
| 15 | **STEP 4** - Submit the following to the Materials and Testing Division (Bituminous Laboratory) for determining the grade of virgin asphalt cement to be used in recycling:<br><br>1. Ten split samples of the RAP (at least 2.5 kg (5 lb) each) with Sample Identification Form 447. Number the samples 1 through 10.<br><br>2. Tables 1, 2 and 3.<br><br>3. Current JMF for the mix using 100% virgin aggregates.<br><br>**STEP 5** - The Materials and Testing Division (MTD) will evaluate the aged asphalt in the RAP after Absen recovery, and using the data from Tables 1, 2 and 3 and the current JMF, the MTD will recommend the grade of virgin asphalt for recycling.<br><br>NOTE: If 15 percent or less RAP is used in the BCBC and ID-2 Binder mixes, the performance grade of neat asphalt binder specified in the current JMF can be used and there is no need to submit the RAP samples to the MTD. |

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| 19 | **STEP 6** - Obtain a sample of the MTD recommended asphalt grade from the asphalt supplier (it is advisable to keep these samples on hand in advance to save time). Prepare 15 Marshall specimens at five different asphalt contents (use half percent increments) bracketing the current JMF asphalt content (based on 100% virgin aggregates). To facilitate the mixing of the RAP, it should be heated in an oven (for not more than 1+ hours) at 127 ± five C (260 ± 10 F) unless directed otherwise. Heat the virgin aggregate(s) to a suitable temperature so that the resulting mix temperature is 127 ± 3 C (260 ± 5 F). Compact the Marshall specimens at 127 ± 3 C (260 ± 5 F). Obtain the Marshall design data and report in Table 4. Plot the data on the six graphs (TR-448B) of the Marshall Design Summary. Submit Table 4 and TR-448B to the District Materials Engineer for review of the JMF. It may not always be possible to establish the optimum asphalt content based on the average of the two asphalt contents at maximum specimen specific gravity and 4% air voids. In such cases, it is recommended to select the asphalt content which essentially gives the air voids content equal to the current JMF using 100% virgin aggregates. If it is intended to vary the percentage of the RAP during production, develop the recycled mix designs using RAP in increments of five percentage points, such as, 10, 15, 20, 25 and 30 percent. If it is desired to use 12% RAP, the asphalt content can be interpolated from the design values at l0 and 15% RAP. |
| 23 | **6. Mix Design Method for Cold Recycled Base Course, In-Place or Central Plant Mix Recycling.**<br><br>**6.1** The following procedures shall be followed when cold recycling is to be done by the Contractor or Department forces:<br><br>**1.** Obtain representative samples of the RAP material by one of the following methods:<br><br>a. <u>From Stockpile:</u> If the material to be recycled is stockpiled, obtain five 2.2 kg (twenty pound) bags of the milled material or RAP from different locations on the stockpile. Remove at least six inches of the material from the stockpile surface before obtaining the sample. Scalp off the material over a (2-inch sieve).<br><br>b. <u>By Milling:</u> If cold recycling is to be done in place without stockpiling the RAP, obtain five 2.2 kg (twenty pound) bags of RAP by milling a representative portion of the project. Use a milling machine similar to the one intended for use on that project.<br><br>c. <u>Cores:</u> Although milled material or RAP is preferred for designing the cold recycled mixture, cores from the existing pavement are acceptable as an alternate. Obtain fifteen 152 mm (6-inch) diameter cores from a representative portion of the project. If the project has areas with different pavement layers and/or thickness, obtain fifteen cores from each area.<br><br>Screen RAP on a one inch sieve. Reduce any material retained on the one inch sieve to 100% passing. If cores are used, crush the cores and sieve over a 25.0 mm (one inch) sieve. Determine the asphalt content based on an average of four samples using either the extraction method or ignition furnace. The correction factor for mass loss in the ignition oven shall be 0.5.<br><br>**2.** Run a minimum of three gradations on the RAP material. Determine if virgin aggregate is needed by reviewing the sieves listed below and ensuring that the RAP material meets the required range for % passing on these sieves. If the RAP does not meet the % passing requirements below, virgin aggregate is needed. |

| | |
|---|---|
| 23 | **Sieve Size** / **% Passing**<br>19 mm (¾") — 52 – 100<br>9.5 mm (3/8") — 36 – 70<br>4.75 mm (#4) — 24 – 50<br><br>**3.** Prepare one thousand (1000) gram samples of RAP material passing the 25.0 mm (1") sieve and retained on the 12.5 mm (1/2") sieve, material passing the 12.5 mm (1/2") sieve and retained on the 4.75 mm (#4) sieve, and material passing the 4.75 mm (#4) sieve and retained in the pan.<br><br>**4.** Keep the moisture content of the prepared RAP samples constant at three percent.<br><br>**5.** Select the grade of emulsion to be used from the following list: MS-2 (E-4), CMS-2 (E-5), SS-1 (E-6A), CSS-1 (E-6C), SS-1h (E-8A), CSS-1h (E-8C), HFMS-2h (E-11-60), HFMS-2 (E-11-90), HFMS-2S (E-11-150)<br><br>Any of these emulsions may be polymer modified. Evaluate the emulsion by a coating test. The ability of the emulsion to coat the aggregate is critical. Typically, compatible emulsions will achieve 80 percent or greater coating with little or no wads. (Non-dispersed asphalt and fines). |
| 24 | **6.** Prepare three mixtures at four different emulsion contents using a three percent moisture content. For mixing purposes, the RAP should be at ambient temperature and the emulsion at 60 C (140°F). Normally, use 2.0%, 2.5%, 3.0% and 3.5% emulsion content. If the RAP is rich in asphalt, start with 1.5% emulsion content and vary by 0.5% increments. If RAP is blended with virgin aggregate, start at 3.0% emulsion.<br><br>**7.** Cure the mixtures in an oven at 40C (105 F) for one hour. Remix for 30 seconds and allow to cool to room temperature.<br><br>**8.** Compact the mixtures using a Marshall hammer with 75 blows on each side. Extrude the compacted specimens the following day.<br><br>**9.** Prior to testing, cure the specimens to constant weight in an oven at 40C (105°F). Lay samples on their side to maximize surface exposure during the curing process. For this test method, constant weight is defined as a sample with a mass loss of less than 0.5 grams when weighed at 15 minute intervals.<br><br>**10.** Record the specimen thickness and weight.<br><br>**11.** Determine the Bulk Specific Gravity for each specimen (five minutes in water bath).<br><br>**12.** On the SSD conditioned specimens, determine the Marshall Stability at 25°C (77°F) and at a flow of 10.<br><br>**13.** Determine the optimum emulsion content based on the averages for maximum stability and specimen density.<br><br>**6.2 Field Adjustments**. Because RAP gradation and composition may vary, field adjustments to the moisture content or emulsion content may be necessary. If the coating of the surface dry mix is not satisfactory (less than 75%), adjust the moisture content first. Cure the mixture if necessary before compaction. Adjust the emulsion content based on mix behavior during and after compaction. |

Optimum compaction should be achieved using nuclear gauge control strip techniques.

**7.2 Guidelines for Selecting Asphalt Emulsions as Stabilizers for Full Depth Reclamation (FDR)**

**Before** using asphalt emulsion as a stabilizer for full depth reclamation, the reclaimed pavement material **must** meet the following characteristics:

* The material should consist of 100% RAP or a blend of RAP and underlying granular base or non-plastic or low plasticity soils.

* The maximum percent passing the 75 μm (No. 200) sieve should be less than 25%. (AASHTO T11)

* The plasticity index (AASHTO T 90) should be less than six or the sand equivalent (AASHTO T 176) 30 or greater, or the product of multiplying the P.I. and the percent passing the 75 μm (No. 200) sieve being less than 72.

Additionally, small amounts of hydrated lime or cement, typically 1.5 and 1.0 percent respectively by weight, can be added with asphalt emulsion to produce reclaimed mixtures with higher early strength and greater resistance to water damage.

**7.3 Design Process for Full Depth Reclamation (FDR) Using Emulsified Asphalts**

25 and 26

**1.** Obtain representative samples of the material (full depth) to be reclaimed. Either loose samples from milling or cores can be utilized. Screen millings on the 25 mm (one inch) sieve. Reduce in size any material retained on the 25 mm (one inch) sieve to 100% passing. If cores are used, crush the cores and sieve over a 25 mm (one inch) sieve. Determine the asphalt content and gradation based on an average of four samples using either the extraction method or ignition furnace. The correction factor for mass loss in the ignition oven shall be 0.5.

**2.** Run a minimum of three gradations on the reclaimed material. Determine if virgin aggregate is needed.

**3.** Prepare one thousand (1000) gram samples of material passing the 25 mm (one inch) sieve and retained on the 12.5 mm (1/2 inch) sieve, material passing the 12.5 mm (1/2 inch) sieve and retained on the 4.75 mm (#4) sieve, and material passing the 4.75 mm (#4) sieve and retained in the pan.

**4.** Keep the moisture content constant at three percent.

**5**. Select the grade of emulsion to be used from the following list: MS-2 (E-4), CMS-2 (E-5), SS-1 (E-6A), CSS-1 (E-6C), SS-1h (E-8A), CSS-1h (E-8C), HFMS-2h (E-11-60), HFMS-2 (E-11-90), HFMS-2S (E-11-150)

**6.** Prepare three mixtures each with four different emulsion contents using a three percent moisture content. For mixing purposes, the reclaimed material should be at ambient temperature and the emulsion at 60°C (140°F). Normally, use 3.0%, 3.5%, 4.0% and 4.5% emulsion content with reclaimed material containing from 75% to 100% RAP by weight. If RAP is rich in asphalt, start with 1.5% emulsion. For reclaimed materials with lesser quantities of RAP, some increase in the emulsion content will probably be necessary, particularly when fine graded soil material is present or virgin aggregate has been added.

**7.** Cure the mixtures in an oven at 40°C (105°F) for one hour. Remix for 30 seconds and allow to cool to room temperature.

**8.** Using a Marshall apparatus, compact the mixtures with 75 blows on each side. Extrude the compacted specimens the following day.

**9.** Prior to testing, cure the specimens to constant weight in an oven at 40°C (105°F). Lay specimens on their side to maximize surface exposure during the curing process. For this test method, constant weight is defined as a specimen with a mass loss of less than 0.5 grams when weighed at 15 minute intervals.

**10**. Record the specimen thickness and weight.

**11.** Determine the Bulk Specific Gravity for each specimen (five minutes in water bath).

**12.** On the SSD conditioned specimens, determine the Marshall Stability at 25°C (77°F) and at a flow of 10.

**13**. Determine the optimum emulsion content based on the averages for maximum stability and specimen density.

## SECTION 345 – BITUMINOUS STABILIZED SUBBASE

**345.2 MATERIAL**

27

**(a) Reclaimed Material.** 95% of the material is required to pass through a 50 mm (2- inch) sieve. Reduce oversize material as required. Incorporate all reclaimed material into the stabilized subbase.

**1. Reclaimed Aggregate Material (RAM).** In situ aggregate material which is incorporated in the stabilization.

**2. Reclaimed Asphalt Pavement (RAP).** Processed paving material containing asphalt cement and aggregates.

**(d) Mix Design.** Remove samples of RAP and RAM to the specified depth and perform the appropriate testing to establish the mix design. Design in accordance with the requirements of this Bulletin and submit to the DMM/DME for review at least three weeks prior to commencement of work on the project.

**(e) Mixture.** Combine the reclaimed material, aggregates (if necessary), and bitumen, in such proportions that the total aggregate and bitumen in the reclaimed mix conform to the requirements and composition specified in the mix design with the recommended optimum moisture and emulsion content. When composition varies sufficiently, make field adjustments as recommended in the design to obtain completed bituminous stabilized subbase, with satisfactory particle coating and optimum compaction.

**345.3 CONSTRUCTION**

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**(b) Mixing.** Maintain adequate total liquids to ensure total mixing of the reclaimed material and aggregate (if required) with the bituminous material. Add water to the surface by a calibrated meter as necessary to aid in mixing and compaction.

| BITUMINOUS CONCRETE MIXTURES, DESIGN PROCEDURES, AND SPECIFICATIONS FOR SPECIAL BITUMINOUS MIXTURES | |
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| ***PUBLICATION 27 JANUARY 2003 EDITION CHANGE 5*** | |
| Chapter 2A<br>Design and Control of Hot-Mix Asphalt (HMA) Mixtures Using the Superpave Asphalt Mixture Design and Analysis System | |
| **Page Number** | **Content** |
| 3 | **AASHTO R 35, Section 4. Summary of the Practice**<br><br>***Revise Subsection 4.1 by adding the following to Note 3:***<br><br>When using RAP or manufacturer waste Recycled Asphalt Shingles (RAS), the Department's modified design procedures (See Appendix H) shall be followed exclusively. |
| 4 | **AASHTO R 35, Section 6. Preparing Aggregate Trial Blend Gradations**<br><br>***Revise Subsection 6.1 completely as follows:***<br><br>**6.1** Select Performance Graded Binders (PG-Binders) as specified in the project Contract, meeting the requirements of AASHTO M 320, except as revised in the applicable sections of Department Publication No. 37 (Bulletin 25). Obtain material from currently approved producers and sources listed in Department Publication No. 35 (Bulletin 15). If 16% or more RAP is included in the mixture or, if 5% or more RAP and 5% RAS is included in the mixture, adjust the PG-Binder grade if necessary in accordance with the requirements of Appendix H and only as recommended by the MTD. |
| 5 | **AASHTO R 35, Section 7. Determining an Initial Trial Binder Content for Each Trial Aggregate Gradation**<br><br>***Replace Note 7 with the following:***<br><br>When using RAP, RAS or a combination of RAP and RAS, the Department's modified design procedures (see Appendix H) shall be followed exclusively. |
| 6 | **AASHTO R 35, Section 10. Selecting the Design Binder Content**<br><br>***Revise Subsection 10.1 by adding the following:***<br><br>When a design using less than 16% RAP or a design using 5% RAS with no RAP is developed based on a previously approved virgin aggregate design of similar composition (gradation, aggregate source, binder content), only specimens with estimated design binder content may be necessary, as directed in the Department's modified design procedure. (see Appendix H) |
| 12 | **AASHTO M 323, Section 5. Binder Requirements**<br><br>***Revise Section 5 completely as follows:***<br><br>Delete M 323, Tables 1 and 2. Requirements are as previously specified in the Department Revisions to AASHTO R 35, Subsection 6.1 and Department Publications 242 (Chapter 5.8) and Bulletin 25. Adjustments made for RAP, RAS or a combination of RAP and RAS usage will be in accordance with the Department's requirements found in Appendix H. |

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| 13 | **AASHTO M 323, Section 6. Combined Aggregate Requirements**<br><br>***Revise Subsection 6.6 completely as follows:***<br><br>Refer to the Department's modified design procedures and requirements (see Appendix H) when RAP, RAS or a combination of RAP and RAS is used in the mixture. |

| Page Number | Content |
|---|---|
| 2 | **TIER 1 DESIGN PROCEDURE**<br>**(MIXTURES CONTAINING UP TO AND INCLUDING 15% RAP OR MIXTURES CONTAINING 5% RAS)**<br>**1. Sampling and Preparation (See Note 1)**<br>**a.** Obtain 5 to 10 representative samples of the reclaimed asphalt pavement (RAP) material or milled material or obtain 5 to 10 representative samples of the manufacturer waste recycled asphalt shingles (RAS) from different locations in the stockpile using the mini-stockpile method. The number of increments selected, should be based on the estimated variability and size of the existing stockpile. The RAP or RAS material to be sampled must be representative of the RAP or RAS product used in production (i.e. The RAP is to be crushed, broken or screened the same as would be entered into the mix. The RAS is to be shredded, screened and perhaps blended with virgin aggregate the same as would be entered into the mix.). When RAP or RAS consists of large quantities from different sources, it is recommended to keep stockpiles separated and identified by source. However, with proper management, uniform RAP can be produced using crushing and screening operations, and uniform RAS can be produced using shredding, screening and perhaps blending operations, to process RAP and RAS coming from different sources. Each sample should consist of at least 30 lbs (14 kg) of RAP or 2 lbs. (≈ 1 kg) of RAS.<br>**Note 1 -** A recommended "best practice" for assuring representative sampling of a stockpile is to randomly sample the pile as it is constructed. After an initial stockpile is established and representative samples analyzed for composition, additional RAP or RAS may be incorporated into the stockpile if the plant's QC plan satisfactorily addresses the management and frequency of additional testing to ensure uniform RAP or RAS composition on a continuous basis. |

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| 3 | **b.** Break up the RAP or RAS into small pieces similar to the AASHTO T 209 sample preparation procedure.<br><br>**c.** Scalp the RAP or RAS over the same size sieve being used during production for the mix being designed.<br><br>**d.** Dry all samples to a constant mass at 50° C. Do not overheat.<br><br>**2. RAP or RAS Gradation and Asphalt Content (n=5 to 10)**<br><br>**a.** Determine the RAP or RAS asphalt content using PTM No. 757 Section 5 or PTM No. 702 (use a specific gravity of 1.030 for the asphalt cement). PTM No. 702 is the referee method if results are questionable or greater accuracy and reliability is desired.<br><br>**b.** Determine the aggregate gradation using PTM No. 757 or PTM No. 739.<br><br>**c.** Average the test results (n=5 to 10) for asphalt content and gradation. Use the average values for design.<br><br>**3. Determination of the RAP or RAS Aggregate Bulk Specific Gravity**<br><br>a. Determine the effective specific gravity of the RAP or RAS using the following procedure and use as the bulk specific gravity for the mix design.<br><br>* Combine the remaining material from the original samples (n=5 to 10) mixing thoroughly as stated in AASHTO T 248.<br><br>* Quarter the combined material in accordance with AASHTO T 248. There will be four samples after combining and quartering.<br><br>* Split each quarter according to AASHTO T 248 to obtain the correct sample mass required for a maximum specific gravity test using AASHTO T 209.<br><br>* Determine the maximum specific gravity (Gmm) of each sample (n=4) using AASHTO T 209 as modified in Appendix I herein. Before performing the Gmm test on RAP or RAS, it is important that the RAP or RAS is prepared as follows:<br><br>1. Dry the test sample to constant mass in a forced draft oven at 110 ± 5°C (230 ± 9F).<br>2. Break up the sample similar to a standard Gmm sample.<br>3. Mix the RAP or RAS sample thoroughly to allow the old RAP or RAS binder to coat the uncoated aggregate particles.<br><br>• Determine the effective specific gravity (Gse) for each sample using the following formula, where Pb: average percent asphalt content of (n=5 to 10) samples, Gmm: maximum theoretical specific gravity, and Gb =1.03 is the binder specific gravity. |

$$G_{se} = \frac{(100-P_b)}{\left(\frac{100}{G_{mm}}\right) - \left(\frac{P_b}{G_b}\right)} = G_{sb}$$

**4. Combined Bulk Specific Gravity of Aggregate**

a. Calculate the combined aggregate bulk specific gravity (RAP or RAS aggregate and virgin aggregate) using the Gse of the RAP or RAS as the Gsb. Use only the aggregate percentage of the RAP or RAS.

Example 1: 10 % RAP with 6.0% asphalt based on the 10 samples tested and averaged, the aggregate contribution is 9.4% and the asphalt contribution is 0.6% of the total mix.

**5. Preparation of Mixture Specimens**

a. Heat the mixture containing the RAP or RAS and virgin aggregate to the mixture temperature. Weigh the RAP or RAS as a completed mass or as sieve size fractions and add to the virgin aggregate. Heat the combined virgin aggregate and RAP or RAS to the required mixing temperature in accordance with AASHTO T 312. The mixture should not be held at the mixing temperature for more than one hour. Calculate the weight of virgin asphalt to be batched (the weight of asphalt required at the individual asphalt content minus the weight of asphalt included in the RAP or RAS) and add to the heated aggregate and RAP or RAS.

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b. After laboratory mixing and prior to compaction, short-term aging is required the same as for a virgin mixture. (AASHTO T 209 as modified in Appendix I herein).

**6. Apparent Specific Gravity and Absorption of RAP or RAS Material**

a. Use the Gse calculated for the RAP or RAS as the apparent specific gravity (Gsa) and assume 0% absorption for the RAP or RAS material.

**7. Consensus Properties**

a. Use only the consensus properties of the virgin aggregate. Consensus properties (AASHTO M 323

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| | Table 5) are waived on the RAP or RAS aggregate, except Crush count requirements on the coarse aggregate will be required for RAP designs ≥ 30 million ESALS to assure crush requirements are met, unless mix is a base course. (See AASHTO R 35 Subsection 8.3 Notes 9 and 10).<br><br>**8. Mix Design**<br>a. A ≤ 15% RAP mix design or a 5% RAS mix design is formulated based on an approved virgin mix design and similar in composition (asphalt content and gradation) to the virgin design. A one-point design (See Note 4) may be sufficient for submission of the mix design for review, if the following occurs. The resulting air void content of the RAP and virgin blend or the RAS and virgin blend shall be 4% ± 0.1% . If the air void content is between 3.5% and 3.9%, or 4.1% and 4.5%, for the initial trial, then adjust the asphalt content accordingly in order to obtain the 4.0% air void content. If a 4.0% ± 0.1% air void content can be achieved by adjusting the asphalt content and the RAP or RAS mixture meets all the requirements in Chapter 2A (excluding Table 5. Superpave Aggregate Consensus Property Requirements), the one-point mix design may be submitted for approval. However, if the air void content is less than 3.5% or greater than 4.5% (based on initial testing at the optimum asphalt content of the virgin mix design) then a complete mix design produced in accordance with Chapter 2A is required.<br><br>b. After optimum asphalt content has been determined, perform moisture sensitivity testing as required in Chapter 2A.<br><br>**Note 4 -** A minimum of 3 volumetric specimens at estimated target A.C. to verify optimum A.C. for the mix is acceptable in lieu of 3 trial blends. |
| 6 | **9. Design Submittal**<br>a. In accordance with Publication 408, submit to the District Materials Engineer/Manager the following:<br><br>RAP or RAS Mix Design Information:<br><br>Table 1 (RAP or RAS) showing the gradations, asphalt contents and averages.<br><br>TR 448 Completed and Signed.<br>Volumetric Testing Summary.<br>Moisture Sensitivity Testing Summary.<br><br>Virgin Mix Design Information (Mix Used as Basis for RAP or RAS Design):<br><br>TR 448 of previously completed, reviewed and signed virgin design.<br>Moisture Sensitivity Testing Summary of previously completed, reviewed and signed virgin mix design. |
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**TIER 2 DESIGN PROCEDURE**

**(MIXTURES CONTAINING GREATER THAN 15% RAP or MIXTURES CONTAINING 5% OR MORE RAP AND 5% RAS)**

1. **Sampling and Preparation (See Note 1, page H - 1)**

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a. Obtain 5 to 10 representative samples of the reclaimed asphalt pavement (RAP) material or milled material from different locations in the stockpile using the mini-stockpile method. If combining ≥ 5% RAP with 5% manufacturer waste recycled asphalt shingles (RAS), obtain 5 to 10 representative samples of the processed RAS from different locations in the stockpile using the mini-stockpile method. The number of increments selected, should be based on the estimated variability and size of the existing stockpile. The RAP and, if used, RAS, material that is to be sampled must be representative of the RAP and RAS product used in production (i.e., The RAP is to be crushed, broken, and screened the same as would be entered into the mix. The RAS is to be shredded, screened and perhaps blended with virgin aggregate the same as would be entered into the mix.). When RAP or RAS consists of large quantities from different sources, it is recommended to keep stockpiles separated and identified by source. However, with proper management, uniform RAP can be produced using crushing and screening operations, and uniform RAS can be produced using shredding, screening and perhaps blending with virgin aggregate operations, to process RAP and RAS coming from different sources. Each sample should consist of at least 60 lbs. (27 kg) of RAP and if used, 4 lbs. (≈ 2 kg) of RAS.

b. Break up the RAP and if used, RAS (keeping it separated from the RAP) into small pieces similar to the AASHTO T 209 sampled preparation procedure.

c. Scalp the RAP and if used, RAS over the same size sieve used during production for the mix being designed.

d. Split each sample of the RAP and if used, RAS into two portions keeping the RAP and RAS materials separated. Identify both portions of each sample (ex., RAP 1A, RAP 1B, and, if used, RAS 1A, RAS 1B).

e. Save a split sample of at least 30 lbs. (14 kg) of RAP and, if used, at least 2 lbs. (≈ 1 kg) of the RAS to send to the Materials and Testing Division.

f. Retain the other split samples at the plant for testing and designing the HMA mixture containing RAP or the HMA mixture containing both RAP and RAS. (See Note 5)

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**Note 5** - When a design is anticipated to incorporate more than 20% RAP (>20%), or anticipated to incorporate greater than or equal to 10% RAP and 5% RAS, it is recommended that the mix design process required by the producer commence well in advance of the anticipated need for the proposed design, due to the potential length of time that may be required to achieve an approved mix design.

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| | **2. RAP and If Used, RAS Gradation and Asphalt Content (n=5 to 10)**<br><br>a. Follow the procedure beginning at Section 1.d of Tier 1 Design procedure and continue following the procedure in Section 2, with the following exceptions: The RAP asphalt content must be determined using PTM No. 702 if >20% RAP is used. PTM No. 702 must be used to determine asphalt content when using 10% or more RAP and 5% RAS.<br><br>**3. PG Binder Grade Evaluation**<br>a. Complete the information required in Table 1. Submit the split samples of RAP, the split samples of RAS (if used), 2 quarts of P.G. binder specified for mix application, TR 448 for the virgin mix design used as a basis for the RAP design or for the combined RAP and RAS design, proposed blend and JMF for the recycled design, and the completed Table 1 to the MTD for evaluation. If the design incorporates >20% RAP or incorporates both RAP and RAS, submit additional samples of P.G. binder that is one grade softer than the specified application.<br><br>b. The MTD will evaluate the aged asphalt in the RAP and if used, RAS, after asphalt binder recovery, and will recommend the grade of virgin asphalt cement for recycling utilizing the procedure outlined in Figure 1 and additional criteria as deemed appropriate. When >20% RAP will be incorporated in a mix, or when both RAP and RAS will be incorporated in the mix, additional analysis will typically include: more thorough evaluation of recovered RAP and RAS (if used) binder properties, relative proportions of required virgin to RAP binder or, to RAP and RAS binder, estimated asphalt film thickness calculated for the proposed mix, more detailed evaluation of long-term aging effects on both volumetric mixture properties and moisture sensitivity, and finally, a statistical evaluation of recycled material component variability based on plant QC records<br><br>**4. Determination of the RAP and RAS (If Used), Aggregate Bulk Specific Gravity**<br><br>a. Follow the procedure in Section 3 of Tier 1 Design Procedure.<br><br>**5. Combined Bulk Specific Gravity of Aggregate**<br><br>a. Follow the procedure in Section 4 of Tier 1 Design Procedure. |
| 10 | **6. Preparation of Mixture Specimen**<br>a. Follow the procedure in Section 5 of Tier 1 Design Procedure, however, note the following recommendations. Reduce the RAP by hand sieving over a 4.75 mm (No. 4) and a 2.36 mm (No. 8) sieve, resulting in the following three size fractions; the minus 2.36 mm (No. 8) sieve, the minus 4.75 mm (No. 4) sieve retained on the 2.36 mm (No. 8) sieve, and the plus 4.75 mm (No. 4) sieve material. This method can significantly reduce the potential for non-uniform or inconsistent mix |

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| | composition of completed mix specimens, which can occur when using higher percentages of RAP. If RAS is included and not pre- blended with virgin fine aggregate, combine with the minus 2.36 mm (No. 8) sieve RAP material.<br><br>**7. Apparent Specific Gravity and Absorption of RAP or RAS Material**<br><br>a. Follow the procedure in Section 6 of Tier 1 Design Procedure.<br><br>**8. Consensus Properties**<br>a. Consensus properties (AASHTO M 323, Table 5) must be determined on the RAP aggregate and mathematically combined with the virgin aggregate consensus properties in proper proportions or the combined blend of RAP aggregate and virgin aggregate in accordance with the requirements in AASHTO R 35 (See Chapter 2A, Subsection 6.9 modification to Note 6). The consensus properties on the aggregate blend using either method must meet or exceed the required consensus properties for the ESAL range the mix is intended for except as modified in AASHTO R 35 Subsection 8.3 Notes 9 and 10 and AASHTO M 323, Subsection 6.6, for RAP or RAS sand equivalent. Assume RAS aggregate consensus properties are negligible unless combined with a virgin fine aggregate as described in Note 3 of Tier 1. In this case, determine consensus properties of the blended RAS aggregate and fine aggregate. PTM No. 757 cannot be used to obtain the aggregate portion of the RAP used for the consensus property testing. PTM No. 702 is an approved method of obtaining the RAP aggregate fraction.<br><br>**9. Mix Design**<br>a. A >15% RAP mix design or, a combined RAP and RAS mix design, is to be formulated based on an approved virgin mix design and similar in composition (asphalt content and gradation) to the virgin mix design. A>15% RAP mix design or, a combined RAP and RAS mix design, requires additional work to evaluate the affect of the RAP or combined RAP and RAS on the mixture volumetric properties and moisture sensitivity. Use Chapter 2A to develop the RAP or combined RAP and RAS mix design (Complete Design Procedure).<br><br>**10. Design Submittal**<br>a. In accordance with Publication 408, submit to the District Materials Engineer/Manager the following: |
| 11 | <u>RAP Mix Design or Combined RAP and RAS Mix Design Information</u>:<br>Table 1 showing the gradations, asphalt contents and averages.<br>TR 448 Completed and Signed.<br>Volumetric Testing Summary.<br>Moisture Sensitivity Testing Summary.<br><u>Virgin Mix Design Information (Mix Used as Basis for Tier 2 Design)</u>:<br>TR 448 of previously completed, reviewed and signed virgin design.<br>Moisture Sensitivity Testing Summary of previously completed, reviewed and signed virgin mix design.<br>b. If requested by the District Materials Engineer/Manager, the MTD will provide testing and analysis of the proposed design, with recommendations. When >20% RAP will be incorporated in a mix or, when 10% or more RAP and 5% RAS will be incorporated in a mix, additional analysis will typically include: evaluation of mix volumetric properties and moisture sensitivity, following |

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| | simulated long-term aging of specimens and a statistical evaluation of recycled material component variability based on plant QC records. |
| 1 | The following data and samples are to be collected and submitted to the Bituminous Laboratory of the Materials and Testing Division (MTD) located at DGS Annex Complex, 81 Lab Lane, Harrisburg, PA 17110-2543:<br><br>**3.** Obtain and submit samples of RAP, RAS or any other modifier or additive included in the mix. Contact the MTD, Bituminous Studies Materials Manager, for the proper sample quantities to be collected for each of these materials. |

| Specification 408/2011, Section 409 | |
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| **Page Number** | **Content** |
| 1 | **341.2 MATERIAL** |
| | **(a) Reclaimed Material.** Reduce oversized materials until 95% of the material passes the 50.0 mm (2-inch) sieve. Incorporate all reclaimed material into the recycled bituminous base course. |
| | *1. RAM.* As specified in Section 703.1, Table A or 703.2, Table B. The Contractor may use RAM from the project or from stockpiles off the project. |
| | *2. RAP.* Processed paving material containing bitumen and aggregates. |
| | **(d) Mixture Design.** Take samples of reclaimed materials, and perform testing to establish the mix design. If RAM is included in the depth indicated for removal, take separate samples of RAP and RAM. Establish the mix design according to Bulletin 27, and submit the mix design to the District Materials Engineer/District Materials Manager for review at least 3 weeks before the planned start of mixture production. |
| | **(e) Mixture.** Combine the reclaimed material, aggregates, and bitumen according to the mix design and recommended optimum moisture and emulsion content. If RAP gradations and composition vary sufficiently, make field adjustments as recommended in the mix design to obtain satisfactory coating and the specified compaction. |
| 2 | **341.3 CONSTRUCTION**<br><br>**(b) Mixing**. Maintain adequate total liquids in the mixture to ensure thorough mixing of the reclaimed material and aggregates with the bituminous material. If necessary, add water at the mill head using a calibrated meter. |
| 1 | **342.2 MATERIAL—Section 341.2 and as follows:**<br><br>**(a) Stockpiling**. Store reclaimed material in a manner that preserves its quality and suitability. Separate |

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| | different types of RAP to prevent contamination. Build stockpiles in horizontal layers to minimize segregation. Keep stockpile height to a maximum of 3 m (10 ft). |
| | **342.3 CONSTRUCTION**<br><br>**(b) Mixing**. Maintain adequate total liquids in the mixture to ensure thorough mixing of the reclaimed material and aggregates with the bituminous material. Add water to the RAP by a calibrated meter, as necessary, to aid in mixing compaction. |
| 1 | **409.2 MATERIALS**<br><br>**(a) Bituminous Material**<br><br>*(1)* Virgin Mix, Mix Containing 5% to 15% RAP, or Mix Containing 5% Recycled Asphalt Shingles(RAS).<br><br>Furnish material conforming to the requirements of Standard Specifications for Performance-Graded Asphalt Binder, AASHTO M 320, except as revised in Bulletin 25. Obtain material from a source listed in Bulletin 15 for the specified grade. Provide QC testing and certification as specified in Sections 106.03(b) and 702.1(b)1.<br><br>*(2)* Mix Containing More than 15% RAP or Mix Containing Both 5% RAS and 5% or More RAP.<br><br>Furnish material conforming to the requirements of Standard Specifications for Performance-Graded Asphalt Binder, AASHTO M 320, except as revised in Bulletin 25. Obtain material from a source listed in Bulletin 15 for the specified grade. Provide QC testing and certification as specified in Sections 106.03(b) and 702.1(b)1.<br><br>**(b) Aggregate and RAM**<br><br>**1. General Requirements:** Aggregate and RAM shall conform to the quality requirements for Superpave Asphalt Mixture Design as specified in Bulletin 27. |
| 2 | **3(c) Recycled Asphalt Material**<br><br>**1. RAP.** If RAP material is proposed for use in the mixture, use at least 5% RAP consisting of cold milled or crushed hot-mix bituminous mixture. Include a plan to control RAP and the procedures to handle RAP of significantly different composition in the producer QC Plan. Maintain all processed material free of foreign materials and minimize segregation. Process the RAP so that the final mixture conforms to Section 409.2(e). |
| 4 | **1.d.2 Asphalt Content**<br>Include in the producer QC Plan a frequency of obtaining mixture samples according to PTM No. 1 and |

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| | performing asphalt content tests to verify that the mixture conforms to the tolerances of Table A. Test the samples according to either PTM No. 757, PTM No. 702, or PTM No. 742. After obtaining a minimum of three test results, determine compliance with the multiple sample tolerances in Table A. After obtaining five or more test results, determine compliance with the multiple sample tolerances in Table A using the running average of the last five consecutive test results.<br><br>Printed ticket results may be used in place of laboratory test results for QC of asphalt content of the mixture if the producer is currently approved to use printed tickets according to Bulletin 27. During mixture production, maintain 90% of printed ticket results for each day of production within 0.2 percentage points of the JMF. If RAP or RAS is used in the mixture, determine asphalt content by testing samples of the completed mixture.<br><br>**1.d.3 Gradation.**<br><br>Sample the completed mixture, or sample the combined aggregate from the hot bins of a batch plant or the combined aggregate belt of a drum plant, according to PTM No. 1 and at the frequency in the producer QC Plan. If mineral filler RAP, or RAS are used in the mixture, determine gradation by testing samples of the completed mixture.<br><br>* Test the completed mixture according to PTM No. 757 or according to PTM No. 702 and PTM No. 739.<br>* Test combined aggregate samples according to PTM No. 743.<br><br>Produce a mixture within the tolerances of Table A. Determine compliance with the multiple-sample tolerance after obtaining a minimum of three test results for the mixture. After obtaining five or more test results for the mixture, determine compliance with the multiple-sample tolerances using the running average of the last five consecutive test results. |
| 6 | **2. Mixtures with RAM, 5% or More RAP, and/or 5% RAS. Section 409.2(e)1 and as follows:**<br><br>**2.a RAM and RAP SRL**. For HMA wearing courses, limit the total combination of RAM and RAP to a maximum of 15% of the mixture by mass (weight) unless documentation of the SRL designation of the coarse aggregate in the RAM and RAP materials is provided to the DME/DMM and the RAM and RAP meet the specified SRL or can be blended for SRL as specified in Section 409.2(b)1. |

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| | **2.b RAP and/or RAS Asphalt Content and Gradation**. Determine the average asphalt content and gradation of the RAP and/or RAS stockpile(s) according to Bulletin 27. Determine the proportions of RAP, RAM, RAS, and virgin materials necessary to conform to the JMF requirements. Maintain and provide the Representative access to records of all sampling, testing, and calculations. |
| 8 | **409.3 CONSTRUCTION**<br>**(c) Bituminous Mixing Plant.**<br><br>Obtain bituminous mixtures from a plant fully automated and recordated and currently listed in Bulletin 41. The necessary facilities for inspection include a plant office as specified in Section 714.5(a), except the minimum floor space is 120 square feet. For recycled mixtures, add the following requirements:<br><br>**1. Batch Plant**. Modify the batch plant to measure the mass (weight) of the RAP and/or RAS before adding it into the pug mill. Design the cold-feed bin(s), conveyor system(s), charging chute(s), and all special bins to prevent RAP and/or RAS from segregating and sticking. Dry the virgin aggregate and RAM and then heat the virgin aggregate and RAM to a temperature that, after adding RAP and/or RAS, produces a completed mixture within the temperatures specified in Table A for the class and type of material used. Ensure that virgin aggregate is free of unburned fuel oil when delivered to the pug mill.<br><br>**2. Drum Mixer Plant.** Modify the drum mixer plant to prevent RAP and/or RAS from directly contacting the burner flame and prevent RAP and/or RAS from overheating. Design the cold-feed bin(s), conveyor system(s), charging chute(s), and all special bins to prevent RAP and/or RAS from segregating and sticking. Produce a completed mixture within the temperatures specified in Table A for the class and type of material used. |

# Publication 2 (Project Office Manual)

| PROJECT OFFICE MANUAL (POM) APRIL 2014 EDITION (PUB 2) | | | | |
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| Part | Section | POM Section Title | Page Number | Content |
| B | 1 | BORROW EXCAVATION AND WASTE AREAS | 12-2 | These (Environmental due diligence activities) do not apply to millings, which are governed under PA DEP's Industry-Wide No. 1: RECLAIMED ASPHALT PAVEMENT (RAP) INDUSTRY-WIDE COPRODUCT DETERMINATION for reclaimed asphalt pavement (RAP). |
| B | 1 | BORROW EXCAVATION AND WASTE AREAS | 12-2 | That (Clean fill determination) does not apply to millings, which are governed under PA DEP's Industry-Wide No. 1: RECLAIMED ASPHALT PAVEMENT (RAP) INDUSTRY-WIDE COPRODUCT DETERMINATION for reclaimed asphalt pavement (RAP). |
| B | 7 | MINIMUM QUALITY CONTROL PLAN FOR BITUMINOUS CONCRETE | 5-4 | **13. RAP Material**<br>**a)** Moisture Content: AASHTO T 255<br>i) Frequency: A minimum of Once Daily.<br>**b)** Extraction for AC and gradation: PTM No. 757 or PTM No. 702 and PTM No. 739<br>i) Frequency: One for each 1000 tons of RAP used or weekly.<br>**c)** Refer to POM, Part B, Section 7, Page 22-1 for additional minimum requirements when incorporating greater than 15% RAP and less than or equal to 35% RAP in a bituminous mixture. |
| | | | 5-8 | **C. Materials Storage and Handling**<br>**1.** Aggregate/RAP/RAM stockpiles. [Specification 408/409.3(c)]<br>a) Refer to POM, Part B, Section 7, Page 22-1 for additional minimum requirements when incorporating greater than 15% RAP and less than or equal to 35% RAP in a bituminous mixture.<br>**2.** Cold-feed systems for aggregates/RAP/RAM [Specification 408/409.3(c)] |
| B | 7 | BITUMINOUS PLANT RECORDS AND DOCUMENTATION | 6-2 | Producer's Documentation: RAP Burnoff Results and Moisture |

**PROJECT OFFICE MANUAL (POM) APRIL 2014 EDITION (PUB 2) - Continued**

Part B, Section 7, MINIMUM QUALITY CONTROL REQUIREMENTS FOR INCOMING RAP STOCKPILES AND PROCESSED RAP STOCKPILES AT BITUMINOUS CONCRETE PLANTS
Pages 22-1 and 22-2

These RAP stockpile requirements are a supplement to the Project Office Manual (POM), Part B, Section 7, Page 5-1, Minimum Quality Control Plan for Bituminous Concrete when a bituminous producer proposes to produce bituminous mixtures containing greater than 15% RAP and less than or equal to 35% RAP. These minimum stockpile requirements are intended for both incoming RAP material (raw RAP) and processed RAP material where the processed RAP material is processed and stockpiled prior to being incorporated into the plant production process. These minimum quality control guidelines do not address incoming RAP material that is processed in-line as part of the plant production process and directly incorporated into the plant production process.
Each bituminous concrete producer intending to produce bituminous mixtures containing greater than 15% RAP and less than or equal to 35% RAP, must include these supplemental minimum requirements in their Quality Control Plan under Section B.13., RAP Material or Section C.1., Aggregate/RAP/RAM Stockpiles of the POM, Part B, Section 7, Page 5-1.

*The following Quality Control Plan is the minimum plan designed to meet these standards:*

**A. Stockpile Preparation of Incoming RAP Material (Raw RAP)**

**1.** Prepare stockpile area by constructing a level pad. Construct the pad according to the aggregate storage requirements in Section 106.05(b) for use in bituminous concrete.

**2.** Producer is responsible to monitor the unprocessed RAP stockpile to prevent the incorporation of contaminated or deleterious material into the stock pile. This type of material must be immediately removed from the stockpile.

**3.** Do not incorporate plant waste material consisting of uncoated or partially coated aggregate material discarded from the plant during mixture transition or plant start-up.

**4.** When RAP material is to be used in wearing courses, the Producer is responsible for monitoring, documenting (SRL and quantity), and segregating (separate stockpiles) the incoming RAP material for SRL from both PennDOT projects and other projects (commercial, municipal, etc.).

**5.** For a specific designated unprocessed RAP stockpile to be utilized in a wearing course, Penn DOT will provide the producer with the SRL of the wearing course(s) to be milled from PennDOT projects (This information is typically provided in the pavement history part of the contract documents). The producer will be responsible for maintaining the integrity of the SRL for that designated stockpile.

**PROJECT OFFICE MANUAL (POM) APRIL 2014 EDITION (PUB 2) - Continued**

Part B, Section 7, MINIMUM QUALITY CONTROL REQUIREMENTS FOR INCOMING RAP STOCKPILES AND PROCESSED RAP STOCKPILES AT BITUMINOUS CONCRETE PLANTS
Pages 22-1 and 22-2

**B. Processing and Sampling of RAP Stockpile (Processed RAP)**

**1.** Prepare a stockpile area by constructing a level pad. Construct the pad according to the aggregate storage requirements in Section 106.05(b) for use in bituminous concrete.

**2.** The maximum size of aggregate in the processed RAP shall be no greater than the maximum aggregate in the JMF.

**3.** During processing, a representative sample shall be taken every 500 tons to determine the asphalt content, aggregate gradation, and effective specific gravity (Gse).

**4.** After obtaining and testing ten (10) samples, calculate the average for each individual sieve, asphalt content, and effective specific gravity (Gse) for these ten (10) samples. These calculated values will serve as a baseline for the aggregate gradation and asphalt content. Each additional RAP sample will be evaluated against the baseline criteria. If the asphalt content varies more than +/- 1.0% from the baseline value, this material will not be added to the stockpile and further production should be halted or placed on a separate stockpile until material can be produced within this guideline. If the gradation of a sample results in a significant variation from the baseline aggregate gradation; production should be halted or placed on a separate pile until the production process has been corrected. Significant variation in gradation is defined as a sample gradation that would result in the completed Bituminous or Asphalt Mixture varying outside the Section 409, Table A, multiple sample ($n \geq 3$) gradation tolerances if the processed RAP was incorporated into the completed mixture at 35%. Maintain an overall average and standard deviation of all samples for each standard sieve size, asphalt content, and the effective specific gravity (Gse) of the processed RAP stockpile.

**5.** Identify the RAP stockpile if being utilized in a wearing course for a Designated Project.

**6**. All RAP stockpiles designated for a specific project must be approved by the District before the material is utilized in the production of an approved JMF. This is to insure that the designated stockpile complies with the projects aggregate and SRL requirements.

# APPENDIX B

**WO#10**

**Deliverable for Task 2**

**Summary of Results from Reviewing NCHRP Report 752**

## What Does NCHRP Report 752 Cover?

This project was conducted in three parts. Part I involved surveying current practices for RAP management, collecting data on RAP stockpile testing, and discussing lessons learned with contractors. Analysis of that information led to the development of Appendix D and an associated webinar, which deals with RAP stockpile management and sampling. Part II focused on answering several questions about testing methods for characterizing RAP materials and preparation of materials for mix designs containing RAP. Preliminary laboratory experiments were conducted to evaluate optional methods for characterizing RAP or RAP components. Preliminary experiments were also conducted to evaluate different methods of drying and heating RAP as part of sample preparation. Part III involved evaluating a series of mix designs using sets of materials from four states. The mix designs generally were prepared in accordance with AASHTO R 35 and M 323. A series of performance tests were conducted on the mix designs to assess their resistance to the major forms of pavement distress.

## Extract from the Summary Section of NCHRP 752

- Processed RAP from multiple sources is typically more consistent than virgin aggregate. This indicates that requirements to limit RAP to single-source materials are not justified.

- The ignition method is more accurate than solvent extraction methods for determining asphalt contents, except for certain aggregate types with high mass losses when heated to the high temperatures used in the ignition method.

- Recovering RAP aggregates using either the ignition method or a solvent extraction procedure is suitable for determining the gradation, specific gravities, and Superpave consensus properties.

- Estimating the RAP aggregate Gsb by determining its Gse and estimating an asphalt absorption value is not recommended for high RAP contents because this will typically lead to a significant and unconservative error in voids in mineral aggregate (VMA) that will likely be detrimental to mixture performance.

- This study proposes to redefine"high RAP" content mixes as asphalt mixes in which 25 percent or more of the total binder is from RAP materials.

- The term "RAP binder ratio" is introduced as the ratio of the RAP binder in the mixture divided by the mixture's total binder content, expressed as a decimal to minimize confusion with the traditional RAP content expressed as a percentage.

- Heating batched samples of RAP to the mixing temperature for 1.5 to 3 hours was found to be satisfactory. Heating more than 3 hours caused additional aging of the RAP binder, which may not be apparent in volumetric mix designs but will likely impact performance-related test results.

- Fractionated RAP was necessary to meet standard Superpave criteria in AASHTO R 35 for all mix designs with 55 percent RAP.

- A limited experiment was performed to assess the effect of using a warm mix asphalt (WMA) technology and decreasing the mixing and compaction temperatures by 19°C (35°F) on a mix design with 55 percent RAP. The concern addressed by this experiment was whether or not the lower temperature might affect the activation of the RAP binder. The results showed that the WMA additive and lower temperatures had a negligible effect on the mix's volumetric properties and tensile strength ratio (TSR) results.

- Results from Dynamic Modulus tests showed that the 25 percent RAP mixes were 30 percent to 43 percent stiffer than companion virgin mixes, with the greatest differences occurring at the intermediate temperature ranges. The 55 percent RAP mixes were about 25 percent to 60 percent stiffer than the virgin mixes with the greatest difference occurring at an intermediate temperature, 21.1°C.

- Some of the high RAP content mixes did not initially meet the standard 0.80 TSR criteria, adding an anti-stripping additive generally improved the TSRs above 0.80. In all cases, the tensile strengths of the high RAP content mixes exceeded those of the virgin mixes from the same materials source. This could indicate that some consideration should also be given to minimum tensile strength values to help assess moisture-damage potential.

- High RAP content mixes had significantly lower fracture energies than corresponding virgin mixes.

- Mixes with smaller nominal maximum aggregate size (NMAS) mixes also had better fracture energy than larger NMAS mixes.

| Part I - Management and Stockpiling | | |
|---|---|---|
| Action | From NCHRP 752 | Page |
| RAP Management | Some references have recommended not combining RAP collected from different sources due to concerns that it will result in greater variability in the RAP stockpile. Milled RAP from a single project typically will have a consistent gradation and asphalt content. Such stockpiles of single-source RAP generally require only screening to remove oversized particles. It is generally accepted that RAP particles larger than 2 inches should be screened out because the larger particles (chunks of pavement or agglomerations) may not break apart during the mixing process. | 92 |
| | Several previous studies and data collected from contractors during this project have shown that processing RAP collected from multiple sources can result in a material that is often more consistent than virgin aggregate. | 92 |
| Processing RAP | A summary of different processes used to produce a consistent RAP product is shown in Table 4-1. It is often appropriate to combine different processes, such as mixing and crushing. A common mistake in RAP processing is to crush all RAP to pass a single screen size (e.g., minus ½-inch) so that the RAP can be used in mixes with a range of nominal maximum aggregate sizes. This single-size crushing approach often leads to generating high dust contents, which can limit the amount of the RAP that can be successfully used in mix designs. | 92 |
| | Contamination of RAP stockpiles is a common complaint. Contamination is best avoided by inspecting the materials before they are unloaded on the unprocessed stockpile. Contaminated materials are better suited for use as shoulder fill or other non-asphalt mix applications. | 92 |
| | Regardless of how the RAP is collected, processed, or stored, it should be sampled and tested on a routine basis to assess uniformity. A sampling and testing frequency of one per 1,000 tons is consistent with QC requirements for virgin aggregates and will provide sufficient information to determine whether a problem exists with the material's consistency. | 92 |
| RAP Stockpiling | RAP should be stockpiled such that its moisture content and segregation are minimized. Large conical stockpiles are commonly used for convenience, and they may tend to help shed precipitation, but they are more prone to segregation. Covering stockpiles and placing them on a sloped surface to drain water away from the side used to feed the plant can help reduce moisture contents. Bunkers (two- or three-walled partitions) can help reduce segregation. | 25 |

| Part II Preliminary Experiments Characterizing RAP Materials for Mix Design | | | |
|---|---|---|---|
| **Experiment** | **Purpose** | **Notes** | **Conclusion/Recommendation** |
| RAP Drying Experiment | To determine if the drying procedures had affected its(RAP Binder) PG true grade. | - | About 6 hours were necessary to dry the approximately 24 kg samples using a conventional drying oven temperature of 110°C (230°F) from an initial moisture content of about 5.3 percent. Fan drying at ambient temperature took about 96 hours. The binders recovered from the RAP samples dried by the two methods had similar PG critical temperatures. This indicates that oven drying at 110°C for about 6 hours did not further age the RAP binder. |
| RAP Heating Experiment | (1) To determine how much time is needed for a sample of RAP to reach the set point temperature for mixing. | The sample size used in this experiment was 2,500 grams, which is representative of the sample size needed to make a Superpave gyratory sample with 50 percent RAP. In this experiment, a typical forced-draft oven was set to 182°C (360°F). Ambient temperature RAP samples were placed in the oven and monitored to determine when the samples reached the oven set point temperature. | A RAP sample reaches the oven set point temperature in about 1½ hours. Other ovens may take a little more or less time. |
| | (2) To evaluate how different methods of heating RAP may affect the characteristics of the RAP binder. | A 50/50 blend of RAP with 4.9% binder content and virgin aggregate was prepared using four heating scenarios. No virgin binder was added. The blend was mixed for 2 minutes following the heating scenarios. The binder was extracted in accordance with AASHTO T 164 using trichloroethylene and recovered using the rotary evaporator apparatus following ASTM D 6847. The grading was done in accordance with AASHTO R 29. The results from heating scenarios were compared to the performance grade of the RAP binder before heating. | The following heating scenario resulted in the least aging of the RAP binder: Virgin aggregate was heated in an oven at 179°C (355°F) for 3 hours, and the RAP was heated in an oven at 179°C (355°F) for 30 minutes. The critical high temperature of the recovered binder from this scenario is practically the same as for the original RAP. The critical low temperature was a few degrees lower than the original RAP. The difference was attributed to possible experimental error. The results of the two heating experiments indicate that an appropriate heating condition for RAP in preparation for making mix design samples is to place the batched RAP samples in an oven for 1½ to 3 hours. |

| Part II Preliminary Experiments Characterizing RAP Materials for Mix Design - Continued | | | |
|---|---|---|---|
| **Experiment** | **Purpose** | **Notes** | **Conclusion/Recommendation** |
| RAP Aggregate Bulk Specific Gravity Experiment | To determine which method should be used for determining the bulk specific gravity of the RAP aggregate. | Three approaches were used for determining the RAP aggregate bulk specific gravity. In method 1, the RAP aggregate was recovered from the centrifuge extraction procedure using trichloroethylene (AASHTO T 164). In method 2, the RAP aggregate was recovered using the ignition method (AASHTO T 308). The recovered RAP aggregates were then tested in accordance with AASHTO T 84 and/or T 85, for fine and coarse aggregate portions, respectively. In method 3, the RAP aggregate bulk specific gravity was back calculated as described in NCHRP Report 452. | Methods 1 (AASHTO T 164) and 2 (AASHTO T 308) provided similar Gsb values, but Method 3 (backcalculation method) provided substantially different Gsb values from a practical point of view. The RAP aggregate Gsb values determined from the centrifuge –T 84/T85 approach were used in determining volumetric properties for the project mixes. The ignition – T 84/T85 approach would also have been acceptable based on these findings. |

| Part III High RAP Content Mix Design | |
|---|---|
| **Materials** | The experimental plan used materials from four locations in the United States. The materials from the four locations included a variety of aggregate types, binder grades, and from contractors' stockpiles in New Hampshire, Utah, Minnesota, and Florida. The contractors also provided samples of the virgin binders they typically use. |
| **Material Characterization** | The materials were characterized as normally done for Superpave mix designs. Virgin aggregates were tested as received for gradation and Superpave aggregate consensus properties. RAP samples were tested to determine asphalt content in accordance with the ignition method, AASHTO T 308, and the centrifuge extraction method, AASHTO T 164. The RAP aggregates were retained following the extraction tests for gradations, consensus properties, and specific gravity tests. The recovered aggregates from the ignition method were also retained for gradation and bulk specific gravity. AASHTO T 84 and T 85 were used to determine the specific gravity of the recovered RAP aggregate, split on the No. 4 sieve for fine and coarse portions, respectively. Trichloroethylene was used as the solvent for the extractions. RAP binders were recovered with a rotary evaporator in accordance with ASTM D5404 and performance graded in accordance with AASHTO M 320-05. The nine virgin asphalt binders received from the four locations were also graded in accordance with AASHTO M 320-05 |
| **Mix Designs** | The objective of the mix design effort was to meet the standard Superpave mix design criteria using the materials provided by contractors in four states. For two sets of materials, the goal was to develop 12.5 mm NMAS mix designs with 0, 25, and 55 percent RAP (by weight of aggregate). For the other two sets, the goal was to develop 9.5 mm and 19.0 mm NMAS mix designs using 0 and 40 percent RAP (by weight of aggregate). One laboratory compactive effort (75 gyrations) was used for all mixes to reduce experimental factors in the study. The approach to designing the high RAP content mixes in this study followed the familiar steps from the current Superpave approach with some additional testing of the component materials and performance testing. A total of 30 mixes were designed, tested, and evaluated in this study. A warm mix asphalt technology was also used with one mix design to evaluate the effects of the lower mixing and compaction temperatures on mix properties. Mixes of different nominal maximum aggregate sizes (NMAS) were used to assess the effects of RAP on base, intermediate, and surface mixes. Some of the mix designs were changed only by using a different binder source without changing the PG grade to determine if compatibility of binders would affect mix properties. Mix designs differing only by polymer modification of the virgin binder were also prepared and tested to determine how polymer-modified binders may affect mixes containing RAP. |

| Part III High RAP Content Performance Testing | | |
|---|---|---|
| **Test** | **Purpose** | **Notes** |
| Dynamic Modulus | The first purpose was to evaluate how changing binder grade, binder source, and RAP content affects mix stiffness over a wide range of temperatures. The second purpose was to try to backcalculate the effective properties of the composite binder using the approach described by Bennert and Dongre. | The test was conducted in accordance with AASHTO TP 62-07 using an IPC Global asphalt mixture performance tester to identify which mix component(s) significantly affect the dynamic modulus values. Also, the following three types of mastercurves were compared to evaluate the amount of blending: 1. the \|G*\| master curves backcalculated from the mixture testing , 2. the \|G*\| master curves measured on the recovered binder from the mix and RAP, and 3. the virgin binder master curves were compared to evaluate the amount of blending. |
| Moisture Susceptibility Testing | To evaluate moisture susceptibility of the mixtures. | The test was performed in accordance with AASHTO T 283-07, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage. |
| Flow Number Testing | To evaluate the rutting potential of asphalt mix designs. To evaluate whether the mixes containing RAP yield results similar to the virgin control mixes. | A test procedure based on recommendations from NCHRP Project 9-30A and FHWA was used. |
| Fatigue Cracking Testing | To evaluate mix designs for resistance to fatigue cracking. | The indirect tensile (IDT) fracture energy test was used. |
| Low-Temperature Cracking Testing | To obtain relevant properties related to the fracture resistance, thermal stress accumulation, and critical low temperature for the mixtures tested. | The semi-circular bend (SCB) fracture test and bending beam rheometer (BBR) creep test were used. |

| Summary of Part III |
| --- |
| The experimental results to determine whether changing the binder grade or binder source affects mix design volumetric properties were not conclusive. |
| Changing the virgin binder source or the virgin binder grade had a negligible effect. This issue is only important if a mix designer completed a mix design with one binder, then wanted to change to another binder source due to supply or economic reasons, or to change binder grades to try to improve mix performance properties. |
| The impact of using WMA and a lower mixing temperature with a high RAP content mix was very limited since WMA was included as a variable with only one mix design containing 55 percent RAP. Including a WMA additive and decreasing the mixing and compaction temperatures by 19°C (35°F) had a negligible effect on the mix's volumetric properties and TSR results. The WMA mix had slightly better rutting test results and the fatigue results were similar to that of the HMA. The dynamic modulus of the WMA was 6 to 15 percent lower than the HMA, with the larger difference observed at the higher temperature range. |
| Dynamic modulus was significantly affected by RAP content and source. Compared to the virgin mixes, stiffnesses of the 25 percent RAP mixes were about 30 to 43 percent higher, with the greatest differences occurring at the intermediate temperature ranges. The 55 percent RAP mixes were about 25 to 60 percent stiffer than the virgin mixes with the greatest difference occurring at 21.1°C. Virgin binder source was significant at 21.1°C. Virgin binder grade was significant at 37.8°C and for results at the lowest frequency. |
| The analyses of backcalculated effective binder properties using dynamic modulus test results and the Hirsch model clearly show that this process did not provide useful results. |
| The mix designs' resistance to moisture damage was evaluated by AASHTO T 283. Several of the high RAP content mixes did not meet the standard 0.80 TSR criteria. Adding an antistripping additive was usually sufficient to improve the TSR above 0.80. In all cases, the conditioned and unconditioned tensile strengths of the high RAP content mixes exceeded those of the virgin mixes from the same materials source. This is a good argument to support the case that TSR values should not solely be used to assess moisture-damage potential. A few states allow a lower TSR criteria if the tensile strengths are maintained above a certain threshold. States that use a softer PG grade of binder would need to use a lower tensile strength criterion. |
| The confined flow number test was performed on the mix designs to assess their resistance to permanent deformation. Using the confined test, none of the samples exhibited tertiary deformation. Therefore, analysis of rutting resistance was based on the total accumulated strain at 20,000 cycles. All of the mixtures had less than 50,000 microstrain, or 5 percent strain. An ANOVA indicated that the total strain was significantly affected by the source of the materials and the high performance grade of the virgin binder, but not RAP content. |

| |
| --- |
| Mix designs were evaluated for resistance to fatigue cracking based on fracture energy determined from indirect tensile strength tests. Specimens were long-term oven-aged before testing. Fracture energy is the amount of strain energy and dissipated energy a mixture can absorb up to the point when cracking is initiated. The fracture energy results showed that the virgin mixes have significantly better fracture energy than high RAP content mixes. Smaller NMAS mixes also had better fracture energy than larger NMAS mixes. |

**Summary of Part III - Continued**

Resistance to thermal cracking was evaluated with two tests: the low-temperature semi-circular bend (SCB) test and the bending beam rheometer (BBR) test on small mix beams cut from gyratory-compacted specimens. The SCB test yields two properties: fracture toughness and fracture energy. Ideally, mixes with high fracture toughness and fracture energy would be expected to perform better than mixes with low fracture properties. However, the experimental results from the SCB test were conflicting. Compared to the corresponding virgin mixes, the high RAP content mixes generally had higher fracture toughness but similar, or lower, fracture energy results. For the BBR results, mixes with RAP generally had higher stiffness and lower m-values, which theoretically should result in more cracking. Yet further analysis of the critical cracking temperatures for the climates where the materials were obtained indicates that the high RAP content mixes would perform similarly to the corresponding virgin mixes with regard to thermal cracking.

| NCHRP 752 Proposed Recommendations |
|---|
| Based on the findings from the literature review and the results of the experimental work, the following recommendations are offered. |

| Item | NCHRP 752 Recommendation | Page |
|---|---|---|
| 1 | The research team proposes to redefine high RAP content mixes as asphalt mixes in which 25 percent or more of the total binder is from RAP materials or, in other words, asphalt mixes having a RAP binder ratio $\geq 0.25$. | 96 |
| 2 | RAP stockpiles should be sampled for quality control testing and characterizing the RAP for mix designs with the aid of a loader or other power equipment to make miniature sampling stockpiles. The miniature sampling stockpiles shall be flattened using the equipment blade and a back-dragging technique. Each sample shall be obtained by taking at least three portions from the flattened surface with a square-ended shovel. The miniature stockpile sampling method will minimize variations in samples due to segregation. This technique shall be repeated at different locations around the main RAP stockpile. Do not combine samples obtained from different locations around the main stockpile since they will be used to determine the amount of variability within the main stockpile. Reduce samples to appropriate test-size portions using the mechanical splitter method described in AASHTO R 47. | 96 |
| 3 | Figure 4-1 shows a flow chart for the proposed sampling and testing of RAP stockpiles for high RAP content mix designs. Table 4-2 provides the proposed test methods, sampling frequencies, and variability guidelines. | 96 |
| 4 | The study found that the current standards for Superpave mix design are applicable to high-RAP content mixes with a few minor but important changes, as discussed below. The proposed revisions to AASHTO R 35 and M 323 are shown in Appendixes B and C, respectively. | 96 |

**NCHRP 752 Proposed Recommendations - Continued**

| Item | NCHRP 752 Recommendation | Page |
|---|---|---|
| 5 | Selection of the grade of virgin binder for high RAP content mixes should be based on knowledge of the true grade of the RAP binder, the high and low critical temperatures for the project location and pavement layer, and one of the following:<br><br>a. The approximate ratio of RAP binder divided by the total binder content or<br><br>b. The high and low critical temperatures for the available virgin binder(s).<br><br>If the RAP binder ratio (RBR) is known, determine the appropriate virgin binder grade using the following formula:<br><br>$$T_c(virgin) = \frac{T_c(need) - (RBR \times T_c(RAP\ Binder))}{(1 - \mathrm{RBR})} \quad [4\text{-}1]$$<br><br>where<br><br>Tc(virgin) = critical temperature (high or low) of the virgin asphalt binder.<br><br>Tc(need) = critical temperature (high or low) needed for the climate and pavement layer.<br><br>RBR = RAP Binder Ratio - the ratio of the RAP binder in the mixture divided by the mixture's total binder content. The mixture's total binder content is an unknown prior to mix design but can be estimated based on historical data for the aggregate type and NMAS.<br><br>Tc(RAP Binder) = Critical temperature (high or low) of the RAP binder determined from extraction, recovery, and PG grading.<br><br>If the virgin binder grade is known, determine the maximum RAP binder ratio using the following formula:<br><br>$$RBR_{max} = \frac{T_c(need) - T_c(virgin)}{T_c(RAP\ Binder) - T_c(virgin)} \quad [4\text{-}2]$$ | 96 and 97 |

**NCHRP 752 Proposed Recommendations - Continued**

| Item | NCHRP 752 Recommendation | Page |
|---|---|---|
| 6 | At the present time, agencies should require moisture damage testing of mix designs incorporating RAP, regardless of RAP content. Agencies should specify either AASHTO T 324 (Hamburg), AASHTO T 283 (TSR) or some variation thereof, as well as appropriate criteria based on historical performance. A rutting test for high RBR mixes seems unnecessary unless a softer grade of virgin binder or rejuvenator is used. In that case, one of several suitable tests could be required, including AASHTO TP 63-07 (Asphalt Pavement Analyzer), AASHTO T 324 (Hamburg), or AASHTO TP 62-07 (Flow Number). If the flow number test is selected, the unconfined test and the criteria recommended in NCHRP Report 673 or NCHRP Report 691, for HMA or WMA, respectively, should be followed. For high RBR surface mixes to be used in climates prone to thermal cracking, agencies may consider either the SCB test, as used in this study, or the disc-shaped compact tension (DCT) test for assessing low-temperature properties. The national pooled-fund study Investigation of Low Temperature Cracking in Asphalt Pavements, Phase II (71) recommended these procedures and accompanying specification criteria as well as an improved thermal cracking model for asphalt pavements. Although no fatigue test can be recommended at this time, it is an important need and worthy of further research and development. The use of any test to assess load-related cracking potential of asphalt mixes, regardless of RAP content, should be done only to gather additional information on the resulting properties of mixes and not to accept or reject mixes until further research is able to establish how the property is related to field performance. | 97 |

**Important Tables and Figures Related to RAP Processing, Sampling, and Characterization**

## Table 4-1. Summary of RAP processing options.

| Type | Description | Suitable Conditions | Possible Concerns |
|---|---|---|---|
| Minimal Processing | Screening only to remove oversized particles (may be accomplished in line during feed of RAP in the plant) | RAP from a single source | Single-source RAP piles are a finite quantity—when a stockpile is depleted, new mix designs will be needed with another RAP stockpile |
| Crushing | Breaking of RAP chunks, agglomerations, and/or aggregate particles in order to avoid large particles that may not break apart during mixing or particles that exceed the mix's NMAS | RAP contains large chunks (anything larger than 2") or RAP aggregate NMAS exceeds the recycled mix's NMAS | Generating excess dust and uncoated surfaces |
| Mixing | Using a loader or excavator to blend RAP from different sources; usually done in combination with crushing and/or fractionating | RAP stockpile contains materials from multiple sources | Good consistency of RAP characteristics must be verified with a RAP QC plan |
| Fractionating | Screening RAP into multiple size ranges | High RAP content mixes (above 30 to 40%) are routine | Highest cost, requires additional RAP bin(s) to simultaneously feed multiple fractions |

## Table 4-2. Proposed RAP sampling and testing guidelines for high RAP content mixes.

| Property | Test Method(s) | Frequency | Minimum Number of Tests per Stockpile | Maximum Standard Deviation |
|---|---|---|---|---|
| Asphalt Content | AASHTO T 164 or AASHTO T 308 | 1 per 1,000 tons | 10 | 0.5 |
| Recovered Aggregate Gradation* | AASHTO T 30 | 1 per 1,000 tons | 10 | 5.0 all sieves<br>1.5 on 75 micron |
| Recovered Aggregate Bulk Specific Gravity | AASHTO T 84 and T 85 | 1 per 3,000 tons | 3 | 0.030** |
| Binder Recovery and PG Grading | AASHTO T 319 or ASTM D5404 and AASHTO R 29 | 1 per 5,000 tons | 1 | n.a. |

* Samples for Superpave aggregate consensus properties or other aggregate testing needs may be obtained by combining the tested aggregates following sieve analyses.

**This is a preliminary value based on limited data and possible impacts to VMA for high RAP content mixes.

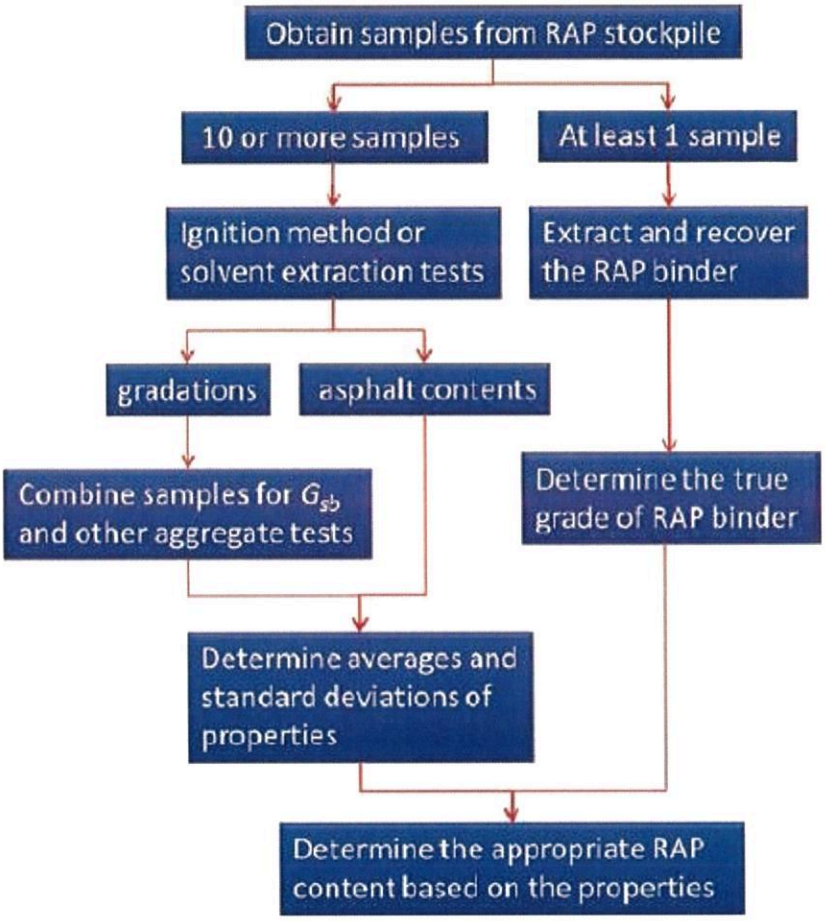


*Figure 4-1. Flow chart for proposed sampling and testing RAP stockpiles.*

# APPENDIX C

**WO#10**
**Deliverable for Task 5**
**Implementation Plan**

## Table of Contents

## INTRODUCTION

Using reclaimed asphalt pavement (RAP) in construction of new pavements has been a practice for decades. The Federal Highway Administration (FHWA) and many state highway agencies have been pursuing usage of high RAP content in asphalt mixes. Within the last decade, there has been a good amount of research and development on high RAP asphalt mixes in terms of design, construction, and performance. Under a PennDOT-sponsored project, Penn State was charged with reviewing and revising some of the PennDOT publications that could be affected by recent findings in regard to RAP usage. The PennDOT documents that were affected by these practices were Publication 27, Specification 408, and Publication 2. Most of the changes incorporated into PennDOT publications were applicable to the RAP usage. However, the changes also covered usage of recycled asphalt shingles (RAS).

Part of the work under this research was to develop a plan for implementation of the new specification changes on the usage of RAP/RAS. This report provides guidance on such a plan.

## OBJECTIVE

The objective of this work is to develop a plan for implementation of revised PennDOT specifications dealing with the usage of RAP and RAS. The plan contains the critical steps in conducting a series of pilot projects as a prerequisite for full implementation.

## IMPLEMENTATION PLAN AND APPROACH

Full implementation of the PennDOT revised specifications requires planning and taking a sequence of steps to ensure success of the system. Preparation and planning must be well thought out and developed before action. Lack of planning, without having a clear vision of the goal and the approach that needs to be taken, will probably lead to failure of the implementation program. Expectations must be realistic in regard to time and the requirements, as the change in mix production using RAP/RAS under new specifications will probably cause some anxiety initially. Partial implementation, such as using pilot projects, increases the chances of success before going the full implemetation route. The plan is proposed to include eight crititcal steps.

1. Identify Requirements for Implementation
2. Identify Producers
3. Conduct Pre-implementation Orientation
4. Develop Implementation Schedule
5. Develop/Execute Performance Monitoring
6. Develop/Execute Measures of Success
7. Conduct Post-Implementation Meeting
8. Conduct Technology Transfer/Training

### *Identify Requirements for Implementation and the Scope*

The first step to a successful implementation will be to set a clear roadmap. Before action takes place in production, it is essential to identify the requirements, the goal, and the path that needs to be taken. Decisions need to be made regarding the number of pilot projects and the number of producers to carry out those projects. Decisions also need to be made with respect to the mix design tiers for production of the pilot projects, and the number of trials for each tier. An example scenario is provided in Table 1.

**Table 1. Proposed Matrix for Partial Implementation through Pilot Projects**

| Producer/Contractor | Design Tiers based on RBR[1] | RAP or RAS |
|---|---|---|
| 1 | 1, 2, and 3 | RAP-only Projects |
| 2 | 2 and 3 | RAP/RAS Projects |
| 3 | 2 and 3 | RAS-only Projects |

[1] *RBR: Reclaimed Asphalt Binder Ratio*

It is best if each producer starts with the lower design tier to reduce the risk and better absorb the applied changes in specifications. Once the lower tier is implemented, then a move can be made to the next level.

In support of plan requirements, the scope of the work must be defined. For example, it must be decided whether the execution and monitoring of the plan will be only focused on RAP/RAS usage in mix design and during production, or if it will also include analysis of results from mixture testing.

### *Identify Producers*

Producers that have a high level of experience in usage of RAP or RAP/RAS in asphalt mix production must be identified and contacted to solicit their willingness to participate in the implementation plan. The producers must be provided with details of requirements and how the work conducted under this implementation plan as pilot projects will be assessed. Obviously, producers must evaluate the availability of time and resources as well as the cost involved for such implementation before commitment and taking action.

### *Pre-implementation Orientation*

Once producers have been identified and accepted to conduct the pilot projects, a meeting should be established to review the requirements, specifications, and the process that must be followed. Such a meeting is essential to ensure there is a clear understanding of specification requirements, especially requirements on testing and sampling. The scope of work must be clearly defined and communicated at this meeting. Otherwise, misunderstandings can result with a possibly painful experience for all.

### *Identify Constraints/Risks*

The pre-implementation meeting is also the place to discuss any potential constraints and risks to successful implementation of the plan. Any constraints in time, space, and resources must be identified and addressed before attempting the implementation. As thoroughly as possible, the key players must attempt to identify the risks and the approach to be taken in responding to those risks. Contingency plans may be needed in case of risks with large impact. Such a risk management plan includes actions to be taken if, as the projects progresses, it appears that changes are needed.

### *Develop Working Document and Implementation Schedule*

The results from meetings with producers, and identification of risks, constraints, and contingency plans should result in a useable document to be used for carrying out the pilot projects. A time frame must be set to conduct the pilot projects, evaluate the results, and assess the success of the projects. The time for execution of the plan must be realistic, and be communicated and coordinated with the producer/contractor. This time frame should also include the time needed for subsequent training and technology transfer.

### *Performance Monitoring*

Proper and detailed documentation through every step of the process is vital for this implementation plan. Pilot projects are at the forefront of this implementation, and will possibly run into issues that could not have been anticipated in the beginning. Tracking details of relevant activities and making diligent record of observations during production and placement will assist with any further modifications needed to specifications. A documentation form could be developed to be used for inclusion of important details, and to assist the personnel involved with the project for proper recording of the whole process. Regular communication among parties involved with implementation will be vital during performance monitoring.

### *Metrics/Benchmark to Measure Success*

Upon completion of the pilot projects, it is important to assess the level of success; as such, assessment will help in any further modifications to specifications before full implementation. It is often difficult to quantify the level of success for projects of this nature, and to establish well-defined, quantified metrics to measure success. Possibly, the best approach will be to consider a combination of comments from personnel involved in production during pilot projects, which cannot be properly quantified, with quantifiable measures such as test results before and after production, and percent within limits found for different parameters. Another important measure of success will be the impact of new specifications on the required time for design and production, the level of resources needed, and the cost of implementation. Furthermore, if the pilot program includes all seven projects, as proposed in Table 1, one could also determine the success rate, by determining which projects out of the seven could be considered a success. In any event, a group must be formed to develop acceptance criteria and interpret/analyze data and information gathered under performance monitoring.

### *Post-Implementation Meeting*

Upon completion of pilot projects, a meeting should be established among all parties involved to review the projects, positive and negative outcomes, and shortcomings. Discussion should be made on the experience, what was learned from the projects, and suggestions for modifications to specifications.

### *Technology Transfer/Training*

The outcome of the pilot projects may or may not lead to revision of specifications. In either case, full implementation will hinge not only on the results from the pilot projects, but also on proper training and technology transfer. A half-day and a full-day course should be developed in the form of PowerPoint presentation, along with handouts, to review RAP/RAP usage and the new specifications. The audience of the short course could be the upper management level. The longer course will be targeted towards technicians and personnel directly involved with the production of mixes.