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Improved Performance of Reclaimed Asphalt Pavement Mixes

Study SD2011-08
Final Report

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DISCLAIMER

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16. Abstract

Utilization of RAP in asphalt pavements has become an important strategy to help offset rising raw material prices and to improve the sustainability of our transportation infrastructure. The South Dakota DOT began to routinely use RAP in main-line asphalt surfaces in 2007. However, some of these pavements have not performed satisfactory, often exhibiting premature raveling and cracking. This prompted the SDDOT to commission this study to identify current practices and specifications that could be improved. The research team reviewed the department's current policies, specification, and procedures as well as the current state of knowledge related to RAP use from recent research and neighboring highway departments. The researchers also reviewed mix design and quality assurance data from a few of the poor performing projects. The research team found that most of SDDOT's current practices regarding RAP use are appropriate, but made several recommendations to better characterize RAP materials during mix design and to verify those characteristics during mixture production. To improve the performance and durability of the mixes containing RAP, a small change in the target air void content during mix design is recommended that will result in slightly higher asphalt contents.

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Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
DOT	Department of Transportation
FAQ	Frequently Asked Questions
FHWA	Federal Highway Administration
G_{sb}	Bulk specific gravity
LTPP	Long Term Pavement Performance
N_{ini}	Initial number of gyrations at which the relative density is evaluated
N_{max}	Maximum number of gyrations at which the relative density is evaluated
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology
NMAS	Nominal maximum aggregate size
SDDOT	South Dakota Department of Transportation
RAP	Reclaimed Asphalt Pavement
VMA	Voids in Mineral Aggregate: the intergranular space occupied by asphalt and air in a compacted asphalt mixture.

1.0 EXECUTIVE SUMMARY

1.1 Background

Greater use of Reclaimed Asphalt Pavement (RAP) in highway construction and rehabilitation projects has become an important strategy to help offset rising costs of raw materials and to improve the sustainability of our surface transportation infrastructure. While most state DOTs have been using RAP in asphalt mixtures for many years, the South Dakota Department of Transportation (SDDOT) began to routinely use RAP in main-line asphalt surfaces in 2007. This practice has resulted in an estimated savings of over $26 million in raw materials costs over the first five years. However, some pavements containing RAP have not performed satisfactorily in South Dakota, often exhibiting premature raveling and cracking. This prompted the SDDOT to commission this study to identify current practices and specifications that could be improved.

1.2 Literature Search

A wide range of useful information was found regarding the use of RAP in asphalt mixtures. Recent surveys indicate that SDDOT's use of 20% RAP in main-line surface mixes is among the highest in the nation.

Recent NCHRP studies and other references have provided guidance on best practices for management of RAP materials, how to determine RAP properties, and how to conduct mix designs using RAP as a mix component. Although the question about the degree of blending that occurs between the RAP binders and virgin binders has not been completely answered, most research studies indicate that the issue is insignificant for RAP contents below about 25% as is the case for South Dakota.

Another important finding came from an analysis of overlays with 30% RAP and all virgin mixes in the LTPP database. Comparisons of field performance data from projects across North America showed that there was not a significant difference in pavement performance measures or service lives for the virgin and RAP mixes.

1.3 Current State of Practice in South Dakota Regarding RAP

Like several other state highway agencies in the Great Plains region, South Dakota takes ownership of millings from projects and pays only for virgin asphalt binder as a separate item from mixes. In effect, these practices tend to demotivate contractors to use RAP.

Perhaps the most unusual practice in South Dakota is that when RAP is used in a new mix, the DOT directs the contractor to use a specific RAP percentage. This policy can be very challenging for contractors since it is both a method specification and an end-result specification. The method part of the specification is the requirement for what material and how much of it shall be used; the end-result specification is enforcing the normal pay item QA requirements such as lab compacted air voids and in-place density.

Like many western US states, the majority of projects in South Dakota are built with portable asphalt plants. This reality puts a high priority on how raw materials are handled. Maintaining the right balance and inventory of raw materials to meet the mix requirements within a single project is a significant logistical challenge since left over materials are a liability rather than an asset and a shortage of any mix component stops all work progress.

Although the research team was unable to observe any contractor's RAP management practices. Interviews with agency and industry stakeholders indicate that contractors working in South Dakota are already following most of the best practices for stockpiling and handling RAP at plants. Given that the RAP is coming directly from milling operations on same projects, there is an expectation that the material is very consistent. However, there is a current lack of testing to verify that assumption.

1.4 Investigation of Poor Performing RAP Projects

SDDOT personnel identified at least seven poor performing projects built between 2009 and 2011 that used Q2 mixes with 20% RAP. Nearly all of the projects were located in the southeastern part of the state. The most common issues with these projects were (1) difficulty in obtaining the required in-place density on the roadway, (2) a "dry" appearance of the mixes, and (3) premature raveling of the pavement surface. Mix design and QC/QA data were obtained from SDDOT for four of these projects for further analysis. In general, the root cause of problems for most of the projects appeared to be slightly low asphalt contents for the mix designs. High dust contents in the virgin aggregates also may have contributed to the problem on at least one job. A few issues with SDDOT's current mix design practices were identified.

1.5 Recommendations

The goal of this research project was to identify opportunities for improving the performance of asphalt mixes containing RAP. Recommendations are provided in four areas: (1) General Practices and Specifications, (2) RAP Characterization and Mix Design, (3) RAP Management, and (4) Asphalt Mixture Production and Quality Assurance for Mixes Containing RAP.

1.5.1 General Practices and Specifications

1. Milling depths for pavement rehabilitation should be selected to satisfy a specific need on the project such as improving the roadway profile, correcting cross slope, maintaining roadway cross-section/pavement width, and/or removing distressed pavement layers. Milling is generally beneficial for the performance of overlays in most cases, but there may be situations where a thicker pavement is needed to carry the expected traffic over soft underlying materials.
2. When there is excess RAP on a project, do not use it or sell it for aggregate or shoulder fill. Stockpile the excess RAP near the job site for future use. Using RAP as an unbound fill material loses the value of the asphalt binder in the RAP. Since RAP asphalt can be reactivated in an asphalt plant, its greatest value is when it is reused in an asphalt mixture.
3. Specific RAP contents should not be specified. Rather, *maximum* RAP contents should be specified which would allow contractors to use RAP contents below the maximum limit in order to meet mix design and/or QC/QA criteria. Reasonable maximum RAP limits for Q mixes, HR mixes, and all other mixes are 20%, 30%, and 15%, respectively. As SDDOT and contractors become comfortable with the production and field performance of mixes with these RAP contents, consideration should be given to increasing those limits.
4. Make the following revisions to **Special Provision for Gyratory Controlled Quality Control/Quality Assurance Specifications for Hot Mixed Asphalt Concrete Pavement.**

   A. Composition of Mixtures

   Delete [Unless otherwise specified in the plans, no reclaimed asphalt pavements (RAP) are allowed in Gyratory Controlled QC/QA hot mixed asphalt pavements.]

Add [Up to 20% RAP may be included in asphalt mixtures unless otherwise noted in the plans provided that all SDDOT mix design and QC/QA requirements are met.]

Add [The mixture shall not contain any particles (including agglomerations of RAP) greater than one inch at the point of discharge from the mixer. This shall be checked at by sampling the mixture at the discharge and immediately screening the sample over a standard 1-inch {25.0 mm} laboratory sieve.]

B. Equipment

Add [Mixtures containing incompletely coated particles that are evident at the time of discharge from the plant or thereafter shall be rejected. Appropriate adjustments shall be immediately made in the production of mixtures to ensure the mixture is completely coated at the time of discharge from the plant.]

1.5.2 RAP Characterization and Mix Design

5. Following the determination of the milling depth for the pavement rehabilitation and prior to the development of the project plans, the SDDOT (or an independent contracted firm) should obtain samples of RAP from the roadway. The most practical best practice is to use a skid steer with a milling attachment to obtain representative samples throughout the project. The samples should be large enough for the department/firm to test the RAP for gradation and asphalt content and retain materials for the winning contractor to use in the mix designs. The asphalt contents and gradations of the samples should be provided in the project plan notes. This will provide contractors more information from which to bid the project and should result in better bids since the information will reduce uncertainty in the RAP. A simple follow-up study is recommended in Section 6.5 to determine differences in gradations from RAP obtained with a skid steer and a full-sized milling machine.
6. Establish a standard method for determining RAP asphalt contents. Although the ignition method is the preferred method by most asphalt technologists and most research indicates that is the most accurate method, obtaining a correct result depends on the correction factor. Since most RAP in SDDOT will contain chip seals and the chip seal aggregate may differ from the aggregate sources in the asphalt mixture, establishing a reliable correction factor is problematic. Therefore, it is recommended that the asphalt content of RAP be determined using a solvent extraction method (AASHTO T 164). The average RAP asphalt content should be shown on the mix design.
7. Establish a standard for determining the RAP aggregate bulk specific gravity. The research team recommends that the recovered aggregate from the solvent extraction should be used to determine the RAP aggregate's bulk specific gravity using SD209 and SD210 (or AASHTO T 84 and T 85) for the fine and coarse aggregate portions, respectively. The RAP aggregate Gsb will impact the calculated VMA, which in turn affects the mixture's durability.
8. For Q mixes, lower the mix design and QC/QA target air void content by 0.1% for every 5% RAP. For example, the target for mixes containing 20% RAP will be 4.0-(0.1x20/5)=3.6%. Keep VMA criteria the same. This will add a little more virgin asphalt binder to RAP mixes which will improve their performance.

1.5.3 RAP Management

9. Contractors should sample and test the RAP received from the project as the stockpile is being built. Testing should be conducted to determine that the asphalt content and gradation are consistent with the results used in the mix design.
10. Fractionation of RAP should be an option in SDDOT specifications for contractors to consider when they are challenged to meet SDDOT mix design or QC/QA criteria.
11. Contractors should verify that in-line RAP processing (such as with a "RAP gator" or "rumble hog") does not substantially alter the gradation of the RAP aggregate before it enters the plant. Reasonable tolerances on the No. 8 and No. 200 sieves are ±4% and ±1%, respectively.

1.5.4 Asphalt Mixture Production and Quality Assurance for Mixes Containing RAP

12. Add to Table M - Minimum Frequency for Production Sampling/Testing:

Test	Min. Frequency	Test Method
RAP Asphalt Content	1/1000 ton (M ton)	AASHTO T 164
RAP Aggregate Gradation	1/1000 ton (M ton)	AASHTO T 30

1.5.5 Recommended Areas for Further Research

13. In order to better understand the quantity of RAP available from milling operations for use in new asphalt mixes and other applications, it is necessary to establish a reliable method to estimate the amount of RAP lost due to stockpiling, processing, and plant operations. A study to inventory RAP generated from project milling, RAP used in mixes and other applications, and unused but recoverable RAP at the project conclusion on several projects would help identify losses associated with stockpiling (due to compression and contamination in the ground), screening (oversized particles), and plant startup and shut-down waste, etc.
14. Much of the RAP in South Dakota contains chip seals and underlying asphalt concrete layers. The properties of the aged binder in this composite material are unknown. A study to collect RAP samples from projects around the state, recover, and grade the RAP binder would be useful in understanding how the preservation treatments affect in-service aging and establish future limits for RAP binder ratios (binder replacement percentages) at which a softer virgin binder is necessary. Similar studies in other states that do not routinely use chip seals have helped establish general percentages at which softer virgin binders are appropriate for mix designs containing RAP.
15. A comment by one technical panel member was that RAP samples obtained from skid steer mills were finer than RAP obtained from a highway-class milling machine. A simple study should be conducted to quantify RAP aggregate gradation differences and determine what changes may be needed in the sampling recommendations and/or mix design procedure to account for the difference.
16. Many highway agencies and contractors are interested in identifying tests to assess the cracking resistance of asphalt mixtures that can be used in mix design and field control. Since this is a national need, and a significant research effort is needed to accomplish this need, South Dakota should consider participating in national or regional studies when such research projects are developed.

2.0 PROBLEM DESCRIPTION

Utilization of Reclaimed Asphalt Pavement (RAP) and other recycled materials in asphalt pavements has become an important strategy to help offset increases in asphalt binder prices and improve the sustainability of our surface transportation infrastructure. The South Dakota Department of Transportation (SDDOT) began to routinely use RAP in main-line asphalt surfaces in 2007. However, some pavements containing RAP have not performed satisfactorily, often exhibiting premature raveling and cracking. This prompted the SDDOT to commission this study to identify current practices and specifications that could be improved.

3.0 RESEARCH OBJECTIVES

The three research objectives for this project were:

1) **Describe current practices for specification, design, production, testing, pavement preservation, and placement of RAP in various types of hot mix and warm mix paving operations in South Dakota and nationally.**

The research team interviewed key SDDOT personnel and asphalt paving contractors about current specifications and practices related to designing and constructing pavements using RAP as a component material. The team also thoroughly reviewed the department's specifications, special provisions, and plan notes, and interviewed materials engineers from neighboring highway departments regarding current practices related to RAP use in the Great Plains region. This background information was compared to the latest research recommendations and trends for using RAP in asphalt paving mixtures.

2) **Identify best practices for specification, design, production, testing, and placement of RAP.**

Best practices for the design, production, and placement for asphalt paving mixes containing RAP were synthesized from numerous sources including the current practices of other highway agencies, especially from those who have had a long history with RAP use, leading contractors, and published research reports.

3) **Suggest revisions and refinements to SDDOT specifications, practices, and pavement preservation practices, and develop guidance for using reclaimed asphalt materials in pavements.**

The research team found that most of SDDOT's current standards and industry practices regarding RAP use in overlays for pavement rehabilitation projects were reasonable and justified. A list of 14 recommendations is provided in Section 7 of this report. The most significant recommendations deal with standardizing methods for characterizing RAP materials for mix design and using a lower target air void content for determining the optimum asphalt content of mixes containing RAP. The expected net effect of these recommendations will be a slight increase in asphalt content (about + 0.2%) for mixes containing 20% RAP. This will help improve compactability during construction, eliminate the "dry" appearance of the mixes, and ultimately lead to better short-term and long-term pavement performance.

4.0 TASK DESCRIPTIONS

Following are the 10 tasks identified in the request for proposals and a brief discussion of the work related to each task.

1) Meet with the project's technical panel to review the project work plan.

The project was initiated on October 1, 2012 with a meeting between the research team and the technical panel to review and refine the proposed work plan as outlined in this proposal. Randy West and Mark Blow met with the project technical panel at the SDDOT Region Office in Pierre, SDto review each task in the work plan and to describe how the research team planned to meet the objectives. Richard Willis and Ray Brown joined the meeting via conference call.

2) Review existing literature to determine current practices for specification, design, production, testing, pavement preservation, and placement of RAP nationwide and regionally.

Richard Willis completed the literature review on specifications, mix design, production control, pavement construction, preservation, and performance related to asphalt mixtures containing RAP. He also conducted an analysis of the financial savings and conservation of raw materials for SDDOT due to the use of RAP in asphalt mixes since 2007.

3) Through review of SDDOT specifications and interviews with select SDDOT staff and contractors with experience in the use of RAP, describe and assess the state-of-practice and identify concerns regarding use of RAP in South Dakota.

Interviews with certain SDDOT personnel and a group of asphalt contractors were conducted by Randy West and Mark Blow between September 30 and October 5, 2012. Table 1 lists the individuals that were interviewed. Mark Blow and Randy West also reviewed the current SDDOT specifications, special provisions, and plan notes related to the utilization of RAP. A summary of the interviews and review of SDDOT specifications were provided in Technical Memorandum #1, submitted on November 26, 2013.

Table 1: Persons Interviewed regarding SDDOT's RAP Specifications

SDDOT Personnel	Title	Contractor Personnel	Company
Gil Hedman	Surfacing Design	Tim Foerster and Mike Lee	Hills Materials
Tom Grannes	Materials Lab Engineer	Kim Garletz	Duininck Bros.
Rick Rowan	Bituminous Engineer	Jeff Brummer, Tim Visger, and Jeremy Holt	Anderson Western
Blair Lunde	Pavement Management Engineer	Korey Bender	Border States Paving
Jim Costello	Mix Design Lab Engineer	Sue Unzelman	Myrl & Roy's Paving
		Mark Jensen	Concrete Materials

4) **Develop a list of interview candidates and an interview guide designed to elicit information from other state departments of transportation in the region with demonstrated expertise in successful application of RAP mixes (including high-content RAP hot and warm mixes) on specifications and practices for design, production, testing, placement, pavement preservation, and long-term performance of RAP.**

Knowledgeable individuals from seven highway agencies in the Great Plains region were identified for a survey about their standard practices with reclaimed asphalt pavement (RAP) and about factors that might have some effect on the use of RAP in their agency. Those agencies and the points of contact in each organization were: Iowa (Scott Schram), Manitoba (Stan Hilderman), Minnesota (John Garrity), Montana (Matt Strizich), Nebraska (Robert Rea), North Dakota (Ron Horner), and Wyoming (Rick Harvey). The list of questions asked to each person interviewed is provided in Appendix A.

5) **Submit and present a technical memorandum summarizing the results of the literature review, the review of South Dakota specifications, practices, and concerns, and the proposed interviews of other state transportation departments.**

The research team submitted the literature review and the preliminary review of SDDOT's RAP specifications on Dec. 5, 2012. A web meeting with the technical panel was held on Dec. 13, 2012 to review the preliminary findings and recommendations.

6) **Upon approval of the technical panel, conduct and summarize findings of the interviews of other state transportation departments.**

Ray Brown interviewed pavement engineers from the six neighboring state DOTs and one Canadian Province listed above under Task 4. Each person interviewed was very helpful in providing information regarding RAP use and practices in their respective agencies. A summary report on this task was submitted to the SDDOT Office of Research on Dec. 12, 2012.

7) **Based on information gleaned from the previous tasks, prepare and present a technical memorandum that identifies best practices, suggests revisions and refinements to SDDOT specifications and practices, and outlines guidance for pavement preservation and for using reclaimed asphalt materials in pavements.**

The web meeting presentation made to the panel on Dec. 13, 2012 included several preliminary findings and recommendations. However, the researchers and panel members agreed that more specific information regarding the problems encountered on the poor performing projects were necessary in order to provide guidance on how to address the problems.

8) **Meet with the project technical panel to present project findings and review the outline of guidance.**

Mark Blow and Randy West corresponded with Mr. Rick Rowan by email and by phone to discuss gathering of additional project data and calculations regarding batching materials for mixes containing RAP. The draft final report which included the research team's recommendations was submitted to SDDOT on August 2, 2013. A second meeting with the technical panel to discuss the draft final report was held on August 21, 2013.

9) In conformance with Guidelines for Performing Research for the South Dakota Department of Transportation, prepare a final report and executive summary of the research methodology, findings, conclusions, and recommendations.

Based on feedback regarding the draft final report by the technical panel, the final report was revised. This report constitutes the final report. It includes results of the literature review, interview summaries, and the research team's findings, conclusions, and recommendations. A separate section on Recommended Best Practices for Using RAP in Asphalt Pavements for South Dakota has been included as Appendix B for use in future training.

10) Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

The executive presentation to the SDDOT Research Review Board was held on August 20, 2013.

5.0 FINDINGS AND CONCLUSIONS

This chapter presents the information collected as part of the research tasks and the findings of the research team. The chapter includes a review of the financial and raw materials savings resulting from the use of RAP in South Dakota, a thorough review of current national research, summaries of the interviews with SDDOT and contractor personnel regarding current practices and problems related to RAP use, a review of available data from a few recent poor performing projects, and a summary of interviews with pavement engineers from neighboring highway departments.

5.1 Benefits of Using RAP in Asphalt Paving Mixtures for SDDOT

The two primary motivations for using RAP in asphalt mixtures are the conservation of natural resources and cost savings resulting from reducing the amount of virgin aggregate and binder in asphalt mixtures. As part of this research effort, the SDDOT provided the research team with data showing which state projects from 2007 to 2012 included RAP in the asphalt mixture designs. The information also included the percentages of new and reclaimed binder used in each of the mixtures as well as the tonnage of the mixes used in the respective projects. Based on these data and the bid prices by year, the researchers quantified the cost savings and the conservation of raw materials on a yearly basis. The results are summarized in Table 2.

Table 2: Materials and Cost Savings Associated with SDDOT's RAP Use since 2007

Year	Mix Using RAP, tons	RAP Use, tons	Virgin Binder Replaced, tons	Aggregate Replaced, tons	Savings from Binder Replacement	Savings from Aggregate Replacement	Total Savings
2007	242,165	45,758	3,645	42,113	$1,458,000	$568,947	$2,026,947
2008	275,840	57,126	3,874	53,252	$2,496,000	$756,711	$3,252,711
2009	743,074	154,802	10,314	144,488	$6,124,811	$2,160,100	$8,284,911
2010	846,566	163,096	10,923	152,173	$6,262,755	$2,393,687	$8,656,442
2011	474,346	93,735	6,232	87,503	$3,625,424	$1,449,053	$5,074,477
2012	697,721	141,506	9,513	131,993	$6,648,095	$2,300,638	$8,948,733
Total	3,279,712	656,023	44,500	611,523	$26,615,085	$9,629,136	$36,244,221

As shown in the table, since 2007, South Dakota has placed over 3.2 million tons of asphalt mix that included RAP with the average RAP content being 20 percent by weight of the aggregate. Over the six years, the 656 thousand tons of RAP that have been used in mixtures have replaced approximately 44.5 thousand tons of virgin binder and 611.5 thousand tons of virgin aggregate. Total economic savings from virgin binder and aggregate replaced with RAP was estimated to be $36.2 million. As can be seen in the table, the savings from binder replacement fluctuates from year to year based on the amount of RAP used in the state. When binder costs were over $700 per ton in 2012, the cost savings from binder replacement were the highest, even though more RAP was used in 2009 and 2010.

5.2 Literature Review on the Current State of Knowledge Regarding Use of RAP in Asphalt Pavements

5.2.1 Background

In 2008, the National Asphalt Pavement Association (NAPA) estimated that the asphalt paving industry in the U.S. averaged approximately 12% RAP in all asphalt mixtures produced (*1*). Rising asphalt binder prices over the past decade has been the primary motivation for using higher RAP contents. By 2011, a NAPA survey indicated that the average RAP content had increased to 19% (*2*).

Economic and environmental awareness have led both state agencies and contractors to investigate the use of RAP in asphalt pavements. Environmentally, RAP is advantageous because it reduces the demand for virgin asphalt binder and aggregates, saving nonrenewable natural resources. From an economic standpoint, RAP reduces materials cost which makes up almost 70% of the production costs for asphalt mixtures (*3*). Economic analyses have shown that using 25% RAP can reduce materials costs by approximately 20% depending on the mix design and RAP properties (*4*).

Although the economic and environmental benefits of using more RAP in asphalt mixtures are easy to grasp, there are several issues that some pavement technologists have raised that have tended to restrict higher RAP contents. These issues include: (1) limited RAP availability in some locations, (2) poor RAP management practices by some contractors and agencies, (3) lack of information on how to appropriately determine RAP properties for mix design, (4) unknown long-term performance of high-RAP content mixes, and (5) how RAP can be incorporated in pavement preservation. These issues were investigated in this literature review.

5.2.2 RAP Availability

In 2008, NCAT conducted a survey of contractors across the US to gather information regarding RAP use. Part of the survey dealt with the available supply of RAP. Of the 81 respondents, 24 percent responded their RAP supply was diminishing while 25 percent indicated their supply was increasing. The median stockpile size was only 25,000 tons. Forty-three percent of the surveyed asphalt plants had enough RAP to use 15% RAP in all mixtures and 25 percent of the plants had enough RAP to use 25% in all of their mixtures. RAP availability is largely related to demographics and location. In many urban areas, the supply of RAP far exceeds the quantity of RAP that can be used, whereas in the majority of rural locations such as most of South Dakota, the supply of RAP is very limited.

Although some contractors have access to higher RAP quantities, they are often impeded from using this material by state specifications. In 2009, the North Carolina Department of Transportation conducted a survey for AASHTO and the Federal Highway Administration (FHWA) RAP Expert Task Group to assess the current state of the practice among state DOTs (*3*). While 23 states had increased their allowable RAP contents from 2007 (Figure 1), six states still did not permit more than 25% RAP in any pavement layer (Figure 2). Despite the fact that many states had increased allowable RAP contents, most still did not use more that 20% RAP (Figure 3).

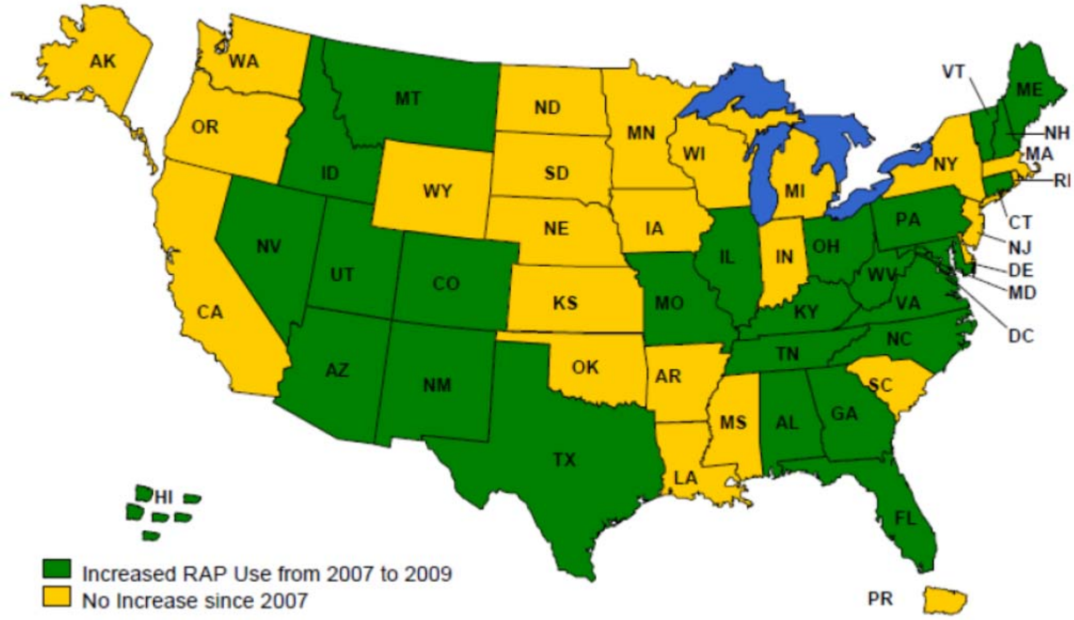

Figure 1: States with Increased RAP Use since 2007 *(3)*

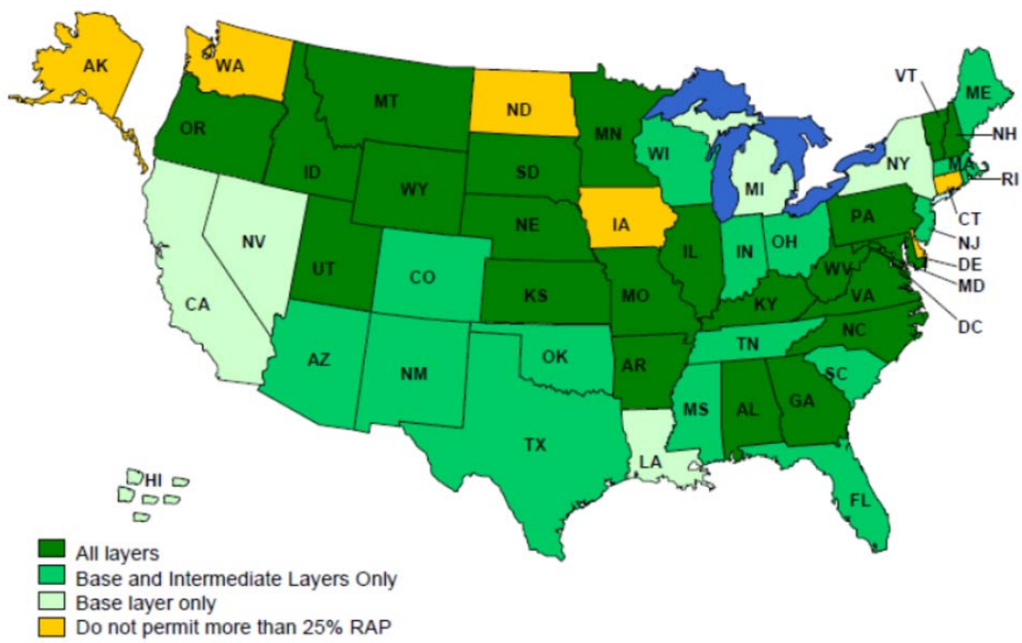

Figure 2: States That Permit More than 25% RAP in HMA Layers *(3)*

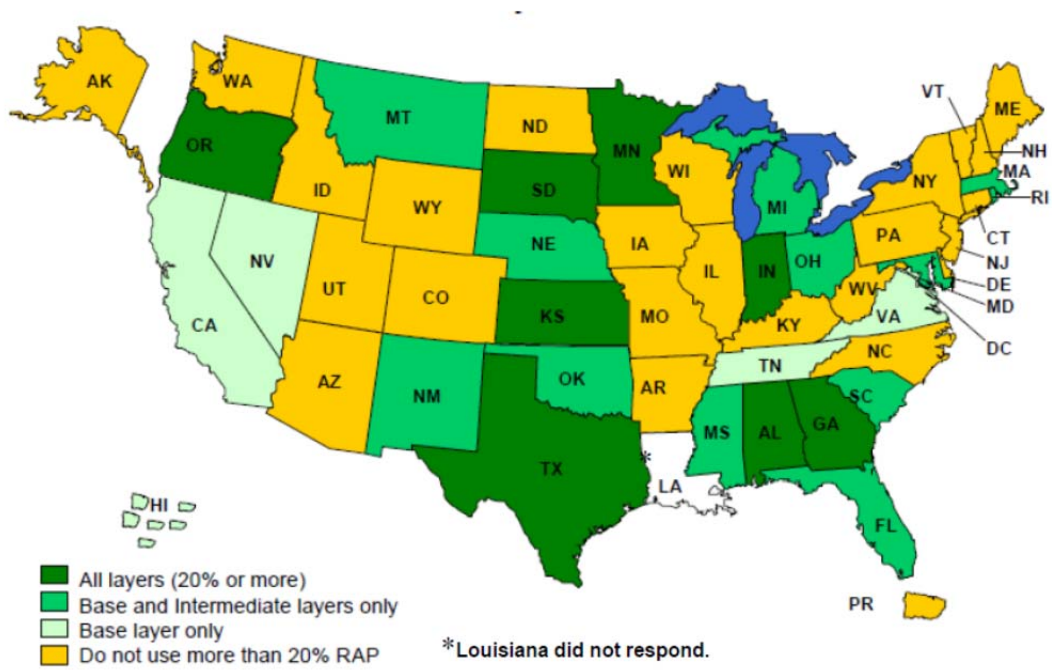

Figure 3: States That Use More than 20% RAP in HMA Layers *(3)*

5.2.3 RAP Management

In order to successfully use RAP in asphalt mixtures, good RAP management practices are necessary to ensure the RAP is processed and stockpiled in a uniform manner. Failure to use good practices can result in the production of poor quality asphalt mixtures.

Some states restrict RAP sources to only millings from DOT projects or require that RAP from different sources be stockpiled separately. One challenge of using RAP materials from multiple sources is inconsistency of RAP characteristics from different origins. NAPA and NCAT have recommended that multisource RAP stockpiles be processed by blending the RAP sources together using a front-end loader while feeding the material into a crusher. This will allow the blended RAP materials to be more consistent (*6, 7*). Although RAP stockpiles have been stigmatized as being extremely variable, studies by the FHWA (*9*), NCAT (*10*), International Center for Aggregate Research (ICAR) (*11*) and the Texas Transportation Institute (TTI) (*12*) have shown that even processed RAP stockpiles from multiple sources can be less variable than virgin aggregate stockpiles. A summary of the RAP variability data from these studies is provided in Table 3.

When it is necessary to crush RAP, it is important to carefully consider the maximum particle size needed. A common practice is to crush all RAP to a size that can be used in any asphalt mixture. However, crushing the RAP increases the material's dust content which can negatively affect a mixture's voids in mineral aggregate (VMA) and dust-to-binder ratio (*3, 5*). Additionally, crushing should occur before the material is fed into the asphalt plant. In-line crushing may alter the RAP aggregate gradation creating issues during the quality control process of the asphalt mixture (*3*).

Table 3: Summary of RAP Variability Statistics (9-12)

Research Org.	Data Source(s)	Pooled Standard Deviations (%)		
		% Passing 2.36 mm	% Passing 0.075 mm	Asphalt Content, %
FHWA	CA, NC, UT, VA	3.4	0.76	0.30
NCAT	GA	3.7	0.87	0.33
ICAR	FL	4.4	0.96	0.35
TTI	TX	3.8	1.14	0.28

One method of processing RAP some contractors employ is fractionation. Fractionation is a screening process that separates the RAP into at least two sizes: coarse (+1/2 or +3/8 inch) and fine (-1/2 or -3/8 inch). A 2009 survey conducted by the North Carolina DOT found that 10 states required RAP fractionation (*3*). One commonly assumed reason for this requirement is that fractionation will improve the consistency of the RAP asphalt content and gradation within the stockpile; however, recent data has shown this assumption is not always correct (*8, 9, 10*).

Agencies should use an end-result specification to ensure the consistency of RAP stockpiles instead of requiring a method specification such as RAP fractionation (*3, 8, 9*). While fractionation may not make a RAP stockpile more consistent, it does provide the mix designer with more flexibility in creating a mixture design; however, this flexibility must be weighed against the increased processing costs and space requirements for fractionated stockpiles. The current school of thought is that RAP fractionation is not necessary until RAP contents exceed 35% to 40%.

RAP stockpiles, like those for virgin aggregates, should be kept free of contaminants (*3*). This requires that truck drivers be given clear instructions on what materials are acceptable for RAP stockpiles. General construction debris or any contaminated pavement materials should be dumped in a different location. Additionally, as part of the quality control procedure, all RAP stockpiles should be monitored to ensure deleterious materials are kept out of the stockpiles (*8*).

Both NAPA and NCAT also stress the importance of maintaining minimal moisture contents in RAP stockpiles. If the RAP material has high moisture content, the moisture must first be converted to steam before the asphalt binder can be heated enough to be reactivated. This energy loss might affect the virgin aggregate temperature (*3*). To alleviate this problem, RAP stockpiles should be built in smaller conical stockpiles to reduce penetration of moisture. The stockpiles should also be placed on a solid surface to aid in drainage or covered to minimize exposure to moisture or precipitation (*6, 7*).

TTI recommended the following practices for RAP management (*12*): (1) eliminate contamination, (2) do not combine RAP from multiple sources, (3) avoid over-processing to minimize generating additional fines, (4) minimize moisture in RAP stockpiles, and (5) thoroughly blend RAP from multiple sources prior to processing. NCAT agrees with all of these points except for number two. TTI's data has shown that RAP from different sources can be processed into a very consistent material despite this recommendation.

5.2.4 RAP Characterization

Before RAP can be used in mix designs, it is important to determine its material properties. Recent studies have examined methods for characterizing the various RAP components including consensus aggregate properties, aggregate bulk specific gravity, gradation, binder content, and binder grade.

Testing methods and frequency of testing are commonly based on agency requirements and RAP type. Processed RAP stockpiles from multiple sources may need to be sampled more frequently than single source stockpiles to ensure uniformity (*3*).

According to the 2008 NCAT survey, the vast majority of contractors use the ignition method (AASHTO T 308) to determine the asphalt content of RAP samples. A Colorado DOT survey also found that more than half of the states use the ignition method (*3*). Besides the ignition method, technicians can also quantify the asphalt content of RAP mixtures using solvent extraction (AASHTO T164). A joint study by NCAT and the University of Nevada at Reno (UNR) assessed the differences between the two methods using laboratory produced RAP. Overall, the ignition oven test results were more accurate than the solvent extraction methods, even without known aggregate correction factors.

The ignition method is also the most common method for recovering RAP aggregates for characterization. Studies conducted in Virginia (*13*) and Arkansas (*14*) examined the effects of the ignition oven on consensus aggregate properties, gradation, and coarse aggregate bulk specific gravity. The results of these examinations showed that only the sand equivalency and bulk specific gravity differed between aggregates recovered through chemical extraction and ignition oven. The Arkansas study concluded that the differences in bulk specific gravity were within the allowed testing variability (*14*).

FHWA has recommended determining the bulk specific gravity of RAP aggregates through a three step process. This method was also recommended in NCHRP Report 452, *Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method: Technicians Guide* (*15*). The first step is to determine the maximum specific gravity (G_{mm}) of the RAP material and the asphalt content of the RAP. Once the G_{mm} and asphalt content are known, the effective specific gravity of the RAP aggregate can be calculated using Equation 1. A specific gravity of the RAP binder consistent with virgin binder is typically assumed in Equation 1. Lastly, a typical asphalt absorption value (P_{ba}) must be assumed for the RAP aggregate and the bulk specific gravity to be calculated using Equation 2 (*3*).

$$G_{se}^{RAP} = \frac{100-P_b}{\frac{100}{G_{mm}}-\frac{P_b}{G_b}} \quad \text{[Equation 1]}$$

$$G_{sb}^{RAP} = G_{se}^{RAP}/[\frac{P_{ba}-G_{se}^{RAP}}{100G_b}+1] \quad \text{[Equation 2]}$$

However, the joint NCAT-UNR study (*16, 17*) recommended solvent extractions be used to recover RAP aggregates for specific gravity testing using conventional procedures. The ignition method may be used only if past data has shown the aggregate will not undergo significant changes in bulk specific gravity due to the extreme temperatures of the ignition method. The NCAT-UNR study strongly recommended always using the bulk specific gravity of each component aggregate in VMA calculations, not the effective specific gravity.

For RAP contents over approximately 20% to 25%, most references recommend that the RAP binder be characterized to determine how much it has aged. For many decades, the most common practice has been to extract and recover the RAP binder, then test the recovered binder using the prevailing method to grade asphalt (*15*). However, many DOTs and contractors will not use the chemical solvents required for the extraction and recovery methods due to potential health concerns associated with handling the solvents. Although several researchers have attempted to develop indirect methods to determine the

RAP binder properties or estimate the properties of the composite binder in a mix containing RAP, the results of these methods have not yielded reliable results.

5.2.5 RAP Mixture Design

Two NCHRP studies on designing asphalt mixes with RAP have been completed in the last 10 years. NCHRP Report 452 provides many of the current recommendations for designing asphalt mixtures with RAP. The final report for the second study, NCHRP Report 752, was published in June 2013. The focus of the second study was designing mixes with RAP contents above 25%.

While both reports recommend that the design of asphalt mixtures with RAP follow the same standards and criteria (AASHTO M323) as a virgin mix design, they offer additional practical guidance to account for the RAP binder weight when batching, minimize RAP heating, select the virgin binder grade, and evaluate the mix designs with additional performance tests.

One challenge for mix designs with RAP is dealing with high dust contents. Many RAP stockpiles have P_{200} contents above 10%, particularly those that have been further crushed during processing. For some rural paving projects utilizing local aggregate pits that only produce material for that job, contractors have little control of the virgin material or the RAP aggregate gradation. When the materials have high dust contents, meeting the standard volumetric criteria can be very difficult. Contractors must establish materials handling practices that will minimize dust in the stockpiles in order to meet quality assurance criteria during mix production. One option could include fractionation and using the coarse fraction of the RAP in their mix designs.

The biggest unresolved issue for mix deigns containing RAP is how much blending occurs between virgin and RAP binders. Numerous studies have attempted to quantify the degree of blending between the old and new binders for mixes containing RAP and/or recycled shingles (*25-28*). Several factors are likely to affect the degree of blending for any particular mix design including compatibility of the RAP and virgin binders, mixing temperature, mixing time, stiffness/viscosity of the RAP and virgin binders, and the relative proportions of the RAP and virgin binders. Most recent research tends to indicate that blending does occur to a substantial degree for most plants.

The current standard (AASHTO M323) recommends that the virgin binder grade be selected based on the RAP content (Table 4). Each level represents a RAP percentage by weight of the aggregate. For RAP contents below 15%, the standard recommends using the same virgin binder grade as if the mix had no RAP. For RAP contents between 15% and 25%, the table recommends that a softer virgin binder grade be used. When more than 25% RAP is used, blending charts should be used to determine the appropriate virgin binder grade.

Table 4: Binder Selection Guidelines for RAP Mixtures According to AASHTO M323

RAP Content, %	Recommended Virgin Asphalt Binder Grade
< 15	No change in binder selection
15-25	Select virgin binder one grade softer than normal (e.g., select a PG 58-28 if PG 64-22 would normally be used)
> 25	Follow recommendations from blending charts

A recent trend in specifications among DOTs has been to establish RAP and RAS limits on the percentage of recycled binder (a.k.a. binder replacement) in the mix rather than RAP or RAS content by percentage of total mix. NCHRP Report 752 recommends that the three tiers in AASHTO M323 be reduced to two tiers as shown in Table 5.

Table 5: Binder Selection Guidelines from NCHRP Report 752

RAP Binder Ratio, %	Recommended Virgin Asphalt Binder Grade
< 0.25	No change in binder selection
≥ 0.25	Use blending equation below (Equation 3)

For mixtures with RAP binder ratios (binder replacement) less than 25%, there is no need to adjust the virgin binder grade. The proposed specification also provides a slightly different methodology for estimating the needed virgin binder based on the RAP binder properties and RAP binder ratio.

$$T_c(\text{virgin}) = \frac{T_c(need) - (RBR \times T_c(RAP\ Binder))}{(1 - \text{RBR})} \qquad \text{[Equation 3]}$$

where

T_c*(virgin)* = critical temperature of virgin asphalt binder (high, intermediate, or low);
T_c*(need)* = critical temperature needed for the climate and pavement layer (high, intermediate, or low);
RBR = RAP Binder Ratio - the ratio of the RAP binder in the mixture divided by the mixture's total binder content; and
T_c*(RAP binder)* = critical temperature of recovered RAP binder (high, intermediate, or low).

While these recommendations have been shown to increase RAP mixture durability, using a softer binder can increase a 25% RAP mixture's susceptibility to rutting in laboratory tests such as the Asphalt Pavement Analyzer (APA). It is critical that engineers ensure a pavement structure will be both durable and stable; therefore, the rutting susceptibility of mixtures containing a softer virgin binder should be assessed using common laboratory performance tests (*4*).

Other methods for increasing the durability of RAP mixtures include increasing the volume of virgin binder in the asphalt mixture by 0.25% or 0.5% or using a warm mix asphalt technology in conjunction with RAP. These methods have been assessed in laboratory cracking tests such as Bending Beam Fatigue Test (BBFT), Simplified Visco-Elastic Continuum Damage (S-VECD), and the overlay tester (*4, 30*).

Conversely, using polymer-modified binders in conjunction with RAP can decrease the durability of a mixture. Results from the NCAT Test Track have shown that using polymer-modified binders with high RAP mixtures can increase cracking (*30*).

RAP mixtures are commonly characterized as being brittle due to increased stiffness (*31*). Several studies have shown that mixes containing high RAP contents do not perform well in high strain tests. NCHRP 9-12 concluded that incorporating recycled materials in asphalt mixtures can reduce fatigue life by about 20% (*24*). Mixture testing by Mohammad et al. (*32*) determined that increasing the RAP content of a mix decreased the fatigue resistance.

However, Huang et al. (*33*) concluded that a 30% RAP mixture had better fatigue performance than a virgin mix while also increasing the mixture's tensile strength. Additionally, Advanced Asphalt Technologies (*34*) examined the fatigue resistance of three field mixtures containing 15%, 35%, and 50% RAP, respectively. While the 9.5 mm mixtures had high effective asphalt contents, continuum damage fatigue testing showed that all three mixtures had excellent fatigue performance. Similar findings were noted for the 19.0 mm mixtures that contained 25%, 45%, and 55% RAP (*35*).

High strain tests are appropriate when one is trying to characterize the performance of thin pavements, as thinner pavements typically exhibit higher strains than thicker pavements. In thin pavements, a high RAP mixture (>25%) might perform poorly in fatigue under high traffic conditions. Low strain tests using both the Bending Beam Fatigue Test and the Simplified Visco-Elastic Continuum Damage (SVECD) procedure show that the cracking resistance of RAP mixtures can be excellent in low strain environments such as thick pavements using stiff materials. This knowledge can be coupled with mechanistic pavement design philosophy to optimize pavement structural designs for both performance and economy (*29*).

5.2.6 Field Performance

One reason some states are hesitant to adopt high RAP content mixtures is the lack of documented long-term performance data. Relatively few research studies have examined field performance of RAP mixes beyond the first few years. One study in Louisiana examined pavement condition, structure, and serviceability of asphalt mixtures that contained 20% to 50% RAP after six to nine years of service life. This study found that the pavements containing RAP had statistically equivalent performance to the virgin mixtures (*37*). Florida DOT also conducted a study that examined the field performance of virgin mixtures and mixtures with more than 30% RAP constructed between 1991 and 1999. The virgin mixtures averaged 11 years of service life before they reached FDOT's cracking threshold. The 30% to 50% RAP mixtures ranged from 10 to 13 years of service life. Florida concluded that 30% RAP mixtures perform equivalently to virgin mixtures in terms of field cracking performance (*38*). A similar study of five projects in Texas compared rutting, cracking, and ride quality for virgin and 35% RAP mixtures. The comparisons showed that high RAP sections have less rutting, similar ride quality, but somewhat higher amounts of cracking. However, the performance of the RAP mixtures was still satisfactory. Therefore, the author concluded that a 35% RAP mixture can provide the same overall performance compared to a virgin mixture (*40*).

On a national level, NCAT analyzed performance data of virgin and RAP mixtures using the Long-term Pavement Performance (LTPP) database. Eighteen projects across North America were included in the analysis which compared overlays with virgin asphalt mixtures to overlays containing 30% RAP. At each project location, overlays were built using two thicknesses, two inches and five inches. The database covered projects ranging from 6 to 17 years old. Statistical analyses were used to compare the rutting, fatigue cracking, longitudinal cracking, transverse cracking, block cracking, and raveling of these test sections. NCAT found that, in most cases, 30% RAP mixes perform equivalent to virgin mixtures in terms of IRI, rutting, block cracking, and raveling. For both thick and thin overlays, the virgin mix overlays had statistically better performance with regard to fatigue cracking and longitudinal cracking, but the RAP mixes were generally still performing well (*39*).

In 2012, NCAT also documented two high RAP content experiments at its Pavement Test Track. One study compared the field performance of two seven-inch asphalt cross sections. The first cross-section was built using a completely virgin mix design while the second test section used 50% RAP in each layer of the pavement structure. At the end of 10 million equivalent single axle loads, neither test section had shown signs of distress in terms of rutting or cracking (*29*). The other experiment examined the performance of 45% RAP mixes using different grades of virgin binder ranging from a PG 52-28 to a PG 76-22. After five years of heavy traffic, field performance showed that the test section using the softer virgin binder was more resistant to cracking and raveling and equally resistant to rutting (*29*).

5.2.7 Pavement Preservation

No research was found that addressed preservation of existing pavements that contain RAP. A few recent studies have explored the use of RAP in thin overlays as a pavement preservation treatment. Mogawer et al. (*41*) conducted a laboratory study with RAP mixtures and a WMA technology for thin asphalt overlays. Virgin, 15%, 30%, and 50% RAP mixes were designed using a 4.75 mm nominal maximum aggregate size and evaluated for stiffness and workability. The study concluded that thin lift mixtures could be designed with high RAP contents and meet volumetric requirements. Using softer binders did not significantly reduce the stiffness of the mixtures. Therefore, rutting was not a concern. A follow up study (*42*) evaluated the mixtures for reflective cracking, low temperature cracking, and moisture damage susceptibility. When RAP was added to the mixtures, the reflective cracking resistance of the mixture decreased using the overlay tester; however, the moisture damage resistance improved in the Hamburg Wheel Tracking Test. The RAP had little to no effect on the low temperature performance of the mixtures. The authors noted that using WMA technologies sometimes improved the mixture’s performance.

NCAT recently placed a series of 25 pavement preservation test cells on a local haul road to a quarry and asphalt plant. The preservation treatments include six cells with thin overlays using 4.75 mm mixes. Three of these thin overlays are virgin mixes with various grades of binder. One of the thin overlays contains 50% fine fractionated RAP and another contains 5% post-consumer recycled asphalt shingles. The last of the thin overlays was constructed over a 6 in. base of 100% RAP processed with foamed asphalt through a cold recycling plant. All of the pavement preservation cells are being monitored weekly, similar to how NCAT assesses performance on the Pavement Test Track.

5.3 The State-of-Practice and Concerns Regarding the Use of RAP in South Dakota

5.3.1 Interviews

Interviews with SDDOT personnel and several contractors provided excellent background regarding South Dakota’s current specifications, practices, and concerns relative to the use of RAP in asphalt pavements. This review indicated that some SDDOT practices regarding RAP use are somewhat unique relative to most state highway agencies. For example, SDDOT is one of few highway agencies that take ownership of RAP generated from milling highway projects during pavement rehabilitation work.

A more distinctive practice is that, on certain projects, SDDOT directs the contractor, through plan notes, how much RAP is to be generated off the project and utilized in the overlay. Most SDDOT projects that required RAP to be used in mainline paving (i.e. Q mixes) specified a 20% RAP content. HR mixes, typically used on shoulders and non-mainline paving, are often specified to contain 15% to 30% RAP, with 30% RAP being more common. In 2012, an HR mix containing 50% RAP was used for an overlay on SD248 from Murdo east to the junction with US83. This is a low traffic roadway. A sand seal was applied to the surface of the HR mix with 50% RAP as part of the project.

Another SDDOT practice that relatively few other highway agencies utilize is paying for asphalt binder as a separate bid item from mixes. Agencies that use this policy typically do so to avoid contractors minimizing the asphalt content of mixes during mix design and/or mix production to be more competitive. Contractors interviewed were supportive of this policy. SDDOT only pays for virgin asphalt. During production, the virgin binder content is verified with calibrated daily tank measurements and binder transport bills of lading. Additional checks are also made by calibrated meters on the plants.

Milling on pavement rehabilitation projects is typically subcontracted to an independent company. Based on interviews with several contractors in South Dakota, milled RAP materials are typically only tested as part of the mix design. Most contractors indicated that they typically only take three samples of millings using a small skid-steer mill head for determining asphalt content, gradation, aggregate specific gravity, and other aggregate testing as needed for mix designs. There was not a consistent practice among contractors on how the RAP characteristics are determined. Some contractors use the ignition method; others use solvent extractions for determining asphalt contents. Depending on the aggregate mineralogy, absorption, and soundness, errors can occur with both test methods. SDDOT central lab personnel indicated that the asphalt contents of the RAP samples submitted by contractors was not checked. Because SDDOT uses chip seals for pavement preservation on most asphalt roadways (except interstates), and milling depths are typically set at an average of 1” (variable for profile), the RAP materials obtained from milling SDDOT projects will consist of the chip seal materials (typically multiple applications) and some of the underlying asphalt concrete layer. This complicates the issues of determining the RAP asphalt content and RAP aggregate specific gravities because the RAP material likely includes varieties of aggregate types. This makes it risky to use an assumed aggregate correction factor for the ignition method.

Using 20% RAP in most mixes is below the amount where more complex testing is considered necessary to properly characterize the RAP binder. Recent research suggests that when the recycled binder content is 25% or more of the total binder, the RAP binder should be fully characterized and used to select an appropriate grade of virgin binder. This often results in the need to use softer virgin binder grades or asphalt rejuvenators which can negate some of the economic savings realized by using RAP. However, it can be assumed that binders in chip seals are less aged and less stiff than asphalts in the hot mix layers because chip seal binders were not subjected to high mixing temperatures and have been on the roadway for shorter periods of time. Therefore, in South Dakota, it is probably unnecessary to use a softer virgin binder even when RAP binder ratios reach 0.25.

Most asphalt mixes are produced for SDDOT using portable plants that are set up near the job site. All of the contractors interviewed indicate that a 20% RAP content is well within the range that their plants can efficiently handle. The cost of hauling materials is one of the most significant factors in bidding projects that utilize portable plants. This motivates contractors to use the entire quantity of RAP that is available.

RAP is generally not tested during HMA production. Since the RAP on a particular project is obtained only from that project, it is assumed that the RAP properties are consistent. There was a consensus among contractors that when a mix adjustment is needed during production to control air voids, the first adjustment is almost always to change the asphalt content (± 0.3%, but typically a reduction), then gradation adjustments or RAP feed percentages are made as needed.

Comments were made that on some projects in western South Dakota where limestone is the predominate aggregate, the VMA criterion was commonly reduced by 0.5% to accommodate the specified RAP content. Although reducing VMA is not considered a good practice, SDDOT personnel indicate that, in such cases, the pavements have performed well.

It was not possible to observe many plant operations or construction practices during the research team's interviews. However, discussions with contractors indicate that they are using good practices for RAP stockpile management, except that the uniformity of the material is not checked. Contractors are willing to, or already have, purchased in-line RAP crushers to assure that millings will pass a 1.5" screen before entering the plant.

Some mixes with 20% RAP are perceived to be "dry". Reported field problems have included trouble getting the specified density and some raveling. It was unclear to the research team if these problems are isolated cases or more widespread. On a few projects with 20% RAP, the SDDOT moved up the schedule to crack seal and chip seal by one year. South Dakota, like many western states, uses a consistent practice of early life pavement preservation activities to keep pavements in good condition. On some projects a sand seal is applied to the finished overlay as part of the project. Typically, crack sealing is applied to thermal cracks and reflection cracks that appear after two years of service, and then a chip seal is applied the following year. When projects show signs of premature wear or cracking, the preservation schedule is moved up one year.

5.3.2 Investigation of Poor Performing RAP Projects in South Dakota

5.3.2.1 Introduction

Seven projects containing 20% RAP built between 2009 and 2011 were identified by SDDOT personnel as having poor performance. In this three year period, 49 projects were built in South Dakota using the same amount of RAP and under the same mix specifications. The implementation of a new requirement, such as the mandated RAP content, often has some "learning curve" challenges as methods and practices adapt to the new requirement. Conversations with SDDOT personnel indicate the primary issues with these projects have been (1) difficulty in obtaining the required in-place density for the mixes containing RAP on the roadway, (2) a "dry" appearance of the mixes, and (3) premature raveling of the pavement surface. Although these problems can generally be attributed to mixes with insufficient asphalt contents, further investigation of the project records was warranted in an attempt to better identify the actual root cause(s) of the poor field performance.

A list of seven poor performing projects identified by SDDOT personnel is shown in Table 6 and shown on the map in Figure 4. This may not be all of the poor performing projects as SDDOT personnel also mentioned a problem project near Yankton that does not appear on this list. As can be seen in this figure, most of the poor performing projects containing RAP were located in the southeastern part of the state. Several of the projects were built by the same contractor. Mix design and QC/QA data were obtained from SDDOT for four of these projects. Analysis of the available information for these four projects is discussed in the following sections.

Table 6: Projects Using Mix Designs Containing RAP That Have Been Reported to Have Problems

Ref. #	Year	Project PCN	Route	County	Month(s) Mix Produced
1	2009	00XK	US12	Walworth	Jun-Jul
2	2009	00HT	SD48	Union	Sep-Oct
3	2010	01CQ	SD25	Kingsbury	n/a
4	2010	00GY	US81	Lake	Sep-Oct
5	2010	024C	SD19	Minnehaha	Oct
6	2011	01SV	SD13	Moody	n/a
7	2011	024V	SD34	Miner	n/a

n/a - information was not available to the research team

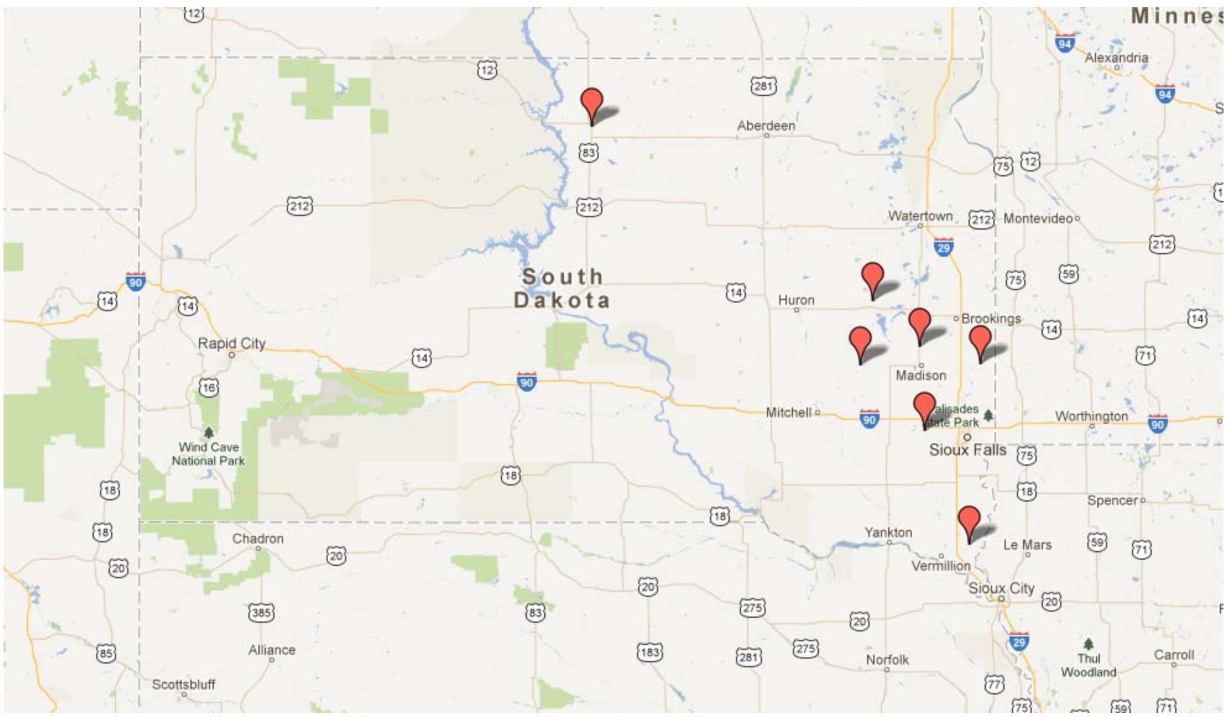

Figure 4: Locations of Seven Poor Performing Projects Containing RAP in South Dakota

Project PCN: 00XK (Project #1 on Table 6)

This project was located on US12 from west of junction US83 to south of Selby in Walworth County in the northern central part of the state (Figure 5). The work on this project consisted of cold milling and asphalt concrete resurfacing. The prime contractor on this project was McLaughlin & Shultz Inc. Based on available QC records, mix production and paving occurred between June 18, 2009 and July 1, 2009.

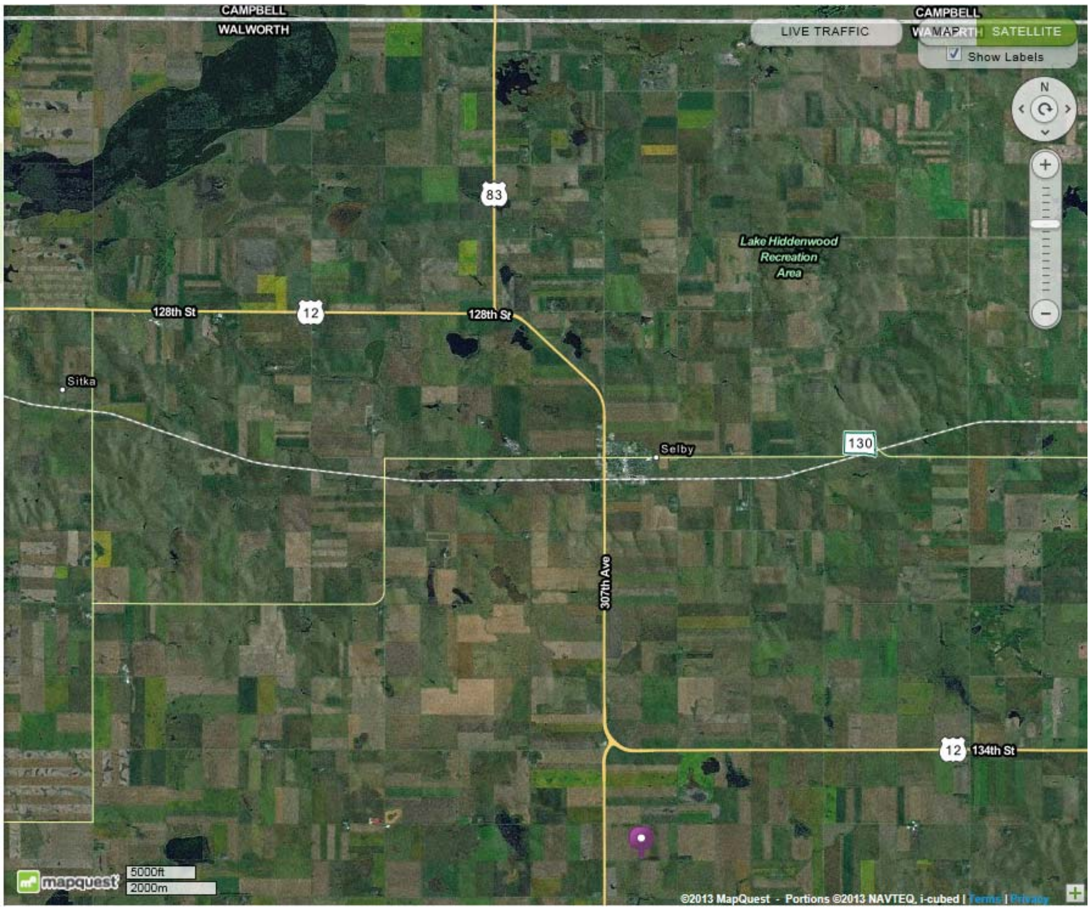

Figure 5: Map Showing the Location of Project 1, US12 in Walworth County

Mix Design Information

The Q2 mix used on the project was a fine-graded 12.5 mm NMAS mix designed with a laboratory compactive effort of 50 gyrations. The total binder content for the mix was given as 5.5% and the virgin binder content was given as 4.2%. This indicates that the RAP contributed 1.3% binder to the mix, which means that the asphalt content of the RAP would have been 6.5%. The mix design used a PG 58-28 asphalt binder, which is the same PG that would be used for a virgin mix.

The volumetric properties from the SDDOT Mix Design Lab and the contractor's mix design were reasonably similar. At the total asphalt content of 5.5%, the SDDOT air voids were 5.1% and the VMA was 14.9%, whereas the contractor results were 4.9% air voids and a VMA of 14.5%.

According to AASHTO M 323, Superpave mix designs should be designed at 4.0% air voids (96.0% of G_{mm}) and the minimum VMA for 12.5 mm NMAS mixes is 14.0%. Therefore, the minimum volume of effective asphalt is 10.0%. For the mix design on this project, the volume of effective asphalt was 9.8% based on SDDOT results and 9.6% for the contractors results. Both results indicate that the mix design was slightly low in asphalt content.

There is also some uncertainty in the current practice of the SDDOT in determining the bulk specific gravity of the RAP aggregate. SDDOT specifications 319 and 316 contain the following:

> When 20 percent or less RAP is used in the mix design, the SDDOT will use the G_{sb} from the virgin mineral aggregate for the G_{sb} of the mixture. If the SDDOT determines from the previous RAP mix design (if available) that the RAP G_{sb} varies by more than 0.030 from the virgin mineral aggregate G_{sb}, the SDDOT will use the old RAP mix design G_{sb} along with the virgin aggregate G_{sb} to get the combined number for the composite G_{sb}. If the RAP G_{sb} is not available and the Contractor determines from the G_{se} for the RAP by conducting two Rice tests (SD312) and using the asphalt absorption from the previous mix design done on the RAP (number from material in same pit area if mix design not available) to back calculate the G_{sb} for the RAP material; that when the RAP G_{sb} varies by more than 0.030 from the virgin mineral aggregate G_{sb} , the SDDOT will verify the RAP G_{se} and G_{sb} and use the combined numbers for the composite G_{sb}.

Since most roadways will have one or more seal coats on the surface at the time the roadway is milled for rehabilitation, the use of the previous mix design G_{sb} for the RAP or estimating the asphalt absorption from the previous mix design will result in an error. In some cases, the error may result in an inflated VMA and a low asphalt content for the new mix design.

Project Construction Test Results

Data from daily “tank sticks” during production of the Q2 mix indicate that the virgin asphalt content ranged from 3.83% to 4.52%. For the three days with the lowest asphalt contents, the report numbers include “-30%” which may indicate that the RAP content was increased from 20% to 30%. Excluding those three days, the average virgin binder content averaged 4.29%, which is consistent with the mix design target of 4.2%.

Gradation results of the plant sampled composite virgin aggregate indicate that the P200 content ranged from 2.0% to 3.9%. The average dust content for the virgin aggregate blend shown on the mix design was 2.8% although the calculated result based on the stockpile gradations was 2.1%. The percent passing the No. 8 sieve ranged from 30% to 49%, which was within the SDDOT specification range. Only 4 of the 25 test results were more than 5% from the virgin aggregate composite of 45% passing the No. 8 sieve on the mix design.

The mix design also indicates that 1.0% hydrated lime was used in the mix. The Lime Content Summary report from field production records confirm that an average of 0.97% lime was added to the mix. On the last few days of production, the lime checks indicate that the lime content was a little higher, ranging from 1.08% to 1.21%.

Table 7 shows the results of the in-place density tests and the QC volumetric properties. Based on these data, the average in-place density was 92.2% of G_{mm} and the average air void content for the lab compacted specimens was 3.8%. These results are satisfactory. The QA and IA results for volumetric tests are not shown here, but they confirm the QC data.

Table 7: Acceptance Test Data for PCN 00XK

In-Place Density	Test #	G_{mm}	G_{mb}	Va
92.5	QC01	2.450	2.358	3.8
91.8	QC02	2.455	2.359	3.9
92.5	QC03	2.458	2.363	3.9
92.9	QC04	2.459	2.373	3.5
92.2	QC05	2.459	2.371	3.6
92.4	QC06	2.463	2.374	3.6
93.1	QC07	2.447	2.355	3.8
90.7	QC08	2.445	2.350	3.9
91.7	QC09	2.454	2.361	3.8

Project #1 Conclusions

The optimum asphalt content for the mix design was slightly low for a 12.5 mm NMAS mix because the air void content was too high. The mix design VMA results are also questionable because of uncertainty on how the RAP aggregate specific gravity was determined. The available quality assurance data indicate that the mix was produced with good control and the field density results were good except for one result slightly below the minimum criteria of 91.0%. Even though the air voids were high during the mix design (approximately 5%) the laboratory air voids during production where good (slightly below 4%).

Project PCN: 00HT (Project #2 on Table 6)

SD48 in Union County was also identified as a poor performing RAP project. As shown in the map in Figure 6, the project extended from I-29 west of Spink to the Big Sioux River. Based on available QC records, mix production and paving occurred between September 18, 2009 and October 10, 2009. The contractor was McLaughlin & Schultz Inc. The research team has no information on the asphalt plant used for this project. The project consisted of milling the existing pavement and placing 7,776 tons of "blade-laid" HMA, followed by 20,999 tons of Q2 mix that contained 20% RAP.

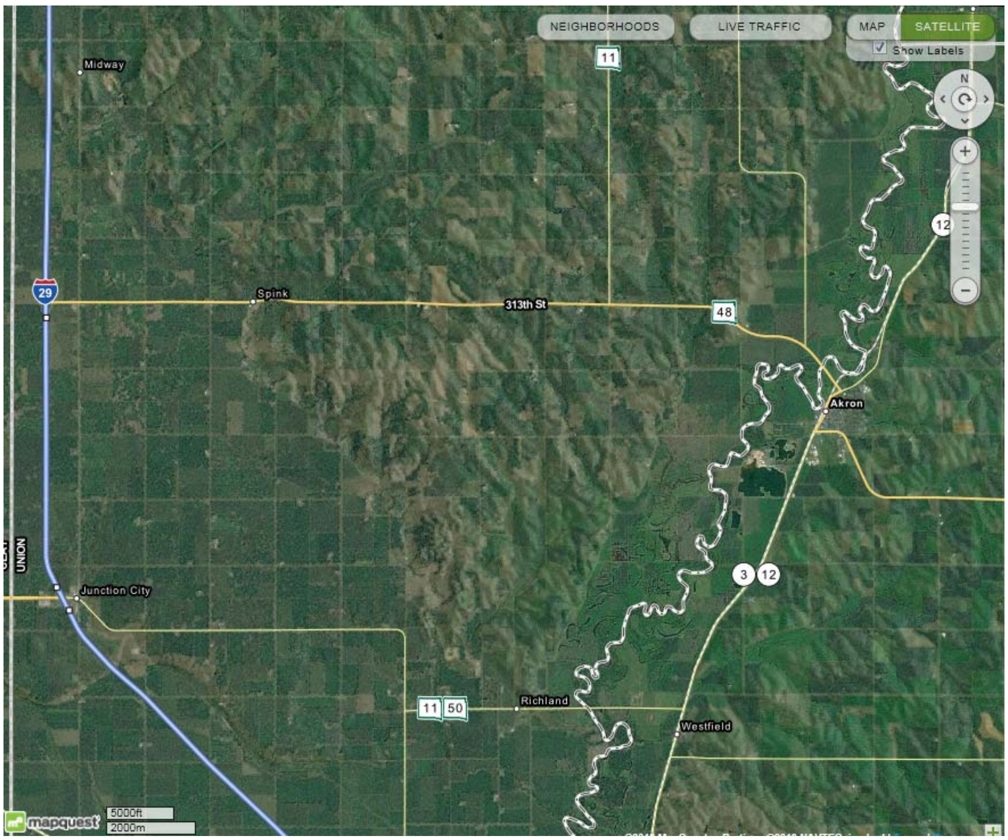

Figure 6: Map Showing the Location of SD48, Extending from I-29 to the Big Sioux River

Mix Design Information

The Q2 mix was a 12.5 mm NMAS mix using a laboratory compactive effort of 50 gyrations. The SDDOT Mix Design Lab results indicate that for a total asphalt content of 4.7%, the air voids were 4.1% and the VMA was 14.9%. The RAP content for the mix design was 20%. The RAP gradation was shown on the mix design, but the RAP asphalt content was not listed. The virgin binder content was given as 3.1%. Therefore, the RAP would have to contribute 1.6% binder, which means that the asphalt content of the RAP would have been 8.0%. This value seems high, but may be higher than typical for HMA RAP if the pavement surface had multiple seal coats prior to the milling.

The VMA calculated from the data given on the mix design sheet should have been 14.2% rather than 14.9% as shown for the SDDOT lab results.

The mix design was revised on September 23, 2009 to increase the virgin binder content from 3.1% to 3.4%. Presumably, this change was requested because of problems with obtaining adequate in-place density during construction. The original virgin binder content for the mix design (3.1%) was the lowest of all of the Q2 mixes from 2008 to 2012. Even with the adjusted asphalt content, it was still the lowest.

Project Construction Test Results

Data from daily "tank sticks" indicate that the average virgin asphalt content ranged from 3.28 to 3.35 over the first five days of Q2 mix production, then increased to between 3.62 and 3.74 over the last six days of production. The records indicate that the increased asphalt content occurred for mix production beginning on September 25, 2009. This was about half way through the job.

Gradation results of the virgin materials taken from the belt prior to entering the dryer indicate that the P200 content trended upward throughout the mix production. A chart of this data is shown in Figure 7. The P200 content began around 4.0% and steadily increased to about 5.4%. The average dust content for the virgin aggregate blend shown on the mix design was 4.4%.

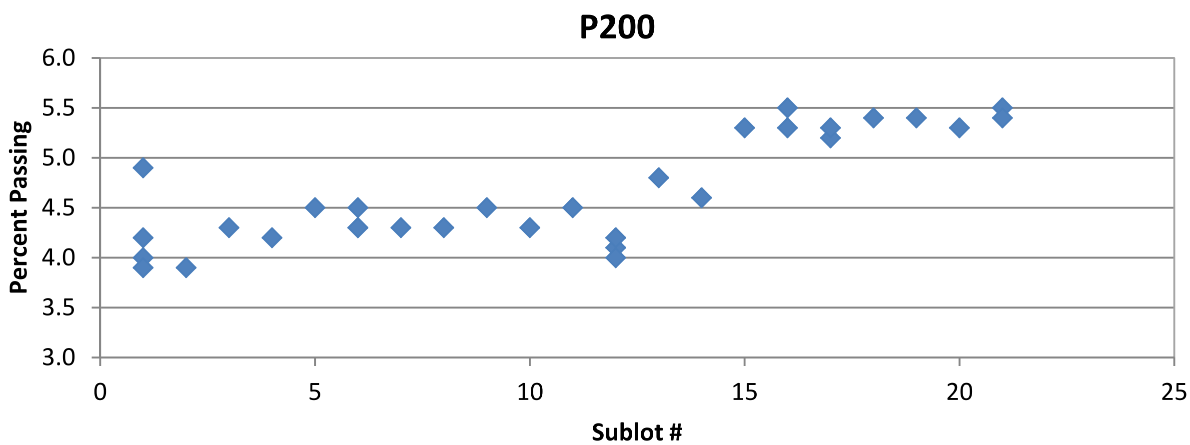

Figure 7: Chart of the P200 Content of Virgin Aggregate Materials taken from Plant's Belt during Production

With no QC testing of the RAP, it is not possible to determine if the characteristics of the RAP may have differed from those used in the mix design.

Test results for the in-place density tests and mix tests are shown in Table 8. Of the 20 in-place density sublots, 12 results (60%) were below the minimum of 91.0% required by SDDOT specifications (Table N). Even after the increase in asphalt content (presumed to be after test # QC11), the in-place density results remained low. The average in-place density for the entire project was 90.6, so it is assumed that a pay reduction was applied to many of the lots on the project. The low in-place density would certainly be a significant factor contributing to poor performance. The lab compacted air voids seem satisfactory and reasonably consistent.

Table 8: Acceptance Test Data for PCN 00HT

In-Place Density	Test #	G_{mm}	G_{mb}	Va
91.3	QC01	2.469	2.361	4.4
91.9	QC02	2.482	2.378	4.2
91.4	QC03	2.474	2.372	4.1
90.1	QC04	2.472	2.382	3.6
91.7	QC05	2.461	2.339	5.0
90.4	QC06	2.488	2.378	4.4
90.0	QC07	2.479	2.379	4.0
89.7	QC08	2.472	2.375	4.0
91.1	QC09	2.474	2.364	4.4
92.3	QC10	2.468	2.364	4.2
90.4	QC11	2.474	2.376	4.0
89.9	QC12	2.477	2.367	4.4
91.3	QC13	2.484	2.388	3.9
91.1	QC14	2.478	2.386	3.7
90.9	QC15	2.465	2.374	3.7
89.3	QC16	2.461	2.382	3.2
90.5	QC17	2.468	2.374	3.8
89.3	QC18	2.471	2.382	3.6
88.7	QC19	2.469	2.393	3.1
90.8	QC20	2.473	2.386	3.5
	QC21	2.463	2.375	3.6

Weather data from Weather Underground (www.wunderground.com) were also analyzed to determine its potential impact on in-place density results. The nearest weather station to the project was Le Mars, IA, which is 32 miles east of Spink, SD. Table 9 summarizes the weather data during the time this project was constructed. These data reflect the seasonal decline expected this time of year in South Dakota with daytime highs beginning in the 80's and falling to the 50's at the conclusion of paving operations. Although cool weather may have contributed to the challenge of obtaining the target density for a few days on this project, most of the days were good for paving.

Table 9: Weather Data for Le Mars, IA during the Time of Paving

Date	Mean Temp., °F	Max. Temp., °F	Min. Temp., °F	Wind speed, mph
18-Sep	68	84	53	1
19-Sep	65	80	50	2
21-Sep	57	68	46	8
22-Sep	61	71	51	1
23-Sep	65	77	53	1
24-Sep	65	73	55	2
25-Sep	64	77	50	2
26-Sep	65	77	53	2
28-Sep	50	53	48	2
29-Sep	60	69	50	3
3-Oct	47	55	39	8

Project #2 Conclusions

The poor performance on this project is most likely due to the low in-place densities, which typically lead to a higher rate of permeability and accelerated aging of the surface layer. The low asphalt content for the mix design probably contributed to the low density results and exacerbated the poor performance observed. Although the asphalt content was increased by a few tenths of a percent during the project, the change did not appear to improve the in-place density results.

Project PCN 00GY (Project #4 on Table 6)

Another poor performing RAP project was US81 in Lake County from SD34 at Madison, north to the Kingsbury County line. Figure 8 shows a map with the location of the project. The contractor was McLaughlin & Schultz, Inc. The plant site was not provided. The QC records indicate that mix production and paving occurred between September 20, 2010 and October 20, 2010.

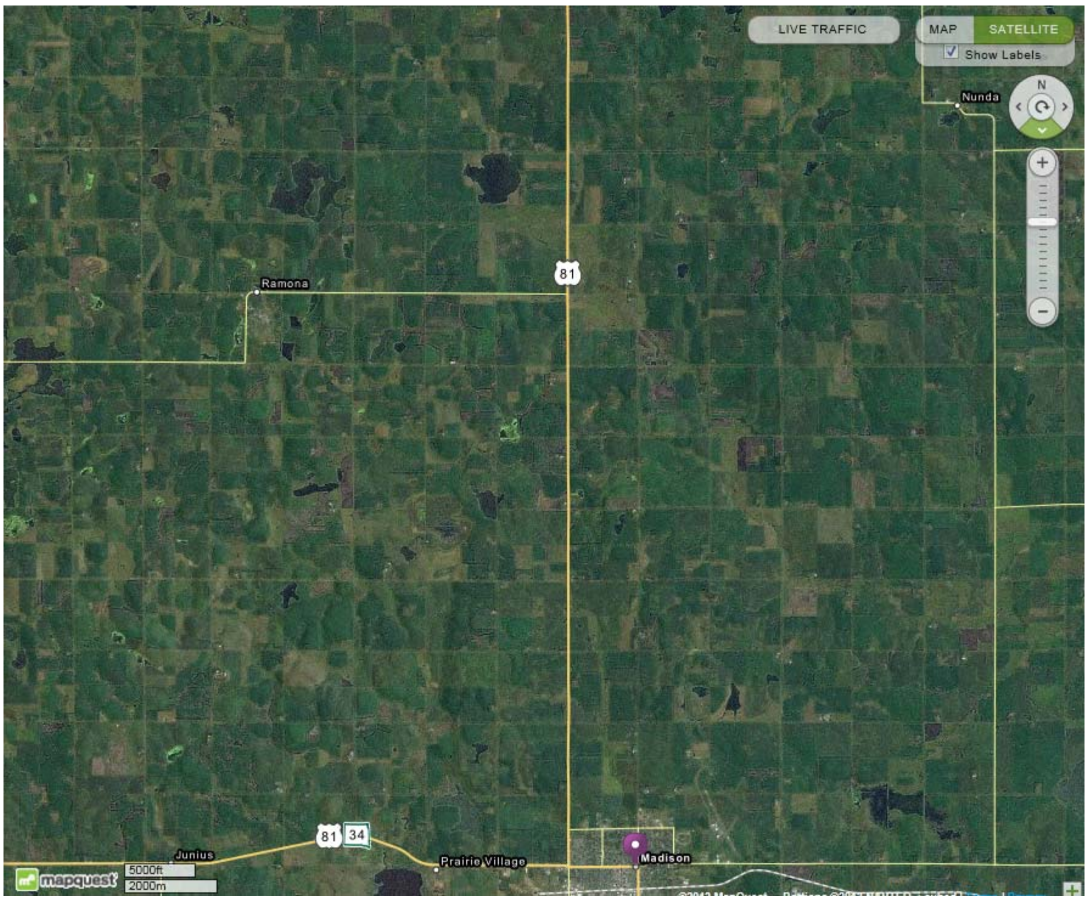

Figure 8: Map Showing the Location of US81, From Madison North to the County Line

Mix Design Information

Like the other projects, the mix design used on this project was a 12.5 mm NMAS Q2 mix containing 20% RAP designed with a laboratory compactive effort of 50 gyrations. The SDDOT Mix Design Lab results indicate that for a total asphalt content of 5.7%, the air voids were 4.6% and the VMA was 15.4%. Based on the "Agg. Composite G_{sb}" shown on the mix design, the VMA would calculate as 15.8%. The virgin binder content was given as 4.7%. Therefore, the RAP would have to contribute 1.0% binder, which indicates that the asphalt content of the RAP would have been 5.0%. Although this value seems appropriate for millings (given that SDDOT Q2 mixes typically have around 5% asphalt), it is lower than for the other mix designs obtained from the poor performing projects. The dust to binder ratio was given as 1.1, which is within the high end of the acceptable range. However, it is unclear whether or not the dust to binder ratio includes the hydrated lime in the mix's dust content. Other mix design parameters meet criteria that are appropriate for this project.

Project Construction Test Results

Data from the DOT-89 summary indicate that the average virgin asphalt content was 4.60% and ranged from 4.38% to 5.01% over the 18 days of Q2 mix production. This indicates that the virgin asphalt content was maintained close to the mix design target of 4.7%. The hydrated lime summary report also showed that the feed rate of the lime was held reasonably consistent except for two days where the daily results were low. On September 27 the hydrated lime content was reported to be 0.4% and on October 12 the lime content was reported as 0.7%.

Test results for the in-place density tests and mix tests are shown in Table 10. Overall, the in-place density results were good; only two of the 21 days had results below the 91.0% criteria. The lab compacted air void results were very consistent with an average of 3.2%. Although this average is on the low end of the acceptable range, it is generally a good practice to keep the lab air voids low for low traffic roadways.

Table 10: Acceptance Test Data for PCN 00GY

In-Place Density	Test #	G_{mm}	G_{mb}	Va
93.1	QC01	2.419	2.369	2.1
91.2	QC02	2.430	2.355	3.1
91.4	QC03	2.424	2.342	3.4
94.0	QC04	2.420	2.337	3.4
90.6	QC05	2.427	2.349	3.2
90.8	QC06	2.422	2.341	3.3
91.6	QC07	2.420	2.336	3.5
92.0	QC08	2.420	2.342	3.2
91.0	QC09	2.424	2.347	3.2
91.5	QC10	2.427	2.352	3.1
91.1	QC11	2.415	2.329	3.6
92.5	QC12	2.422	2.347	3.1
92.9	QC13	2.420	2.343	3.2
92.3	QC14	2.422	2.345	3.2
92.5	QC15	2.430	2.350	3.3
95.0	QC16	2.420	2.341	3.3
93.5	QC17	2.431	2.355	3.1
92.3	QC18	2.423	2.348	3.1
92.4	QC19	2.416	2.331	3.5
92.7	QC20	2.422	2.345	3.2
93.6	QC21	2.420	2.339	3.3

Weather data were gathered from Weather Underground to determine its possible effect on project construction. The weather station at Madison, SD was used for this data. Table 11 summarizes the weather data for the dates the Q2 mix was produced. These data indicate that the weather was generally favorable for paving conditions.

Table 11: Weather Data for Madison, SDduring the Time of Paving

Date	Mean Temp., °F	Max. Temp., °F	Min. Temp., °F	Wind speed, mph
20-Sep	68	86	50	13
21-Sep	59	68	50	8
22-Sep	55	66	44	9
27-Sep	60	75	46	10
28-Sep	58	71	46	7
29-Sep	60	71	48	11
30-Sep	58	69	46	8
1-Oct	58	75	42	5
2-Oct	45	55	35	8
4-Oct.	52	66	39	11
5-Oct	62	77	46	13
6-Oct	60	69	50	9
7-Oct	55	73	37	4
8-Oct	67	84	50	7
9-Oct	60	71	50	6
11-Oct	62	77	48	5
12-Oct	56	62	48	10
19-Oct	46	60	32	5
20-Oct	52	66	37	10

Project #4 Conclusions

The mix design air void content was 4.6%. Had it been set at 4.0%, as recommended by AASHTO M323, then the asphalt content would probably have been a few tenths higher. Control of the plant produced mix and roadway compaction appear to be satisfactory. Weather was generally favorable during construction and does not appear to have been a contributing factor to poor performance.

Project PCN 024C (Project #5 on Table 6)

Another RAP project identified as performing below expectations is SD19 west of Sioux Falls from the east junction of SD42 to the west junction of SD38 in Minnehaha County. This northern end of this project is near I-90 Exit 379 at Humboldt. The contractor was Myrl & Roy's Paving, so it is presumed the mix was hauled from Sioux Falls which is about a 20 mile haul. Based on DOT-89 test dates, the paving on this project was accomplished between October 5 and October 15 in 2010.

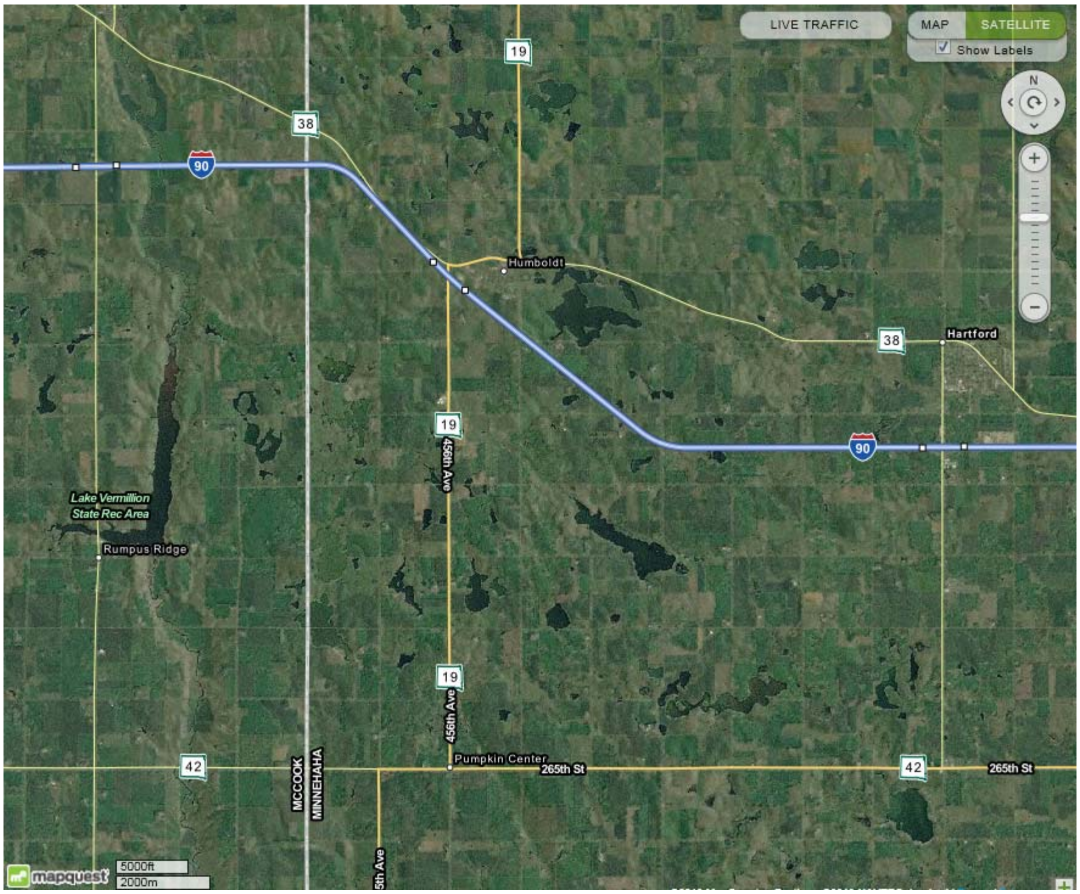

Figure 9: Map Showing the Location of SD19, from SD42 to SD38

Mix Design Information

This project utilized a Q2 mix design containing 20% RAP. This was a 12.5 mm NMAS mix using a laboratory compactive effort of 50 gyrations. The mix design shows large differences in G_{mm} and G_{mb} results between the contactor and the SD lab in Pierre. Therefore, air voids results differed by 1.8% and VMA results differed by 1.3%. The fine aggregate angularity (FAA) reported for this mix was 41.3 (SDDOT) and 42.5 (M&R), which indicates that the fine aggregate portion of the blend contained a high proportion of rounded particles. The gradation of the RAP indicates that its dust content was 14.3%. It can be inferred from the difference between the total binder and virgin binder contents that the RAP asphalt content was 8.0%. It is therefore presumed that the RAP includes one or more chip seals.

Project Construction Test Results

Data from the form DOT-89 (Bitumen Content Determination) indicate that the virgin asphalt content was controlled very well and close to the target. The average virgin binder content was 4.17% with a standard deviation of 0.12%. The optimum virgin binder content from the mix design was 4.3%.

Test results for the in-place density tests and mix tests are shown in Table 12. About half (6 of 13) of the in-place density sublots were below the minimum of 91.0% required by SDDOT specifications (Table N). The low in-place density would certainly be a significant factor contributing to poor performance. This project was mentioned in the interview with Sue Unzelman, owner of Myrl & Roy's Paving. She indicated that the inconsistent densities were due to a bad cross slope left by the milling. The average lab compacted air voids was 4.3% with a standard deviation of 0.34%. These results were satisfactory and consistent. QA and IA results also confirmed the lab volumetric data from the QC testing. It is worth noting that the G_{mm} and G_{mb} data from the field produced mix are consistent with the contractor's mix design.

Table 12: Acceptance Test Data for PCN 024C

In-Place Density	Test #	G_{mm}	G_{mb}	Va
91.6	QC01	2.460	2.353	4.3
92.9	QC02	2.466	2.346	4.9
89.6	QC03	2.453	2.356	4.0
93.0	QC04	2.452	2.357	3.9
91.9	QC05	2.459	2.361	4.0
89.2	QC06	2.454	2.344	4.5
90.8	QC07	2.461	2.344	4.8
91.0	QC08	2.464	2.356	4.4
89.1	QC09	2.462	2.353	4.4
89.8	QC10	2.463	2.350	4.6
91.3	QC11	2.455	2.359	3.9
90.1	QC12	2.438	2.346	3.8
92.1	QC13	2.459	2.348	4.5

Weather data were gathered from Weather Underground to determine its possible effect on project construction. The weather station at Sioux Falls, SD was used for this data. Table 13 summarizes the weather data for the dates the Q2 mix was produced. No precipitation was recorded over the 11 days of paving on the project. This temperature data indicates that there were several cool nights during this project, but temperatures warmed up to suitable temperatures in the daytime. Cool underlying layers could have contributed to the density problems on this project.

Table 13: Weather Data for Sioux Falls, SDduring the Time of Paving

Date	Mean Temp., °F	Max. Temp., °F	Min. Temp., °F	Wind speed, mph
5-Oct	63	76	49	15
6-Oct	57	71	42	7
7-Oct	55	73	36	6
8-Oct	67	84	50	5
11-Oct	63	79	46	1
12-Oct	54	65	42	10
13-Oct	50	62	37	5
14-Oct	52	67	36	8
15-Oct	50	67	32	8

Project #5 Conclusions

This project had a high percentage of failing densities. Also, the laboratory voids during construction were slightly high indicating that the asphalt content was a little low. However, given the available data, there is not a clear cause for the density problems on this project. The contractor stated that the underlying milled surface had an irregular cross slope that may have contributed to density problems. It is possible that cool temperatures may have had an impact on densities. It is concerning that the SDDOT mix design lab was unable to replicate the contractor's mix design results.

5.3.2.2 Overall Conclusions Regarding the Investigation of the Poor Performing Projects Using RAP

Data were obtained for only four projects that had not provided satisfactory early performance. Although most of the poor performing projects were from the southeastern part of the state, there were few commonalities among the materials. The asphalt contents for three of the four projects appeared to be low by a couple of tenths of asphalt. This is consistent with the general observation that the mixes looked "dry" and the pavements tended to have problems meeting density criteria and were showing signs of raveling.

There are several recommendations that can be offered to improve mix designs containing RAP. First, the department should establish a single method for determining the asphalt content of RAP samples. Given that most RAP will contain multiple chip seals and an asphalt mixture with aggregates from different sources, it is unlikely that an ignition test result for asphalt content would be accurate since there is no way to reliably determine an aggregate correction factor. Therefore, the best approach would seem to be to determine the asphalt content using a solvent extraction procedure. The second critical item for improving mix designs containing RAP is to establish one method for determining the RAP aggregate specific gravity. The bulk specific gravity of the RAP aggregate, as well as the specific gravities of the other aggregate components, must be determined as accurately as possible in order to obtain the correct VMA for the mix. VMA and air void content criteria together establish the minimum acceptable volume of asphalt for the mix and are therefore paramount to achieving a durable mix. Another option to consider is to intentionally set a lower target air void content for RAP mixes while leaving the VMA criteria unchanged. Several states have used this approach to improve the durability of all mixes, regardless of RAP content. As noted above, the net effect is a slight increase in asphalt contents.

Although the NCAT team was unable to visit or observe the operations of the particular plants used on these problem projects, plant issues were described by SDDOT personnel interviewed, as noted in Section 5.3.1, included incomplete coating, possible incomplete drying, dust control, and oversized RAP particles in the mix. Several of these issues may be related to inefficiencies of heating, drying, and mixing RAP in the drum mixer. To effectively produce a suitable mix containing RAP, the plant should be designed to handle RAP from the beginning. Variations in moisture in the stockpiles, particularly in the RAP, can cause significant problems with mix quality and consistency. Although a full discussion of plant operations for mixes containing RAP is beyond the scope of this report, the agency does have the authority to cease operations if: (a) the mix has incompletely coated aggregates, (b) the mix temperature is outside of the allowable production temperature range, (c) contains oversized particles. Problems with dust control are typically evident in gradation checks and volumetric properties.

5.4 Findings from Interviews with Neighboring Highway Agencies

5.4.1 Background

Pavement engineers representing seven highway agencies near South Dakota were interviewed to gather information regarding their current practices concerning the use of RAP in asphalt paving mixtures. A summary of some of the information collected from those surveyed is provided in Table 14. Current practices for South Dakota DOT are shown at the top of the table for comparison. More detail about what was learned from the individuals from each neighboring highway agency is provided in the following sections.

Table 14: Summary of Survey from Neighboring Agencies on RAP Use

	South Dakota	Iowa	Manitoba	Minnesota	Montana	Nebraska	North Dakota	Wyoming
Amount of RAP Allowed	20% typically specified in mainline surface mixes, up to 30% in shoulder mixes	Unknown RAP: 10% underlying layers, 0% in top layer. Unknown RAP but classified: 20% in underlying layers, 10% in surface. RAP known: unlimited in bottom layer, 30% in top layer	Up to 40% in bottom layers and 15-20% in top layer	Generally allow up to 30% binder from RAP	15% in top and 30% underneath	Up to 50% for all layers and all traffic levels	20±5% on mainline, 30±5% on shoulder	Not much RAP used, generally no more than 15%
RAS Use	Has not used RAS to date	Up to 5%	Have not used shingles so no effect on RAP	Up to 5% RAS used, no more than 30% binder from RAP and RAS	Some interest but not used at this point	Very little RAS used partially due to high use of RAP	RAS not used so does not affect RAP	No RAS used, no effect on RAP
WMA Use	Limited use, only pilot projects to date	Permissive spec but no effect on RAP	Used some WMA. Interested in increasing RAP with WMA but have not done this	Starting to use WMA but no effect on RAP	Minor amount used with no effect on RAP	Used routinely but does not affect RAP	WMA used routinely but does not affect RAP	Not much WMA used, no effect on RAP
Ownership of Millings	Agency owns RAP; typically provided to contractor on projects requiring RAP in asphalt mixes	Contractor	Agency owns but may give contractor approval to use	RAP belongs to contractor	Owned by DOT but may provide to contractor in contract	Sometime state owns and sometimes contractor owns	Millings from project used on project; any leftover is owned by contractor	State owns millings
Source of RAP	Typically RAP from the same project	Any source but must be tested	Generally from existing project but may allow to use nearby state stockpile	Any source of RAP can be used	Any source	Any source of RAP	Only RAP from project being constructed	RAP used from same project from which recovered
Testing of RAP	Gradation, asphalt content, and specific gravity for mix design	Gradation, asphalt content, and fractured face count	No special testing except during mix design	No specific reqts., quality controlled in mix	No testing, mix must meet reqts.	No testing reqts., mix must meet spec reqts.	No special reqts., limit on maximum size	Gradation and asphalt content tests
Grade of Virgin Binder	PG 58-28 in past, now using PG 58-34 on most projects using RAP	Over 20% then drop 1 grade. If RAS then drop grade at 15% RAP	Grade determined based on testing on blended binder	A xx-28 grade is used for RAP mixes	No change in binder grade	Typically use PG 64-34 in all mixes, maybe 52-34 on shoulders	Typically use PG 58-28 for all mixes	Use same grade of asphalt

5.4.2 Typical RAP Contents

The allowable amount of RAP used in asphalt mixtures varies considerably from agency to agency, but each agency has justification for the limits that are being used. For example, the amount of RAP allowed by the agencies ranged from as low as 15% in Wyoming up to 50% in Nebraska. All agencies would like to use as much RAP as available as long as they can be sure that the quality of the recycled mixture is satisfactory. It is clear to all of the agencies that increased RAP content in mixtures will result in lower construction costs. There were a number of reasons for the lower amount of RAP used in Wyoming. In the past, Wyoming allowed more RAP in their mixtures (up to 40%), but they had some performance issues on some early projects, and around the same time the state legislature passed a law requiring the state to provide millings to the counties. For a period of time, this took most of the millings generated and there was very little RAP available for use by the DOT. Since that time, the amount of RAP used by the counties has decreased some as the funding originally available to utilize this RAP has been discontinued. At the time of the interview, the WYDOT was using about 15% RAP which consumes most of the RAP available to the state. They do not anticipate using a significantly higher amount of RAP in the near future.

Nebraska is a big user of RAP. They estimate that 80 percent of their projects use 43% RAP on average, and the other 20 percent of the projects use 25% RAP on average. This results in an average RAP content of 39.4% for all projects. The state gives contractors an incentive to use RAP, and as a result the amount of RAP use has increased. The DOT estimates that they saved $40 million in 2011 as a result of their use of high RAP content mixes.

For most agencies, the actual RAP contents being used on projects are believed to be near the upper limit set by the agency. However, only two states had actually examined how much RAP is being used. Iowa estimates that they use 18% RAP and Nebraska estimates that they use 39.4% RAP. Several agencies interviewed perform the mix designs, so they control how much RAP is used in the mixes. When the agency performs the mix design, the RAP likely comes from the project millings.

Most agencies interviewed do not have any specific issues that control the amount of RAP being used other than the desire to ensure mixture quality and the lack of availability of RAP. All states, without exception, indicate that they do not have any performance issues with the recycled mixtures they are currently using. When increasing the amount of RAP allowed for use, each agency worked to ensure that the approach used for increasing the amount of RAP did not affect overall performance of the pavement. North Dakota mentioned that they had observed plant emissions issues with higher RAP contents in the past and they were reluctant to increase the amount of allowable RAP for this reason. Wyoming and Montana mentioned that they work with counties to provide some of the millings to them for use and this practice had reduced the availability of RAP for use on state projects. Iowa mentioned that they have requirements for asphalt film thickness and this often limits the amount of RAP that can be used due to the tendency for higher dust content in RAP materials.

All agencies interviewed except for Minnesota currently have asphalt binder as a separate bid item, similar to South Dakota. Minnesota had asphalt binder as a separate bid item until 1990 when they changed to make it inclusive in the cost of the asphalt mixture. Depending on how the cost of asphalt binder is bid, it can discourage the use of RAP. To encourage the use of RAP, Nebraska pays for the new asphalt binder based on the contract bid price. They then give contractors an incentive to use RAP by paying for 15% of the binder coming from the RAP if it is milled from the existing project. They pay for 35% of the RAP binder if the RAP was milled from another DOT project. They pay for 50% of the RAP binder from RAP that is owned by the contractor if collected from non-DOT sources.

Most agencies allow more RAP to be used in the underlying layers than in the surface. Also, most states use more RAP recovered from DOT projects than that recovered from other sources. In fact, many agencies require that the RAP be milled from the existing DOT project. Most of the agencies apparently own the millings and they generally try to use most of the RAP that is collected from the milled state projects. The first preference is generally to use the available RAP in asphalt mixtures since this provides the most economical savings. The second option is to provide some of this RAP to a local county or to use it on shoulders.

In most agencies, the available RAP is used at about the same rate that it is being recovered. In other words, there are no significant increases or decreases in the quantity of available RAP from year to year, so there is no need for an agency to increase the amount of RAP allowed unless more becomes available. The amount of RAP actually used on projects in the various agencies is 15% or less in states such as Wyoming and Montana and up to approximately 40% in Nebraska.

The agencies were asked if they use warm mix asphalt (WMA) and reclaimed asphalt shingles (RAS) and if this has an effect on RAP use. Four of the DOTs have begun to use a significant amount of WMA but it has not affected the amount of RAP used. Two of the states, Iowa and Minnesota, have used a significant amount of RAS. The use of RAS has generally reduced the amount of RAP that can potentially be used. Minnesota requires that no more than 30% of the total binder can come from RAP and RAS so the use of RAS will decrease the amount of RAP that can be used. Iowa uses a fracture energy test to evaluate cracking potential of asphalt mixtures and this tends to reduce the amount of RAP that can be used when RAS is used. The Nebraska DOT has not used much RAS to date, and they believe this is due to the high quantities of RAP that they are using. Contractors see no advantage of adding RAS when high quantities of RAP are being used.

5.4.3 Pavement Performance

All agencies were asked how well the mixes with RAP are performing, and without exception the states indicated that field performance has been good. The mixes using RAP have performed just as well as mixes without RAP are expected to perform. There are no specific performance problems noted with the recycled mixtures.

Most states have begun to use a number of pavement preservation techniques. In two states, Wyoming and Montana, new overlays and new pavements are treated with a chip seal within one or two years of the surface being constructed. The main purpose of the chip seal is to provide a good seal to the surface to improve durability. Several DOTs use microsurfacing on a regular basis. Manitoba mentioned using rejuvenators as long as friction can be maintained satisfactorily. The most common practice is to add a pavement preservation treatment between 5 and 10 years after construction depending on conditions of the surface. The treatments and time lines for placement of treatments are no different for mixes containing RAP and mixes without RAP.

Pavement rehabilitation designs are normally performed by most of the agencies using the AASHTO standards. Sometimes overlays are placed simply to improve the surface conditions, and in this case a structural design is not always performed. But if there is any question, performing a pavement structural design is a standard procedure.

Most work requires milling to remove the surface, which may have had rutting, raveling, and other problems. This technique provides a dense and hard level surface on which to place the overlay. The milling depths used by most states range from 1 to 3 inches. Most states evaluate the condition of the pavement before making a final judgment on the milling depth. In some states, aggregate with high friction is typically used to improve the friction of the surface layers. For this situation, milling is sometimes done to remove the top surface to keep the high friction aggregate in one stockpile and not have the stockpile mixed with aggregate that may tend to polish. If additional milling is needed it can be performed in a second lift. Sometimes when milling close to the bottom of a layer, scabbing may occur where material breaks loose at the interface or the bond of the remaining layer to the underlying asphalt concrete is compromised. For this reason, some states require that the milling be deep enough to go through an existing layer and into the layer underneath. This procedure should be able to reduce scabbing.

5.4.4 RAP Management

About half of the agencies interviewed take ownership of the RAP after milling. In most cases, when the agency owns the RAP they try to use as much of it as acceptable in the asphalt mixtures being produced for the project. Some agencies include a plan for using the millings in the project and ownership of the remaining RAP in the contract documents. In these cases, agencies that have a need for the RAP generally keep as much as needed and if they had no need for the RAP it is given to the contractor at the end of the project.

Some agencies only allow RAP from the existing project to be used in mixtures for that project. Other agencies allow the use of RAP from the existing project or from other projects within the agency. Other agencies allow RAP from any source as long as the total mixture meets the specification requirements. This seems to be the most common approach. Four of the agencies interviewed allow RAP from any source to be used. The amount of RAP that can be used in an asphalt mixture sometimes varies depending on the source. Three of the agencies interviewed require that the RAP come from state DOT projects.

RAP stockpiled in most states is generally used at about the same rate as it is being generated, so there is no excessive amount of RAP being produced. However, Minnesota said that the industry has indicated that the amount of RAP is steadily increasing in their state. It is best if the RAP can be used in asphalt mix, which is the greatest value, but in some cases it is used for other purposes such as shoulders and surfacing material for low volume roads.

Generally, there are no special requirements for processing RAP other than feeding the RAP over a scalping screen to remove the oversized material. Some contractors fractionate RAP for better control, but this is not typically a requirement of any of the agencies interviewed. In Nebraska, fractionation is sometimes required simply to ensure that the RAP is fine enough to be used in thin asphalt pavement layers. Manitoba sometimes requires that the RAP stockpile be crushed when it is from a stockpile that has been in place for a long period of time.

Most DOTs do not require any significant testing of RAP stockpiles. However, the contractor has to ensure that the RAP stockpile is satisfactory in order to meet specification requirements. The contractors typically measure asphalt content and aggregate gradation, and if asphalt blending testing is required, the contractor will check the properties of the binder in the RAP. Most DOTs require that the mixture meet the specification requirements, but there are no additional requirements for testing of the RAP alone.

5.4.5 Mix Designs Containing RAP

In most cases, the mix designs containing RAP do not have to meet any additional requirements. However, some states do require that the blended binder be tested, and in this case, extractions and recoveries of the blended binders are required before the binder can be tested. About half of the agencies use the same grade of virgin binder when RAP is added, and about half require a lower grade of virgin binder. When a softer grade of virgin binder is used, this grade is typically one grade softer (typically on the low end). There are considerable differences among agencies in how the virgin asphalt binder grade is selected for RAP mixtures. Two agencies, Minnesota and Manitoba, use blending charts to determine the desired grade of blended asphalt. Manitoba uses the penetration grading system. This testing is somewhat different than Minnesota, which uses the PG grading system. Many states have tried to get away from using solvents as much as possible and hence have looked for ways to determine the virgin binder grade without having to test the blended binder. Also, many believe that recovering the asphalt binder results in thorough mixing of the binders and this is not representative of what happens in actual mixes containing RAP. Iowa and Nebraska drop a binder grade in some cases when using RAP. Iowa drops one grade if using over 20% RAP or over 15% if shingles are also used. Nebraska typically uses a 64-34 grade of asphalt whether RAP is included or not. For shoulder mixes, they typically use a 52-34 grade of asphalt when using RAP. Three state DOTs typically have no change in grade when using RAP. These three states were Montana, North Dakota, and Wyoming. North Dakota typically uses a PG 58-28 for mixes without RAP and saw no need to use a softer grade when RAP is used. Montana and Wyoming typically do not use much RAP and saw no reason to change PG grade.

The bulk specific gravity of the aggregate in the RAP has to be determined so that one can calculate the VMA of the recycled mixture. The state of Iowa extracts the binder from the mix, removes the aggregate, and conducts the bulk specific gravity on the recovered aggregate. The Nebraska DOT assigns a bulk specific gravity to each aggregate source based on experience with local materials. They then control the air voids and asphalt content. The Wyoming and North Dakota DOTs use the effective specific gravity for the aggregate in the RAP for estimating the bulk specific gravity of the aggregate.

Three states (Montana, Nebraska, and Wyoming) require that lime be used as an anti-strip agent in all of their mixtures. The application rate for lime is 1.0% to 1.5% of the total mixture. Wyoming used open-graded friction courses on the surface and found out years ago that the mixtures underlying the open-graded friction course stripped until they began to use lime. The use of lime has stopped the stripping problem and they have resumed using open-graded friction courses. Three states (Iowa, Minnesota, and North Dakota) test the mix and use an anti-strip agent if necessary to meet specification requirements. Iowa uses the Hamburg for moisture susceptibility and Minnesota and North Dakota use the TSR. Manitoba does not have any requirements for moisture susceptibility testing. They were not aware of any moisture damage problems in the Province and they saw no need to test for this.

The Iowa DOT requires a fracture energy test be conducted on the mix for more critical projects when RAP is used.

5.4.6 Production and Paving with Mixtures Containing RAP

Some engineers have expressed concern about the potential for high moisture contents in RAP mixtures and the likelihood that this moisture is not removed during production. However, the individuals that were interviewed did not express any significant concern for moisture in the stockpiles. In general, they felt that moisture contents of RAP stockpiles should be tested as with other stockpiles, but they did not see any major problems. They generally use a conventional oven for this testing.

The mix temperatures for recycled mixtures are approximately the same or slightly higher than that for virgin mixtures. Some increase in mixture temperature during production may be necessary for higher RAP content mixtures. The mixture temperature is typically a decision the contractor makes that is best for project conditions. Temperature measurements should be taken on a regular basis during production to ensure that the mixing temperature is satisfactory and the temperature variability is not too large.

Another concern that has been expressed by some engineers is the potential for incomplete coatings on the virgin aggregate when RAP is used. All agencies indicated that they have not observed any problems with coating the virgin aggregates and do not anticipate any problems in the future. The mixture requirements and testing during construction are generally the same as for virgin mixtures. Some DOTs have added performance testing for some or all of their virgin mixtures. These performance tests are also often specified for recycled mixtures. Two DOTs use the Hamburg for evaluating rutting and moisture susceptibility and one uses the APA to collect data for information purposes.

Milling and tack coat operations are often judgment calls as far as depth of milling, texture of milling, quantity of tack coat, and application of tack coat. Everyone has tried to eliminate scabbing during milling operations and inspect the texture of the milled surface to ensure that it is satisfactory. The tack coat application rate is typically a little higher for milled surfaces than for surfaces that have not been milled, primarily due to the differences in texture, but the details about acceptability were generally left up to the local staff.

Most of the agencies use the windrow process for placing mixtures and sample the mix from behind the paver for acceptance testing. This method of sampling provides a good measure of what actually goes down on the pavement. However, care must be taken if using the test results for adjusting mixes since segregation will show up as a mix problem even though it may be the result of a handling problem after the mix is produced.

For most of the agencies interviewed, the density measurement for acceptance is typically made on cores removed from the pavement. Measuring density from cores is generally the more accurate approach. Some agencies don’t like to remove cores from the surface course since this will require the core hole to be filled and compacted and it will be visible to the driving public. If not done properly this can lead to roughness or other types of localized deterioration over time. Using good procedures to clean out the core holes and for filling and compacting the material put back in the core holes will result in a patch that won’t be noticeable after a period of time and one that will provide good performance.

In summary, there are many variations among the adjacent states and the Manitoba Province with regard to the use of RAP in asphalt mixtures. The amount of RAP that is being used is highly variable. Mix design practices for mixtures that include RAP are also inconsistent among the states. However, all agencies believed that the approach they are using provides a good product which has good performance and reduces the construction cost of asphalt pavements.

6.0 RECOMMENDATIONS

This chapter presents the research team's recommendations to the South Dakota Department of Transportation based on the research findings. The recommendations are organized into four areas: (1) General Practices and Specifications, (2) RAP Characterization and Mix Design, (3) RAP Management, and (4) Asphalt Mixture Production and Quality Assurance for Mixes Containing RAP. A list of additional research needs is included at the end of this chapter.

6.1 General Practices and Specifications

17. Milling depths for pavement rehabilitation should be selected to satisfy a specific need on the project such as improving the roadway profile, correcting cross slope, maintaining roadway cross-section/pavement width, and/or removing distressed pavement layers. Milling is generally beneficial for the performance of overlays in most cases, but there may be situations where a thicker pavement is needed to carry the expected traffic over soft underlying materials.
18. When there is excess RAP on a project, do not use it or sell it for aggregate or shoulder fill. Stockpile the excess RAP near the job site for future use. Using RAP as an unbound fill material loses the value of the asphalt binder in the RAP. Since RAP asphalt can be reactivated in an asphalt plant, its greatest value is when it is reused in an asphalt mixture.
19. Specific RAP contents should not be specified. Rather, *maximum* RAP contents should be specified which would allow contractors to use RAP contents below the maximum limit in order to meet mix design and/or QC/QA criteria. Reasonable maximum RAP limits for Q mixes, HR mixes, and all other mixes are 20%, 30%, and 15%, respectively. As SDDOT and contractors become comfortable with the production and field performance of mixes with these RAP contents, consideration should be given to increasing those limits.
20. Make the following revisions to **Special Provision for Gyratory Controlled Quality Control/Quality Assurance Specifications for Hot Mixed Asphalt Concrete Pavement**

    A. Composition of Mixtures

    Delete [Unless otherwise specified in the plans, no reclaimed asphalt pavements (RAP) are allowed in Gyratory Controlled QC/QA hot mixed asphalt pavements.]

    Add [Up to 20% RAP may be included in asphalt mixtures unless otherwise noted in the plans provided that all SDDOT mix design and QC/QA requirements are met.]

    Add [The mixture shall not contain any particles (including agglomerations of RAP) greater than one inch at the point of discharge from the mixer. This shall be checked at by sampling the mixture at the discharge and immediately screening the sample over a standard 1-inch {25.0 mm} laboratory sieve.]

    B. Equipment

    Add [Mixtures containing incompletely coated particles that are evident at the time of discharge from the plant or thereafter shall be rejected. Appropriate adjustments shall be immediately made in the production of mixtures to ensure the mixture is completely coated at the time of discharge from the plant.]

6.2 RAP Characterization and Mix Design

21. Following the determination of the milling depth for the pavement rehabilitation and prior to the development of the project plans, the SDDOT (or an independent contracted firm) should obtain samples of RAP from the roadway. The most practical best practice is to use a skid steer with a milling attachment to obtain representative samples throughout the project. The samples should be large enough for the department/firm to test the RAP for gradation and asphalt content and retain materials for the winning contractor to use in the mix designs. The asphalt contents and gradations of the samples should be provided in the project plan notes. This will provide contractors more information from which to bid the project and should result in better bids since the information will reduce uncertainty in the RAP. A simple follow-up study is recommended in Section 6.5 to determine differences in gradations from RAP obtained with a skid steer and a full-sized milling machine.
22. Establish a standard method for determining RAP asphalt contents. Although the ignition method is the preferred method by most asphalt technologists and most research indicates that is the most accurate method, obtaining a correct result depends on the correction factor. Since most RAP in SDDOT will contain chip seals and the chip seal aggregate may differ from the aggregate sources in the asphalt mixture, establishing a reliable correction factor is problematic. Therefore, it is recommended that the asphalt content of RAP be determined using a solvent extraction method (AASHTO T 164). The average RAP asphalt content should be shown on the mix design.
23. Establish a standard for determining the RAP aggregate bulk specific gravity. The research team recommends that the recovered aggregate from the solvent extraction should be used to determine the RAP aggregate's bulk specific gravity using SD209 and SD210 (or AASHTO T 84 and T 85) for the fine and coarse aggregate portions, respectively. The RAP aggregate Gsb will impact the calculated VMA, which in turn affects the mixture's durability.
24. For Q mixes, lower the mix design and QC/QA target air void content by 0.1% for every 5% RAP. For example, the target for mixes containing 20% RAP will be 4.0-(0.1x20/5)=3.6%. Keep VMA criteria the same. This will add a little more virgin asphalt binder to RAP mixes which will improve their performance.

6.3 RAP Management

25. Contractors should sample and test the RAP received from the project as the stockpile is being built. Testing should be conducted to determine that the asphalt content and gradation are consistent with the results used in the mix design.
26. Fractionation of RAP should not be required in SDDOT specifications. Fractionation should be an option for contractors to consider when they are challenged to meet SDDOT mix design or QC/QA criteria.
27. Contractors should verify that in-line RAP processing (such as with a "RAP gator" or "rumble hog") does not substantially alter the gradation of the RAP aggregate before it enters the plant. Reasonable tolerances on the No. 8 and No. 200 sieves are ±4% and ±1%, respectively.

6.4 Asphalt Mixture Production and Quality Assurance for Mixes Containing RAP

28. Add to Table M - Minimum Frequency for Production Sampling/Testing:

Test	Min. Frequency	Test Method
RAP Asphalt Content	1/1000 ton (M ton)	AASHTO T 164
RAP Aggregate Gradation	1/1000 ton (M ton)	AASHTO T 30

6.5 Recommended Areas for Further Research

29. In order to better understand the quantity of RAP available from milling operations for use in new asphalt mixes and other applications, it is necessary to establish a reliable method to estimate the amount of RAP lost due to stockpiling, processing, and plant operations. A study to inventory RAP generated from project milling, RAP used in mixes and other applications, and unused but recoverable RAP at the project conclusion on several projects would help identify losses associated with stockpiling (due to compression and contamination in the ground), screening (oversized particles), and plant startup and shut-down waste, etc.
30. Much of the RAP in South Dakota contains chip seals and underlying asphalt concrete layers. The properties of the aged binder in this composite material are unknown. A study to collect RAP samples from projects around the state, recover, and grade the RAP binder would be useful in understanding how the preservation treatments affect in-service aging and establish future limits for RAP binder ratios (binder replacement percentages) at which a softer virgin binder is necessary. Similar studies in other states that do not routinely use chip seals have helped establish general percentages at which softer virgin binders are appropriate for mix designs containing RAP.
31. A comment by one technical panel member was that RAP samples obtained from skid steer mills were finer than RAP obtained from a highway-class milling machine. A simple study should be conducted to quantify RAP aggregate gradation differences and determine what changes may be needed in the sampling recommendations and/or mix design procedure to account for the difference.
32. Many highway agencies and contractors are interested in identifying tests to assess the cracking resistance of asphalt mixtures that can be used in mix design and field control. Since this is a national need, and a significant research effort is needed to accomplish this need, South Dakota should consider participating in national or regional studies when such research projects are developed.

7.0 RESEARCH BENEFITS

As noted in Section 5.1, the successful utilization of RAP in asphalt mixtures at current levels is estimated to save the SDDOT over $7 million per year. This estimate is based on the annual amount of RAP used on projects and the unit prices for asphalt binder and an estimated aggregate cost per ton. An underlying assumption in this estimate is that the mixtures containing RAP will perform equal to mixtures without RAP. The recommendations from this research study should substantially reduce problems on the projects using RAP and lead to lower price bids on future contracts by eliminating uncertainty associated with unknown characteristics of RAP at the time of bidding.

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Appendix A: Interview Questions for Pavement Engineers of Neighboring Agencies

<u>General Background Questions</u>

- How much RAP allowed (by pavement layers, mix type, etc.)?
- How much RAP are contractors actually putting in their mix designs?
- What unique issues exist in your state that impact your specifications and practices regarding RAP (e.g. geology, climate, traffic, etc.)?
- Does your state include asphalt binder in the mix bid item, or is asphalt a separate bid item?
- Is WMA used routinely in your state?
  - If so, does the use of WMA impact RAP use?
- Is RAS used in your state?
  - Does it affect RAP use?

<u>Pavement Performance</u>

- Please describe any performance problems that can be attributed to using RAP.
- When do/did those performance problems occur in the life of the pavement?
- What pavement preservation treatments are used in your state?
  - When are they applied?
  - How do they impact the state's recycling program?
- How are pavement rehabilitation designs conducted?
  - How are milling depths determined?

<u>RAP Management</u>

- Does your state take ownership of millings from projects?
  - If so, do contractors have the opportunity to buy the RAP or trade other materials?
- What sources of RAP are allowed for use in the state's mixes?
- How does available supply of RAP balance with the RAP demand in your state?
- What methods are required/used for processing RAP?
- What QC requirements are used for RAP management?
  - How are those requirements monitored?
- How are RAP materials characterized (identify the test methods)?
  - RAP binder content and properties
  - Aggregate gradation and properties

<u>Mix Designs Containing RAP</u>

- Do mix designs containing RAP have to meet any additional requirements?
- How is the bulk specific gravity of the RAP aggregate determined for mix design?
- Does your state require anti-stripping additives?
  - If so, how is the dosage specified and checked?
- How is the grade of the virgin binder selected for mixes containing RAP?

<u>Production and Paving with Mixes Containing RAP</u>

- How are the moisture contents of stockpiles determined?
- What temperatures are used for producing mixes containing RAP (compared to mixes with no RAP)?
- Is coating of virgin aggregate an issue with RAP mixes?
- What are the QA requirements for asphalt mixes (e.g. what mix parameters are checked and what are pay items)?

- Do mixes containing RAP have any additional QA requirements?
- What QA requirements are used for milling? (e.g. checks on texture, surface cleanliness, scabbing)
- Are windrows used for paving?
- What QA requirements are used for paving?
    - Tack application rate?
    - Thickness?
    - Temperature?
    - Density?
    - Smoothness?
    - Segregation (thermal and mix)?

Any other thoughts about recycling?

Appendix B: Recommended Best Practices for Using RAP in Asphalt Pavements for South Dakota

1.0 Introduction

This document provides guidance for the effective use of reclaimed asphalt pavement (RAP) materials in pavements specifically for the state of South Dakota. The document includes recommendations on when milling should be considered as part of pavement rehabilitation, best practices for handling and stockpiling RAP, testing the RAP, designing mixes with RAP, production of mixes containing RAP, and quality control practices during production of mixtures containing RAP.

The goal of this guide is to facilitate the most effective utilization of RAP that ensures the greatest economic benefit and the highest quality of recycled asphalt mixtures.

1.1 Background

Increasing the use of RAP in highway construction and rehabilitation projects has become an important strategy to help offset rising costs of raw materials and to improve the sustainability of surface transportation infrastructures. While most state DOTs have been using RAP in asphalt mixtures for many years, the South Dakota Department of Transportation (SDDOT) began to routinely use RAP in main-line asphalt surfaces in 2007. This has resulted in an estimated savings of over $26 million in raw materials costs over the first five years. However, some South Dakota pavements containing RAP have exhibited premature raveling and cracking and have not performed satisfactorily. This prompted the SDDOT to commission a study conducted by the National Center for Asphalt Technology (NCAT) to identify current practices and specifications that could be improved.

Although research continues to explore ways to use ever higher percentages of RAP in asphalt mixtures, several agencies have long histories of successfully using RAP contents in the range of 30% or more. An analysis of data from projects across North America in the Long Term Pavement Performance program showed that there was not a significant difference in pavement performance measures or service lives for overlays using virgin materials and mixes containing 30% RAP.

Recent national studies have provided new guidance on best practices for management of RAP materials, how to determine RAP properties, and how to conduct mix designs using RAP as a mix component. There are, however, some pavement construction and rehabilitation practices in South Dakota and the Great Plains region that differ from other parts of the country. Therefore, many of the recommendations provided in this document are based on discussions with experts in South Dakota and surrounding states.

1.2 Current State of Practice in South Dakota Regarding RAP

The two primary motivations for using RAP are (1) the conservation of natural resources and (2) cost savings resulting from reducing the amount of virgin aggregate and binder in asphalt mixtures. Since 2007, South Dakota has contracted over 3.2 million tons of asphalt mix that included RAP with the average RAP content at 20% by weight of the aggregate. Over the six years, the 656 thousand tons of RAP that have been used in mixtures have replaced approximately 45 thousand tons of virgin binder and 612 thousand tons of virgin aggregate. Total economic savings from the use of RAP in asphalt mixes over a six-year period was estimated to be $36.2 million.

An unusual practice in South Dakota is that RAP use is mandated rather than permitted. On certain projects, the SDDOT directs the contractor to use a specific RAP percentage. This policy can be very challenging for contractors since it is both a method specification and an end-result specification. The method part of the specification is the requirement for what material and how much of it shall be used;

the end-result specification is enforcing the normal pay item QA requirements such as lab compacted air voids and in-place density.

Interviews with agency and industry stakeholders indicate that contractors working in South Dakota are already following most of the best practices for stockpiling and handling RAP at plants. Given that the RAP is coming directly from milling operations on same projects, there is an expectation that the material is very consistent. However, there is a current lack of testing to verify that assumption.

1.3 Content of this Guide

This guide is organized into the following eight areas: Milling, Preliminary RAP Characterization, Mix Design for Mixtures Containing RAP, RAP Management, Production and Quality Assurance for Mixes Containing RAP, Using WMA with Mixes Containing RAP, Pavement Structural Considerations, and Pavement Preservation.

2.0 Milling

2.1 Benefits of Milling

Most RAP in South Dakota is generated during pavement rehabilitation projects. Milling the existing pavement can be beneficial for the following reasons:

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

However, in some cases it may be better to overlay the existing pavement without milling, such as when the existing pavement is thin (<2 inches) or when the pavement simply needs additional thickness to carry future traffic. The decision on when and how much to mill is clearly an important one in the design of a pavement’s rehabilitation.

2.2 Selecting the Milling Depth

When milling is appropriate, the milling depth should be selected to achieve a specific need such as removing distressed pavement layers, correcting cross slope, improving the roadway profile, and/or maintaining the pavement width. Information needed to make an informed decision on when to mill and how much to mill include the pavement condition survey, existing cross-slope surveys, analysis of Falling Weight Deflectometer (FWD) data to ascertain the structural supporting value of the existing pavement, cores of the existing asphalt to identify distressed layers and verify layer thicknesses, and an estimate of future traffic loading.

2.3 Ownership of the RAP

SDDOT and several other Great Plains states take ownership of millings from most projects. However, it is much more common across the U.S. for RAP to become the property of the project contractor. It is widely accepted that the greatest economic value for RAP is achieved when it is used in new asphalt mixtures since the valuable RAP asphalt binder becomes part of the total asphalt content of the mixture. Other uses of RAP, such as shoulder fill material, essentially ignore the RAP binder and treat the material as a granular fill.

2.4 Considerations for Excess RAP

Projects that have milling through the majority of the job will typically generate significantly more RAP than can be used in a standard one-lift overlay, even when the allowable RAP content in the new mix is high. Therefore, an important consideration in the project planning process is what is the best use of the millings that will remain after all of the RAP can be used in the overlay is consumed. Options include adding paved shoulders in areas with a significant amount of traffic from farm equipment, using the RAP as shoulder base, shoulder fill, or for driveway turn-outs, giving the excess RAP to the contractor, selling the RAP to the county road department, or stockpiling the RAP for a nearby future project that will not have milling. As previously noted, using the excess RAP for shoulder material or turn-outs fails to capture the value of the asphalt binder in the RAP.

Since the majority of paving projects in South Dakota utilize portable asphalt plants, maintaining the right balance and inventory of raw materials (including RAP) to meet the project needs is a significant logistical challenge. A shortage of any mix component will stop all work progress. In some cases for portable plants, left over materials can be a liability when there is no opportunity to use or sell it. It seems logical to assume that if contractors are given flexibility in how the RAP is used, they will optimize its value on the job to yield the lowest overall project cost.

2.5 RAP from Non-Project Sources

For projects near cities where contractors have fixed plant sites, those sites may have stockpiled RAP from previous SDDOT jobs and other non-DOT sources. Several industry sources have shown that RAP from multiple sources can be processed into a very consistent material. If these contractors provide sufficient test data to document good consistency of such RAP, SDDOT should permit its use in asphalt mixes. Further recommendations regarding consistency requirements for RAP are provided in Section 5.3.

3.0 Preliminary RAP Characterization

3.1 Obtaining Representative Samples of RAP Prior to the Contract

After the milling depth has been determined but prior to the development of final project plans, representative samples of the pavement to be milled should be obtained for preliminary characterization of the RAP to be obtained during the project. The best method for obtaining such samples is to use a highway class milling machine. An alternative, and probably a more practical option, is to use a skid steer with a milling attachment. The samples should be large enough to test the material for asphalt content and gradation of the recovered aggregate with sufficient additional material for the winning contractor to use in the mix designs.

Since most South Dakota roads are chip sealed multiple times before a rehabilitation project, the upper layers of the pavement will consist of these surface treatments. For projects where the milling operation will be used to improve the pavement cross-slope, it is likely that the milling depth will increase toward the edge of pavement. Therefore, the millings from near the centerline could contain materials entirely from the chip seals, whereas millings from the outer part of the lane could include the chip seals and the underlying asphalt concrete. Therefore, the characteristics of the RAP from the inside and outside parts of the lane could differ significantly. In such cases, separate samples for the preliminary RAP characterization should be taken from the inside and outside portion of the lanes.

3.2 Adding Useful Information to the Plan Notes

SDDOT currently provides limited information about the RAP in the plan notes regarding the Los Angeles Abrasion Loss of the RAP aggregate, which is helpful to milling contractors in estimating wear and milling teeth replacement costs for bids. Providing the asphalt contents, gradations, and aggregate bulk specific gravities of the RAP samples in the project plan notes will provide contractors more information from which to bid the project and should result in more competitive bids, as the information will reduce uncertainty in the characteristics of the RAP and what virgin materials will be necessary to produce an acceptable mix design. Since experience has indicated that the gradations of RAP obtained from skid steer samples tend to be finer than gradation of the RAP obtained from a full-sized milling machine, the plan note should reference the type of machine used to obtain the samples.

3.3 Test Methods for Characterizing the RAP

The solvent extraction method (AASHTO T 164) should be used for determining the asphalt content of RAP samples. The gradation of the extracted aggregate from the RAP samples should be determined in accordance with AASHTO T 30. The RAP aggregate’s bulk specific gravity should be determined using SD209 and SD210 (or AASHTO T84 and T 85) for the fine and coarse portions, respectively, of the aggregate recovered from the extraction tests. Estimating the RAP aggregate specific gravity from the maximum specific gravity and asphalt content of the RAP is not recommended since this will lead to an inflated Gsb and an error in the calculated VMA that would likely result in a poor performing mixture.

4.0 Designing Mixes with RAP

4.1 Recommended RAP Contents

Rather than requiring a specific RAP content in SDDOT mixes on a project by project basis, it is recommended that maximum RAP contents be provided in the department's standard specifications. This will allow contractors to establish appropriate RAP contents that can be used to meet all mix design and Quality Assurance criteria given the available materials and their possible plant limitations. It is generally expected that contractors will use as much RAP as possible since higher RAP contents will reduce mix costs (even with asphalt paid as a separate item) and allow the contractors' bids to be more competitive. Other states have found that the actual RAP contents used by contractors are somewhat below the maximum allowed by specification. This is because other factors besides the maximum RAP content such as the minimum VMA, the dust to asphalt ratio, or production pay factors often limit how much RAP can be used. Reasonable maximum RAP limits for SDDOT mixes are:

- 20% for Q mixes,
- 30% for R mixes, and
- 15% for all other mixes.

Higher RAP contents may be considered on a case-by-case basis when it benefits SDDOT.

4.2 Characteristics of the RAP Needed for Mix Designs

Contractors must obtain representative samples of the RAP in order to complete the mix designs. Properties of the RAP required for mix design calculations include (1) asphalt content, (2) aggregate gradation, (3) bulk specific gravity of the aggregate, and (4) consensus properties of the aggregate. All of these properties should be shown on the mix design. It is recommended that the asphalt content of the RAP be determined using a solvent extraction method (AASHTO T 164) since the ignition method is not reliable if the aggregate correction factor cannot be determined. It is important that the RAP aggregate specific gravity be determined in accordance with SD209 and SD210 for the fine and coarse portions, respectively, of the RAP aggregate recovered from the extraction tests. Using a back calculated effective specific gravity of the RAP aggregate is not recommended since this will cause the VMA of the mix to be higher than it actually is. Using the new virgin aggregate specific gravity or the aggregate specific gravity from the previous project's mix design for the RAP aggregate specific gravity is also not recommended since the RAP is likely to include chip seals and underlying asphalt concrete that have different aggregate sources. Samples of the dried RAP must also be batched and included in the laboratory prepared mixes used to determine the volumetric properties and optimum asphalt content for the mix design.

4.3 Managing High Dust Contents

One challenge for mix designs with RAP is dealing with high dust contents. In most cases, the dust content of the RAP is key factor in meeting minimum VMA criteria and dust-to-asphalt ratio limits. Many RAP stockpiles have P_{200} contents above 10%, particularly those that have been further crushed during processing. For many rural paving projects utilizing local aggregate pits that only produce material for that job, contractors have little control of the virgin material or the RAP aggregate gradation. Contractors should establish materials handling practices that will minimize dust in the stockpiles in order to meet QC/QA criteria during mix production.

Some aggregate breakdown is expected during mix production. Sharp edges on aggregates are rounded off and additional fines are generated. These changes typically result in a decrease in QC/QA air voids and VMA for the plant produced mix. In many parts of the U.S., mix designers add one to two percent baghouse fines to the mix design to account for the production breakdown. The amount of baghouse fines added is based on experience with the particular aggregate and plant. The baghouse fines are included as a mix design component and the composite gradation.

A related issue is including hydrated lime in mix designs. Since hydrated lime is a fine mineral filler, it must be included in the composite gradation and the calculation of dust-to-asphalt ratio.

4.4 Adjusting Volumetric Mix Targets for RAP Mixes

Over the past decade, several states have lowered their mix design target air void contents to try to improve the durability of Superpave mixes. The same durability concern has been expressed by SDDOT regarding some mixes that contain RAP. Therefore, the same approach is suggested as a way to make RAP mixes more resistant to cracking and raveling. Lowering the target air void content for mix design and QC/QA by 0.1% for every 5% RAP will result in slightly higher asphalt content for RAP mixes. For example, the target air void content for mixes containing 20% RAP would be 4.0-(0.1x20/5)=3.6%. It is important that the VMA criteria for mix design or QC/QA not be changed. Reducing the air void content while maintaining VMA will result in an increase in the volume of effective asphalt in RAP mixes which will improve mix compactability and improve resistance to cracking and raveling.

4.5 The Grade of Virgin Binder

One question about mix deigns containing RAP that numerous research studies have tried to answer is how much blending occurs between virgin and RAP binders. This question is central to selecting the grade of virgin binder for mixes containing RAP. Several factors are likely to affect the degree of blending for any particular mix design including compatibility of the RAP and virgin binders, mixing temperature, mixing time, stiffness/viscosity of the RAP and virgin binders, and the relative proportions of the RAP and virgin binders. Most recent research tends to indicate that blending does occur to a substantial degree for most plants. Although the question about the degree of blending has not been completely answered, most research studies indicate that the issue is insignificant for RAP contents below about 25%, as is the case for South Dakota.

The current AASHTO standard recommends that the virgin binder grade be selected based on the RAP content as percentage by weight of the total mix. A recent trend in specifications among DOTs has been to establish RAP (and RAS) limits on the percentage of recycled binder (a.k.a. binder replacement) in the mix rather than RAP or RAS content by percentage of total mix. On a national basis (NCHRP Report 752), NCAT recommends that there is no need to adjust the virgin binder grade for mixtures that have RAP binder ratios (binder replacement) less than 25%. For mixes with RAP binder ratios greater than 25%, it is recommended that the virgin binder grade be based on the following formula:

$$T_c(\text{virgin}) = \frac{T_c(need) - (RBR \times T_c(RAP\ Binder))}{(1 - \text{RBR})}$$

where

T_c*(virgin)* = critical temperature of virgin asphalt binder (high, intermediate, or low);
T_c*(need)* = critical temperature needed for the climate and pavement layer (high, intermediate, or low);
RBR = RAP Binder Ratio - the ratio of the RAP binder in the mixture divided by the mixture's total binder content, and
T_c*(RAP binder)* = critical temperature of recovered RAP binder (high, intermediate, or low).

A challenge associated with the above method of selecting the grade of the virgin binder is that the RAP binder has to be extracted, recovered, and "true-graded". However, most DOTs and contractors want to avoid using the particular chemical solvents necessary for the extraction and recovery methods due to potential health concerns associated with handling the solvents. By using RAP contents below 25%, this process can be avoided.

4.6 Additional Tests to Evaluate Mix Durability

For mixes used on mainline paving lanes with RAP contents equal to or lower than 25% RAP, additional tests are not considered necessary since there is a good historical field performance record across the U.S. with such mixes. There is, however, a strong desire among many agencies and contractors to establish a test, or perhaps multiple tests, to assess cracking resistance of asphalt mixtures. Different tests may be needed to evaluate different modes of cracking (e.g. fatigue, reflection, thermal, top-down). Table 1 lists the more well-known tests that have been reported in recent literature as potential methods to assess different modes of cracking. However, most of these tests need further development, ruggedness and precision studies, and field validation research before they are suitable for use in specifications.

Table 1: Potential Tests for Assessing Different Modes of Cracking

Cracking Mode	Test	Ref. Std.	Comments
Thermal	Indirect Tensile Creep Compliance and Strength	AASHTO T 322-	The most commonly used test used to obtain mix properties used with climatic modeling to predict critical cracking temperature.
Thermal	Thermal Stress Restrained Specimen Test (TSRST)	AASHTO TP-10	Provisional standard. Only a few labs perform it. Cracking temperature is measured directly. Testing variability and challenging sample preparation are main concerns.
Thermal	Disc-Shaped Compact Tension Test (DCT)	ASTM D7313-07	One of tests recommended by a regional pooled-fund study on thermal cracking. "Pac-man" specimens made from gyratory cylinders. Result is fracture energy. Field validated criteria are provided in the study final report.
Thermal	Semi-Circular Bend (SCB)	Draft AASHTO	The other test recommended by the regional pooled-fund low-temperature cracking study.
Reflection	Texas Overlay Tester	TEX-248-F	Developed to evaluate asphalt overlays on concrete pavements. Recently used by a few researchers to assess general cracking susceptibility. Extremely high strain used in the test is very unfavorable to mixes containing recycled binders. Test results are highly variable.
Fatigue	Simplified ViscoElastic Continuum Damage Test (SVECD) AKA the AMPT push-pull fatigue test	AASHTO PP 60-10	Cyclic load test can be performed in the AMPT. Sample preparation is similar to E*. Analysis is complex. No field validation yet.
Fatigue	Bending Beam Fatigue	AASHTO T 321-07 ASTM D7460-10	Most well-known fatigue test. Not practical for routine use due to challenges in making beam specimens and extremely long time to conduct tests.
Fatigue	Semi-Circular Bend Test	under development	Simple monotonic test on notched half-moon specimens at 25C. Very limited field validation. No national method for test. Needs ruggedness and precision studies.
Fatigue	Indirect Tensile Fracture Energy	under development	Simple monotonic indirect tensile strength test with on-specimen strain gauges. Area under stress-strain curve is fracture energy. Very limited field validation. No national method for test. Needs ruggedness and precision studies.

For evaluation of thermal cracking, the DCT has gained popularity after being recommended by a national pooled fund study on low temperature cracking (*43*). Several northern states have begun to use this test on trial projects. The Iowa DOT has begun to require the DCT low-temperature fracture energy test be conducted on mixes containing greater than 30% RAP.

Texas and New Jersey DOTs are using the Texas Overlay Tester in their standard specifications for certain asphalt mixes including surface mixes used for overlays. Several other researchers, including NCAT, have used the Overlay Tester in numerous studies. The test is fairly user friendly and can now be run in the AMPT, but the TxDOT criteria tends to fail a lot of mixes, particularly those containing moderate or high RAP contents and mixes containing shingles, many of which have proven to have very good field performance. Another simple test that is gaining popularity is the Semi-Circular Bend test conducted at 25°C. This test is user friendly and could be the easiest to implement for mix design and process control testing, but, to date, its only extensive use is by the Louisiana Transportation Research Center (LTRC). LTRC also recently stated that the test can be performed in the AMPT. South Dakota should consider the Overlay Tester and the Semi-Circular Bend test for research purposes to gain more information on whether or not these tests provide an indication of field performance.

A few highway agencies have begun to use the Hamburg wheel tracking test more frequently to evaluate rutting and moisture susceptibility. Some people in the industry consider the Hamburg a torture test for evaluating overall mix durability.

5.0 RAP Management during the Project

In order to achieve good-performing asphalt mixtures that contain RAP, good management practices are necessary to ensure the RAP is handled and evaluated in an organized manner. Good RAP management practices are also helpful for inventory control.

5.1 Establishing a RAP Stockpiling Plan

Prior to milling, the contractor should devise a stockpiling plan which may include keeping some portions of the RAP in separate stockpiles. This decision can be based on visual observations of changes in the roadway surface materials, different milling depths, and information provided by SDDOT in the plan notes. RAP materials delivered to the plant site should be inventoried with truck scales or stockpile surveys. As with virgin aggregates, RAP stockpiles must be kept free of contaminants. This requires that truck drivers be given clear instructions on how and where RAP should be unloaded and where materials unacceptable for RAP should be unloaded. As part of the contractor’s quality control procedure, all RAP stockpiles should be monitored to ensure deleterious materials are kept out of the stockpiles.

5.2 Inspecting the Milling Operation

The milling process should be inspected to ensure that the RAP material is not contaminated, the RAP particles are not too large, and that the milled surface is uniform and suitable for use in the overlay. Contaminants could include soil and/or vegetation from shoulders, excessive crack sealant, paving fabric, and roadway trash (e.g. chunks of tire rubber). SDDOT specifications currently state that the maximum particle size for RAP not exceed 1 ½” at the point where RAP is fed into the plant. The milling process can affect the size of the particles and result in too many oversized particles that would have to be screened and crushed or disposed of. Sometimes, milling over poorly bonded layers will result in scabbing of the surface which, if not corrected, will lead to rapid deterioration of the overlay. Another problem to watch for is uneven texture of the milled surface due to worn or missing teeth on the milling drum. An uneven texture could lead to the dragging of mix under the screed and/or issues with variability in density readings. Inspecting the milling process and subsequent brooming operation is recommended to catch problems and take corrective actions. Similarly, the milled surface cross-slope should be consistent across the lane. An irregular cross-slope will result in thickness variations across the mat and impact compaction and density results. Large digital levels are helpful in checking cross slope during milling operations.

5.3 Checking the Uniformity of the RAP

Interviews with several contractors in 2013 indicate that RAP stockpiles are generally not tested during HMA production. Presumably, this practice became acceptable based on the notion that RAP properties determined during mix design is sufficient information. NCAT recommends that contractors sample and test the RAP received from the project as it is being stockpiled. Testing should be conducted to determine if the asphalt content and gradation are consistent with the results used in the mix design and that the material is consistent throughout the RAP stockpile. Asphalt content and gradation tests on the RAP materials used in mix production should be tested at a frequency of one test per 1000 tons of material used. Processed RAP stockpiles from multiple sources may need to be sampled more frequently than single source stockpiles to ensure uniformity.

All test results should be recorded in a spreadsheet to organize and summarize the data. The spreadsheet should calculate the average and standard deviation of each property. It is considered a good practice to include at least 10 results to estimate the statistics for the stockpile. Table 2 shows guidelines for standard deviations of key RAP properties. The standard deviation statistic is a basic measure of uniformity. The median sieve is the sieve closest to having an average of 50% passing. Typically, this is the sieve with the largest standard deviation. In the example spreadsheet above, the median sieve is the 2.36 mm sieve.

Table 2: Guidelines for Uniformity of RAP

RAP Property	Recommended Max. Standard Deviation, %
Asphalt Content	0.5
Percent Passing Median Sieve	5.0
Percent Passing 0.075 mm Sieve	1.5

5.4 Processing the RAP

Further processing of milled material may or may not be necessary to obtain suitable consistency. As a minimum, RAP materials should be screened over a 1.5-inch screen before entering the plant to ensure that larger chunks of RAP do not get through the mixing process. Heat may not thoroughly penetrate through dense particles of RAP larger than 1.5-inches during the mixing process. Most contractors in South Dakota have installed or purchased in-line RAP crushers to assure that millings will pass a 1.5-inch screen. Contractors using in-line RAP processing (such as with a “RAP gator” or “rumble hog”) should verify that the in-line crusher does not substantially alter the gradation of the RAP aggregate before it enters the plant. Reasonable tolerances between before and after gradations of the extracted RAP aggregate are ±4% on the No. 8 and ±1% on the No. 200 sieve.

When it is necessary to crush RAP, it is important to carefully consider the impact on the material’s dust content, which can negatively affect a mixture’s voids in mineral aggregate (VMA) and dust-to-binder ratio.

One method of processing RAP required by a few states is fractionation. Fractionation is a screening process that separates the RAP into at least two sizes: coarse (+1/2 or +3/8 inch) and fine (-1/2 or -3/8 inch). Although there is no evidence that fractionation improves the uniformity of RAP stockpiles, it does provide the mix designer with more flexibility in creating a mixture design. However, this flexibility must be weighed against the increased processing cost, the expense of a second RAP bin, and additional space requirements for fractionated stockpiles. The current school of thought is that RAP fractionation is not necessary until the RAP content exceeds 35% to 40%. Fractionation of RAP should not be required in SDDOT specifications. Fractionation should be an option for contractors to consider when they are challenged to meet SDDOT mix design or QA criteria.

Minimizing the moisture content in RAP stockpiles is important for quality and plant efficiency. If the RAP material has a high moisture content, the moisture must first be converted to steam before the asphalt binder can be heated enough to be reactivated. This energy consumed in drying the RAP moisture affects the temperature to which the virgin aggregate is heated. To minimize moisture in RAP, stockpiles should be built in a conical shape in areas that drain water away from the base.

6.0 Asphalt Mixture Production and Quality Assurance for Mixes Containing RAP

6.1 Verifying the Percentage of RAP

The plant's belt scales for virgin aggregate and RAP should be verified prior to production for portable plants and at least once per year for stationary plants. This will allow the RAP feed rate as a percentage of the total aggregate to be calculated at any point in time. Note that moisture in the material on the belts must be subtracted from the total weight to get the dry material feed rates.

6.2 Mix Temperature

Plant discharge temperatures for mixes containing RAP should be approximately the same or slightly higher than that for virgin mixtures. An increase of 10°F to 15°F in the mix temperature during production may be necessary for higher RAP content mixtures. The mix temperature is typically a decision the contractor makes based on project conditions. Mix temperature measurements should be made on a regular basis during production at a consistent point in the plant to ensure that the mixing temperature is satisfactory and the temperature variability is not too large.

6.2 Incompletely Coated Mixes

A concern expressed by certain SDDOT personnel for some mixes with RAP is the observation of incomplete coating on virgin aggregates for mixes containing RAP. This may be caused by high moisture contents in the RAP. A rapid temperature loss after mix discharge can be an indicator of incomplete drying of the moisture from the RAP. Incomplete coating may also be simply due to the mixing zone in the plant being too short or due to worn mixing flights in the drum. SDDOT specifications should reject mixes that contain incompletely coated particles that are evident at the time of discharge from the plant. Possible remedies include reducing the mix production rate, reducing the RAP content, replacing worn plant mixer parts, modifying the plant to increase mixing time, and using WMA foaming technologies to expand the asphalt volume during mixing.

6.3 Target Air Void Contents for QC/QA Testing

The target air void content for Quality Control and Quality Assurance testing during mix production should also be the same target air void content used in the mix design. If the target air void content for the mix design is lowered as recommended in Section 4.4, then the lab molded gyratory specimens during field production should have the same air void target. The QC/QA tolerance of ±1% for air voids should be applied to the mix design air void target.

6.4 Making Mix Adjustments

When a mix adjustment is needed during production to control air voids, the first adjustment should be to the composite gradation. Reducing the dust content of the composite mix is the best way to increase the air void content of mixes. In some cases, contractors may find it necessary to waste some of the baghouse fines. This may require reducing the percentage of fine aggregate(s) and/or RAP used in the mixture. Reducing the virgin asphalt content may seem to be a simple solution to adjusting a mix's laboratory air voids, but this will have a negative consequence to contractors' ability to meet the in-place density pay factor. It will also negatively affect the durability of mixes, particularly mixes containing RAP. As with adjustments to virgin aggregate cold feed percentages, RAP percentages should be allowed to be reduced from the mix design by 5% in order to maintain control of mix properties during mix design. However, increasing the RAP content above the percentage designated in the mix design should not be permitted.

7.0 Using WMA with Mixes Containing RAP

Across the U.S., the use of WMA continues to gain popularity. On a national average, about 30% of all plant-produced asphalt mixes now utilize WMA technologies. However, the percentage of WMA use varies from state to state, with several states using about 70% and a few states still only using WMA on an experimental basis. The majority of states have implemented a "permissive" specification for WMA that allows contractors to choose when to use WMA and which technology to use. The most popular WMA category is water-injection foaming systems because they are the most economical over the long run. Chemical additives are the second most used WMA category. Potential benefits cited for WMA use include energy savings, reduced plant emissions, better workability, higher RAP contents, better work environment for paving crews, longer haul distances, minimizing bumps when paving over crack sealed pavements, and paving in cool weather/extended paving seasons. Some of the chemical additive WMA technologies are also formulated to provide anti-stripping capabilities.

Some of the early WMA projects have now been in service for about six years. Other than a very few projects with mix problems that occurred during construction, reports of constructability and field performance have been very good.

Relative to the subject of this guide and using WMA with mixes containing RAP, there is some limited but encouraging information. Since the use of RAP is common in most states, where WMA is used it has been with mixes containing RAP. Practically all field experience and research studies have indicated that the combination of RAP and WMA is positive. The most cited benefit associated with using WMA and RAP together is the reduced aging of the virgin binder when producing mixes at lower temperatures. In essence, the reduced aging is thought to result in a slightly softer binder. In the Superpave binder grading system the reductions in the high and low critical temperatures associated with WMA are typically on the order of just a few degrees, not a full grade drop. However, it is believed that the slightly softer virgin binder will better counteract the stiff aged binder from the RAP as the two binders blend in the mix. A few states allow RAP contents to be increased by 5% when the mix is produced at lower WMA temperatures. Although several lab studies have shown that mixture properties are slightly improved when WMA is used with RAP mixes, there is little field performance information to validate that the mixes with RAP and WMA are more resistant to cracking.

There are also possible benefits associated with plant operations and field compaction when RAP and WMA are combined. Since the use of RAP requires the virgin aggregate to be superheated, burners stay in a more efficient operation range and baghouse temperatures operate well above the dew point avoiding potential issues with muddying of bags and corrosion. In pavement construction, WMA is commonly described as a compaction aid. Many contractors use WMA simply because they believe it allows them to improve their in-place density results and pay factors. In-place density is one of the most critical factors for good long-term field performance. Some projects with mixes containing RAP in South Dakota have had trouble with density. One note of caution is that WMA should not be expected to fix mix problems such as low asphalt content, or paving problems such as segregation or lifts that are too thin for the mix NMAS.

8.0 Pavement Structural Considerations

In general, mixes containing RAP should not be considered any different than a virgin mix of the same classification from a pavement design perspective. Mixes containing moderate RAP contents (e.g. 25%) may be slightly stiffer (higher modulus) than similarly designed virgin mixes which could conceivably impact a mechanistic-based pavement design procedure (i.e. MEPDG). However, a small modulus difference for a single layer in a new or existing pavement structure is likely insignificant. Only when the entire asphalt cross-section contains high RAP contents (e.g. 50%) would the impact likely be of practical significance.

For interstate pavements and highways with heavy loadings, SDDOT should consider utilizing the Perpetual Pavement design concept. A full discussion of this concept is beyond the scope of this guide. However, in a Perpetual Pavement design the mixes in each layer should be designed for specific engineering characteristics. Research at the NCAT Pavement Test Track is underway to demonstrate that RAP can be used effectively in each layer of a Perpetual Pavement.

9.0 Pavement Preservation

Like many western states, South Dakota uses a consistent practice of early life pavement preservation treatments to keep pavements in good condition. Typically, crack sealing is applied to thermal cracks and reflection cracks that appear after two years of service, and then a chip seal is applied the following year. When any project shows signs of premature wear or cracking, the preservation schedule is moved up one year. In some cases, a sand seal is applied to a pavement soon after construction if there are problems with raveling. Additional chip seals may be applied to pavements after five to ten years to maintain the expected level of service. These practices are based on years of experience and are considered to be an efficient utilization of the state's resources. When projects do have early signs of cracking or surface wear, crack sealing and/or chip seals are appropriate treatments to avoid rapid deterioration of the pavement.