TechBrief

The Asphalt Pavement Technology Program is an integrated national effort to improve the long-term performance and cost-effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement suggestions, methods, procedures, and other tools for asphalt pavement materials selection, mixture design, testing, construction, and quality control.

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Resource Responsible Use of Reclaimed Asphalt Pavement in Asphalt Mixtures

This Technical Brief summarizes techniques employed by State DOTs in the use of high doses of reclaimed asphalt pavement (RAP) in asphalt mixtures and communicates the benefits observed.

Introduction

Reclaimed asphalt pavement (RAP) has been used in asphalt pavement rehabilitation and reconstruction for decades. However, since the 2008 peak in asphalt binder price, the desire to increase the use of RAP has continued (1). It has been driven by the goal for cost-effective alternatives to virgin asphalt binder and the desire to make asphalt pavements more sustainable. However, this has created challenges for some State Departments of Transportation (DOTs) to specify, design, and control the quality of asphalt mixtures containing RAP. Other State DOTs have had success with varying RAP dosages. The primary concern is assuring that the high stiffness RAP binder in the mixture does not lead to long-term pavement durability issues such as raveling and cracking.

According to the National Asphalt Pavement Association (NAPA), the amount of RAP accepted/delivered to asphalt mixture producer facilities in 2019 was 97.01 million tons, and the RAP used in asphalt mixtures was 89.2 million tons (2). More than 97 percent of asphalt mixture reclaimed from old asphalt pavements was used in new pavement. Since 2009, the average percentage of RAP used in asphalt mixtures by weight has increased from 15.6 percent to 21.1 percent. All State DOTs allow the use of RAP at some dosages and conditions.

Benefits and Risks of Using RAP

Positive, sustainable benefits (cost, environmental and societal) have been documented by NAPA, and State DOTs have embraced the use of RAP (2). Based on a review of a national literature summary including individual State DOT and Long Term Pavement Performance (LTPP) program data compiled for the 2011 FHWA Report No. FHWA-HRT-11-021

titled, "Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice." According to the report, "RAP has successfully been used for more than 30 years. Based on documented past experience, recycled asphalt mixtures designed under established mixture design procedures and produced under appropriate QC/quality assurance measures perform comparably to conventional asphalt mixtures" (3).

Similarly, the 2013 NCHRP Report 752 titled "Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content" stated "In-service performance of asphalt pavements containing up to 50 percent RAP in projects with diverse climates and traffic has been very positive … (S)tudies have shown that the overlays containing 30 percent RAP have been performing equal to, or better than, virgin mixes for most measures of pavement performance" (4). More recent work has shown the potential influence of combinations of RAP asphalt binder source, virgin binder source, and recycling agents on mixture performance test results (5, 6,7).

On October 20, 2014, the Federal Highway Administration (FHWA) issued Recycled Materials in Asphalt Pavements memorandum (HIAP-1) indicating that a number of State DOTs were reporting premature cracking in relatively new asphalt pavements, and similarity in many of the pavements was a high percentage of recycled asphalt binder (8). The memorandum concluded with recommendations to consider that included following existing AASHTO standards and past performance when establishing standards for RAP and reclaimed asphalt shingle (RAS) use. In September 2018, FHWA published FHWA-HIF-18-059, "State of the Knowledge for the Use of Asphalt Mixtures with Reclaimed Binder Content," providing an overview of current practices relating to design and use of asphalt mixtures incorporating high levels of reclaimed asphalt binder from RAP and/or RAS (9). The concept of using reclaimed binder ratio (RBR) was introduced to account for differences in fractionated RAP and using RAP and RAS.

Site Visits

Virtual site visits and interviews of key State DOTs and some contractors that performed work for them were used to learn more about practices. Figure 1 shows the participating State DOTs were geographically dispersed across the U.S. The following characteristics were used to select the six State DOTs:

- Florida DOT (FDOT): RAP use is unlimited for some mixture types, and several producers use about 40 percent RAP, with the highest being 50 percent in the unlimited RAP mixture type.
- Nebraska DOT (NDOT): The overall average RAP used in NDOT mixtures has been 39 percent for the past six years. When used, typical RAP percentages range from 35 to 50 percent.
- New Jersey (NJDOT): has implemented a High RAP mixture specification, with minimum RAP percentages of 20 percent for surface mixtures and 30 percent for intermediate and base mixtures with integrated performance tests in a balanced mixture design (BMD) approach.
- South Carolina DOT (SCDOT): specifies some mixtures with 25 to 35 percent RAP, and it also finds alternative uses of RAP, such as full-depth reclamation (FDR).
- Washington DOT (WSDOT): allows up to 40 percent recycled binder in mixtures, with no more than 20 percent from RAS using a BMD approach with rutting and cracking performance tests.
- Wisconsin DOT (WisDOT): over 95 percent of the 2.8 million tons of asphalt used by WisDOT contains RAP, with 40 percent used in some mixture, and in-place recycling is used when possible.

Some State DOTs allow use of both RAP with RAS in mixture, collectively referred to as reclaimed asphalt materials (RAM).

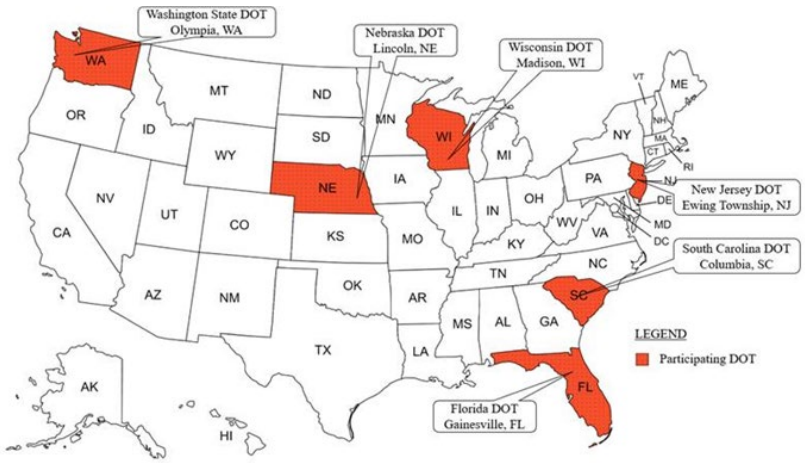

Image: University of Nevada Reno

Figure 1. Map of Participating State DOTs.

Quantifying and Communicating Recycling Benefits

NDOT and SCDOT have quantified the financial benefits of recycling. NDOT publicly communicates the success of its recycling goals in an NDOT Annual Report illustrating its commitment to recycling and environmental stewardship (10). Figure 2 is a post-consumer labeling content example. Post-consumer labeling content is included in individual project plan sets, and NDOT has reported the quantities and cost savings in its annual report since 2014. The reported information is based on quantities of asphalt and concrete and calculated recycled contents. The estimated dollar value of the post-consumer recycled content is also reported on the labeling.

NDOT indicated that a key driver leading to the success of its recycling efforts is NDOT Special Provision 10-7-1217, Incentive Payment for the Use of Recycled Asphaltic Pavement (RAP) for Asphalt Mixtures (11). This special provision provides a financial incentive to contractors to use RAP. Depending on the RAP source, saving associated with using RAP is shared between NDOT and the contractor. Cost savings that go to the contractor as an incentive to use RAP range from 15 to 50 percent of the total cost saving. Use of the RAP incentive special provision, coupled with the fact that NDOT pays for asphalt binder as a separate item, encourages the design and production of mixtures with adequate asphalt binder. From 2008 to 2020, approximately 9.2 million tons of aggregates have been recycled, and 498,000 tons of asphalt binder have been recycled or replaced with an estimated cost saving realized of $408 million in binder and aggregate. The average annual saving over this period has been $34 million.

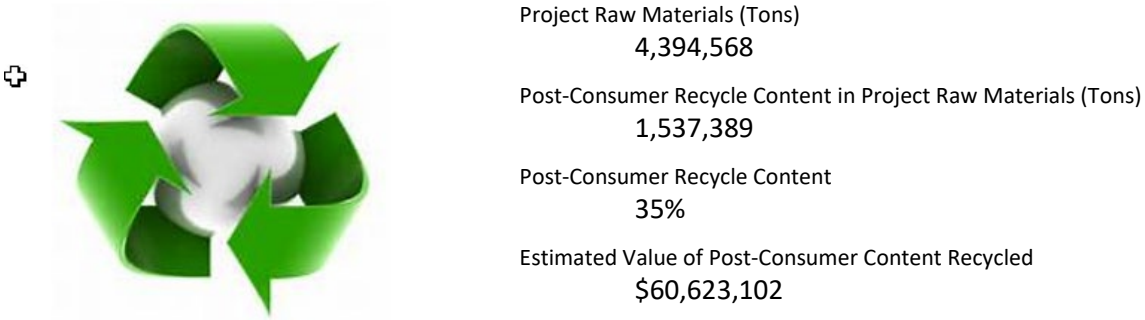

Image: University of Nevada Reno

Figure 2. Post-Consumer Labeling Content Showing Recycling and Cost Summary Data.

SCDOT has estimated the percent cost savings from using RAP expressed as a percent of the total mix cost paid. The saving increased steadily from 9 percent in 2008 to 16 percent in 2013. The total SCDOT savings from using RAP mixtures from 2008 and 2013 was estimated to be $90.7 million.

Pavement Performance Observations

Monitoring pavement performance over time is a method some DOTs use to assess how specifications and changes to them influence performance. An FDOT assessment of the impact of RAP on pavement performance was published in 2012 (12). The mixtures were designed by the Marshall Method and placed below the surface course mix in the pavement structures. The performance period reviewed was 1991-1998. The conclusions included the importance of including traffic volume when analyzing performance life, rather than just age when resurfacing is performed. When accounting for traffic volume, as shown in Figure 3, there is a trend suggesting that as percent RAP increases, performance decreases. However, in the range of percent RAP analyzed (30-50), all mixtures containing RAP performed better than the mixtures without RAP.

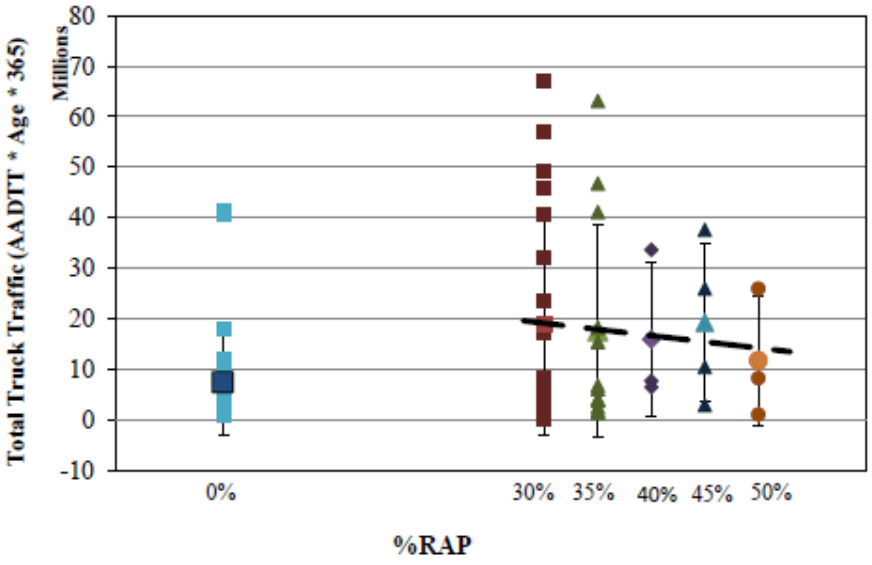

Image: Florida Department of Transportation

Figure 3. Pavement Performance versus Percent RAP in Intermediate Course Mixtures.

The NDOT Annual Report contains a section on asset management highlighting performance measures developed to monitor the condition of Nebraska's roadways, bridges, and fleet (9). Figure 4 is an excerpt from the report showing Nebraska Serviceability Index (NSI) over time. NSI is a composite index incorporating automated and visual inspection data with a scale of 0 to 100. An NSI rating of 70 or above is considered Good" performance, and NDOT's goal is to have 80 to 85 percent of the highway system in the Good" category. Figure 19 shows that 92 percent of the Interstate routes are in good condition, and 83 percent of the total highway system is in good condition. The overall condition of the highway system has improved since the implementation of high RAP asphalt mixtures.

WSDOT analyzed the performance of mixture with and without recycled materials in the mid 1980s with data indicating the equally promising performance of RAP and virgin mixtures (14). Because of the positive pavement performance, together with conservation of natural resources, the feasibility of construction, and cost savings, recycling became an attractive addition to the WSDOT paving program. In 2017, University of Washington (UW) researchers analyzed the WSDOT pavement management system database considering individual distress types and composite factors to compare the performance of high and low RAP mixtures (15). There was no statistical evidence to suggest a difference in performance between high-RAP (greater than 20 percent) and up to 20 percent RAP mixtures. The UW researchers indicated that the in-service pavement data approach is a repeatable framework useful for better understanding the relationship between in-service performance and mixture design.

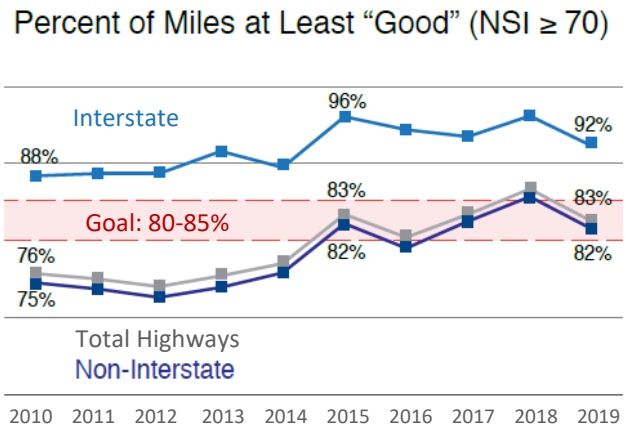

Image: University of Nevada Reno

Figure 4. Nebraska Highways NSI Scores.

Summary of Observations by Category

Each State DOT has a methodology to accommodate the use of RAP. Over time standard mixture design requirements and specifications have been revised to accommodate RAP. Table 1 contains a list of State DOT requirements for RAP. Note that not every State DOT uses every requirement listed in the table.

Table 1. State DOT RAP Use Requirements.

DOT RAP Use Requirements	FDOT	NDOT	NJDOT	SCDOT	WisDOT	WSDOT
% RAP Criteria	X	X	X			X[7]
RBR Criteria	X[1]			X	X	X
% RAS Criteria			X	X	X	X
Specifications Used by Others	X	X		X	X	X
Lift Location Criteria	X	X	X	X	X	
Traffic Criteria	X			X	X	X
Specialty Mixture Criteria	X		X	X	X	X
Binder Type Criteria	X	X		X		X
Softer Binder by Grade Bump	X	X	X[5]			
Softer Binder by Blending Chart			X[5]		X	X
Softer Binder by PG of Actual Blend			X[5]		X	X
Recycling Agent Additive		X	X[5]			X
WMA Additive	X	X	X[5]	X	X	X
Additional Asphalt at Design	X	X	X	X	X	
Additional Asphalt at Acceptance			X	X	X	
Gsb for RAP Aggregates					X	X
Mixture Performance Test(s)			X	X[4]		X
Pay for Binder Separately		X		X		
RAP Fractionation	X[2]			X[2]	X[2]	
RAP QC Plan	X		X	X		
Dedicated RAP Stockpiles	X[3]			X[6]		

[1]Contractor option for RAP over 20 percent, but RBR may not exceed 0.20; [2]Contractor option, use may be greater for FRAP than RAP; [3]Contractor option; [4]APA rutting test only; [5]Contractor option to meet performance test criteria; [6]If not fractionated; [7]RAS percent specified but overruled by RBR.

Mixture design requirements, specifications, and other methodologies identified in Table 1 were grouped into seven categories. This allowed for a better understanding and the ability to compare and contrast them. Key observations are highlighted by State DOT in each category.

RAM Criteria by Weight and RBR

When an agency allows both RAP and RAS, it is important that policy, materials selection, mixture design, and specifications clarify how to integrate both. The criteria (by weight and RBR) used by participating State DOTs for RAS and RAP are summarized in Table 2. In many cases, the ranges in the table were associated with where the mixture was placed in the pavement structure (e.g., surface, the intermediate of base layer), roadway functional classification, or mix type.

- Half of the States (FDOT, NDOT, and NJDOT) use percent by weight, and half (SCDOT, WisDOT, and WSDOT) use RBR.
- FDOT and NDOT do not allow RAS, while NJDOT, SCDOT, WisDOT, and WSDOT do.
- NJDOT is generating less RAP because it embraces pavement preservation treatments that create little or no RAP. NJDOT also allows a small amount of other recycled asphalt materials.

Table 2. RAM Ranges Among Participating State DOTs**.**

State DOT	RAM Content Allowed (% by Weight)		RAM Content Allowed (RBR)	
	RAS	RAP	RAS	RAP
FDOT	0%	0% or 0-20% or Unlimited	NA	NA
NDOT	0%	0-35% or 20-35% or 0-55% or 35-65%	NA	NA
NJDOT	0%	≥ 20% or ≥ 30%	NA	NA
SCDOT	NA	NA	0.05	0.00-0.30 or 0.15-0.45 FRAP
WisDOT	NA	NA	0.20-0.25	0.25-0.40 RAP+FRAP or 0.25-0.35 RAS+RAP+FRAP
WSDOT	NA	NA	0.20	0.40 or 0.20 RAS+0.20RAP (0.40 total)

Rationale and Location for Using RAP

There are a variety of rationales for the use of RAP, and some examples are described below.

- FDOT allowance for RAP is based on mix type, location, binder type, and geographic location. Granite aggregate is used in the northern part of the state, while limestone is used in the southern part of the state. There is no limit on the amount of RAP that can be used in intermediate and base mixes made with granite aggregate. Twenty percent RAP is allowed in dense-graded friction course (DGFC) and intermediate mixtures containing PG 76-22 binder made with granite aggregate. FDOT does not allow RAP in OGFC, High Polymer (HP) mixtures, or dense graded friction course (DGFC) mixtures containing south Florida limestone.
- NDOT criteria for using RAP in mixes is dependent on location in the pavement structure. Premium surface course mixes (SPH and SLX) can contain up to 35 percent RAP, and the SPR workhorse" mixes (about 70 percent of asphalt mix used by NDOT) can contain up to 55 percent RAP, while base and shoulder mixes can contain up to 65 percent RAP. NDOT reports that most mixes produced by contractors are at 50 percent or near the maximum allowable RAP percentage.
- NJDOT has minimum RAP contents of 20 percent for surface mixtures and 30 percent for intermediate and base mixtures, and it uses a BMD approach for high RAP mixtures. RAP is

primarily allowed in dense-graded mixtures. Small amounts of other recycled materials are allowed in some NJDOT mix types also. Recycled materials are not allowed in most specialty mixtures. This is one reason for a reduction in the percentage of asphalt mix tons with RAP in recent years, and another is less RAP is generated using pavement preservation treatments

- SCDOT has a comprehensive mixture type selection guide which includes mixture type based on location and classification/traffic (15). The allowable amounts of RAP and RAS are a function of mix type and location also. As traffic level decreases and depth into the pavement structure increases, allowable RAP increases. The amount of RAP allowed increases by about 10 percent if the RAP is fractionated, which incentivizes contractors to fractionate. SCDOT RAP usage and amount in asphalt mixture are not consistent across the state, with urban areas having more available supply and thus using more. RAS is also allowed.
- WisDOT allows both RAP and RAS in all mix types except for a specialty interlayer mix. The criteria for the amount of RAM are based on location, traffic level, RAM type, and whether or not RAP is fractionated.
- WSDOT allows both RAP and RAS in dense-graded mixture regardless of location in the pavement structure. RAP and RAS are not allowed specialty mixes (SMA). Criteria related to traffic is not explicit in the specifications, but it is indirectly incorporated.

Use of Softer Binder

Many States use a softer binder with RAP. This can be done by bumping the PG binder's low and high temperature down, using blending charts, or extracting and grading the binder from a final mixture. Examples of the criteria used for softer binder are summarized in Table 3 and described below.

Table 3. Summary of Criteria for Using Softer Binder by State.

State	Softer Binder	Blending Chart	PG of Blended Asphalt
FDOT	One to two PG bumps down based on RAP dose.	N/A	N/A
NDOT	Low PG bumped down one grade. Only MSCR grades are specified.	N/A	N/A
NJDOT	PG64-22, Engineer may Direct Softer Grade.	N/A	N/A
SCDOT	N/A	N/A	N/A
WisDOT	N/A	Only to demonstrate that at higher RBR, blended binder meets the specified (PG) for the project per AASHTO M 332.	Only to demonstrate that at higher RBR, blended binder meets the specified (PG) for the project per AASHTO M 332
WSDOT	N/A	N/A	For all mixes containing RAS or > 20% RAP.

- FDOT specifies PG based on RAP usage for mixes containing neat asphalt only. Softer binders are specified as the RAP dose increases. Three RAP levels and required binder grades used are: 0-15 percent RAP: PG 67-22, 16-30 percent RAP: PG 58-22, and greater than 30 percent RAP: PG 52-28. These levels and binder grades were established based on a statewide in-house FDOT research effort. FDOT used blending charts for many years, and with the data collection over time, the levels above were established, eliminating the need for FDOT and contractors to have to perform extractions and blending chart analyses for each mixture design.

- NDOT only specifies MSCR PG, and the low temperature of the virgin binder was bumped down from a "-28" based on the climate in Nebraska to a "-34." NDOT has also been researching using a "-40" PG binder to improve low-temperature performance with high recycled content mixtures.
- NJDOT requires PG64-22 for Standard mixtures, though the Materials Engineer may require a one PG drop. For high RAP mixtures, the contractor selects the PG required to meet mixture performance test (APA and TxOL) criteria.
- WisDOT specifies PG binders meet the requirements of AASHTO M 332, *Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Recovery (MSCR) Test* (16), a voluntary standard not required under Federal law. Blending chart analysis or physical blending of virgin and RAM binder may be done to demonstrate that higher than allowed RBR can be used if the blended binder meets the specified performance grade (PG).
- WSDOT specifies PG binders meeting the requirements of AASHTO M 332 Table 1, a voluntary standard not required under Federal law (17). However, the binders do not have to meet RTFO Jnr_{diff} and the PAV direct tension criteria. WSDOT typically specifies H and V grades.

Use of Additives

Some State DOTs are using additives to support their recycling processes. These include WMA additives, anti-strip additives, and recycling agents. Examples of the State requirements for additives used are described below.

- All six State DOTs allow the use of WMA, typically at the contractor's option. All allow chemical WMA, and four allow foamed WMA. FDOT specifies maximum WMA production temperatures of 305°F for polymer-modified asphalts and 285°F for neat asphalts. The maximum mixing temperature is 275°F, and the maximum temperature behind the paver is 215°F. Specifying WMA at lower temperatures is done to minimize the activation or mobilization of the RAP binder.
- Five of the six DOTs allow or require liquid anti-strip and one (WisDOT) includes hydrated lime.
- NJDOT and WSDOT allow recycling agents to be used. For NJDOT, they are at the contractor's option to meet high RAP mixture performance test requirements. Similarly, it is the contractor's option in Washington State as long as the blended binder (virgin, RAP, and recycling agent) meets the PG requirement for the project location.
- FDOT has a virgin binder quality aging characteristic safeguard. A combination of ΔT_c, a waste oil provision, and an 8 percent maximum allowable re-refined engine oil bottoms (REOBs) are used to manage the use of REOB and other blending stock that may be susceptible to aging.

Additional Asphalt Content

It is important that asphalt mixtures contain an adequate amount of virgin asphalt binder. All participating DOTs required mixture designs performed per AASHTO M 323, *Standard Specification for Superpave Volumetric Mix Design* and AASHTO R 35, *Standard Practice for Superpave Volumetric Design for Asphalt Mixtures* with a few exceptions, often specifically to increase the amount of virgin binder (18, 19). AASHTO M323 and AASHTO R35 are voluntary standards not required under Federal law. Examples of methods used to ensure that there is an adequate amount of virgin binder are described below.

- FDOT uses a reduced number of gyrations and all volumetric requirements of AASHTO M 323 (18).
- NDOT uses a reduced number of gyrations, minimum asphalt content and design air voids range up to 2.5 percent lower than AASHTO M 323 (18).

- NJDOT uses a reduced number of gyrations; minimum VMA 1.0 percent higher than AASHTO M323 , in mixture design and production (18); maximum allowable aggregate absorption; asphalt binder is paid as a separate item; and rutting and cracking performance tests in a BMD approach.
- SCDOT uses a reduced number of gyrations; minimum VMA of 0.5 percent higher than AASHTO M 323 (18) in mixture design and production, OBC selected at 96 to 97 percent of G_{mm} at the mixture designer's discretion (normally 96 percent of G_{mm} for RAM mixtures and 96.5 percent of G_{mm} for virgin mixtures). Asphalt binder is paid as a separate item. There are a few other adjustments related to aggregates and gradation.

  Most notably, Corrective Optimum Asphalt Content (COAC) is used to adjust the optimum asphalt content up to account for binder availability of RAM. RAM binder availability is fixed at 75 percent. The other 25 percent is considered to be "black rock." The COAC is used to add virgin binder to account for the black rock. The COAC is determined by multiplying the asphalt content of the aged binder by 25 percent and adding it to the optimum asphalt content determined from the volumetric mixture design. For example, if the optimum asphalt content from volumetric mixture design were 5.0 percent and the asphalt content from the aged binder was 1.56 percent, then the COAC would be 5.0 + 0.25 x 1.56 = 5.0 + 0.39 = 5.4 percent. So, the optimum asphalt content would be increased by 0.39 percent to account for reduced binder availability of the RAM.
- WisDOT uses a reduced number of gyrations; regressed design air voids with OBC selected at 97 percent of G_{mm}, and minimum VMA increased 0.5 percent above AASHTO M 323 criteria (18).
- WSDOT uses G_{sb} of aggregates and RAM when determining VMA. Rutting and cracking performance tests are used during mixture design, test sections, and 1/10,000 tons of mixture production.

Mixture Performance Tests

Mixture performance tests with results correlating to field performance are desired by contractors and State DOTs. This would allow contractors to be innovative with materials selection and proportioning. Some State DOTs are using performance tests, and others are evaluating their use of them. The addition of recycled materials makes an asphalt mixture more susceptible to cracking while using softer binder and recycling agents could make a mixture more susceptible to rutting. Since cracking is related to long-term aging (LTA), it is important that cracking performance tests be conducted on aged materials. Several State DOTs indicated an interest in using performance tests for mixture design, test strips, and production acceptance. It is important to note, however, they also indicated that they did not have the resources to do so. This was especially clear for product acceptance testing when considering the test turnaround time. Several State DOTs also indicated that they had ongoing performance tests or BMD research or had recently completed some related research. Table 4 is a summary of performance tests use by the participating State DOTs, along with when they are used.

- FDOT has successfully used the asphalt pavement analyzer (APA) during the mixture design process in the past, though it is not a current requirement. Research is planned for evaluating the IDEAL-CT test for mixture design and production.
- NDOT is investigating the potential for the use of HWT and SCB tests in the future.
- NJDOT high RAP specifications include the APA rutting test and a modified TxOL test for mixture design and production acceptance purposes.
- SCDOT is not likely to develop a full, balanced mixture design process but is likely to use performance tests as an additional check on the volumetric properties in the future.
- WisDOT plans to implement a BMD method and conduct performance tests during test strips or within the first 50,000 tons of production.

- WSDOT high RAP standard specifications have included a BMD approach since 2018. The HWT is used for a rutting test, and indirect tensile strength (IDT) is used for a cracking test during mixture design, test section, and optionally 1/10,000 tons of mixture production. Criteria used are shown in Table 5. WSDOT is currently evaluating the IDEAL-CT test and may transition to it.

Table 4. Current State DOT Performance Tests and Use.

State	FDOT	NDOT	NJDOT	SCDOT	WisDOT	WSDOT
Rutting Test			APA	APA		HWT
Cracking Test			TxOL			IDT
Mixture Design			APA and TxOL	APA		HWT and IDT
Test Strip			APA and TxOL	APA		IDT
Production or Acceptance			APA and TxOL			1/10,000 tons
Recent or On-going Research	RAP Dose and Cracking Tests	Recycling Agents, Value of Recycling	BMD, Performance Tests, Value of Recycling	E*, RAP property estimates without extraction	BMD, Performance Tests	BMD, Performance Tests
Test(s) of Interest	IDEAL-CT	HWT, SCB		HWT, IDEAL-CT	HWT, IDEAL-CT	HWT, IDT, IDEAL-CT

Table 5. WSDOT BMD Performance Test Requirements.

Design ESALs (millions)	N_{des}	Minimum HWT passes without stripping and maximum rut depth of 10mm	Indirect tensile strength (maximum, psi)
Less than 0.3	50	10,000	175
0.3 to less than 3.0	75	12,500	175
Greater than 3.0	100	15,000	175

RAP Processing, Handling, and QC

Highlights of the participating State DOTs RAP processing, QC, or stockpile requirements include the following.

- FDOT allows RAP fractionation at the contractor's option. The clumping of fine RAP stockpiles can be problematic in the Florida climate. There is an allowance to increase RAP with fractionation. RAP stockpiles have a minimum binder content of 4.0 percent. If RAP is fractionated, the coarse stockpile minimum binder content is 2.5 percent. Stockpiles can be designated as “continuous" at the contractor's option. Then a contractor can add to a stockpile while performing material property tests on each addition. All projects require a QC plan with RAP processing, handling, and testing. Prior to use, RAP stockpiles are tested, visually inspected, and approved by FDOT. Millings from an FDOT project can be used. RAP gradation and G_{mm} are monitored during production. RAP cold feed bins must have scalping screens to prevent clumps in the bins.
- NDOT requires a project QC plan. RAP must be pre-processed by fractionating, screening, and or crushing prior to use to a size such that the combined hot mixture meets the required gradation. NDOT indicated that contractors diligently monitor RAP properties, although not required by specifications, because RAP is a large proportion of mixtures. Other NDOT controls include

accurate baghouse fines metering, continuous recording of plant control settings, and vibrating screens over RAP cold feed bins.

- NJDOT does not require RAP fractionation and the allowable amount of RAP is not related to fractionation. Some contractors do fractionate RAP. RAP must be processed through a screening and crushing operations so100 percent is passing the maximum aggregate size for the mixture.
- SCDOT suggests that part of the reason for the successful use of high RAP is due to stringent RAP processing and handling requirements. A RAP QC plan is required of the contractor, and it has to include one ignition furnace asphalt content and gradation test per 1000 tons of production, and two moisture content tests per day. Data has to be available to SCDOT staff. Non-fractionated stockpiles have to be dedicated, and cannot be replenished. This has led to fractionated piles, which can be replenished, becoming the contractor's preference. Fractionation also increases allowable RAP by 10 percent. SCDOT requires plant control software printouts with mixture proportions reported by printing every 15 minutes, and data is saved such that it can be retrieved for any past period.
- WisDOT has recycled material dose criteria related to RAP fractionation, but it indicates that contractors do not fractionate unless supplying mixture in a neighboring state that requires it.
- WSDOT specifies that for High RAP/Any RAS mixes, stockpiles be dedicated and not supplemented. RAP fractionation is not required. RAP testing for High RAP/Any RAS classification ignition furnace asphalt content and washed sieve analysis. For mixture with greater than 20 percent RAP by total weight of HMA, the RAP has to be processed so 100 percent passes a sieve twice the size of the maximum aggregate size for the class of mixture.

Contractor Input on Successful RAP Use

High RAP is relative to each DOT's historic allowable limit; when the limit is raised contractors make adjustments. During interviews, contractors identified practices used when producing RAP and using RAP in asphalt mixtures, as well as some challenges with it that are summarized in Table 6. The contractors expressed challenges with having representative RAP in a timely fashion to get mixture designs completed on portable projects. They included: unbalanced RAP supply and demand in some markets, not having RAP millings for mixture design purposes, meeting or cost-effectively meeting the DP requirement in AASHTO M 323 (17), a voluntary standard not required under Federal Law, when producing high RAM mixtures, and having to wait after test section construction to get performance test results to keep producing on projects.

Table 6. Contractor Identified Focus Items by State DOT.

State	FDOT	NDOT	NJDOT[1]	SCDOT	WisDOT	WSDOT
Heat Transfer	X	X		X		
RAM Feed Bins	X	X		X		
Dust Control	X	X			X	X
Moisture Control				X	X	
Quantity Management				X		
Verify RAP Percentage	X	X		X	X	X
Milling in Mix Design		X			X	

[1]New Jersey contractors were not interviewed.

Contractors identified several positive practices used to improve the quality of high RAP mixtures. The highlights follow, and Reference 9 includes lists of detailed items associated with each bullet below:

- Obtaining representative RAP samples for mixture design with full-size cold milling machines to obtain 300 to 400-ton samples.

- Having the appropriate plant equipment to produce high RAP mixtures.
- Minimizing and monitoring RAP stockpile moisture, especially in wet climates.
- Processing and handling RAP to improve consistency.
- Controlling fines (material passing the #200 sieve) when producing aggregates by washing crusher fines and during plant production by accurately metering back or wasting baghouse fines.
- Performing contractor process control and QC, then leveraging the information for consistency.
- A State DOT requirement that each asphalt plant has an on-site QC lab.
- Having a full-time State DOT inspector at the asphalt plant.
- State DOT PWL specifications incentivize contractors to produce consistent RAP and leads to adequate contractor process control and QC.

RAP Implementation Considerations

Some high RAP implementation considerations identified by participating State DOTs follow with examples of each, and State DOTs using the considerations are identified in parentheses.

RAP Programmatic Considerations

Programmatic considerations some of the participating State DOTs identified include:

- Using project selection criteria and or mixture type criteria that define what mixtures may contain RAP and allowable RAP content in mixtures in specific locations in a pavement structure (FDOT, NDOT, NJDOT, SCDOT, WisDOT).
- Having a strong QA program that defines QC responsibilities for contractors and acceptance responsibilities for DOTs (All participating DOTs).
- Tracking and reporting the use of RAP annually (NDOT).
- Providing a financial incentive to contractors for using RAP (NDOT).
- Tracking and reporting the cost savings associated with using RAP (NDOT, SCDOT).
- Monitoring the performance of mixtures containing RAP and making specification changes to optimize performance over time, that is often coupled with research (All participating DOTs).

RAP Mixture Design Considerations

RAP mixture design considerations some of the participating State DOTs identified include:

- Using mixture performance tests in a BMD approach (NJDOT, WSDOT).
- Having criteria for RAP that is a percent by weight and/or RBR (All participating DOTs).
- Separating RBR from the RAP and RAS (NJDOT, SCDOT, WisDOT, WSDOT).
- Specifying softer binders (FDOT, NDOT, SCDOT, WisDOT, WSDOT).
- Using binder performance testing like ΔT_c or the Glover-Rowe parameter (FDOT).
- Use of recycling agent and warm mix technology additives (NDOT, NJDOT, WisDOT).
- Characterizing RAP using asphalt content and gradation (All participating State DOTs).
- Using additional asphalt binder through regressed design air voids, increased minimum VMA or other means (All participating State DOTs).
- Using G_{sb} of the RAP aggregates, rather than G_{se}, to assure the most accurate indication of VMA possible (WisDOT, WSDOT).
- Using mixture performance tests, typically rutting and cracking tests, to assess mixture performance and optimize mixture designs (NJDOT, WSDOT).

RAP Mixture Acceptance Considerations

RAP mixture acceptance considerations some of the participating State DOTs identified include:

- Using mixture performance tests during test strips and acceptance (NJDOT, WSDOT).
- Paying for asphalt binder as a separate item (NDOT, SCDOT).
- Using PWL in acceptance specifications that include volumetric properties as producers indicated that this led to consistent production (FDOT, WisDOT, WSDOT).

RAP Production Considerations

RAP production considerations participating State DOTs or contractors in the states identified include:

- Requiring dedicated RAP stockpiles (FDOT, SCDOT, WSDOT).
- Processing by blending, screening, and crushing over-size materials for consistency (FDOT, SCDOT, WisDOT, WSDOT).
- Requiring or allowing fractionation of RAP for consistency (FDOT, SCDOT, WisDOT).

RAP Mixture QC and other Quality-Related Considerations

RAP mixture QC considerations participating State DOTs or contractors in the states identified include:

- Requiring RAP QC plans or having provisions for RAP be included in Project QC plans (FDOT, NDOT, NJDOT, SCDOT).
- Having full-time inspectors at the asphalt plant during production (FDOT).
- Requiring plant control reports indicating proportioning (FDOT, NDOT, SCDOT).

Research and Training Needs Identified

The State DOTs identified research needs associated with RAP. Most identified research needs are associated with the use of BMD and index-based performance tests. Additionally, the following needs were identified.

- FDOT indicated a need for a high RAP mixture design methodology for very low volume roads.
- NDOT and WSDOT indicated a need for research to support the use of recycling agents.
- NJDOT indicated a need to identify alternative RAP uses because thin high-performance surface mixtures are more frequently being successfully used that do not contain RAP.
- SCDOT indicated a need to determine if top-down cracking is due to higher RAP levels.
- WisDOT indicated a need for regularly performing research to optimize the use of recycled materials.
- WSDOT, SCDOT, and WisDOT indicated a need for training and education for staff and local agencies on the successful use of high RAP mixtures.

Alternative Uses of RAP

Several participating State DOTs identified alternative uses for RAP. This is important as the combination of using RAP in asphalt mixtures and the use of RAP for other purposes leads to balancing of available supply and use of it.

- FDOT currently allows the use of RAP in asphalt mixtures, soil stabilization, and embankment. A contractor interviewed indicated that they made a recycled-based course material from poor quality or contaminated RAP and other materials, including crushed portland cement concrete. Another indicated that excess RAP processed to meet FDOT project specification requirements is used for agricultural applications and port facilities in thickness up to 18 inches un-stabilized with heavy cranes operated on it.
- NDOT specifications strongly encourage the use of RAP in asphalt mixtures. The primary

alternative use of RAP is for bituminous base course material for the reconstruction of asphalt and portland cement concrete pavements. NDOT maintenance forces also use portable small batch asphalt recycling machines with binder pods containing a recycling agent to produce 100 percent recycled high-performance hot mix patch material that includes millings, binder, and special additives.

- NJDOT currently allows the use of RAP in a 50/50 aggregate/RAP blend for the base course. RAP millings can also be used in soil aggregates. NJDOT has had limited but positive experiences using RAP for cold in-place recycling (CIR) and full-depth reclamation (FDR) with cement. CIR and FDR with foamed asphalt and emulsified asphalt were identified by NJDOT as techniques that could be used more frequently in the future.
- SCDOT indicated the most commonly used alternate for RAP is in CMRB (a.k.a. FDR). This is logical since SCDOT is a leader in the use of this in-place recycling technique in the U.S. Cold in-place recycling (CIR) foaming method was successfully used on a US123 project, so it will likely be used more in the future, and there is an interest in cold central plant recycling (CCPR).
- WisDOT currently allows the use of RAM per WisDOT standard specifications and standard special provisions for in-place pulverizing, partial and full-depth milling with and without active filler and stabilizers. The use of in-place recycling techniques may be decreasing with fewer reconstruction projects in recent years. However, when used, these techniques lead to the use of RAM in cost-effective and sound engineering applications.
- WSDOT currently allows the use of up to 25 percent RAP blended in ballast, permeable ballast, crushed surfacing, aggregate for gravel base, gravel backfill for foundations, gravel borrow, select borrow, and common borrow. It can be 100 percent of select and common borrow that is at least 3 feet below the subgrade. Although allowed, RAP is not commonly used for these applications due to its value in asphalt mixture.

Summary

Using RAP in asphalt mixtures can provide initial cost savings by replacing a portion of the aggregate and virgin asphalt binder in the asphalt mixture. It may also provide other sustainable benefits, as long as RAP haul distance does not offset them. This keeps the RAP from being discarded in landfills. Improvements in mixture design and materials processing and handling have increased the amount of RAP that can be used in asphalt mixtures today. The performance history of RAP mixtures over the past 50 years, when properly engineered, produced, and constructed, can provide comparable levels of service as asphalt mixtures with no reclaimed materials, referred to as virgin asphalt mixtures (2, 3, 12, 16).

While NAPA has determined the average use of RAP is 21.1 percent, several participating State DOTs reported successful pavement performance with 35 to 50 percent RAP. The participating State DOTs indicated that optimizing RAP for good pavement performance can be accomplished through 1) regular review of DOT specifications, mixture design procedures, and performance test methods; 2) monitoring pavement performance; 3) working with asphalt producers for improvement, and 4) performing research as a basis for changes. Other uses, such as in-place recycling, were key parts of several State DOT programs.

This TechBrief summarized a wide range of techniques and criteria used by State DOTs to specify and design mixtures and pavements that incorporate RAP. Important considerations identified by the State DOTs and contractors for implementing the use of RAP were also summarized and included programmatic, mixture design, mixture production, mixture acceptance, RAP production, and QC considerations Together, such considerations demonstrate that care should be taken during design, production, and construction to ensure desired performance. This TechBrief also revealed that there are opportunities for future improvements that can be accomplished through identified research needs.

All participating State DOTs indicated the desire to use mixture performance tests. Some State DOTs are using them in mixture design in a BMD approach, and some State DOTs indicated use for test strips and production or acceptance. Common themes were the need to get adequate virgin asphalt binder in mixtures, the need for appropriately setting performance test criteria and recognition of the benefit of long-term aging cracking test specimens. Another common theme was recognition that the resources that would be required to implement a BMD or use of performance tests on a regular basis are significant, and they may not be available in the short term. Finally, all of the State DOTs had strong partnerships with academia that they leveraged to evaluate performance and/or refine specifications and test methods directly related to the implementation of recycled mixtures.

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Responsible Use of Reclaimed Asphalt Pavement in Asphalt Mixtures

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