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Review

Understanding the State Agency Policies toward RAP Usage in the United States: State of Practice

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Abstract: The usage of Reclaimed Asphalt Pavement (RAP) material is a highly resource-conservative, economical, and sustainable practice in flexible pavement construction. However, its usage in hot mix asphalt (HMA) is capped at 25% by the majority of state transportation agencies due to its aging levels, stiffness characteristics, and handling capabilities, which may result in early-age pavement distress. Though researchers suggest methodologies to increase RAP usage, higher RAP percentages in asphalt pavements require the support of state authorities. The main objective of this paper is to provide information on how different states design their mixtures with high RAP percentages. This study reviewed the current state of practice of fifty (50) state DOTs in the United States (US) with respect to RAP usage and the factors governing its regulations. It was observed that the limit of RAP content is mainly governed by traffic levels, gradation, binder content, and stiffness contributed by RAP and layer position in a pavement structure. The specifications also suggest that apart from volumetric and performance justification, blending charts, fractionation, and virgin binder grade selection would facilitate the use of higher RAP content in HMA. Controlled mixture design abiding by state specifications can increase the allowable RAP to 40–100%.

Keywords: reclaimed asphalt pavement; fractionation; blending charts; low-volume roads; aged binder

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1. Introduction

Reclaimed asphalt pavement (RAP) is obtained from the demolition of old pavements and comprises aggregates coated with aged binder. It is the most recyclable material in the United States of America (USA) with close to 94.6 million tons of usage in 2021 as per the National Asphalt Pavement Association. The average content of RAP material in the construction of new flexible pavements in the USA is 20.1% [1]. The usage of RAP reduces the demand for natural aggregates, virgin asphalt binders, and energy consumption in hot mix asphalt (HMA) production. Although additional operations such as crushing, grading, fractionation, and homogenization are necessary when using RAP in HMA, the reduction in cost of binders and hauling of quality materials reduces the overall cost of pavement construction [2]. Hence, RAP usage is considered not only as an environmentally friendly operation but also as an economic and sustainable construction practice [3]. According to the Federal Highway Administration (FHWA) [4], the usage of 25% or more RAP is considered to be High RAP in a new pavement construction.

Higher RAP in asphalt mixtures is observed to improve the rutting resistance of asphalt pavements as the value of $G^*/\sin\delta$ increases with the increase in RAP binder content. This is due to an increase in the stiffness of the binder imparted from the RAP binder. Also, the rutting resistance is indicated by the lower non-recoverable creep compliance (Jnr) at even 3.2 kPa creep stress level [5]. Such high stiffness of binders due to aging results in mixtures highly prone to cracking [6,7]. To reduce the influence of aged binders and improve the interaction between RAP material and virgin material, researchers suggest rejuvenation, which softens aged binders and improves their cracking resistance [8]. In addition, to address the variation in gradation and non-homogeneity in RAP materials, studies mention fractionation for controlled mixture designs [9]. The increase in efficiency of using high RAP material reflects environmental sustainability in terms of natural resource conservation and emission reduction.

In view of these aspects, many construction companies inclined their interests towards using High RAP content in new pavement constructions. Prior to increasing the RAP content and redeeming the benefits, mixture design and construction practices should be in accordance with state specifications, which restrict RAP usage to certain limits. This practice of limiting RAP usage is typically due to the perception of poor performance of pavements prepared using high RAP content [10]. Studies mentioned that high RAP mixtures would perform as consistently as virgin mixtures through proper stockpile management, mixture design, and aggregate gradation [9,11,12]. The lack of confidence by agencies and assurance of high quality from contractors has led to framing restrictions on the usage of High RAP for long-service pavements.

Despite the promotion of High RAP by several research studies, field-level application of high RAP content is limited to a few cases [13–16]. Specifically, with US projects, the limited RAP content and infield high RAP trail sections are predominantly due to the limitations imposed by state Department of Transportations (DOTs). This may be due to concern about high variability in mixture production, plant operating policies and capabilities, placement, and compaction challenges. Also, there are still some unresolved issues with RAP such as understanding the active RAP binder, lack of a standardized method for softener utilization, resistance to binder grade adjustment, etc. Furthermore, state agencies are not yet inclined to adopt new technologies unless proven with confidence. Correspondingly, mixtures created in the laboratory also do not reflect a similar performance in the field due to several factors including mixture type, climatic conditions, construction techniques, and plant mixing capabilities [10]. Despite these concerns, state agencies have specified a few methods for the use of RAP at high content in asphalt mixtures through their specifications [17–73]. The usage of reclaimed asphalt materials in the USA is followed according to these methods mentioned by respective states.

In this scenario, there is a need for a comprehensive understanding of state DOT policies toward RAP incorporation in asphalt pavements. It is important to understand the limitations on RAP usage from the state agency perspective. Such an understanding would streamline the researchers' and contractors' efforts to get promoted to field-level implementations. Incorporating these limitations in ongoing study designs eliminates the unencouraged methodologies in increasing the RAP content, along with evaluating new techniques within the state agency acceptance policies. The present study emerged to comprehend such techniques that can be explored for increasing the RAP content towards sustainable pavements. Establishing RAP utilization techniques within the comprehended boundaries would overcome the resistance to field implementation.

2. Goal and Significance

The fundamental goal of the study is to review and summarize the current state of practice in the US with regard to the use of RAP in the production of new HMA mixtures for newly constructed friction courses. In general, this study focused on presenting a review of how various transportation agencies across the USA are successfully using high RAP contents in their asphalt mixtures on a regular basis. The summary is essential to provide a clear understanding of high RAP asphalt mixtures, their limitations, and design considerations. The specific goals of the study include:

- Summarizing the state specifications in the United States for the usage of RAP;
- Identifying and evaluating the factors governing the RAP usage policy by state transportation agency;
- Reviewing RAP utilization with respect to low-volume roads;
- Evaluating the state agency research approaches to promote RAP content.

3. Research Approach

The research approach includes reviewing the specifications of fifty (50) state agencies in the United States regarding the usage of RAP in newly constructed asphalt pavements. Initially, after identifying the maximum allowable RAP in each state, the states were divided in terms of quantification basis, i.e., in terms of RAP binder content and RAP material content, as seen in Figure 1. Following quantification, information on the agency requirements for allowing the RAP-modified mixtures was collected from the specifications to understand the acceptance policies for RAP. Subsequently, major factors governing the RAP usage regulations were identified and the limitations for each state were summarized accordingly. Following that, four major research studies performed by state agencies to overcome the concerns about RAP before establishing these limitations were presented.

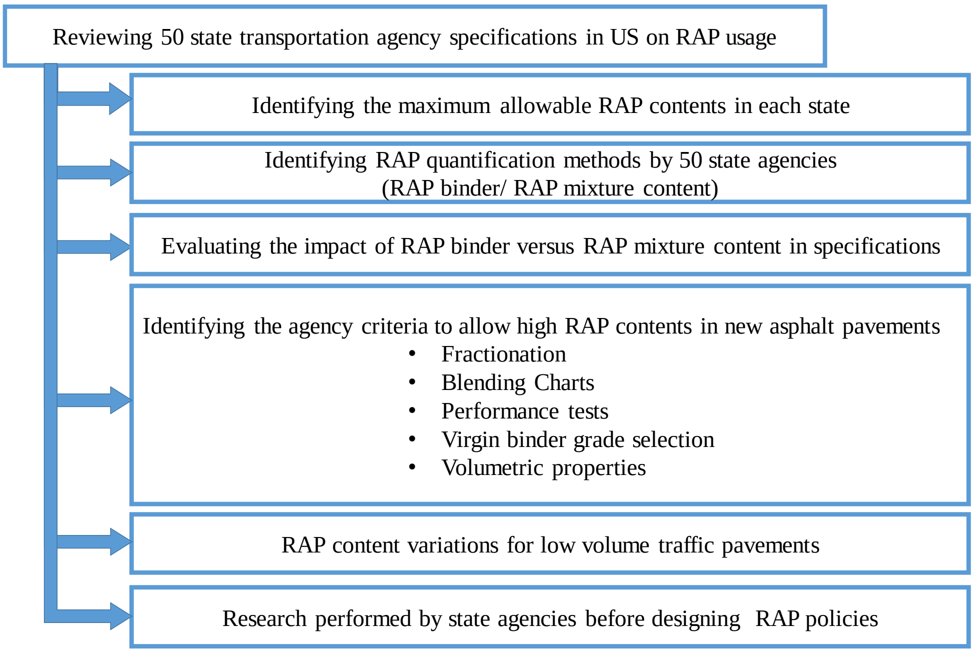

Figure 1. Research approach and tasks adopted for the study.

4. Assessment of Fifty (50) State Specifications

4.1. Usage of RAP in the United States

Figure 2 presents the map of the maximum allowable RAP content in surface mixtures across the USA as of 2023. States such as Massachusetts, Nevada, Pennsylvania, and New Jersey allow a maximum RAP content of 15% in their asphalt mixtures. The New Jersey Department of Transportation (NJDOT) also has a special RAP mixture that allows a minimum of 20% to a maximum of 100% RAP provided that the mixture meets the desired rutting and cracking criteria. The Vermont DOT allows a maximum of 50% RAP in their asphalt mixtures.

It was identified from the specifications that the majority of states (38) limited the usage of reclaimed material content to 30%. With the increase in the interval boundaries of allowable RAP usage, the number of states using RAP has decreased. Out of 38 states, 16 states are restricted to 20%, another 12 states to 25%, and the remaining 10 states to 30%. Only two (2) states are identified in the interval of 45% and 50%. The states using 30% RAP and above in the surface frictional course of hot mix asphalt are classified as High RAP in this study. The majority of southeast states in the United States agencies (8 out of 13 states) are observed to allow 30% RAP and above in the surface course.

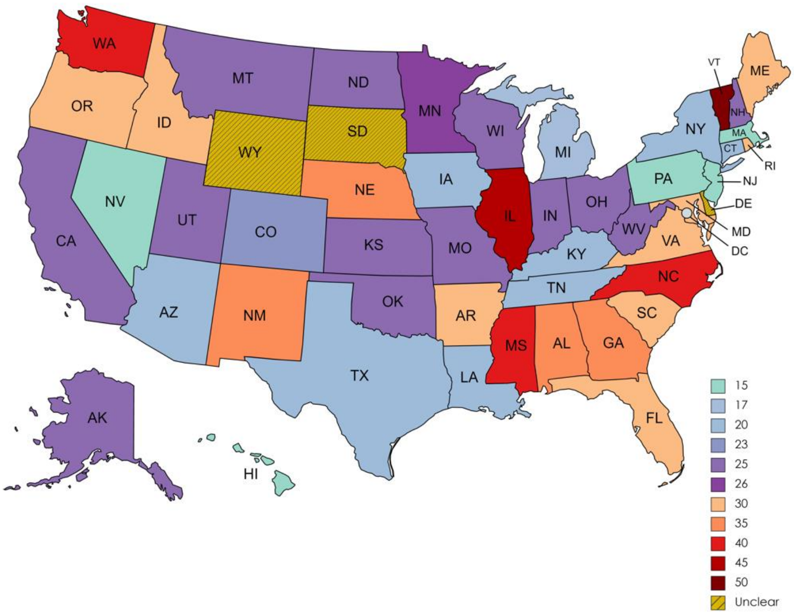

Figure 2. Allowable RAP content in the US as specified by state specifications.

4.2. RAP Quantification Basis by State Agencies in the United States

RAP usage by a state agency in the United States is basically in terms of either binder replacement or mixture replacement. When the agency mentions RAP usage as an allowable binder replacement, it represents the amount of virgin binder that can be reduced in the mixture design, considering the binder contribution from the RAP material. If a state mentions 10% as the allowable binder replacement, it indicates that in a design optimum binder content of 5%, up to 0.5% of virgin binder can be reduced and considered as a contribution from RAP material.

The term allowable mixture replacement content represents the amount of asphalt mixture that can be replaced in the mixture design; considering total reclaimed aggregate and binder. In this case, if a state specifies 20% as the allowable RAP content, it indicates that for every ton of asphalt mixture, 200 kg of RAP material (including RAP binder and RAP aggregate) can be incorporated into the pavement construction. As shown in Figure 3, it was determined that 19 states use binder replacement as a quantifying measure of using RAP content, while 28 states use RAP in terms of mixture replacement. However, the basis for this divergence in quantification by a state agency is unknown.

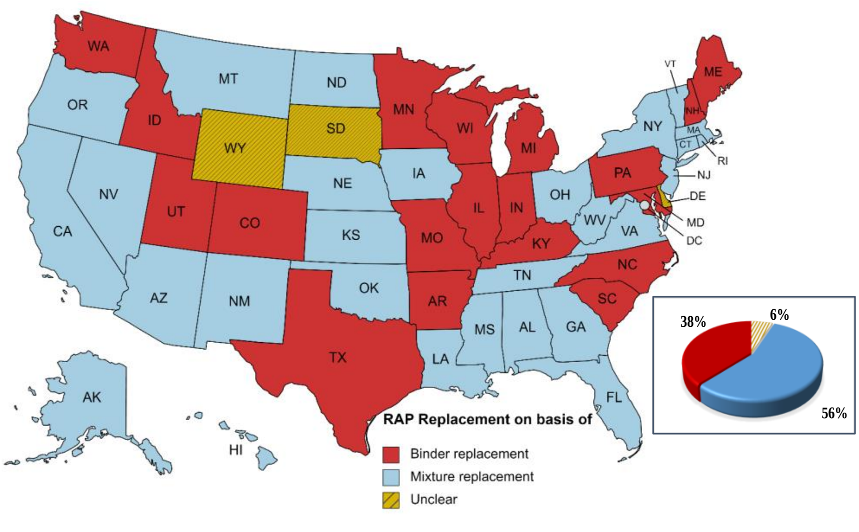

Figure 3. Map representing the states with RAP as mixture and binder replacements.

4.3. RAP Binder Content Versus RAP Mixture Content in Specifications

The DOT specifications were observed to prioritize the impact of binder content contributed from RAP rather than the mixture content. The gradation of the RAP material and the binder content contributed from the material was observed to govern a few states' policies in using the RAP content. When the gradation of RAP is observed to contribute a higher proportion of aged binder in the mixture, the states considered the impact and regulated the RAP usage limit.

Florida state [25] lowered the allowable RAP content considering the gradation of RAP fineness. When the material passing through the #16 sieve is more than 50%, the allowable RAP content is just 20%. This is due to higher RAP binder contribution from the material when the RAP aggregate is dominated by fines. Even though the allowable RAP content is 30%, considering the binder contribution from the RAP material, the threshold was lowered to 20%. A similar observation was seen in Georgia state allowing 35% RAP when the % passing through the #200 sieve is in the range of 5.1–7.0 [26]. However, when the % passing is greater than 8.8%, representing higher fines in RAP, the allowable RAP content is limited to 15% only. Maine DOT classified the usage of RAP into three classes on the basis of RAP material passing through a 0.075 mm sieve. The maximum allowed RAP in Maine is 30% and 10% when the percent passing through a 0.075 mm sieve is 1.8% and 4%, respectively. New Hampshire state limited the total binder contributed from the RAP material to 1.5% of the total asphalt content in the mixture [45]. This observation reflects that agency policies and guidelines are designed for less contribution from the aged binder with a coarser gradation of RAP.

Typically, the structural asphalt layers below the frictional asphalt course consist of gradation with a nominal size greater than that of the surface course, leading to lower binder content in the structural asphalt layers. Towards designing a mixture with higher RAP content, a coarser gradation can lead to lower RAP binder contribution. This relation of increasing RAP content with an increase in the NMAS of a mixture is reflected in the states of Louisiana, Massachusetts, Michigan, Minnesota, Mississippi, North Carolina, Ohio, South Carolina, and Texas [34,37–40,49,50,55,58]. These states allow higher RAP contents in the structural asphalt course when compared to the frictional asphalt course.

5. Factors Governing the Usage of RAP

This study identified the factors that govern the state DOTs for the usage of RAP in asphalt pavements and increasing the content. The assessment was that five factors including fractionation, blending charts, performance tests, blending, guidance in virgin binder grade selection, and volumetric criteria would encourage the DOTs to promote the increased usage of RAP. Figure 4 represents the number of states that use each factor as a governing criterion in using RAP.

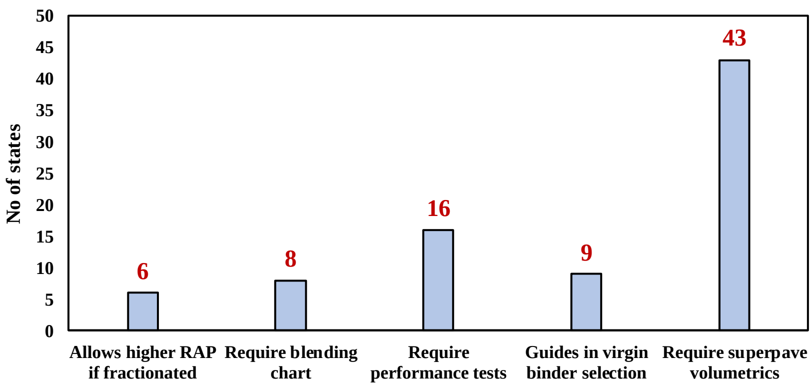

Figure 4. Graph representing number of states which provide additional regulations in using RAP in asphalt mixtures.

5.1. Fractionation

The term fractionation indicates the separation of RAP mixture from a stockpile into aggregate-size fractions, typically into coarser and finer fractions [2]. The RAP material obtained after milling and processing is not usually uniform in gradation. This results in the non-homogeneity of binder content when the material is sampled for mixture design. For example, when the sampled material from the unfractionated RAP source contains more fines, the aged binder content would be higher. Likewise, when the sample contains a predominant coarser aggregate fraction, the binder content would be relatively low. This misguides the binder content selection during the asphalt mixture design, which eventually leads to mixtures being prone to cracking. The fractionation process allows the separation of RAP materials into different levels of gradation, which enables controlled gradation and binder content in the mixture design. It was identified that six states (Tennessee, California, Illinois, Ohio, and South Carolina), as mentioned in Table 1, out of 50 allow a higher content of RAP if the stockpile has been fractionated. While Tennessee and Ohio states allow up to a maximum of a 5% increase in RAP usage if fractionated, states like Illinois and Texas allow up to 25% and 30%, respectively, in the pavement structure with a conventional binder. When a polymer-modified binder is used with RAP, states prefer a reduction in RAP usage irrespective of traffic level. For instance, states like Ohio and Illinois reduce RAP while using polymer-modified binders on the surface course, as mentioned in Table 1. The allowable increase in fractionated RAP content was observed to be just 5% in the case of polymer-modified surface course, while the non-polymer surface course has a leverage of 15 to 25% increase, as seen in the case of Illinois state.

Table 1. Table mentioning the details of fractionation criteria.

State (Reference)	Allowable RAP Contents (%)		Comments	Increase in Allowable RAP (%)
	Unfractionated	Fractionated		
Tennessee	15	20	Friction course	5
	30	35	Shoulder	5
California	15	25	2-level fractionation: >3/8 inch, <3/8 inch	10
Ohio	10	15	Heavy Traffic polymer-modified surface course	5
	20	25	Medium Traffic polymer-modified surface course	5
	20	25	Light Traffic polymer-modified surface course	5
	20	25	Non-polymer-modified surface course	5
South Carolina	15	25	Surface course	10
	20	30	Fine RAP fractionation	10
Illinois	30	45	N design = 30, Surface course	15
	15	40	N design = 50, Surface course	25
	10	35	N design = 70, Surface course	25
	10	35	N design = 90, Surface course	25
	10	15	N design = 30, Polymer-modified surface course	5
	10	15	N design = 50, Polymer-modified surface course	5
	10	15	N design = 70, Polymer-modified surface course	5
	10	15	N design = 90, Polymer-modified surface course	5
Texas	20	30	Non-surface	10
	10	20	Dense graded HMA—Surface	10
	10	30	Dense graded HMA—Intermediate	20
	10	40	Dense graded HMA—Base	30

5.2. Blending Charts

Blending charts are used to determine the proportion of RAP quantity with the base binder that meets the desired binder grade after RAP proportioning. Usually, charts are developed to confirm if the final grade of the binder meets the requirement mentioned in a contract. Eight agencies (Pennsylvania, Massachusetts, Iowa, Connecticut, Maryland, New Mexico, Missouri, and Vermont) are identified to follow this procedure for incorporating RAP material in asphalt pavement construction. AASHTO M323, Appendix XI is recommended for developing the blending charts with RAP and virgin binder [69].

5.3. Volumetric Criteria

The majority of state DOTs require the asphalt mixture to accomplish the Superpave volumetric requirements in terms of air voids, Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA), effective binder content, etc. Even on the incorporation of RAP in HMA construction, the designed asphalt mixtures are required to satisfy the volumetric properties specified by respective DOTs. This criterion is sometimes extended to special volumetric requirements such as explicit VMA and air voids for various specified RAP contents. This is for the states of Missouri, New Mexico, Georgia, Arkansas, and New York. States such as Alaska and Hawaii require RAP mixture design as per the Marshall mix design procedure. Two states (Wyoming and Delaware) were observed to have unclear specifications regarding RAP usage and their requirements.

5.4. Performance Tests

Along with the volumetric fulfillment and Superpave mixture design criteria, a few agencies also require the resultant RAP-modified mixture to satisfy some special performance tests mentioned in Table 2. This criterion is to justify the quality of the mixtures when RAP is incorporated into the design. The agency requires the performance of the mixture to be reflected in the laboratory at the design stage and also in the field with pavement coring.

Table 2. States and their performance test requirements.

Number	State	Performance Test
1	New Jersey	HWT, OT
2	South Dakota	TSR, APA
3	Vermont	TSR
4	Illinois	TSR. HWT, IFIT
5	North Carolina	Rut test
6	Washington	HWT
7	Georgia	Permeability, HWT, TSR
8	Oregon	TSR
9	Virginia	Rut test
10	Arkansas	HWT, TSR
11	Montana	HWT
12	Oklahoma	HWT
13	California	HWT, TSR
14	Texas	HWT
15	Connecticut	TSR
16	Louisiana	LWT, SCB

HWT = Hamburg Wheel Tracking; OT = Overlay Test; TSR = Tensile Strength Ratio; APA = Asphalt Pavement Analyzer; IFIT = Illinois Flexibility Index Test; LWT = Hamburg Loaded Wheel Tester; SCB = Semi-Circular Bend test.

Rutting resistance is observed to be the most common performance criterion with Hamburg Wheel Tracking (HWT), Asphalt Pavement Analyzer (APA), and Rut tests. Tensile Strength Ratio (TSR), though part of Superpave specification, is also mentioned by states like South Dakota, Vermont, Illinois, Georgia, Arkansas, California, and Connecticut. A few states required unique requirements like the overlay test for New Jersey, the Illinois Flexibility Index test for Illinois, and the Permeability test for Georgia, as mentioned in Table 2.

5.5. Guidance in Virgin Binder Grade Selection

Few agencies guide contractors to use the virgin grade for varying RAP contents, as seen in Table 3. It would be mandatory to use that virgin grade of binder in construction. Massachusetts, Kentucky, Oklahoma, Utah, West Virginia, Idaho, Virginia, Vermont, and Florida are observed to have this regulation in their road construction specifications.

Table 3. States with guidance on virgin binder grade selection.

DOT (Reference)	RAP Content (%)	Guidance in Virgin Binder Grade	Binder Grade without RAP
Massachusetts	<25	Project-specified grade	Project-specified grade
	>25	AASHTO M 323 Appendix X1	Project-specified grade
Kentucky	≤17	PG 64-22	PG 64-23
	18–23	PG 58-28	PG 64-24
	≤17	PG 76-22	PG 76-23
Oklahoma	15	PG 76-28/PG 70-28	PG 76-28
	25	PG 64-22/PG 58-28	PG 76-29
Utah	<15	No change in binder grade	Project-specified grade
	15–25	High PG grade should be softer by one grade	Project-specified grade
West Virginia	≤15	No change in binder grade	Project-specified grade
	16–25	High and low grade should be softer by one grade	Project-specified grade
	>25	According to blending charts	Project-specified grade
Idaho	≤17	No change in binder grade	Project-specified grade
	>17	58-34	PG 58-28
	>17	No adjustment needed	PG 58-34
	>17	58-34	PG 64-28
	>17	58-34	PG 64-34
	>17	64-34	PG 70-28
	>17	70-34	PG 76-28
Virginia	≤25	PG 64H-22	Project-specified grade
	26–30	PG 64S-22	Project-specified grade
Vermont	≤20	PG 70-28	Project-specified grade
	21–25	PG 70-24	Project-specified grade
	26–50	Blending chart	Project-specified grade
Florida	0–15	PG 67-22	PG 67-22
	16–30	PG 58-22	PG 67-22
	>30	PG 52-28	PG 67-22

When RAP content is around 15% and lower, the states are observed to use the same virgin binder grade as mentioned in the project. Softer binder grades and blending charts are observed to be opted for when the RAP content is higher than 15%. This is to reduce the stiffness imparted by higher proportions of aged binder. Figure 5 summarizes the states mentioning the criteria to adopt when RAP is used for designing asphalt mixtures.

The majority of states imposed a volumetric requirement as a major criterion, followed by performance tests and virgin binder grade selection.

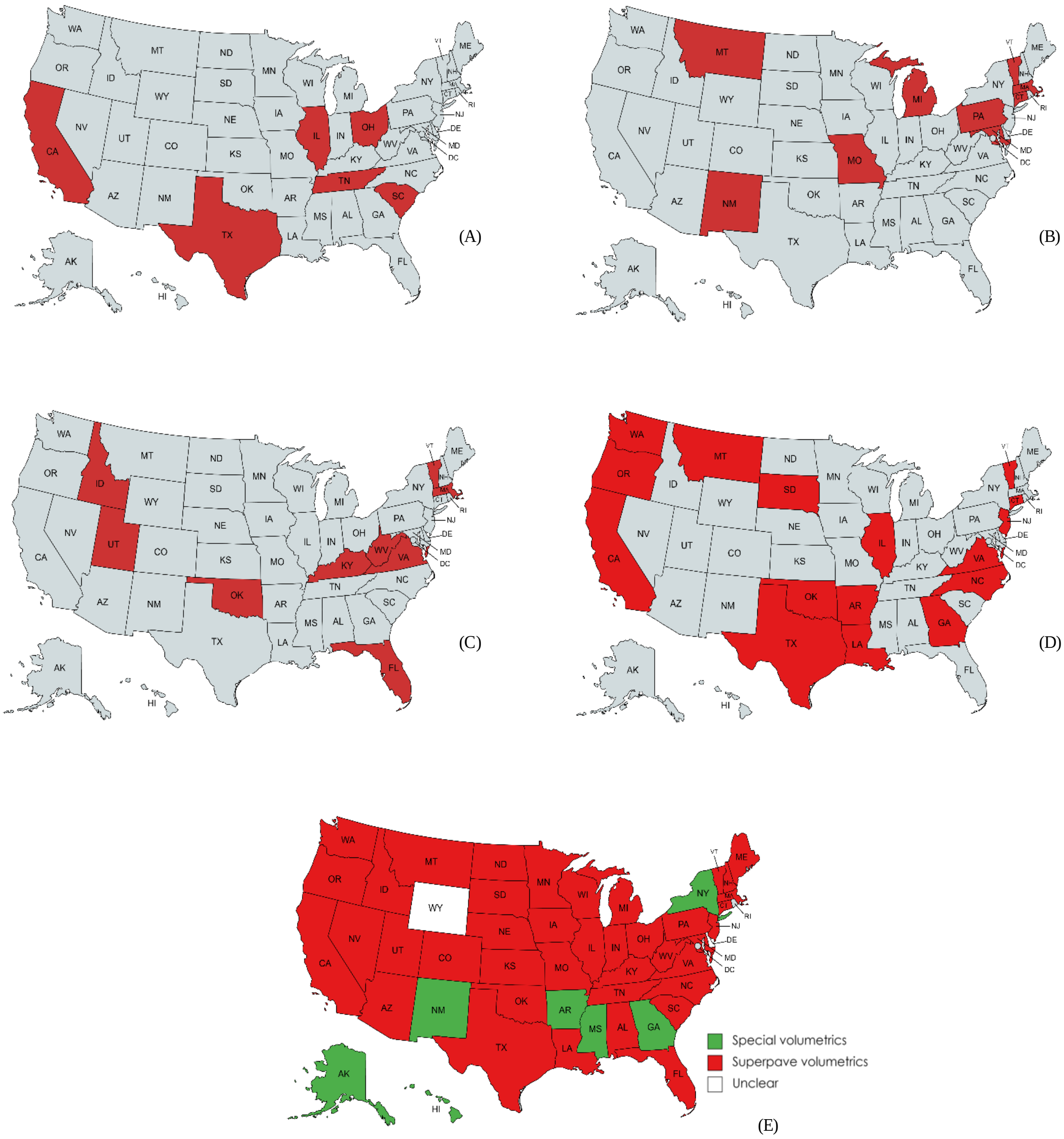

Figure 5. States using (**A**) fractionation, (**B**) blending charts, (**C**) guidance on virgin binder grade, (**D**) performance tests, and (**E**) volumetric criteria for designing RAP mixtures.

While only eight (8) states require only one factor in regulating the RAP content, the majority of states (40) use at least two factors to regulate the RAP contents. Specifically, states such as Massachusetts, Tennessee, California, Oklahoma, Virginia, Georgia, Illinois, and Vermont use three factors for finalizing the RAP mixture. Interestingly, all these eight states allow at least 25% RAP content and above, which is greater than the average allowable RAP content in the country. It can be interpreted that the policies and RAP mixture design requirements get more stringent with higher contents of RAP. However, the reason for individual state limitations cannot be understood through specification analysis.

6. Allowable RAP in Low-Volume Roads

A low volume of traffic has extended the allowable limits of RAP usage on HMA from the specification perspective. The state DOTs of Ohio, Kansas, Oklahoma, Florida, and Nebraska and the city DOTs of New York City and Eugene City were identified to allow more than the conventional limit of RAP. The usage of RAP in low-volume roads is higher when compared to high-volume surface friction courses. This is the case as the low volumes experience lesser severity of traffic, loadings, and frequency when compared to highways. New York City law has a special provision for allowing RAP as of January 2015. The law mentions that a minimum of 10% RAP should be used in heavy-duty asphalt mix and a minimum of 30% should be used in asphalt mixes other than heavy-duty mixes. Also, the law permits the usage of 100% RAP in city road construction [71]. States like Florida and Kansas allow up to 50% RAP in low-volume roads. While the term low-volume roads refer to a traffic level of less than 10 million ESALs (Equivalent Standard Axle Loads), Kansas state defines it as an Annual Daily Traffic (ADT) of 1200 vehicles per day or less in the design year [72]. Nebraska has limited RAP to 55% for low-volume roads with 750 trucks per day and 65% for shoulder construction [43]. Eugene City, Oregon, allows up to 30% RAP material in the construction of new hot-mix asphalt [73]. With the fractionation of RAP, Ohio state allows up to 30% RAP on light- and medium-traffic surface courses and up to 25% with unfractionated RAP. Oklahoma state allows up to 35% RAP for temporary detours, provided the Superpave mixture meets the air quality standards set by the Department of Environmental Quality.

7. Studies Supporting the State Limitations

The limitations on RAP mentioned by various agencies had profound research studies before implementing or modifying the guidelines. However, the concerns of agencies were different from each other, varying from rheological concerns, the grade of the virgin binder that has to be utilized, the percentage of binder contributed by RAP, the amount of fineness in RAP, the cracking behavior of RAP-modified mixtures, etc. Nevertheless, a common agenda among these studies is to reduce the undesirable influence of aged binder in the final RAP-incorporated mixtures.

7.1. Florida State: Based on Fineness of RAP

Roque et al. (2020) [74] carried out an extensive study on the cracking performance of RAP with eight sources based on the Dominant Aggregate Size Range–Interstitial Component (DASR–IC). While the DASR range forms the aggregate skeleton in the pavement that resists shear, the IC portion consists of fine aggregate, binder, and air voids which fill the volume in the DASR, resisting tension and shear. This requirement and interlocking is governed by the DASR porosity value and the study has a limit of 38–52% for good mixture performance. The eight RAP sources selected based on the DASR range were varied, with 0%, 20%, 30%, and 40% mixture proportioning. The mixture combinations were subjected to direct tension for interstitial component fracture energy (FEIC) to determine the maximum allowable RAP content. The eight RAP sources were further classified depending on the basis of RAP gradation passing through sieve No. 16 into fine (<40%), intermediate (40–50%), and coarse sizes (>50%). The classification further led to identifying the binder replacement ratio in the mixture combinations, which gives the ratio of RAP binder weight in IC to total binder weight in IC. This is believed to be an important parameter that regulates the fracture energy. It was observed that an increase in the binder replacement ratio decreased the fracture energy of the mixture. However, the important point to be identified while using this ratio is that this is hugely influenced by the gradation of RAP rather than the content of RAP. This is because similar contents of RAP can have different ratios depending on the fineness content.

The conclusions mentioned that when the RAP content contains higher fine proportions, the fracture energy is expected to decrease, and hence, a lower proportion needs to be used. When a coarser RAP is used as a replacement, a higher proportion can be adopted as the fracture energy performance would still be better than that of a finer mix. When the asphalt mixture has high polymer asphalt instead of conventional asphalt, the RAP combination at coarser and intermediate levels of gradation is observed to increase as the

FEIC has an improvement. But when finer RAP is used, the influence of high-polymer binder is negligible.

Florida state now allows up to a maximum of 50% RAP by weight of a mixture on roads with traffic levels A (<0.3 million ESALs), B (0.3 to <3 million ESALs), and C (3 to 10 million ESALs) without any performance requirement by just meeting the volumetrics as mentioned in 334-3.2.5 of the state specification [25].

7.2. North Carolina State: Based on Rheology of Blended Binder

In 2016, the North Carolina DOT realized the percentage limitation of RAP based on the total weight of the mix does not characterize the properties of blended binders due to source variability. Further, the state carried out a detailed study [75] to better capture the rheological properties of the blended binder. The study used the RAP resources in North Carolina state based on the requirement, availability, and accessibility aspects. Initially, the binder content of RAP material was identified by burning the samples in an ignition oven, and the aggregate residue was used for analyzing the gradation of the RAP aggregate. A binder extraction was also performed for blending purposes and rheological analysis. Blended binders were prepared with recycled binders at dosages of 25%, 40%, and 100% with PG 58-28 and PG 64-40. The resultant binders were analyzed for Superpave binder tests for high-temperature PG grading and intermediate temperature criteria using a Dynamic Shear Rheometer.

Further, RAP material along with virgin aggregates and binders are used for determining the dynamic modulus of the mixtures maintaining the aggregate gradations. The analysis suggested that mixtures with 40% RAP-replaced binder can be used for paving operations with 58-28 binder and 20% when PG 64-40 is used. However, it is again highly dependent on the variability between the stockpile characteristics and sometimes within the stockpile. To address this situation, the state carried out another study [76] to understand the variability along with the statistical significance of various RAP sources in the state. Assuming there is a 100% blending between the RAP binder and the virgin binder, the study recommended that the gradation of the stockpile should be given due importance as the high fine content would increase the binder content even for a small quantity of RAP mixture. Also, the techniques adopted by the industry should be considered for RAP implementation for selection criteria to reduce the variability.

North Carolina state currently allows 40% RAP in surface course and 45% in intermediate and base mixes based on recycled binder replacement.

7.3. New Hampshire State: Based on Virgin Binder Modification

New Hampshire state encourages the usage of approximately 15–25% RAP in pavement construction as a safe limit. When the content of RAP increases in the paving operations, the pavement perceptively experiences changes at both the binder and mixture level. In order to assess the impact of changing the binder grade when high RAP content is used, the agency sponsored a study using two binders, namely PG 52-34 and PG 58-28 [77]. Varying the RAP content at 15% and 25% in PG 52-34 and 25%, 30%, and 40% in PG 58-28, respectively, the influence on the performance of in-place pavements was assessed for a period of three years. PG grade, shear modulus master curve, and the multiple stress creep recovery test were carried out at the binder level, whereas complex modulus, flow numbers, Hamburg Wheel tracking, and fatigue tests were performed at the mixture level.

The analysis was carried out on four types of mixture including plant mixed and plant compacted (PMPC), plant mixed and laboratory compacted (PMLC), laboratory mixed and laboratory compacted (LMLC), and from the field section. But a major proportion of the study and conclusions emphasized the binder's influence when High RAP content is used. A greater impact on the binder characteristics was observed than the RAP content in this study. This is mainly because the overall binder in the mixture combination would undergo greater stiffness during aging processes when a softer binder is combined. The PG 58-28 base binder mixtures show a decrease in phase angle with increasing RAP content, whereas the mixtures with the PG 52-34 base binder have lower phase angles and show an increase in phase angle with increasing RAP content. This is something not expected and the authors claimed that the PG 52-34 could have been influenced by recycled engine oil bottoms during the binder manufacturing.

Although the study recommended a limitation of 1% total recycled binder for surface mixtures, the state specification mentioned a maximum usage of 1.5% as per section 2.10.1 [45]. For instance, if the binder content in the mixture is 5%, the state allows only 3.5% of the virgin grade binder with 1.5% being the RAP binder.

7.4. Illinois State: Based on Stringent Gradation of RAP-Modified Mixtures

In the study carried out by the Illinois DOT in 2012 with the University of Illinois [9], it was reported that high-quality HMA can be designed using 50% RAP, meeting the volumetric requirements and performance standards equal to better than the control mixture when an appropriate binder was used. According to the Illinois DOT, when the specification mentions the use of 15% RAP, that does not indicate 15% RAP aggregate but 15% total RAP content, which includes the binder. The RAP aggregate content was less than 15%. The approach was based on maintaining the same VMA percentage for various proportions of mixtures using the Bailey method of mixture proportioning. This is conducted to ensure there is no influence of VMA in RAP mixture performances. Till the size of No. 200, the percentages of RAP and virgin material are maintained the same as the mixture design as it is tough to control the fines of RAP below the #200 sieve.

The study was carried out using 30%, 40%, and 50% RAP from two sources in Illinois and mixture characterization tests such as complex modulus, flow number, beam fatigue test, wheel tracking test, and semi-circular bending fracture test for the analysis of High RAP performance. The tight gradation regulations mentioned above have resulted in stiffer mixes as 50% RAP showed higher and maximum modulus values at different frequencies. Also, using softer binders at 30% reduced the modulus values compared to stiffer binders. Though there is a decrease in fracture energy with the addition of 30% RAP, a further increase in RAP resulted in the same fracture energy but still less than the virgin mixture. On the whole, there was a satisfactory performance from the study, suggesting that the volumetric requirements should be maintained when using RAP with proper fractionation. The final combination of the mixture would be influenced by binder grade, either single-grade bumping or double-grade bumping, depending on the requirement.

The Illinois state DOT currently allows up to 45% Binder Replacement Ratio (BRR) in surface mixtures if the RAP is fractionated and gradation is controlled. For unfractionated RAP, the ratio is capped at only 30%. Similarly, 55% BRR is allowed for fractioned RAP in the case of binder course and only 25% for unfractionated RAP.

8. Conclusions

This study was initiated to synthesize the state of practice pertaining to the use of high quantities of RAP (30% or more by mix weight) in asphalt mixtures across DOTs and other local highway agencies in the US. This study also aimed to establish a better understanding of how different DOTs successfully determined high RAP percentages in asphalt mixture specifications.

- Out of the 50 state DOTs, 47 agencies have clear guidelines on the maximum RAP content allowed in mixtures and each state DOT has its own unique guidelines on RAP usage.
- The majority of states use RAP in terms of mixture replacement; however, all the recent revisions of different states prefer RAP in terms of binder replacement.
- Only 16 states require performance tests as a criterion in approving the RAP mixture design. Those agencies that require performance testing do so in the design stage.
- Five (5) factors including fractionation, blending charts, performance tests, guidance on virgin binder grade selection, and volumetric satisfaction were identified by the study, which govern the state policy in deciding the usage of RAP.

- With the fractionation of RAP, a 5–30% increase in the usage of RAP was accommodated by different states. However, when RAP is used in the construction of friction courses with polymer-modified binders, the usage of RAP is restricted to lower contents.
- The state agencies are more concerned about the fraction of binder content that the RAP material contributes to the final mixture than the total amount of RAP material. With an increase in binder contribution, states impose restrictions on gradation to reduce the amount of fines in the RAP.
- The use of high RAP percentages in low-volume roads is allowed in the range of 25 to 100%, typically higher than in high-volume roads along with less stringent requirements (i.e., only volumetric requirements). New York City has a provision of allowing 100% RAP in city road construction.
- From background studies assessed, it is understood that addressing binder contributions from fine RAP, characteristics of blended binders, gradation of RAP-modified asphalt mixtures, and virgin binder grade modification are a few of the crucial justifications that extended the RAP usage limits for state agencies.

This study comprehended the understanding that state agencies prefer to have organized material processing and design justifications while handling higher RAP contents. Though the usage of high RAP would be an economical and sustainable path, state agencies have the intention to reduce the impacts of aged binders from RAP on the final mix. To overcome this, the mixture design should consist of the least possible aged binder contribution from the RAP material so that the properties of the mixture would not be influenced. This can be achieved by using the coarser part of RAP gradation as per state specifications with a softer binder using blending charts. Future research on rejuvenation techniques, warm mix additives, and cold-in-place recycling techniques may further enhance the confidence of state agencies to increase the usage of recycled material in newly constructed pavements.

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