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Engineered Frameworks for Evaluating the Use of Recycling Agents in Surface Asphalt Mixtures for Virginia

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Virginia Transportation Research Council

Virginia Asphalt Association – Mid-Atlantic Asphalt Expo

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Research Team

VTRC Virginia Transportation Research Council

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Background
Use of RAP in Asphalt Mixtures

- RAP content of 15-20% is becoming a standard practice
  - Much higher in Netherlands and Japan vs. stagnant in United States
  - NCHRP Report 452 recommended using the same binder grade for up to 20% RAP (depending on RAP binder stiffness)
- State highway agencies introduced special provisions and specifications to allow the use of relatively higher RAP / RAS contents in AC mixtures
  - Offset the continuously rising cost of oil

Background

Evolution of RAP Contents in Virginia

2007

- Specifications for higher % of RAP (up to 30%)
- No need to adjust the virgin binder grade

2013

- Considering the feasibility of using up to 45% RAP
- Trial sections were constructed

2017 **BMD**

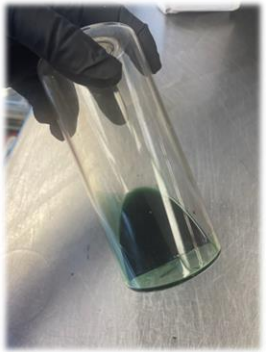
2019 2023

- Construction of field trials to evaluate high RAP mixes designed following the Balanced Mix Design (BMD) special provision

Background
Challenges and Solutions

- Challenges arising from the use of asphalt mixtures with high RAP content
  - Performance issues: over stiffening and more brittleness
    → *prone to premature cracking*
  - Construction issues → *Compactability and Workability*
- Potential Solutions
  - Using a softer asphalt binder (lower Performance Grade)
  - **Using recycling agents**

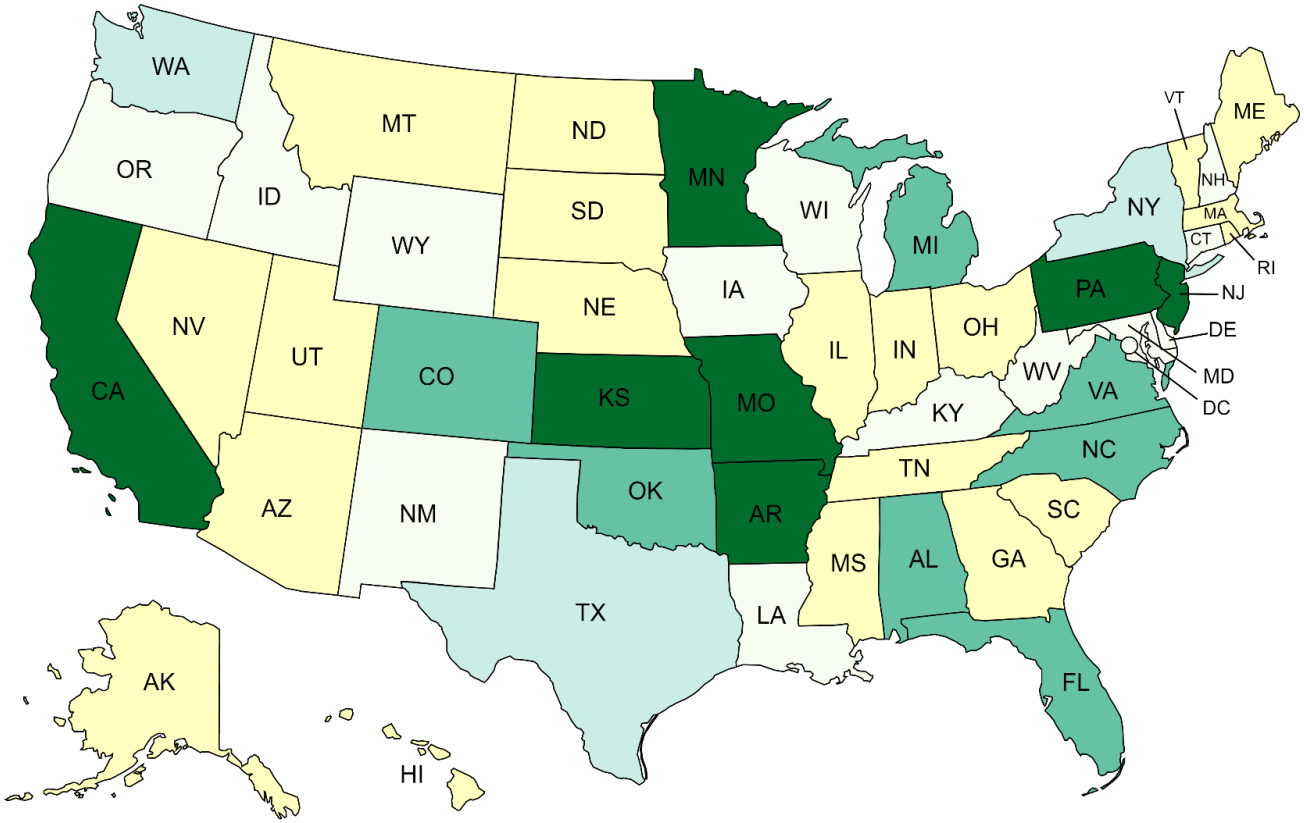
Background
Classification Systems for RAs



- ASTM D4552, based on physical properties
  - Screen RAs for safety, handling, and durability purposes
- NCAT, based on chemical properties
  - Three categories: petroleum-based, organic or non-petroleum-based, and emulsion-based
- Nebraska, based on the nature of the source of RA
  - Highlights the effectiveness of RAs based on changes in low / high temperatures and cracking resistance
- Texas A&M, based on rejuvenation mechanism
  - Three categories: softeners, replenishers, and emulsifiers

Background

State-of-the-Practice



Currently allow or previously experienced the use of RAs in AC mixtures + Responded YES in the survey *(Group A)*

Currently allow or previously experienced the use of RAs in AC mixtures + Responded NO in the survey *(Group B)*

Currently allow or previously experienced the use of RAs in AC mixtures + Survey responses NOT received *(Group C)*

Do NOT allow the use of RAs in AC mixtures + Survey responses received

NO available literature on previous experience related to the use of RAs in AC mixtures + Survey responses NOT received

RA Acceptance Framework

Objectives and Scope of Work

- Establish a performance-based approach to facilitate the determination of acceptability of a specific RA product for inclusion in VDOT APL.
  - Benchmarking of RA modified binder blends and mixtures
  - Comparing the properties and similarities of RA-modified binder blends to the "***VDOT QA reference binder dataset***"
- Develop a framework to evaluate short- and long-term effectiveness of RAs in improving the performance of asphalt mixtures (especially with high RAP contents).

RA Acceptance Framework

Evaluated Materials

- **Asphalt Binders**
  - **B1:** PG 64S-22 (Hopewell, VA) **(PG 68.1-22.4)**
  - **B2:** PG 64S-22 (Roanoke, VA) **(PG 67.0-24.6)**
  - **B2:** PG 58-28 (Greensboro, NC) **(PG 60.6-30.3)**
- **RAP Sources**
  - **R1: PG 95.5-7.9**; AC=4.9%; Content 45% (Salem, VA)
  - **R2: PG 107.1-4.7**; AC=5.2%; Content 35% (Burkeville, VA)
  - **R3: PG 94.5-10.3**; AC=4.4%; Content 40% (Chesapeake, VA)
- **Recycling Agents (RA)**
  - Paraffinic Oil (**RA1**) ***~10% by total weight of virgin binder*** (max per AI)
  - Aromatic Extracts (**RA2**) and Tall Oils and Fatty Acids (**RA3**)
  - Triglycerides and Fatty Acids (**RA4**, **RA5**, and **RA6**) **~2 to 6%**

RA Acceptance Framework

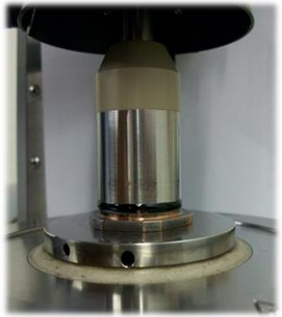
Dosages

Binder Source	RAP Source	Name	Recycling Agents						No RA
			RA1	RA2	RA3	RA4	RA5	RA6	
Hopewell, VA **(B1)**	Salem (R1)	**B1R1**	15.52%	4.29%	5.90%	6.25%		5.71%	
	Richmond (R2)	**B1R2**		5.29%	5.70%	5.79%	8.49%	5.20%	
	Chesapeake (R3)	**B1R3**		3.80%	4.10%	4.50%	8.68%	3.90%	
Roanoke, VA **(B2)**	Salem (R1)	**B2R1**			4.40%		9.31%	4.62%	
	Richmond (R2)	**B2R2**				4.52%	8.49%		
	Chesapeake (R3)	**B2R3**	14.47%	3.52%	2.60%				
Greensboro, NC **(B3)**	Salem (R1)	**B3R1**							0.00%
	Richmond (R2)	**B3R2**				1.21%			
	Chesapeake (R3)	**B3R3**							0.00%

Dosage provided by manufacturer by total weight of virgin binder to meet a PG 64-22

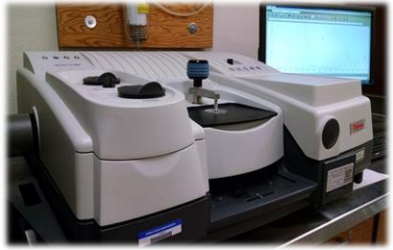
RA Acceptance Framework

Experimental Program – **Phase I**



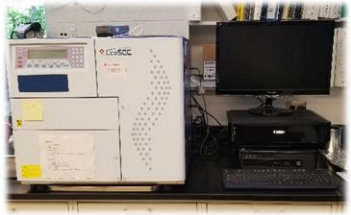
Evaluation of RAP-RA-Binder Blends at Various Aging Levels

Rheology ⟷ **Chemistry**



- **DSR:** PG High & Int. Temp
- **DSR**: Frequency Sweep Test (G-R parameter, R-value, and others)
- **BBR**: T_S,T_m,& ΔT_c

Original; RTFO; PAV-20; and PAV-40



- **FTIR**: Functional Groups through absorbance quantification

Selection of fewer blends to be evaluated as *Mixes*

RA Acceptance Framework

Continuous Binder Performance Grade (PG)

Binder Source	RAP Source	Name	No RA	RA1 **Paraffinic Oil**	RA2 **Aromatic Extract**	RA3 **Other**	RA4 **TFA**	RA5 **TFA**	RA6 **TFA**
1, PG 64-22	1	B1R1	76-16	73.6-19.5	75.3-18.6	69.6-20.7	71.5-27.5		71.1-25.5
	2	B1R2	76-16		76.2-20.2	71.8-23.7	73.0-24.1	70.2-30.2	73.3-23.3
	3	B1R3	76-16		73.2-22.9	69.6-23.3	71.9-27.9	64.5-30.9	70.4-23.9
2, PG 64-22	1	B2R1	76-16			71.7-22.7		66.7-30.3	71.8-28.6
	2	B2R2	76-16				74.5-23.6	67.7-31.6	
	3	B2R3	76-16	69.0-24.9	72.6-24.9	70.4-26.3			
3, PG 58-28	1	B3R1	**70-22**						
	2	B3R2	70-22				72.8-24.1		
	3	B3R3	**70-22**						

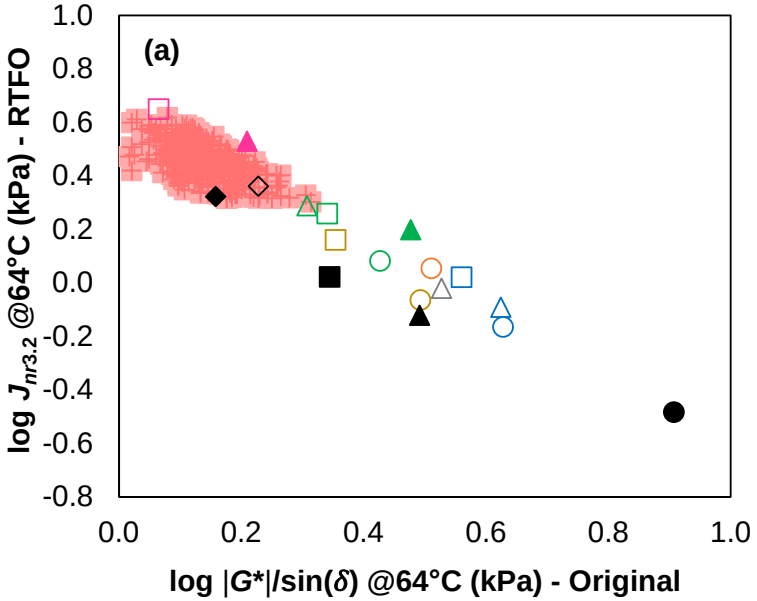
Did not restore low temperature PG

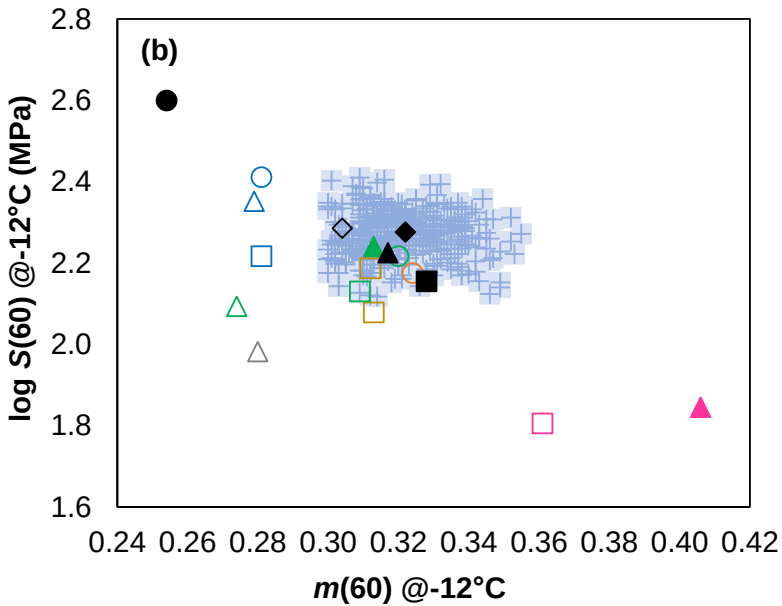
Restored low temperature PG

Low temperature PG improved

RA Acceptance Framework

Similarity Analysis - Example

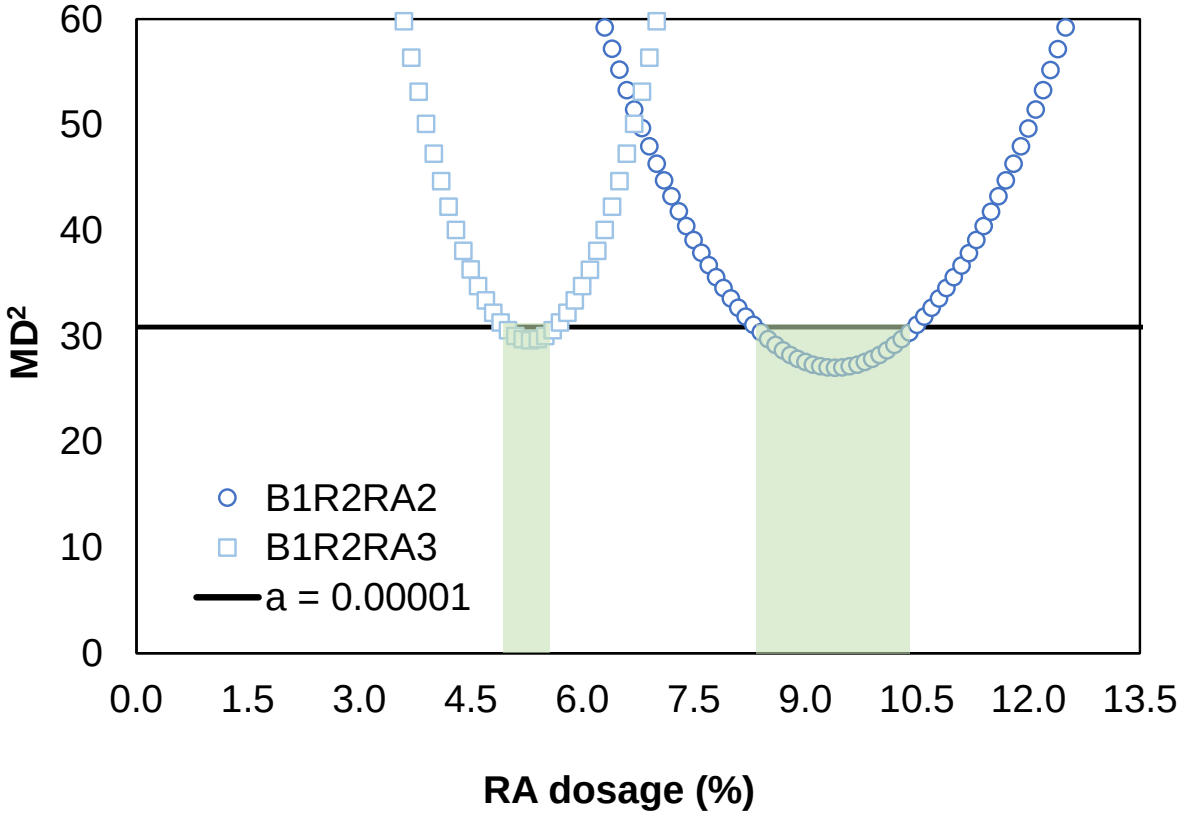




PG 64S-22 (VA) - HT
PG 64S-22 (VA) - LT
B2R1RA5
B2
B1R3RA3
B1R2
B1R2RA4
B1R3RA6
B1R1RA2
B1
B1R1RA1
B1R3RA2
B2R1RA3
B1R1RA3
B3R1
B1R2RA3
B1R3RA5
B1R2RA6
B1R2RA2
B3R3

RA Acceptance Framework

Multivariate Control Procedure



Mahalanobis Distance (MD)

vs.

Euclidean Distance (ED)

- Provide unitless measure
- Considers data variability and correlation

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RA Acceptance Framework 1

Framework for Inclusion of RAs into the VDOT Approved Product List (APL)

RA Acceptance Framework

Recommended VDOT APL - Procedure

***Note:* The work prescribed under this framework is to be completed by an accredited third-party laboratory.**

- Step 1 – Selection and Baseline Evaluation of Component Materials
  - ***Virgin Asphalt Binder PG 64S-22*** sent by VDOT with all necessary properties: $|G^*|/\sin\delta$ at 64ºC; PGH_c; $|G^*|\sin\delta$ at 25ºC; PGI_c; PGL_c; ΔTc; and $J_{nr,3.2}$ at 64ºC.

RA Acceptance Framework 1

Recommended VDOT APL – Procedure *(Cont'd)*

- Step 1 – Selection and Baseline Evaluation of Component Materials
  - ***RAP Material and Extracted & Recovered RAP Binder***
    - Representative source of RAP will be sent by VDOT
    - Properties: **94ºC < PGH < 106ºC** & **-10ºC < PGL < -4ºC**
    - Perform Extraction & Recovery
    - Determine necessary properties: $|G^*|/\sin\delta$ at 64ºC; PGH_c; $|G^*|\sin\delta$ at 25ºC; PGI_c; PGL_c; and ΔT_c.
  - ***Recycling Agent***
    - Collect a sample from a batch produced within a year period of the evaluation period.

RA Acceptance Framework

Recommended VDOT APL – Procedure *(Cont'd)*

- Step 2 – Evaluation of the Recycled Binder System
  - ***Recycled Binder System (VB + RAP) = <u>Virgin Binder</u> (VB, PG 64S-22 from Step 1) + <u>RAP binder</u> (equivalent of 40% RAP by total weight of mixtures)***
    - Determine necessary properties: $|G^*|/\sin\delta$ at 64ºC; PGH_c; $|G^*|\sin\delta$ at 25ºC; PGI_c; PGL_c; ΔT_c; and $J_{nr,3.2}$ at 64ºC.
- Step 3 – Dosage of Recycling Agent
  - ***RA supplier to provide an "initial" dosage (ID) that would produce a blended binder system with max PGL of "<u>-22ºC</u>".***

RA Acceptance Framework

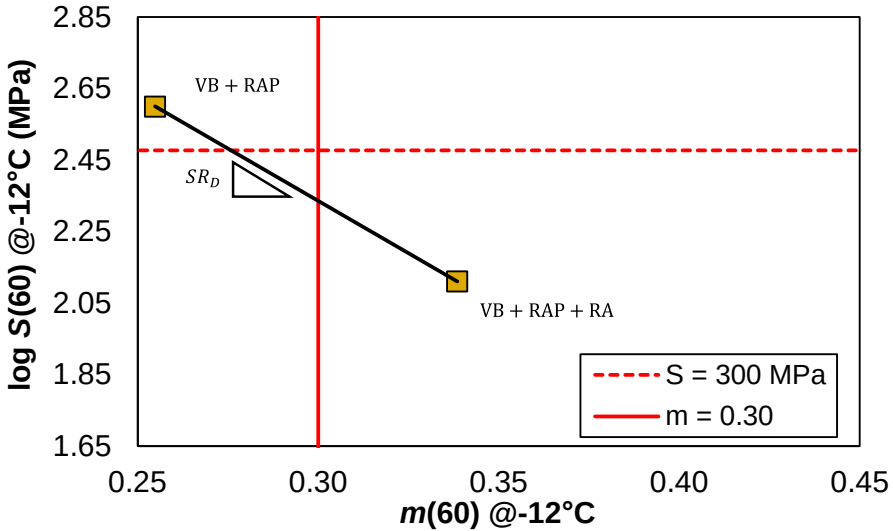
Recommended VDOT APL – Procedure *(Cont'd)*

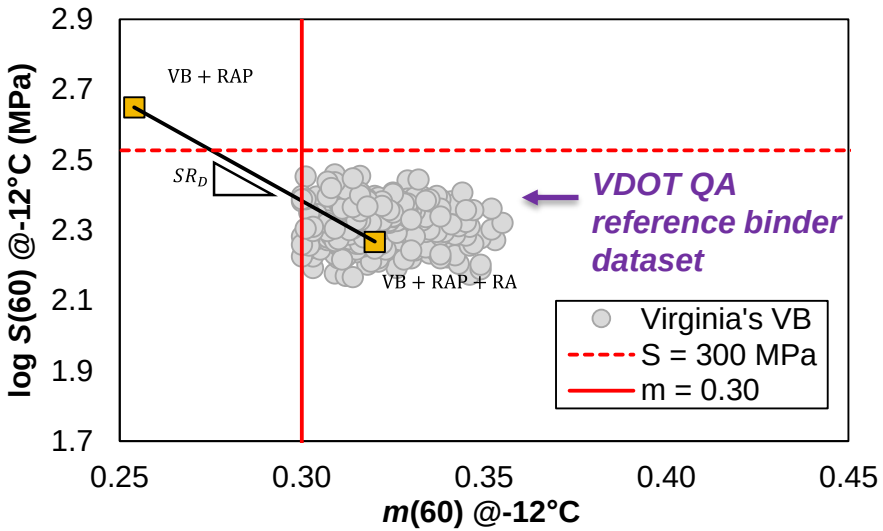
- Step 4 – Evaluation of RA-Modified Binder System
  - ***RA-Modified Binder System (VB + RAP + RA) = <u>Virgin Binder</u> (VB, PG 64S-22 from Step 1) + <u>RAP binder</u> (equivalent of 40% RAP by total weight of mixtures) + <u>RA</u> (ID dosage from Step 3)***
    - Determine necessary properties: $|G^*|/\sin\delta$ at 64ºC; PGH_c; $|G^*|\sin\delta$ at 25ºC; PGI_c; PGL_c; ΔT_c; and $J_{nr,3.2}$ at 64ºC.

RA Acceptance Framework

Recommended VDOT APL – Procedure *(Cont'd)*

- Step 5 – Low Temperature Binder Similarity Analysis





RA Acceptance Framework

Recommended VDOT APL – Procedure *(Cont'd)*

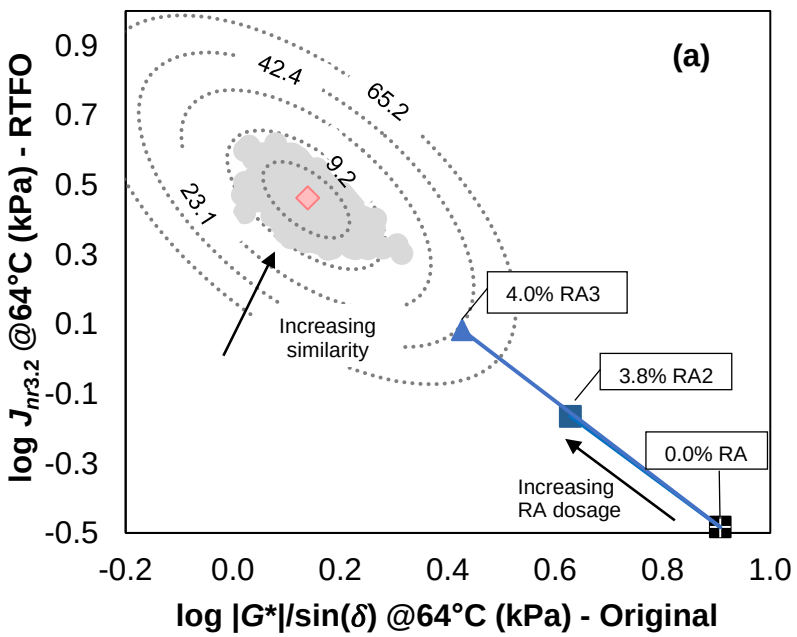
- Step 6 – Temp-Specific and Global Binder Similarity Analysis
  - ***Select a 2nd dosage: 0.5xID or 1.5xID (2nd dosage should be < 10%; ID = initial dosage selected in Step 3)***
  - ***RA-Modified Binder System (VB + RAP + RA) = Virgin Binder (VB, PG 64S-22 from Step 1) + RAP binder (equivalent of 40% RAP by total weight of mixtures) + RA (2nd dosage)***
    - Determine necessary properties: $|G^*|/\sin\delta$ at 64ºC; PGH_c; $|G^*|\sin\delta$ at 25ºC; PGI_c; PGL_c; ΔT_c; and $J_{nr,3.2}$ at 64ºC.
  - ***Perform similarity analysis using MD (distance !)***

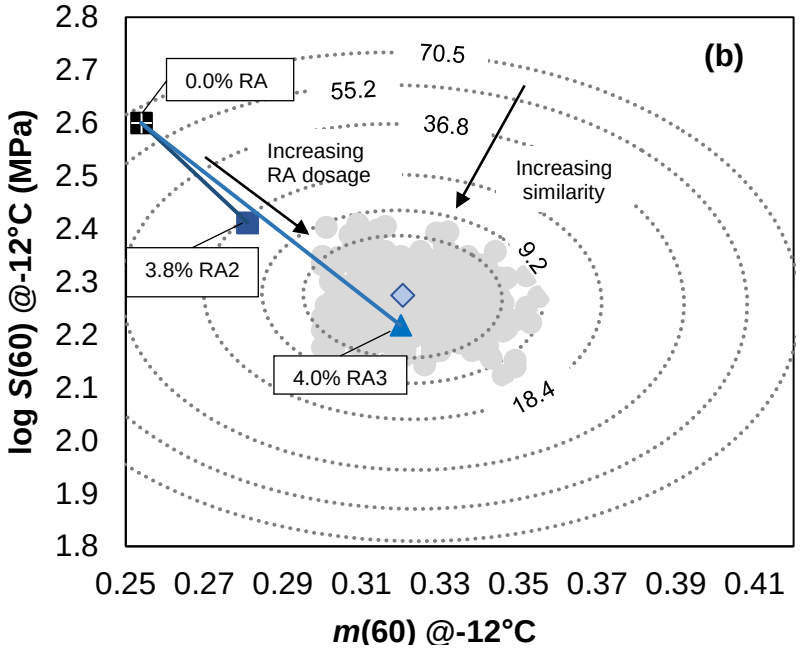
Note: Approval remains in effect for up to 3 years

(if formulation has not been altered !!!)

RA Acceptance Framework

Effect of RA Dosage on RA Similarity





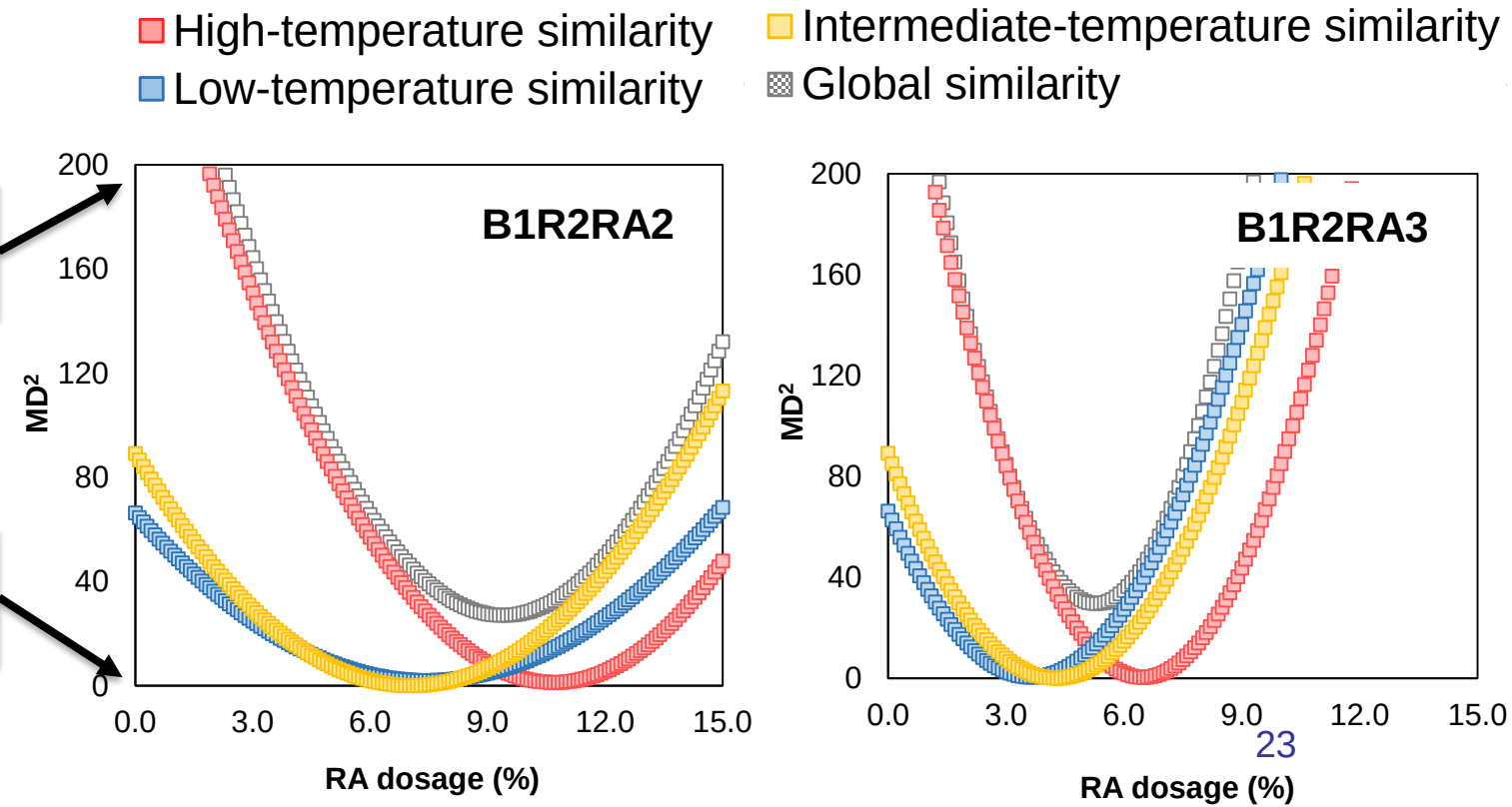
HT mean LT mean B1R2 B1R2RA3 B1R2RA2

RA Acceptance Framework

MD – Examples

Very different from benchmark

Similar to benchmark



RA Acceptance Framework

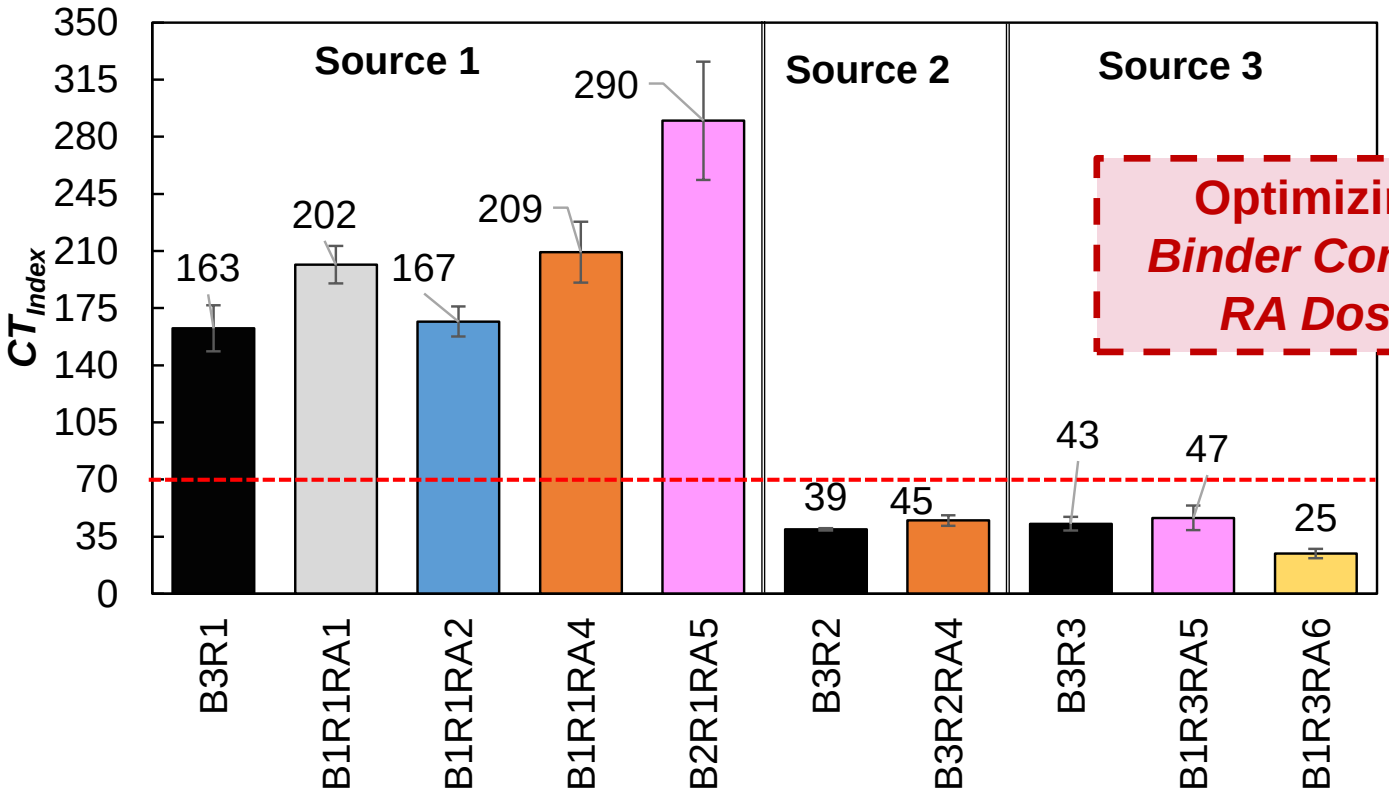
Experimental Program – **Phase II**

Binder Source	RAP Source	Name	Recycling Agents						No RA
			RA1	RA2	RA3	RA4	RA5	RA6	
Hopewell, VA **(B1)**	Salem (R1)	**B1R1**	**15.52%**	**4.29%**	5.90%	**6.25%**		5.71%	
	Richmond (R2)	**B1R2**		5.29%	5.70%	5.79%	8.49%	5.20%	
	Chesapeake (R3)	**B1R3**		3.80%	4.10%	4.50%	**8.68%**	**3.90%**	
Roanoke, VA **(B2)**	Salem (R1)	**B2R1**			4.40%		**9.31%**	4.62%	
	Richmond (R2)	**B2R2**				4.52%	8.49%		
	Chesapeake (R3)	**B2R3**	14.47%	3.52%	2.60%				
Greensboro, NC **(B3)**	Salem (R1)	**B3R1**							**0.00%**
	Richmond (R2)	**B3R2**				**1.21%**			
	Chesapeake (R3)	**B3R3**							**0.00%**

Volumetrics/Gradations; CML; APA; IDT-CT; E*; CF; SSR; + STOA vs. LTOA (3 D) vs. LTOA (1 D)

RA Acceptance Framework

Evaluated Mixtures – CT index Data



Optimizing <u>both</u>
***Binder Content* and**
***RA Dosage* !!!**

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RA Acceptance Framework 2

Framework for Design BMD Surface Mixtures with RAs

RA Acceptance Framework

Mix Design – Recommended Procedure

***Note:* Work to be completed by Contractor & RA Supplier**

- Step 1 – Selection and Evaluation of Component Materials
  - ***Virgin Binder PG 64S-22 comparable to that of production***
    - Determine necessary properties: $|G^*|/\sin\delta$ at 64ºC; PGH_c; $|G^*|\sin\delta$ at 25ºC; PGI_c; PGL_c; ΔT_c; and $J_{nr,3.2}$ at 64ºC.
  - ***RAP Material and Extracted & Recovered RAP Binder***
    - Representative sample of RAP ***comparable to that of production***
    - Perform Extraction & Recovery
    - Determine necessary properties: $|G^*|/\sin\delta$ at 64ºC; PGH_c; $|G^*|\sin\delta$ at 25ºC; PGI_c; PGL_c; and ΔT_c.
  - ***Recycling Agent***

RA Acceptance Framework

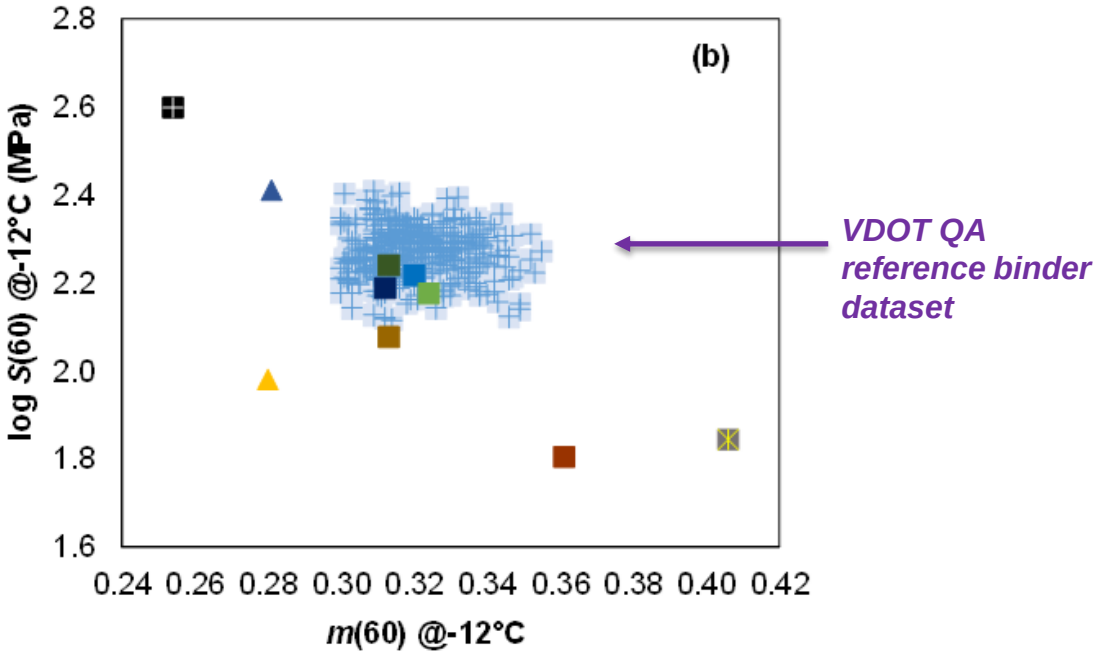
Mix Design – Recommended Procedure *(Cont'd)*

- Step 2 – Dosage of Recycling Agent
  - ***RA supplier to provide a dosage that would produce a blended binder system with max PGL of "-22ºC" (<10%).***
- Step 3 – Evaluation of RA-Modified Binder System
  - ***RA-Modified Binder System (VB + RAP + RA) = Virgin Binder (VB, PG 64S-22 from Step 1) + RAP binder (equivalent of RAP content to be used during production + RA (ID dosage from Step 2)***
    - Determine necessary properties: $|G^*|/\sin\delta$ at 64ºC; PGH_c; $|G^*|\sin\delta$ at 25ºC; PGI_c; PGL_c; ΔT_c; and $J_{nr,3.2}$ at 64ºC.

RA Acceptance Framework

Mix Design – Recommended Procedure *(Cont'd)*

- Step 4 – Low Temperature Binder Similarity Analysis



RA Acceptance Framework

Mix Design – Recommended Procedure *(Cont'd)*

- Step 5 – Design of BMD SM with RA
  - ***Follow VDOT BMD Special Provisions***
    - Aggregate gradations and Volumetric properties
    - Short-term aged properties ***(only!)***: CML<7.5%, APA rut depth < 8.0 mm and CT_{index} > 70.
  - ***New LTOA Protocol***
    - Condition loose mixtures for 1 day (24 hours) at 95ºC
    - Evaluate 1-D LTOA mixtures in terms of IDT-CT + *check for variability!*

RA Acceptance Framework

Mix Design – Recommended Procedure *(Cont'd)*

- Step 5 – Design of BMD SM with RA
  - ***CT_{index} Aging Sensitivity***

$$(CT_{index})^{1day\ \ LTOA}_{aging\ sensitivity} = \left[\frac{(CT_{index})_{STOA} - (CT_{index})_{1day\ LTOA}}{(CT_{index})_{STOA}}\right] * 100$$

    - **CT_{index} Aging Sensitivity should be < 45%.**

Note: ***if a mix design is not achieved with a PG 64S-22 and RA dosage < 10%, the producer CAN restart from Step 1 while considering a virgin binder of PG 58-28 instead of PG 64S-22.***

RA Acceptance Framework
Ongoing Efforts

- Validation of Both Frameworks
  - Three high RAP trials with RAs in Virginia: 2022(x1) and 2023(x2)
  - Develop a draft Virginia Test Method + Automated Tool
- RAP Binder Availability and Activity
  - Looking at 14 representative RAP sources in Virginia
  - RA is a major element for the activity assessment
- Field Assessment and Specifications Validation
  - All BMD sections / mixtures in general
  - Consider high RAP with RA sections
  - Accelerated Pavement Testing

RA Acceptance Framework

Acknowledgments

- Asphalt Contractors
  - Allan Myers; Colony Construction; Boxley; Superior; & Branscome
- Asphalt Binder Supplier
  - Associated Asphalt & Russel Standards
- Recycling Agents Suppliers
  - Arkema Science; Cargill; Holly Frontier; Ingevity; Safety-Kleen Oil; Sripath Technology; KAO Chemical; & Sasol.
- Research Team Staff
  - VDOT Materials Division and Districts; VTRC; & NCSU

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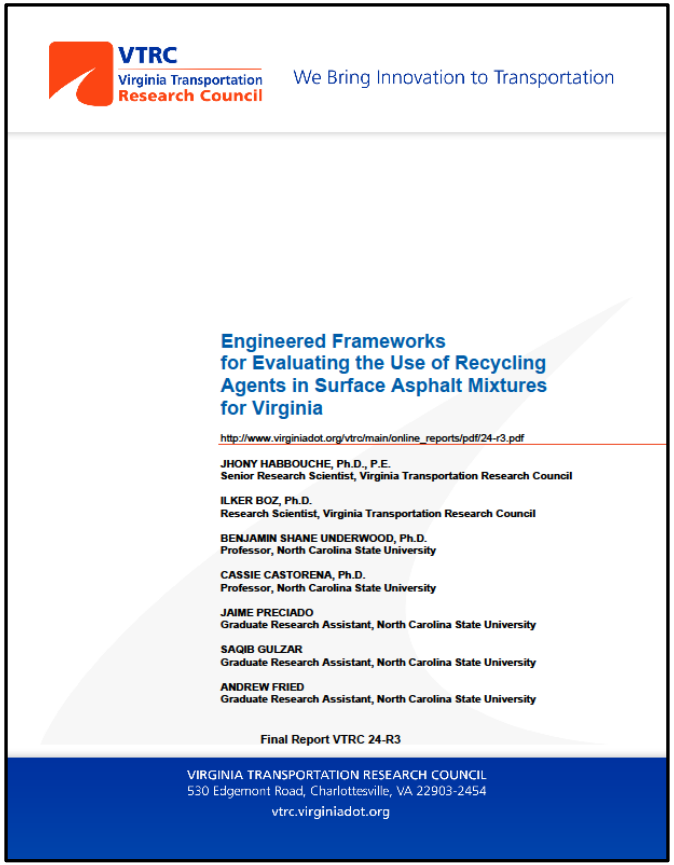
Thank You!
Questions?



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