



JACKSONVILLE, FL

HYATT REGENCY RIVERFRONT

2023 ANNUAL CONFERENCE & WORKSHOP

October 17-19



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

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Research Team



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Virginia's BMD Specifications

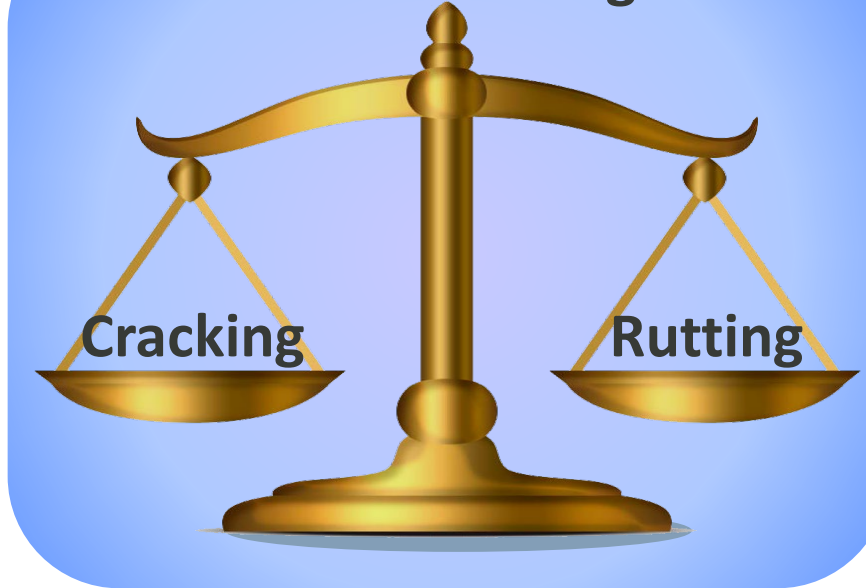
Cracking

Indirect Tensile
(IDT) Test
(ASTM D8225)

CT index ≥ 70



Balanced Design



Rutting

Asphalt Pavement
Analyzer (APA) Rut
Test (AASHTO T 340)

RD < 8.0 mm



Durability

Cantabro Mass
Loss Test
(AASHTO TP 108)

CML < 7.5 %

Moisture Damage

Tensile Strength
Ratio Test
(AASHTO T 283)

TSR > 80 %



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 Approved Product List (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.





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Experimental Program – Phase I

Laboratory Characterization of Asphalt Binders and Binder Blends

Evaluated Materials

- **Asphalt Binders**

- B1: PG64S-22 (Hopewell, VA) **(PG 68.1-22.4)**
- B2: PG64S-22 (Roanoke, VA) **(PG 67.0-24.6)**
- B2: PG58-28 (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 NCHRP 09-58 & AI)
- Aromatic Extracts (**RA2**) and Tall Oils and Fatty Acids (**RA3**)
- Triglycerides and Fatty Acids (**RA4**, **RA5**, and **RA6**) **~2 to 6%**



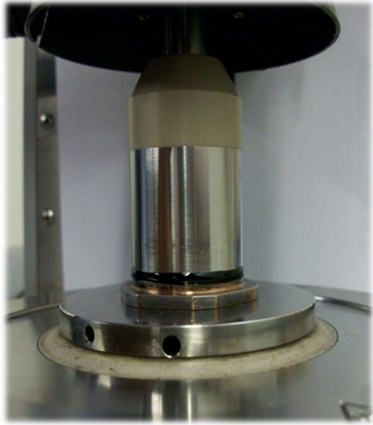
RA Dosages

Binder Source	RAP Source	Name	Recycling Agents (RA)						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

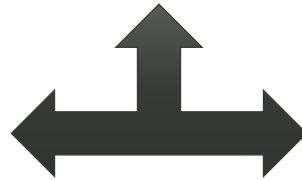


Testing Details

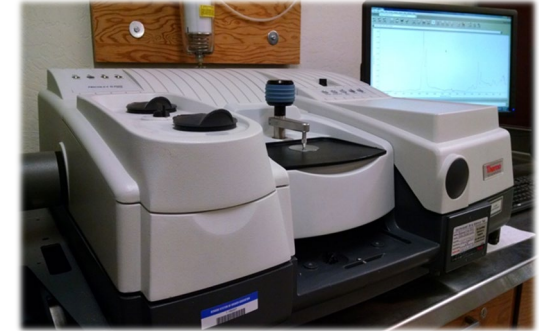


Evaluation of RAP-RA-Binder Blends at Various Aging Levels

Rheology

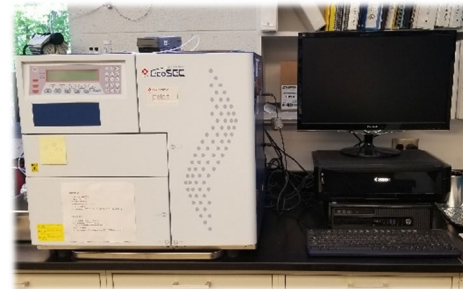
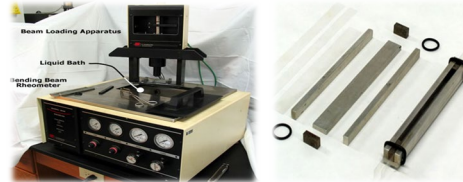


Chemistry



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

Original; RTFO; PAV20hrs; and PAV40hrs



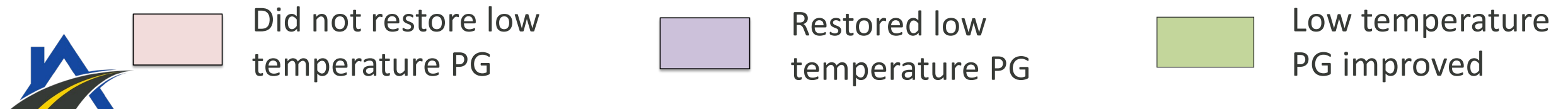
- **FTIR:** Functional Groups through absorbance quantification

Selection of fewer blends to be evaluated as Mixes

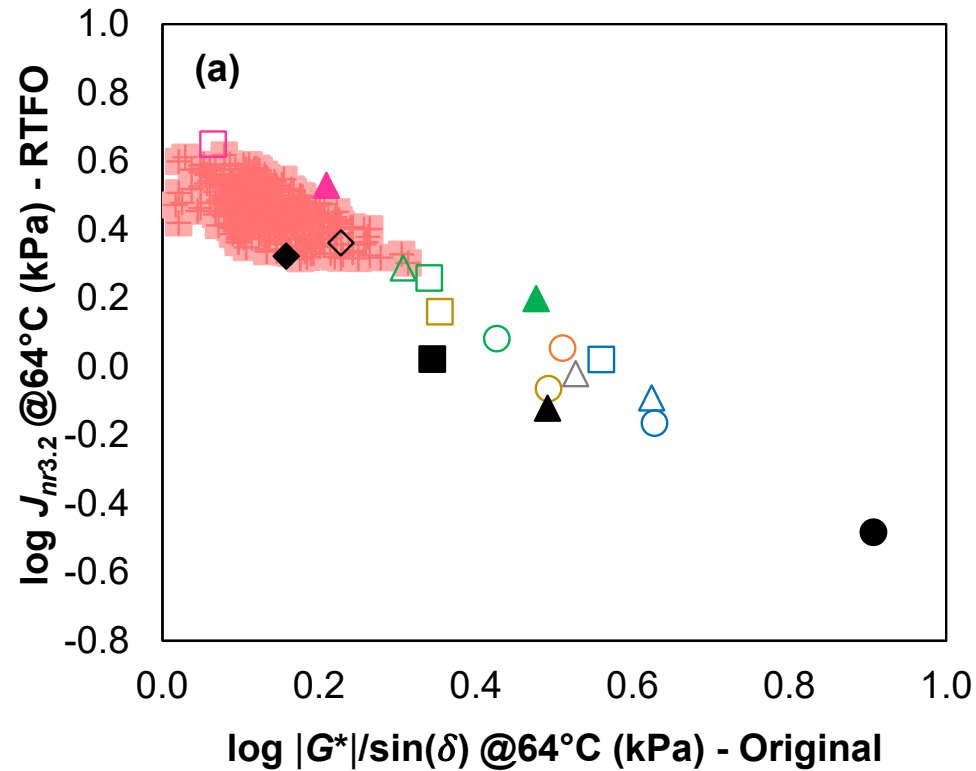


Continuous Binder Performance Grade

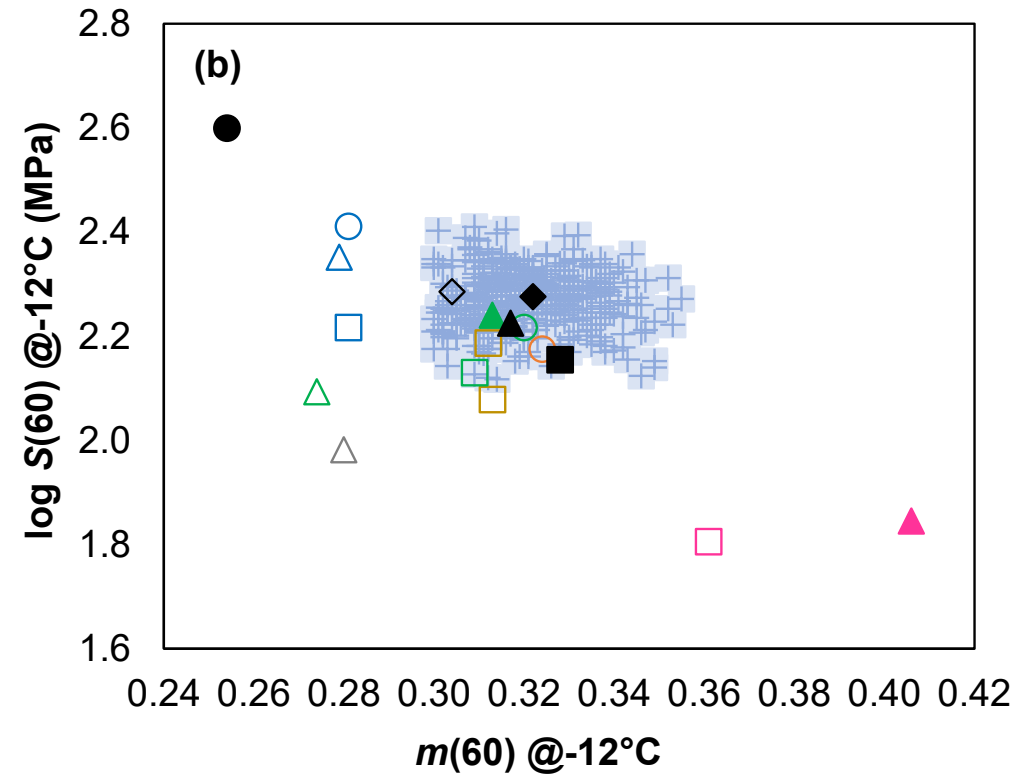
Binder Source	RAP Source	Name	No RA	RA1 Paraffinic Oil	RA2 Aromatic Extract	RA3 Other	RA4 TFA	RA5 TFA	RA6 TFA
1, PG 64-22	1	B1R1	76-16	73.6-19.5	75.3-18.6	69.6-20.7	71.5-27.5		71.1-25.5
	2	B1R2	76-16		76.2-20.2	71.8-23.7	73.0-24.1	70.2-30.2	73.3-23.3
	3	B1R3	76-16		73.2-22.9	69.6-23.3	71.9-27.9	64.5-30.9	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						



Similarity Analysis - Example



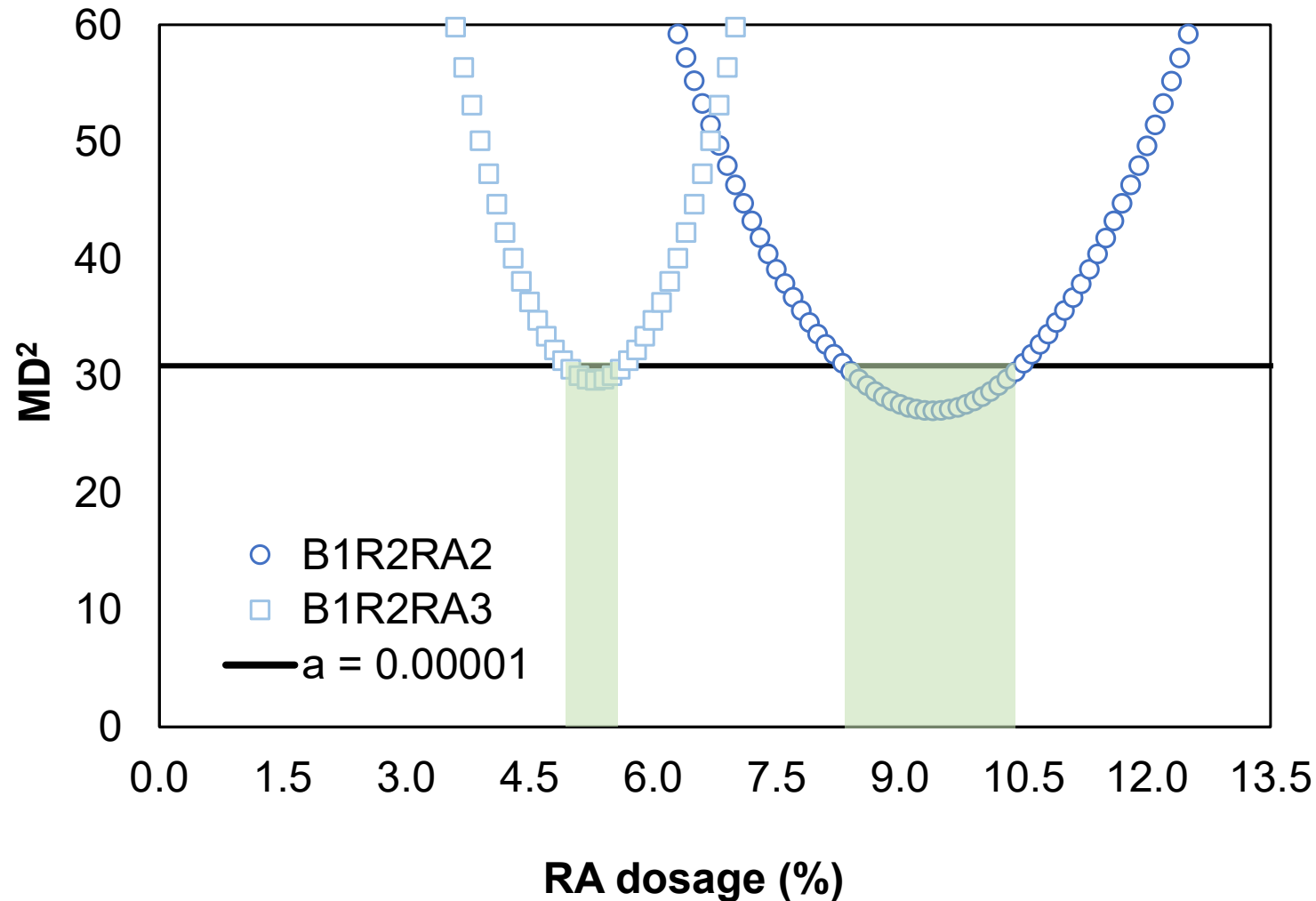
- | | |
|---------------------|-----------|
| PG 64S-22 (VA) - HT | ● B1R2 |
| PG 64S-22 (VA) - LT | ○ B1R2RA4 |
| ▲ B2R1RA5 | □ B1R3RA6 |
| ◆ B2 | △ B1R1RA2 |
| □ B1R3RA3 | ◇ B1 |



- | | |
|-----------|-----------|
| △ B1R1RA1 | ○ B1R2RA3 |
| □ B1R3RA2 | □ B1R3RA5 |
| ▲ B2R1RA3 | ○ B1R2RA6 |
| △ B1R1RA3 | ○ B1R2RA2 |
| ▲ B3R1 | ■ B3R3 |



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)

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 64°C; PGH_c ; $|G^*|\sin\delta$ at 25°C; PGI_c ; PGL_c ; ΔT_c ; and $J_{nr,3.2}$ at 64°C.
- **RAP Material and Extracted & Recovered RAP Binder**
 - Representative source of RAP will be sent by VDOT
 - Properties: **94°C < PGH < 106°C** & **-10°C < PGL < -4°C**
 - Perform Extraction & Recovery
 - Determine necessary properties: $|G^*|/\sin\delta$ at 64°C; PGH_c ; $|G^*|\sin\delta$ at 25°C; PGI_c ; PGL_c ; and ΔT_c .
- **Recycling Agent**
 - Collect a sample from a batch produced within a year period of the evaluation period.



VDOT APL – Procedure *(Cont'd)*

- **Step 2 – Evaluation of the Recycled Binder System**

- *Recycled Binder System (VB + RAP) = Virgin Binder (VB, PG 64S-22 from Step 1) + RAP binder (equivalent of 40% RAP by total weight of mixtures)*
 - Determine necessary properties: $|G^*|/\sin\delta$ at 64°C; PGHc; $|G^*|\sin\delta$ at 25°C; PGlc; PGLc; ΔT_c ; and Jnr,3.2 at 64°C.

- **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 “-22°C”.*



VDOT APL – Procedure *(Cont'd)*

- **Step 4 – Evaluation of RA-Modified Binder System**

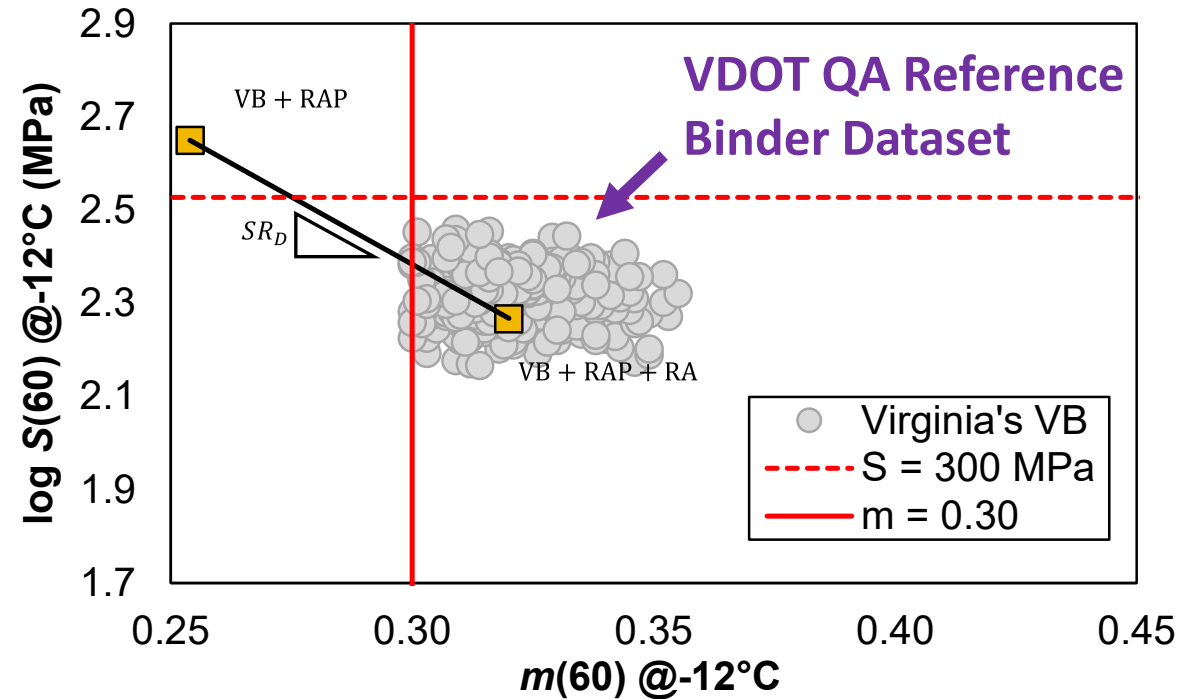
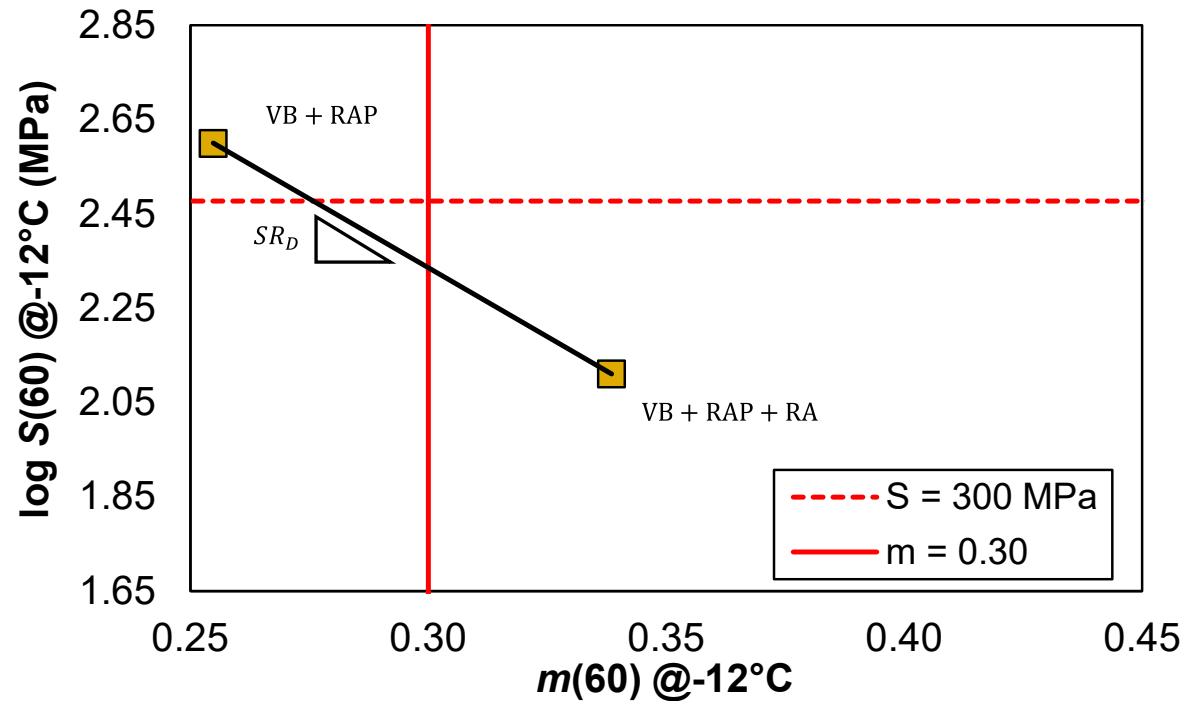
- *RA-Modified Binder System (VB + RAP + RA) = Virgin Binder (VB, PG 64S-22 from Step 1) + RAP binder (equivalent of 40% RAP by total weight of mixtures) + RA (ID dosage from Step 3)*

- Determine necessary properties: $|G^*|/\sin\delta$ at 64°C; PGHc; $|G^*|\sin\delta$ at 25°C; PGlc; PGLc; ΔT_c ; and Jnr,3.2 at 64°C.



VDOT APL - Procedure (Cont'd)

- Step 5 – Low Temperature Binder Similarity Analysis



VDOT APL – Procedure (Cont'd)

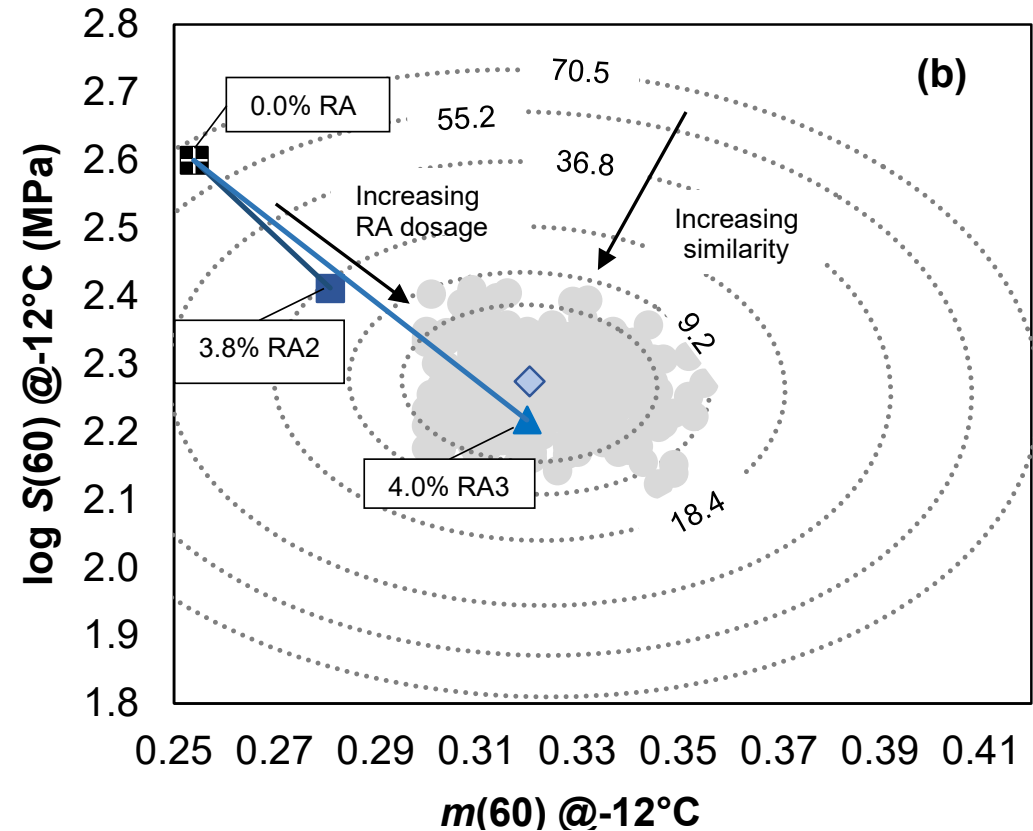
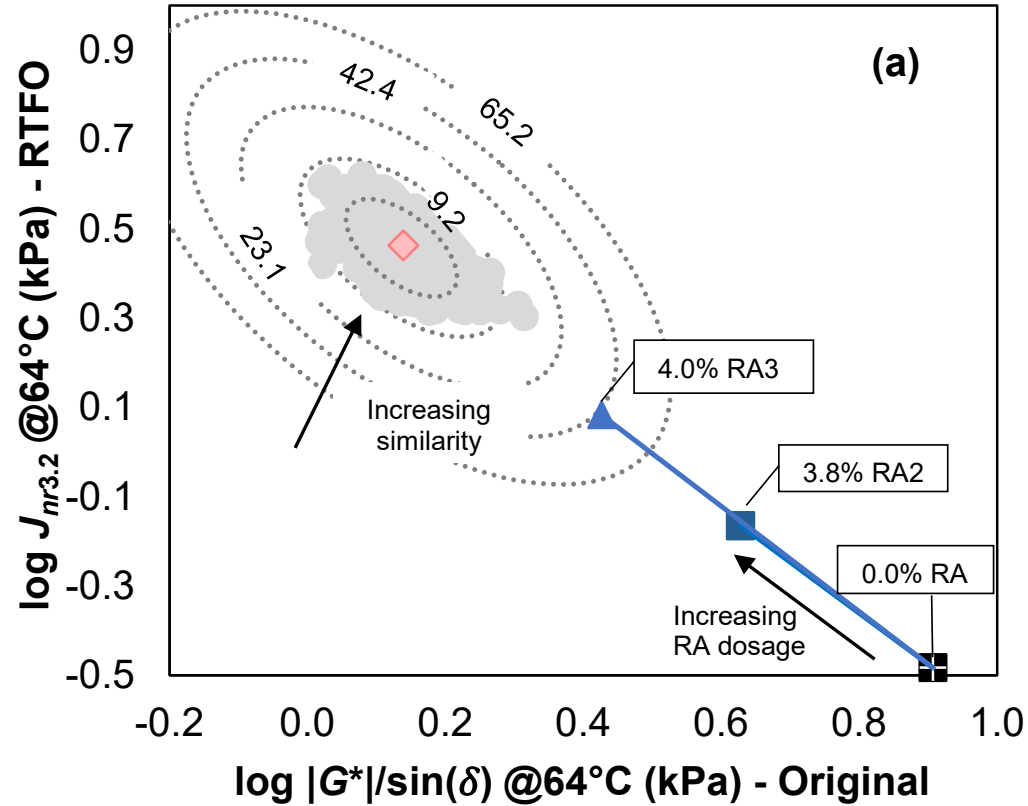
- **Step 6 – Temp-Specific and Global Binder Similarity Analysis**

- *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 64°C; PGH_c; $|G^*|\sin\delta$ at 25°C; PGI_c; PGL_c; ΔT_c ; and J_{nr,3.2} at 64°C.
- *Perform similarity analysis using **MD** (distance !)*

Note: *Approval remains in effect for up to 3 years
(if formulation has not been altered !!!)*



Effect of RA Dosage on Blend Similarity



◆ HT mean

◆ LT mean

■ B1R2

▲ B1R2RA3

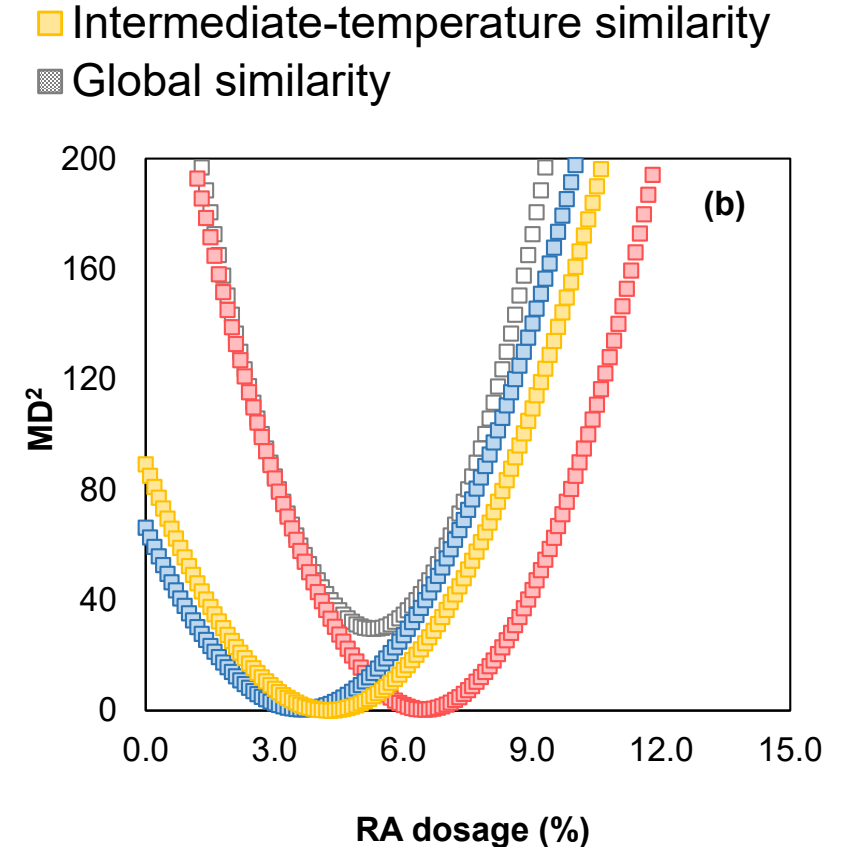
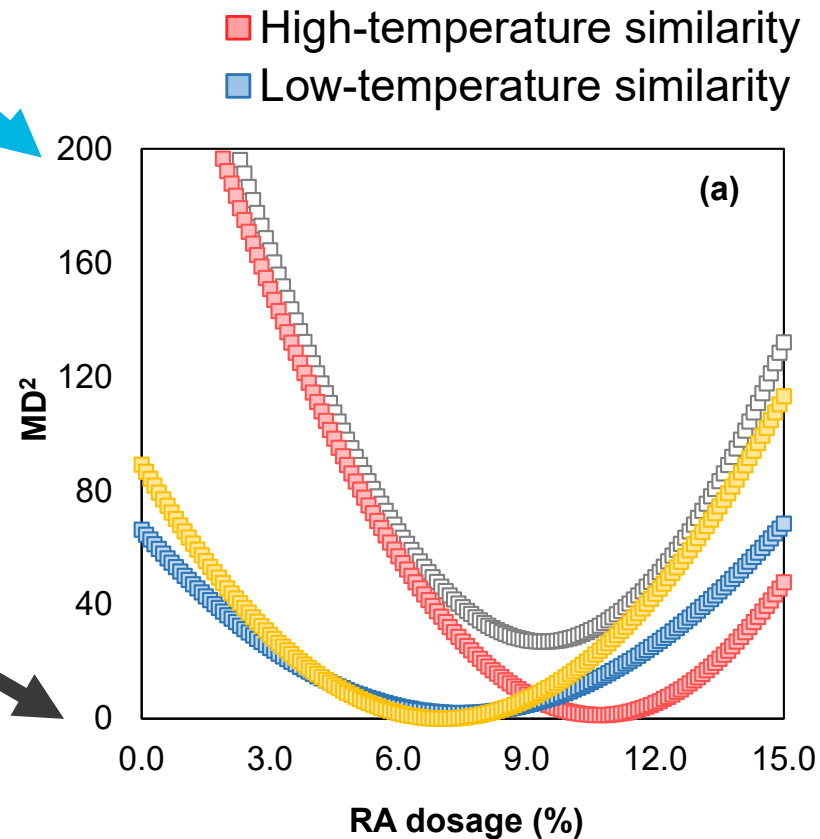
■ B1R2RA2



Similarity by means of MD - Examples

Very different
from benchmark

Similar to
benchmark



If similarity is achieved, the RA product, along with all corresponding details, can be added to the VDOT APL. This validity remains in effect for up to 3 years from the approval date, provided that the formulation of the RA product has not been altered.





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Experimental Program – Phase II

Laboratory Characterization of Asphalt Mixtures

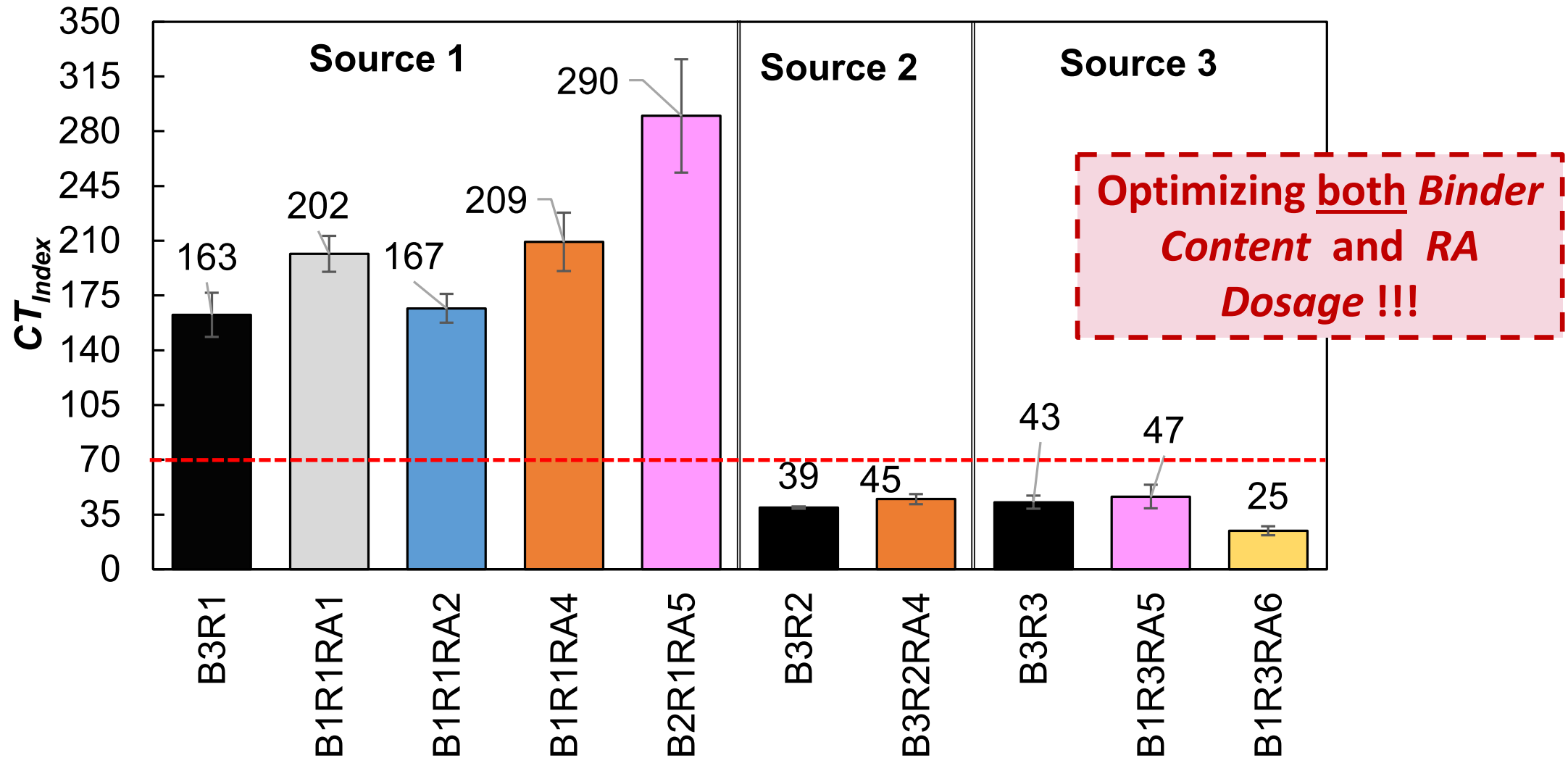
Evaluated Mixtures

Binder Source	RAP Source	Name	Recycling Agents (RA)						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							0.0%★
	Richmond (R2)	B3R2				1.21%★			★
	Chesapeake (R3)	B3R3							0.0%★



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

Evaluated Mixtures - CT Index Data





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RA Acceptance Framework 2

Framework for Design BMD Surface Mixtures with RAs

Mix Design - Procedure

Note: Work to be completed by Contractor & RA Supplier &/or an accredited third-party laboratory.

- **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 64°C; PGH_c ; $|G^*|\sin\delta$ at 25°C; PGL_c ; PGL_c ; ΔT_c ; and $J_{nr,3.2}$ at 64°C.

- **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 64°C; PGH_c ; $|G^*|\sin\delta$ at 25°C; PGL_c ; PGL_c ; and ΔT_c .

- **Recycling Agent**



Mix Design – 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 “-22°C” (<10%).*

- **Step 3 – Evaluation of RA-Modified Binder System**

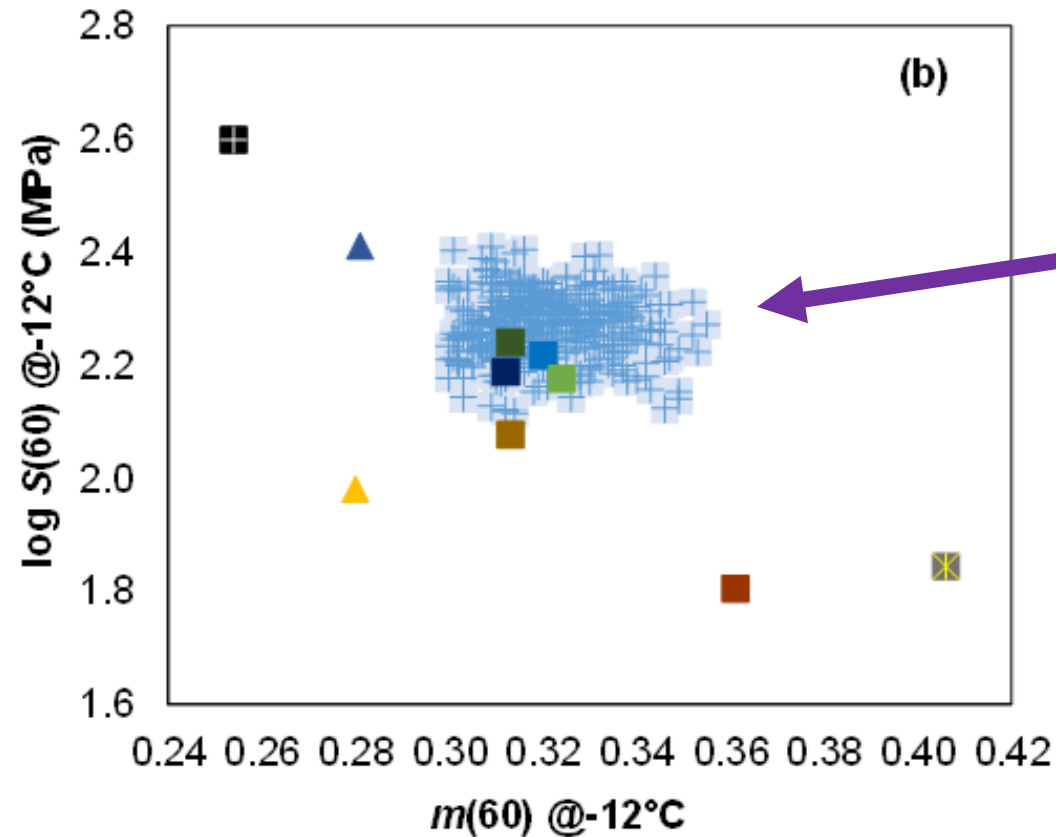
- *RA-Modified Binder System (VB + RAP + RA) = Virgin Binder (VB, PG 64S-22 from Step 1) + RAP binder (equivalent of RAP content to be used during production + RA (ID dosage from Step 2)*

- Determine necessary properties: $|G^*|/\sin\delta$ at 64°C; PGHc; $|G^*|\sin\delta$ at 25°C; PGlc; PGLc; ΔT_c ; and Jnr,3.2 at 64°C.



Mix Design - Procedure *(Cont'd)*

- Step 4 – Low Temperature Binder Similarity Analysis



VDOT QA
Reference Binder
Dataset



Mix Design – Procedure *(Cont'd)*

- **Step 5 – Design of BMD Surface Mixtures 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 95°C
 - Evaluate 1-D LTOA mixtures in terms of IDT-CT + ***check for variability!!!***



Mix Design – Procedure *(Cont'd)*

- **Step 5 – Design of BMD Surface Mixtures with RA**

- *CT index Aging Sensitivity*

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

→ 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.



On-Going 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 (e.g., excel)*

- **RAP Binder Availability and Activity**

- *Looking at 14 representative RAP sources in Virginia*
- *RA is a major element for the activity assessment*

- **Field Performance Assessment and Spec Validation**

- *All BMD sections / mixtures in general*
- *Focus on high RAP with RA sections*
- *Accelerated Pavement Testing*



Acknowledgements

- **Asphalt Contractors**

- *Allan Myers; Colony Construction; and Boxley*

- **Asphalt Binder Supplier**

- *Associated Asphalt*

- **Recycling Agents Suppliers**

- *Arkema Science; Cargill; Holly Frontier; Ingevity; Safety-Kleen Oil; and Sripath Technology.*

- **Research Team Staff**

- *VDOT Materials Division and Districts; VTRC; and NCSU*



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Thank You!



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