63rd Annual Idaho Asphalt Conference
University of Idaho, Moscow, Idaho
October 25-26, 2023

Conference Program

Wednesday, October 25, 2023	
Noon - 5:00 pm	Workshop "**Crack Seal and Hot Applied Mastic**" offered with partner CRAFCO. Separate registration is required
4:00 pm	**IAC registration *opens***
5:00 – 7:00 pm	***Icebreaker in Exhibit Hall – Sponsored by Western States Equipment / Caterpillar***
Thursday, October 26, 2023	
7:00 am	***Registration opens – Continental Breakfast in Exhibit Room***
8:00 am	***Opening Comments*** Dr. Emad Kassem, PE, Associate Professor, University of Idaho
8:15 am	***Welcome Remarks*** Dr. Gabriel Potirniche, P.E., Associate Dean of College of Engineering, University of Idaho

Morning Session

Presiding	Dave Johnson, PE The Asphalt Institute
8:30 am	***Balanced Mix Design*** Scott Quire, PE Materials Science Director E&B Paving
9:30 am	***Stone Matrix Asphalt (SMA) Mix Design*** Tim Murphy, PE Murphy Pavement Technology
10:15 am	**Break**
10:40 am	***Asphalt Mixtures with RAP and Rejuvenators*** Hussain Al Hatailah and Dr. Emad Kassem, PE University of Idaho
11:20 am	***Advanced Asphalt Binder Characterization*** Mike Anderson, PE The Asphalt Institute
Noon – 1:45 pm	**Lunch and Expo**

Afternoon Session

Presiding	John Arambarri, PE Idaho Transportation Department
1:45 pm	***Longitudinal Joint Density, State of Practice*** Dave Johnson, PE The Asphalt Institute
2:20 pm	***Asphalt Plant Production*** Jarrett Welch Quality Paving Consultants
3:00 pm	**Break**
3:15 pm	***Scrub Seal: Past, Present and Future*** Doug Olsen Idaho Asphalt Supply
4:00 pm	***Segregation: The Cardiac Arrest of Hot Mix Asphalt Pavements*** Tim Murphy, PE Murphy Pavement Technology
4:45 pm	**Adjourn**

Speakers of the 63rd Idaho Asphalt Conference, Oct. 26, 2023

From left to right: Hussain Al Hatailah, James Clark, Emad Kassem, Dave Johnson, Brett Rankin, Mike Anderson, John Arambarri, Tim Murphy, Jarrett Welch, Doug Olsen, Scott Quire, and Muhammad Zubery.

63rd Idaho Asphalt Conference – October 25-26, 2023
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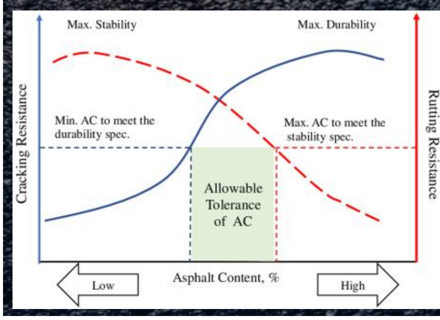
Balanced Mix Design



Presented by:
Scott Quire
Materials Science Director
E & B Paving
October 26,2023

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Balanced Mix Design

Scott Quire, P.E.
Material Science Director
E & B Paving

Scott is the Material Science Director for E & B Paving. He is a registered engineer in Kentucky.

Scott has 38 years experience in the design, control, and placement of asphalt mixtures for racing courses, highways, commercial projects, and airport pavements across the United States and around the globe.

His experience also includes testing and oversite of construction materials (aggregate, asphalt mixtures, Portland cement concrete, asphalt binders) testing, writing specifications, and training courses for construction materials testing.

Scott is an active Technical Committee Member for the Plantmix Asphalt Industry of Kentucky (PAIKY), Flexible Pavements of Ohio, Asphalt Pavement Association of Indiana (APAI), and the Missouri Asphalt Pavement Association (MAPA).

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Balanced Mix Design

Where we are coming from…

What Balanced Mix Design(BMD) is…

- **Definition**
- **Approaches**

What Balanced Mix Design can be!

- **Using the tools of BMD to explore opportunities**
- **Using the tools of BMD to answer questions**

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4

Where We are Coming From(Prescriptive Specifications)

405.02 Materials. Provide Superpave HMA composed of a combination of aggregate, approved additives, mineral filler (if required), RAP (if used), WMA additives or process (if used), and performance graded (PG) asphalt binder material. Provide a job mix formula (JMF) and a Superpave HMA pavement as specified in this section, 703, and 720.

Table 405.02-1 – Superpave Mixture Requirements

Mixture Type	SP 2 (50 gyrations)	SP 3 (75 gyrations)	SP 5 (100 gyrations)
Design ESALs [a] (millions)	< 1	1 < 10	≥ 10
Gyratory Compaction Gyrations for N_{ini} Gyrations for N_{des} Gyrations for N_{max}	 6 50 75	 7 75 115	 8 100 160
Relative Density, % G_{mm} @ N_{ini}	≤ 90.5	≤ 89.0	≤ 89.0
Relative Density, % G_{mm} @ N_{des}	96.0	96.0	96.0
Relative Density, % G_{mm} @ N_{max}	≤ 98.0	≤ 98.0	≤ 98.0
Air Voids, % P_a	4.0	4.0	4.0
Dust to Binder Ratio Range [b]	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2
Voids Filled with Asphalt (VFA) Range [c], %	65 – 78	65 -75 [d]	65 – 75 [d]

Table 405.02-2 – Grade Adjustment for RAP Usage

Level	RAP binder by weight of the total binder in the mixture, %	Binder Grade Adjustment to account for the stiffness of the asphalt binder in the RAP
1	0 to 17	No binder grade adjustment is made.
2	> 17 to 30	The selected binder grade adjustment for the binder grade specified on the plans is one grade lower for the high and the low temperatures designated. Or determine the asphalt binder grade adjustment using a blending chart. Note: See AASHTO M 323 for recommended blending chart procedure.

Table 405.02-3 identifies the typical binder grades used and the recommended binder grade adjustments for each binder grade at the RAP level described in Table 405.02-2. If the binder grade adjustment is not in Table 405.02-3, use Table 405.02-2 to determine the binder grade adjustment needed.

Table 405.02-3 – Typical Adjusted Binder Grades

	Level 2	Level 1
Binder Grade Specified in Contract	Adjusted Binder Grade	Adjusted Binder Grade
58-28	58-34	No adjustment needed
58-34	No Adjustment Needed	
64-28	58-34	
64-34	58-34	
70-28	64-34	
76-28	70-34	

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Where We are Coming From(Prescriptive Specifications)

Table 703.05-2a – Nominal Maximum Aggregate Size-Control Points (Percent Passing) and VMA Requirements PCS Control Points for Mixture Nominal Maximum Aggregate Size [b]

Sieve Size	1½ in		1 in		¾ in	
	Restricted Zone	Control Points	Restricted Zone	Control Points	Restricted Zone	Control Points
2 in	—	—	—	—	—	—
1½ in	—	90 to 100	—	100	—	—
1 in	—	90 max	—	90 to 100[a]	—	100
¾ in	—	—	—	90 max	—	90 to 100[a]
½ in	—	40 to 70[a]	—	—	—	90 max
⅜ in	—	—	—	42 to 70[a]	—	52 to 80[a]
No. 4	34.7	—	39.5	—	—	—
No. 8	23.3	15 to 41[a]	26.8	19 to 45[a]	34.6	23 to 49[a]
No. 16	15.5	—	18.1	—	23.1	—
No. 30	11.7	—	13.6	—	16.7	—
No. 50	10	—	11.4	—	13.7	—
No. 100	—	—	—	—	—	—
No. 200	—	0.0 to 6.0[a]	—	1.0 to 7.0[a]	—	2.0 to 8.0[a]
VMA	11.0		12.0		13.0	
Primary Control Sieve	⅜ in		No. 4		No. 4	
PCS Control Point (% passing)	47		40		47	

Table 703.05-2b – Nominal Maximum Aggregate Size-Control Points (Percent Passing) and VMA Requirements PCS Control Points for Mixture Nominal Maximum Aggregate Size [b]

Sieve Size	½ in		⅜ in		#4	
	Restricted Zone	Control Points	Restricted Zone	Control Points	Restricted Zone	Control Points
2 in	—	—	—	—	—	—
1½ in	—	—	—	—	—	—
1 in	—	—	—	—	—	—
¾ in	—	100	—	—	—	—
½ in	—	90 to 100[a]	—	100	—	100
⅜ in	—	90 max	—	90 to 100[a]	—	95 to 100[a]
No. 4	—	—	—	90 max	—	90 to 100
No. 8	39.1	28 to 58[a]	47.2	32 to 67[a]	—	—
No. 16	25.6	—	31.6	—	—	30 to 55[a]
No. 30	19.1	—	23.5	—	—	—
No. 50	15.5	—	18.7	—	—	—
No. 100	—	—	—	—	—	—
No. 200	—	2.0 to 10.0[a]	—	2.0 to 10.0[a]	—	6.0 to 13.0[a]
VMA	14.0		15.0		16.0	
Primary Control Sieve	No. 8		No. 8		No. 16	
PCS Control Point (% passing)	39		47		42	

(a) Denotes the sieves that will be used for mix design control points and quality analysis sieves for a Class SP 2 mix.

(b) The combined aggregate gradation will be classified as coarse graded when it passes below the primary control sieve (PCS) control point as defined in Table 703.05-2a and Table 703.05-2b. Other gradations will be classified as fine graded. This classification is based on the Contractor's job mix formula and not individual gradation tests. Coarse graded mixtures will not pass through the restricted zone.

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Where We are Coming From

Agency Perspective:

- History
  - Prescriptive specifications
    - To best insure performance
    - Best practices of the day
    - To protect against materials that don't perform
  - To control quality of materials
    - Aggregate
    - RAP
    - Asphalt Binder
  - To control how the materials are put together
  - To control how the pavement is constructed
  - "Technology of the Day" warranted prescriptive specifications
  - Little opportunity for innovation

Mix design process
Mix design volumetric criteria


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Where are We Going?

Balanced Mix Design

WHAT IS A BALANCED MIX DESIGN?

In September 2015, the FHWA Expert Task Group on Mixtures and Construction formed a Balanced Mix Design Task Force.

This group defined balanced mix design (BMD) as "asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure."

In short, BMD incorporates two or more mechanical tests such as a rutting test and a cracking test to assess how well the mixture resists common forms of distress. (Source: "Moving Towards Balanced Mix Design for Asphalt Mixtures."-NCAT)

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Where are We Going?

Performance Engineered Mix Design(PEMD)

- The Performance Engineered Mixture Design (PEMD) is a comprehensive engineering analysis and testing of asphalt mixtures on constituent materials and/or mixtures to meet or exceed the pavement design requirements and performance lifecycle.
- PEMD seeks to achieve the combination of binder, aggregate, and mixture proportions that will meet performance criteria for a diverse number of pavement distresses and a specified level of traffic, climate, and pavement.
- **The PEMD process for asphalt mixtures can be categorized as index-based PEMD or predictive PEMD**

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Where are We Going?

Balanced Mix Design (using index-based tests)

The index-based PEMD process, which is similar to what many call the Balanced Mix Design (BMD) process, is an asphalt mixture design process that uses performance tests on appropriately conditioned specimens to address primary modes of distress while taking into consideration asphalt mixture aging, traffic, climate, and location of the mixture within the pavement structure.

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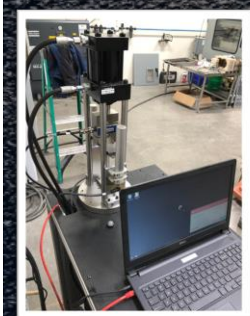
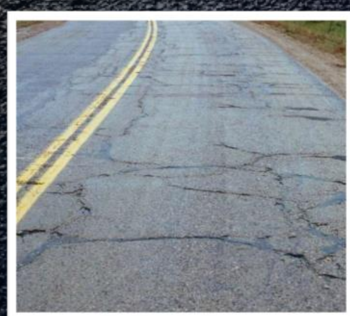
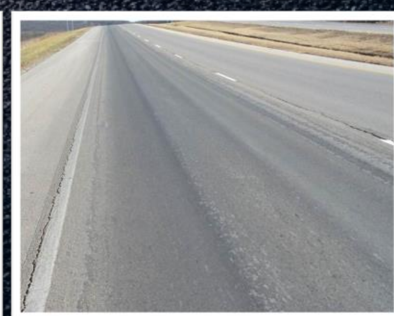
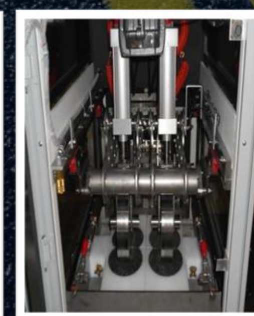
Balanced Mix Design

- The BMD process focus has been on using performance tests to balance asphalt pavement rutting performance with durability/cracking performance and, to make tradeoffs between the two distresses to maximize overall pavement performance.

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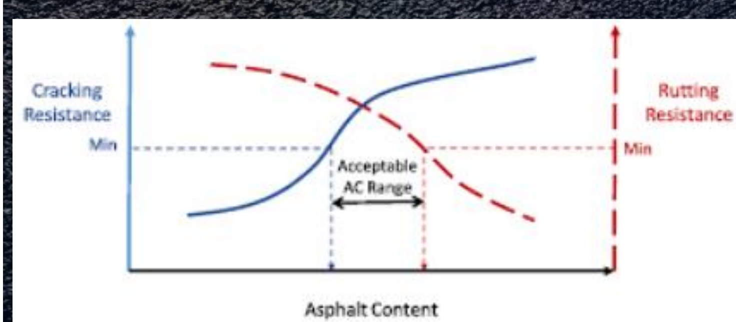
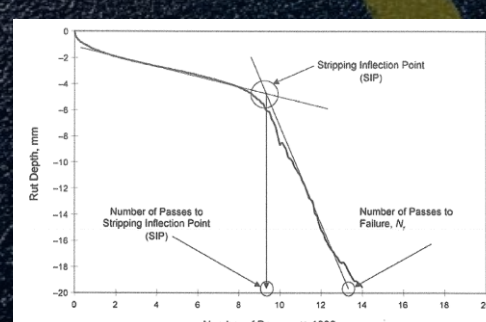
Balanced Mix Design

- Mix properties balanced between :
  - Cracking (IDEAL CT-Index Testing, ASTM D 8225)
  - Rutting (Hamburg Loaded Wheel Testing, AASHTO T324)
  - Moisture Damage Susceptibility :
    - Hamburg Loaded Wheel Test Indicated Stripping Inflection Point, AASHTO T324
    - AASHTO T283/ASTM D4867





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Balanced Mix Design

AASHTO PP 105-20:

- Design Methodology for Balanced Mix Design
- Balanced Mix Design Approaches:
  - Approach A
  - Approach B
  - Approach C
  - Approach D

Standard Practice for

Balanced Design of Asphalt Mixtures

AASHTO Designation: PP 105-20 (2022)[1]

AASHTO

First Published: 2020 Reviewed but Not Updated: 2022

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Where are We at Present?

Balanced Mix Design

- BMD Approach (AASHTO PP105): Approach A→B→C→D
  - APPROACH A (Volumetric Design w/Performance Verification) (KYTC)
  - APPROACH B (Volumetric Design with Performance Optimization)
  - APPROACH C (Performance-Modified Volumetric Mix Design)
  - APPROACH D (Performance Design)
- Agencies will initially bench mark their mixes for performance tests
  - Cracking (minimum) and Rutting (maximum) limits established
- Lab index based performance test results to be correlated w/field
- APPROACH A="SPECIFICATION CREEP"

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Balanced Mix Design

AASHTO PP 105-20:

- **Balanced Mix Design Approach A**
  - **Volumetric Design with Performance Verification**
  - **Start with volumetrically optimized mix design**
  - **Conduct rutting and cracking tests**
  - **Perform moisture damage susceptibility test**
  - **Most restrictive of the four approaches**

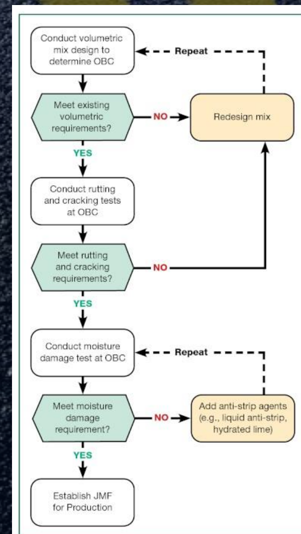

Figure 1. Graphical Illustration of the Volumetric Design with Performance Verification Approach (Approach A)

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IDAHO Transportation Dept 2023 Specs

Table 405.02-1 – Superpave Mixture Requirements

Mixture Type	SP 2 (50 gyrations)	SP 3 (75 gyrations)	SP 5 (100 gyrations)
Design ESALs (a) (millions)	< 1	1 < 10	≥ 10
Gyratory Compaction Gyrations for Nini Gyrations for Ndes Gyrations for Nmax	6 50 75	7 75 115	8 100 160
Relative Density, % Gmm @ Nini	≤ 90.5	≤ 89.0	≤ 89.0
Relative Density, % Gmm @ Ndes	96.0	96.0	96.0
Relative Density, % Gmm @ Nmax	≤ 98.0	≤ 98.0	≤ 98.0
Air Voids, % Pa	4.0	4.0	4.0
Dust Proportion Range (b)	0.6 – 1.4	0.6 – 1.4	0.6 – 1.4
Voids Filled with Asphalt (VFA) Range, % 1½" 1" ¾" ½" 3/8" #4	64 – 80 65 – 78 65 – 78 65 – 78 65 – 78 67 – 79	64 – 75 65 – 75 65 – 75 65 – 75 73 – 76 67 – 77	64 – 75 65 – 75 65 – 75 65 – 75 73 – 76 67 – 77
Rut Depth, mm (c)	≤ 10.0 mm	≤ 10.0 mm	≤ 10.0 mm
Stripping, passes (d)	12,500	15,000	15,000
Cracking Test, IDEAL-CTIndex (e)	80 (index value)	80 (index value)	80 (index value)

(a) The anticipated project traffic level expected on the design lane over a 20 year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.
(b) For No. 4 nominal maximum size mixtures, the dust proportion is 1.0 to 2.0 for SP 2 mixes and 1.5 to 2.0 for SP 3 and SP 5 mixes. For coarse graded 3/8, ½, and ¾ inch nominal maximum size mixtures, the dust proportion is 0.6 – 1.5. (Fine and coarse graded mixtures are defined in 703.05).
(c) Maximum depth after specified number of stripping passes. The Hamburg must have passing test results in the mix design.
(d) Minimum number of passes with no stripping inflection point. The Hamburg must have passing test results in the mix design.
(e) The Ideal-CT value and the associated data generated will be included in the mix design submittal; the data will only be used for information.

Table 703.05-2b – Nominal Maximum Aggregate Size-Control Points (Percent Passing) and VMA Requirements PCS Control Points for Mixture Nominal Maximum Aggregate Size (b)

Sieve Size	1/2 in		3/8 in		#4	
	Restricted Zone	Control Points	Restricted Zone	Control Points	Restricted Zone	Control Points
2 in	—	—	—	—	—	—
1 1/2 in	—	—	—	—	—	—
1 in	—	—	—	—	—	—
3/4 in	—	100	—	—	—	—
1/2 in	—	90 to 100 (a)	—	100	—	100
3/8 in	—	90 max	—	90 to 100 (a)	—	95 to 100 (a)
No. 4	—	—	—	90 max	—	90 to 100
No. 8	39.1	28 to 58 (a)	47.2	32 to 67 (a)	—	—
No. 16	25.6	—	31.6	—	—	30 to 55 (a)
No. 30	19.1	—	23.5	—	—	—
No. 50	15.5	—	18.7	—	—	—
No. 100	—	—	—	—	—	—
No. 200	—	2.0 to 10.0 (a)	—	2.0 to 10.0 (a)	—	6.0 to 13.0 (a)
VMA	14.0		15.0		16.0	
Primary Control Sieve	No. 8		No. 8		No. 16	
PCS Control Point (% passing)	39		47		42	

(a) Denotes the sieves that will be used for mix design control points and quality analysis sieves for a Class SP 2 mix.
(b) The combined aggregate gradation will be classified as coarse-graded when it passes below the primary control sieve (PCS) control point as defined in Table 703.05-2a and Table 703.05-2b. Other gradations will be classified as fine graded. This classification is based on the Contractor's job mix formula and not individual gradation tests. Coarse graded mixtures will not pass through the restricted zone.

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IDAHO Transportation Dept 2023 Specs

BMD Approach A

Table 405.02-2 – Grade Adjustment for RAP Usage

Level	RAP binder by weight of the total binder in the mixture, %	Binder Grade Adjustment to account for the stiffness of the asphalt binder in the RAP
1	0 to 17.0	No binder grade adjustment is made.
2	> 17.0 to 30.0	The selected binder grade adjustment for the binder grade specified on the plans is one grade lower for the high and the low temperatures designated. Or determine the asphalt binder grade adjustment using a blending chart. Note: See AASHTO M 323 for recommended blending chart procedure.

able 405.02-3 identifies the typical binder grades used and the recommended binder grade djustments for each binder grade at the RAP level described in Table 405.02-2. If the binder grade djustment is not in Table 405.02-3, use Table 405.02-2 to determine the binder grade adjustment eeded.

Table 405.02-3 – Typical Adjusted Binder Grades

	Level 2	Level 1
Binder Grade Specified in Contract	Adjusted Binder Grade	Adjusted Binder Grade
58-28	58-34	No adjustment needed
58-34	No Adjustment Needed	
64-28	58-34	
64-34	58-34	
70-28	64-34	
76-28	70-34	

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Where We Hope to Go?

- **EXAMPLE: Virginia DOT High RAP Project**
- **TEST MIX(w/40% RAP & PG 58-28):**
  - **4 IDEAL CT-INDEX GROUPS**
  - **Long Term Oven Aged Group @ Optimum**

IDEAL-CT at 25°C

Binder	Mix ID	Sample ID	AC (%)	Rice (Gmm)	Dry weight (g)	Weight in water (g)	SSD weight (g)	Air Voids (%)	Thickness (mm)	Diameter (mm)	P100 (kN)	L75 (mm)	m75 (kN/mm)	Work of Failure (kN.mm)	Fracture Energy (kN/mm)	IDT Strength (kPa)	FST (mm x 10^6)	CTindex	Average	Std. Dev.	COV	Spec
Optimum AC - 0.5%	0	1	5.3	2.645	2585.4	1551.8	2607.4	7.41	62.0	150.0	13.723	3.906	3.028	73.3	0.008	939.4	8.386	67.7	68	#DIV/0!	#DIV/0!	70.0
		2			2586.6	1548.0	2605.1	7.50	62.0	150.0	13.250	4.254	2.611	68.1	0.007	907.0	8.071	79.5				
		3			2585.2	1554.5	2610.6	7.46	62.0	150.0	12.587	4.148	3.244	61.6	0.007	861.6	7.681	56.4				
								#DIV/0!			0.000	0.000	#DIV/0!	0.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
								#DIV/0!			0.000	0.000	#DIV/0!	0.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
Optimum AC	0	1	5.8	2.624	2569.1	1532.7	2590.0	7.41	62.0	150.0	9.844	6.754	1.587	67.7	0.007	673.9	10.809	206.7	168	84	0.5029	70.0
		2			2568.8	1536.0	2584.8	6.67	62.0	150.0	12.738	4.900	2.466	74.9	0.008	872.0	9.240	106.7				
		3			2569.6	1533.9	2590.5	7.33	62.0	150.0	9.961	6.860	1.248	75.5	0.008	681.9	11.908	297.6				
		4			2568.9	1535.9	2587.6	6.93	62.0	150.0	11.849	4.996	2.480	66.8	0.007	811.1	8.850	96.4				
		5			2579.2	1545.8	2598.8	6.67	62.0	150.0	12.459	6.364	2.747	79.3	0.009	852.9	10.000	131.7				
Optimum AC + 0.5%	0	1	6.3	2.602	2585.2	1535.0	2598.9	6.61	62.0	150.0	10.827	6.033	1.915	73.4	0.008	741.1	10.648	165.7	179	#DIV/0!	#DIV/0!	70.0
		2			2583.9	1535.1	2599.7	6.72	62.0	150.0	11.457	6.015	1.787	85.3	0.009	784.3	11.693	205.8				
		3			2584.5	1535.8	2599.4	6.61	62.0	150.0	10.824	5.791	1.837	72.6	0.008	740.9	10.539	164.1				
								#DIV/0!			0.000	0.000	#DIV/0!	0.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
								#DIV/0!			0.000	0.000	#DIV/0!	0.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
Optimum AC LTOA	0	1	5.8	2.624	2569.2	1534.9	2589.1	7.14	62.0	150.0	13.934	4.422	3.331	74.0	0.008	953.9	8.344	70.4	83	15	0.186	70.0
		2			2568.5	1542.1	2593.9	6.95	62.0	150.0	13.460	5.650	2.954	79.8	0.009	921.4	9.315	109.4				
		3			2569.1	1533.0	2583.1	6.78	62.0	150.0	14.898	4.363	3.245	76.7	0.008	1019.9	8.084	73.9				
		4			2569.5	1533.1	2589.8	7.34	62.0	150.0	14.273	4.504	2.960	75.9	0.008	977.0	8.351	82.7				
		5			2569.3	1532.2	2585.0	7.01	62.0	150.0	13.815	4.792	3.144	72.3	0.008	945.7	8.226	79.0				

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Where We Hope to Go?

- **EXAMPLE: Virginia DOT High RAP Project**
- **TEST MIX(w/40% RAP & PG 58-28):**
  - 4 IDEAL CT-INDEX GROUPS
  - Long Term Oven Aged Group @ Optimum
  - 2 APA Groups

APA Rutting at 64°C

Binder	Mix ID	Sample ID	AC (%)	Rice (Gmm)	Dry weight (g)	Weight in water (g)	SSD weight (g)	Air Voids (%)	Thickness (mm)	Diameter (mm)	Rut Depth (mm)	Average	Std. Dev.	COV	Spec	Rut Depth Pass / Fail
Optimum AC	SM-9.5D	1	5.8	2.624	3119.9	1855.6	3137.2	7.24	75.0	150.0	5.543	4.9	0.708	14.34113697	8.0	Pass
		3			3114.2	1862.5	3141.3	7.21	75.0	150.0	5.555					
		2			3121.5	1868.6	3149.1	7.11	75.0	150.0	4.331					
		4			3122.4	1875.3	3153.2	6.90	75.0	150.0	4.315					
Optimum AC + 0.5%	SM-9.5D	1	6.3	2.602	3119.3	1857.7	3142.6	6.70	75.0	150.0	6.486	6.0	0.528	#DIV/0!	8.0	Pass
		2			3117.6	1851.5	3143.3	7.24	75.0	150.0	6.486					
		3			3118.2	1854.1	3138.2	6.67	75.0	150.0	5.571					
		4			3119.5	1857.3	3142.2	6.69	75.0	150.0	5.571					

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Where We Hope to Go?

- **EXAMPLE: Virginia DOT High RAP Project**

- **TEST MIX(w/40 % RAP and PG 58-28):**
  - 4 IDEAL CT-INDEX GROUPS
  - Long Term Oven Aged Group @ Optimum
  - 2 APA Groups
  - 2 Durability (Cantabro) Groups

Durability

Tester	Mix ID	Sample ID	AC (%)	Rice (Gmm)	Dry weight (g)	Weight in water (g)	SSD weight (g)	Air Voids (%)	Weight after bulk (g)	Weight after test (g)	Mass Loss (%)	Average	Std. Dev.	COV	Spec	Mass Loss Pass / Fail
Optimum AC	SM-9.5D	1	5.80	2.624	4976.6	3011.5	4984.7	3.90	4979.8	4742.1	4.8	4.4	0.4	10.146	7.5	Pass
		2			4976.5	3019.4	4984.3	3.49	4979.5	4785.2	3.9					
		3			4981.1	3014.0	4993.4	4.11	4986.8	4762.4	4.5					
Optimum -0.5% AC	SM-9.5D	1	5.30	2.645	4945.5	2992.0	4968.2	5.39	4965.4	4607.9	7.2	6.5	0.7	10.729	7.5	Pass
		2			4957.2	3000.1	4971.3	4.93	4966.9	4678.7	5.8					
		3			4954.4	2991.2	4971.2	5.40	4967.1	4639.3	6.6					

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Where We Hope to Go?

- **EXAMPLE: Virginia DOT High RAP Project**
- **Control MIX(w/25 % RAP and PG 64-22):**
  - **2 IDEAL CT-INDEX GROUPS**
  - **Long Term Oven Aged Group @ Optimum**

Control Mix

Binder	Mix ID	Sample ID	AC (%)	Rice (Gmm)	Dry weight (g)	Weight in water (g)	SSD weight (g)	Air Voids (%)	Thickness (mm)	Diameter (mm)	P100 (kN)	L75 (mm)	m75 (kN/mm)	Work of Failure (kN.mm)	Fracture Energy (kN/mm)	IDT Strength (kPa)	FST (mm x 10^6)	CTindex	Average	Std. Dev.	COV	Spec
Optimum AC LTOA	0	1	5.8	2.607	2584.1	1542.3	2605.0	6.73	62.0	150.0	13.630	4.782	2.436	77.8	0.008	933.0	8.971	109.5	99	12	0.1207	70.0
		2			2583.7	1542.0	2605.4	6.81	62.0	150.0	14.805	4.525	3.042	77.4	0.008	1013.4	8.213	82.5				
		3			2584.3	1540.6	2602.9	6.69	62.0	150.0	14.888	4.664	2.719	86.4	0.009	1019.2	9.111	106.2				
		4			2585.0	1538.1	2600.2	6.64	62.0	150.0	14.220	4.560	2.825	77.8	0.008	973.4	8.593	90.0				
		5			2584.8	1541.3	2602.0	6.53	62.0	150.0	14.196	4.663	2.507	79.9	0.009	971.7	8.838	106.5				
Optimum AC STOA	0	1	5.8	2.607	2586.7	1539.4	2602.5	6.67	62.0	150.0	13.867	6.521	3.656	104.7	0.011	949.2	11.865	133.9	122	20	0.1665	70.0
		2			2583.8	1539.6	2599.8	6.52	62.0	150.0	15.160	5.547	3.456	104.1	0.011	1037.8	10.790	119.8				
		3			2586.8	1540.3	2604.5	6.76	62.0	150.0	17.139	5.547	4.665	107.7	0.012	1173.2	9.873	91.8				
		4			2587.0	1540.5	2603.4	6.64	62.0	150.0	16.435	6.342	3.547	114.2	0.012	1125.0	10.912	146.3				
		5			2582.6	1540.0	5.8	164.57	62.0	150.0	15.746	5.740	3.567	103.3	0.011	1077.9	10.310	119.2				

TOTAL:
- Volumetric Mix Design (Optimum @ 4.0 % Air Voids, VMA>16%)
- IDEAL CT GROUPS: 6 (4 @ Standard Aging, 2 @ LTOA)
- APA (Rut) Groups: 2
- Durability Groups: 2
- **BOTTOMLINE: A LOT OF SPECIMENS!**

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Balanced Mix Design

AASHTO PP 105-20:

- **Balanced Mix Design Approach B:**
  - **Volumetric Design with Performance Optimization**
  - **Start with volumetrically optimized mix design**
    - **Select Preliminary Optimum Binder Content (OBC)**
  - **Conduct rutting and cracking tests at:**
    - **Preliminary Optimum Binder Content**
    - **Additional Binder Contents**
    - **If rutting/cracking satisfied, set final OBC**
  - **Perform moisture damage susceptibility test**

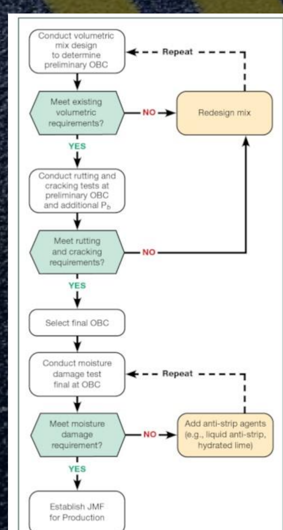

Figure 2. Graphical Illustration of the Volumetric Design with Performance Optimization Approach (Approach B)

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Balanced Mix Design

AASHTO PP 105-20:

- Balanced Mix Design Approach C:
  - Performance-Modified Volumetric Mix Design
  - Start with volumetric mix design method
    - Establish initial component material properties
    - Proportions
    - Binder content
  - Performance testing results used to adjust initial values
  - Performance test criteria satisfied
  - May not be required to meet all volumetric criteria

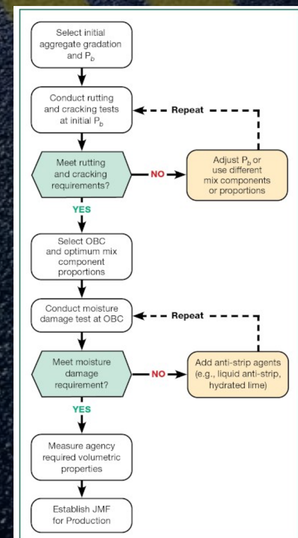

Figure 3. Graphical Illustration of the Performance-Modified Volumetric Design Approach (Approach C)

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Balanced Mix Design

AASHTO PP 105-20:

- Balanced Mix Design Approach D:
  - Performance Mix Design
    - Initial mixture component and proportions
      - Based on performance tests
      - Little or no requirements for volumetric properties
    - Minimum requirements may be set for:
      - Asphalt binder
      - Aggregate properties
    - Mixture volumetric properties may be checked
    - Lest restrictive of the approaches

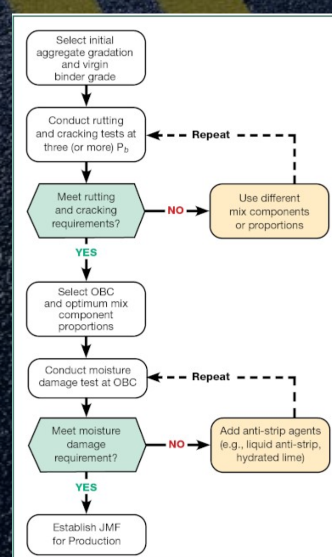

Figure 4. Graphical Illustration of the Performance Design Approach (Approach D)

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Approach D Example

State of Tennessee

Department of Transportation

Draft Specification for Performance Based Mix Design of Asphalt Mixtures

A. Materials

Asphalt Cement:

Provide at a minimum a PG 64-22. PG 70-22 and PG 76-22 may also be utilized in the mix design. All grades of asphalt shall meet **904.01** and be supplied by a TDOT approved Asphalt Cement Producer.

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Approach D Example

State of Tennessee

Department of Transportation

Draft Specification for Performance Based Mix Design of Asphalt Mixtures

Aggregate:

Gradation Requirements: minimum 90% passing the nominal maximum size specified

<1.25" thick mat; NMAS = 3/8"

1.25-1.50" thick mat; NMAS = ½"

>1.5" thick mat; NMAS = ¾"

Mix to be used as a riding surface shall contain a minimum 75% of a surface approved aggregate per **903.24** as calculated by weight of the combined aggregate. For the purpose of this calculation any RAP utilized may be assumed to contain 75% surface approved aggregate.

If gravel is used a minimum of 70% of the gravel must have at least 2 crushed faces by count.

If slag is used a maximum 20% of the slag stockpile may be glassy particles by weight.

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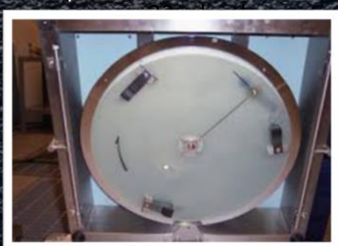
Approach D Example

Coming: Dynamic Friction Testing:

Dynamic Friction Tester



3 wheel polishing machine

Slab Compactor

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Approach D Example

State of Tennessee

Department of Transportation

Draft Specification for Performance Based Mix Design of Asphalt Mixtures

RAP:

In surface mix: no more that 50% by wt of aggregate

Base/Binder mix: no more than 65% by wt of aggregate

Antistrip Additive shall be used in at least 0.3% by weight of asphalt cement.

Other Additives: the use of additives such as rejuvenators, fibers, crumb rubber, etc; are permitted as long as the dosage of the proposed design can be replicated in a controlled manner at the asphalt plant. The Department reserves the right to deny the use of any aggregate at its discretion for reasons such but not limited to reducing the potential recyclability of the mix, or containing potentially hazardous waste.

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Approach D Example

State of Tennessee

Department of Transportation

Draft Specification for Performance Based Mix Design of Asphalt Mixtures

B. Performance Specifications:

Design mixes to comply with the table below. The Department will test mixes on the following criteria for mix design approval.

Road Classification	Rutting Depth per Hamburg Wheel Tracking Test (AASHTO T324) at 50C (min passes to 12.5mm rutting)	Stripping Inflection Point at 50C per Hamburg Wheel Tracking Test (AASHTO T324) (min. passes that SIP occurred)	CT Index per IDEAL CT (ASTM D8225) (Mixture to be aged as loose mix for 4 hours in a forced draft oven at 135C)
State Routes (not controlled access) 10,000 ADT max	10,000	No Inflection Point Allowed	50
State Routes (not controlled access) 10,000+ ADT	15,000	10,000	75
Interstates and Controlled Access State Routes	20,000	10,000	100

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Approach D Example

State of Tennessee

Department of Transportation

Draft Specification for Performance Based Mix Design of Asphalt Mixtures

C. Job Mix Formula:

Once design gradation, additives and optimal AC are determined establish a Job Mix Formula (JMF). The JMF shall provide the following information:

1. Combined aggregate gradation for the following sieves sizes: ¾", ½", 3/8", #4, #8, #30, #50, #100, #200
2. The source and gradation of all aggregate/RAP stockpiles
3. Optimum AC content
4. Grade of Asphalt, Producer and Terminal Location
5. Identity and dosage rate of any additive material utilized
6. Brand, Product, and dosage rate of Antistrip additive
7. Theoretical Maximum Specific Gravity of the Mixture (Gmm)
8. Lab Compaction Temperature of the Mix
9. VTM at 75 blows per side with a rotating/slanted foot Marshall Hammer.
10. For surface mixes establish a Loss on Ignition Percentage of each surface approved virgin aggregate stockpile

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Approach D Example

D. Submittal

Provide individual samples of each stockpile aggregate, binder, and all additives to the Department for replicating the design and approval testing. Submit Job Mix Formula and Materials to the HQ Laboratory a minimum of one month prior to paving.

E. Quality Control

Daily verify the mixture is within the following ranges. Stop work and correct the mix before continuing work if material test outside of the identified ranges.

(option 1 Volumetric):

1. AC% and Gradations: within the tolerance for 0.95 pay factor for a single test per Table 407.20-2.
2. Gmm within 0.025 of the established JMF value.
3. VTM within 1% of the JMF value at the established compaction temperature.

(option 2 Performance):

1. AC% and Gradations: within the tolerance for 0.95 pay factor for a single test per Table 407.20-2.
2. Gmm within 0.025 of the established JMF value.
3. CT-index within 10 points of Design. To be ran by the IDEAL-CT test method on 6" gyratory compacted specimens from loose plant mix, without further aging.
4. (Some yet undefined) IDEAL-RT or Hot Indirect Tensile Strength value

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Performance Testing Concerns or Thoughts

HAMBURG TESTING CONCERNS:

- **Can satisfy IDEAL CT Index but having difficulty passing Hamburg criteria**
- **Length of time for testing**
  - **Surrogate Tests**
    - **HTIDT**
    - **IDEAL-RT**

Specimen Fabrication, Cooling , Gmb Determination: **40 minutes**

Specimen cuts, putting in molds: **30 minutes**

Temperature conditioning of specimens: **45 minutes**

Machine Run Time:

- 20,000 passes(@52 passes/minute)taking **6.4** hours run time (TOTAL TIME=**8.3** hrs)
- 15,000 passes taking 4.8 hours run time (TOTAL TIME=6.7 hrs.)
- 10,000 passes taking 3.2 hours run time (TOTAL TIME=5.1 hrs.)
- 7,500 passes taking 2.4 hours run time (TOTAL TIME=4.3 hrs)

- With the time elapsed to accomplish Hamburg Testing, is there a need for a test that will yield (at least interim) test results for a confidence check?

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What Balanced Mix Design Can Be

Using the tools of BMD to explore opportunities

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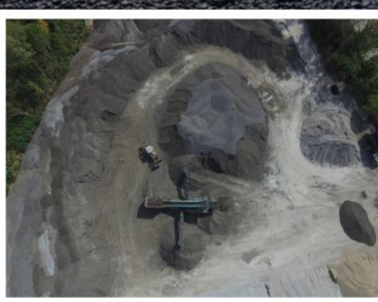
What Balanced Mix Design Can Be

Using the tools of BMD to explore:

- **Increase use of RAP**
- **Rap utilization and impact on EPD's**
- **Impact of binder source and grade on performance tests**
- **Concerns**



An Environmental Product Declaration for Asphalt Mixtures

TABLE 3. ENVIRONMENTAL IMPACT SUMMARY TABLE

IMPACT CATEGORY	POTENTIAL IMPACT PER METRIC TONNE ASPHALT MIXTURE (PER TON ASPHALT MIXTURE)
Global warming potential (GWP-100)	*230.86 (209.44) kg CO2 Equiv.*
Ozone depletion potential (ODP)	*9.15e-07 (8.30e-07) kg CFC-11 Equiv.*
Eutrophication potential (EP)	*3.06e-02 (2.78e-02) kg N Equiv.*
Acidification potential (AP)	*6.76e-01 (6.13e-01) kg SO2 Equiv*
Photochemical ozone creation potential (POCP)	*10.61 (9.63) kg O3 Equiv.*

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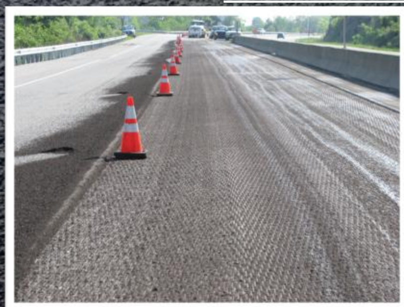
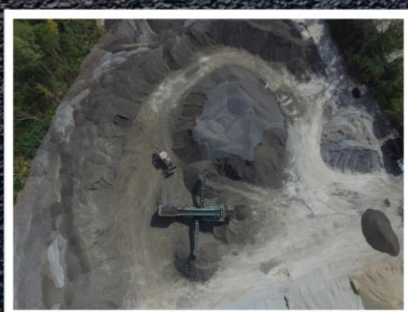
RAP DESIGN CONSIDERATIONS





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What Balanced Mix Design Can Be

Increase use of RAP and concerns:

- **Agencies have concerns of negative impacts on long term mixture performance**
  - **Increased potential of cracking**
  - **If using rejuvenator what is the long term benefit**
- **RAP binder availability**

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DESIGN CONSIDERATIONS WHEN USING RAP IN ASPHALT MIXTURES

- RAP is comprised of mineral aggregate and residual asphalt binder
- **Responsible utilization of RAP** in production of asphalt mixtures warrants the consideration of several key RAP material properties:
  - Residual binder content of RAP
  - Asphalt binder grading of residual binder in RAP
  - Characterization of the properties of the mineral aggregate portion of RAP



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DESIGN CONSIDERATIONS WHEN USING RAP IN ASPHALT MIXTURES

- Responsible utilization of RAP in production of asphalt mixtures warrants the consideration of several key issues relative to:
  - As RAP percentage increases, the effect of the RAP binder influence increases and brings the need to address the increasingly stiff resultant combined binder
  - As RAP percentage increases, the influence of the RAP mineral aggregate increases and the effect on the consensus aggregate properties


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RAP Binder Grade Considerations

BOTTOMLINE:

- RAP Binder/Factors
- RAP Binder Availability (100 %, 75 %, 60 %,??)
- "Black Rock" Concept
- RAP Binder Grading
  - (PG 88-16, PG 94-10, PG 106-4)
  - Do we continue to recycle the recycle?
    - Japanese specification <20 pen=LANDFILL Material
  - MSCR % Recovery + 50 %
    - The elastic response didn't go away?
    - Effect on performance tests
- RAS Binder Grading
  - (PG 180+??)

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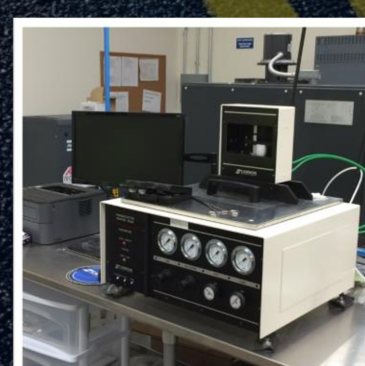
DESIGN CONSIDERATIONS WHEN USING ELEVATED RAP

- RAP Analysis (Important to accurately determine the RAP characteristics):
  - Recovered RAP binder should be graded:
    - AASHTO M320 (Standard Spec for Performance-Graded Asphalt Binder)
    - AASHTO M332 (Standard Spec for Performance-Graded Binder Using Multiple Stress Creep Recovery (MSCR) Test



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Binder Grade Considerations

EXTRACTED, RECOVERED RAP BINDER GRADING:

EXAMPLE: PG 88-16/PG 58-28 Blend Chart

RAP Binder Content, %	High Temp Continuous Grade	Intermedite Temp Continuous Grade	Low Temperature Continuous Grade
0	59.0	13.7	-31.4
2	59.7	14.1	-31.1
4	60.4	14.4	-30.8
6	61.0	14.8	-30.5
8	61.7	15.2	-30.2
10	62.4	15.5	-30.0
12	63.1	15.9	-29.7
14	63.7	16.2	-29.4
16	64.4	16.6	-29.1
18	65.1	17.0	-28.8
20	65.8	17.3	-28.5
22	66.4	17.7	-28.2
24	67.1	18.1	-27.9
26	67.8	18.4	-27.7
28	68.5	18.8	-27.4
30	69.1	19.2	-27.1
32	69.8	19.5	-26.8
34	70.5	19.9	-26.5
36	71.2	20.3	-26.2
38	71.8	20.6	-25.9
40	72.5	21.0	-25.6
42	73.2	21.3	-25.4
44	73.9	21.7	-25.1
46	74.5	22.1	-24.8
48	75.2	22.4	-24.5
50	75.9	22.8	-24.2
55	77.6	23.7	-23.5
60	79.3	24.6	-22.8
65	81.0	25.5	-22.0
70	82.7	26.4	-21.3
75	84.4	27.4	-20.6
80	86.0	28.3	-19.9
85	87.7	29.2	-19.2
90	89.4	30.1	-18.4
95	91.1	31.0	-17.7
100	92.8	31.9	-17.0

PG 58S-28/PG 58-28

High Temp Continuous Grade	Intermedite Temp Continuous Grade	Low Temperature Continuous Grade
59.0	13.7	-31.4

SPECIFIED GRADE	Virgin Binder	Minimum RAP Bin Replacement %	Maximum RAP Binder Replacement %
PG 58S-28/PG 58-28		24	61
		Based on Low Temperature Continuous Grade	Based on Intermediate Temperature Continuous Grade

RAP TESTING RESULTS

The purpose of this testing is to develop blending charts for high RAP mixtures produced at our plants

Results of Recovered RAP Binder Testing, AASHTO M323 Appendix

Condition	Test	Temperature,°C	Results
Recovered	Binder Content, % AASHTO T164	NA	5.5
	G*/sinδ, kPa AASHTO T315	94 100	1.84 0.94
Rolling Thin Film Residue	G*/sinδ, kPa AASHTO T315	88 94	3.59 1.853
Pressure Aging Vessel Residue	G*sinδ, kPa AASHTO T315	31 34	5456 3982
	Creep Stiffness(Mpa)/ Slope(m value) AASHTO T313	-16 -22	148/0.308 343/0.265
Grade	AASHTO M320	PG 88-16	
Continuous Grade		PG 92.8(31.9)-17.0	

Linear blending charts for high, intermediate, and low temperature properties are needed in accordance with the Appendix of AASHTO M323 for each AC supplier and each suppliers location.

VALUES USED FOR SELECTION(per AASHTO M320, Table 1)

Property	Temp(°C) determined	Property Limits
High DSR	99.6	(for G*/sin°δ=1.00 min.)
RTFO DSR	92.8	(for G*/sin°δ=2.20 min.)
Intermediate DSR	31.9	(for G*sinδ=5000 max.)
Low Temp m-value	-17.0	(for m value-0.300)
Creep Stiffness	-20.7	(for creep stiffness=300)

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DESIGN CONSIDERATIONS WHEN USING RAP IN ASPHALT MIXTURES

- Responsible utilization of RAP in production of asphalt mixtures requires that careful consideration be given to:
  - Percent of RAP desired in asphalt mix production (10%>20%>30%>40%>…)
  - Capability of asphalt plant to incorporate targeted RAP %

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DESIGN CONSIDERATIONS WHEN USING RAP IN ASPHALT MIXTURES

Taking the opportunity to use performance testing to innovate

- **HIGH RAP:**
- **Ammann Plant @ Columbus, OH**
- **Capable of very high RAP %'s :**
  - **60 % RAP Surface**
  - **70% RAP Base**
- **Capable of 100 % cold central plant mix**
- **Started designs in 2018 with volumetrics and continuous binder grading as principal controls**
- **Started 2019 with performance testing, validating volumetrics and continuous binder grading**

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DESIGN CONSIDERATIONS WHEN USING RAP IN ASPHALT MIXTURES

DATE:	5/28/2019	
PROJECT NAME:	60 % RAP w/REJUVENATOR and PG 58-28 vs 25 % RAP w/PG 64-22	
MIX TYPE:	9.5mm Surface	
	Mix A (50 % Binder Replacement)	Mix B (21 % Binder Replaceent)
MIXTURE COMBINATION TEST PROPERTY	60 % RAP w/0.10 % (wt. of mix) REJUVENATOR and PG 58-28	25 % RAP w/ PG 64-22
IDEAL CT-INDEX	126.3	108.2
Disk-Shaped Compact Tension (DCT), Fracture Energy (J/m^2)	**389.7** (@ -12 C)	**362.3** (@ -12 C)
Hamburg Loaded Wheel Rut Depth (mm):	3.4 mm @ 10,000 cycles	4.1mm @ 10,000 cycles

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What Balanced Mix Design Can Be

Increase use of RAP and concerns:

Product Ingredients

The product ingredients as identified in the mix design are provided in the table below.

TABLE 1. PRODUCT INGREDIENTS

COMPONENT	MATERIAL	WEIGHT %
Aggregate	Natural Stone	18
Aggregate	Natural Stone	20
Aggregate	Natural Stone	15
Aggregate	Natural Stone	16
RAP	Reclaimed Asphalt Pavement	27
Binder	Unmodified	5

TABLE 3. ENVIRONMENTAL IMPACT SUMMARY TABLE

IMPACT CATEGORY	POTENTIAL IMPACT PER METRIC TONNE ASPHALT MIXTURE (PER TON ASPHALT MIXTURE)
Global warming potential (GWP-100)	54.40 (49.35) kg CO_2 Equiv.
Ozone depletion potential (ODP)	8.20e-08 (7.44e-08) kg CFC-11 Equiv.
Eutrophication potential (EP)	1.10e-02 (9.93e-03) kg N Equiv.
Acidification potential (AP)	1.35e-01 (1.23e-01) kg SO_2 Equiv
Photochemical ozone creation potential (POCP)	3.23 (2.93) kg O_3 Equiv.

Product Ingredients

The product ingredients as identified in the mix design are provided in the table below.

TABLE 1. PRODUCT INGREDIENTS

COMPONENT	MATERIAL	WEIGHT %
Aggregate	Natural Stone	22
Aggregate	Natural Stone	39
Aggregate	Natural Stone	15
RAP	Reclaimed Asphalt Pavement	18
Binder	Unmodified	5

TABLE 3. ENVIRONMENTAL IMPACT SUMMARY TABLE

IMPACT CATEGORY	POTENTIAL IMPACT PER METRIC TONNE ASPHALT MIXTURE (PER TON ASPHALT MIXTURE)
Global warming potential (GWP-100)	56.41 (51.17) kg CO_2 Equiv.
Ozone depletion potential (ODP)	7.93e-08 (7.20e-08) kg CFC-11 Equiv.
Eutrophication potential (EP)	1.14e-02 (1.04e-02) kg N Equiv.
Acidification potential (AP)	1.39e-01 (1.26e-01) kg SO_2 Equiv
Photochemical ozone creation potential (POCP)	3.26 (2.96) kg O_3 Equiv.

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Balanced Mix Design

- Why look at 5% or 7% Target Air Voids?

Increase target air voids to 5.0%

Increase minimum VMA +1.0%

Aggregate quality requirements remain the same

All INDOT designs since 2020 are Superpave5

	Superpave4	Superpave5
Design target air voids	4.0%	5.0%
Minimum VMA	15.0%	16.0%
Minimum Vbe	11.0%	11.0%
Density (in-place air voids)	93.0% (7.0%)	95.0% (5.0%)

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Balanced Mix Design

- If INDOT looks at Index-Based tests for Balanced Mix Designs(BMD) some things to consider:
  - If BMD Approach A is used to "Baseline" the present mixes
  - Target Design Air Voids is 5.0 % and desired target density is 95.0 % of theoretical maximum specific gravity (Gmm)
  - Index Based Tests being considered for use:
    - Hamburg Wheel Tracking Test for rutting
      - AASHTO T324
      - (typical target air voids is 7.0 % (93.0% of Gmm)
    - IDEAL CT-Index for cracking potential
      - ASTM D 8225
      - (typical target air voids is 7.0 % (93.0% of Gmm)
    - What are the effects of running the Index tests at 5.0 % instead of 7.0 %?

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Balanced Mix Design

- EXAMPLE:
- INDOT QC/QA,HMA,3,64,Surface, 9.5mm
- Mix Blend:
  - dolomite #11's @ 33.0 %
  - natural sand @ 10.0%
  - Washed dolomite mfg. sand @ 17.0%
  - Washed limestone mfg. sand @ 20. %
  - RAP @ 20.0 %
  - Design Binder Content @ 5.8 % (TOTAL)(rbr=0.17)

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Balanced Mix Design

- Example:
  - Design % Air Voids =5.0 %
  - % VMA =16.7 %
  - Performance Tests:
    - Rutting Test: Hamburg Wheel Track Test(run @ 50̊C,158 lbf wheel load, 12.5mm target max. rut depth, PG 64-22)
      - Run with specimen air voids @ 5.0% (3.6mm @ 10,000 and 7.0mm @ 20,000 passes)
      - Run with specimen air voids @ 7.0 %(5.9mm @ 10,000 and FAIL @ 20,000 passes)
    - Rutting Test: Hamburg Wheel Track Test(run @ 50̊C,158 lbf wheel load, 12.5mm target max. rut depth, PG 76-22)
      - Run with specimen air voids @ 5.0% (2.1mm @ 10,000 and 4.1mm @ 20,000 passes)
      - Run with specimen air voids @ 7.0 %(2.8mm @ 10,000 and 3.6mm @ 20,000 passes)

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Balanced Mix Design

- Example:
- IDEAL CT-Index Test (run at 25 ̊C, 4.0 hour oven aging @ 135 ̊C, PG 64-22)
  - Run with specimens @ 5.0 %: IDEAL CT-Index=55
  - Run with specimens @ 7.0 %: IDEAL CT-Index=84
- IDEAL CT-Index Test (run at 25 ̊C, 4.0 hour oven aging @ 135 ̊C, PG 76-22)
  - Run with specimens @ 5.0 %: IDEAL CT-Index=33
  - Run with specimens @ 7.0 %: IDEAL CT-Index=38
- IDEAL CT-Index Test (run at 31 ̊C, 4.0 hour oven aging @ 135 ̊C, PG 76-22)
  - Run with specimens @ 5.0 %: IDEAL CT-Index=43
  - Run with specimens @ 7.0 %: IDEAL CT-Index=56

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DESIGN CONSIDERATIONS WHEN USING RAP IN ASPHALT MIXTURES

- 2024 Climate INDOT Initiative:
- Will allow Contractor to take edge of RAP spec limit mix and compare against elevated RAP % mixture
  - -Elevated RAP mix has to equal or exceed edge of spec limit mixture
  - EPD's to be published for both mixes

HMA mixtures utilizing RAP or RAS or a blend of RAP and RAS

MAXIMUM BINDER REPLACEMENT, %										
Mixture Category	Base and Intermediate							Surface		
	Dense Graded				Open Graded			Dense Graded		
	25.0 mm	19.0 mm	12.5 mm	9.5 mm	25.0 mm	19.0 mm	9.5 mm	12.5 mm	9.5 mm	4.75 mm
2	25.0*				25.0*			25.0*		
3	25.0*				25.0*			25.0*		
4	25.0*				25.0*			25.0*		

* The contribution of RAS to any HMA mixture shall be ≤ 3.0% by total mass of mixture and ≤ 15.0% binder replacement.

TABLE 3. ENVIRONMENTAL IMPACT SUMMARY TABLE

IMPACT CATEGORY	POTENTIAL IMPACT PER METRIC TONNE ASPHALT MIXTURE (PER TON ASPHALT MIXTURE)
Global warming potential (GWP-100)	*54.40 (49.35) kg CO2 Equiv.*
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Eutrophication potential (EP)	*1.10e-02 (9.93e-03) kg N Equiv.*
Acidification potential (AP)	*1.35e-01 (1.23e-01) kg SO2 Equiv*
Photochemical ozone creation potential (POCP)	*3.23 (2.93) kg O3 Equiv.*

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Effect of Binder Source on Performance Testing

- **KYCT INDEX TESTING CONCERNS:**
  - **What is the influence of binder source?**
  - **ΔTc used as a tool to determine aging characteristics of the binder**
    - **IF using RAP/RAS in the mix , extracted recovered binder with virgin and recycled binder combined should be evaluated**
  - **EX: Two PG 64-22 binder suppliers in an area:**
    - **Binder Source A: ΔTc(40 hour PAV aging)= -7.3˚C**
    - **Binder Source B: ΔTc (40 hour PAV aging)= -0.1˚C**
    - **IDEAL CT-Index testing on lab standard mix**
    - **Typical specification limit ≥ -5˚C**

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Performance Testing Concerns or Thoughts

- **IDEAL CT INDEX TESTING CONCERNS:**
  - **If long term aging is more indicative of where cracking is observed to begin:**
    - **Shouldn't we be using a long term aging protocol as part of our mix design process.**
    - **If long term aging is more indicative of where cracking begins, does that leave (what was the 4 hour aging for IDEAL CT INDEX testing) (and now 2 hour aging) simply a ranking tool?**

Laboratory Conditioning of Asphalt Mixtures

AASHTO Designation: R 30-22[1] AASHTO

Technically Revised: 2022 Editorially Revised: 2022

Note 4—Short-term conditioning is now applicable to both determination of volumetric properties as well as mechanical tests intended to assess the behavior of the mixture in the early years of the pavement's life (e.g., rutting tests). Prior versions of this standard included a section titled "Short-Term Conditioning for Mixture and Mechanical Property Testing", which required conditioning for 4 h ± 5 min at 135 ± 3°C. That requirement has since been deleted. Specification limits developed based on the prior conditioning requirement may no longer be appropriate.

After 2 h ± 5 min, remove the mixture from the forced-draft oven. The conditioned mixture is now ready for compaction or testing.

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Performance Testing Concerns or Thoughts

- **IDEAL CT- INDEX TESTING CONCERNS:**

Selecting a Laboratory Loose Mix Aging Protocol for the NCAT Top-Down Cracking Experiment

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Performance Testing Concerns or Thoughts

- **IDEAL CT-INDEX TESTING CONCERNS:**

Chen, Yin, Turner, West, and Tran 2

ABSTRACT

The objective of this study was to select a laboratory loose mix aging protocol for the NCAT top-down cracking (TDC) experiment. Literature review was first conducted to determine a critical field aging condition for evaluating TDC. In this study, field aging of asphalt mixtures was characterized using the cumulative degree-days (CDD), which was defined as the accumulation of daily high temperature throughout mixtures' service life. Performance data from a number of existing pavements showed that TDC typically initiated after approximately 70,000 CDD. A laboratory experiment was then conducted to select an aging protocol that was representative of this critical CDD. Materials used in the experiment were from five projects in Michigan, Washington, and Alabama. Four loose mix aging protocols were evaluated in terms of their effects on the rheological and oxidation properties of asphalt binders. Results from the dynamic shear rheometer (DSR), bending beam rheometer (BBR), and Fourier Transform Infrared Spectroscopy (FT-IR) tests showed that the 24-hour, 135°C protocol yielded the most significant level of asphalt aging, followed by the 12-hour, 135°C protocol, 5-day, 95°C protocol, and 6-hour, 135°C protocol, respectively. No significant difference in the oxidation-hardening relationship of asphalt binders was observed for mixes aged at 95°C versus 135°C. Among the four aging protocols, the 5-day, 95°C protocol was most representative of 70,000 CDD of field aging. Finally, DSR and FT-IR results indicated that loose mix aging of 8 hours at 135°C and 5 days at 95°C were likely to achieve an equivalent aging level; thus, the 8-hour, 135°C protocol was recommended as an alternative protocol to simulate 70,000 CDD of field aging.

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Conclusions

- **Balanced** Mix Design offers the opportunities:
  - To the agencies for increased confidence in mixture performance
  - To the contracting industry for increased opportunities to innovate

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Stone Matrix Asphalt (SMA)

IDAHO ASPHALT CONFERENCE

Timothy R. Murphy, P.E.
MURPHY PAVEMENT TECHNOLOGY, INC
MEMBER Board Certified NATIONAL ACADEMY OF FORENSIC ENGINEERS

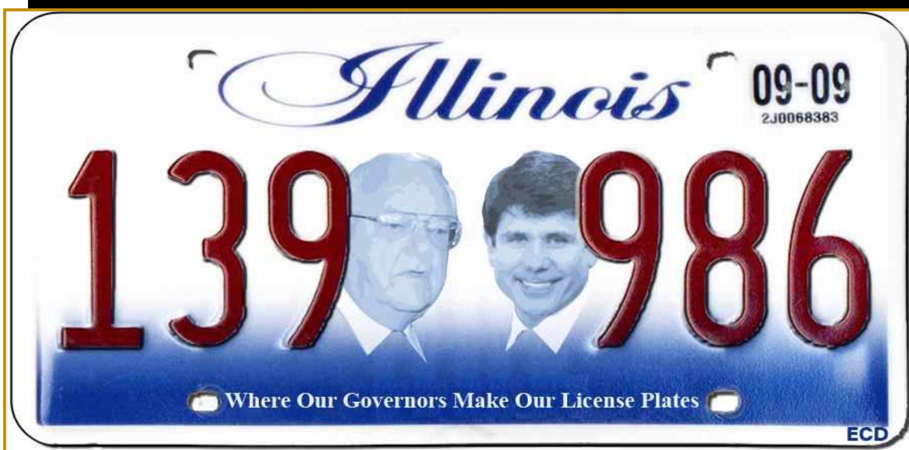
63rd Annual Idaho Asphalt Conference
University of Idaho, Moscow, Idaho
October 25-26, 2023

1

Where I'm Located

2

In Illinois we Perpetually Recycle our Politicians



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3

Transportation Research Board's Report 202

"Asphalt, more than any other single product, sustains the nation's highway system and facilitates the flow of commerce."

4

4

Stone Matrix Asphalt

High Type Traffic Solution: Stress + Volume

5

Rutting

How Did We Get Here?

- Interstate rutting during late 1970's accelerated. Factors affecting rutting were Weight, Speed & Number of Trucks.
- Stresses exceeding HMA *aggregate structure* load capacity typically occurs in top 4" inches of pavement.

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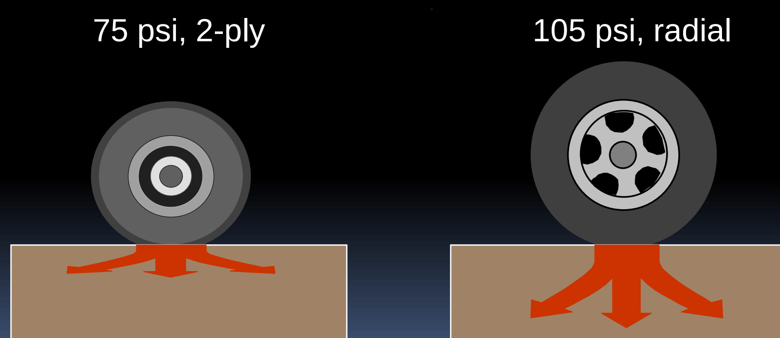
How Did We Get Here?

Truck tire footprint changed drastically!



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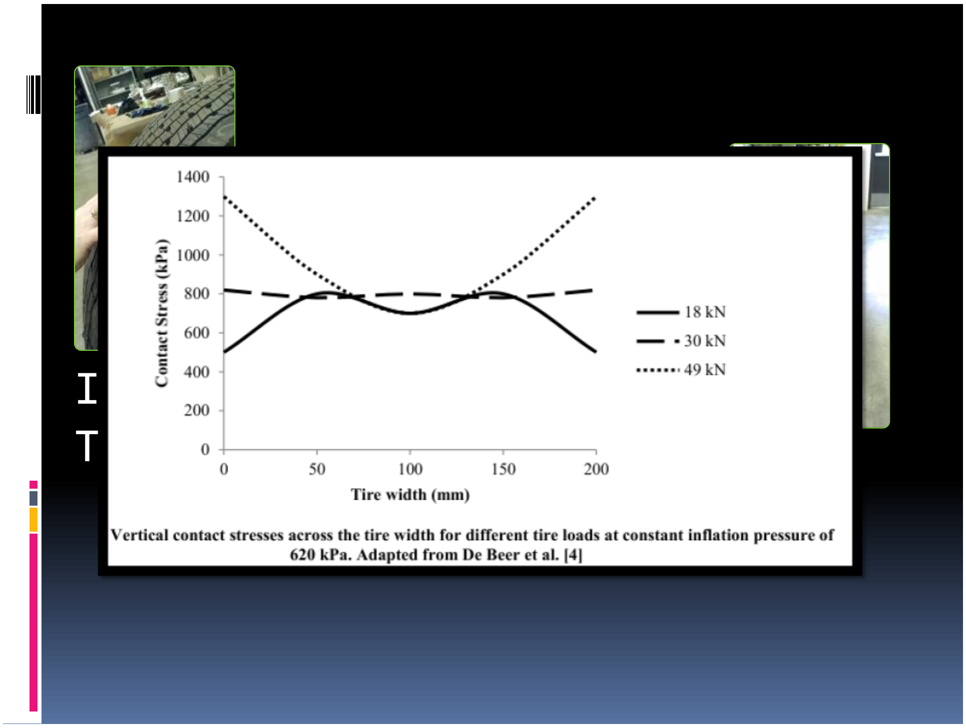
A. Traffic type and volume

8



1400
1200
1000
800
600
400
200
0
Contact Stress (kPa)
0
50
100
150
200
Tire width (mm)
18 kN
30 kN
49 kN
Vertical contact stresses across the tire width for different tire loads at constant inflation pressure of 620 kPa. Adapted from De Beer et al. [4]

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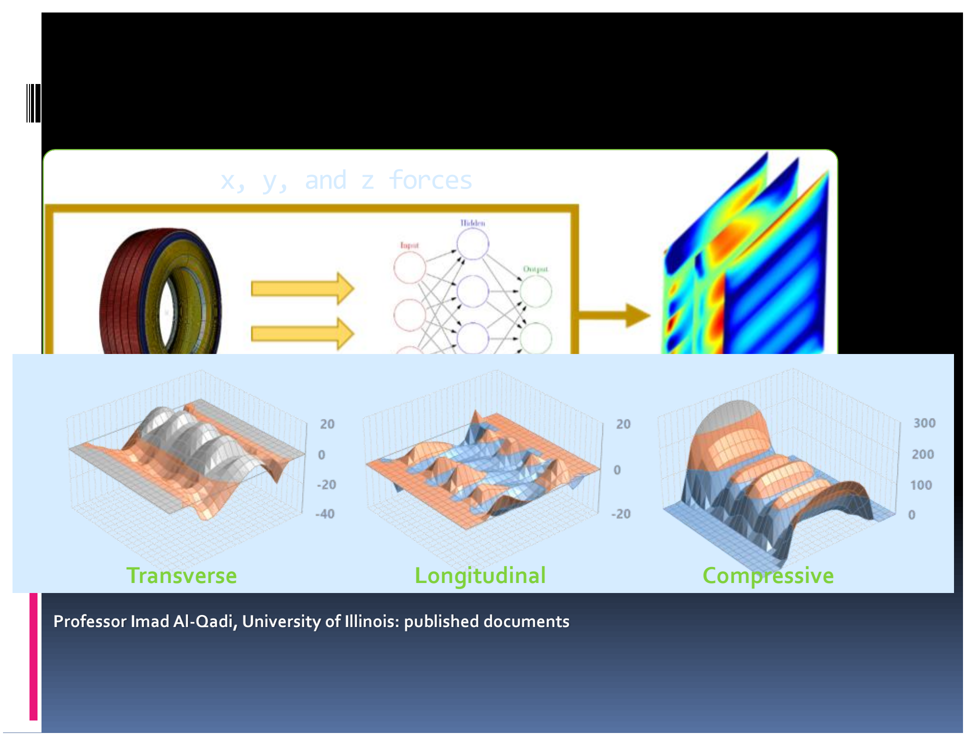
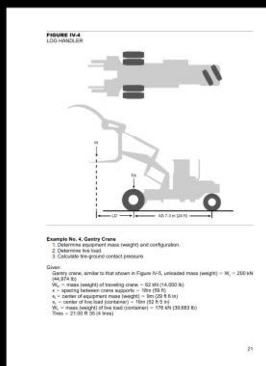
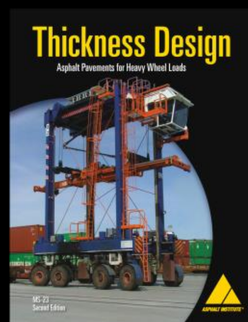
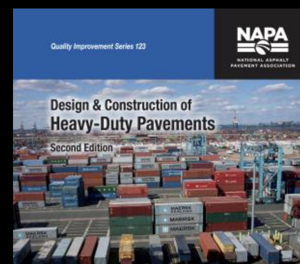


x, y, and z forces
Hidden
Input
Output
20
0
-20
-40
Transverse
20
0
-20
Longitudinal
300
200
100
0
Compressive
Professor Imad Al-Qadi, University of Illinois: published documents

10







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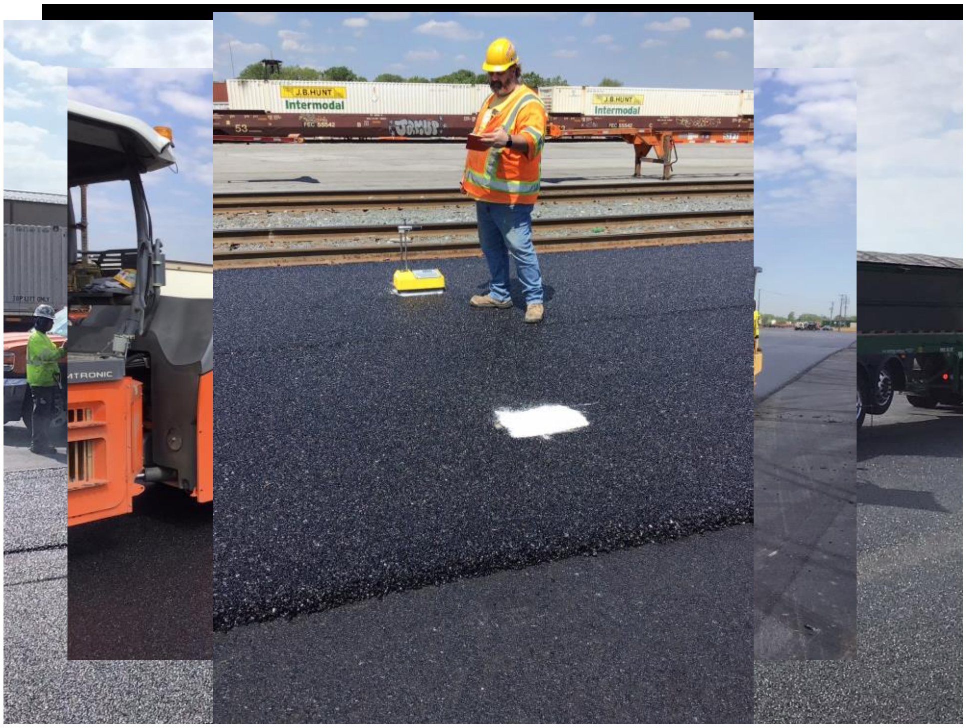
Utilize Three Wheel, Vibratory, and / or Oscillatory rollers

12

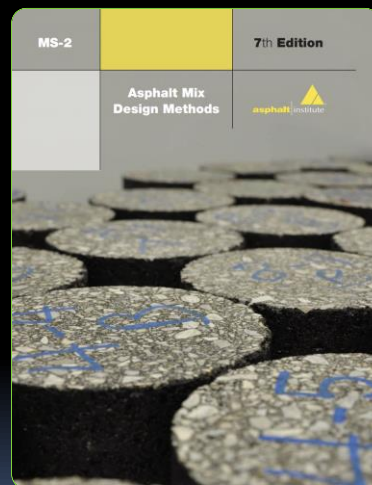


13

Log Yard

14

Universal
Asphalt Mix Design
Methods Manual
(require)



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Importance of VMA to Compaction Efforts and Pavement Performance

Improve	Improve Mechanical Stability
Improve	Improve Resistance to Permanent Deformation
Reduce	Reduce Moisture / Air Penetration
Improve	Improve Fatigue Resistance
Reduce	Reduce Low-Temperature Cracking Potential

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17

Mix Properties

- Much coarser blend than Superpave
- Uses highly modified AC, high dust content and fibers
- Stability from coarse aggregate structure
- Durability from mastic
- Very sensitive to changes in production and placement

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BUILT IN 1997

World's Strongest Intersection

(Williams & Margaret in Thornton, IL)

19

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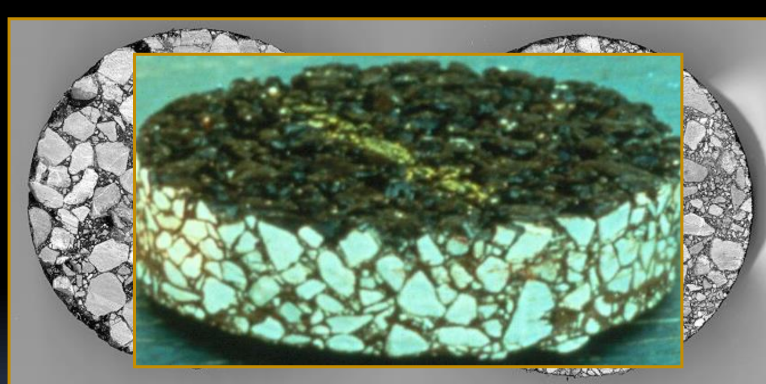
Comparison SMA vs. Dense-Graded



Stone Matrix Asphalt | Dense-graded Asphalt

20

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Mix Properties, Job-Mix Formula

Mixture Composition

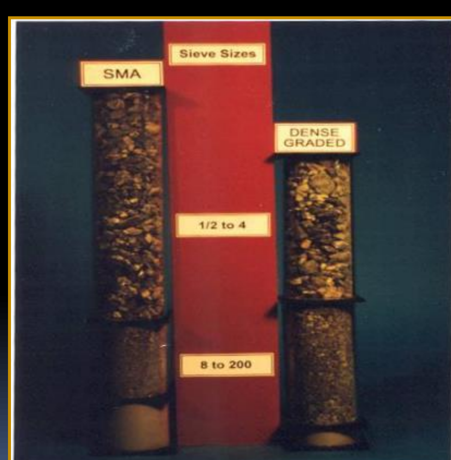
Sieve	*Lower*	*Upper*
¾" (19.0 mm)		100
½" (12.5 mm)	90	99
⅜" (9.5 mm)	50	85
#4 (4.75 mm)	20	40
#8 (2.36 mm)	16	28
#200 (0.075 mm)	8	12

Typically = +6% Polymerized AC

21

21

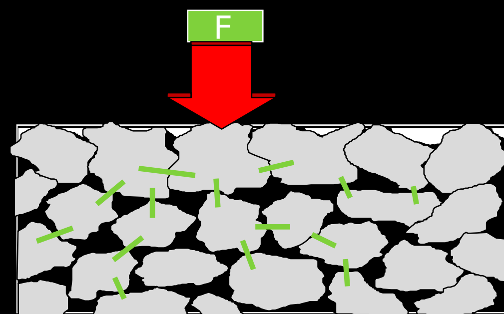
SMA vs. Dense-Graded



22

22

Stability in SMA



Stability in a SMA-mix is obtained through the

<u>internal friction</u>

in the self-supporting stone skeleton

23

24

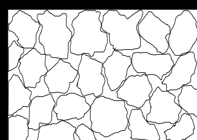
AGGREGATE AND ASPHALT

25

26

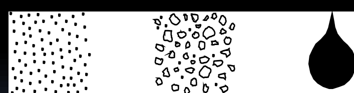
SMA

Stone Skeleton



Stones + Mastic

Filler Sand Bitumen



Stabilizer/Fibers

27

Stone Matrix Asphalt (SMA)

28

Mix Properties, NCAT Draindown Method

- Measures draindown of liquid asphalt,
- Deduct stone in draindown,
- Monitor during production,
- Review procedure.

29

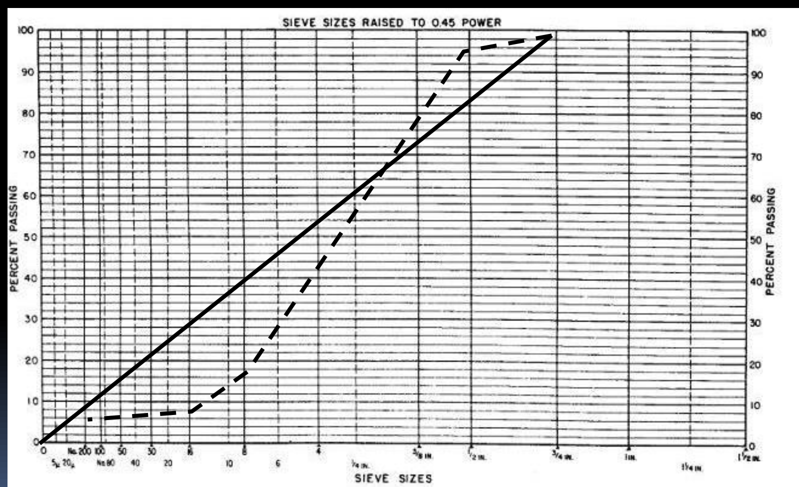
SMA Aggregate Gradation

3 – 2 - 1

%Passing	
Sieve Size	Nominal Maximum Aggregate Size Control Points
¾ inch	100
½ inch	90 – 100
3/8 inch	50 – 80
No. 4	20 – 35
No. 8	16 – 24
No. 200	8.0 – 11.0

30

Mix Properties, Gradation



31

Integrating Steel Slag Aggregates into Asphalt Paving by Harmonizing Availability, Quality, Economics, and the Environment

Timothy R. Murphy
Mississippi State University
Thesis Defense
March 23, 2023

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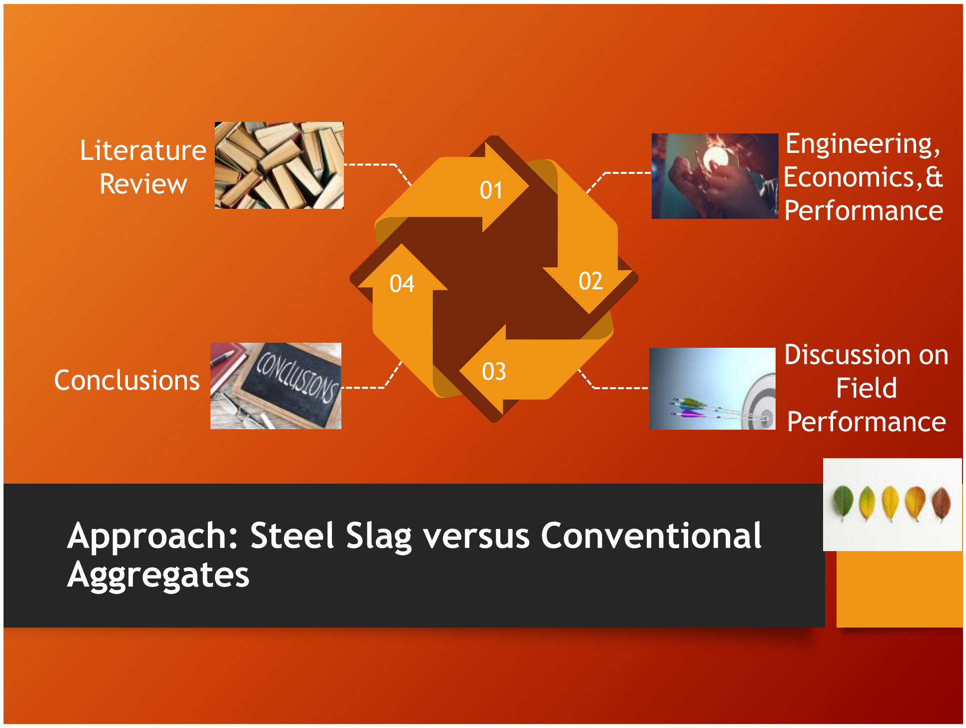

Literature Review
01
Engineering, Economics, & Performance
04
02
Conclusions
03
Discussion on Field Performance
Approach: Steel Slag versus Conventional Aggregates

33


Historical Footprint of Slag
Oxygen Furnace
Fluxes and coolant
Furnace gasses
Water jacketed oxygen lance
Tap hole
Molten slag
Molten iron
Electric Arc Furnace
Power cables
Hatch for coke, iron ore, & limestone
Oxygen inlet
Electrodes
Molten slag
Slag door
Molten iron
Tap hole
Illustration of Furnaces in Use Today (NSA, 2021)
Slag Poured from Ladle in Molten State To Cool

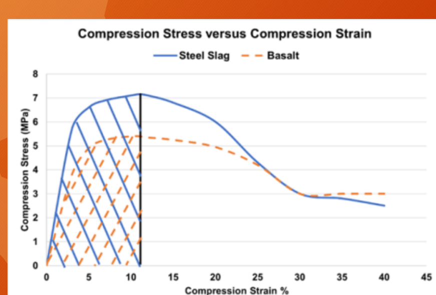
34

Various Asphalt Mixtures - SMA

Advantages of Stone Matrix Asphalt

35

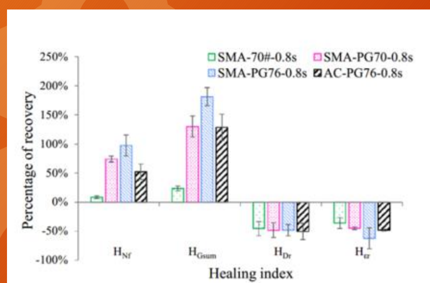
Various Asphalt Mixtures - SMA



Compression Stress Strain Curves of SMA Mixture with Slag and Basalt (adapted from Wu et al., 2007)

36

Various Asphalt Mixtures - SMA

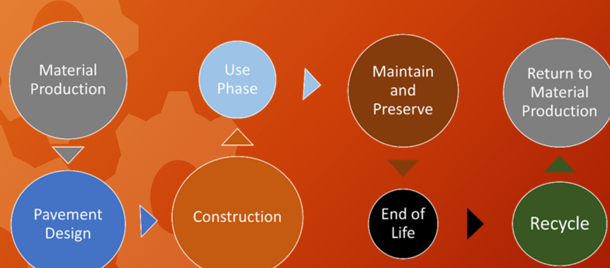


Healing Indexes of Different Asphalt Mixtures (Jiang et al., 2019)

Steel Slag SMA Surface Course and Dolomitic SMA Intermediate Course

37

Engineering



Aggregate Cradle to Cradle: Life-Cycle

38

Steel Slag in Stone Matrix Asphalt: 20-Year Case Study

Before and After Slab Cut-Aways

39

Interstate 84

IDAHO'S TEN-YEAR CASE STUDY

40

Perpetual Pavement Defined

Asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement.

41

Perpetual Pavement Defined

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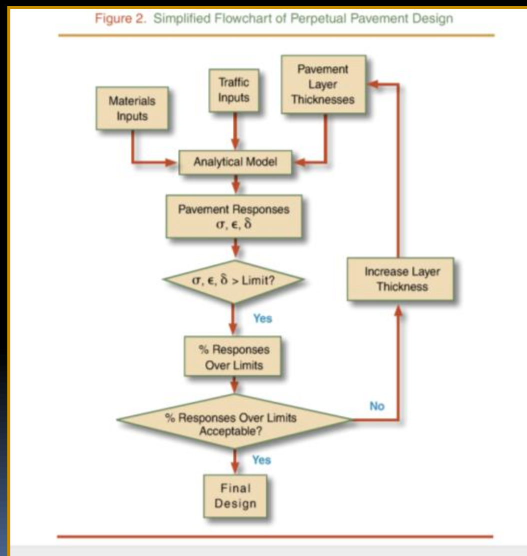
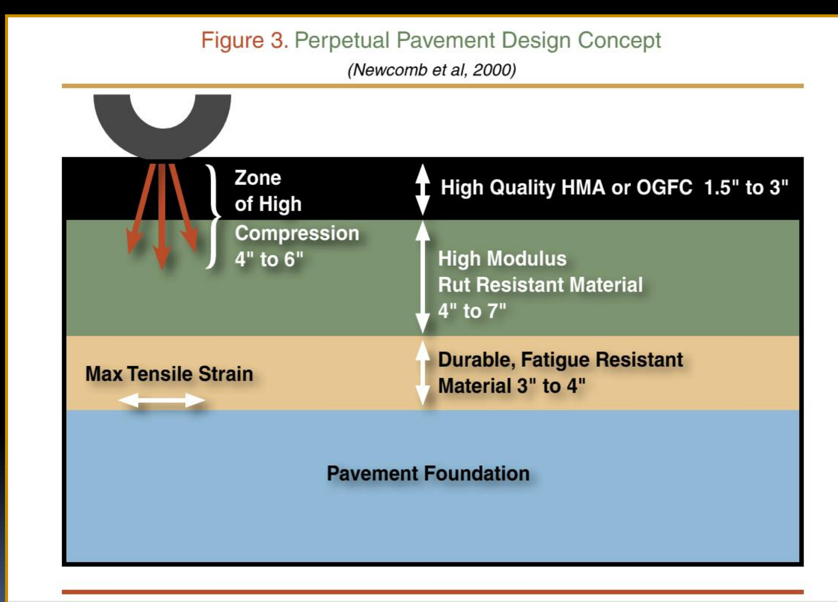
Perpetual Design



From APA

43



From APA

44

Strategy consists of four steps:

- Assess the opportunity
- Ensure structural adequacy
- Select high-performance materials and confirm the mixture design
- Use proper construction techniques

45

45

Strong

Use aggregates with:

- High crush
- Hard particles
- Consistent gradation (clean) and gravity
- Proper Quality Control (QC)

46

46

What Surface Mixture to Use?

47

Benefits of SMA

- More stable,
- More durable,
- Less water spray,
- Improved friction numbers,
- Reduced tire noise.

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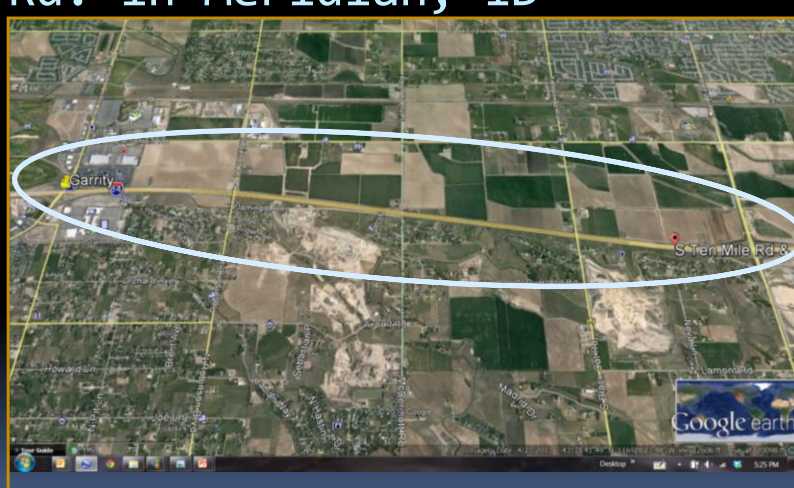
STRONG + DURABLE = SUSTAINABLE

49

I-84: Garrity to Ten Mile Rd. in Meridian, ID



50

TEAM Approach

- Meeting with all parties involved (ITD, J-U-B Engineers, Inc., and Idaho Sand & Gravel).
- Reviewing engineering reports available, including:
  - ESAL determination (M. Dehlin),
  - Thickness design and typical section (M. Dehlin, HDR, and Terracon),
  - Mix selection (Terracon, M. Dehlin, and T. Murphy),

(Cont'd.)

51

TEAM Approach

- Reviewing engineering reports available, including:
  - Specification writing (M. Dehlin),
  - Mix design verification versus Acceptance Test strips versus Production (ITD HQ, and GeoTek),
  - Paving equipment requirements versus actual (JUB and ITD D3), and
  - Job specific variations for materials, machinery, and methods, particularly the impact of change orders and construction issues (JUB and ITD D3).

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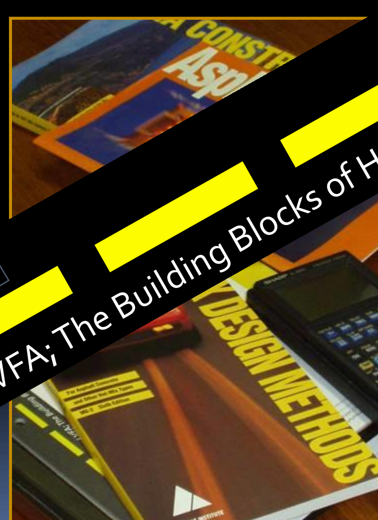
Building the Roadway

53

The Job Mix Formula



Voids, VMA, and VFA; The Building Blocks of Hot Mix Asphalt

54

Laboratory Mix Designs vs. Plant - Produced Mixture

55

Properly Ballast Rollers

56

Properly Ballast Rollers

57

Ballast Rollers

58

Rolling Pattern on I-84

59

Findings

- SMA surface mixture voids did not trend about the target of 4.0% for the entire project.
- Voids actually average close to 5.0%, the upper limit for voids.
- Density was difficult to achieve.

Recommended
Higher VMA and Lower Voids = More AC

60

Sound Specifications

- **Scientifically and mathematically sound,**
- **Related to performance,**
- **Easy to understand and apply,**
- **Provide strong incentives to produce good quality,**
- **Provide strong disincentives for poor quality, and**
- **Take into account construction phases.**

61

I-84 Field Review of 2023

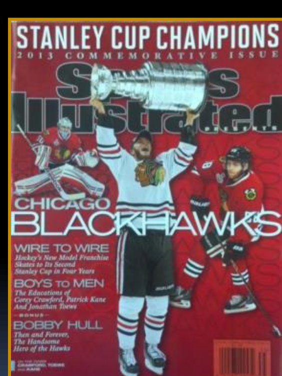
- Site review reveals acceptable ride, lane configuration, and performance to date.
- Allow use of any acceptable material transfer device provided that volumetric measures and smoothness are achieved.

62

West bound near EOJ
2023 Review is Exceptional

63

STRONG + DURABLE = SUSTAINABLE



64

64

SMA 2023 – District 6

Laboratory Testing

- Increase Voids in the Mineral Aggregate
- Decreased Air Voids
- Increased Effective Volume of Asphalt

Field Testing

- Required 94.0% density of mat and 92.0 density of longitudinal joints
- Gave contractor options on paving, rollers, and production techniques

65

Rut Testing, current day:
Hamburg Wheel / Asphalt Pavement Analyzer

AASHTO T32

- Lab samples com
- Field samples can
- 122°F water bath
- Minimum numbe typically depende
- Example: 12.5 mr

Chicago Testing Laboratory
chicagotestinglab.com

Pavement Technology Inc.

66

Required versus Actual

Rut Depth, mm, and Stripping, passes @ Optimum AC and plus and minus 0.5% Optimum AC (Hamburg)	< 10.0 mm @ 20,000 passes *Additional samples required to build SMA database
Cracking Test, IDEAL-CT_{Index} @ Optimum AC and plus and minus 0.5% Optimum AC	80 (index value) *Additional samples required to build SMA database

Rut Depth = 2

IDEAL-CT = 490

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Corelok for SMA Validated by NCAT on SMA (2002)

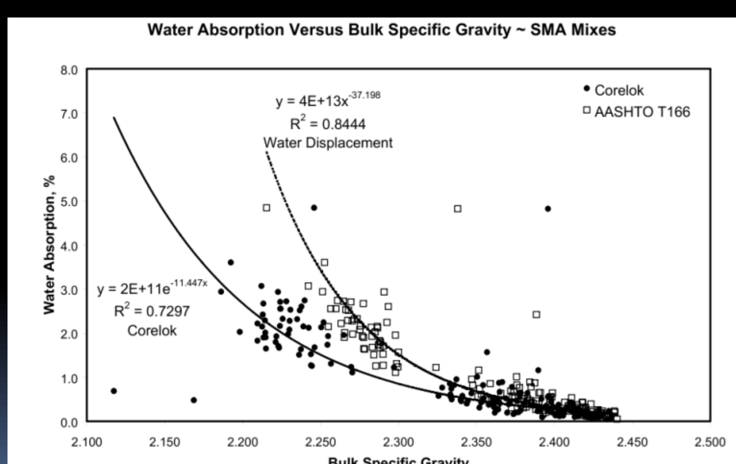

Figure 25. Relationship Between Water Absorption and G_{mb} for SMA Mixes

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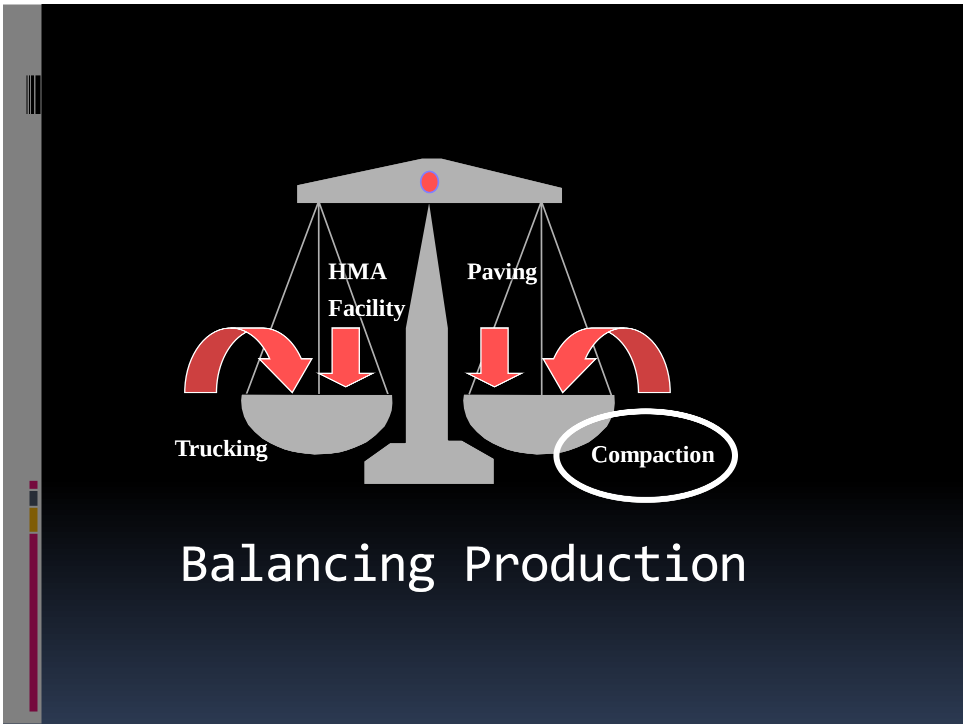
HMA
Facility
Paving
Trucking
Compaction
Balancing Production

69


Dense-graded = Mat – 2%
SMA = 92.0%+

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Echelon Paving, Part I

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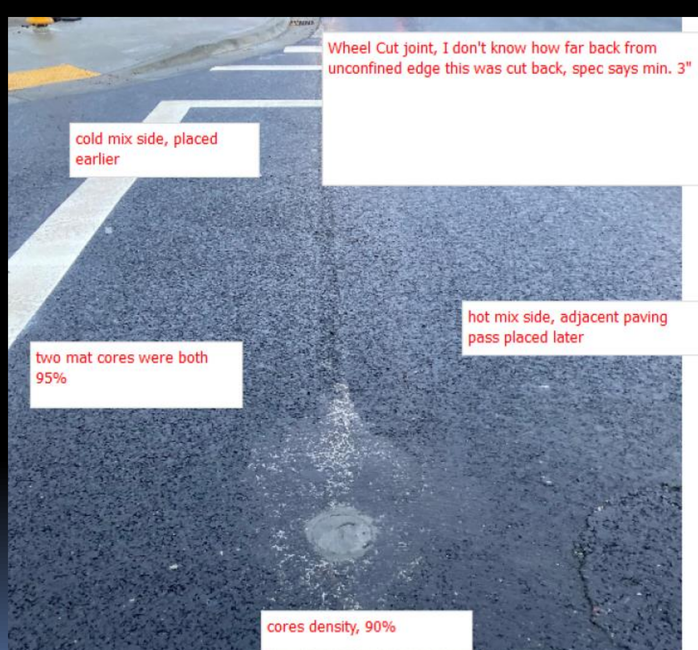

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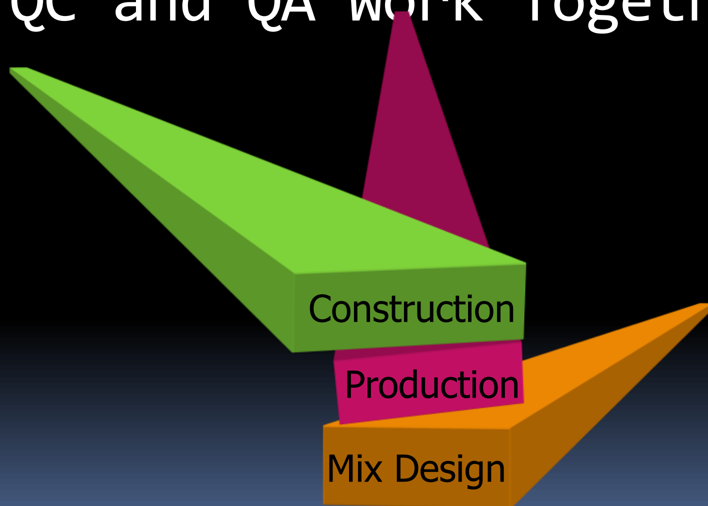
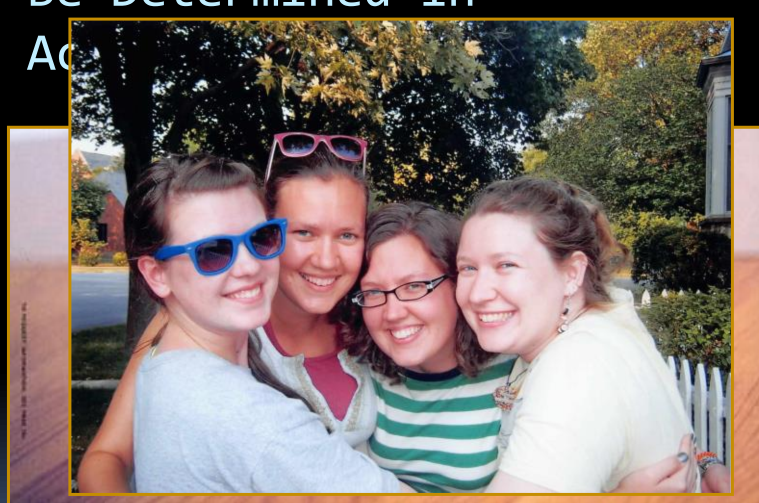
Successful HMA is when QC and QA Work Together



73

Be Determined in
Ac



It Takes Teamwork!!!

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2024 AAPT Annual Meeting September 9-12, 2024

75

75

2024 AAPT Annual Meeting September 9-12, 2024

- Dedicated Task Force
  Chicago, Illinois
  LOEWS Chicago Hotel
- Centennial Event @ Shedd Aquarium
- Yearlong Centennial Celebration
  - AAPT/NAPA Member Reception in DC @ TRB: Old Ebbitt Grill, 1/7/2024, 6-8:30pm
  - Webinars & Monthly Events on Social Media

Sponsorships Available

76

76

Time fo(u)r questions

77

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ASPHALT MIXTURES WITH RAP AND REJUVENATORS

Hussain Al Hatailah
Emad Kassem

October 26, 2023

1

OUTLINE

- Motivation
- Objectives
- Methodology and Tasks
- Findings
- Conclusions

2

OUTLINE

- Motivation
- Objectives
- Methodology and Tasks
- Findings
- Conclusions

3

MOTIVATION

BACKGROUND

- Reclaimed Asphalt Pavement (RAP)
  - America's most recycled product
    - 95% being put back to use in new pavement
    - 5% used in other engineering practice like unbound aggregate base
  - The total RAP stockpiled nationwide is estimated to be 137 million ton in the year of 2021
  - The average percentage of RAP used by all sector is only 21.9%

RAP Use by Sector (Million Tons) and Average Percent RAP Used by Sector (NAPA 2021)

4

MOTIVATION

BACKGROUND

- The use of RAP
  - Promotes and integrates sustainable solutions
  - Contribute toward the net zero carbon emissions initiatives
    - *NAPA 2022; "Nationwide, increasing the amount of RAP in new asphalt mixtures by one percentage would result in 0.14MMT CO_2e in avoided emissions- equivalent to an annual emissions from approximately 30,000 passenger vehicles.*
  - Reduces the use of virgin materials (binder and aggregate)
  - Contribute to potential environmental benefits and cost savings.

The Road Forward
A Vision for Net Zero Carbon Emissions for the Asphalt Pavement Industry

5

MOTIVATION

BACKGROUND

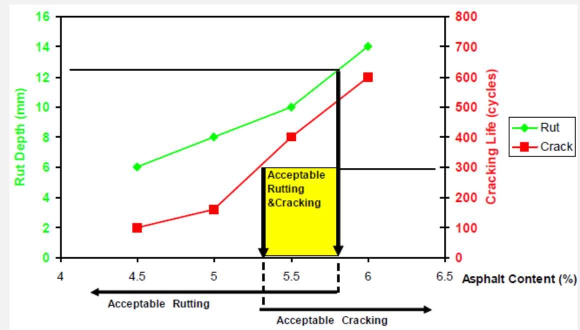
- Many DOTs allow the use of RAP into asphalt mixtures; however, many limit the amount used to about (~ 25-30%)
- Idaho Transportation Department allows only up to 30% RAP in asphalt mixtures with binder grade adjustment.
- Higher percent of RAP (> 50%) results in stiffer mix and thus prone to fatigue cracking

6

MOTIVATION

BACKGROUND

- The Balanced Mix Design (BMD) approach relies on balancing the cracking and rutting performance makes it possible to increase the RAP percentage in the mix
- Rejuvenators also known as recycling agents are organic and petroleum products that helps to restore the rheological properties of such mixtures



Zhou et al. 2006

- Were first introduced back in 1960's as a pavement preservation practice
- The maltenes in rejuvenators, helps to improve the cracking by restoring the asphaltene to maltene ratio in RAP

7

OUTLINE

- Motivation
- Objectives
- Methodology and Tasks
- Findings
- Conclusions

8

OBJECTIVES

- Evaluate the effect of rejuvenators on improving the performance of asphalt mixtures containing different percentages of RAP and **reducing the need for softer binders which are costly to obtain**
- Apply the balanced (engineered) mix design concept and performance thresholds, developed in RP 261, to optimize the mix design of **HMA papered with RAP and rejuvenators** for improved performance
- Study the **economic savings** of using rejuvenators and RAP in asphalt mixtures
- Evaluate the rheological properties of selected extracted binders

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OUTLINE

- **Motivation**
- **Objectives**
- **Methodology and Tasks**
- **Findings**
- **Conclusions**

10

RESEARCH TASKS

TASK 1: CONDUCT LITERATURE REVIEW

- Effect of using rejuvenators and recycling agents on the performance of asphalt mixtures containing RAP
- Economic benefits of using rejuvenators and recycling agents in asphalt mixtures
- Methods used to evaluate the rheological properties of asphalt binders

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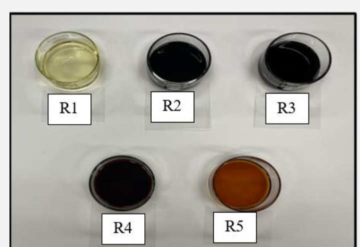
RESEARCH TASKS

TASK 2: DEVELOP TESTING MATRIX

RAP %	0	25	50	≥70	-
RAP Source	1	2	3	-	-
Air Void %	7%				
Binder Grade	PG 70-28	PG 64-28	PG 58-34	PG 58-28*	-
Binder Content %	OBC	OBC+0.5%	-	-	-
Rejuvenators	R1	R2	R3	R4	R5

*Only used with the 3rd source of RAP.



Rejuvenator No.	Examined Doses	Rejuvenator Type.	Doses Description
R1	3.5%, 5%, and 7%	Tall Oil	By weight of total binder
R2	6%, 10%, and 12%	Engineered Product	By weight of reclaimed binder
R3	12.5% and 15%	Forestry Product	By weight of reclaimed binder
R4	1% and 2%	Engineered Product	By weight of RAP
R5	12% and 16%	Waste Cooking Oil	By weight of reclaimed binder

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RESEARCH TASKS

TASK 3: PREPARE ASPHALT MIXTURE TEST SPECIMENS

- The IDEAL-CT$_{Index}$ test specimens are 150 mm in diameter and 62 mm in height and **<u>don't need to be cut or notched</u>** which is an advantage over the semi-circular test specimens
- The HWTT test specimens are 150 mm in diameter and 60 mm thick
- The IDT thermal specimens are 150 mm in diameter and 43 mm thick
- The testing matrix includes laboratory-mixed laboratory-compacted samples that will be prepared with the following characteristics.
  - Different RAP content (e.g., 0, 25, 50, and 70%)
  - Different rejuvenators and recycling agents. The content varies to obtain optimum cracking and rutting performance
  - Different binder type (PG 70-22, PG 64-28, PG 58-34, and PG 58-28)
  - Different binder content (Optimum and Optimum + 0.5%)

RESEARCH TASKS

TASK 4: CONDUCT LABORATORY TESTING PROGRAM

- Fatigue cracking resistance (e.g., IDEAL-CT$_{Index}$)
- Rutting resistance and moisture susceptibility using HWTT
- Thermal cracking resistance at low temperature (Indirect Tensile Strength [IDT])
- Binder rheological properties using Dynamic Shear Rheometer (DSR)

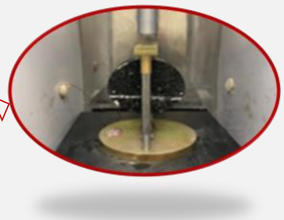
Materials Testing System (MTS) and data acquisition

IDT Thermal

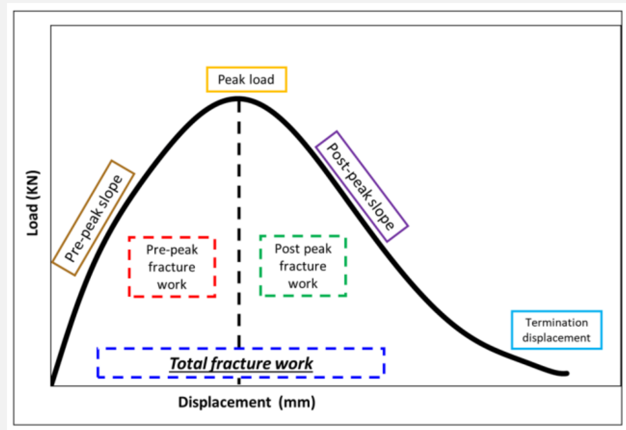
Asphalt Pavement Analyzer Junior (APA Jr.)

Dynamic Shear Rheometer

INDIRECT TENSILE (IDT) TEST



Indirect Tensile (IDT) Strength Test



- A compressive load at a constant rate of 50±5 mm per minute until failure

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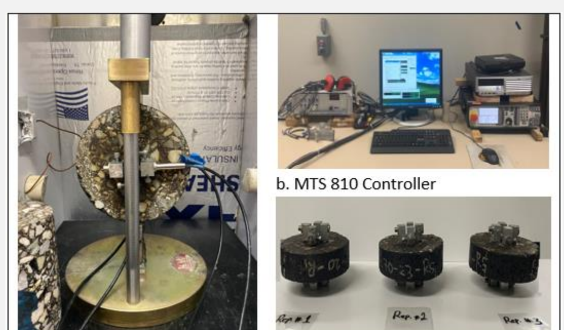
IDT THERMAL TEST

CREEP-COMPLIANCE AND STRENGTH TEST

- In accordance with AASHTO T322
  - Conducted at three temperatures (-20, -10, and 0˚C)
  - By applying a sufficient constant vertical load (cause a deformation between 0.00125 to 0.0190 mm) for 100 sec



a. Test Setup b. MTS 810 Controller c. Test Specimen

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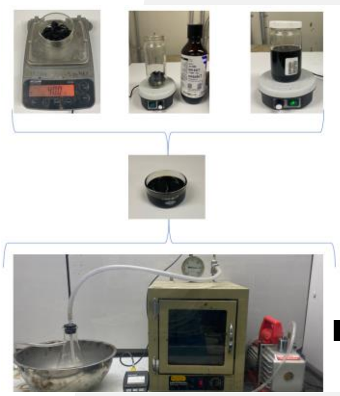
RESEARCH TASKS

TASK 4: CONDUCT LABORATORY TESTING PROGRAM

- Binder micro-extraction by UT Austin Filonzi et al. 2020



- Part A: Binder-Toluene Extraction
  - 40 g of asphalt mixture
  - 140 ml of toluene
  - Stir for 12 hours

- Part B: Binder recovery
  - Place on a vacuum oven
  - Initial temp 40 °C and increase gradually until 165 °C for two hours
  - Vacuum pressure 70 cm-HG

OUTLINE

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PRODUCED ARTIFICIAL RAP (RAP NO.1)

- Loose Mix (Project No. 20975) was aged at 135˚C for 3 days (Sirin et al. 2018)

Project #	District	Mix Type	Specified Binder PG	Virgin Binder PG	Binder Content Pb (%)	RAP (%)	NMAS	Theoretical Specific Gravity (G_{mm})
20975	D1	SP3	PG64-28	PG 58-34	5.3	30	1/2"	2.465

- **Advantages:**
  - Same mixture, same aggregate gradation
  - No need to adjust neither the binder content or aggregate gradation at different percentages of RAP

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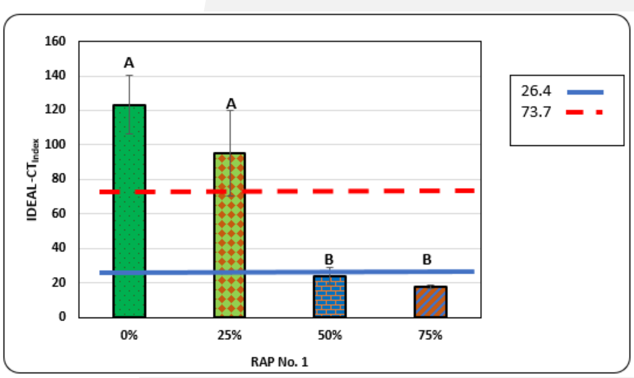
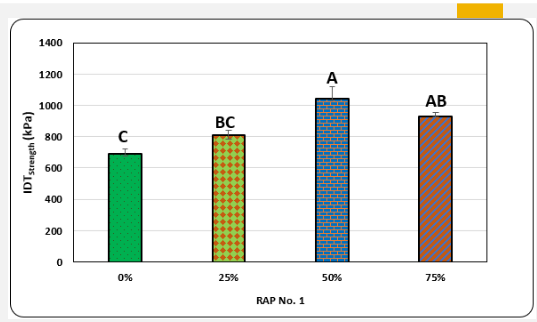
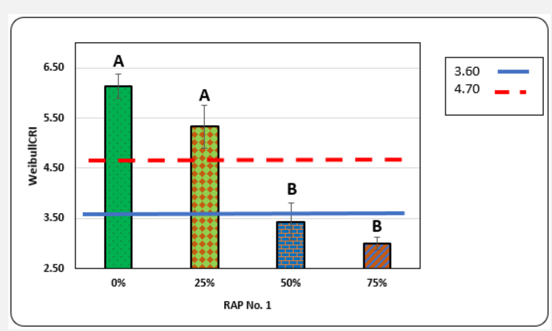
RAP NO. 1

- Effect of RAP content





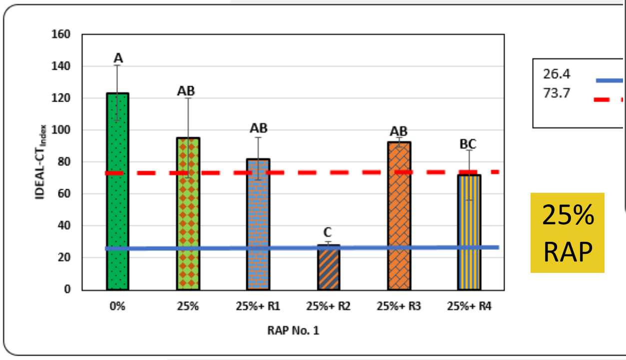


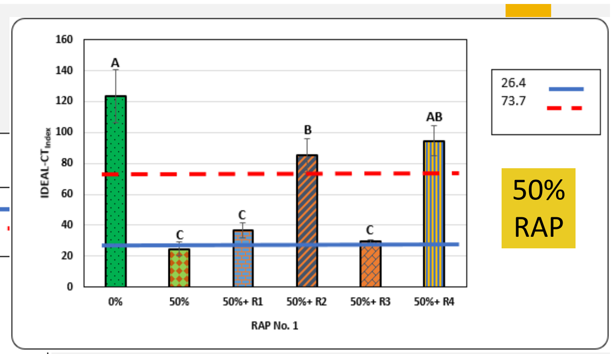
- Increasing the RAP content resulted in stiffer mixture with reduced cracking resistance

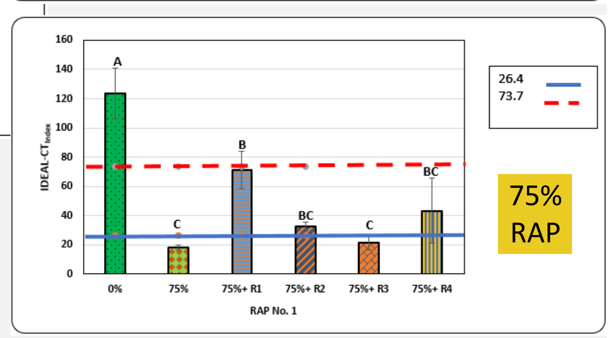
20

RAP NO. 1

Effect of Rejuvenator type





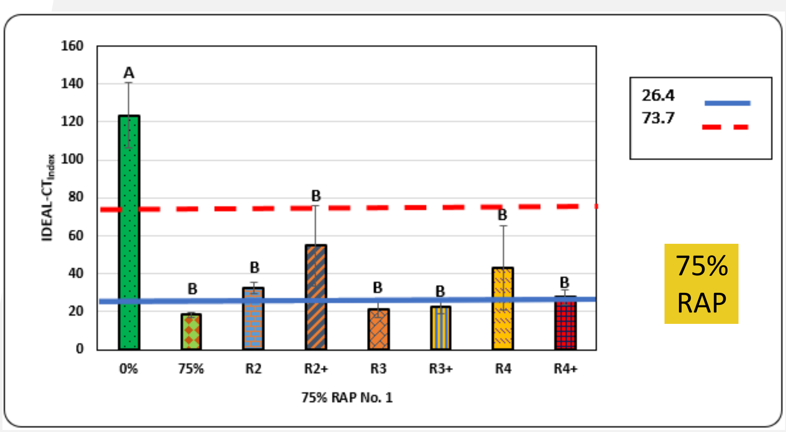


- At lower RAP content (i.e., 25%), rejuvenators didn't significantly impact the cracking resistance except for R2 which showed negative impact
- At higher RAP content (i.e., 50 and 75%) R2 and R4 significantly improved the cracking resistance

21

RAP NO. 1

Effect of Rejuvenator dose



- Some rejuvenators like R2, had a favorable effect on the cracking resistance as the dose increase while other like R4 adversely impacted the cracking resistance

22

RAP NO. 2

- **Material Properties of Mix with (Virgin Aggregate Coarse, Fine and RAP No. 2)**
  - Obtained from Lewiston, ID
  - SP3
  - 12.5 mm
  - Target binder content 5.8%
  - RAP Pb 5.37%
  - PG 58-34

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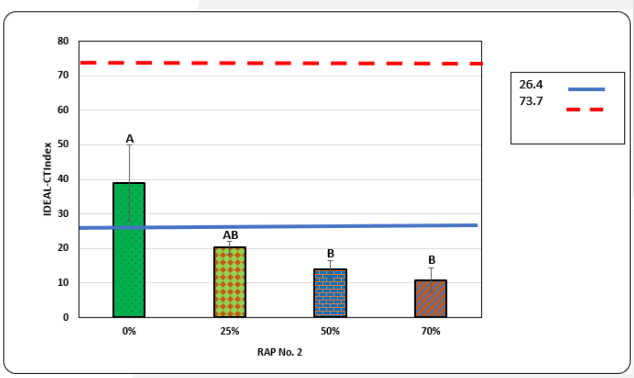
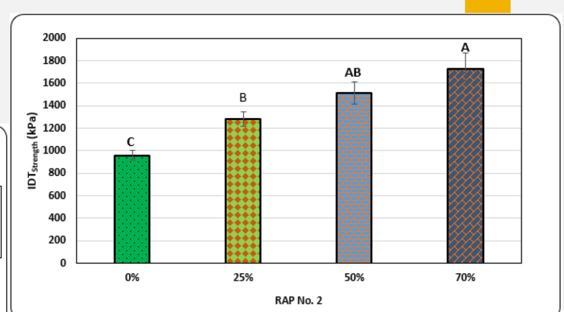
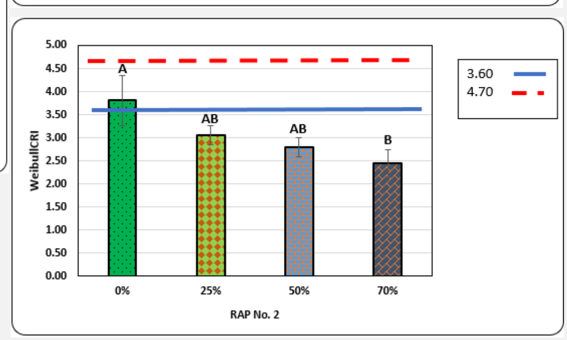
RAP NO. 2

- Effect of RAP content







- Increasing the RAP content resulted in stiffer mixture with reduced cracking resistance

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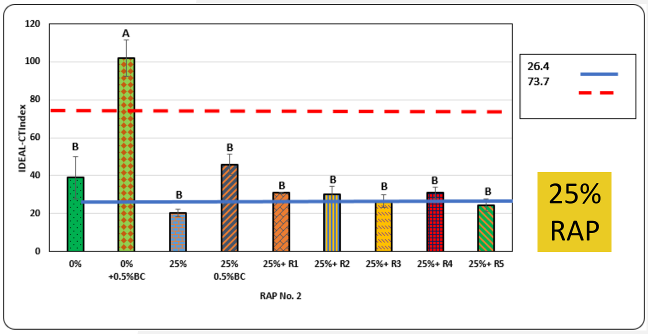
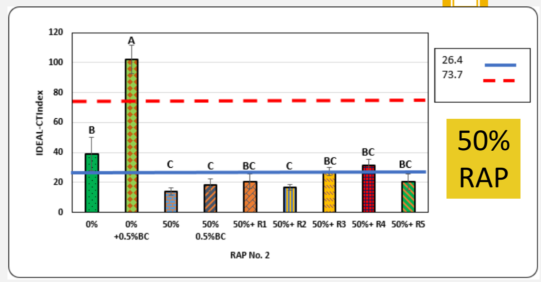
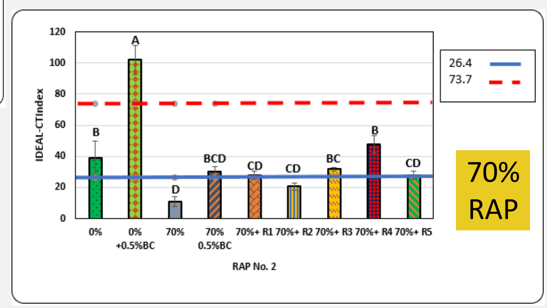
RAP NO. 2

Effect of Rejuvenator Type





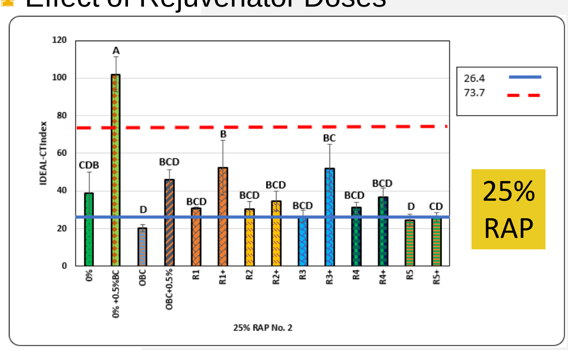


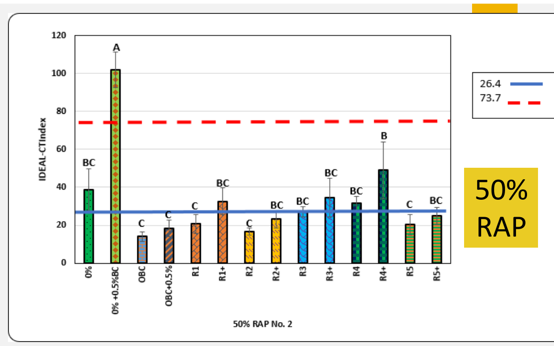
- All rejuvenators improved the cracking resistance of mixes at different RAP content
- Increasing the binder content showed similar results as the rejuvenators

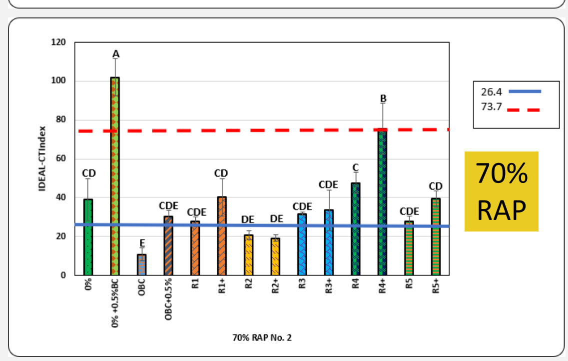
25

RAP NO. 2

Effect of Rejuvenator Doses







- Increasing the rejuvenator dose improved the cracking resistance for all mixes
- At higher RAP content (i.e., 70% RAP No. 2) the effect of rejuvenator dose is clear. Specially for R4 which provided better performance than the virgin mix. However, this mix didn't pass the rutting criteria

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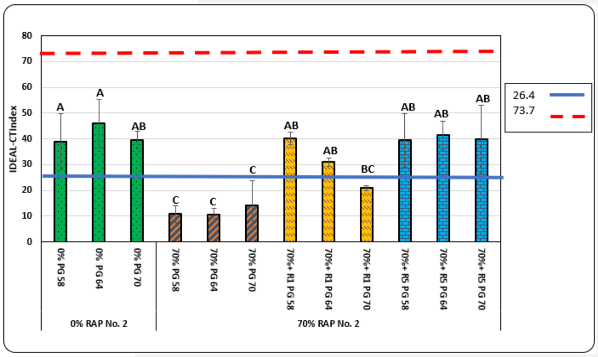
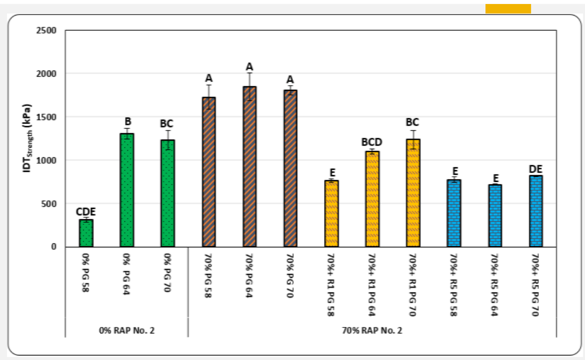
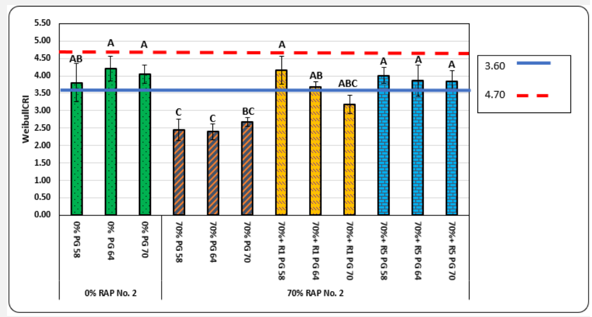
RAP NO. 2

Effect of Rejuvenator using Different Binder PG



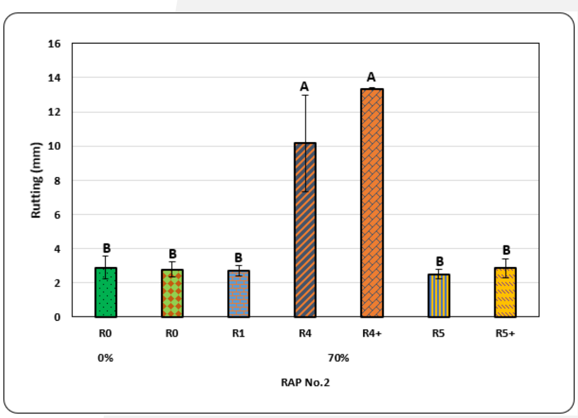




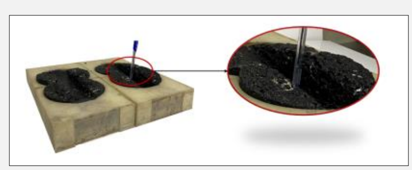
- The binder grade did not affect the IDEAL-CT_{Index} for mixtures without RAP (0 percent RAP) and those prepared with 70 percent RAP
- $IDT_{Strength}$ for mixtures with PG 64-28 and PG 70-28 was higher compared to the ones for PG 58-34 for the mixtures without RAP

RAP NO. 2

Effect of Rejuvenator on Rutting Performance



R4



R4+

- R1 and R5, didn't significantly impact the rutting depth while R4, which had the highest cracking performance, failed the rutting criteria prematurely

RAP NO. 3

- **Material Properties of Mix with (Virgin Aggregate Coarse, Fine and RAP3)**
  - Obtained from Lewiston, ID
  - SP3
  - 12.5 mm
  - Target binder content 5.8%
  - RAP Pb 4.3%
  - PG 70-28

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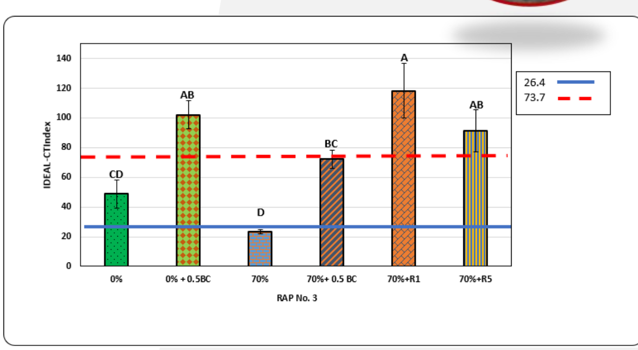
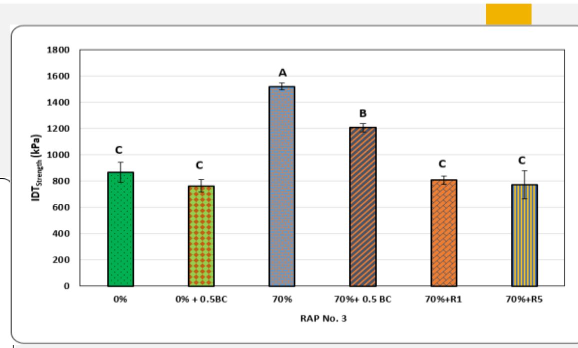
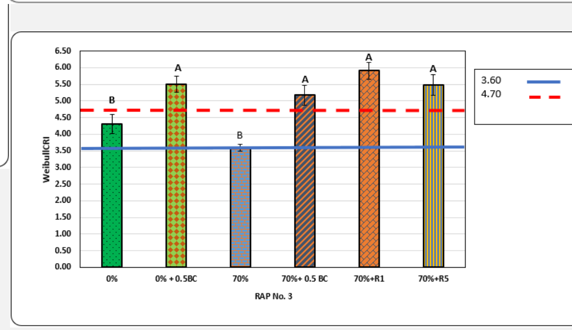
RAP NO. 3

- Effect of RAP content and rejuvenator type







- Increasing RAP content, reduces the cracking resistance
- Both rejuvenators (i.e., R1 and R5) at optimum dose provided better performance than the virgin mix and comparable to mix with increased binder content

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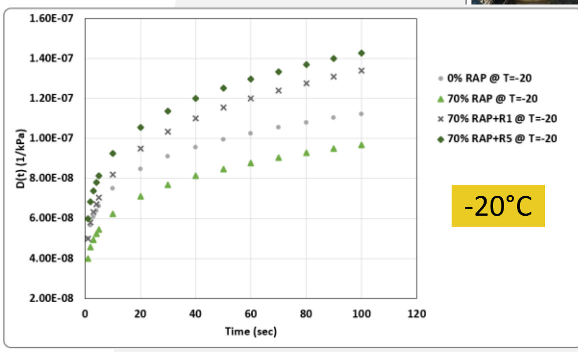
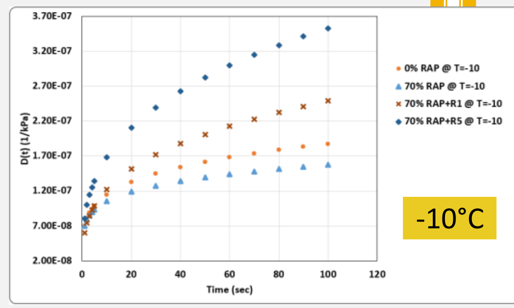
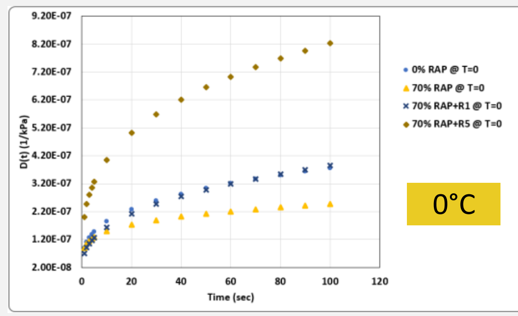
RAP NO. 3

- Effect of Rejuvenator on Low-Temperature Cracking







- Rejuvenators (R1 & R5) provide better low-temp. cracking performance as compared to the control mix (i.e., 70% RAP) and virgin mix (0% RAP)

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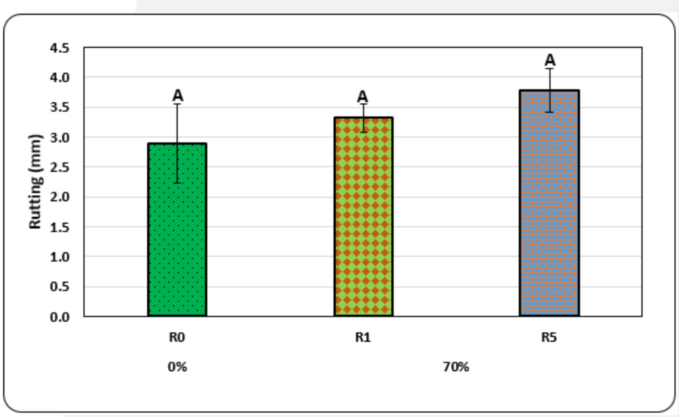
RAP NO. 3

- Effect of Rejuvenator on Rutting performance



- RAP 2, both rejuvenators didn't impact the rutting performance

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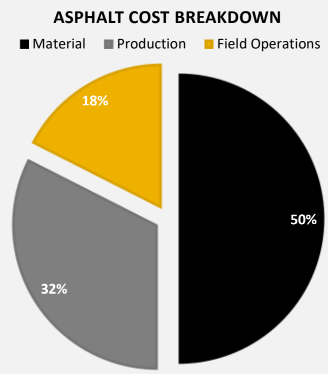
COST ANALYSIS

Material Cost

- NCHRP 927; estimated the cost of materials is in the order of 45-55%, field operation is in the order of 15-20% and the production cost is in the order of 30-35%
- NCHRP 927; production and field operations are "little affected", therefore only material cost are considered

Material Type	Material Description	$Price/ton	
		Low	High
Aggregate	Virgin Aggregates	12	15
	RAP Aggregates	5	8
Virgin Binder	PG 58-28	750	-
	PG 58-34	875	-
	PG 64-28	800	-
	PG 64-34	925	-
	PG 70-28	825	-
Rejuvenator (R1)	Tall oil	4000	4900
Rejuvenator (R5)	Waste Vegetable Oil	3800	-



COST ANALYSIS

Cost Breakdown of RAP No. 2

Mix type		Control 0%		IDEAL-CT_{index}	Control 0% +0.5BC		IDEAL-CT_{index}	25% RAP		IDEAL-CT_{index}	25% RAP + 0.5 BC		IDEAL-CT_{index}	25% RAP + R1		IDEAL-CT_{index}	25% RAP + R5		IDEAL-CT_{index}
Material	Unit Cost $/Ton	Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $	
Virgin Aggregate	$ 13.5	0.94	$12.72		0.94	$11.92		0.71	$ 9.54		0.70	$ 9.49		0.71	$ 9.54		0.71	$ 9.54	
RAP Aggregate	$ 6.5	-	-		-	-		0.25	$ 1.62		0.25	$ 1.61		0.25	$ 1.62		0.25	$ 1.62	
RAP Binder		-	-		-	-		-	-		-	-		-	-		-	-	
Binder Content		0.06	-		0.06	-		0.04	-		0.05	-		0.04	-		0.04	-	
PG 58-28	$ 750	0.06	$43.50		6.3%↑	$47.25		5.80	$33.06		6.3↑	$36.86		5.80	$33.06		5.80	$33.06	
PG 58-34	$ 875		$50.75			$55.13			$38.57			$43.00			$38.57			$40.00	
PG 64-28	$ 800		$46.40			$50.40			$35.26			$39.31			$35.26			$35.26	
PG 70-28	$ 825		$47.85			$51.98			$36.37			$40.54			$36.37			$36.36	
Tall Oil	$ 4,450	-	-		-	-		-	-		-	-		0.004	$18.07		-	-	
Waste Vegetable Oil	$ 3,800	-	-		-	-		-	-		-	-		-	-		0.002	$ 8.46	
Total Cost $	PG 58-28	-	-		-	-		-	-		-	-		-	-		-	-	
	PG 58-34	-	$ 63	39	-	$ 67	102	-	$ 50	20	-	$ 54	46	-	$ 68	52	-	$ 60	26
	PG 64-28	-	-		-	-		-	-		-	-	-	-	-		-	-	
	PG 70-28	-	-		-	-		-	-		-	-	-	-	-		-	-	

Mix type		Control 0%		IDEAL-CT_{index}	Control 0% +0.5BC		IDEAL-CT_{index}	50% RAP		IDEAL-CT_{index}	50% RAP + 0.5 BC		IDEAL-CT_{index}	50% RAP + R1		IDEAL-CT_{index}	50% RAP + R5		IDEAL-CT_{index}
Material	Unit Cost $/Ton	Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $	
Virgin Aggregate	$ 13.5	0.94	$12.72		0.94	$11.92		0.47	$ 6.36		0.47	$ 6.32		0.47	$ 6.36		0.47	$ 6.36	
RAP Aggregate	$ 6.5	-	-		-	-		0.50	$ 3.24		0.50	$ 3.22		0.50	$ 3.24		0.50	$ 3.24	
RAP Binder		-	-		-	-		-	-		-	-		-	-		-	-	
Binder Content		0.06	-		0.06	-		0.03	-		0.04	-		0.03	-		0.03	-	
PG 58-28	$ 750	0.06	$43.50		6.3%↑	$47.25		5.80	$23.06		6.3↑	$26.93		5.80	$23.06		5.80	$23.06	
PG 58-34	$ 875		$50.75			$55.13			$26.90			$31.42			$26.90			$26.90	
PG 64-28	$ 800		$46.40			$50.40			$24.59			$28.73			$24.59			$24.59	
PG 70-28	$ 825		$47.85			$51.98			$25.36			$29.63			$25.36			$25.36	
Tall Oil	$ 4,450	-	-		-	-		-	-		-	-		0.004	$18.07		-	-	
Waste Vegetable Oil	$ 3,800	-	-		-	-		-	-		-	-		-	-		0.004	$16.57	
Total Cost $	PG 58-28	-	-		-	-		-	-		-	-		-	-		-	-	
	PG 58-34	-	$ 63	39	-	$ 67	102	-	$ 36	14	-	$ 41	18	-	$ 55	33	-	$ 53	25
	PG 64-28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	PG 70-28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Mix type		Control 0%		IDEAL-CT_{index}	Control 0% +0.5BC		IDEAL-CT_{index}	70% RAP		IDEAL-CT_{index}	70% RAP + 0.5 BC		IDEAL-CT_{index}	70% RAP + R1		IDEAL-CT_{index}	70% RAP + R5		IDEAL-CT_{index}
Material	Unit Cost $/Ton	Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $		Quantity (Ton)	Cost $	
Virgin Aggregate	$ 13.5	0.94	$12.72		0.94	$11.92		0.28	$ 3.82		0.28	$ 3.79		0.28	$ 3.82		0.28	$ 3.82	
RAP Aggregate	$ 6.5	-	-		-	-		0.70	$ 4.53		0.69	$ 4.51		0.70	$ 4.53		0.70	$ 4.53	
RAP Binder		-	-		-	-		-	-		-	-					-	-	
Binder Content		0.06	-		0.06	-		0.02	-		0.04	-		0.02			0.02	-	
PG 58-28	$ 750	0.06	$43.50		6.3%↑	$47.25		5.80	$15.23		6.3↑	$28.35		5.80	$15.23		5.80	$15.23	
PG 58-34	$ 875		$50.75			$55.13			$17.76			$33.08			$17.76			$17.76	
PG 64-28	$ 800		$46.40			$50.40			$16.24			$30.24			$16.24			$16.24	
PG 70-28	$ 825		$47.85			$51.98			$16.75			$31.19			$16.75			$16.75	
Tall Oil	$ 4,450	-	-		-	-		-	-		-	-		0.004	$18.07		-	-	
Waste Vegetable Oil	$ 3,800	-	-		-	-		-	-		-	-					0.004	$16.57	
Total Cost $	PG 58-28	-	-		-	-		-	-		-	-		-	-		-	-	
	PG 58-34	-	$ 63	39	-	$ 67	102	-	$ 26	14	-	$ 41	30	-	$ 44	40	-	$ 43	39
	PG 64-28	-	$ 59	46	-	-		-	$ 25	10	-	-		-	$ 43	31	-	$ 41	41
	PG 70-28	-	$ 61	40	-	-		-	$ 25	14	-	-		-	$ 43	21	-	$ 42	40

BINDER EVALUATION

Binder evaluation parameters

Glover-Rowe (G-R):

- At temperature of 15 ºC and angular frequency of 0.005 rad/sec.
- $G - R = G^* \cos(\delta)^2 / \sin(\delta)$
- Higher G-R values indicates stiffer binder and brittle behavior
- Threshold 180-600 kPa for block cracking

SuperPave Intermediate-Temperature Specifications PGI:

- AASHTO M 320
- The SuperPave intermediate temperature is, the temperature at which the fatigue parameter G*.sin δ equals to 5000 kPa
- As the percent of RAP increase, PGI temperature increase as well, which indicates more prone to cracking

The Crossover Temperature T_δ=45º:

- The temperature at which the phase angle is equals to 45º or at which the storage modulus is equals to the loss modulus (G'=G")
- Higher temperature indicates stiffer binder and brittle behavior

The Rheological Index (R-value):

- The difference between Log G* at the crossover frequency and the glassy modulus G_g
- Higher R-value indicates stiffer binder and brittle behavior

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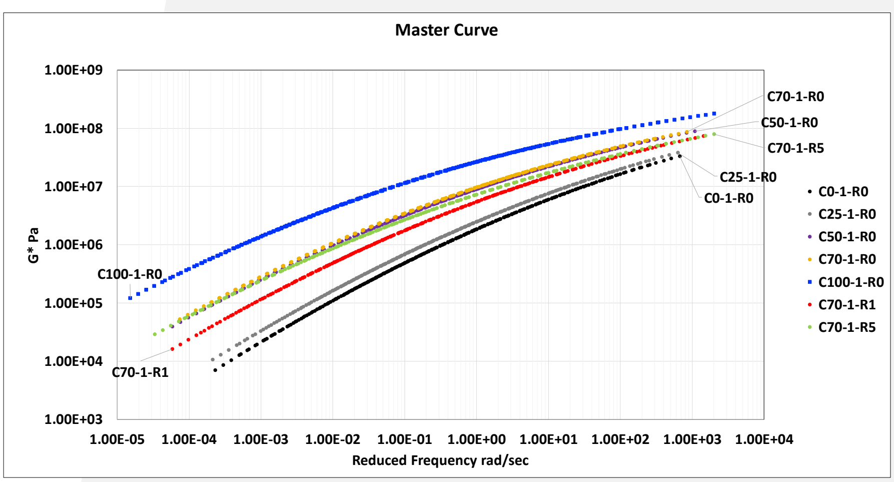
BINDER RESULTS (RAP NO. 2)

Master Curve



- R1 and R5, improved performance as compared to RAP binder (70%)

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OUTLINE

- Motivation
- Objectives
- Methodology and Tasks
- Findings
- Conclusions

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CONCLUSIONS

- The use of rejuvenators in mixtures with low RAP content (e.g., 25 percent), especially for mixtures with good cracking performance, didn't improve the cracking resistance
- The favorable effect of rejuvenators in asphalt mixtures is observed in mixtures with higher RAP content (e.g., 70 percent) for different RAP sources. it was possible to produce mixtures prepared with 70 percent RAP and rejuvenators that provided comparable cracking performance to the mixture without RAP
- The rejuvenator R4 (engineered product) at a higher dose improved the cracking performance of mixtures with RAP; however, these mixtures failed the rutting criteria prematurely (i.e., the mixtures were over softened). These results demonstrated the importance of following a balanced mix design (BMD) approach to satisfy both cracking and rutting criteria

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CONCLUSIONS

- At 25 percent RAP, increasing the binder content was more effective than using rejuvenators in terms of cracking performance and associated cost reduction. This leads to cost savings as well as producing mixtures with comparable or improved performance
- At 50 percent RAP, the use of rejuvenator R1 (tall oil) was the most cost-effective alternative to improve performance as compared to the other rejuvenators including R5 (waste vegetable oil) or increasing the binder content
- At a higher percentage of RAP (e.g., 70 percent), the use of rejuvenators (especially R1) was very effective in improving the cracking resistance with associated cost savings
- Examined Rejuvenators were able to improve the rheological properties of high RAP (i.e., 70% RAP)

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Advanced Asphalt Binder Characterization

Mike Anderson, Asphalt Institute

IDAHO ASPHALT CONFERENCE

October 26, 2023

Acknowledgments

- National Cooperative Highway Research Program (NCHRP)
  - 20-44(19) Project Panel and Program Officers
- Research Teams for NCHRP Projects 09-59, 09-60, and 09-61
- Member Companies of the Asphalt Institute

Asphalt Binders: Improved Aging and Characterization of Asphalt Binder Fatigue and Durability

- NCHRP 09-59
  - Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
- NCHRP 09-60
  - Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
- NCHRP 09-61
  - Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures

Basics First…

- How are asphalt pavements affected by temperature and traffic loading?
- How does aging affect an asphalt pavement's performance?
- What distresses are we trying to minimize?
- What do we want from an asphalt binder specification?

High Temperature Asphalt Pavement Behavior

- **Rutting and depressions**
- **Depends on…**
  - ➢ Asphalt binder (some)
  - ➢ Mineral aggregate (some)
  - ➢ Volumetric proportioning (some)

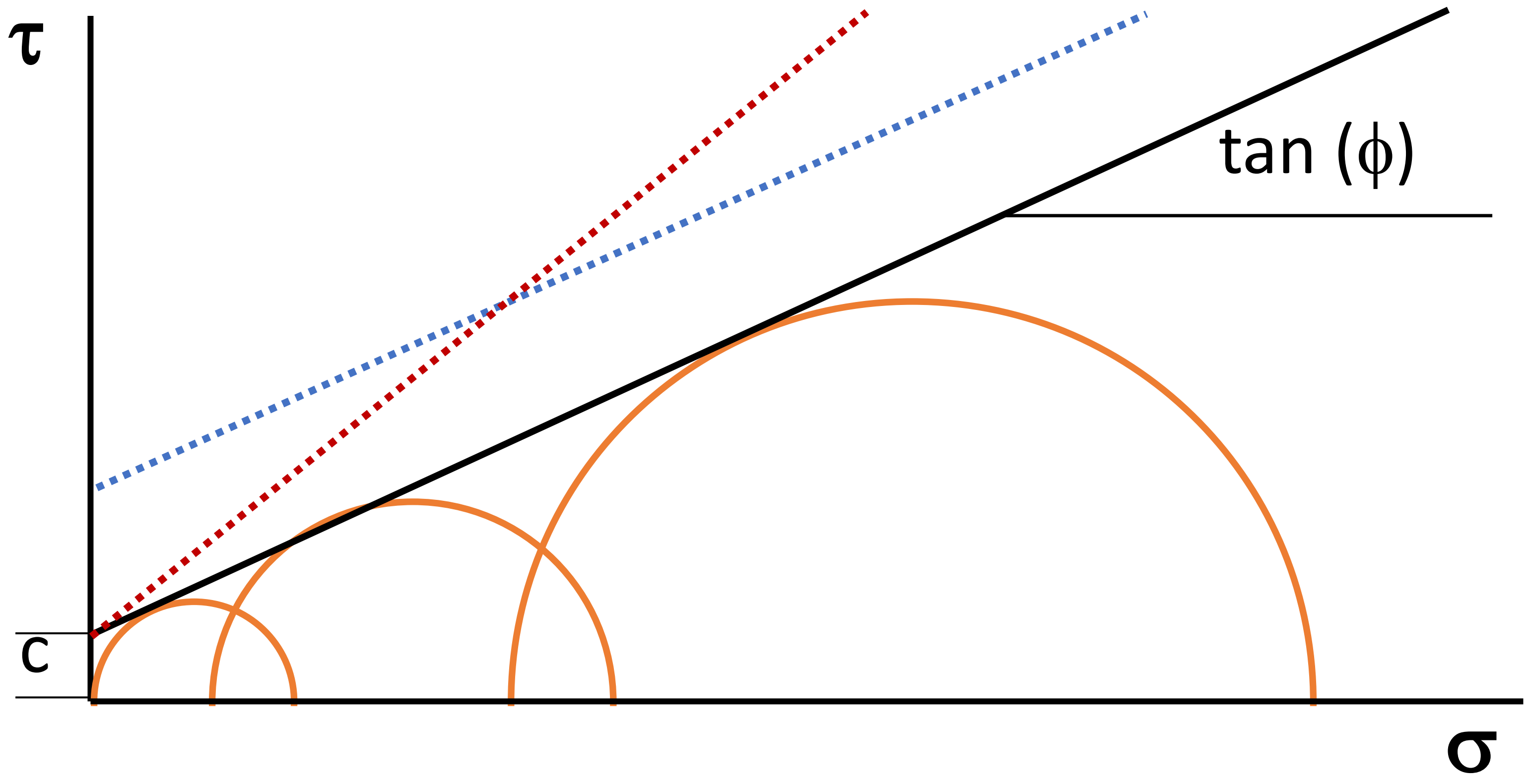
Depression on parking apron


Rutting in wheel path on TW, caused from instable surface mix.

Principles of Rutting in Asphalt Mixtures

- Mohr-Coulomb Failure Theory
  - Described by Nijboer in 1948
    - Simplification of the rutting model considered in SHRP
    - Separated shear strength of asphalt mixture into three components
      - Internal friction of the aggregate structure (ϕ)
      - Initial resistance or cohesion (c) independent of deformation rate
      - Viscous, or rate-dependent, cohesion
  - Cohesion (c)
    - Largely a function of asphalt binder characteristics
  - Angle of internal friction (ϕ)
    - Largely a function of aggregate structure including gradation, particle shape (angularity), and texture

Principles of Rutting in Asphalt Mixtures



Aggregate Structure (Angular)

Asphalt Binder Stiffness (Modification)

Addressing Asphalt Binder Contribution to Rutting: MSCR

Standard Method of Test for

Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

AASHTO Designation: T 350-19 (2023)[1]

AASHTO

Technically Revised: 2019 Reviewed but Not Updated: 2023 Editorially Revised: 2021

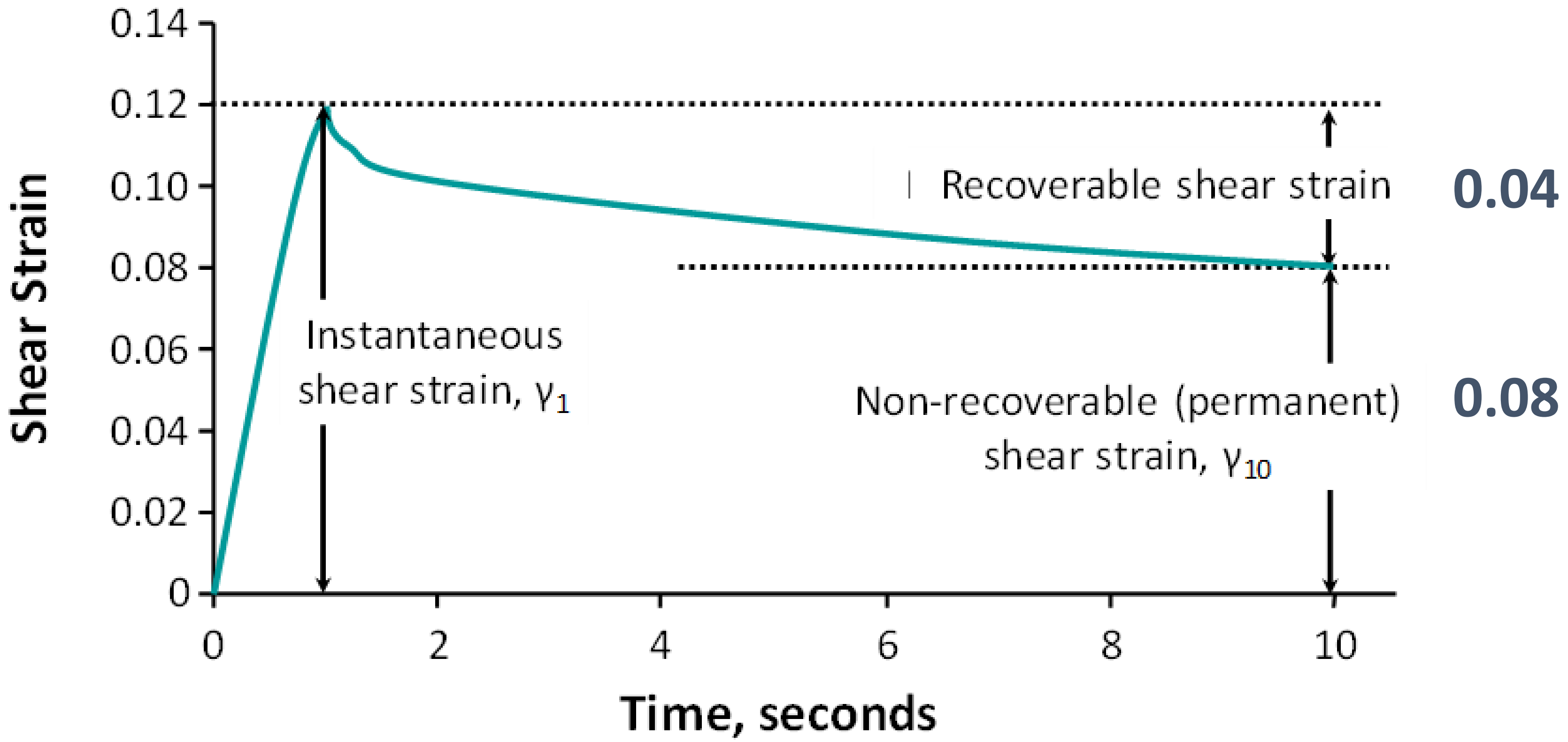
Technical Subcommittee: 2b, Liquid Asphalt

1. SCOPE

1.1. This test method covers the determination of percent recovery and nonrecoverable creep compliance of asphalt binders by means of the Multiple Stress Creep Recovery (MSCR) test. The MSCR test is conducted using the Dynamic Shear Rheometer (DSR) at a specified temperature. It is intended for use with residue from T 240 (Rolling Thin-Film Oven Test (RTFOT)).

1.2. The percent recovery value is intended to provide a means for determining the elastic response and stress dependence of polymer modified and unmodified asphalt binders.

MSCR Specifications for High Temperature Behavior



Assume $\tau = 0.1$ kPa

$J_{nr0.1} = \gamma_{nr}/\tau$

$J_{nr0.1} = 0.08/0.1\text{ kPa} = 0.8\text{ kPa}^{-1}$

Assume $\tau = 0.1$ kPa

$R_{0.1} = \gamma_r / \gamma_i$

$R_{0.1} = 0.04/0.12 = 0.33$ or 33%

Low Temperature Asphalt Pavement Behavior

- **Thermal cracks**
  - Internal stresses induced by rapid temperature drop
  - If binder is too brittle, ability to relax stresses is lessened
  - When stresses exceed strength, cracking occurs
    - Transverse, equal spacing, full width
    - a.k.a. low-temp. cracking

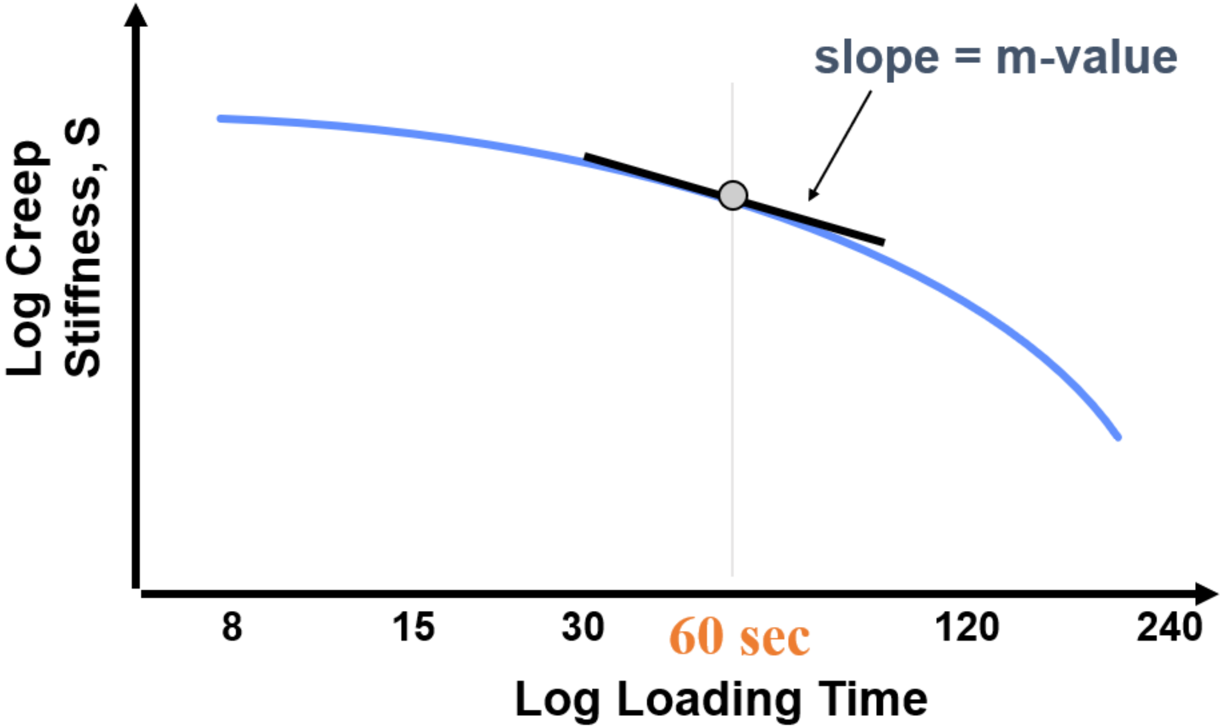
- **Depends on…**
  - ➢ Asphalt binder (lots)
  - ➢ Mineral aggregate (little)
  - ➢ Volumetric proportioning (some)

Low Temperature Cracking in Mix Design

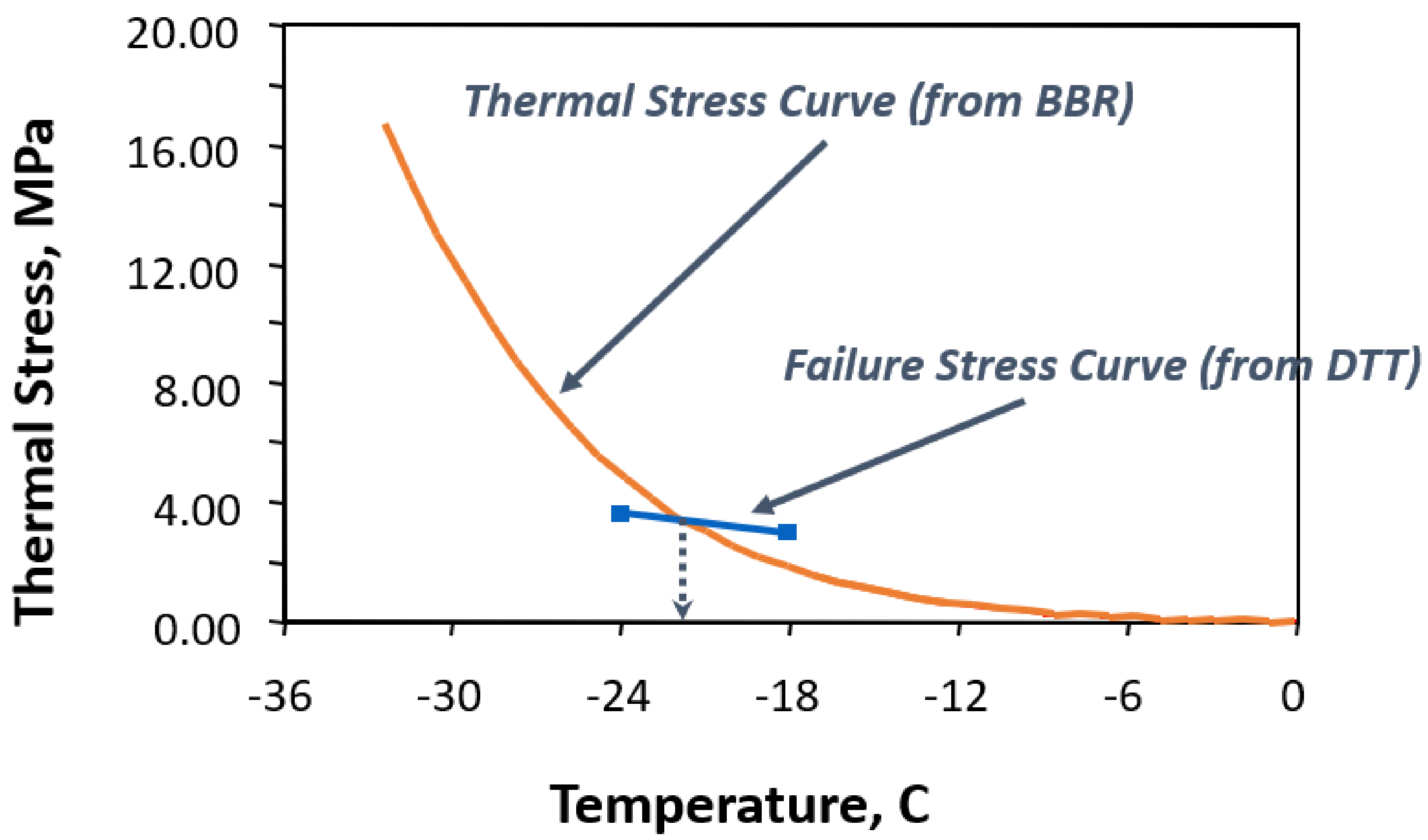
- Recommended Tests and Conditions
  - NCHRP Report 673
    - Research also has shown that thermal cracking performance of asphalt mixtures is most strongly affected by the asphalt binder properties.
      - As long as the asphalt binder that is used in the mixture has the appropriate low temperature properties for the expected use, the expectation for conventional asphalt mixtures will be that they will have adequate laboratory thermal cracking performance.

Linear coefficient of thermal expansion for asphalt binder is on average about 17 times greater than the coefficient of thermal expansion for aggregate

Low Temperature Behavior of Asphalt Binders



Low Temperature Behavior of Asphalt Binders

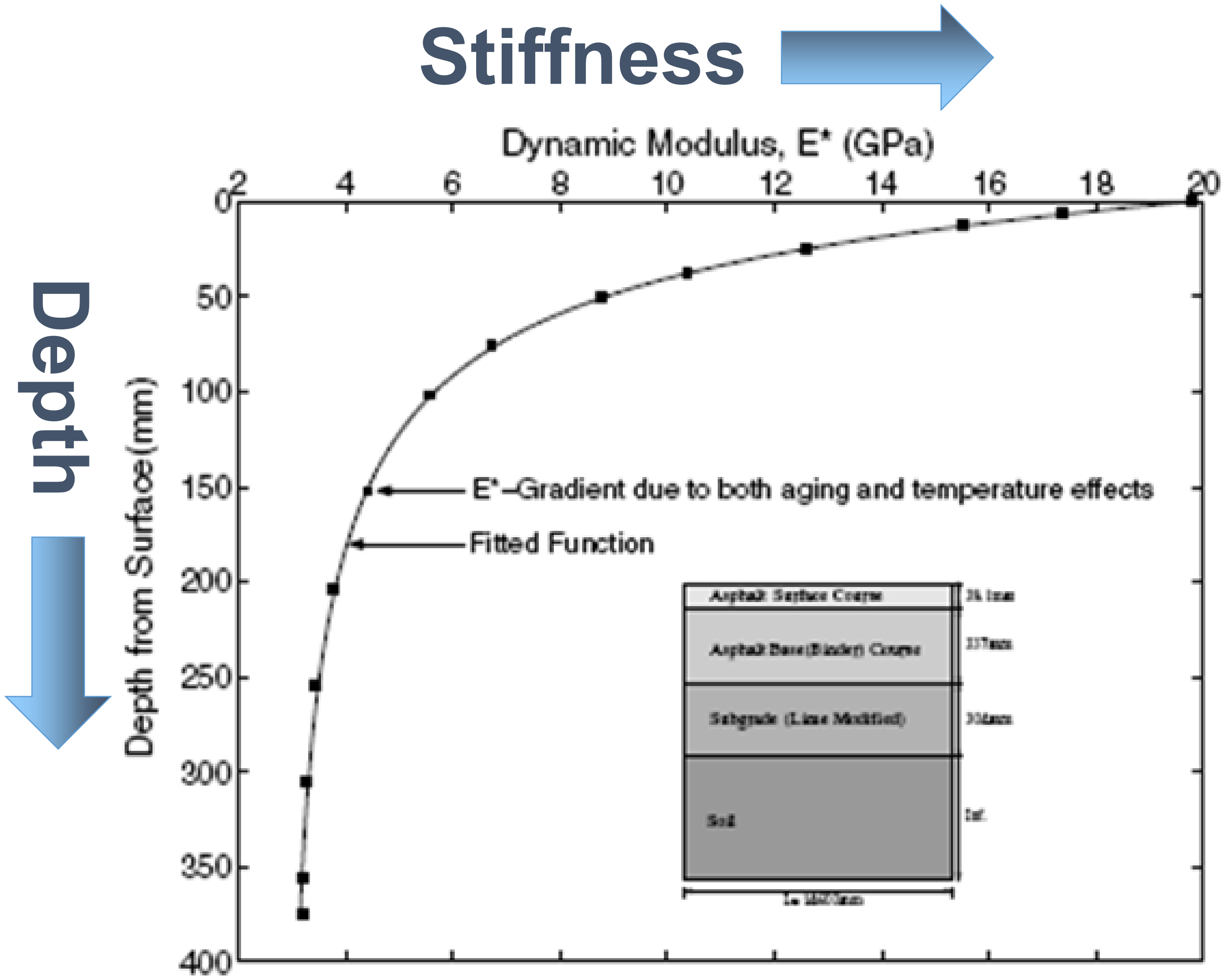


How Asphalt Pavements Behave with Aging

- Durability Cracks
  - Mixture is brittle
  - Random, wandering cracking
  - Longitudinal

- Depends on…
  - Asphalt binder (some)
  - Mineral aggregate (little)
  - Volumetric proportioning (some)

Witczak and Mirza: Global Aging Model (1995)



Basics First…

- What do we want from an asphalt binder specification?
  - SHRP-90-007, The SHRP Asphalt Research Program: 1990 Strategic Planning Document
    - The SHRP asphalt program was based on the premise that **asphalt pavement performance is significantly influenced by the properties of the asphalt binder**.
      - The mix designer must select an asphalt binder having properties that meet required minimum performance levels in order for the asphalt pavement to perform as expected for both its present and future environment and traffic loading conditions.

Basics First…

- What do we want from an asphalt binder specification?
  - SHRP-90-007, The SHRP Asphalt Research Program: 1990 Strategic Planning Document
    - The SHRP asphalt program was originally designed to develop specifications that addressed six pavement performance factors: **permanent deformation (rutting)**; **fatigue cracking; low-temperature (thermal) cracking**; moisture sensitivity; aging; and adhesion.
      - Aging was not considered a distress, per se, but was considered important so that the asphalt binder could be tested in a state approximating that which would be attained after a period of time in service.

Basics First…

- What do we want from an asphalt binder specification?
  - The asphalt binder needs to minimize its contribution to any distress
  - Other factors than asphalt binder properties can lead to distress
    - Aggregate properties
    - Aggregate proportion
    - Volumetric properties
    - Effective asphalt binder content
    - Production in the mixing plant
    - Laydown and compaction
    - Thickness design
    - Drainage

NCHRP 09-59

Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Don Christensen (PI, AAT) and Nam Tran (NCAT)
  - Objectives
    - determine asphalt binder properties that are significant indicators of the fatigue performance of asphalt mixtures
    - identify or develop a practical, implementable binder test (or tests) to measure properties that are significant indicators of mixture fatigue performance for use in a performance-related binder purchase specification such as AASHTO M 320 and M 332

  - NCHRP Report 982, *Relationships Between the Fatigue Properties of Asphalt Binders and the Fatigue Performance of Asphalt Mixtures*

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Key Findings
    - Fatigue life of an asphalt pavement depends upon many factors, but the factors that can be addressed as part of a binder fatigue specification are applied binder strain, binder failure strain and the fatigue exponent.
      - Fatigue life increases with decreasing applied binder strain relative to failure strain and increasing fatigue exponent.
      - Binder failure strain is primarily a function of binder modulus, with failure strain decreasing dramatically with increasing modulus.
      - The fatigue exponent for an asphalt mixture is inversely related to the binder phase angle.

As the binder becomes stiffer (G* increases) fatigue life, or resistance to fatigue damage, decreases

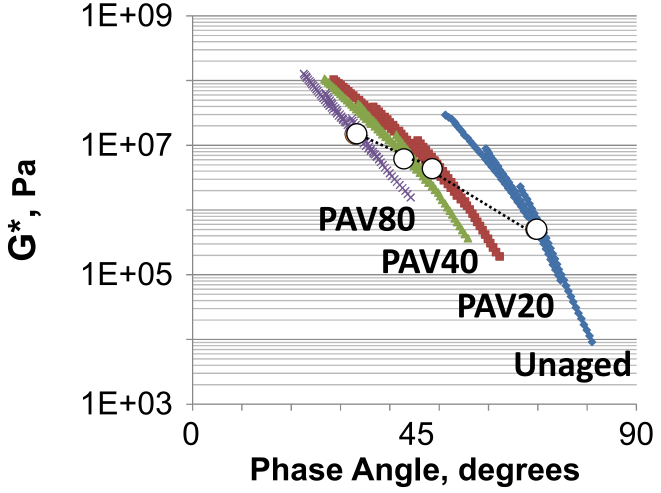
As the binder becomes more brittle (δ decreases) fatigue life, or resistance to fatigue damage, decreases

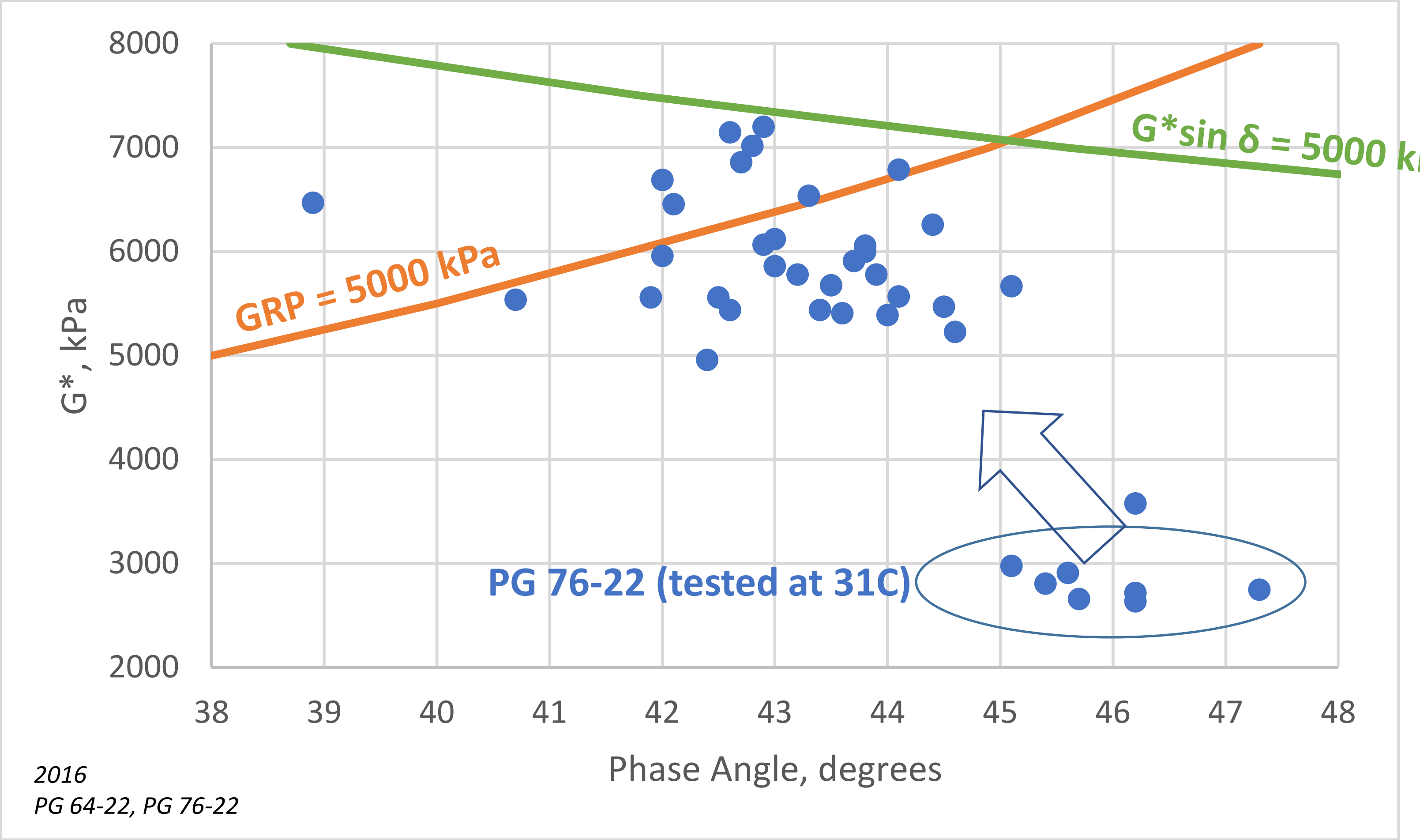
NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Recommendations
    - The current intermediate binder specification parameter, $G^*\sin\delta$, should be replaced by the Glover-Rowe parameter (GRP) determined at a frequency of 10 rad/s. The maximum allowable value for GRP after 20-hour PAV aging should be 5,000 kPa.
    - $GRP = G^*(\cos\delta)^2 / (\sin\delta)$

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Expected Impacts





NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Recommendations
    - The binder fatigue specification should include an allowable range for the Christensen-Anderson R-value of from 1.5 to 2.5, after 20-hour PAV aging.
    - The R-value should be calculated using the following equation:

$$R = log(2)\frac{log(S/3{,}000)}{log(1-m)}$$

Where

R = Christensen-Anderson R (rheologic index)
S = BBR creep stiffness at 60 seconds, MPa
m = BBR m-value at 60 seconds

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance

Project :	sga	Target Temp (°C) :	-18.0	Conf Test (GPa) :	221
Operator :	mrp	Min. Temp (°C) :	-18.0	Conf Date :	05/20/2016
Specimen :	NC-B-1	Max. Temp (°C) :	-17.9	Force Const (mN/bit) :	0.15
Test Time :	04:36:30 PM	Temp Cal Date :	05/20/2016	Defl Const (µm/bit) :	0.139
Test Date :	05/20/2016	Soak Time (min) :	60.0	Cmpl (µm/N) :	6.25
File Name :	16052005	Beam Width (mm) :	12.70	Cal Date :	05/19/2016
BBR ID :	3474	Thickness (mm) :	6.35	Software Version :	BBRw 1.24

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value	R-value
8.0	978	0.228	346	346	0.000	0.282	1.96
15.0	977	0.273	289	288	-0.346	0.306	1.93
30.0	976	0.341	231	231	0.000	0.332	1.91
60.0	976	0.433	182	182	0.000	0.357	1.91
120.0	975	0.560	140	141	0.714	0.383	1.91
240.0	974	0.734	107	107	0.000	0.409	1.91

A = 2.76 B = -0.205 C = -0.0428 R^2 = 0.999988

Force (t=0.0s) = 36 mN Deflection (t=0.0s) = 0.000 mm
Force (t=0.5s) = 955 mN Deflection (t=0.5s) = 0.113 mm

Max Force Deviation (t=0.5 - 5.0s) = -20, +4 mN
Max Force Deviation (t=5.0 - 240.0s) = -3, +4 mN

Average Force (t=0.5 - 240.0s) = 975 mN
Maximum Force (t=0.5 - 240.0s) = 979 mN
Minimum Force (t=0.5 - 240.0s) = 955 mN

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value	R-value
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240.0	974	0.734	107	107	0.000	0.409	1.91

$$R = \log(2) * \frac{\log\left(\frac{S}{3000}\right)}{\log(1-m)} = \quad 0.30 * \frac{log\left(\frac{182}{3000}\right)}{log(1-0.357)} = 1.91$$

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Recommendations
    - The current intermediate test temperatures in AASHTO M 320 and M 332 should be replaced by temperatures based on the low PG of the asphalt binder instead of the current temperatures which use the average of the High and Low PG temperatures plus 4°C.

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Recommendations

Low PG	Intermediate Test Temperature, °C
-10	29
-16	27
-22	25
-28	22
-34	19

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
    - Expected Impacts

High PG	PG 52							PG 58					PG 64						PG 70						PG 76				
Low PG	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34
≤ 5000 kPa	**DSR G*sin** δ (Dynamic Shear Rheometer), AASHTO T 315																												
	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16	34	31	28	25	22	19	37	34	31	28	25
	29	**27**	**25**	**22**	**19**			**27**	**25**	**22**	**19**		**29**	**27**	**25**	**22**	**19**		**29**	**27**	**25**	**22**	**19**		**29**	**27**	**25**	**22**	**19**

NCHRP 09-60

Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Jean-Pascal Planche (PI, WRI), Michael D. Elwardany (WRI), Donald Christensen (AAT), Gayle King (Consultant), Carolina Rodezno (NCAT),and Snehalata Huzurbazar (Consultant/Statistician)
  - Objectives
    - propose changes to the current performance-graded (PG) asphalt binder specifications, tests, and practices to remedy gaps and shortcomings related to the premature loss of asphalt pavement durability in the form of cracking and raveling.
  - Status
    - The draft final report for Phases I and II will be published in conjunction with that for the prospective Phase III.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Key Findings
    - Recommend adding ΔT_c to AASHTO M 320 and M 332 as a specification parameter.
      - Relates to the relaxation properties of unmodified binders and generally relates to the colloidal structure of the asphalt binder.
    - The use of ΔT_c alone can underestimate the performance of some complex binders such as polymer modified asphalt (PMA) binders
      - Due to an inability to capture failure properties outside the linear viscoelastic (LVE) domain such as strength/strain tolerance of PMAs.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Key Findings
    - To capture strength/strain tolerance, it is recommended to use the Asphalt Binder Cracking Device (ABCD) to determine the critical cracking temperature, T_{cr}
      - AASHTO T 387, Determining the Cracking Temperature of Asphalt Binder Using the Asphalt Binder Cracking Device (ABCD)
    - T_{cr} is used with the temperature at which BBR Stiffness at 60 seconds of loading is equal to the specification value of 300 MPa ($T_{c,S}$)

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Key Findings
    - A new parameter, ΔT_f is determined as the difference between $T_{c,S}$ and T_{cr}
      - Higher values of ΔT_f are associated with better asphalt binder strength/strain tolerance relative to its stiffness.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations

$\Delta T_c < -6°C$	FAIL
$\Delta T_c > -2°C$	PASS
$-6°C < \Delta T_c < -2°C$	TBD

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations

$-6°C < \Delta T_c < -2°C$ TBD

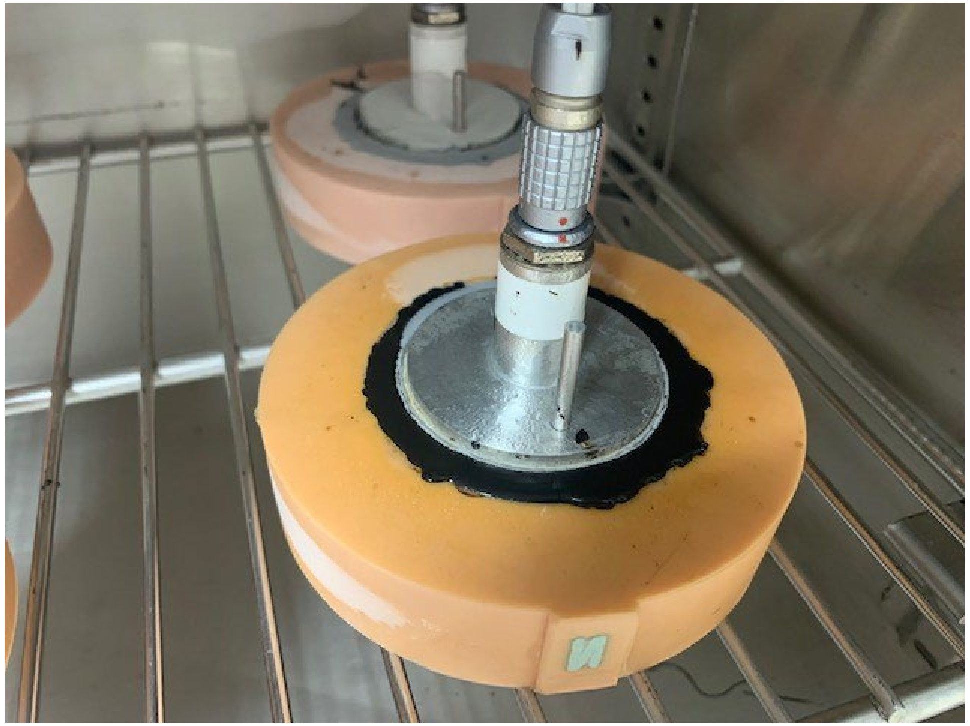
ABCD test is used to determine T_{cr} and, subsequently, ΔT_f.

For PAV20 asphalt binders, ΔT_f must be greater than a specified value from 7 to 10°C as a function of the ΔT_c value to meet the specification.

NCHRP 09-60

- ABCD
  - AASHTO T 387
  - Summary of Method
    - Asphalt binder is heated and poured into silicone mold with strain gauge
    - Sample is cooled at a constant rate
      - From 20°C to 0°C in 30 minutes (40°C/hr) **20°C/hr (NCHRP 09-60)**
      - From 0°C to cracking temperature at a rate of 20°C/hr **10°C/hr (NCHRP 09-60)**
    - Sample cracks when jump in strain appears
      - T_{cr} is temperature at which that jump occurs

AASHTO T 387



Photos taken at Ohio DOT Office of Materials Management

AASHTO T 387

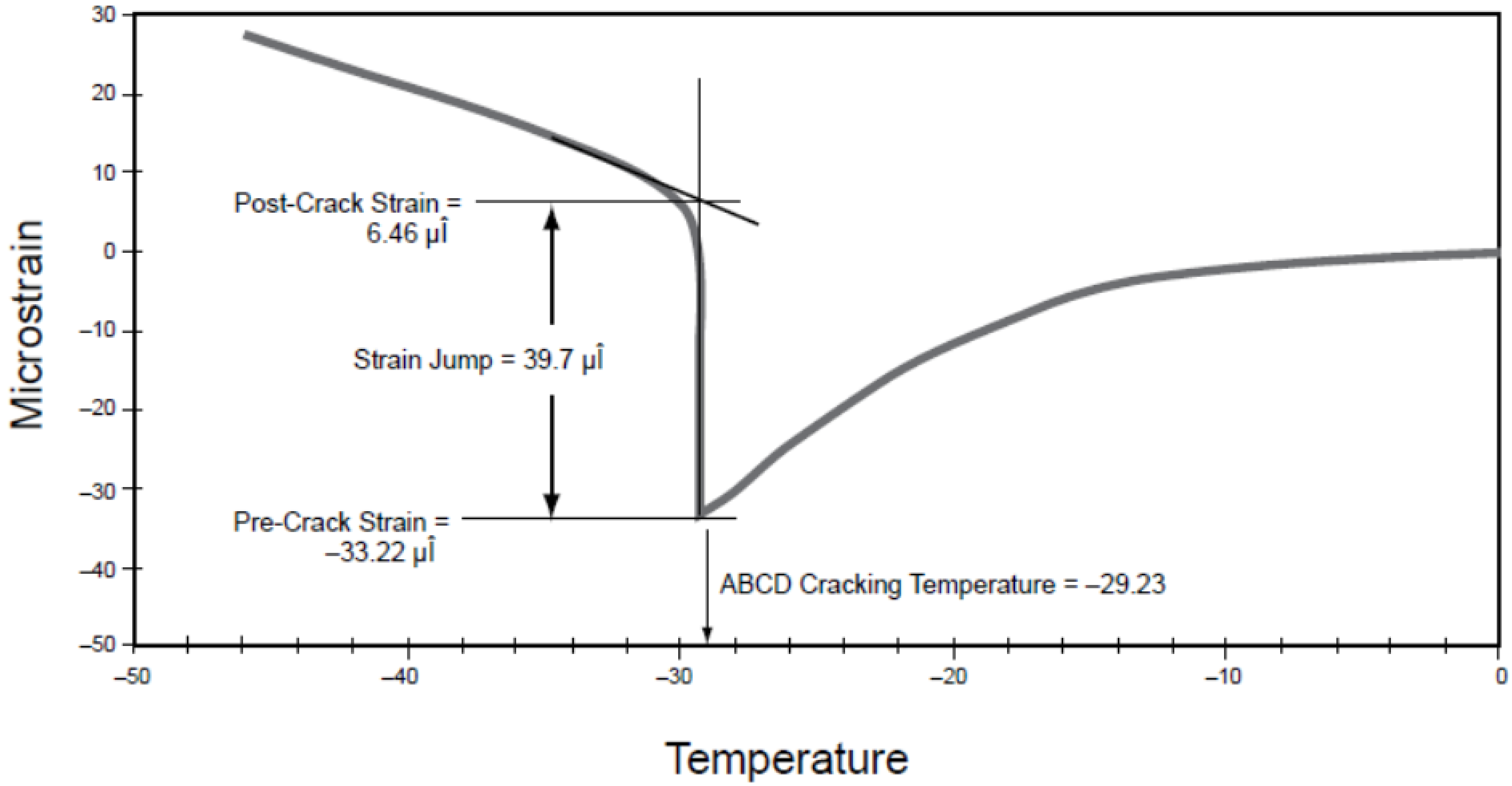


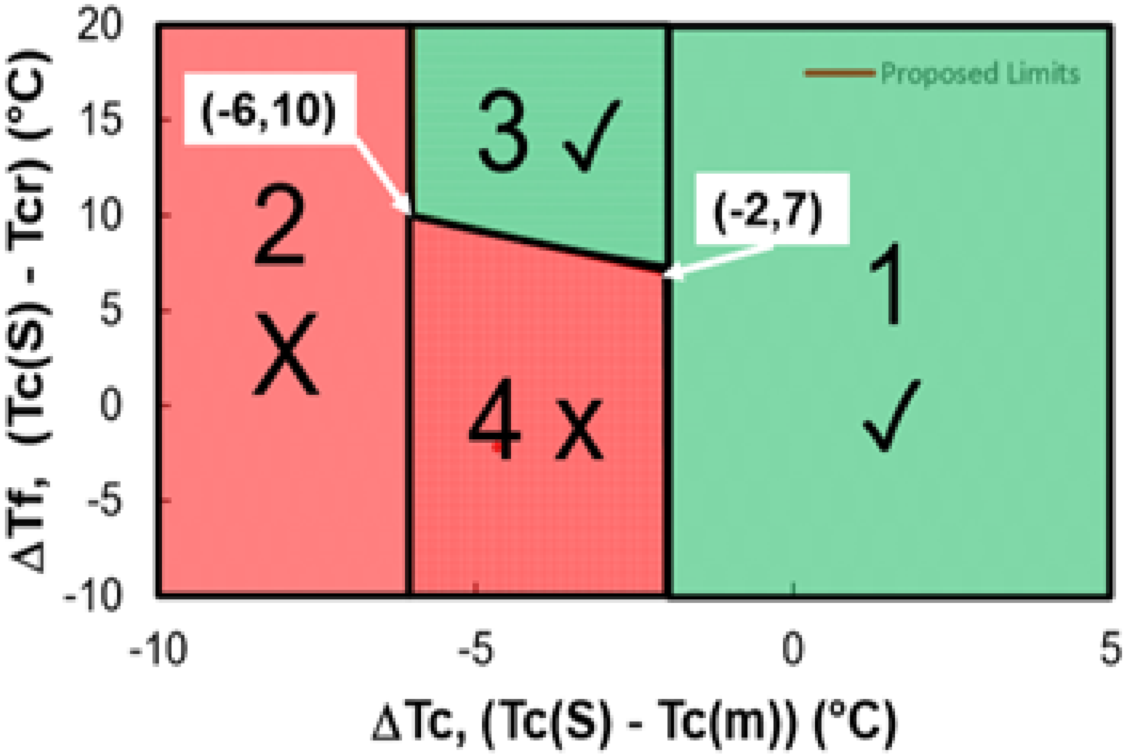
Figure 6—Typical ABCD Test Results: Strain versus Temperature

NCHRP 09-60

Summary on Proposed Specs Based on ABCD & BBR

Testing

- RTFO+PAV20
- LPG: BBR test + ABCD test only for critical binders
- 3 PAV pans are sufficient for both BBR & ABCD Tests



Proposed specifications framework

- Addition to current Climate-based PG
- Universal - blind
- BBR alone when
  ΔTc > -2°C (Accepted)
  ΔTc <-6°C (Rejected)
- BBR & ABCD for
  -6°C<ΔTc <-2°C
  ΔTf min = 7°C at -2°C
  ΔTf min = 10°C at -6°C

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Expected Impacts
    - The determination of ΔT_c requires testing at two or more BBR temperatures. This may be an operational challenge for user agencies who are most often just verifying the grade of the asphalt binder.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Expected Impacts
    - The determination of ΔT_f requires the use of the ABCD test to first determine T_{cr}.
    - The ABCD equipment is not widely available commercially at this time.
    - Estimated equipment cost is likely to be in the range of $40,000 to $50,000.
      - AI has ordered ABCD to be delivered later in 2022.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Expected Impacts
    - The use of the ABCD test with BBR testing means that 1-2 additional pans of PAV-aged asphalt binder may be needed.

Asphalt Binder Specification Objectives

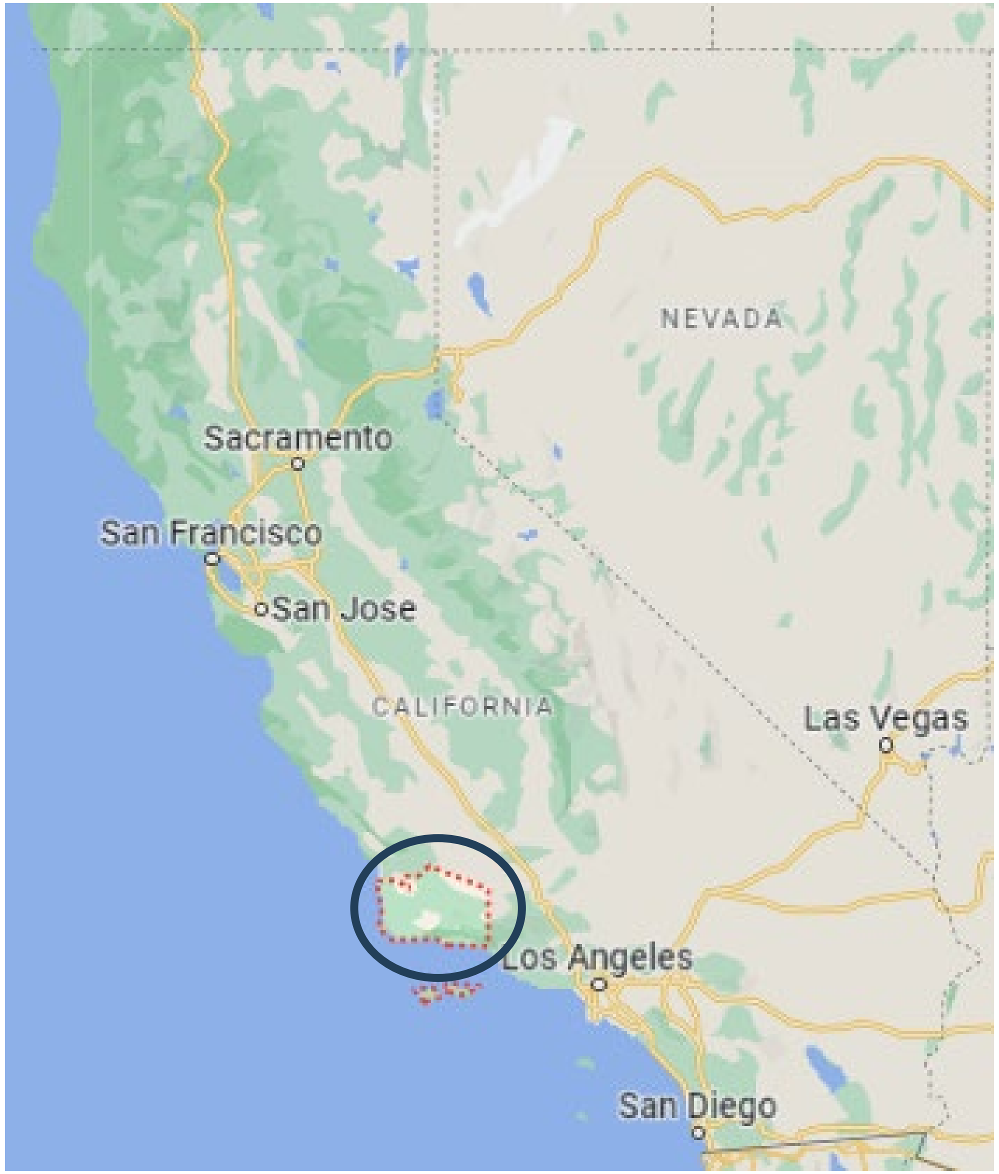
- NCHRP 09-59 Objectives
  - determine asphalt binder properties that are significant indicators of the **fatigue** performance of asphalt mixtures
  - identify or develop a practical, implementable binder test (or tests) to measure properties that are significant indicators of mixture fatigue performance for use in a performance-related binder purchase specification such as AASHTO M 320 and M 332
- NCHRP 09-60 Objectives
  - propose changes to the current performance-graded (PG) asphalt binder specifications, tests, and practices to remedy gaps and shortcomings related to the premature loss of asphalt pavement **durability in the form of cracking and raveling**.

Zube and Skog:
"Final Report on the Zaca-Wigmore Asphalt Test Road"

- 1969 AAPT Paper
- Relevance to PG Specification
  - From SHRP Report A-367 (Pages 36-37):
    - "At the suggestion of the A-003A researchers, and in light of an **evaluation of the fatigue performance in field trials such as Zaca-Wigmore** (figure 2.22), the fatigue criterion was changed to reflect the energy dissipated per load cycle. Dissipated energy in a dynamic shear test is appropriately **calculated as G*sin δ** (Ferry 1980)."

Zube and Skog:
"Final Report on the Zaca-Wigmore Asphalt Test Road"

- Two main types of failure during service life were encountered on the project
  - Fatigue Cracking
    - Most prevalent
    - Related to recovered asphalt binder consistency (i.e., stiffness)
  - Block Cracking with Raveling
    - Most prevalent in the passing lane
    - Gain in shear susceptibility during weathering
    - Drop in ductility (i.e., viscoelastic behavior) during service life

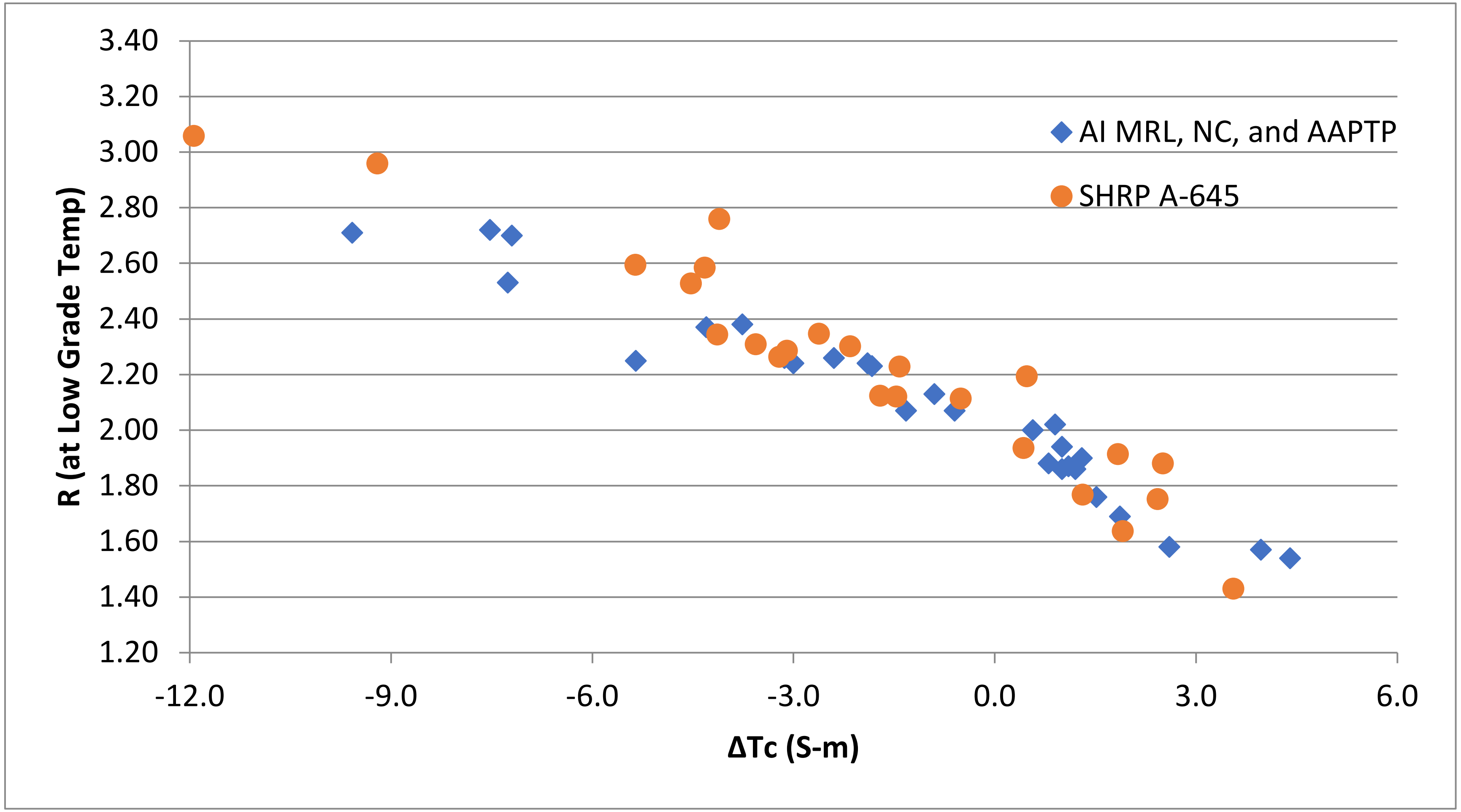


Lessons from the Zaca-Wigmore Asphalt Test Road

Specification	Fatigue Cracking	Block Cracking (Durability)
Current (M 320 and M 332)	$G^*\sin\delta$	n/a
Research (M 320 and M 332)	GRP ($G^*\cos^2\delta/\sin\delta$)	R-value **or** ΔT_c **or** δ at $G^*_{critical}$

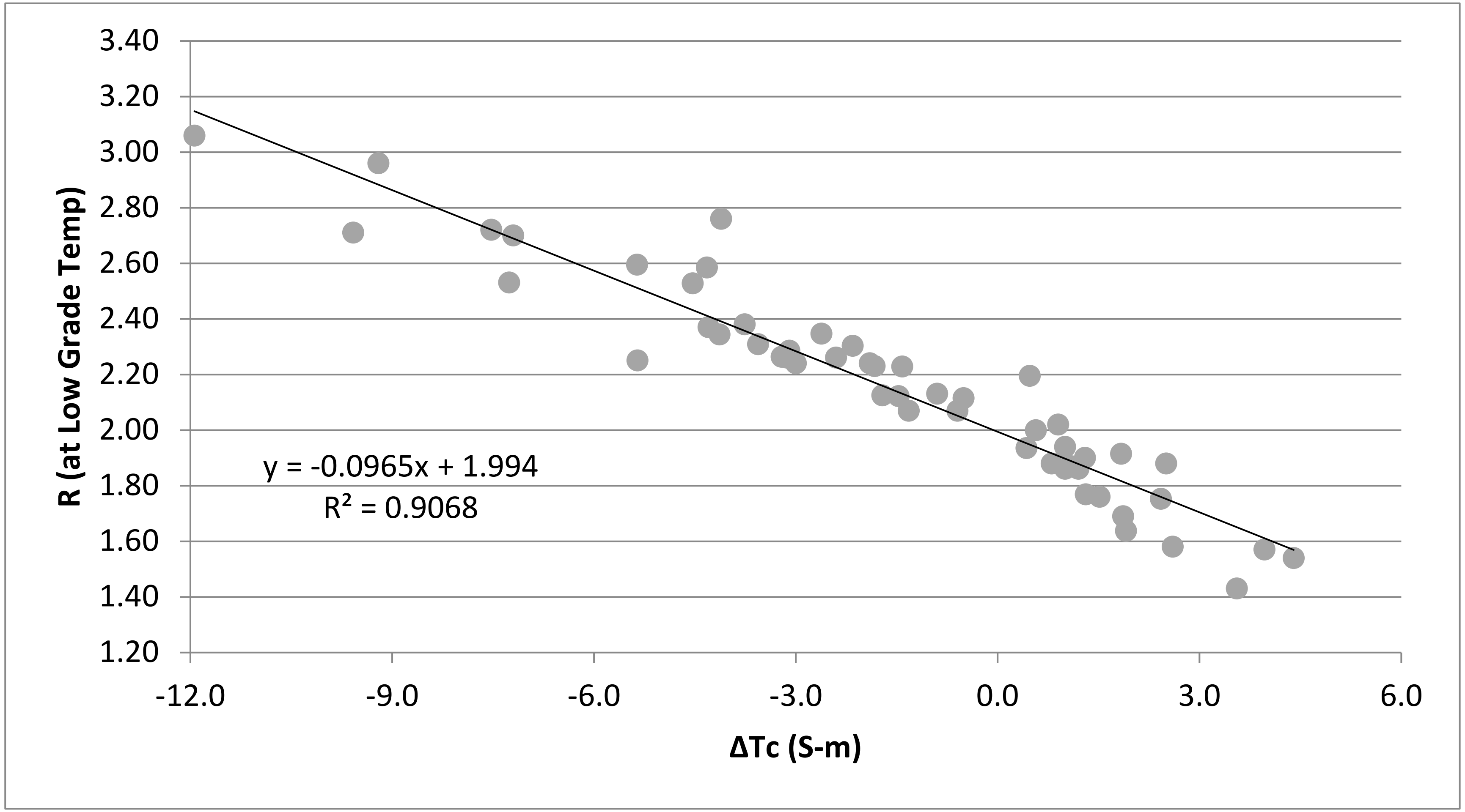
NCHRP 09-59 and NCHRP 09-60

- Relationship between **R** (09-59) and **ΔTc** (09-60)



Relating Slope Parameters (R and ΔTc)

- Unmodified Asphalt Binders (SHRP MRL, SHRP A-645, AAPTP 06-01)



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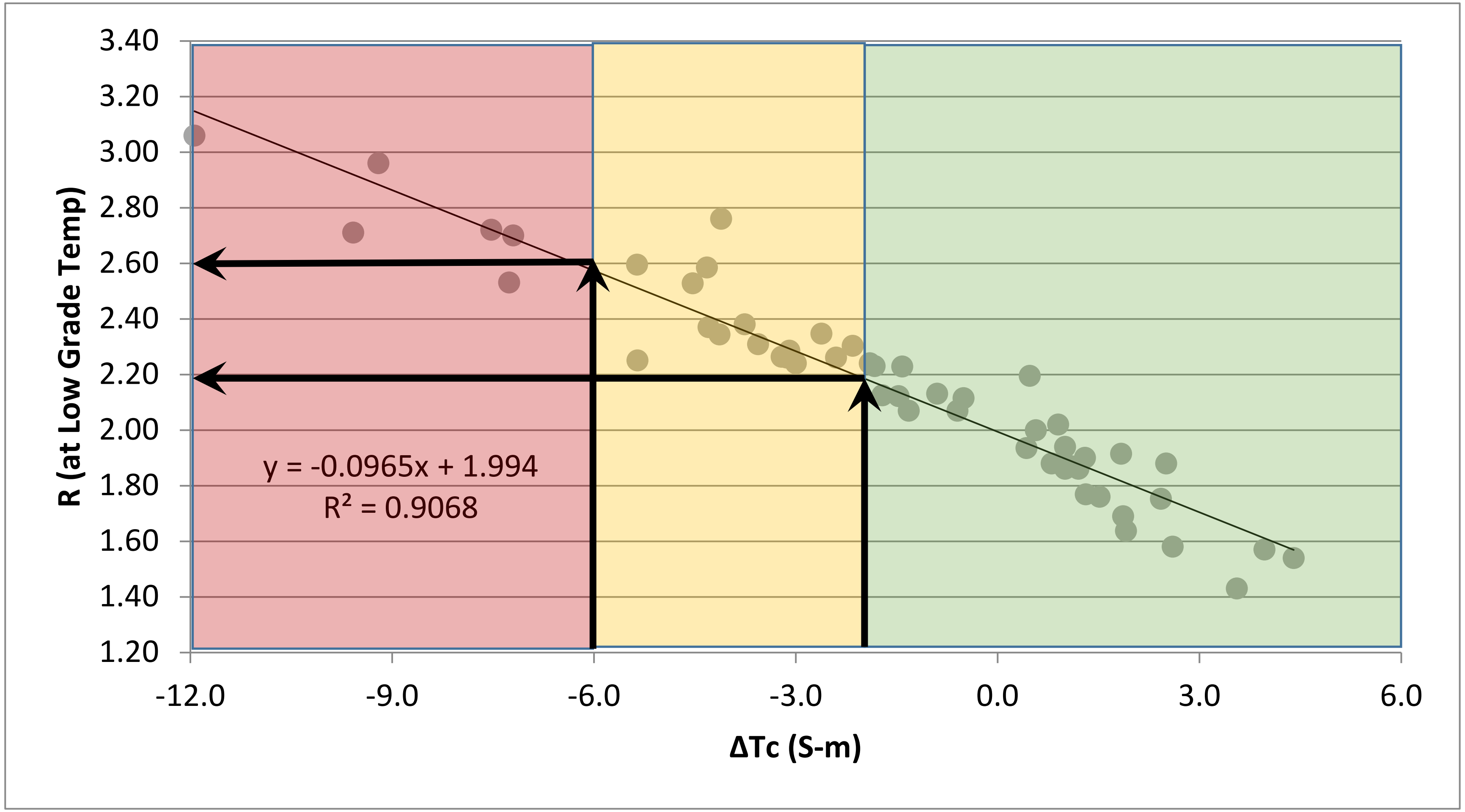

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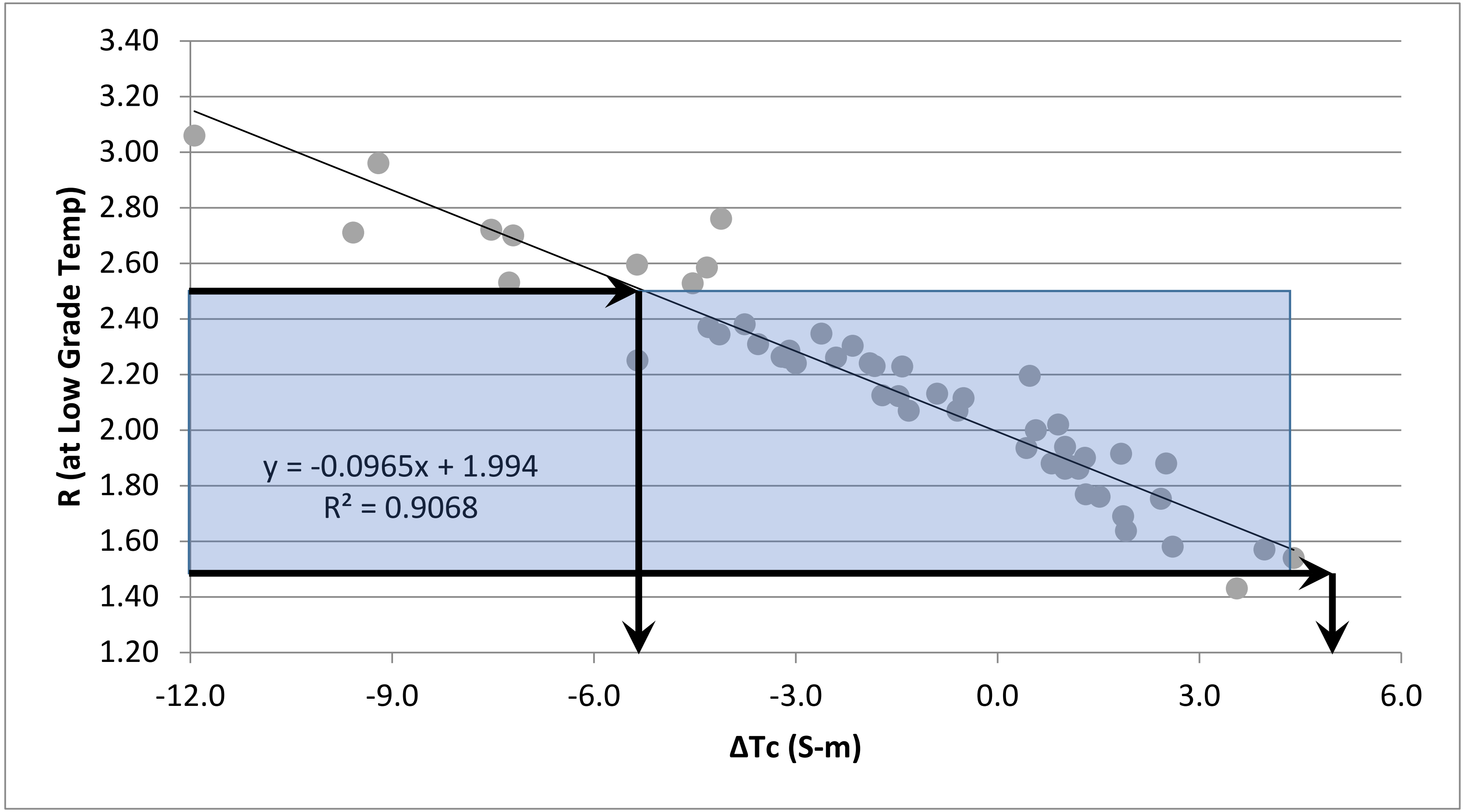

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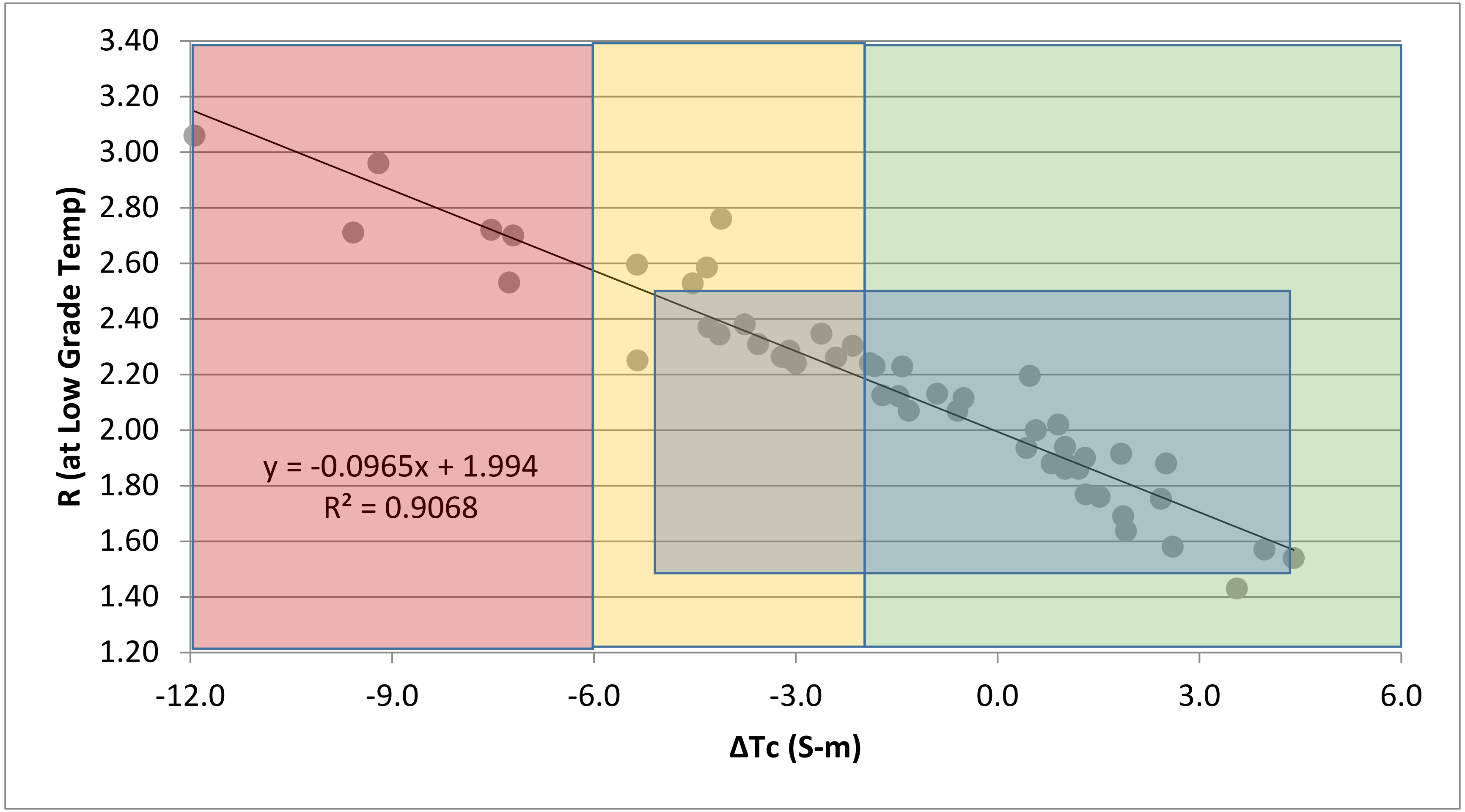
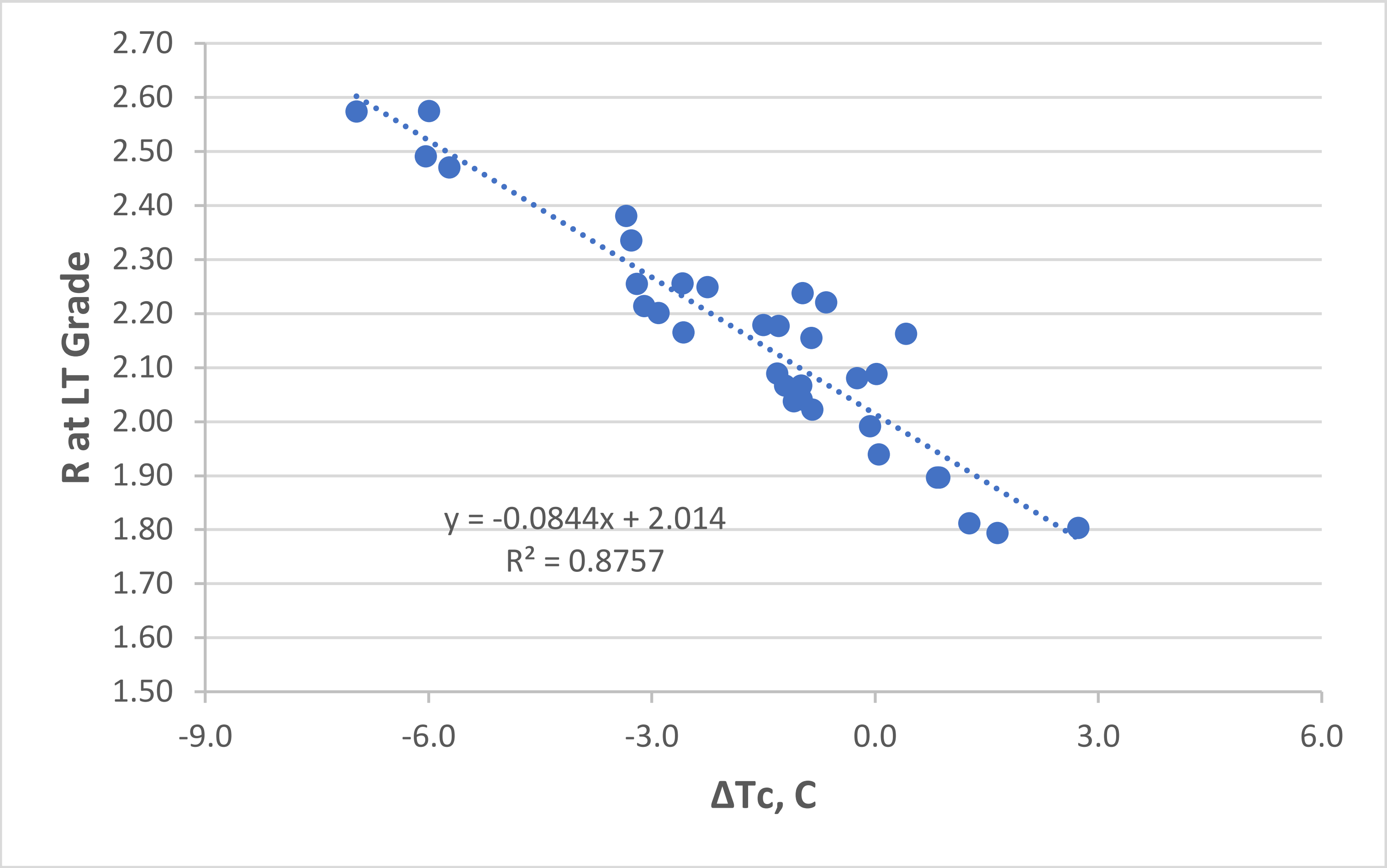


Relating Slope Parameters (R and ΔTc)

- Modified Asphalt Binders (NCHRP 09-10 Research, Report 459)



12 Modification Materials/Processes

- SBS Triblock
- SBS Radial
- SB
- SBR LMW
- SBR HMW
- EVA
- Ethylene Terpolymer
- Polyethylene (Unstabilized)
- Polyethylene (Stabilized)
- Steam Distilled
- Oxidized (Straight Run)
- Oxidized (Back Blended)

14 Grades

- From 46-88 on High PG
- From -16 to -40 on Low PG

NCHRP 09-61

Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Ramon Bonaquist (PI, AAT), Jeramie J. Adams (WRI), and David A. Anderson (Consultant)
  - Objectives
    - develop practical laboratory aging methods to accurately simulate the short-term (from production to placement) and long-term (in-service) aging of asphalt binders.
    - determine the relationship between different methods of laboratory aging of asphalt binders and the actual aging that occurs during mixture production, transport, and placement as well as during the service life of the pavement structure.
  - NCHRP Report 967, *Asphalt Binder Aging Methods to Accurately Reflect Mixture Aging*

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Key Findings
    - The recommendation for short-term conditioning of asphalt binders is to continue to use AASHTO T 240
    - Although the film thickness and its renewal during the test depend on the consistency of the asphalt binder, properties of residue from AASHTO T 240 agree reasonably well with the properties of asphalt binder recovered from mixtures which were short-term conditioned in accordance with the recommendations from NCHRP 09-52

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Key Findings
    - The recommendation for long-term conditioning of asphalt binders is that changing the operating parameters of the PAV (AASHTO R 28) can produce residue that reasonably simulates near-surface aging after 10 years in-service.
    - Changes will generally require thinner films and high temperatures in the PAV.

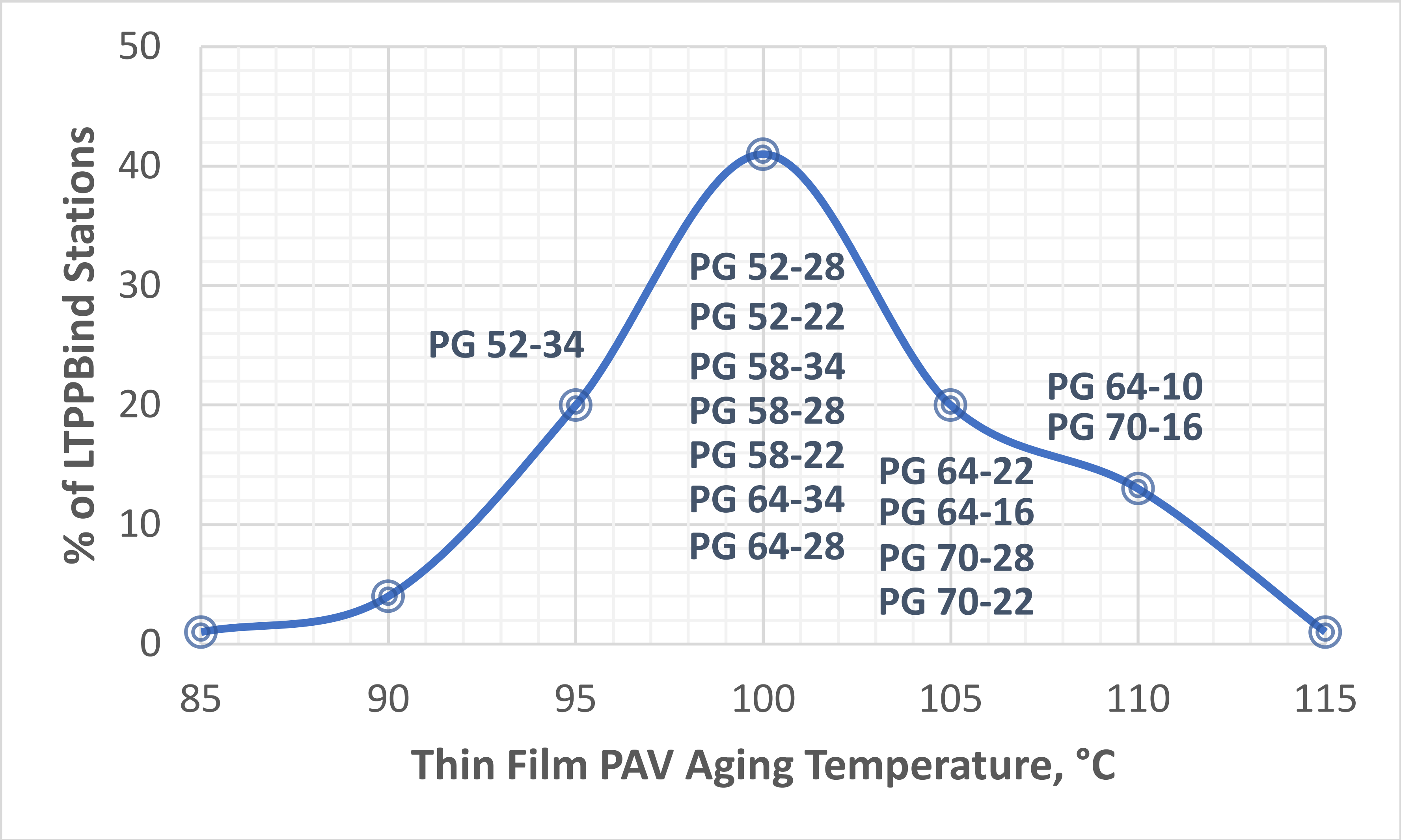
NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Key Findings
    - Use PAV procedure with the standard 20-hr aging at 2.1 MPa pressure but only 12.5 grams of asphalt binder in the pan (instead of 50 grams)
      - Calibrated results to the properties of recovered asphalt binders from 26 LTPP pavement sections where original binder and cores from 8 to 16 years in-service were available.
      - The findings of that calibration indicate that the PAV temperature to use depends on the average of the 98 percent reliability high and low pavement temperature from LTPPBind3.1.

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Recommendations
    - Continue to use RTFO for short-term aging of asphalt binders
    - If 20-hour PAV is to be used then no changes recommended
    - If longer aging simulation is required then instead of 40-hour PAV using 50 grams of asphalt binder at 90, 100, or 110°C use 20-hour PAV with 12.5 grams of asphalt binder at varying temperature based on high and low pavement temperature.

NCHRP 09-61



Thin Film PAV Aging Temperature is calculated

Function of average of high and low pavement temperature at 98% reliability

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Expected Impacts
    - The challenge with using thinner films is maintaining a consistent film thickness.
      - Requires very level pans that are not warped.
      - Operationally could pose a significant challenge for labs to routinely ensure levelness.
      - An extra levelling step conducted at a higher temperature under inert atmosphere may be needed for some modified asphalt binders.

Future Performance-Graded Asphalt Binder Specifications

Developments in Asphalt Binder Tests and Specifications Resulting from National Research

- **NCHRP 09-59**
  - Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance

    - Recommend Glover-Rowe Parameter (GRP) on PAV-aged Asphalt Binder instead of G*sin δ
      - $G^*\cos^2\delta/\sin\delta \leq 5000$ kPa at 10 rad/s and intermediate temperature
    - Recommend R-value calculated from BBR data as additional parameter for durability
      - $1.50 \leq R \leq 2.50$
    - Recommend intermediate temperatures to be based only on low temperature grade rather than as a function of high and low temperatures

- **NCHRP 09-60**
  - Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications

- Recommend using ΔT_c as added parameter for durability, relaxation
  - ΔT_c minimum of -6°C
    - $\Delta T_c < -2$°C requires passing value of ΔT_f to qualify
    - Similar to Footnote g in AASHTO M 320 Table 1
  - ΔT_f determined using T_{cr} from ABCD and $T_{c,S}$ from BBR

- **NCHRP 09-61**
  - Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
    - No change in RTFO procedure
      - Note elevation change in new version of AASHTO T 240
    - No change in PAV procedure for standard long-term aging
    - If considering extended aging (to simulate 40-hour PAV), use…
      - Thinner film in PAV pan (12.5 grams)
      - 20 hours, 2.1 MPa air pressure
      - Revised temperature based on average of 98% high and low PG
        - 5°C increments

Conceptual PG Asphalt Binder Specification (Standard PAV)

Performance Grade:	PG 64						PG 70					
	–10	–16	–22	–28	–34	–40	–10	–16	–22	–28	–34	–40
Average 7-day max pavement design temp, °C[a]	<64						<70					
Design low pavement temperature, °C[a]	>–10	>–16	>–22	>–28	>–34	>–40	>–10	>–16	>–22	>–28	>–34	>–40
Tests on Residue from Pressure Aging Vessel (R 28)												
PAV aging temperature, °C[f]	100						100 (110)					
Dynamic shear, T 315: $G^* (\cos\delta)^2 / \sin\delta$,[d] maximum value 5,000 kPa, at 10 rad/s and test temperature, °C[g,h]	29	27	25	22	19	17	29	27	25	22	19	17
Creep stiffness, T 313:[f] Stiffness, maximum value 300 Mpa m-value, minimum value 0.30, at 60 sec and test temperature, °C	0	–6	–12	–18	–24	–30	0	–6	–12	–18	–24	–30
Creep stiffness, T313: R=log(2) log(S/3,000)/log(1-m) at 60 sec and specified test temperature minimum / maximum	1.50/2.50											
ΔT_c $T_{c,S} - T_{c,m}$	≥ -2.0[m]											
ΔT_f[m] $T_{c,S} - T_{cr}$	$\Delta T_{f,min} = \frac{22 - 3 * \Delta T_c}{4}$											

[m] If ΔT_c is greater than or equal to -2.0 then the determination of ΔT_f is not required. If ΔT_c is between -2.0 and -6.0 then ΔT_f may be determined. In that case, if ΔT_f exceeds the minimum value the sample is considered to meet the ΔT_c requirement.

Thanks!

Mike Anderson
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859.288.4984 office
502.641.2262 cell

Longitudinal Joint Density
State of Practice

Dave Johnson, P.E.
Idaho Asphalt Conference
Moscow Idaho
October 26, 2023

1

Outline

- Background Information
- Case Studies
- Best Practices
- Questions

2

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Background

What we "know"

3

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Asphalt Institute study (2012) showed that longitudinal joint construction is an area where consensus is nearly unachievable, but that with attention to detail, we can produce good joints with differing techniques.

4

Areas of General Agreement

- Longitudinal Joints are most pavement's weakest point
- Typically, joint density is ~2% less than mat density
- Unsupported edge will usually have the lowest density
- Joint density specifications typically 89-92% of TMD
- For each 1% loss in density = about 10% loss of life

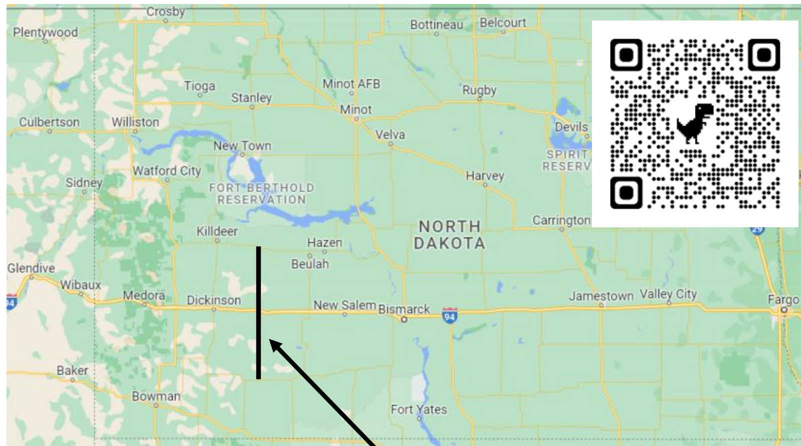
5

Case Studies

6

North Dakota

- August 2021
- 26-Mile Project
- State Highway #8
- 3” CIR
- Two 1.5” 12.5 mm Superpave Lifts
- 58S-28 (MSCR)
- Mix Temperatures 250-280°F at Paver
- 90.5 Joint Density Required

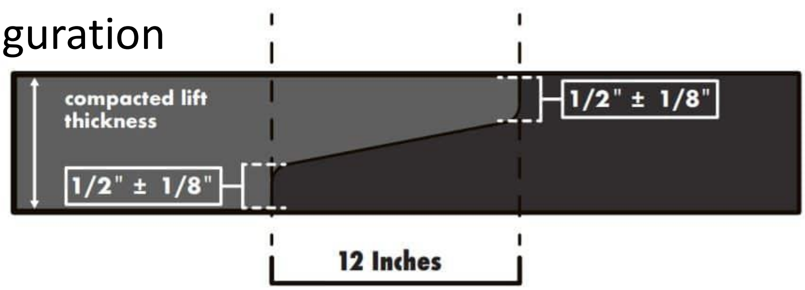


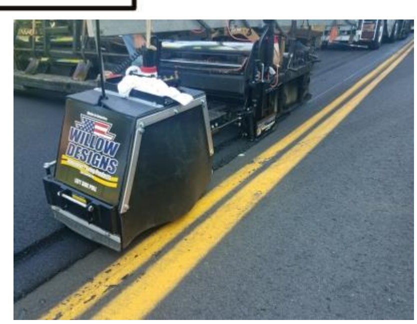
ND Highway 8

7

Unique Features

- Notched Wedge Configuration
- Willow Design Devise
- PaveScan RMD 2.0





Photos and graphics from Asphalt Pro Magazine and Willow Design

8

Unique Features

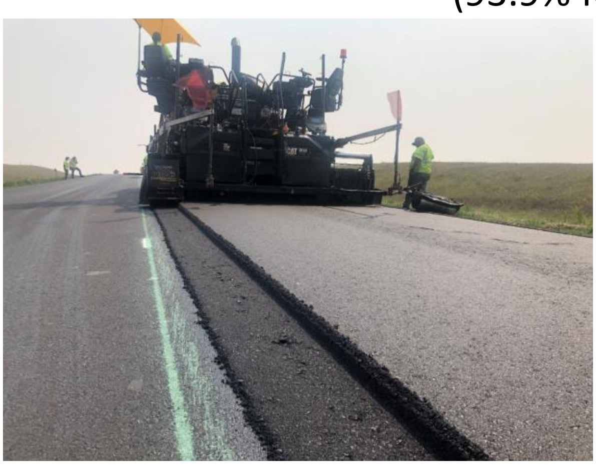
- Breakdown Roller
  - CAT Oscillatory
- Intermediate Roller(s)
  - CAT Vibratory (Primarily used)
  - Sakai Vibratory Pneumatic (Used on hot days when tenderness appeared)
- Finish Roller
  - CAT Vibratory in Static Mode

9

Results

94.8 % Joint Density

(93.9% Matt Density)



Courtesy of Asphalt Pro Magazine

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Wisconsin

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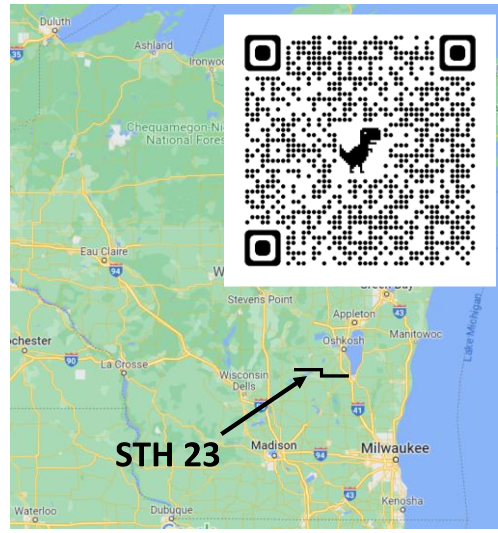
- State Trunk Highway 23
- 7.5-Mile Project
  - 22,230 T 19 mm
  - 2.25” 1st lift
  - 18,289 T 12.5 mm
  - 1.75” 2nd lift
  - 58-28S (MSCR)
- ~290°F at Breakdown Roller
- 90.5 Joint Density Required



11

Unique Features

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- Paving Speed Set as 22ft/min
- Breakdown Roller
  - Sakai High Frequency Vibratory
- Intermediate Roller(s)
  - BOMAG Pneumatic
- Finish Roller
  - BOMAG Steel

Courtesy of Asphalt Pro Magazine

12

Results

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- Unconfined Joints
  - 206 Nuclear Tests
  - Averaged **93.3%**
- Confined Joints
  - 224 Nuclear Tests
  - Averaged **94.5%**
- **+95%** of joints received maximum bonuses

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Other Technology

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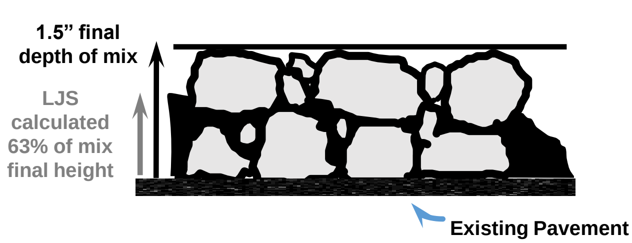
- Void Reducing Asphalt Membrane
  - Heavy application of modified binder
  - 18 inches in total
  - Material wicks up to fill voids



Cross Sectional View at Longitudinal Joint

14

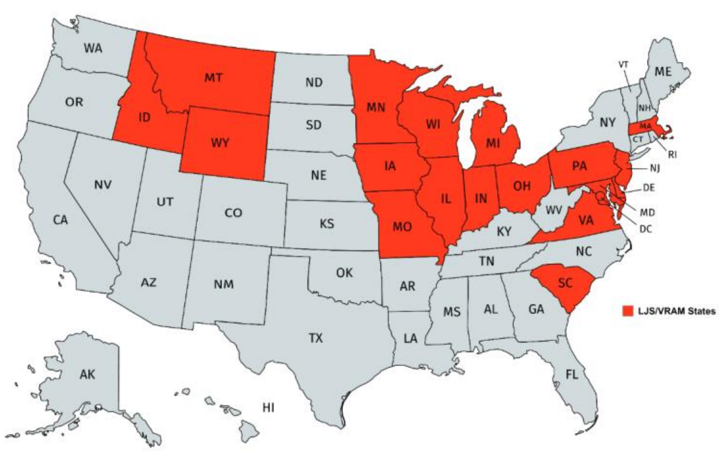
VRAM Application Methods

Placed by pressure distributor with mechanical agitation in tank

Manual strike off box fed from melting kettle

Tow behind melter applicator

States implementing specs or have had demos (2021)



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Best Practices

17

Echelon Paving

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- Common on Airports
- No cold joint
- Creates the best possible joint
- Not practical for all projects
  - Traffic
  - Production
  - Equipment


Courtesy of Gohkan Alay

18

Cutting Back the Joint

- Required on most airports
- Eliminates low density material
- "Waists" material
- Avoid tearing
  - Must do when mix still warm (temperature sweet spot)
- Critical to cut straight (stringline)
  - Easier with long wheelbase vehicle


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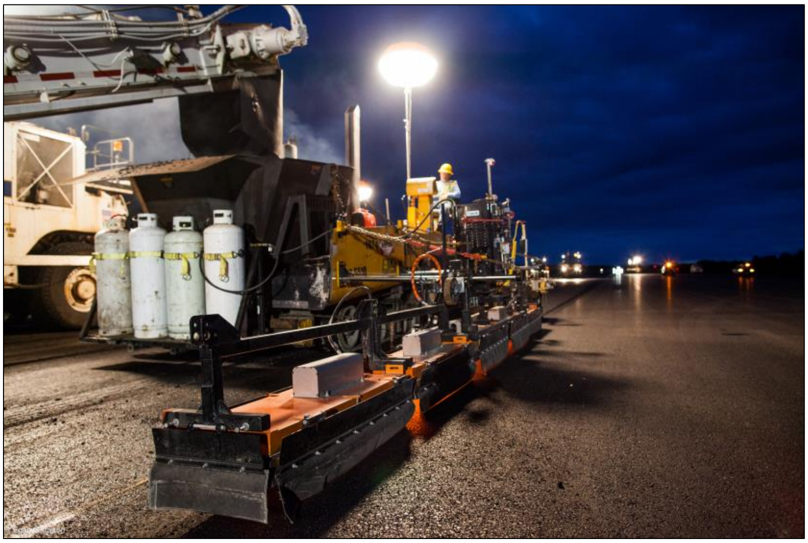
Unacceptable Cutting

20

Joint Construction Methods



Reference Knik Construction

Infrared Joint Heater

Pros:
- Can achieve good density and aggregate interlock
- No additional labor required
- No waste asphalt or edge cleanup
- “pretty” joint – no bridging/stacking

Cons:
- Limits paving production
- Additional aging of asphalt
- Will not work well with any moisture in the pavement
- Does not heat full depth

THE TRANSTEC GROUP

21

First Pass Must Be Straight!

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String-line should be used to assure first pass is straight

Stringline for reference, and/or Skip Paint, Guide for following

22

If not straight, impossible to get consistent overlap with next pass

23

Best Way to Roll an Asphalt Joint

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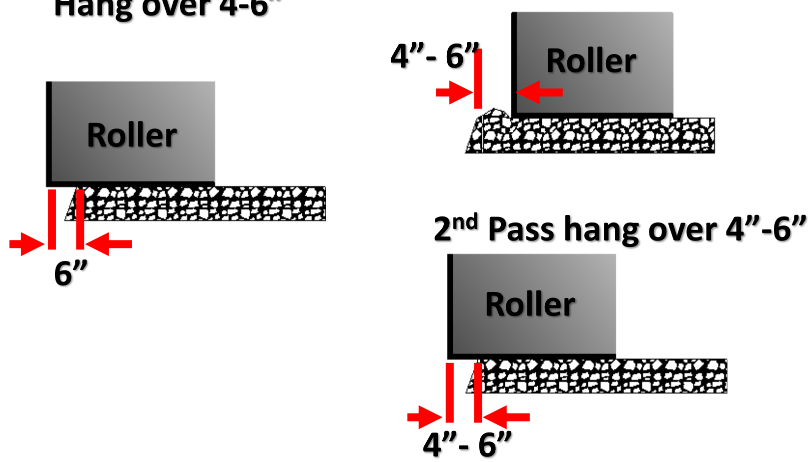
Rolling Unconfined Side?
50-50 on Where to Put 1st Pass

Option 1
Hang over 4-6”

Option 2
1st Pass 4”-6” inside



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When Closing Joint, Set Paver Automation to Never Starve the Joint of Material

- Target final height difference of +0.1” on hot-side versus cold side
  - NH spec requires 1/8” higher
- If hot-side is starved, roller drum will “bridge” onto cold mat and no further densification occurs at joint

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Proper Overlap:

- Cutback or milled: .5” + 0.5”
- If not cutback: then 1.0” + 0.5”

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Bumping the Joint?

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Rolling Confined Side

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1st pass entire drum on hot mat with roller edge off joint approx. 6-12”

2nd pass overlaps on cold mat 3-6”

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Consider Pneumatic Rubber Tired Rollers

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- Kneading action helps provide tighter surface that is more dense and less permeable compared to drum rollers.
- Keep these away from unsupported edge to avoid excessive lateral movement of mat
- Use during intermediate rolling of supported edge
    - ◦Not finish rolling

30

Key Steps in Implementing New LJ Spec

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- Agency and Industry Work Together
- Offer training (Best Practices, Alternatives)
- If trying new technologies, products, or methods, measure effectiveness
- Establish baseline of existing joint densities by randomly selecting projects
- Implement minimum density spec, but 1st year only show bonus/penalty without adding/subtracting dollars
- Incrementally increase minimum density requirement to reach at least 90%, or possibly higher as it can be shown to be accomplished on regular basis

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AI Longitudinal Joint Webpage

Go CATS!!

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Asphalt Plant Production

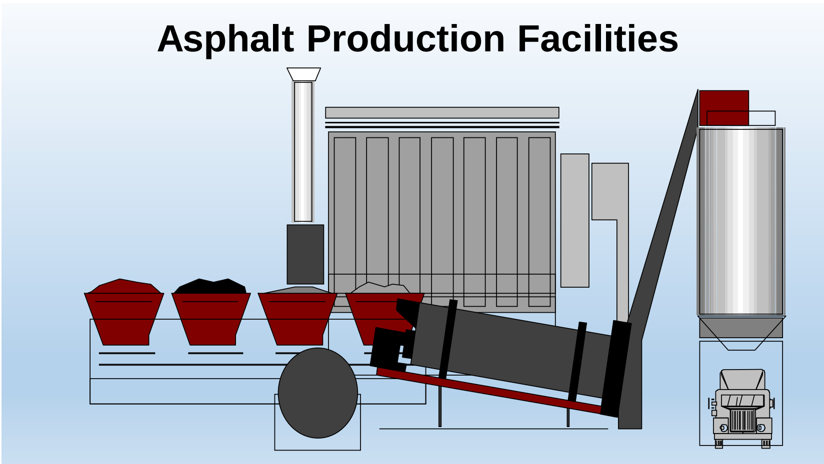
IDAHO ASPHALT CONFERENCE

1

What is the Purpose of An Asphalt Plant?

- *To Consistently* produce a *quality* Asphalt mixture that contains the desired proportions of binder and aggregate within the job mix tolerances and specified temperatures
- The facilities must comply with laws, rules, regulations and statutes of….
  - Federal Government
  - State Agencies
  - Counties
  - Cities

2



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4

Asphalt Plant

PLANT FUNCTIONS

- PROPORTIONING
- DRYING & HEATING
- BINDER ADDITION
- MIXING
- STORING & DISPATCHING

5

There are 2 Basic types of Asphalt production facilities

- Batch plant
  - Not many of these are in use today in U.S.
- Continuous (Drum-mixer) plant
  - This is the most common type of plant used today
    - Parallel Flow Drum
    - Counter Flow Drum
    - Double Barrel Drum
    - Double Drum
    - Triple Drum

6

System Components of the Basic Plants

- Aggregate Handling
- Asphalt Handling
- Mixing
- Discharge
- Additives

These are specific to the plant type, A Batch Plant or Continuous Drum Plant

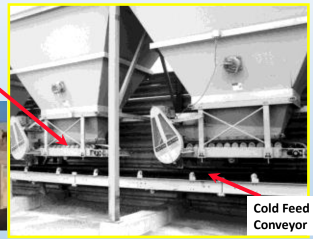
- Dust Control
- Systems Control

These components are generic to all plants

Cold Feed Bins

- Composite gradation is controlled by the individual bins containing the various gradations/sizes of aggregate
  - Gradation and quality of aggregate is controlled at the quarry

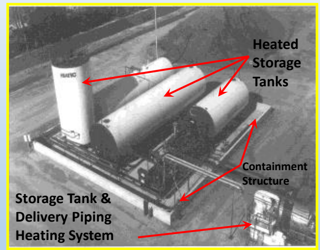
Cold Feed Conveyor



- Collects the aggregates from the various cold bins feeders and transports the cold aggregates to the dryer/heating drum
- Proportioning flow from each feeder is controlled by a variable speed belt and adjustable feeder gate beneath the cold feed bin

Asphalt Binder and Storage System

- Heated storage tanks
- Pump delivery system
- Binder weigh system



Binder Delivery System ~ Storage Facilities

Surge and Storage Silos – Loading Doors

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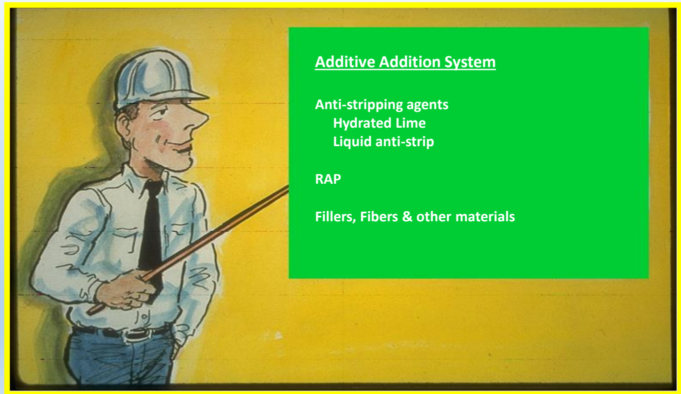
Additive Addition



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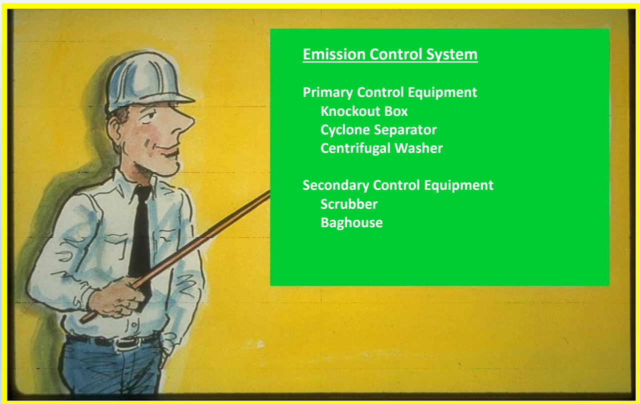
Additive Addition System – RAP

Other Additive Systems

- Chemicals (Warm Mix or Compaction Aid, Antistrips)
- Fibers (cellulose or reinforcing - kevlar)
- Ground Tire Rubber
- Plastics
- RAS

Emission Control



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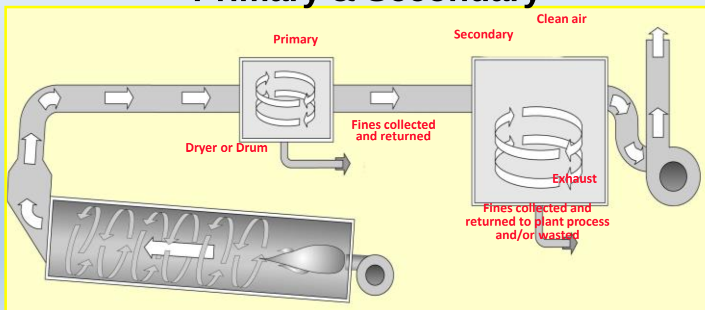
Emissions Control Equipment

Primary & Secondary



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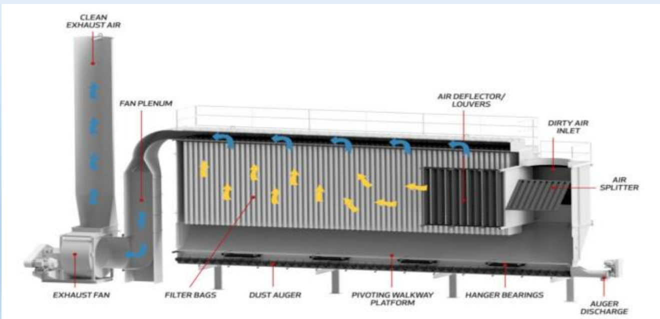
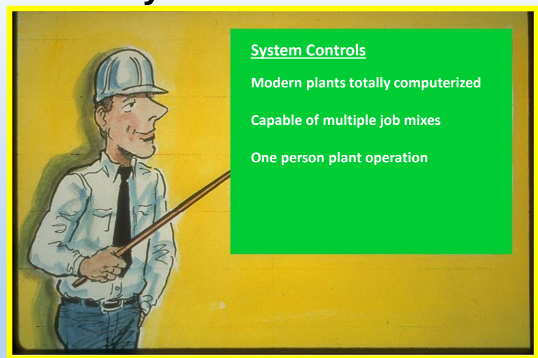
Emissions Control Equipment

Secondary, Baghouse



System Controls

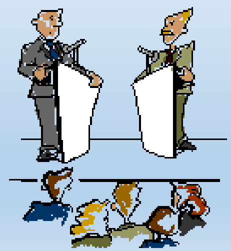


System Controls

System Controls – Computerized Drum Plant

System Controls - Control House

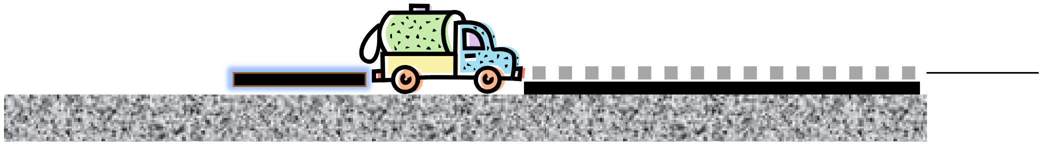
Questions ??

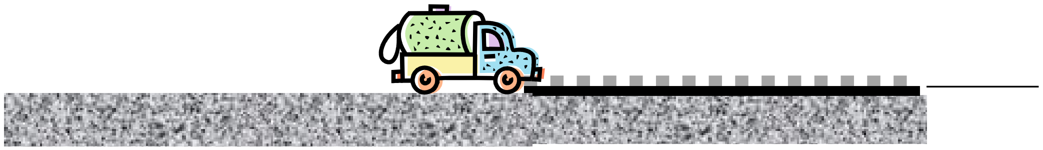


Scrub Seals an Evolving Process

Doug Olsen

Terminology





PASS: The First PMRE

PASS is a Polymer Asphalt Surface Sealer used as a binder for aggregate chips while also sealing cracks in distressed pavements. (original PMRE)

It contains:

- Asphalt
- Solvent-free rejuvenating agent (15%)
- High-quality emulsifier
  - (The emulsifier is changed to facilitate the end use)
- Tough Polychloroprene Polymer (3.5%) PA-AS-1

Aggregates

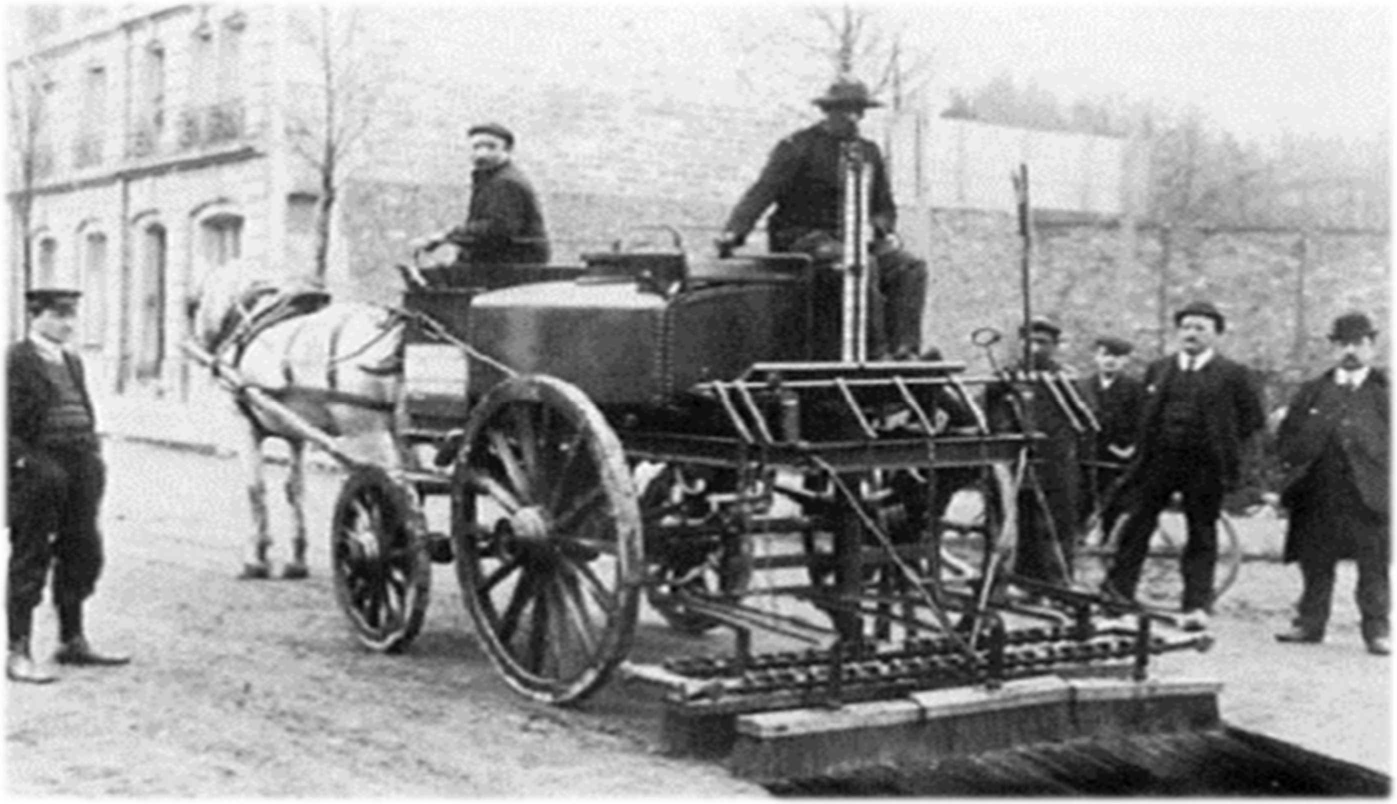
- All Common Chip Seal Sizes
- Cinders - Colored
- Crushed Fines
- RAP
- Slags

Limitations

Structural failures need to be identified and repaired prior to application

Long History

Why?



90s' Comeback!

Western Emulsions

Scrub Seals

Scrub Seals

Why Scrub Seals

Consider Scrub Seal / Cape

Scrub Box

- Curb & Gutter
- Intersections
- Stops / Starts
- Broom Replacement
- Slopes
- Up Hill / Down Hill
- Track Out
- On Site Portability

Scrub Box: Enhancements

- Storage Stands
- Cordless Control
- Multiple Broom Selections
- Eliminated Axles
- Hydraulic Width Adjustment
- Emulsion Containment
- Positive Height Adjustment
- On Site Construction Flexibility

Lift Box Mechanism

- Self Contained electric over Hydraulic
- 12V chargeable through unit
- Cordless Controls
- Manual back up controls
- Removable between jobs

Trimming: On Site Flexibility

Speed Adjusment

Box allows for real time speed adjustment: 100 to 350 fee per minute

Cleaner Job Site

- Less Drag Out
- Quicker Re-Start
- Better Joints
- Product Containment

Construction Mobility

- Jumping Between Roads
- Loading Material
- Broom Cleanup
- On the fly adjustment

Broom Heads

Broom heads allow for multiple surface textures

Why Scrub?

Scrub Box

Flexibility to chip when you need to! Don't Scrub to Scrub!

Scrub Box

Will bring Scrub Sealing to more environments

Scrub Box

Multiple variations to consider for your toolbox!

Sami's Under HMA

Scrub Seal Placed as an Interlayer

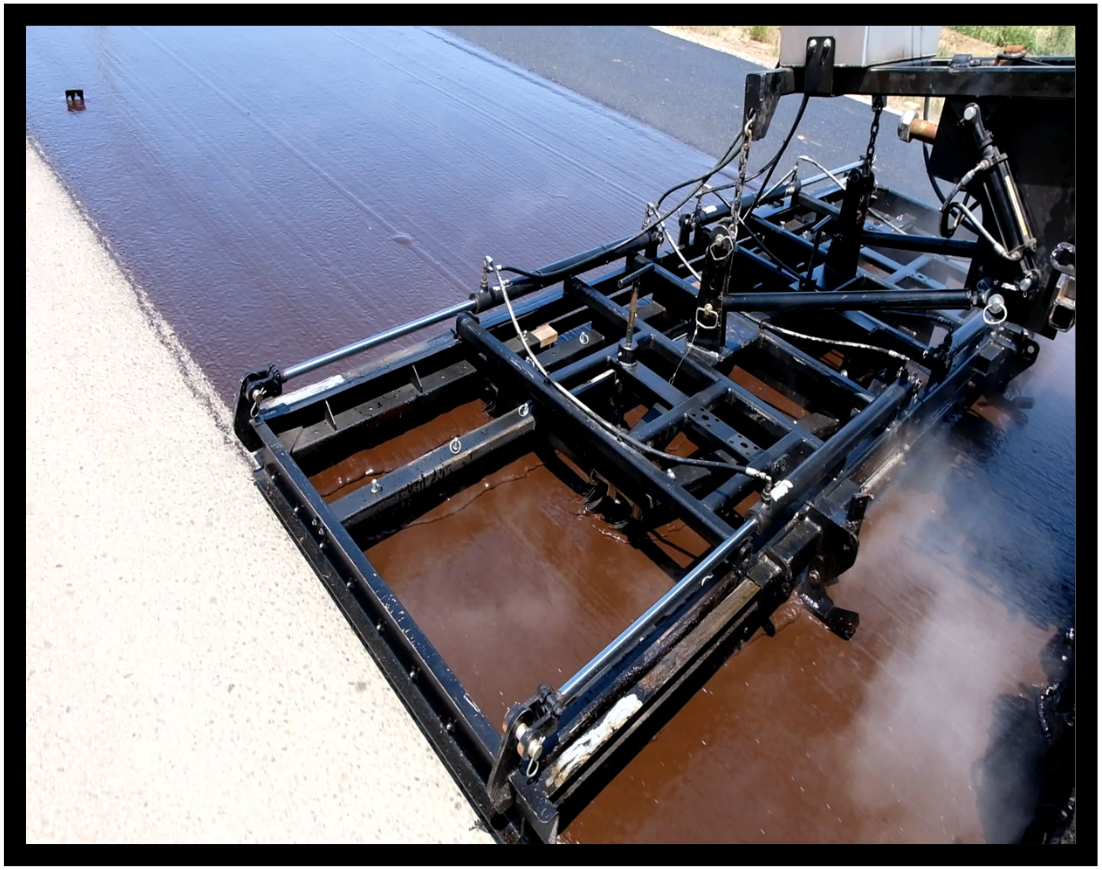
- Dense Grades
- SMA's
- Open Grades
- HI MOD

Cape Seal

Scrub / Chip Seal Application

Lessons Learned from 2023

- Operator Learning Curve
- Start/Stops
- Broom Selection
- Aggregate / Road Texture
- Box Height
- Broom Maintenance
- Mobilizing
- Box Care



Questions?

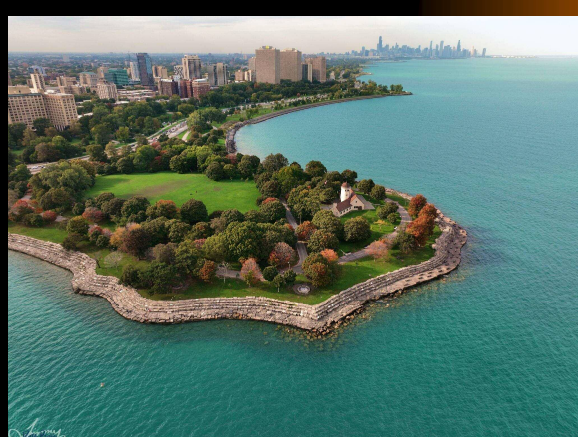
Segregation

The Cardiac Arrest of Hot Mix Asphalt Pavements

Timothy R. Murphy, P.E., M. ASCE
President
MURPHY PAVEMENT TECHNOLOGY, inc.
MEMBER Board Certified NATIONAL ACADEMY OF FORENSIC ENGINEERS

1

Welcome from Chicago



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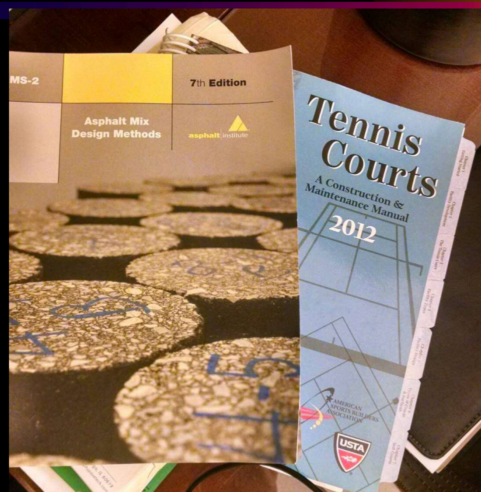
So What Do You Do Murphy?



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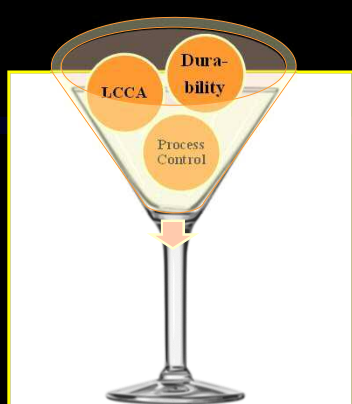
Our Job is to Evaluate Risk



Rugged review of practices with numerous agencies and contractors throughout the nation has been performed over 20+ years.

Text in your Q:773-874-9800

5

Mitigating Mechanical Segregation

Discussion on Thermal Cameras within

6

Segregation is the…

"non-uniform distribution of the various aggregate sizes throughout the mass"

7


Separation of Coarse & Fine Materials
Accelerated pavement distress.
- NCHRP Report 441

8


Separation of Coarse & Fine Materials
Uniform asphalt.
Segregated area.

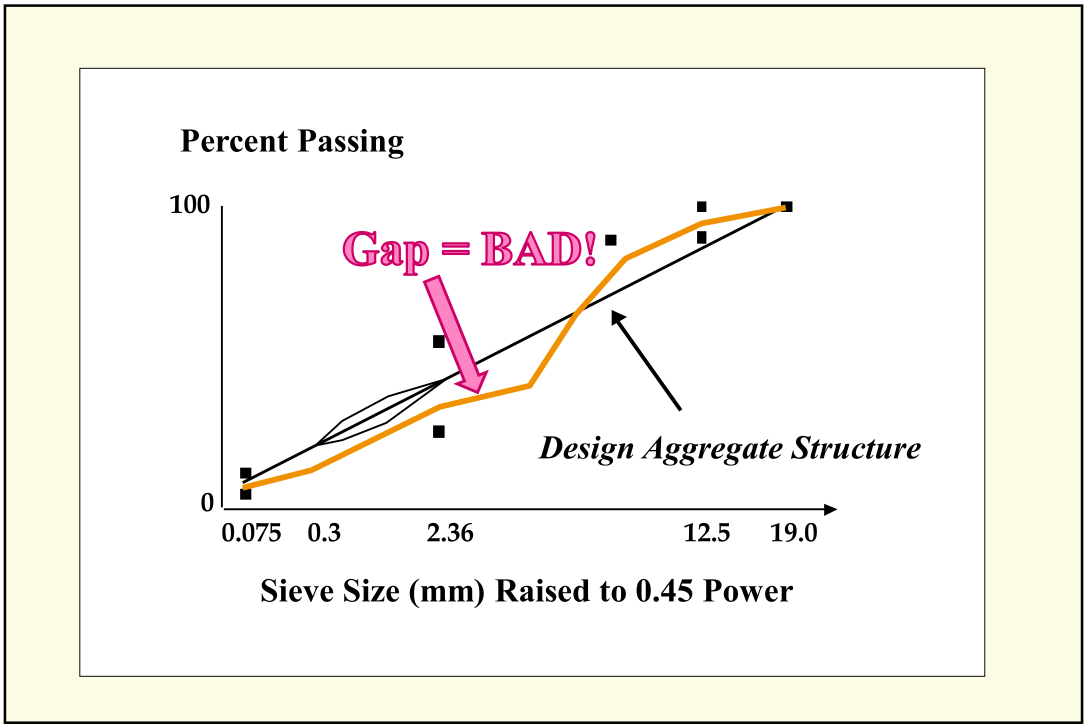
9


Segregation of Asphalt Mixtures
Segregation May Occur Because Of:
– Mix Designs
– Aggregate Handling
– Asphalt Plant Particulars
– Truck Loading & Unloading
– Paver Operations

10


Segregation of Asphalt Mixtures
Mix Designs (Gap-Graded)
– Job-Mix Formula Not Well Graded Down Through Fines
– Steep Grading Curve
Large Stone Present Challenges

11


Percent Passing
100
Gap = BAD!
0
Design Aggregate Structure
0.075
0.3
2.36
12.5
19.0
Sieve Size (mm) Raised to 0.45 Power

12


Large Top Size plus
Gap Grading = Trouble

13

Big Rock Requires Attention to Detail

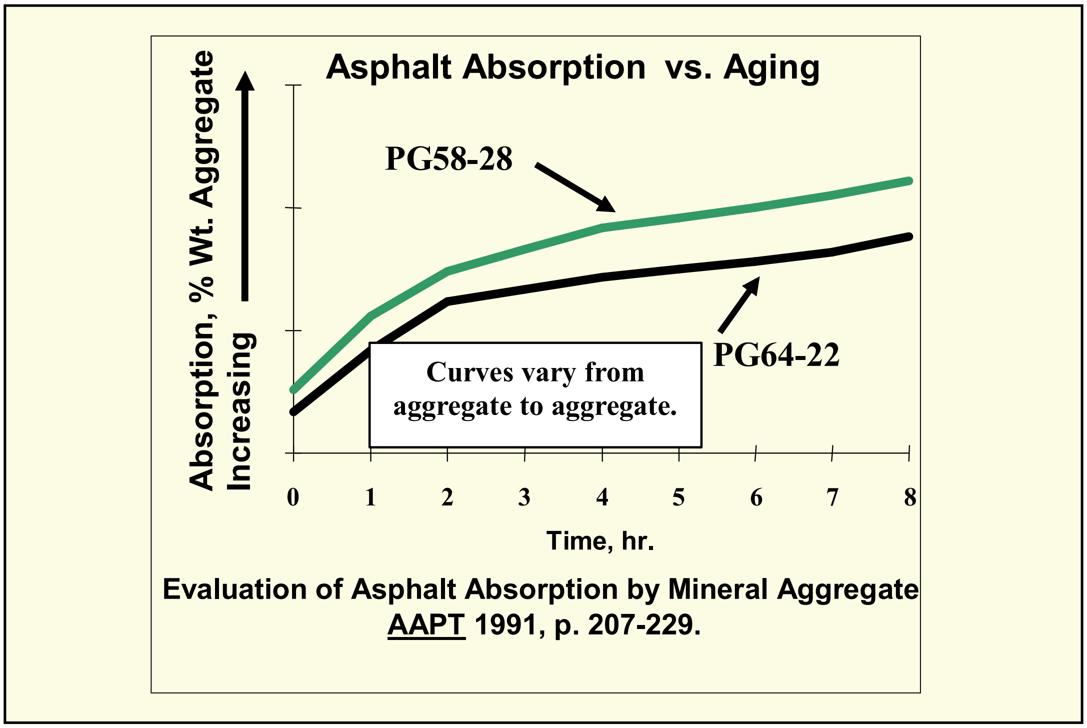
14

Increase Effective Volume of Asphalt

Voids in the Mineral Aggregate (VMA) equals the Effective Volume of Asphalt (Vbe) plus Air Voids (Va)

$$Vbe = VMA - Va$$

15



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Laboratory Mixture Analysis

Segregation Potential?

- Batch Sample in Laboratory
- Discharge Sample 1 meter
- Analyze Segregated Sample

17

Laboratory Mixture Analysis

18

Laboratory Mixture Analysis

19

Laboratory Mixture Analysis

20

Laboratory Mixture Analysis

Sieve Size	Outside	Inside	Factor
12.5mm (1/2”)	100	100	0
4.75mm (#4)	45	59	14
Marshall Data			
AC	5.5	5.8	0.3
Voids	5.2	3.6	1.6
Stability/Flow			~0

21

Segregation of Asphalt Mixtures

Segregation May Lead To:

- Smoothness Problems
- Density Below Specification
- Loss Of Overall Mat Durability

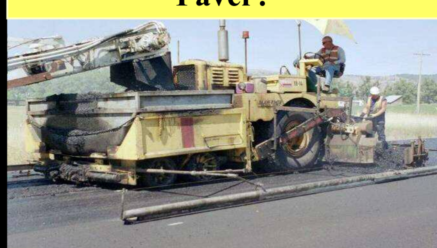
22

At the Plant?

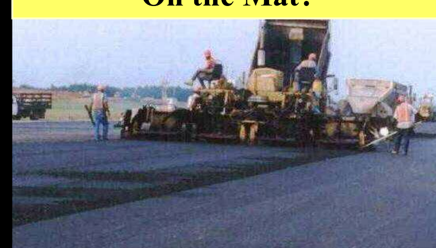
During Haul?

Where do we cause segregation to happen?

Paver?



On the Mat?



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Segregation of Asphalt Mixtures

Aggregate Handling

- Producer Stockpiles
- End User Stockpiles
- Loading Cold Bins

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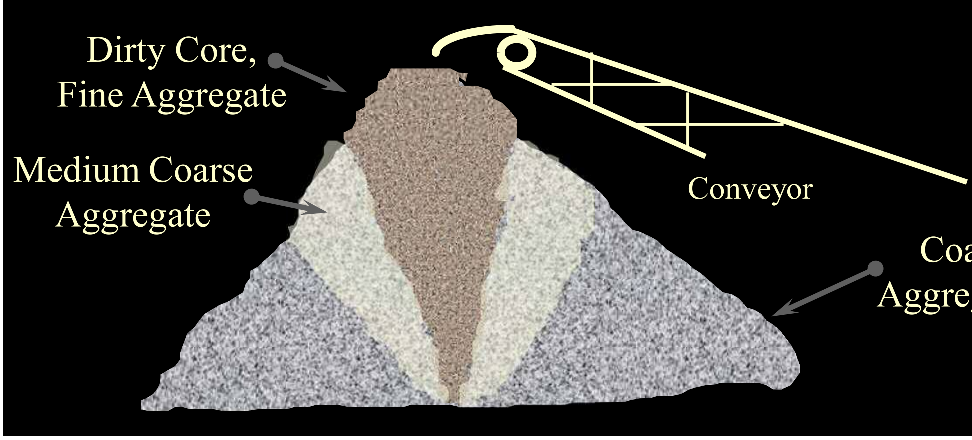
Segregation of Asphalt Mixtures

Aggregate Handling



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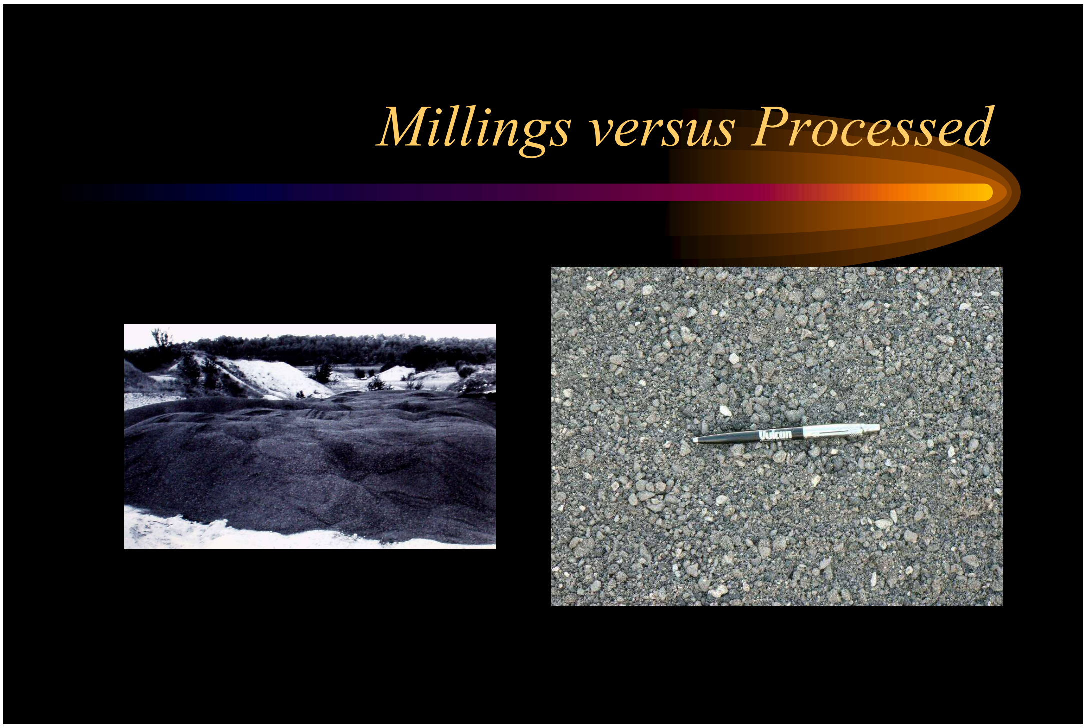
Segregation of Asphalt Mixtures

In General, Segregation Potential Increases the More a Material is Handled.

26

Cut-Away of Aggregate Handling of Windrow

27



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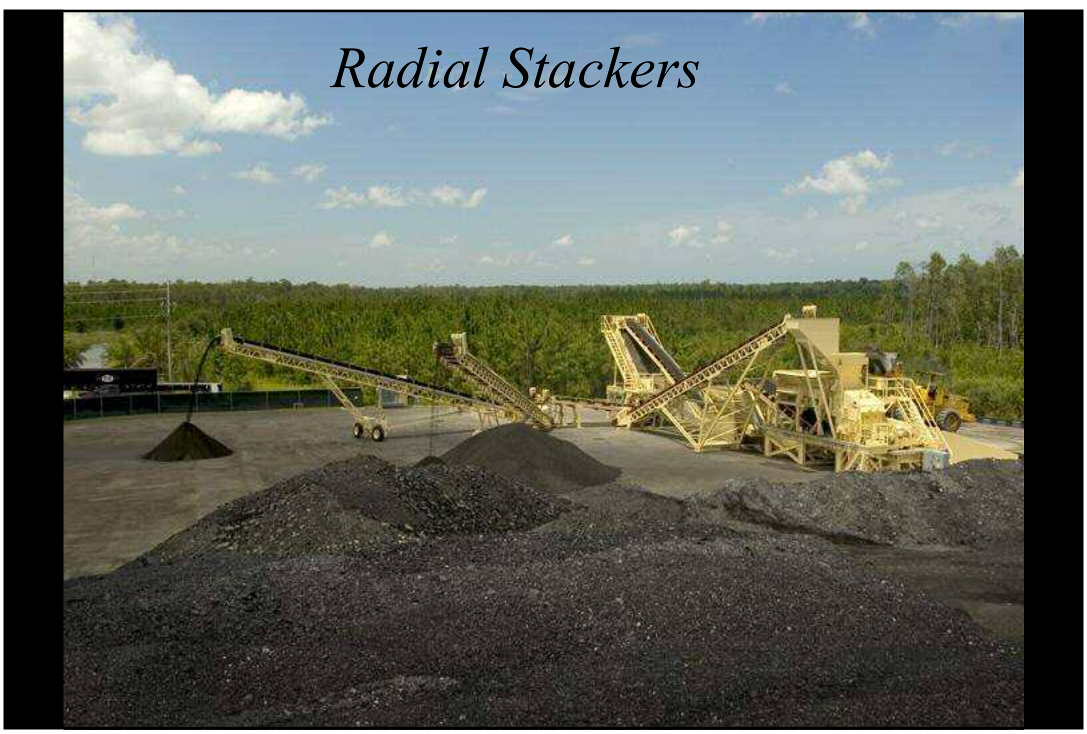

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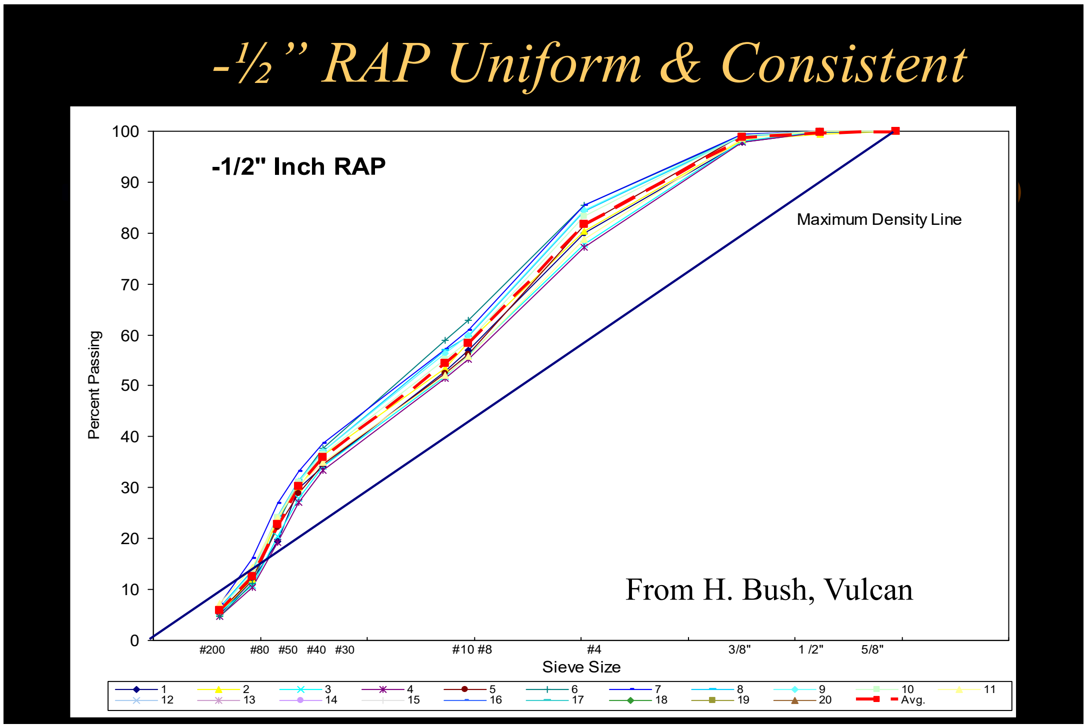
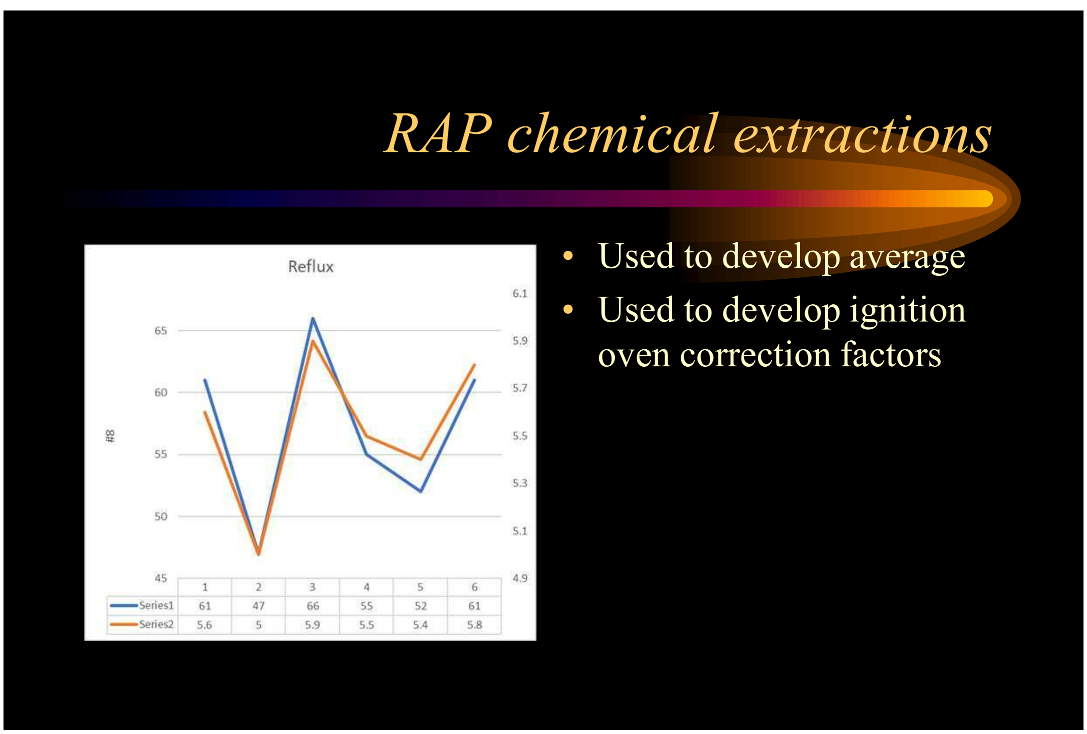
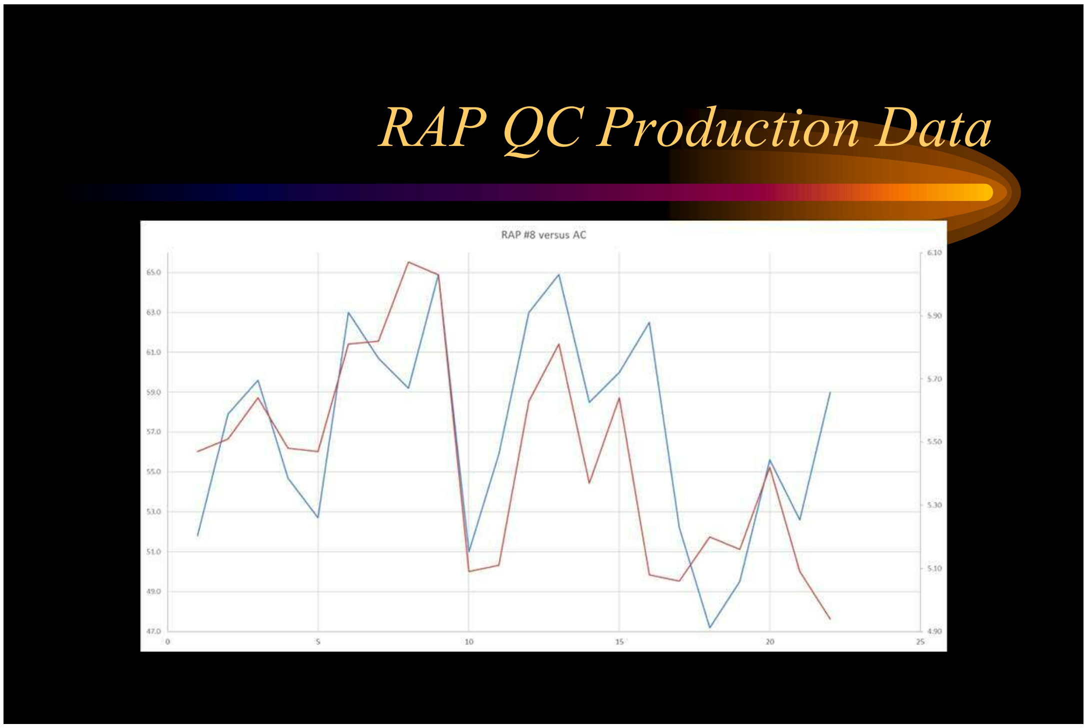

-½" RAP Uniform & Consistent
-1/2" Inch RAP
Maximum Density Line
From H. Bush, Vulcan
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
#200
#80
#50
#40
#30
#10 #8
#4
3/8"
1 /2"
5/8"
Sieve Size
1 2 3 4 5 6 7 8 9 10 11
12 13 14 15 16 17 18 19 20 Avg.

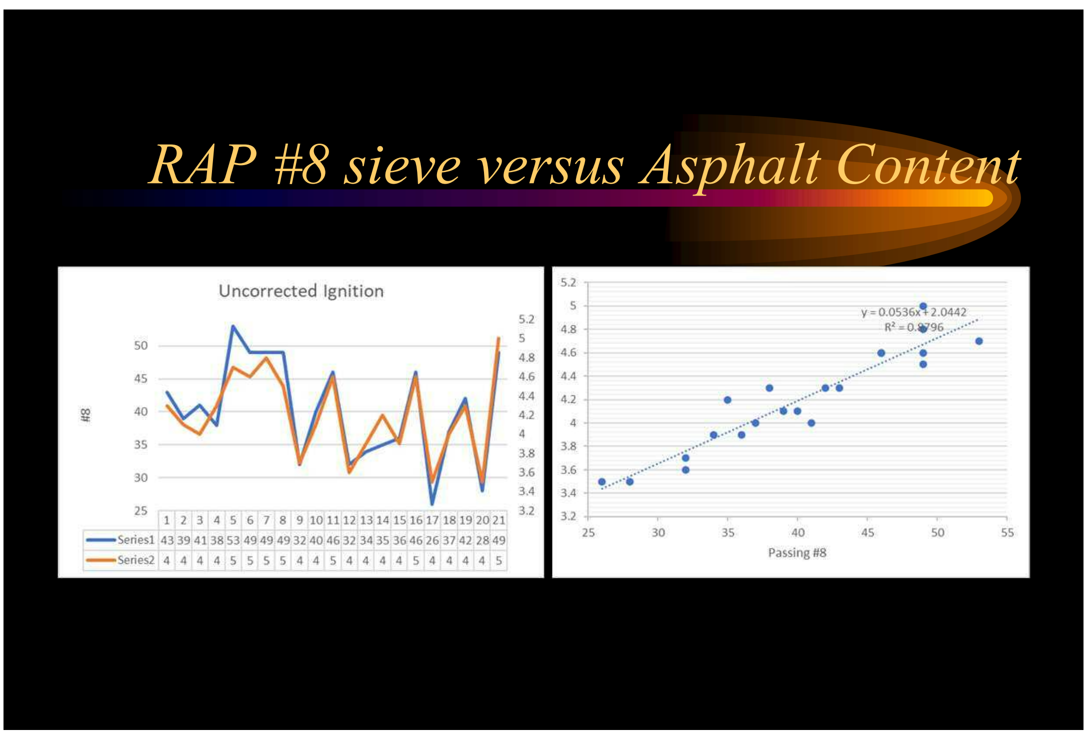
30


RAP chemical extractions
Used to develop average
Used to develop ignition oven correction factors
Reflux
#8
65
60
55
50
45
6.1
5.9
5.7
5.5
5.3
5.1
4.9
1 2 3 4 5 6
Series1 61 47 66 55 52 61
Series2 5.6 5 5.9 5.5 5.4 5.8

31


RAP QC Production Data
RAP #8 versus AC

32


RAP #8 sieve versus Asphalt Content
Uncorrected Ignition
#8
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Series1 43 39 41 38 53 49 49 49 32 40 46 32 34 35 36 46 26 37 42 28 49
Series2 4 4 4 4 5 5 5 5 4 4 5 4 4 4 4 5 4 4 4 4 5
y = 0.0536x + 2.0442
R² = 0.8796
Passing #8

33

Coarse versus Fine RAP

34

Segregation of Asphalt Mixtures

Asphalt Plant Particulars

(After Cold Bin Feeding)

- Drum Mixers
- Hot Bins on Batch Plants
- Surge & Storage Bins

35

Head Pulley and Main Weigh Bridge Discharge

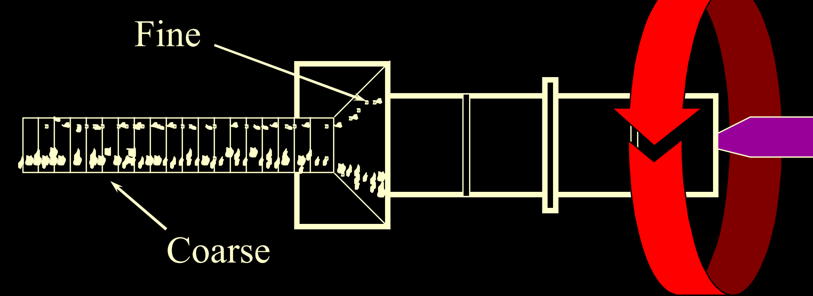
36

Head Pulley and Main Weigh Bridge Discharge

37

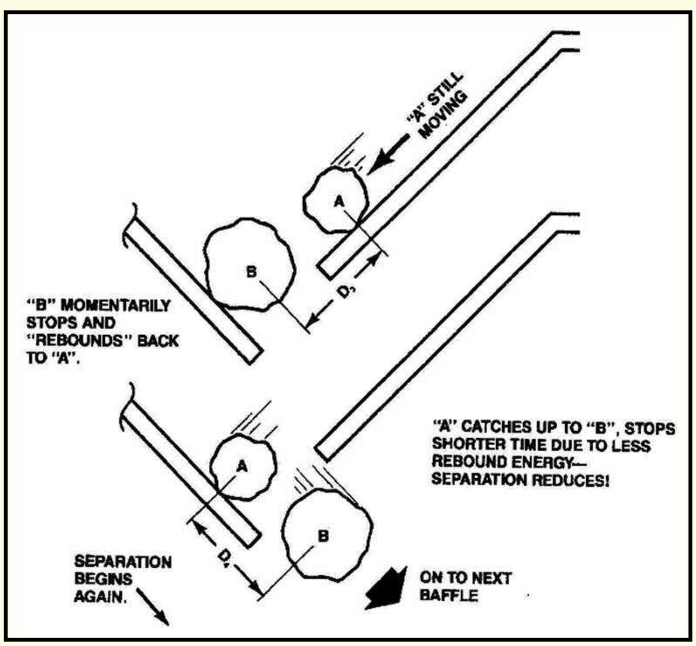
Segregation of Asphalt Mixtures

Drum Mixers

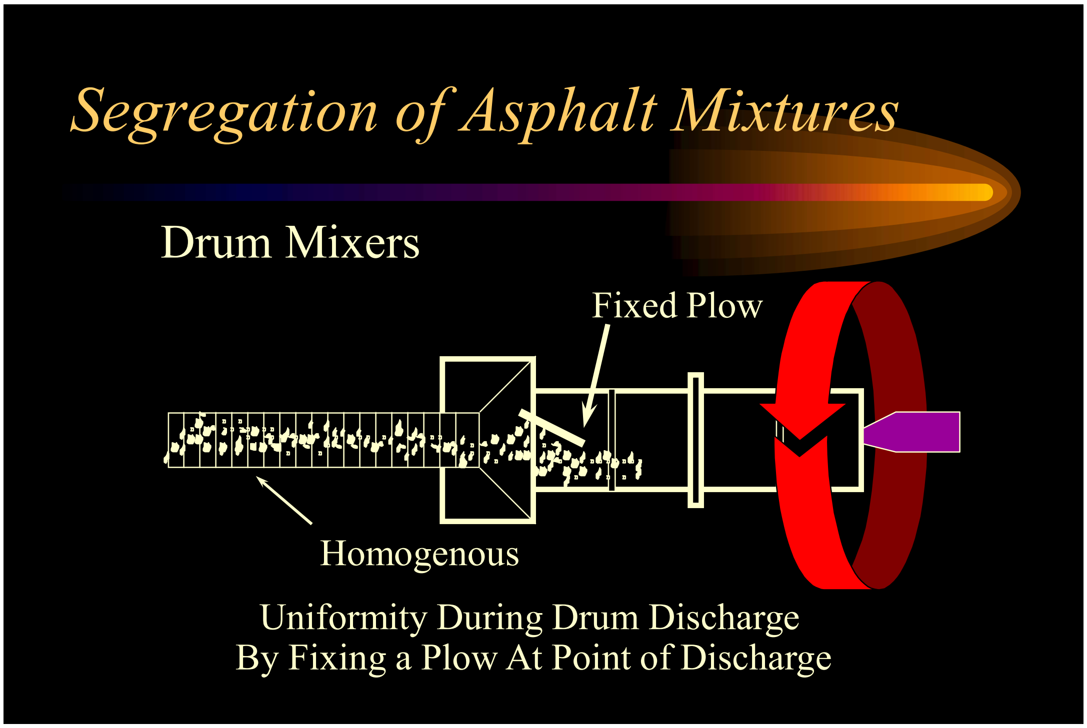


Segregation During Drum Discharge

38



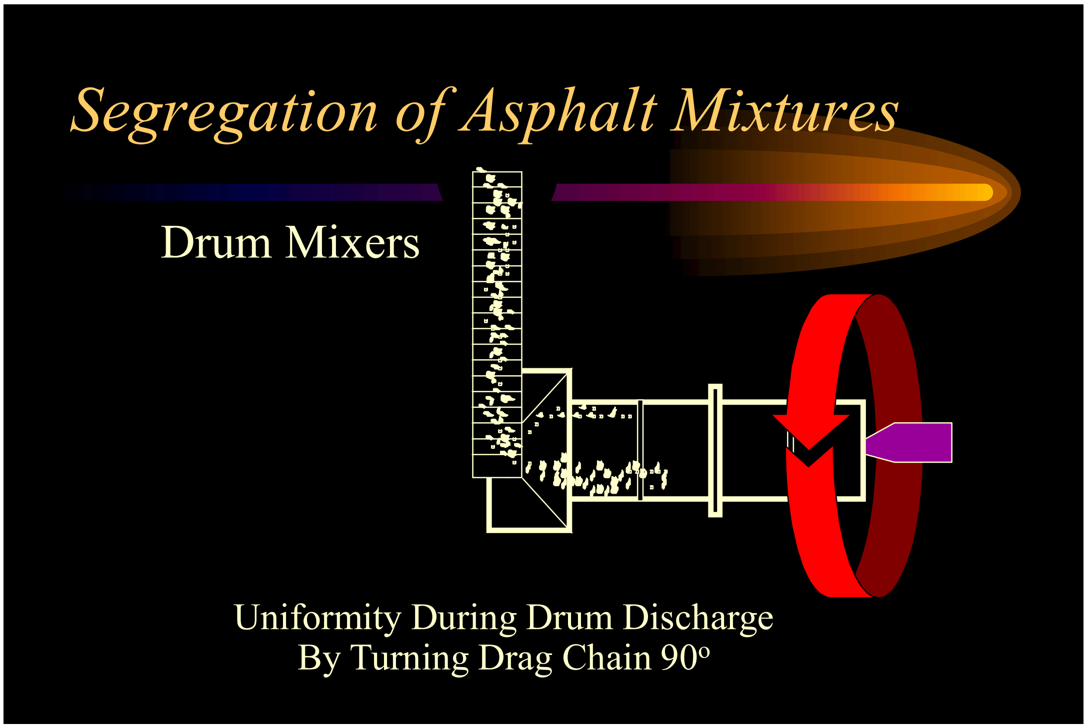
39


Segregation of Asphalt Mixtures
Drum Mixers
Fixed Plow
Homogenous
Uniformity During Drum Discharge
By Fixing a Plow At Point of Discharge

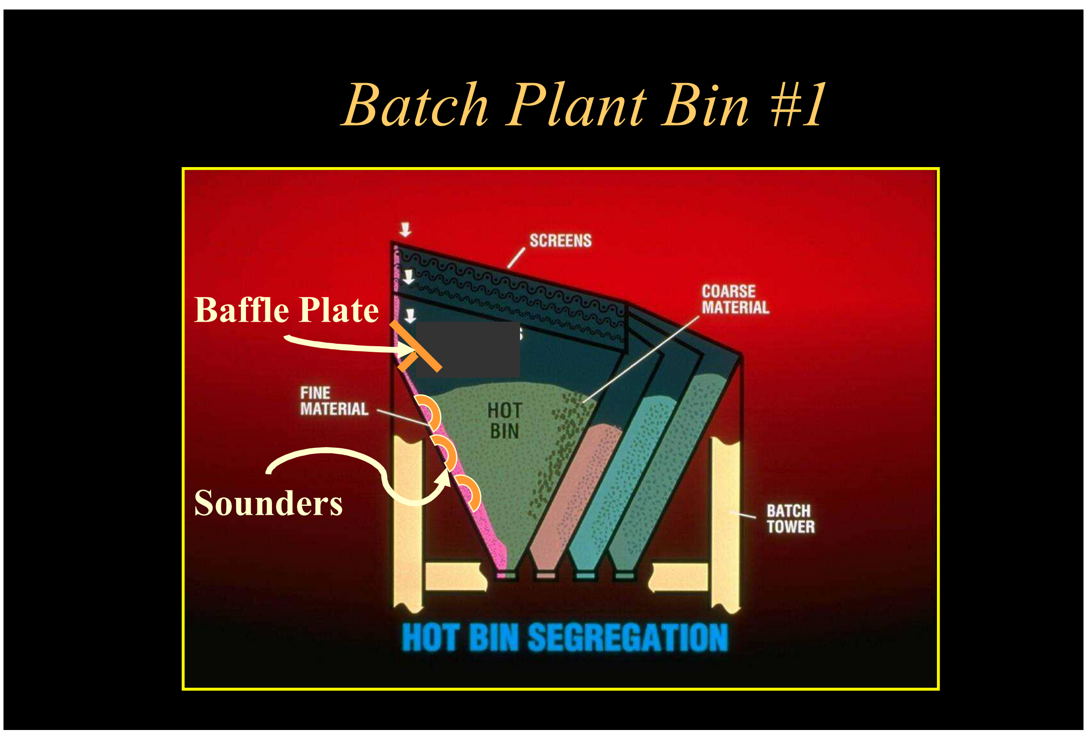
40


Drum Discharge

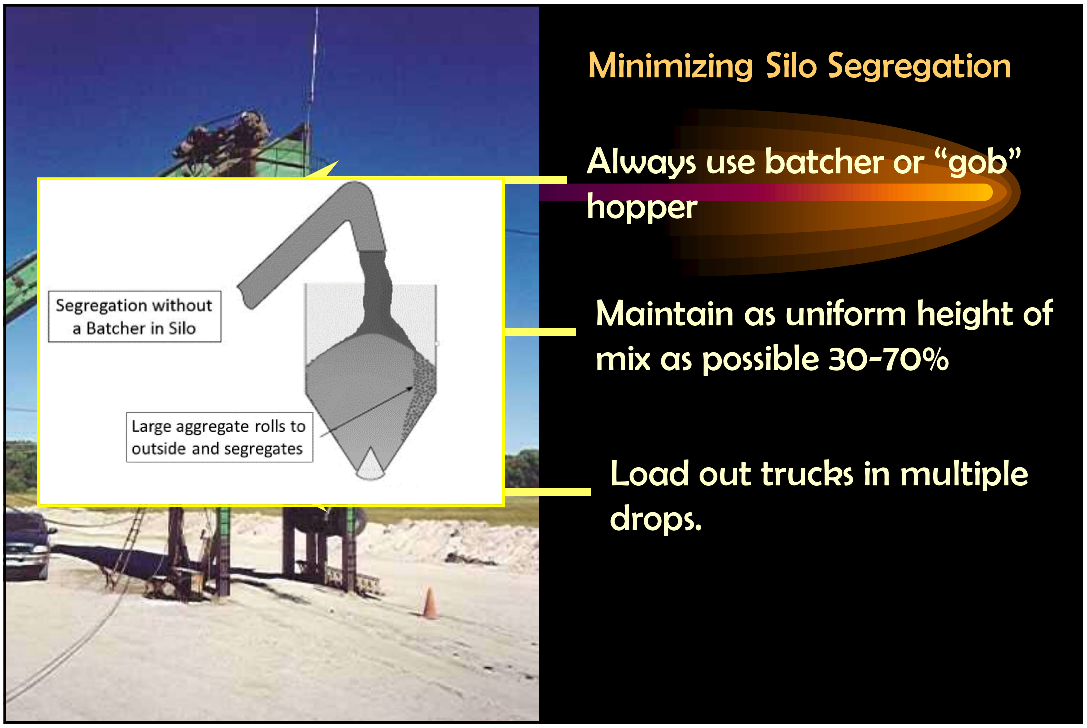
41


Segregation of Asphalt Mixtures
Drum Mixers
Uniformity During Drum Discharge
By Turning Drag Chain 90°

42


Batch Plant Bin #1
SCREENS
Baffle Plate
COARSE MATERIAL
FINE MATERIAL
HOT BIN
Sounders
BATCH TOWER
HOT BIN SEGREGATION

43


Minimizing Silo Segregation
Always use batcher or "gob" hopper
Maintain as uniform height of mix as possible 30-70%
Load out trucks in multiple drops.
Segregation without a Batcher in Silo
Large aggregate rolls to outside and segregates

44


Sampling Materials
Aggregate
Liquid Asphalt
Asphaltic Mixture

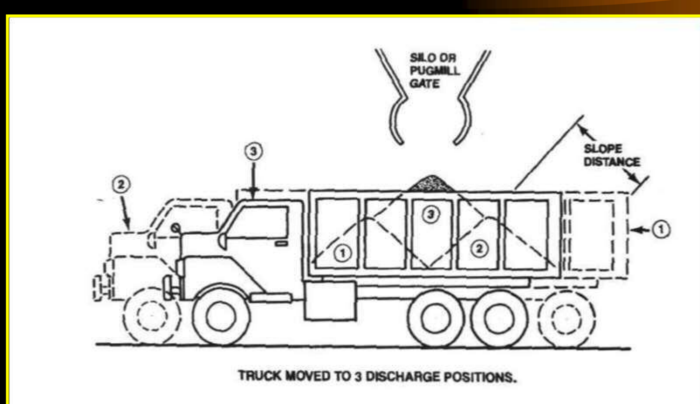
45

Splitting Materials

- **Aggregate**
  - Location Location Location
  - Coarse v. Fine
- **Liquid Asphalt**
  - Safety Protocol
  - Plant Personnel
- **Asphaltic Mixture**
  - Truck and / or Roadway
  - Random v. Bias

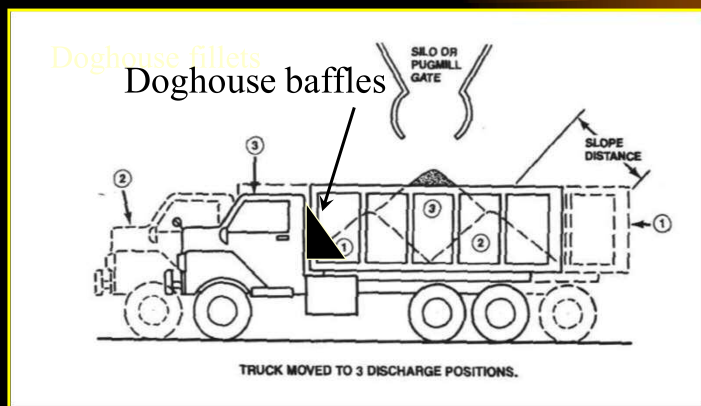
46

Segregation of Asphalt Mixtures



47

Segregation of Asphalt Mixtures



48

Segregation of Asphalt Mixtures

Truck Unloading

- Tip the Truck Bed Prior to Releasing Tailgate
- Baffles at the Point of Discharge
- Flood the Paver Hopper

49


End of load segregation
with belly-dump.

50


Use Longer Trucks
RED RIVER
LIVE BOTTOM SYSTEMS

51

Segregation of Asphalt Mixtures

Segregation May Lead To: (Cont'd.)
- Moisture Damage & Raveling
- Cracking
- Streaky Pavement Surfaces

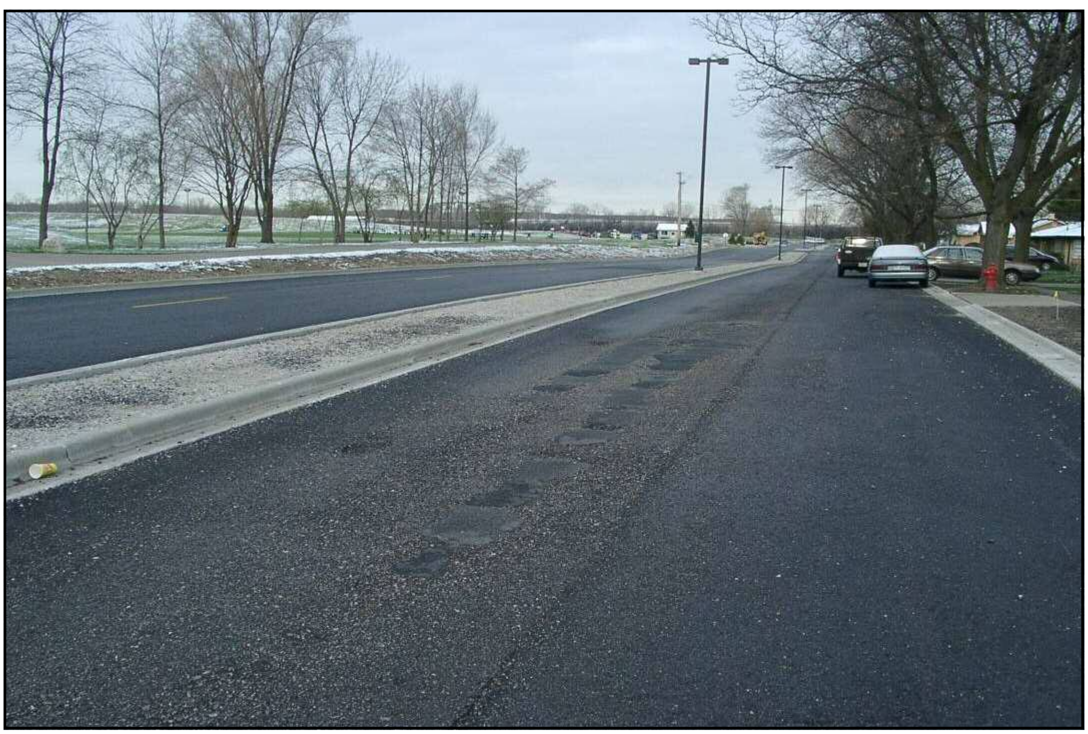
52

Segregation Leads to Failure

Moisture Often Plays a Role

53

54



55

Far-Away of HMA

56

Segregation of Asphalt Mixtures

Streaky Pavement Surfaces Resemble:

- Chevrons
- Longitudinal Streaks
- Blotchy Areas

57

58

Segregation of Asphalt Mixtures

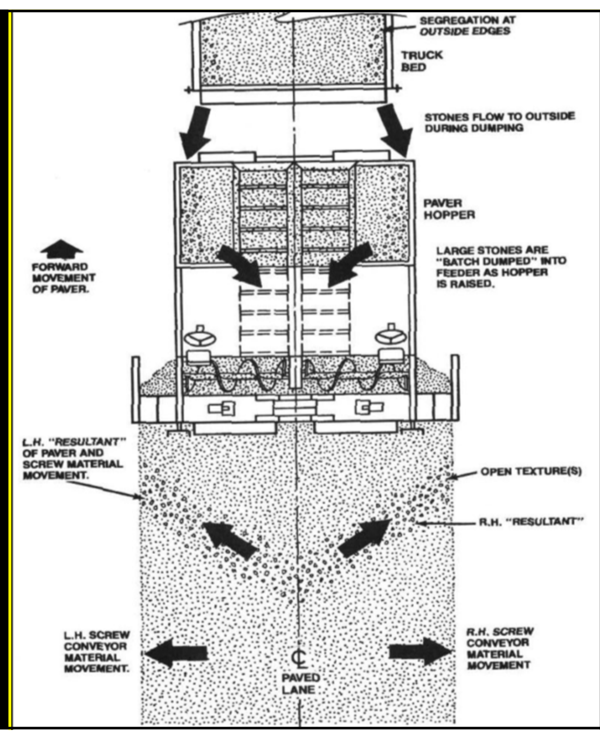
Paver Operation

- Keep The Paver Moving
- Maintain 25% Capacity in Hopper
- Dump Wings Only When Material is in Hopper

59

Paver Operation

60



61

Segregation of Asphalt Mixtures

Paver Operation (Cont'd.)

- Fillets in Corners
- Kick-Back Plates
- Head in Augers
- Auger Extensions

62

Paver Operation, Hopper

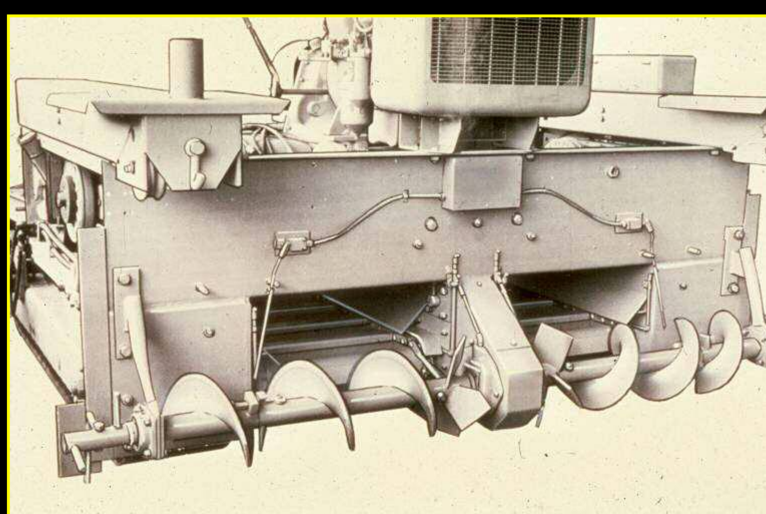
63

Superpave Specification Requirement

Reverse screw augers with a minimum efficiency of 75% shall be installed at the gear box for all paving activities.

64

Longitudinal Cracking Mitigation



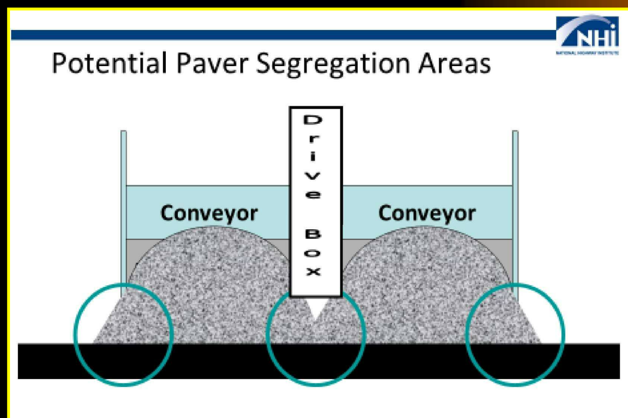
65

Longitudinal Cracking Mitigation

66

67

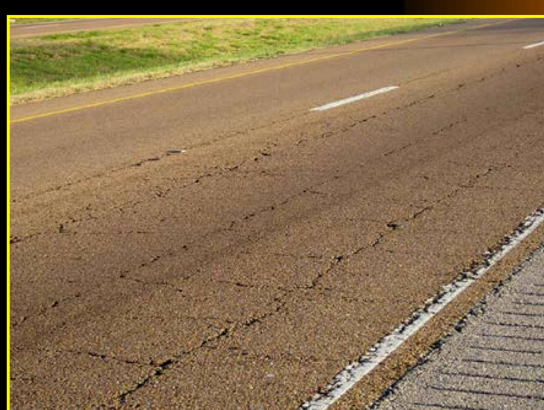
Figure of Poor Paver Set-Up



-from NHI (Colorado Study)

68

Paver Segregation After a Few Years



-from NHI (Colorado Study)

69

Extended screeds must be installed…

Extended screeds shall be provided with corresponding auger and tunnel extensions to ensure a uniform head of fresh material across the entire screed.

70

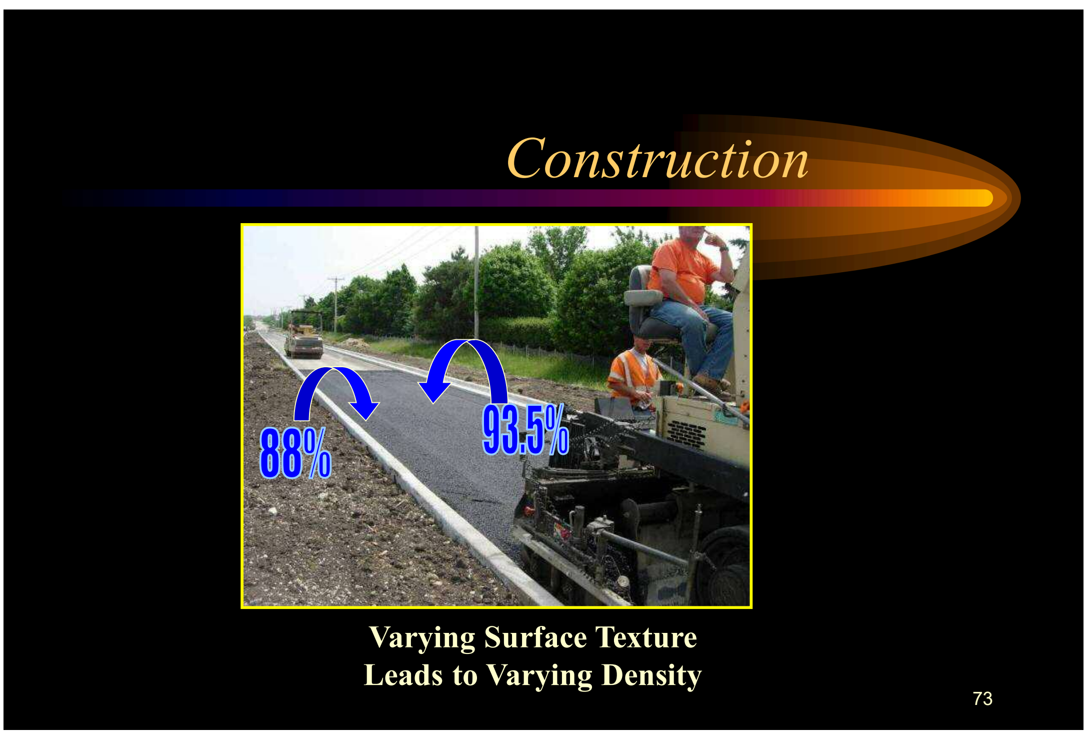
Effect – Visually Dark Outer Area

71

71


Cause - Auger Extensions Missing
72

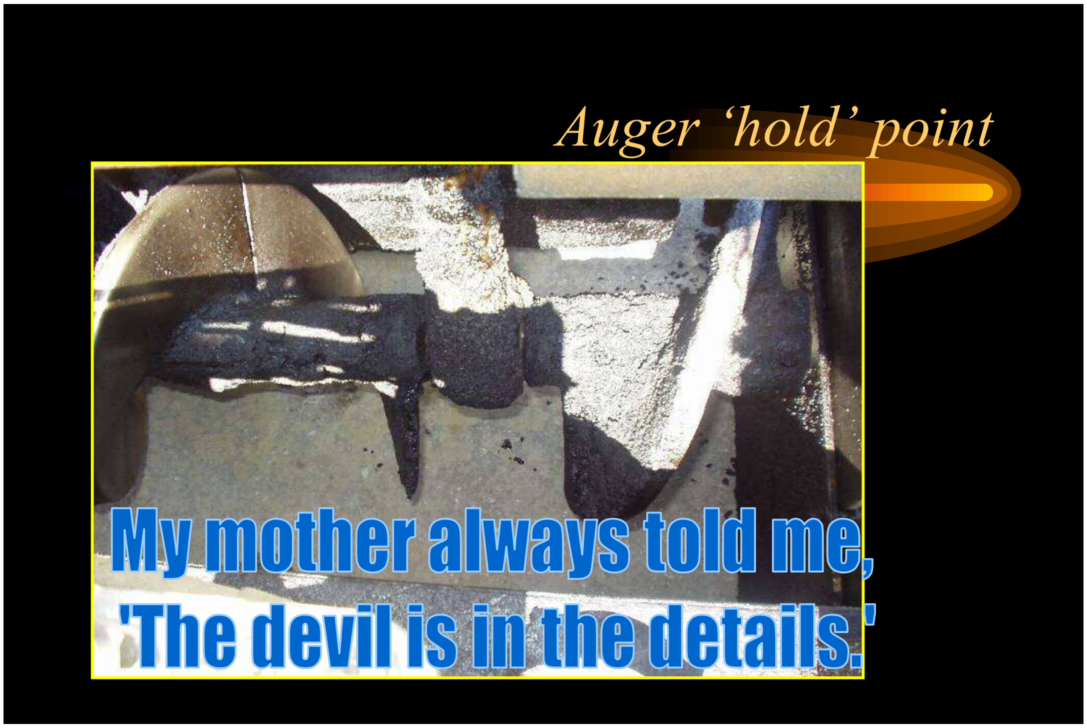
72


Construction
88%
93.5%
Varying Surface Texture
Leads to Varying Density
73

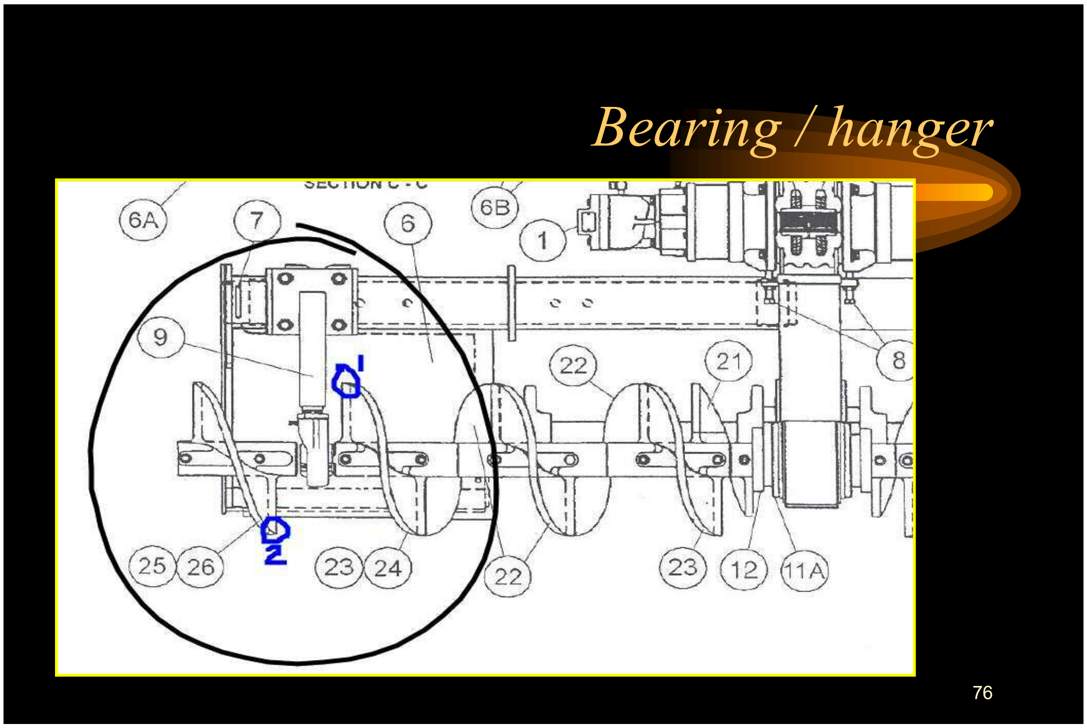
73


Right side
segregation.

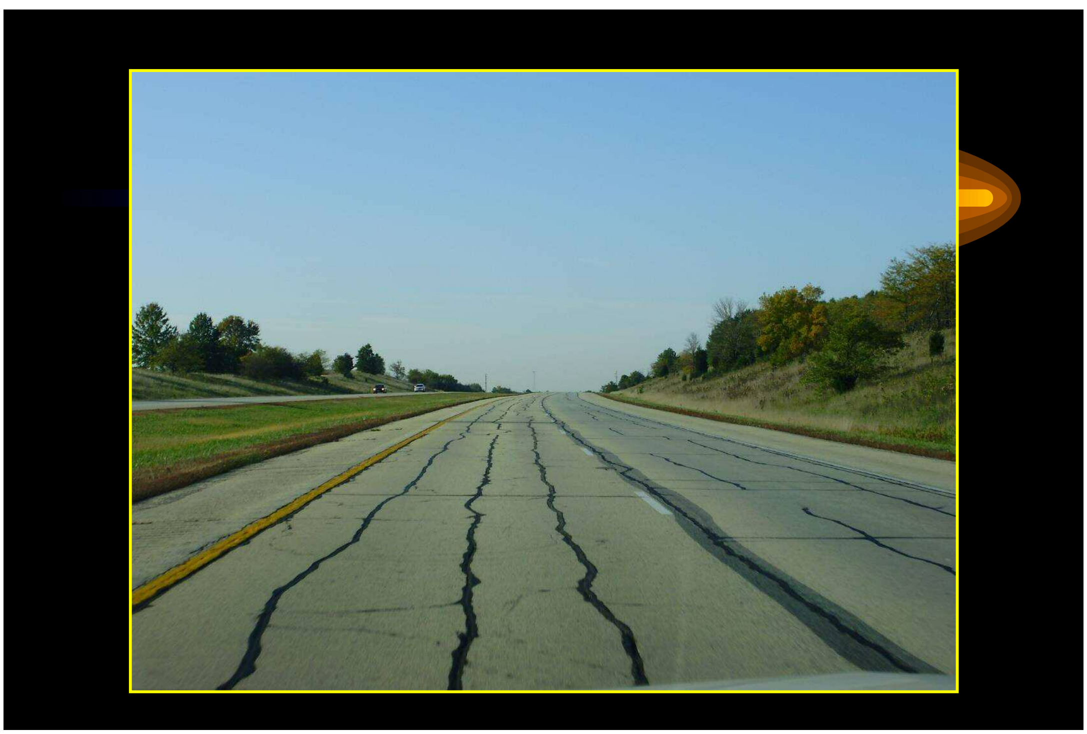
74


Auger 'hold' point
My mother always told me,
'The devil is in the details.'

75


Bearing / hanger
SECTION C - C
6A
7
6
6B
1
9
8
22
21
25
26
23
24
22
23
12
11A
76

76



77

Luting

78

Model Segregation Specification

Agencies now use one of the following for quantifying segregation:

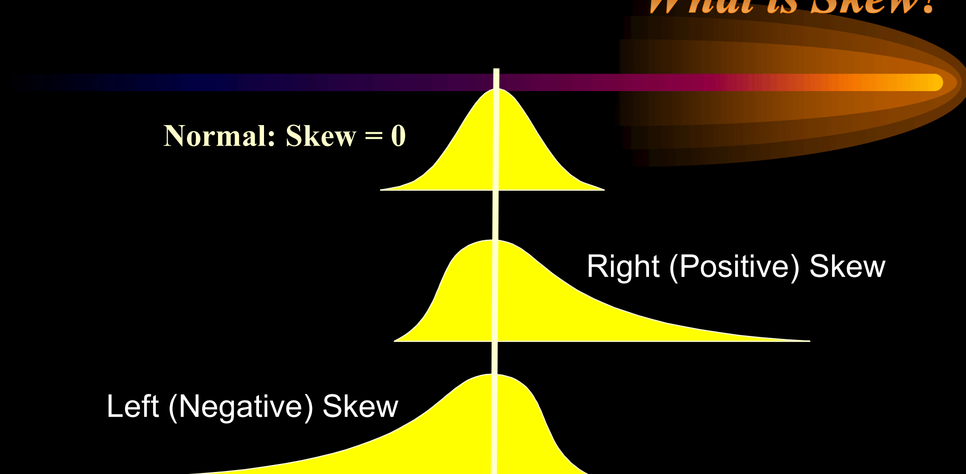
- Deviation from the approved JMF via extraction
- Sand patch measurement
- Nuclear density gauge

79

Model Segregation Specification: Measuring Segregation with a Nuke Gauge

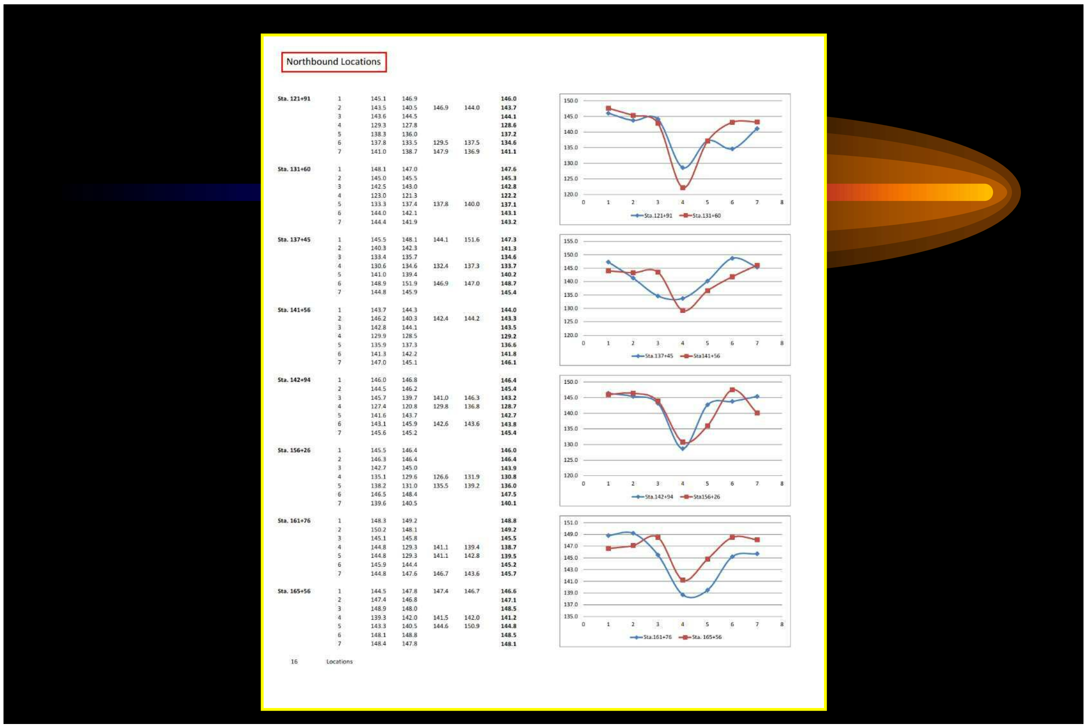
80

What is Skew?

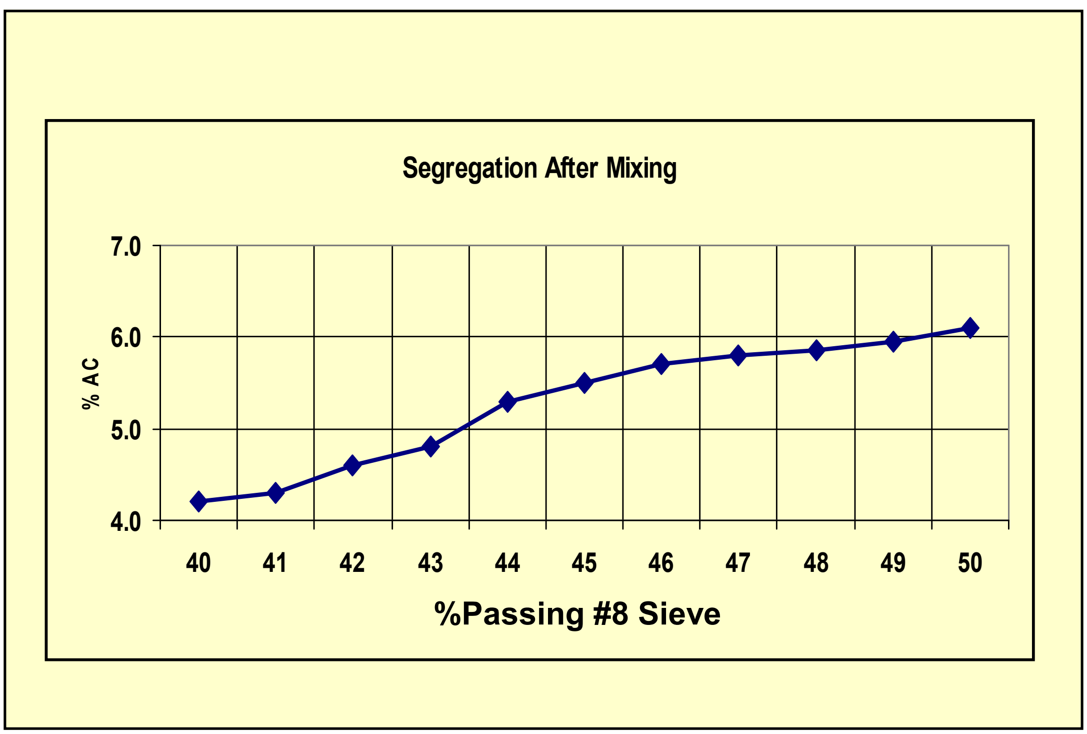


81

81


Northbound Locations

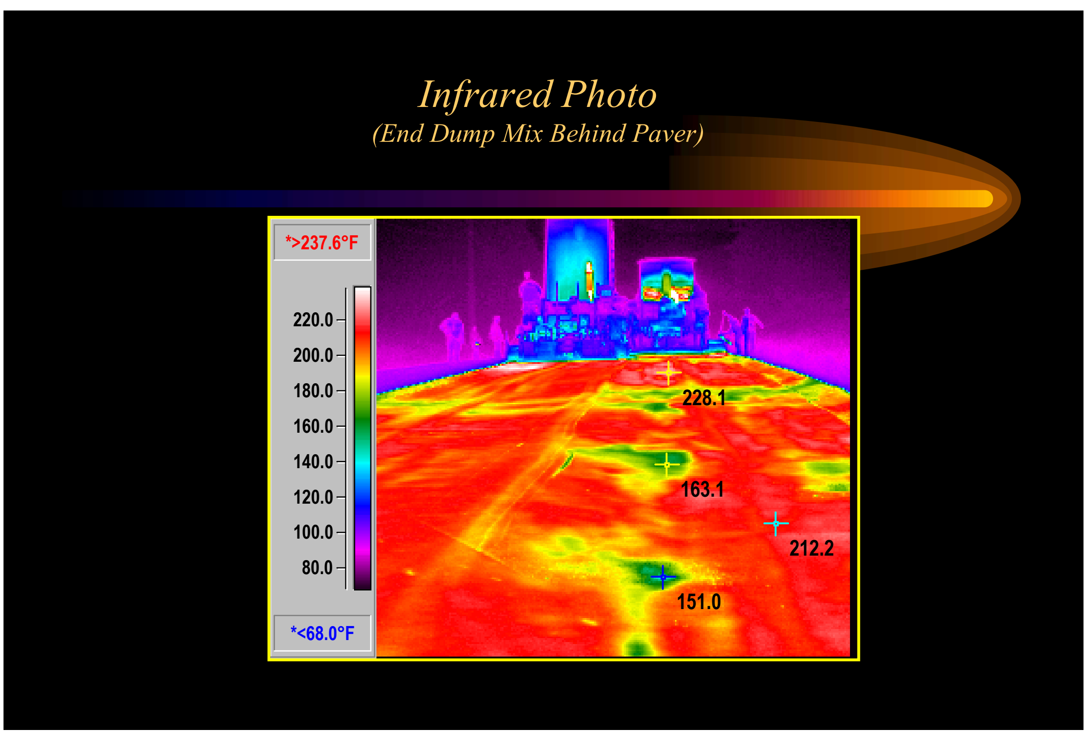
82


Segregation After Mixing
% AC
7.0
6.0
5.0
4.0
40
41
42
43
44
45
46
47
48
49
50
%Passing #8 Sieve

83

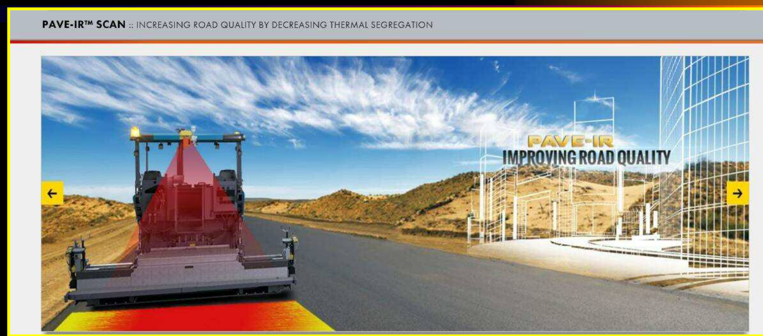

A Few References on Segregation
SEGREGATION
The Cardiac Arrest of Hot Mix Asphalt Pavements
Murphy Pavement Technology
MSU: The Final Report
DETECTING AND QUANTIFYING SEGREGATION IN BITUMINOUS PAVEMENTS AND RELATING ITS EFFECT TO CONDITION
NCHRP SYNTHESIS 477
Methods and Practices on Reduction and Elimination of Asphalt Mix Segregation
A Synthesis of Highway Practice
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Enhanced MS-22 is Here…
Just Ask Dave!

84


Infrared Photo
(End Dump Mix Behind Paver)
*>237.6°F
220.0
200.0
180.0
160.0
140.0
120.0
100.0
80.0
*<68.0°F
228.1
163.1
212.2
151.0

85

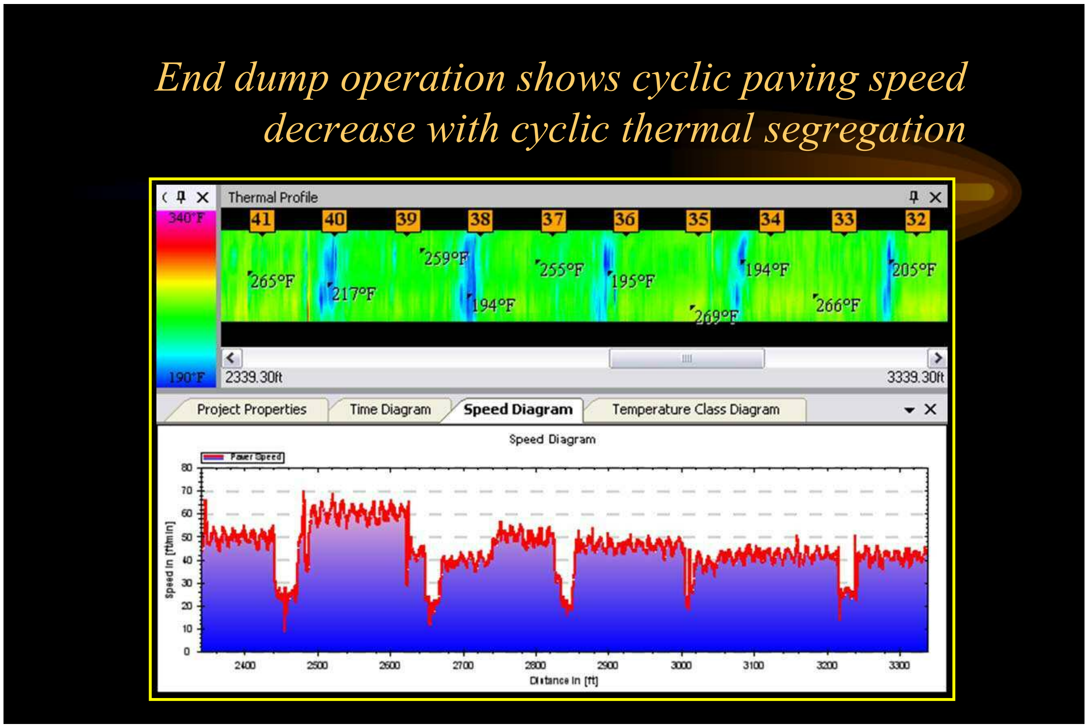
Real-time PAVE-IR *(from MOBA)*



86

Real-time PAVE-IR

87



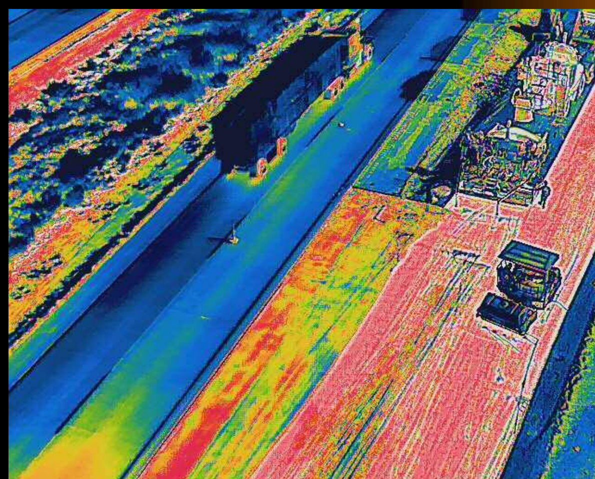
88

ITD Drone Infrared

2023 Research / Experimenting

89

Infrared Camera at Grade then on Drone



90

Segregation of Asphalt Mixtures

Homogeneous Asphalt Mixtures Ensure Us Of Having

Smoother and More Durable Asphalt Pavements

98

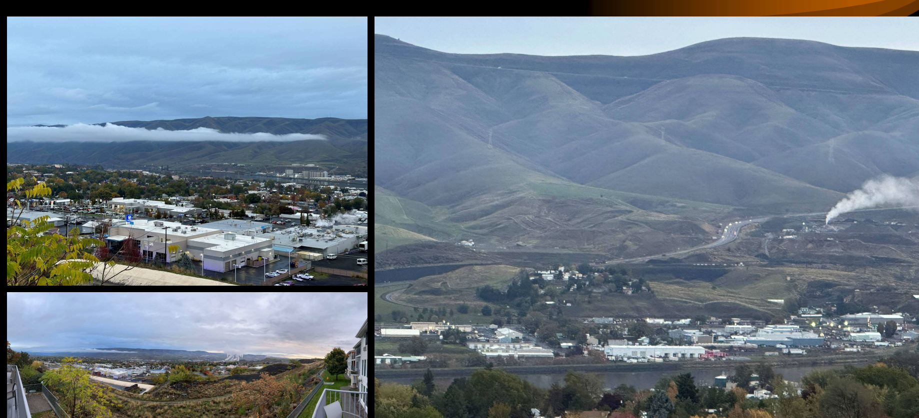
Murphy's Material Minute

Asphalt Production & Construction:

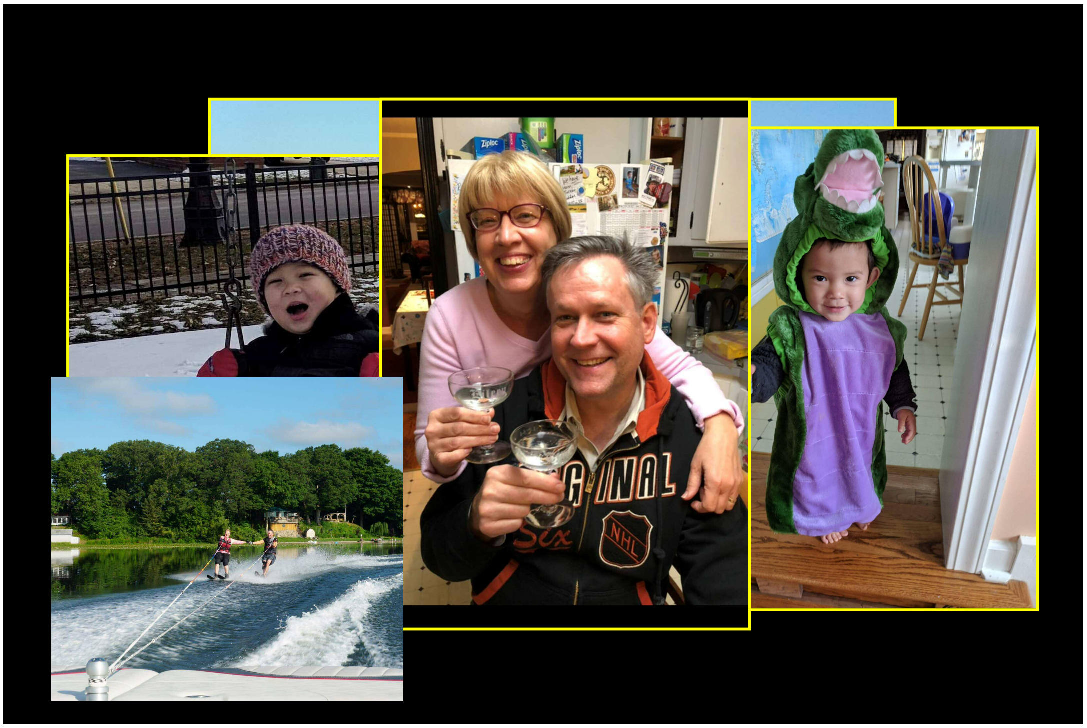
'Use all equipment in accordance with the manufacturers recommendation.'

99

Thank you for sharing Idaho



100



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Departure.
Arrival.
Questions?
tmurphy@murphypavetech.com
c. 773-874-9800

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