HSRC
Highway Sustainability Research Center

Innovative Research in Asphalt Pavements

Effect of Asphalt Binder Formulations and Sources on Binder and Mixture Performance

NEAUPG

Northeast Asphalt User Producer Group Meeting

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Research Team

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Background

- Under SHRP, the researchers used straight run asphalt binders to develop the PG asphalt binder specifications to address three common modes of distress: (Rutting, Fatigue cracking, thermal cracking.
- Recently, there has been an increase in the use of asphalt binder additives and chemical modification: polymers, polyphosphoric acid (PPA), re-refined engine oil bottoms (REOB), paraffinic base oils, bio binders, and ground tire rubber (GTR),…etc.

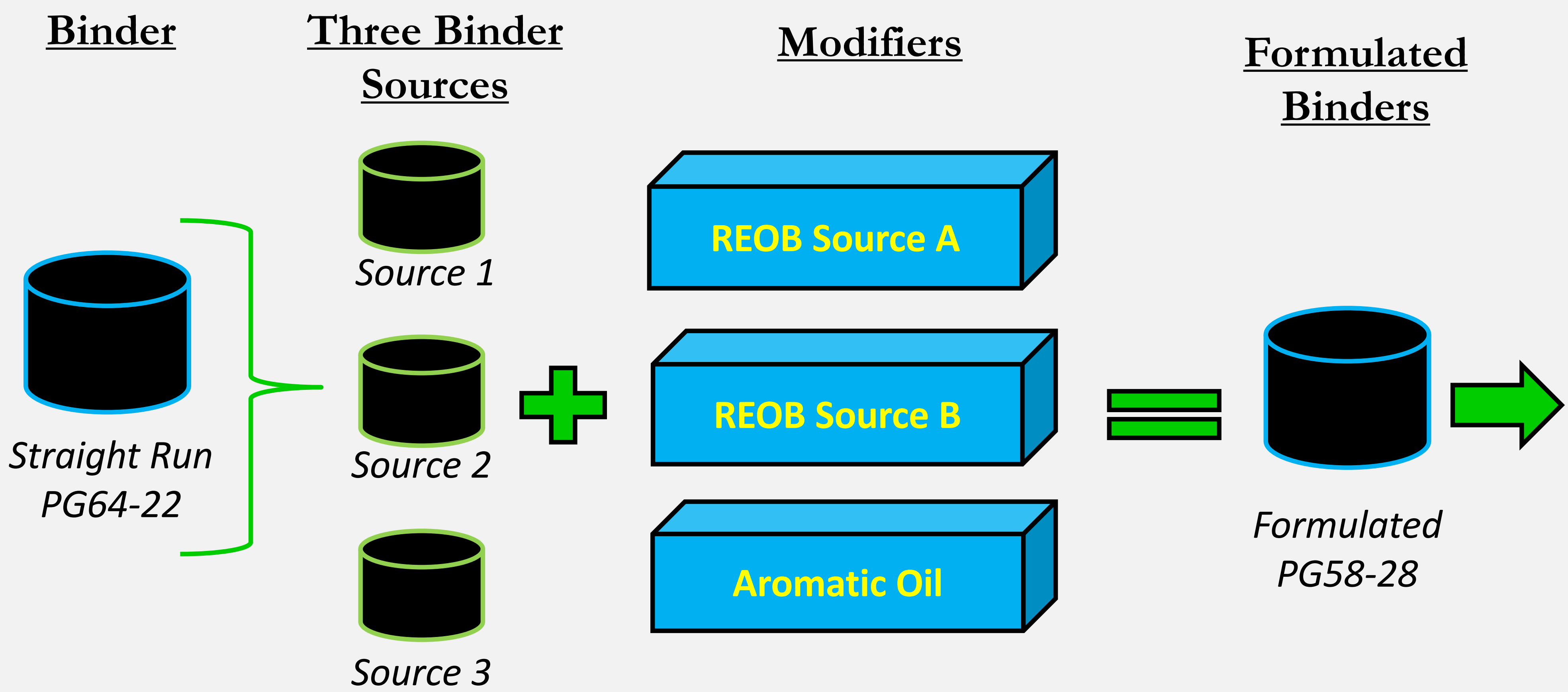
Background

- Agencies are increasingly experiencing premature failures of newly constructed pavements despite conformance with mix design standards, construction methods, and materials specifications.
- This has led to concerns of reduced quality of the asphalt binders used today, which may or may not be a function of the formulation techniques and modifiers being used.

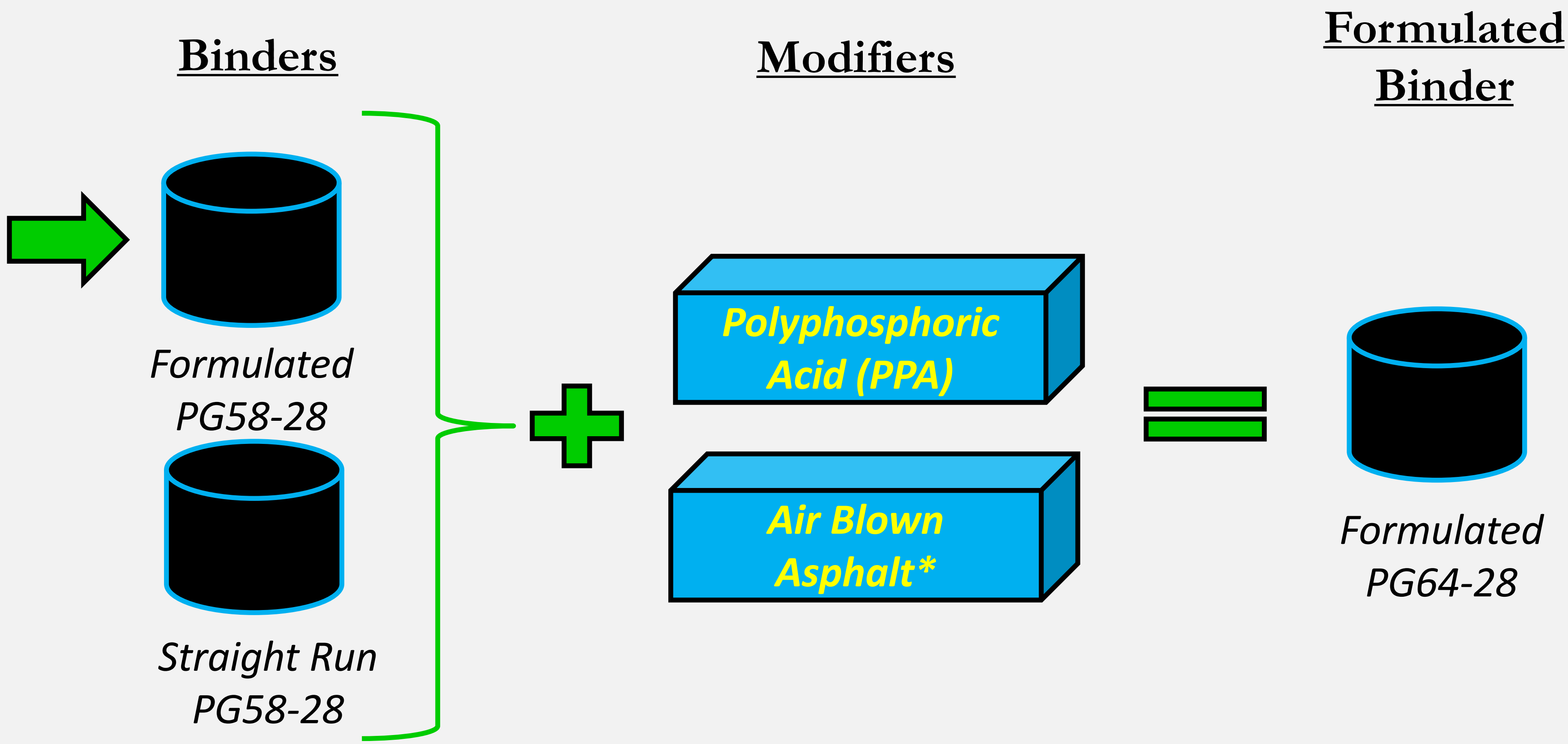
Background

- Other modes of common distresses are ignored and need consideration including adhesion and non-load associated cracking due to hardening/aging.
- Aging of an asphalt binder needs consideration as it is speculated that some methods of formulation increase an asphalt binder's rate of aging. Increased aging would result in an increase in the likelihood of premature distress.
- Tools now exist to further characterize the performance and composition of an asphalt binder.

Overall Project Scope



Overall Project Scope (Continued)



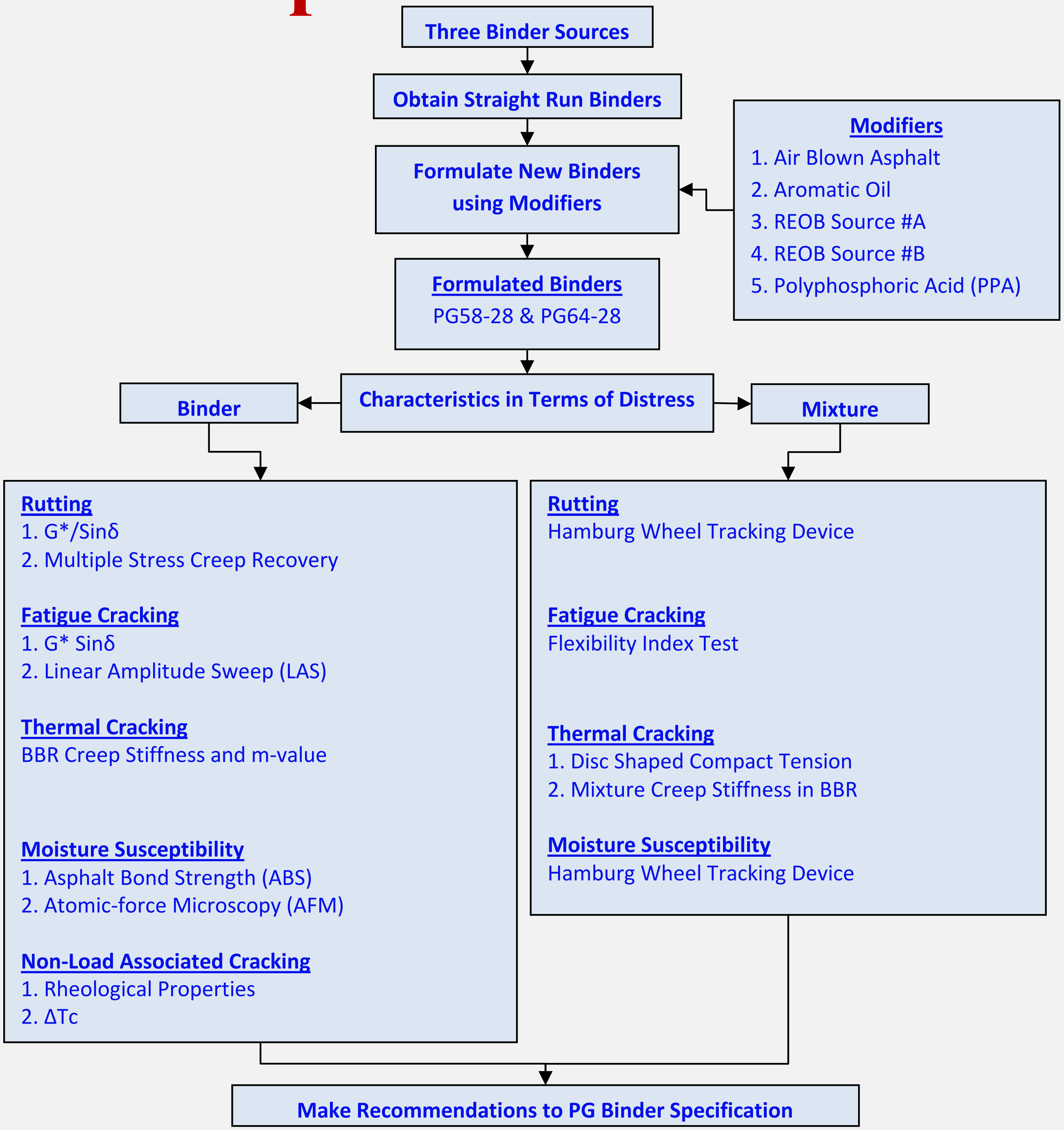
* Using air blown asphalt as a modifier was only able to yield a formulated PG58-28.

Objective

To investigate the impact of asphalt binder source and formulation (modifiers) on the resultant asphalt binder characteristics in terms of specific distresses.

For comparison, these asphalt binder characteristics were then compared to equivalent mixture distress characteristics whenever possible using the same binders.

Experimental Plan



Modifiers

- Two different sources of REOB.
- Aromatic oil.
- Polyphosphoric Acid (PPA) was limited to 1% which is a typical industry limit.
- Air blown asphalt.

PG58-28 Binder Formulations
Binder Source #1

Straight Run Binder	Binder Source	Modifier(s)	Resultant Continuous Grade	Resultant Performance Grade
PG58-28	**1**	**NONE- Straight Run**	**CG 61.1-28.2**	**PG58-28**
PG64-22	1	NONE- Straight Run	CG 67.0-24.2	PG64-22
PG64-22	1	2% REOB Source #A	CG 65.5-24.9	PG64-22
PG64-22	1	6% REOB Source #A	CG 63.3-27.7	PG58-22
PG64-22	**1**	**10% REOB Source #A**	**CG 61.0-28.3**	**PG58-28**
PG64-22	1	13% REOB Source #A	CG 59.4-29.2	PG58-28
PG64-22	1	18% REOB Source #A	CG 56.7-30.4	PG52-28
PG64-22	1	8% REOB Source #B	CG 63.1-31.7	PG58-28
PG64-22	**1**	**10% REOB Source #B**	**CG 60.3-30.6**	**PG58-28**
PG64-22	1	3% Aromatic Oil	CG 63.0-27.7	PG58-22
PG64-22	**1**	**6% Aromatic Oil**	**CG 60.6-29.0**	**PG58-28**
PG64-22	1	10% Aromatic Oil	CG 56.3-31.4	PG52-28
PG64-22	1	13.5% REOB Source #A + 25% Air Blown	CG 68.4-26.4	PG64-22
PG64-22	1	15% REOB Source #A + 25% Air Blown	CG 68.4-22.9	PG64-22
PG64-22	**1**	**15.3% REOB Source #A + 15% Air Blown**	**CG 63.7-29.2**	**PG58-28**
PG64-22	1	18.8% REOB Source #A + 25% Air Blown	CG 65.7-25.3	PG64-22
PG64-22	1	17.1% REOB Source #A + 5% Air Blown	CG 59.2-30.9	PG58-28

PG58-28 Binder Formulations
Binder Source #2

Straight Run Binder	Binder Source	Modifier(s)	Resultant Continuous Grade	Resultant Performance Grade
PG58-28	**2**	**NONE- Straight Run**	**CG 61.1-30.0**	**PG58-28**
PG64-22	2	NONE- Straight Run	CG 67.9-24.8	PG64-22
PG64-22	2	6% REOB Source #A	CG 64.6-26.6	PG64-22
PG64-22	**2**	**10% REOB Source #A**	**CG 62.9-28.3**	**PG58-28**
PG64-22	2	12% REOB Source #A	CG 61.3-27.5	PG58-22
PG64-22	2	18% REOB Source #A	CG 57.9-27.5	PG52-22
PG64-22	2	25% REOB Source #A	CG 54.9-26.7	PG52-22
PG64-22	2	6% REOB Source #B	CG 63.6-26.7	PG58-22
PG64-22	**2**	**10% REOB Source #B**	**CG 60.8-28.4**	**PG58-28**
PG64-22	2	12% REOB Source #B	CG 59.5-26.4	PG58-22
PG64-22	2	18% REOB Source #B	CG 55.2-25.4	PG52-22
PG64-22	2	25% REOB Source #B	CG 51.4-21.2	PG46-16
PG64-22	**2**	**6% Aromatic Oil**	**CG 62.4-28.1**	**PG58-28**
PG64-22	2	18% REOB Source #A + 25% Air Blown	CG 66.0-17.2	PG64-16

PG58-28 Binder Formulations Binder Source #3

Straight Run Binder	Binder Source	Modifier(s)	Resultant Continuous Grade	Resultant Performance Grade
PG58-28	3	NONE- Straight Run	CG 61.1-30.0	PG58-28
PG64-22	3	NONE- Straight Run	CG 67.5-23.6	PG64-22
PG64-22	3	10% REOB Source #A	CG 61.7-24.4	PG58-22
PG64-22	3	13% REOB Source #A	CG 60.5-25.9	PG58-22
PG64-22	3	16% REOB Source #A	CG 58.9-24.9	PG58-22
PG64-22	3	18% REOB Source #A	CG 57.1-28.4	PG52-28
PG64-22	3	20% REOB Source #A	CG 57.6-33.6	PG52-28
PG64-22	3	10% REOB Source #B	CG 60.5-26.3	PG58-22
PG64-22	3	15% REOB Source #B	CG 57.6-26.1	PG52-22
PG64-22	3	18% REOB Source #B	CG 57.5-30.7	PG52-28
PG64-22	3	20% REOB Source #B	CG 54.8-34.0	PG52-34
PG64-22	3	3% Aromatic Oil	CG 65.4-27.7	PG64-22
PG64-22	3	5% Aromatic Oil	CG 62.1-28.1	PG58-28
PG64-22	3	6% Aromatic Oil	CG 61.2-29.0	PG58-28

PG64-28 Binder Formulations
Binder Source #1

Straight Run Binder	Binder Source	Modifier(s)	Resultant Continuous Grade	Resultant Performance Grade
PG64-28	**Typical**	**NONE- Typical**	**CG 65.6-29.4**	**PG64-28**
PG58-28	**1**	**1% PPA**	**CG 67.0-29.1**	**PG64-28**
PG64-22	1	2% REOB Source #A + 1% PPA	CG 72.0-26.1	PG70-22
PG64-22	1	6% REOB Source #A + 1% PPA	CG 67.7-27.4	PG64-22
PG64-22	**1**	**10% REOB Source #A + 1% PPA**	**CG 64.4-29.8**	**PG64-28**
PG64-22	1	13% REOB Source #A + 1% PPA	CG 61.6-30.4	PG58-28
PG64-22	1	18% REOB Source #A + 1% PPA	CG 58.9-32.0	PG58-28
PG64-22	1	8% REOB Source #B + 1% PPA	CG 64.5-28.8	PG64-28
PG64-22	**1**	**10% REOB Source #B + 1% PPA**	**CG 63.8-29.6**	**PG58-28**
PG64-22	**1**	**6% Aromatic Oil + 1% PPA**	**CG 66.9-30.0**	**PG64-28**
PG64-22	1	10% Aromatic Oil + 1% PPA	CG 61.4-32.3	PG58-28

PG68-28 Binder Formulations Binder Source #2

Straight Run Binder	Binder Source	Modifier(s)	Resultant Continuous Grade	Resultant Performance Grade
PG64-28	Typical	NONE- Typical	CG 65.6-29.4	PG64-28
PG58-28	2	1% PPA	CG 68.7-30.5	PG64-28
PG64-22	2	10% REOB Source #A + 1% PPA	CG 66.0-28.0	PG64-28
PG64-22	2	10% REOB Source #B + 1% PPA	CG 64.4-27.0	PG64-28
PG64-22	2	6% Aromatic Oil + 1% PPA	CG 68.3-29.2	PG64-28

PG68-28 Binder Formulations
Binder Source #3

Straight Run Binder	Binder Source	Modifier(s)	Resultant Continuous Grade	Resultant Performance Grade
PG64-28	Typical	NONE- Typical	CG 65.6-29.4	PG64-28
PG58-28	3	1% PPA	CG 66.5-31.4	PG64-28
PG64-22	3	18% REOB Source #A + 1% PPA	CG 61.4-20.8	PG58-16
PG64-22	3	18% REOB Source #B + 1% PPA	CG 60.6-19.4	PG58-16
PG64-22	3	6% Aromatic Oil + 1% PPA	CG 63.4-30.1	PG58-28

Binder Formulation Discussion

- Binder source #3 was eliminated from any further testing and analysis because formulations could be achieved using only two modifiers.
- A total of 18 binders were evaluated in this study.

Mixture Design

- An approved 12.5mm mixture utilized in Massachusetts was selected for use in this study.
- Mixture was verified for acceptable volumetric properties and performance in the Hamburg Wheel Tracking Device.

Sieve Size	Sieve Size (mm)	Approved Mixture Gradation	MassDOT Mixture Specification	Tolerance
3/4"	19.0 mm	100	-	-
1/2"	12.5 mm	98	100 min	± 6%
3/8"	9.5 mm	84	90-100	± 6%
No. 4	4.75 mm	52	90 max	± 6%
No. 8	2.36 mm	32	32-67	± 5%
No. 16	1.18 mm	22	-	± 3%
No. 30	0.600 mm	15	-	± 3%
No. 50	0.300 mm	10	-	± 3%
No. 100	0.150 mm	6	-	± 2%
No. 200	0.075 mm	4	2-10	± 1%
Binder Content		5.2%	-	± 0.3%

Distress Evaluation - Rutting

Binder

- AASHTO M320 - G*/Sinδ of 1.00 kPa for original asphalt
- AASHTO M320 - G*/Sinδ of 2.20 kPa after RTFO aging
- AASHTO T350 - Multiple Stress Creep Recovery (MSCR) Non-recoverable Creep Compliance ($J_{nr3.2}$) at 64°C

Mixture

- AASHTO T324 – HWTD rut depth prior to onset of stripping (5,000 & 8,000 passes). Test temperature of 45°C.

Rutting/Moisture Susceptibility -

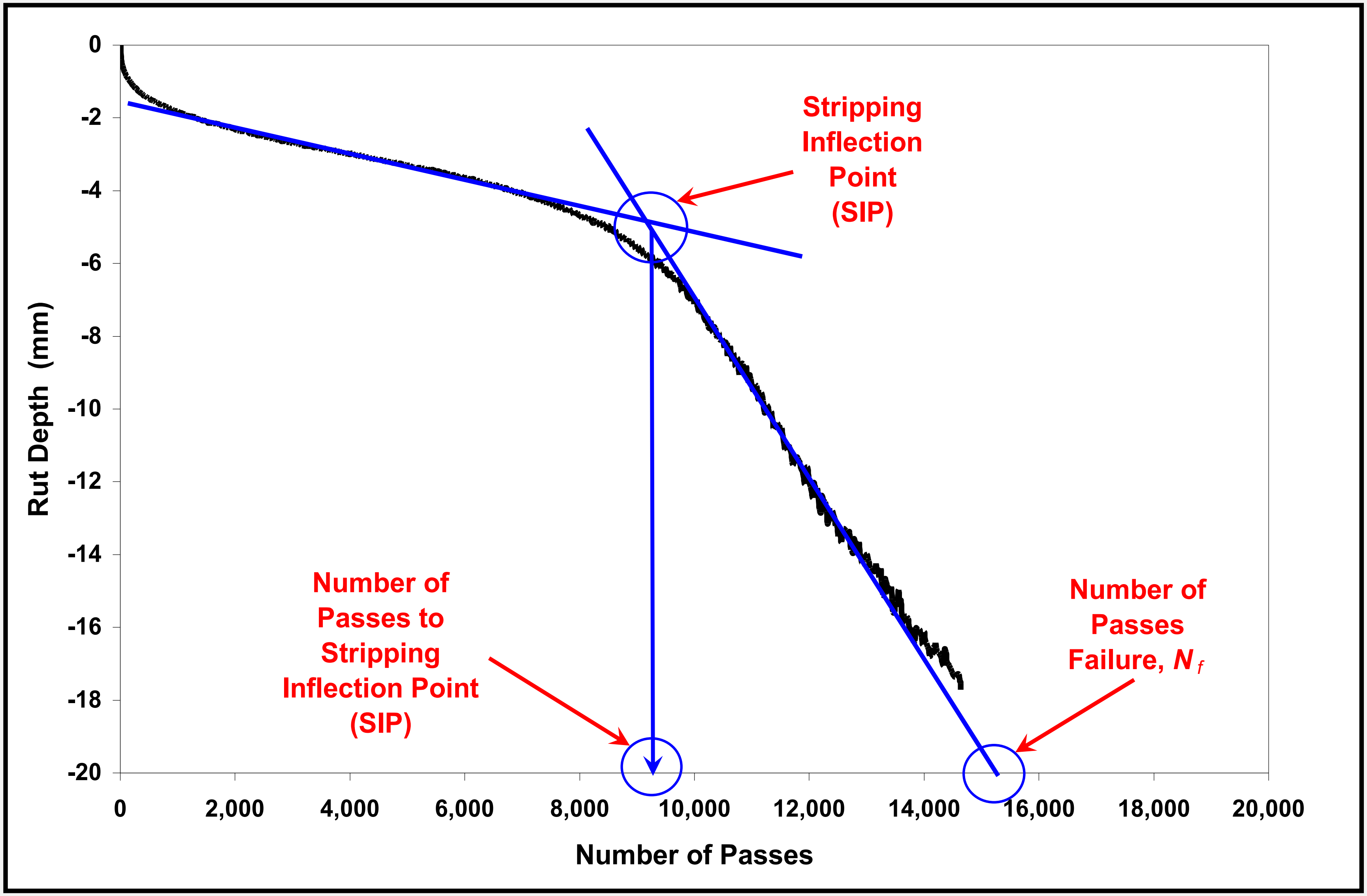
Hamburg Wheel Tracking Device (HWTD)

- HWTD testing conducted in accordance with AASHTO T324

- Water temperature of 45ºC (113ºF) per MassDOT specification

- Test duration of 20,000 passes

Stripping Inflection Point (SIP)



Distress Evaluation – Rutting for PG58-28 Binders & Mixtures

Binder Source	Modifier	AVG. G*/sinδ (kPa) @ 58°C Original	AVG. G*/sinδ (kPa) @ 58°C RTFO	AVG MSCR $J_{nr3.2}$	AVG HWTD Rut Depth at 5,000 Passes (mm)	AVG HWTD Rut Depth at 8,000 Passes (mm)
1	NONE- Straight Run	1.49	4.08	3.8	3.16	4.17
1	10% REOB Source #A	1.45	5.23	3.9	1.53	2.08
1	10% REOB Source #B	1.25	4.04	3.7	3.05	3.51
1	6% Aromatic Oil	1.42	4.71	3.3	1.47	1.96
1	15.3% REOB Source #A + 15% Air Blown	1.00	7.46	2.6	1.97	2.63
2	NONE- Straight Run	1.50	3.68	6.2	2.94	3.51
2	10% REOB Source #A	1.88	5.03	4.5	2.03	2.48
2	10% REOB Source #B	1.43	4.25	5.3	2.47	3.02
2	6% Aromatic Oil	1.77	4.44	5.3	1.25	1.42

Distress Evaluation – Rutting for PG64-28 Binders & Mixtures

Binder Source	Modifier	AVG G*/sinδ (kPa) @ 64°C Original	AVG G*/sinδ (kPa) @ 64°C RTFO	AVG MSCR $J_{nr3.2}$	AVG HWTD Rut Depth at 5,000 Passes (mm)	AVG HWTD Rut Depth at 8,000 Passes (mm)
Typical	NONE- Typical	1.21	3.09	2.5	2.33	2.61
1	1% PPA	1.42	3.43	1.8	2.05	2.18
1	10% REOB Source #A + 1% PPA	1.07	3.59	0.2	1.70	1.97
1	10% REOB Source #B + 1% PPA	0.97	2.90	1.9	3.00	3.72
1	6% Aromatic Oil + 1% PPA	1.40	2.30	2.6	1.30	1.45
2	1% PPA	1.76	4.00	2.2	2.28	2.91
2	10% REOB Source #A + 1% PPA	1.28	2.82	4.6	2.08	2.50
2	10% REOB Source #B + 1% PPA	1.04	2.41	5.0	0.87	0.90
2	6% Aromatic Oil + 1% PPA	1.68	3.63	2.5	0.90	1.08

Rutting Discussion

- All binders passed the PG specification for either a PG58 or PG64 based on G*/sinδ.
- For PG58-28 binder, binder source had a significant effect on $J_{nr3.2}$.
- MSCR data indicated that modifier type can have an effect on rutting performance.
- G*/sinδ and $J_{nr3.2}$ did not always support the same ranking of binders.
- The HWTD data had better agreement with G*/sinδ. The reason for poor agreement with $J_{nr3.2}$ is unknown.

Distress Evaluation - Fatigue

Binder

- AASHTO M320 - G*Sinδ of 5,000 kPa max. after PAV aging
- AASHTO TP101 - Linear Amplitude Sweep (LAS) test at 15°C

Mixture

- Flexibility index (FI) and fracture energy from Flexibility Index Test (FIT) at 25°C.

Intermediate Cracking

Illinois Flexibility Index Test (I-FIT) Using the SCB

- I-FIT testing conducted in accordance with standard protocols developed recently at Illinois Center for Transportation study R27-128
- Test temperature of 25ºC (77ºF)
- Load applied along the vertical diameter of the specimen at a displacement rate of 50 mm/min
- Fracture energy and Flexibility Index (FI) were calculated and recorded for each mixture

Flexibility Index (FI)

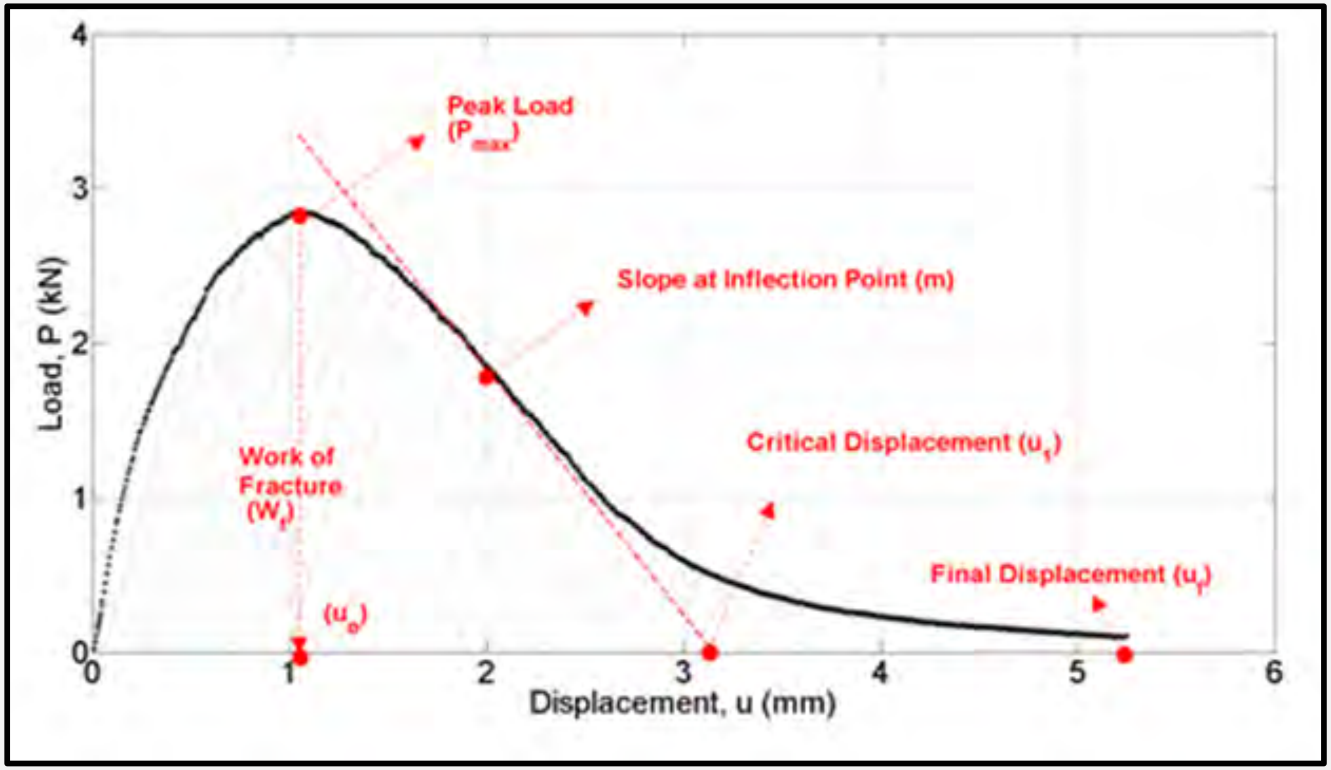
$$FI = A \times \frac{G_f}{abs(M)}$$

Where:

G_f = fracture energy in Joules/m^2, calculated from Work of Fracture (W_f)

M = slope of the post-peak curve at the inflection point in kN/mm

A = unit conversion factor and scaling coefficient (0.01).



Distress Evaluation – Fatigue PG58-28

Binder Source	Modifier	AVG Temp. G*sinδ (kPa) <5,000, °C	AVG LAS N_f @2.5% Strain	AVG LAS N_f @5% Strain	AVG LAS N_f @10% Strain	AVG FIT FI	AVG Fracture Energy (J/m²)
1	NONE- Straight Run	19°C	53,602	2,841	152	13.4	1,757
1	10% REOB Source #A	16°C	247,726	8,790	312	8.3	1,233
1	10% REOB Source #B	13°C	132,274	5,147	200	7.8	1,150
1	6% Aromatic Oil	19°C	85,889	4,493	236	15.0	1,585
1	15.3% REOB Source #A + 15% Air Blown	13°C	300,430	7,603	193	5.1	1,113
2	NONE- Straight Run	19°C	15,338	1,021	68	12.4	1,887
2	10% REOB Source #A	19°C	199,013	8,768	386	10.6	1,689
2	10% REOB Source #B	19°C	90,993	4,248	199	10.5	1,598
2	6% Aromatic Oil	22°C	35,266	2,215	139	13.6	2,217

Fatigue Discussion

- Results illustrated that modifier type and binder source can have an effect on the fatigue characteristics of the asphalt binder.
- The mixture FI was significantly reduced with the use of any modifier except aromatic oil indicating different fatigue performance in the mixtures.

Distress Evaluation – Thermal Cracking

Binder

- AASHTO M320 – BBR Creep stiffness (S) < 300 MPa and slope (m-value) > 0.300 after PAV aging

Mixture

- AASHTO TP125 - Mixture creep stiffness (S) and slope (m-value) tested in BBR
- ASTM D7313 - Disk Shaped Compact Tension Test DC(T) at -18°C

Distress Evaluation – Thermal Cracking PG58-28

Binder Source	Modifier	AVG Binder BBR Creep Stiffness S (MPa) at -18°C @ 60 Seconds	AVG Binder BBR m-value at -18°C @ 60 Seconds	AVG DCT Fracture Energy at -18°C (J/m^2)
1	NONE- Straight Run	265	0.300	517
1	10% REOB Source #A	164	0.303	649
1	10% REOB Source #B	136	0.313	556
1	6% Aromatic Oil	243	0.309	504
1	15.3% REOB Source #A + 15% Air Blown	116	0.320	731
2	NONE- Straight Run	245	0.319	655
2	10% REOB Source #A	170	0.301	649
2	10% REOB Source #B	160	0.303	695
2	6% Aromatic Oil	303	0.304	555

Distress Evaluation – Thermal Cracking PG58-28

Binder Source	Modifier	AVG Mixture BBR Creep Stiffness S (MPa) at -18°C @ 60 sec	AVG Mixture BBR m-value at -18°C@ 60 sec
1	NONE- Straight Run	10,440	0.083
1	10% REOB Source #A	6,385	0.084
1	10% REOB Source #B	8,783	0.090
1	6% Aromatic Oil	6,222	0.064
1	15.3% REOB Source #A + 15% Air Blown	6,121	0.106
2	NONE- Straight Run	6,975	0.082
2	10% REOB Source #A	7,625	0.088
2	10% REOB Source #B	7,308	0.076
2	6% Aromatic Oil	7,045	0.056

Distress Evaluation – Thermal Cracking PG64-28

Binder Source	Modifier	AVG Binder BBR Creep Stiffness S (MPa) at -18°C @ 60 Seconds	AVG Binder BBR m-value at -18°C @ 60 Seconds	AVG DCT Fracture Energy at -18°C (J/m²)
Typical	NONE- Typical	253	0.322	507
1	1% PPA	239	0.315	684
1	10% REOB Source #A + 1% PPA	140	0.310	620
1	10% REOB Source #B + 1% PPA	134	0.309	679
1	6% Aromatic Oil + 1% PPA	214	0.319	660
2	1% PPA	218	0.327	587
2	10% REOB Source #A + 1% PPA	169	0.300	745
2	10% REOB Source #B + 1% PPA	164	0.300	699
2	6% Aromatic Oil + 1% PPA	260	0.324	616

Distress Evaluation – Thermal Cracking PG64-28

Binder Source	Modifier	AVG Mixture BBR Creep Stiffness S (MPa) at -18°C @ 60 sec	AVG Mixture BBR m-value at -18°C@ 60 sec
1	NONE- Typical	5,457	0.079
1	1% PPA	6,117	0.090
1	10% REOB Source #A + 1% PPA	8,014	0.088
1	10% REOB Source #B + 1% PPA	8,186	0.068
1	6% Aromatic Oil + 1% PPA	6,781	0.067
2	1% PPA	9,038	0.095
2	10% REOB Source #A + 1% PPA	8,186	0.068
2	10% REOB Source #B + 1% PPA	7,227	0.094
2	6% Aromatic Oil + 1% PPA	7,399	0.065

Thermal Cracking Discussion

- Binder S and m-values demonstrated that the type of modifier can affect the test results.
- All mixture BBR testing met the proposed criteria of S <15,000 MPa & m-value <0.12 at 60 seconds. Similar to the binder testing, the type of modifier did influence the test results.
- DC(T) results indicated that all mixtures met the threshold for medium traffic (>460 J/m^2) which was the traffic level used to design the mixtures for this study.
- DC(T) results illustrated that the type of modifier and source of binder does have an impact on the fracture energy values.

Distress Evaluation – Moisture Susceptibility

Binder

- AASHTO TP091 - Asphalt Bond Strength (ABS) Test on granite substrate.
- Atomic-force Microscopy (AFM) for adhesive bonding energy determination.

Mixture

- AASHTO T324 – HWTD Stripping Inflection point (SIP). Test temperature of 45°C.

Distress Evaluation – Moisture Susceptibility PG58-28

Binder Source	Modifier	ABS Test Pull-Off Tensile Strength (MPa)	AFM Bonding Energy (kPa)	HWTD SIP @ 45°C
1	NONE- Straight Run	1.65	8,300	NONE
1	10% REOB Source #A	1.15	5,504	14,200
1	10% REOB Source #B	1.20	5,102	12,700
1	6% Aromatic Oil	1.51	10,522	12,900
1	15.3% REOB Source #A + 15% Air Blown	1.31	4,901	12,100
2	NONE- Straight Run	1.84	7,477	NONE
2	10% REOB Source #A	1.16	4,545	12,900
2	10% REOB Source #B	1.35	5,384	14,500
2	6% Aromatic Oil	1.78	9,753	NONE

Distress Evaluation – Moisture Susceptibility PG64-28

Binder Source	Modifier	ABS Test Pull-Off Tensile Strength (MPa)	AFM Bonding Energy (kPa)	HWTD SIP @ 45°C
Typical	NONE- Typical	1.57	-	NONE
1	1% PPA	1.72	-	NONE
1	10% REOB Source #A + 1% PPA	1.61	6,272	NONE
1	10% REOB Source #B + 1% PPA	1.55	5,968	8,200
1	6% Aromatic Oil + 1% PPA	1.95	9,218	NONE
2	1% PPA	1.96	-	8,400
2	10% REOB Source #A + 1% PPA	0.98	5,943	11,100
2	10% REOB Source #B + 1% PPA	1.02	6,554	NONE
2	6% Aromatic Oil + 1% PPA	1.90	8,741	NONE

Moisture Susceptibility Discussion

- ABS testing indicated a reduction in pull off strength for the binders modified with REOB (either source), REOB in combination with PPA, or combination of REOB and air blown asphalt as compared to the straight run and typical binder counterparts.
- Generally, ABS testing indicated comparative results for straight run binders and binders modified with aromatic oil.
- ABS results suggested that some modifiers will decrease the adhesive properties of the binders without a resultant change in PG.
- The AFM bonding energy results supported the ABS test results suggesting the use of certain modifiers will decrease the adhesive quality of the binder.

Moisture Susceptibility Discussion

- Generally, mixtures exhibiting a SIP also had lower adhesion values from the ABS test and AFM testing.
- As stated in the background, there have been premature failures reported in the field such as raveling which could be due to the adhesion characteristics of the binder. Thus, this suggests that an adhesion test of the binder is warranted for inclusion in asphalt binder specifications.

Distress Evaluation – Non Load Associated Cracking (Block Cracking)

Binder

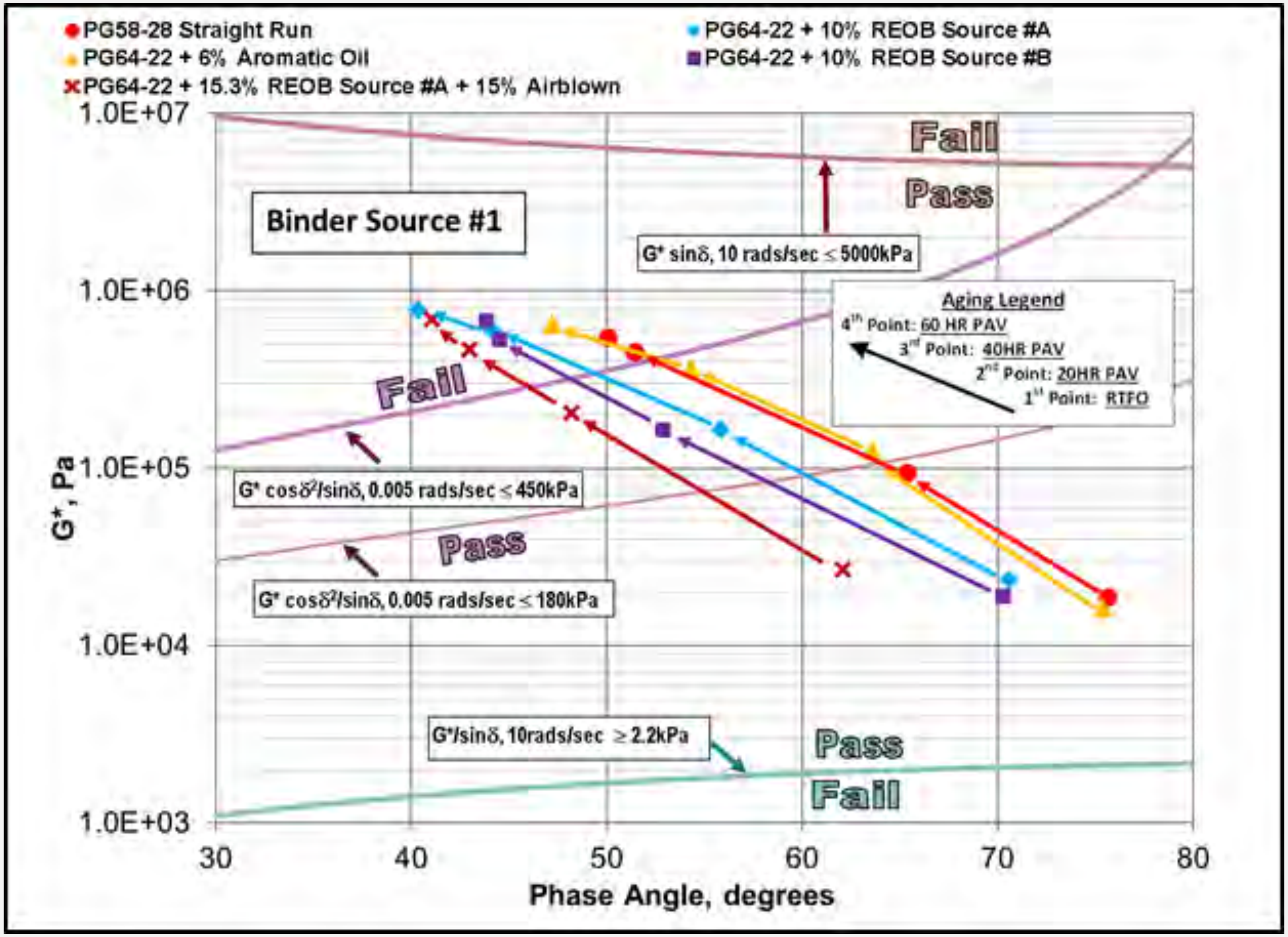
- Black Space Diagram with Glover-Rowe thresholds

  - Limits plotted on black space diagram showing the onset of block cracking to failure from block cracking.

- Delta T_c (ΔT_c) from BBR measurements

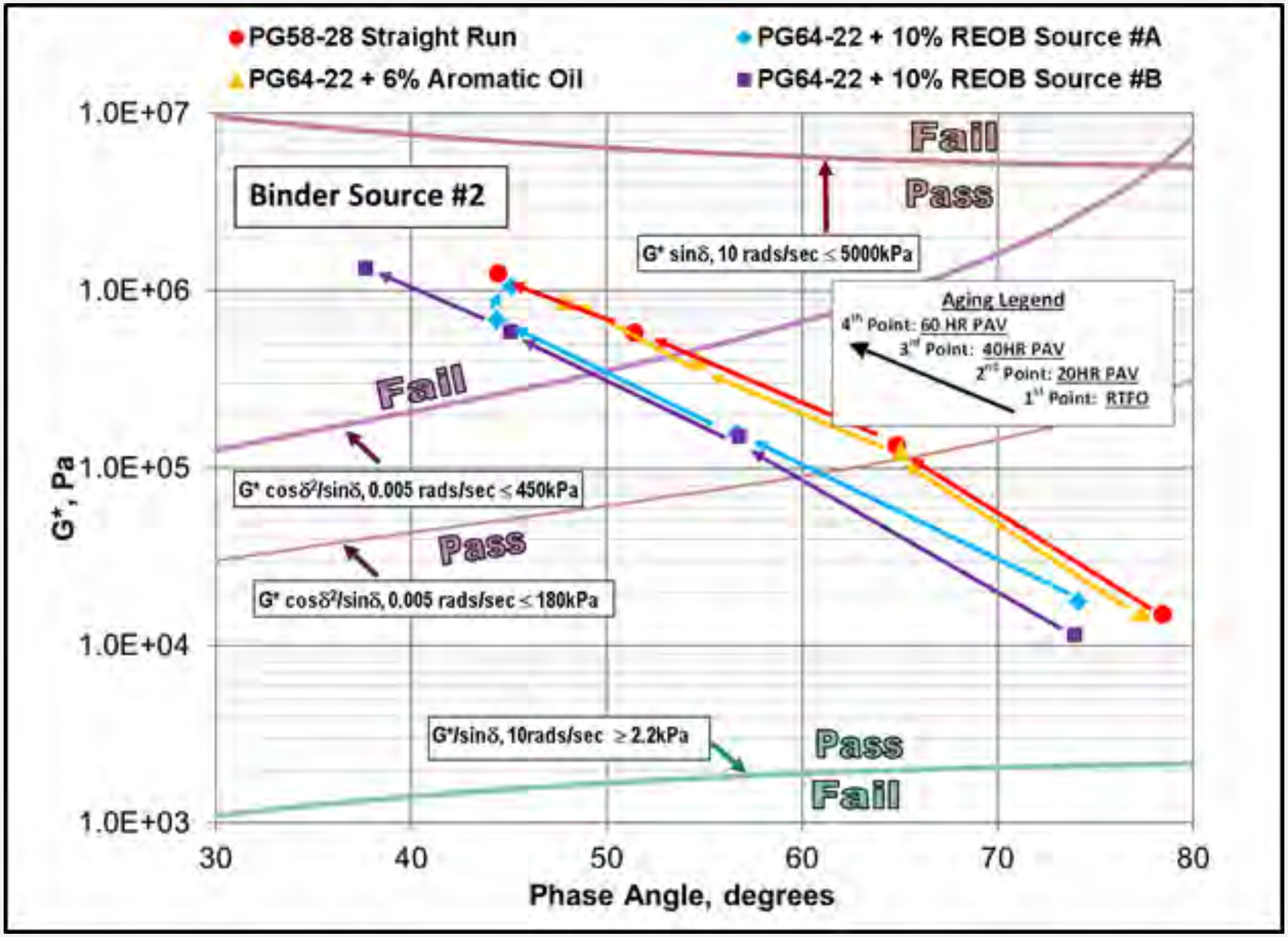
  - ΔT_c limit of -2.5°C suggested by Anderson et al. (2011)

Distress Evaluation – Non Load Associated Cracking (Block Cracking)



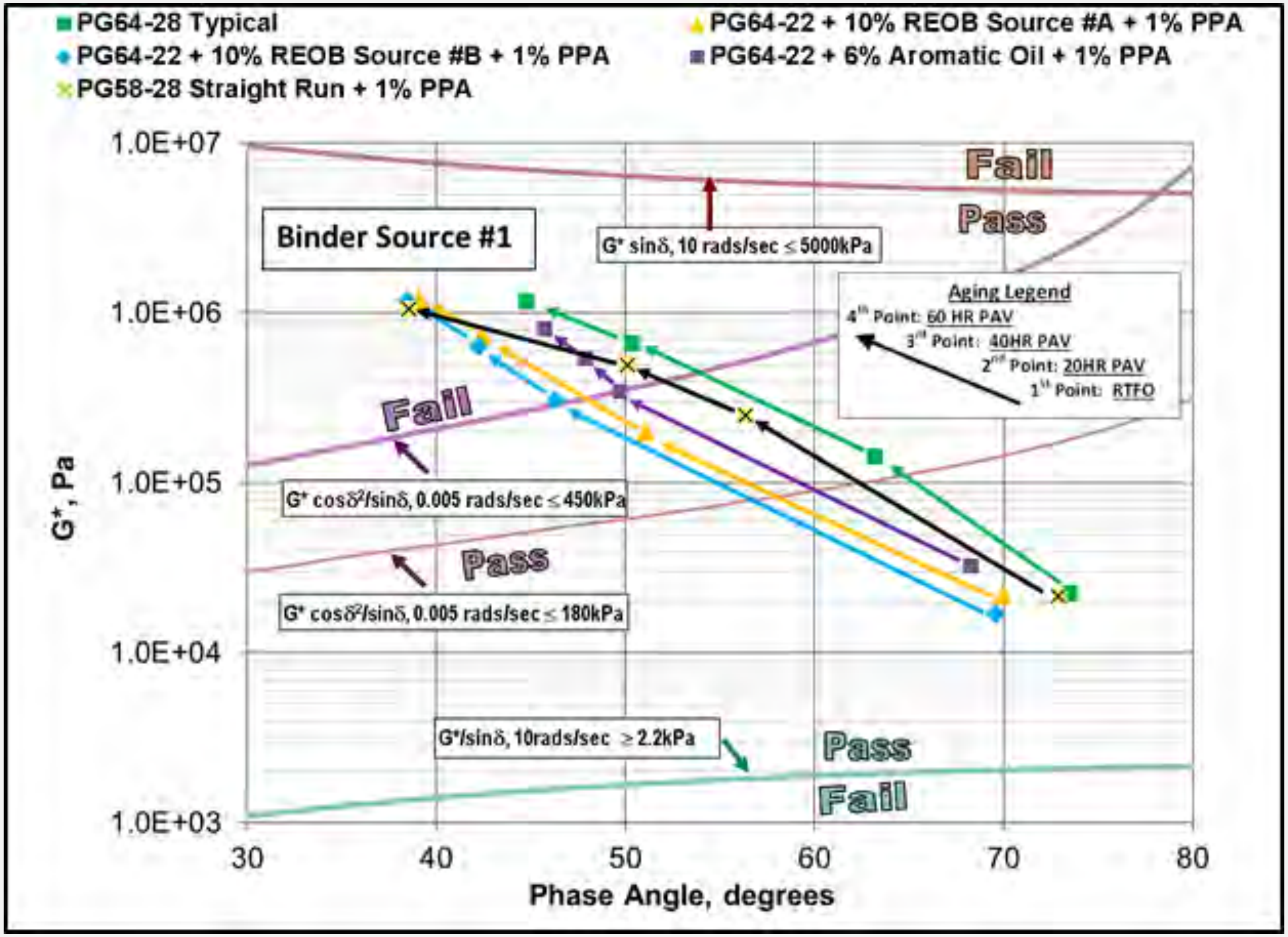
PG58-28 Binders Formulated from Binder Source #1

Distress Evaluation – Non Load Associated Cracking (Block Cracking)



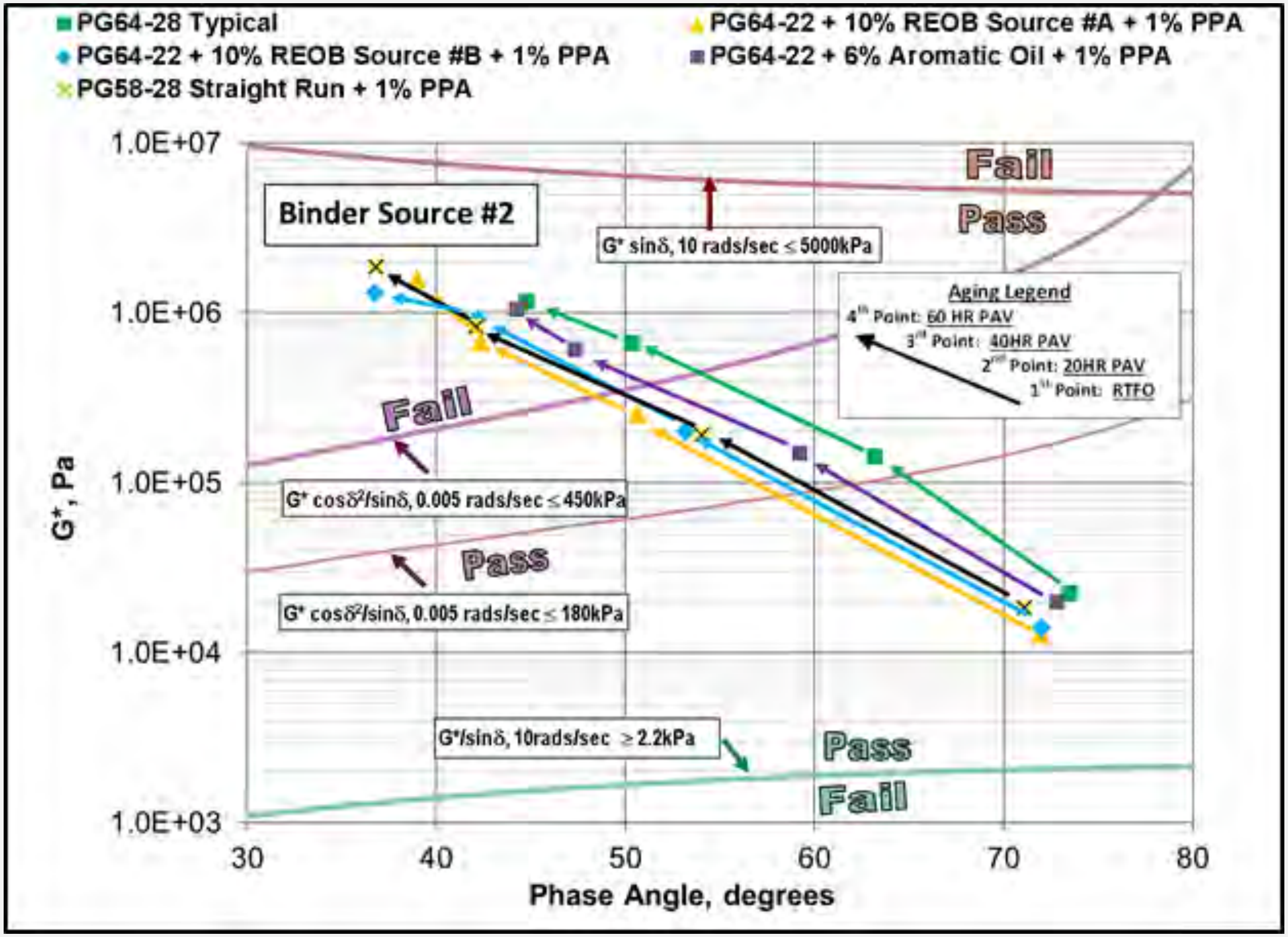
PG58-28 Binders Formulated from Binder Source #2

Distress Evaluation – Non Load Associated Cracking (Block Cracking)



PG64-28 Binders Formulated from Binder Source #1

Distress Evaluation – Non Load Associated Cracking (Block Cracking)



PG64-28 Binders Formulated from Binder Source #2

Distress Evaluation – Non Load Associated Cracking (Block Cracking)

ΔT_c from BBR measurements

$\Delta T_c = T_c$ (S based) - T_c (m based)

Binder Source	Modifier	AVG ΔT_c (°C)
1	NONE- Straight Run	-1.1
1	10% REOB Source #A	-5.3
1	10% REOB Source #B	-4.3
1	6% Aromatic Oil	-0.7
1	15.3% REOB Source #A + 15% Air Blown	-6.0
2	NONE- Straight Run	-0.1
2	10% REOB Source #A	-4.4
2	10% REOB Source #B	-5.2
2	6% Aromatic Oil	+0.5

Non Load Associated Cracking Discussion

- Interpretations of the Black Space diagrams with associated limits for non-load associated cracking (block cracking) suggest that there is quantifiable difference in the block cracking resistance between straight run and formulated binders even though the PG of the binders is the same.

- ΔT_c values with associated limits (-2.5°C) suggested by Anderson et al. 2011 suggested that non-load associated cracking could be an issue for certain binders even though the PG of the binders is the same.

Conclusions

- Based on the results of this study, effective binder modification is binder source, modifier type and modifier dose dependent.

- Results suggested that not all binders with the same PG will perform the same.

Conclusions

- For PG58-28 binders, the binder formulations incorporating REOB and REOB in combination with air blown asphalt were beyond the -2.5°C ΔTc threshold suggested by Anderson et al. (2011).

- This testing identified these binders as susceptible to non-load associated cracking.

Conclusions

- Generally, results from the mixture tests used in this study supported the current Superpave PG specification. However, the modifiers used did impact other distresses not currently included in the PG specification.

- To better evaluate the impact of binder source and formulation on performance, new tools to evaluate binder quality can be added to the existing PG specification.

Conclusions

- In this study, the ABS test and AFM were used to evaluate adhesion failures and Black Space Diagrams and the parameter ΔTc were used to evaluate non-load associated (block) cracking. Each of these tools can complement the existing PG specification.

Acknowledgements

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Thank you!