Influence of Asphalt Binder Formulation & Source on the Performances of Binders with the Same Continuous PG

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Background

- PG asphalt binder specifications addresses three common modes of distress: rutting, fatigue cracking, and thermal cracking.

- Because agencies are increasingly experiencing premature failures of newly constructed pavements, other modes of common distresses should be considered such as adhesion and non-load associated cracking due to hardening/aging.

- Also, since the development of the PG specs, there has been an increase in the use of asphalt binder additives and chemical modification.

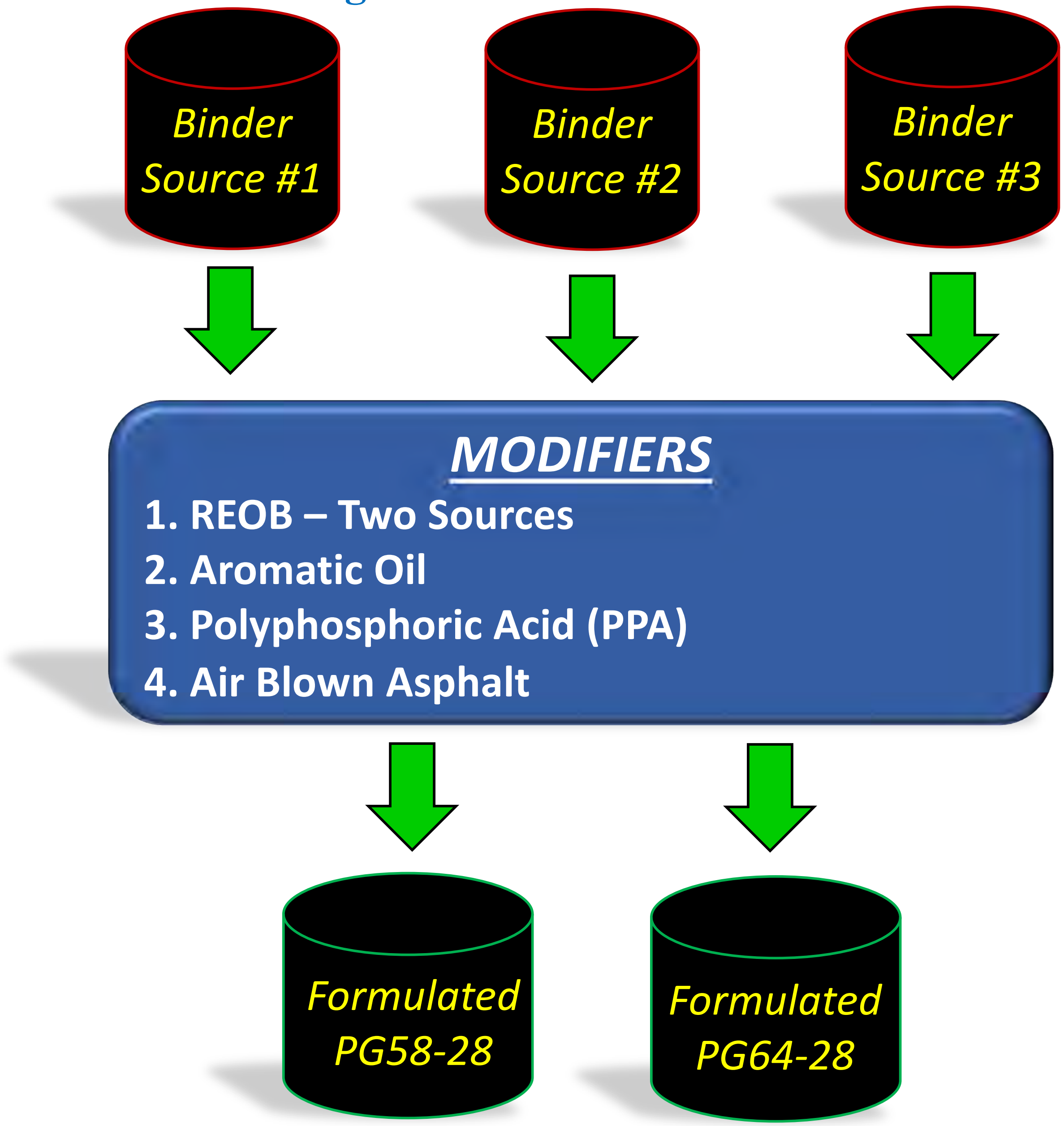
- Tools now exist to further characterize the performance and composition of an asphalt binder.

Objective

Determine the effects of asphalt binder formulation and source on the performances of binders having the same continuous PG.

Scope of Work

Straight Run PG58-28 & PG64-22



BINDER

Rutting

1. G*/Sinδ
2. Multiple Stress Creep Recovery

Fatigue Cracking

1. G*Sinδ
2. Linear Amplitude Sweep

Thermal Cracking

1. BBR Binder S and m-value
2. Extended BBR

Adhesion and Moisture Susceptibility

1. Asphalt Bond Strength
2. Atomic-force Microscopy

Non-Load Associated Cracking

1. Black Space
2. ΔT_c

MIXTURE

Rutting

1. Hamburg Wheel Tracking Device
2. Flow Number

Fatigue Cracking

Illinois Flexibility Index Test

Thermal Cracking

1. BBR Mixture S and m-value
2. Disc Shaped Compact Tension

Adhesion and Moisture Susceptibility

Hamburg Wheel Tracking Device

Mixture Design

- An approved 12.5mm mixture utilized in Massachusetts was selected for use in this study.

Sieve Size	Sieve Size (mm)	Mixture Aggregate Gradation % Passing	Superpave and MassDOT Specification	Tolerance
3/4"	19.0	100	100 min	-
1/2"	12.5	98	90-100	± 6%
3/8"	9.5	84	90 max	± 6%
No. 4	4.75	52	-	± 6%
No. 8	2.36	32	28-58	± 5%
No. 16	1.18	22	-	± 3%
No. 30	0.600	15	-	± 3%
No. 50	0.300	10	-	± 3%
No. 100	0.150	6	-	± 2%
No. 200	0.075	4	2-10	± 1%
Binder Content		5.2%	-	± 0.3%

Binder Formulations

- Eighteen asphalt binders were selected for testing consisting of fifteen formulations, two straight run PG58-28 asphalt binders and the typical PG64-28 asphalt binder.

- Using Binder Source #3, a PG58-28 could only be achieved using aromatic oil while a PG64-28 could only be achieved using PPA. Because of these limitations, Binder Source #3 was eliminated from this study.

Binder Formulations

Straight Run Binder	Binder Source	Modifier	Resultant Continuous Grade	Resultant Performance Grade
PG58-28	1	NONE- Straight Run	CG 61.1-28.2	PG58-28
PG64-22	1	10% REOB Source A	CG 61.0-28.3	PG58-28
PG64-22	1	10% REOB Source B	CG 60.3-30.6	PG58-28
PG64-22	1	6% Aromatic Oil	CG 60.6-29.0	PG58-28
PG64-22	1	15.3% REOB Source A + 15% Air Blown	CG 63.7-29.2	PG58-28
PG58-28	2	NONE- Straight Run	CG 61.1-30.0	PG58-28
PG64-22	2	10% REOB Source A	CG 62.9-28.3	PG58-28
PG64-22	2	10% REOB Source B	CG 60.8-28.4	PG58-28
PG64-22	2	6% Aromatic Oil	CG 62.4-28.1	PG58-28
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	10% REOB Source A+ 1% PPA	CG 64.4-29.8	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
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 64.4-28.0	PG64-28
PG64-22	2	6% Aromatic Oil + 1% PPA	CG 68.3-29.2	PG64-28

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.
- AASHTO TP79 - Minimum required flow number for 3 to <10 million ESALs is 50 cycles.

Rutting Evaluation For PG58-28

Binder Source	Modifier	Binder Tests			Mixture Tests	
		G*/sinδ at 58°C Original	G*/sinδ at 58°C RTFO	MSCR $J_{nr3.2}$ at 64°C	HWTD Rut Depth at 45°C and 8,000 Wheel Passes	Flow Number at 50°C
1	NONE- Straight Run	✓	✓	✓	✓	✓
1	REOB Source A	✓	✓	✓	✓	✓
1	REOB Source B	✓	✓	✓	✓	✓
1	Aromatic Oil	✓	✓	✓	✓	✓
1	REOB Source A + Air Blown	✓	✓	✓	✓	✓
2	NONE- Straight Run	✓	✓	✗	✓	✓
2	REOB Source A	✓	✓	✓	✓	✓
2	REOB Source B	✓	✓	✗	✓	✓
2	Aromatic Oil	✓	✓	✗	✓	✓

✗ MSCR $J_{nr3.2} > 4.5\ kPa^{-1}$.

Rutting Evaluation For PG64-28

Binder Source	Modifier	Binder Tests			Mixture Tests	
		G*/sinδ at 64°C Original	G*/sinδ at 64°C RTFO	MSCR $J_{nr3.2}$ at 64°C	HWTD Rut Depth at 45°C and 8,000 Wheel Passes	Flow Number at 50°C
Typical	NONE- Typical	✓	✓	✓	✓	✓
1	PPA	✓	✓	✓	✓	✓
1	REOB Source A + PPA	✓	✓	✓	✓	✓
1	REOB Source B + PPA	✓	✓	✓	✓	✓
1	Aromatic Oil + PPA	✓	✓	✓	✓	✓
2	PPA	✓	✓	✓	✓	✓
2	REOB Source A + PPA	✓	✓	✗	✓	✓
2	REOB Source B + PPA	✓	✓	✗	✓	✓
2	Aromatic Oil + PPA	✓	✓	✓	✓	✓

✗ MSCR $J_{nr3.2} > 4.5\ kPa^{-1}$.

Discussion - Rutting

- Asphalt binder formulation and source had no effect on rutting performance when measured by the HWTD and Flow Number because these tests provided no evidence that any of the mixtures would fail by rutting.
- They had an effect on rutting performance when measured by the MSCR even though the binders had closely matching high temperature PGs. Thus, the mixture tests agreed with the high temperature PGs rather than with MSCR.

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.

Fatigue Evaluation For PG58-28

Binder Source	Modifier	Binder Tests				Mixture Tests	
		G*sinδ (Pass at 19°C)	LAS N_f at 2.5% Strain	LAS N_f at 5% Strain	LAS N_f at 10% Strain	I-FIT FI	I-FIT Fracture Energy (J/m^2)
1	NONE- Straight Run	✓19°C	53,602	2,841	152	3.07	1,570
1	REOB Source A	✓16°C	247,726	8,790	312	2.70	1,240
1	REOB Source B	✓13°C	132,274	5,147	200	3.49	1,320
1	Aromatic Oil	✓19°C	85,889	4,493	236	3.55	1,270
1	REOB Source A + Air Blown	✓13°C	300,430	7,603	193	1.87	1,104
2	NONE- Straight Run	✓19°C	15,338	1,021	68	1.78	1,650
2	REOB Source A	✓19°C	199,013	8,768	386	1.51	1,130
2	REOB Source B	✓19°C	90,993	4,248	199	1.93	1,230
2	Aromatic Oil	✓22°C	35,266	2,215	139	1.49	1,510

Fatigue Evaluation For PG64-28

Binder Source	Modifier	Binder Tests				Mixture Tests	
		G*sinδ (Pass at 22°C)	LAS N_f at 2.5% Strain	LAS N_f at 5% Strain	LAS N_f at 10% Strain	I-FIT FI	I-FIT Fracture Energy (J/m²)
1	NONE- Typical	✓19°C	64,757	4,075	257	2.08	1,370
1	PPA	✓16°C	152,460	6,264	258	2.50	1,257
1	REOB Source A + PPA	✓16°C	288,819	9,523	315	2.36	998
1	REOB Source B + PPA	✓16°C	290,558	8,909	273	1.85	969
1	Aromatic Oil + PPA	✓16°C	176,539	5,596	178	3.32	1,317
2	PPA	✓19°C	140,621	7,353	385	1.79	1,692
2	REOB Source A + PPA	✓16°C	114,225	4,598	185	1.61	1,395
2	REOB Source B + PPA	✓16°C	104,086	4,148	166	1.49	1,251
2	Aromatic Oil + PPA	✓19°C	107,583	6,148	351	1.46	1,579

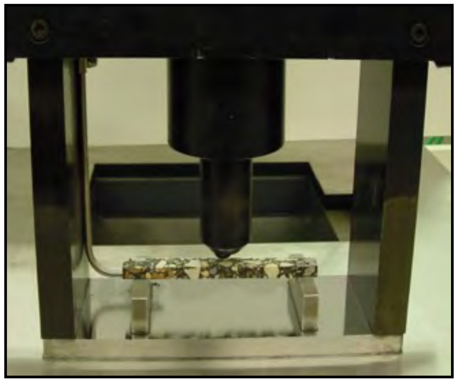
Discussion – Fatigue Cracking

- Asphalt binder formulation and source had an effect on fatigue cracking performance based on both the FI and fracture energy from the I-FIT.
- Formulation and source also had an effect based on G*sinδ and the LAS. Although this agreed with the I-FIT, there was no correlation between any of the tests. They are not measuring the exact same property.

Distress Evaluation – Thermal Cracking

Binder

- AASHTO M320 – BBR Creep stiffness (S) < 300 MPa and slope (m-value) > 0.300 after PAV aging
- Ontario Test Method LS-308 EBBR - Grade Loss < 6° C



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

Thermal Cracking Evaluation For PG58-28

Binder Source	Modifier	Binder Tests			Mixture Tests		
		BBR S Value	BBR m-value	EBBR Grade Loss	BBR S Value	BBR m-value	DC(T) Fracture Energy
1	NONE- Straight Run	✓	✓	✗	✓	✓	✓
1	REOB Source A	✓	✓	✗	✓	✓	✓
1	REOB Source B	✓	✓	✗	✓	✓	✓
1	Aromatic Oil	✓	✓	✗	✓	✓	✓
1	REOB Source A + Air Blown	✓	✓	✗	✓	✓	✓
2	NONE- Straight Run	✓	✓	✓	✓	✓	✓
2	REOB Source A	✓	✓	✓	✓	✓	✓
2	REOB Source B	✓	✓	✓	✓	✓	✓
2	Aromatic Oil	✓	✓	✓	✓	✓	✓

✗ EBBR Grade Loss > 6°C.

Thermal Cracking Evaluation For PG64-28

Binder Source	Modifier	Binder Tests			Mixture Tests		
		BBR S Value	BBR m-value	EBBR Grade Loss	BBR S Value	BBR m-value	DC(T) Fracture Energy
1	NONE- Typical	✓	✓	✓	✓	✓	✓
1	PPA	✓	✓	✗	✓	✓	✓
1	REOB Source A + PPA	✓	✓	✗	✓	✓	✓
1	REOB Source B + PPA	✓	✓	✗	✓	✓	✓
1	Aromatic Oil + PPA	✓	✓	✗	✓	✓	✓
2	PPA	✓	✓	✓	✓	✓	✓
2	REOB Source A + PPA	✓	✓	✗	✓	✓	✓
2	REOB Source B + PPA	✓	✓	✓	✓	✓	✓
2	Aromatic Oil + PPA	✓	✓	✓	✓	✓	✓

✗ EBBR Grade Loss > 6°C.

Discussion – Thermal Cracking

- Asphalt binder formulation and source had no effect on thermal cracking performance when measured by the BBR mixture test and the DC(T) mixture test.

- Asphalt binder formulation and source had an effect on thermal cracking when measured by the EBBR even though the binders had closely matching low temperature PGs. Thus, the mixture tests agreed with the low temperature PGs rather than with EBBR.

Distress Evaluation - Adhesion & Moisture Susceptibility

Binder

- AASHTO T361 – Asphalt Bond Strength (ABS) Test
- Atomic-force Microscopy (AFM)

Mixture

- AASHTO T324 - Test temperature of 45°C with SIP >15,000 passes.

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Discussion – Adhesion & Moisture

- Asphalt binder formulation had an effect on cohesion, adhesion and moisture susceptibility even though the binders had closely matching continuous PGs based on high and low temperature properties.

Distress Evaluation – Non-load Associated Cracking

Binder

- Black Space Diagrams
- Delta T_c (ΔT_c) - ΔT_c limit of -2.5°C has been recommended.

$$\Delta T_c = T_{c(S)} - T_{c(m)}$$

Distress Evaluation – Non-load Associated Cracking

Binder Source	Modifier	ΔT_c (°C)
1	NONE- Straight Run	✓
1	REOB Source A	✗
1	REOB Source B	✗
1	Aromatic Oil	✓
1	REOB Source A + Air Blown	✗
2	NONE- Straight Run	✓
2	REOB Source A	✗
2	REOB Source B	✗
2	Aromatic Oil	✓

✗ $\Delta T_c > -2.5$°C

Distress Evaluation – Non-load Associated Cracking

Binder Source	Modifier	ΔT_c (°C)
Typical	NONE- Typical	✓
1	PPA	✓
1	REOB Source A + PPA	✗
1	REOB Source B + PPA	✗
1	Aromatic Oil + PPA	✓
2	PPA	✓
2	REOB Source A + PPA	✗
2	REOB Source B + PPA	✗
2	Aromatic Oil + PPA	✓

✗ $\Delta T_c > -2.5°C$

Discussion – Non-load Associated Cracking

- Asphalt binder formulation had an effect on non-load associated cracking performance using both Black Space Diagrams and ΔTc even though the binders had closely matching continuous PGs based on high and low temperature properties.

- Asphalt binder source had an effect using Black Space Diagrams but not using ΔTc. The two methodologies did not always agree with each other.

Study Conclusions

1. Asphalt binder formulation and source had an effect on fatigue cracking, cohesion, adhesion, moisture susceptibility and non-load associated cracking.

2. They had no effect on rutting performance except when measured by the MSCR, or thermal cracking performance except when measured by the EBBR.

3. In this study, the mixture tests for rutting and thermal cracking supported the AASHTO M320 specification.

Thank you

Distress Evaluation – Non-load Associated Cracking