HSRC
Highway Sustainability Research Center

Innovative Research in Asphalt Pavements

Using Binder and Mixture Space Diagrams to Evaluate the Effect of REOB on Binders and Mixtures after Aging

NEAUPG

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REOB

- Re-refined Engine Oil Bottoms (REOB) is the heavy distillation residue from refining used engine oil.
- Primarily used because it costs less than typical additives/modifiers.
- REOB is also known by other names including:
  - Vacuum Tower Asphalt Extender (VTAE)
  - Waste Oil Distillation Bottoms (WODB)
  - Engine Oil Residues (EOR)
  - Re-refined Heavy Vacuum Distillation Oil (RHVDO)
  - Re-refined Vacuum Tower Bottoms (RVTB)

Concerns with Using REOB

- New roads in Ontario Canada were exhibiting transverse cracks and ruts. Cores were taken from the roads and researchers reported finding metals such as zinc present in the asphalt.
- The zinc and other metals were consistent with engine oil (REOB) and had not been previously found in asphalt binders. Researchers concluded that the engine oil was the cause of the road problems.
- Similar distress problems experienced in New England led to concerns that REOB may be the cause.

Concerns with Using REOB

- Will pavement performance degrade when REOB is used?
- Is REOB environmentally friendly, recyclable, and safe for construction workers to use?
- What is the effect of the dosage of REOB on low temperature performance?

Concerns Addressed in this Study

- How does a PG64-28 formulated using REOB compare to other products used to produce a PG64-28 such as (1) modifying a PG58-28 with up to 1% PPA and (2) using aromatic oil instead of REOB?
- What is the effect of REOB on short-term and long-term performance of asphalt binders?
- What is the effect of REOB on the short-term and long-term performance of a typical asphalt mixture used in New England states?
- Since several companies produce REOB, do different REOB sources use the same dosage to reach the target low temperature grade?

Objectives

- Determine the range of REOB dosages required to bump a straight run PG64-22 binder down to a PG58-28 binder. Repeat using aromatic oil as a modifier.

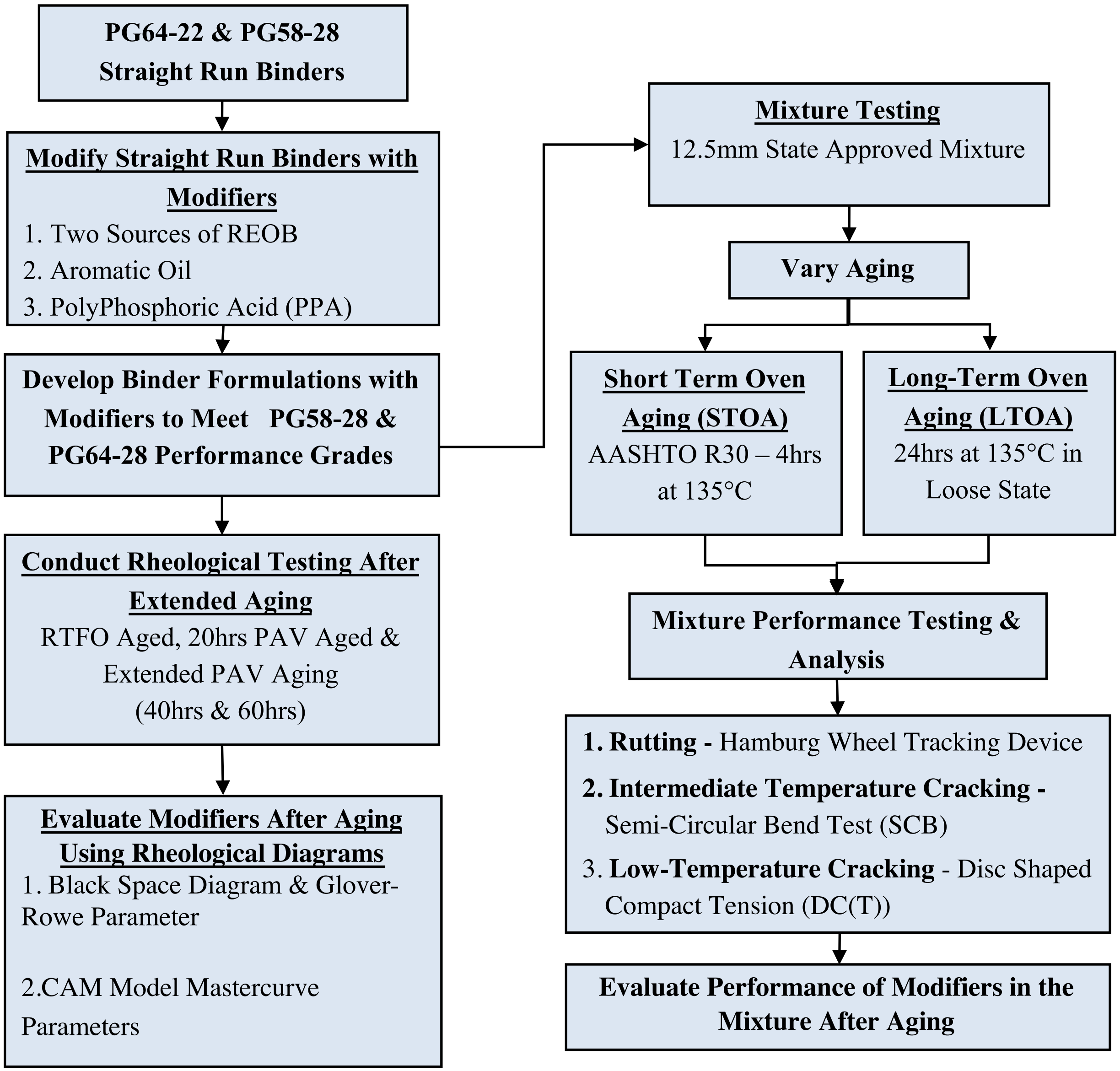
- Measure the rheological properties of the REOB modified and aromatic oil modified PG58-28 binders after AASHTO specified short-term, long-term and extended long-term aging. Compare the properties to a straight run PG58-28 binder.

Objectives

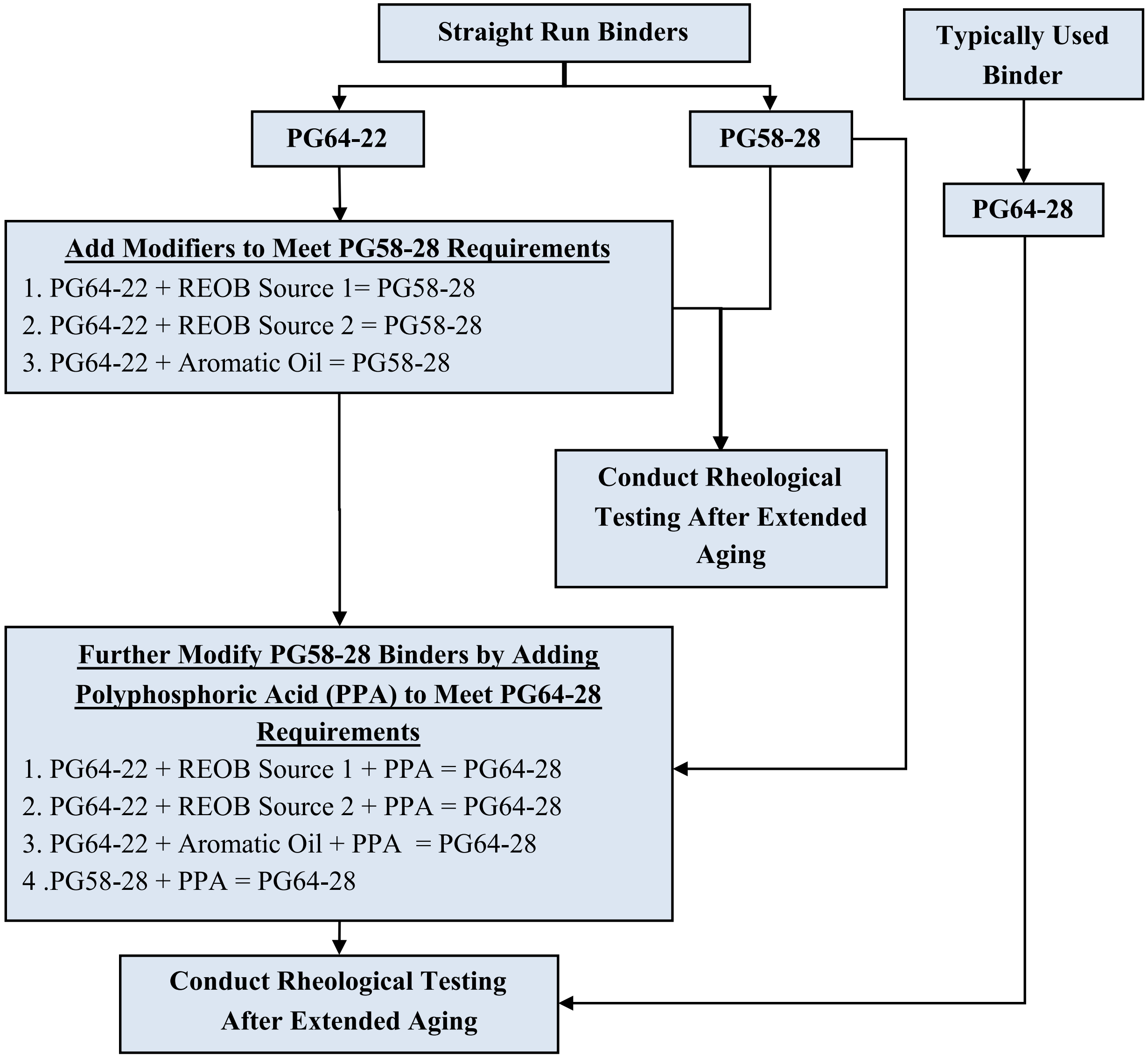
- Measure the rheological properties of the REOB and PPA modified PG64-28 binder and aromatic oil and PPA modified PG64-28 binder after short-term, long-term and extended long-term aging. Compare the properties to a typical PG64-28 used in projects placed within the last 5 to 7 years with known field performance.

- Conduct mixture performance testing after aging using the REOB modified binders, aromatic oil modified binders, the straight run PG58-28 binder, and the typical PG64-28 binder.

Experimental Plan



Binder Formulation Plan



PG58-28 Binder Formulations

Binder	Modifier	Continuous Grade	Performance Grade
PG58-28	NONE- Straight Run	CG 61.1-28.2	PG58-28
PG64-22	NONE- Straight Run	CG 67.0-24.2	PG64-22
PG64-22	2% REOB Source #1	CG 65.5-24.9	PG64-22
PG64-22	6% REOB Source #1	CG 63.3-27.7	PG58-22
PG64-22	10% REOB Source #1	CG 61.0-28.3	PG58-28
PG64-22	13% REOB Source #1	CG 59.4-29.2	PG58-28
PG64-22	18% REOB Source #1	CG 56.7-32.4	PG52-28
PG64-22	8% REOB Source #2	CG 63.1-31.7	PG58-28
PG64-22	10% REOB Source #2	CG 60.3-30.6	PG58-28
PG64-22	3% Aromatic Oil	CG 63.9-27.7	PG58-22
PG64-22	6% Aromatic Oil	CG 60.6-29.0	PG58-28
PG64-22	10% Aromatic Oil	CG 56.3-31.4	PG52-28

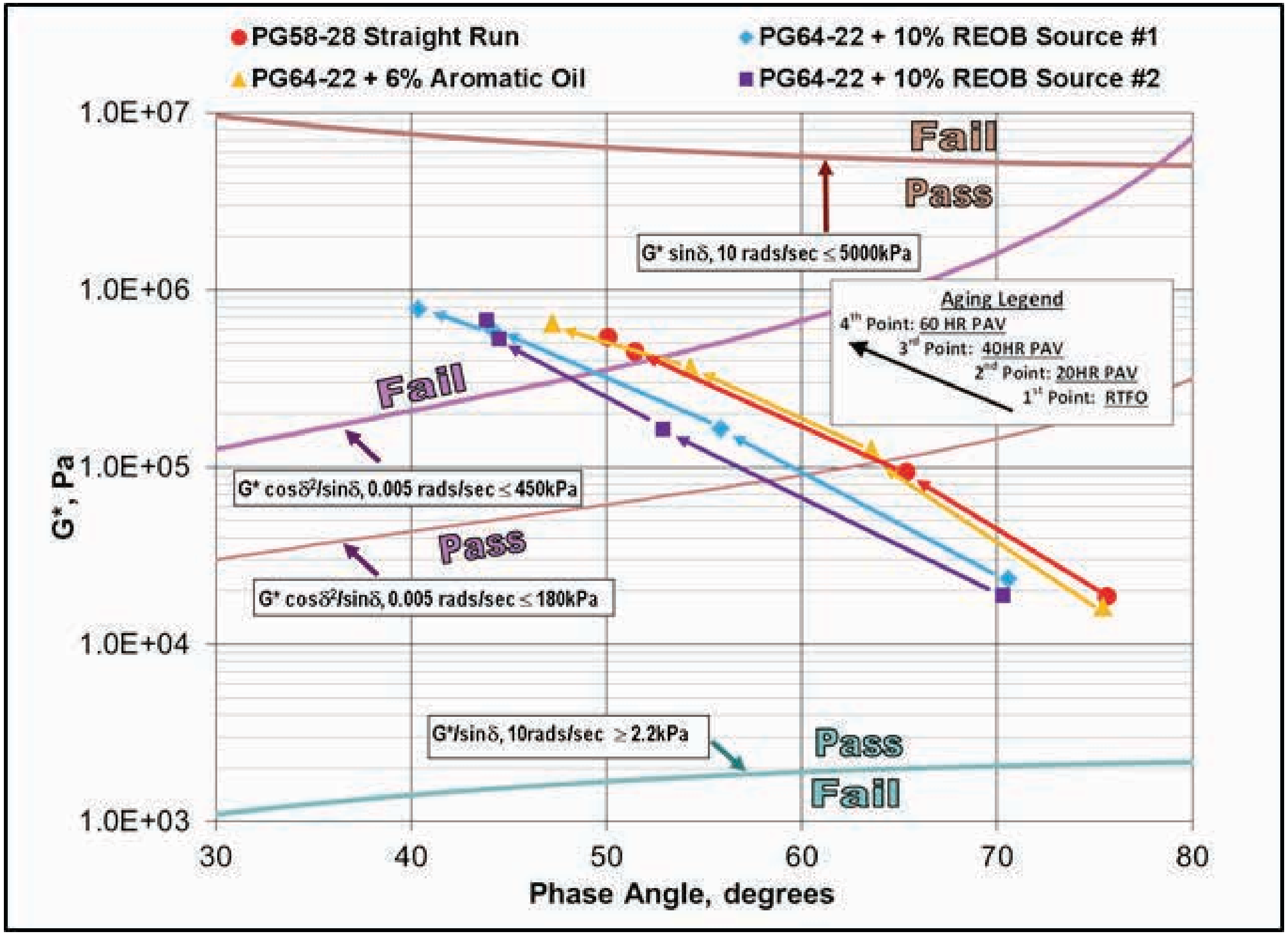
PG64-28 Binder Formulations

Binder	Modifier (s)	Continuous Grade	Performance Grade
PG64-28	Unknown - Typical Binder	CG 65.6-29.4	PG64-28
PG58-28	1% PPA	CG 67.0-29.1	PG64-28
PG64-22	2% REOB Source #1 + 1% PPA	CG 72.0-26.1	PG70-22
PG64-22	6% REOB Source #1 + 1% PPA	CG 67.7-27.4	PG64-22
PG64-22	10% REOB Source #1+ 1% PPA	CG 64.4-29.8	PG64-28
PG64-22	13% REOB Source #1 + 1% PPA	CG 61.6-30.4	PG58-28
PG64-22	18% REOB Source #1 + 1% PPA	CG 58.8-32.0	PG58-28
PG64-22	8% REOB Source #2 + 1% PPA	CG 64.5-28.8	PG64-28
PG64-22	10% REOB Source #2 + 1% PPA	CG 63.8-29.6	PG58-28
PG64-22	6% Aromatic Oil + 1% PPA	CG 66.9-30.0	PG64-28
PG64-22	10% Aromatic Oil + 1% PPA	CG 61.4-32.3	PG58.28

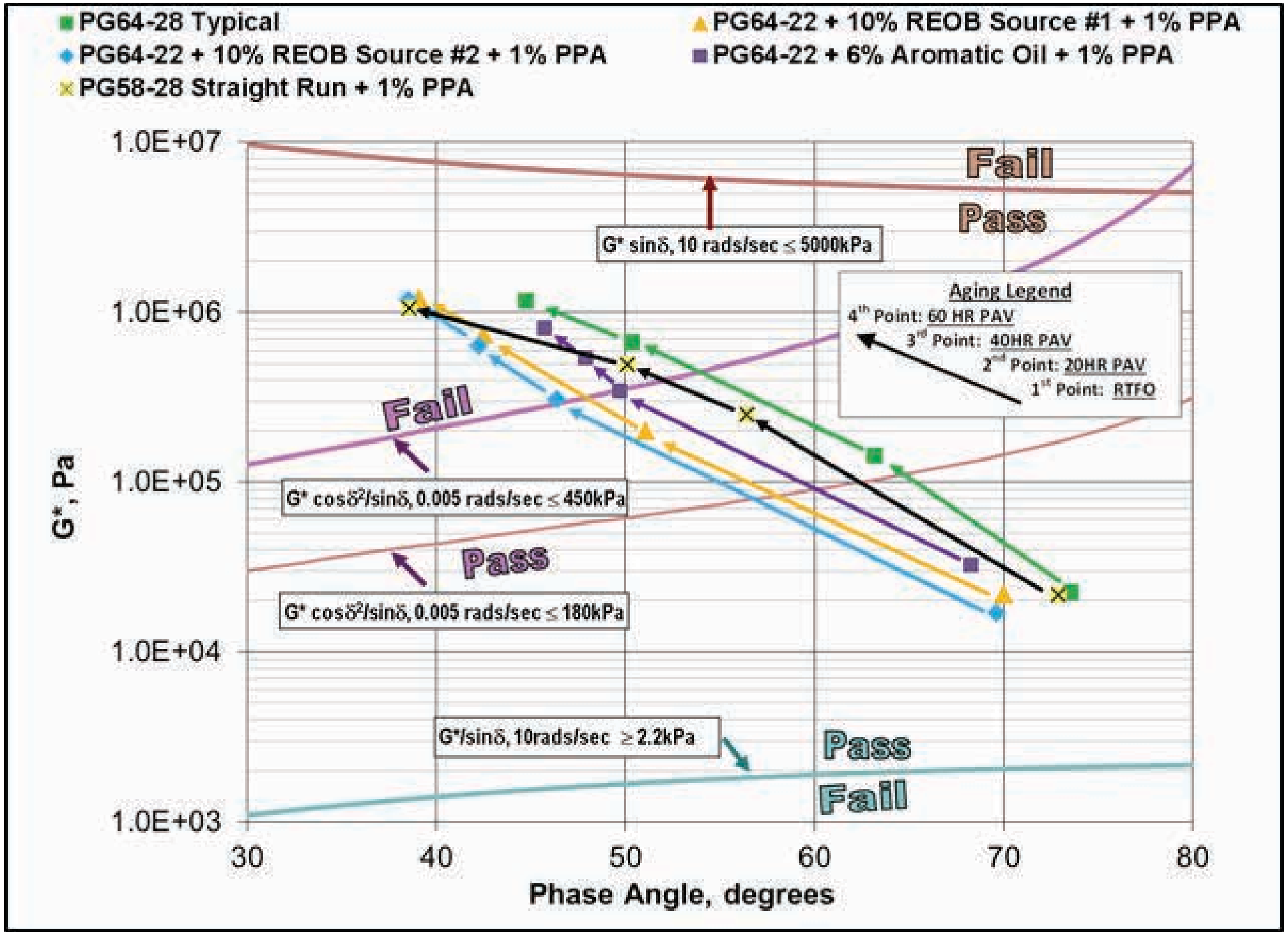
Rheological Methods Used to Assess Binder Aging

- **Black Space Diagram and the Glover-Rowe Damage Parameter**
  - **If the addition of REOB is increasing the aging of the binder, the trend should be movement toward the upper left of the Black Space Diagram**
- **Christenson-Anderson Model (CAM) Master Curve Parameters**
  - **Asphalt binders that have increased aging should move towards the lower right in ω_o - R-value space diagram**

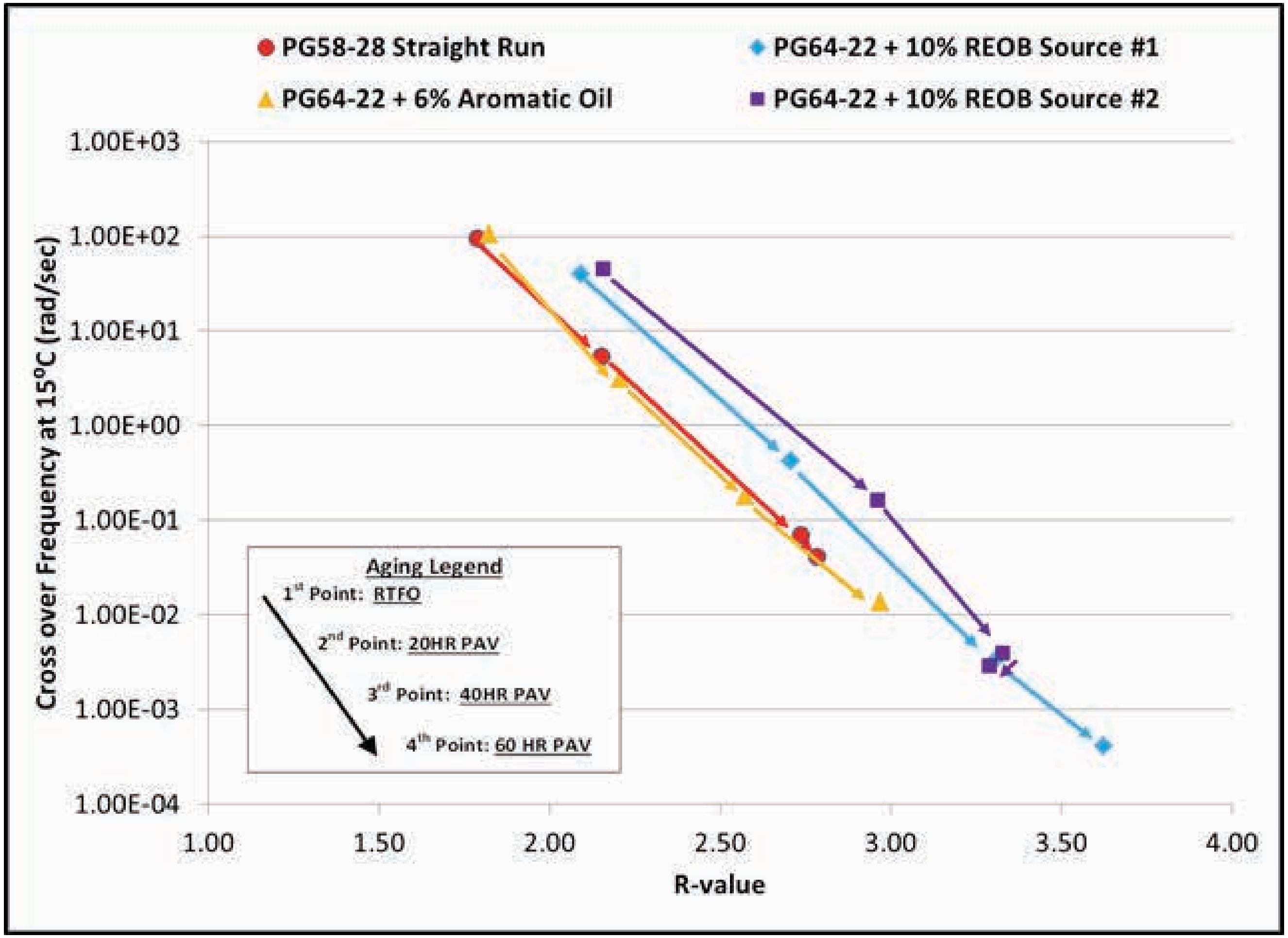
Black Space Diagram – PG58-28



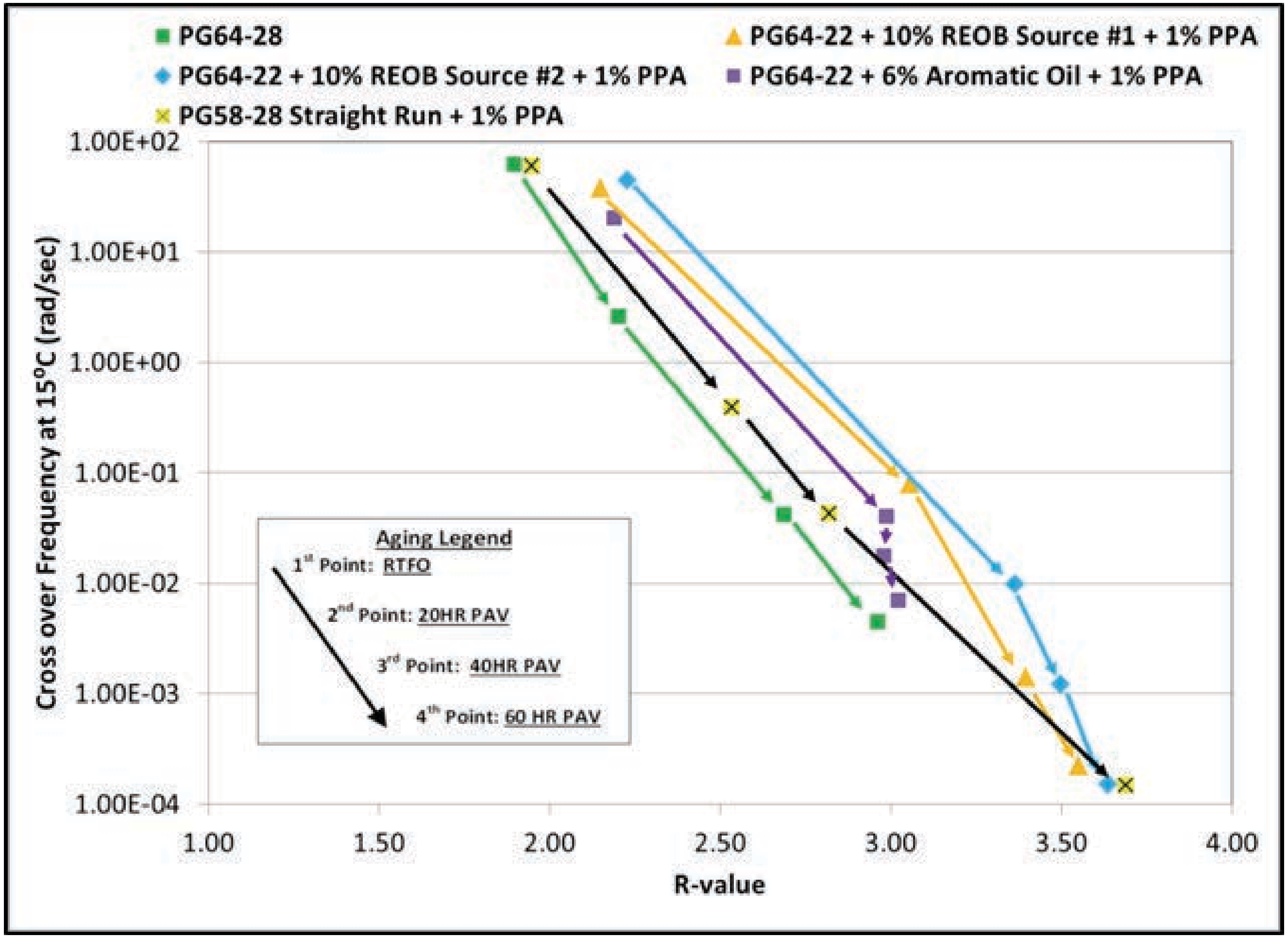
Black Space Diagram – PG64-28



ω_o- R value Space Diagram PG58-28



ω_o- R value Space Diagram PG64-28



Rheology Discussion

- The rheological plots indicated that the straight run and typical binders experienced the least aging.
- REOB modified binders, with or without PPA, experienced the most change (generally an increase) in aging which would indicate they may be more susceptible to cracking as compared to their non-modified counterparts.
- As the dosage of REOB was increased, increased aging also occurred in the binders. Aromatic oil generally showed less change in aging as compared to the REOB modified binders.

Mixture Design

- An approved 12.5mm mixture utilized in Massachusetts was selected for use in this study.
- Mixture was produced and placed throughout the 2014 paving season.

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%

Mixture Aging Procedures

- **Short-Term Oven Aging (STOA)**
  - Conducted in accordance with AASHTO R30. Specimens of each mixture were batched, mixed and aged at 135 ± 3°C (275± 5°F) for 4 hours ± 5 minutes in a loose state.
- **Long-Term Oven Aging (LTOA)**
  - LTOA was conducted as outlined in a study by Braham et al. (2009) which determined it better simulated field aging. Specimens of each mixture were batched, mixed and aged at 135°C (275°F) for 24 hours in a loose state.

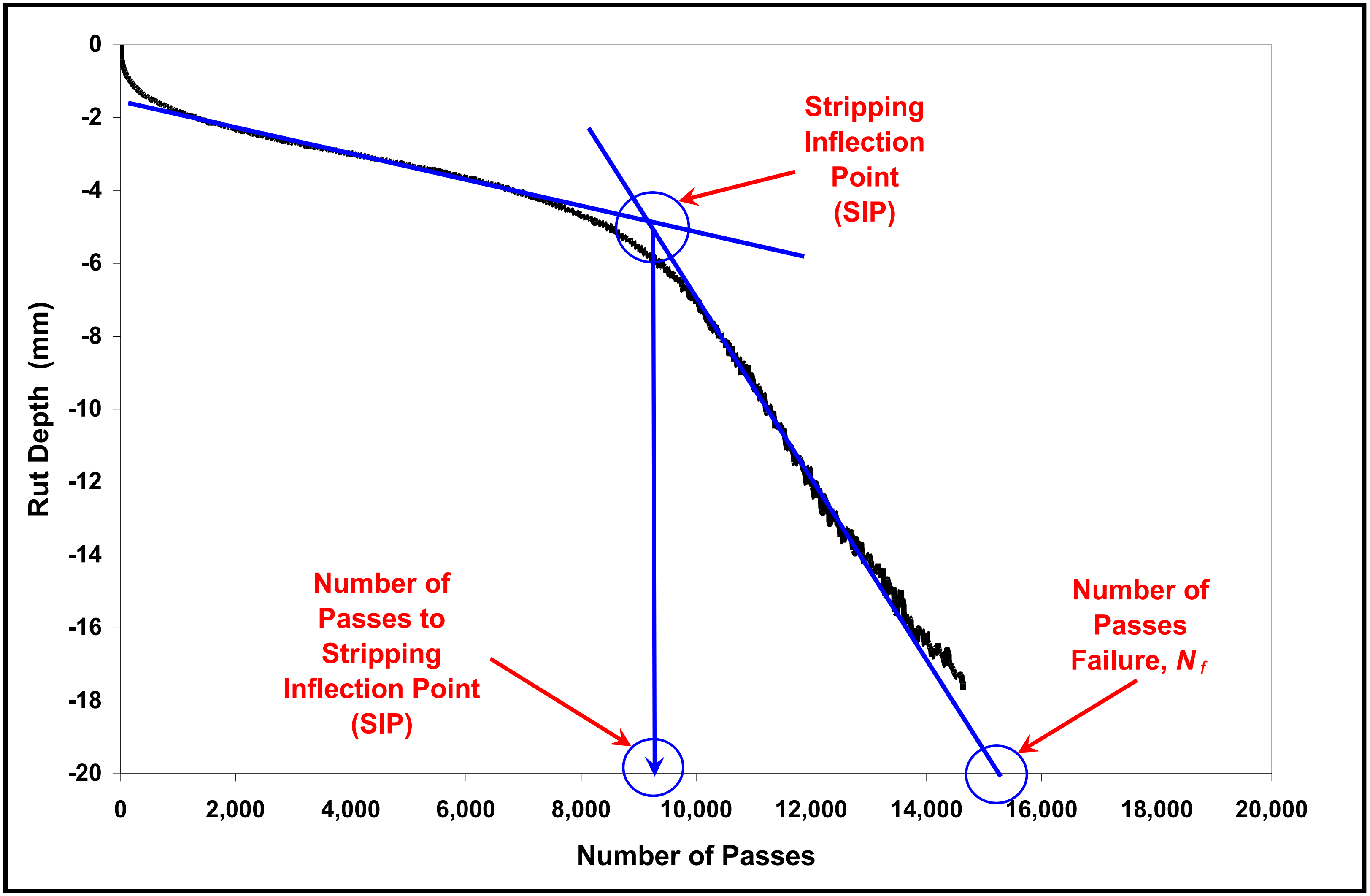
Rutting/Moisture Susceptibility -

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)



HWTD Results - STOA

Binder Formulation	Stripping Inflection Point	Rut Depth at 10,000 Passes (mm)	Rut Depth at 20,000 Passes (mm)
PG58-28 Straight Run	NONE	4.61	5.97
PG64-22 + 10% REOB Source #1	14,200	2.46	6.81
PG64-22 + 10% REOB Source #2	12,700	4.32	10.84
PG64-22 + 6% Aromatic Oil	12,900	2.43	9.64
PG64-28 Typical	NONE	2.71	3.26
PG64-22 + 10% REOB Source #1 + 1% PPA	NONE	2.28	3.34
PG64-22 + 10% REOB Source #2 + 1% PPA	8,200	5.42	11.22
PG64-22 + 6% Aromatic Oil + 1% PPA	NONE	1.57	2.05
PG58-28 + 1% PPA	NONE	2.26	2.99

HWTD Results - LTOA

Binder Formulation	Stripping Inflection Point	Rut Depth at 10,000 Passes (mm)	Rut Depth at 20,000 Passes (mm)
PG58-28 Straight Run	NONE	2.13	2.63
PG64-22 + 10% REOB Source #1	NONE	0.72	0.94
PG64-22 + 10% REOB Source #2	NONE	1.37	2.15
PG64-22 + 6% Aromatic Oil	NONE	1.02	1.35
PG64-28 Typical	NONE	1.02	1.26
PG64-22 + 10% REOB Source #1 + 1% PPA	NONE	0.55	0.86
PG64-22 + 10% REOB Source #2 + 1% PPA	NONE	1.28	1.96
PG64-22 + 6% Aromatic Oil + 1% PPA	NONE	0.58	0.73
PG58-28 + 1% PPA	NONE	1.87	2.14

Cracking at Intermediate Temperature -

Semi-Circular Bend Test (SCB)

- SCB testing conducted in accordance with standard protocols developed recently in 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
- SCB fracture energy and FI were calculated and recorded for each mixture

Flexibility Index

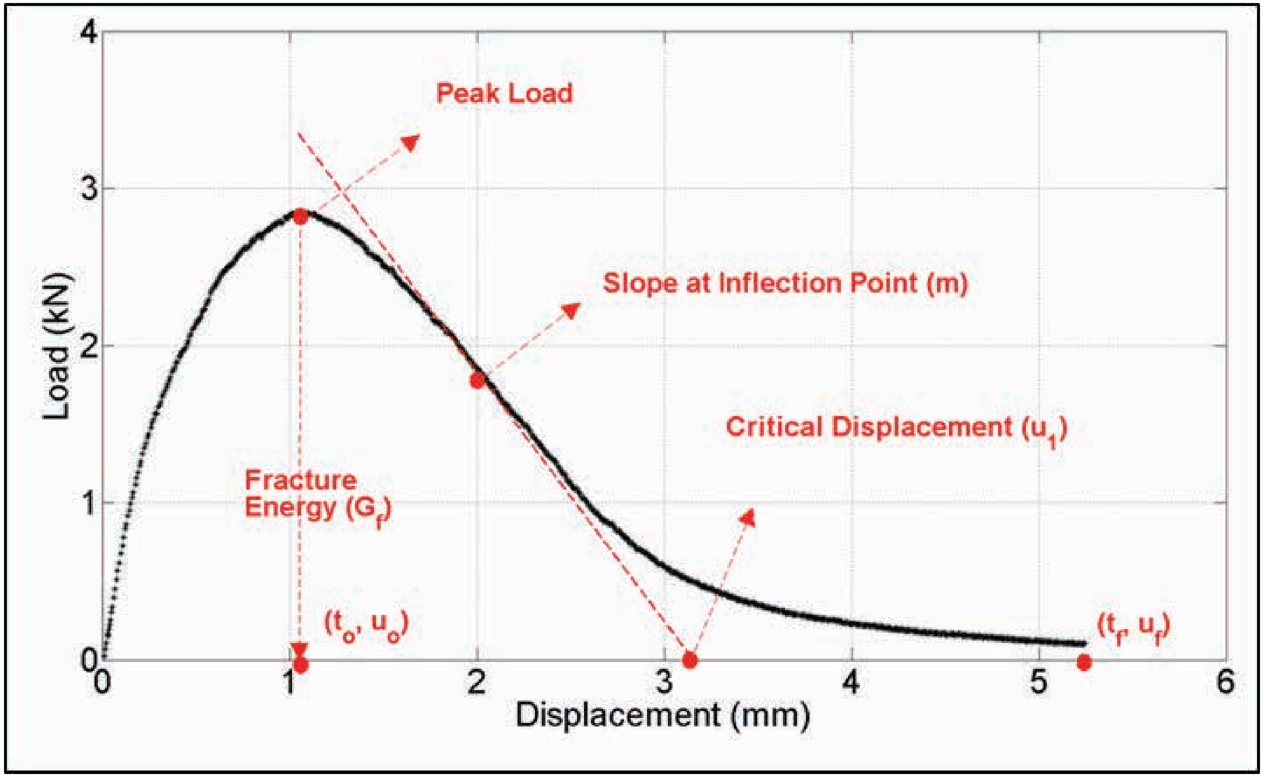
$$FI = A \times \frac{G_f}{abs(M)}$$

Where:

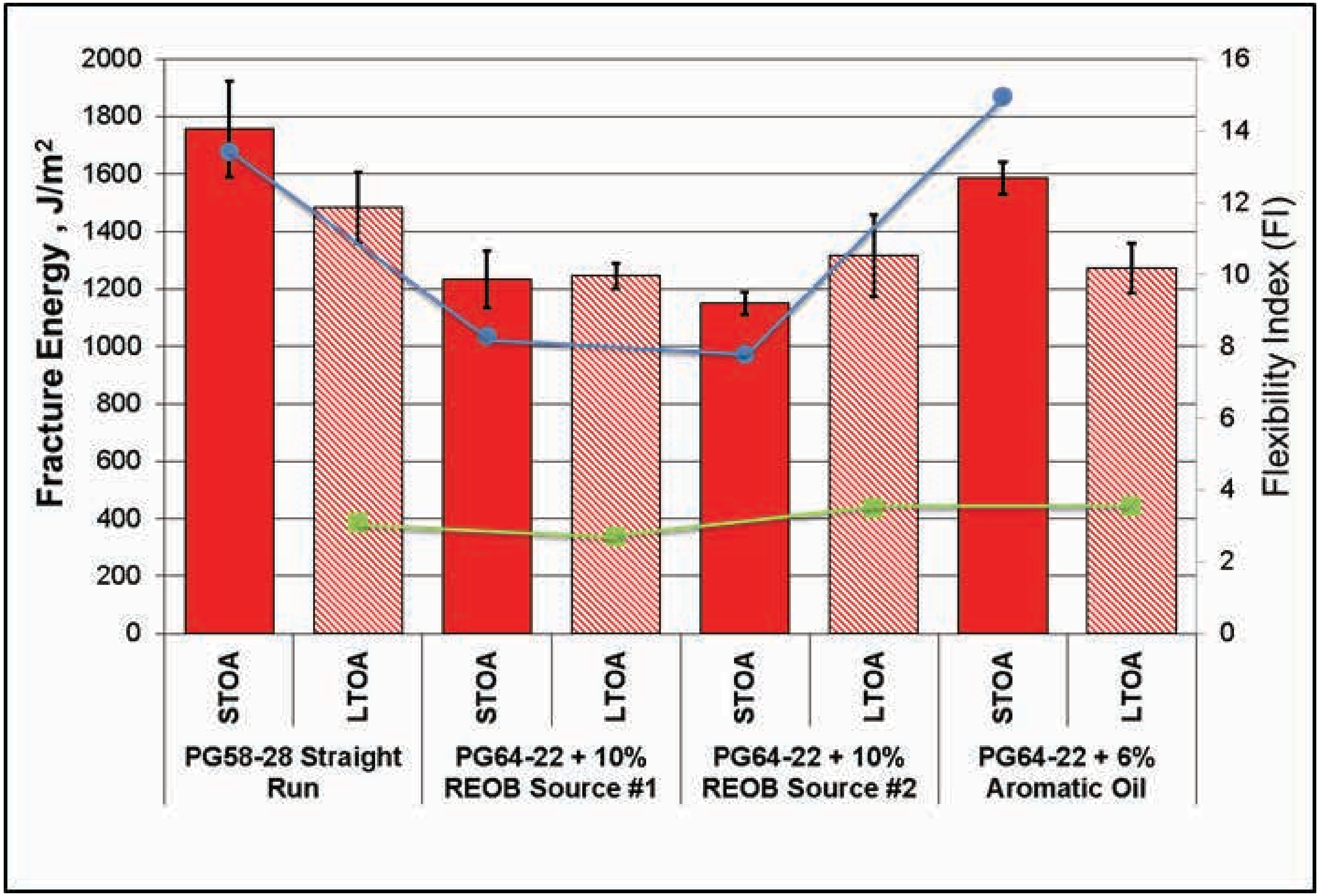
G_f = fracture energy in Joules/m^2

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

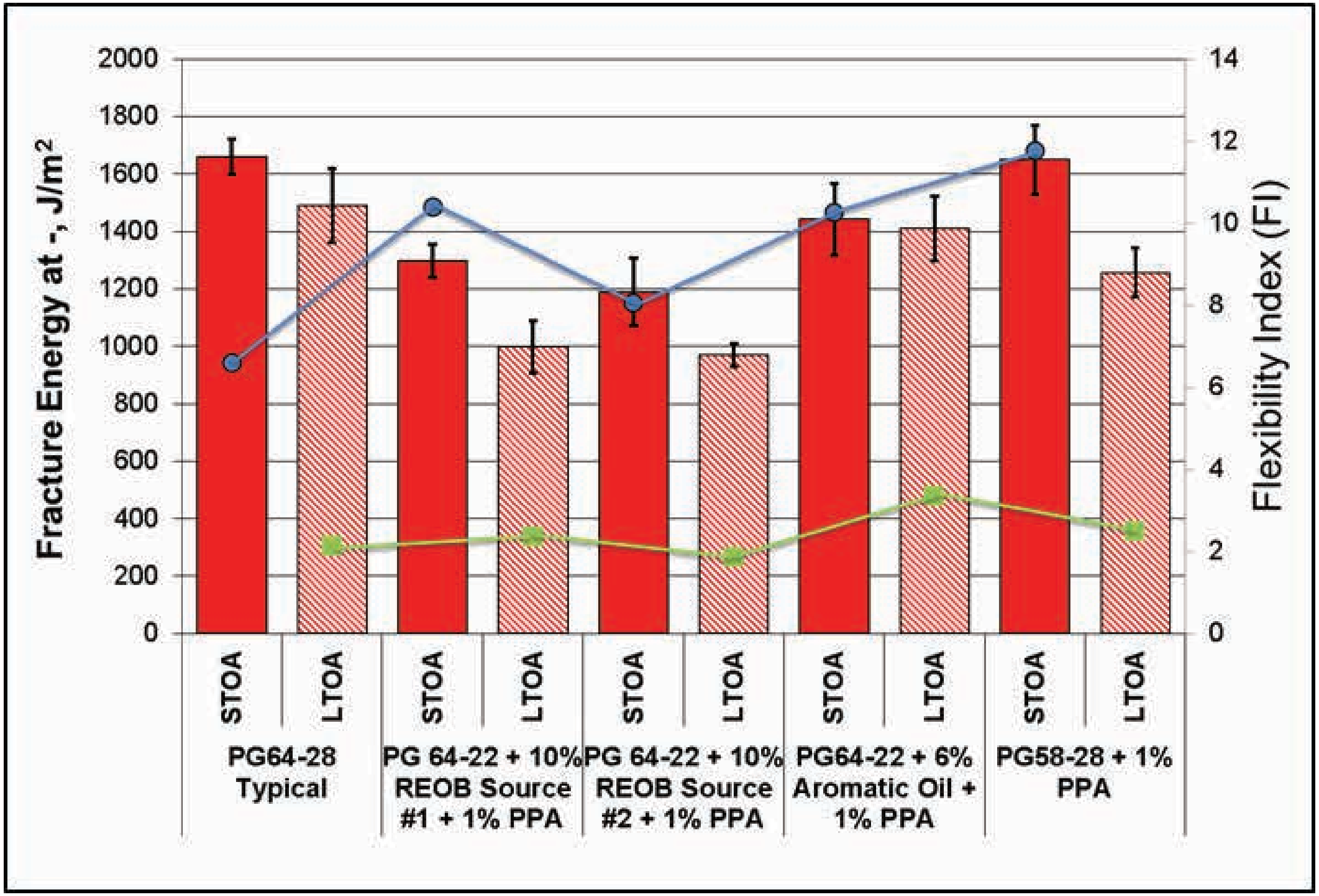
A = unit conversion factor and scaling coefficient.



SCB Results – PG58-28 Mixtures

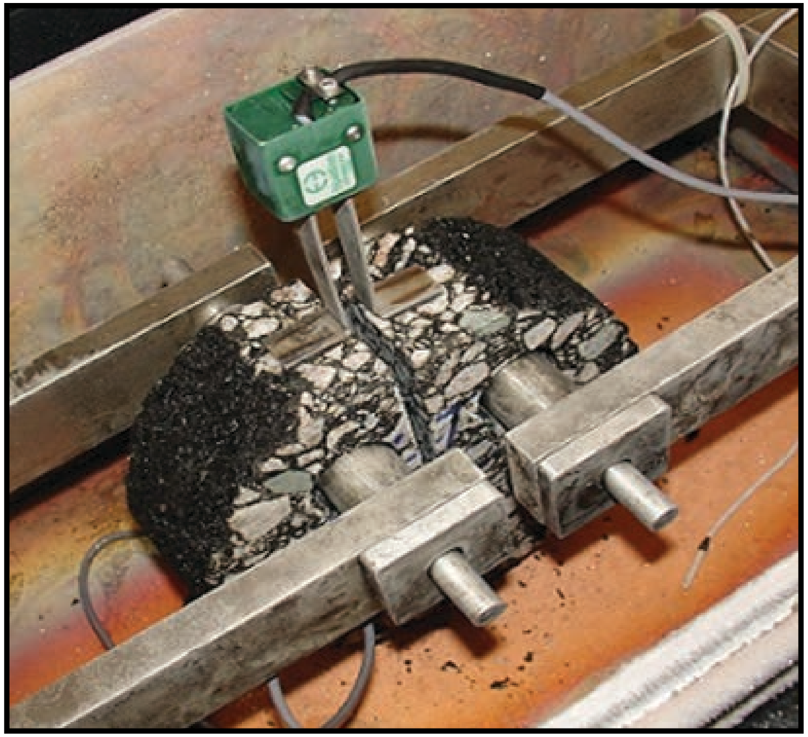


SCB Results – PG64-28 Mixtures



Cracking at Low Temperature -

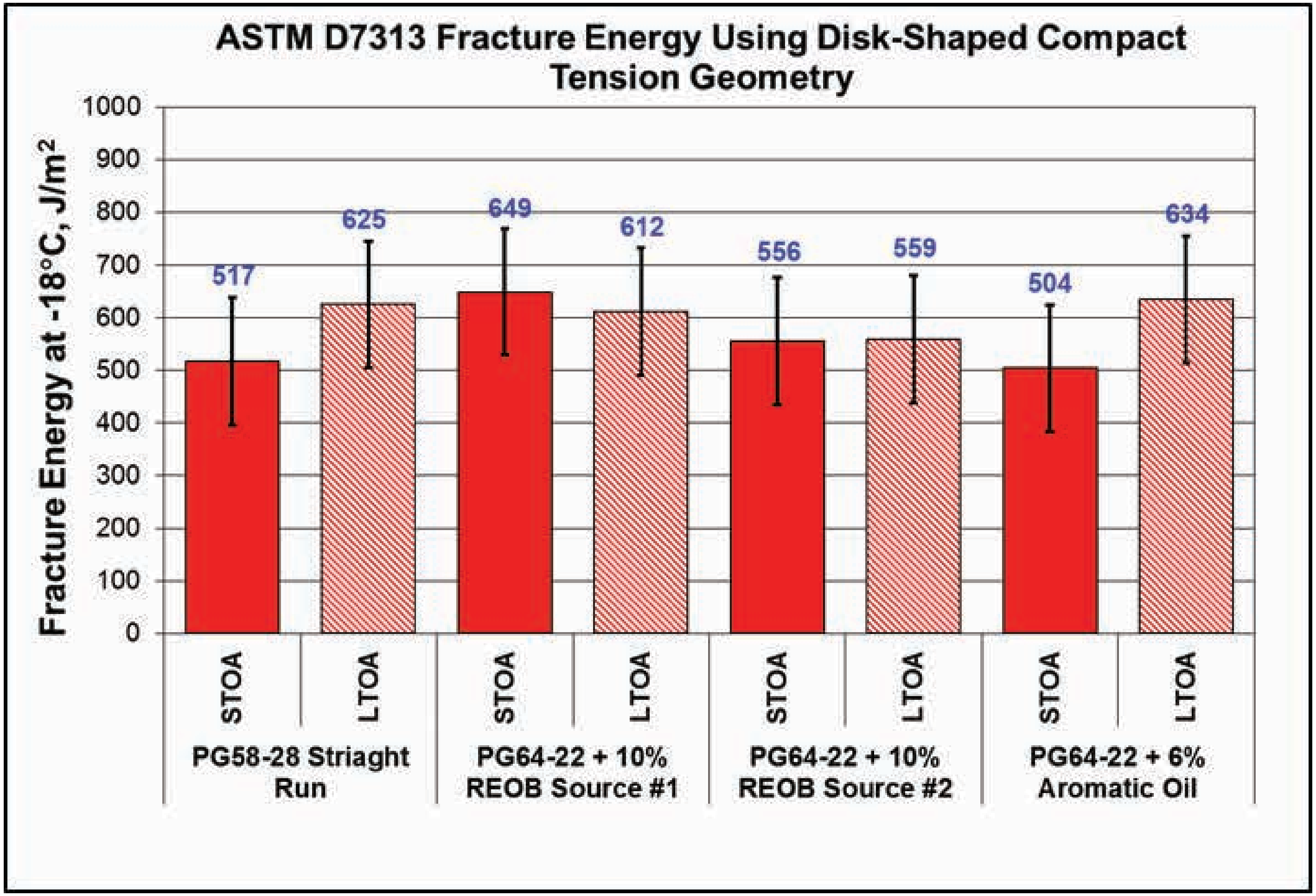
Disc Shaped Compact Tension (DC(T))



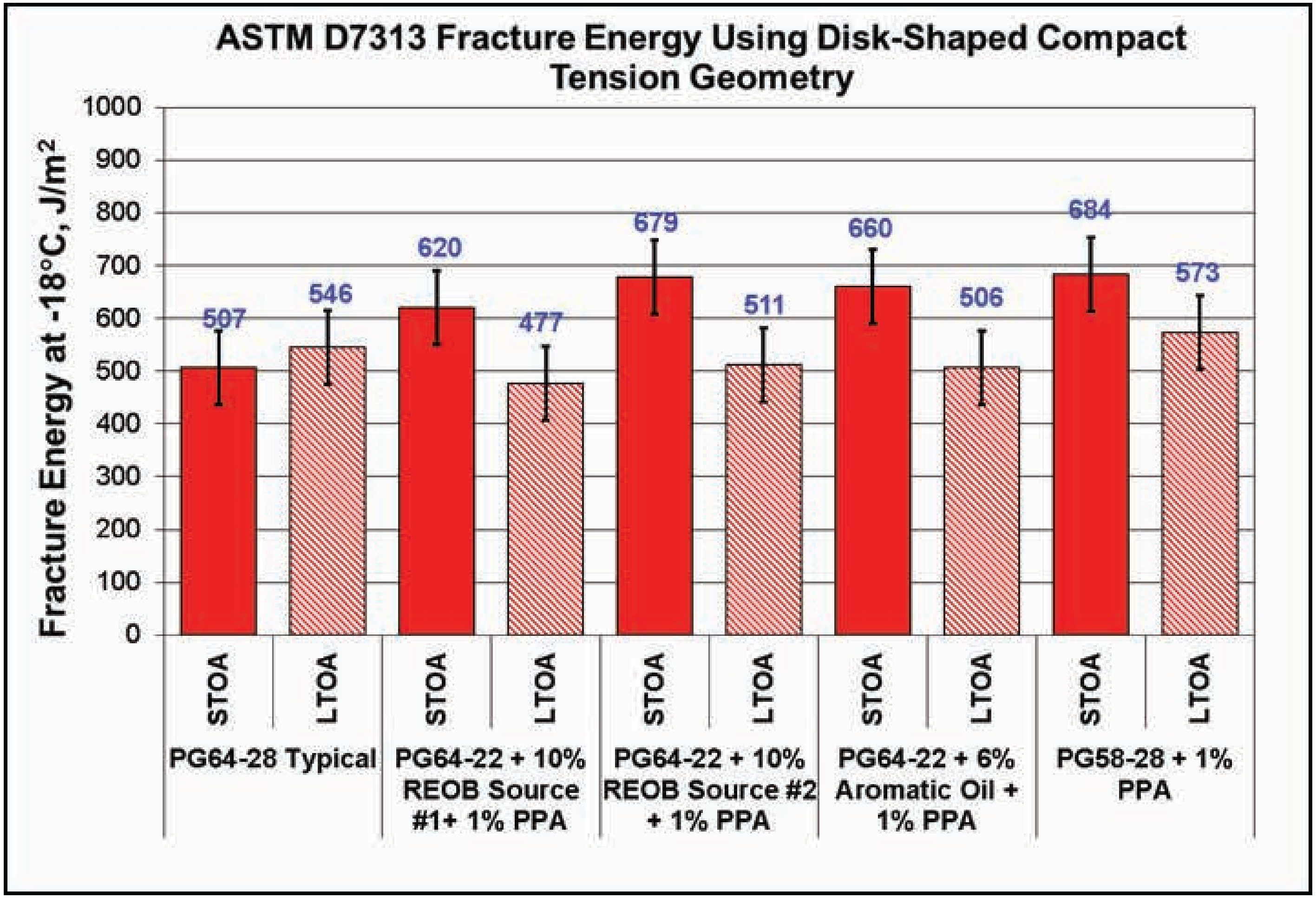
- DC(T) testing conducted in accordance with ASTM D7313

- Test temperature of -18ºC which is 10ºC warmer than low temperature PG grade

DC(T) Results – PG58-28 Mixtures



DC(T) Results – PG64-28 Mixtures



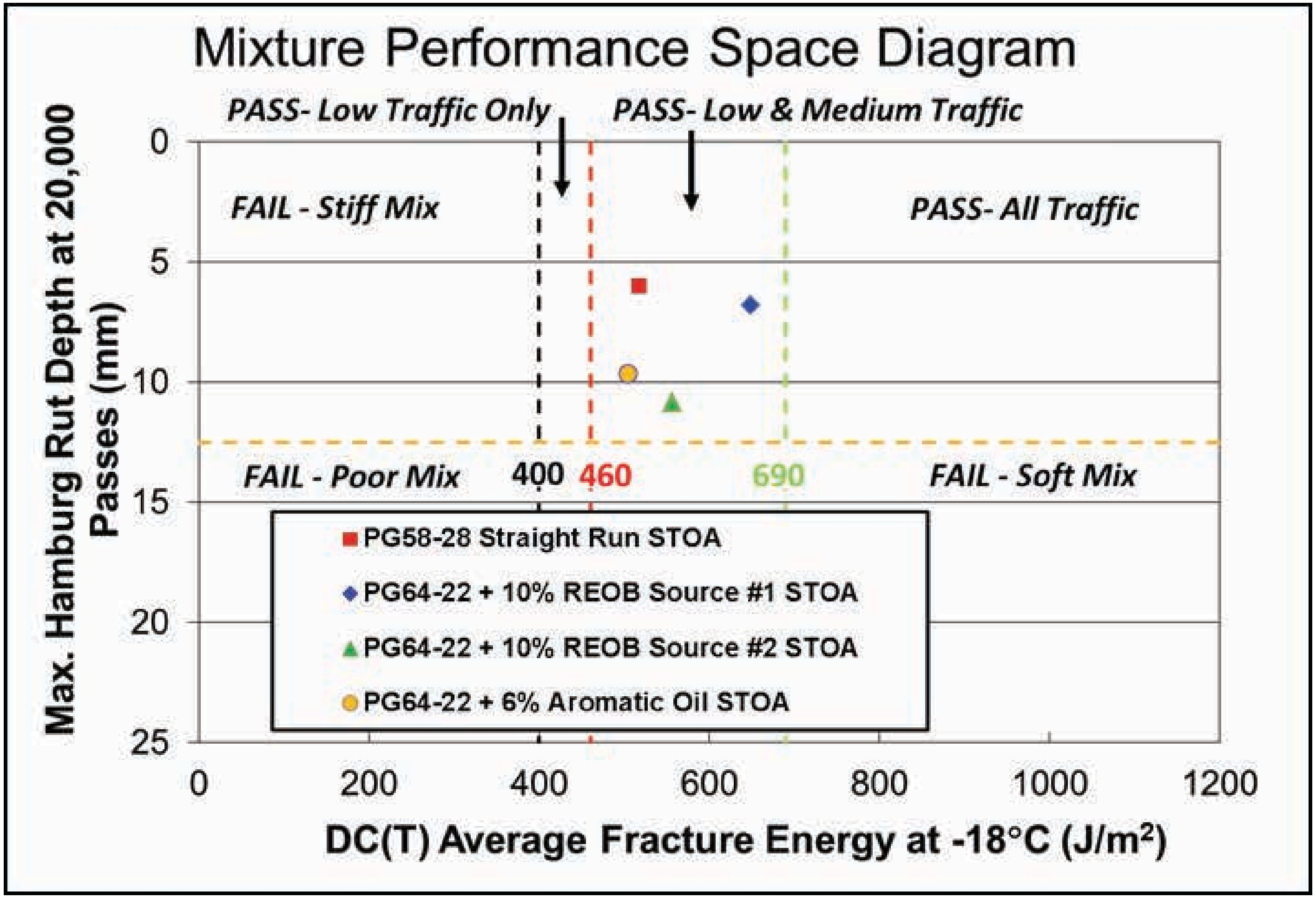
Hamburg-DC(T) Performance-Space Diagram

- Graphical approach for examining the relationship between high-temperature rutting and low-temperature cracking mixture performance.

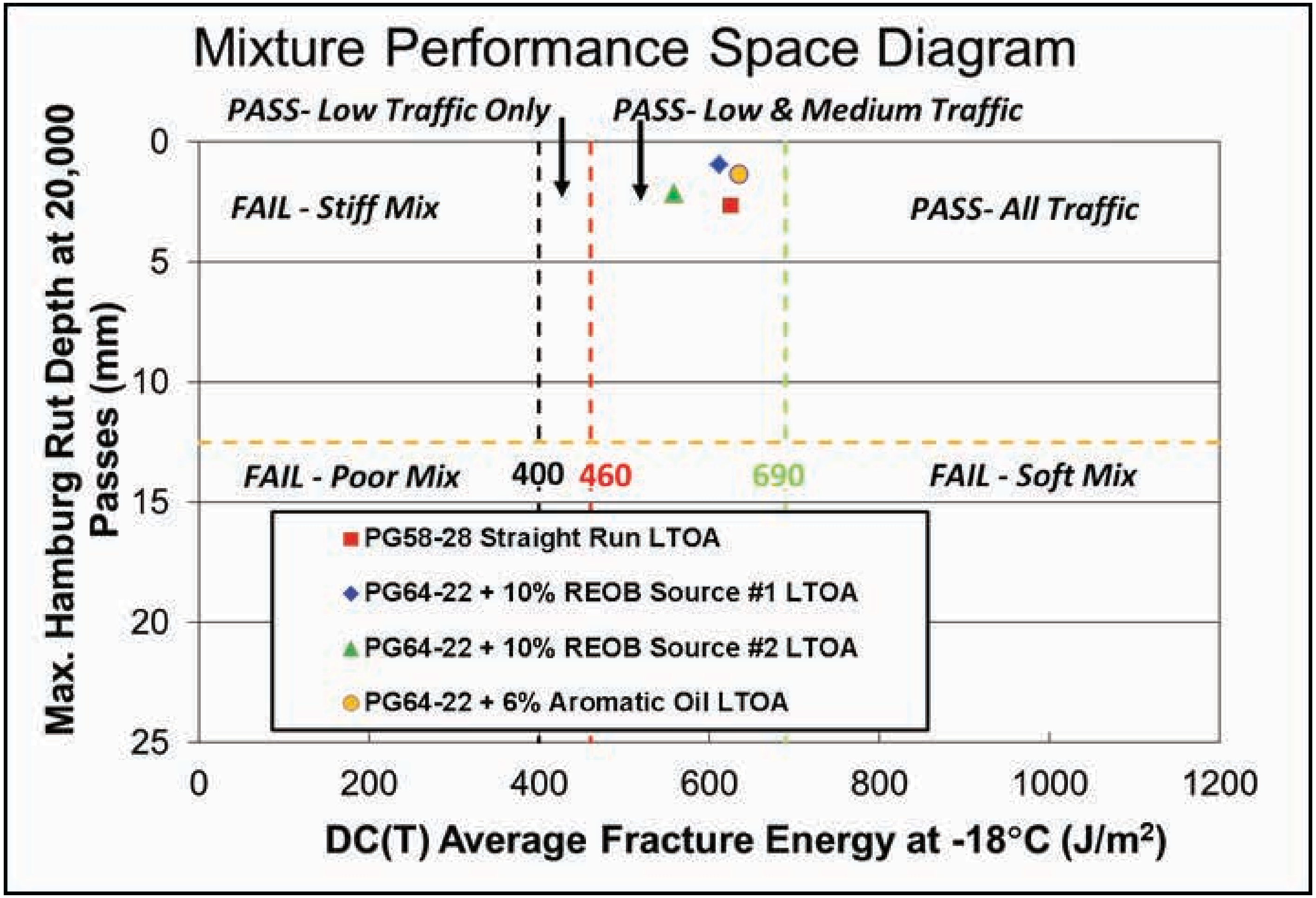
- Originally presented at the FHWA Mixture Expert Task Group meeting and further discussed in Hill et al. (2015).

- The diagram imposes thermal cracking specification thresholds through vertical regions based upon low, medium, and high traffic specification limits.

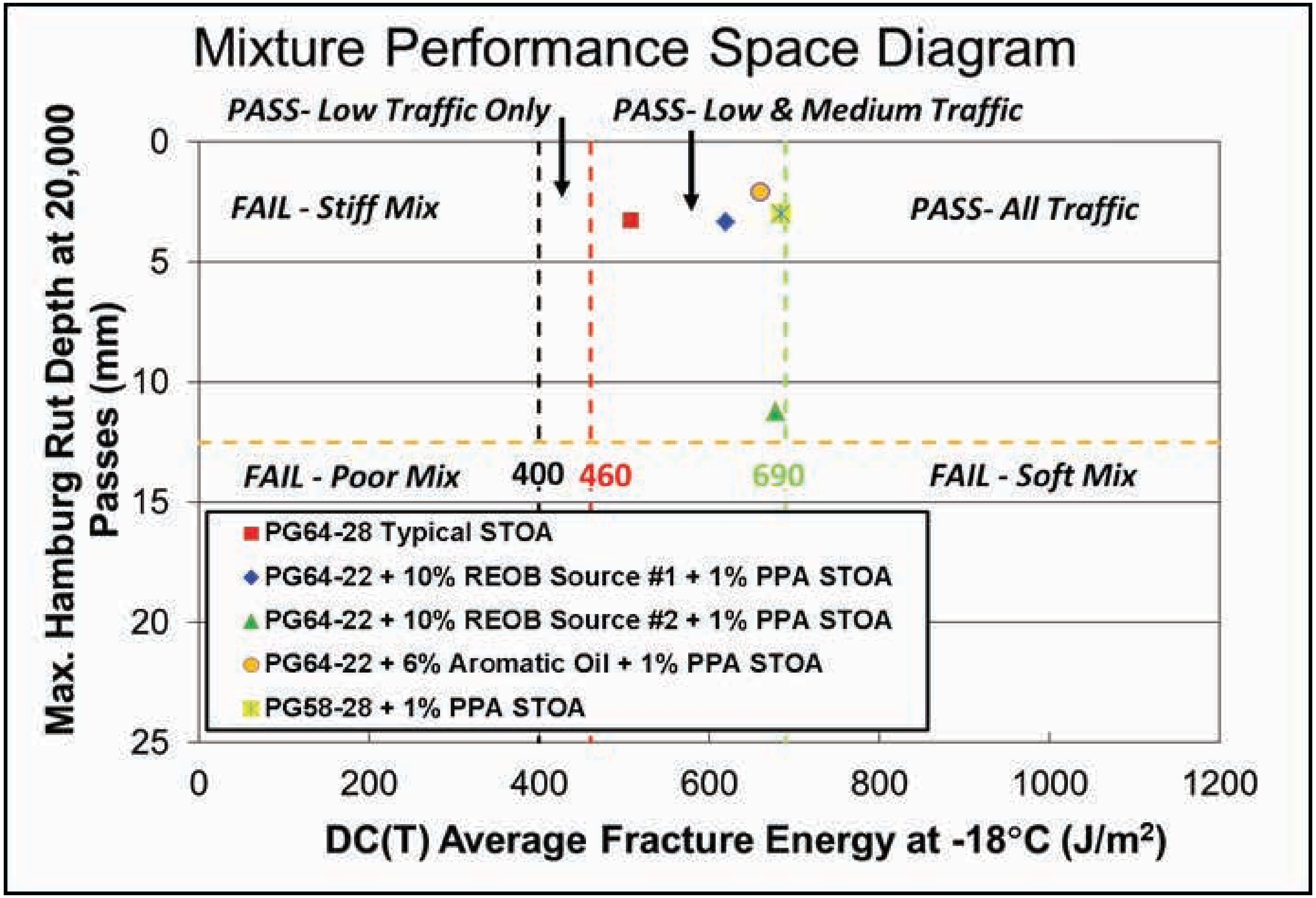
Hamburg-DC(T) Diagram – PG58-28 STOA



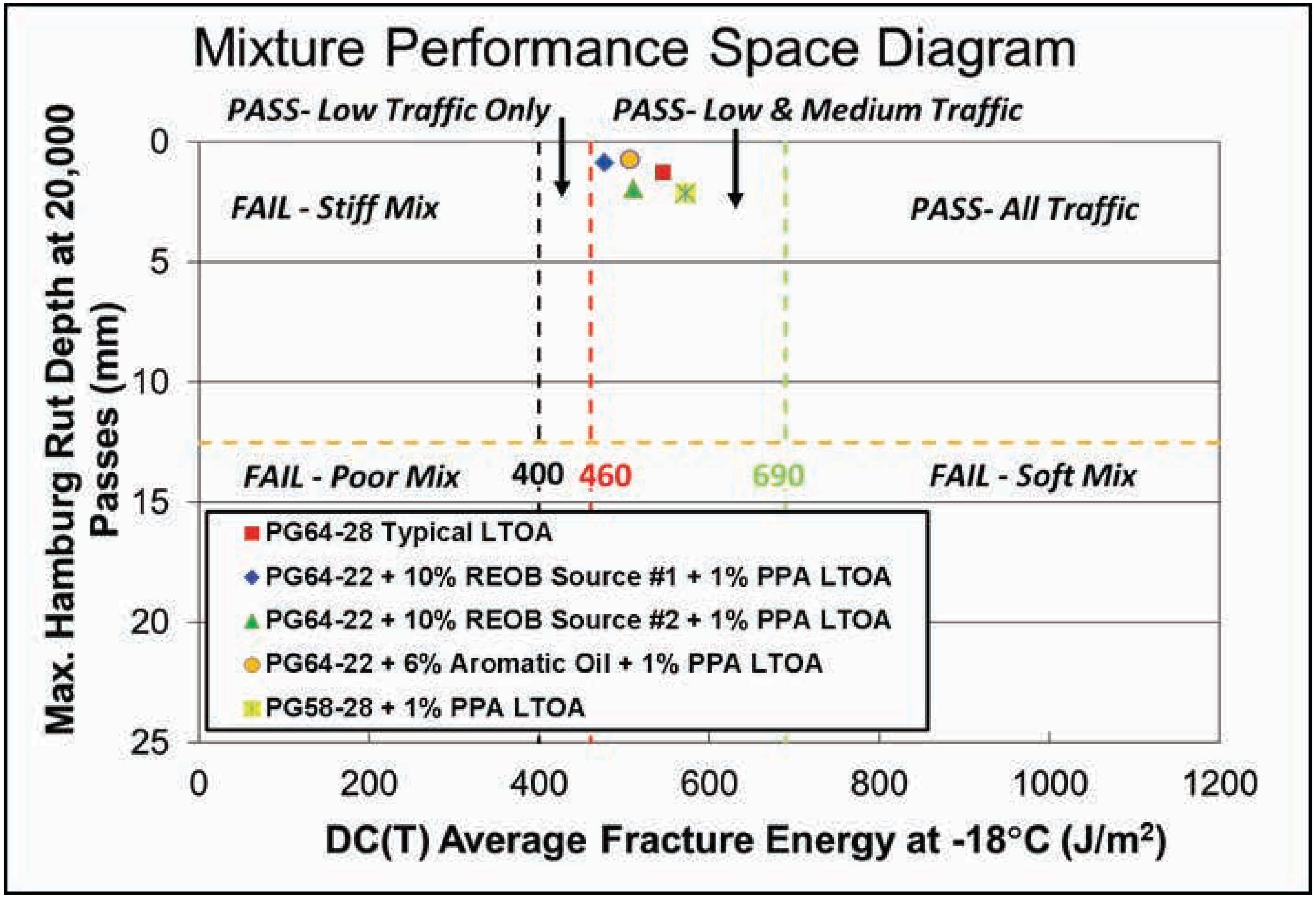
Hamburg-DC(T) Diagram – PG58-28 LTOA



Hamburg-DC(T) Diagram – PG64-28 STOA



Hamburg-DC(T) Diagram – PG64-28 LTOA



Conclusions

- The binder rheology results showed that the addition of REOB at the dosage required to attain the target PG58-28 caused the asphalt binders to age more relative to the straight run binders.
- The results also indicated that the use of higher dosages of REOB which provide the same target PG can cause increased binder aging.
- The aromatic oil modifier caused less aging of the asphalt binder relative to the REOB.

Conclusions

- HWTD stripping inflection point data after STOA for the mixtures with PG58-28 indicated the two REOB's and the aromatic oil failed whereas the straight run PG58-28 passed, thereby indicating the modifiers decreased moisture damage performance. For mixtures with PG64-28, only one mixture failed. This mixture incorporated REOB.

Conclusions

- Generally, the SCB indicated a reduction in fracture energy when REOB modifiers were added, however the aromatic oil modified mixtures exhibited less reduction.

- The DC(T) test only detected minor effects of the various binders on low-temperature fracture properties.

- The Hamburg-DC(T) Performance Space Diagrams had all mixtures, irrespective of the modifier, falling within the passing zone for a low to medium traffic level.

Conclusions

- Overall, the particular mixture tests used in this study did not provide evidence that using REOB will always decrease performance.
- The performance data collected by using the two REOB sources varied by the particular test, and sometimes by the type of REOB or by the PG of the binder.
- The use of aromatic oil did not show this variability and the results generally indicated good performance.
- The variability of the data when REOB was used underscores the importance of thoroughly testing REOB modified binder and mixture for performance. Finally, other important issues like dosage and consistency of REOB are still currently being investigated.

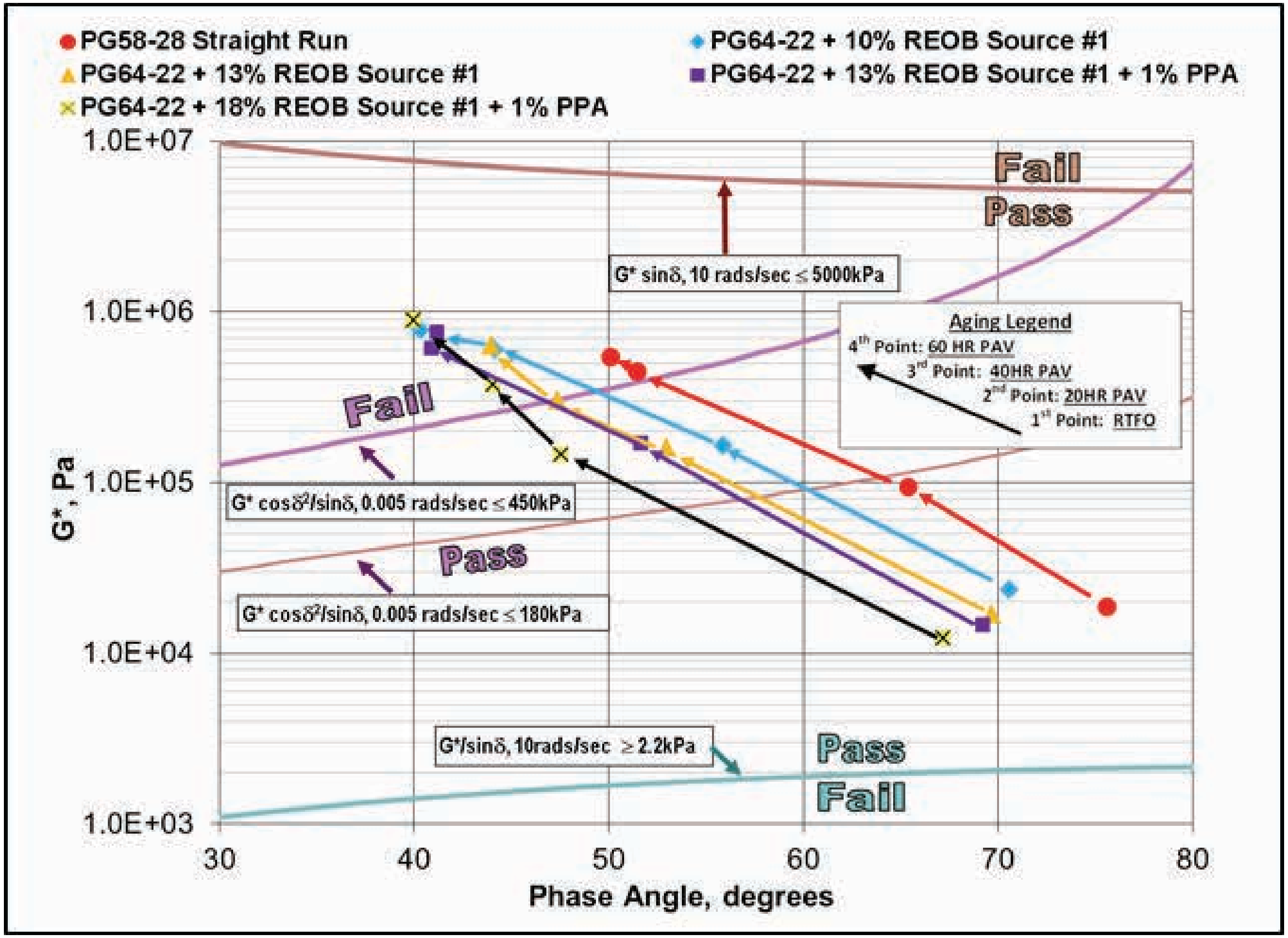
Acknowledgements

The research data and results presented in this paper were part of a study entitled "Evaluating the Performance of a Typical New England Asphalt Mixture Designed Using Asphalt Binders Modified with Re-refined Engine Oil Bottoms (REOB)" funded by the Massachusetts Department of Transportation.

Thank you!

Black Space Diagram – PG58-28

Increased Dosages of REOB Source #1



ω_o- R value Space Diagram PG58-28

Increased Dosages of REOB Source #1