Evaluation of Binder Test Procedures to Help Address Top-Down Fatigue Cracking

Presented By:

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(Somewhere from my house)

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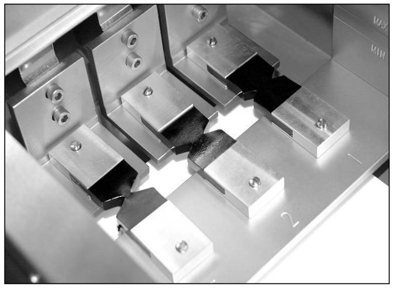
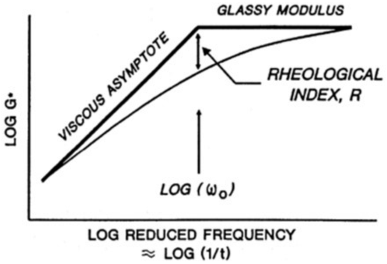
Project Overview

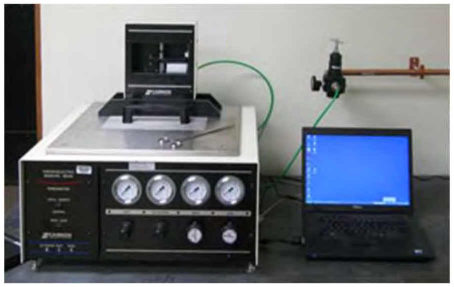
- Fatigue cracking in asphalt pavements extremely complex (excluding construction practices!)
  - Temperature
  - Loading rate and magnitude
  - Strain levels
  - Asphalt binder rheology
  - Mixture volumetrics
  - Performance test procedures
- Basically a condition of lower temperature with higher asphalt stiffness under critical strain conditions will drive cracking
- Objective of the study to evaluate a number of asphalt binder test procedures with the potential to identify asphalt binders prone to top-down cracking

Asphalt Binder Testing

- Binder test methods selected from literature and local experience;
  - PG grading (intermediate & Low PG)
    - ΔTc
  - Master curves for Rheological Properties
    - Generated using method proposed by Rowe (2015) and constructed using RHEA software
      - Glover-Rowe Parameter, Loss Tangent, C-A Parameter (NCHRP 9-59)
  - Double Edge Notched Tension (DENT)
  - NCHRP 9-60 approach (post project)







Mixture Testing – Lab Mix Phase

- FAA (P401) specs currently incorporates the Asphalt Pavement Analyzer or Hamburg Wheel Tracking to evaluate rutting potential
    - Currently no fatigue cracking mixture tests
- Study used SCB FI (AASHTO TP124) and IDEAL-CT (ASTM D8225)
    - Can be used for both mix design and quality control testing

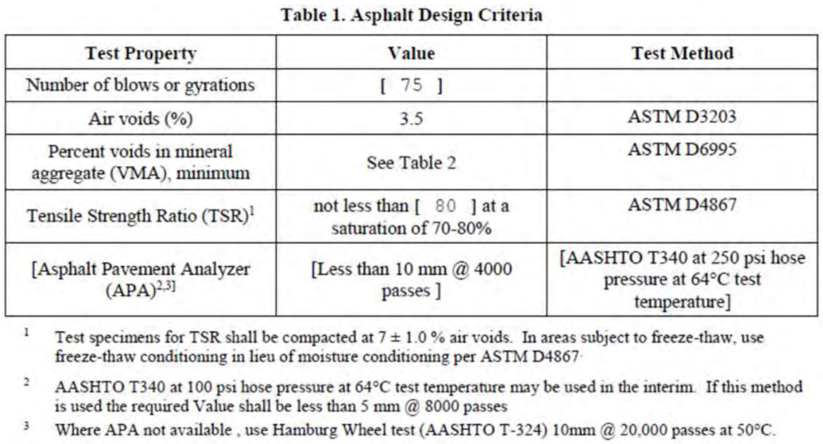


Table 1. Asphalt Design Criteria

Test Property	Value	Test Method
Number of blows or gyrations	[75]	
Air voids (%)	3.5	ASTM D3203
Percent voids in mineral aggregate (VMA), minimum	See Table 2	ASTM D6995
Tensile Strength Ratio (TSR)[1]	not less than [80] at a saturation of 70-80%	ASTM D4867
[Asphalt Pavement Analyzer (APA)[2,3]]	[Less than 10 mm @ 4000 passes]	[AASHTO T340 at 250 psi hose pressure at 64°C test temperature]

[1] Test specimens for TSR shall be compacted at 7 ± 1.0 % air voids. In areas subject to freeze-thaw, use freeze-thaw conditioning in lieu of moisture conditioning per ASTM D4867.

[2] AASHTO T340 at 100 psi hose pressure at 64°C test temperature may be used in the interim. If this method is used the required Value shall be less than 5 mm @ 8000 passes

[3] Where APA not available , use Hamburg Wheel test (AASHTO T-324) 10mm @ 20,000 passes at 50°C.

Laboratory Evaluation – Phase 1

- Materials
  - 3 Binder suppliers
    - Supplier #1: 58-28; 58-28 (64-22 + 10% REOB), 64-22, 64-28, 64-34, 70-28
    - Supplier #2: 64-22, 64-28, 64-28 (64-22 + 10% REOB), 76-22
    - Supplier #3: 64-34, 70-28, 76-28
  - 2 mix designs
    - P401 ½” Max (VBE = 14.2%)
    - P401 ¾” Max (VBE = 11.9%)
    - Same aggregate source
    - 3 levels of laboratory conditioning

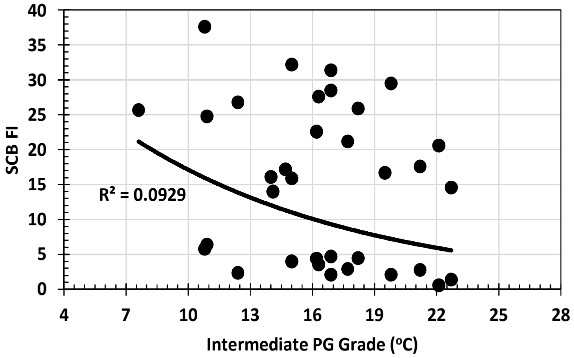
Field Experiments for Verification – Phase 2

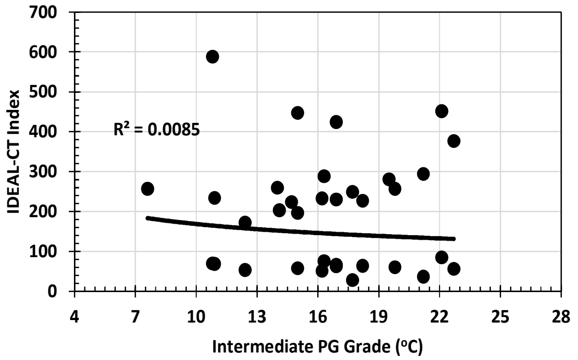
- PANYNJ Newark and JFK Airports
  - Varying levels of fatigue cracking
  - Different PG grades
- FAA Extended Life Pavement Study
  - Tucson, Kansas City, Salt Lake City, BWI, Columbus and Greensboro
  - Not all testing available due to limited materials
- FHWA ALF
  - Experiment specifically designed for evaluating fatigue cracking
    - Advanced Use of Recycled Asphalt in Flexible Pavement Infrastructure
    - 64-22 & 58-28, WMA (different production temps), RAP, RAS

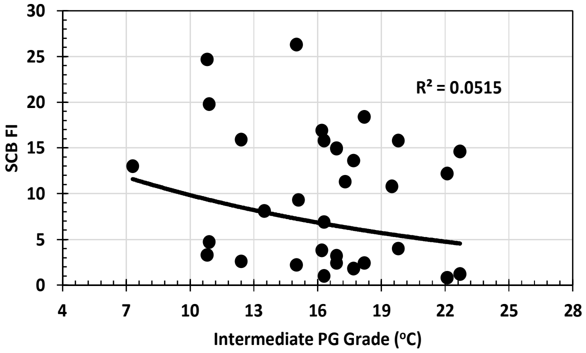
Phase 1 - Laboratory Evaluation

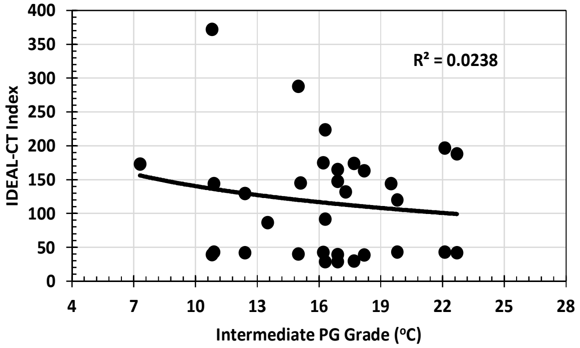
Lab Mix Phase – Examples of Results

- Intermediate PG Grade
  - Shown to illustrate the current practice
  - As expected, no relationship exists between the binder parameter and mixture fatigue performance





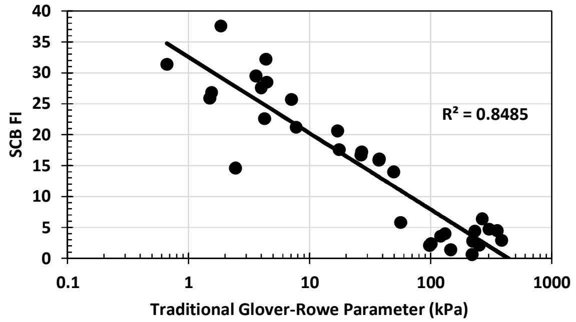


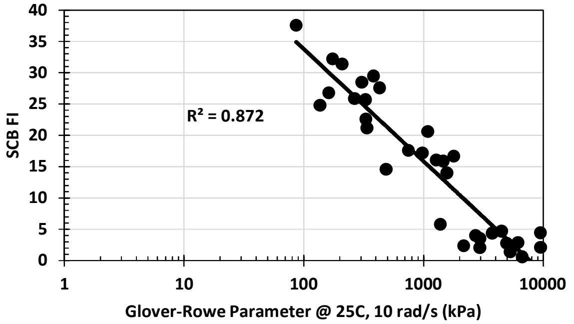


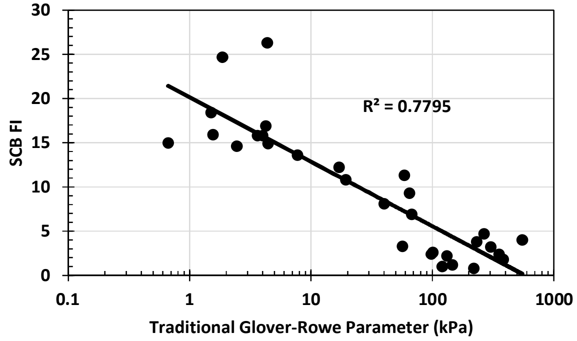
Lab Mix Phase – Examples of Results

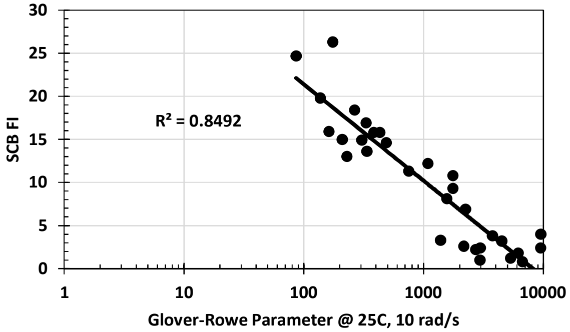
- Glover-Rowe Parameter
  - Two methods evaluated
    - Traditional (15C, 0.005 rad/s)
    - Measured at mix performance temperature, 10 rad/s
  - Both methods show good relationship with the "modified" version resulting is a slightly stronger correlation

$$\frac{G'}{\eta'/G'} = \frac{|G^*|\cdot(\cos\delta)^2}{\sin\delta}\cdot\omega$$



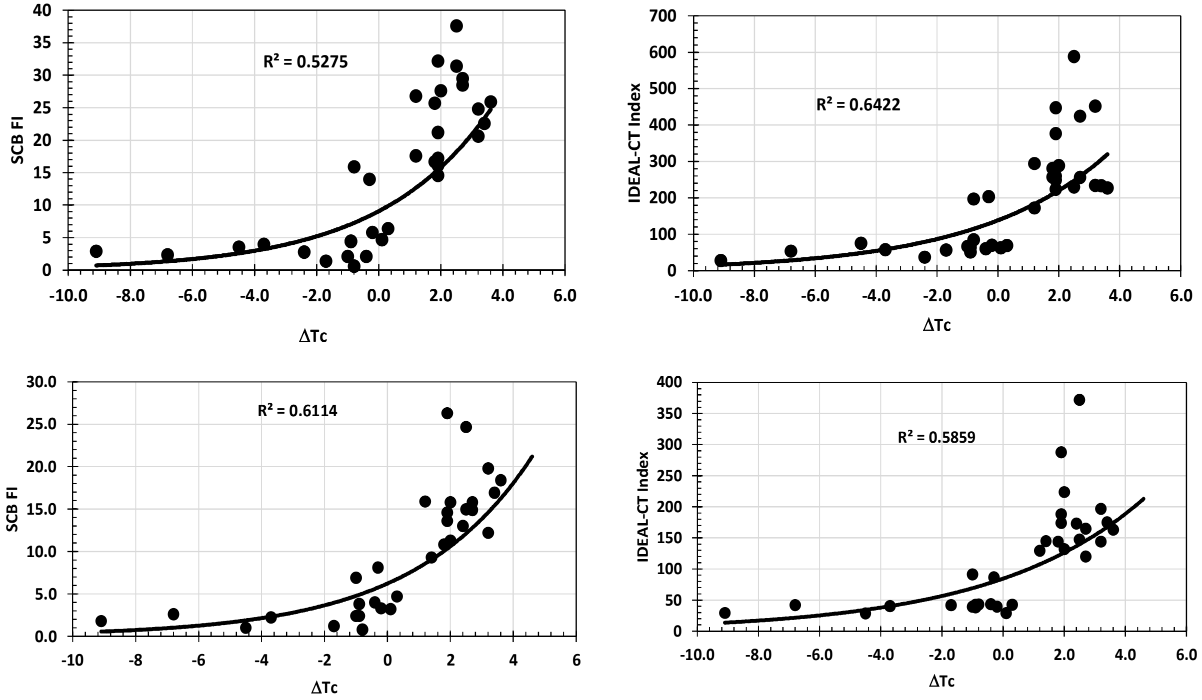






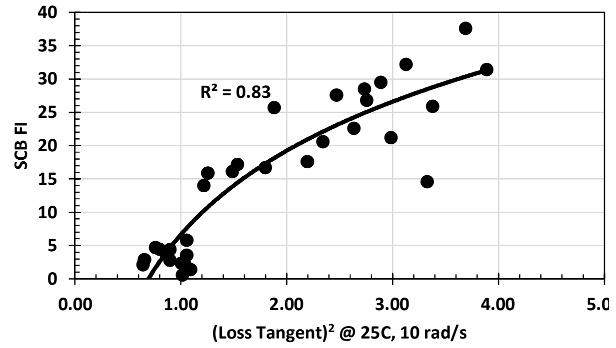
Lab Mix Phase – Examples of Results

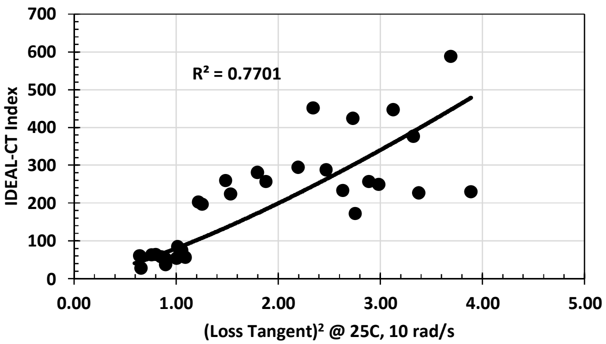
- ΔTc
  - BBR testing conducted for passing and failing Stiffness and m-values
    - More conditioning resulted in additional test temperatures
  - Comparison to the 2 mixtures and 2 cracking tests showed moderate relationship

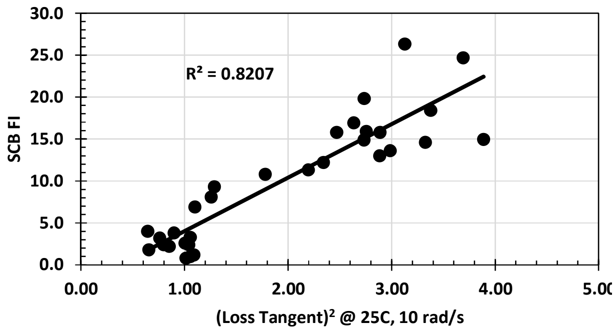


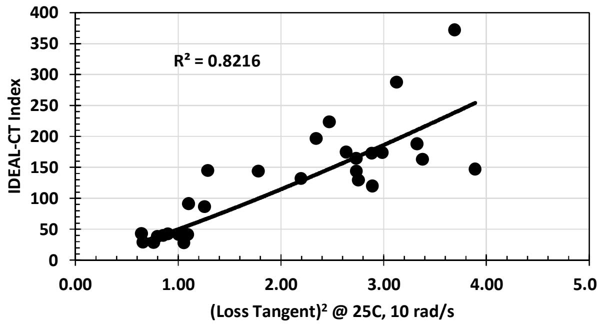
Lab Mix Phase – Examples of Results

- (Loss Tangent)^2 at mix temp
  - Ratio between viscous and elastic component asphalt binder
    - "… an excellent indicator of whether an asphalt behaves as a brittle elastic solid or maintains a viscous component" (Goodrich, 1991)
  - Showed good correlation to mixture fatigue tests





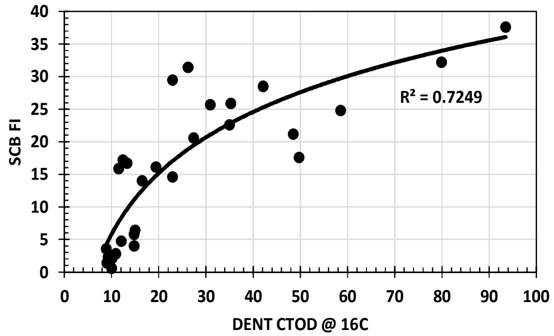


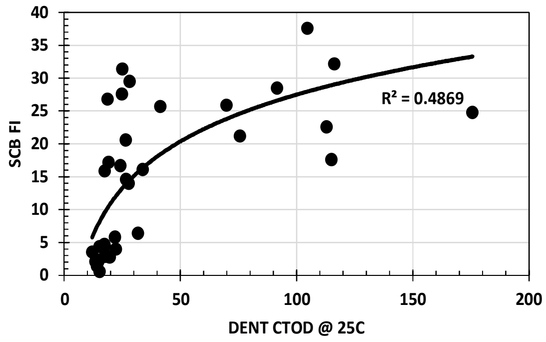


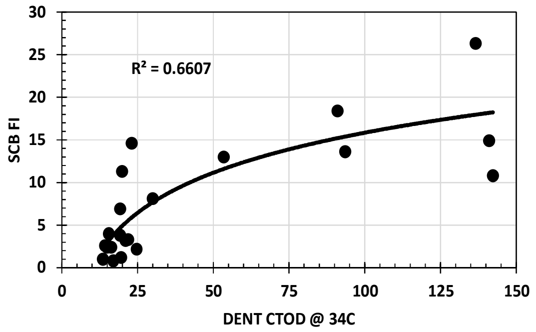
$$\text{Loss Tangent} = \frac{G''}{G'} = \tan\delta$$

Lab Mix Phase – Examples of Results

- Double Edge Notched Tension (DENT), CTOD
  - Tests conducted at 4 temps (16, 22, 25 and 34C)
  - Mixed results with respect to DENT CTOD and mixture cracking performance
  - Overall, better relationship at lower temps, but makes mounting specimens more difficult

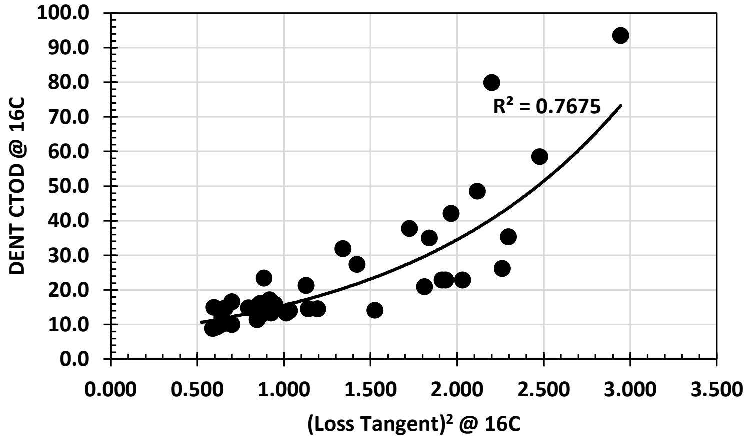


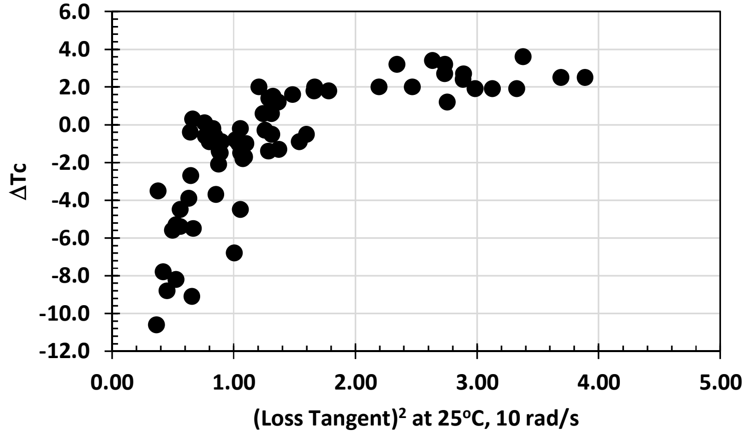




Laboratory Phase – Selection for Field

- In the end, parameters chosen for field evaluation were;
  - Glover-Rowe Parameters
    - Traditional & At Intermediate Temperature
  - Loss Tangent Parameters
    - At Intermediate Temperature & G* = 10 MPa
      - Measured at the same binder stiffness to reduce stiffness dependency issues regarding loading rate and temperature
- Selected parameters resulted in similar to better correlations to mixture tests while illustrating similar behavior to other tests (DENT, ΔTc)

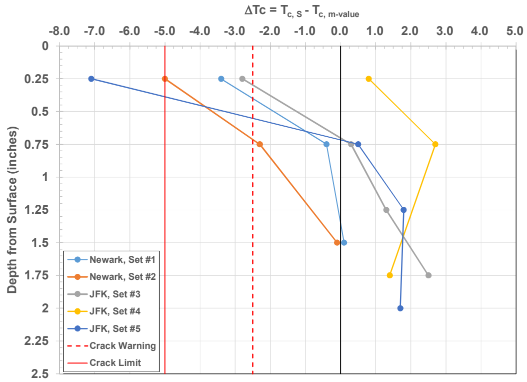


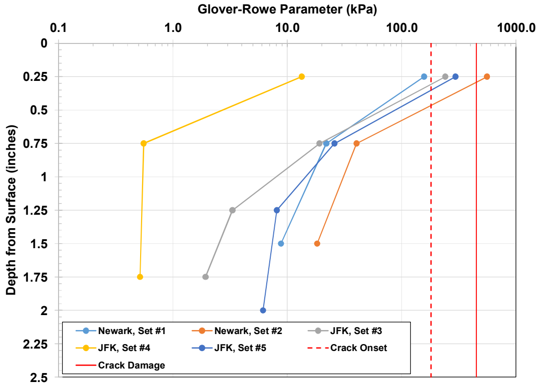


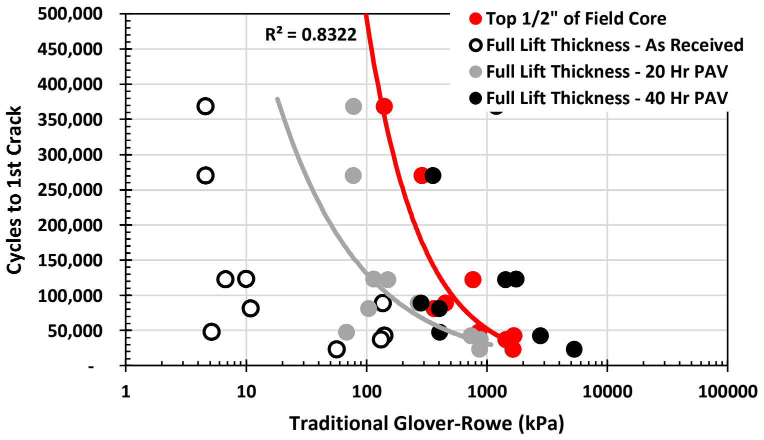
Phase 2 - Field Verification and Initial Criteria

Evaluation of Field Cores

- Significant aging gradient observed in field cores
  - Top ½″ highest stiffness
  - Below 1″ similar to when originally produced
    - Function of air voids, climate conditions
- Top ½″ to ¾″ of field core used for recovery
  - Area of highest aging from field
  - Important to consider when looking at top-down or surface related durability

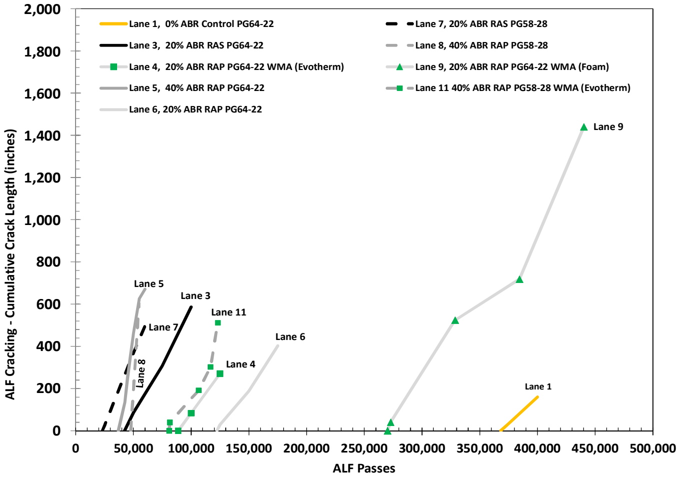






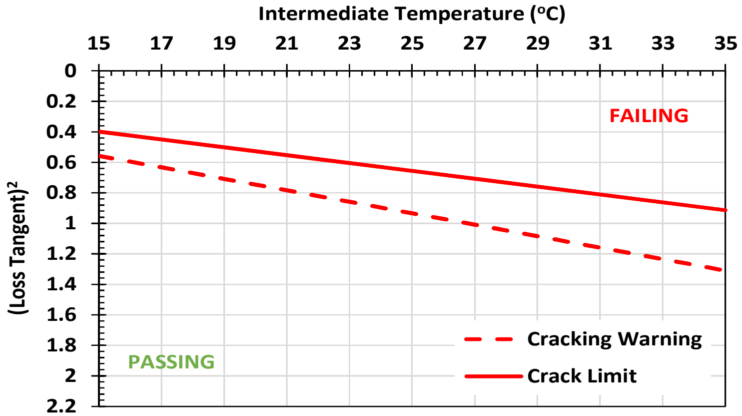
Field Verification

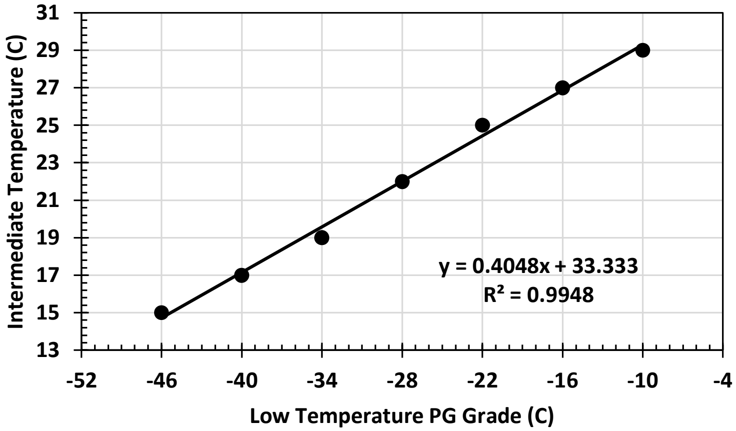
- Multiple pavements noted as having top-down cracking used to help validate tests and proposed criteria
  - JFK & Newark Airports
    - PANYNJ field engineers observations
  - FAA Extended Pavement Life project
    - Consultant visual distress surveys
  - FHWA ALF Experiment
    - Cycles to 1st Crack



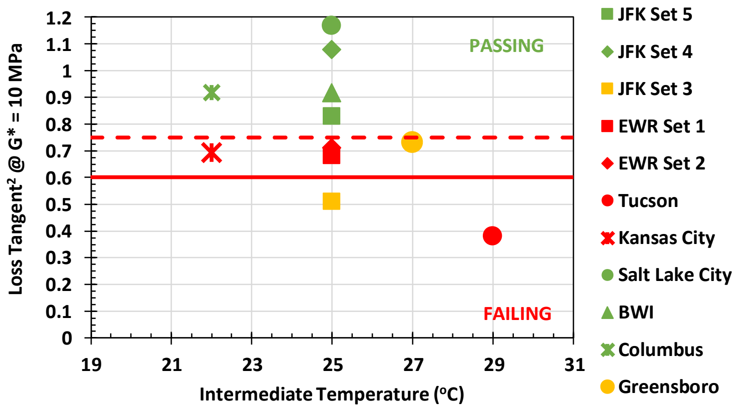
Initial Criteria

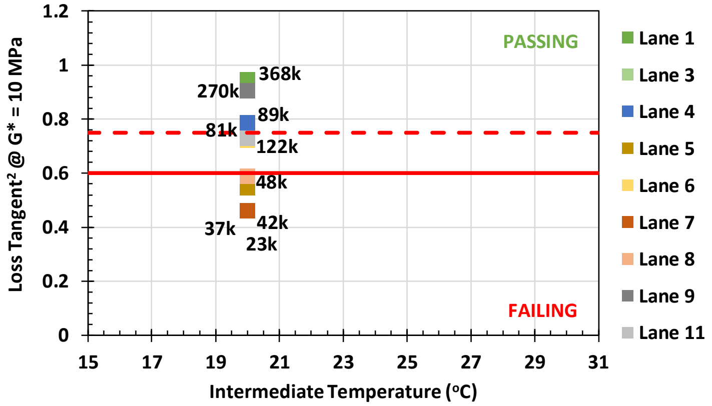
- Initial criteria was based on current Glover-Rowe parameters
  - > 180 kPa = Cracking Warning
  - > 600 kPa = Crack Limit
- When applicable, relationships generated at different intermediate temperatures
  - Allows binder testing to be conducted at the appropriate intermediate pavement temp
  - Temps based on NCHRP 9-59 recommendations





(Loss Tangent)^2 @ G* = 10 MPa

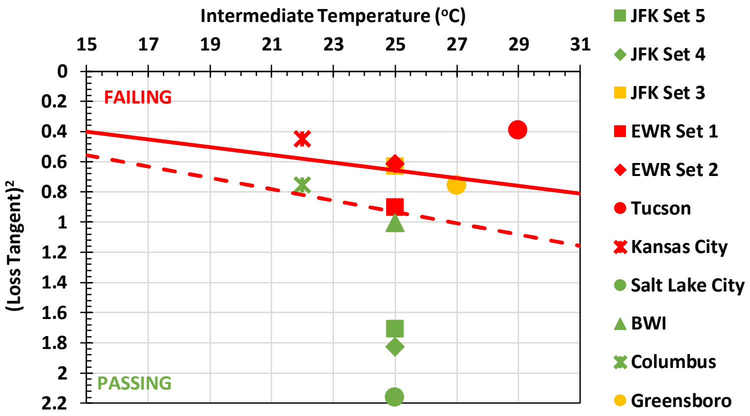


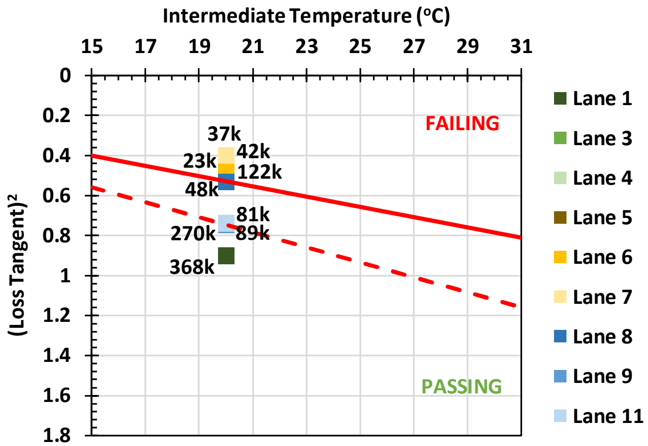


Airfield Pavement	Intermediate Temp	(Loss Tangent)^2 @ G* = 10 Mpa	Cracking Performance	Visual Distress
JFK 4L-22R (Set 5)	25	0.829	Pass	No Cracking
JFK 4L-22R (Set 4)	25	1.080	Pass	No Cracking
JFK 4L-22R (Set 3)	25	0.510	Fail	Minor T Cracking
EWR 11-29 (Set 1)	25	0.683	Warning	Severe L&T Cracking
EWR 11-29 (Set 2)	25	0.713	Warning	Severe L&T Cracking
Tuscon	29	0.381	Fail	Block, L&T Cracking, PCI = 56 (+/- 20)
Kansas City	22	0.694	Warning	Block, L&T Cracking, PCI = 57 (+/- 17)
Salt Lake City	25	1.168	Pass	No Cracking, PCI = 94 (+/- 4)
BWI	25	0.918	Pass	Low Severity Weathering, PCI = 93 (+/- 3)
Columbus	22	0.918	Pass	No Cracking, PCI = 100
Greensboro	27	0.731	Warning	Low Severity Weathering/Cracking, PCI = 89 (+/- 2)

FHWA ALF Lane	Intermediate Temp	(Loss Tangent)^2 @ G* = 10 Mpa	Cracking Performance	Cycles to 1st Crack
Lane 1	20	0.946	Pass	368254
Lane 3	20	0.556	Cracking Limit	42399
Lane 4	20	0.788	Pass	88740
Lane 5	20	0.548	Cracking Limit	36946
Lane 6	20	0.724	Cracking Warning	122363
Lane 7	20	0.462	Cracking Limit	23005
Lane 8	20	0.589	Cracking Limit	47679
Lane 9	20	0.907	Pass	270058
Lane 11	20	0.729	Cracking Warning	81044

(Loss Tangent)^2 @ Intermediate Temp

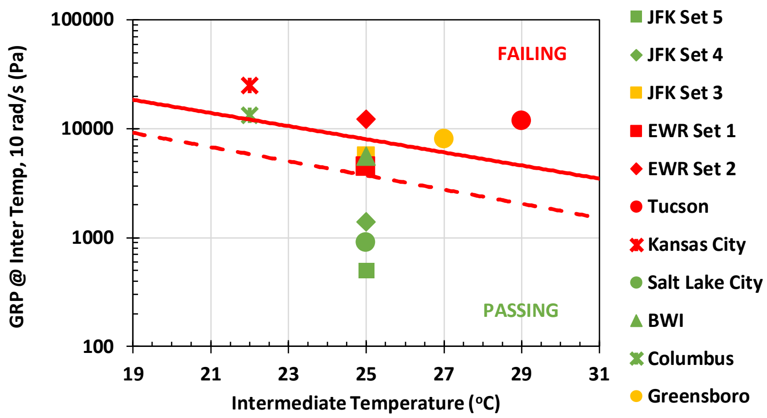




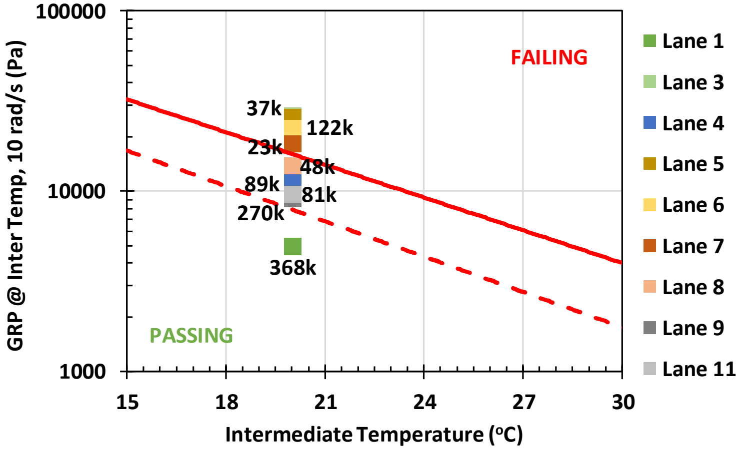
Airfield Pavement	Intermediate Temp	(Tangent Loss)^2 @ Intermed Temp	Crack Warning	Crack Limit	Visual Distress
JFK 4L-22R (Set 5)	25	1.708	PASS	PASS	No Cracking
JFK 4L-22R (Set 4)	25	1.826	PASS	PASS	No Cracking
JFK 4L-22R (Set 3)	25	0.630	FAIL	FAIL	Minor T Cracking
EWR 11-29 (Set 1)	25	0.902	FAIL	PASS	Severe L&T Cracking
EWR 11-29 (Set 2)	25	0.613	FAIL	FAIL	Severe L&T Cracking
Tuscon	29	0.394	FAIL	FAIL	Block, L&T Cracking, PCI = 56 (+/- 20)
Kansas City	22	0.448	FAIL	FAIL	Block, L&T Cracking, PCI = 57 (+/- 17)
Salt Lake City	25	2.162	PASS	PASS	No Cracking, PCI = 94 (+/- 4)
BWI	25	1.003	PASS	PASS	Low Severity Weathering, PCI = 93 (+/- 3)
Columbus	22	0.755	FAIL	PASS	No Cracking, PCI = 100
Greensboro	27	0.756	FAIL	PASS	Low Severity Weathering/Cracking, PCI = 89 (+/- 2)

FHWA ALF Lane	Intermediate Temp	(Tangent Loss)^2 @ Intermed Temp	Crack Warning	Crack Limit	Cycles to 1st Crack
Lane 1	20	0.898	PASS	PASS	368254
Lane 3	20	0.414	FAIL	FAIL	42399
Lane 4	20	0.742	FAIL	PASS	88740
Lane 5	20	0.409	FAIL	FAIL	36946
Lane 6	20	0.451	FAIL	FAIL	122363
Lane 7	20	0.399	FAIL	FAIL	23005
Lane 8	20	0.529	FAIL	PASS	47679
Lane 9	20	0.746	PASS	PASS	270058
Lane 11	20	0.736	FAIL	PASS	81044

Glover-Rowe @ Intermediate Temp

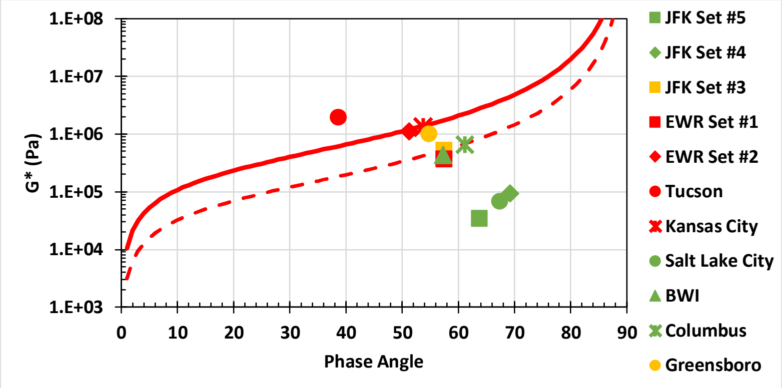


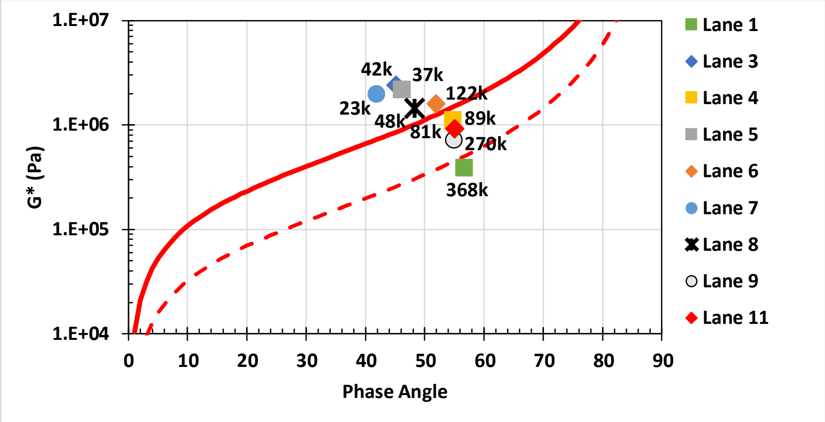
Airfield Pavement	Intermediate Temp	GRP @ Intmed Temp	Crack Warning	Crack Limit	Visual Distress
JFK 4L-22R (Set 5)	25	505	PASS	PASS	No Cracking
JFK 4L-22R (Set 4)	25	1394	PASS	PASS	No Cracking
JFK 4L-22R (Set 3)	25	5699	Fail	PASS	Minor T Cracking
EWR 11-29 (Set 1)	25	4503	Fail	PASS	Severe L&T Cracking
EWR 11-29 (Set 2)	25	12228	Fail	Fail	Severe L&T Cracking
Tuscon	29	11795	Fail	Fail	Block, L&T Cracking, PCI = 56 (+/- 20)
Kansas City	22	25162	Fail	Fail	Block, L&T Cracking, PCI = 57 (+/- 17)
Salt Lake City	25	906	PASS	PASS	No Cracking, PCI = 94 (+/- 4)
BWI	25	5591	Fail	PASS	Low Severity Weathering/Cracking, PCI = 93 (+/- 3)
Columbus	22	13378	Fail	Fail	No Cracking, PCI = 100
Greensboro	27	8062	Fail	Fail	Low Severity Weathering/Cracking, PCI = 89 (+/- 2)



FHWA ALF Lane	Intermediate Temp	New GRP @ Int	Crack Warning	Crack Limit	Cycles to 1st Crack
Lane 1	20	4980	PASS	PASS	368254
Lane 3	20	26208	Fail	Fail	42399
Lane 4	20	11886	Fail	PASS	88740
Lane 5	20	25939	Fail	Fail	36946
Lane 6	20	22357	Fail	Fail	122363
Lane 7	20	18440	Fail	Fail	23005
Lane 8	20	13861	Fail	PASS	47679
Lane 9	20	9177	Fail	PASS	270058
Lane 11	20	9710	Fail	PASS	81044

Traditional Glover-Rowe



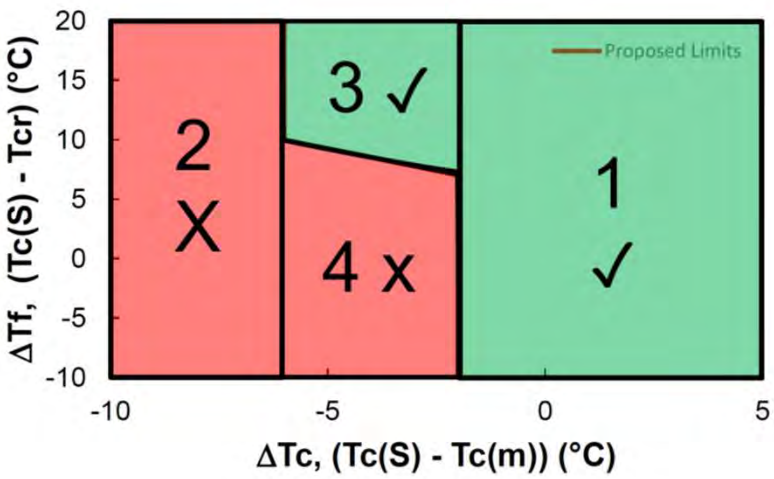


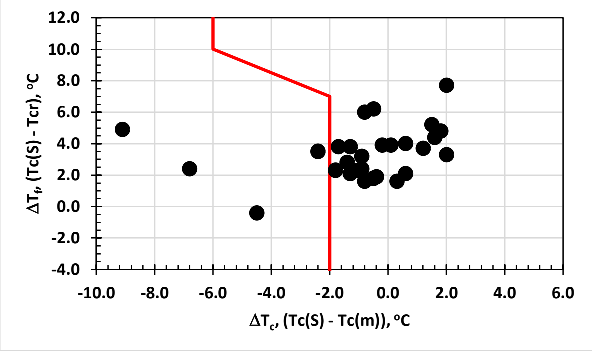
Airfield Pavement	Intermediate Temp	G* (Pa)	Phase Angle	GRP @ Intmed Temp	Crack Warning	Crack Limit	Visual Distress
JFK 4L-22R (Set 5)	25	34260	63.7	7.5	PASS	PASS	No Cracking
JFK 4L-22R (Set 4)	25	92580	69.2	12.5	PASS	PASS	No Cracking
JFK 4L-22R (Set 3)	25	513830	49.5	285.8	Fail	PASS	Minor T Cracking
EWR 11-29 (Set 1)	25	363810	57.4	125.4	PASS	PASS	Severe L&T Cracking
EWR 11-29 (Set 2)	25	1125340	51.2	566.3	Fail	PASS	Severe L&T Cracking
Tuscon	29	1930460	38.6	1890.8	Fail	Fail	Block, L&T Cracking, PCI = 56 (+/- 20)
Kansas City	22	1319420	53.7	572.4	Fail	PASS	Block, L&T Cracking, PCI = 57 (+/- 17)
Salt Lake City	25	67930	67.4	10.9	PASS	PASS	No Cracking, PCI = 94 (+/- 4)
BWI	25	434660	57.3	151.0	PASS	PASS	Low Severity Weathering/Cracking, PCI = 93 (+/- 3)
Columbus	22	657740	61.12	175.2	PASS	PASS	No Cracking, PCI = 100
Greensboro	27	998970	54.72	408.2	Fail	PASS	Low Severity Weathering/Cracking, PCI = 89 (+/- 2)

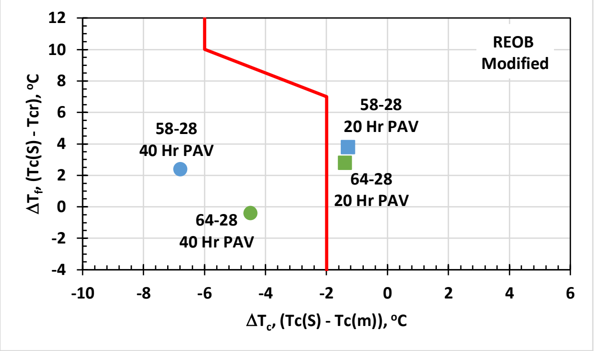
FHWA ALF Lane	δ at 15C, 0.005 rad/sec	G* @ 15C, 0.005 rad/s (Pa)	Traditional Glower-Rowe (kPa)	Crack Warning	Crack Limit	Cycles to 1st Crack
Lane 1	56.6	3.86E+05	140.0	PASS	PASS	368,254
Lane 3	45.1	2.39E+06	1677.7	Fail	Fail	42,399
Lane 4	54.7	1.11E+06	453.3	Fail	PASS	88,740
Lane 5	46.1	2.16E+06	1439.9	Fail	Fail	36,946
Lane 6	51.9	1.58E+06	766.3	Fail	Fail	122,363
Lane 7	41.8	1.98E+06	1647.3	Fail	Fail	23,005
Lane 8	48.2	1.43E+06	853.8	Fail	Fail	47,679
Lane 9	54.9	7.15E+05	288.7	Fail	PASS	270,058
Lane 11	55.0	9.13E+05	366.8	Fail	PASS	81,044

NCHRP 9-60

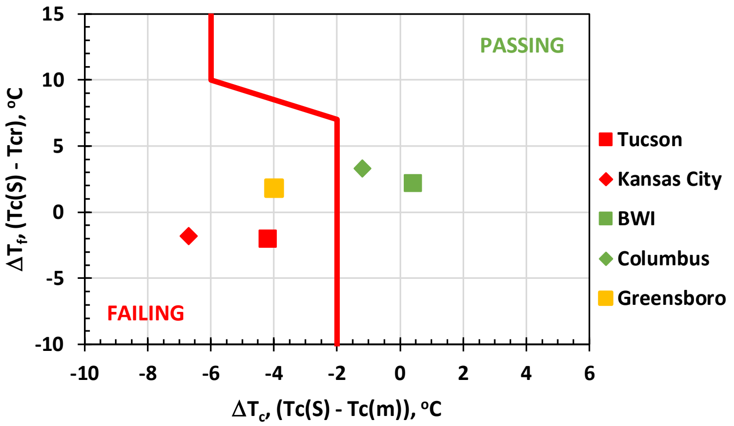
- FAA project completed before NCHRP 9-60 study completed
  - With proposed criteria for durability, remaining binders were evaluated
  - Sent to FHWA Turner-Fairbanks for Asphalt Binder Cracking Device (ABCD) testing to determine Tcr
- NCHRP 9-60 approach uses a performance space of ΔTc and ΔTf



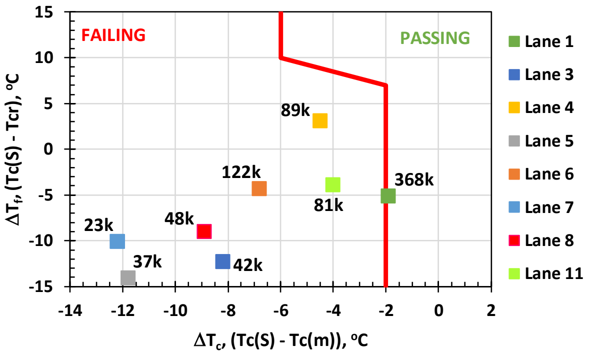




NCHRP 9-60



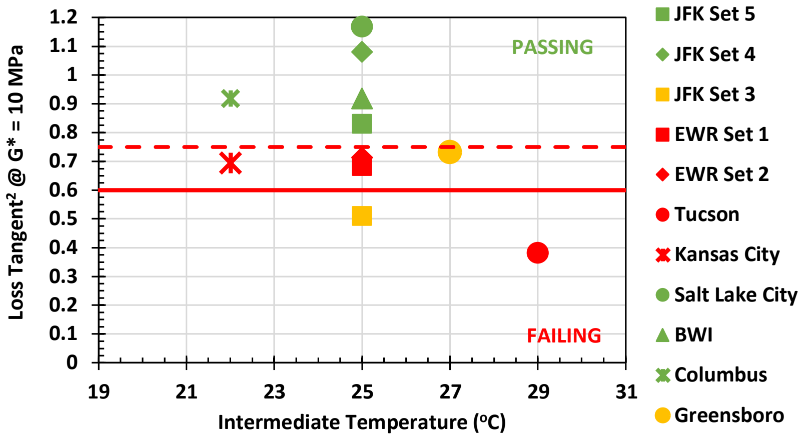
Airfield Pavement	Intermediate Temp	ΔTc	ΔTf	Visual Distress
Tuscon	29	-4.2	-2.0	Block, L&T Cracking, PCI = 56 (+/- 20)
Kansas City	22	-6.8	-1.8	Block, L&T Cracking, PCI = 57 (+/- 17)
BWI	25	0.4	2.2	Low Severity Weathering, PCI = 93 (+/- 3)
Columbus	22	-1.2	3.3	No Cracking, PCI = 100
Greensboro	27	-4.0	1.8	Low Severity Weathering/Cracking, PCI = 89 (+/- 2)

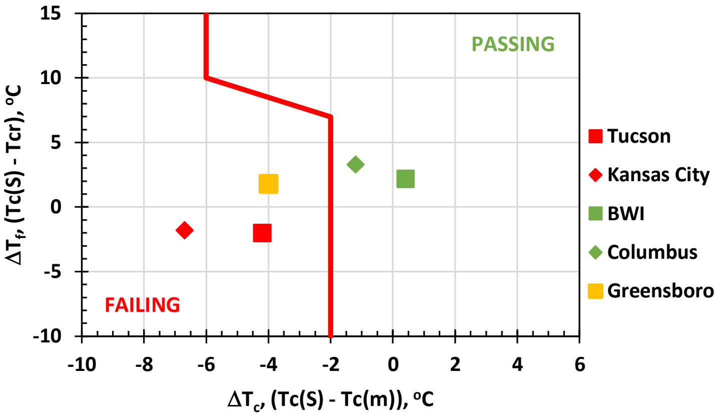


Lane	ΔTc	ΔTf	ABCD Tcr	LT (s)	LT (m)	Cycles to 1st Crack
Lane 1	-1.9	-5.1	-23.0	-28.1	-26.2	368,254
Lane 3	-8.2	-12.3	-15.0	-27.3	-19.1	42,399
Lane 4	-4.5	3.1	-26.3	-23.2	-18.7	88,740
Lane 5	-11.8	-14.1	-9.9	-24.0	-12.2	36,946
Lane 6	-6.8	-4.3	-19.5	-23.8	-17.0	122,363
Lane 7	-12.2	-10.1	-19.5	-29.6	-17.4	23,005
Lane 8	-8.9	-9.0	-17.7	-26.7	-17.8	47,679
Lane 9	-2.4			-25.9	-23.5	270,058
Lane 11	-4.0	-3.9	-21.1	-25.0	-21.0	81,044

Summary of Field Verification

- (Loss Tangent)^2 @ G* = 10 MPa resulted in best ranking of field performance
  - Only method to correctly identify Lane #6 performance at FHWA ALF
- Most methods were able to differentiate “Good” from “Poor”
  - Further verify criteria to better distinguish the performance in the middle
- NCHRP 9-60 method also showed ability to rank performance of asphalt binders for top-down cracking
  - Limited data compared to other tests evaluated
- Regional calibration efforts can help to improve criteria and reliability

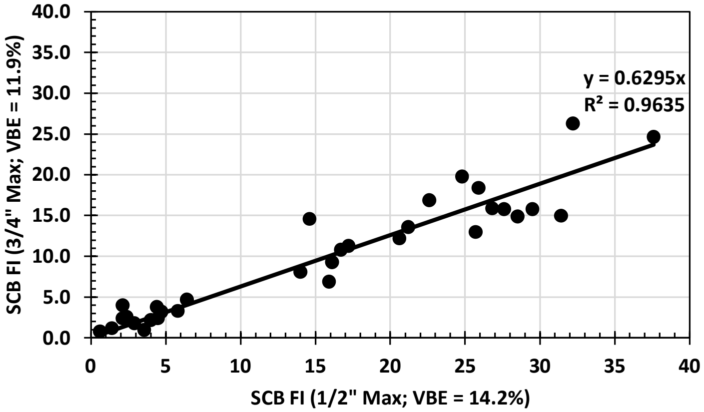


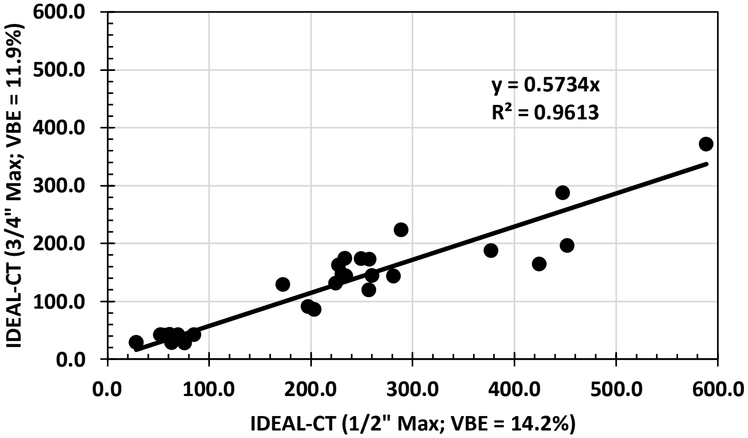


Other Considerations

Other Considerations

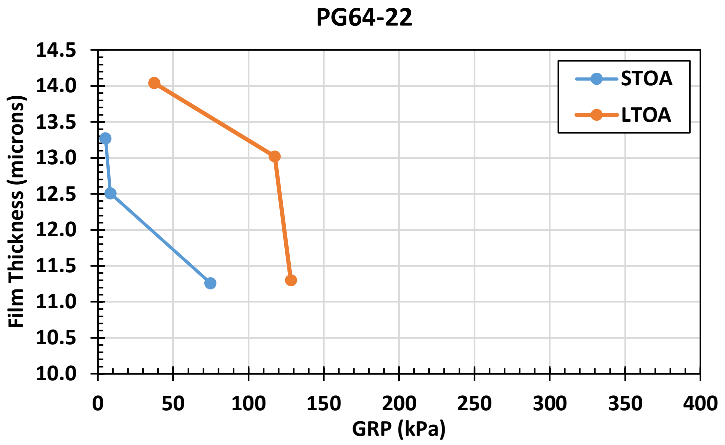
- A good binder test helps to strengthen a purchase spec for material selection
- However, still need to ensure enough asphalt binder in the mix
- Ex. Phase 1 – Laboratory Mixes
  - ½" Max: VBE = 14.2%
  - ¾" Max: VBE = 11.9%
    - VBE reduction of 2.3% reduced
      - SCB FI by 37%
      - IDEAL-CT Index by 43%

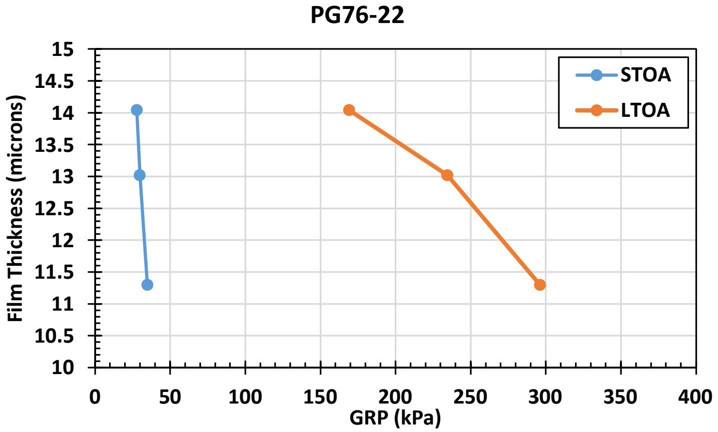




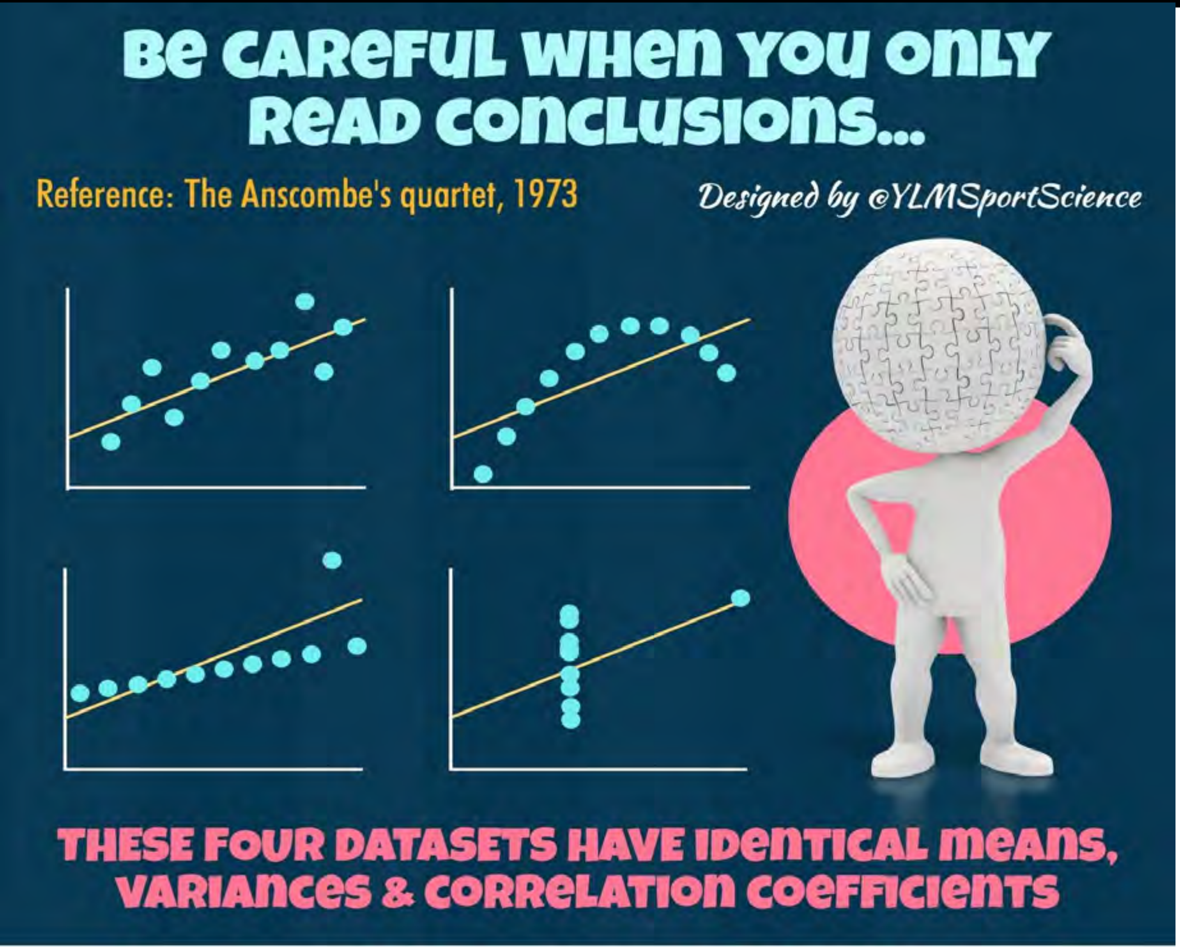
Other Considerations

- Proper effective binder content (VBE) not only improves fatigue cracking performance, higher film thickness helps to reduce impact of binder aging
- Phase 1 – Laboratory Mixes
  - Higher film thickness will also reduce overall aging of asphalt binder
    - Recovered from mix produced at -0.5%, Opt, +0.5%





Thank you for your time!
Questions?



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