Relationship of Asphalt Binder Properties and Asphalt Mix Specimen Properties

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- Rutgers Staff
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Objective of Study

- Evaluate different asphalt binder test methods that show promise at identifying asphalt binder durability/fatigue performance
- Evaluate different asphalt mixture performance tests that can be utilized to determine fatigue performance of asphalt mixtures
- Propose:
  - A purchase specification that can be used to specify asphalt binder performance to minimum fatigue damage
  - A quality control test that can be used to evaluate fatigue performance of asphalt mixtures

Important Considerations

- Stiffness of materials
  - Aging & test temperature will play a significant role on the stiffness of the asphalt binder
  - Important that when comparing binder and mixture testing, materials are evaluated at similar conditions (i.e. – aging and temperature).
  - Differences in loading rates – may be harder to quantify due to volume/specimen size effects
- Field projects provide for good comparison and also provide field performance
- Lab testing needs to verify materials are conditioned in a similar manner

Laboratory Conditioning

- Currently, there is no agreed upon means of conditioning asphalt binder and mixtures that will result in the same "stiffness"
  - NCHRP 9-54: Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction
  - NCHRP 9-59: Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Properties
  - NCHRP 9-61: Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
- Therefore, field cores and plant produced asphalt mixtures provide best means to develop relationships
  - Field cores also provide field performance!

Asphalt Binder Test Identification

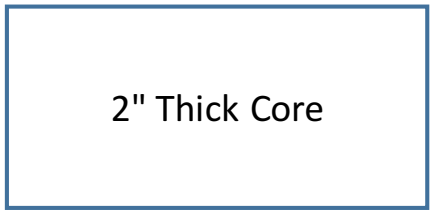
PANYNJ Airfield Cracking - Field Observations

- No rutting
- Longitudinal and transverse cracking observed
- Cracking top-down
  - Stops approximately 0.5" to 0.75" below surface

Binder and Mixture Sampling from Field Cores – Approximate Dimensions

- Asphalt binder testing conducted every 0.5" to evaluate change in binder properties due to aging
- Asphalt mixture testing conducted at bottom of core to provide "initial" mixture performance

Overlay Samples



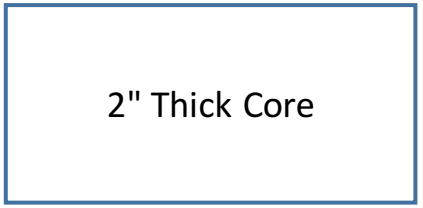
0.5" Top

1.5" OT Sample

0.5" Top
0.5" 2nd Layer
0.5" 3rd Layer

1.5" OT Sample

SCB Samples



0.5" Top
0.5" 2nd Layer

1.0" Bottom (SCB)

0.5" Top
0.5" 2nd Layer

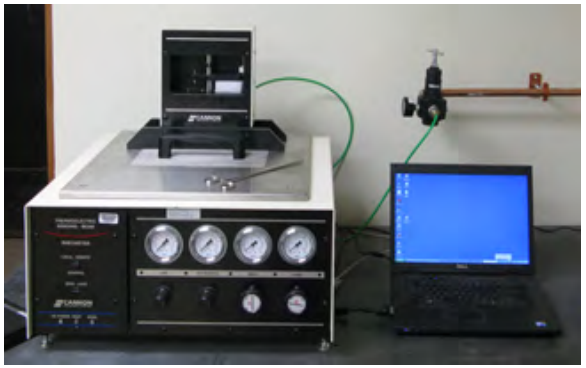
1.0" 3rd Layer

1.0" Bottom (SCB)

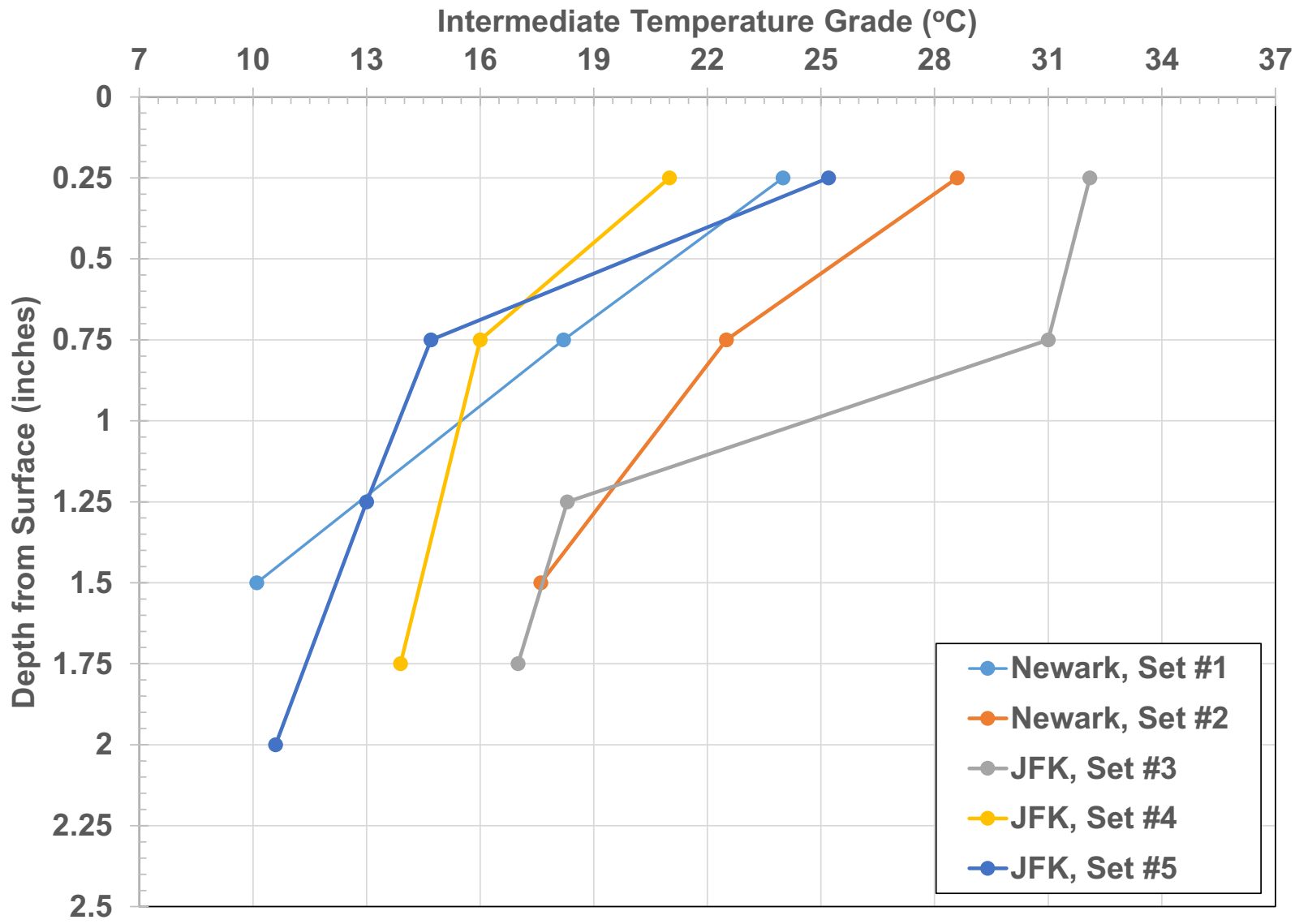
Asphalt Binder Testing & Results

Asphalt Binder Testing

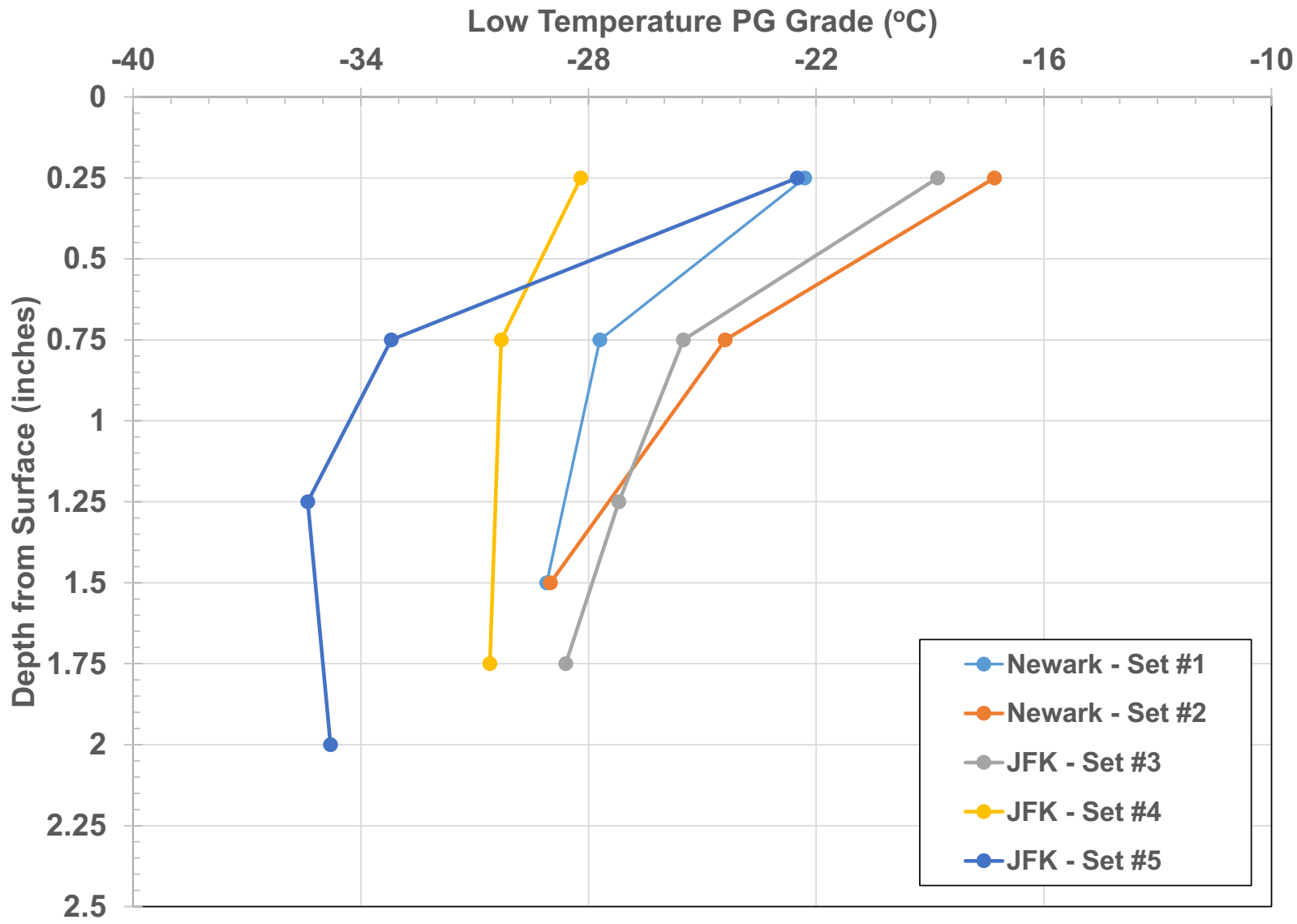
- Asphalt binders recovered using solvent extraction and Rotovapor Recovery
- Binder testing included;
  - PG grading (intermediate & Low PG)
  - Master curves
    - Rheological Properties
    - Glover-Rowe Parameter
  - Double Edge Notched Tension (DENT)
  - Linear Amplitude Sweep (LAS)



Intermediate Temperature PG Grade



Low Temperature PG Grade

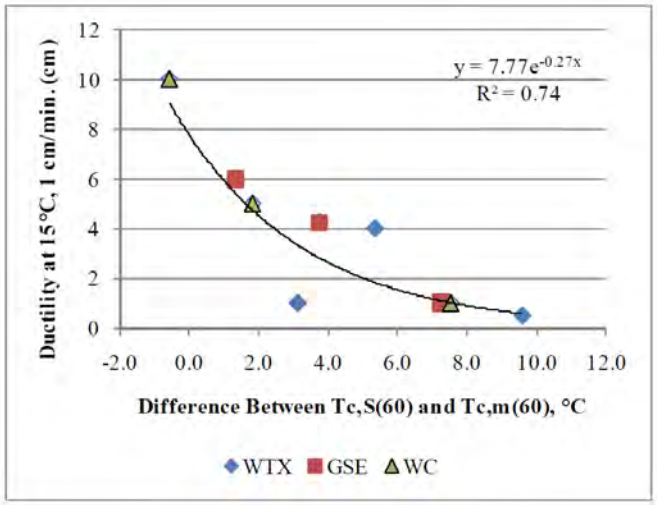


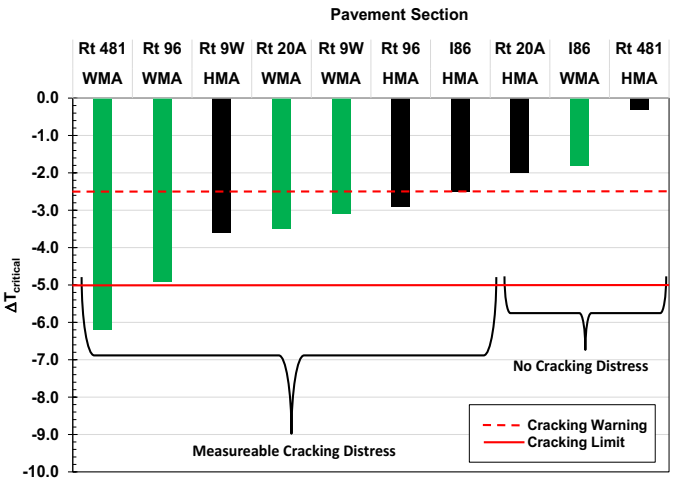
ΔT_c from BBR Testing

- Ductility has always been correlated to fatigue performance of asphalt mixtures and clearly decreases with aging
- As asphalt binders age, the relaxation properties (m-value) are negatively affected at greater rate than the stiffness (S)
- The difference between the low temperature cracking grade of m-value and S is defined as the ΔT_c

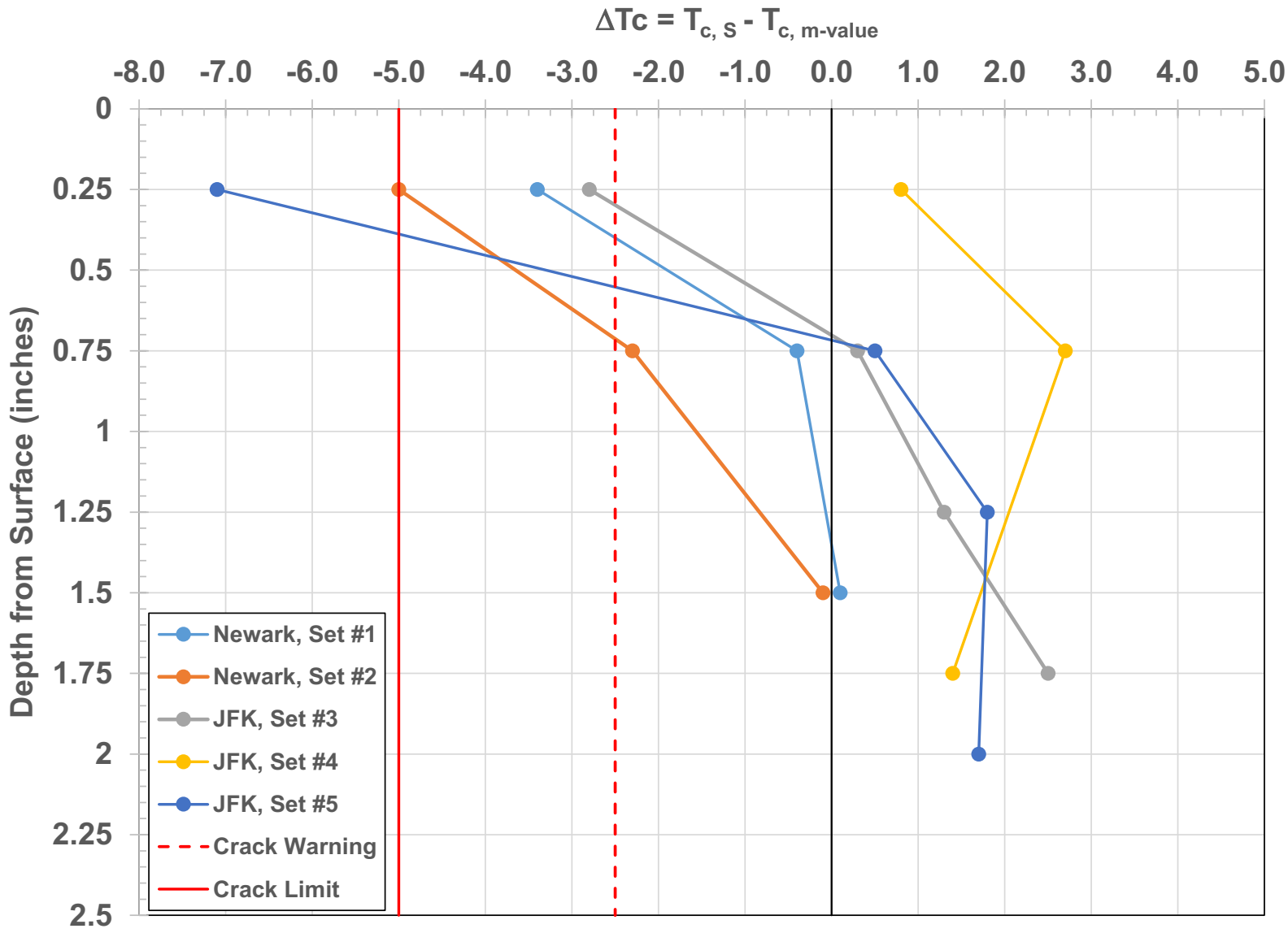
$$\Delta T_c = T_{c,\,S} - T_{c,\,m\text{-value}}$$

- AAPT (Anderson et al., 2011) showed that the ΔT_c correlated to non-load associated cracking on airfields (i.e. – cracking mainly due to aging), as well as ductility



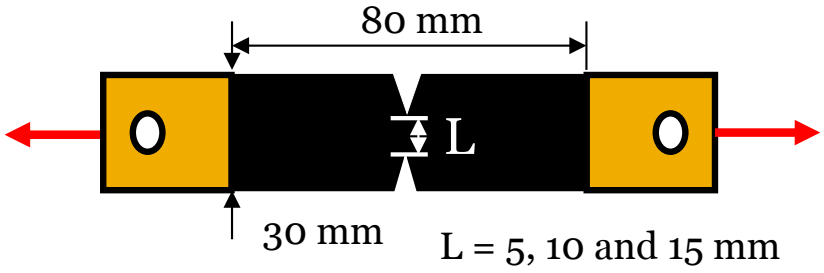


Change in Low Temperature Critical Cracking (ΔT_c)

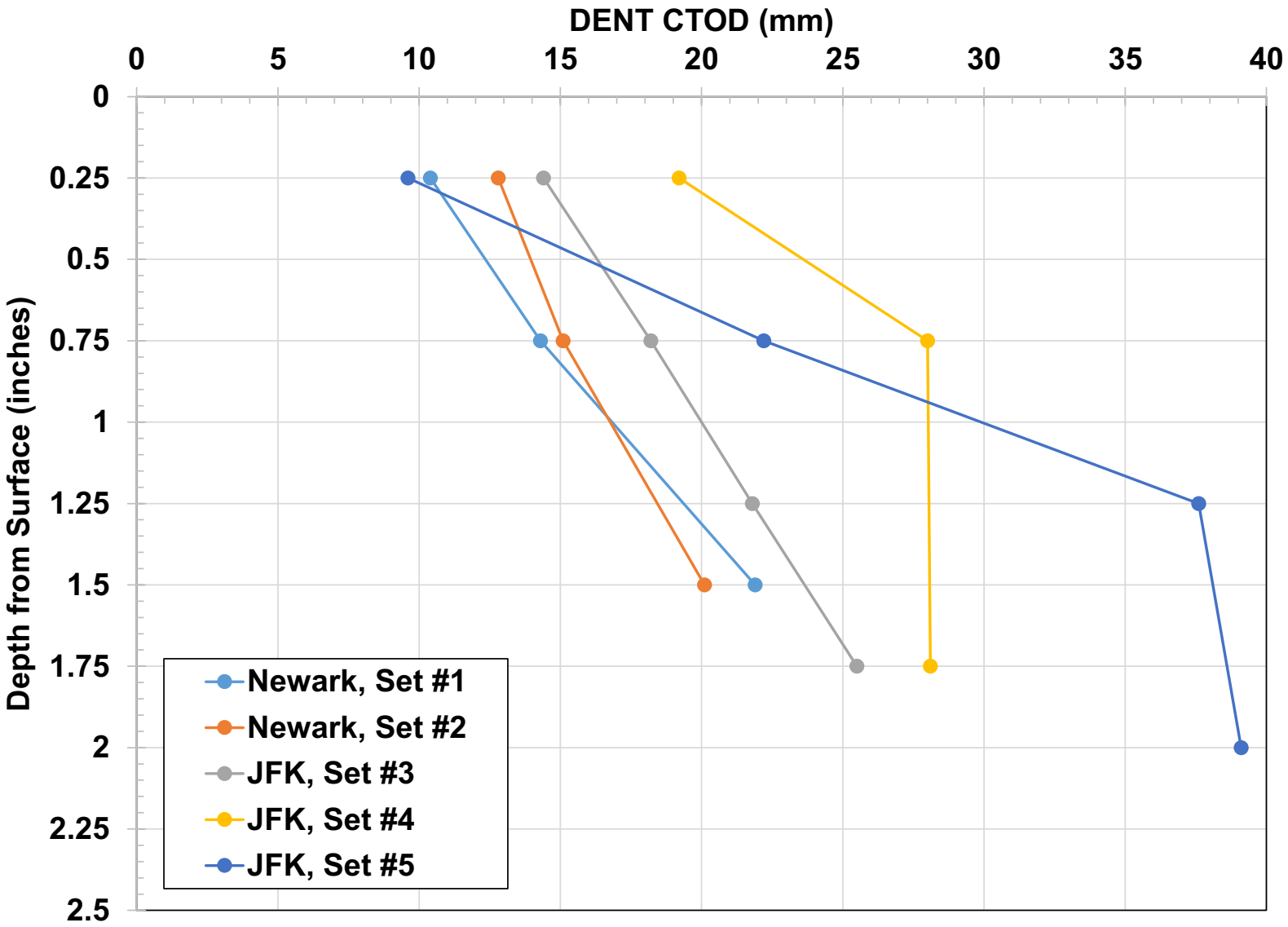


Double Edge Notched Tension (DENT) Test – AASHTO TP113

- Test evaluates the energy required for fracturing ductile materials
  - Test measures the Work of Fracture and Critical Opening Displacement (CTOD)
  - CTOD represents ultimate elongation, or strain tolerance, in the vicinity of a crack (i.e. – notch)
  - As CTOD increases, more resistant to fracturing

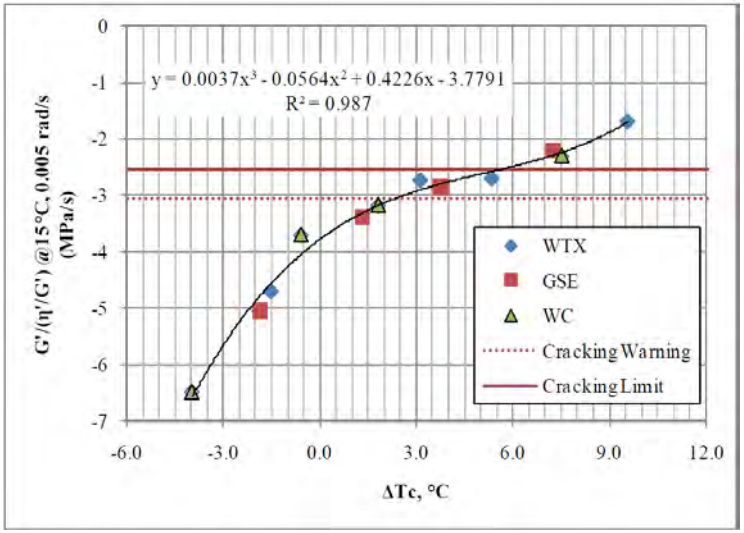


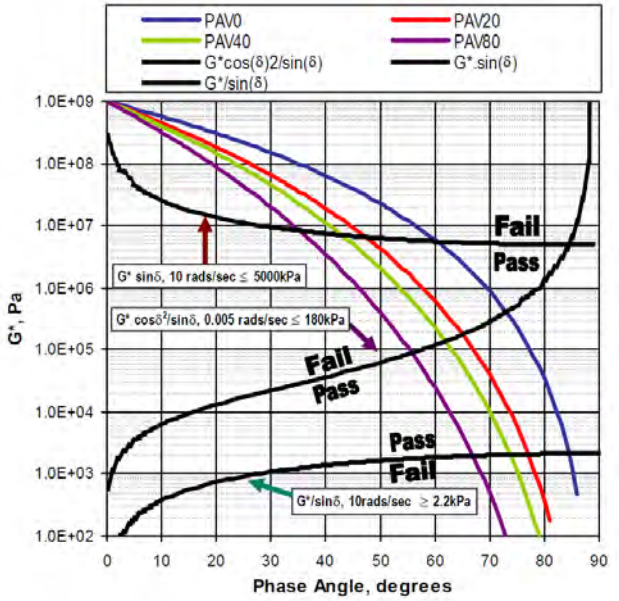
Double Edge Notched Tension (DENT) Test – AASHTO TP113 (20°C)



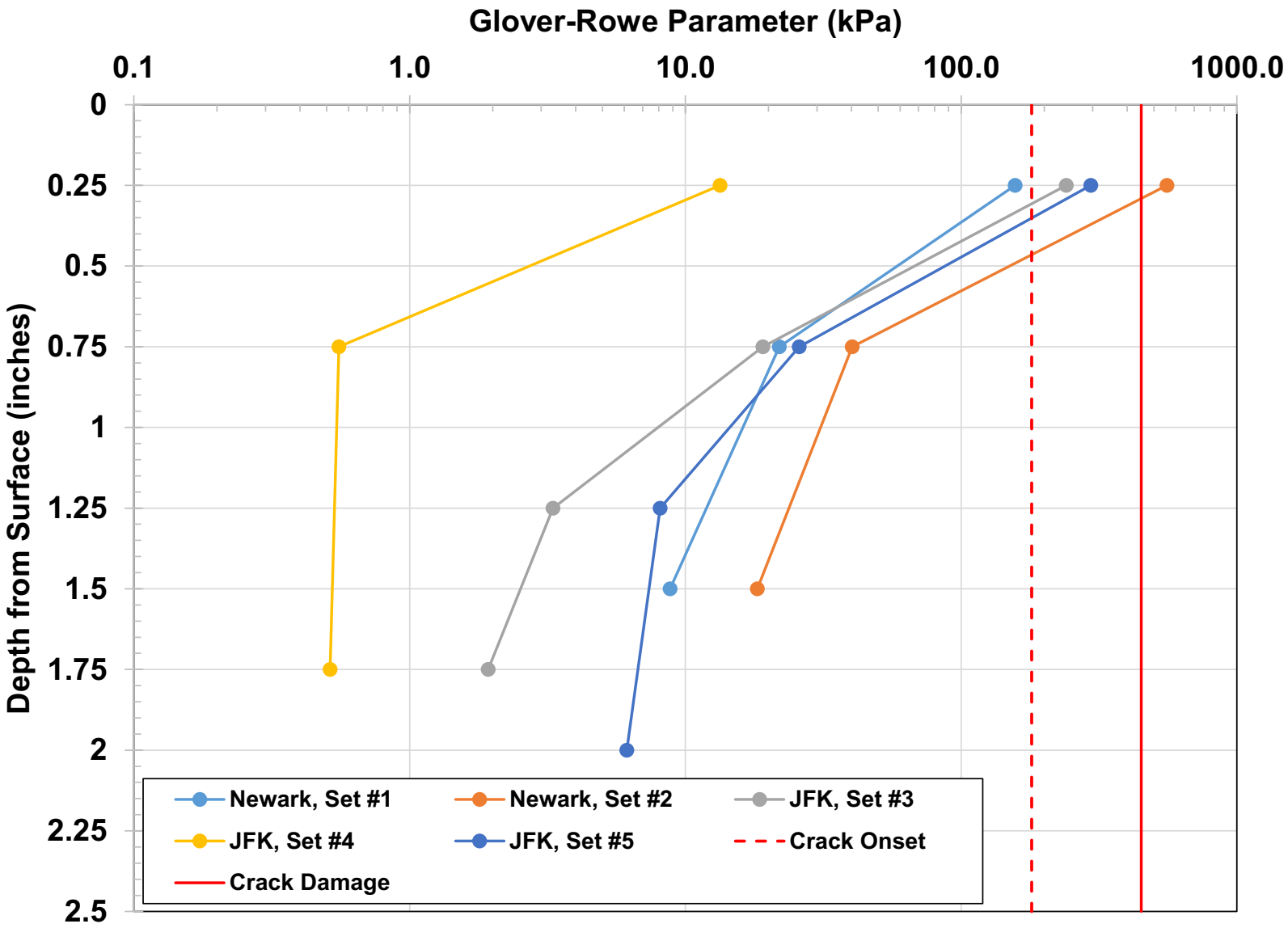
Glover-Rowe Parameter (G-R)

- Due to equipment and material size restraints, Ductility testing may not be available
- Rowe (AAPT, 2011) proposed the DSR master curve analysis to calculate the "Glover-Rowe" parameter
  - As G-R parameter increases, the binder is more prone to fatigue cracking
  - Correlates to both ductility and BBR ΔTc



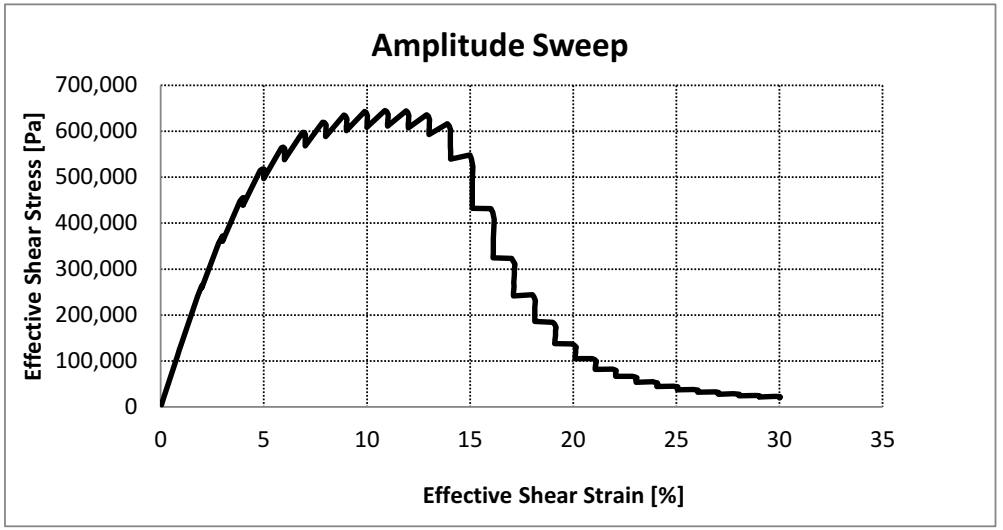


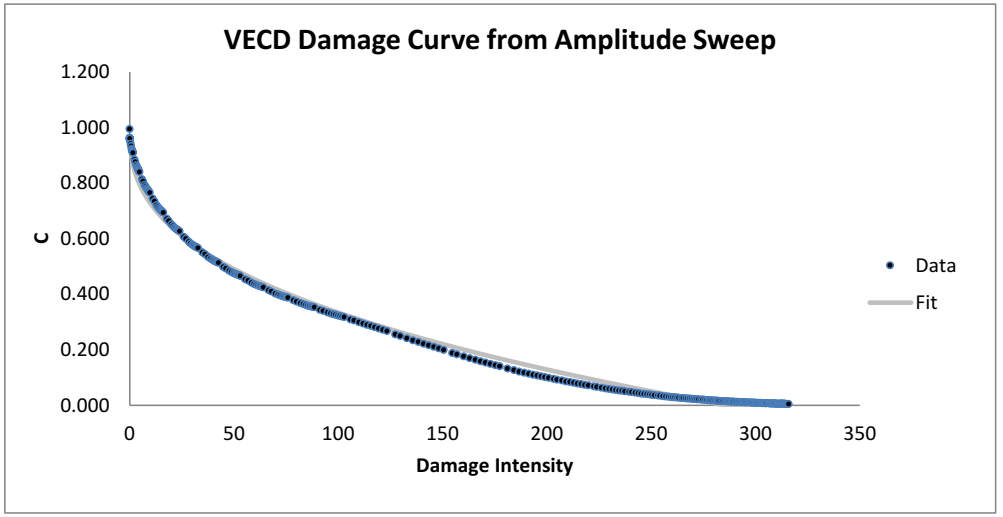
Glover-Rowe Parameter (G-R)



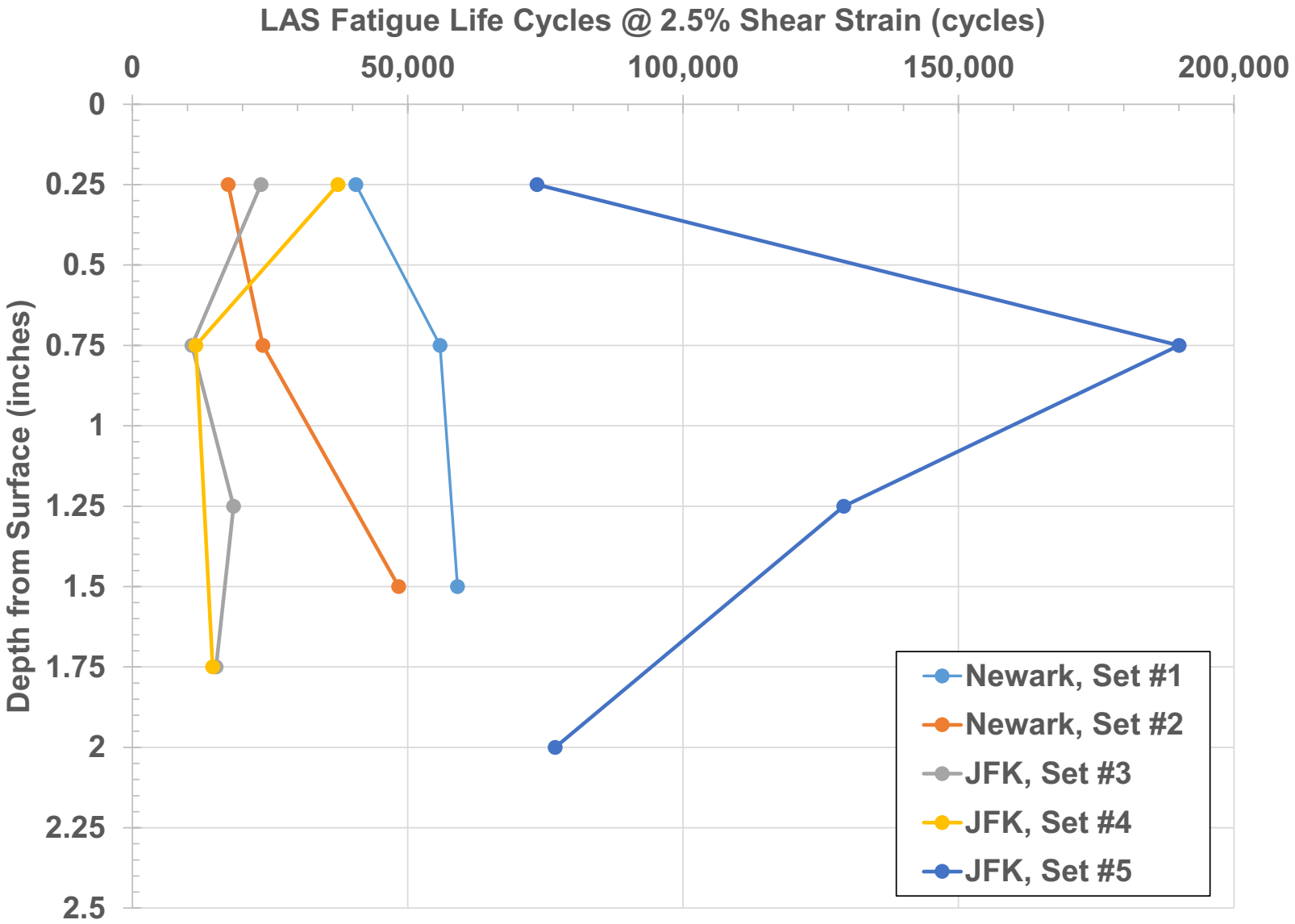
Linear Amplitude Sweep (LAS) – AASHTO TP101

- Utilizes cyclic testing in the DSR to evaluate the undamaged and damaged condition of asphalt binders under increased accelerated damage.
- Analysis allows for the determination of asphalt binder fatigue life (cycles) at different shear strain levels
- Comparison to FHWA-ALF and LTPP sections show relatively well correlations





Linear Amplitude Sweep @ 2.5% Shear Strain



Binder "Fatigue" Test - Ranking of Core Sets

Runway	Binder Type	Visual Observations	Date Placed (Age)
EWR 11-29 (Core Set 1)	PG64-22 + 7% Vestoplast	Not performing well; Excessive cracking	9/20/2008 (6 Yrs, 9 Months)
EWR 11-29 (Core Set 2)	PG64-22 + 7% Vestoplast	Not performing well; Excessive cracking	8/9/2008 (6 Yrs, 10 Months)
JFK 4R-22L (Core Set 3)	PG76-22	Performing well; No cracking	9/5/2002 (12 Yrs, 9 Months)
JFK 4L-22R (Core Set 4)	PG76-28	Performing well; Very few cracks	6/4/2000 (15 Yrs)
JFK 4L-22R (Core Set 5)	PG76-28	Performing well; some cracking	6/4/2000 (15 Yrs)

1.5" Depth	ΔTcr	CTOD (mm)	Glover-Rowe	***Average***
Newark, Set #1	4	4	4	***4.0***
Newark, Set #2	5	5	5	***5.0***
JFK, Set #3	1	3	2	***2.0***
JFK, Set #4	3	2	1	***2.0***
JFK, Set #5	2	1	3	***2.0***

Summary for PANYNJ Binder "Fatigue" Testing

- BBR ΔT_C , DENT CTOD and Glover-Rowe properties correlated to field observations
  - Intermediate PG grade & LAS conflicted to field observations
- "Fatigue" properties of recovered asphalt binder improved with depth
  - At depths > 0.75 inches, appears to be little aging
    - Would change based on in-situ air voids – these mixtures all placed at air voids < 6.5%
    - Regional climatic effects

FHWA Accelerated Loading Facility (ALF)

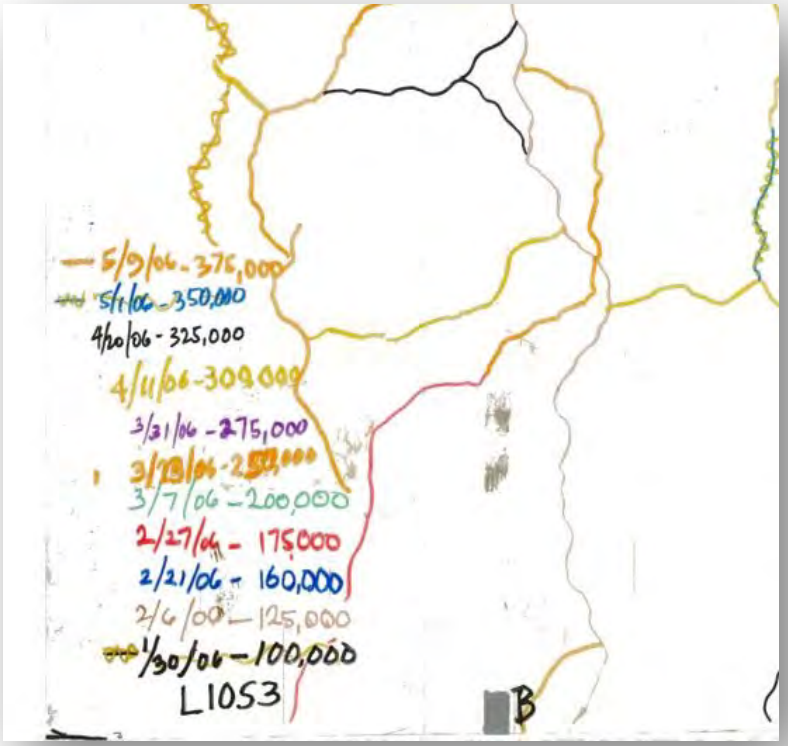
- Recently completed High Recycle with WMA Fatigue Cracking Experiment
- Focus on fatigue cracking, temp. controlled at 20°C
  - No high temperature rutting*
- Three year completion
  - 2 years of loading
  - 2 ALF units allow simultaneous loading
- Unmodified binder for all lanes, but 2 different grades
- WMA Technology which does not change PG grade
- 10 kip single wheel = 20 kip equivalent axle
- Same set of asphalt binder testing as PANYNJ Study

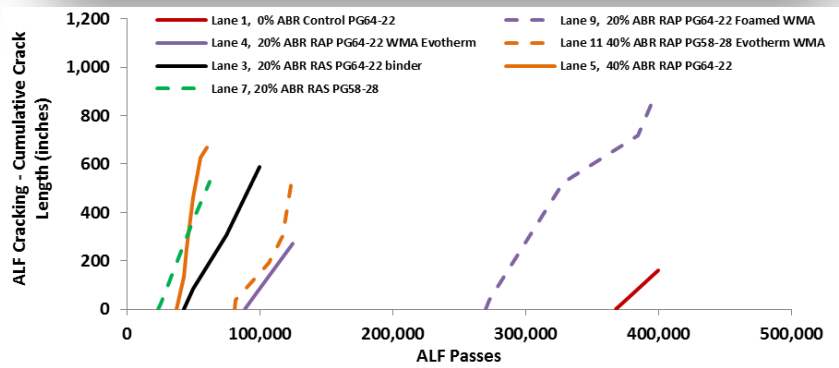
FHWA Accelerated Loading Facility (ALF)

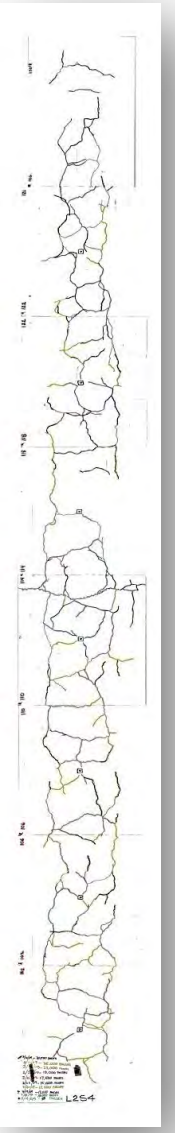
	ALF Lane	% RBR		Virgin Binder PG	WMA Process
		RAP	RAS		
	1	0	-	64-22	-
Re-running	2	40	-	58-28	Water
	3	-	20	64-22	-
	4	20	-	64-22	Chemical
	5	40	-	64-22	-
	6	20	-	64-22	-
	7	-	20	58-28	-
Re-running	8	40	-	58-28	-
	9	20	-	64-22	Water
	11	40	-	58-28	Chemical

FHWA Accelerated Loading Facility (ALF)

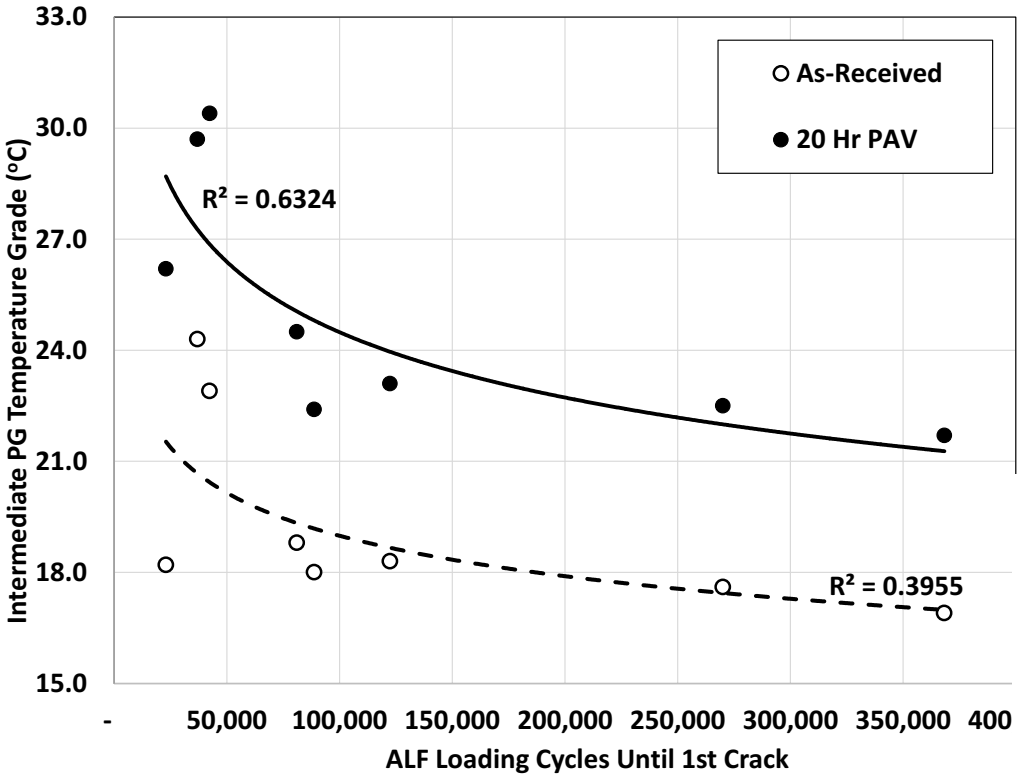
- Cracking performance measured and quantified in two indices
  - Number of cycles until 1st Crack observed
  - Cracking Rate

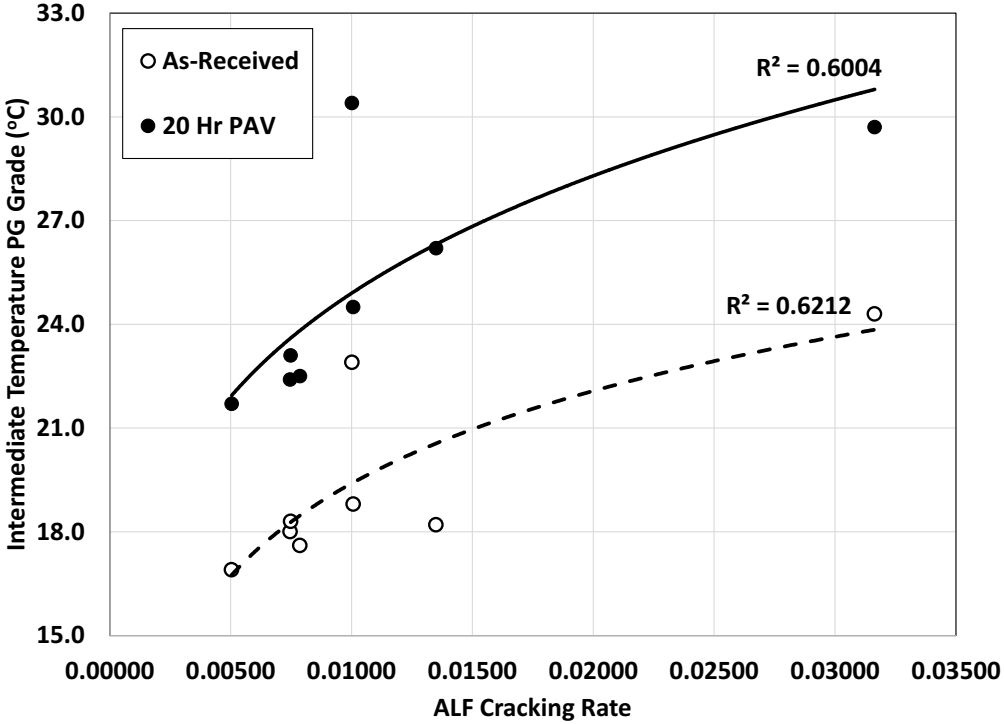




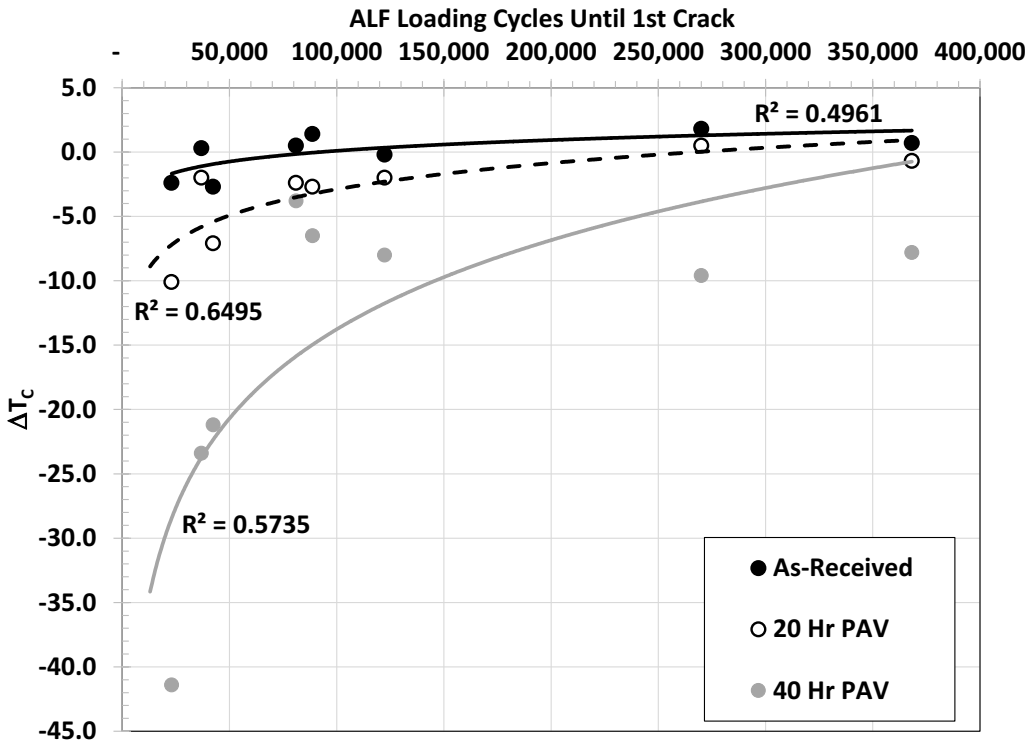


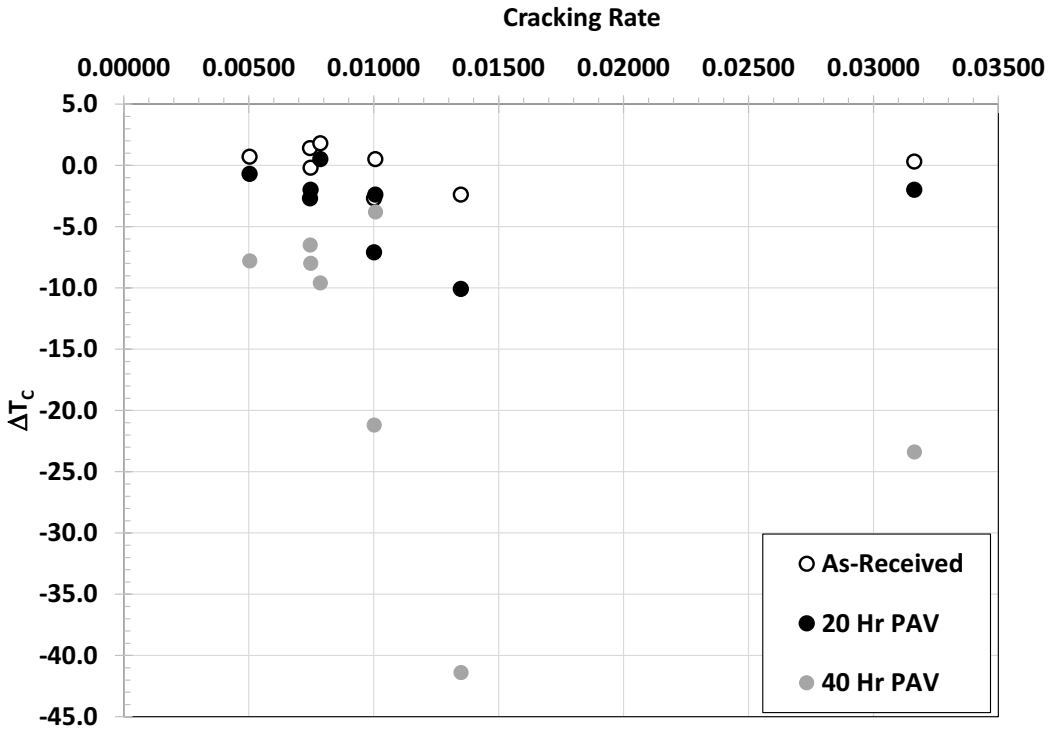
Intermediate PG Grade – ALF Study



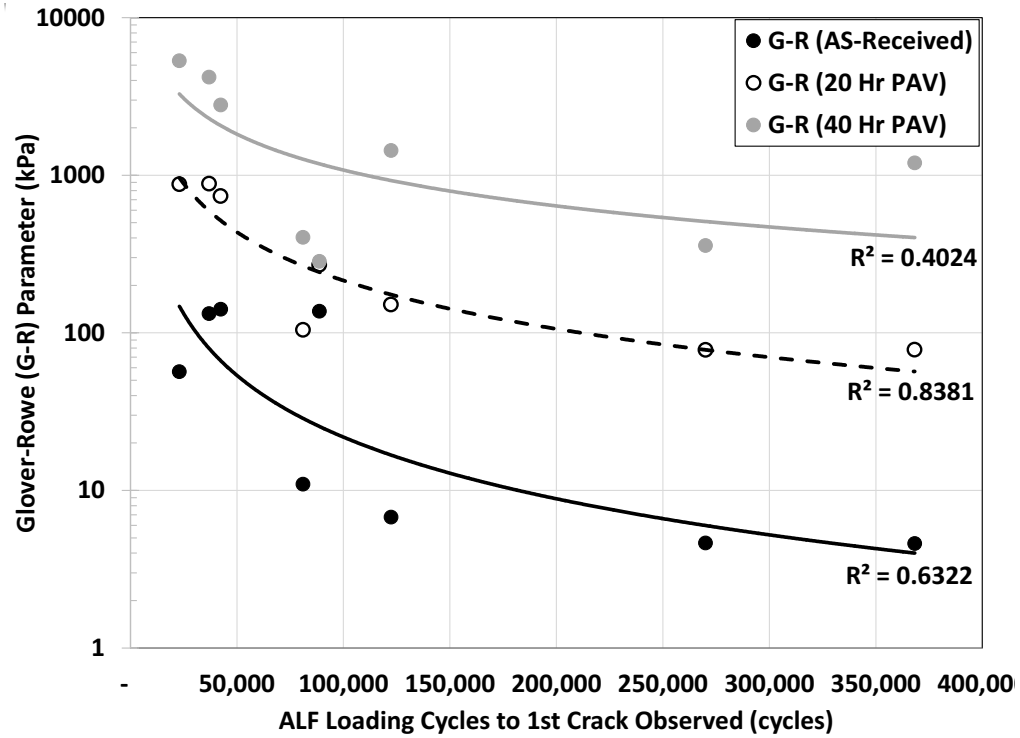


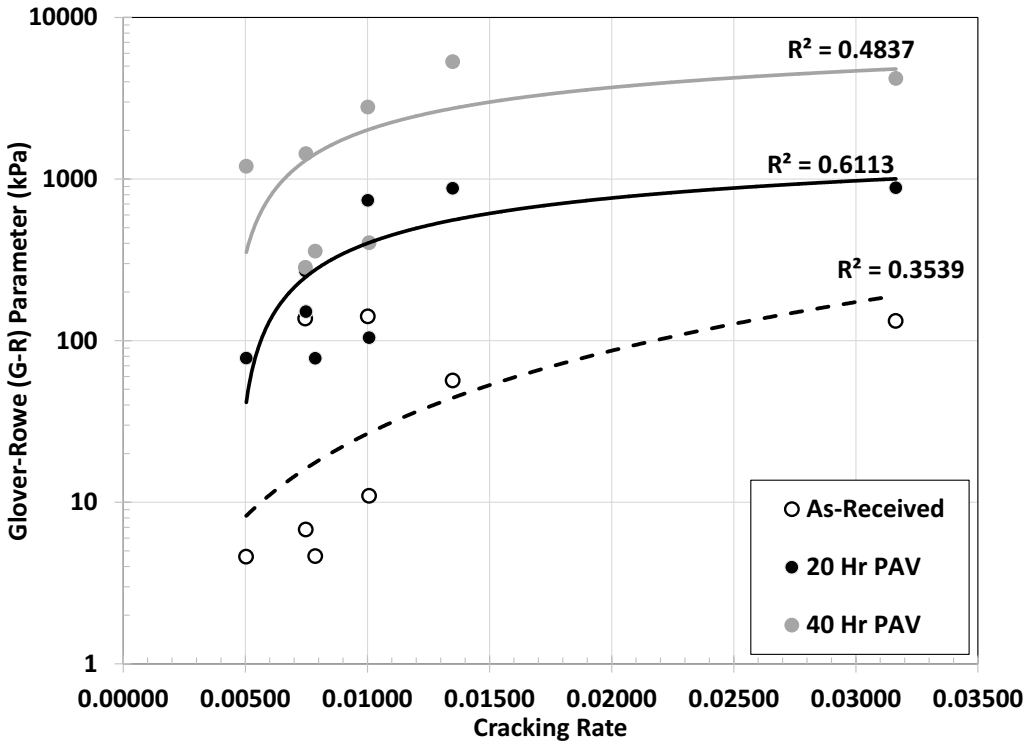
ΔT_C – ALF Study



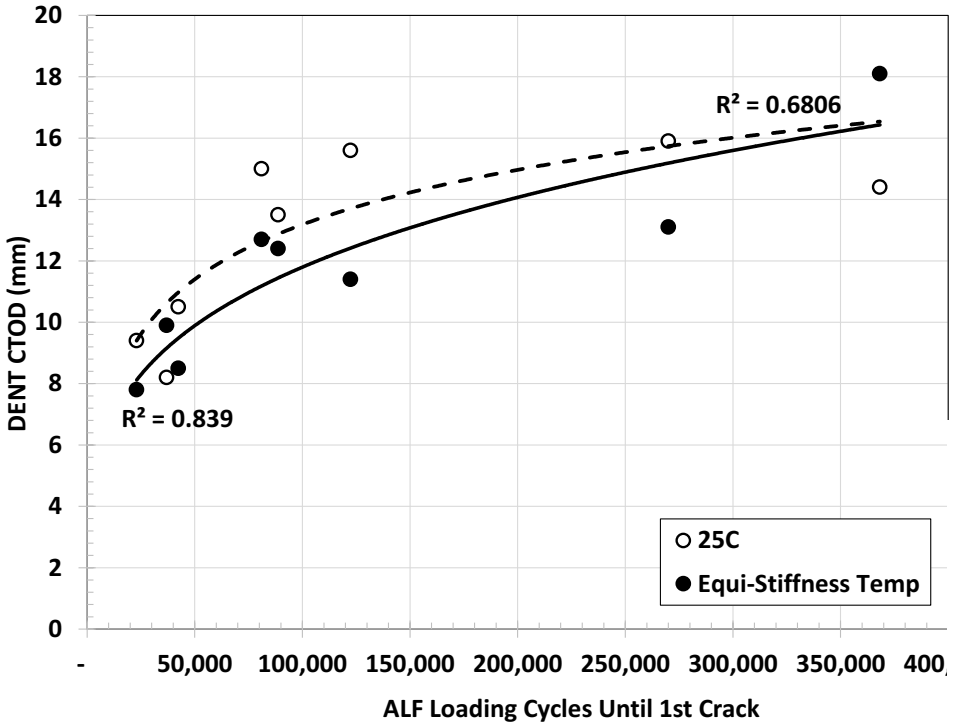


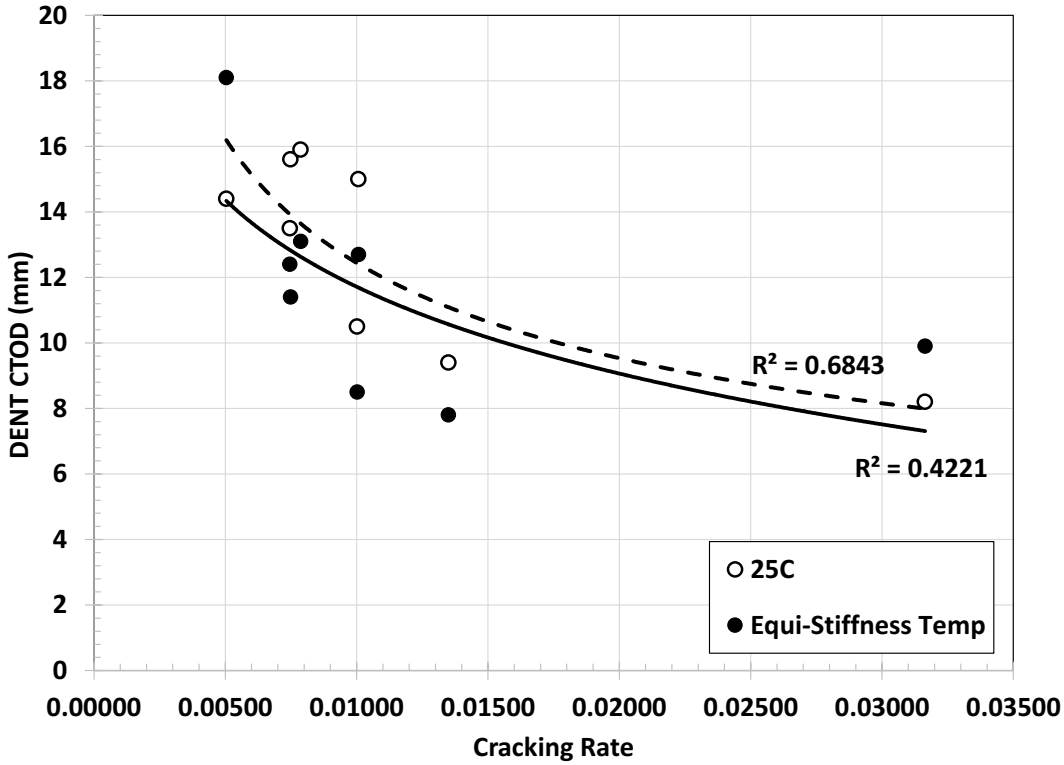
Glover-Rowe Parameter – ALF Study





DENT CTOD – ALF Study





FHWA ALF Asphalt Binder Testing

- Glover-Rowe Parameter and DENT correlated best with Crack Initiation (Cycles to 1st Crack)
  - None of the tests correlated well with ALF Crack Rate
  - ΔT_C had moderate correlation – believe it was due to only 20 hour PAV, most likely needed 40 hours to differentiate binders with high recycle contents

Overall Asphalt Binder Test Methods

- The Glover-Rowe and DENT test methods appear to best capture the field fatigue performance of the asphalt mixtures
  - Glover-Rowe requires DSR
  - DENT requires ductilometer
- ΔT_C has potential but most likely requires 40 hr of PAV conditioning
- LAS and intermediate temperature grade did not correlate well to field performance

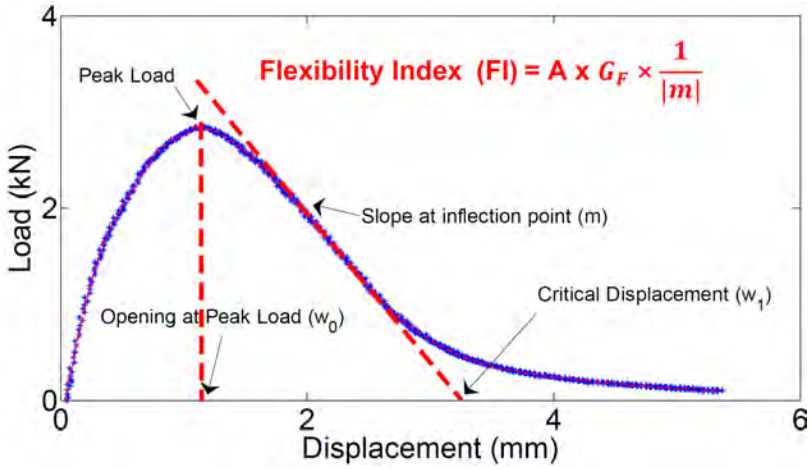
Asphalt Binder Test to Mixture Test Comparisons

Asphalt Binder to Mixture Comparison

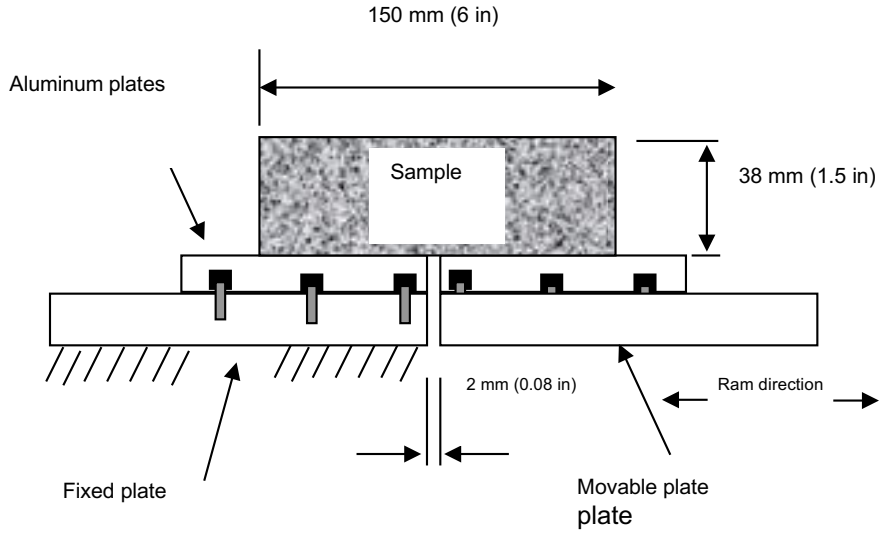
- Consistency in results are important to spec development
  - Binder and mixture test should tell the same story
- Test methods used were at standard conditions
  - No change in loading rate, etc.
- Binder and mixture tests conducted on material of same aged condition (extracted from field cores)
  - Laboratory conditioning methods required to conduct laboratory evaluation – discussed later
- Limitations
  - Testing conducted on limited binder type
  - Testing conducted on limited specimen type (i.e. – field core)

Semi-circular Bend (SCB) Test

- Uses 3-point bending on a semi-circular asphalt sample
- Can use same equipment at AASHTO T283 (50 mm/min)
- Notch cut to initiate cracking
- Test evaluates the energy required to fracture the specimen and propagate a crack at the notch
  - Work of Fracture
- Additional analysis was used to calculate the Flexibility Index (FI)
  - Post peak response



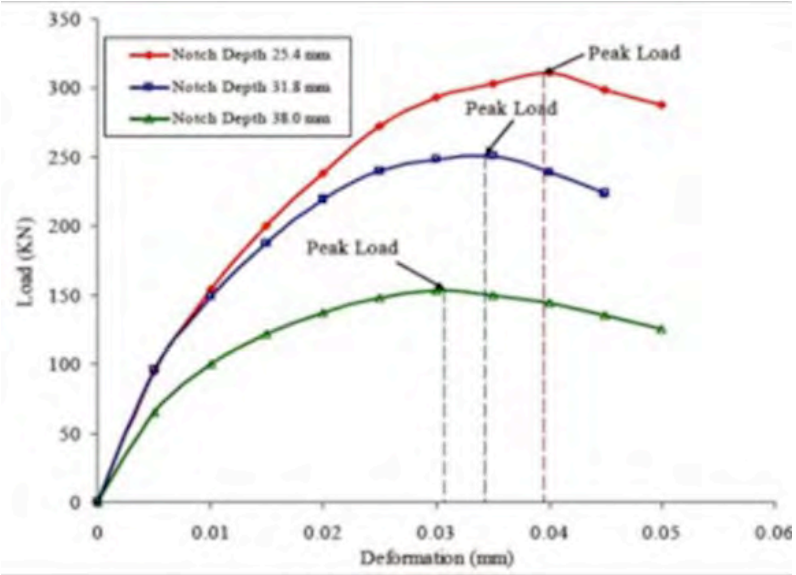
Overlay Tester

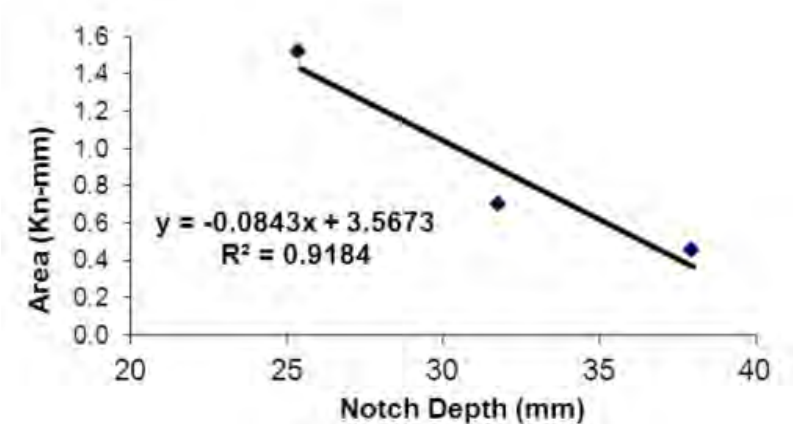


- Sample size: 6" long by 3" wide by 1.5" high
- Loading: Continuously triangular displacement 5 sec loading and 5 sec unloading
- Definition of failure
  - Discontinuity in Load vs Displacement curve

SCB – LTRC Method

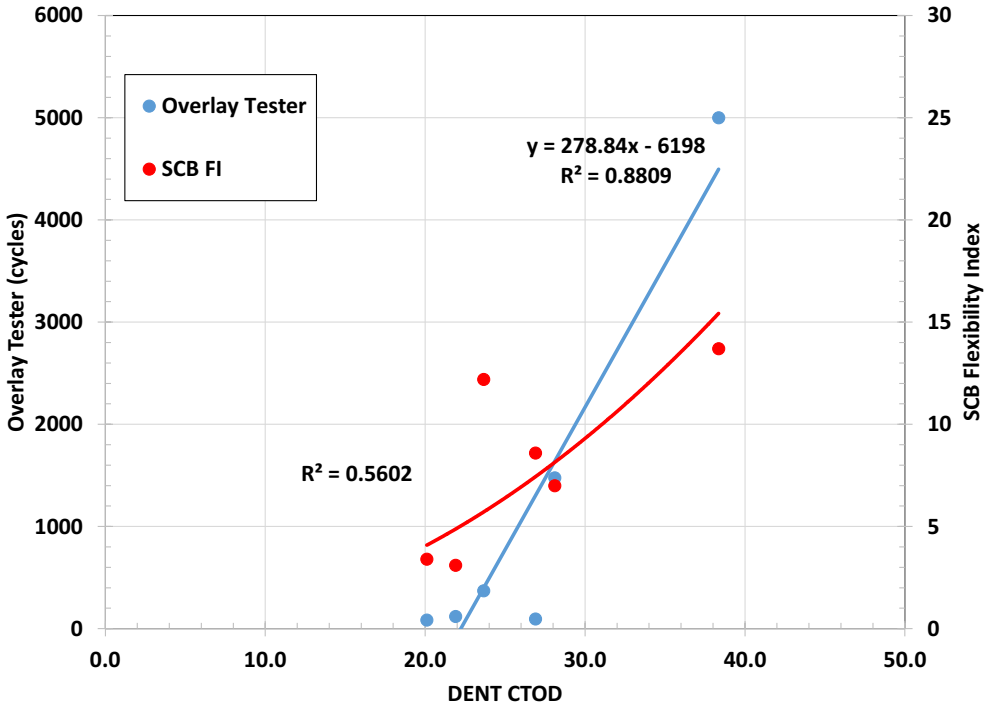
- Semi-circulate test specimen
- Test measures the potential energy at failure for 3 notch depths
- Potential energy plotted vs notch depth to compute Critical Strain Energy (J_c)
- Deformation rate of 0.5 mm/min

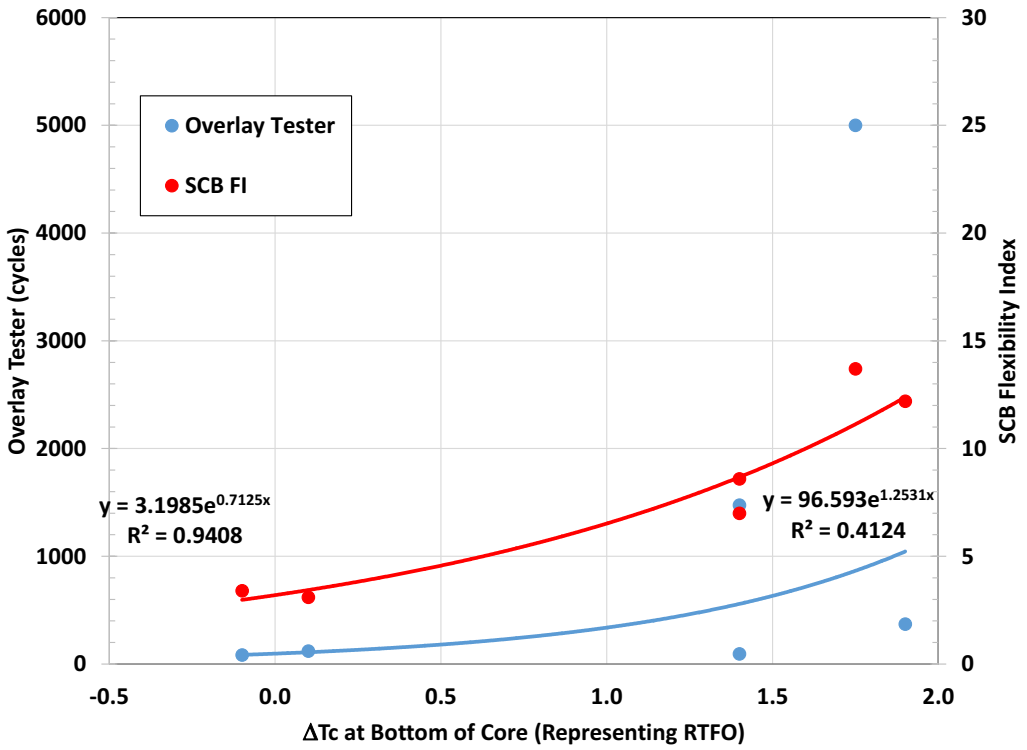




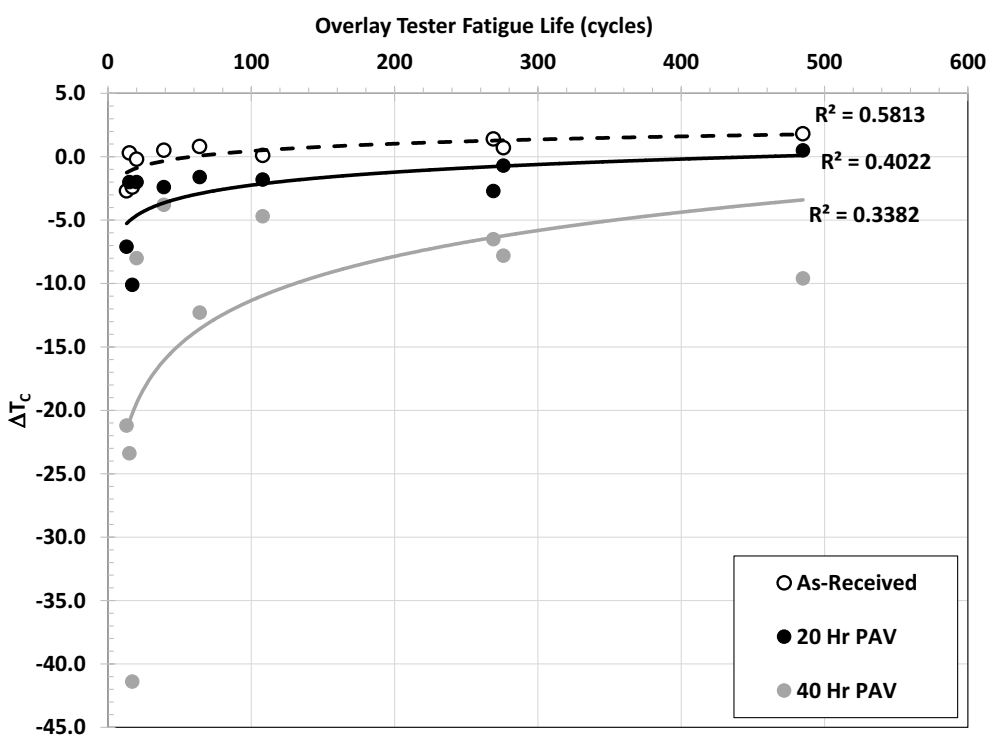
Asphalt Binder Test to Mixture Test Comparisons – PANYNJ Airfields

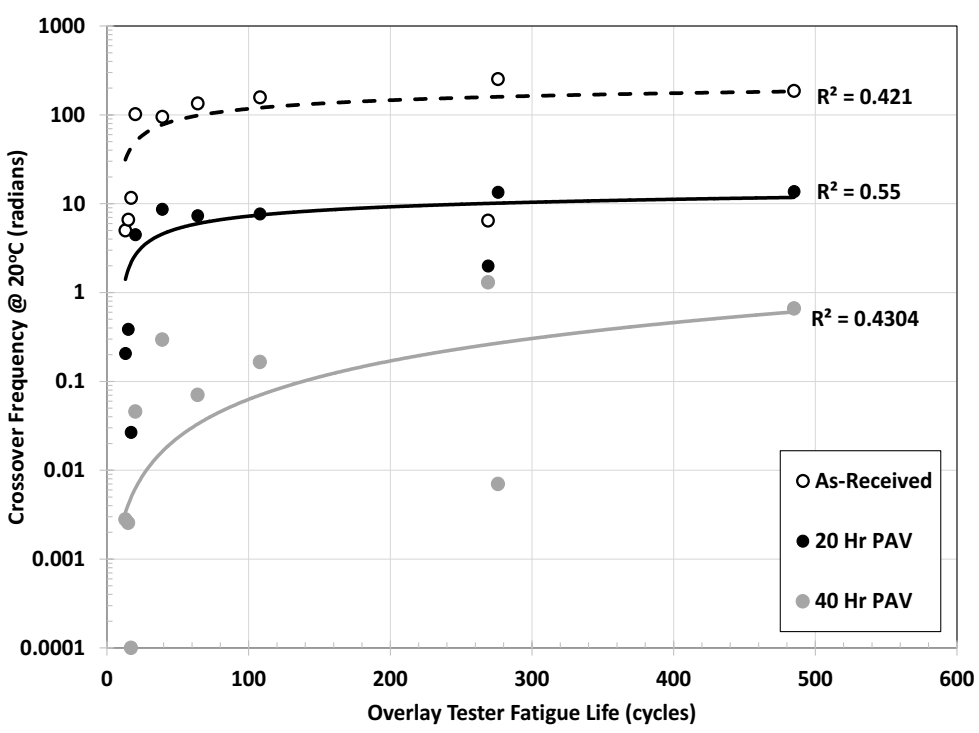
PANYNJ – Binder to Mixture

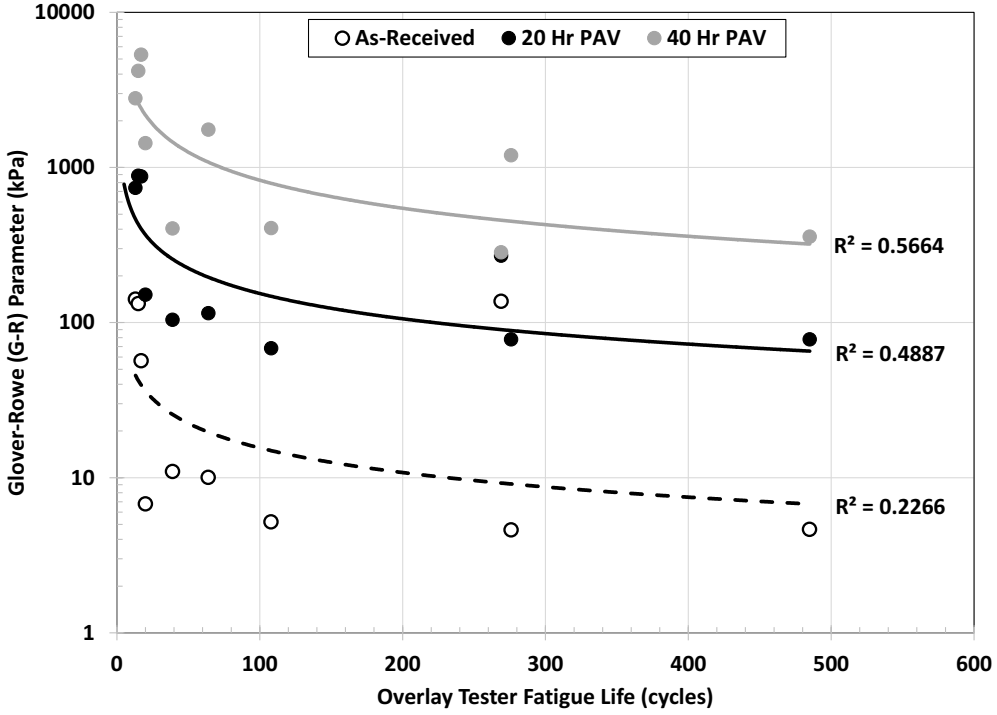


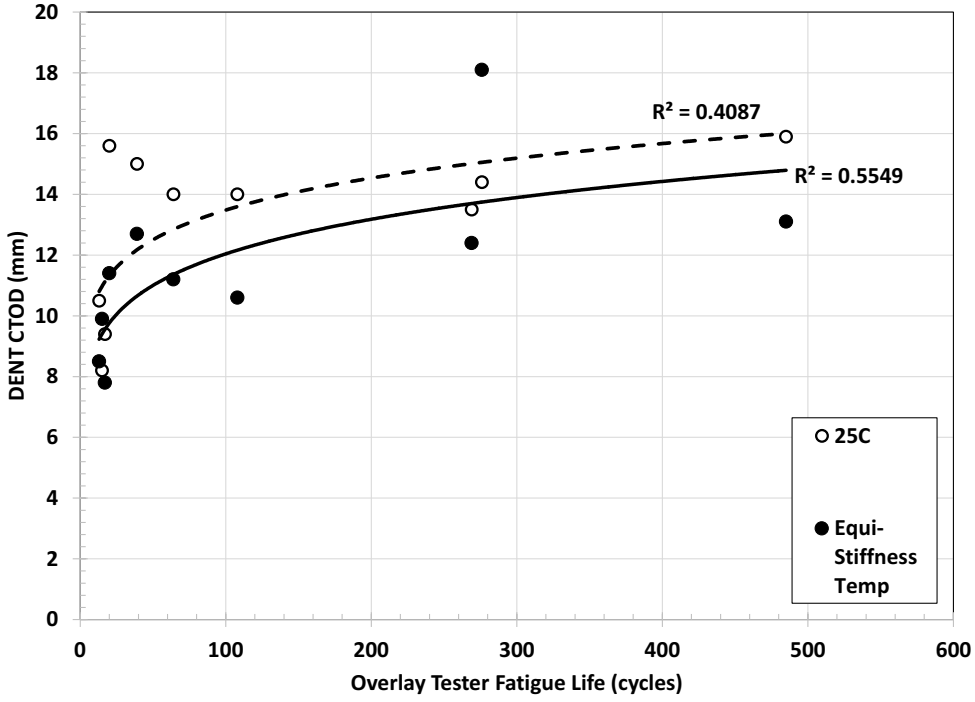


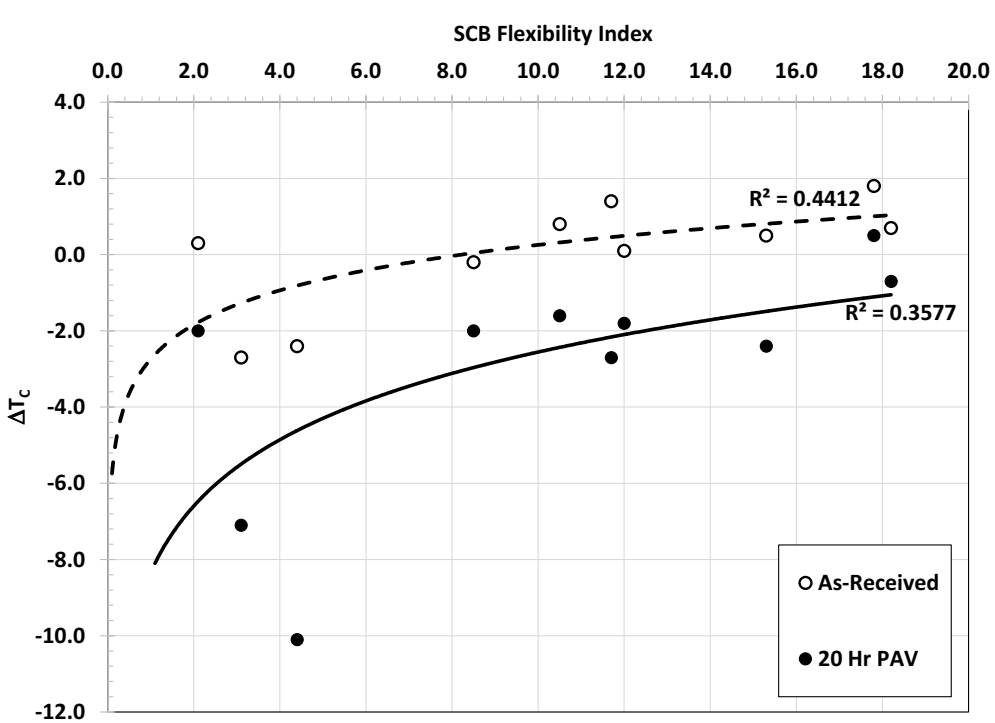
Asphalt Binder Test to Mixture Test Comparisons – FHWA ALF

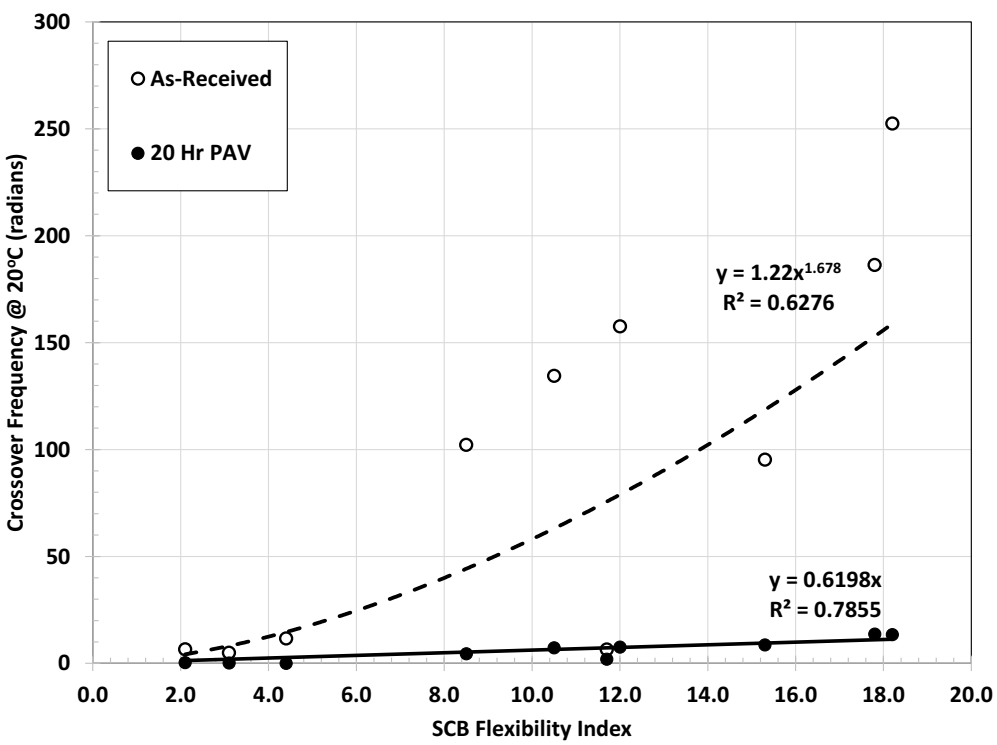

Overlay Tester Fatigue Life (cycles)
0
100
200
300
400
500
600
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
ΔTc
R² = 0.5813
R² = 0.4022
R² = 0.3382
As-Received
20 Hr PAV
40 Hr PAV

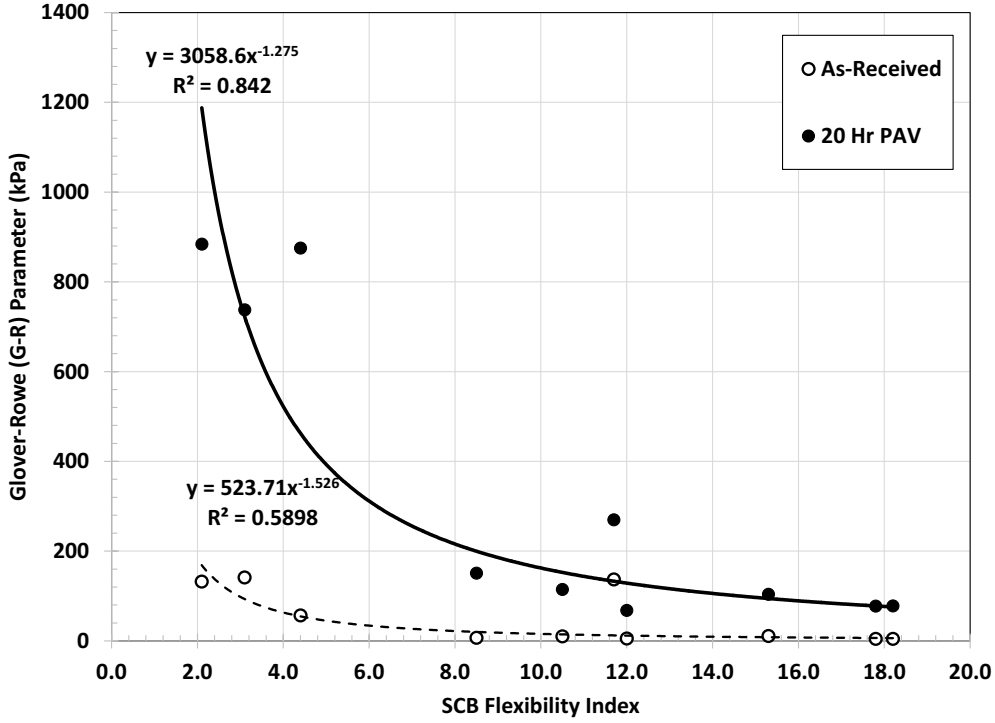

1000
100
10
1
0.1
0.01
0.001
0.0001
Crossover Frequency @ 20°C (radians)
R² = 0.421
R² = 0.55
R² = 0.4304
As-Received
20 Hr PAV
40 Hr PAV
0
100
200
300
400
500
600
Overlay Tester Fatigue Life (cycles)

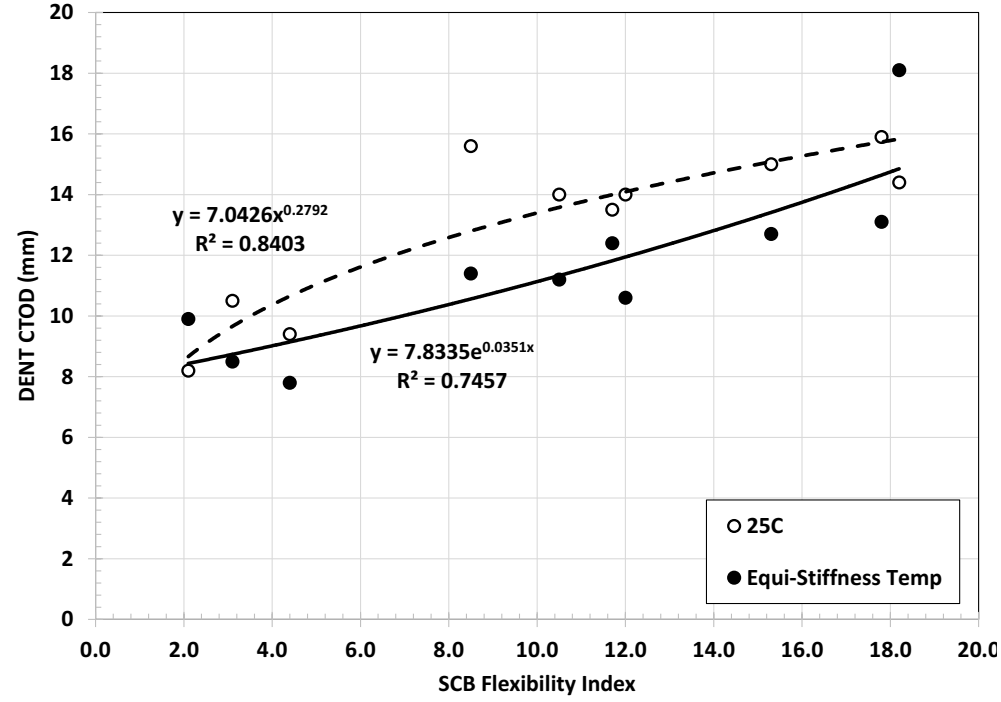

10000
1000
100
10
1
Glover-Rowe (G-R) Parameter (kPa)
As-Received
20 Hr PAV
40 Hr PAV
R² = 0.5664
R² = 0.4887
R² = 0.2266
0
100
200
300
400
500
600
Overlay Tester Fatigue Life (cycles)

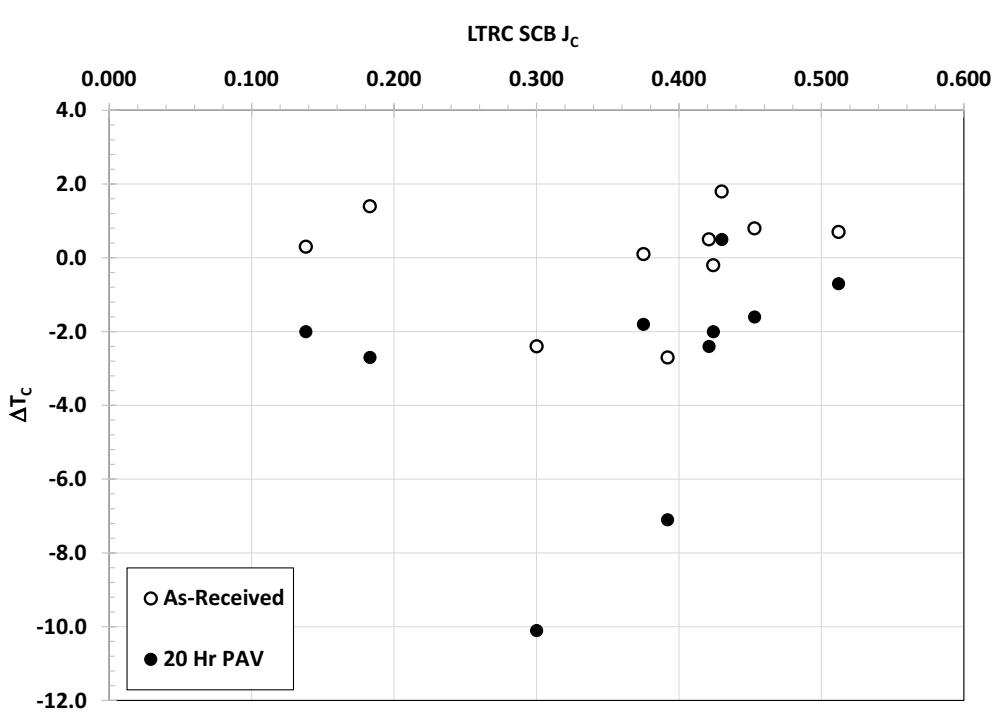

20
18
16
14
12
10
8
6
4
2
0
DENT CTOD (mm)
R² = 0.4087
R² = 0.5549
25C
Equi-Stiffness Temp
0
100
200
300
400
500
600
Overlay Tester Fatigue Life (cycles)

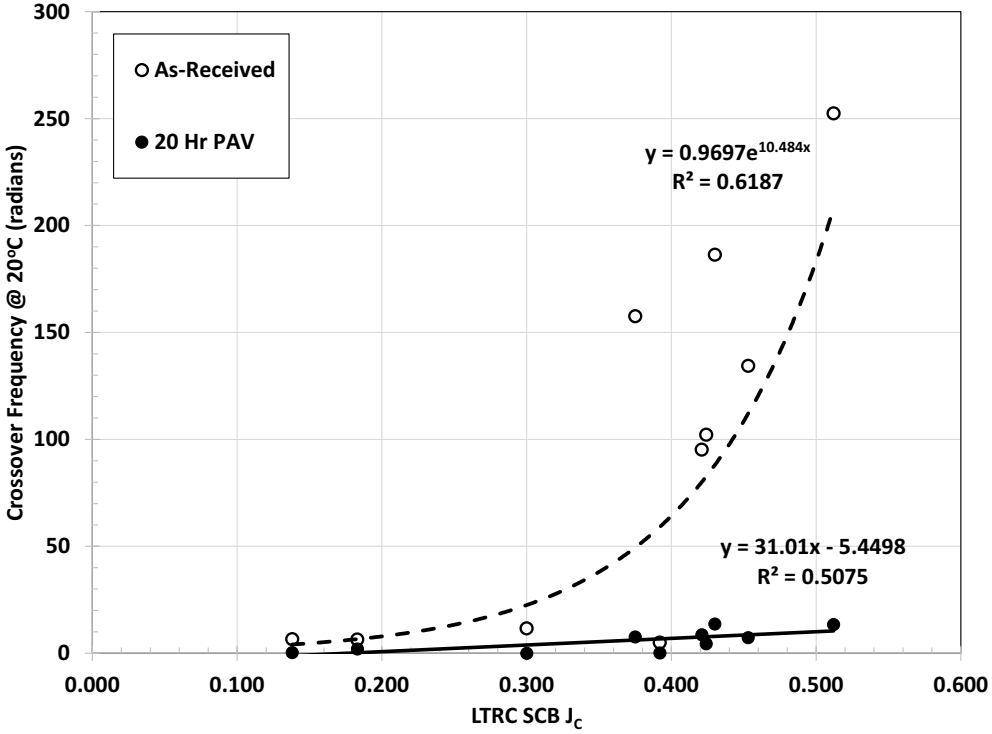

SCB Flexibility Index
ΔTc
R² = 0.4412
R² = 0.3577
As-Received
20 Hr PAV

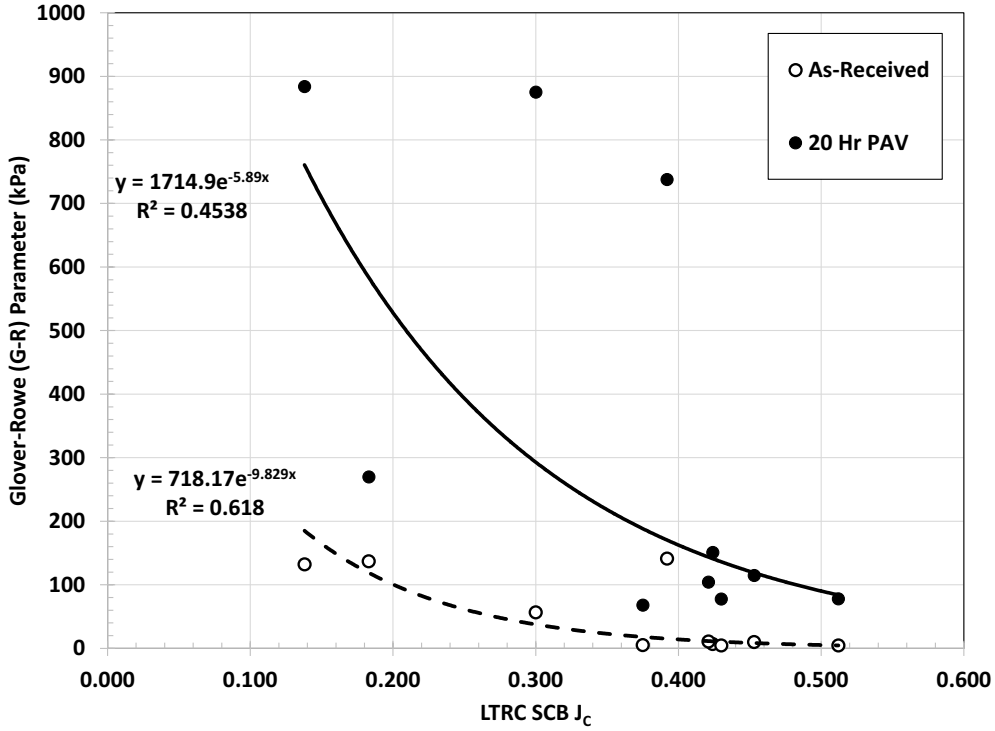

Crossover Frequency @ 20°C (radians)
y = 1.22x^1.678
R² = 0.6276
y = 0.6198x
R² = 0.7855
As-Received
20 Hr PAV
SCB Flexibility Index

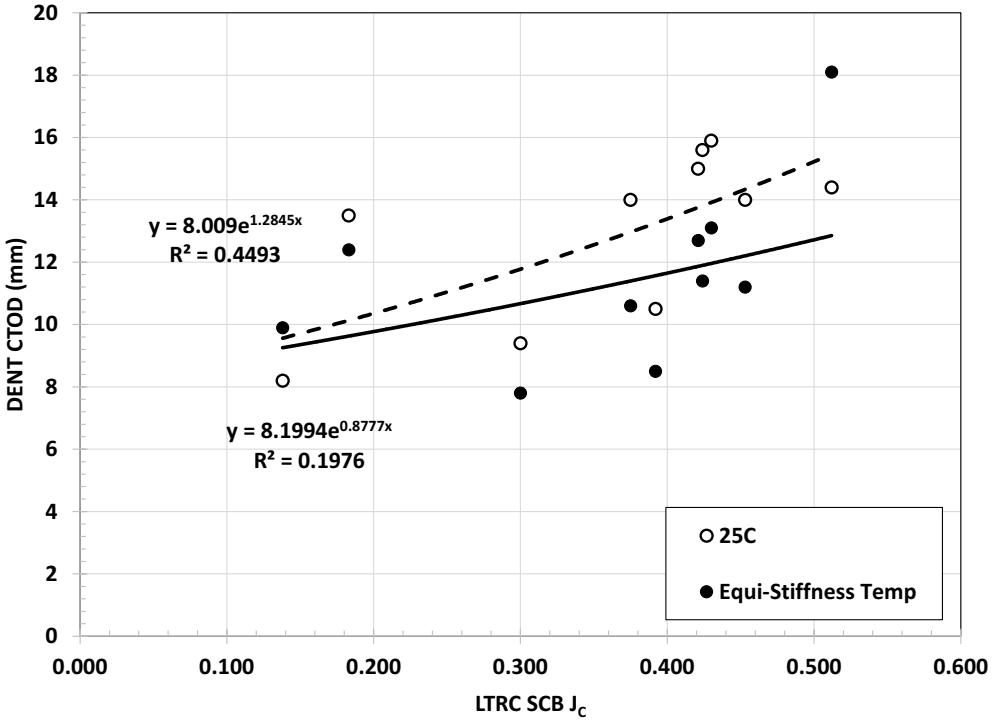

Glover-Rowe (G-R) Parameter (kPa)
y = 3058.6x^-1.275
R² = 0.842
y = 523.71x^-1.526
R² = 0.5898
As-Received
20 Hr PAV
SCB Flexibility Index


DENT CTOD (mm)
y = 7.0426x^0.2792
R² = 0.8403
y = 7.8335e^0.0351x
R² = 0.7457
25C
Equi-Stiffness Temp
SCB Flexibility Index


LTRC SCB J_c
0.000
0.100
0.200
0.300
0.400
0.500
0.600
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
ΔT_c
As-Received
20 Hr PAV


300
250
200
150
100
50
0
Crossover Frequency @ 20°C (radians)
As-Received
20 Hr PAV
$y = 0.9697e^{10.484x}$
$R^2 = 0.6187$
$y = 31.01x - 5.4498$
$R^2 = 0.5075$
0.000
0.100
0.200
0.300
0.400
0.500
0.600
LTRC SCB J_c


1000
900
800
700
600
500
400
300
200
100
0
Glover-Rowe (G-R) Parameter (kPa)
As-Received
20 Hr PAV
$y = 1714.9e^{-5.89x}$
$R^2 = 0.4538$
$y = 718.17e^{-9.829x}$
$R^2 = 0.618$
0.000
0.100
0.200
0.300
0.400
0.500
0.600
LTRC SCB J_c


20
18
16
14
12
10
8
6
4
2
0
DENT CTOD (mm)
$y = 8.009e^{1.2845x}$
$R^2 = 0.4493$
$y = 8.1994e^{0.8777x}$
$R^2 = 0.1976$
25C
Equi-Stiffness Temp
0.000
0.100
0.200
0.300
0.400
0.500
0.600
LTRC SCB J_c

Asphalt Binder & Mixture Test Correlations

- The SCB Flexibility Index correlated well with
  - Glover-Rowe
  - DENT
- The Overlay Tester had an average correlation with
  - DENT
- The LTRC SCB had an average correlation with
  - Glover-Rowe

Field Trial Results

MIXTURE TESTING

- SCB Flexibility Index
- Overlay Tester

BINDER TESTING

- Glover-Rowe
- DENT

Field Trial Results

MIXTURE TESTING

- SCB Flexibility Index
- Overlay Tester

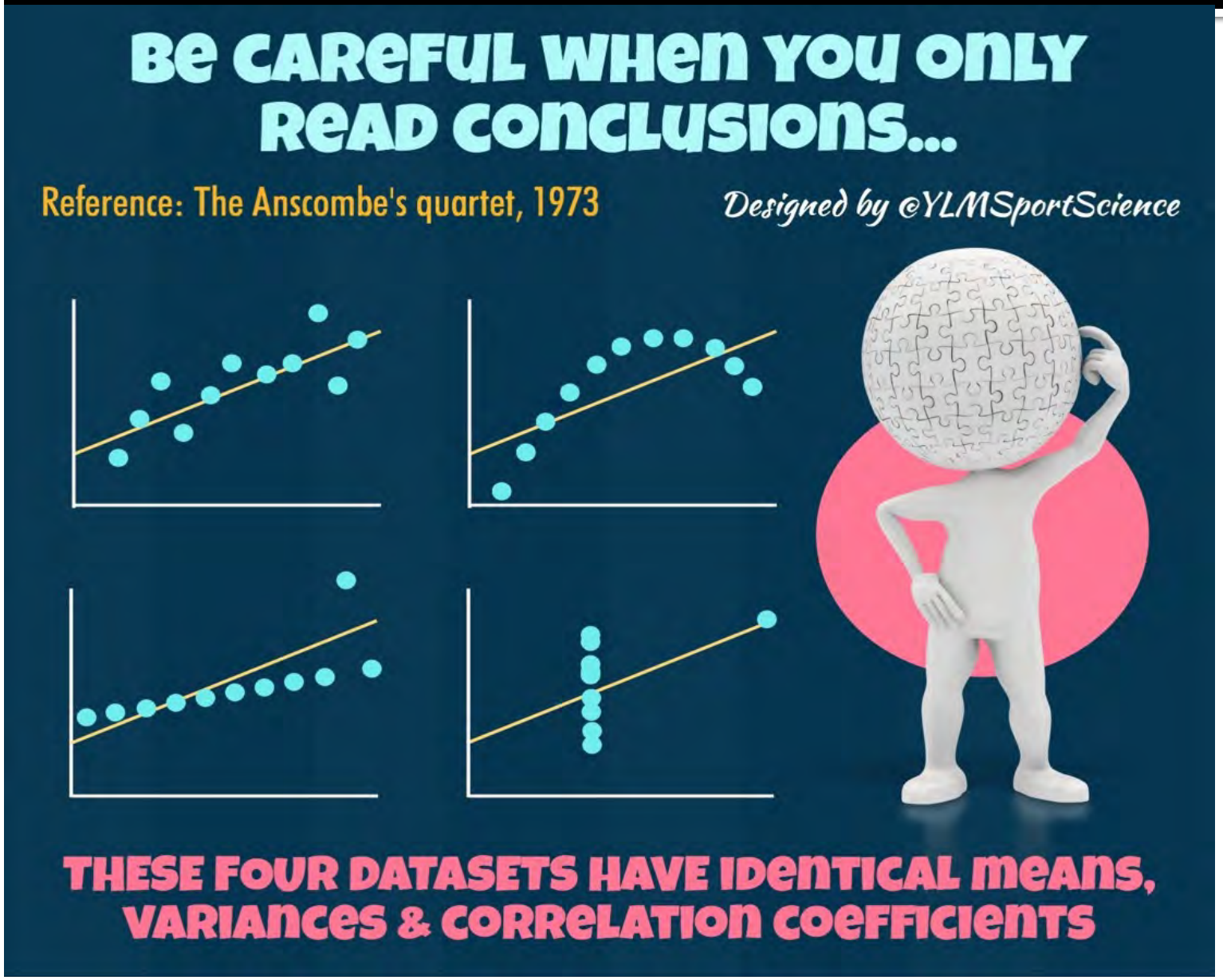
BINDER TESTING

- Glover-Rowe
- DENT

Conclusions

- Field studies conducted to compare asphalt binder and mixture tests to field performance
  - Is there an asphalt binder test that relates to field fatigue cracking performance?
  - How do mixture tests compare?
- Two large field studies indicated that Glover-Rowe and DENT test show promise as asphalt binder tests
  - NCHRP 9-59 also looking at DENT
- Practical issues to consider
  - DENT requires more binder & separate piece of equipment
  - Both tests need further development to determine thresholds for cracking performance

Thank you for your time!
Questions?



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