Methodology to Improve the Selection of Asphalt Binders to Minimize Fatigue Cracking Issues
- Wisconsin DOT Study -

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WHRP

abatech
consulting engineers

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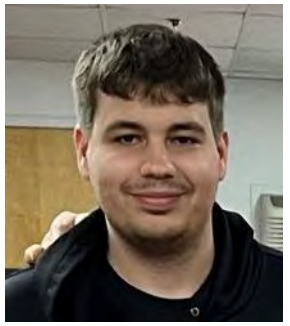
Chris Ericson



Jake Tulanowski

Ultimate Goal – Improved Asphalt Binder Specifications for Fatigue Cracking (Anderson, 2023)

PAV Aging Temperature (°C)	100						100 (110)					
Dynamic Shear, T315 $G^*(\cos\delta)^2/\sin\delta^2$, 10 rad/s, at intermediate temp [a] **< 5,000 kPa (< 8,000 kPa)**	29	27	25	22	19	17	29	27	25	22	19	17
Creep Stiffness, T313 Stiffness < 300 Mpa m-value > 0.300 at 60 sec & low temp	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30
Creep Stiffness, T313 R=log(2)log(S/3000)/log(1-m) at 60 sec & low temp min < R < max	**1.50 < R < 2.50** **1.50 < R < 3.20**											
ΔTc Tc,S - Tc,m	**≥ -2.0** [b] **≥ -3.0** [c]											
ΔTf [b] Tc,S - Tcr	**≥ +8.5** **≥ +4.5**											

[a] - Based on low temperature PG requirement of area (NCHRP 9-59)

[b] - Only determine ΔTf when -6 ≤ ΔTc ≤ -2.0; [c] - Only determine ΔTf when -7.0 ≤ ΔTc ≤ -3.0

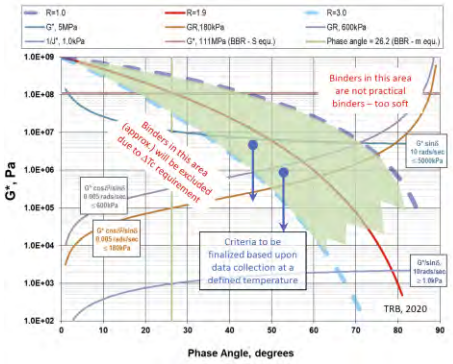
Performance-related Specification Development

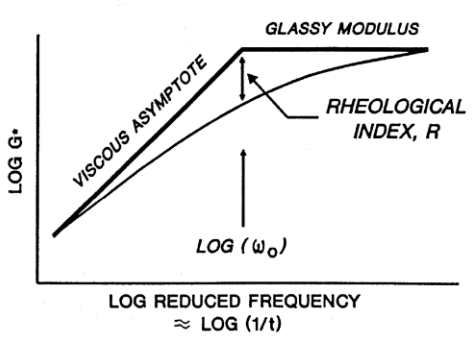
- What is the distress type?
  - Durability? Thermal?
  - *Improved overall fatigue performance…*
- What is the appropriate intermediate test temperature to use?
  - a) Current PG grade averaging approach? b) NCHRP 9-59?
- What are you comparing binder performance to?
  - Field performance?
  - *Mixture performance…*
- Ease of inclusion in existing specification system?
  - New equipment? Additional testing? Additional quantity of material?
- Consistency in conditioning/aging? (i.e. – Binder vs Mix)
- Impact on existing asphalt binder supply?
- Impact on allowable recycled asphalt?

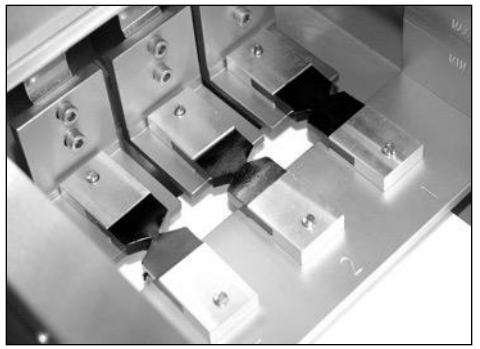
Asphalt Binder Testing

Asphalt Binder Testing

- Binder testing included;
  - PG grading (high, intermediate & Low PG)
  - Master curves
    - Rheological Properties
      - Point Parameter (location in Black Space based on "hardness" of asphalt binder)
        - "Where you are" – Mike Anderson
      - Shape Parameter (how the Point parameter will change under varying temperatures and loading rates)
        - "Where you are going" – Mike Anderson
  - Fracture testing
    - Double Edge Notched Tension (DENT) & ABCD





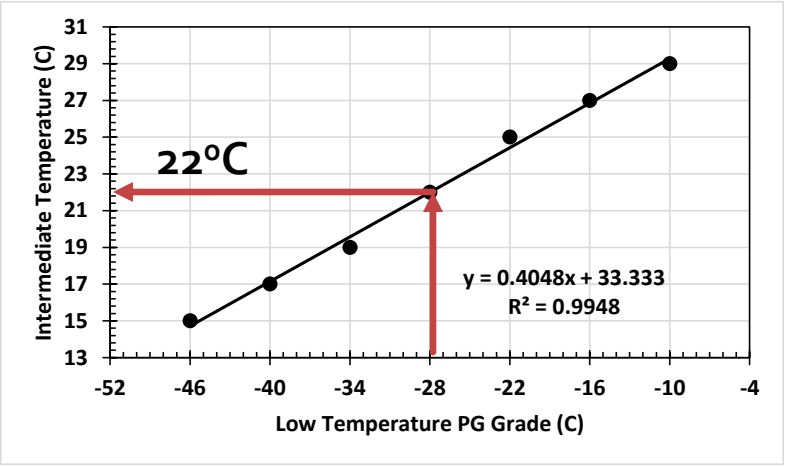


Final Selection of Intermediate Test Temperatures

- For ease, previous intermediate test temperatures were a function of PG grade
  - Ex.: PG58-28
    - Averaging high and low PG temps may not necessarily meet realistic "intermediate" temperature
    - Confusion with "grade bumping"
- NCHRP 9-59 recommended using low temperature as a means for selecting intermediate temperature
  - Similar issue

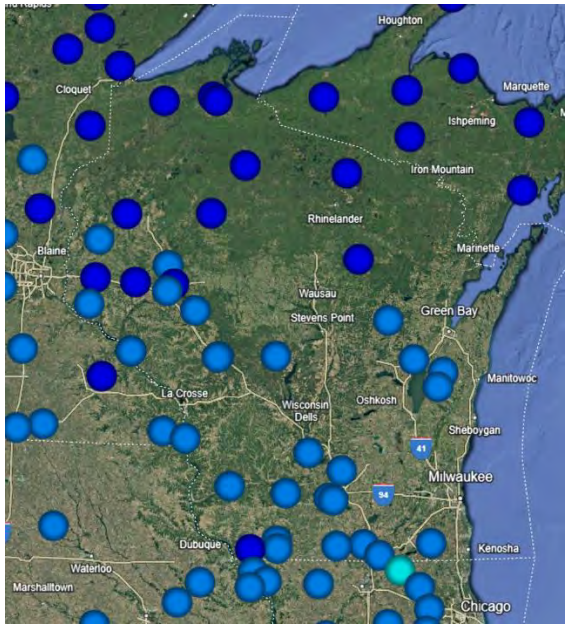
PG58-28

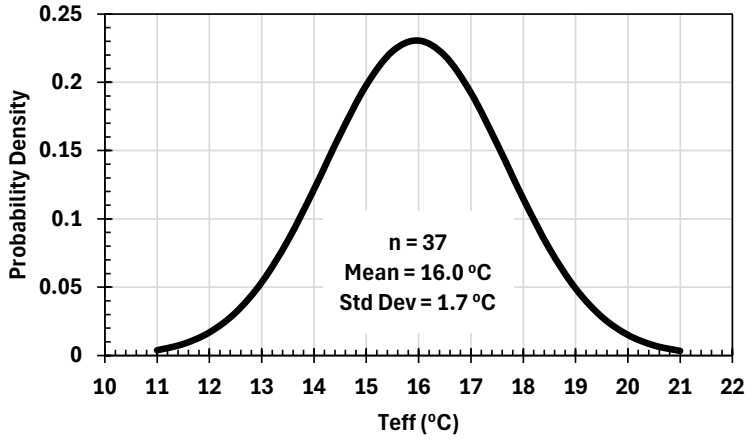
$$\frac{58+(-28)}{2} + 4 = \frac{30}{2} + 4 = 19°C$$



Final Selection of Intermediate Test Temperatures

- Recommend method developed in original SHRP work
  - Based on in-situ temperature in surface lift
  - Not a function of PG grade
  - Based on NOAA climatic databases across US
  - Approach follows that recommended by Rowe and Raposa (2023)





Reviewing the Wisconsin database compiled by Rowe and Raposa (2023), a total of 37 weather locations were collected for the analysis. The analysis resulted in the following;

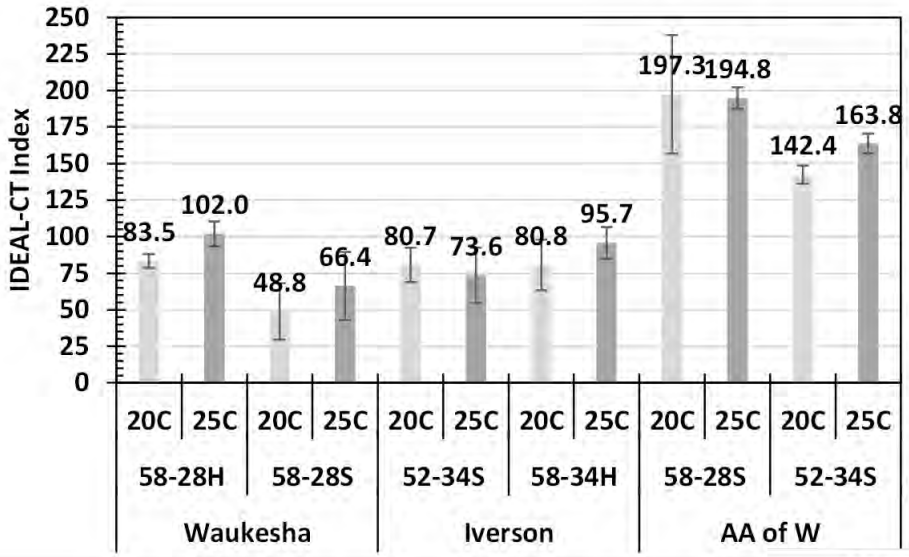
- Average *Teff (FC)* = 16.0°C
- Standard Deviation *Teff (FC)* = 1.7°C
- 98% Confidence Lower Bound *Teff (FC)* = 15.3°C

Performance Comparison

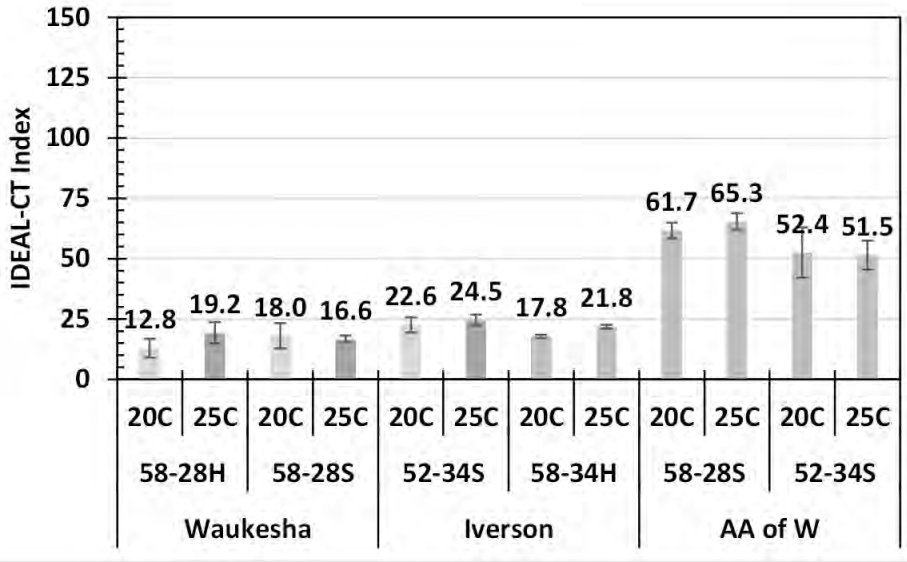
Performance Comparison

- Field performance not available for comparison
  - Would require collection of field cores as well
- Mix performance used as performance comparison
  - IDEAL-CT Index value of 30.0 after WisDOT aging (6 hrs loose @ 135C)
- Included aging conditions less (2 hrs) and greater (10 hrs) to ensure asphalt binders of varying IDEAL-CT Index and aged condition
  - Recovered asphalt binders after IDEAL-CT Index testing for characterization
  - Utilized recovered binder to also develop a laboratory aging protocol to mirror the 6 hrs loose mix at 135C
    - Consistency between asphalt mixture and binder fatigue testing
- Incorporated Overlay Tester as a means to compare to a different fatigue cracking test
  - Monotonic vs cyclic

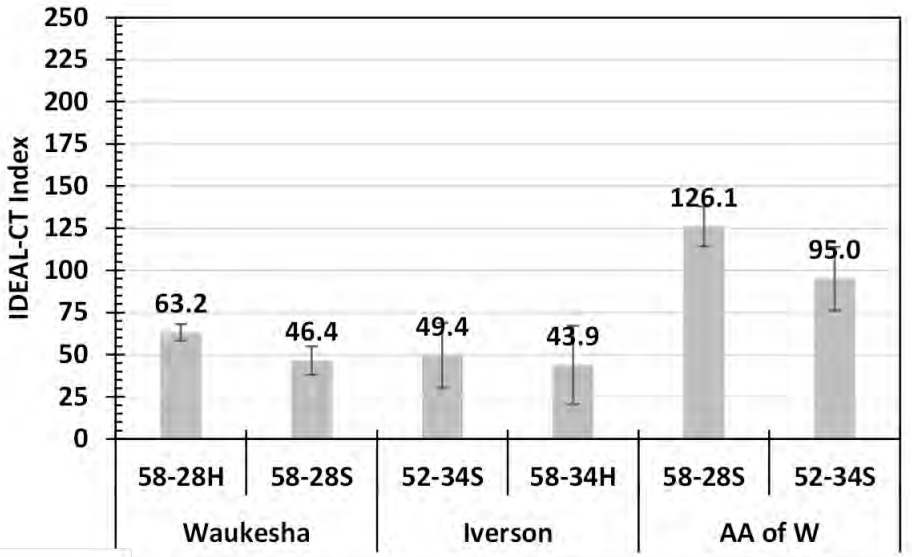
IDEAL-CT Index



2 Hrs Conditioning

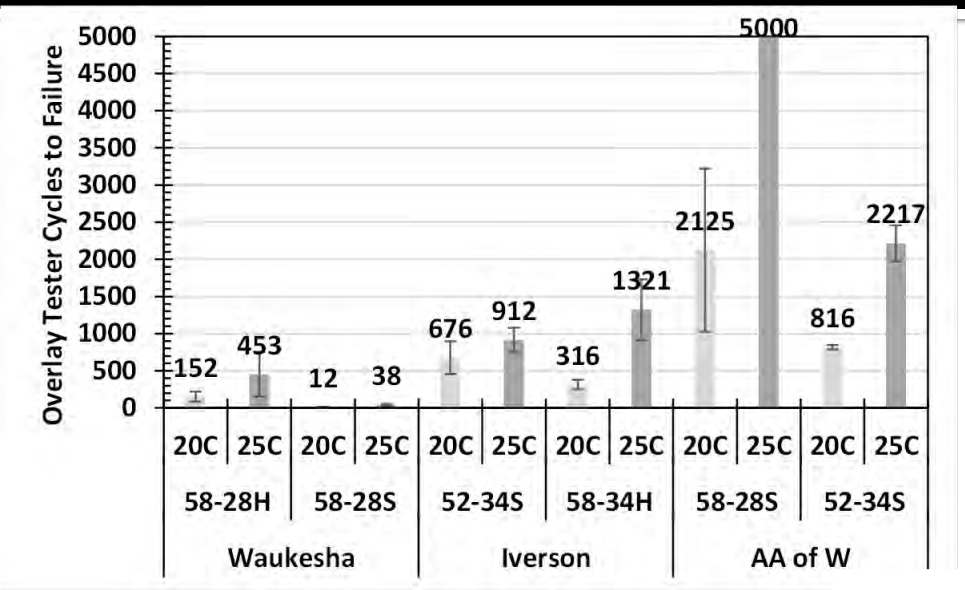


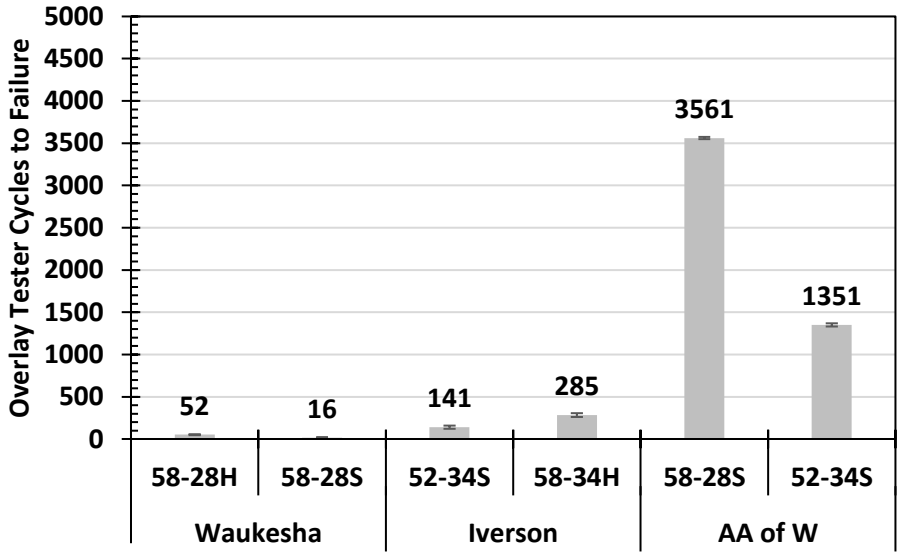
10 Hrs Conditioning

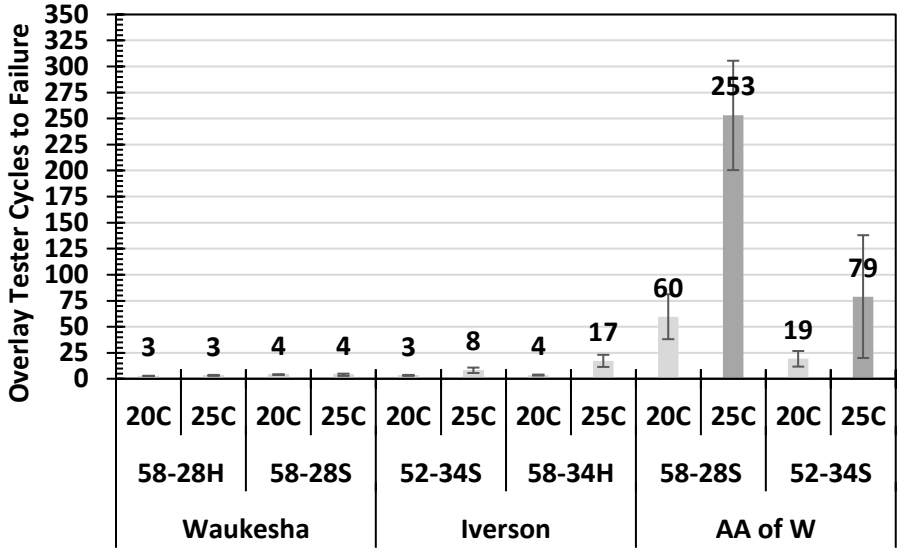


6 Hrs Conditioning

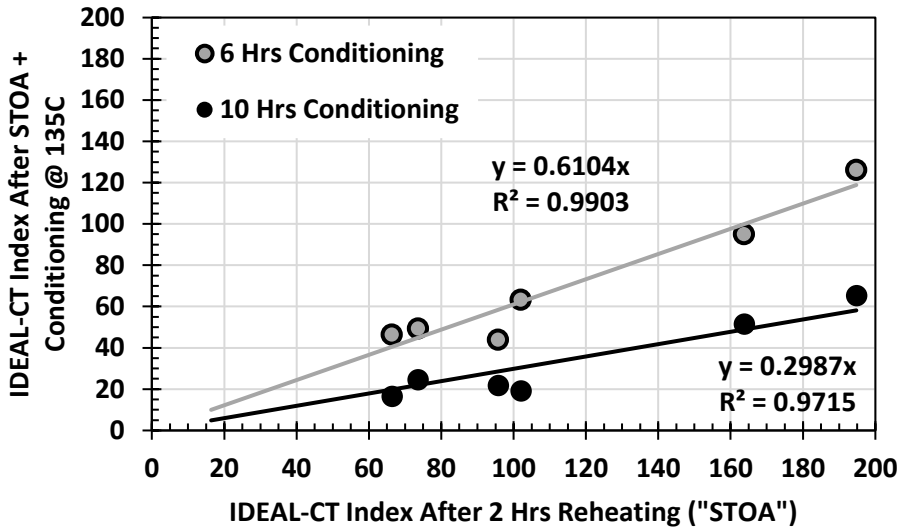
Overlay Tester Results

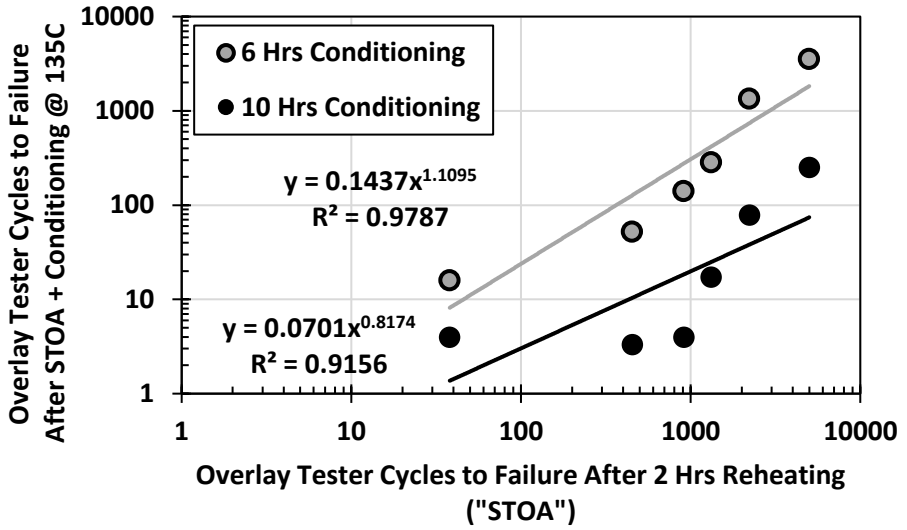


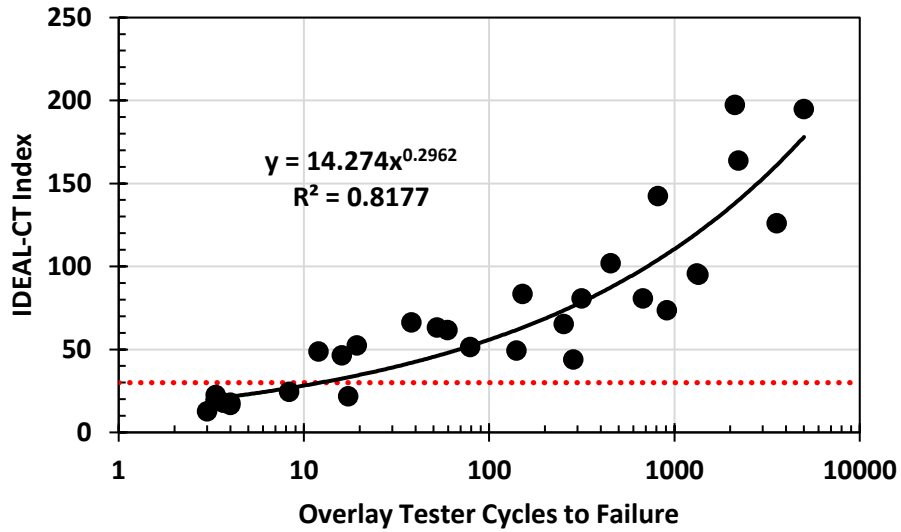




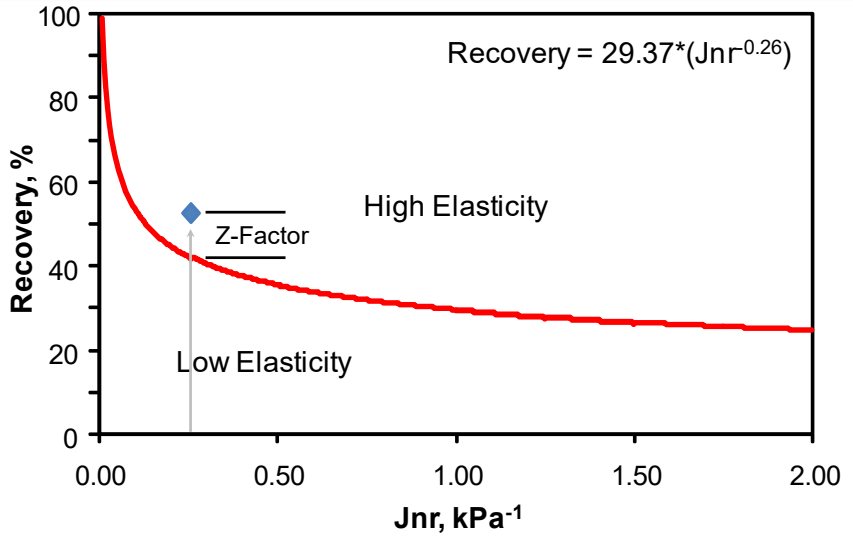
Mixture Testing with Aging







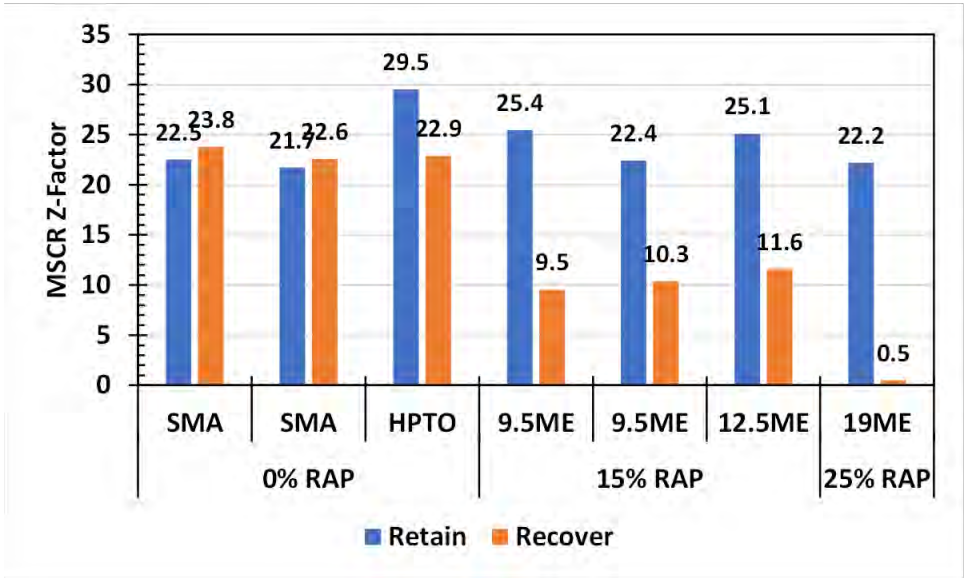
Asphalt Binder Recovery

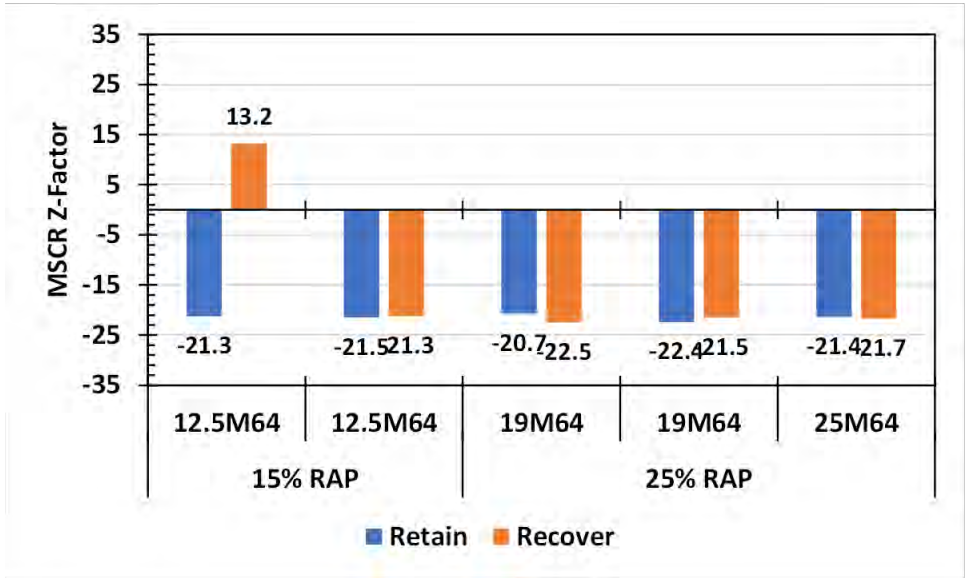


	Mix Designation	52C			58C		
		Jnr (1/kPa)	% Rec	Z-Factor	Jnr (1/kPa)	% Rec	Z-Factor
PMA	Iverson H Oil	0.28	43.2	2.3	0.83	29.4	-1.6
	Iverson S Oil	1.44	2.5	-24.3	3.64	0.2	-20.7
PMA	Waukesha H	0.14	43.9	-5.3	0.42	29.2	-7.7
	Waukesha S	0.09	37.9	-17.1	0.29	23.0	-17.9
PMA	American 2A	0.68	22.2	-10.3	1.91	10.8	-13.9
	American 2C	0.58	11.1	-22.8	1.68	2.9	-22.8

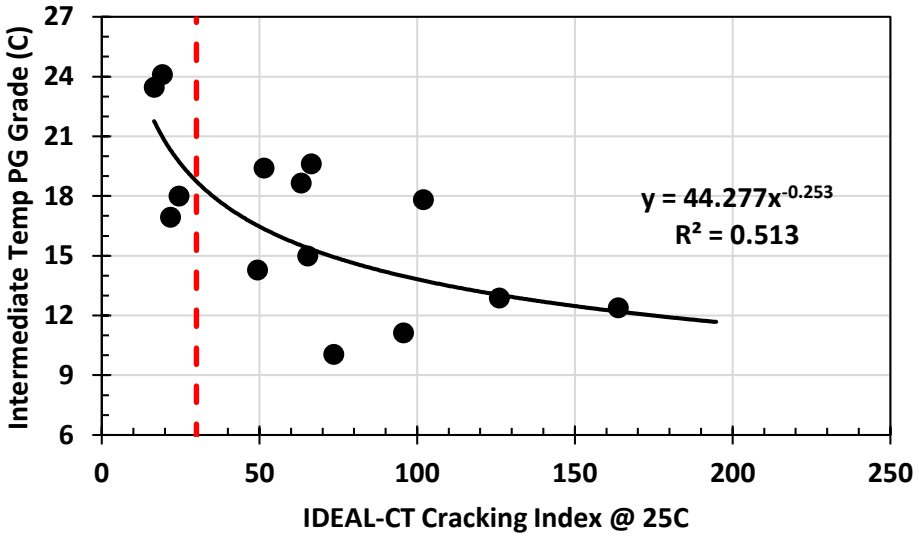
Specified vs Actual

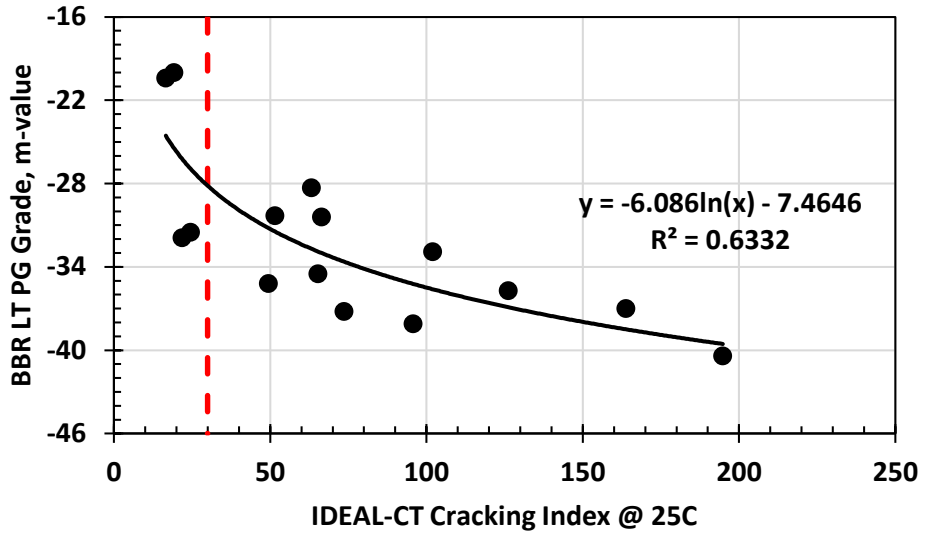
- Addition of RAP generally decreases elastomeric response
  - NJ binders – % Recovery drops approximately 1% for every 1% RAP included
    - Neat binders (64S-22) generally -20 to -22% on the Z-factor

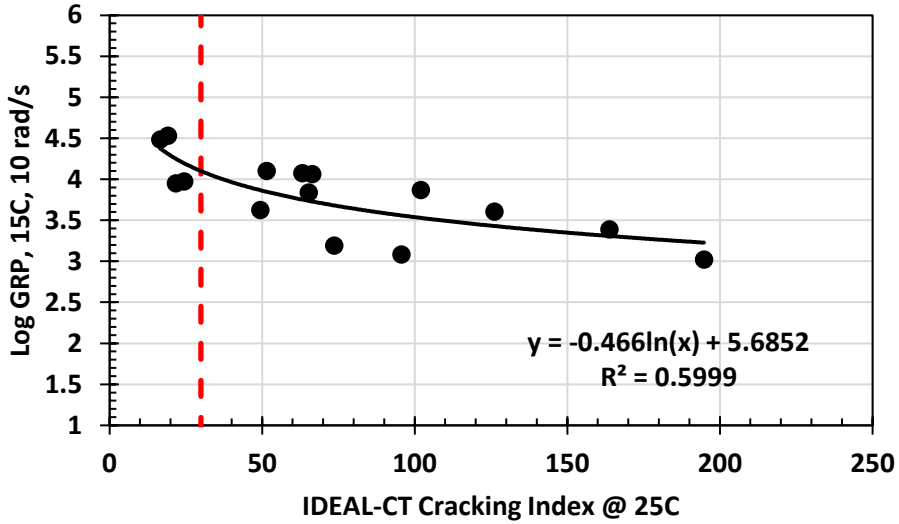




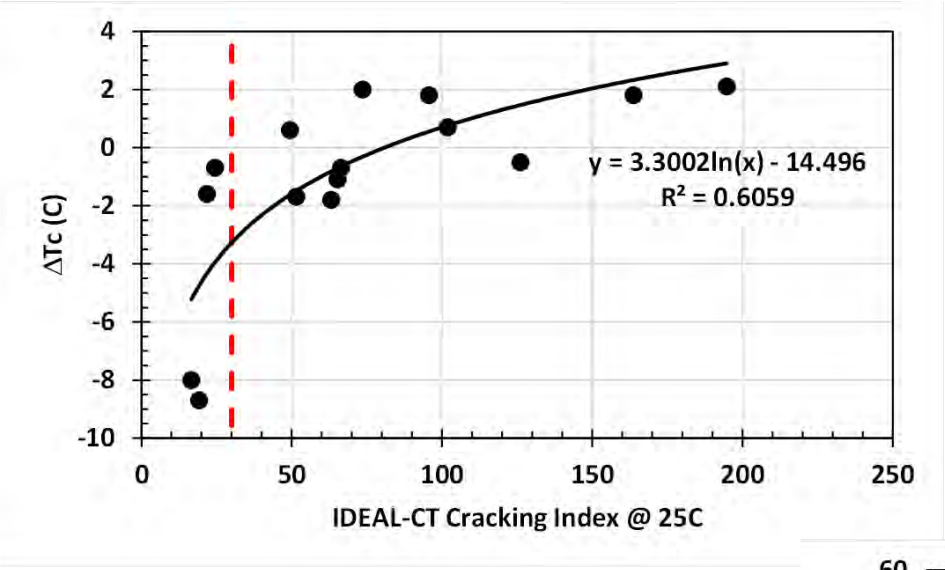
Point Parameters

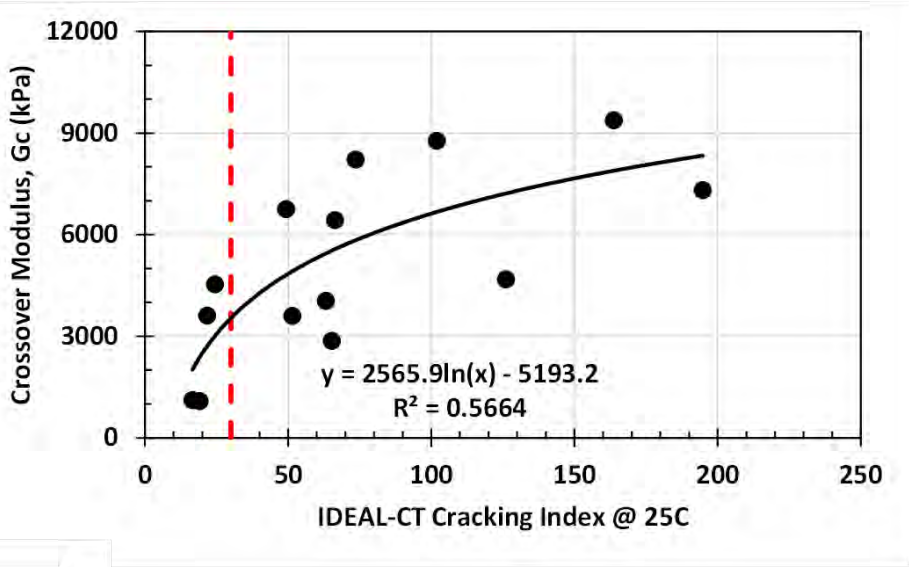


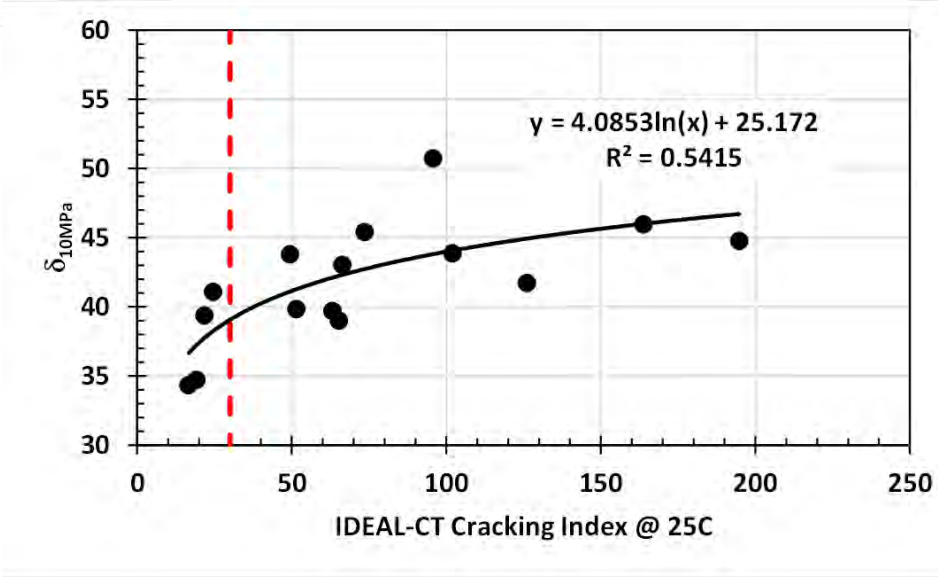




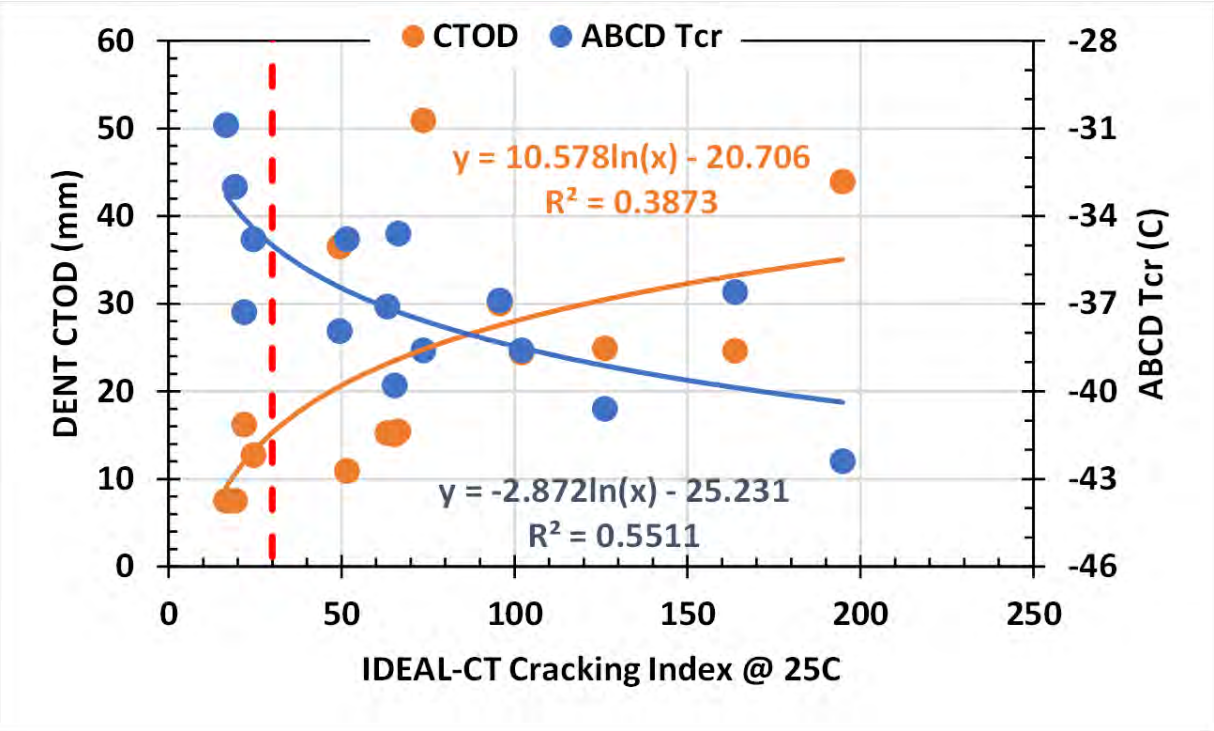
Shape Parameters

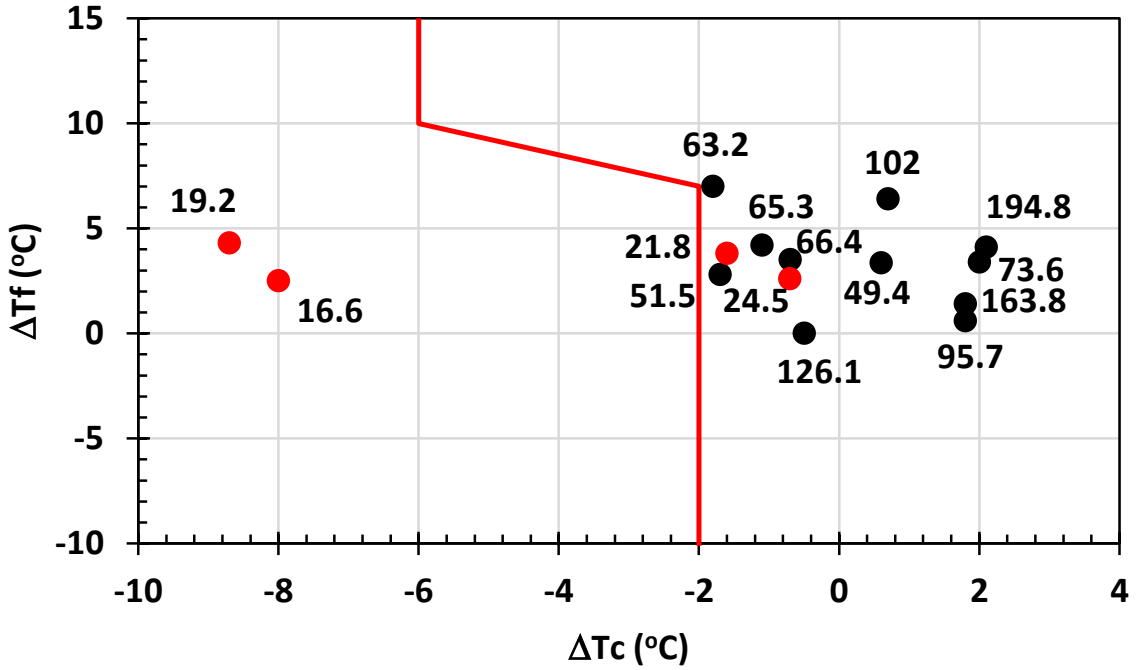






Fracture-based Parameters





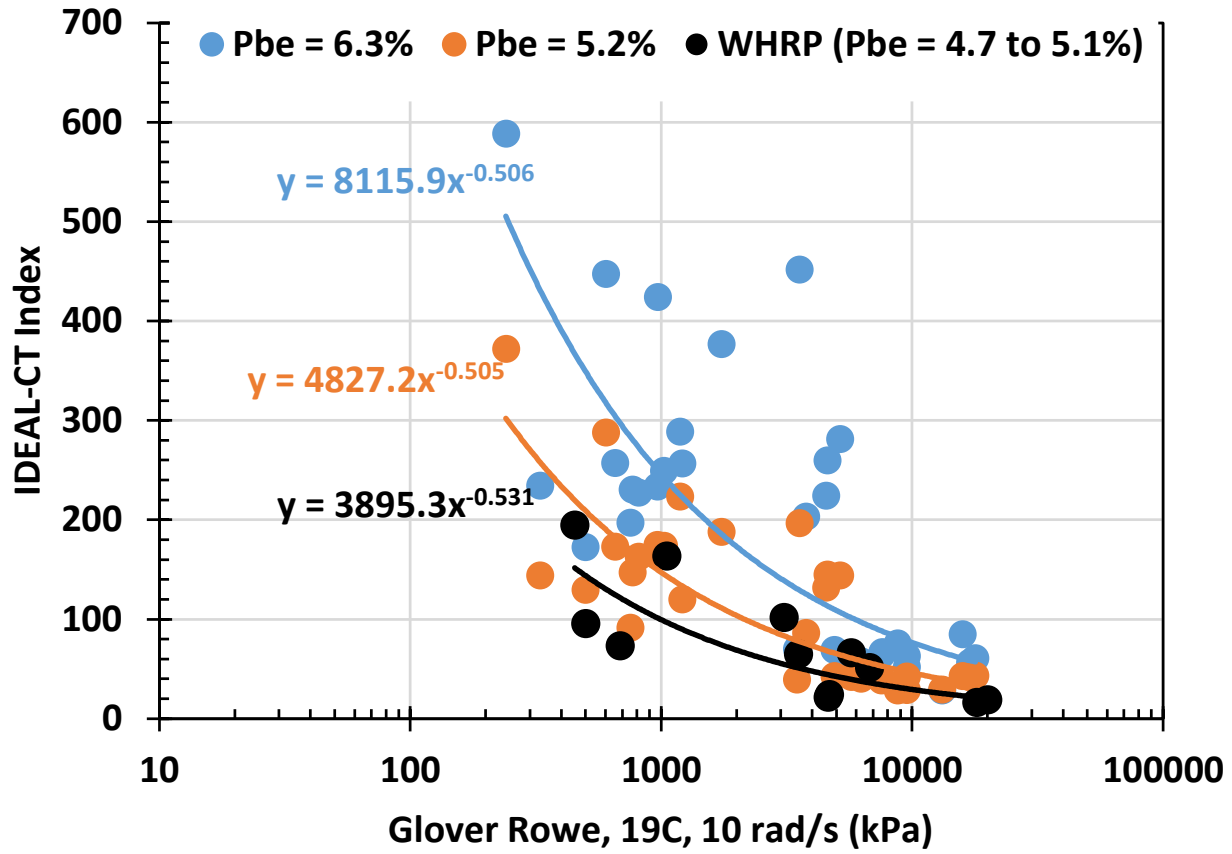
Final Parameter Selection

- Based on relationship to IDEAL-CT Cracking performance
  - Point Parameter: Glover Rowe Parameter ranked highest
  - Shape Parameter: ΔTc ranked highest
  - Fracture: ABCD Tcr ranked highest
  - Note: Asphalt Content also showed to correlate to IDEAL-CT Index
    - Indicates final cracking performance a function of binder property and how much of that binder in mix

Parameter Type	Binder Parameter	Correlation
Point Parameters	Log G-R kPa (10 rad., 15ºC)	-0.75
	Log G-R kPa (10 rad., 19ºC)	-0.74
	Log G-R kPa (10 rad., 22ºC)	-0.74
	Low Temp PG, m-value	-0.72
	(G* x sin(δ)) (10 rad)	-0.65
	CA ω0 25ºC ref Temp	0.53
	Log G-R G* (0.005 rad., 15ºC)	-0.50
Shape Parameters	ΔTc	0.65
	Log Gc	0.64
	δº (G*= 10 MPa)	0.62
	R value at 15ºC	-0.61
	δº (G*= 8.967 MPa)	0.59
Fracture Test	ABCD Tcr	-0.69
	CTOD (19ºC; 22ºC)	0.59
Asphalt Content (%)		0.57

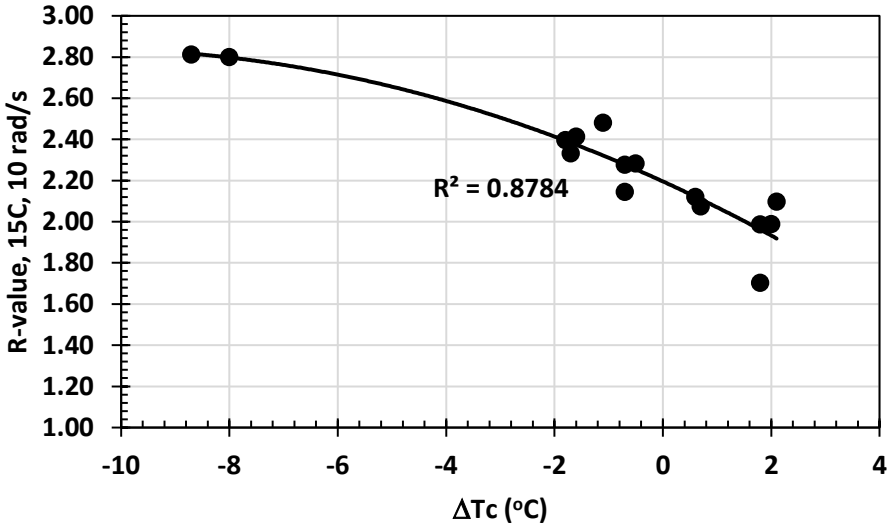
Binder Parameter Selection

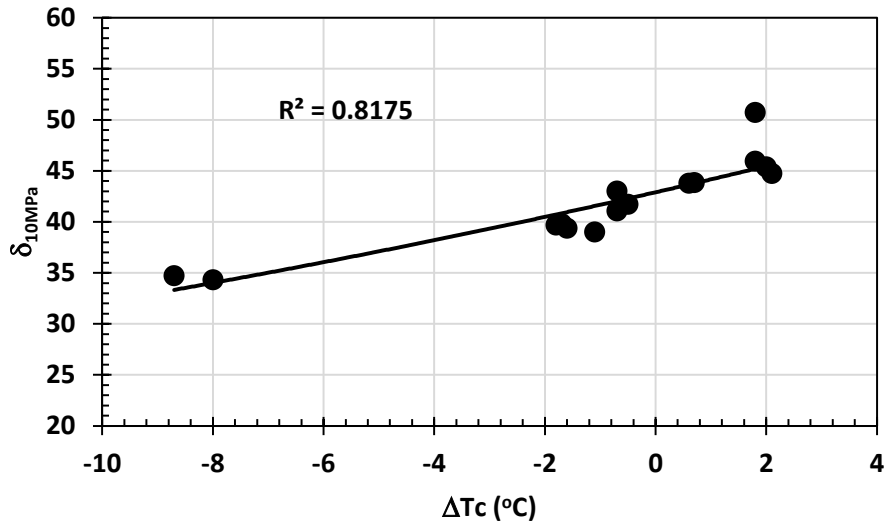
- Final mixture performance will be a function of both the asphalt binder performance and the amount of effective asphalt binder in the mix

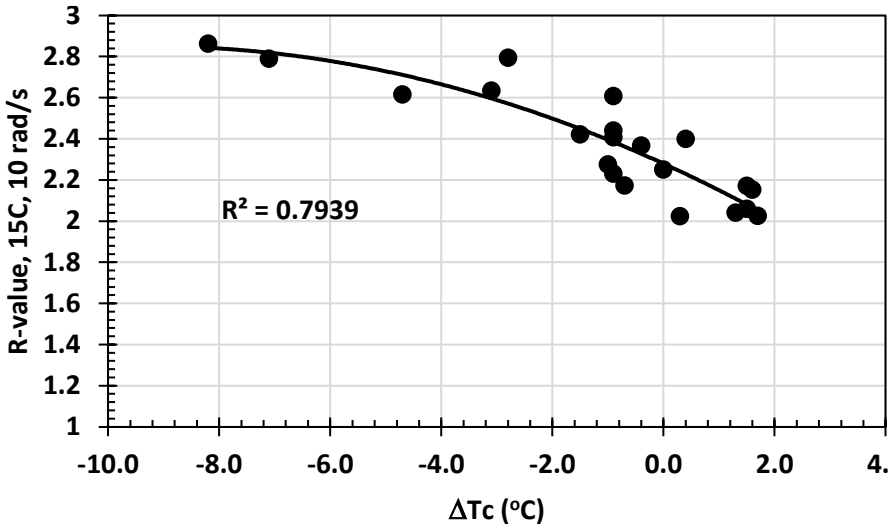


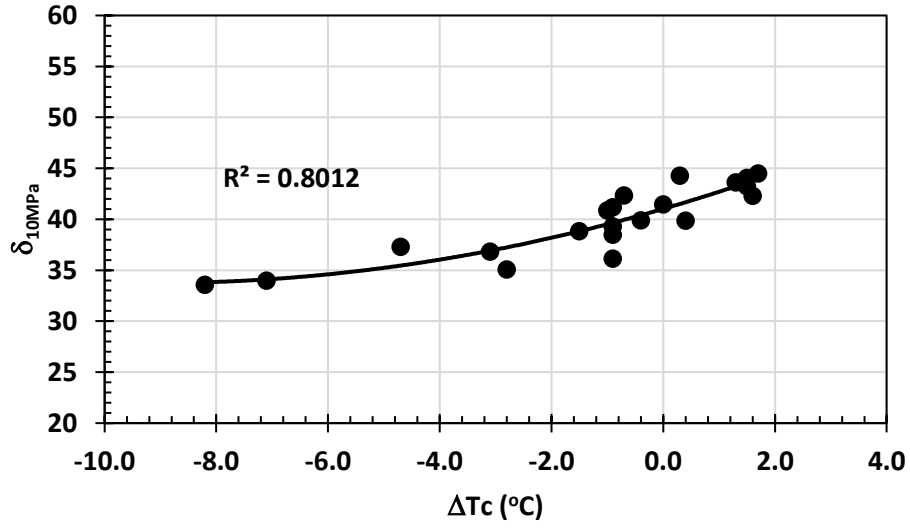
ΔTc vs Other Shape Parameters

- Concern over repeatability of ΔTc
- Other parameters correlate well to ΔTc and found more repeatable









Proposed Recommendation

- Proposed recommendation is to utilize
  - GRP @ 15C to replace intermediate temp PG
  - R-value @ 15C to be included instead of ΔTc
  - Both conducted at DSR
  - Simple one temperature test (no pass & fail temperature)
  - Repeatability of measurements better than ΔTc

PAV Aging Temperature (°C)	**100**						**100 (110)**					
Dynamic Shear, T315 $G^*(\cos\delta)^2/\sin\delta$, 10 rad/s; **< 20,000 kPa**	**15°C**						**15°C**					
Dynamic Shear, T315 $R=\log(2)\log(G^*/1E9)/\log(1-(\delta/90))$ at 10 rad/s; **1.0 < R < 2.7**	**15°C**						**15°C**					
Creep Stiffness, T313 at 60 sec & low temp **Stiffness < 300 MPa** **m-value > 0.300**	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30

Final Recommendation Procedure

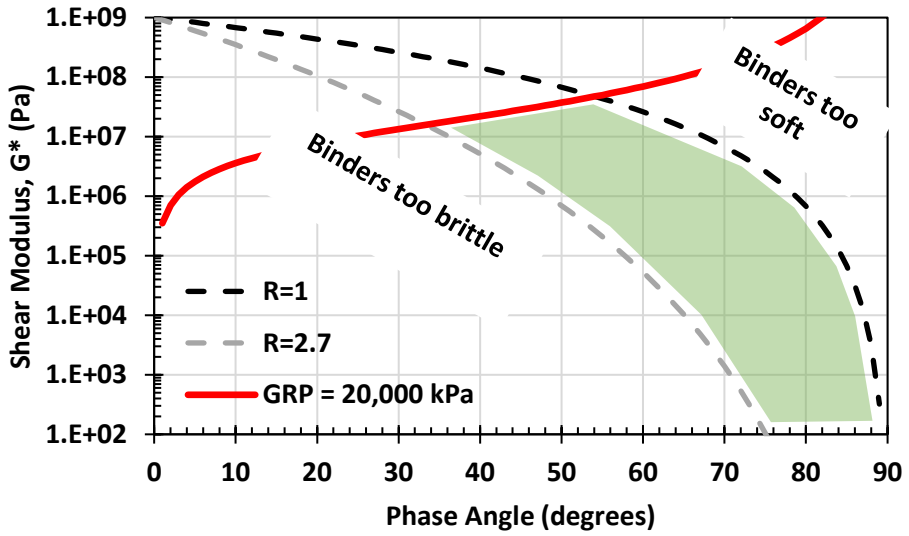
1. RTFO the respective asphalt binder in accordance to AASHTO and WisDOT specifications;
2. PAV condition the asphalt binder for 20 hours in accordance to AASHTO and WisDOT specifications;
3. Determine the shear modulus (G*) and phase angle (δ) at 15ºC and 10 rad/s. Determine the following parameters;
   a. Glover-Rowe Parameter (GRP_{15C})

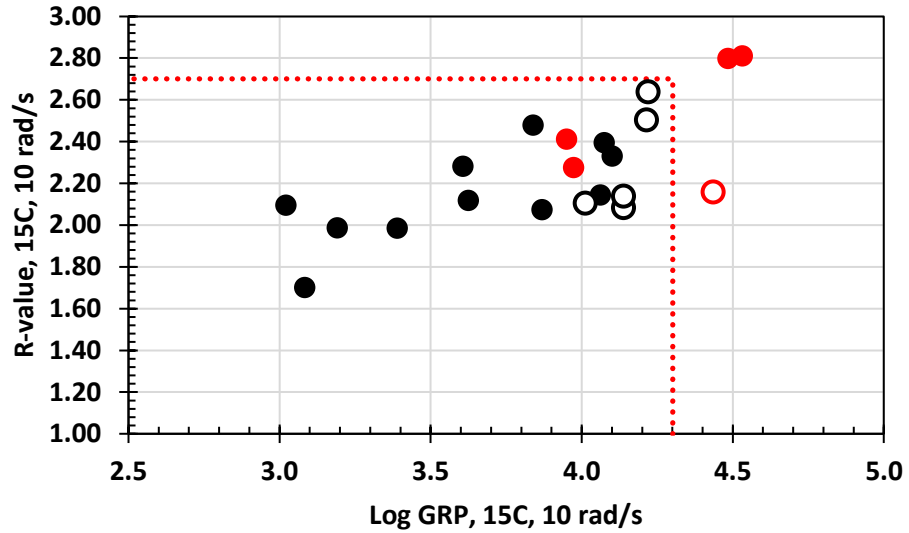
$$G^* \left(\frac{(\cos \delta)^2}{(\sin \delta)} \right) < 20{,}000\ kPa$$

   a. Rheological Index (R-value)

$$1.0 < \frac{(\log 2) \times log\left(\frac{G^*(\omega)}{G_g}\right)}{log\left(1 - \left(\frac{\delta(\omega)}{90}\right)\right)} < 2.7$$

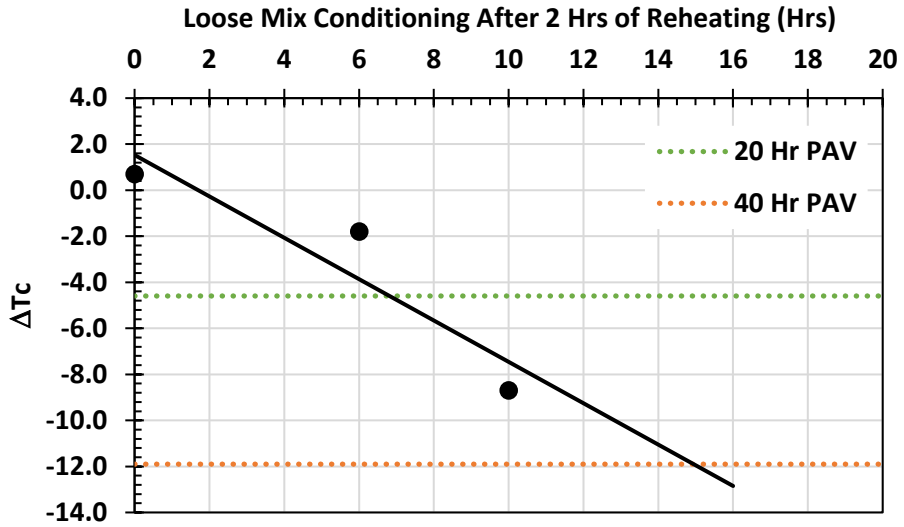
1. Determine Low Temperature PG Grade in accordance to AASHTO and WisDOT specifications and meet the Stiffness and Creep (m-value) requirements;





Binder Aging Protocol

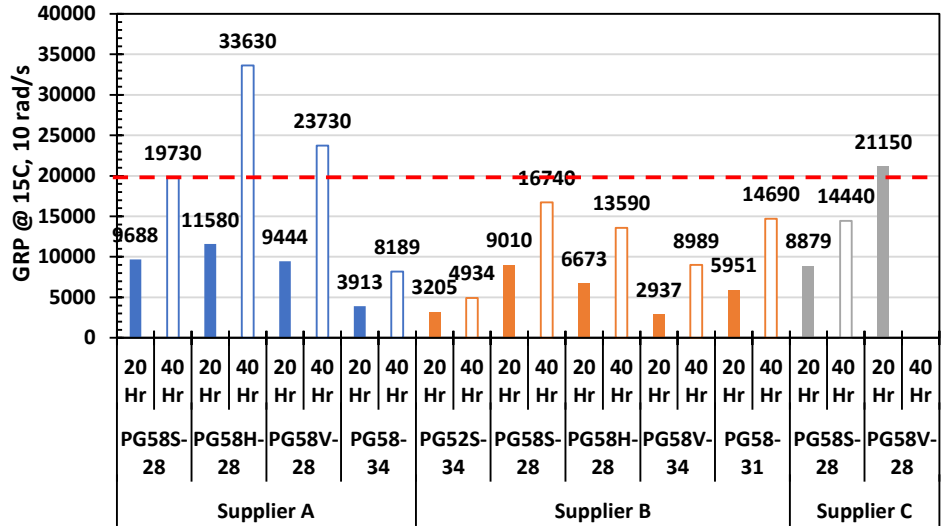
- Goal was to correlate to equivalent mixture aging
  - Consistency within criteria
- Utilized PAV conditioning on unaged recovered material to compare
  - 20 hr PAV conditioning rheologically equivalent to approximately 8 hrs of loose mix conditioning
  - 40 hr PAV conditioning rheologically equivalent to 16 hrs of loose mix conditioning
  - **Utilizing existing 20 hr PAV requirements would be slightly conservative compared to mixture conditioning**
    - **i.e. – binder spec would condition the asphalt binder slightly more than expected from loose mix conditioning**

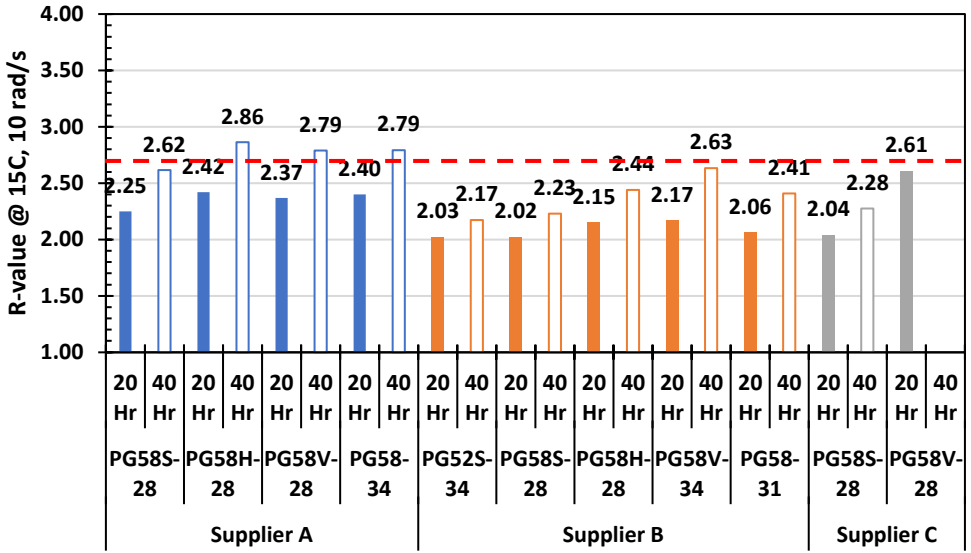


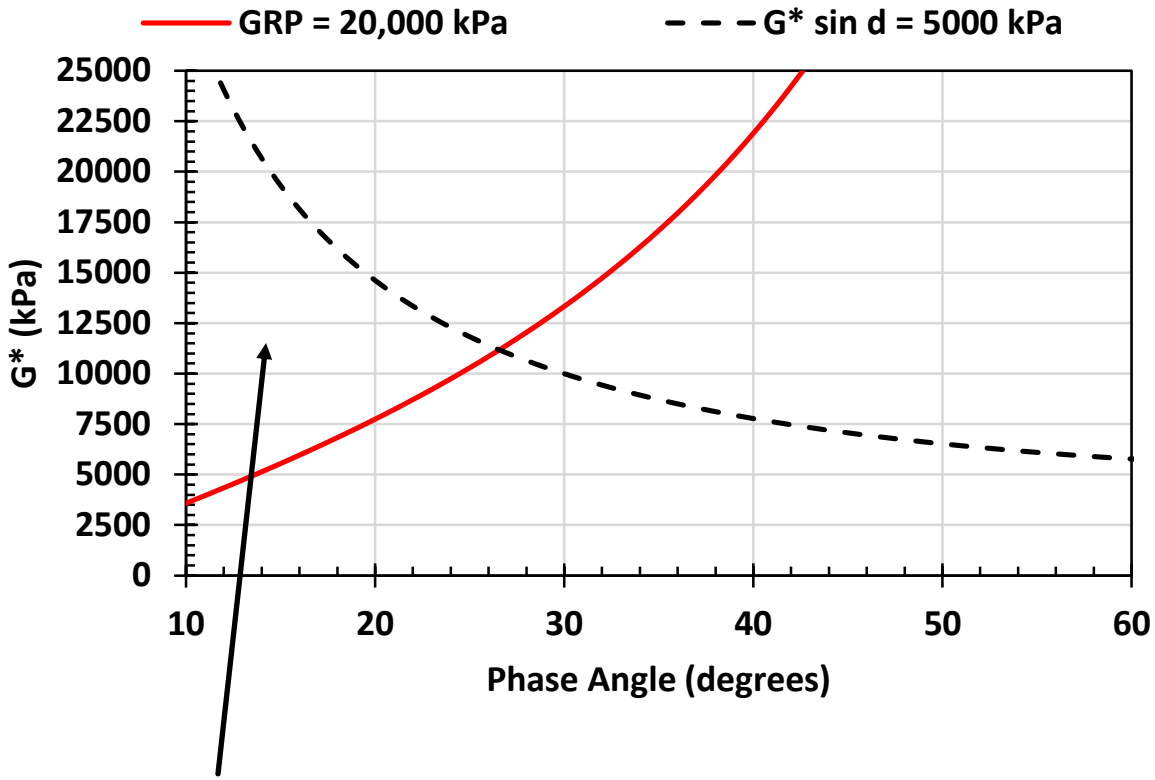
Asphalt Binder Test Parameter	20 Hr PAV		40 Hr PAV	
	Ave	Std Dev	Ave	Std Dev
GRP, 15C, 0.005 rad/s	8.1	3.4		
GRP, 19C, 10 rad/s	8.5	1.5	20.0	2.3
δ @ G* = 10 MPa	8.5	1.6	15.1	3.7
LT PG Grade, m-value	8.0	1.3	16.6	2.5
ΔTc	7.6	2.4	20.2	6.4
ABCD Tcr	8.3	1.5	13.2	6.1
DENT CTOD	8.7	1.0	13.2	3.5
Average (All Tests)	***8.2***	***0.4***	***16.4***	***3.1***

Impact of Proposed Specifications

Impact on Proposed Parameters with Current PG Graded Binders



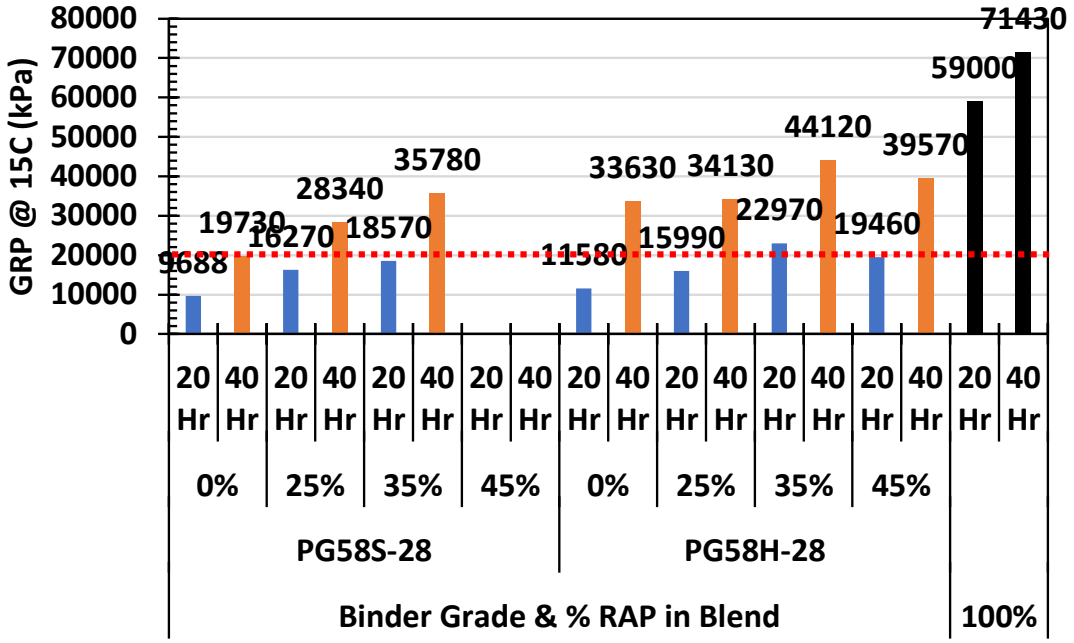




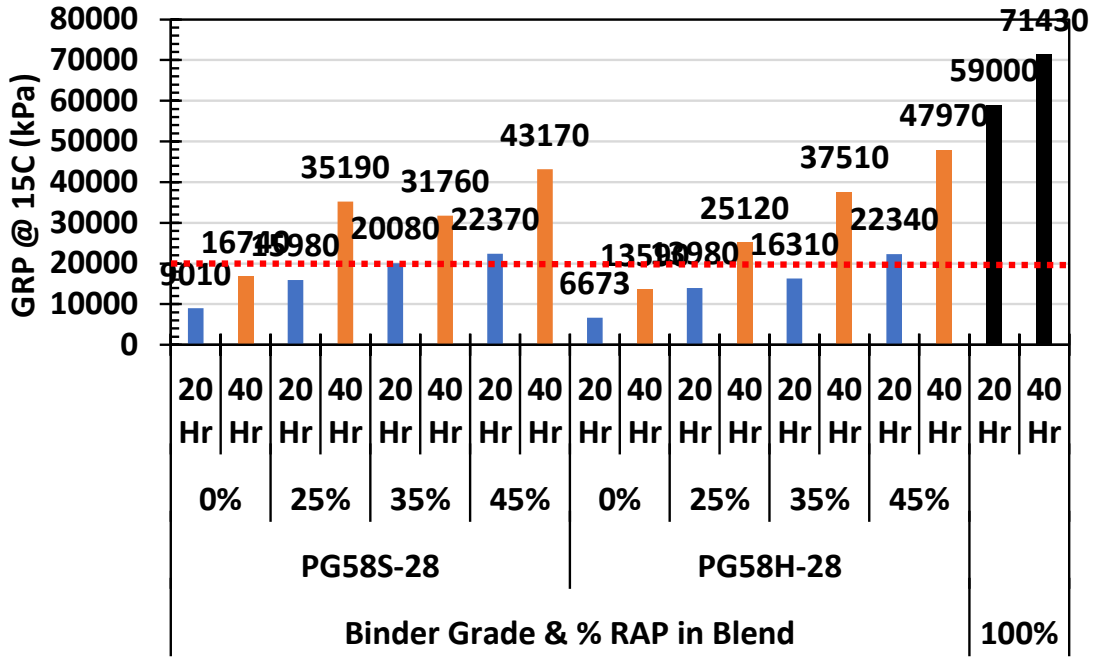
Area of Where Existing Intermediate PG Grade Incorrectly Ranks "Good" Performance

Impact of Recycled Asphalt on Proposed Parameters

- Supplier A
  - For the PG58S-28 and PG58H-28, GRP would limit RAP content to under 35%



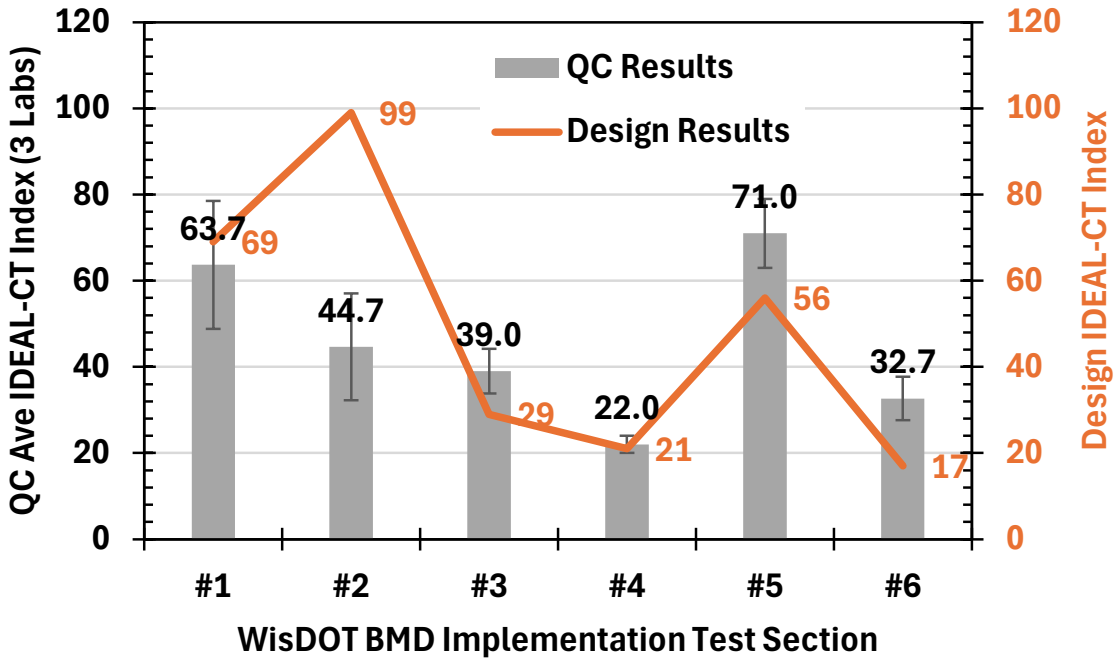
- Supplier B
  - For the PG58S-28 and PG58H-28, GRP would limit RAP content to under 35%

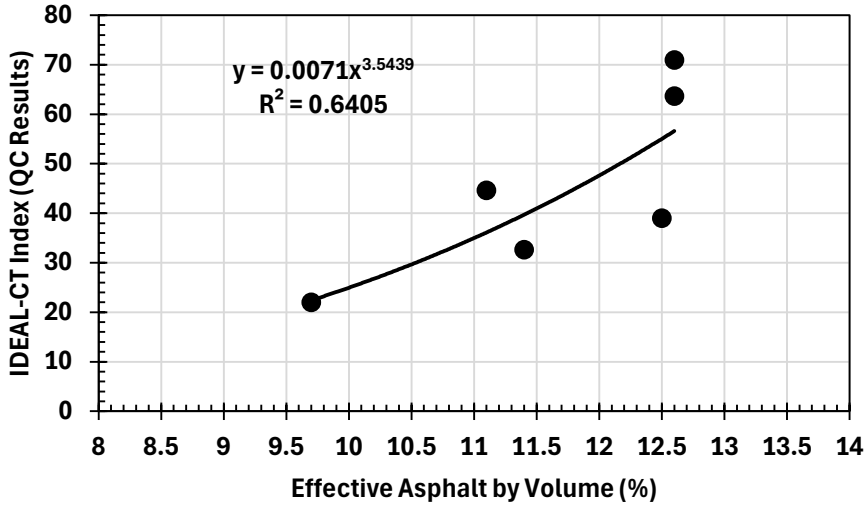


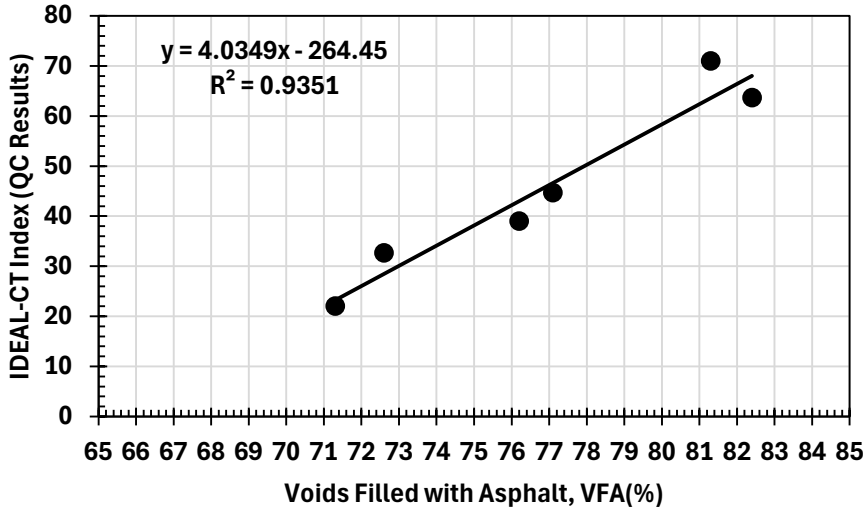
Proposed Parameters on Wisconsin BMD Implementation Sections

Wisconsin BMD Implementation Sections

- 6 mixes designed to achieve a different level of rutting and cracking performance





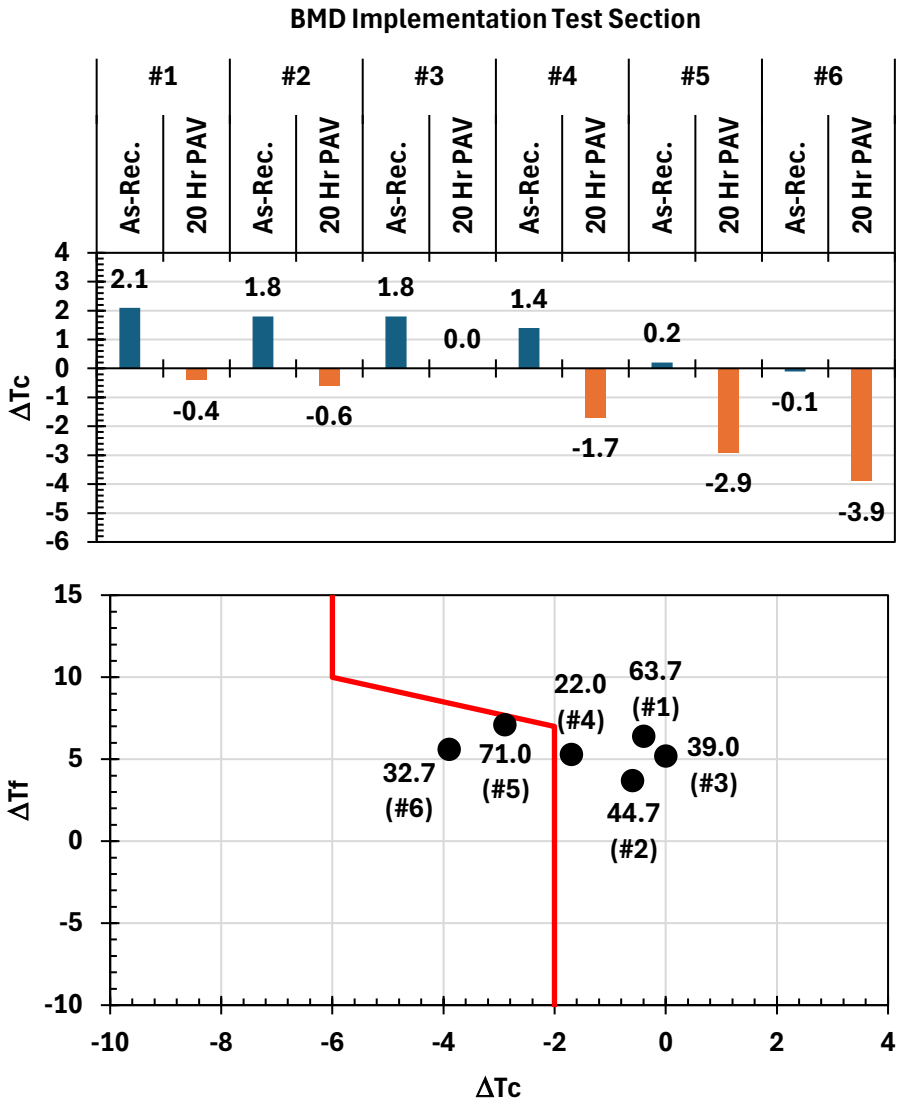


Wisconsin BMD Implementation Sections

- Different parameters compared to BMD sections mixture performance
  - As-received condition & 20 hr PAV
    - 20 hr PAV condition compared to IDEAL-CT Index

Table 4. Summary of Contractor Mix Designs for the Six Test Sections

Test Section	CT_{Index}	HWTT Corr. Rut Depth @20k (mm)	Asphalt Content (%)	Binder Grade	Reclaimed Asphalt Pavement (RAP)Content (%)
1	69	10.4	6.5	58-28 S	8
2	99	3.3	6.3	58-28 S	15
3	29	8.1	6.0	58-28 S	0
4	21	2.8	5.3	58-28 S	27
5	56	3.7	6.5	58-28 V	8
6	17	3.2	6.0	58-28 V	0



Wisconsin BMD Implementation Sections

- Proposed GRP15C and R-value at 15C methodology identifies Section #4 as potentially having cracking issues
  - IDEAL-CT Index = 22
    - Combined lowest asphalt content and highest RAP content

Table 4. Summary of Contractor Mix Designs for the Six Test Sections

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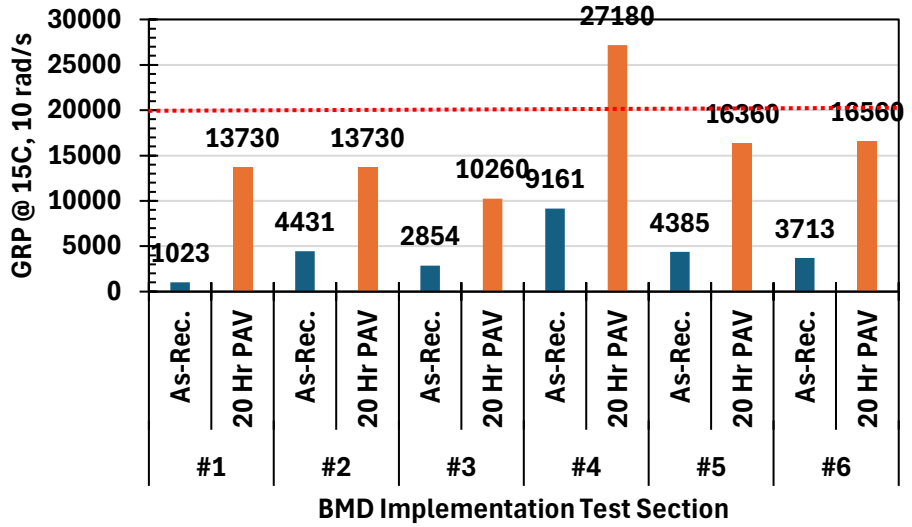
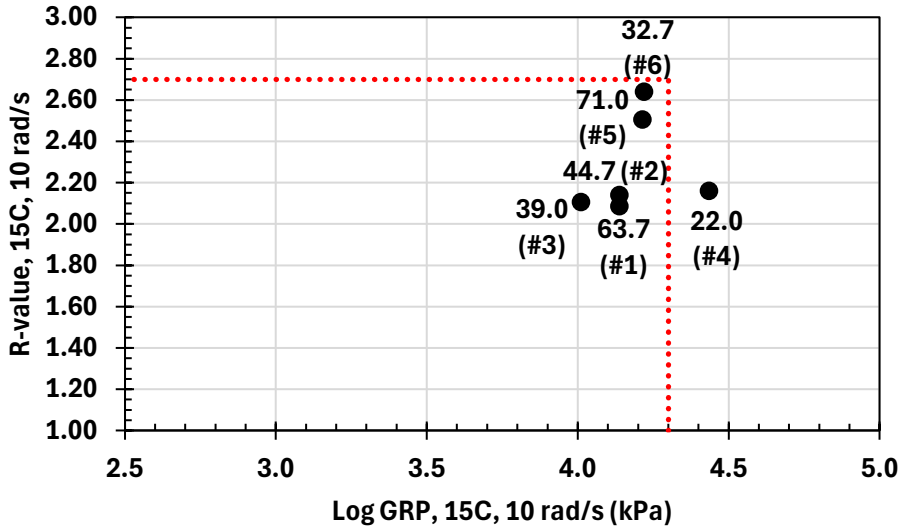


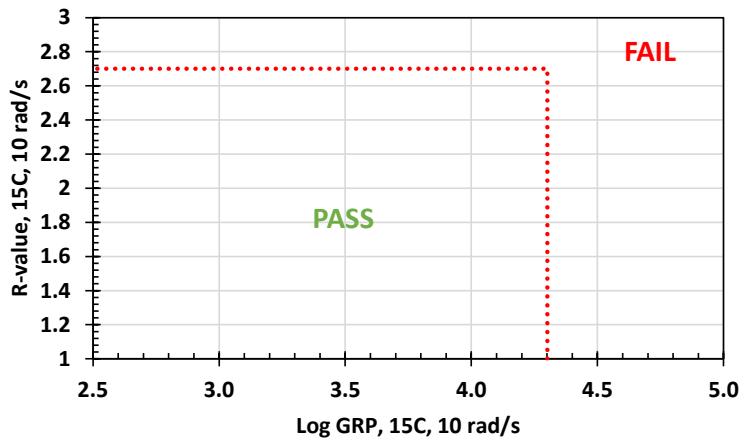


Conclusions and Implementation Plan

Project Summary & Implementation

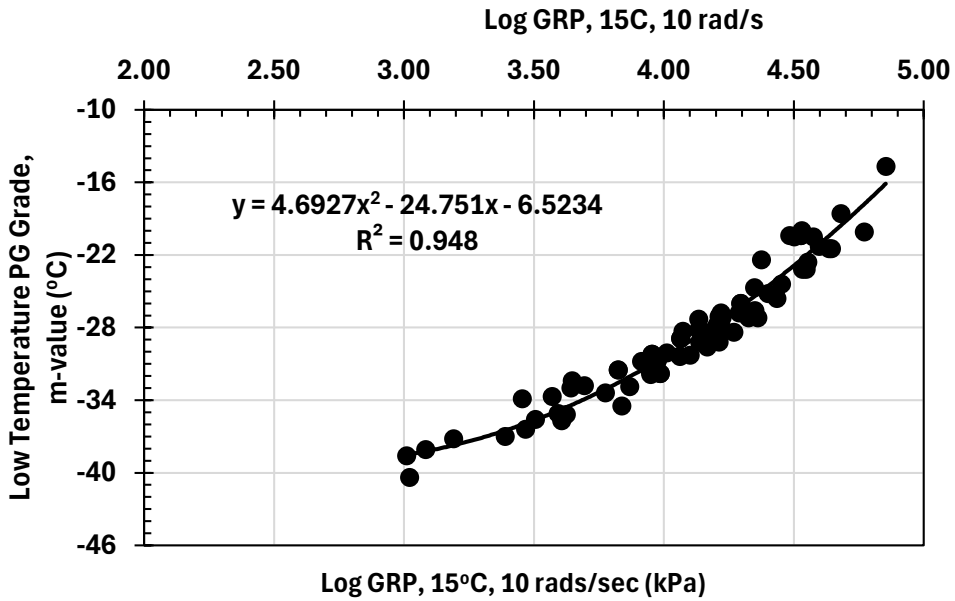
- Proposed method fundamentally sound from rheological standpoint (point & shape parameters)
- Strong relationships to mixture cracking (IDEAL-CT Index)
- Ease of use (1 measurement needed provides data for both GRP and R-value)
- Better repeatability, less binder material required, and no additional equipment needed

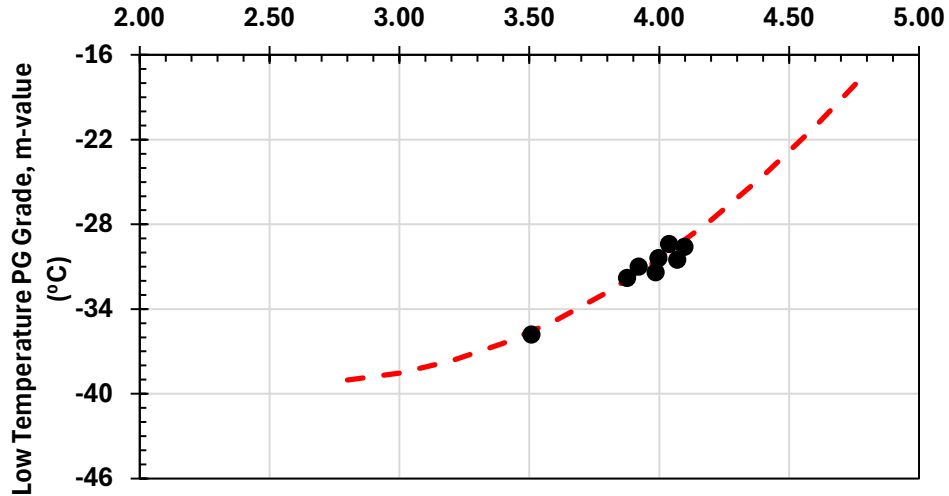
PAV Aging Temperature (°C)	100						100 (110)					
Dynamic Shear, T315 $G^*(\cos\delta)^2/\sin\delta^2$, 10 rad/s; **< 20,000 kPa**	**15**						**15**					
Dynamic Shear, T315 R=log(2)log(G*/1E9)/log(1-(δ/90)) at 10 rad/s; **1.0 < R < 2.7**	**15**						**15**					
Creep Stiffness, T313 at 60 sec & low temp **Stiffness < 300 MPa** **m-value > 0.300**	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30



Project Summary & Implementation

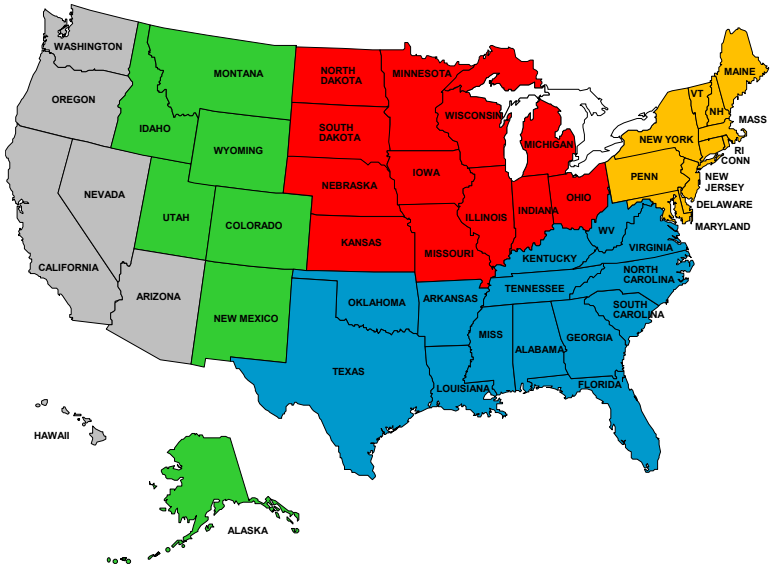
- Log GRP at 15C also found to have excellent correlation to BBR m-value
  - Could be potentially used a quick method to verify low temperature PG grade
  - Relationship found valid and fundamental for binders from other parts of country as well

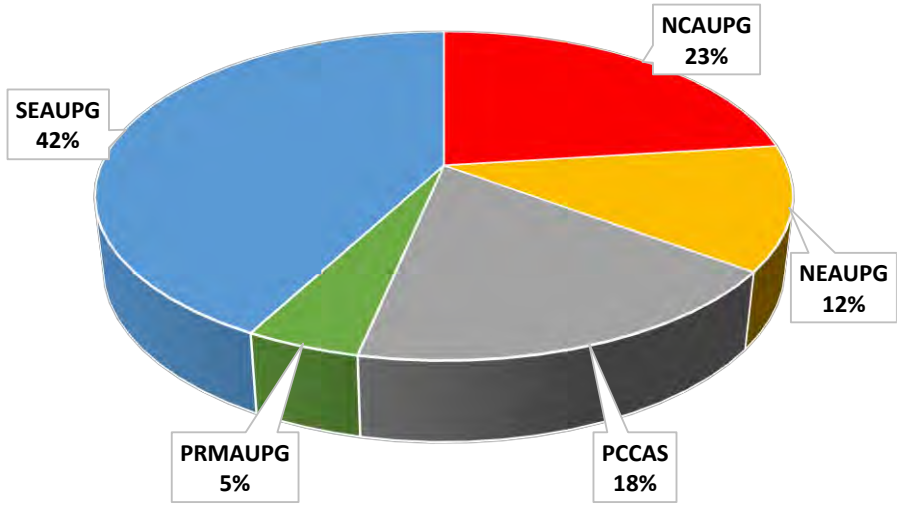




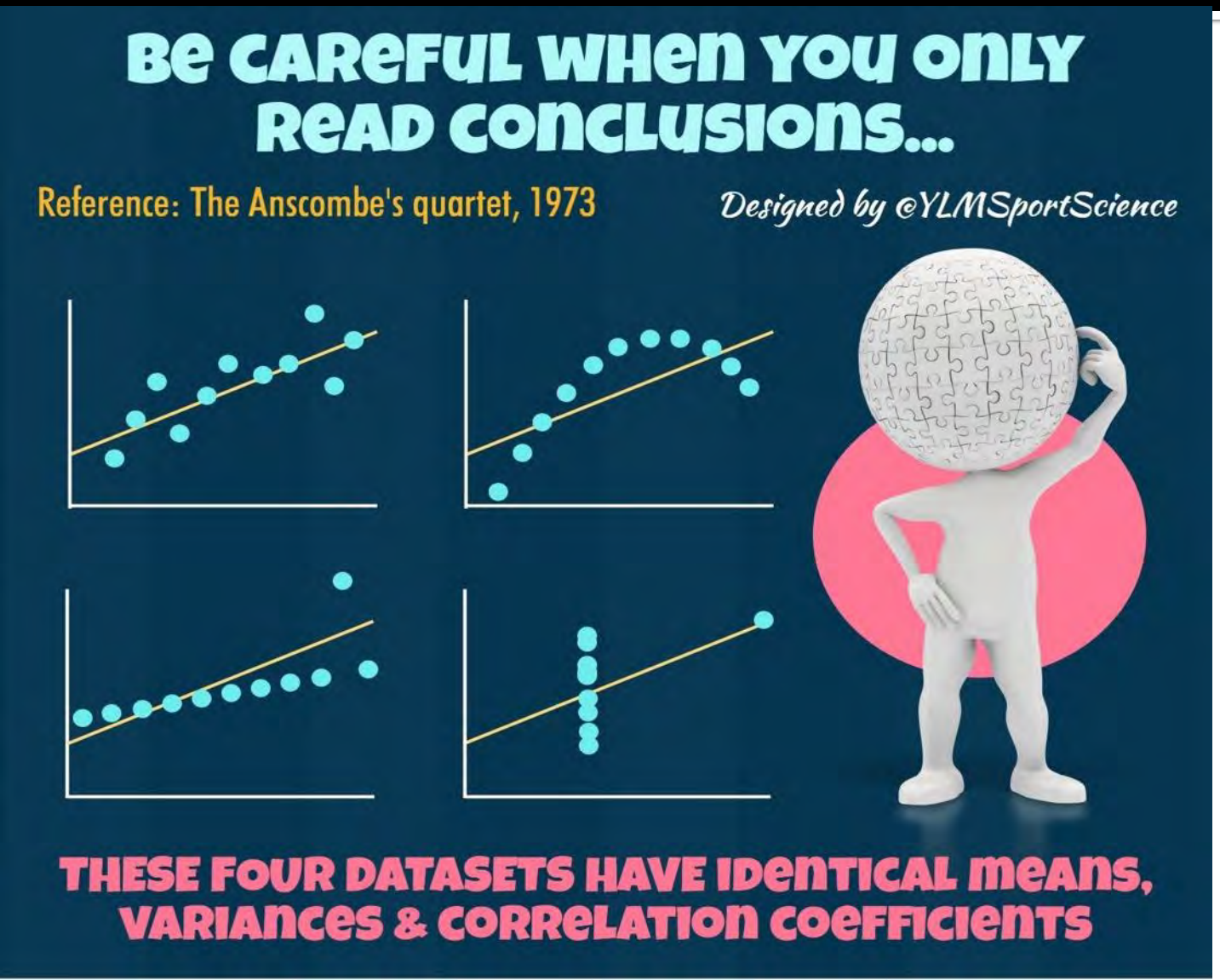
Recent binders from MaineDOT

AAPT Coming to Boston in March 2026





Thank you for your time!
Questions?



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