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TRANSPORTATION RESEARCH BOARD

TRB Webinar: Asphalt Killers—Fatigue, Formulation, and Old Age in Binders

July 8, 2021

1:00- 2:30 PM Eastern

@NASEMTRB
#TRBwebinar

PDH Certification Information:

•1.5 Professional Development Hours (PDH) – see follow-up email for instructions

•You must attend the entire webinar to be eligible to receive PDH credits

•Questions? Contact Beth Ewoldsen at Bewoldsen@nas.edu

#TRBwebinar

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

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REGISTERED CONTINUING EDUCATION PROGRAM

Learning Objectives

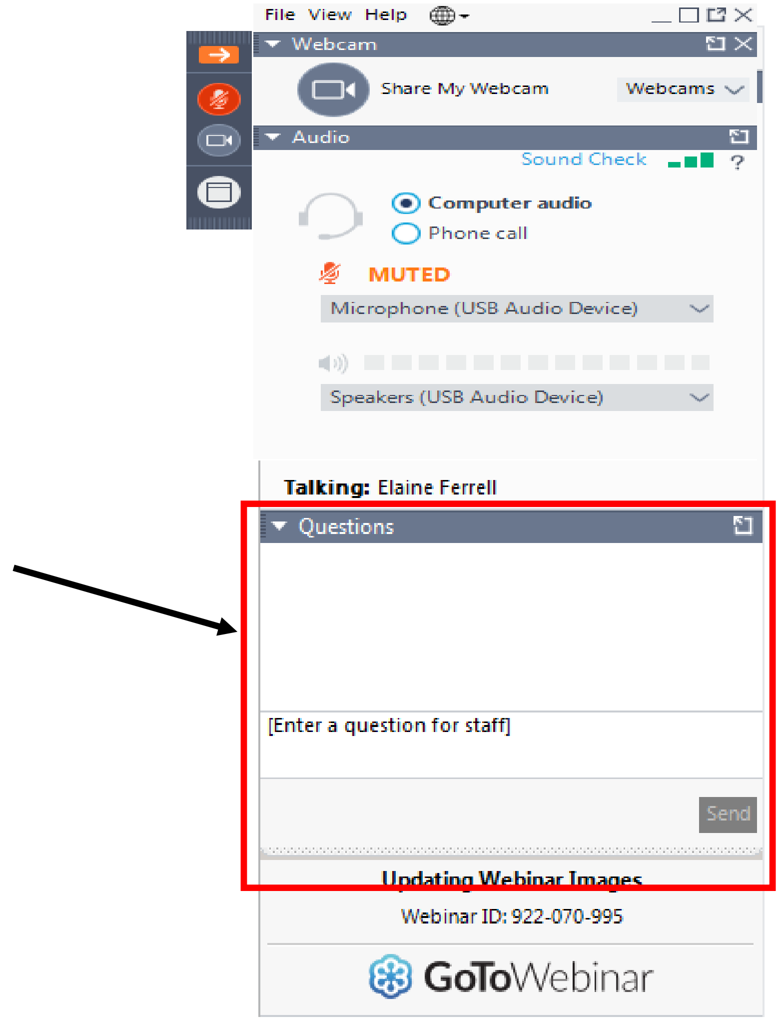
- Make informed decisions about implementing new research to issues of asphalt binders

#TRBwebinar

Questions and Answers

- Please type your questions into your webinar control panel

- We will read your questions out loud, and answer as many as time allows



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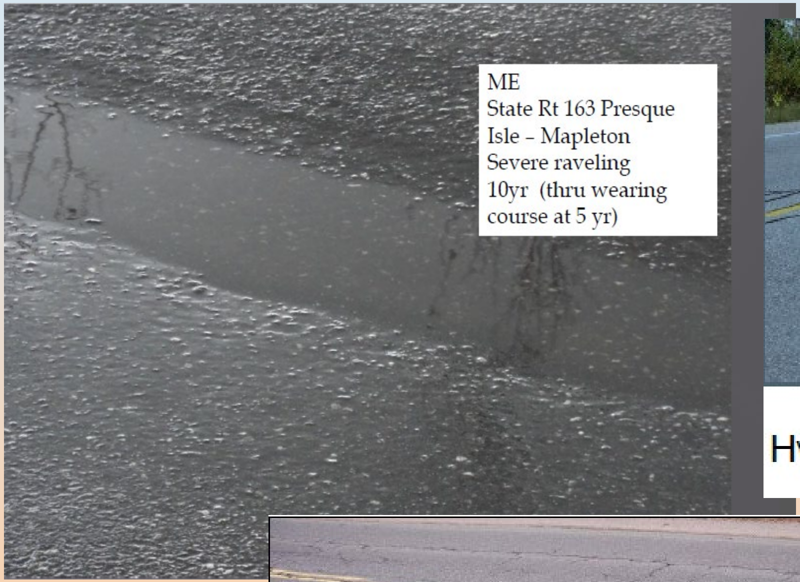
What Kills Asphalt?

NCHRP 9-59 Findings

Don Christensen
Advanced Asphalt Technologies, LLC
July 2021

NCHRP 9-59: an improved binder fatigue specification



Hwy 41 North of Kaladar (1999)

Hesp et al., *Proceedings CTAA*, 2009

Bill Ahearn,
Pamela Marks,
Simon Hesp

What binder properties do we need to specify to maximize fatigue performance?

ΔTc?

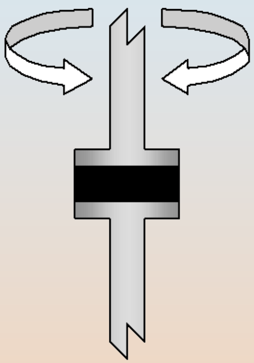
Glover-Rowe parameter (GRP)?

Extension/ductility?

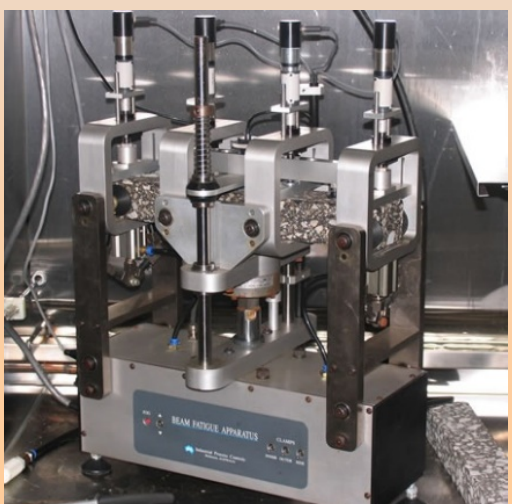
Elastic recovery?

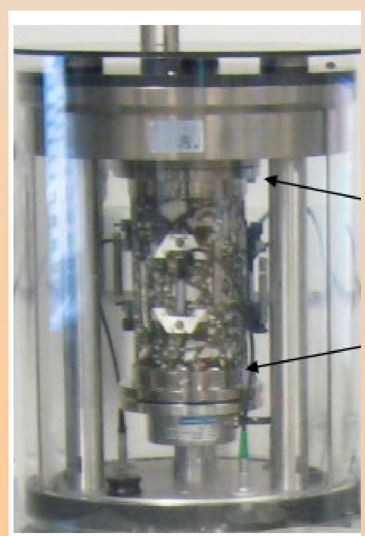
NCHRP 9-59: Lab Testing

16



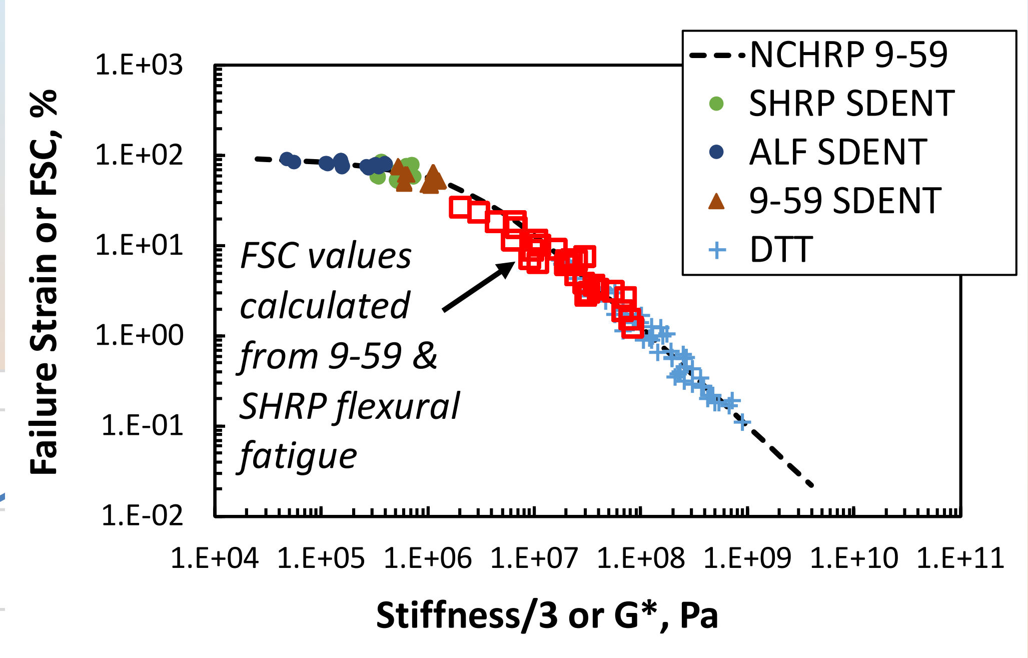


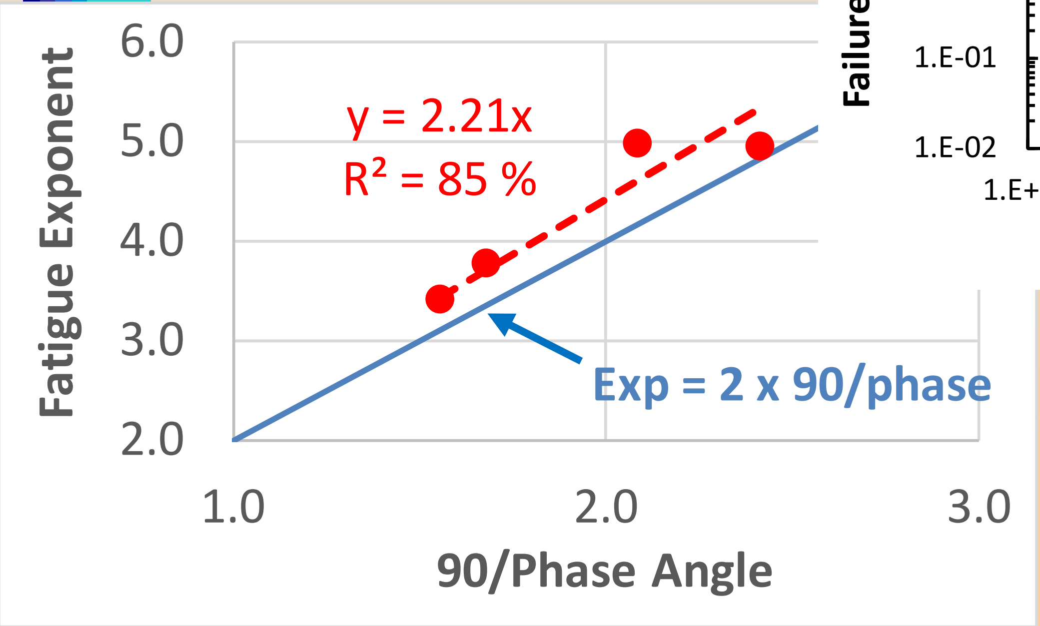





Fatigue life: fatigue strain capacity and fatigue exponent

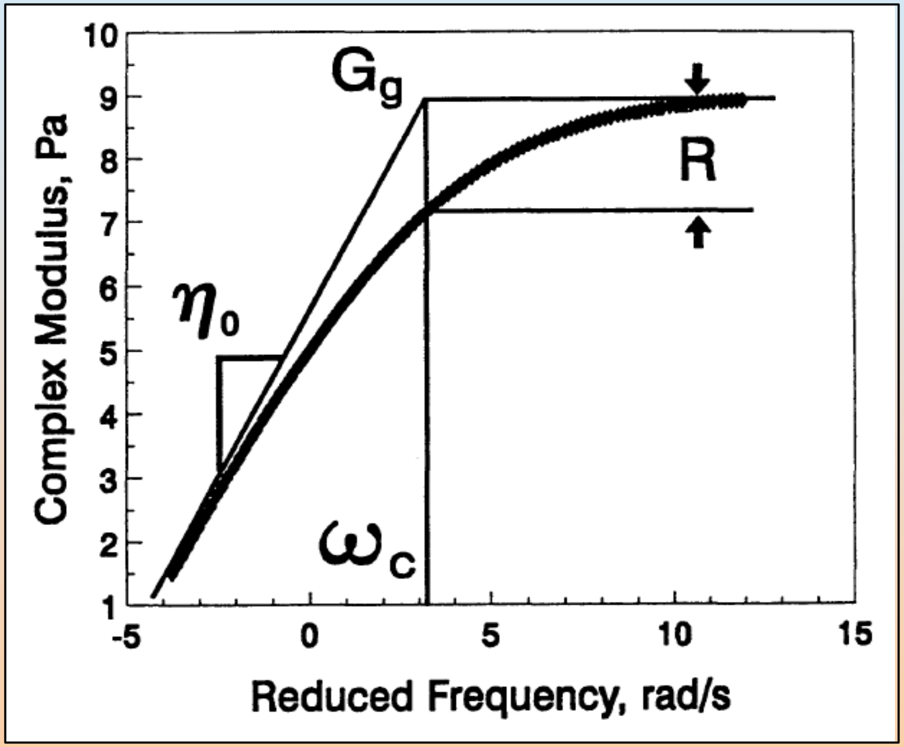
$$N_f = \left(\frac{FSC}{\varepsilon_b}\right)^{180/\delta}$$





Fatigue Model

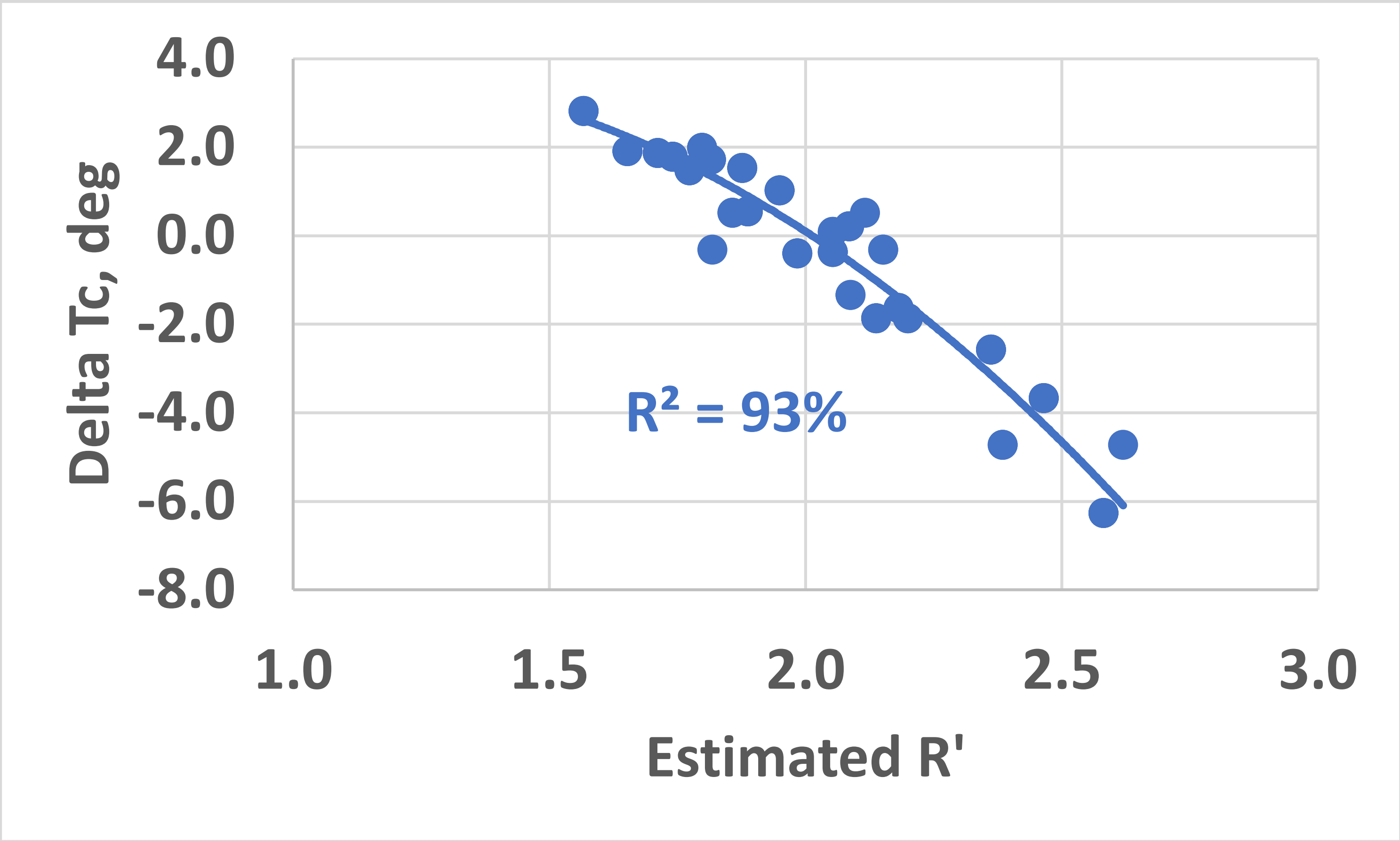
Binder rheologic type / R' value



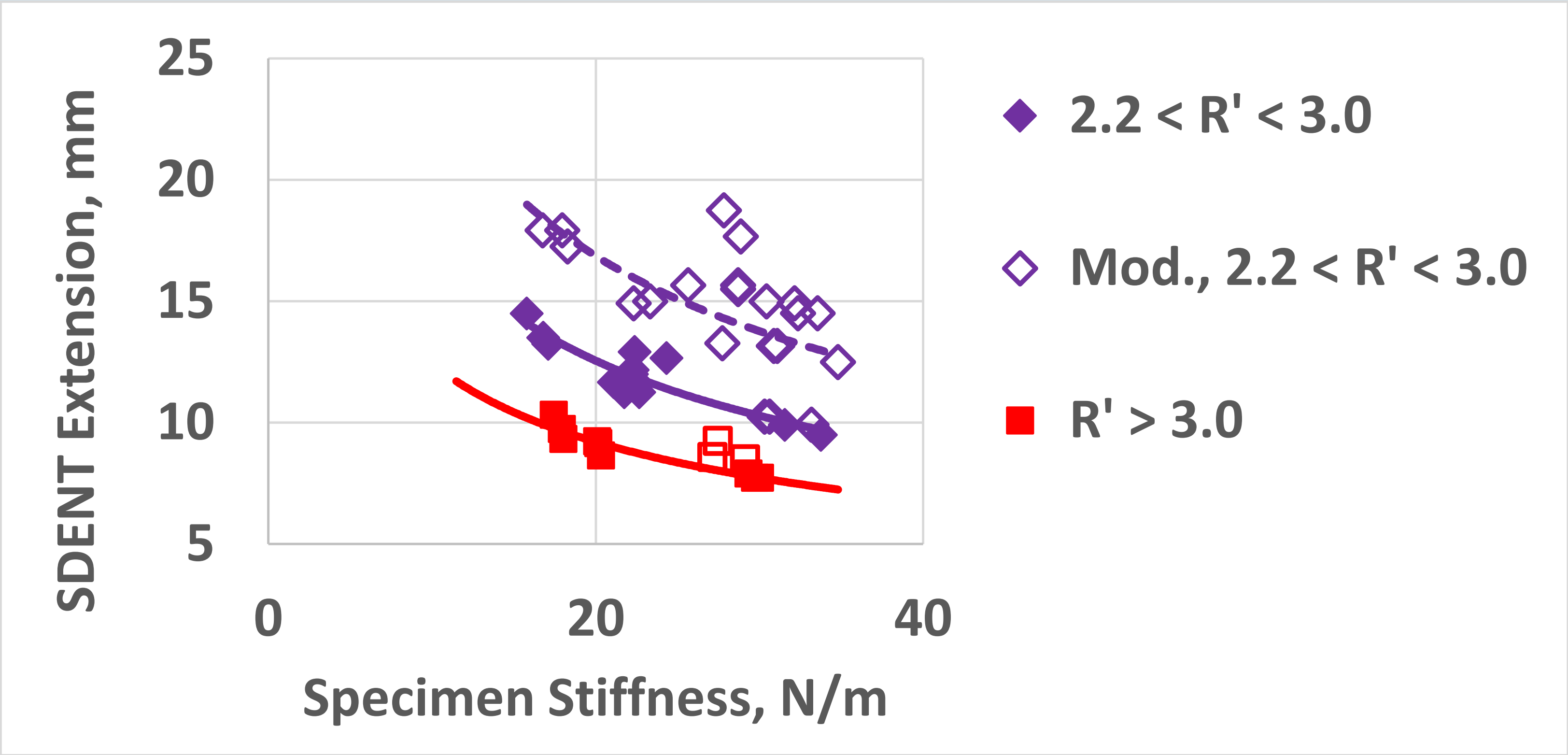
R' is R estimated using a constant glassy modulus of 1.0 GPa.

R and R' are related but not equal…

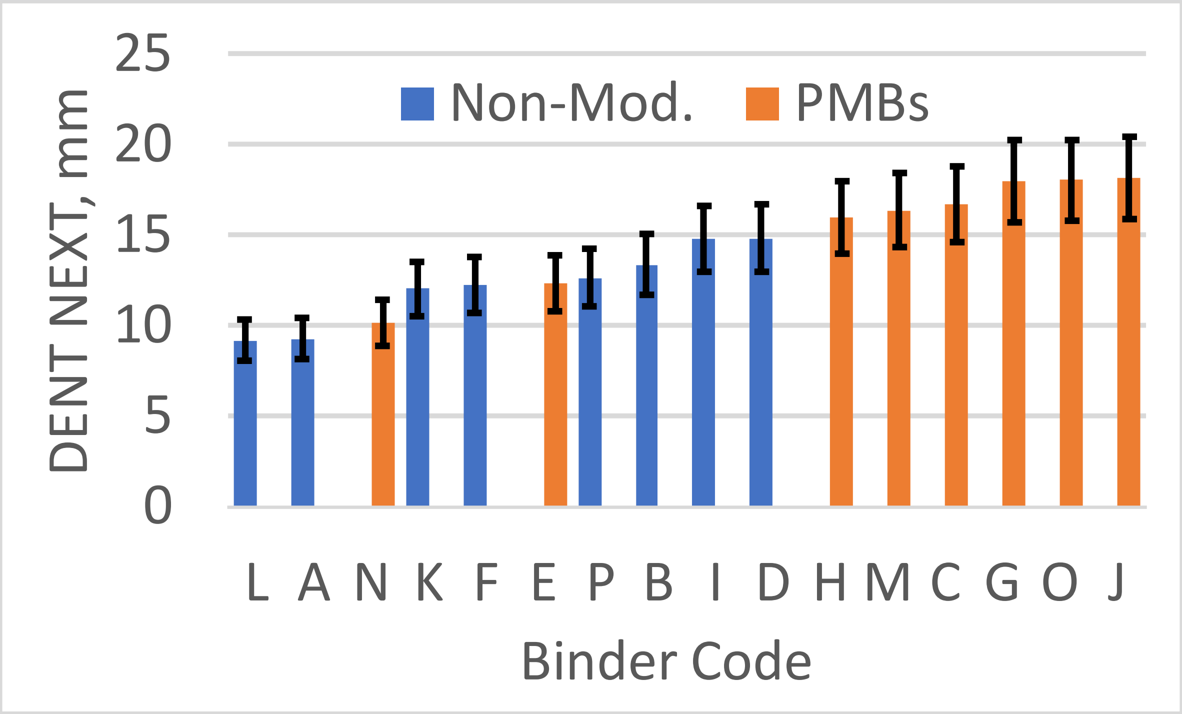
ΔTc and R'-Value are closely related…



DENT extension vs G*

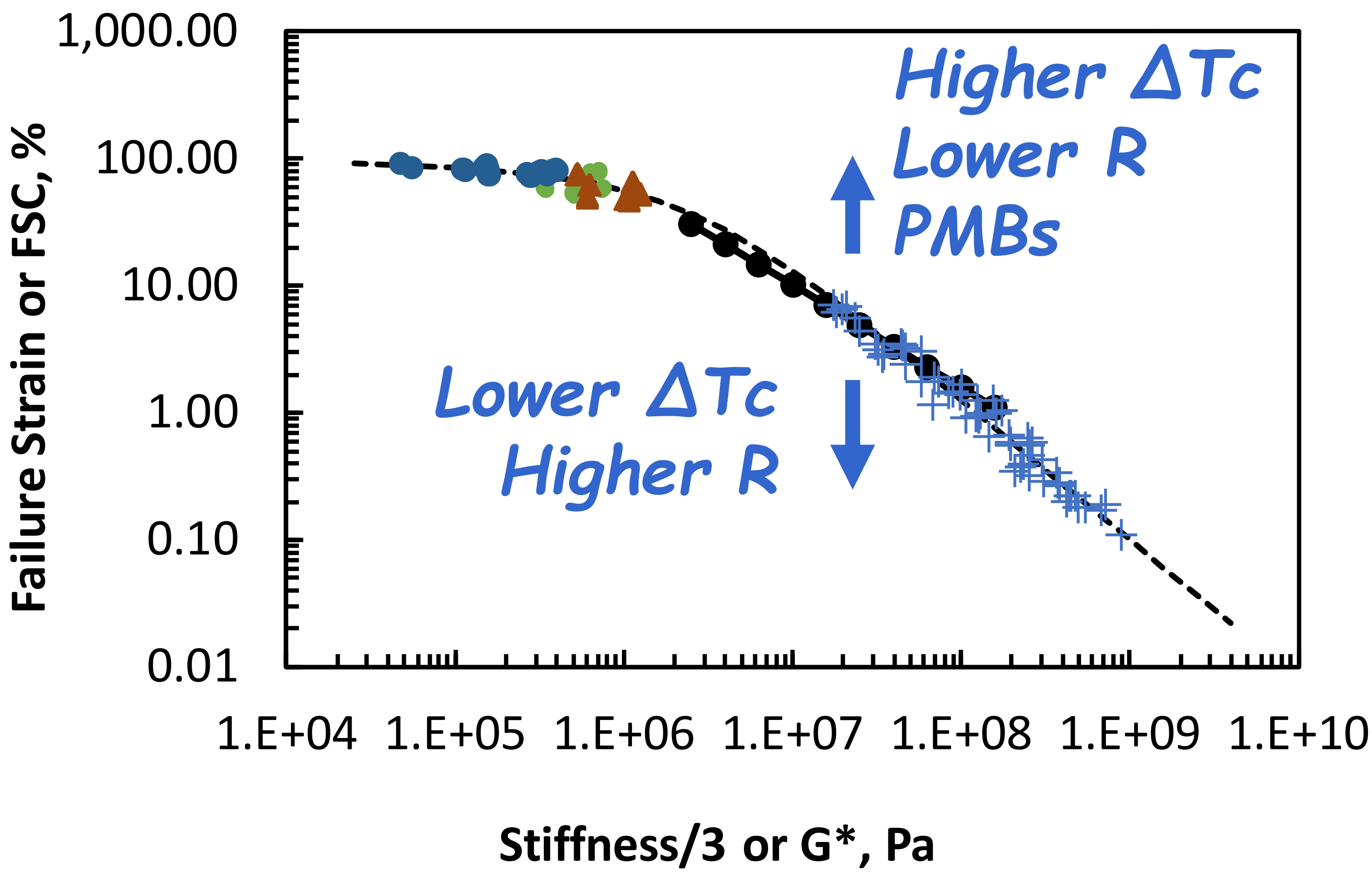


DENT normalized extension (NEXT)

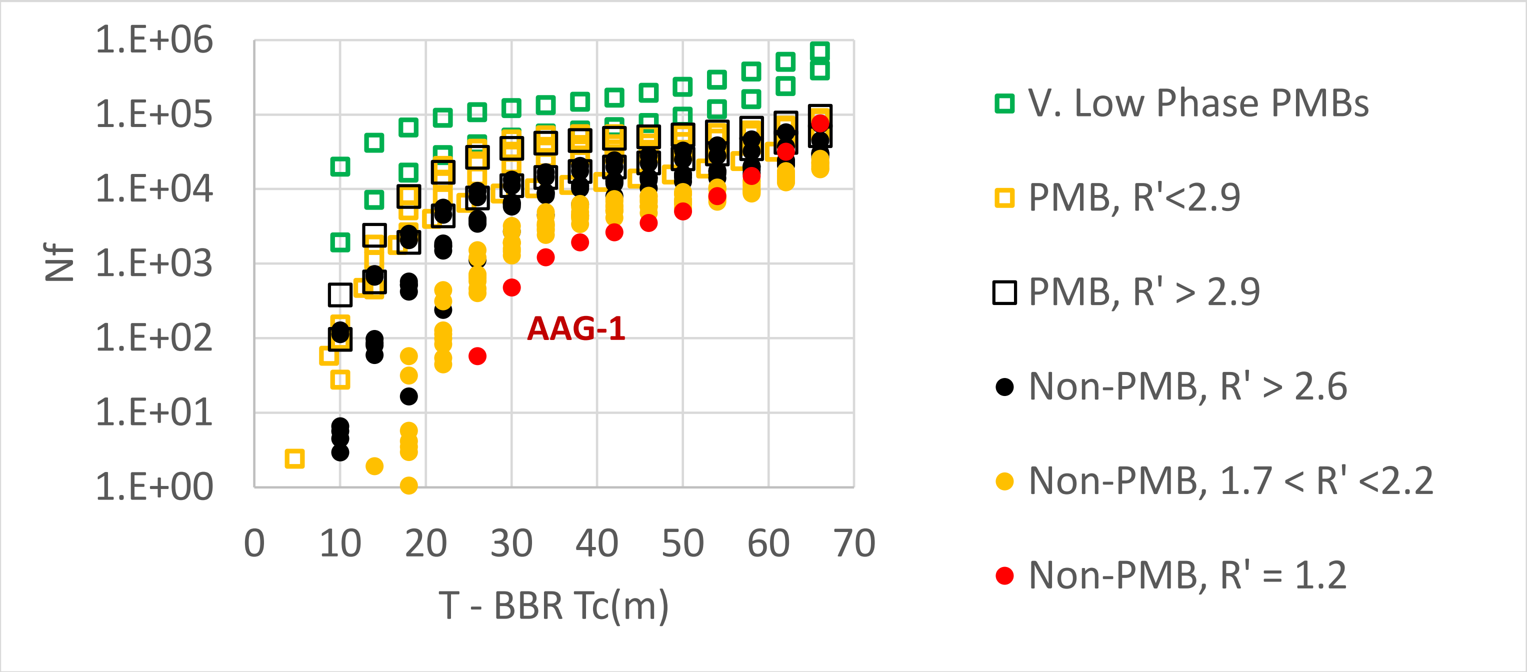


NEXT is the extension estimated at a constant initial specimen stiffness of 20 kN/m

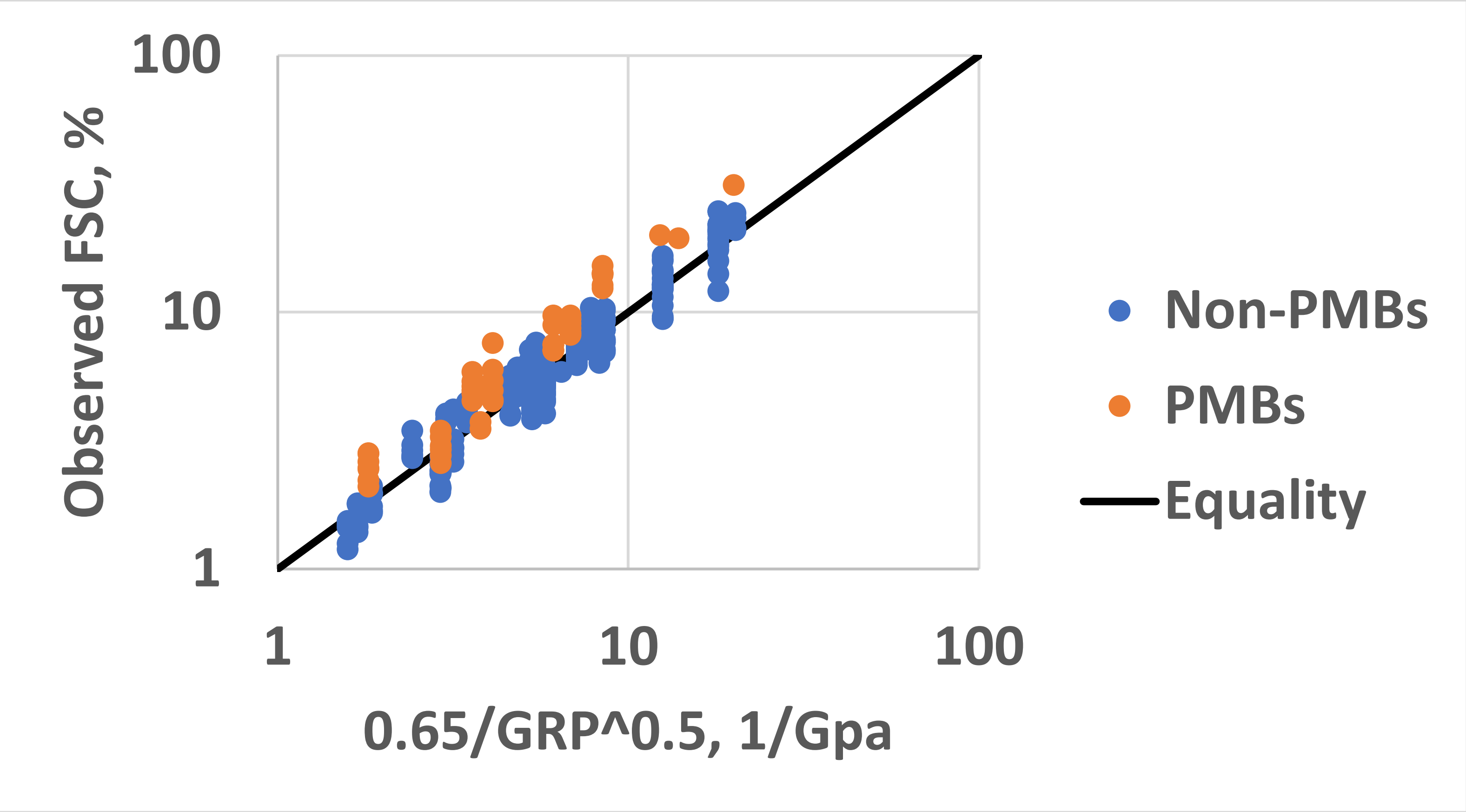
Factors affecting FSC



Layered elastic analysis
Based on ALF2 100 mm sections

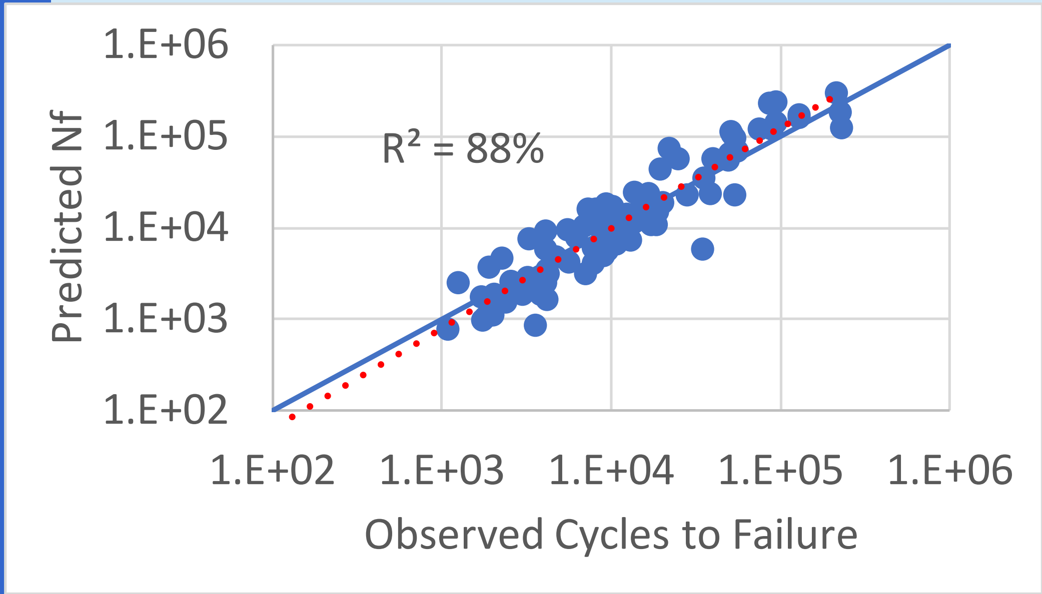


What about Glover-Rowe?



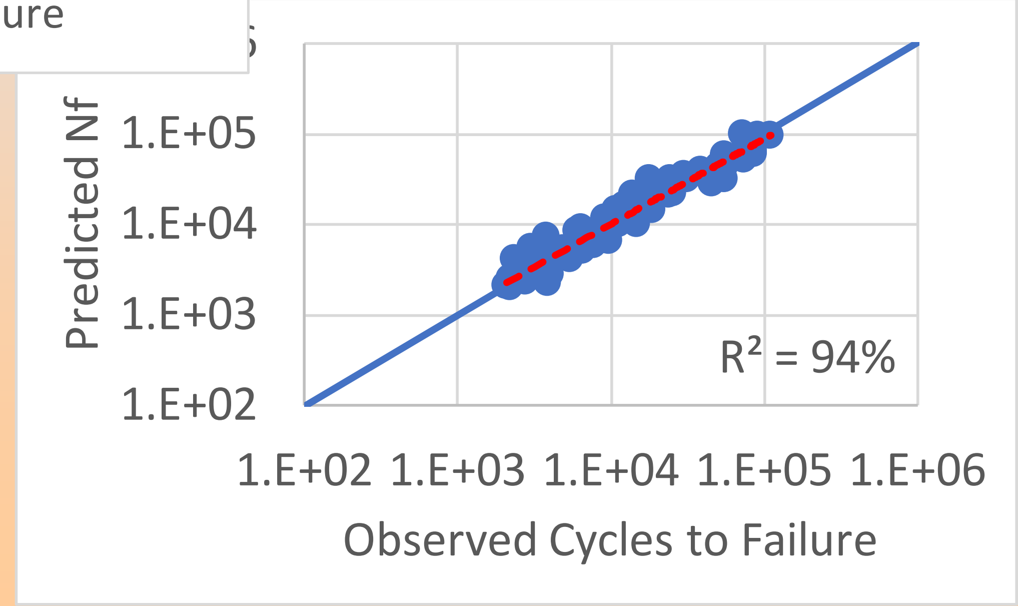
$$Observed\ FSC = N_f^{\delta/180} \varepsilon_b$$

Uniaxial fatigue model

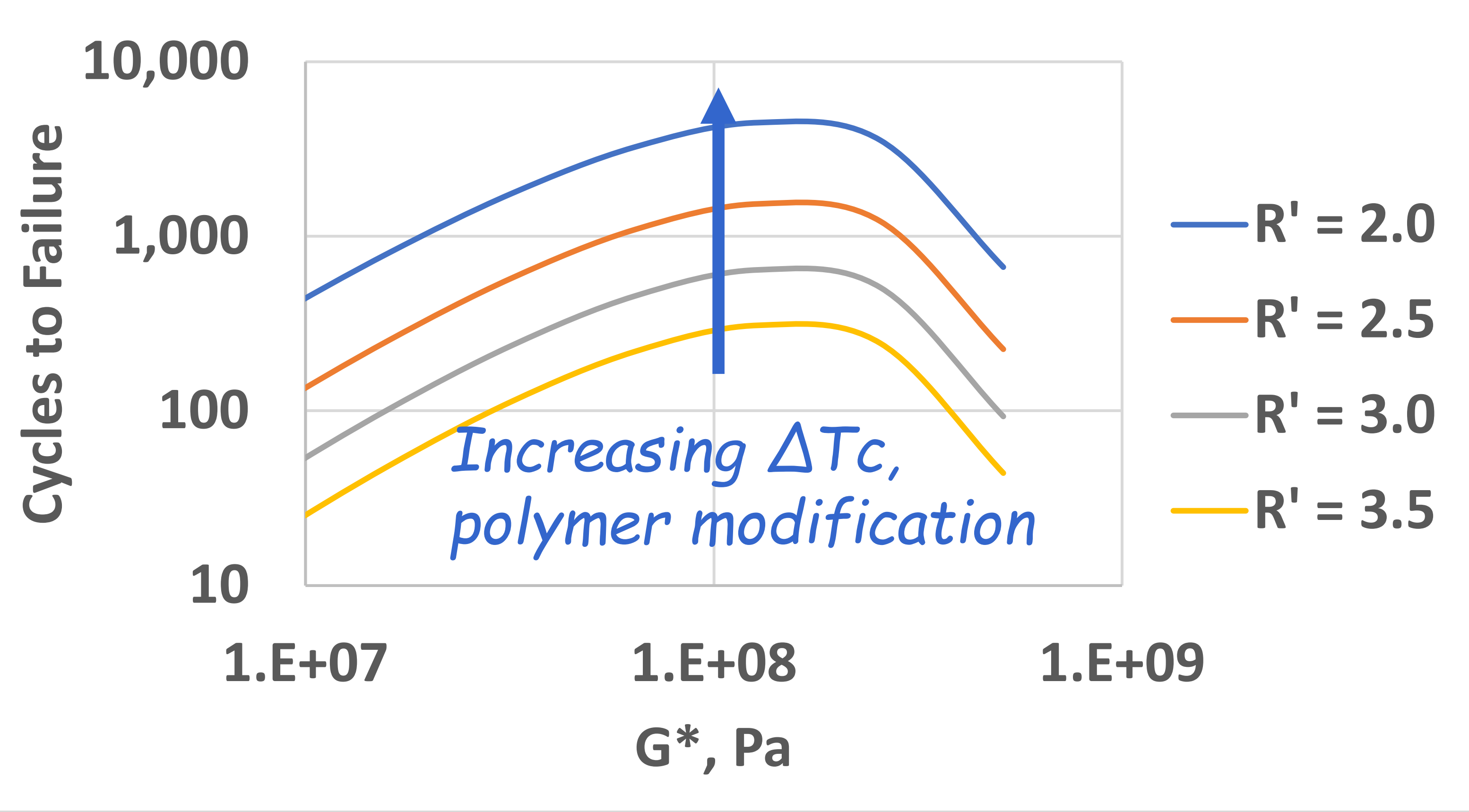


Strain-based damage

Stress-based damage



Stress-based fatigue model



$$N_f = \left(\frac{FSsC}{\sigma_b}\right)^{5.0} \;;\quad FSsC = FSC \times E$$

What kills asphalt…

- High R’ values/low delta Tc values produce weak and brittle binders that are prone to top-down cracking
- Can be caused by a poor-quality binder (REOB), age-hardening, or both
- Age-hardening will also increase stiffness, making thermal cracking more likely
- Polymer modification can dramatically improve fatigue performance

What kills asphalt…

- Damage due to thermal cracking and traffic loading likely superposes, making it difficult to separate these distress modes
- Minimum ΔTc, adjusted for modified binders—NCHRP 9-60
- Are binders with low R’/high delta Tc values a problem?

Acknowledgements

- Nam Tran and his associates at NCAT
- NCHRP
- The 9-59 Project Panel
- Industry suppliers
- My associates at AAT

Asphalt Killers Thermal Stress, Formulation, and Old Age in Binders

Outcomes of NCHRP 9-60

**Jean-Pascal Planche,
Gayle King, Michael Elwardany,
Don Christensen, Carolina Rodezno
WRI, GHK Inc., AAT, NCAT**

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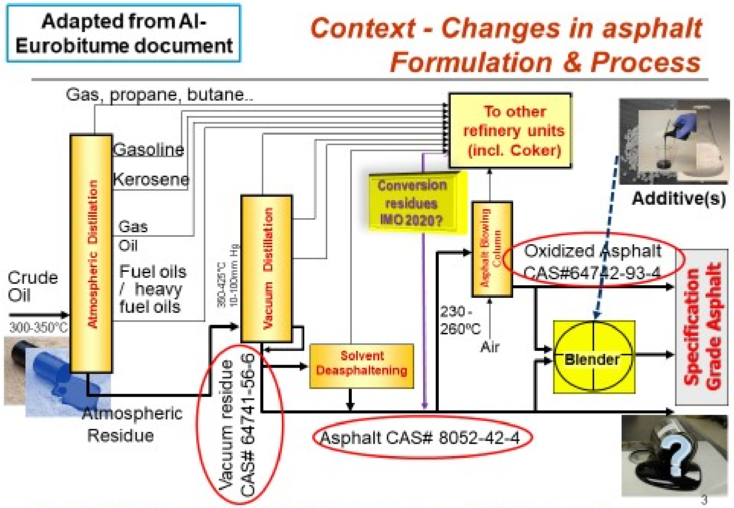
Outline

- ❑ **Introduction – context**
- ❑ **NCHRP 9-60 proposal on test methods and specification**
- ❑ **9-60 proposal genesis: What drives changes in binder physical properties – thermal, rheological, and failure**
  - **Thermal stress**
  - **Binder formulation**
  - **Aging – oxidative and physical**
- ❑ **Summary**

Context - Introduction

- **Bitumen chemical complexity**
  - **Variable continuum can have an unstable balance**
- **SuperPave binder specs and quality issues outdated for 2021 binders with high variability**
  - **Polymers, Modifiers, RAP/RAS, Recycling Agents, Bio-binders, Conversion residues (IMO 2020), Plastics...**
- **Characterization methods lack an holistic approach**
- **Binder quality impacts performance**

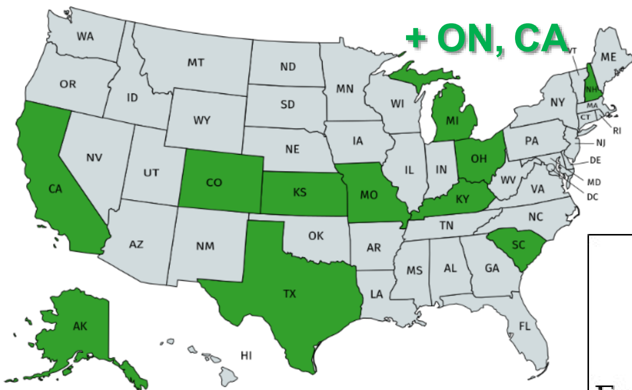


Asphalt/bitumen production process (US-Europe)

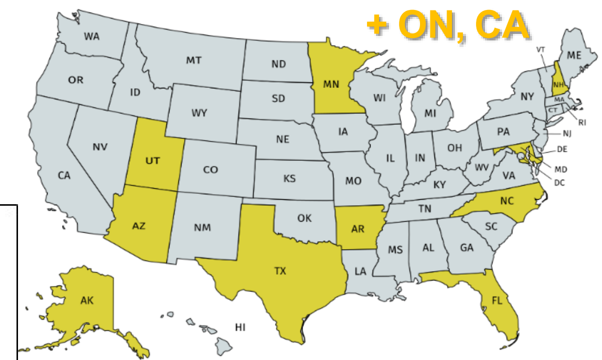
Binder Impacts on Performance from Agency Survey

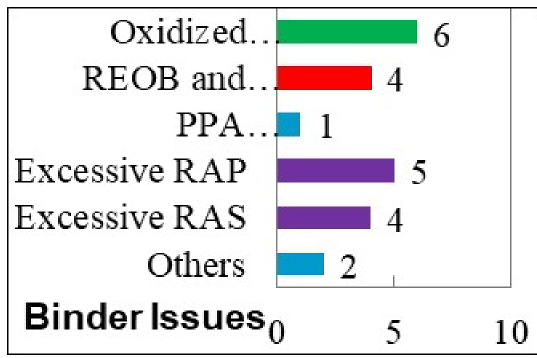
- **Surface Damage**

Transverse Cracking



Misc. Surface Cracking



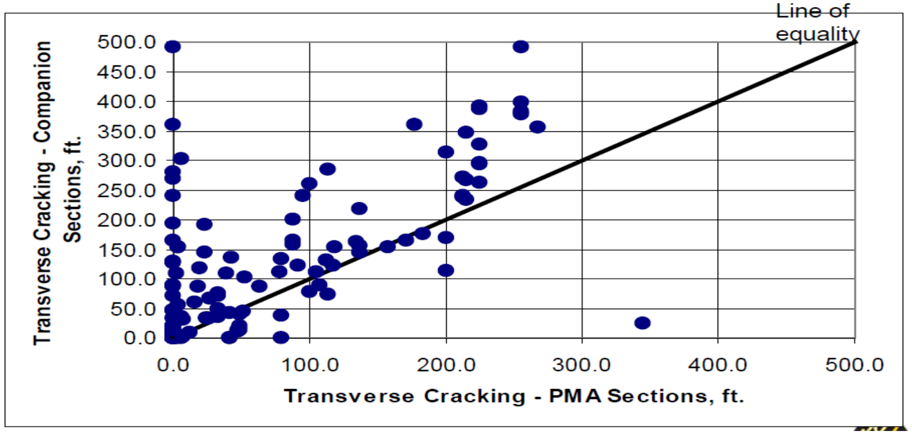


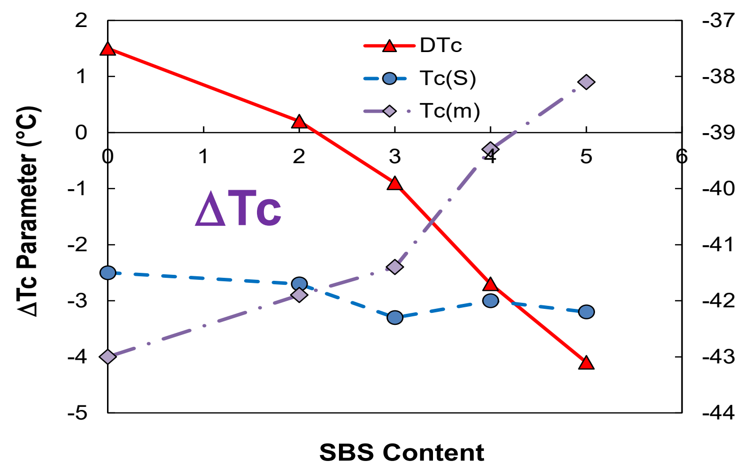
Block Cracking

Raveling

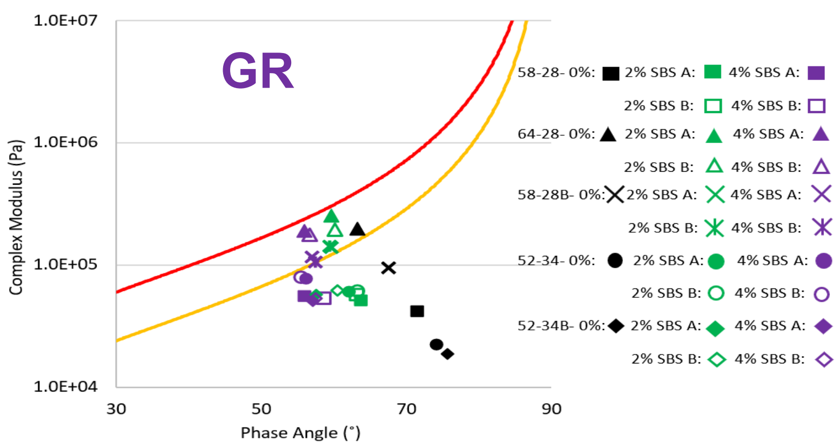
Performance and Rheological parameters of PMA's

- **PMA field proven performance** - Von Quintus, 2005

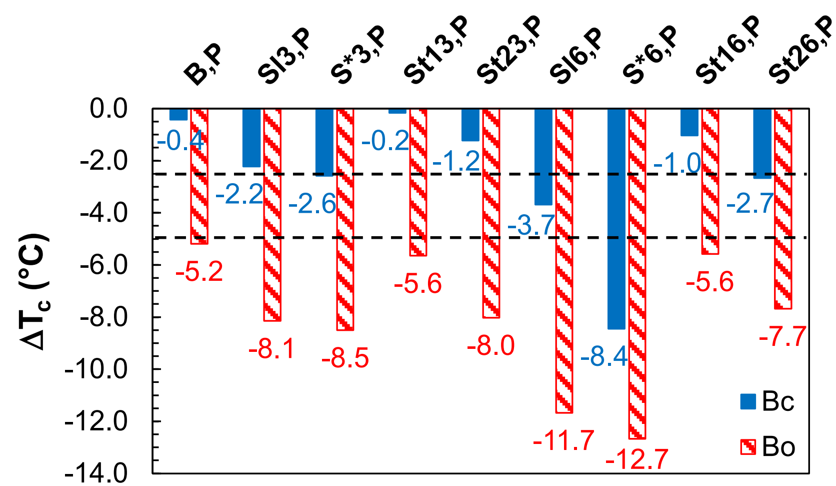




- **Rheologically "disproven"?**



(Aurilio et al.; CTAA 2020)

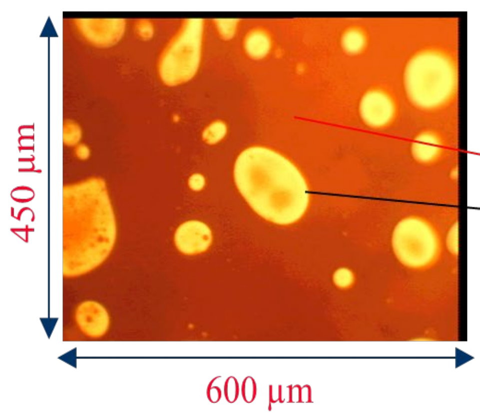


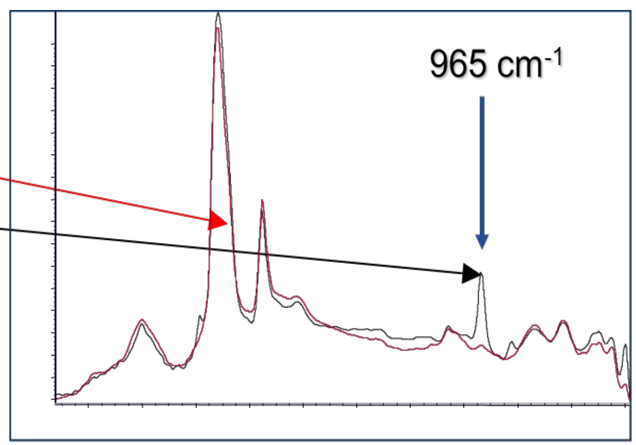
(Elwardany et al., C&BM, 2020)

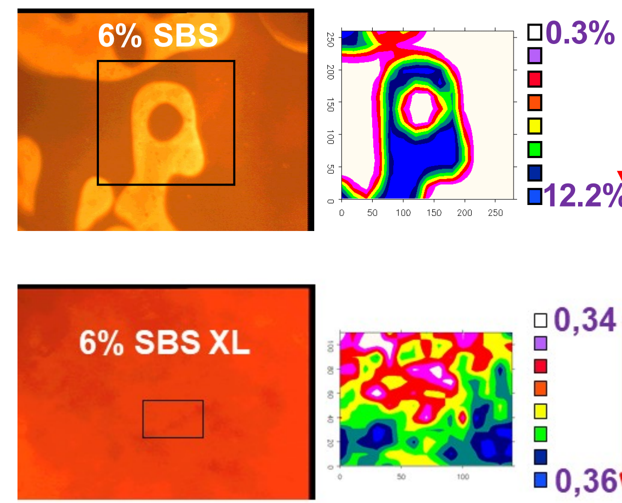
PMA microstructure considerations

Multiphase microstructure (IR microscopy)

- Polymer phase dispersed in an asphaltene rich continuous phase
- Swollen by slightly condensed aromatics and aliphatics
- Influenced by base binder, % polymer, reaction and processing
- Impacts both phase properties – PMA not just “P in A”!







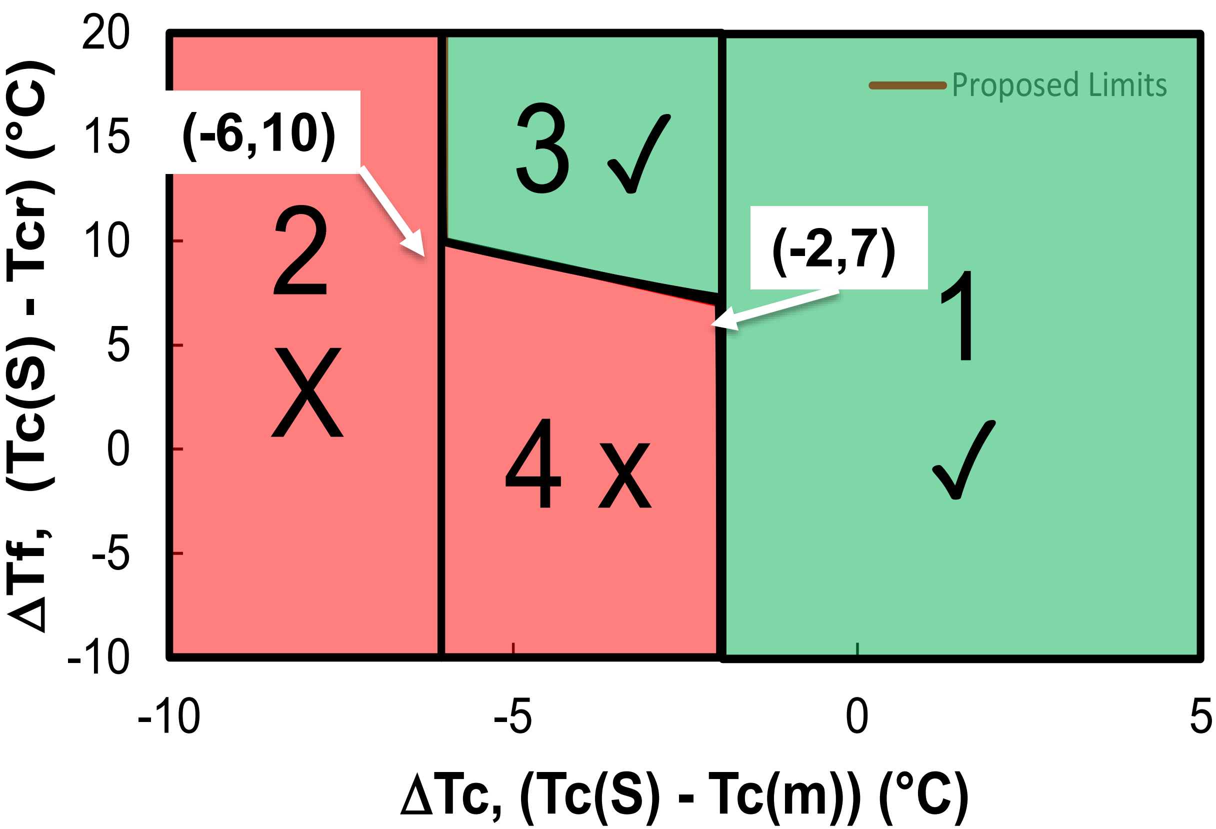
(Mouillet, 2008)

(Elwardany et al, C&BM 2020)

9-60 Proposed Specifications Based on ABCD & BBR and Added to PG

Testing

- **RTFO+PAV20**
- **LPG: BBR + ABCD <u>only</u> for critical binders**
- 3 PAV pans - sufficient for both BBR & ABCD Tests



Proposed specifications framework

- **Addition to current Climate-based PG**
- **Universal - blind**

- **BBR alone when**

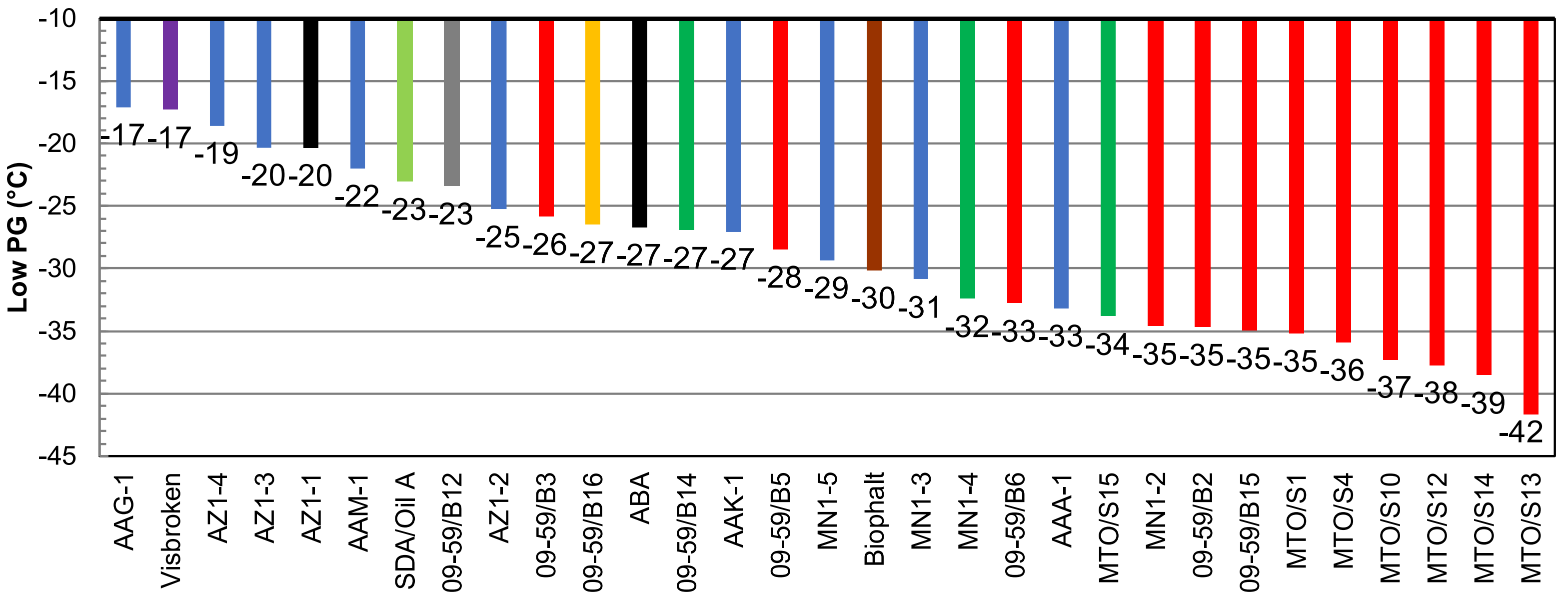
ΔTc > -2°C (Accepted)
ΔTc <-6°C (Rejected)

- **BBR & ABCD for**

-6°C<ΔTc <-2°C
ΔTf min = 7°C at -2°C
ΔTf min = 10°C at -6°C

09-60 Binder Matrix – LTPG ranking

- **Low PG Ranking after PAV20h-Aging from BBR**
  - **Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Visbroken**

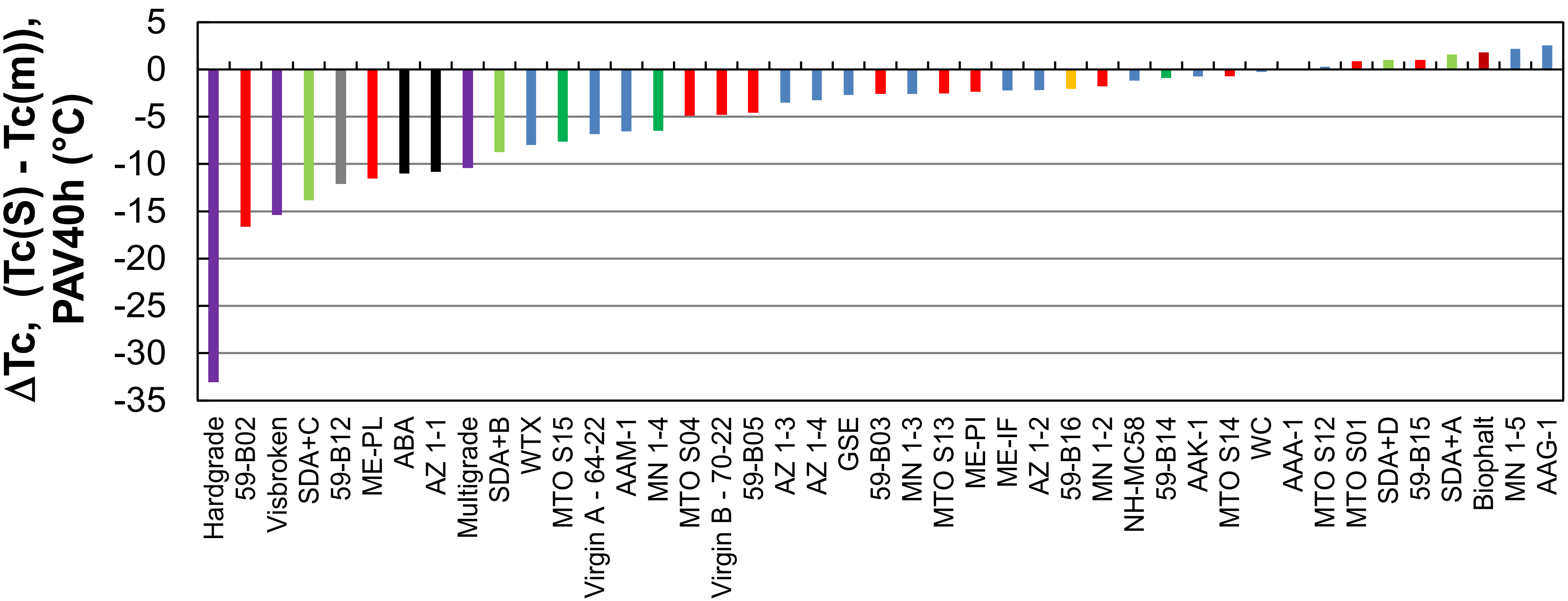


(Elwardany et al, C&BM 2020)

09-60 Binder Matrix – ΔTc ranking

❑ BBR & Corrected 4mm-DSR ΔT_c Ranking after PAV40h

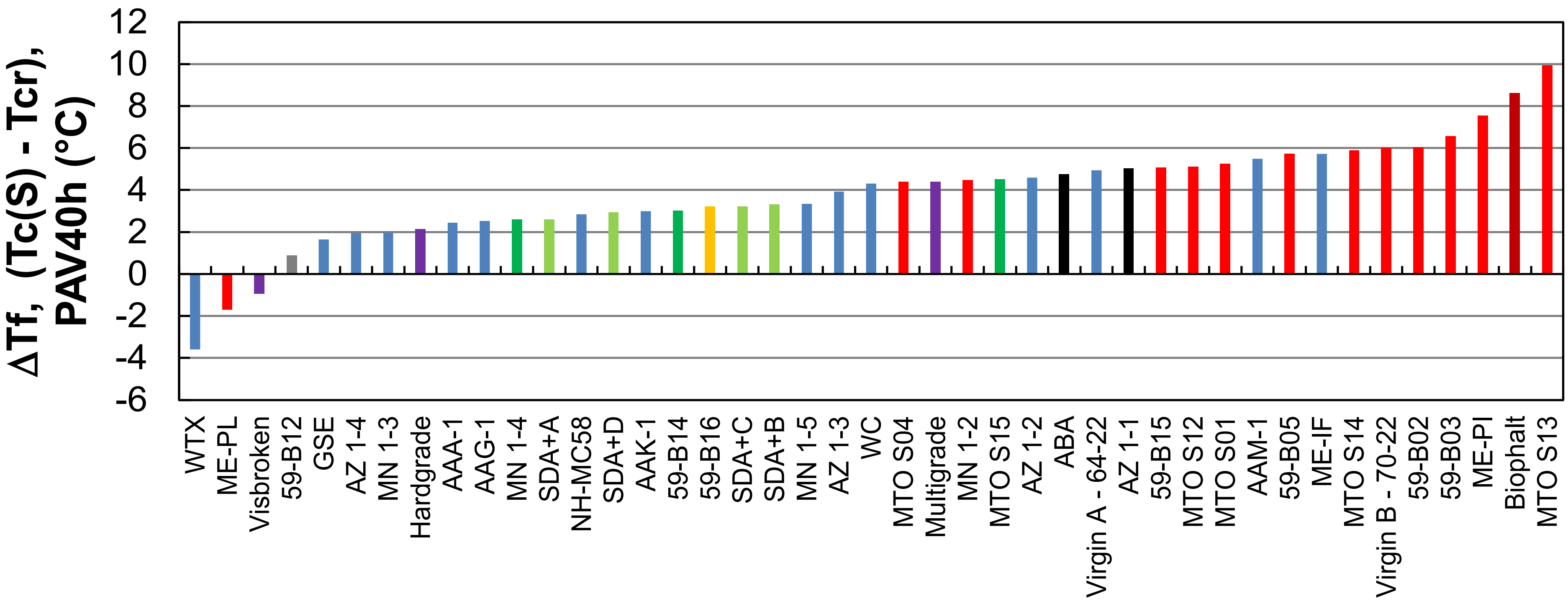
➢ Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, special binders.



(Elwardany et al., C&BM 2020)

09-60 Binder Matrix – ΔTf ranking

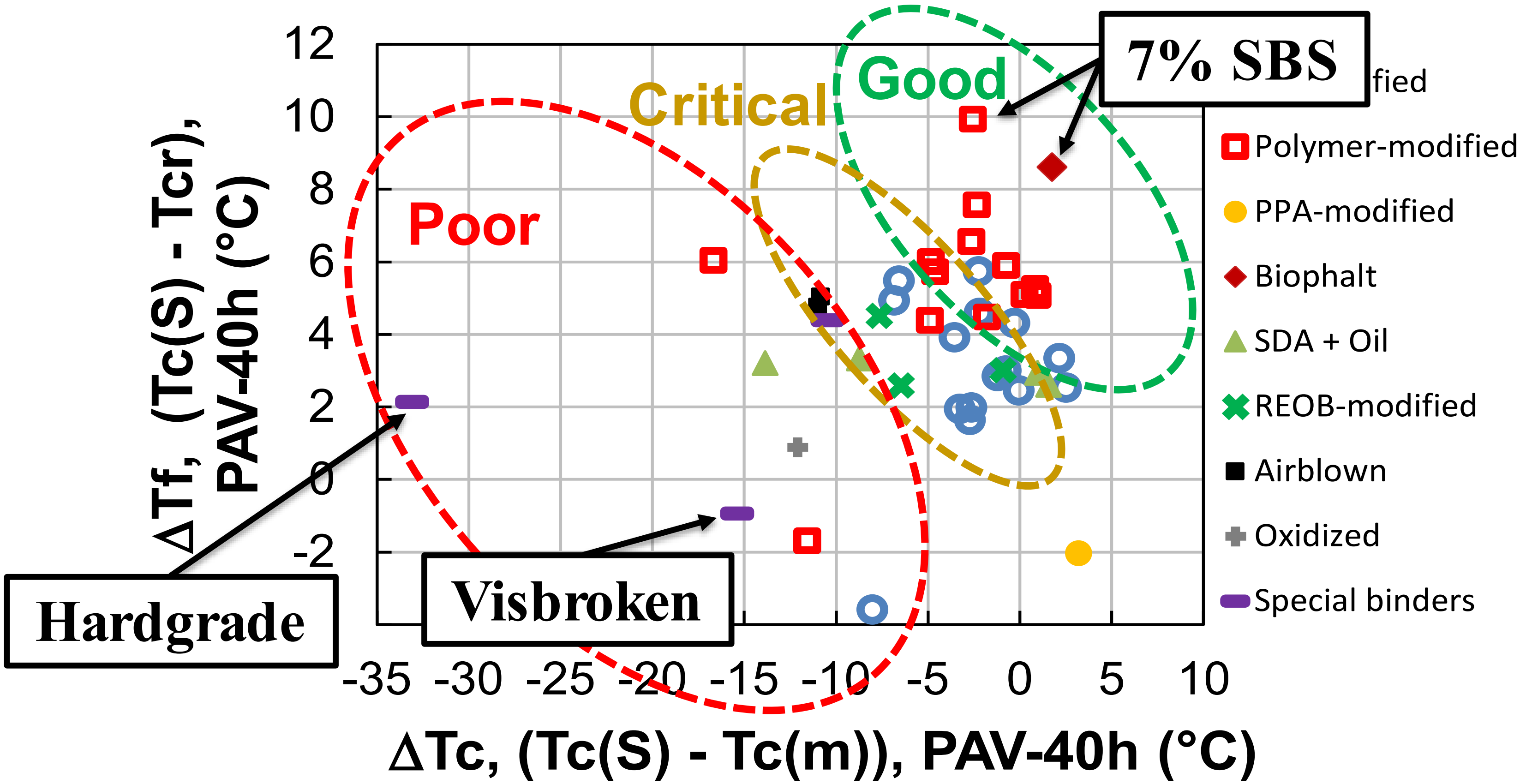
- **BBR & ABCD ΔT_f Ranking after PAV<u>40h</u>**
  - **Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Visbroken.**



(Elwardany et al., C&BM 2020)

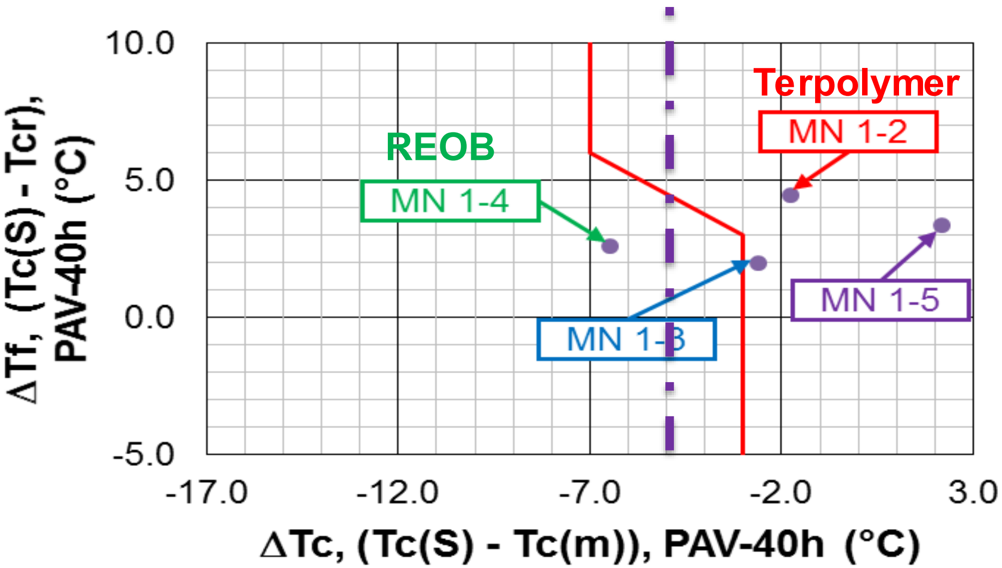
09-60 Binder Matrix – Combined ranking and assumed performance

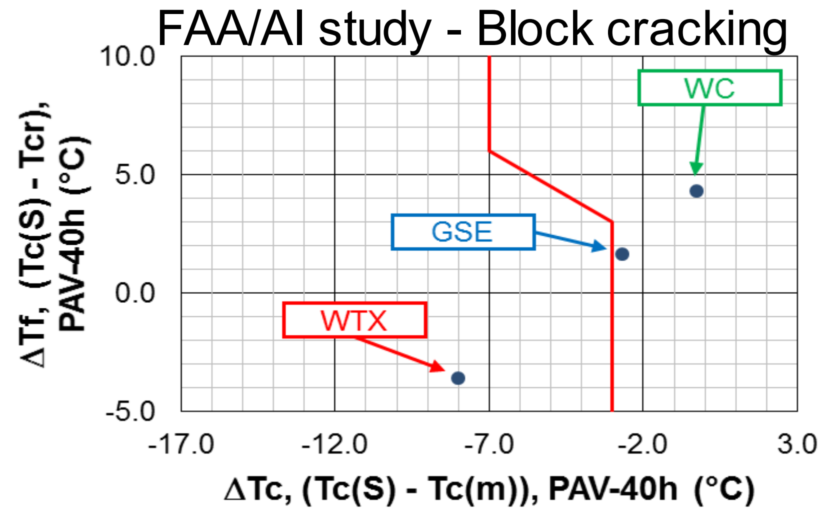
- **BBR & ABCD ΔT_f Ranking after PAV40h**
  - Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Special binders.

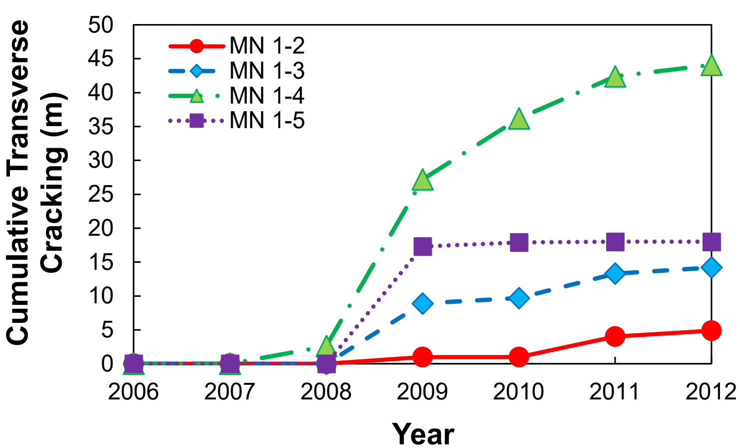


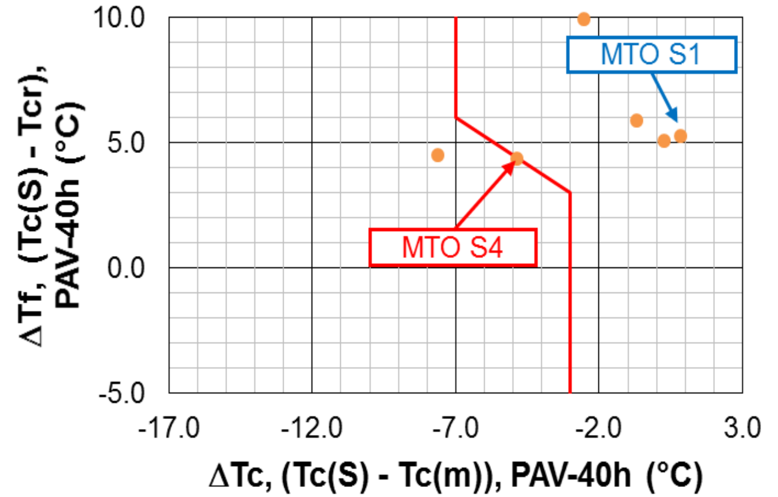
(Elwardany et al., C&BM 2020)

ΔTc & ΔTf Ranking Field validation





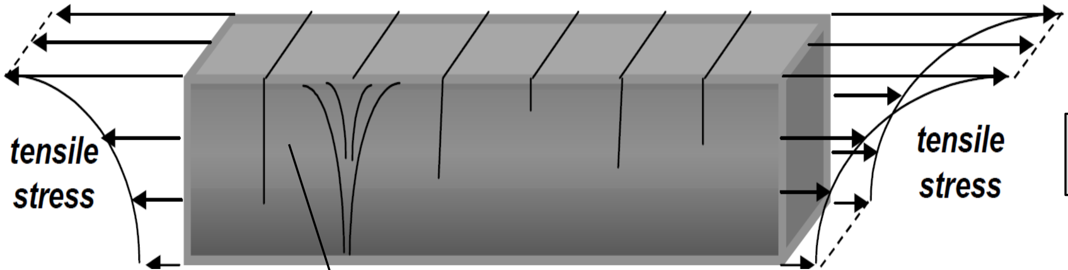


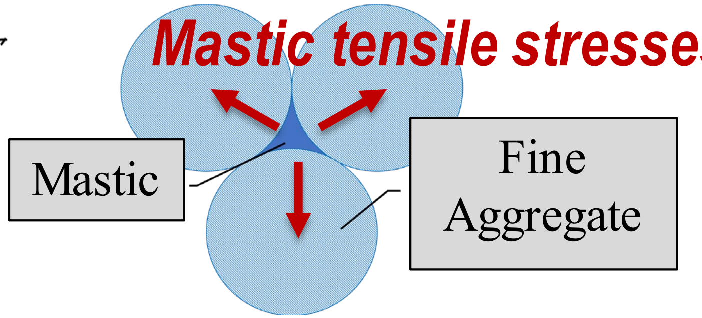


Thermal Stress Mechanism(s) for Damage

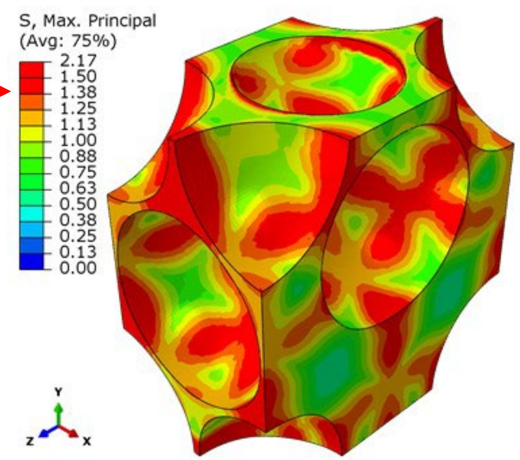
❑ Hypothesis: Two Thermally-Induced Damage Mechanisms

- ➢ **Mix Restraint (External)**
- ➢ **Mastic Restraint (Internal)**





Failure

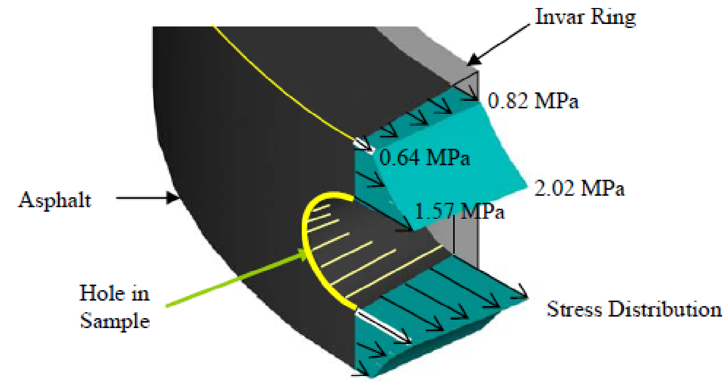


Viscoelastic
No External Restraint
-10°C/hr cooling rate

❑ Evidence for Unrestraint Specimens

- ➢ **Acoustic Emissions Results** (Behnia et al., 2018)
- ➢ **FEA & Mix-BBR(Sliver) Results** (Elwardany et al., AAPT 2019)

ABCD Failure Test to capture Stress build-up

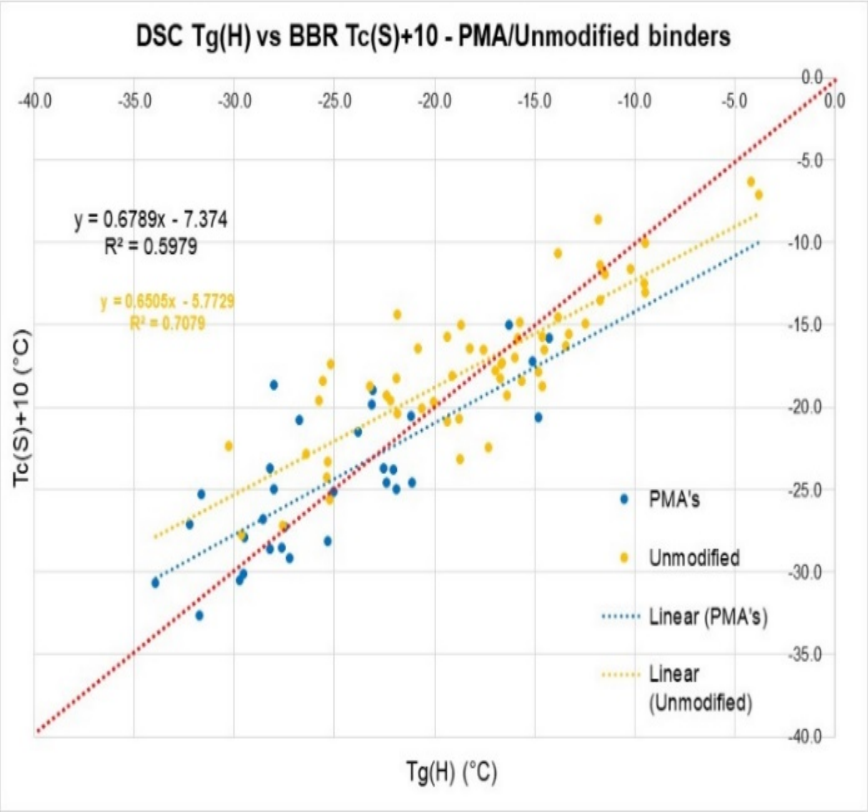


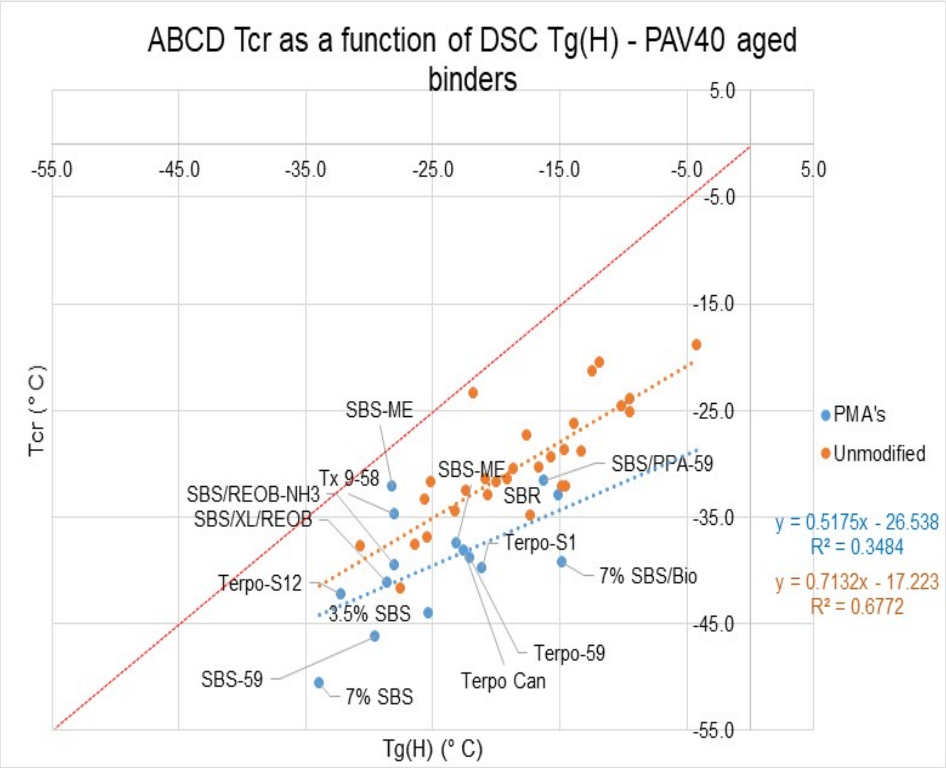
❑ Factors affecting ABCD - T_{cr}

- Coeff of Thermal Contraction controls volumetric change rate
- Binder LVE properties G* and δ
  - ✓ Ability to relax stresses
  - ✓ Thermal stress developed under given cooling conditions
- Binder Strength
- Parameters function of glass transition temperature T_g
  - ✓ T_g : transition region and not a single temperature
  - ✓ Complex binders usually have a wider T_g region

(Elwardany et al.; C&BM 2020)

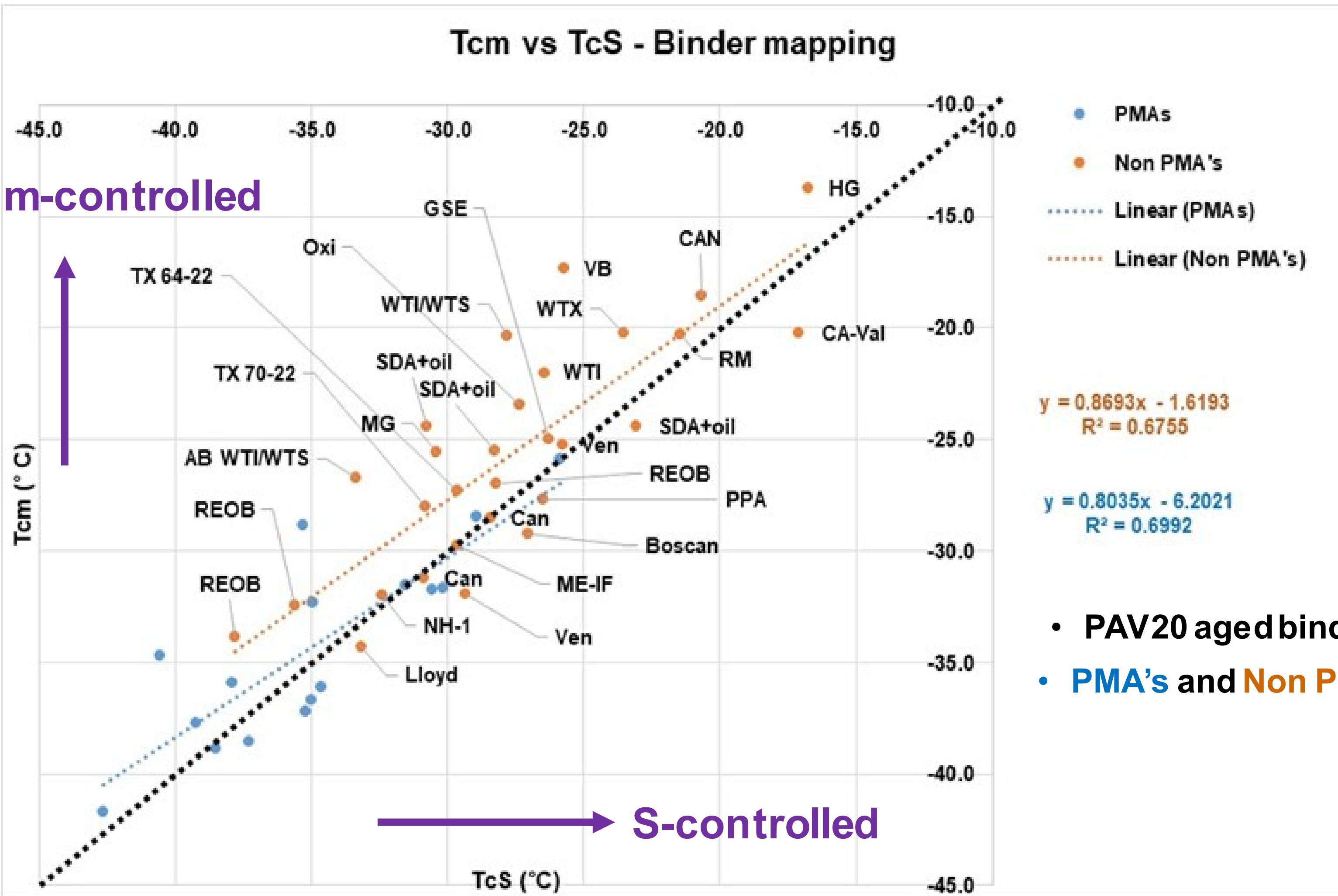
Tg influence on BBR Tc and ABCD Tcr





- **Tg (H) and Tc(S) correlation: better for unmodified, impacted by aging level** - **Confirms other works (Lesueur, Olard, Bahia)**
- **Tg and Tcr: lower correlations, shows PMA features**

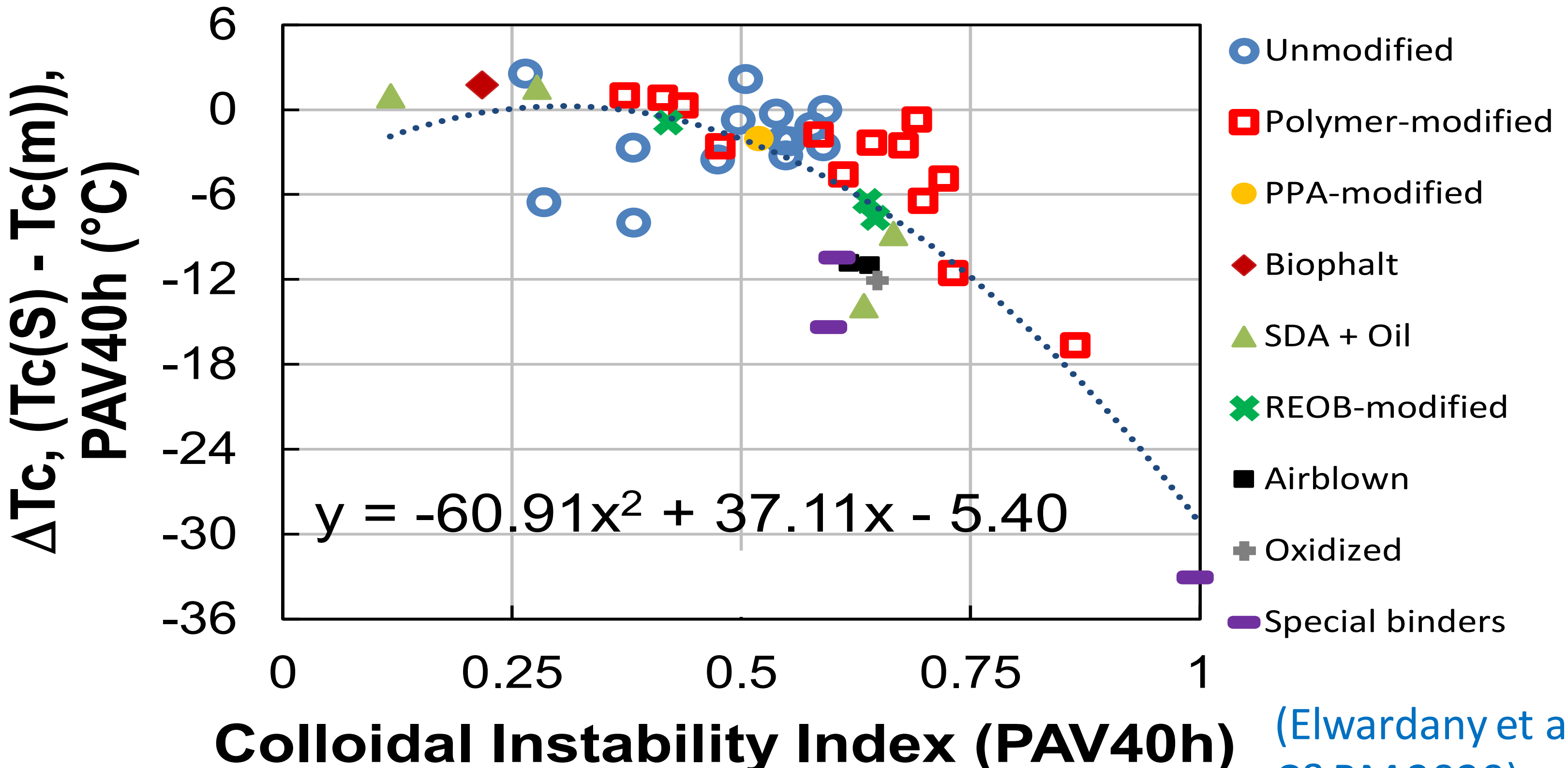
NCHRP 9-60 Binder Mapping



- PAV20 aged binders
- PMA's and Non PMA's

❑ Correlations between ΔT_c and CII after PAV40h

➢ Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Special binders

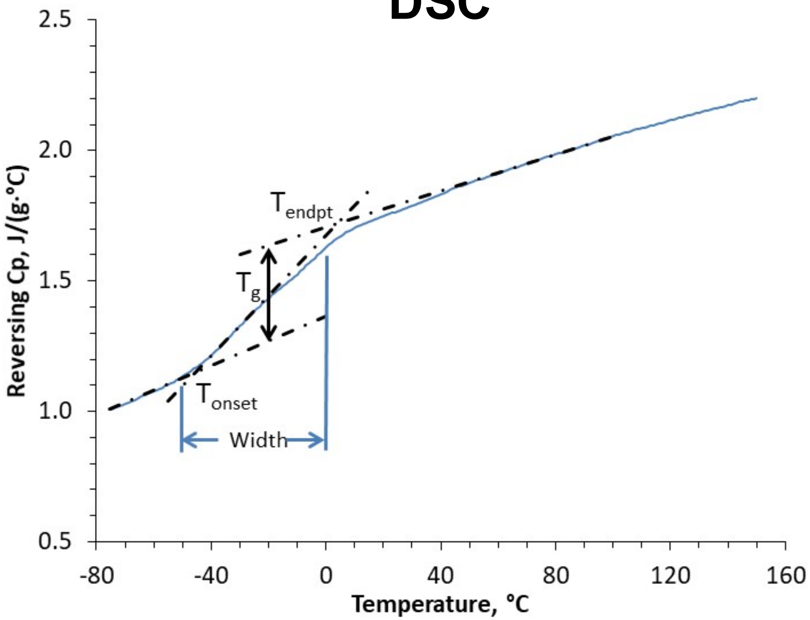


(Elwardany et al., C&BM 2020)

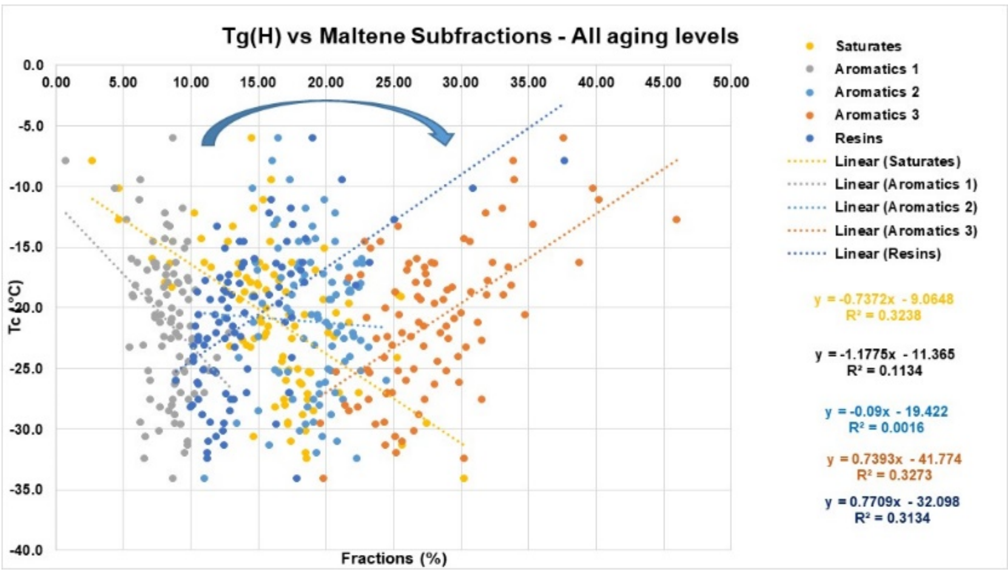
❖ Classical CII= (Sat+Asph)/(Arom+Res)

Tg and Maltenes

Glass Transition (Tg), Modulated DSC

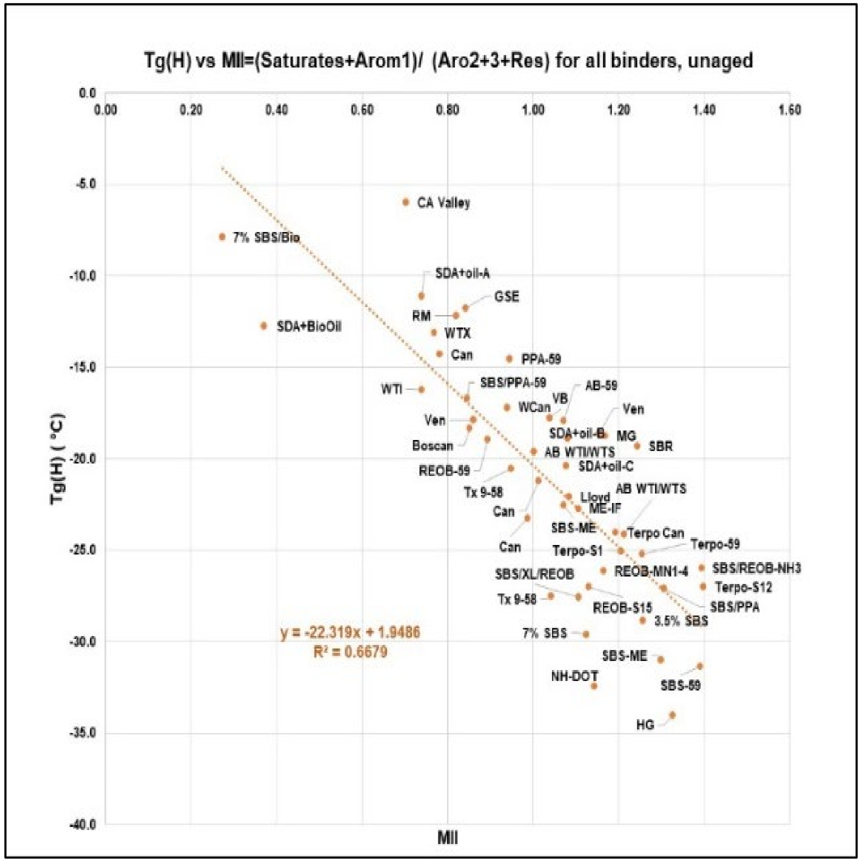


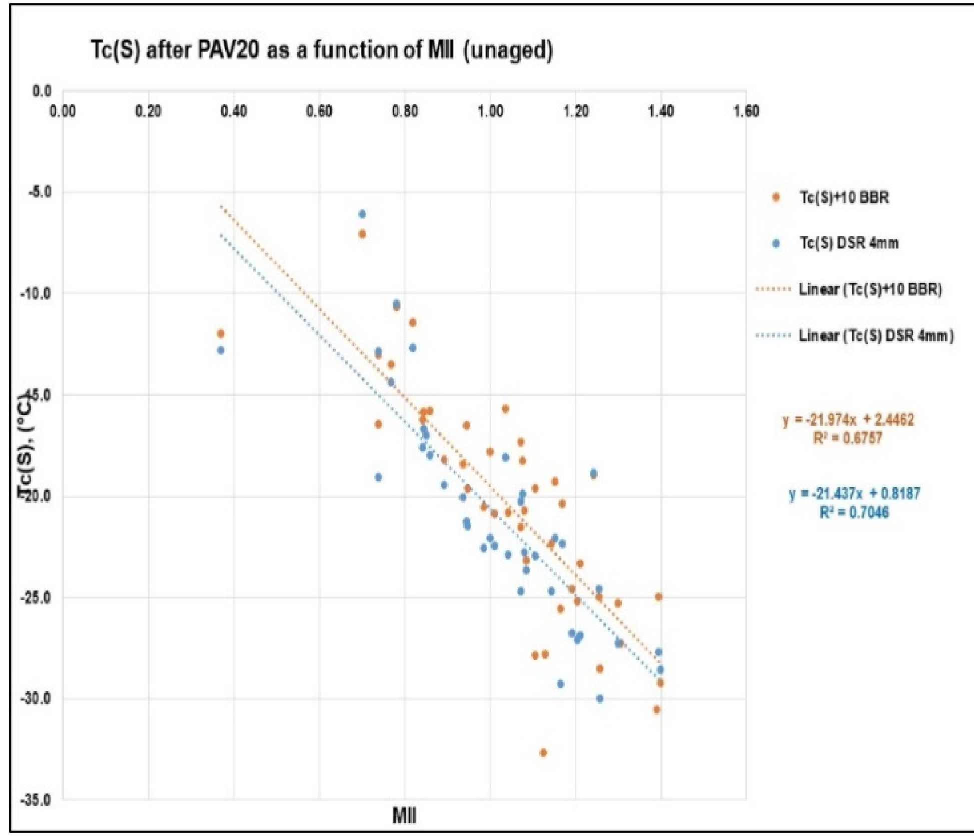
SAR-AD Maltene Subfractions



- **SAR-AD maltene subfractions effect on DSC Tg(H)**
- **Continuous trend evolution from Saturates (negative slope) to highly Aromatics and Resins (positive slope)**
- **No trend with asphaltenes: no direct effect on Tg**

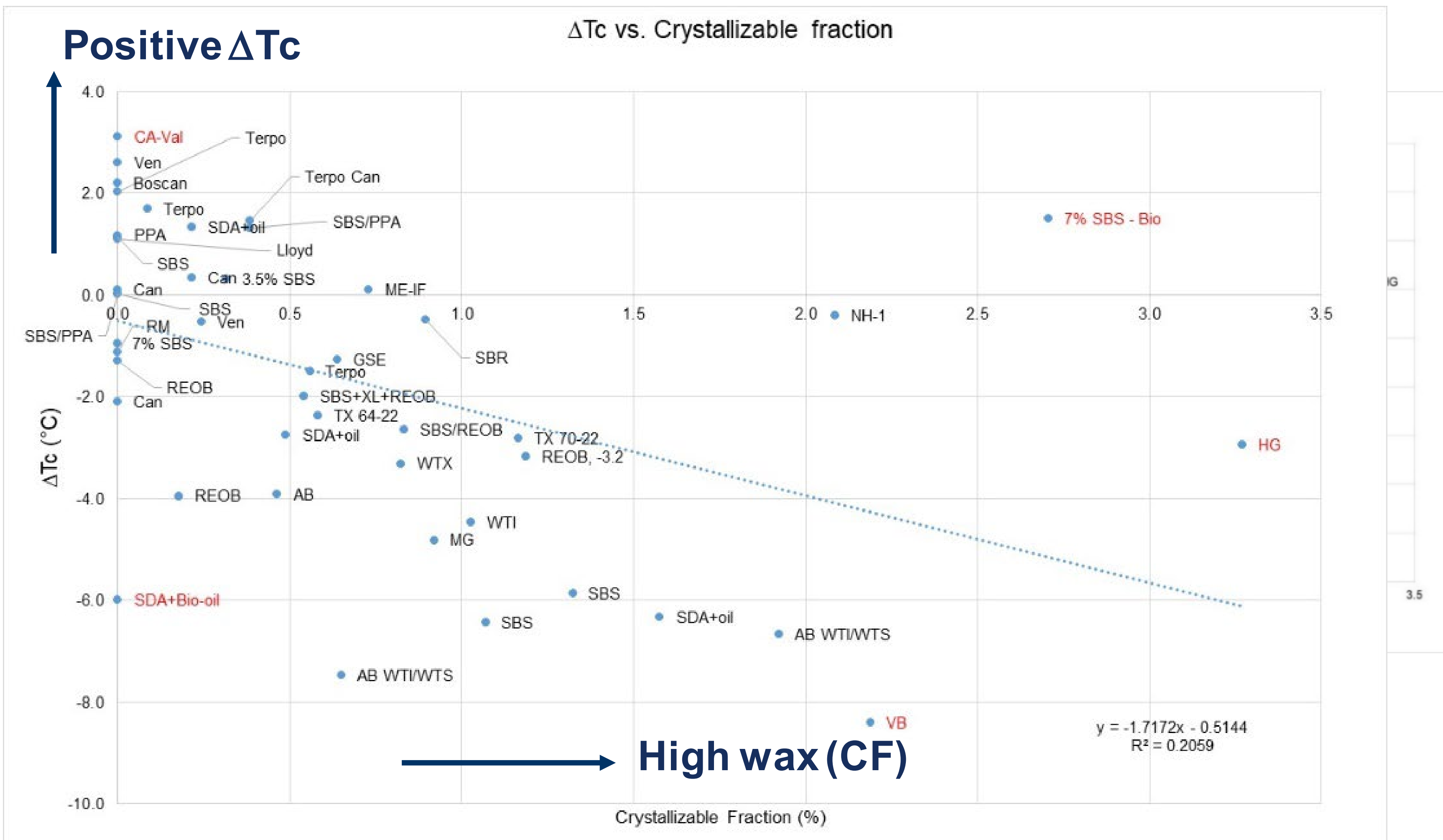
Tg(H) and Tc(S) and Maltenes





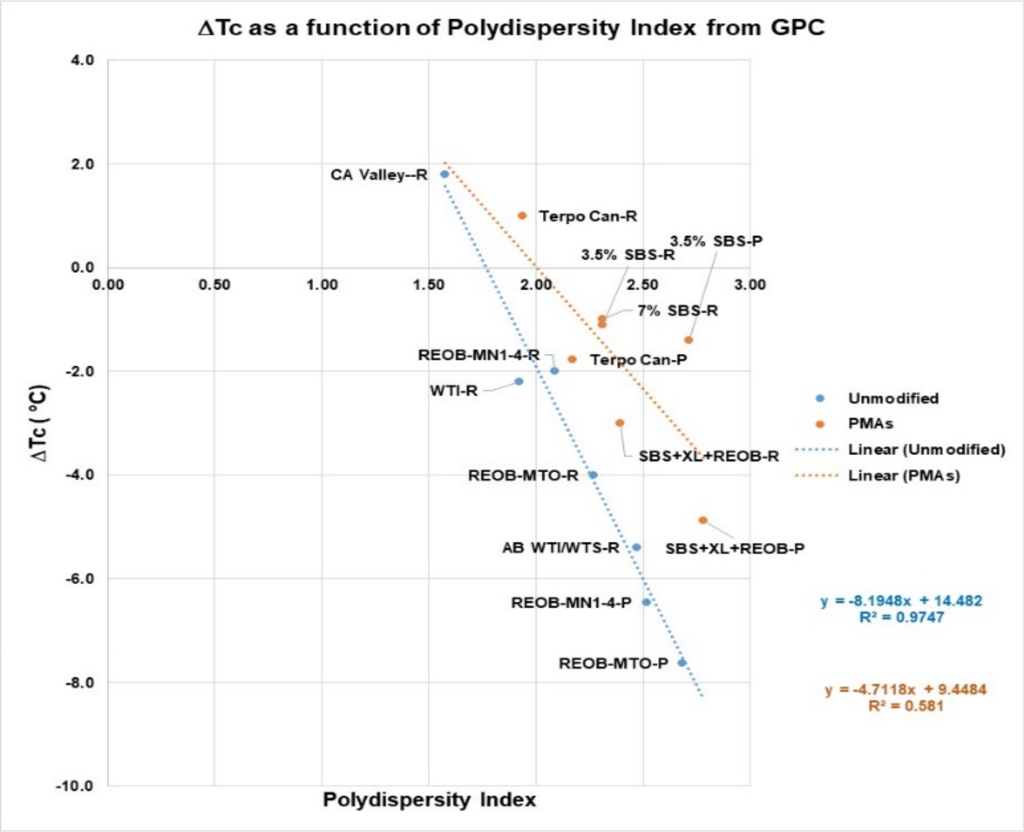
- **Relationship between Tg(H) or Tc(S) with MII**
- **New composition balance index: Maltene Instability Index MII: (Sat+Aro1)/(Aro2+Aro3+Res)**

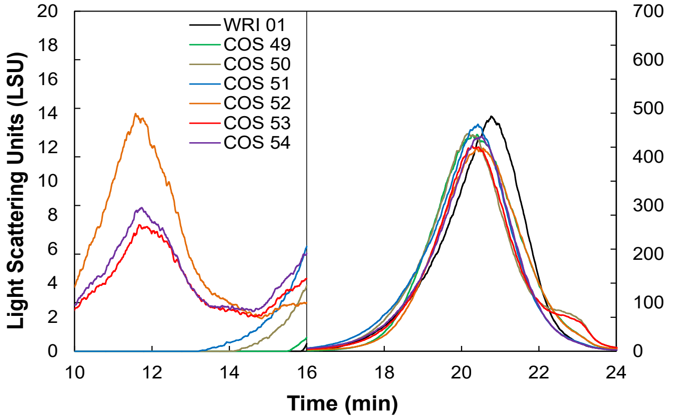
ΔTc and wax



- **Waxy crudes stand out in mapping**
- **… and ΔTc**

Relaxation and Molecular Weight Distribution





- ***ΔTc from BBR vs. binder polydispersity from GPC***
- **ΔTc is more complex than either Tc, and relates on GPC/SEC polydispersity index or molecular associations – captures PMA's singular features**

Summary

- **Thermal stress mechanisms**
  - Internal and external - Macro and micro scales
  - Influence of the glass transition
- **Formulation**
  - Crude oil origin and refinery process
  - Chemical composition
  - Balance – maltenes, asphaltenes and waxes (CF)
  - Additives / polymers interactions with the base
- **Aging, both chemical (oxidative) and physical**
- **Testing**
  - Importance of glass transition and equi-stiffness temperature on defining testing conditions – Ref. temperature needed
  - Power and limitations of rheological parameters
  - Usefulness of failure, particularly for PMA's
  - Combination proposed for future specifications

DRAFT

Summary

	Wax from asphalts	REOB	Air blowing	Thermal Conversion visbreaking	Polymers Physical blends	Crosslinked SBS or reacted Terpolymers
CII						
PI (GPC)						
Oxidation						
PH						
PG Low						
Tc(S)						
Tc(m)						
ΔT_c						
Tcr (ABCD)						
ΔT_f						
Failure Modulus (DTT)						

What kills asphalt?

Poor formulation and poor testing…

Neither one is simple, but progress is possible!

Thank You!

Questions?

Contact: jplanche@uwyo.edu

Findings and Recommendations From NCHRP Project 9-61

Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures

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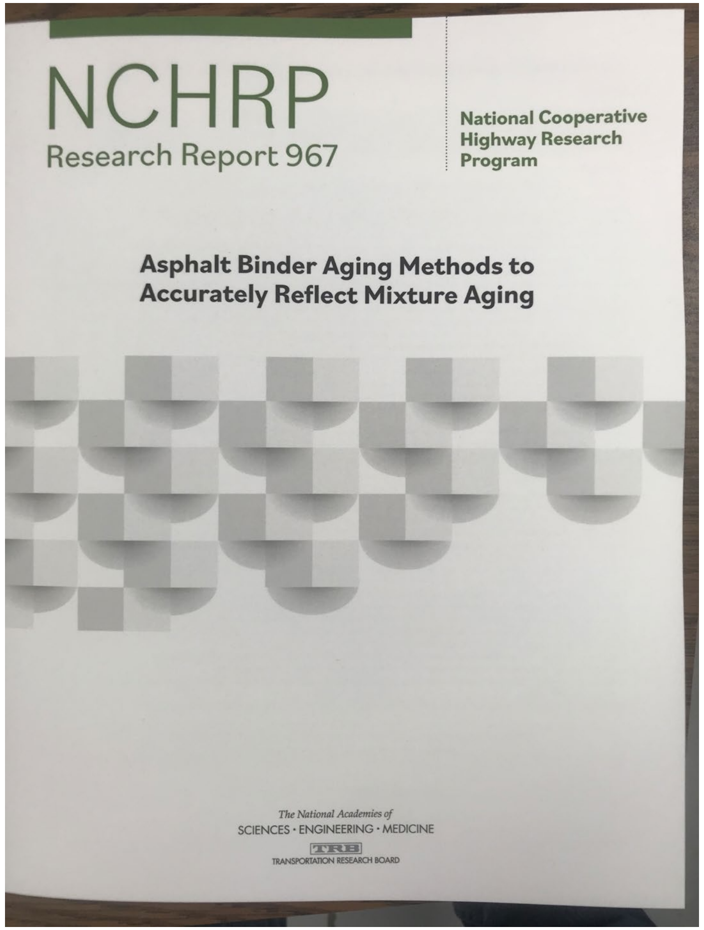
Advanced Asphalt Technologies, LLC

NCHRP Project 9-61

- Completed December 2020
  - NCHRP Report 967
- Research Team
  - Advanced Asphalt Technologies, LLC
    - Ramon Bonaquist - PI
  - Western Research Institute
    - Jeramie Adams - Co-PI
  - Consultants
    - Dave Anderson
    - Gayle King
    - Erick Sharp



Today's Outline

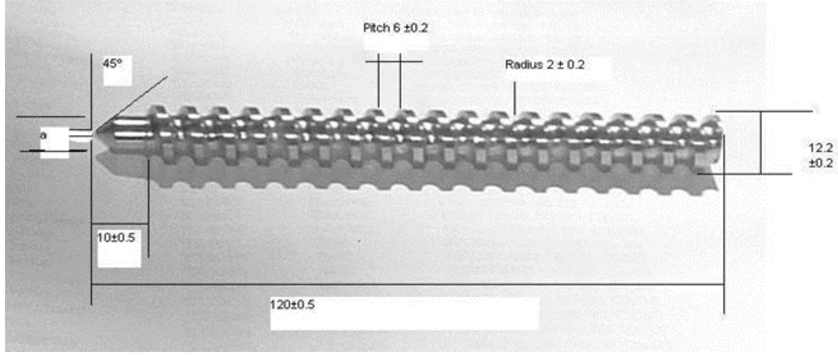
- Objectives
- Short-Term Conditioning
  - Approach
  - Findings
  - Recommendations
- Long-Term Conditioning
  - Approach
  - Findings
  - Recommendations

Objectives

- Evaluate laboratory conditioning procedures
  - AASHTO T 240, AASHTO R 28 and alternatives
- Recommend improvements
  - New procedure
  - Modifications to existing procedures
- Calibrate the improved procedures to accurately simulate aging
  - Mixture production, transport, and placement
  - Service life of the pavement

Short-Term Conditioning

- Concerns with AASHTO T 240
  - Uniformity of the film and how well it is renewed is viscosity dependent
  - Some modified binders tend to crawl out of the bottle
- Alternatives Evaluated
  - AASHTO T 240
  - AASHTO T 240 with preheated containers
  - Modifications to AASHTO T 240 made in the U.K. Ageing Profile Test
  - Static Thin Film Test (12.5 g binder in PAV pan)



Short-Term Evaluation

- Compare binder conditioning procedures to binder recovered from short-term oven conditioned mixtures
  - NCHRP 9-52 recommendations
  - Designed as a paired difference experiment
  - HMA and WMA temperatures
  - Eight Binders

Neat PG 52-34	SBS PG 64-34
Terpolymer PG 64-34	SBS PG 76-28
Neat PG 64-22	PG 64-22 with 3 % SBR Latex
SBS PG 76-22	SBS 82-22

Binder Loss Survey

- Maine DOT
- 33 Agencies responded
  - 10,500 annual tests
- Binder loss occurred in about 4 % of samples
  - 15 Agencies list only modified binders as susceptible
  - 7 Agencies list only neat binders as susceptible
  - 2 Agencies list both modified and neat binders as susceptible

Major Short-Term Conditioning Findings

- For HMA Conditions
  - No significant difference in aging index for any of the short-term binder conditioning procedures and short-term oven aging of mixtures
  - No viscosity effect identified for AASHTO T 240 or any of the alternatives
  - Binder leakage in AASHTO T 240 occurs in about 4 % of samples
- For WMA Conditions
  - Mixing screw procedures are needed when the viscosity of the binder at the conditioning temperature exceeds about 0.55 Pa·s

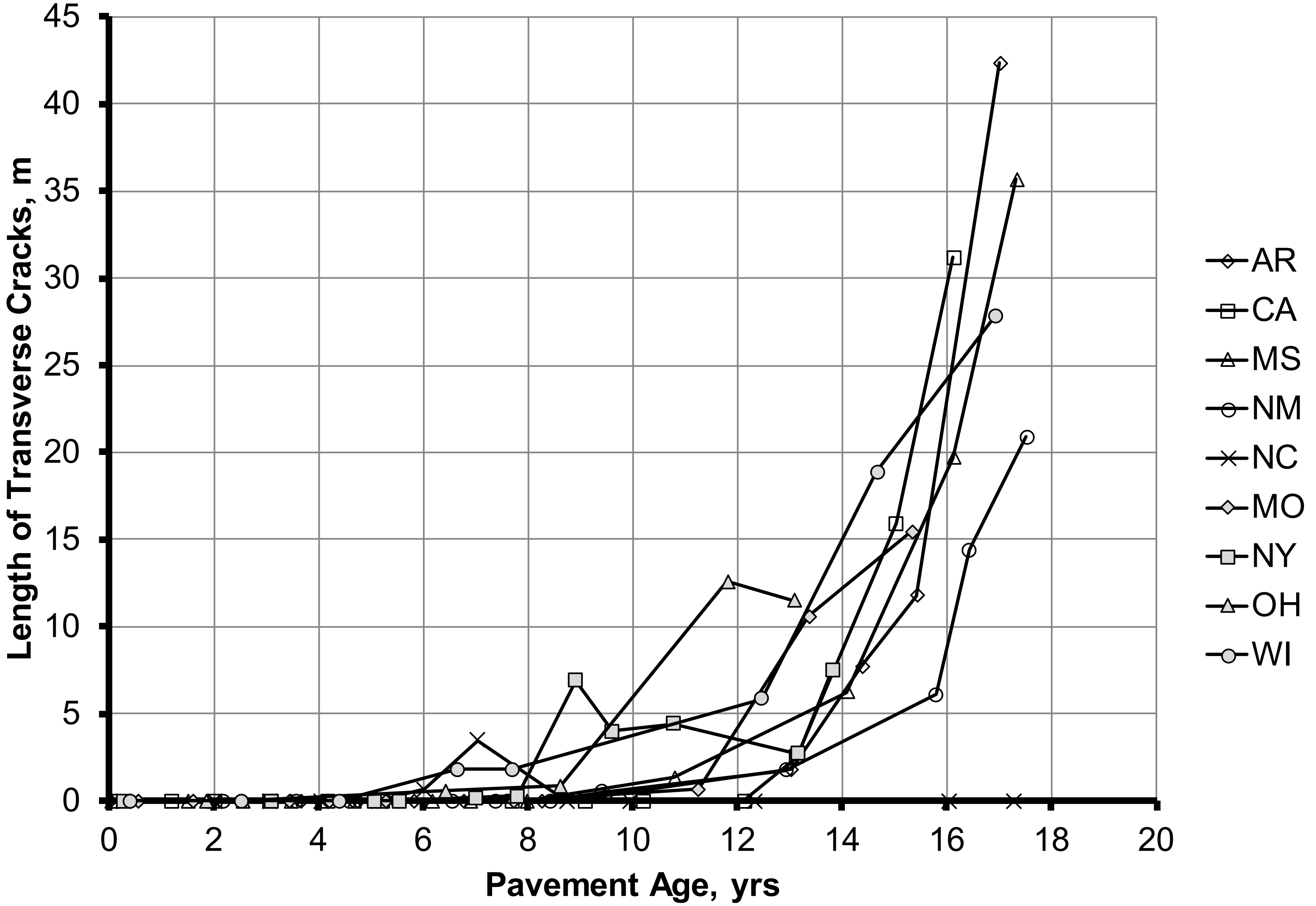
Short-Term Conditioning Recommendations

- Keep AASTHO T 240
  - Further investigate procedure/training to reduce instances of binder loss
- Consider Static Thin Film If 12.5 g PAV Adopted
  - Eliminates binder transfer between short- and long-term conditioning
  - Condition binder using a small positive pressure to eliminate elevation effect
    - Project 20-07/Task 400, Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder

Long-Term Conditioning

- Concerns with AASHTO R 28
  - Conditioning is not severe enough
  - Service life that is simulated is not well defined
- Alternatives Evaluated
  - PAV film thickness
  - PAV temperature
  - PAV conditioning time

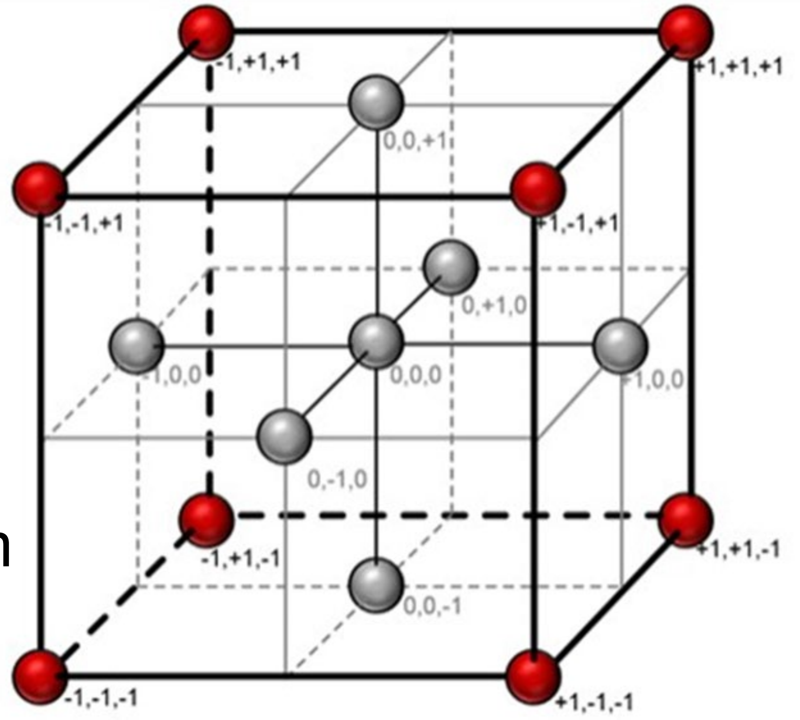
What is Target Age for Long-Term?



Transverse Cracking in SPS 8 Sections

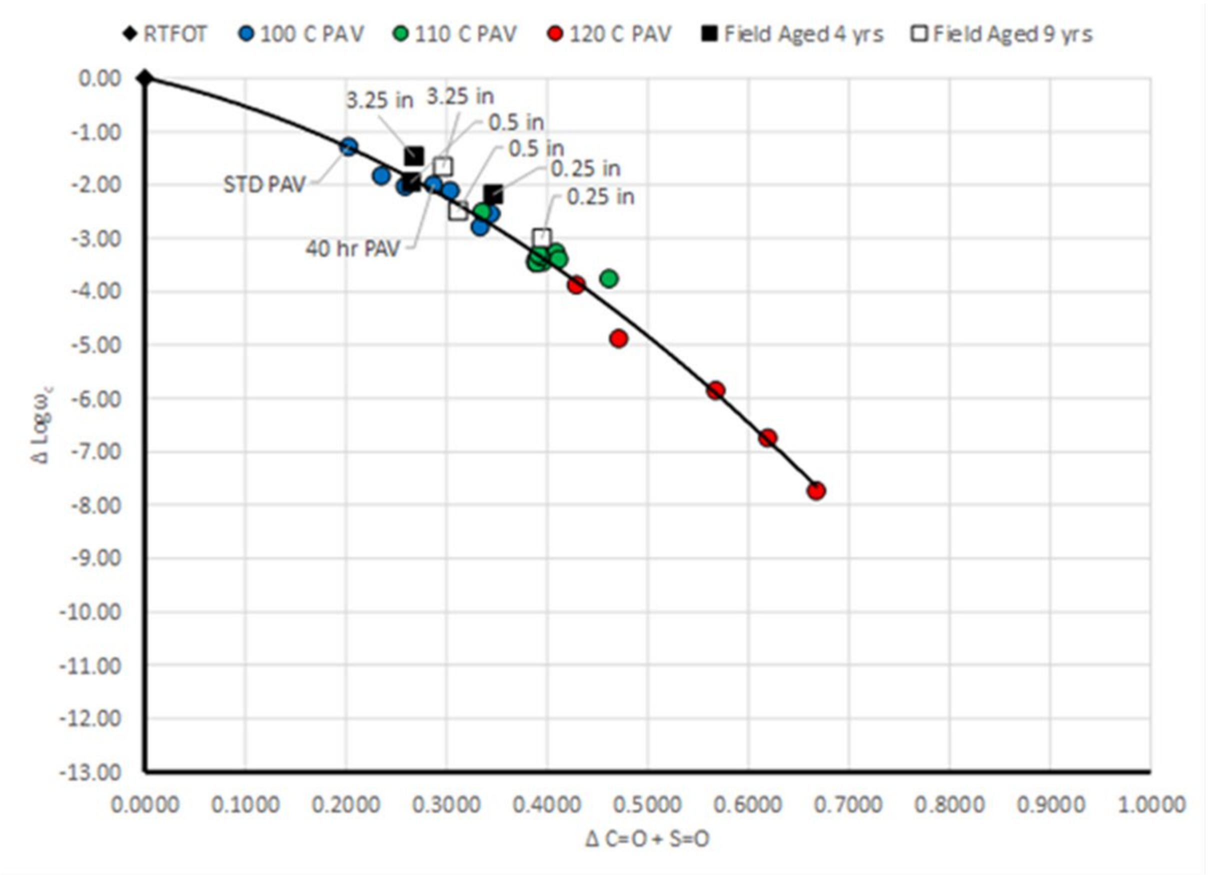
Long-Term Evaluation

- Response Surface Experiment
  - Varied temperature, film thickness, and conditioning time
  - Compare lab conditioned recovered binder from ARC AZ and MN sites
  - Master curve parameters and FTIR data
- Calibration Experiment
  - 26 Pavement Sections from LTPP
  - Cores and Original Binder
  - Age: 8 to 19 yrs
  - Wide range of climates



Major Long-Term Response Surface Findings

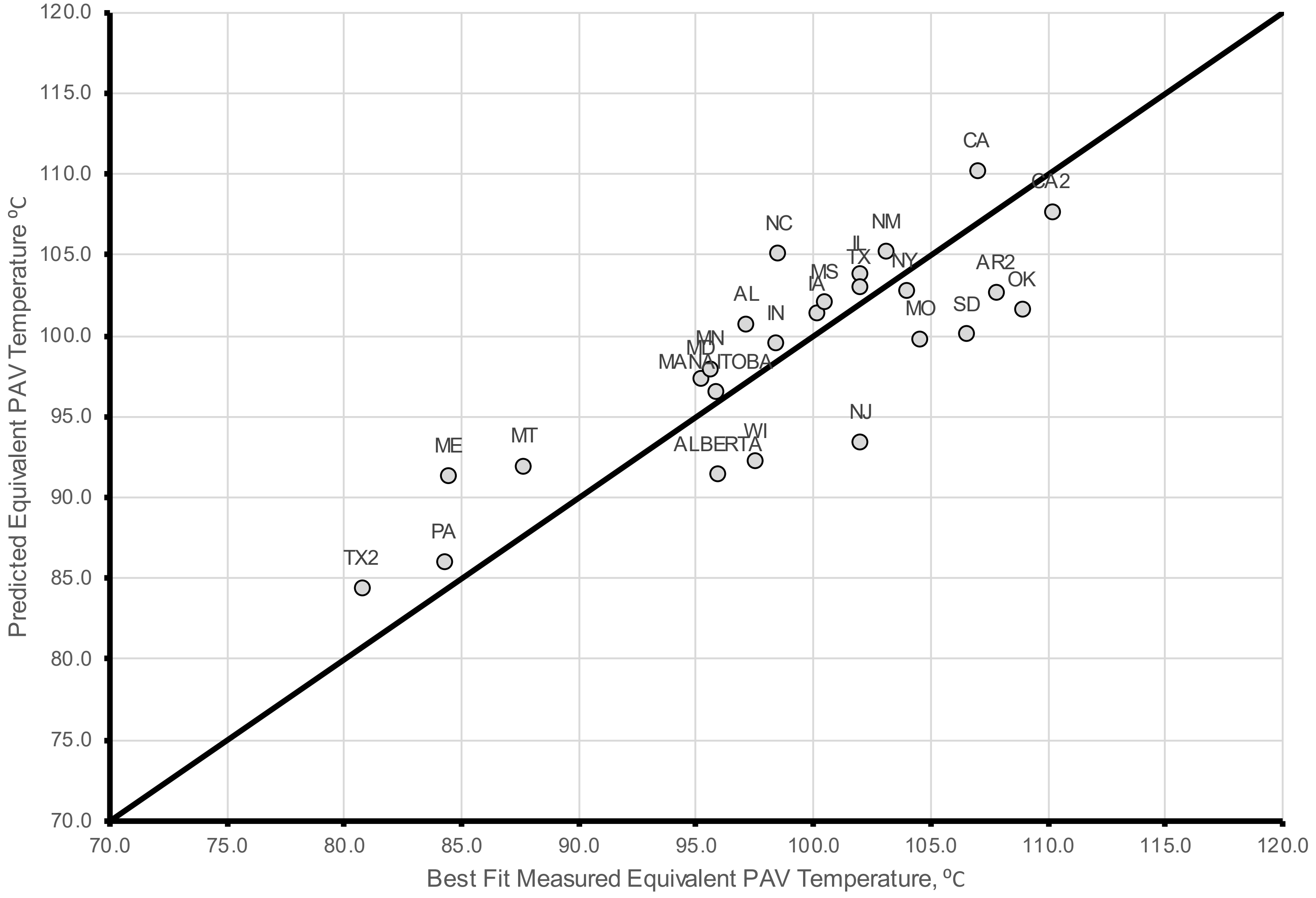
- Smooth evolution of aging in PAV
- PAV reproduces field aging
- Higher temperature, thinner films, and/or longer conditioning times needed to simulate near surface aging
- 40 hr, 50 mm thickness and 20 hr, 12.5 mm thickness approximately equal



Long-Term Calibration Experiment

- Calibration Experiment
  - 12.5 g Mass
  - 20 hr Conditioning Time
  - Varied PAV Conditioning Temperature To Match Recovered Binder Properties
  - Statistical Model to Account for
    - Temperature
    - Age
    - Air Voids
    - Binder Temperature Aging Sensitivity
    - Depth

PAV Conditioning Temperature Model



12.5 g, 20 hr PAV Temperatures to Simulate 10 years of In-Service Aging in Top 1 Inch

Average 98 % Reliability High and Low Pavement Temperature	Calculated PAV Temperature °C	Recommended Temperature °C	% of LTPPBind 3.1 Stations	PG Grade Based on Environment
-6[1]	84.4	85	1	PG 40-52; PG 46-52; PG 40-46
-3[1]	86.6			
0[1]	88.9	90	4	PG 52-52; PG 46-46; PG 40-40 PG 46-40; PG 52-46; PG 40-34
3	91.1			
6	93.4	95	20	PG 58-46; PG 52-40; PG 46-34; PG 40-28 PG 58-40; PG 52-34; PG 46-28; PG 40-22
9	95.7			
12	97.9	100	41	PG 64-40; PG 58-34; PG 52-28; PG 46-22; PG 40-16 PG 64-34; PG 58-28: PG 52-22; PG 46-16; PG 40-10 PG 64-28; PG 58-22; PG 52-16; PG 46-10
15	100.2			
18	102.5			
21	104.8	105	20	PG 70-28; PG 64-22; PG 58-16; PG 52-10 PG 70-22; PG 64-16; PG 58-10
24	107.1			
27	109.3	110	13	PG 70-16; PG 64-10; PG 70-10
30	111.6			
33[1]	115.0	115	1	PG 76-10

[1] Outside range of data used in calibration

Major Long-Term Conditioning Findings

- Feasible to simulate approximately 10 years of near surface, in-service aging using the PAV
  - 12.5 g conditioned for 20 hours
  - 50 g conditioned for 40 hours
  - Temperatures between 85 and 115 C depending on climate
  - Pressure of 2.1 MPa
- Residue from 12.5 g PAV conditioning is significantly more aged than standard PAV residue
  - Need to adjust performance grading criteria

Major Long-Term Conditioning Findings (Continued)

- 12.5 g PAV conditioning requires greater attention to detail
  - Thicker pans to reduce warpage
  - Tighter tolerance on levelness

Long-Term Conditioning Recommendations

- Current Performance Grading
  - No change
- Conditioning for Adoption of ΔT_c Criterion
  - Single 20 hr PAV run
  - Use 2 50 g pans for low temperature/intermediate grading
  - Use 8 12.5 g for ΔT_c evaluation using 40 hour ΔT_c criterion
- Conditioning for Revised Performance Grading
  - Static thin film conditioning for short-term conditioning
  - 12.5 g PAV for long-term

Questions/Discussion

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Other TRB events for you

- *July 16:* **Review of Federal Highway Administration Infrastructure R&D - Expert Task Group on Pavements**

- *August 10*: **National Conference on Transportation Asset Management**

- *August 25*: **Best Practices for Unsurfaced Road Evaluation and Rating**

https://www.nationalacademies.org/trb/events

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