3.3 A Tale of Two Deltas: Analysis approach, proposed limits, and validation work to address binder quality-related thermally induced surface damage

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Federal Highway Administration, and Western Research Institute, USA

Abstract:

Superpave specifications address binder properties that may lead to rutting, transverse cracking, and fatigue damage with varying degrees of success. However, asphalt binder production and formulation has significantly changed and introduced much more variability in terms of quality since the development of Superpave Performance-Grade system because of economic, technical, and environmental reasons. Consequently, aged-induced surface distresses under combined thermal and traffic loading have become the main challenge for highway agencies. Thermally induced surface deterioration appears in the form of traditional transverse cracking, block cracking, and raveling, or accelerating damage at construction joints. This study evaluated the limitations of the proposed linear viscoelastic (LVE) rheological cracking surrogates, such as ΔT_c, R-value, and G-R parameters, and the ability of the Asphalt Binder Cracking Device (ABCD) failure test to overcome these limitations. ABCD is particularly appropriate to rank binder performance because the measured cracking temperature (T_{cr}) encompasses binder LVE properties, failure strength, coefficient of thermal contraction, and cooling rate. The proposed parameter ($\Delta T_f = T_c$ (S=300 MPa) from BBR - T_{cr} from ABCD) relates the failure temperature to the equi-stiffness temperature and gives credit to well-formulated and compatible polymer-modified binders expected to increase binder strength and strain tolerance. This paper proposes a specification framework based on both ΔT_c and ΔT_f, universally applicable, regardless of binder composition. Additionally, preliminary specification limits are proposed based on the analysis of 44 binders, 15 with corresponding field performance data. Obviously as confirmed by a recent stakeholder workshop and industry feedbacks, these preliminary specification limits need further validation and possible adjustments to account for regional experience and local challenges. Current efforts at FHWA TFHRC, in collaboration with various State Highway Agencies (SHA's), are focused to further validate the framework and specification limits.

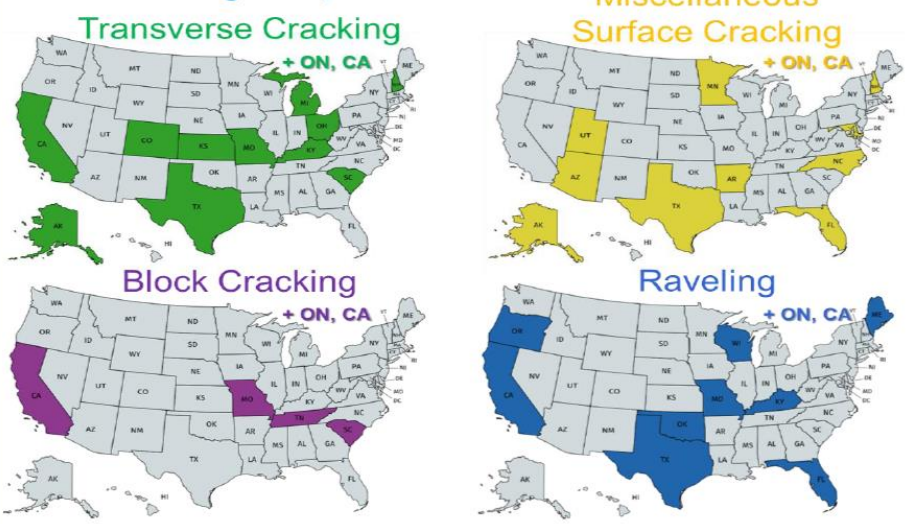
About the speakers

Dr. Michael Elwardany is the manager of the Asphalt Binder and Mixture Laboratories (ABML) at the Federal Highway Administration (FHWA) Turner Fairbank Highway Research Center. He was the program manager for paving asphalts at the Western Research Institute (WRI) for three years. Dr. Elwardany served as project lead to the National Cooperative Highway Research Program (NCHRP) 09-60 Project and the project manager for the Asphalt Industry Research Consortium (AIRC). He is an active member of several Transportation Research Board's Standing Committees, Association of Asphalt Paving Technologists (AAPT), RILEM, and ASCE-Airfield Pavement Committee. Dr. Elwardany holds Master's degrees from University of New Hampshire and a Ph.D. from North Carolina State University. He is a licensed professional engineer in the State of Wyoming, USA.

Dr. David Mensching is the Asphalt Materials Research Program Manager for the Federal Highway Administration (FHWA). He is the director of Turner-Fairbank Highway Research Center's Asphalt Binder and Mixture Laboratory and has research interests in automation and data science, connected pavements, resilience, and performance specifications. He is the chair of the Transportation Research Board's Standing Committee on Binders for Flexible Pavement and an active member of the Association of Asphalt Paving Technologists. Dr. Mensching holds Bachelors and Masters degrees from Villanova University and a Ph.D. from the University of New Hampshire. He is a licensed professional engineer in the Commonwealth of Virginia.

Post-SHRP Era (i.e., Superpave Specs in the 1990's)

- NCHRP 09-60 Survey in 2017
  - Potential issues identified by DOT's: Oxidized asphalt, REOB, High RAP/RAS, PPA, others.



Elwardany, M. D., G. King, J. P. Planche, C. Rodezno, D. Christense, R. Fertig III, K. Kuhn, and F. Bhuiyan. 2019. "Internal restraint damage mechanism for age-induced pavement surface distresses: Black cracking and raveling." *Journal of the Asphalt Paving Technologists*, vol. 88, p. 1-47.

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Post-SHRP Market Trends and Consequences

- Technical, Economic, and Environmental Impacts
- Unconventional Binders (sometimes problematic)
  - Some out of balance and incompatible blends
  - Waxy binders
  - Airblown, oxidized blends
  - Hard Solvent Deasphalting residues w/ soft blends
  - Multigrades and Hardgrades
  - Conversion residues "Visbroken residues" (IMO 2020)
  - Modified binders
    - Polymers: SBS, SBR, Terpolymer, EVA, rPE ...etc.
    - Additives: REOB, PPA, Wax, Biomass
    - Bio-binders and more ...
  - High RAP/RAS
  - Incompatible crudes (Fracking/Heavy)?!

Planche, J.P., Elwardany, M., Adams, J., Boysen, R. and Rovani, J., 2019. Linking Binder Characteristics with Performance: The Recipe to Cope with Changes in Bitumen Binder Quality. In 26th World Road Association (PIARC).

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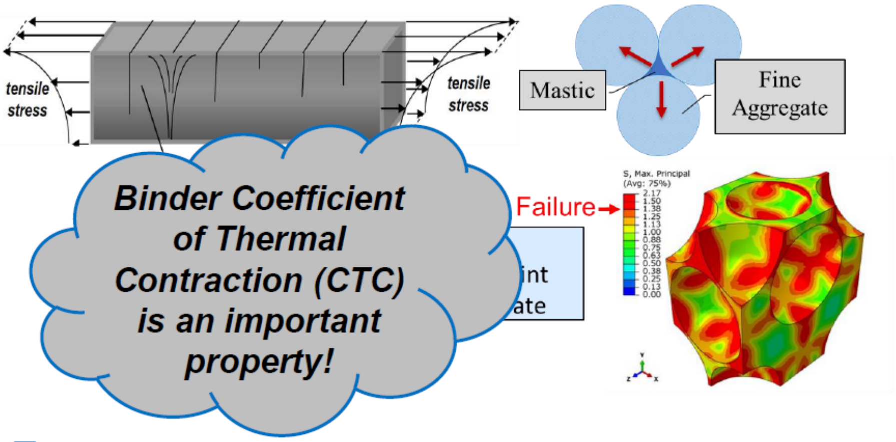
Two Thermally Induced Damage Mechanisms

Mix Restraint (External) and Mastic Restraint (Internal)



- ❑ **Evidence for internal restraint damage**
  - ➢ **FEA & Mix-BBR(Sliver) Results** (Elwardany et al., AAPT 2019)
  - ➢ **Ohio CTE Device** (Behnia et al., 2019)
  - ➢ **Acoustic Emissions Results** (Behnia et al., 2018)

Elwardany, M. D., G. King, J. P. Planche, C. Rodezno, D. Christense, R. Fertig III, K. Kuhn, and F. Bhuiyan. 2019. "Internal restraint damage mechanism for age-induced pavement surface distresses: Black cracking and raveling." *Journal of the Asphalt Paving Technologists*, vol. 88, p. 1-47.

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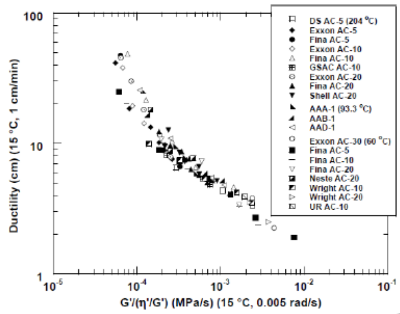
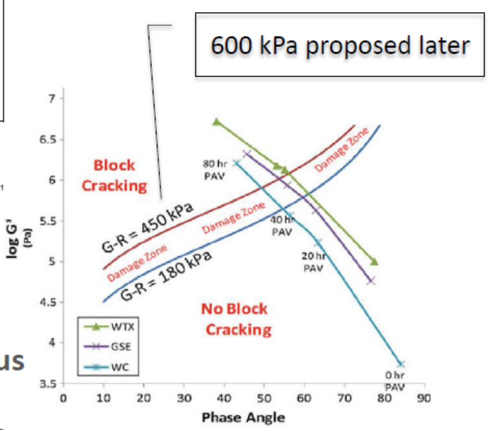
Proposed Rheological Surrogates in the Past Decade

- ❑ **Black Space Analysis**
  - ➢ Glover Function (Glover et al., 2005) $G'/(\eta'/G')$
  - ➢ G-R Parameter (G. Rowe et al., 2011) $\frac{G^*(\cos\delta)^2}{\sin\delta}$





- ➢ Other proposals
  - Crossover Temp.
  - Crossover Modulus
  - δ at critical G*
  - Temp. at critical δ

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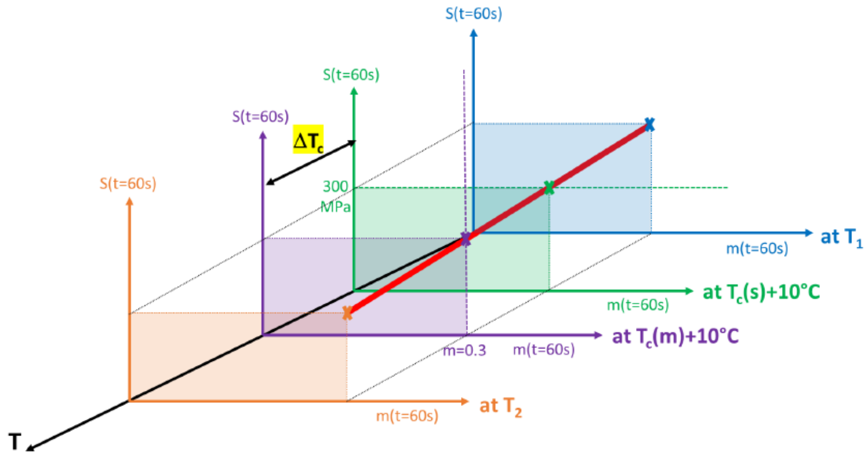
Proposed Rheological Surrogates in the Past Decade

- **ΔT_c Parameter**
  - $\Delta T_c = T_c(S = 300\ MPa) - T_c(m = 0.3)$.
  - ΔT_c is in a third dimension from the Black space.
  - No "real" correlations between ΔT_c and G-R



NCHRP 09-60 workshop under NCHRP 20-44(25), Planche, Elwardany, and King, 2020.

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Proposed Rheological Surrogates in the Past Decade

- **History of ΔT_c Parameter**
  - (Robertson et al. 2001)
  - Linked to field performance and proposed as a binder spec by (Mike Anderson et al., 2011)
  - Now implemented in at least 10 States/HSA's

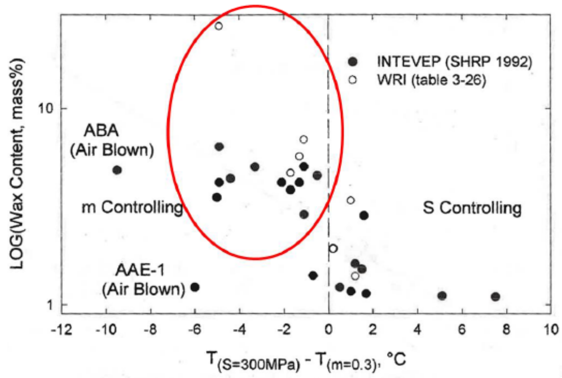

Figure 3-27. Relationship between wax content of asphalts and whether S or m controls the low-temperature SHRP specification.

Elwardany, M., J.-P. Planche, and G. King. 2020. "Universal and practical approach to evaluate asphalt binder resistance to thermally-induced surface damage". Construction and Building Materials, 255, p.119331.

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Proposed Rheological Surrogates in the Past Decade

- ❑ **ΔT_c Parameter is fundamentally inter-related to the rheological parameter from CA model (R-value)**
  - ➢ **R = 1.94 is equivalent to ΔT_c = 0 (Lesueur et al., 2021)**

$$\Delta T_C = R\frac{E_A}{2.303\overline{R}\log 2} \times \frac{\log\left[\frac{1}{0.3}-1\right]-\log\left[\left(\frac{300}{S_g}\right)^{-\beta}-1\right]}{\left(\log a_{T_{c,(S)}}+\frac{E_A}{2.303\overline{R}T_r}\right)\left(\log a_{T_{c,(m)}}+\frac{E_A}{2.303\overline{R}T_r}\right)} \qquad (12)$$

where E_A is the activation energy, $\overline{R}$, the ideal gas constant, β = log 2/R, T_r, the reference temperature, S_g the Glassy modulus (in MPa).

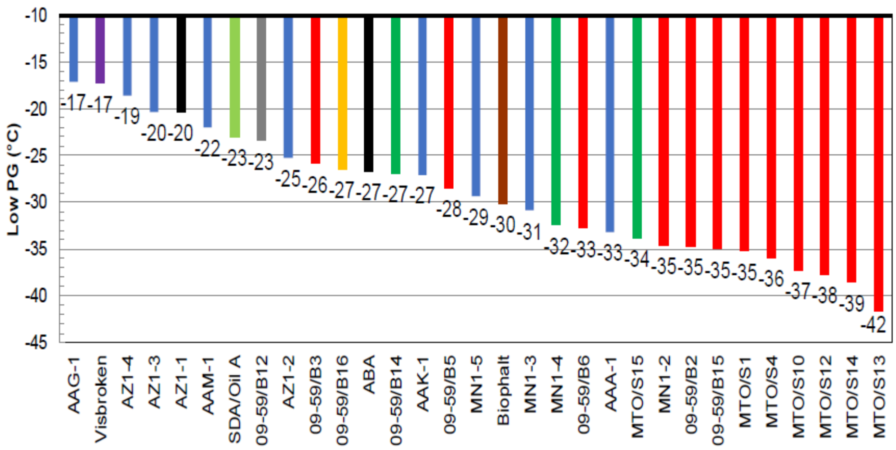
  - ➢ **ΔT_c is related to T_{IR} = (T_x-T_g) (Elwardany et al., 2019)**
  - ➢ **ΔT_c is easier and more practical for implementation**
  - ➢ **ΔT_c is related to both low- and intermediate-temperature behaviors.**

Lesueur, D., Elwardany, M.D., Planche, J.P., Christensen, D. and King, G.N. 2021. "Impact of the asphalt binder rheological behavior on the value of the ΔTc parameter", *Construction and Building Materials*, 293, p.123464.

Elwardany, M.D., Planche, J.P. and Adams, J.J. 2019. "Determination of binder glass transition and crossover temperatures using 4-mm plates on a dynamic shear rheometer", *Transportation Research Record*, 2673(10), pp.247-260.

NCHRP 09-60 Binder Database Mapping

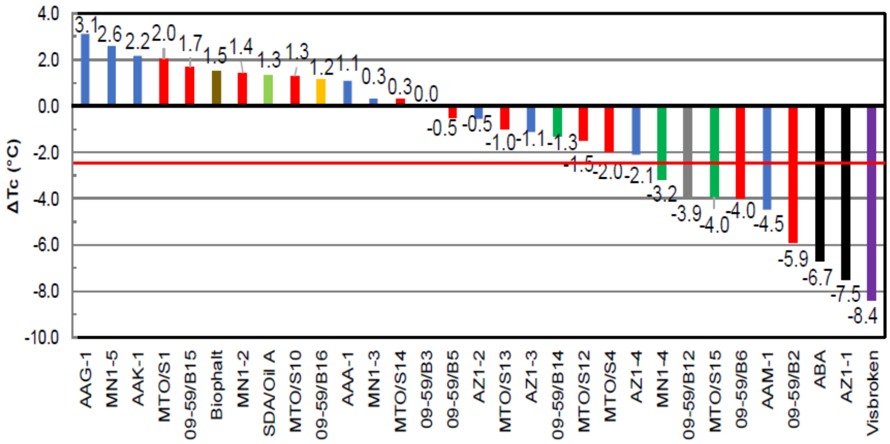
- ❑ **BBR, Low PG Ranking of 31 Binders after PAV<u>20h</u> Aging**
  - ➢ **Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Visbroken.**



Elwardany, M., J.-P. Planche, and G. King. 2020. "Universal and practical approach to evaluate asphalt binder resistance to thermally-induced surface damage". Construction and Building Materials, 255, p.119331.

NCHRP 09-60 Binder Database Mapping

- BBR, ΔT_c Ranking of 31 Binders after PAV20h Aging
  - Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Visbroken.



Elwardany, M., J.-P. Planche, and G. King. 2020. "Universal and practical approach to evaluate asphalt binder resistance to thermally-induced surface damage". Construction and Building Materials, 255, p.119331.

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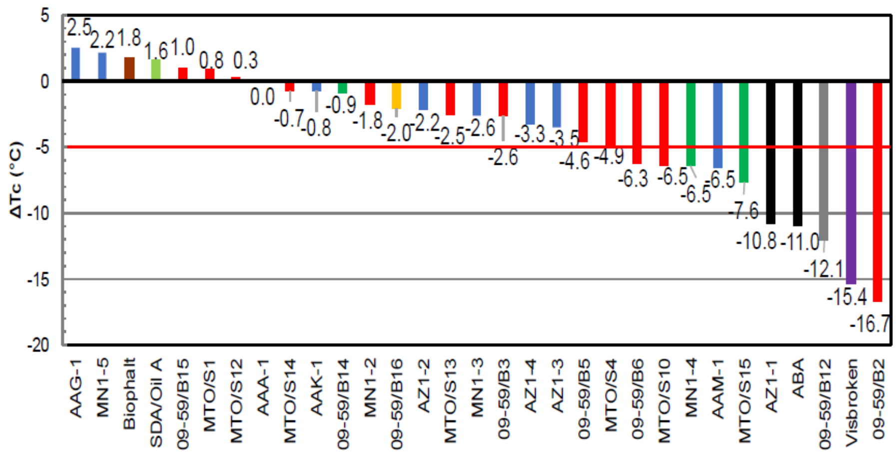
NCHRP 09-60 Binder Database Mapping

- BBR, ΔT_c Ranking of 31 Binders after PAV40h Aging
  - Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Visbroken.



Elwardany, M., J.-P. Planche, and G. King. 2020. "Universal and practical approach to evaluate asphalt binder resistance to thermally-induced surface damage". Construction and Building Materials, 255, p.119331.

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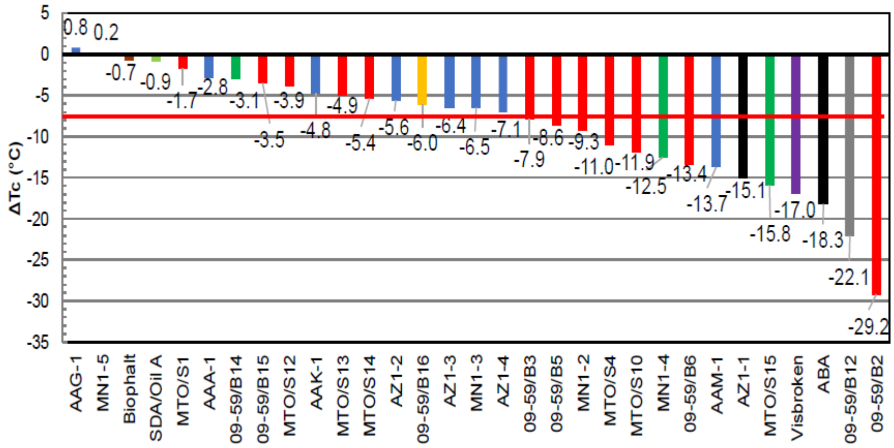
NCHRP 09-60 Binder Database Mapping

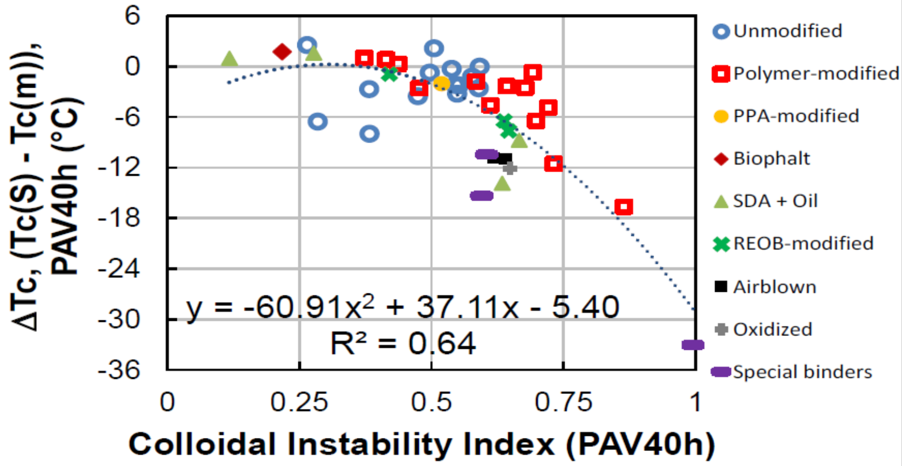
- BBR, ΔT_c Ranking of 31 Binders after PAV40h+PH72h Aging
  - Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Visbroken.



Elwardany, M., J.-P. Planche, and G. King. 2020. "Universal and practical approach to evaluate asphalt binder resistance to thermally-induced surface damage". Construction and Building Materials, 255, p.119331.

NCHRP 09-60 Binder Database Mapping

- Correlation between ΔTc and CII after PAV40h
  - Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Special.

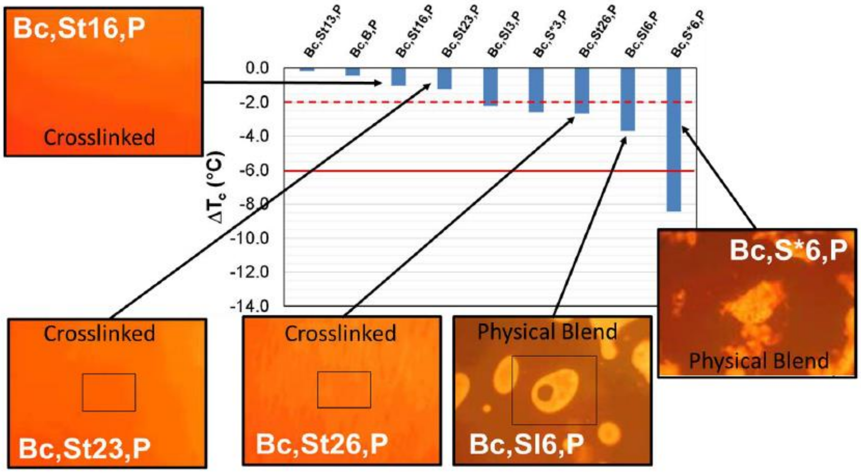


❖ Classical CII= (Sat+Asph)/(Arom+Res)

Elwardany, M., J.-P. Planche, and G. King. 2020. "Universal and practical approach to evaluate asphalt binder resistance to thermally-induced surface damage". Construction and Building Materials, 255, p.119331.

NCHRP 09-60 Revisiting the TOTAL literature

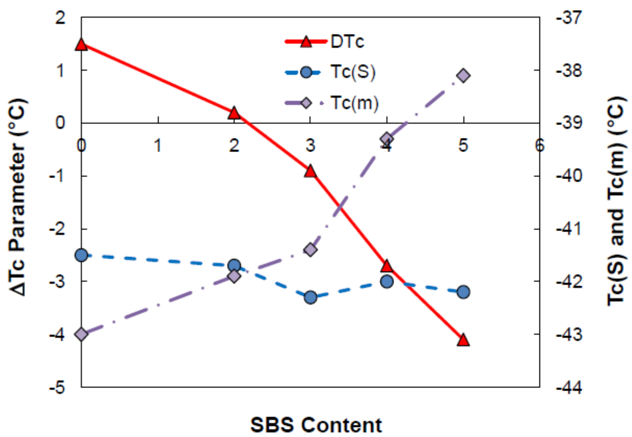
- ❑ ΔTc Index and phase structure
  - ➢ Data collected from Durrieu et al, Lapalu et al, Mouillet et al, Planche et al, 2004-2008 & Revisited in Elwardany et al., 2020.



Elwardany, M., J.-P. Planche, and G. King. 2020. "Universal and practical approach to evaluate asphalt binder resistance to thermally-induced surface damage". Construction and Building Materials, 255, p.119331.

Limitations of Rheological Surrogates for PMA's

- ❑ BBR, ΔT_c Parameter
  - ➢ Systematic SBS-modification Study.



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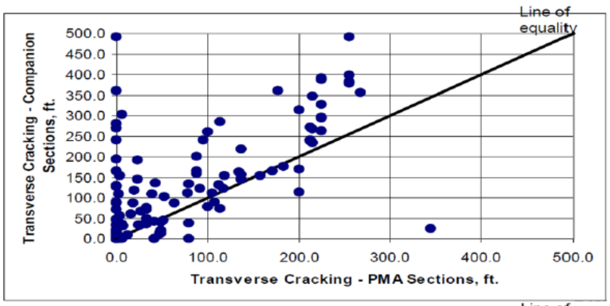
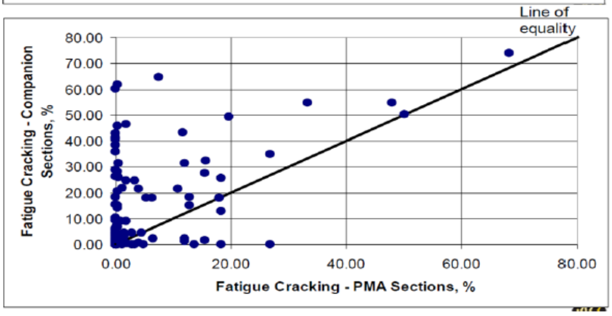
Limitations of Rheological Surrogates for PMA's

- PMA sections vs. companion unmodified sections
  - (Von Quintus, 2005)





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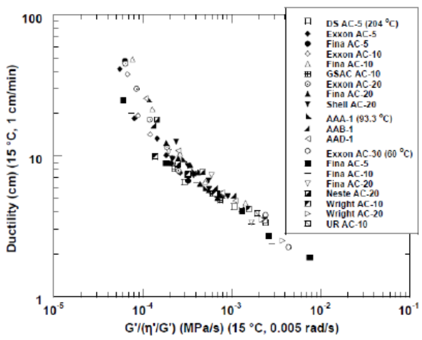
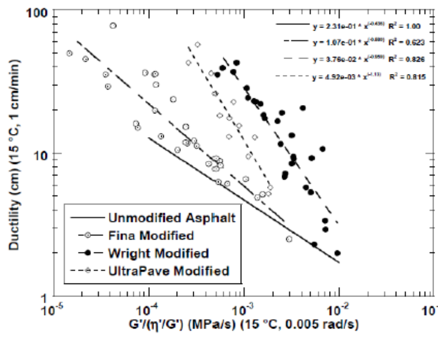
Limitations of Rheological Surrogates for PMA's

- DSR, Glover function and Glover-Rowe Parameter
  - G-R has limited applicability to PMA's (Glover, 2005).





Elwardany, M., J.-P. Planche, and G. King. 2020. "A Tale of Two Deltas" TRB AFK20 sponsored session, Washington, D.C.

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Insights, so far…

- **BBR, ΔT_c Parameter**
  - ✓ Captures relaxation properties of unmodified binders.
  - ✓ Generally, relates to asphalt colloidal structure.
  - ➢ Underestimates the performance of some complex binders such as PMA's.
  - ➢ Fail to capture failure properties outside the LVE domain such as strength/strain tolerance of PMA's.

- **Need to consider failure tests!**
  - ✓ DTT was introduced by SHRP pioneer researchers!
  - ➢ DTT failed due to lack of reproducibility.

- **What do we do now?**

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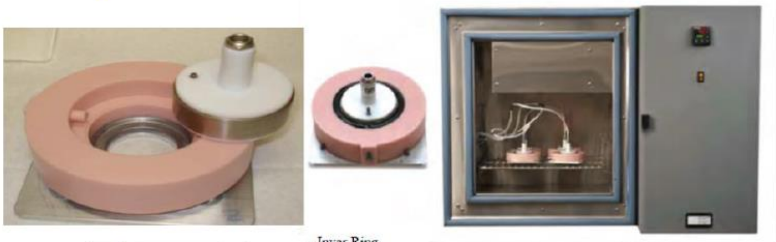
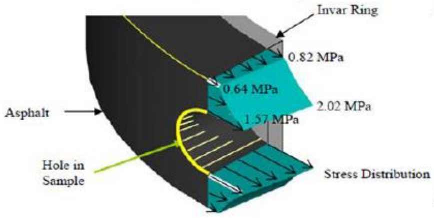
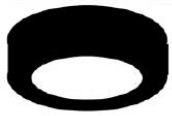
ABCD as a Replacement for DTT (NCHRP 09-60)

- **Asphalt Binder Cracking Device**
  - ➢ Test developed by SS Kim.
  - ➢ Proposed by NCHRP 09-60 as a failure test and a replacement for DTT.







15g X 3-4 Rings
= 1 additional PAV pan
(3 Pans for both BBR & ABCD)

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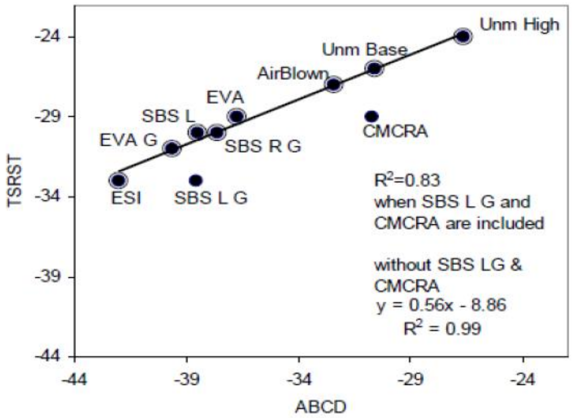
ABCD as a Replacement for DTT (NCHRP 09-60)

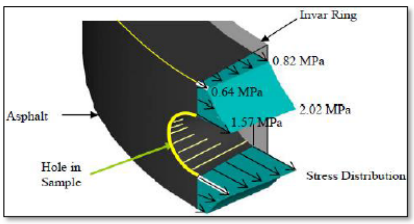
- Asphalt Binder Cracking Device
  - Equivalent to the TSRST test for mixtures.
  - Effective and sensitive to well-formulated and compatible PMA's



Kim, S.S. 2007. "*Development of an asphalt binder cracking device*". IDEA Program, Transportation Research Board, 2007.

ABCD as a Replacement for DTT (NCHRP 09-60)

- Factors affecting ABCD cracking temperature, T_{cr}
  - CTC controls rate of volumetric changes.
  - LVE rheological properties G* and δ.
  - Strength (Viscoelastic property (t-TSP) with damage).
  - Glass transition temperature (T_g) impacts all parameters.
    - Glass transition takes place over a range of temperatures, confirmed by DSC.
    - Wider T_g region for complex and /or aged binders.



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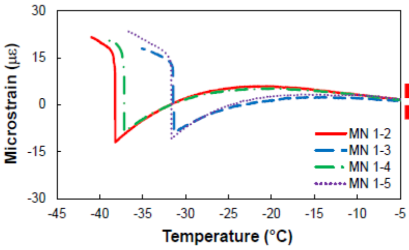

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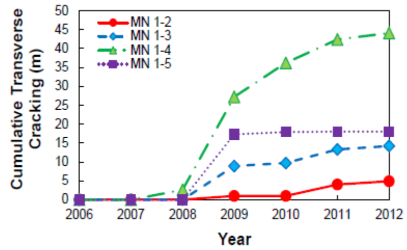
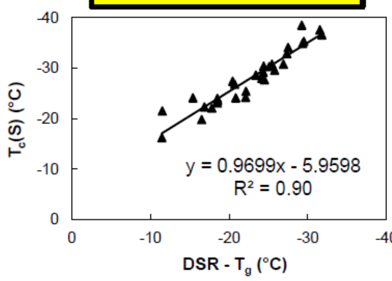


T_g of REOB around -80°c

(Planche et al., TRB 2015)

T_{cr} needs to be normalized to an equi-stiffness temperature! Also, $T_c(S)$ is a practical surrogate for T_g

Asphalt Industry Research Consortium



(Elwardany et al., TRR 2019)

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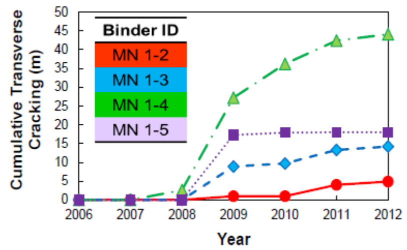
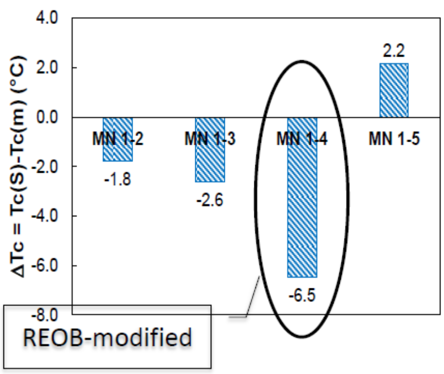
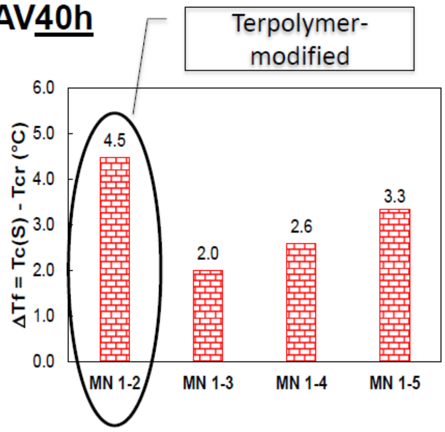
A Tale of Two Delta's

- $\Delta T_f = T_c(S) - T_{cr}$
  - ABCD cracking temperature normalized to equi-stiffness temperature.



- ΔT_c & ΔT_f ranking after PAV<u>40h</u>





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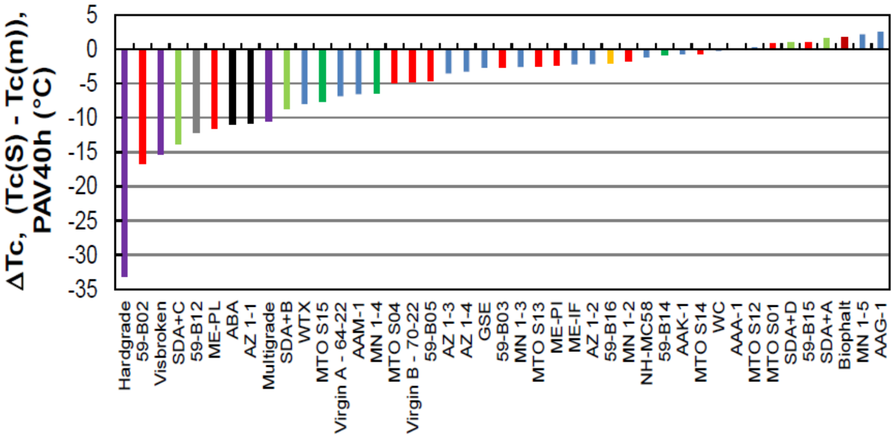
A Tale of Two Delta's

- **BBR & Corrected 4mm-DSR ΔT_c Ranking after PAV40h Aging**
  - **Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Special.**



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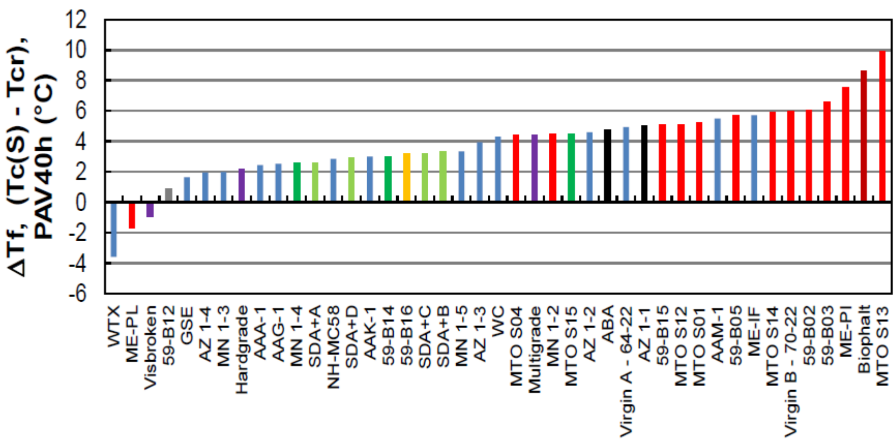
A Tale of Two Delta's

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



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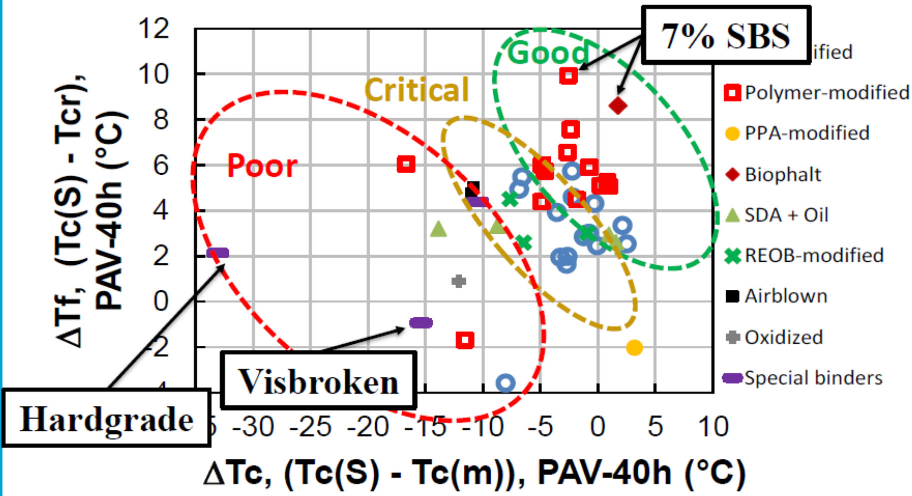
A Tale of Two Delta's

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



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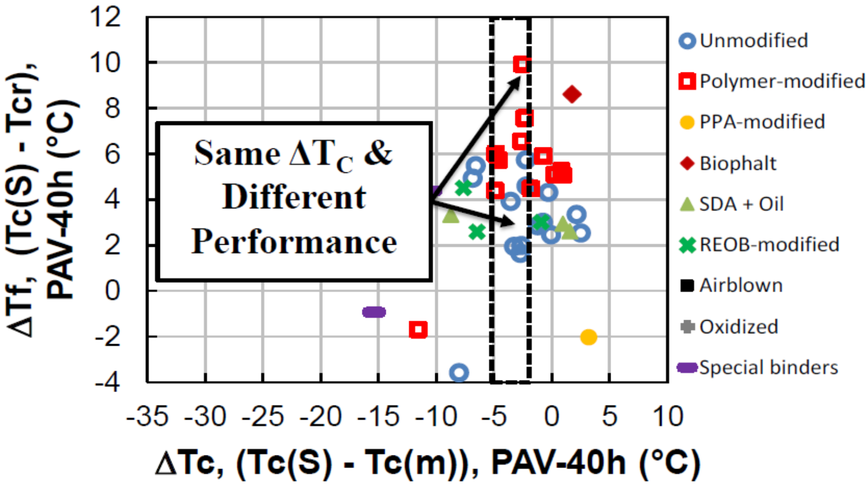
A Tale of Two Delta's

- BBR & ABCD ΔT_c & ΔT_f Ranking after PAV40h Aging
  - Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Special



Elwardany, M., J.-P. Planche, and G. King. 2020. "Universal and practical approach to evaluate asphalt binder resistance to thermally-induced surface damage". Construction and Building Materials, 255, p.119331.

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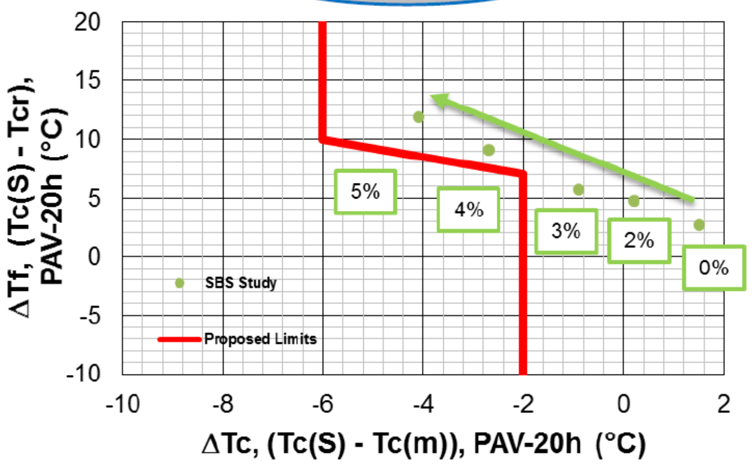
A Tale of Two Delta's

- SBS-modified binder systematic study

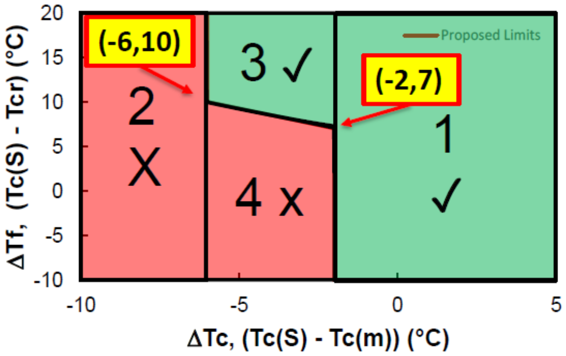
Importance of Cracking (Failure) Tests for Universal "Blind" Specs



Elwardany, M., J.-P. Planche, and G. King. 2021. "Proposed Changes to Asphalt Binder Specifications to Address Binder-Quality Related Thermally Induced Surface Damage". Association of Asphalt Paving Technologists Annual Meeting.

A Tale of Two Delta's

- Framework is later validated after PAV20h aging with various field sections in MN, AZ, TX, ME, and ON.
  - Field Validation will be presented at AAPT – Sept. 2021 in Nashville (Online and in-person meeting).



Proposed specifications framework

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

- **BBR alone when**

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

- **BBR & ABCD for**

-6°C<ΔT_c <-2°C
ΔT_f min = 7°C at -2°C
ΔT_f min = 10°C at -6°C

Elwardany, M., J.-P. Planche, and G. King. 2021. "Proposed Changes to Asphalt Binder Specifications to Address Binder-Quality Related Thermally Induced Surface Damage". Association of Asphalt Paving Technologists Annual Meeting.

iFRAE DELFT 2021

5th International Symposium on Frontiers of Road and Airport Engineering

Workshop: Changes in binder properties and the role of additives

A Tale of Two Deltas:

Analysis Approach, Proposed Limits, and ***Validation Work*** to Address Binder Quality-Related Thermally Induced Surface Damage

Michael Elwardany, ESC Inc.; David Mensching, FHWA

U.S. Department of Transportation
Federal Highway Administration

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DISCLAIMER

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ABBREVIATIONS

- ABCD: asphalt binder cracking device.
- ABR: asphalt binder replacement.
- ALF: accelerated loading facility.
- HMA: hot mix asphalt.
- HP: High Polymer modified asphalt binders.
- PG: performance grading.
- PMA: polymer modified asphalt.
- RAP/RAS: reclaimed asphalt pavement/reclaimed asphalt shingle.
- SBS: styrene-butadiene-styrene polymer.
- WMA: warm mix asphalt.

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FHWA VALIDATION EFFORTS: LESSONS AND GAPS

- **FHWA in collaboration with Rutgers University.**
- **FHWA-ALF Study, RAP/RAS mixtures.**


Source: FHWA.


Source: FHWA.

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FHWA VALIDATION EFFORTS: LESSONS AND GAPS

FHWA-ALF Study, RAP/RAS mixtures.

	HMA/WMA Drum Discharge Temp	149°C (300°F) – 160°C (320°F)		116°C (240°F) – 132°C (270°F)	
	Warm Mix Technology	None		Foam	Chemical
Recycle Content	0%	PG 64-22 L1		N/A	N/A
Recycle Content	20% ABR RAP ≈ 23% RAP by weight	PG 64-22 L6		PG 64-22 L9	PG 64-22 L4
Recycle Content	20% ABR RAS ≈ 6% RAS by weight	PG 64-22 L3	PG 58-28 L7	N/A	N/A
Recycle Content	40% ABR RAP ≈ 44% RAP by weight	PG 64-22 L5	PG 58-28 L8	PG 58-28 L2	PG 58-28 L11

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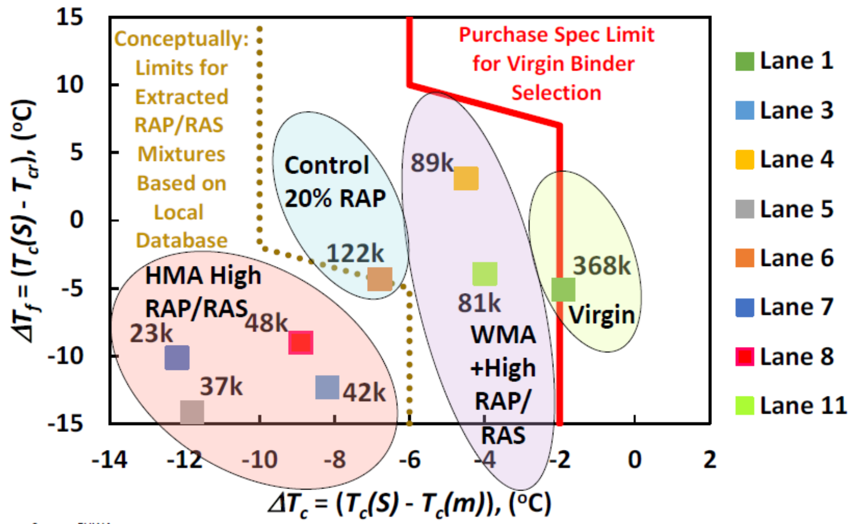
FHWA VALIDATION EFFORTS: LESSONS AND GAPS

SBS Systematic Study, analysis framework.



Source: FHWA.

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FHWA current and future work in collaboration with:

- **Rutgers University**: Field sections at ALF, New Jersey Department of Transportation, and Federal Aviation Administration.
- **University of Waterloo**: Systematic SBS content.
- **University of Nevada Reno**: PMA/HP.
- **Virginia Transportation Research Center**: PMA/HP.
- **International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) members**: complex binders.
- Others under discussion.

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iFRAE DELFT 2021 **5th International Symposium on Frontiers of Road and Airport Engineering**

Workshop: Changes in binder properties and the role of additives

Thank you!

Michael Elwardany, m.elwardany.ctr@dot.gov
David Mensching, david.mensching@dot.gov

3.4 Recycling practices and additives in asphalt: Current practices and the future trends

Lily Poulikakos, Ph.D, Senior Scientist

Empa - Swiss Federal Laboratories for Materials, Switzerland

About the speaker

Dr. Lily Poulikakos received her B.S in architectural engineering from the university of Colorado, Boulder USA, M.S. in civil engineering from university of Illinois USA and PhD in civil engineering from ETH Zurich, Switzerland. She is currently a senior scientist at Empa, the Swiss federal laboratories for materials science and technology. Her research focus is on using multi scale characterization methods to study innovative bituminous materials chemically and mechanically. She is a leading member of Rilem as former deputy chair of the technical committee TC-231 NBM on nano bituminous materials and TC-252 CMB chemo mechanical characterization of bituminous materials and currently chair of TC-279 WMR on waste and marginal materials for roads. Dr. Poulikakos is the author of over 100 publications in peer reviewed journals and editor of Elsevier journal Construction and Building Materials CBM.

Outline

- Introduction and Motivation
- Rejuvenators
- Waste additives
- Facts and Figures
- Rilem TC-279 WMR
- Performance Results
- Environmental assessment
- Life cycle assessment
- Conclusions

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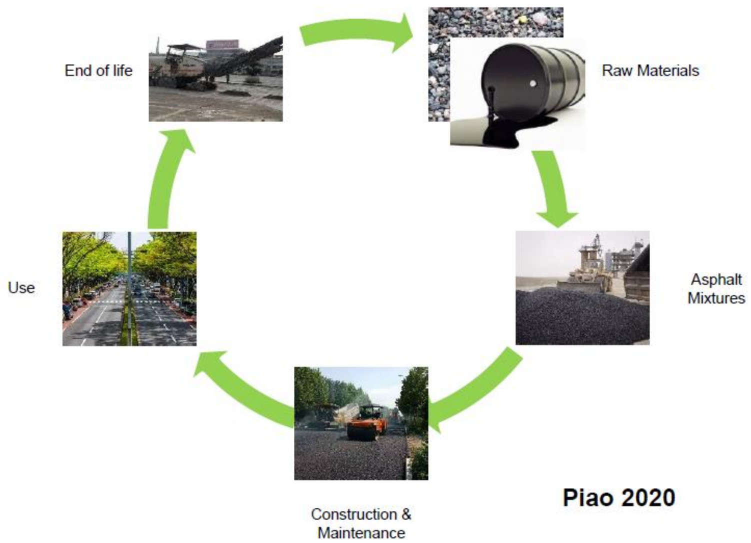
Motivation-Improve Properties

- Circular economy



Piao 2020

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Rejuvenators

Seed Oil

www.renovableenergy.com

Cashew nut shell based Oil

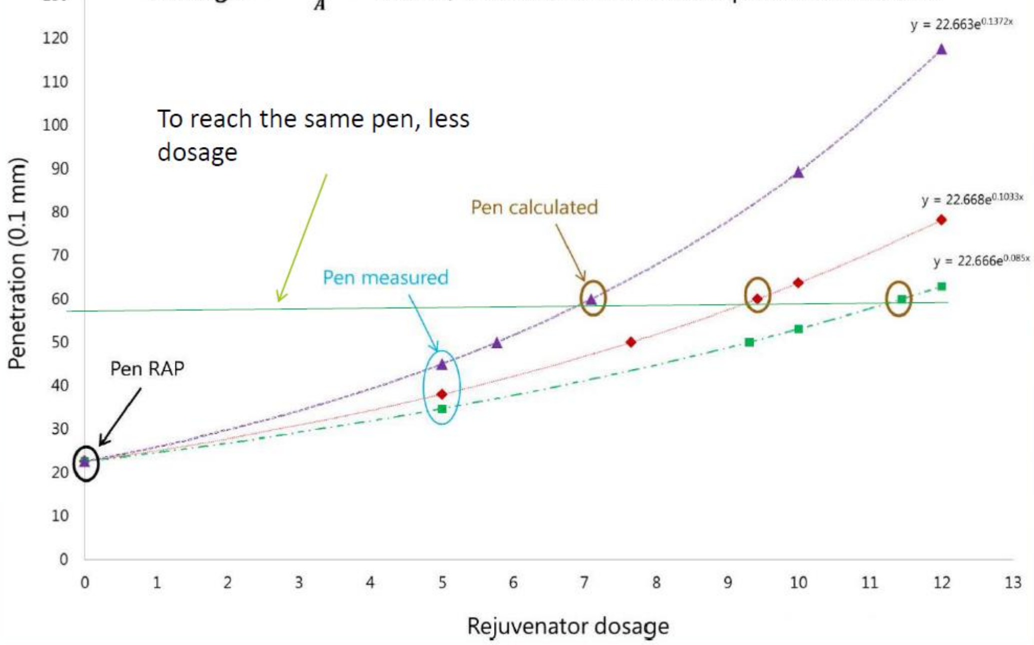
www.rawcashewnuts.com

Tall based Oil

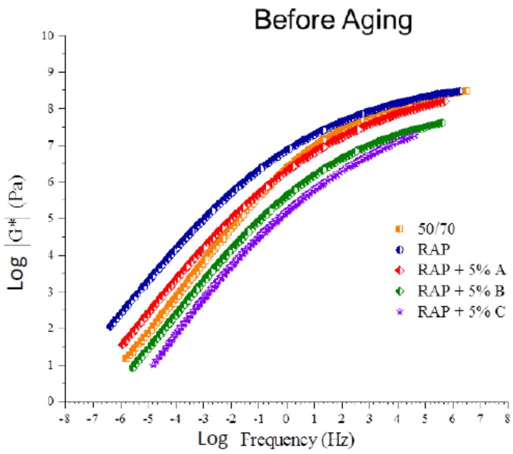
www.ucienergies.com

PhD Cavalli, 2018

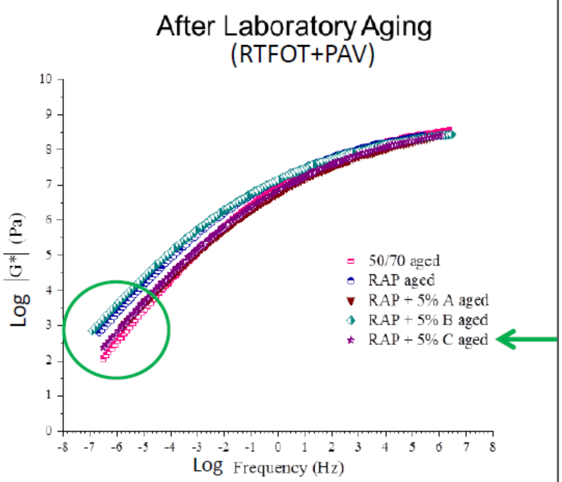
$$Dosage = \frac{Log\frac{Pen}{B}}{A}$$ with A, B constants from the exponential function



Cavalli 2017



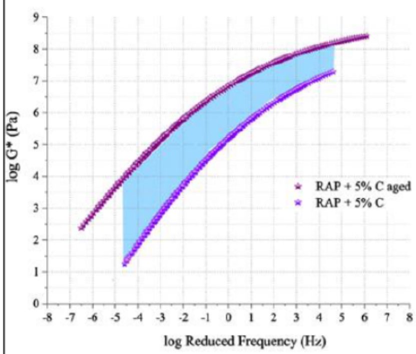
Effect of ageing on the Rheological properties (DSR)

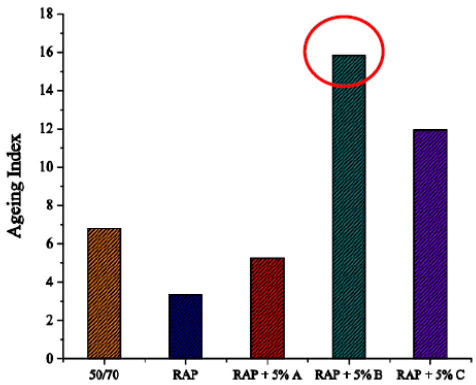


Cavalli MC, Zaumanis M, Mazza E, Partl MN, Poulikakos LD. Effect of ageing on the mechanical and chemical properties of binder from RAP treated with bio-based rejuvenators. Compos Part B Eng 2018;141:174–81. doi:10.1016/j.compositesb.2017.12.060.

Characterising Aging

Empa
Materials Science and Technology





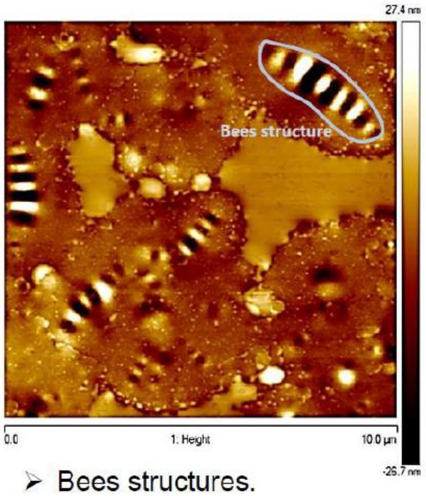
Rejuvenator type affects aging susceptibility

Cavalli MC, Zaumanis M, Mazza E, Partl MN, Poulikakos LD. Effect of ageing on the mechanical and chemical properties of binder from RAP treated with bio-based rejuvenators. Compos Part B Eng 2018;141:174–81. doi:10.1016/j.compositesb.2017.12.060.

Atomic Force Microscopy (AFM)

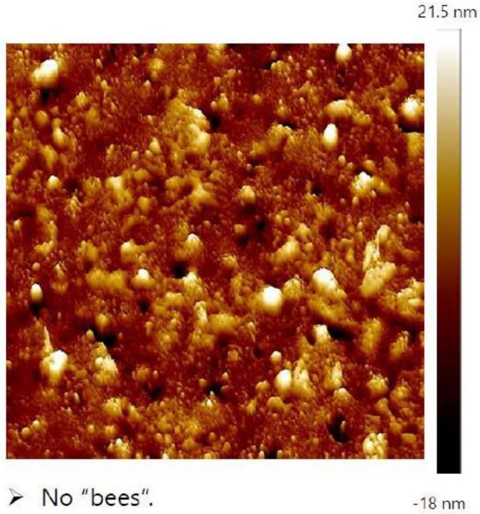
Empa
Materials Science and Technology

Virgin Binder 5070



➢ Bees structures.

RAP Binder



➢ No "bees".

Cavalli, M.C., Zaumanis, M., Mazza, E., Partl, M.N., Poulikakos, L.D. Effect of ageing on the mechanical and chemical properties of binder from RAP treated with bio-based rejuvenators (2018) Composites Part B: Engineering, 141, pp. 174-181.

AFM QNM (Quantitative nano mechanical analysis)

a) Virgin binder 50/70 unaged

c) Virgin binder 50/70 aged

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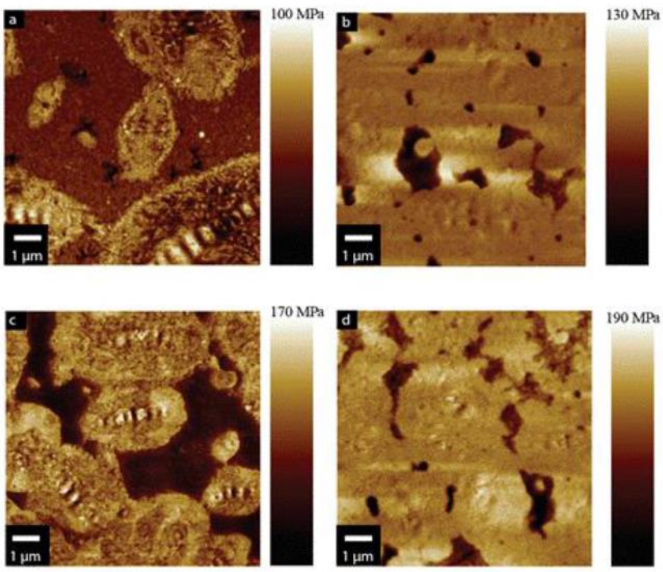

b) RAP binder unaged

d) RAP binder aged.

Source: Cavalli, M.C., Zaumanis, M., Mazza, E., Partl, M.N., Poulikakos, L.D. Effect of ageing on the mechanical and chemical properties of binder from RAP treated with bio-based rejuvenators (2018) Composites Part B: Engineering, 141, pp. 174-181.

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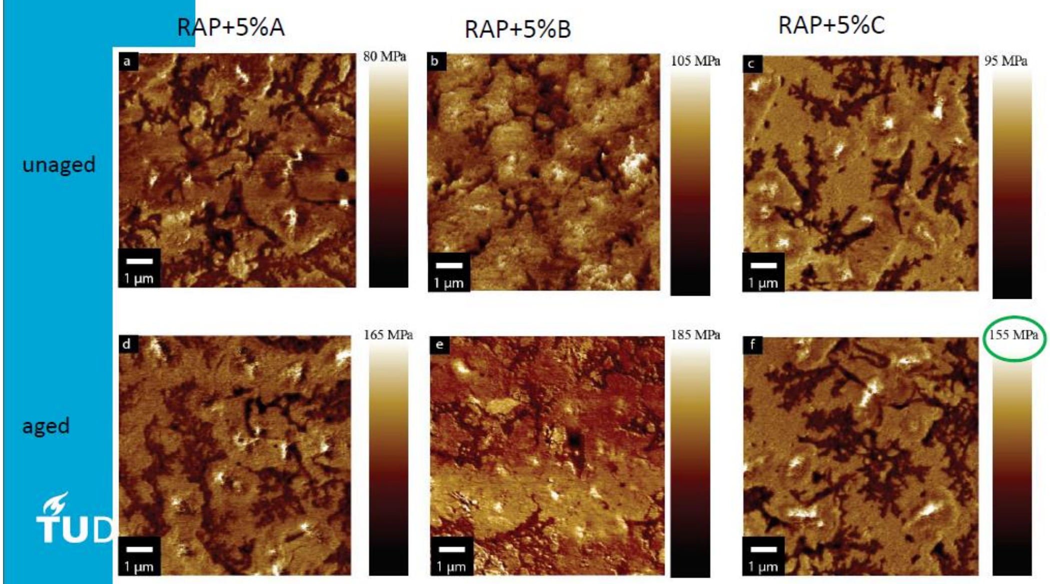
Surface microstructure using AFM QNM sample size 10µmx10µm



Reached mechanical performance but no restoration of bees

10

Source: Cavalli, M.C., Zaumanis, M., Mazza, E., Partl, M.N., Poulikakos, L.D. Effect of ageing on the mechanical and chemical properties of binder from RAP treated with bio-based rejuvenators (2018) Composites Part B: Engineering, 141, pp. 174-181.

Use of waste materials as additives

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The Numbers in Europe

Material	Source	Generated Mt/y	Available Mt/y
Concrete	C&D	350	262.5
Ceramics	C&D	200	162
Glass	Var.	20.2	5.4
Steel slag	Steel industry	21.8	15.7
Plastics	MRF	15.1	4.5
Tires	ELV	3.3	1.8

Waste is a substantial problem worldwide

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Technology Readiness Level (TRL)

FNSNF

Urban wastes	Estimated TRL
Crumb rubber (wet process)	7 – 9 (application is partially or completely industrialized)
Crumb rubber (dry process)	5 – 7 (application is validated in the field)
Recycled concrete aggregate (RCA)	< 4 (laboratory scale or lower)
Recycled ceramics	< 4 (laboratory scale or lower)
Recycled glass	< 4 (laboratory scale or lower)
Recycled plastics	5 – 7 (application is validated in the field)

Banke, J., 2017. Technology Readiness Levels Demystified. https://www.nasa.gov/topics/aeronautics/features/trl_demystified.html. (Accessed May 2019).
Piao, Z., Mikhailenko, P., Kakar, M.R., Bueno, M., Hellweg, S., Poulikakos, L.D., 2020. Urban Mining for Asphalt Pavement: A Review. Journal of Cleaner Production 280 (2021)

Suitable waste materials for roads

Table 2
Summary of the effects using waste materials in the asphalt mixture at laboratory scale.

Waste material	Rutting resistance	Moisture resistance	Stiffness modulus	Fatigue resi
CR from ELT (wet process)[a]	↑	~	~	↑
CR from ELT (dry process)[b]	↑	↓	↑	~
RCA[c]	~	~	↑	~
Waste ceramics[d]	~	~	↑	↑
Waste PE (wet process)[e]	↑	↑	↑	↑
Waste PE (dry process)[f]	↑	↑	~	→
Waste PET[g]	↑	↑	~	↑
Waste PVC[h]	↑	↑	×	×
Waste PP[i]	↑	~	↑	→
Steel slag[j]	↑	↑	↑	↑

Source: Piao, Z., Mikhailenko, P., Kakar, M.R., Bueno, M., Hellweg, S., Poulikakos, L.D., (2021). Urban mining for asphalt pavements: A review. Journal of Cleaner Production 280, 124916. https://doi.org/10.1016/j.jclepro.2020.124916.

Overview of Rilem TC Waste and Marginal Materials WMR

- Chair:Lily Poulikakos, Empa, Switzerland
- Emiliano Pasquini, U Padua, Italy

- The TC will be active for 5 years (2017-2022)

- Combination of literature review, experimental work and test protocol descriptions documented in a STAR report and papers

- Workshop 2020 Rilem symposium Lyon

- Symposium or dedicated TC day at end of TC

Rilem: International Union of Laboratories and Experts in Construction Materials, Systems and Structures https://www.rilem.net/

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Waste Plastics

➢ Inno-recycling produces 16'000 Tonnes/year of PE „Regranulate".

PE-
Pellets

PE-
Shreds

https://innorecycling.ch/

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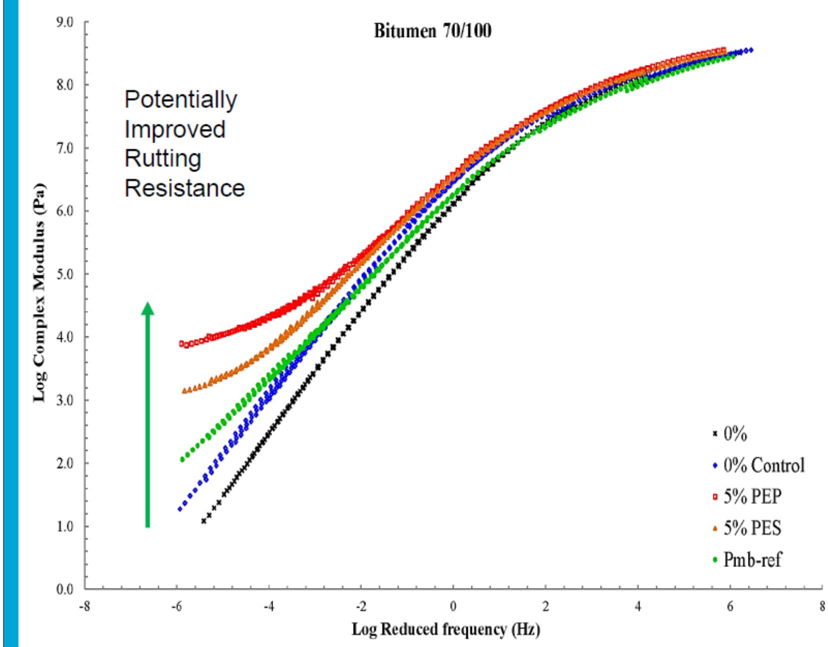
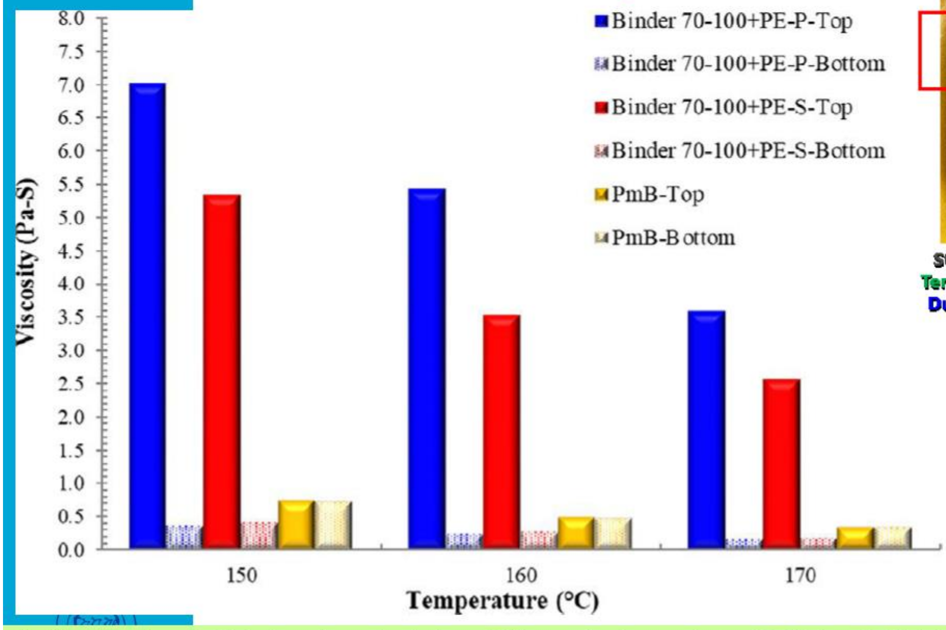
Plastic Modified Bitumen: Dynamic Shear Rheometer

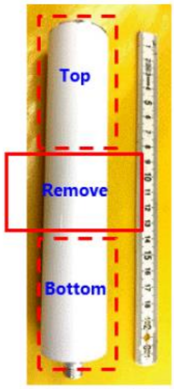
FNSNF



Modification of asphalt binder using polyethylene (PE) recycling by-products, *M R Kakar, P Mikhailenko, Z Piao, M Bueno, L Poulikakos Construction and Building Materials 280 (2021)*

Plastics: Stability

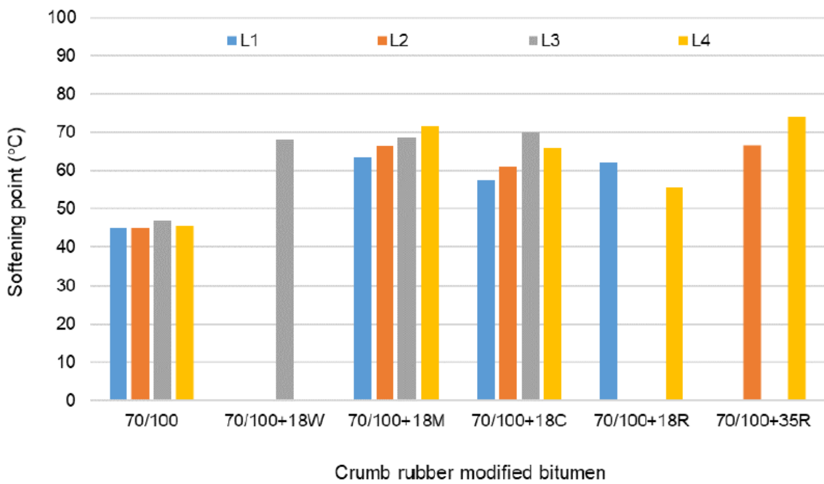




Stability Test Tube
Temperature = 180°C
Duration = 72hours

Modification of asphalt binder using polyethylene (PE) recycling by-products, *M R Kakar, P Mikhailenko, Z Piao, M Bueno, L Poulikakos Construction and Building Materials 280 (2021)*

Round Robin Crumb Rubber Modified Bitumen



Pais et al, submitted

W-Water jet
M-Mechanical grinding
C-Cryogenic
R-RARx

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Environment/LCA

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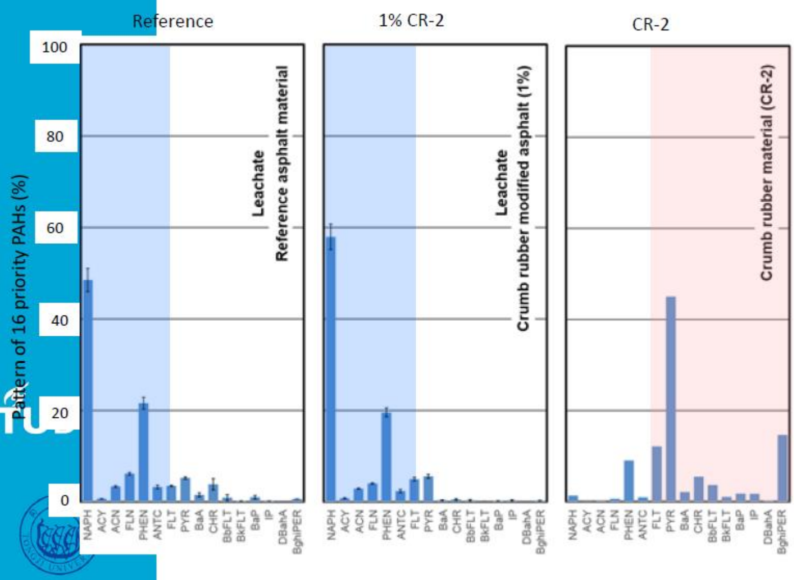
Comparison of PAH pattern in leachates: Crumb Rubber Modified Mixture

Pattern of 16 priority PAHs in leachates and CR-2 material



-Acidic solution18 h liquid-to-solid ratio 20 to 1

- Soluble 2-3-ring PAHs like naphthalene dominate in leachates
- Less soluble 4-6-ring PAHs dominate in CR-2

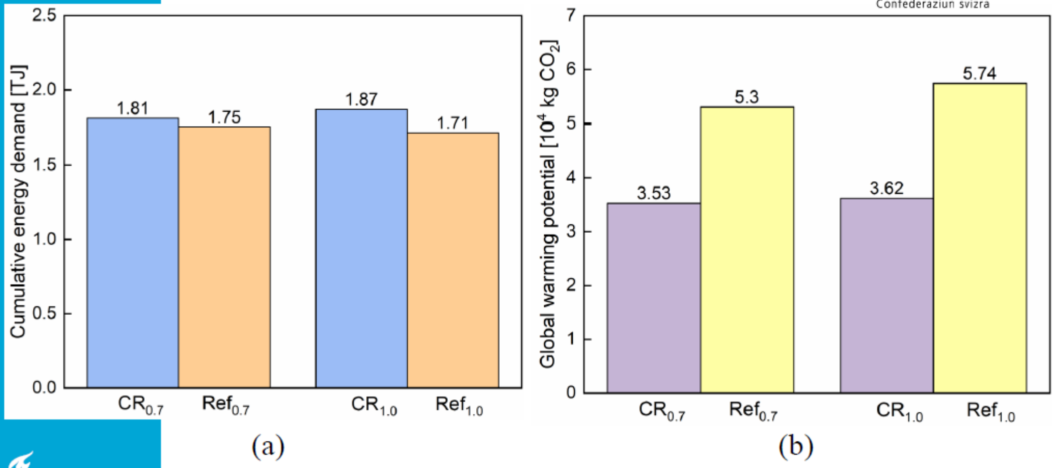
-Leaching of PAHs is asphalt-related

Norbert Heeb

Life Cycle Assessment (LCA): Crumb Rubber

Innosuisse

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra



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SDA wearing courses. $CR_{0.7}$ =SDA + 0.7% CR, $CR_{1.0}$ =SDA + 1.0% CR; $Ref_{1.0}$ =SDA+ PmB CR

Z Piao, M Bueno, P Mikhailenko, M R Kakar, L Poulikakos, S Hellweg Life cycle assessment of asphalt pavements using crumb rubber: a comparative analysis, Rilem ISBN symposium Lyon 2020

Conclusions

- Additives can have a complex effect on the performance of binder
- Use of waste materials add a degree of complexity
- Appropriate characterization techniques
  - Focus on mixture performance
- Environmental effects
- LCA-cradel to grave, recycling potential

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