

Oil Exudation and Impaired Stress Relaxation: Unintended Consequences of Gel Formation in Excessively Modified Asphalt Binders

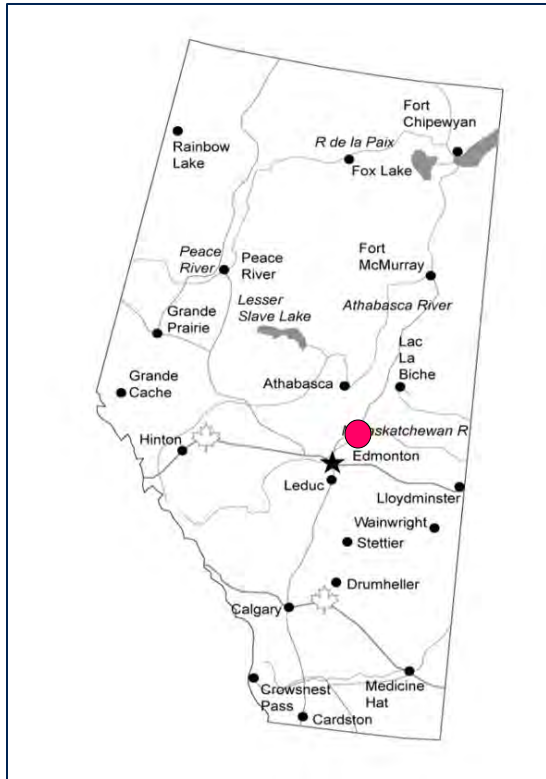
Aidan Woods, Jianmin Ma, Chanaka Nawarathna and
Simon A.M. Hesp

Queen's University, Kingston, Ontario

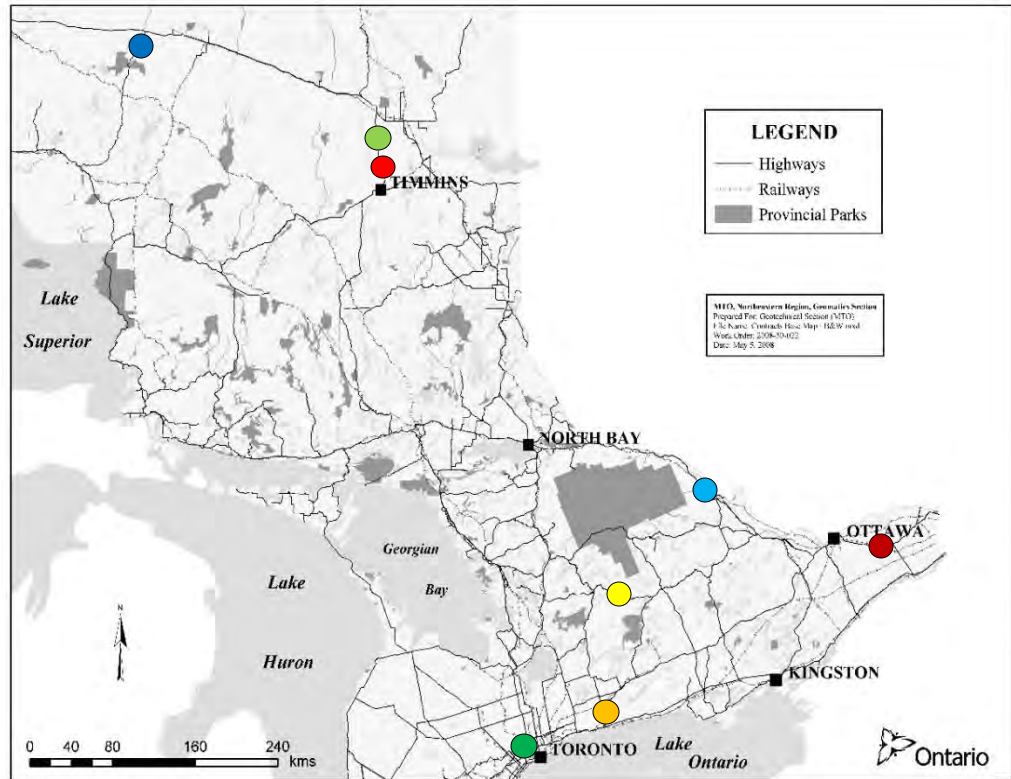
NESMEA, Harrisburg, Pennsylvania, USA
October 28-29, 2025

Alberta and Ontario Pavement Trials

(56 Sections, 1992-2022, 30 Years)



● Lamont (7, 1992)



● Hearst (4, 1992)

● Bracebridge (7, 1994)

● Petawawa (6, 1996)

● Timmins I (7, 2003)

● Casselman (7, 2006)

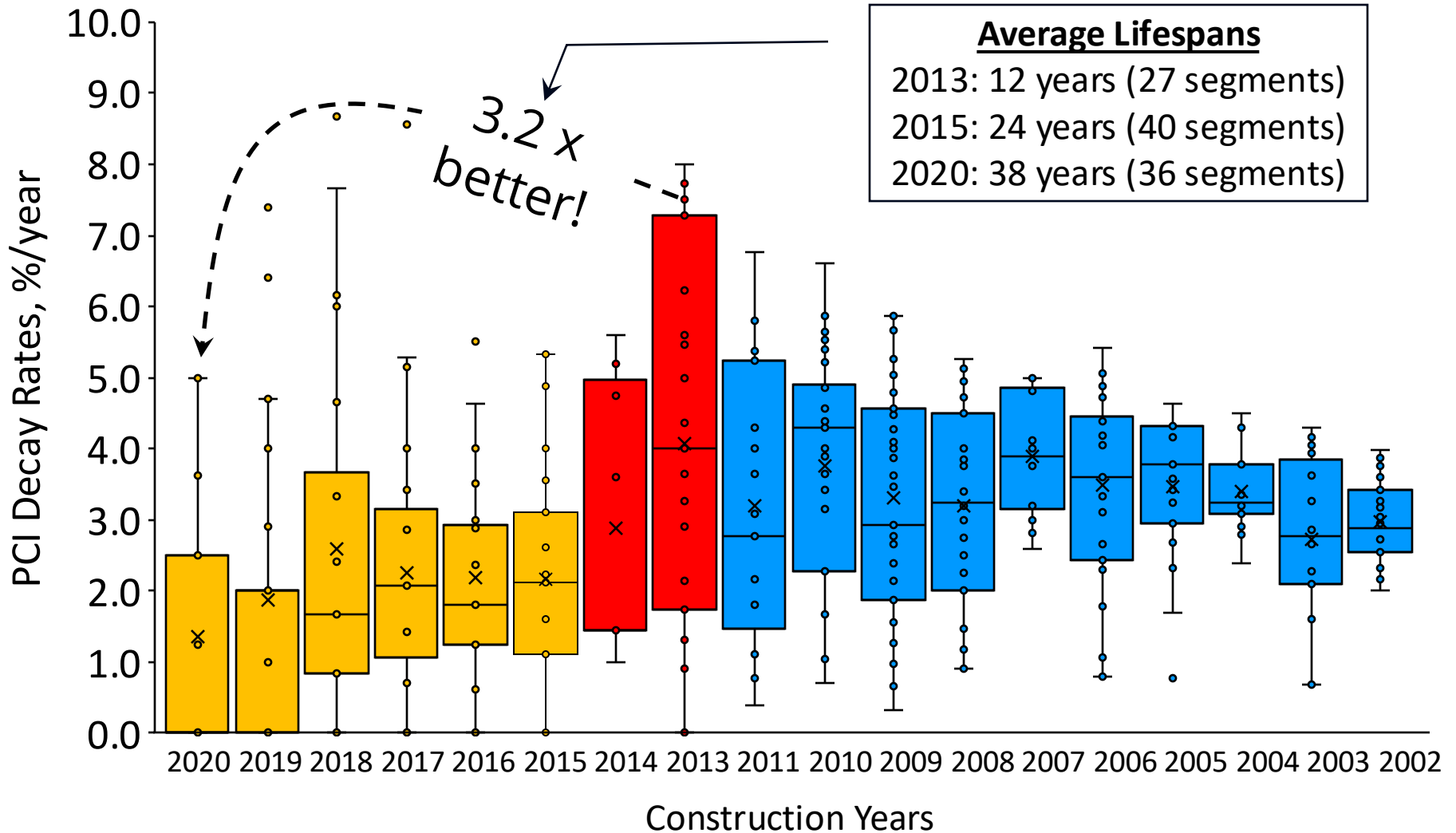
● Timmins II (8, 2007)

● Toronto (5, 2008)

● Durham (5, 2022)

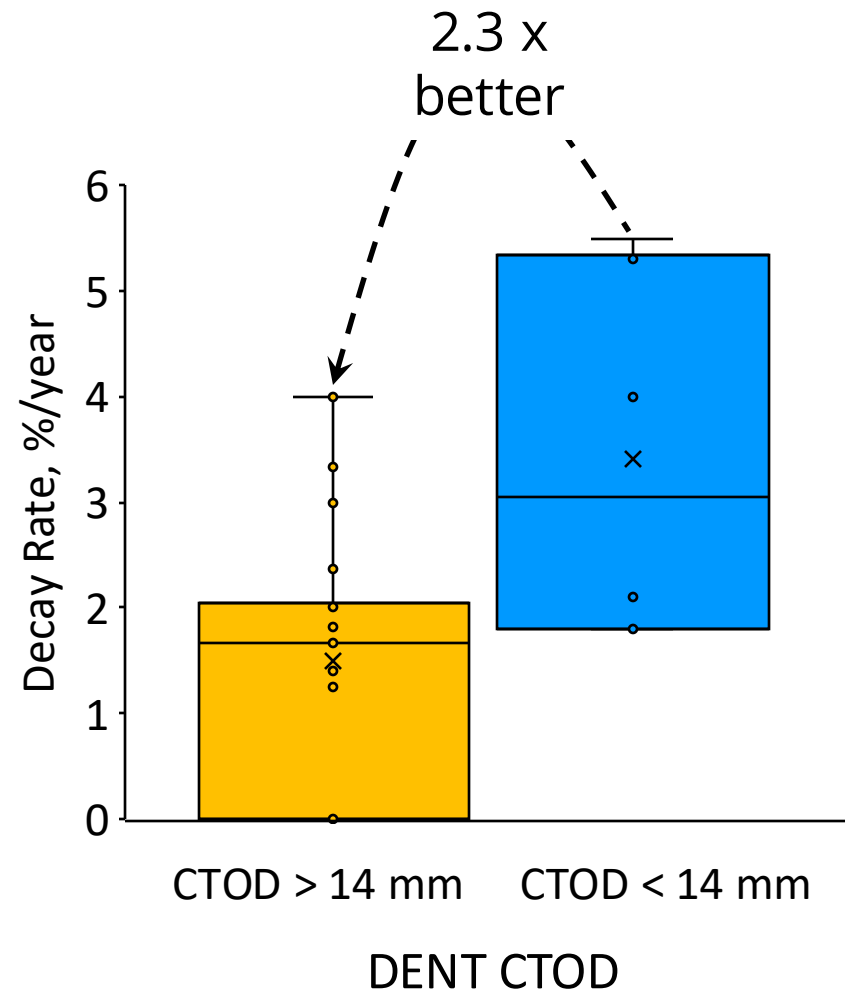
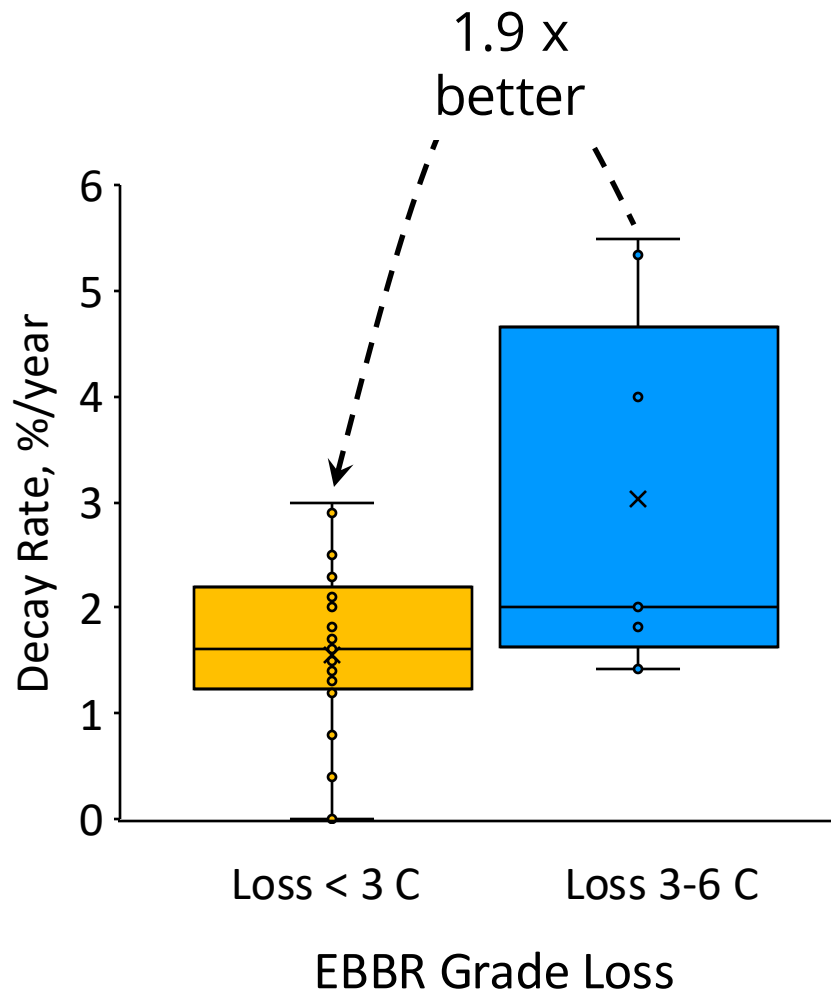
Implementation of EBBR and DENT (2015)

Durham Region (538 Contract Segments)



Sensitivity of Grade Loss and CTOD

Durham Region (41 Recovered Binders, 2015-2020)



Peel Region Pavement Conditions (2025)

2002

23 Years of Age
Early Superpave
AC @ \$300/tonne



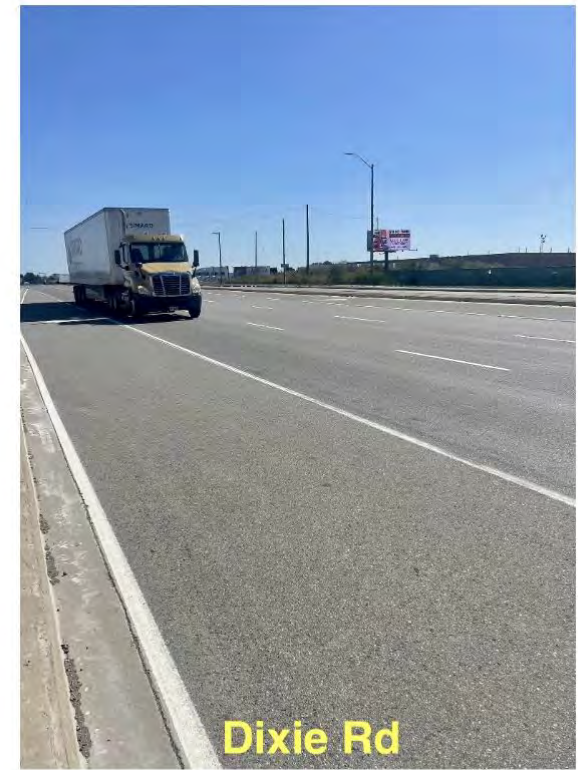
2010

15 Years of Age
Established Superpave
AC @ \$900/tonne



2015

10 Years of Age
Early DENT and EBBR
AC @ \$500/tonne



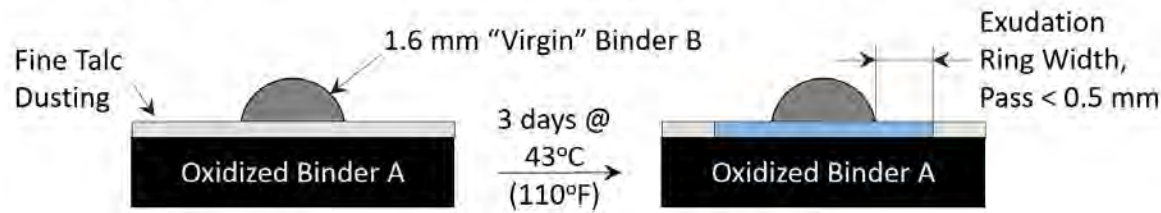
Durham Region Early Stripping (2022)

- Newtonville Road (RR 18) pavement trial.
- Constructed late 2022 and binder stripped before winter.
- Binder was over modified (PG 64-34 versus PG 58-34).
- High natural sand mix.



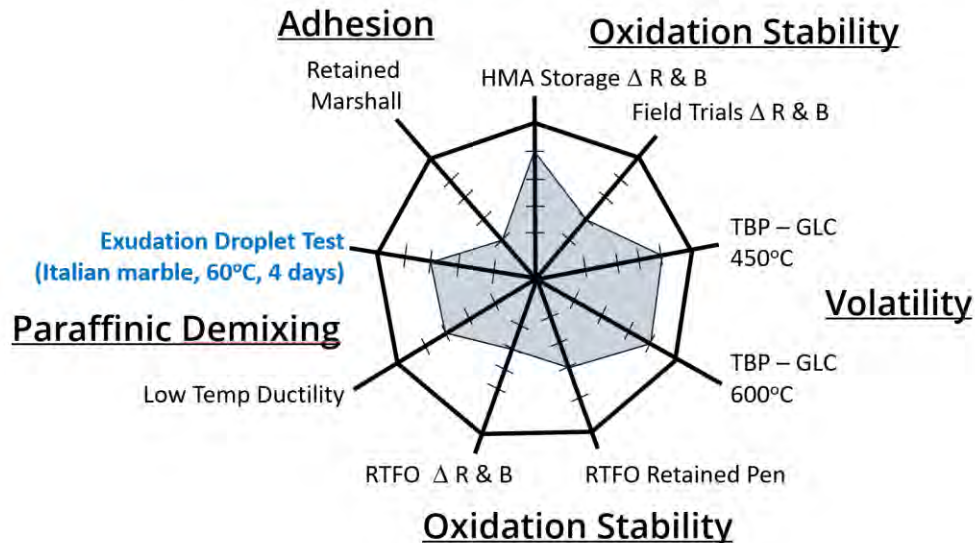
Historical Exudation Tests (1930-80s)

(1) Oliensis Exudation Test (1930s)



Oliensis GL, The Exudation Test for "Bleeding" in Bituminous Roofing, *Ind. Eng. Chem.*, 10(4), 199, 1938

(2) Shell Qualagon™ (1980s)

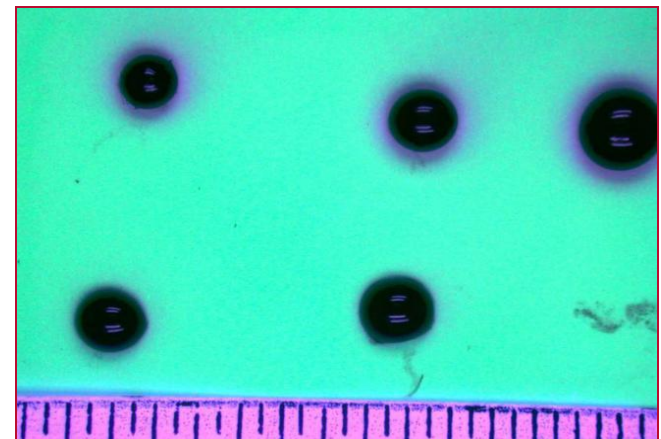


Van Gooswilligen et al., *Proceedings, Eurobitumen*, Madrid, 1989

(3) Australian Exudation Test

Fluorescence Microscopy

Merck Silica Gel 60 F254, 65°C, 2.5 days

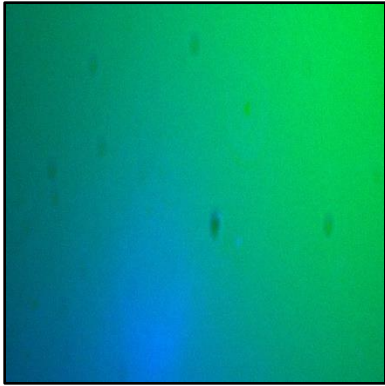


Cunningham, RTA Technology, 1989

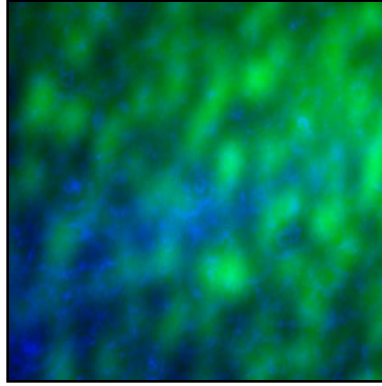
Where There Is Smoke, There Is Fire

“Gel-Type” Structures Retain Stress and Sweat Oils

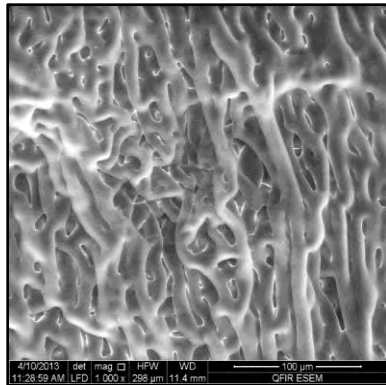
Soft Cold Lake



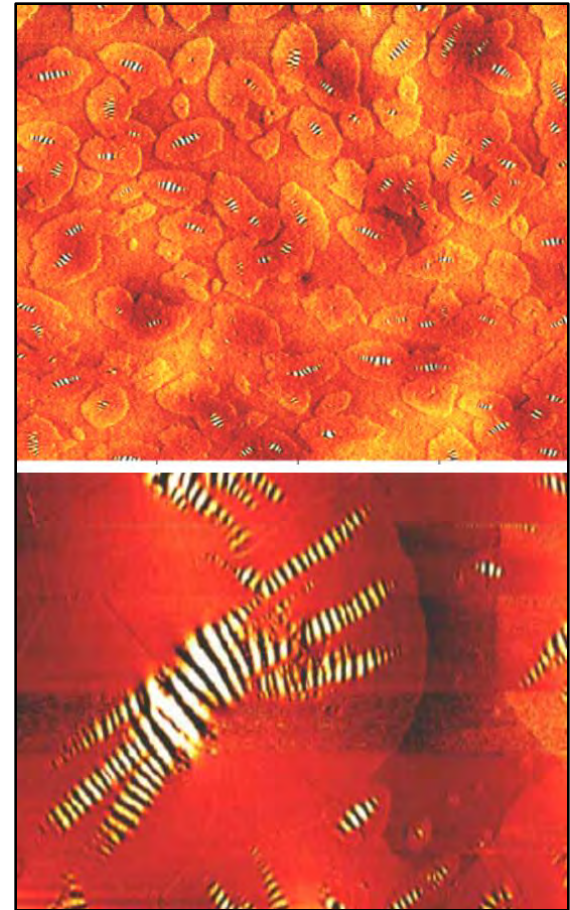
REOB Tainted Binder



Phase Compatibility by
Fluorescence Microscopy



ESEM of Resins + Asphaltenes



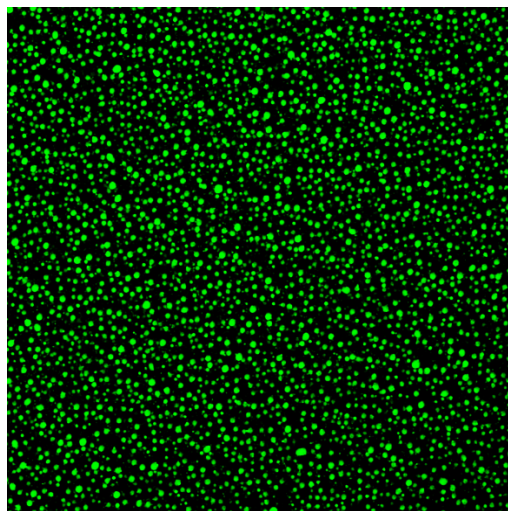
AFM of Waxes + Asphaltenes
(Pauli et al., *IJPE* 2011)

High SBS Causes Phase Inversion and Gelation

Trans-Canada Highway 417 Trial Binders (2006)

Section 417-1

3.5% SBS

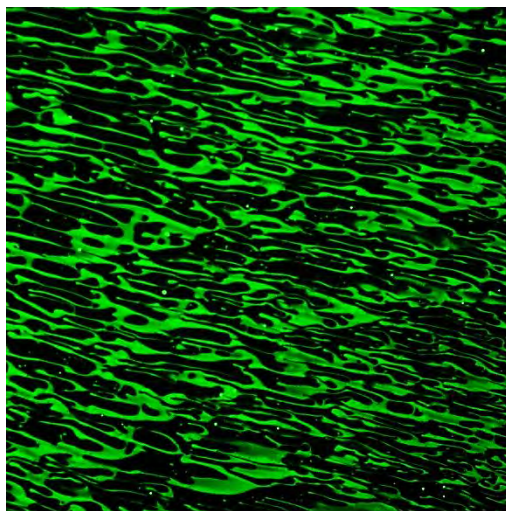


PG 64-34

Projected Lifespan
to 65% PCI =
32 Years

Section 417-2

6.0% SBS

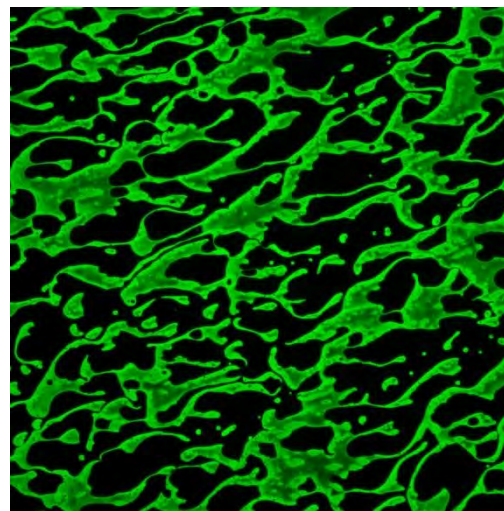


PG 70-34

Projected Lifespan
to 65% PCI =
32 Years

Section 417-3

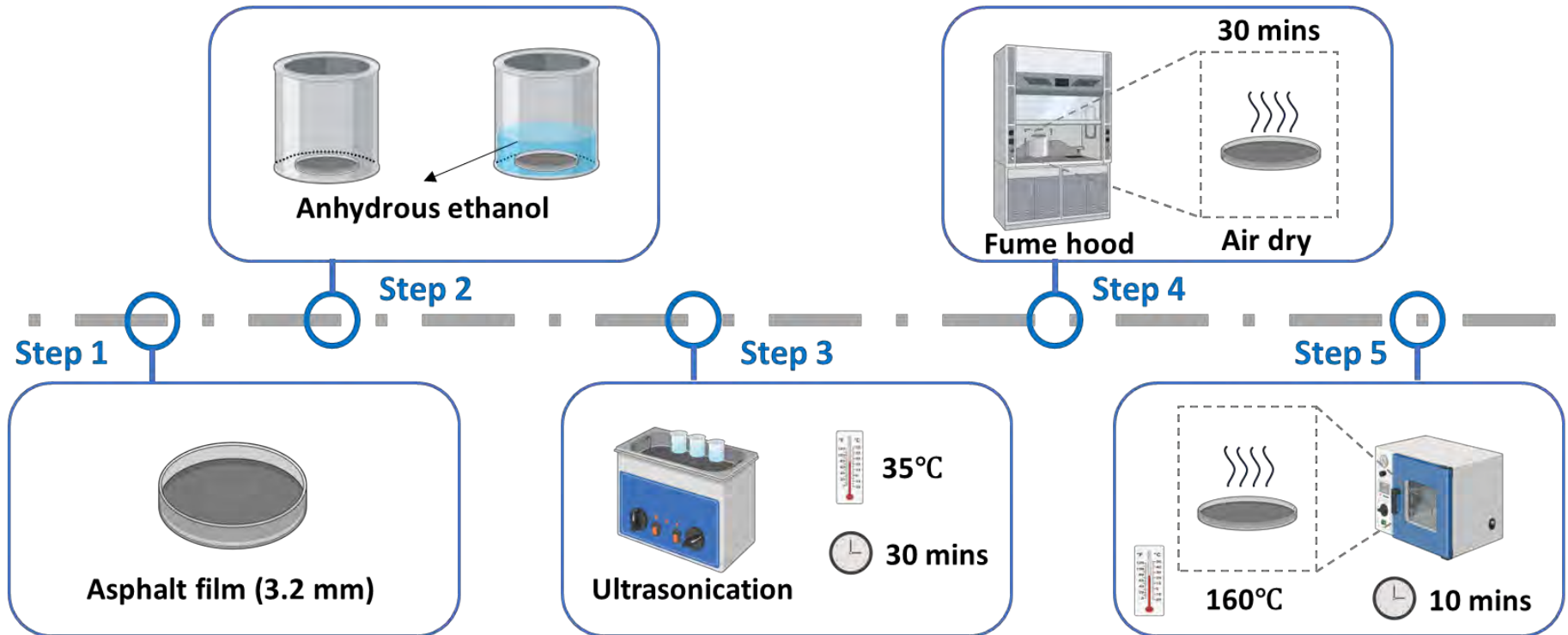
6.0% SBS



PG 82-40

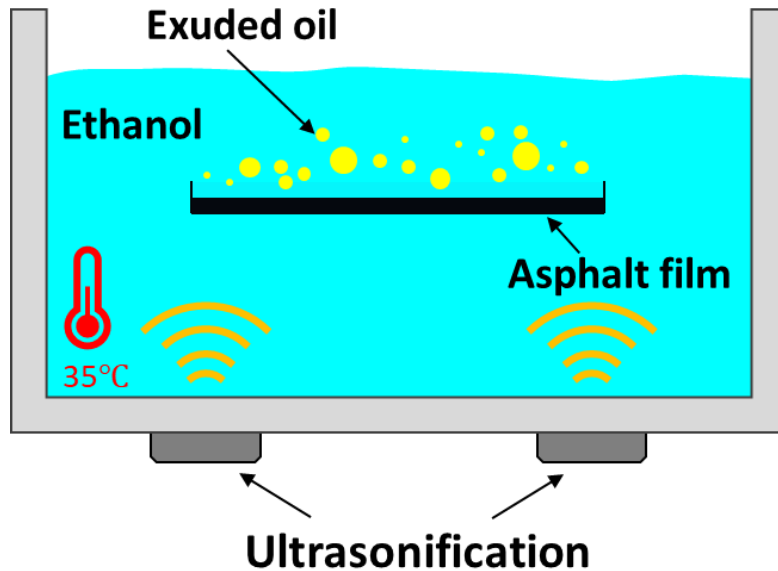
Projected Lifespan
to 65% PCI =
21 Years

Accelerated Oil Exudation (AOE) Test



Study Design

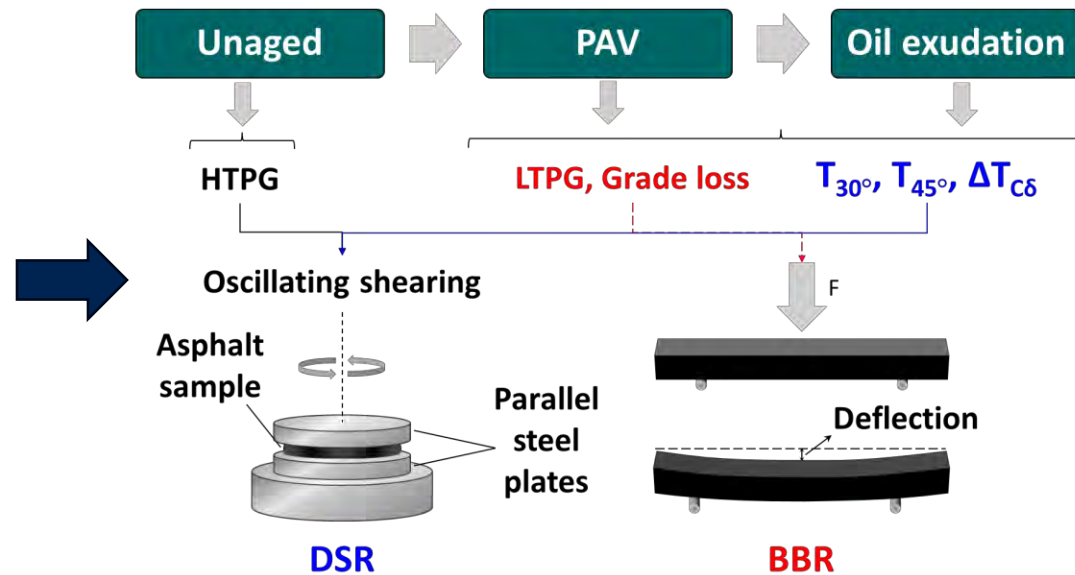
① AOE



Quantification of Exudation

Difference in sensitivity for indicators.

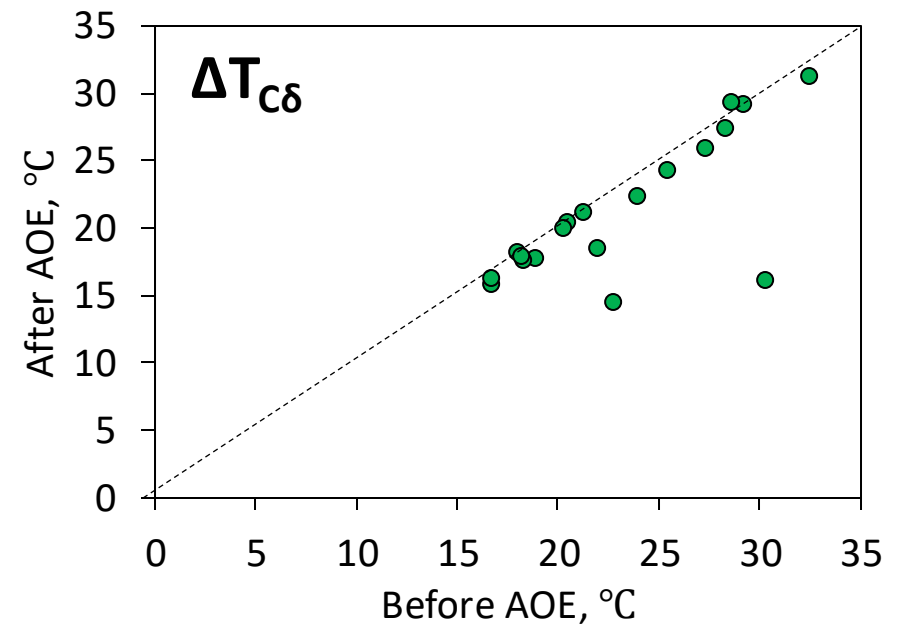
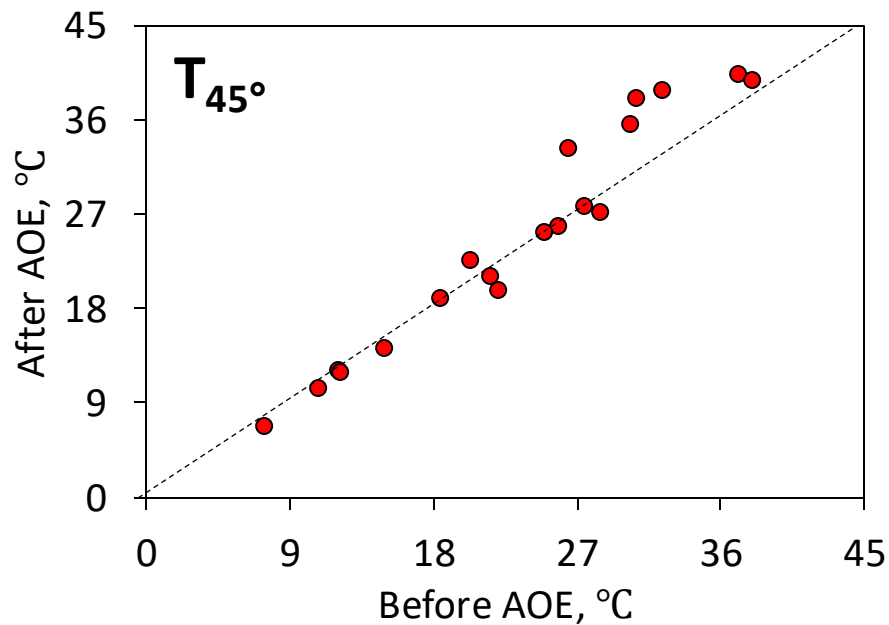
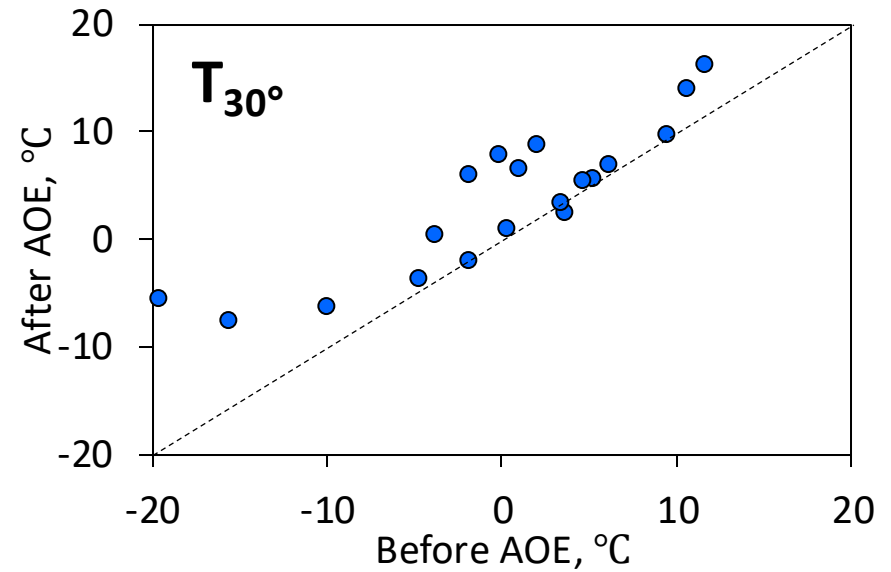
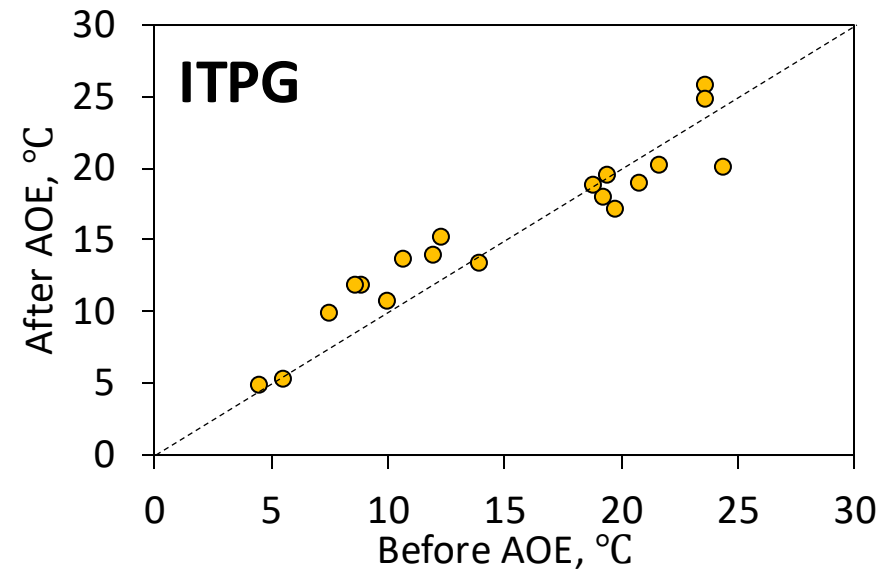
② Rheological Testing



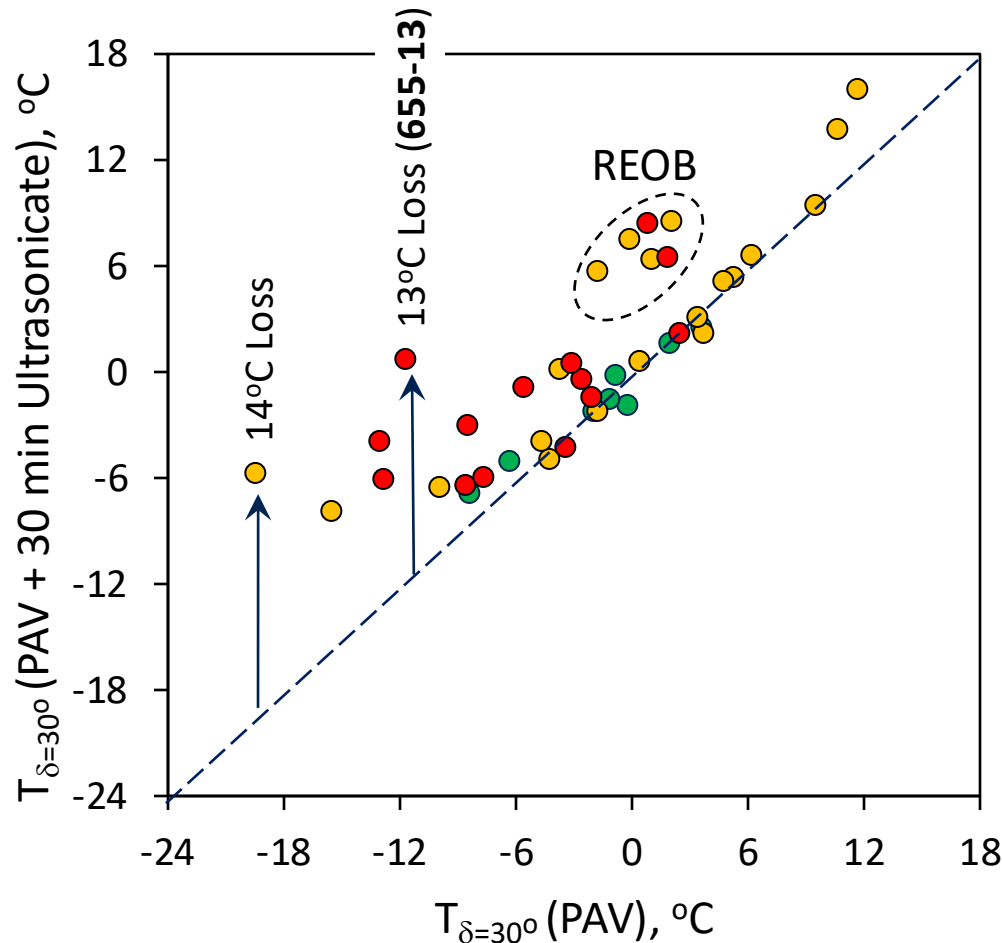
Effect of Binder Type

Binder source, modification, RAP, etc.

Quantification of Exudation



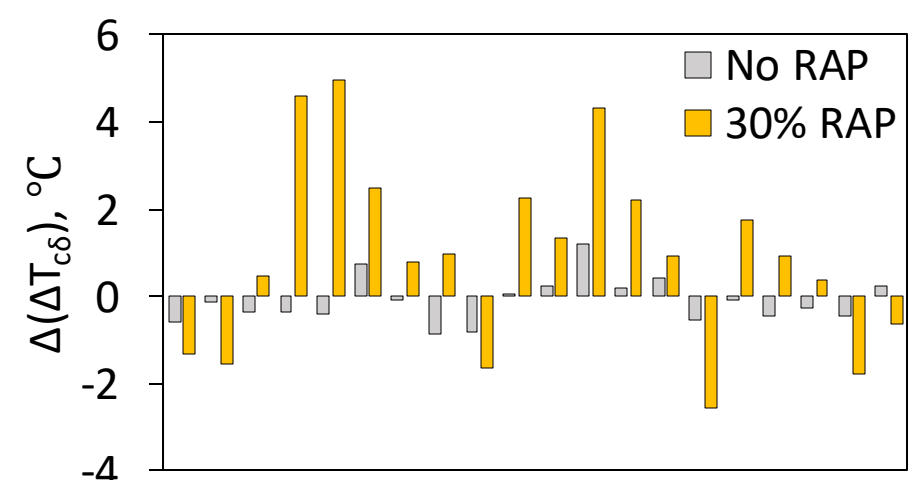
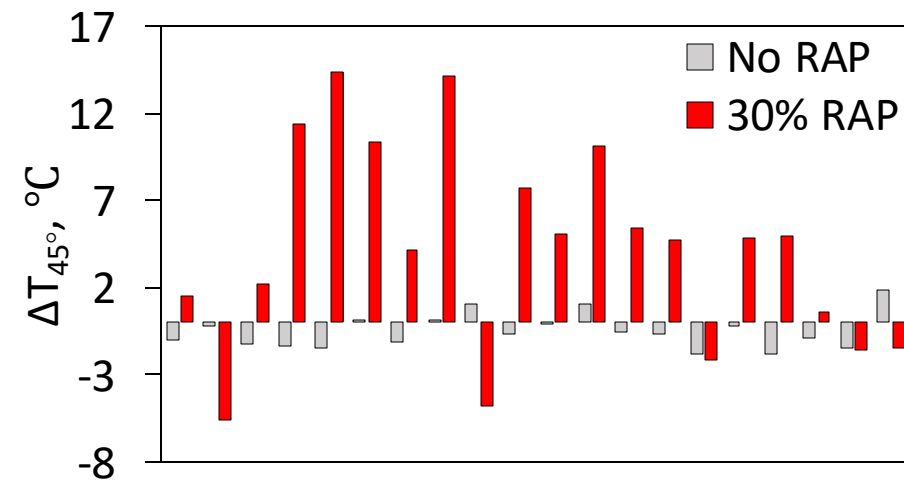
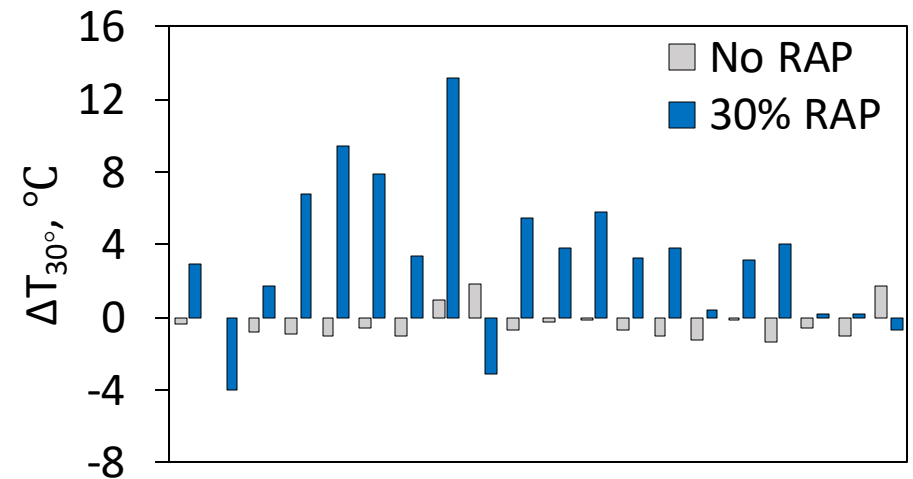
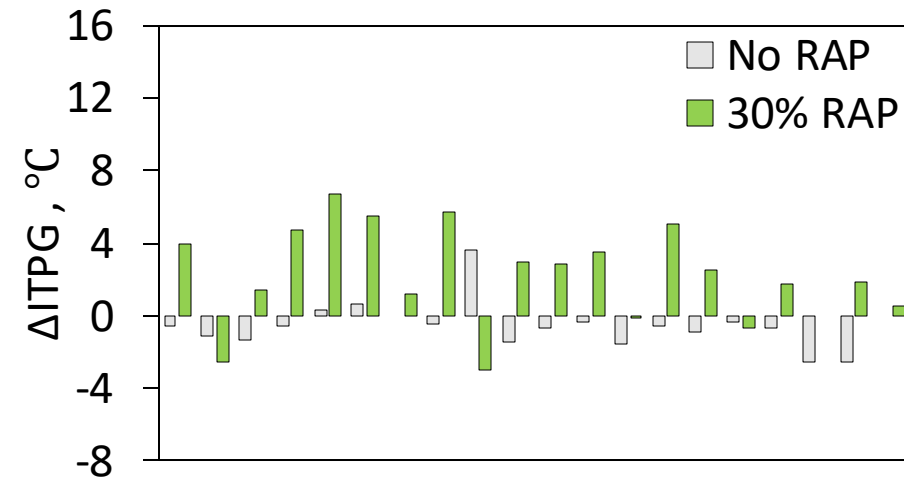
Effect of Binder Source and Modification



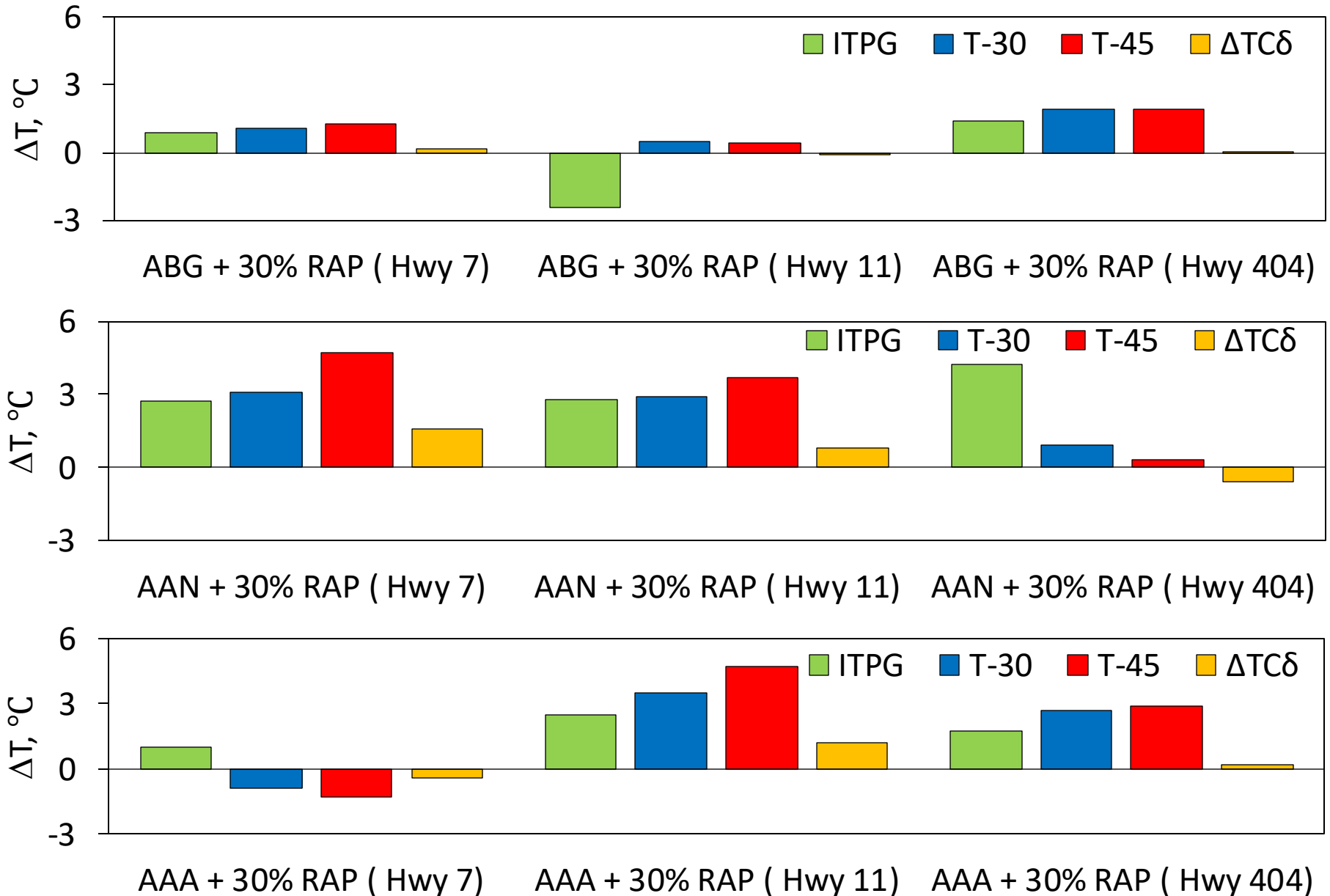
Binders	Exudation Grade Loss, $^\circ\text{C}$
Straight Alberta (8)	0.0 ± 1.1
Commercial (20)	3.2 ± 4.0
Trial Section (14)	4.4 ± 3.8

- Straight Alberta binders show superior durability.
- A high SBS binder lost 14 $^\circ\text{C}$ through exudative hardening!
- Several others with REOB lost 8 $^\circ\text{C}$!

Effect of Reclaimed Asphalt (RAP)

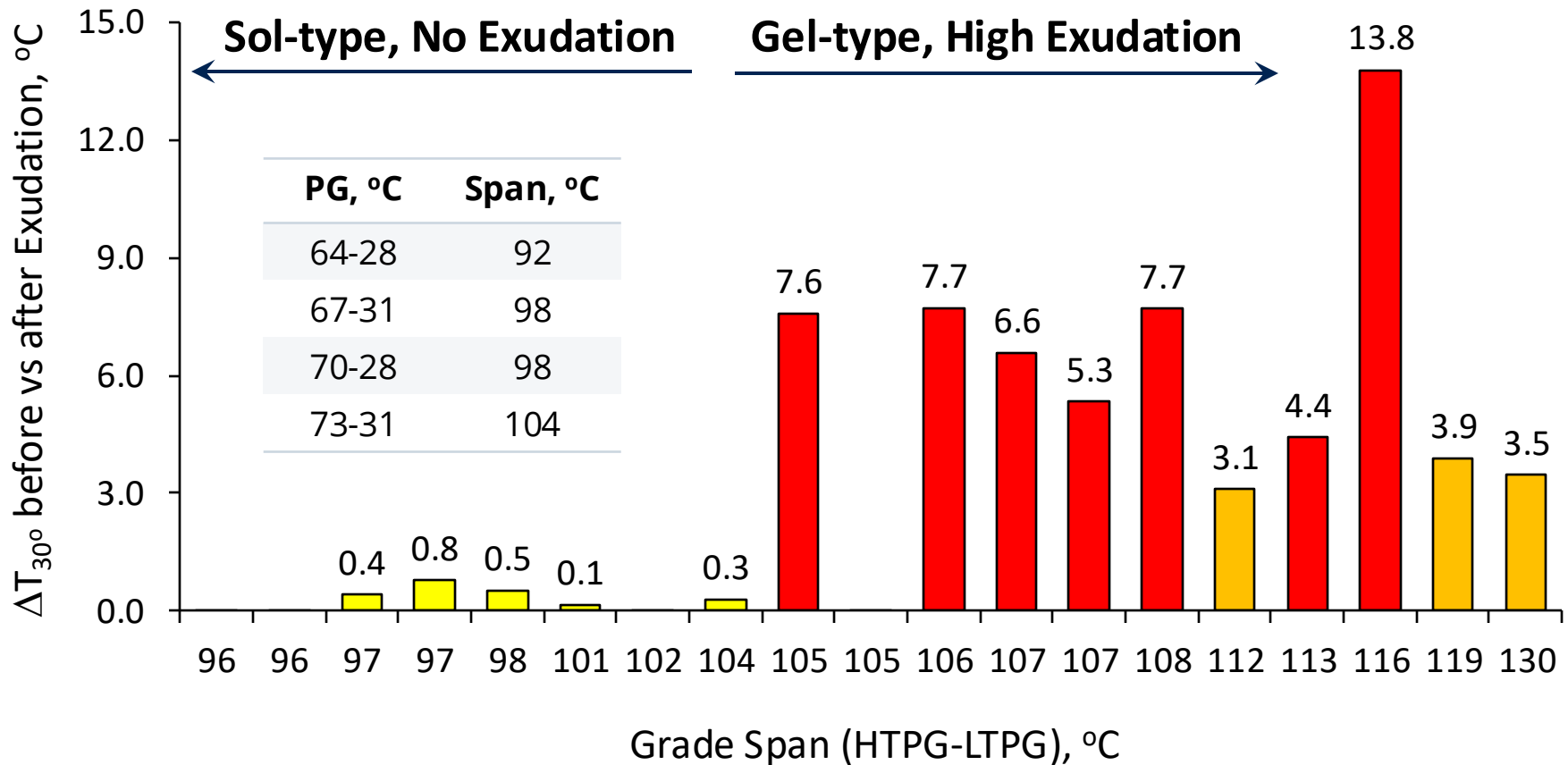


Effect of Binder and RAP Source



Effect of Grade Span on Exudation Loss

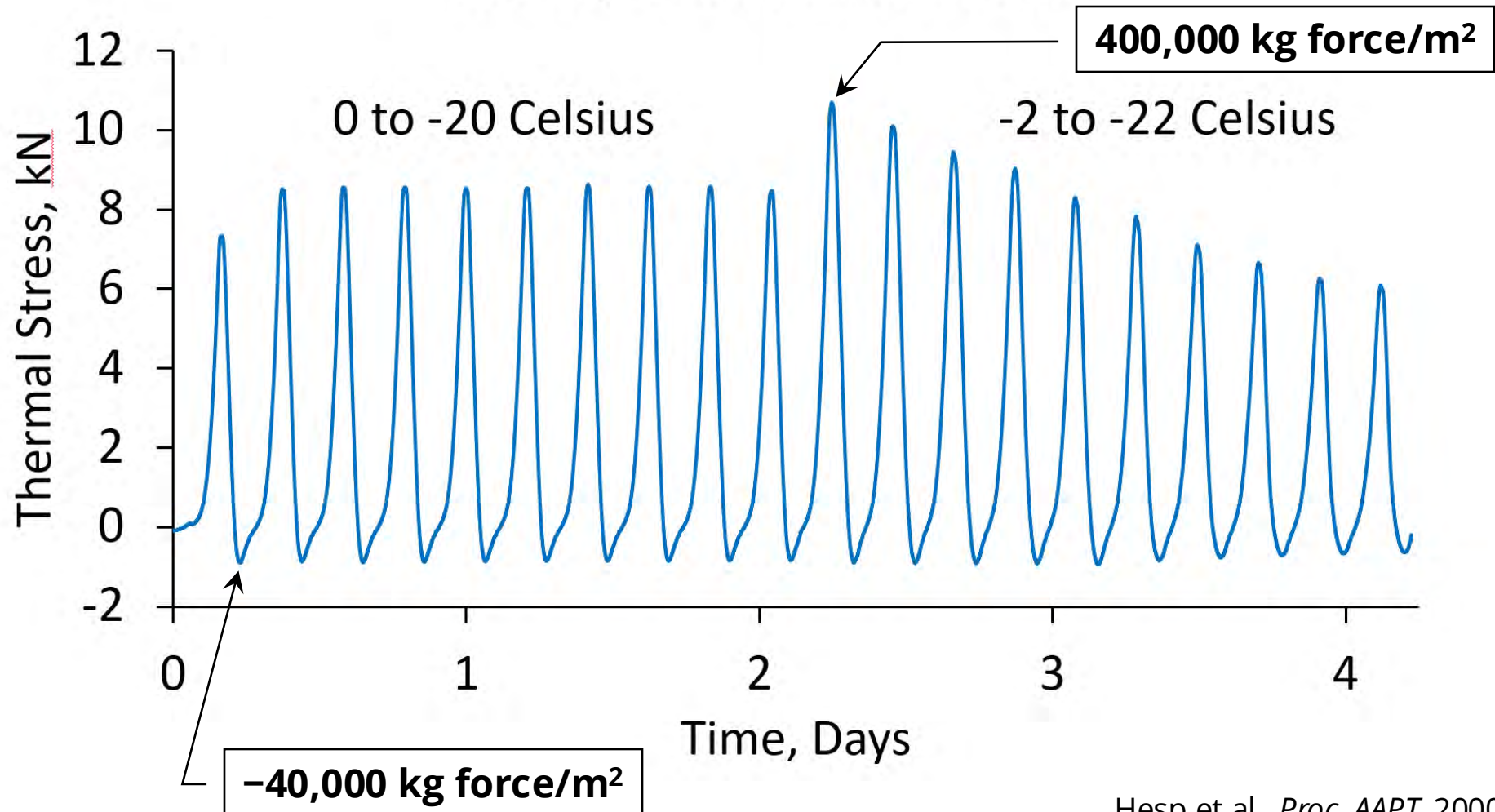
Commercial Sources (18 US, 1 Canadian)



Thermal Stress Restrained Specimen Test

Thermal Fatigue in PG -26 Mix Beam

5% SBS, 5 cm x 5 cm x 17 cm



Effect of Grade Span on Stress Relaxation

Contract 1, PG 85-29 (red, grade span = 114):

Seriously overdesigned with SBS and RAP? Lifecycle likely 10-15 years. Little conventional transverse cracking but lots of thermal fatigue cracking due to exudation. $T_{\delta=30} = -5.6\text{ }^{\circ}\text{C}$ and $\Delta T_{c\delta} = 21.8\text{ }^{\circ}\text{C}$

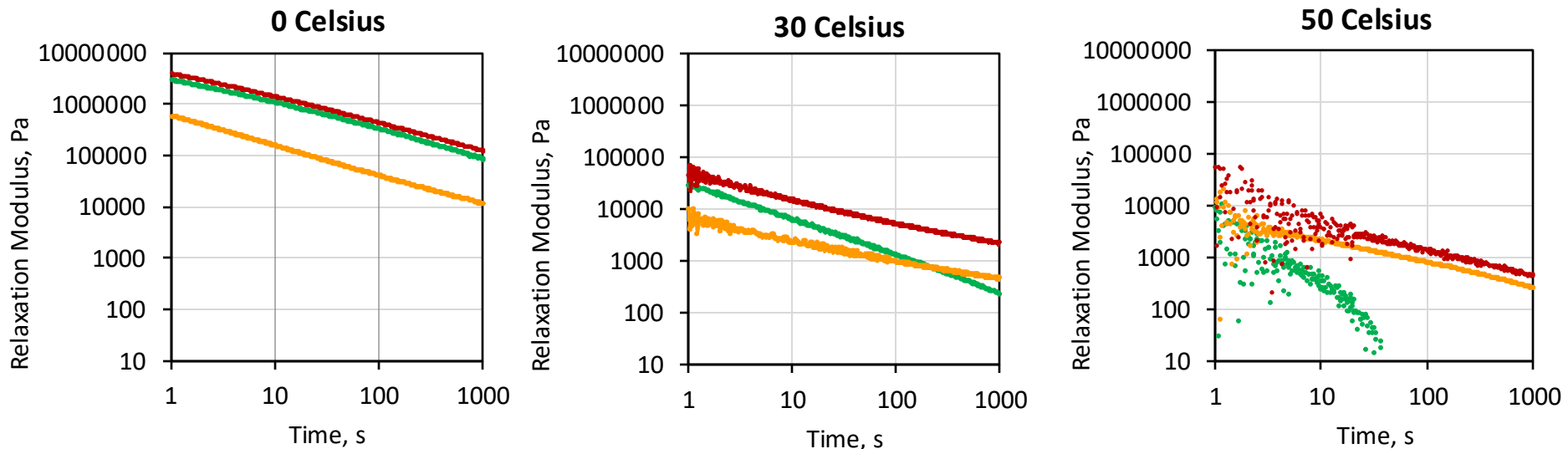
Contract 2, PG 70-28 (green, grade span = 98):

Slightly overdesigned. Lifecycle about 25 years.

Conventional transverse cracking. $T_{\delta=30} = -0.1\text{ }^{\circ}\text{C}$ and $\Delta T_{c\delta} = 16.5\text{ }^{\circ}\text{C}$

Contract 3, PG 70-39 (orange, grade span = 109):

Seriously overdesigned with high amount of SBS. Lifecycle likely 10-15 years. Reduced crack initiation, excessive propagation, thermal fatigue due to exudation. $T_{\delta=30} = -12.5\text{ }^{\circ}\text{C}$ and $\Delta T_{c\delta} = 22.2\text{ }^{\circ}\text{C}$



Effect of Conditioning on IDEAL-CT

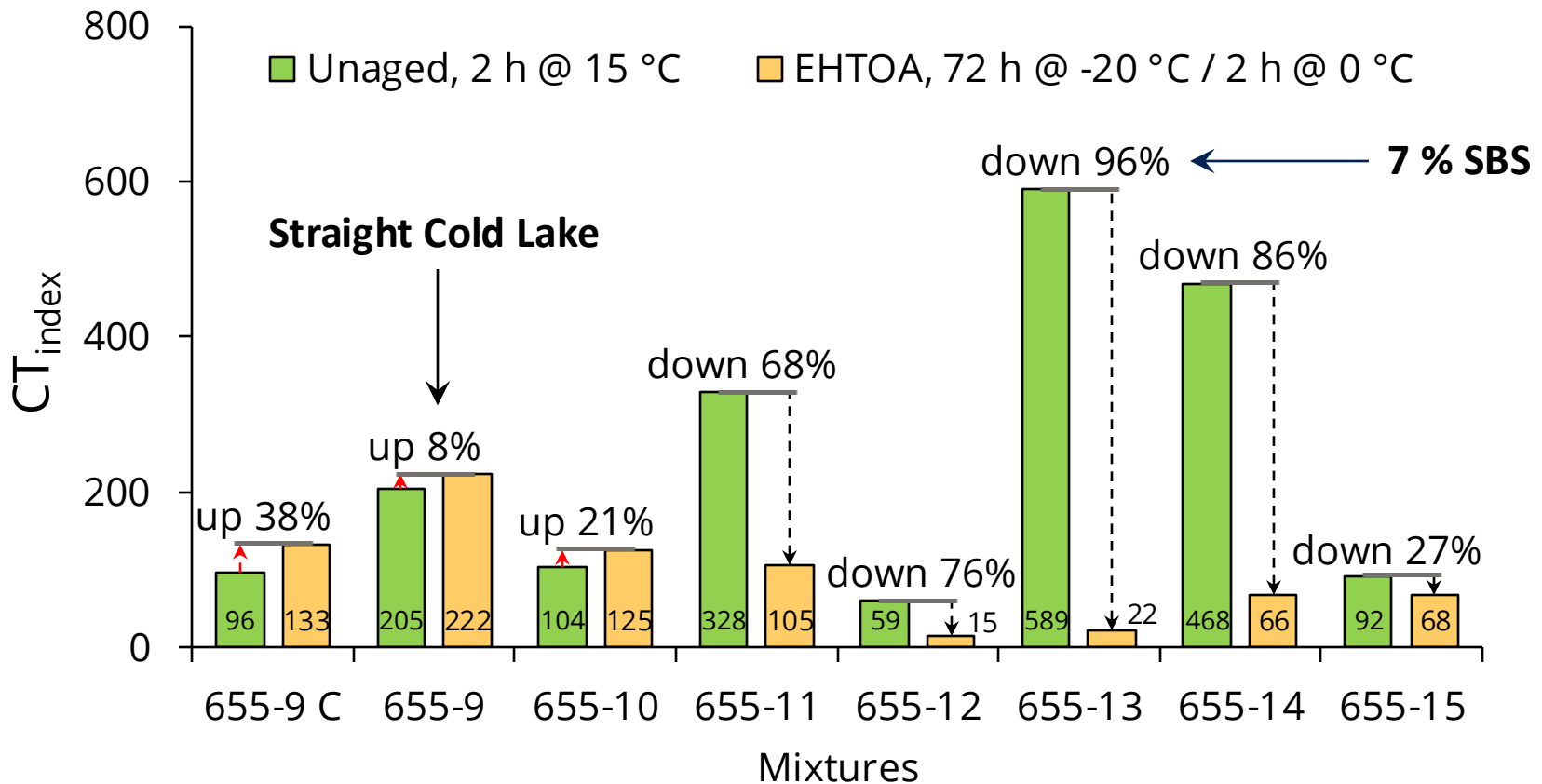
Unaged versus EHTOA and Cold Conditioned (Hwy 655, Phase II)

Best Performance:

655-9, Straight Cold Lake 300/400 pen + PET fiber
38-year lifespan, benefit/cost ratio = 0.81

Worst Performance:

655-13, 7 % SBS, PG 82-40
23-year lifespan, benefit/cost ratio = 0.40



Highway 655 Cold Lake Trial (2007-2024)



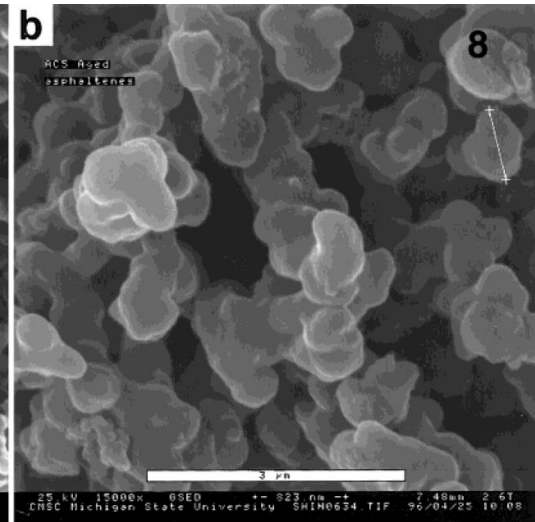
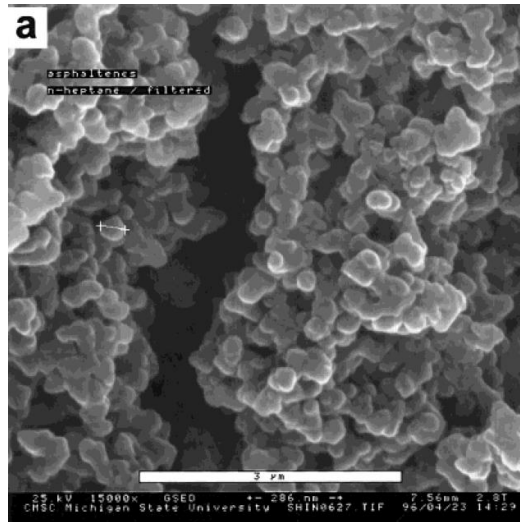
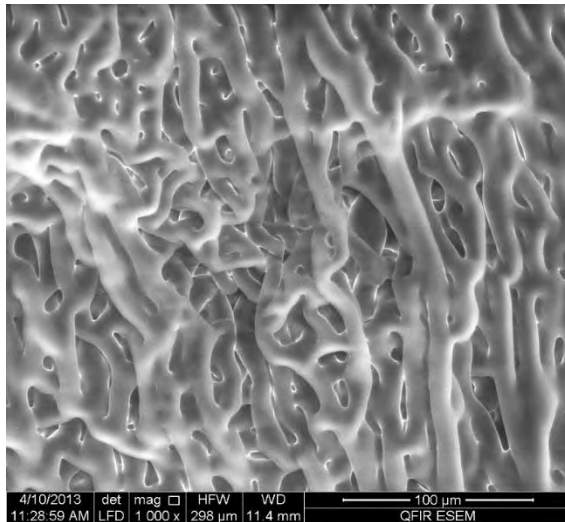
Section	Lifespan, years (PCI = 50 %)
655-9	38
655-13	23
655-14	36



Gel Formation in Rheology

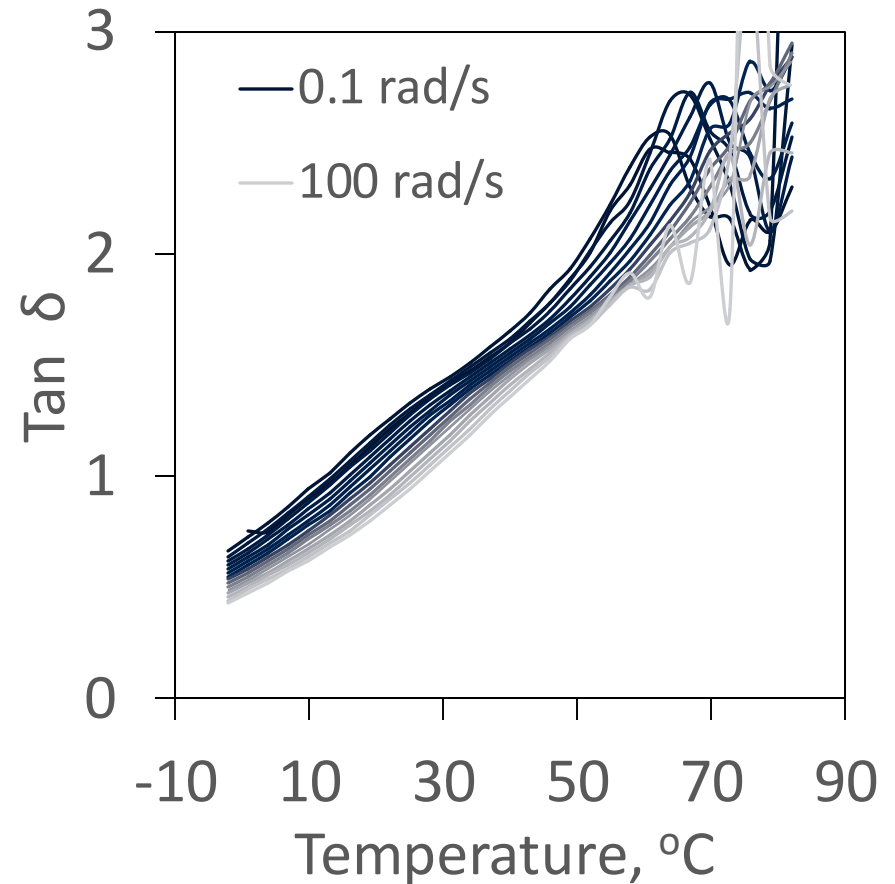
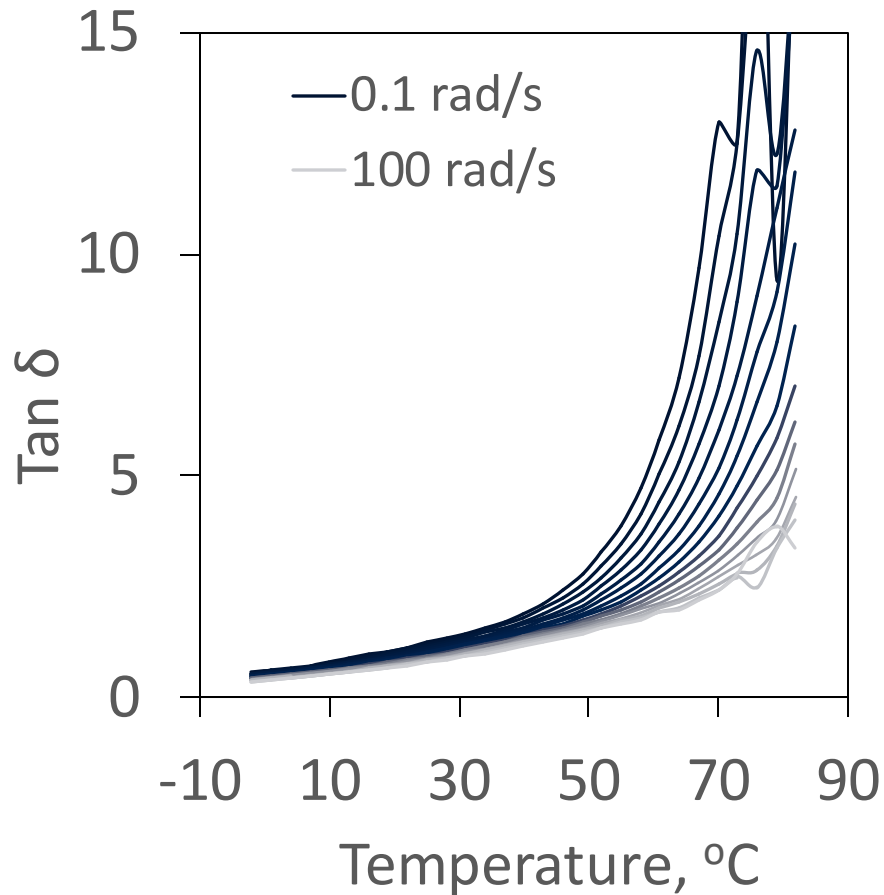
Rheometer Setup:

- 8 mm plates
 - 0.1-100 rad/s
 - -2 to 70°C (3°C step)
1. Chemical versus physical.
 2. Frequency independence of $\tan \delta$.
 3. Less stress relaxation.



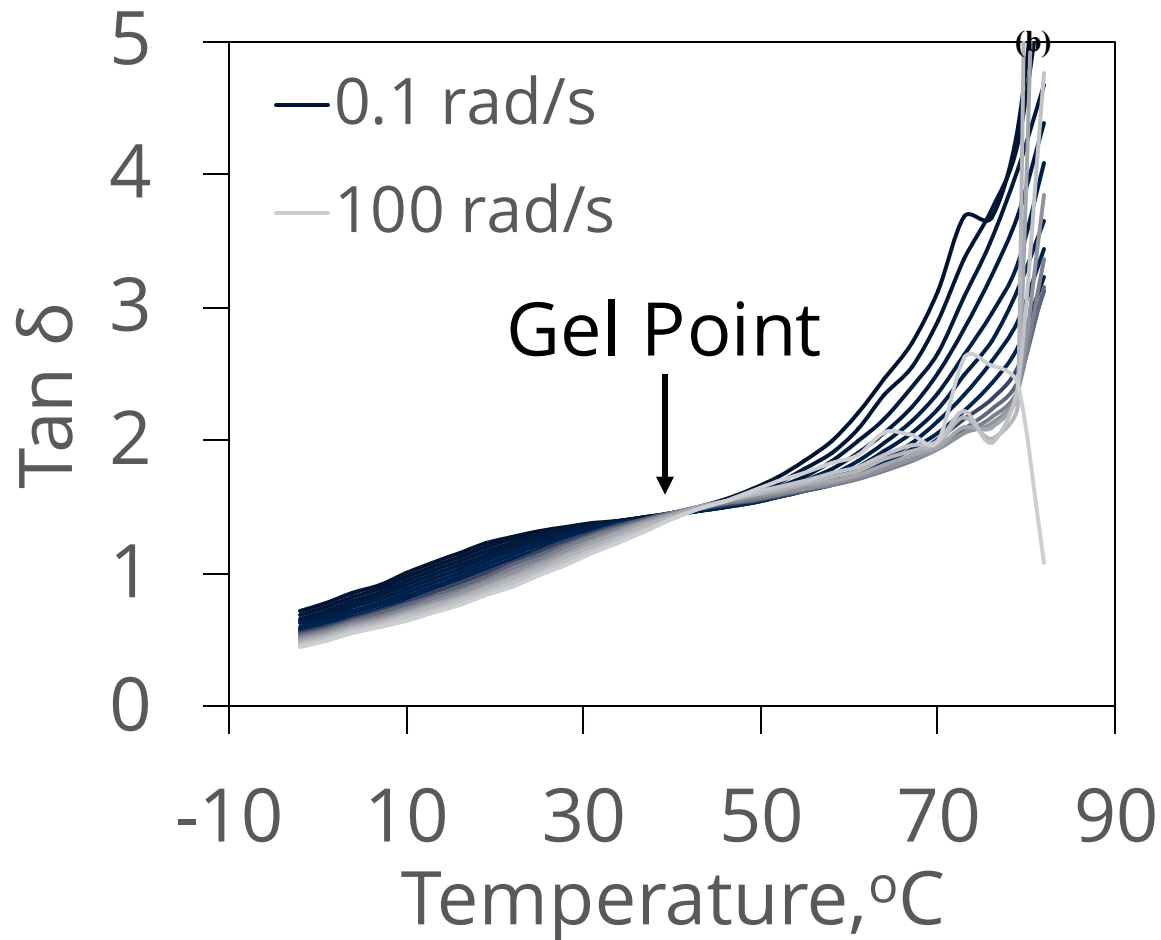
Rheological Analysis of Gel Formation

Type 1: Sol or Sol-Gel



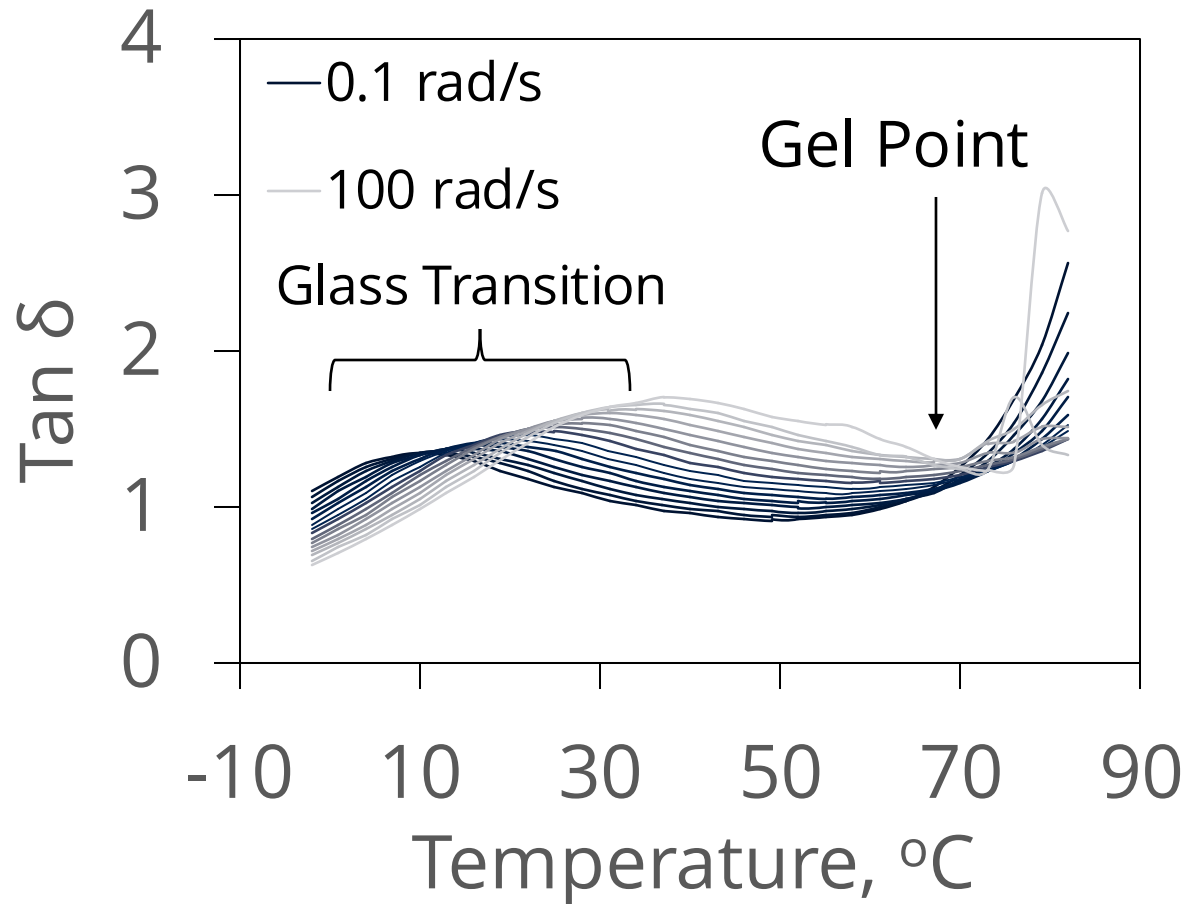
Rheological Analysis of Gel Formation

Type 2: Sol-Gel or Gel



Rheological Analysis of Gel Formation

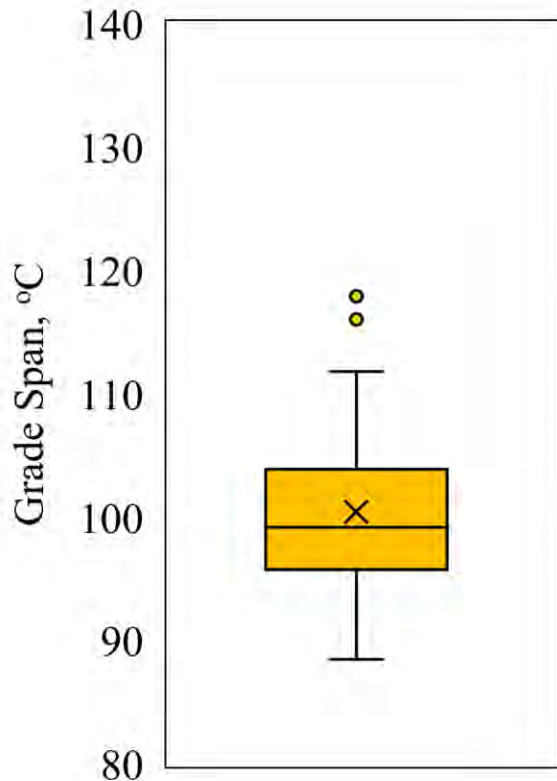
Type 3: Gel with Phase Separation



Gel Formation Findings

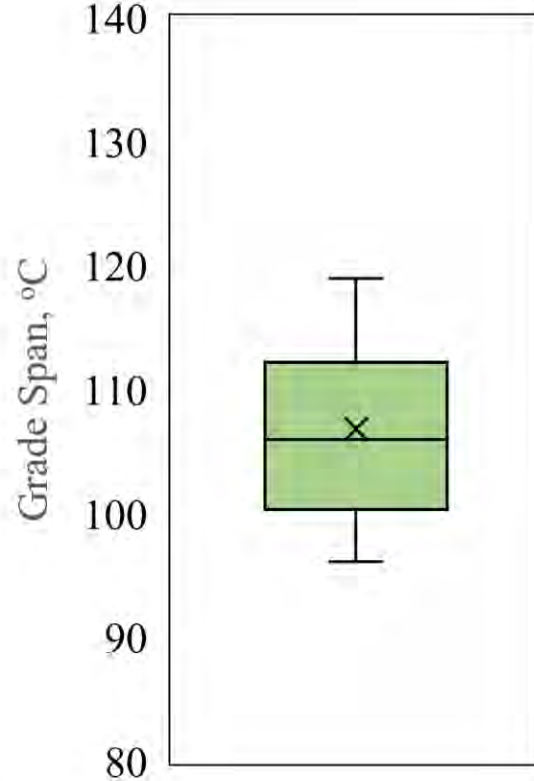
Type 1

No Gel Point or
Glass Transition



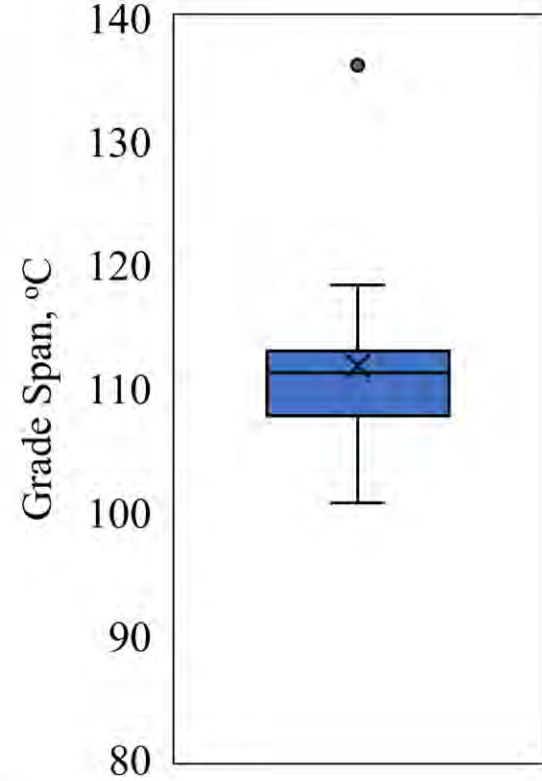
Type 2

Gel Point Only



Type 3

Gel Point and
Glass Transition



Derry Road East, Peel Region, Ontario

- Total reconstruction in 2015.
- 0 cracks/2,800 m @ 6 lanes in 2025.
- One of Canada's busiest municipal truck routes.
- Recovered grade spans ranged from 97.6-108.6 Celsius.



Conclusions

- Pavement service lives for Ontario municipal users dropped by ~ 66 percent in 30 years (1980-2010).
- EBBR and DENT have provided immediate relief.
- Must test recovered binder and enforce reasonable acceptance criteria to be effective.
- An accelerated oil exudation test was proposed and validated as a good method to identify unstable and incompatible asphalt binders.
- Over modification of asphalt, characterized by high grade spans, causes gel formation and exudation.

Questions?

E-mail: Simon.Hesp@queensu.ca

Phone or Text: (613) 876-1742

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- Discovery Grant program of NSERC

