Early Findings for EBBR and DENT Implementation and Prospects for Simplification

Simon A.M. Hesp
Queen's University, Kingston, Ontario

Imperial Oil-OAPC Technical Symposium, Sarnia, Ontario
June 18, 2019

Acknowledgements

Imperial Oil of Canada

Ministry of Transportation of Ontario

Natural Sciences and Engineering Research Council of Canada

Ontario Municipalities

Others

Acknowledgements

Graduate Thesis Students (39): Li, Nawarathna, Lemaitre, Asiedu, Benavides, Ding, Gyasi, Tetteh, Somuah, Ubaid, Gotame, Sowah, Omari, Omo, Ghimire, Agarwal, Abiodun, Adhikari, Kumar, Agbovi, Kanabar, Kanabar, Soleimani, Subramani, Togunde, Iliuta, Andriescu, Zhao, Ploeger, Xing, Roy, Smith, Lazar, Crossley, Richardson, Petroff, Garcés-Rodriguez, Lee

Undergraduate Thesis Students (39): Toews, Van der Heyden, Strojek, Klus, Penstone, Verigin, Klein, Maurer, Ritchie, Fong, Armstrong, McEwan, Burke, Whitelaw, Scafe, Evans, Kehoe, Houlihan, Walsh, Faba, Gates, Malmberg, Pipkin, Chee Sing, Carran, Kurys, Sohn, Aida, Wagner, Knowles, Thom, Manolis, Cook, Crossley, Fairclough, Sharpe, Roberts, Coutts, Morrison

Postdoctoral Fellows, Assistants & Associates (85): Pan, Ding, de Loe, Diak, Young, Lien, Viau, Yang, Zhang, Matthews, Bird, Clarke, Zacks, Beier, Akentuna, Khan, Campbell, Angius, Berkowitz, Filipovich, Assuras, Duff, Kaskow, Rigg, Nie, Paliukaite, Rudson, Aggrawal, Freeston, Gillespie, Howell, Rudson, Johnson, Thomas, Marr, Larsen, Roff, McGurn, McIntyre, Bricker, Kinross, Moore, Smith, Xu, Skoko, Warburton, Rubab, Ahmed, Taylor, Erskine, Eveleigh, Rubab, Marchildon, Zhang, Kim, Moult, Wright, Wei, Genin, Schellen, Yuan, Budiwarman, Wong, Bodley, Kodrat, Bodley, Edwards, Yee, McLaren, Coulson, Smith, Hoare, Noseworthy, Lau, Luttmer, vanLoon, Moore, Morrison, Cullen, Klenkler, Stel, Hui, Mainland, Hedmark, Lee

Superpave™ Performance Graded Asphalt Cement

② RTFO

④ PAV

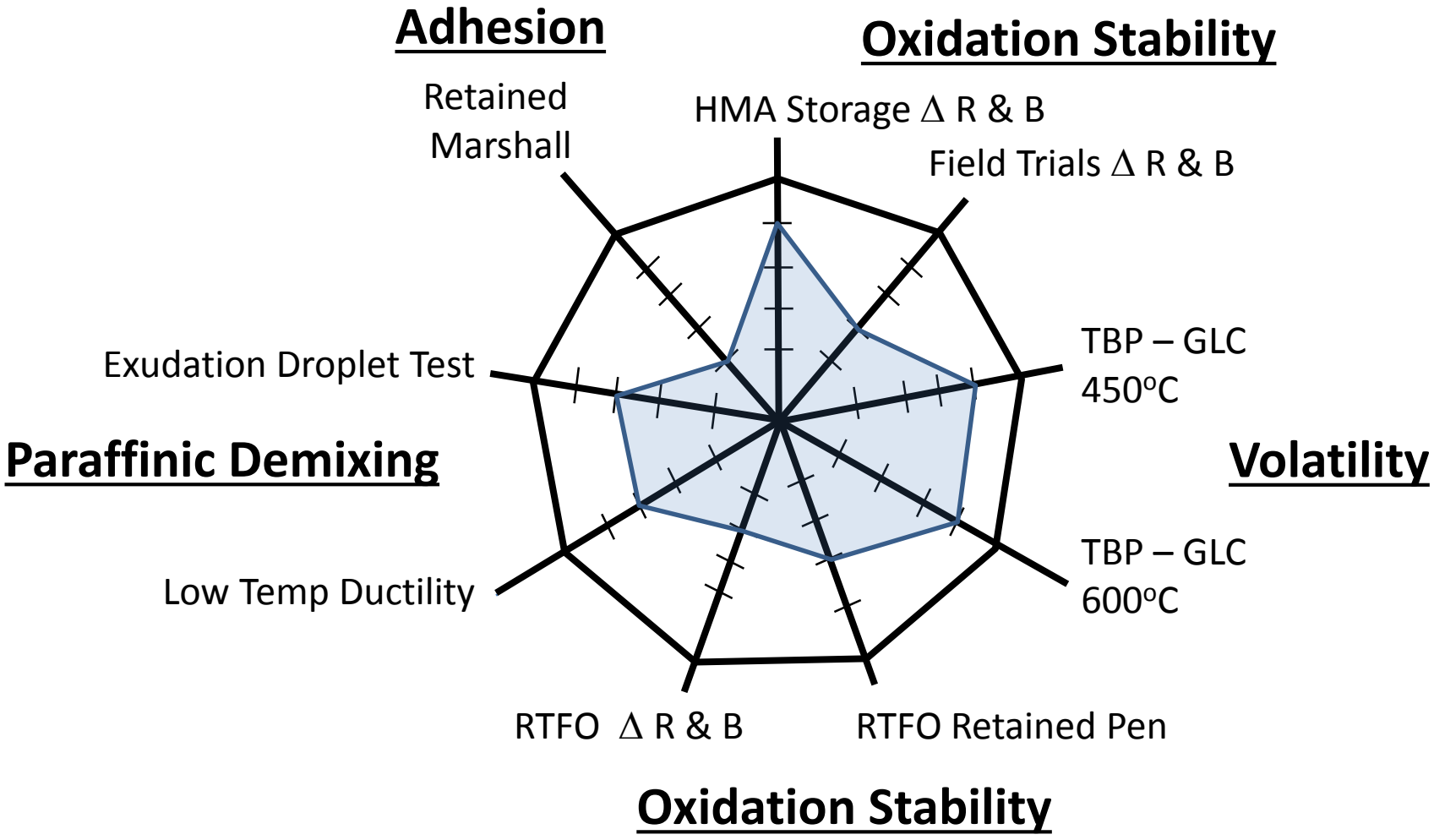
③ ⑤ DSR

①

⑥ BBR

PG XX-II-YY

Shell Qualagon™ (1980s)



Van Gooswilligen et al., Eurobitumen, Madrid, 1989

Identical PG 64-34 Grades, Timmins

(Constructed 2003, Photographs 2008)

655-1 Sol-type: Low physical/oxidative hardening, R-value, S-controlled, and high CTOD. **Little or no cracking.**

Stable RET + PPA

655-4 Gel-type: High physical/oxidative hardening, R-value, m-controlled. **Major cracking and moisture damage.**

Unstable SBS + REOB

Modus Operandi for Municipalities

1. **Control or ban what we can:**
   - REOB, paraffin oils, etc.
   - Waste bio industry oil, vegetable oils, etc.
   - RAP, RAS, waxes, cracked/oxidized residues, etc.
2. **Test <u>extracted and recovered</u> AC for what we cannot predict or imagine:**
   - LS-228 Modified Pressure Aging Vessel (2012)
   - LS-299 Double-Edge-Notched Tension Test (2006)
   - LS-308 Extended Bending Beam Rheometer Test (2005)
3. **As materials change so will the test methods and acceptance criteria.**

AASHTO Adopted LS-308 EBBR as Provisional Standard TP 122-16

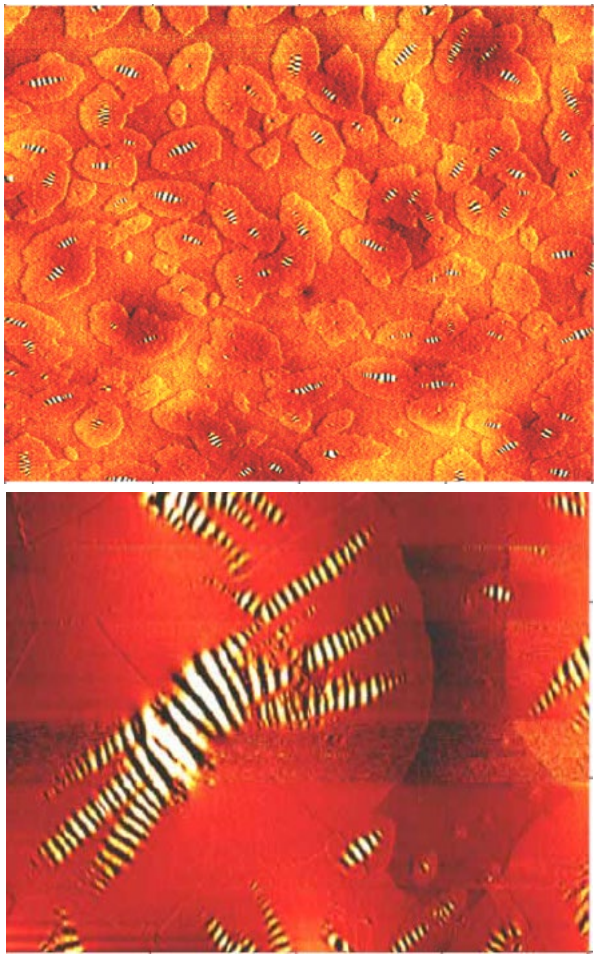
Standard Method of Test for

Determination of Performance Grade of Physically Aged Asphalt Binder Using Extended Bending Beam Rheometer (BBR) Method

AASHTO Designation: TP 122-16

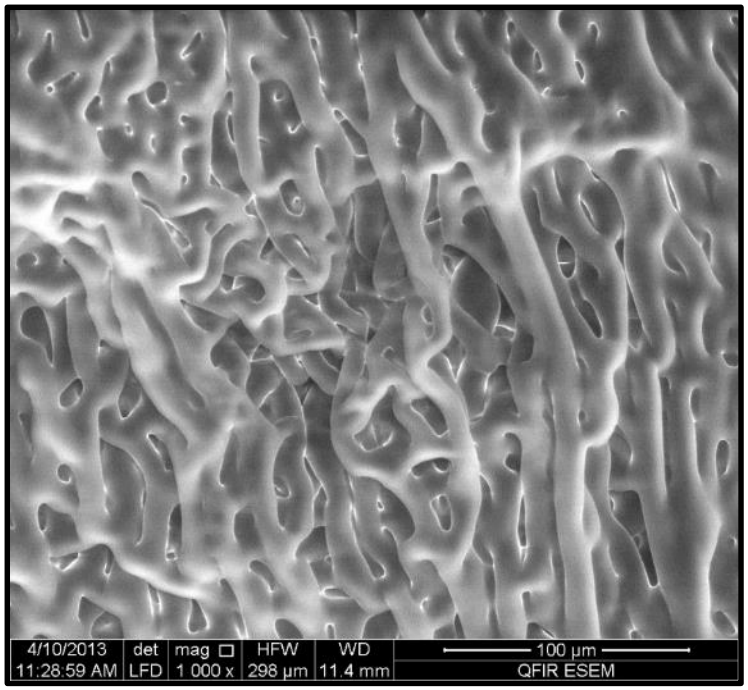
AASHTO
THE VOICE OF TRANSPORTATION

Thermoreversible Aging of "Gel-Type" Structures in Asphalt Cement



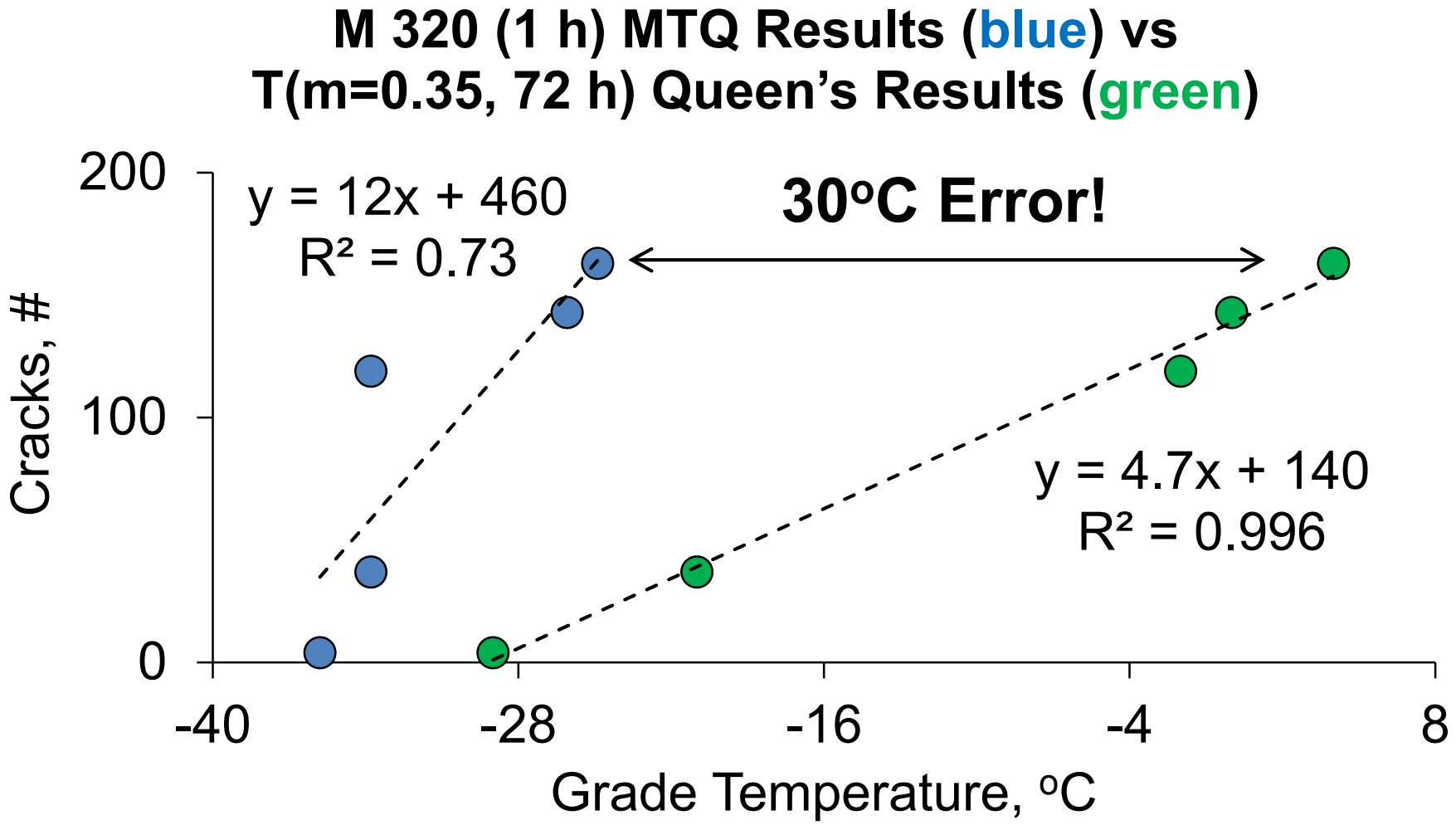
AFM of Waxes + Saturates

Pauli et al., IJPE, 2011



ESEM of Resins + Asphaltenes

Lamont C-SHRP Cracking Correlations (2006)

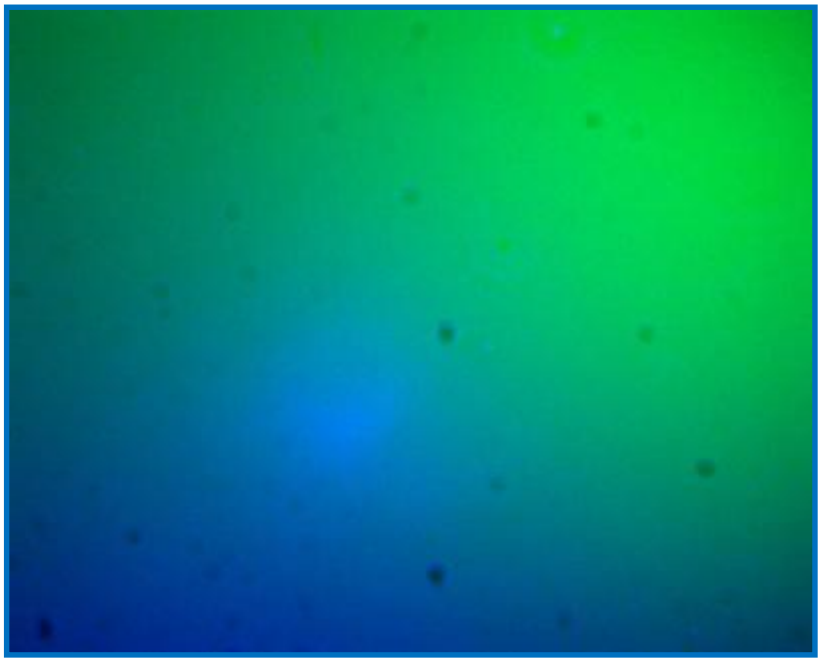


Gavin et al., CTAA, 2003 and Zhao and Hesp, IJPE, 2006

Phase Contrast and Fluorescence Microscopy on Asphalt Cement (2007)

No Paraffinic Demixing

Lamont RR-7L Cold Lake



False Blue = Phase Contrast

False Green = Fluorescence

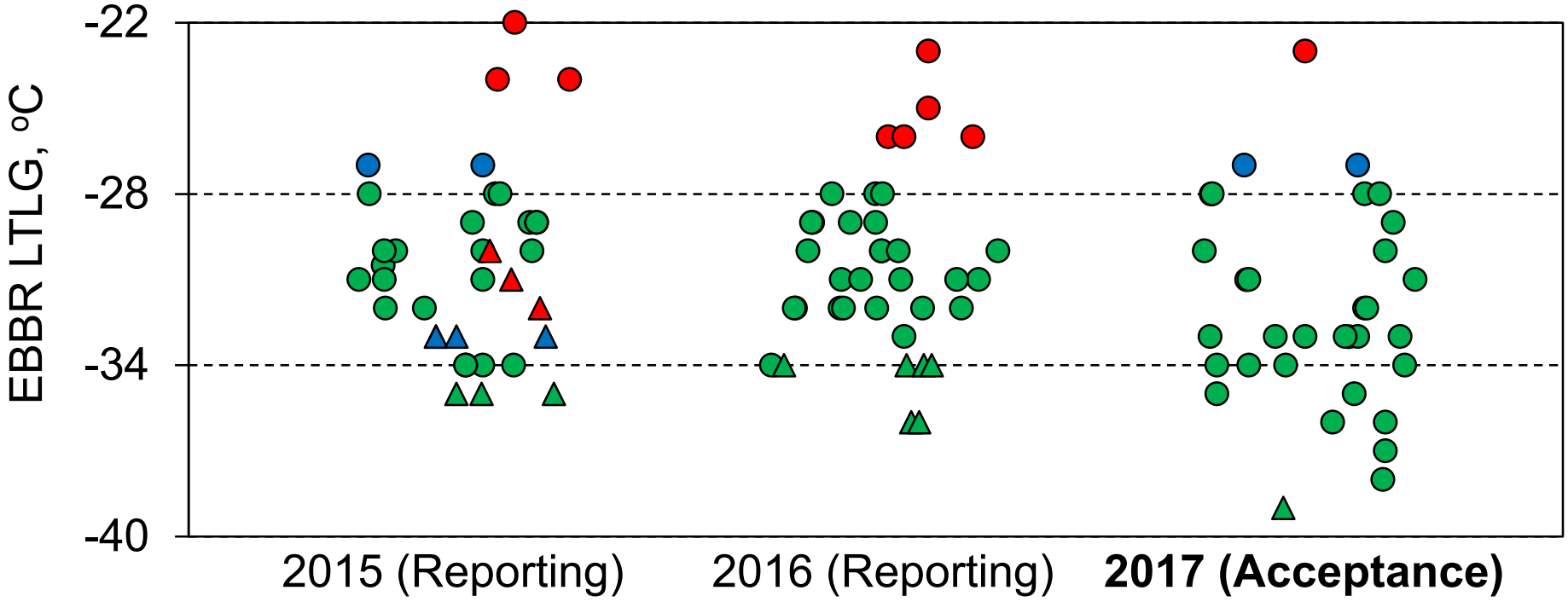
Hesp et al., Energy and Fuels, 2007

Stable 300/400 pen Cold Lake binder from Section 7 in Lamont never cracked for 22 years until trial site was reconstructed:

- Little or no phase separation;
- Low physical hardening;
- Low oxidative hardening;
- Low R-value;
- S-controlled; and
- high CTOD

Recovered Grading by EBBR (MTO LS-308)

106 Contract Samples (-28 and -34 zones)



	2015 (Reporting)	2016 (Reporting)	2017 (Acceptance)
Acceptable:	26	29	32
Borderline:	5	0	2
Failed:	6	5	1

Ding et al., CTAA, Regina, 2018

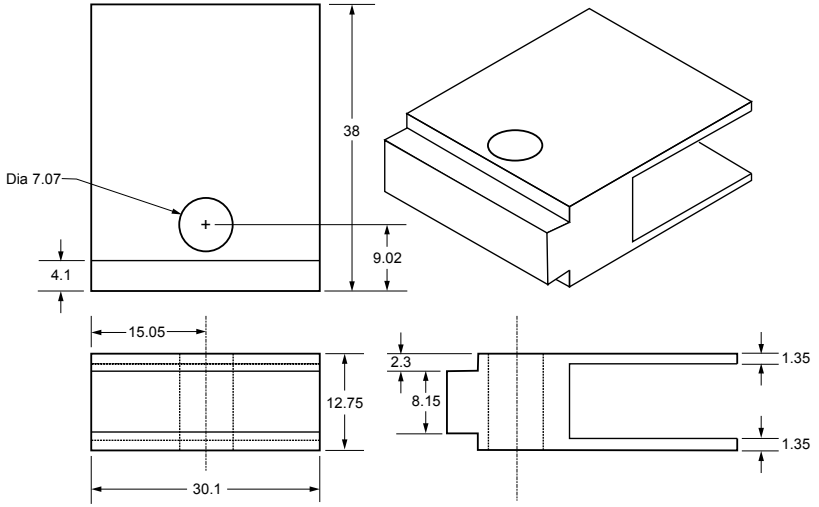
AASHTO Adopted DENT as Provisional Standard TP 113-15

Standard Method of Test for

Determination of Asphalt Binder Resistance to Ductile Failure Using Double-Edge-Notched Tension (DENT) Test

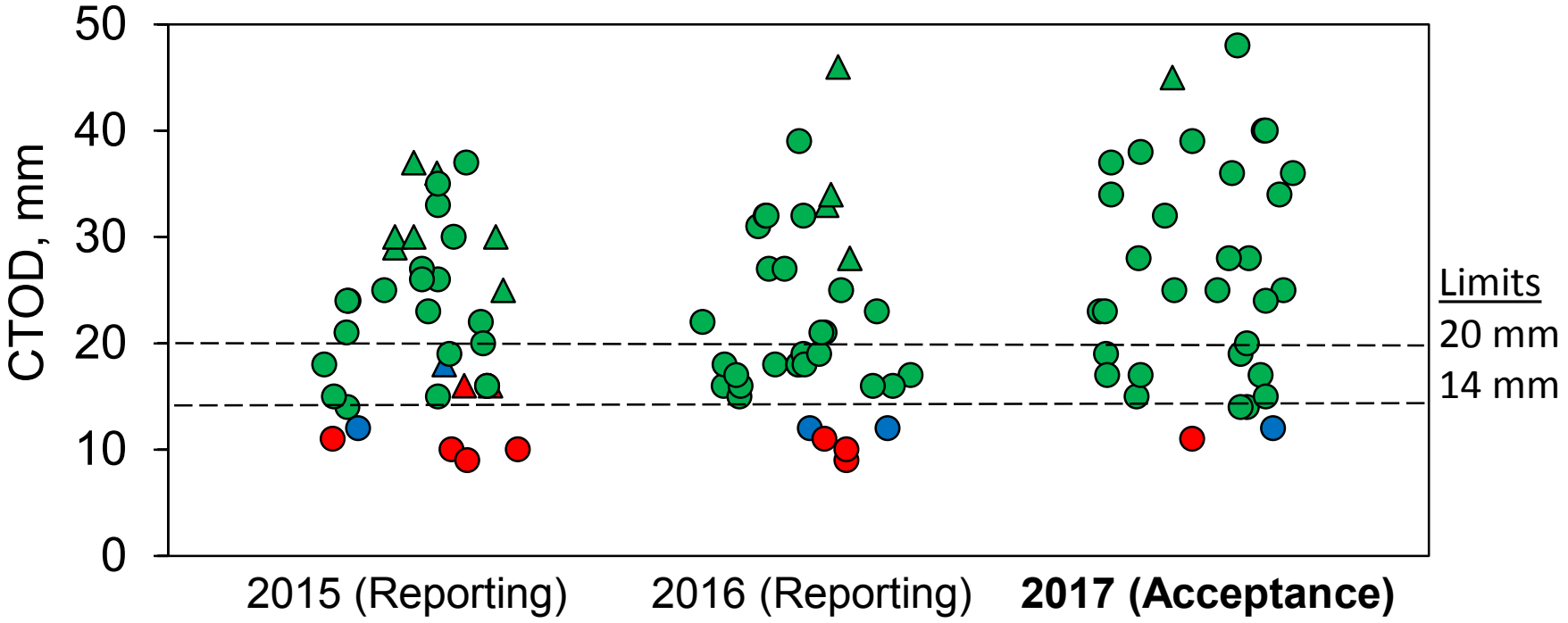
AASHTO Designation: TP 113-15

AASHTO
THE VOICE OF TRANSPORTATION



Recovered Grading by DENT (TP 113-15)

106 Contract Samples (-28 and -34 zones)



	2015 (Reporting)	2016 (Reporting)	2017 (Acceptance)
Acceptable:	29	29	33
Borderline:	2	2	1
Failed:	6	3	1

Ding et al., CTAA, Regina, 2018

Corrélations entre la fissuration et les caractéristiques des bitumes (1998)

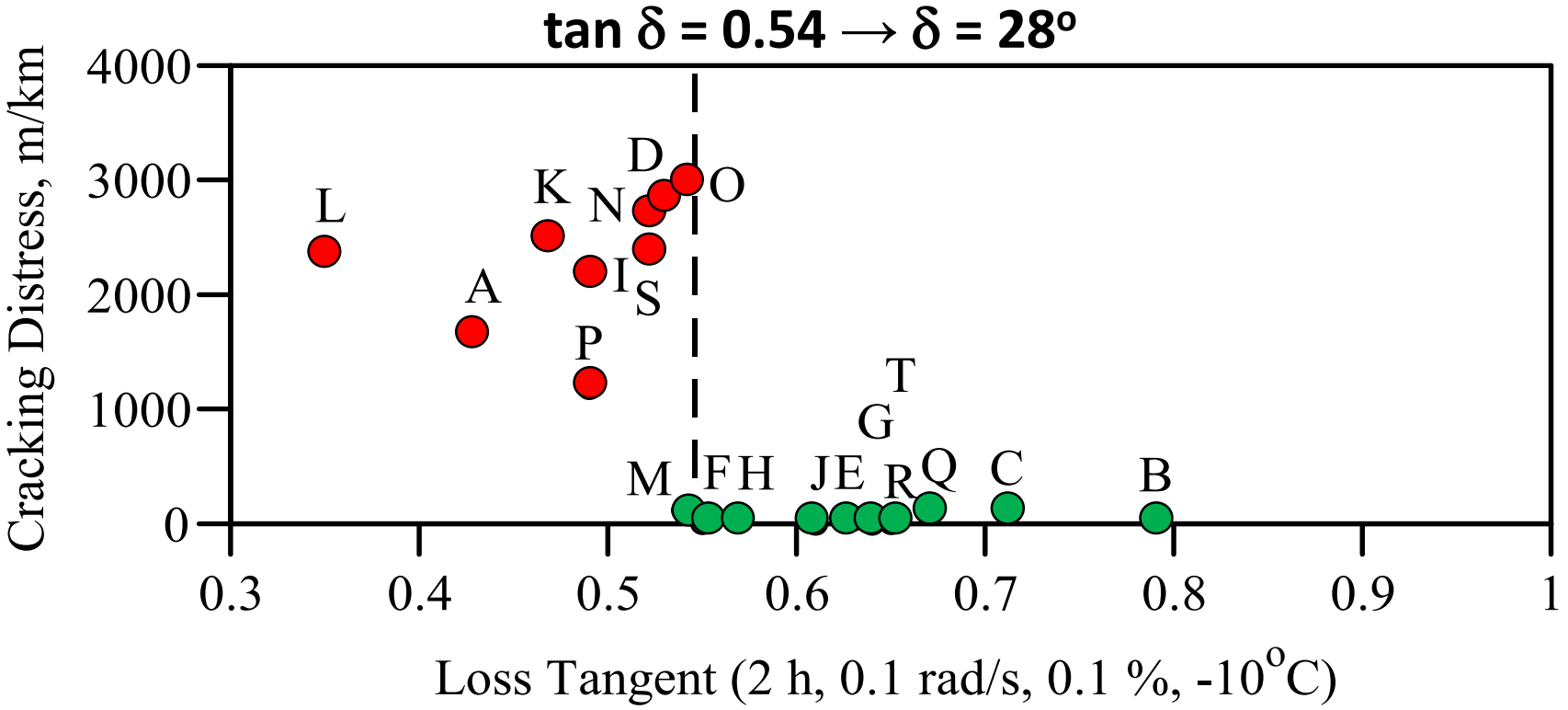
(Correlation of Cracking Distress with Bitumen Properties)

Parameter	Field Cracking (7 Years)	Change Field/Unaged
T(δ=27°, 7.8 Hz)	*****	*****
T(δ=45°, 7.8 Hz)	****	****
T(S=300 MPa)		****
m-value	****	***
T(m=0.300)	*****	*****

Migliori et al., Eurobitumen, Luxembourg, 1998 **(LCPC, Colas, Shell, Mobil, BP, Esso)** (this followed earlier papers in Europe, USA and Canada on phase angle measurements to study/mitigate cracking).

Correlation of Cracking Distress with Asphalt Cement Phase Angle (2009)

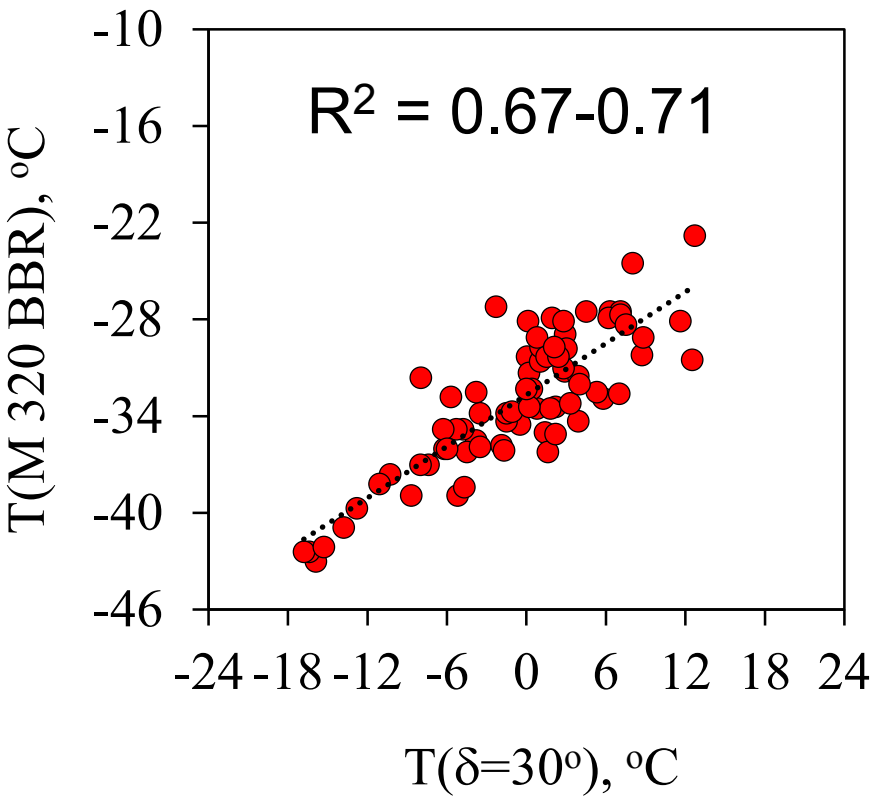
Contracts from Eastern Ontario (20 samples)

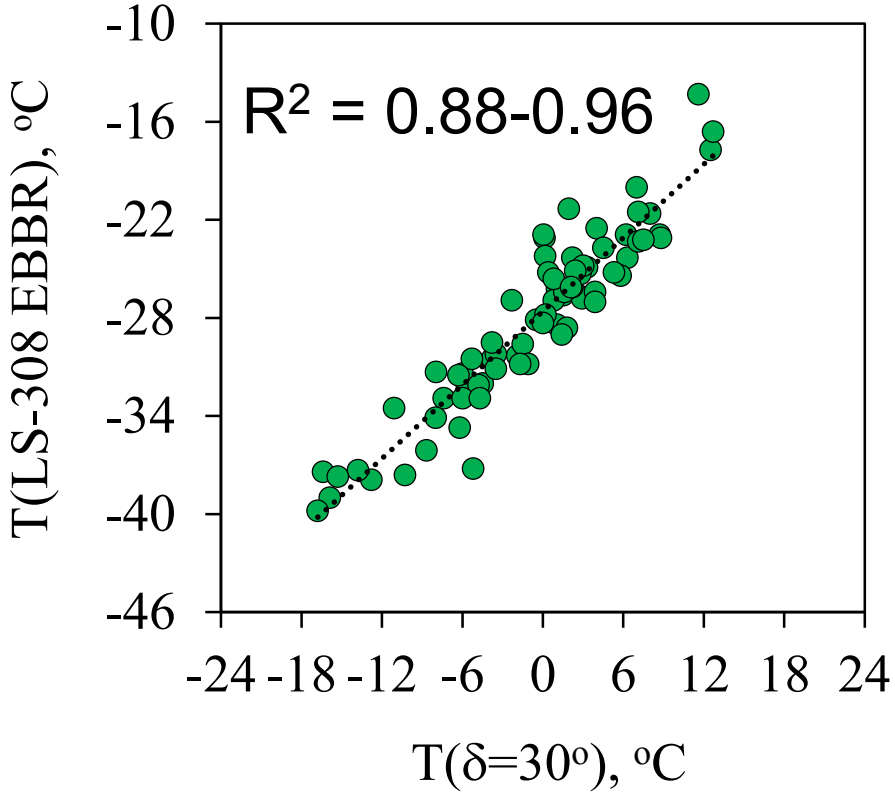


Soleimani et al., JTRB, 2009

Limiting Phase Angle vs M320 or LS-308

2011 Implementation Contracts (60+ samples, 2018-2019)





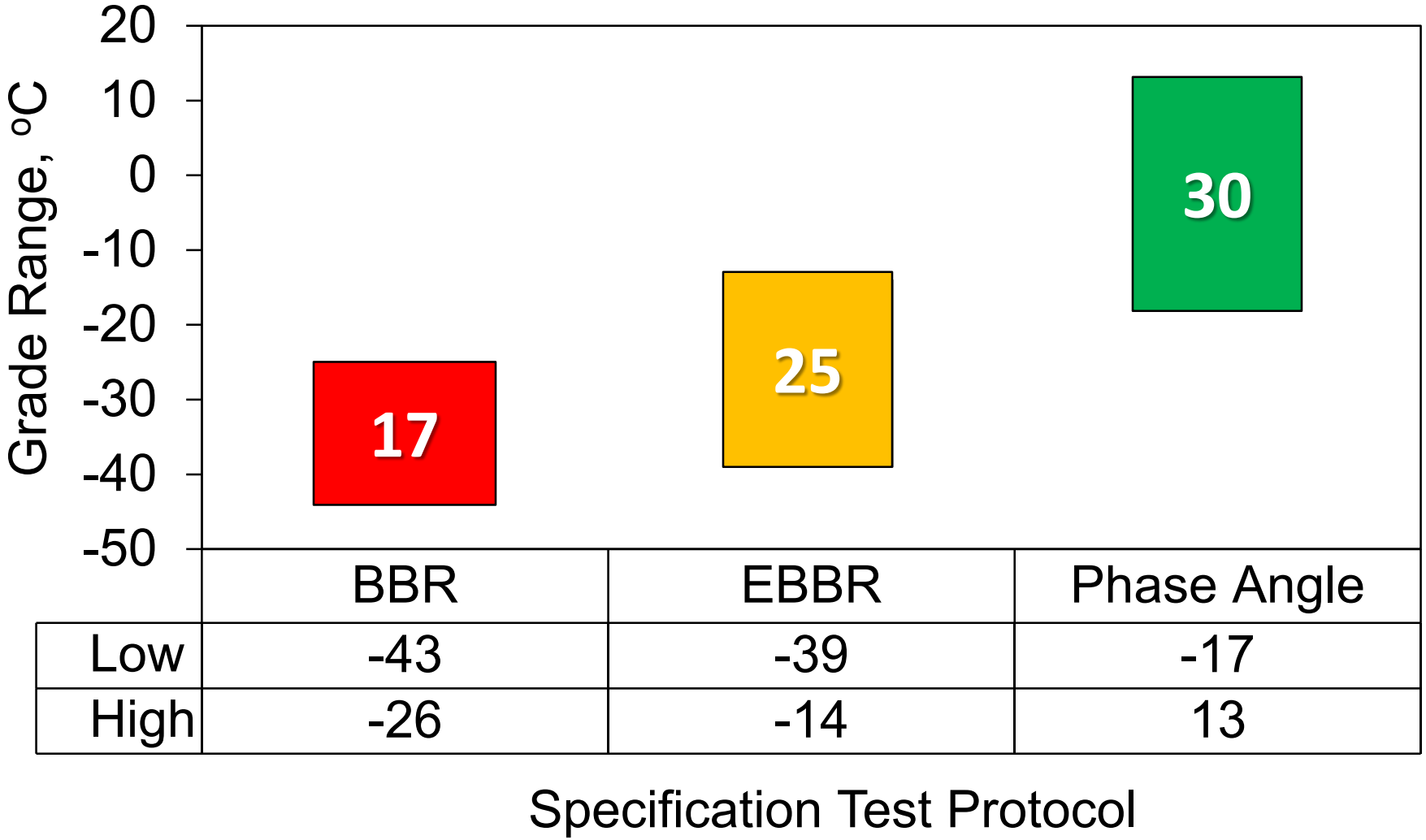
Ding et al., CTAA, Regina, 2018 and Lill et al., CTAA, Montreal, 2019

Performance Graded AC Testing Correlation Program of MTO (2015)

Test	Parameter	COV
DSR_{Unaged}	Complex Modulus, G*	0.042
	Phase Angle, δ	0.005
DSR_{RTFO}	Complex Modulus, G*	0.064
	Phase Angle, δ	0.007
DSR_{PAV}	Complex Modulus, G*	0.110
	Phase Angle, δ	0.017
BBR_{PAV}	Creep Stiffness, S	0.060
	Creep Rate, m	0.021

M320 and LS-308 vs Phase Angle

2011 Implementation Contracts (60+ samples, 2019)

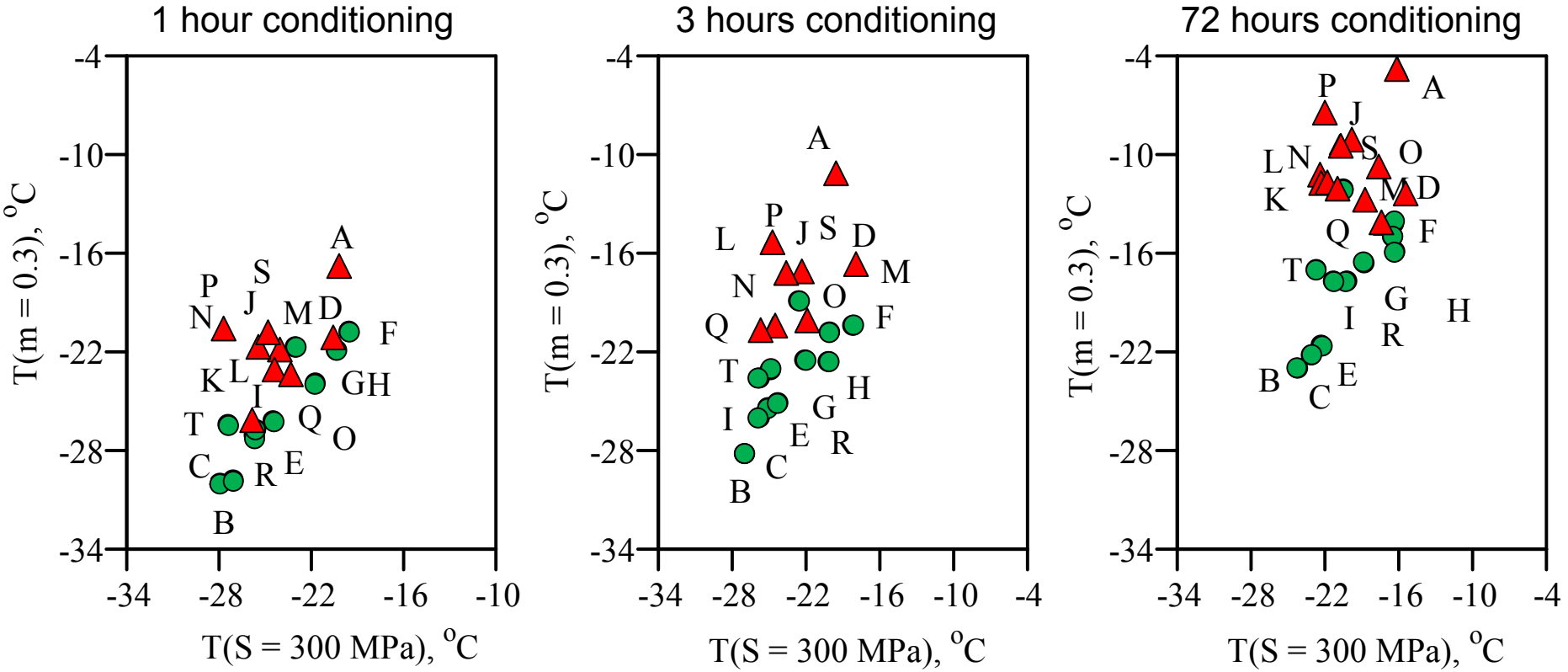


	BBR	EBBR	Phase Angle
Low	-43	-39	-17
High	-26	-14	13

Lill et al., CTAA, Montreal, 2019

Effect of Cold Conditioning on ΔT_c BBR

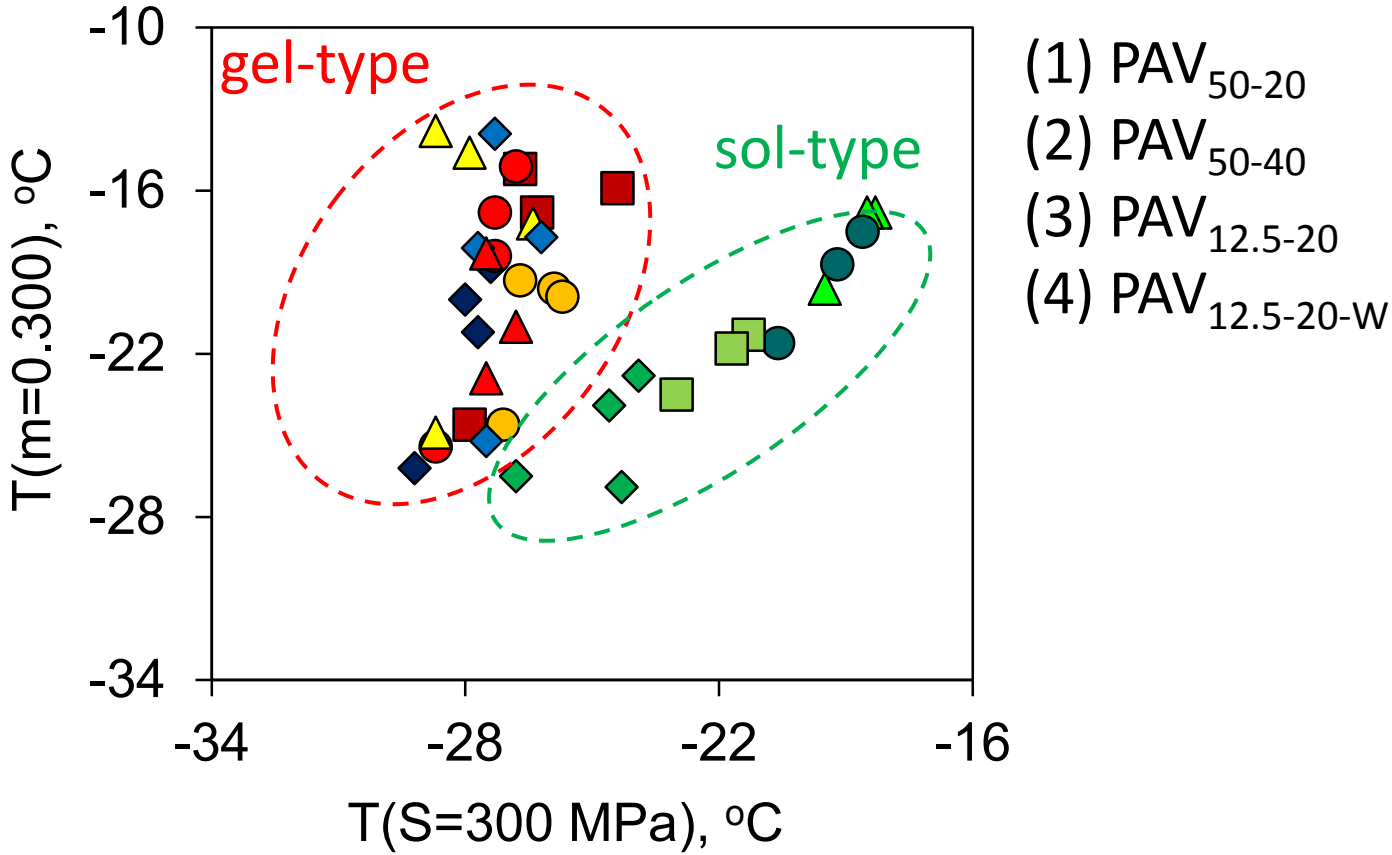
Contracts from Eastern Ontario (20 samples, 2009)



Hesp and Subramani, MAIREPAV6, Turin, Italy, 2009

AASHTO M 320 and MTO LS-308 vs LS-228 Modified PAV

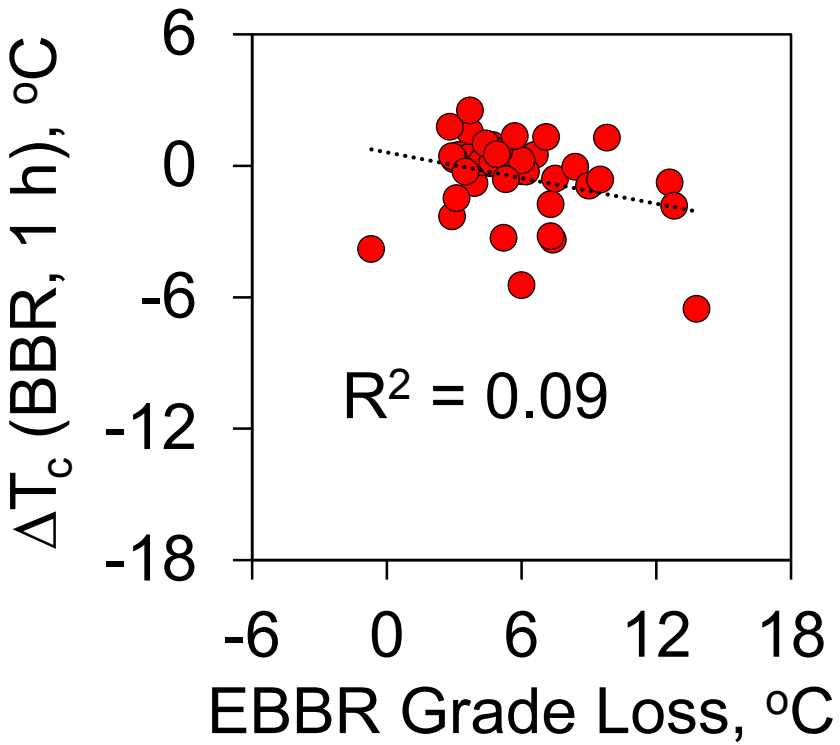
655 Trial Sections + Alberta Binders (11 samples, 2012)

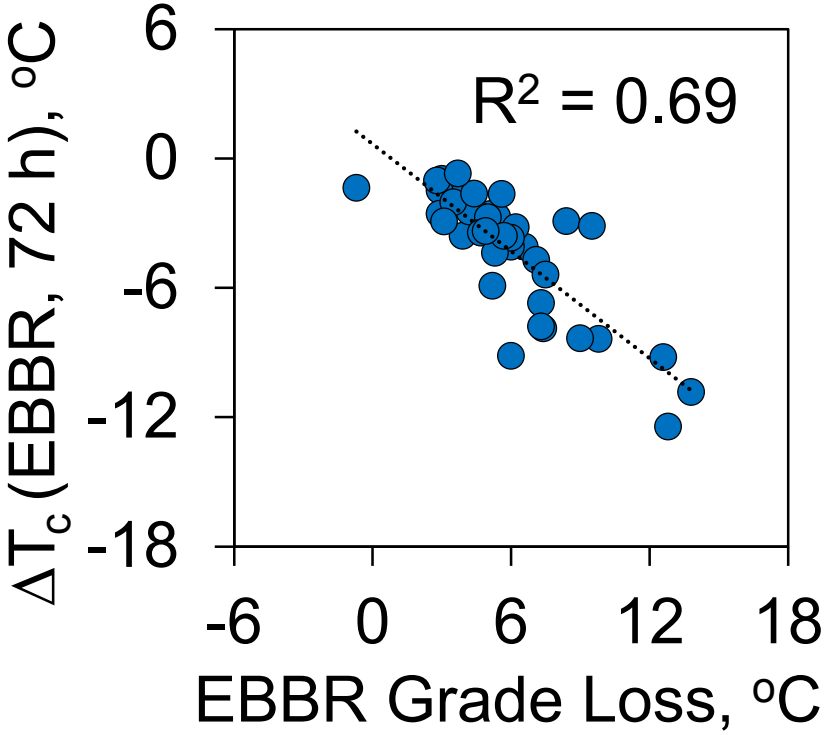


Erskine et al., Eurobitumen, Istanbul, Turkey, 2012

Rheological Type Determination with ΔT_c BBR

2011 Implementation Contracts (42 samples, 2018)

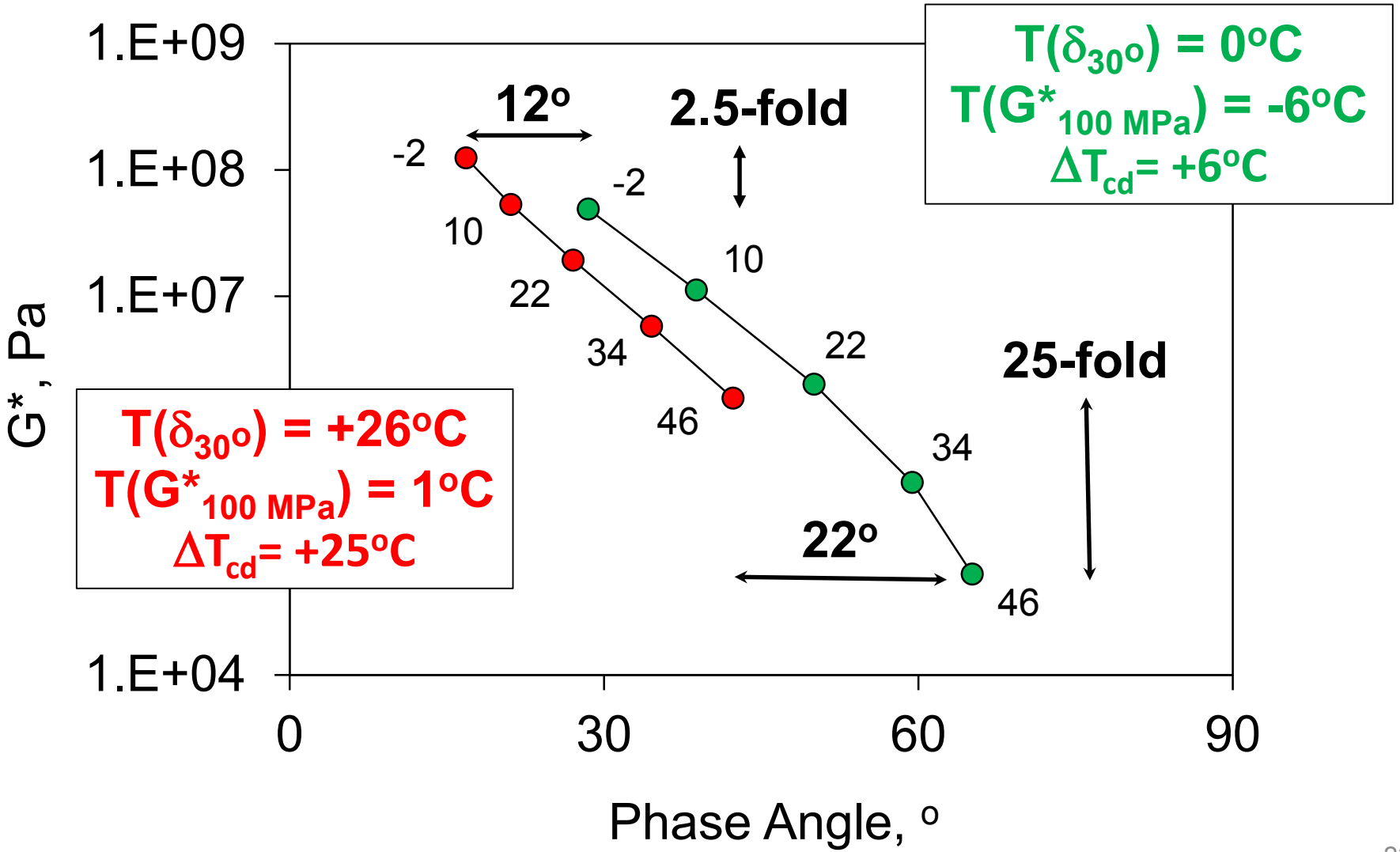




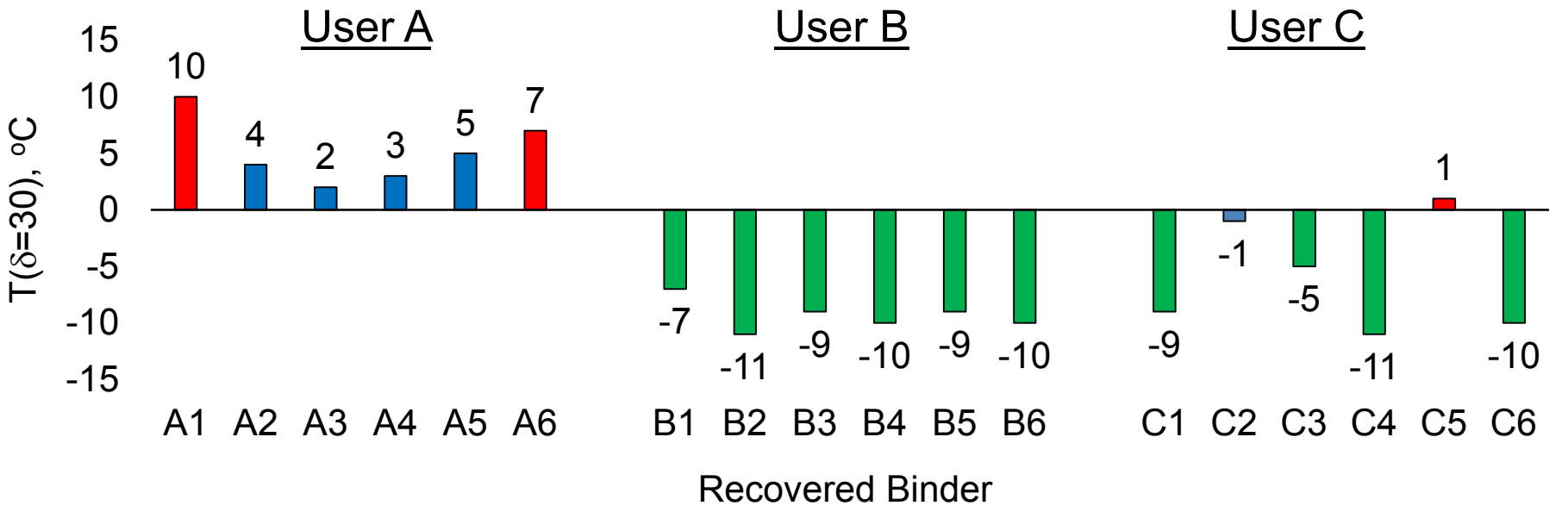
Ding et al., JCBM, 2018

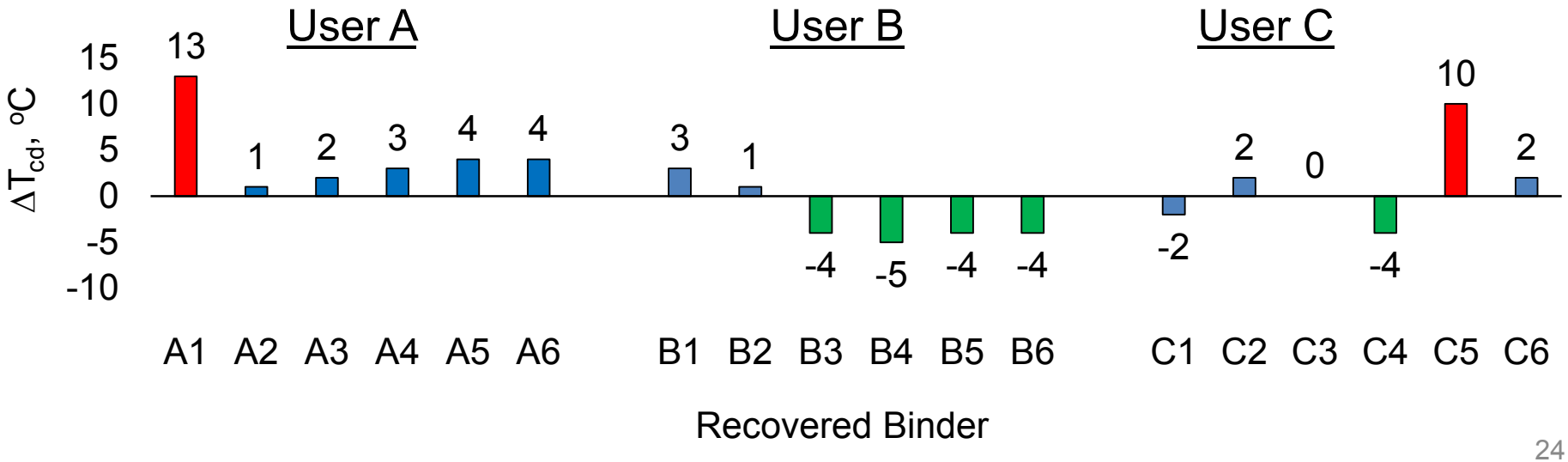
655 Black Space Diagram (15 Years, 2018)

655-1 (Best ●) vs 655-4 (Worst ●)



Limiting Phase Angle and Stiffness (2018)

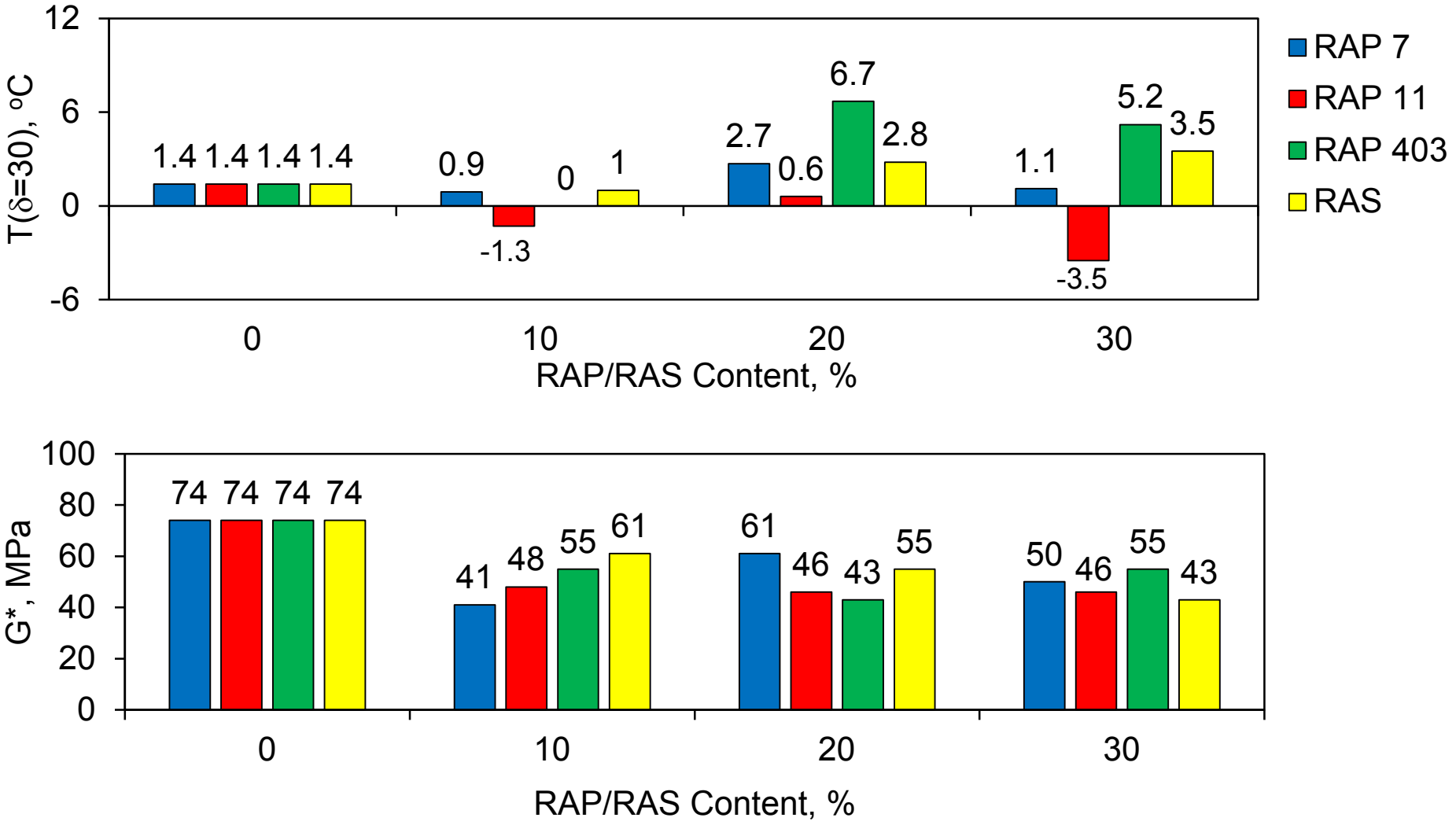




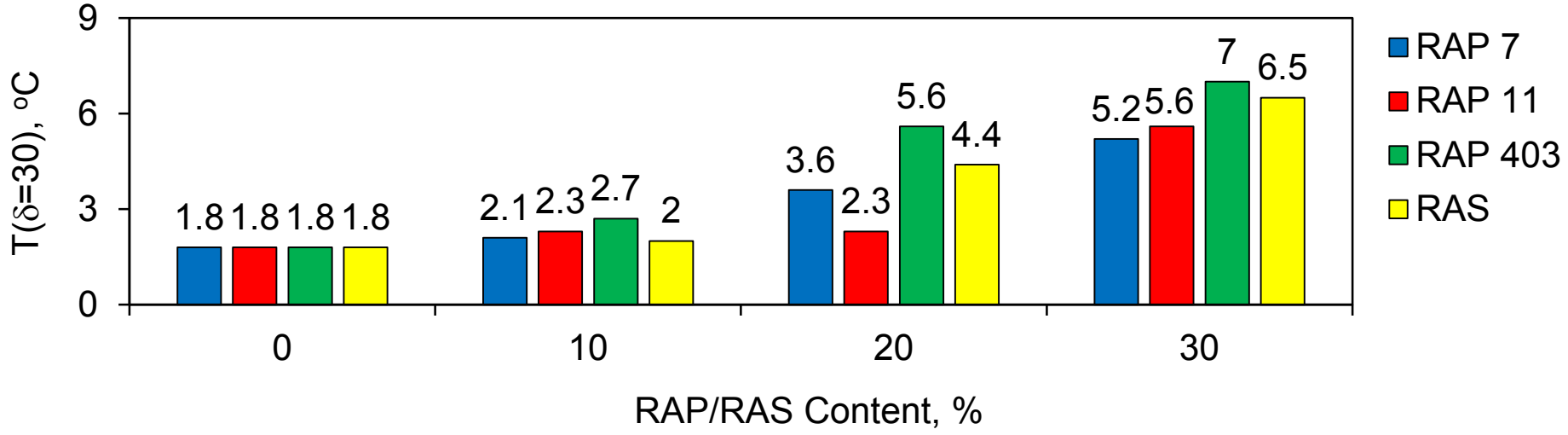
Current Research on Limiting Phase Angle and Limiting Stiffness (2018-2021)

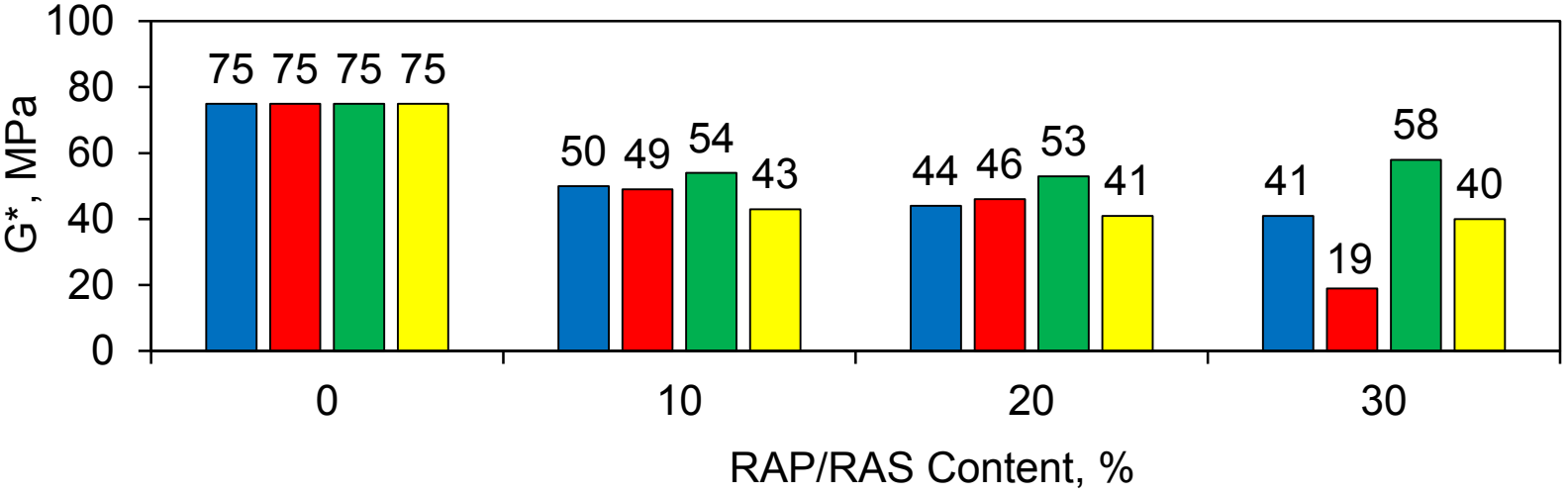
- Effect of 10, 20 and 30 % RAP on PG 58-28 A & B
- Effect of 10, 20 and 30 % RAS on PG 58-28 A & B
- Effect of 4, 8, 12 and 16 % REOB on PG 58-28 C
- Effect of binder source and grade on G*
- Effect of PAV aging time
- Effect of PAV film thickness

Effect of RAP/RAS on PG 58-28 A

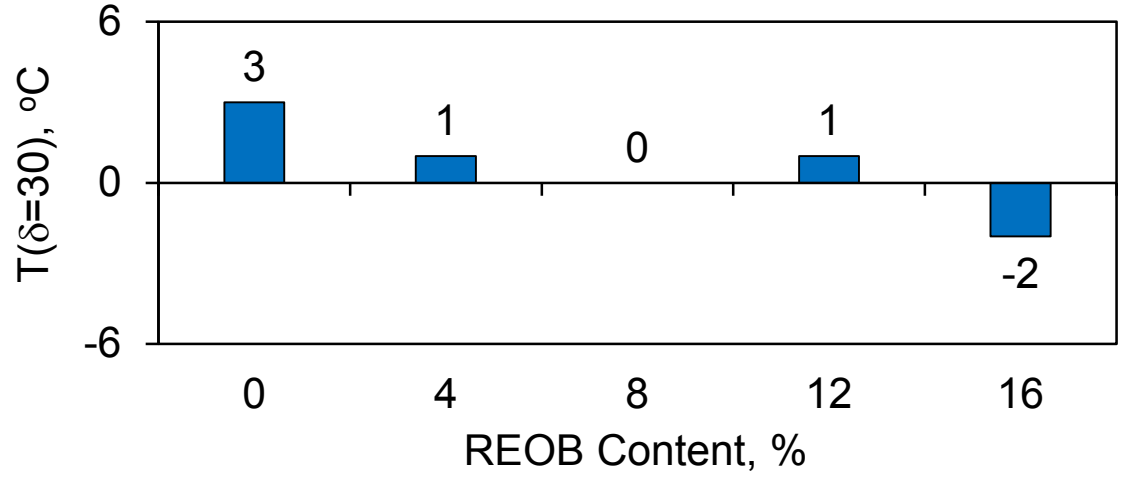


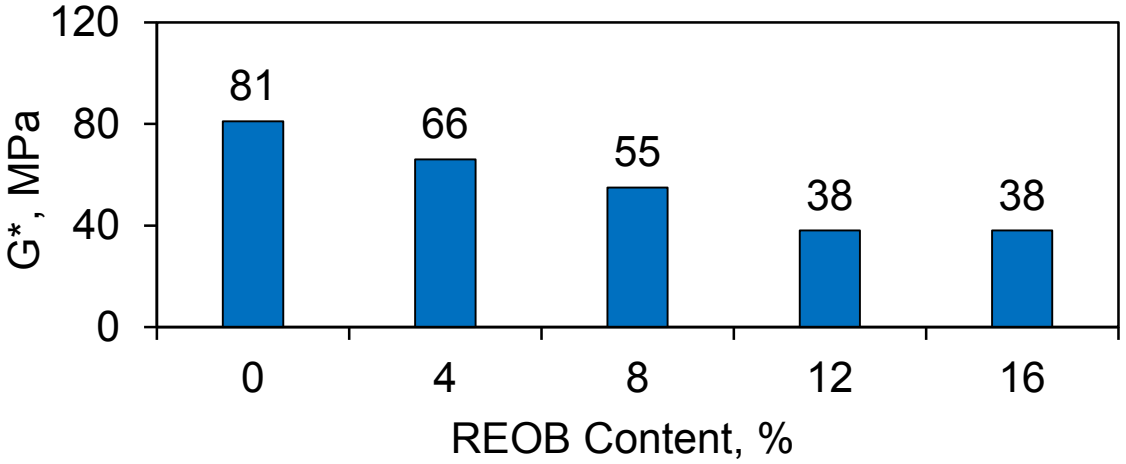
Effect of RAP/RAS on PG 58-28 B



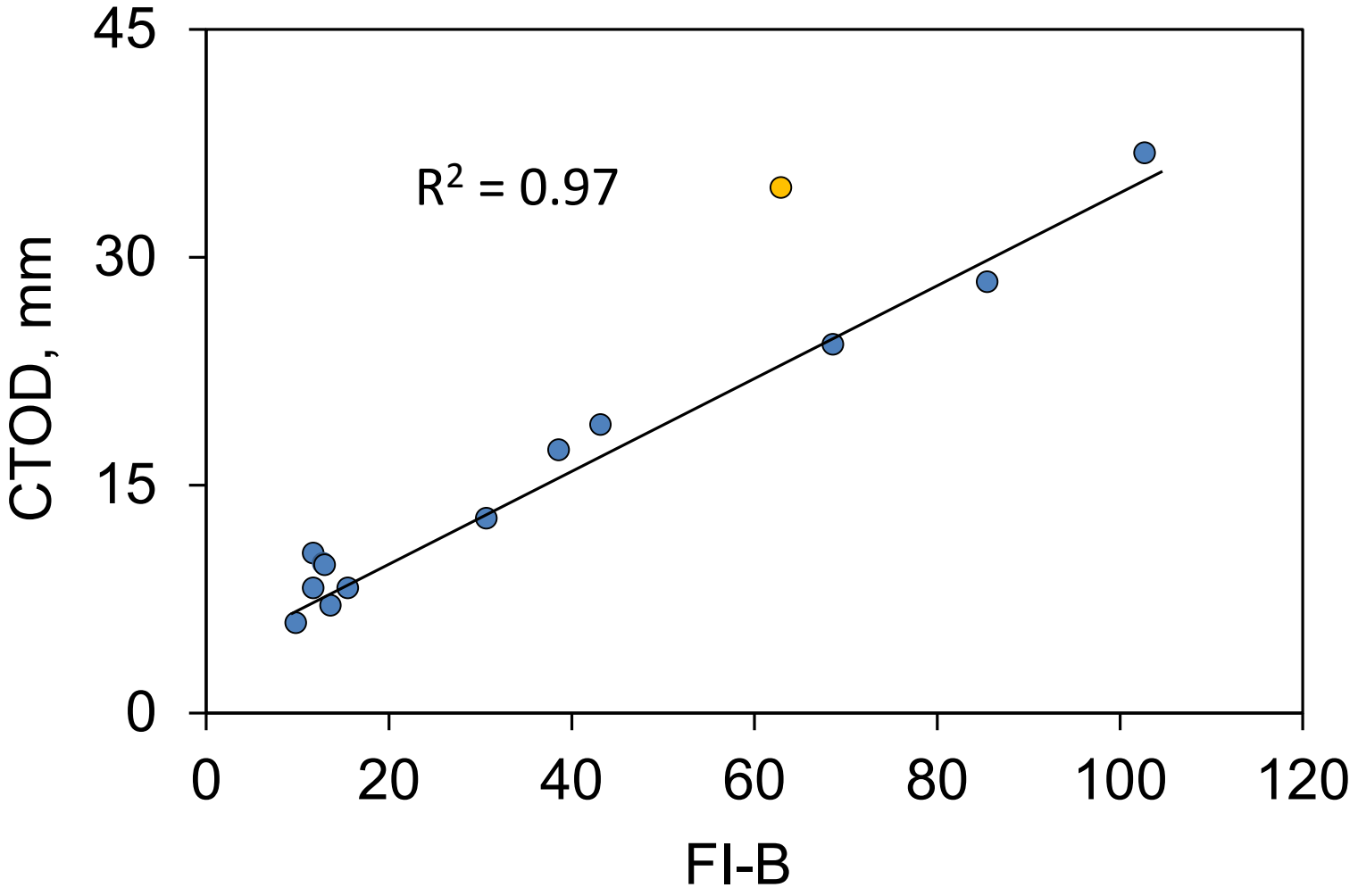


Effect of REOB on PG 58-28 C

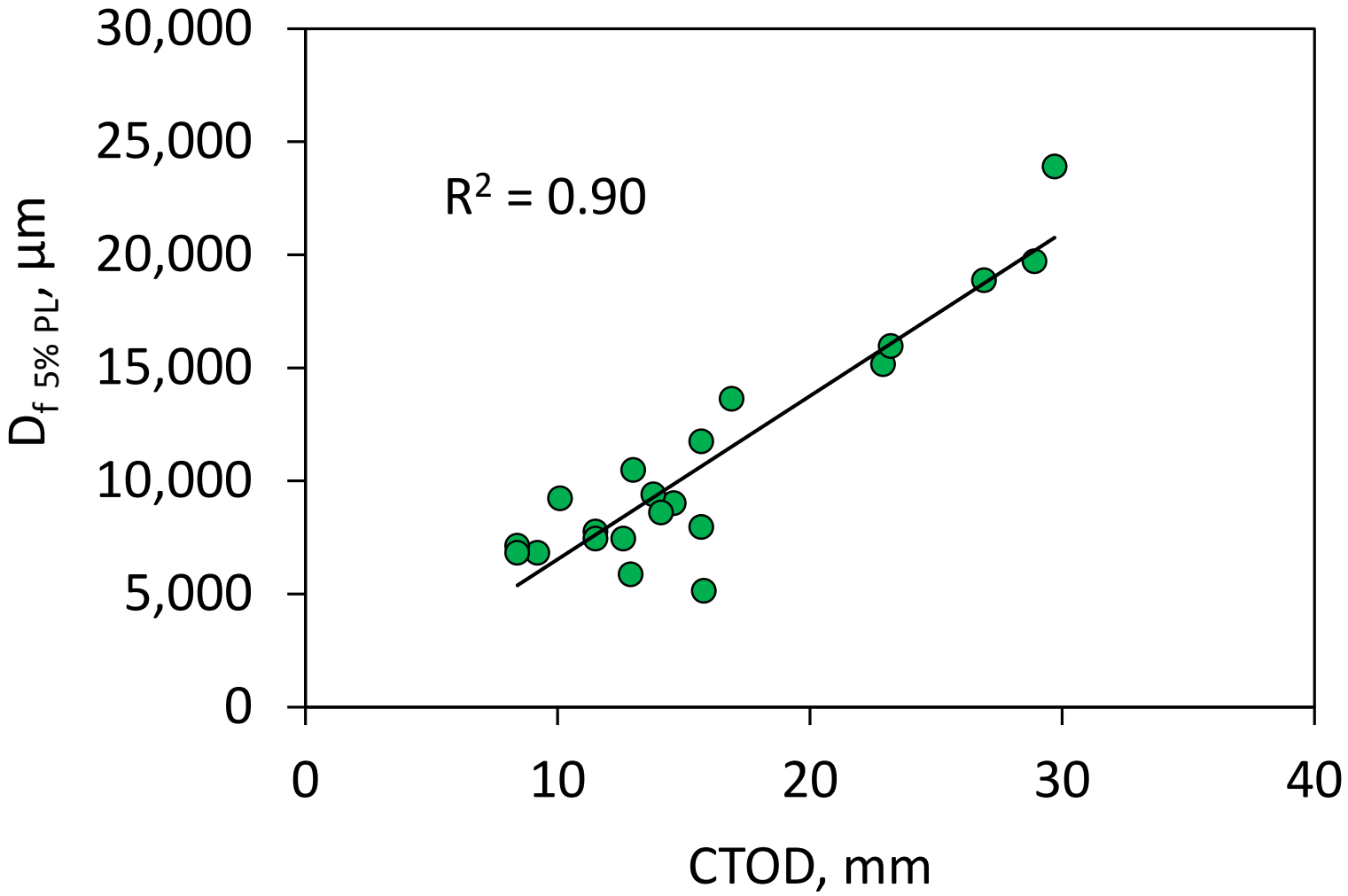




CTOD vs Flexibility Index-B

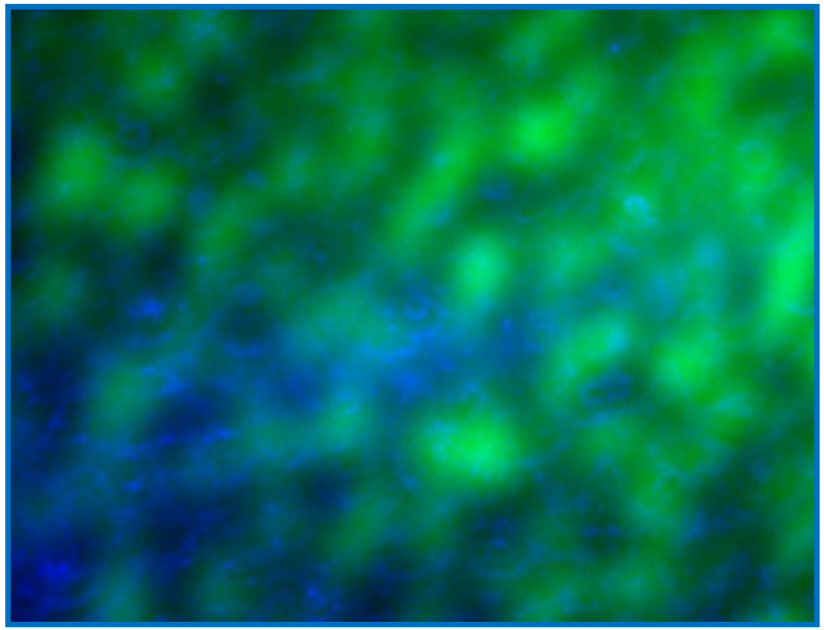


CTOD vs Butt Joint Failure Strain (D_f)



Final Perspective

MTO NER PG 52-40



False Blue = Phase Contrast
False Green = Fluorescence

Unstable binder showing excessive degree of paraffinic demixing (REOB > 30%):

$T(\delta = 30^{o}) = 28^{o}C$
$T(G^{*} = 100\ MPa) = -16^{o}C$
$\Delta T_{cd} = 44^{o}C$ …

40-46°C grading error !?

Hesp et al., Energy and Fuels, 2007

Summary and Conclusions

- EBBR and DENT tests are highly sensitive indicators for AC quality and durability and for that reason are being implemented by user agencies.
- PAV protocol needs to be improved or replaced.
- Phase angle and complex modulus need more study but show promise to replace EBBR test.
- Fatigue index and pull-off strain at failure need more study but show promise to replace the DENT test.
- It is important to test recovered AC!

Queen's Chemistry

Chemistry Department
25 faculty, 100 graduate students &
1000+ undergraduate students

Queen's University
1,000 faculty, 4,000 graduate students &
20,000 undergraduate students

THANK YOU!
QUESTIONS?