Evaluation of Temperature and Laboratory Aging on Pavement Cracking Performance Fracture Tests

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North East User Producer Group Meeting

Newark, Delaware

20th October 2016

UNH CIRC

Overview

- Introduction
  - –Motivation and Objectives
  - –DCT and SCB Fracture Tests
- Methodology and Materials
- Results
  - –Temperature Effects
  - –Aging Effects
- Summary & Conclusion

Balanced Mix Design

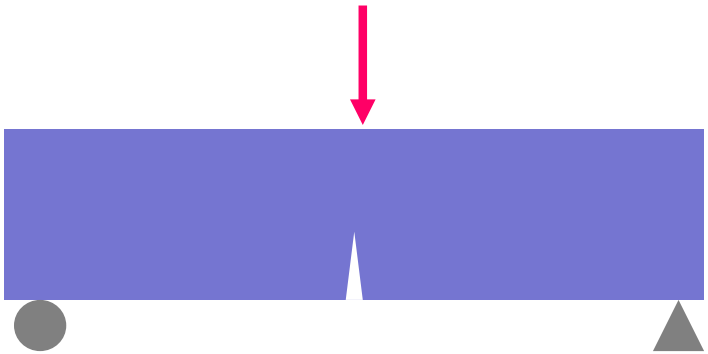
- Asphalt mix design using *performance tests* on appropriately *conditioned specimens* that address *multiple modes of distress* taking into consideration mix aging, traffic, climate and location within the pavement structure

Motivation

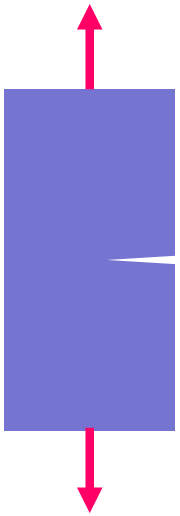
- White House: 65 percent of America's major roads are rated in less than good condition
- Performance tests are starting to become mature and field validation data is becoming available for developing performance related/based specifications
- Fracture testing based cracking tests are starting to get adopted
- There is need for understanding of effects of aging and temperature on fracture behavior of asphalt mixtures

Fracture Test Geometries

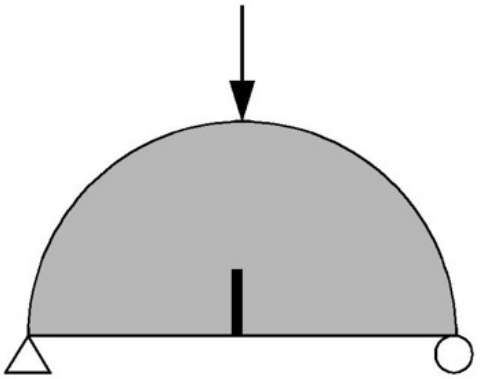
- Fracture tests on HMA date back to 1971



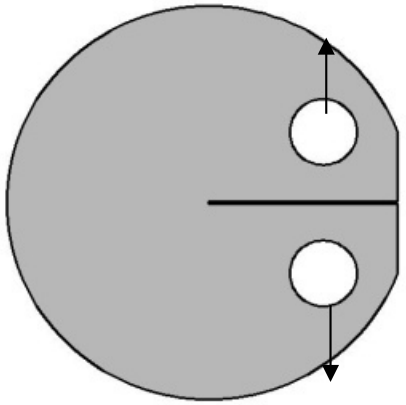
Single-edge Notched Beam (SE(B))



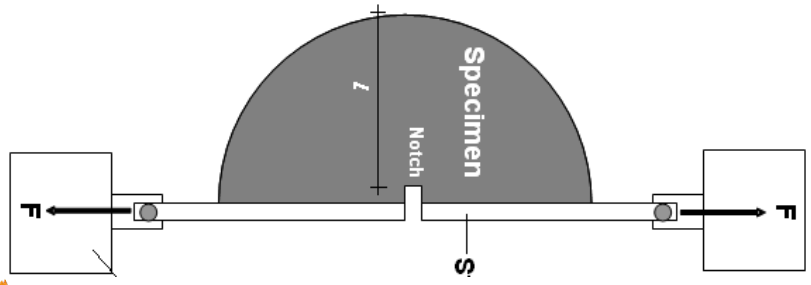
Direct Tension



Semi-Circular Bend (SCB)



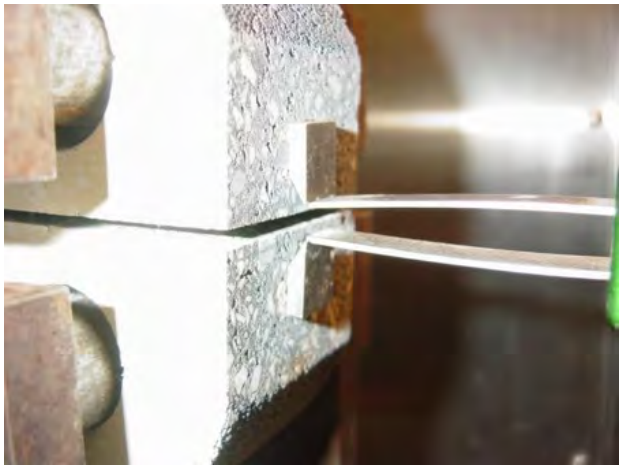
Disk-shaped Compact Tension (DCT)

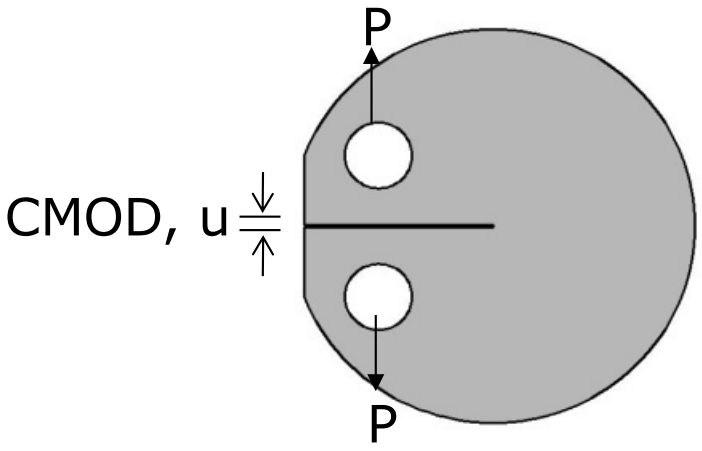


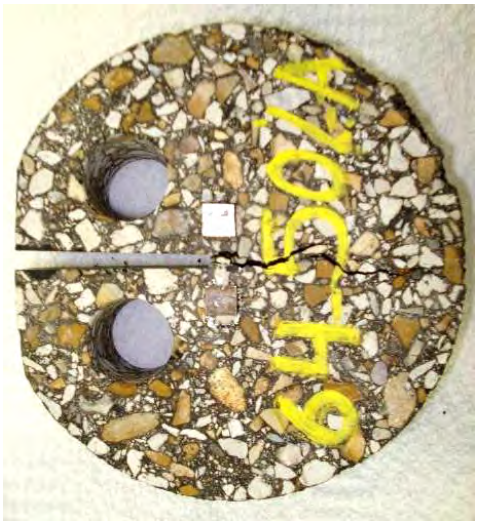
Fenix Test

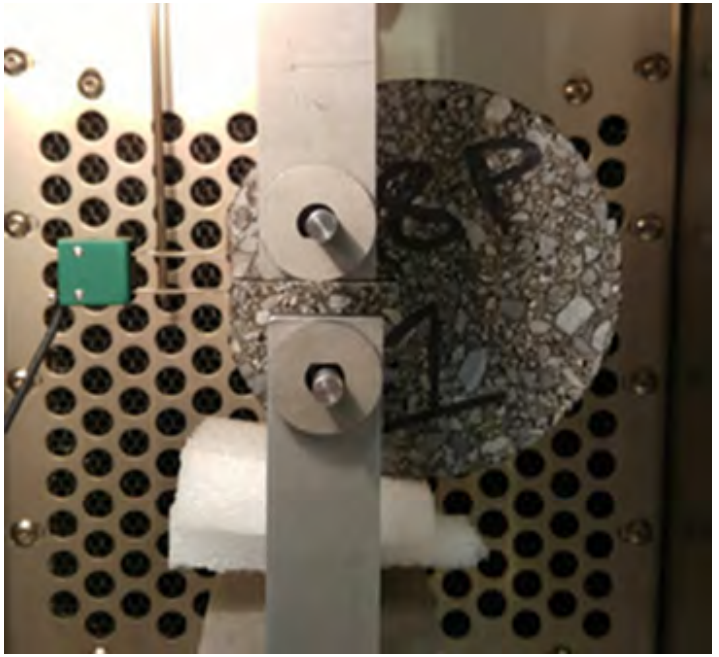
Disk-Shaped Compact Tension (DCT) Test

- ASTM D7313-13
- Loading Rate:
  - Crack Mouth Opening Displacement
  - CMOD Rate = 1.0 mm/min
- Measurements:
  - CMOD
  - Load



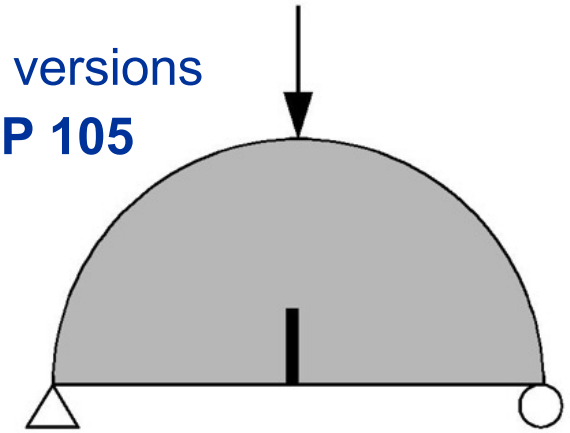




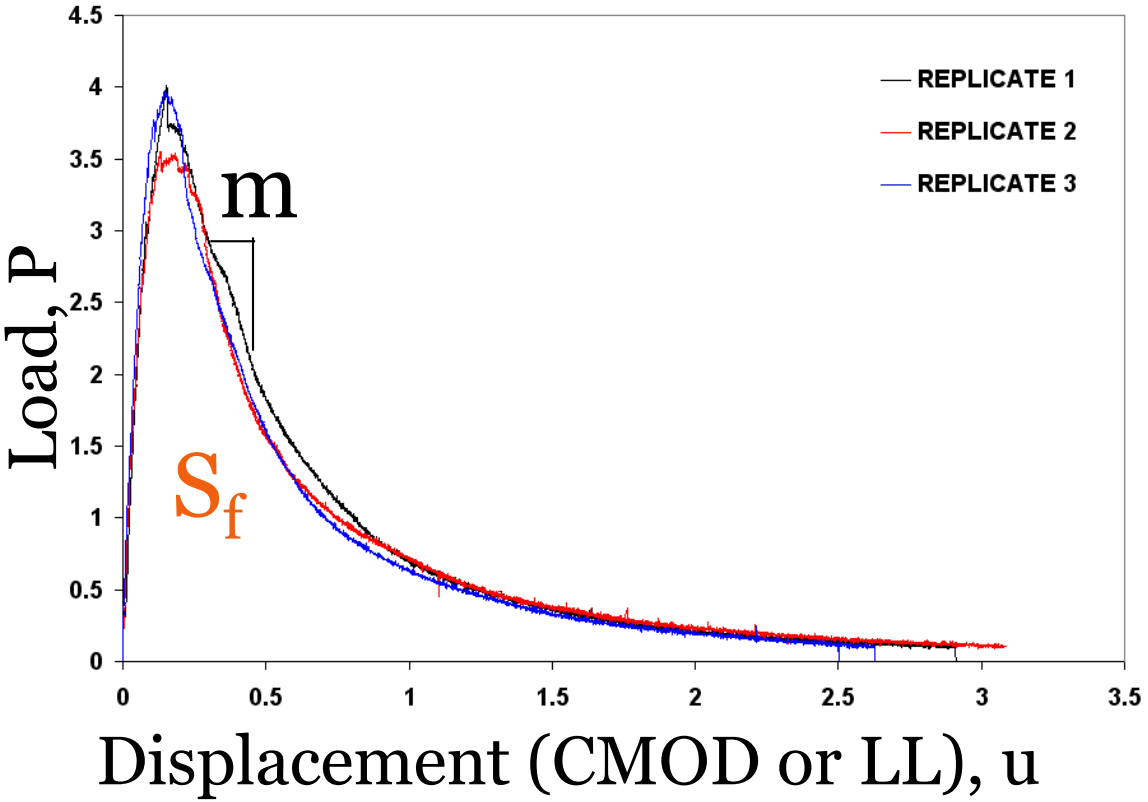


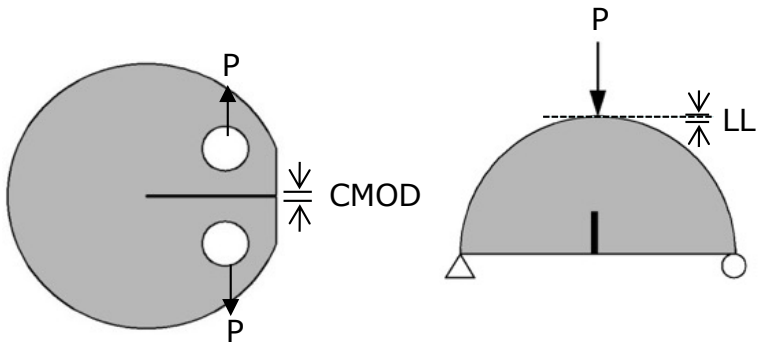
Semi-Circular Bend (SCB) Test

- Multiple variants exist
  - Early work in Europe
  - Simultaneous cold (Marasteanu et al. – MN) and intermediate temperature (Mohamed et al. – LA) versions
  - **Recent work from Al-Qadi et al. (IL) → AASHTO TP 105**
- AASHTO TP 107
  - Line load control, loading rate = 50 mm/min
  - Test temperature = 25 deg. C
- Measurements:
  - Displacement
  - Load
- Outcomes
  - Fracture Energy
  - Flexibility Index (FI)



Fracture Parameters





Fracture work: Area under Load-Displacement curve

Fracture Energy, G_f: Energy required to create unit fracture surface

$$G_f = \frac{\text{Fracture Work, } S_f}{\text{Fracture Area}}$$

Flexibility Index, FI:

$FI = G_f / m$

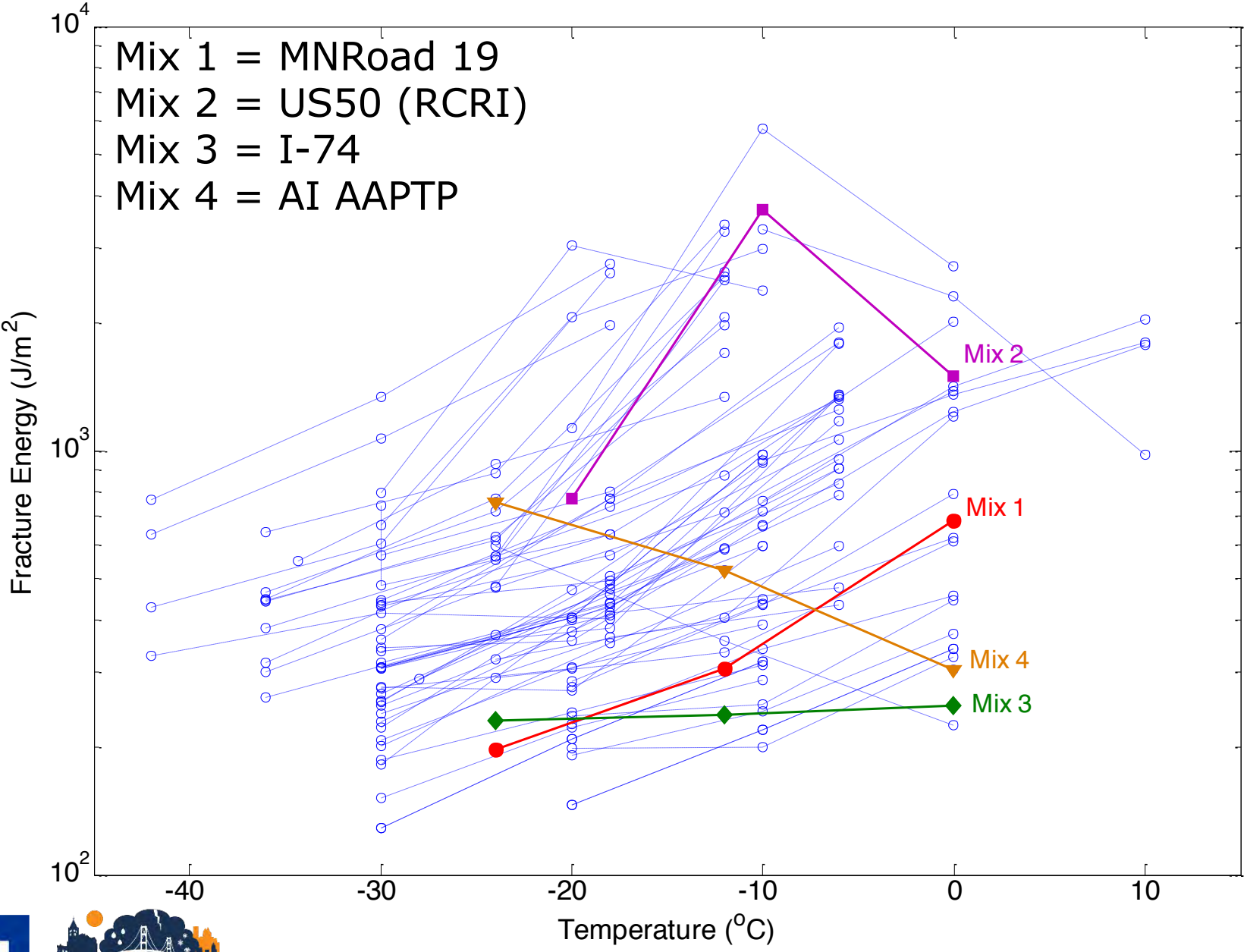
Current Adoption Efforts of Fracture Tests

- Semi-Circular Bend
  - LA Version Intermediate Temperature → Louisiana DOTD
    - *Wisconsin for High RAM Projects (Hanz et al. NEAUPG 2015)*
  - IL and MN Version at Intermediate Temperature:
    - *Illinois in pilot implementation stages*
- Disk-shaped Compact Tension
  - City of Chicago
  - Illinois Tollways
  - Wisconsin for High RAM Projects (Hanz et al. NEAUPG 2015)
  - Minnesota Department of Transportation
    - *Pilot implementation on 7 projects in 2013*
    - *Multi-lab round-robin testing in 2015 (17 projects)*
    - *Fabrication and conditioning process effects in 2015-16 (11 projects)*
    - *Provisional specification is now available*

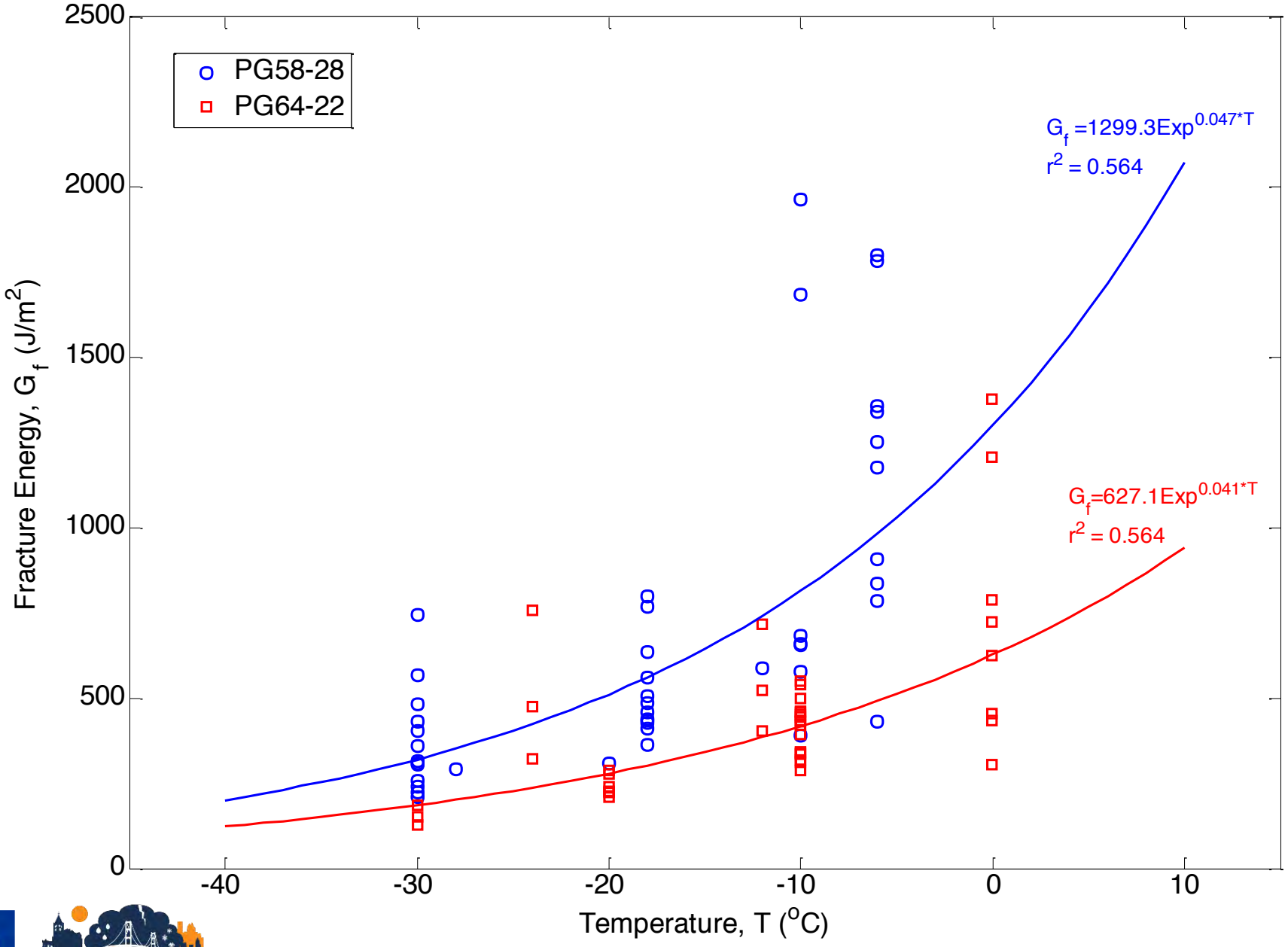
Current Specifications / Adoption Approaches

- Illinois Research on SCB Flexibility Index:
  - *Single Test Temperature = 25 deg. C*
  - *Short term aged specimens following AASHTO R30*
- Wisconsin High RAM Projects
  - SCB testing at 25 deg. C
  - DCT testing at specified PG LT + 10 deg. C
  - Both SCB and DCT on AASHTO R 30 long term aged procedure
    - *5 days at 85 deg. C on compacted specimens*
- Minnesota Specification
  - DCT testing at 10 deg. C warmer than required 95% reliability PG LT (in other words, without 6 deg. C rounding)
  - AASHTO R30 short term aging
- Challenges: Is 25 deg. C temperature suitable for all locations? How to handle reheating and long term aging?

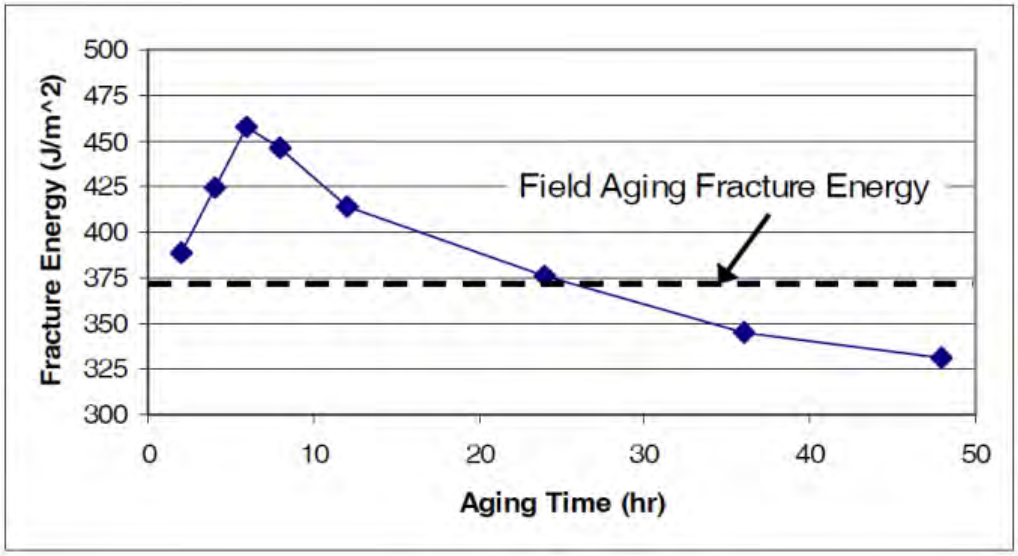
Effect of Temperature on Fracture Energy

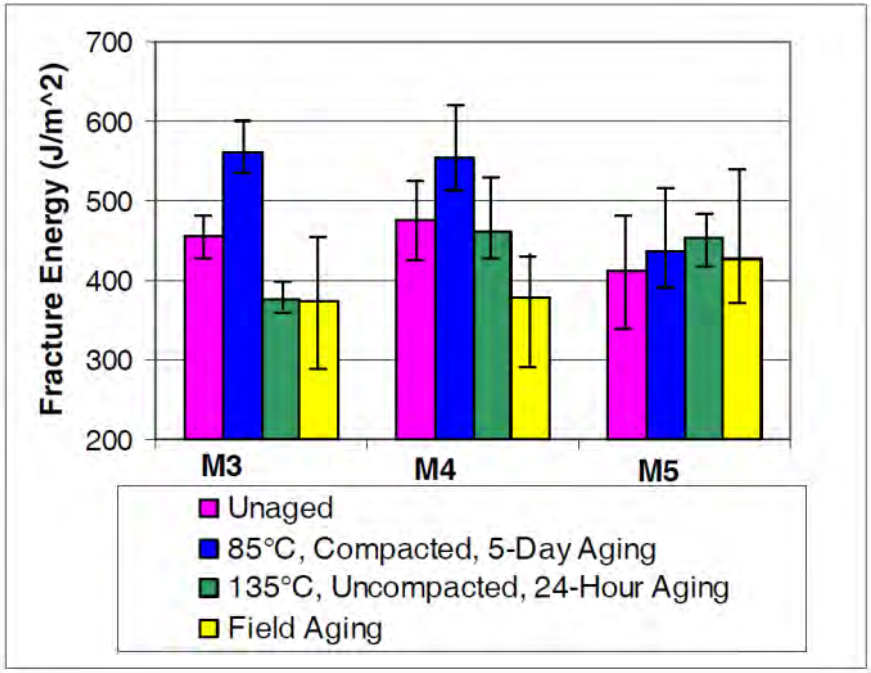


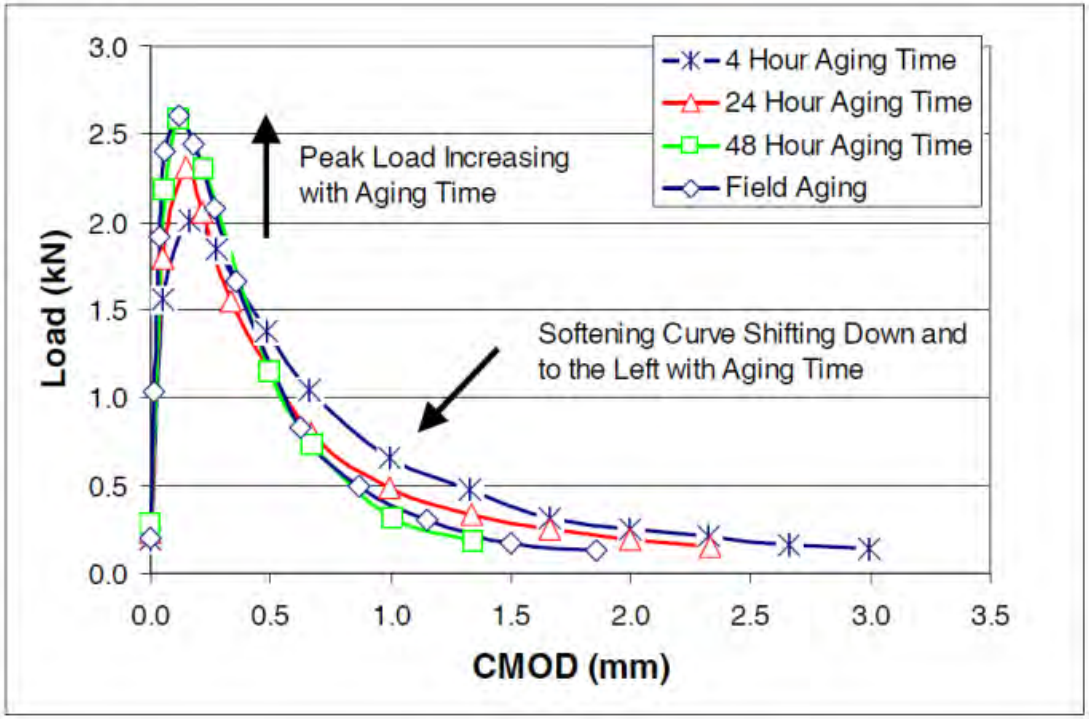
Effect of Temperature is Not Uniform: PG64-22 vs. PG58-28



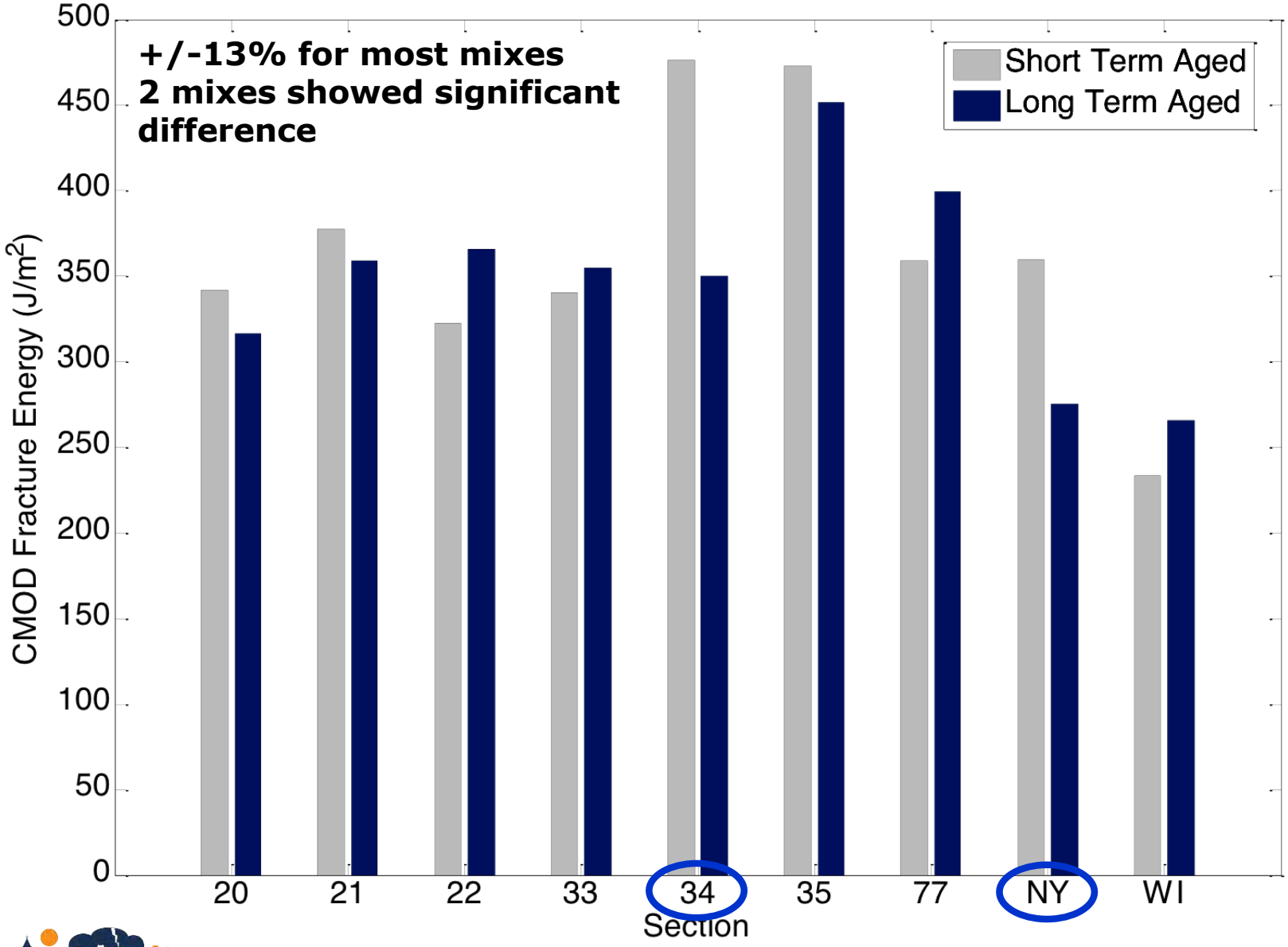
Effects of Aging on Fracture (Braham et al., 2009)





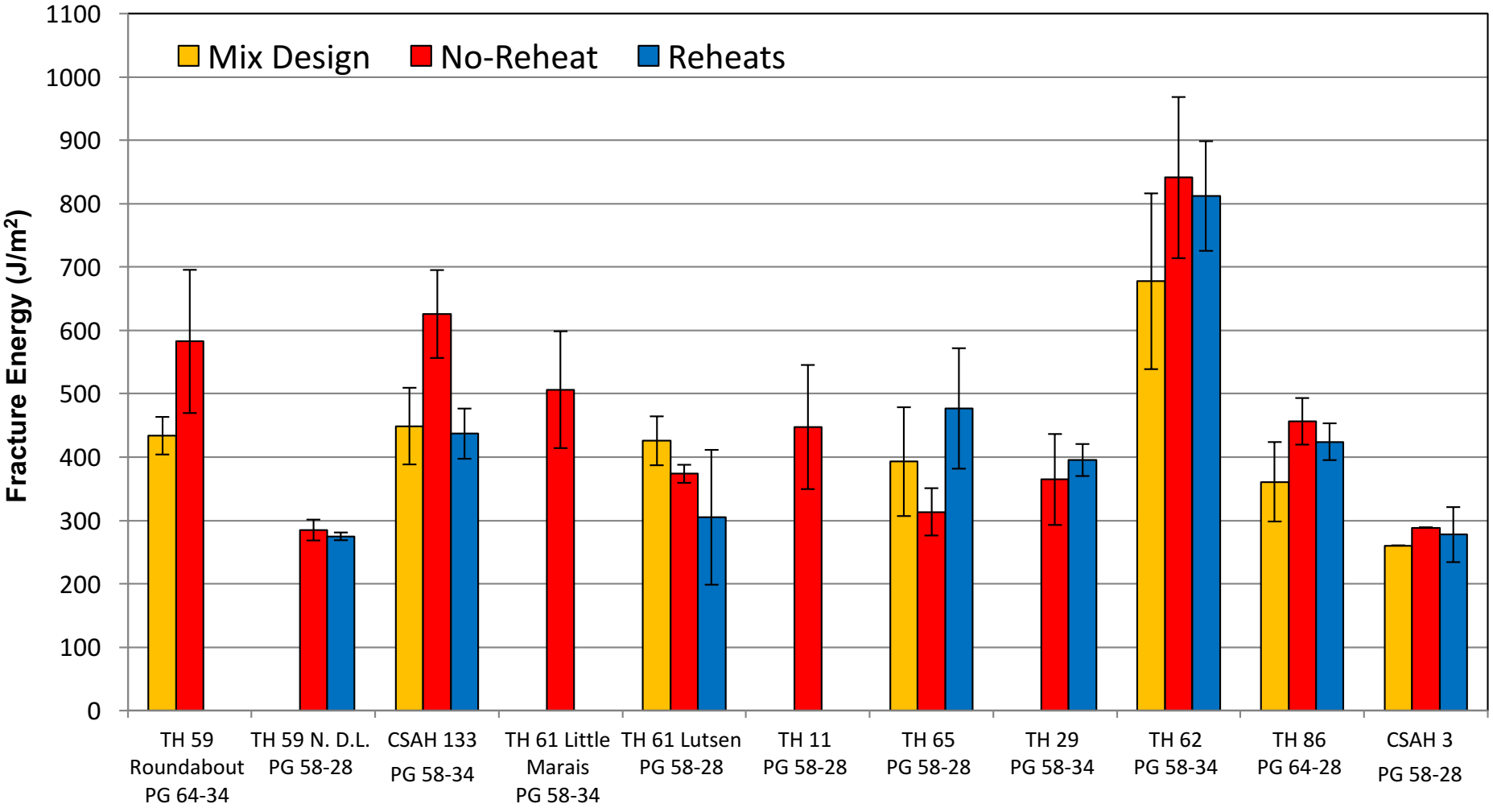


Effect of AASHTO R30 Lab Aging (Dave et al., 2011)



Section 34 → SBS+PPA, NY → Unmodified
Section 33 → PPA and Section 35 → SBS

MnDOT DCT Implementation Aging Evaluation Study



Objectives

- Assess effects of long term laboratory aging on cracking (fracture) performance tests
- Determine effects of test temperature on cracking performance parameters from SCB and DCT tests
- Secondary Outcomes:
  - What can we learn from fracture behavior regarding asphalt mixtures?
    - *Effect of RAP amount*
    - *Effect of binder type*

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Testing Matrix

- Age Conditioning

Mix	PG	RAP
New York	PG 64-22	0%
		30%
New Hampshire	PG 64-28	0%
		30%

- Test Temperature Study:

Mix	PG	RAP
Virginia	76-22	0%
	70-22	20%
	64-22	40%
Vermont	52-34	20%
	52-34	40%

- Short Term Aging: Plant Production
- Long Term Aging: NCHRP 09-54
- Long term oven aging of loose mix
  - Aging Temperature = 95 ºC
  - Aging Duration → Geography and structure specific
  - Current study: 0, 14 and 21 days
- All tests on plant mix, lab compacted samples

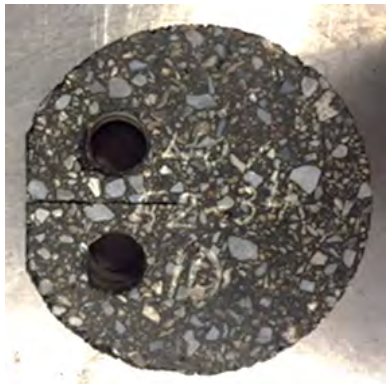
- SCB and DCT tests at multiple temperatures
- SCB: 25, 13 and 1ºC
- DCT: PG LT + 10 ºC
- All tests on plant mixed, plant compacted samples

Specimen Preparations

Gyratory Specimen

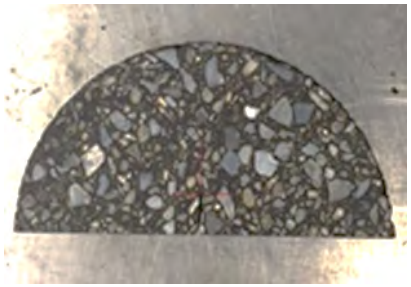
50 mm (2 inch) Disk

Core loading holes → Notched



DCT

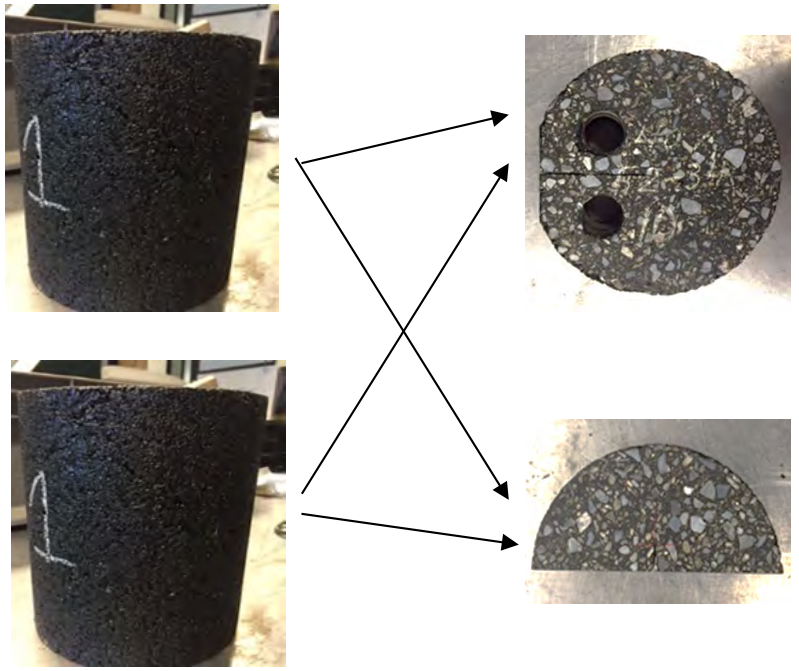
Cut disk into two halves → Notched



SCB

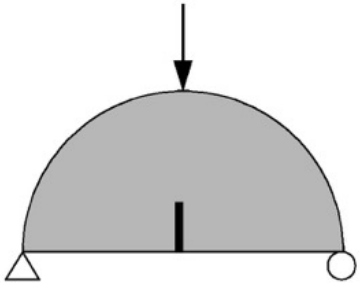
Specimen Distribution

NH 0% RAP			NH 30% RAP			NY 0% RAP			NY 30% RAP		
Short-term aged			Short-term aged			Short-term aged			Short-term aged		
Discs	AV	test	Discs	AV	test	Discs	AV	test	Discs	AV	test
1.A	6.6%	SCB	1.A	6.6%	DCT	1.A	6.2%	SCB	1.A	6.4%	DCT
1.B	6.5%	DCT	1.B	6.6%	SCB	1.B	6.3%	DCT	1.B	7.1%	DCT
1.C	5.7%	Extra	1.C	6.6%	Extra	1.C	7.8%	DCT	1.C	6.1%	SCB
2.A	6.5%	SCB	2.A	6.6%	SCB	2.A	6.8%	SCB	2.A	6.6%	DCT
2.B	6.3%	DCT	2.B	6.8%	DCT	2.B	7.9%	Extra	2.B	7.2%	SCB
2.C	5.8%	DCT	2.C	6.5%	DCT	2.C	6.6%	DCT	2.C	6.3%	Extra
14 days aged			14 days aged			14 days aged			14 days aged		
Discs	AV	test	Discs	AV	test	Discs	AV	test	Discs	AV	test
1.A	5.5%	Extra	1.A	7.9%	Extra	1.A	5.8%	DCT	1.A	6.9%	SCB
1.B	5.6%	DCT	1.B	7.4%	SCB	1.B	7.4%	SCB	1.B	7.6%	Extra
1.C	5.8%	SCB	1.C	6.9%	DCT	1.C	6.4%	DCT	1.C	6.2%	DCT
2.A	6.7%	DCT	2.A	7.1%	SCB	2.A	6.2%	SCB	2.A	6.5%	DCT
2.B	6.5%	SCB	2.B	7.2%	DCT	2.B	6.7%	DCT	2.B	7.1%	DCT
2.C	6.3%	DCT	2.C	6.9%	DCT	2.C	5.7%	Extra	2.C	7.5%	SCB
21 days aged			21 days aged			21 days aged			21 days aged		
Discs	AV	test	Discs	AV	test	Discs	AV	test	Discs	AV	test
1.A	6.5%	DCT	1.A	6.9%	SCB	1.A	6.8%	DCT	1.A	6.8%	DCT
1.B	6.1%	SCB	1.B	7.0%	Extra	1.B	7.4%	SCB	1.B	7.4%	DCT
1.C	6.0%	Extra	1.C	6.6%	DCT	1.C	6.3%	Extra	1.C	7.0%	SCB
2.A	6.5%	DCT	2.A	6.7%	SCB	2.A	6.5%	DCT	2.A	7.2%	SCB
2.B	6.4%	DCT	2.B	6.6%	DCT	2.B	6.8%	DCT	2.B	7.5%	DCT
2.C	6.3%	SCB	2.C	6.4%	DCT	2.C	6.6%	SCB	2.C	6.7%	Extra

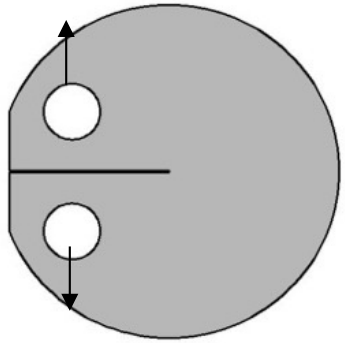


Test Conditions

- Aging Study
  - Plant Production (Short Term)
  - Loose mix oven aging @ 95 ºC
  - 0, 14 and 21 days
  - Total: 3 conditions, 2 test types

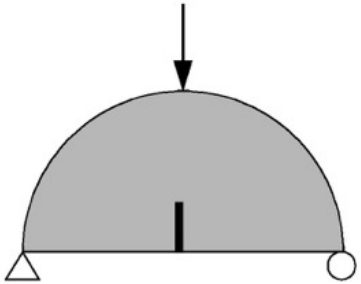


SCB: 25ºC

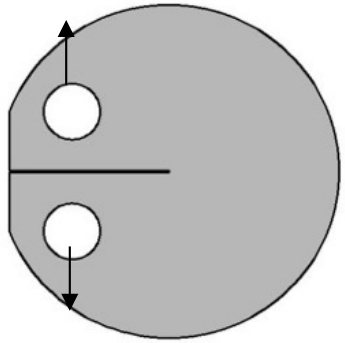


DCT: -12 or -18ºC

- Temperature Study
  - All specimens are plant mixed, plant compacted
  - Total: 1 condition, 2 test types, 3 temperatures



SCB: 25, 13 and 1ºC



DCT: -12 or -18ºC

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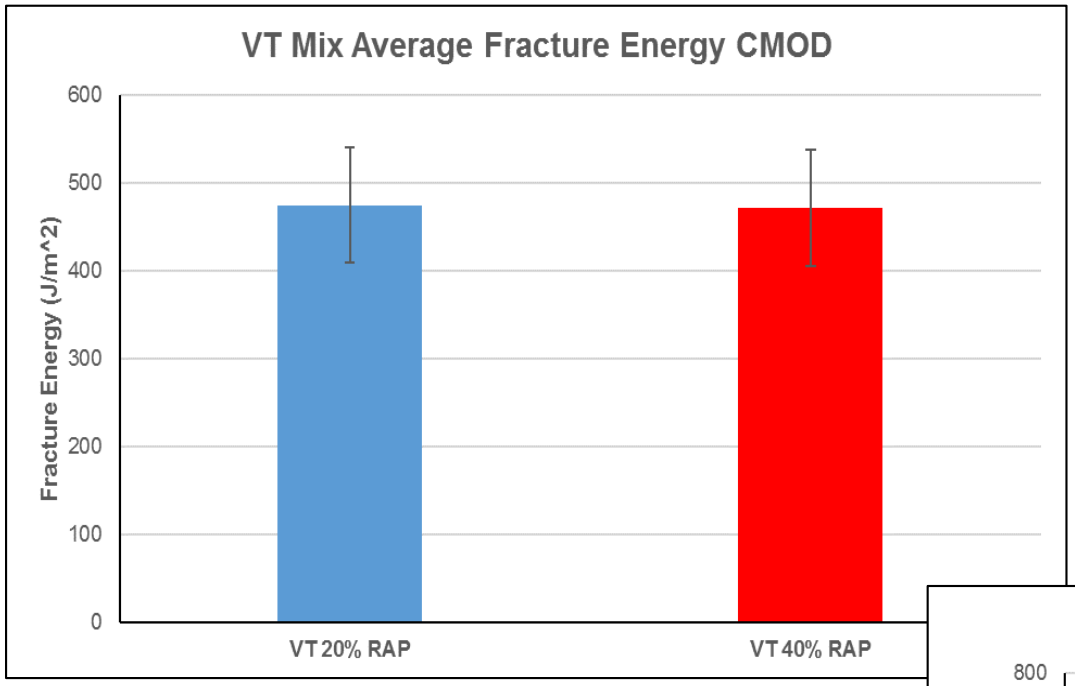
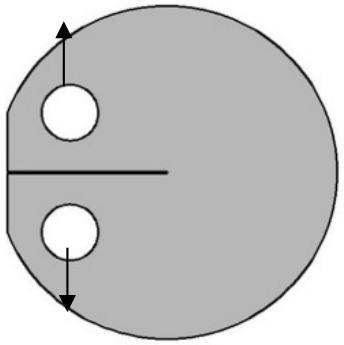
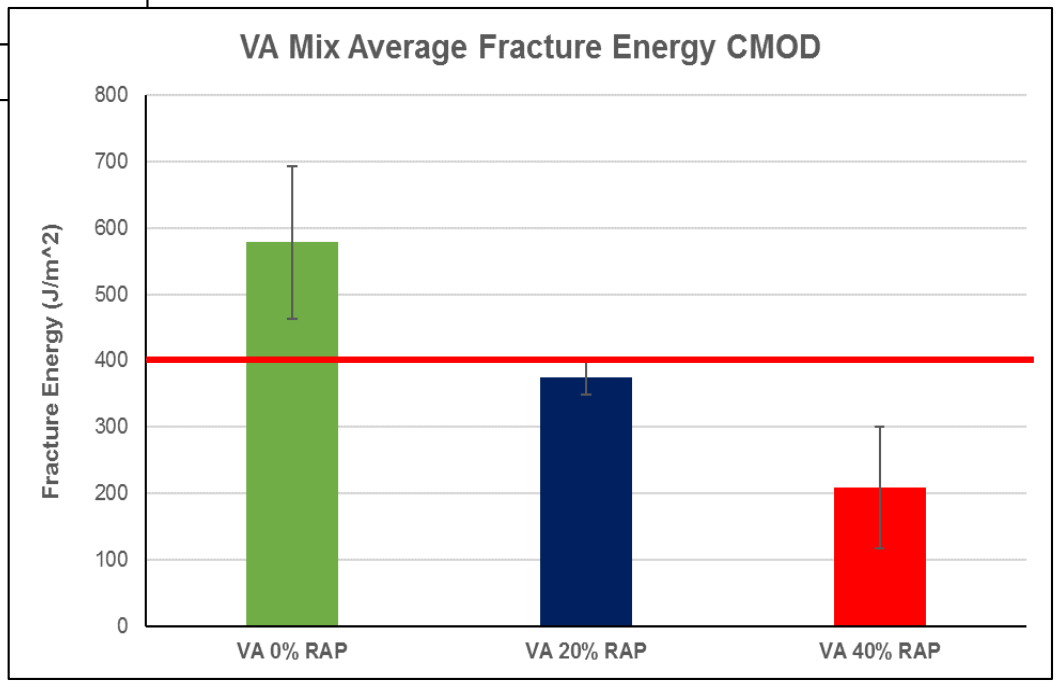
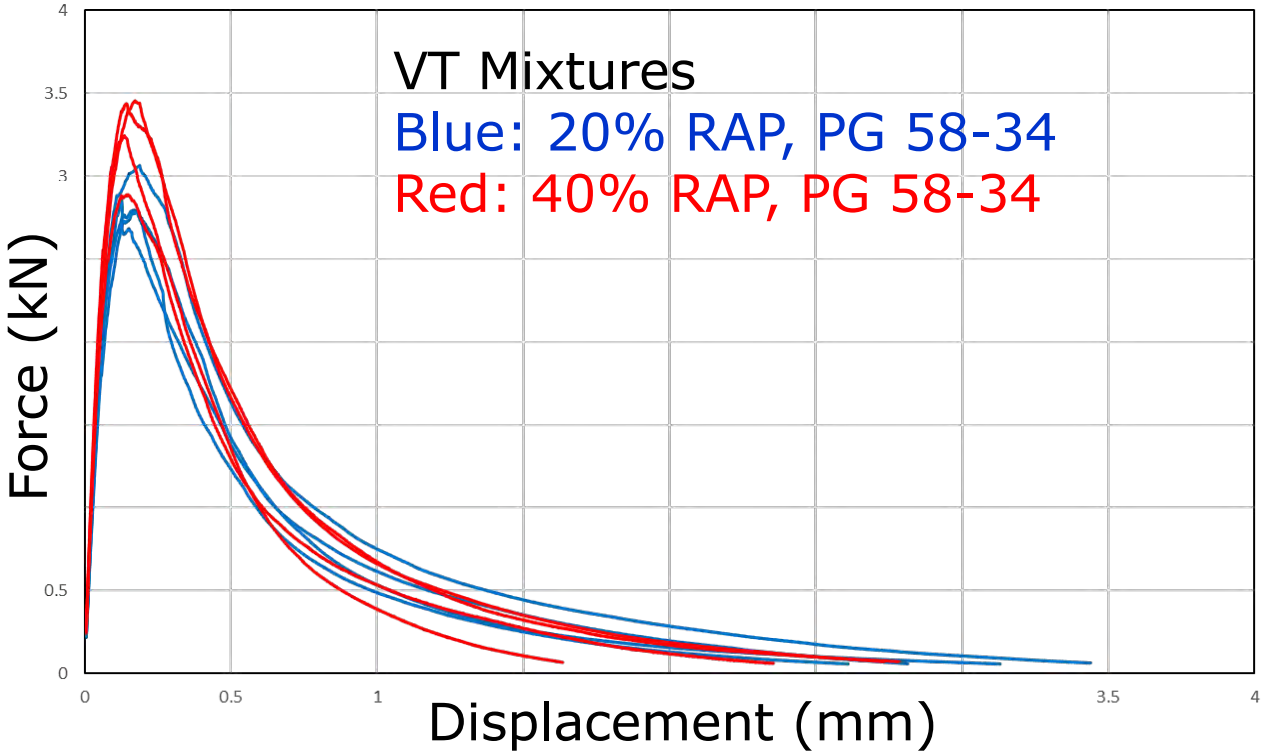
Temperature Study: Low Temperature Performance

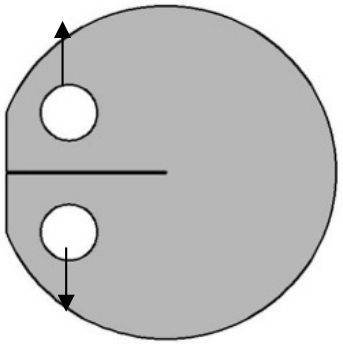


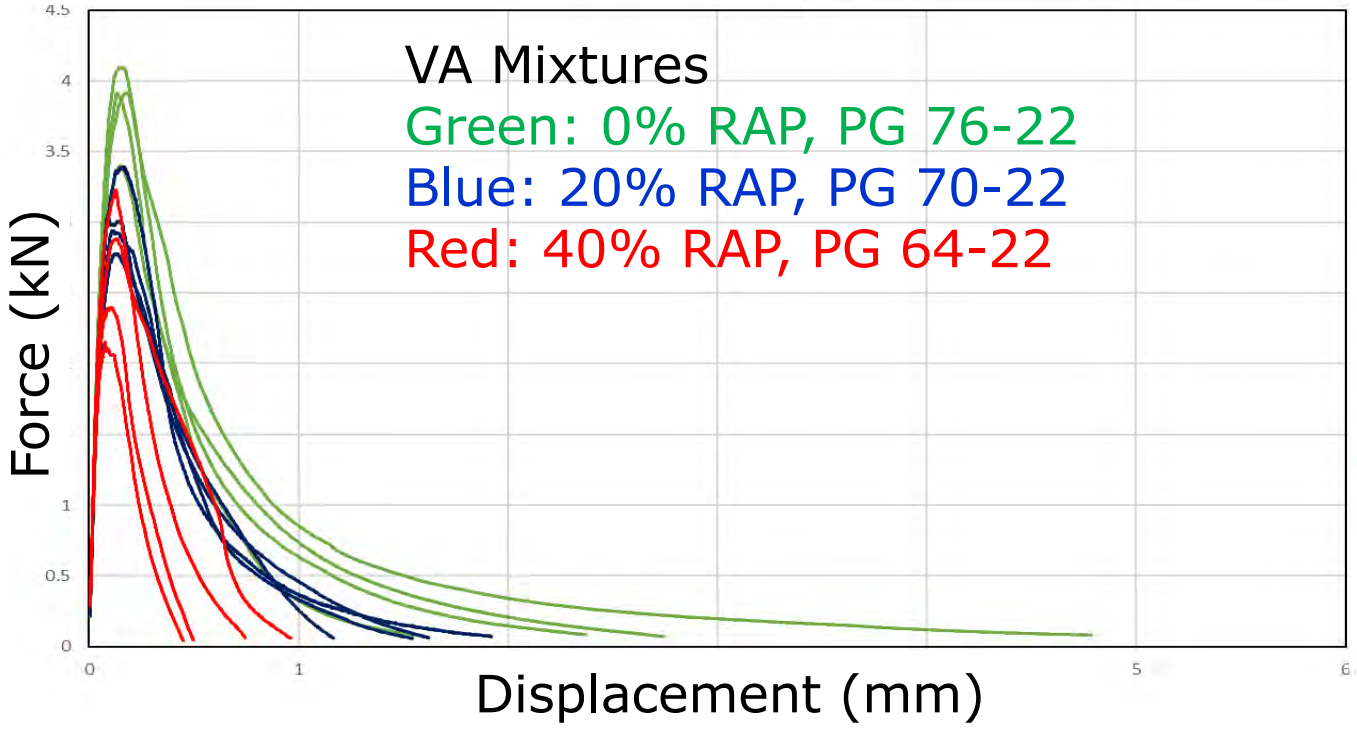


- Minimal difference between VT 20% and 40% RAP mixtures
- Substantial difference between VA mixtures

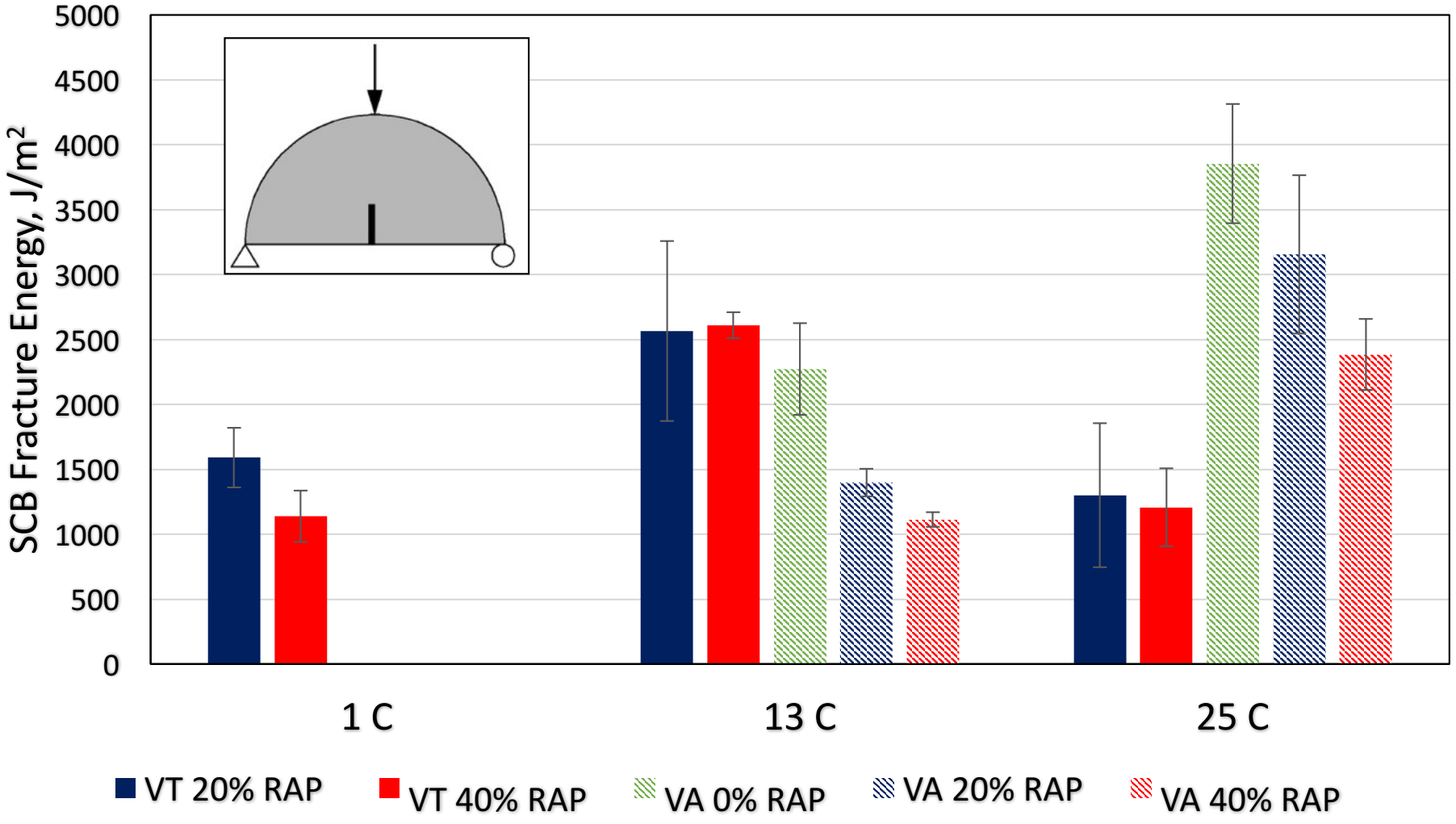



VT Mixtures
Blue: 20% RAP, PG 58-34
Red: 40% RAP, PG 58-34
Force (kN)
Displacement (mm)
0
0.5
1
3.5
4

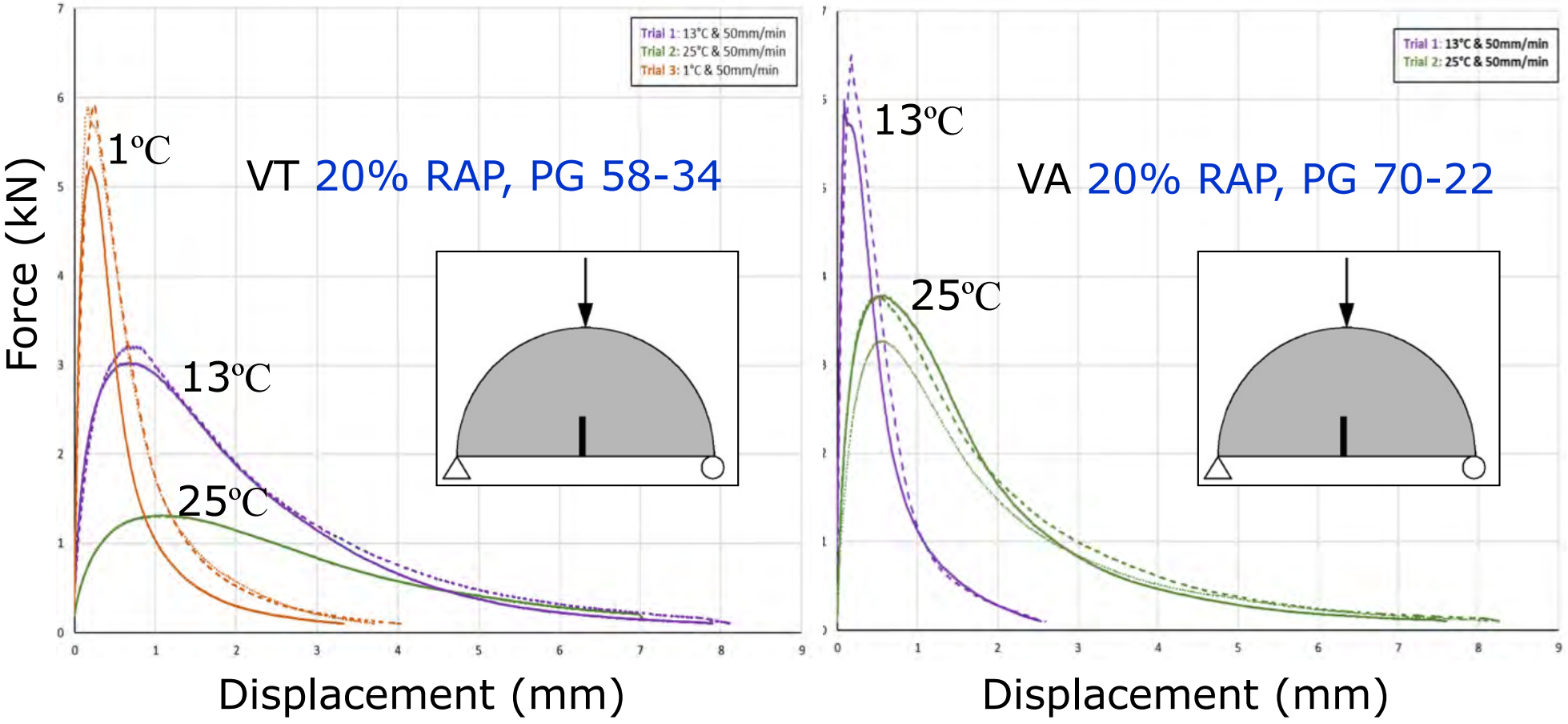


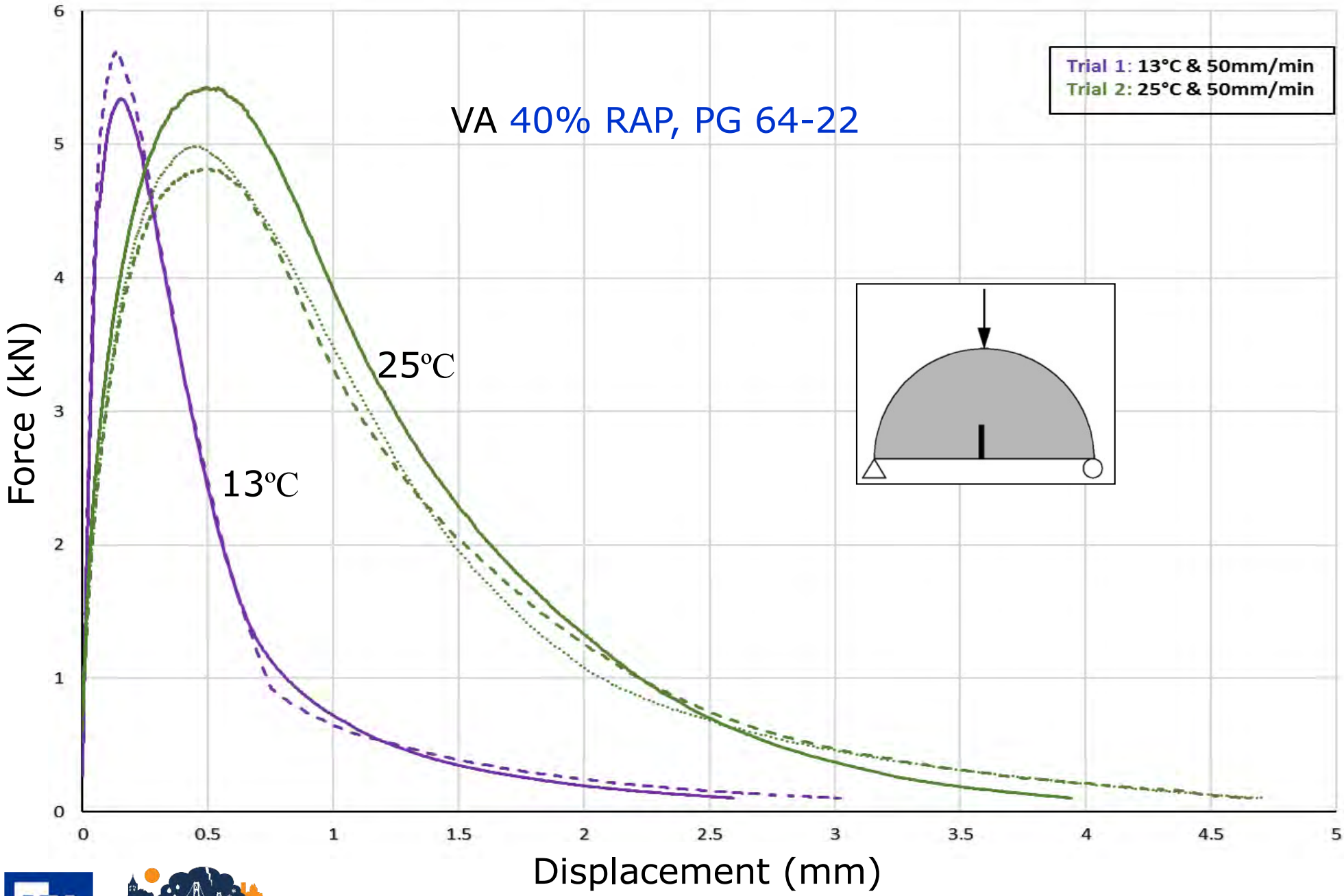

VA Mixtures
Green: 0% RAP, PG 76-22
Blue: 20% RAP, PG 70-22
Red: 40% RAP, PG 64-22
Force (kN)
Displacement (mm)
0
0.5
1
3.5
4
4.5
5
6

Effect of Temperature on SCB Results



Effect of Temperature on Fracture Behavior at Intermediate Temperatures




VA 40% RAP, PG 64-22
Trial 1: 13°C & 50mm/min
Trial 2: 25°C & 50mm/min
25°C
13°C
Force (kN)
Displacement (mm)
0
1
2
3
4
5
6
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

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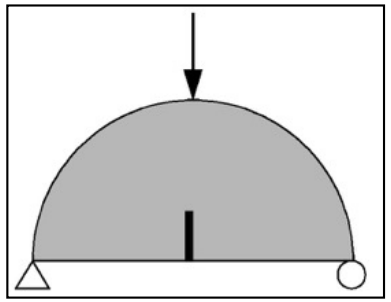
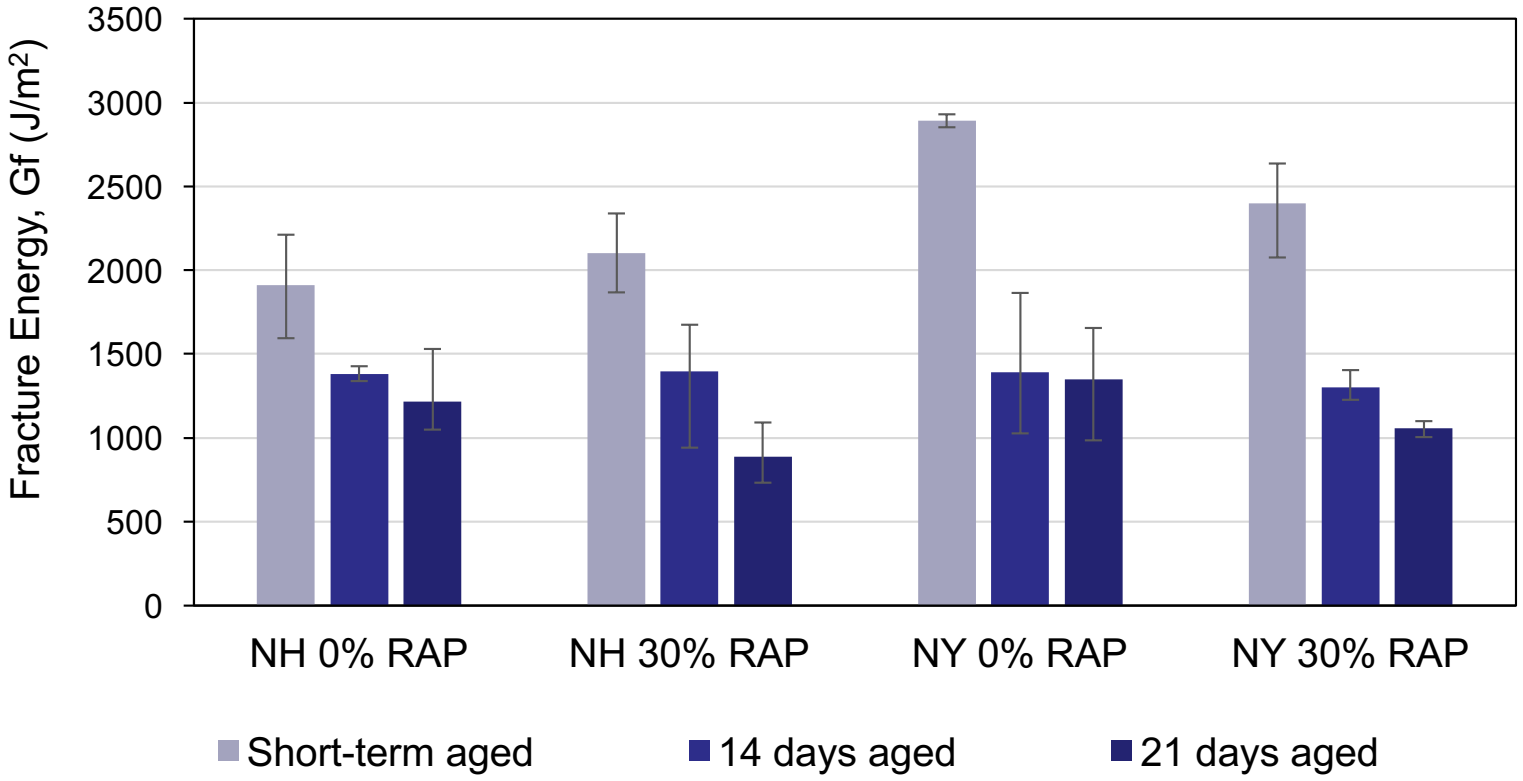
Aging Study Results

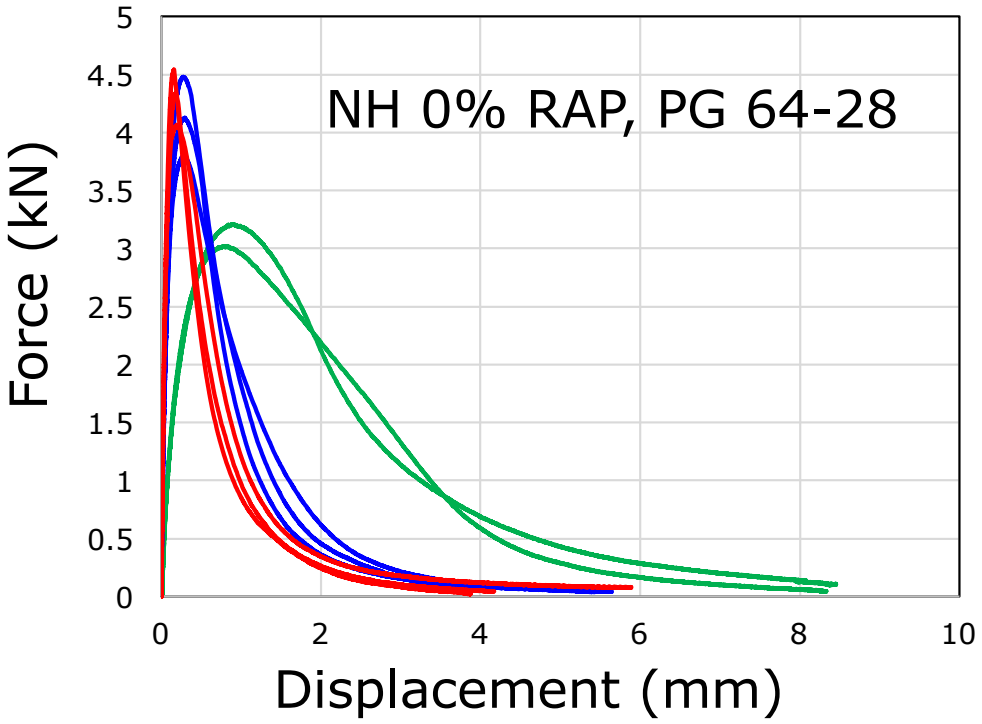


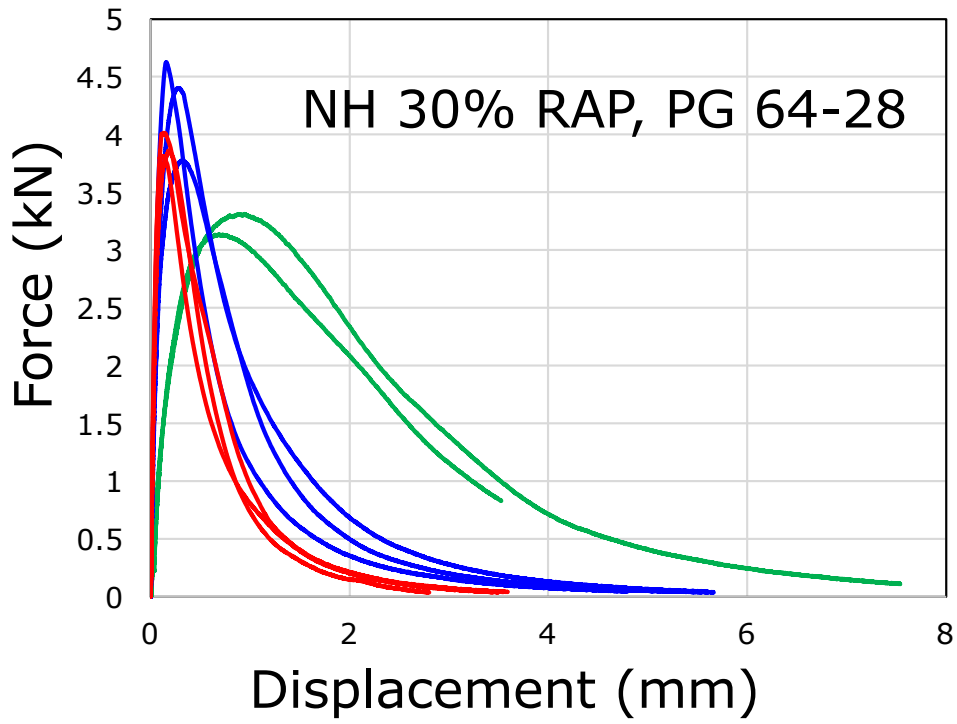
- SCB Fracture Energy at Intermediate Temperature



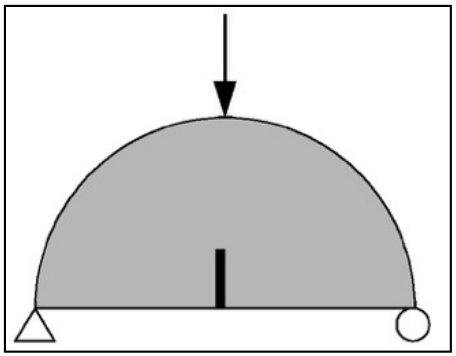
- Drop in fracture energy with increasing aging levels
- Extent of drop is not consistent with RAP amount

Effect of Aging on Fracture Behavior

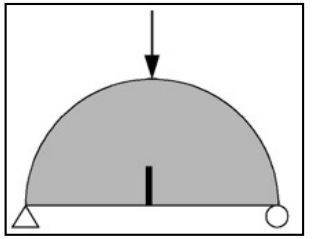




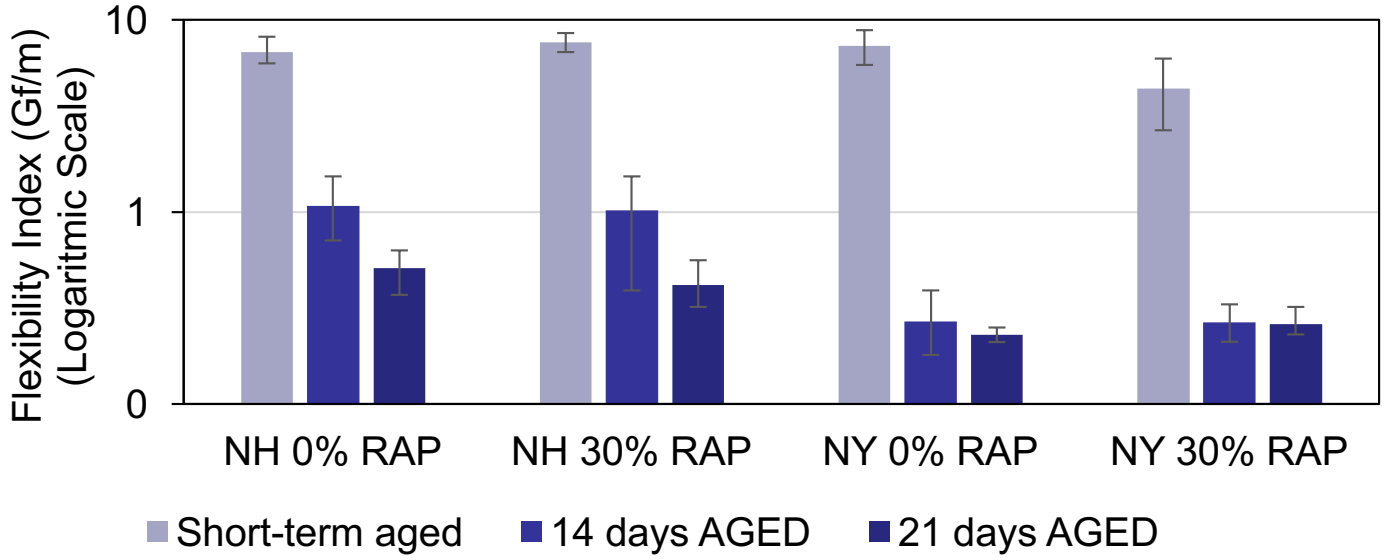
Green: Short-term aged
Blue: 14 days at 95 deg. C
Red: 21 days at 95 deg. C

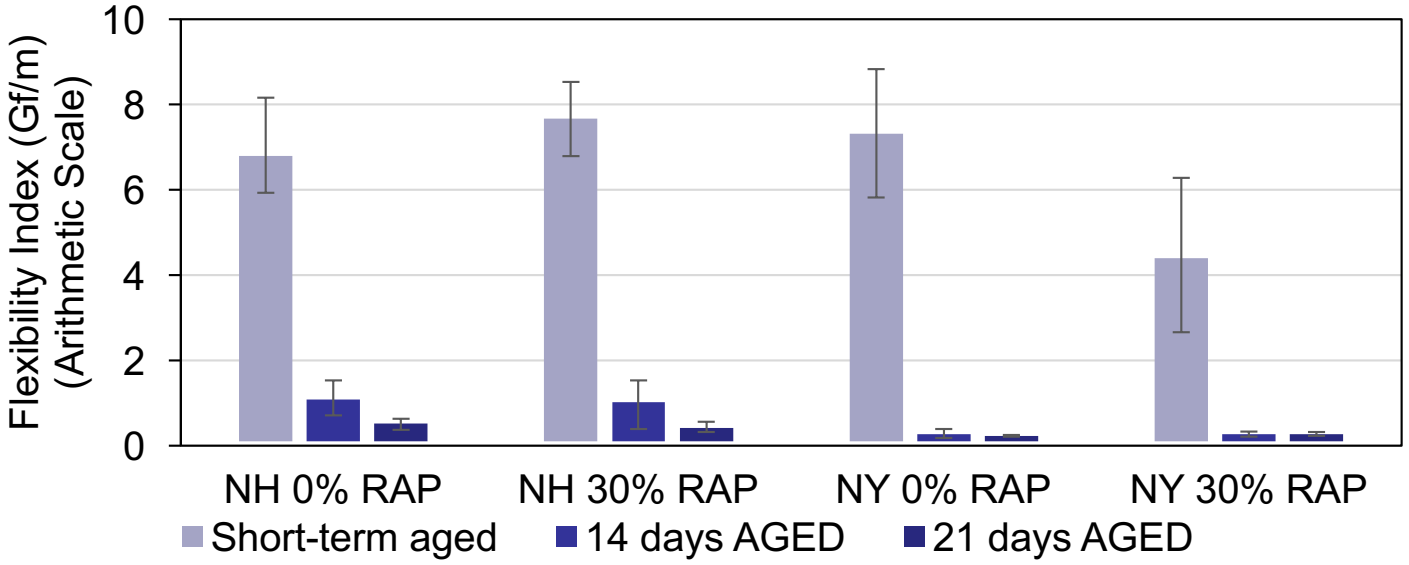


Aging Study Results



- SCB Flexibility Index at Intermediate Temperature





Overview

- Introduction
  - –Motivation and Objectives
  - –DCT and SCB Fracture Tests
- Methodology and Materials
- Results
  - –Temperature
  - –Aging Effects
- **Summary & Conclusion**

Summary and Conclusions

- Effect of temperature on fracture behavior of asphalt mixtures:
  - Increasing temperature → Lower peak load (lower fracture stress) and Increased ductility
  - Non unique response between mixtures
  - Transition from ductile to brittle is mix (binder and other constituent) dependent
  - Use of single 25 deg. C for all regions may not be a good idea!

Summary and Conclusions (cont.)

- Effect of aging on fracture behavior of asphalt mixtures:
  - New draft aging protocol from NCHRP 09-54 was evaluated here
    - *Big drop in cracking resistance from short term to 14 day aging, small change from 14 to 21 day aging*
  - Aging substantially changes fracture behavior at intermediate temperature
  - Age conditioning should be included in cracking (fracture) performance test

Summary and Conclusions (cont.)

- Performance testing can provide insight into mixture behavior:
  - 20% and 40% VT RAP mixes showed similar cracking performance at intermediate and low temperatures
  - Sensitivity to effects of aging were comparable between 0% and 30% NH and NY mixes
  - 40% RAP VA mixture with “PG HT only” grade bumping led to substantial drop in cracking resistance

Thank you for your attention!

Acknowledgements:
UNH SURF Program
North-East High RAP Pooled Fund Study

Questions / Comments?

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