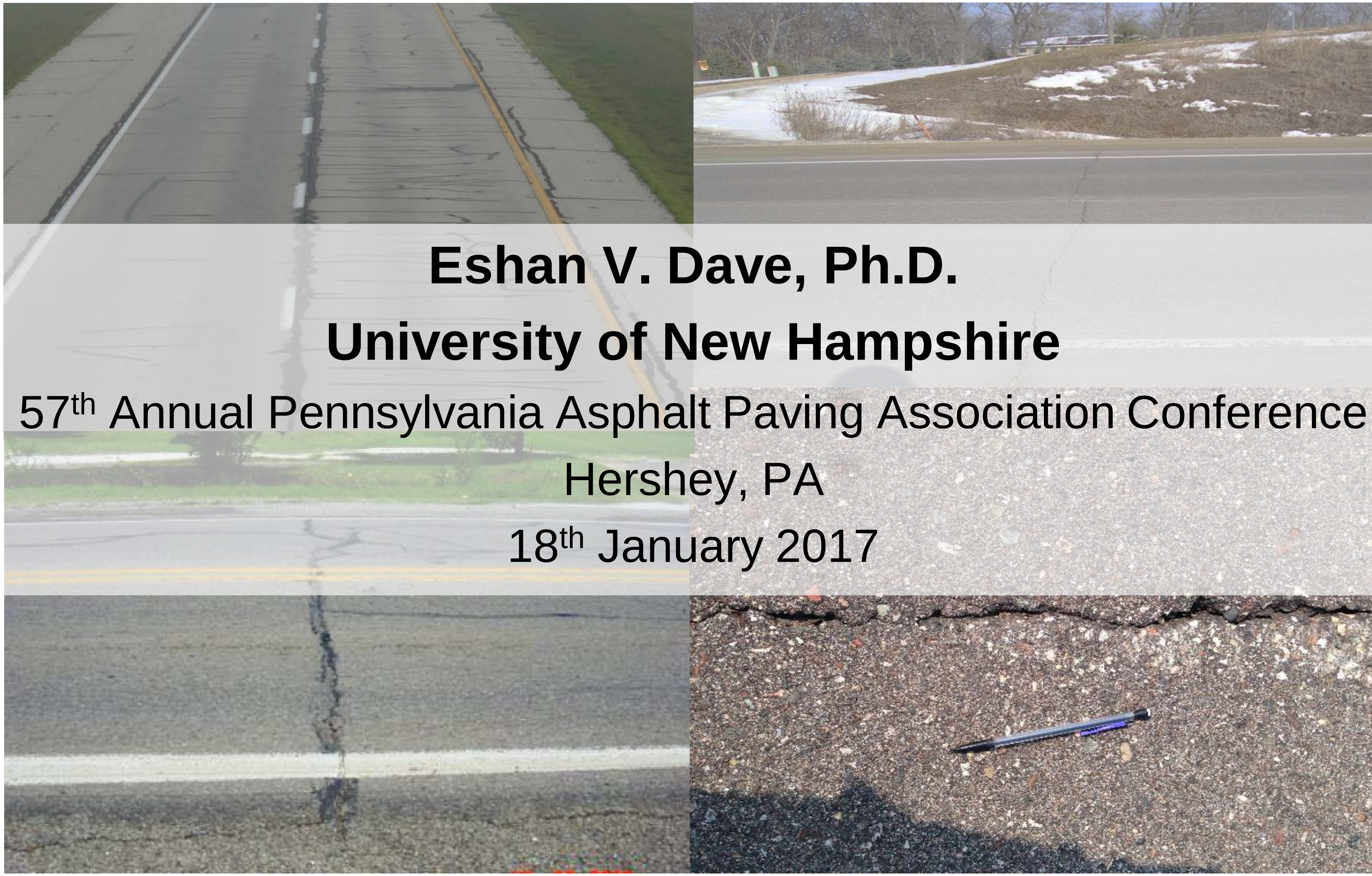
Asphalt Performance Testing and Specification Development



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University of New Hampshire

57th Annual Pennsylvania Asphalt Paving Association Conference

Hershey, PA

18th January 2017

Overview

- Introduction: Performance-based Specifications
- Fracture Energy as Performance Measure
- MnDOT Performance Based Specification
  - Regional Validation
  - Pilot Implementation
  - Sensitivity of Fracture Energy to Thermal Cracking Performance
  - Specification Refinement Efforts
  - Round Robin Testing
- Summary & Conclusion

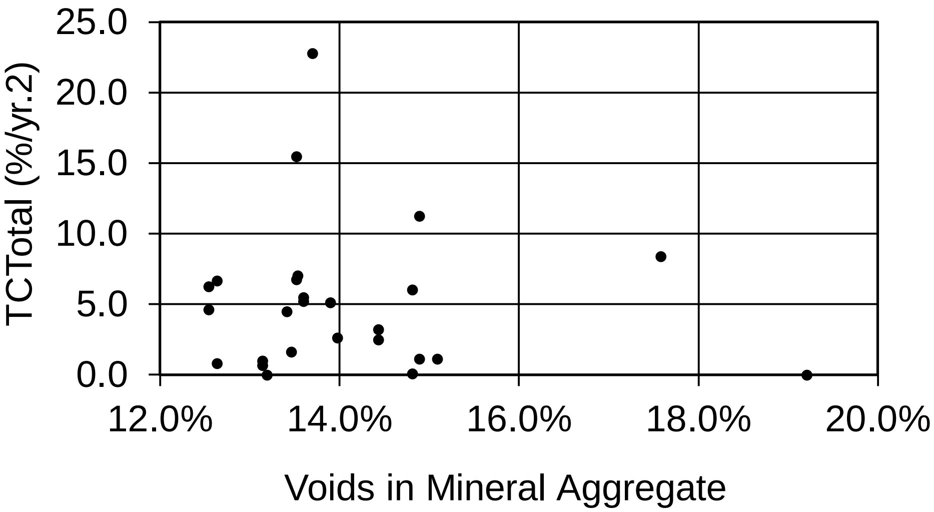


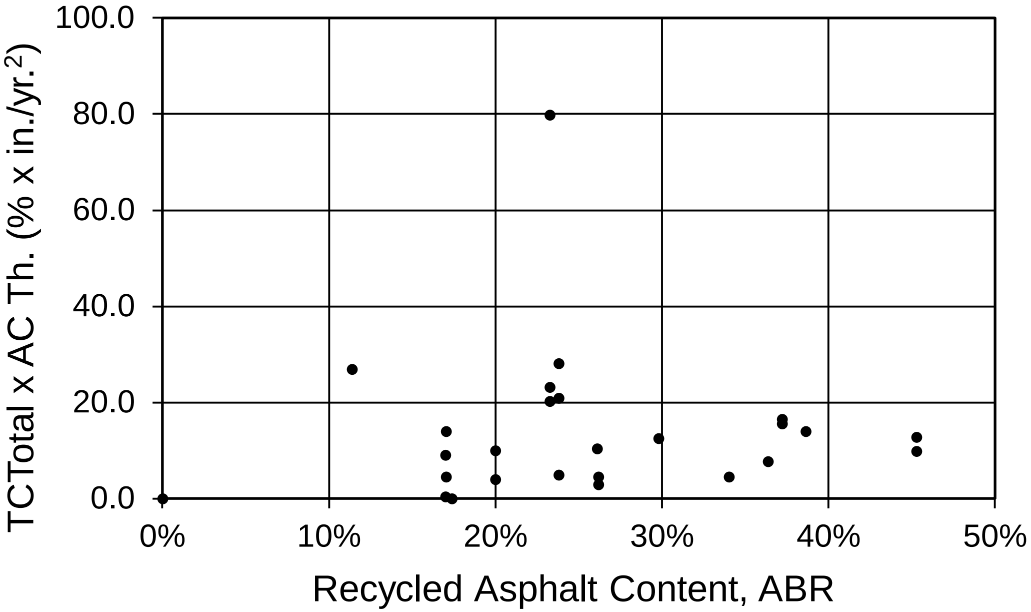
Asphalt Performance Testing

- Goals:
  - Identify mixtures prone to performance problems during the mix design process
  - Identify potential performance problems during production
  - Predict performance during mix design and production
    - *Warranties*
    - ***Performance Specifications***
  - Evaluate new materials or design tools to improve performance

Field Cracking and Volumetric Measures

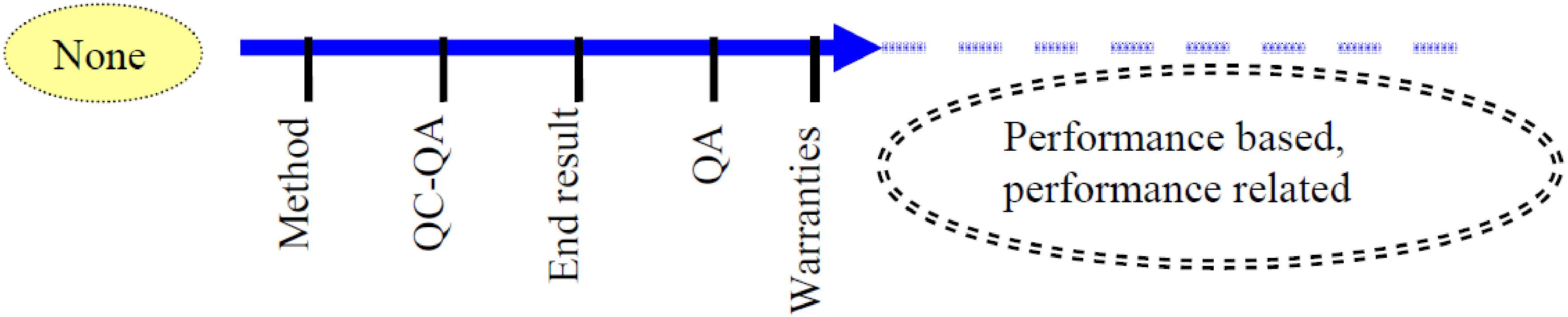
- 26 Pavement Sections
- Field Cracking Rates





Material Specifications

- Specification Development Continuum
  - TRB Circular on "Development of Warranty Programs for HMA Pavements"



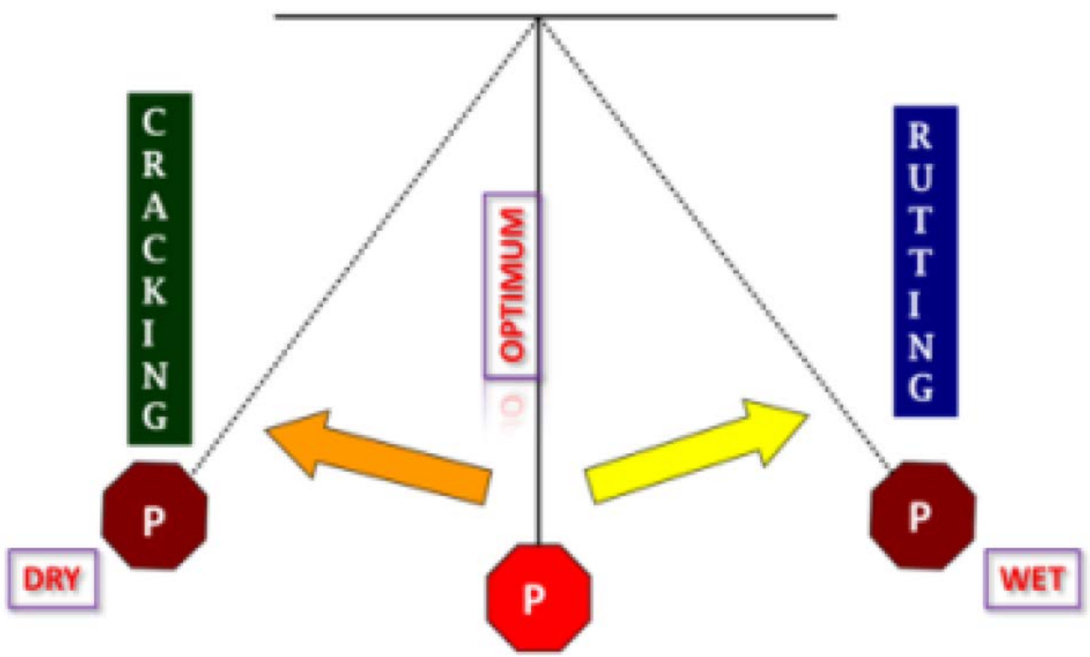
- Use of performance tests in material specifications is an alternative to wide-spread warranty pavement requirements

Challenges in Implementation of Performance Based Specifications

- Availability of suitable performance indicator(s)
  - Requires a **performance test**
- Implementation Needs:
  - Spec. needs to be relevant, repeatable, achievable, and reliable
  - Sampling and specimen conditioning
- Cost
  - Manpower needs
  - Equipment needs
- Other challenges:
  - Time limit on obtaining lab results
  - Teething problems

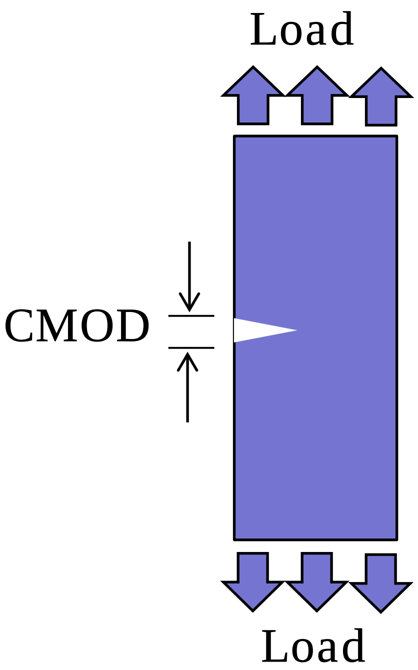
Balanced Mix Design: ETG Definition

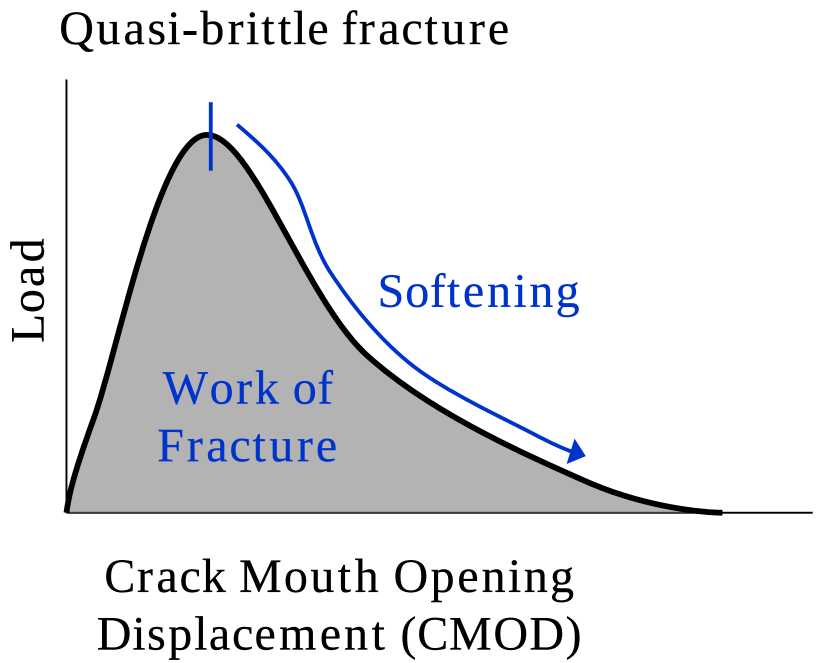
- Asphalt mix design using *performance tests* on appropriately *conditioned specimens* that address *multiple modes of distress* taking into consideration mix aging, traffic, climate and location within the pavement structure

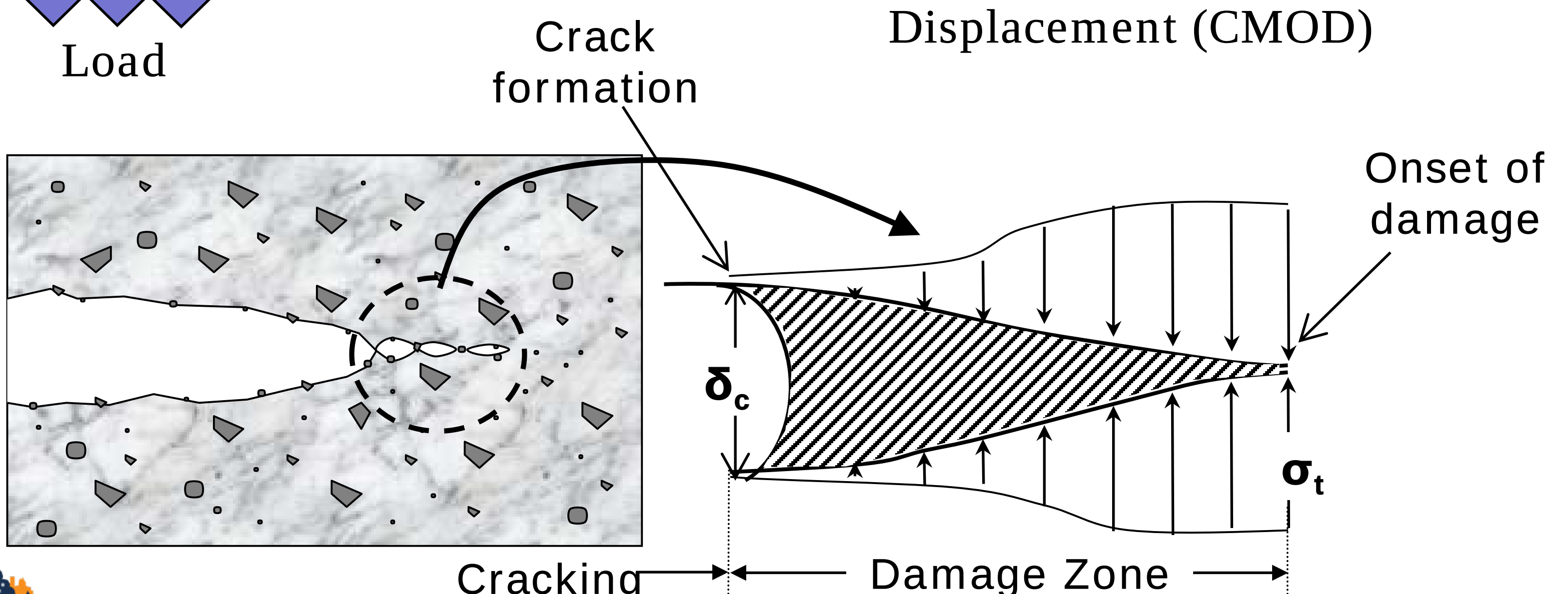


Performance Pendulum (Shane Buchanan, Oldcastle)

Cracking Process in Asphalt Materials

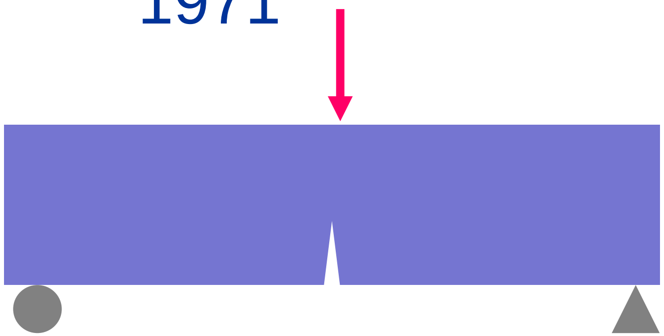




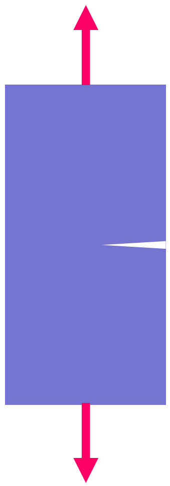


Fracture Test Geometries

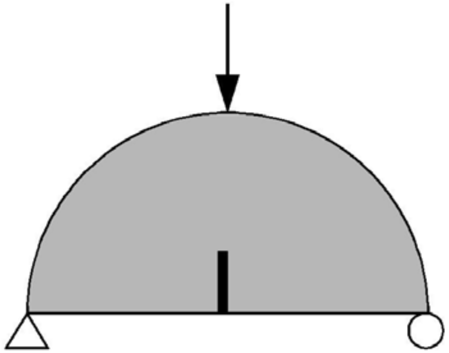
- Fracture tests on asphalt date back to 1971



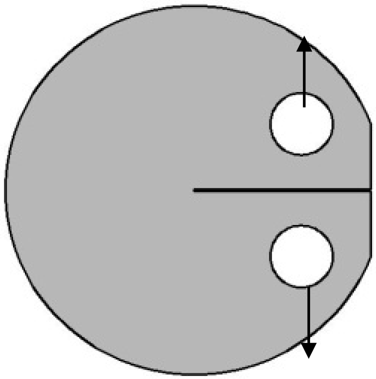
Single-edge Notched Beam (SE(B))



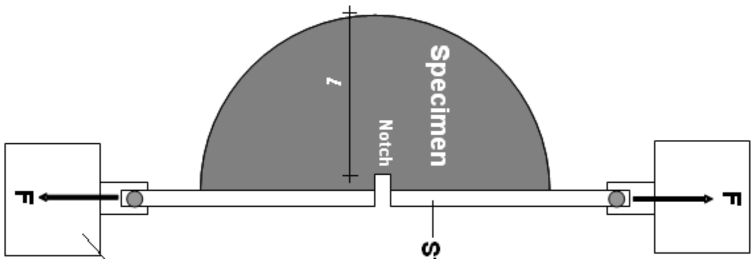
Direct Tension



Semi-Circular Bend (SCB)



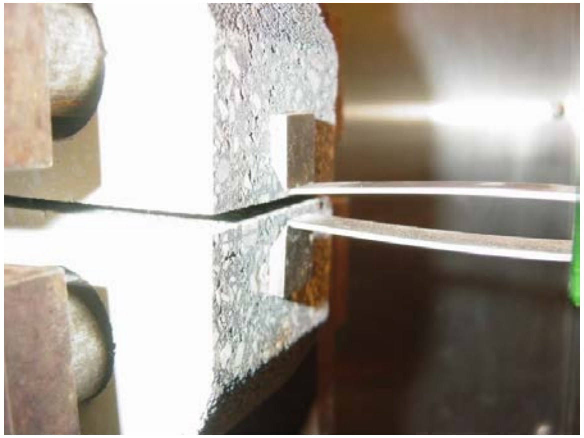
Disk-shaped Compact Tension (DCT)

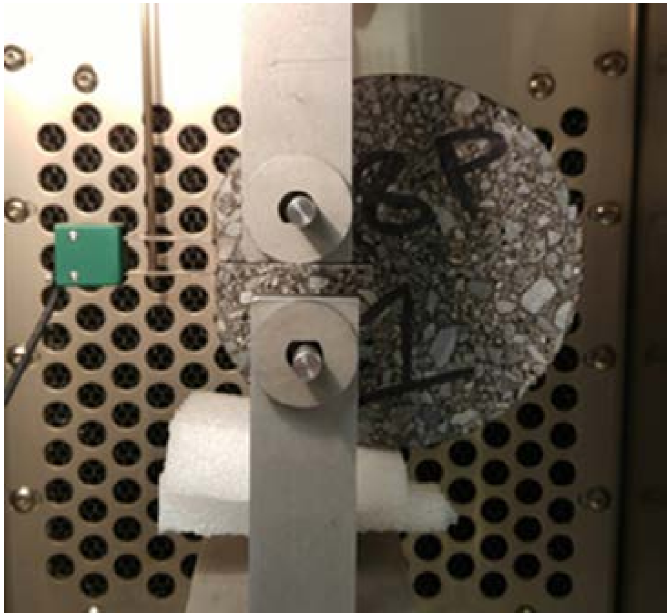


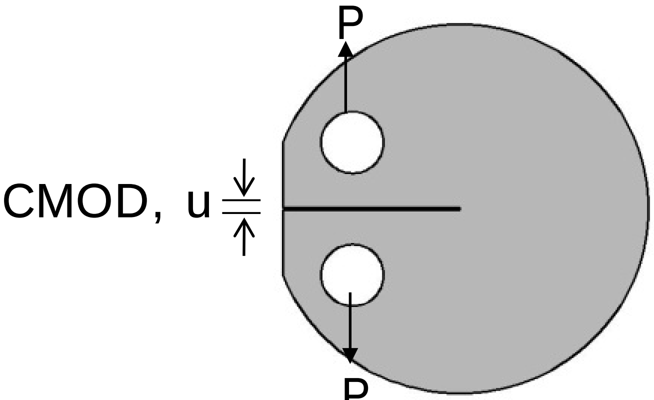
Fenix Test

Disk-Shaped Compact Tension (DCT) Test

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

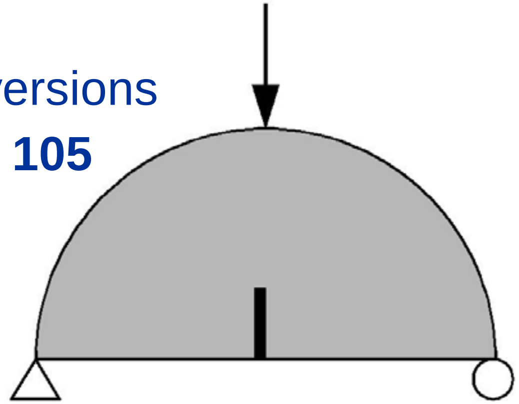


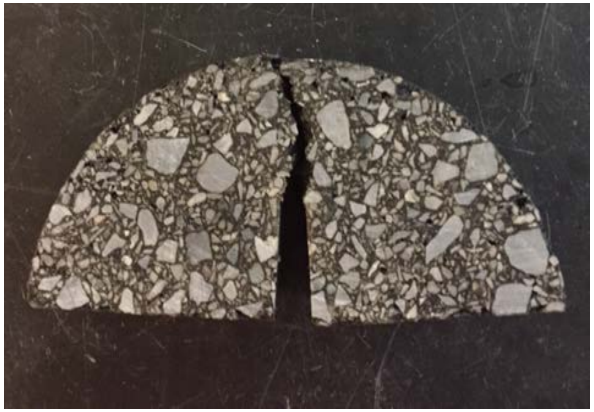




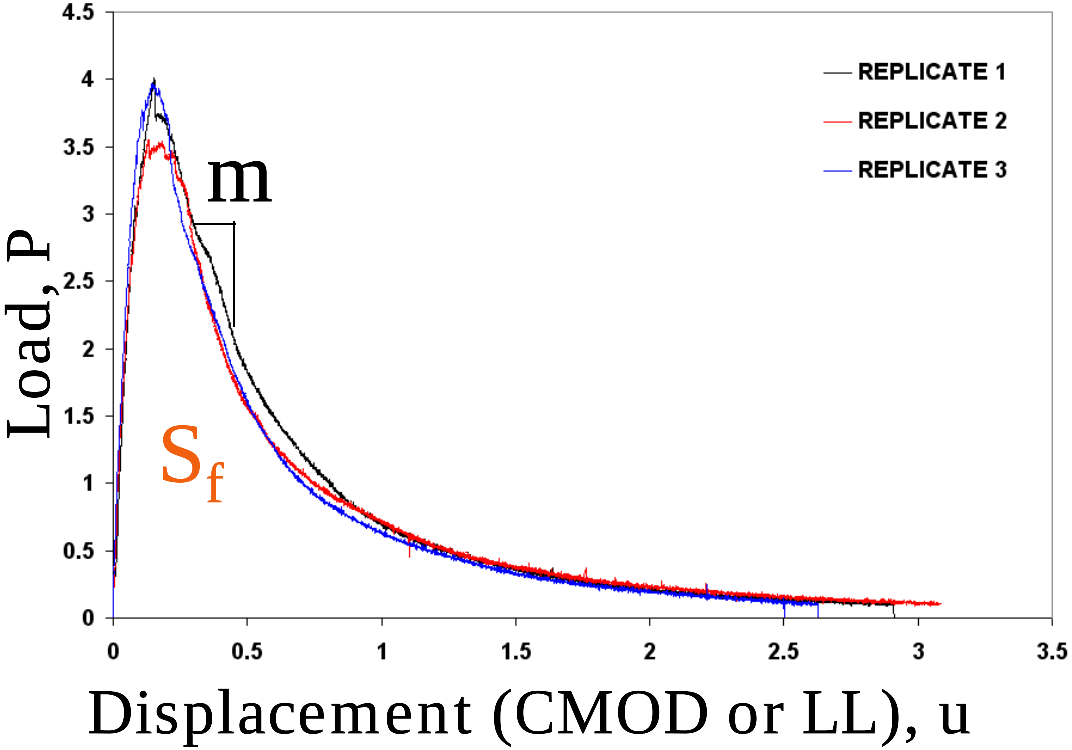
Semi-Circular Bend (SCB) Test

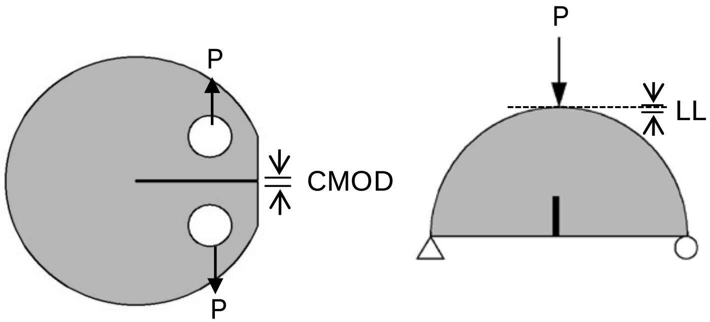
- Multiple variants exist
  - Early work in Europe
  - Simultaneous cold (Marasteanu et al. – MN) and intermediate temperature (Mohamed et al. – LA) versions
  - **Recent work from Al-Qadi et al. (IL) → AASHTO TP 105**
- AASHTO TP 105 (I-FIT)
  - Line load control, loading rate = 50 mm/min
  - Test temperature = 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

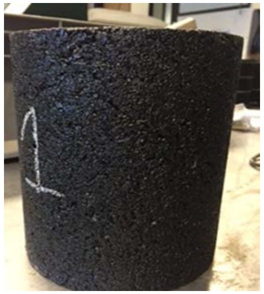
$$G_f = \frac{\text{Fracture Work, } S_f}{\text{Fracture Area}}$$

Flexibility Index, FI:

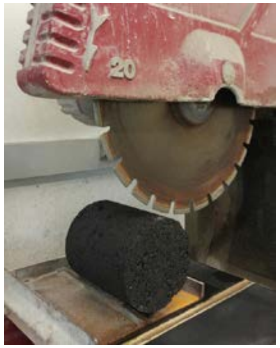
$FI = G_f \;/\; m$

Specimen Preparations

Gyratory Specimen

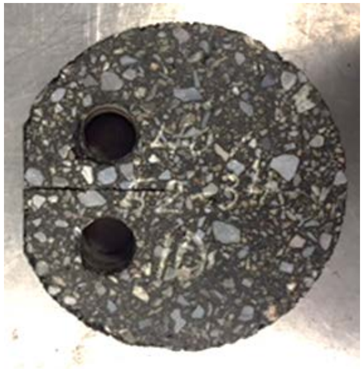


50 mm (2 inch) Disk



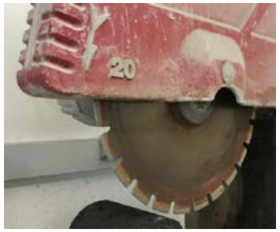
Core loading holes

Notched

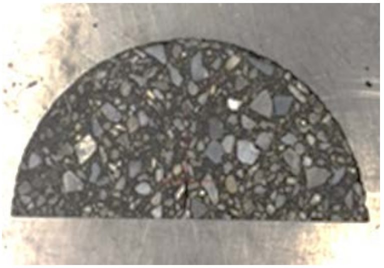


DCT

Cut disk into two halves



Notched



SCB

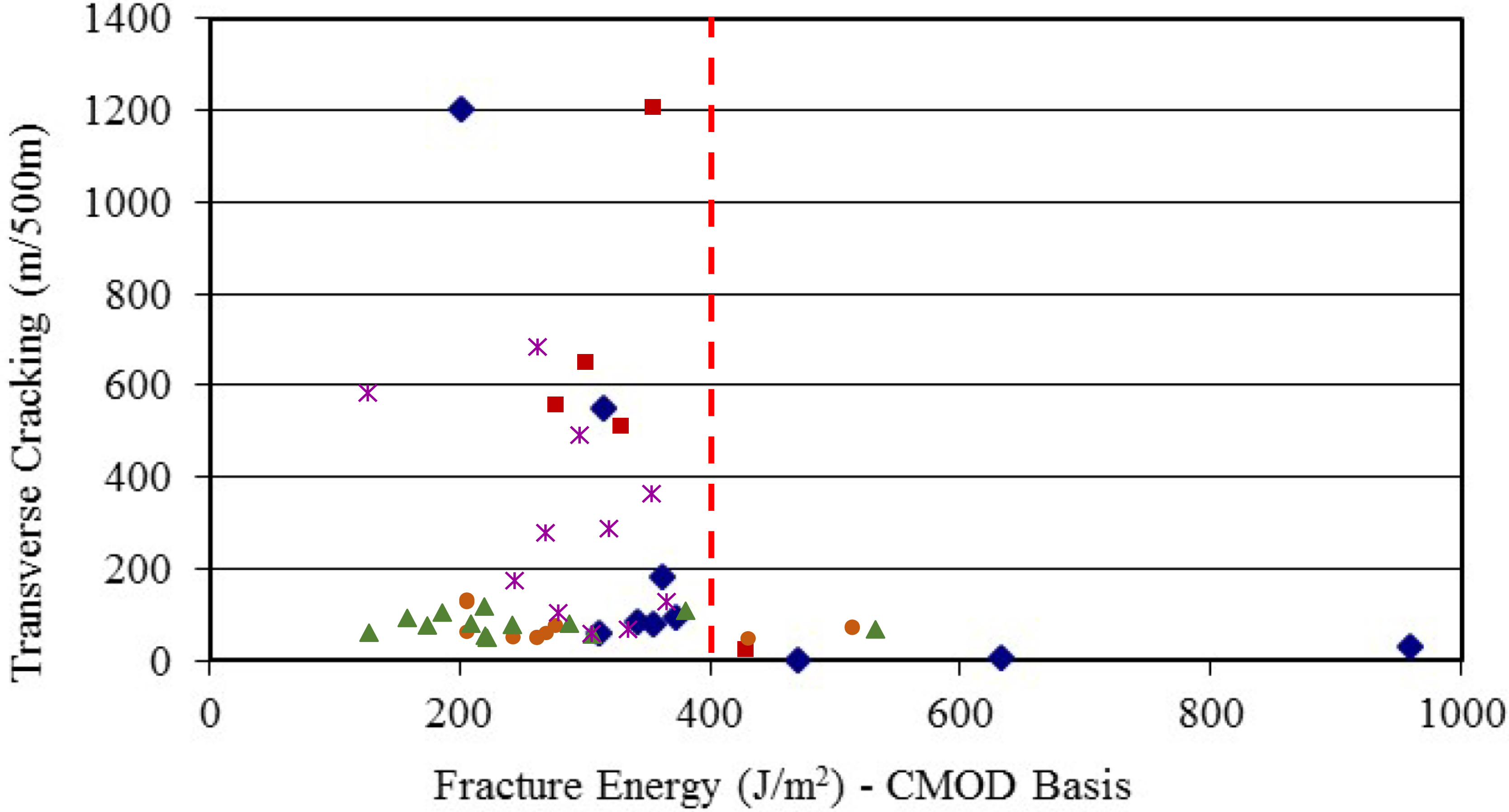
Current Adoption Efforts of Fracture Tests in Performance Based Specifications

- Semi-Circular Bend (SCB)
  - LA Version Intermediate Temperature → Louisiana DOTD
    - *Wisconsin for High RAM Projects (2014 and 2015)*
  - IL and MN Version at Intermediate Temperature:
    - *Illinois in pilot implementation stages: Combination of Hamburg Wheel Tracking Test and SCB Flexibility Index (I-FIT)*
- Disk-shaped Compact Tension (DCT)
  - City of Chicago
  - Illinois Tollways
  - Wisconsin for High RAM Projects (2014 and 2015)
  - Minnesota Department of Transportation → **Discussed here**

Low Temperature Cracking Pooled Fund Study

- Primary Distress: Thermal cracking
- Minnesota (Lead State), Connecticut, Iowa, Illinois, New York, North Dakota, Wisconsin
- TPF-5(080): 2004 – 2006 (Phase-I)
  - Extensive evaluation of performance tests (binder and mixtures)
- TPF-5(132): 2008 – 2012 (Phase-II)
  - SCB and DCT fracture energy tests evaluated for nine pavement sections
  - 4 and 7% air void level, short term and long term aging conditions
  - Outcome: Performance specifications with limited validation through five field sections

Fracture Energy as Performance Measure: Results from Various Studies (~ 50 sections)



Pooled Fund Study LTC Performance Specifications

- Based on traffic levels
- Limits based on:
  - Fracture energy test @ 10°C above 98% reliability Superpave Low Temperature PG (PGLT)
  - Low temperature cracking performance model (*IlliTC*)

Limits	**Project Criticality / Traffic Level**		
	High (> 30M ESALs)	Medium (10 – 30M ESALs)	Low (< 10M ESALs)
DCT Fracture Energy (J/m^2)	690	460	400
IlliTC Cracking Prediction (m/km)	< 4	< 64	Not required

MnDOT Implementation of Performance Specification

3. Determine sensitivity of fracture energy to thermal cracking performance (2013)

4. Specification refinement efforts (specimen conditioning, practicality revisions etc.)
(2014-present)

2. Pilot Implementation (2013)

Implementation of Performance-based Specification (MnDOT)

5. Round-robin Testing (2014-16)

1. Regional Validation of Performance Specifications (2011-2016)

Communications and Training

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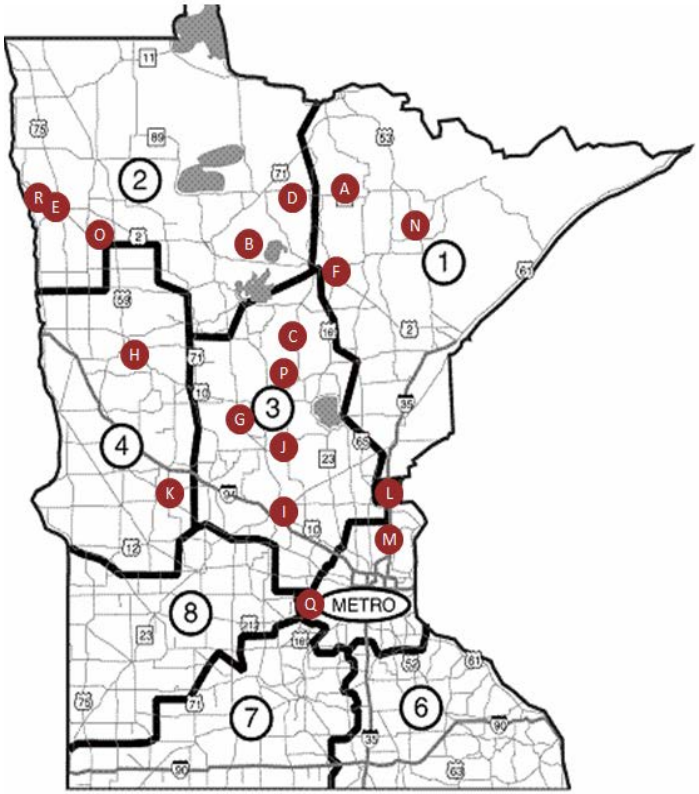
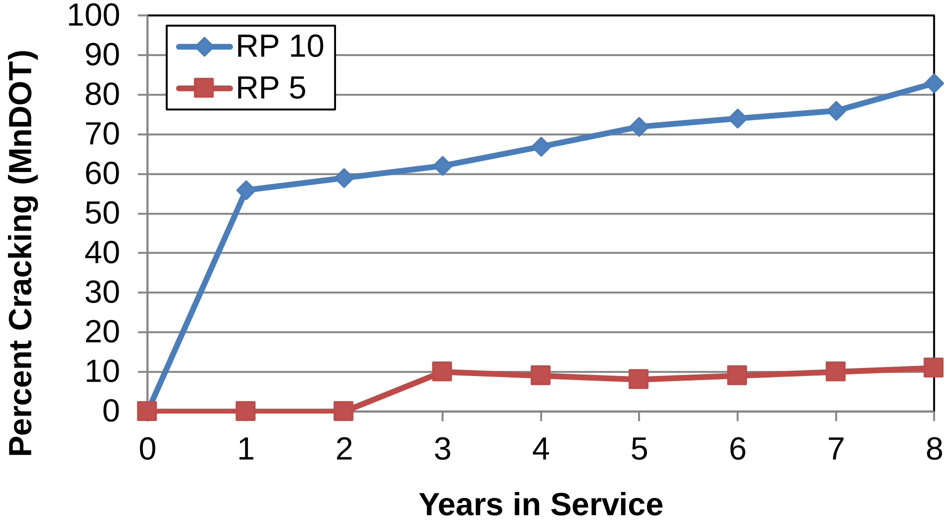
Communications and Training

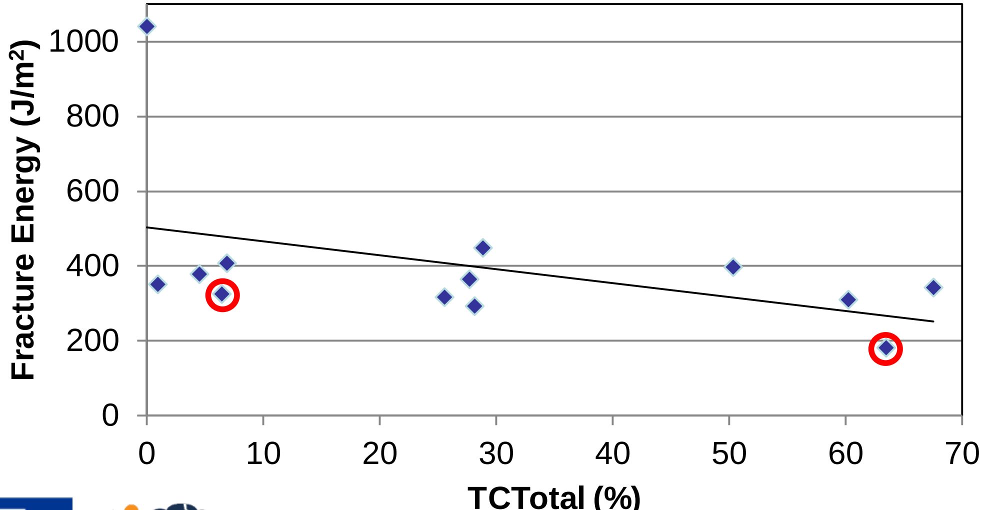
Development and Implementation of MnDOT Performance Based Specifications

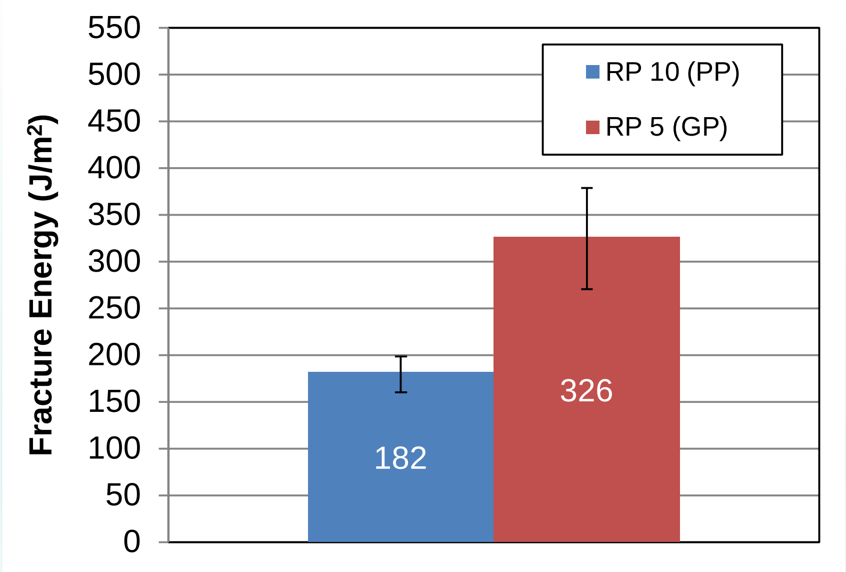
- Started with LTC Specifications from Pooled Fund Study
- Minnesota Regional Validation Studies (2011 – 2015)
  - 18 sites and 26 sections
    - *Companion sections*
  - 2004 – 2013 construction years
  - Captures different binder grades and aggregates in Minnesota
  - Different construction types: New construction, overlay, and full-depth reclamation
  - Different design traffic levels



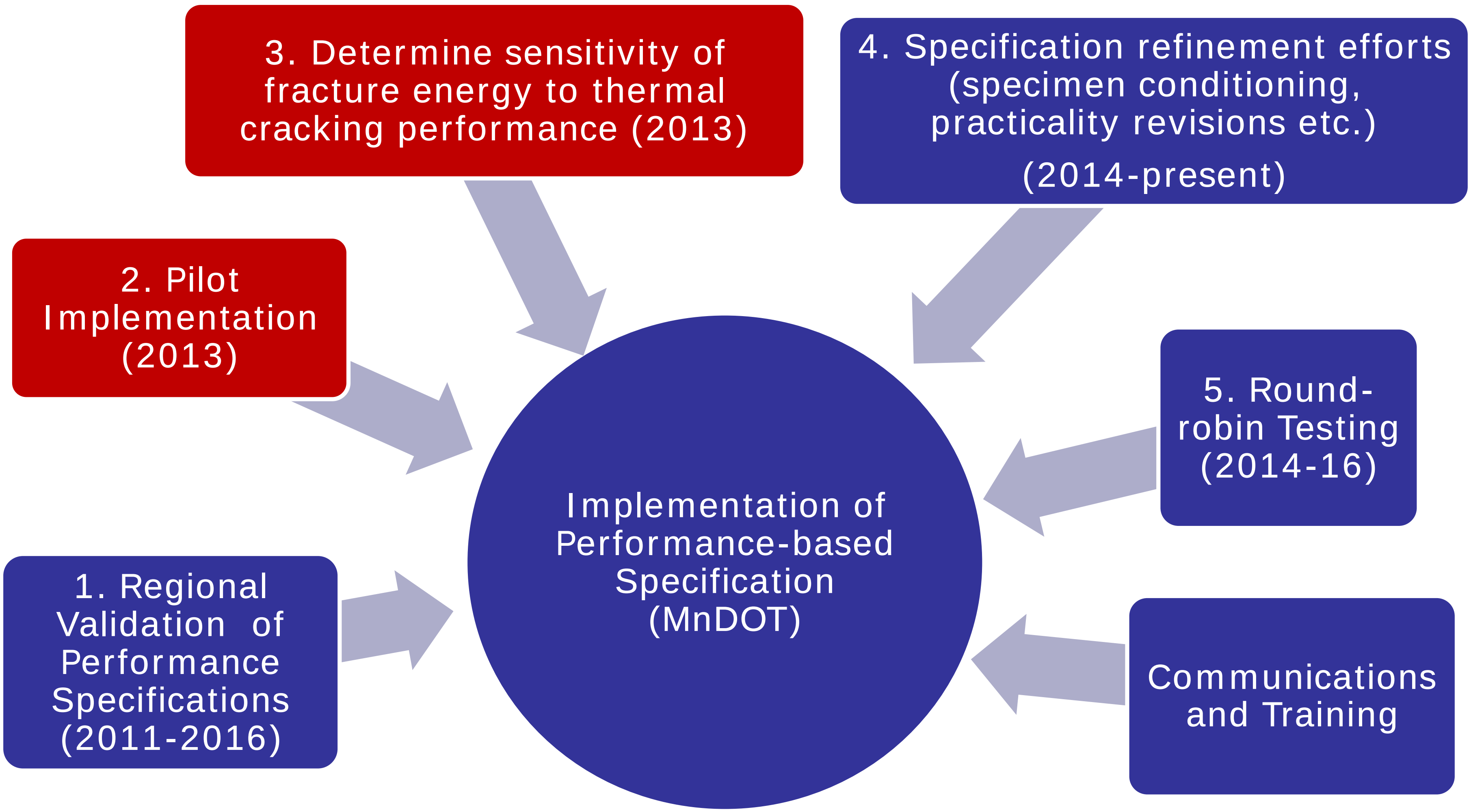
Local Validation Example: Field Cracking Performance vs. Fracture Energy





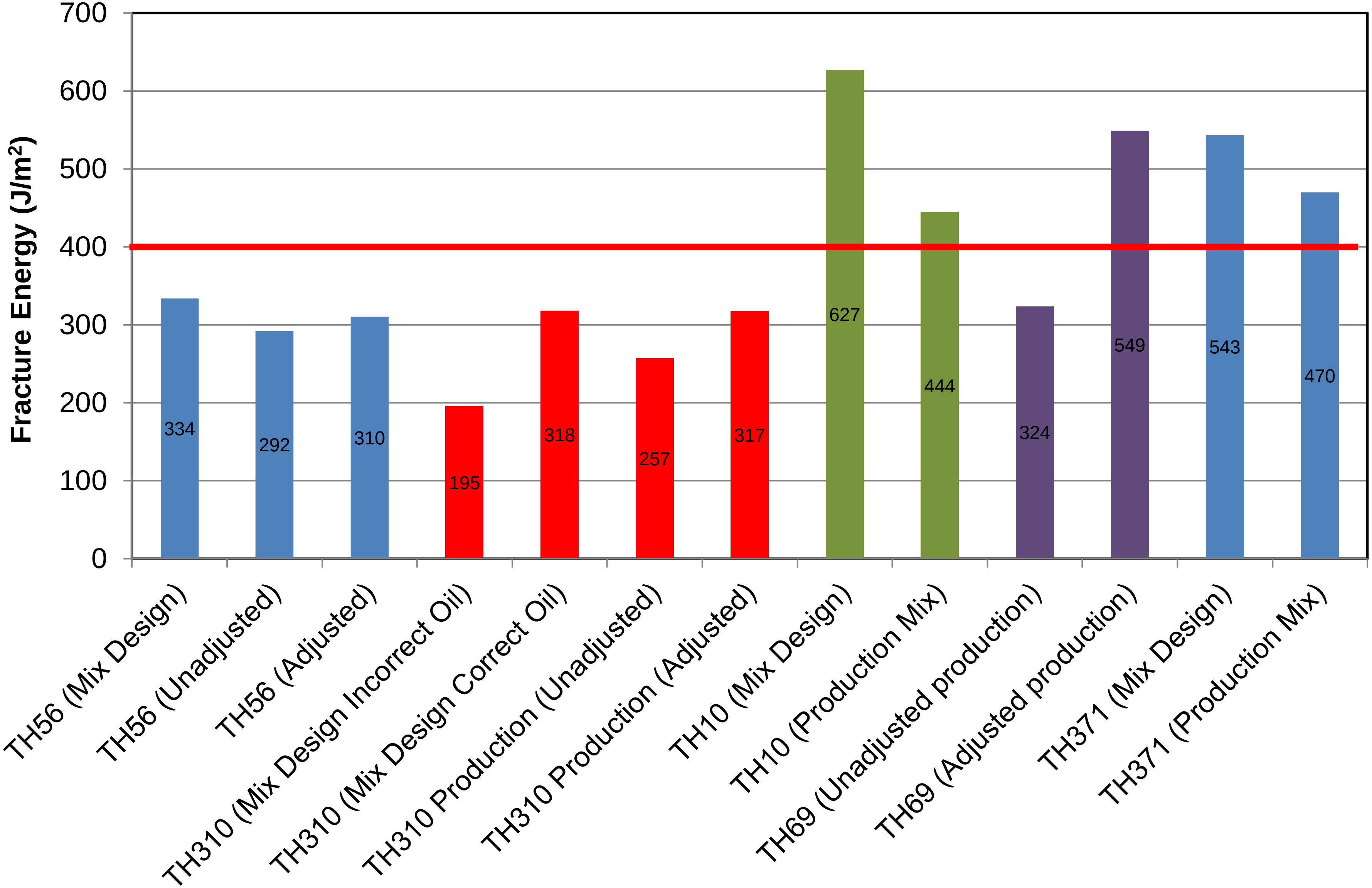


Implementation of Performance Specification



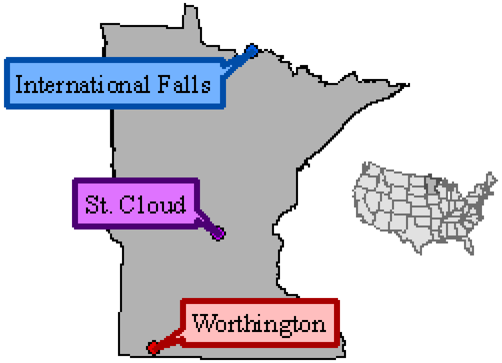
Development and Implementation of MnDOT Performance Based Specifications (cont.)

- Pilot Implementation on 5 projects (2013)
  - Contractor provide samples at mix design
    - *TSR pucks, 7% AV, +/- 0.5%*
  - DCT tests are conducted
    - *If mix passes, approve for paving*
    - *Passing value of G_f > 400 J/m^2*
  - If mix fails, adjust mix & try again
    - *MnDOT paid for difference in cost (D-I funds)*
    - *Adjusted mix was used for paving a section of project*
  - Testing is also conducted on production mixes


Fracture Energy (J/m²)
700
600
500
400
300
200
100
0
334
292
310
195
318
257
317
627
444
324
549
543
470
TH56 (Mix Design)
TH56 (Unadjusted)
TH56 (Adjusted)
TH310 (Mix Design Incorrect Oil)
TH310 (Mix Design Correct Oil)
TH310 Production (Unadjusted)
TH310 Production (Adjusted)
TH10 (Mix Design)
TH10 (Production Mix)
TH69 (Unadjusted production)
TH69 (Adjusted production)
TH371 (Mix Design)
TH371 (Production Mix)

Determine Sensitivity of Thermal Cracking to Fracture Energy

- Objective: Determine the allowable variability in fracture energy for purposes of job specification
  - Req. fracture energy = 400 J/m^2 (if actual is 375 J/m^2 is it too low?)
- Approach:
  - Simulate different combinations of climates, mixes, pavement structures with different fracture energies using *IlliTC*



Asphalt Mix	PG28R	PG28R	PG34R	PG34
Clima				ld
Paven				5
Fra				els
No Damage (ND)	No data	No data	No data	≥425
Damaged (D)	450	425-450	375-450	300-375
Cracked (C)	≤425	≤400	≤350	No data

Variation of fracture energy by 25 J/m^2 might be sufficient in changing the thermal cracking performance of the pavement

Implementation of Performance Specification

3. Determine sensitivity of fracture energy to thermal cracking performance (2013)

4. Specification refinement efforts (specimen conditioning, practicality revisions etc.)

(2014-present)

2. Pilot Implementation (2013)

Implementation of Performance-based Specification (MnDOT)

5. Round-robin Testing (2014-16)

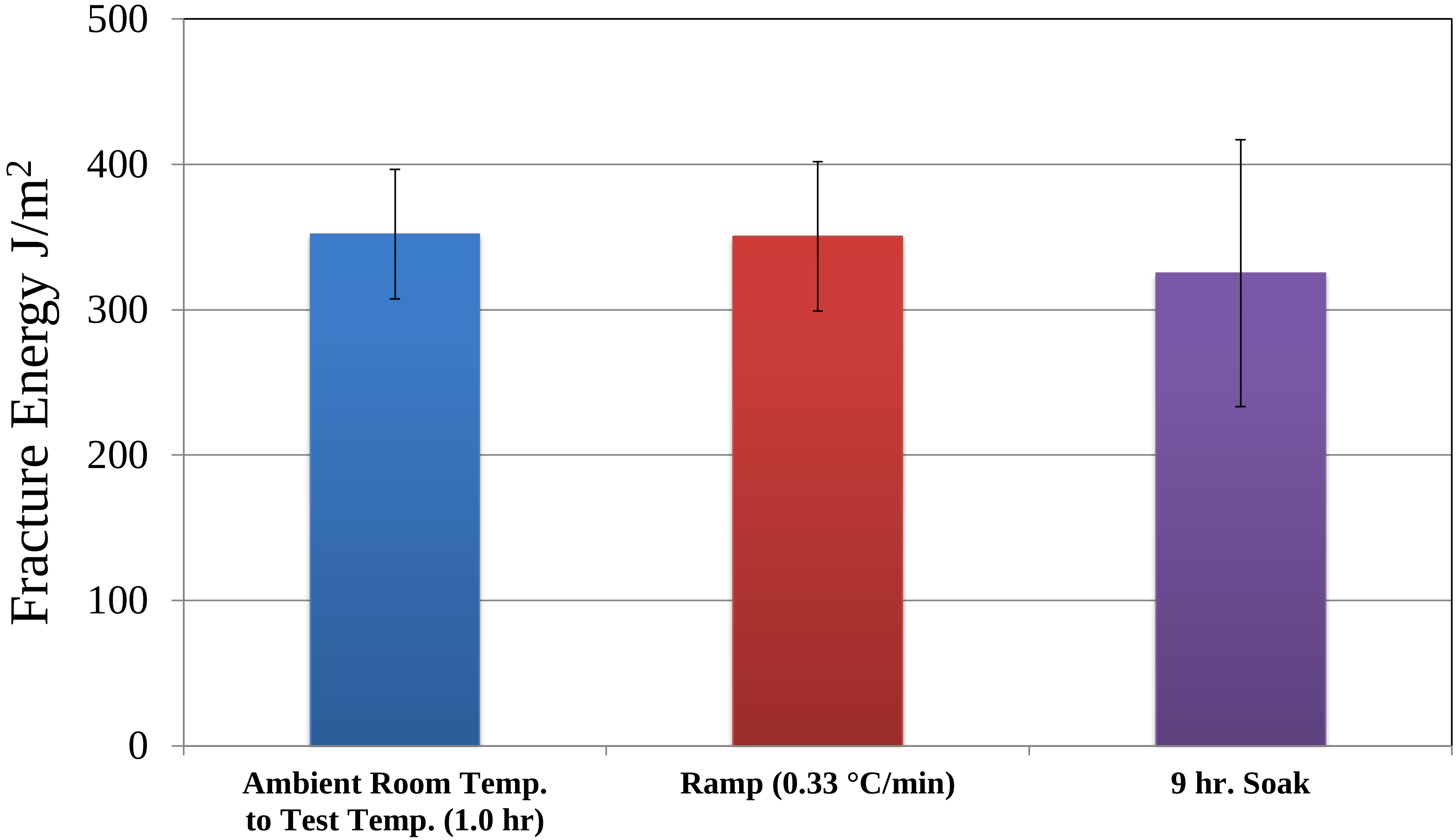
1. Regional Validation of Performance Specifications (2011-2016)

Communications and Training

Specification Refinement

- GOAL: Improve ease, practicality and repeatability of test procedure
- Research was needed to increase ease and practicality of DCT testing
  - *ASTM D7313-13 requires DCT specimens to be conditioned between 8-16 hours at test temperature before testing begins.*
- Extensive evaluation of temperature conditioning procedures was conducted to investigate different temperature conditioning scenarios

Temperature Conditioning Study: Sample Results



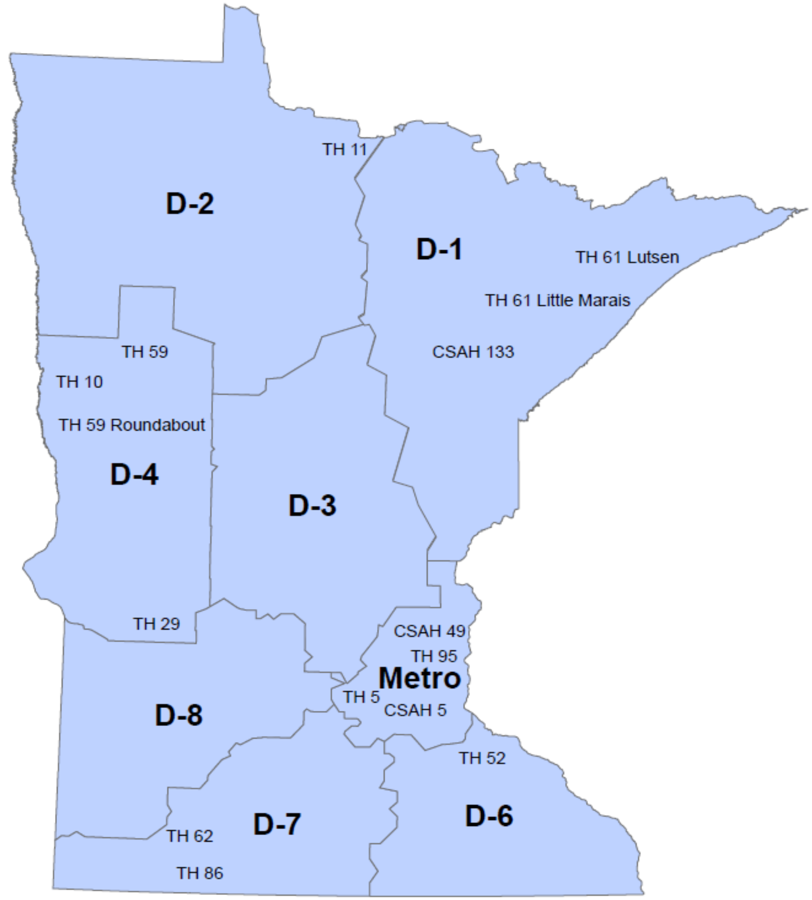
Specification Refinement

- Several changes/additions to ASTM specification
  - "MnDOT Modified" version

- Temperature Conditioning Study Final Results
  - Specimens must reach test temperature in no faster than 0.75 hours, but within 1.5 hours.
  - Specimens must stay in conditioning chamber for a minimum of 2 hours before testing.
  - All testing must be finished within 6 hours of initial placement into conditioning chamber

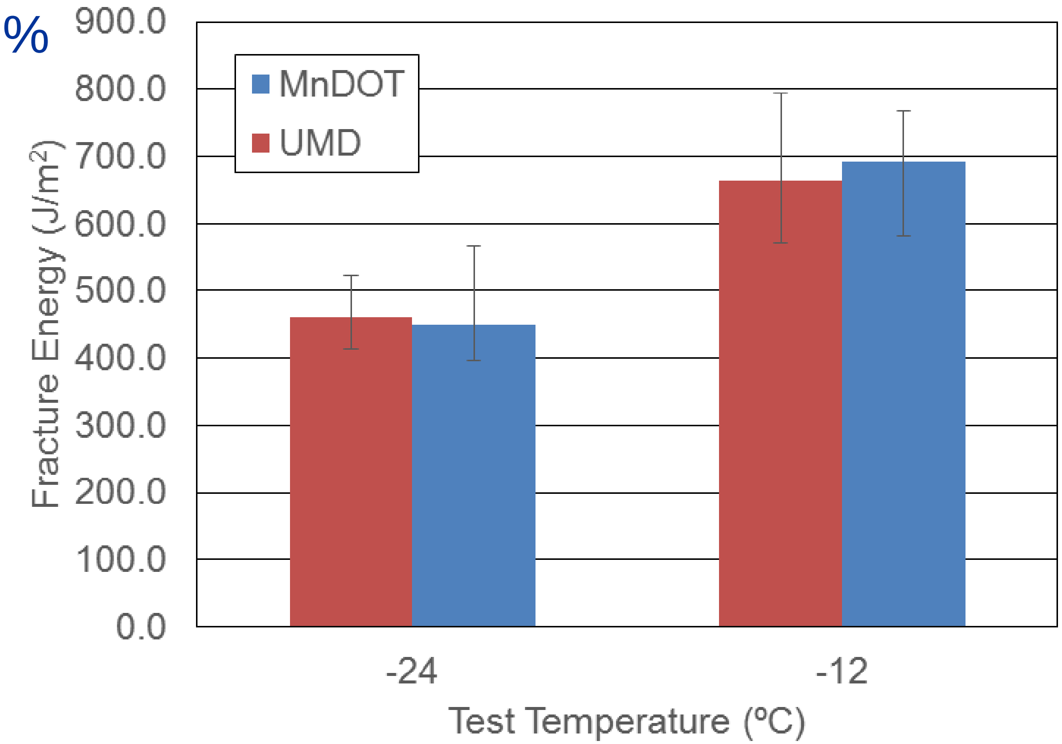
DCT Specifications: Inter-laboratory "Round Robin" Comparison Study

- *Loose mix sampled from 16 projects*
- *Participating labs include:*
  - *American Engineering Testing*
  - *Braun Intertec*
  - *MnDOT OMRR*
  - *UMD/UNH*
  - 4 specimens/project tested by each lab
- *Gyratory specimens compacted by MnDOT*

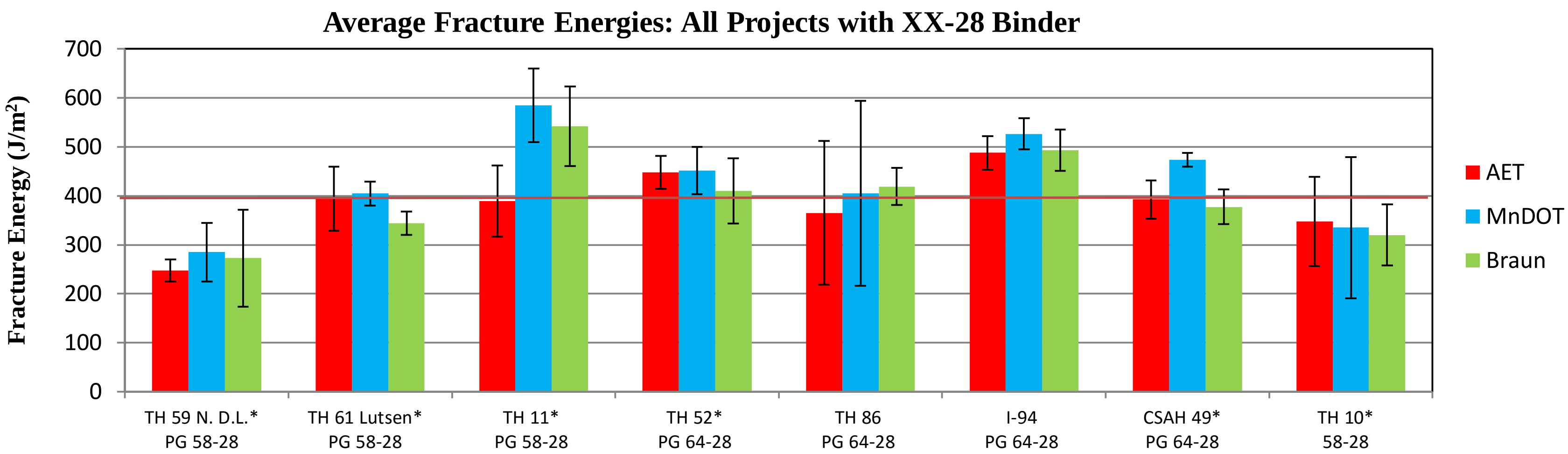


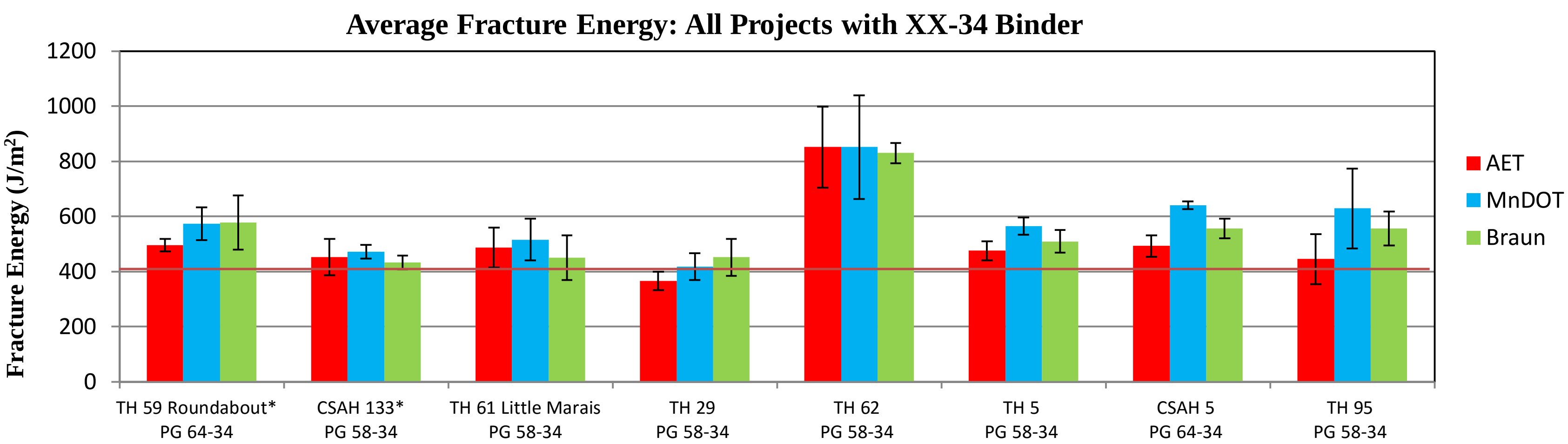
Preliminary Interlab Comparison Study

- Field sampled material (I-94)
  - SPWEA540E, PG 64-28
- Samples tested at MnDOT and UMD
- Interlab differences:
  - Fracture Energy: 2.4–8.1%
  - Peak Load: 0.7–4.6%



Round Robin Testing: 8 Projects, 4 Labs

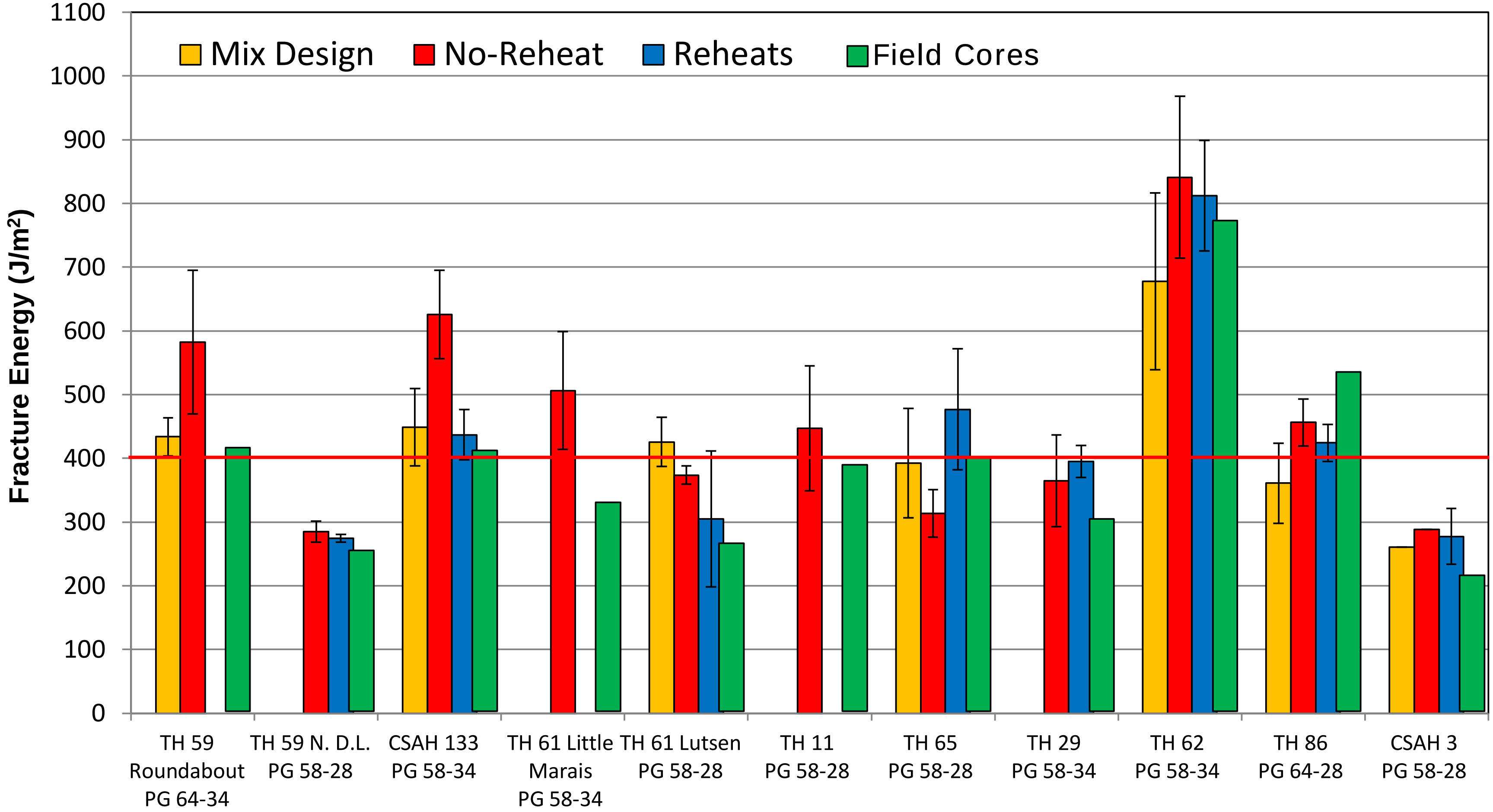




DCT Specifications: Effects of Specimen Preparation and Sampling on Fracture Energy

- *Issue: Change in fracture energy between mix design samples and production samples*
- *Samples collected from 11 locations across MN*
- *Sample Types:*
  - *At mix design (provided by contractor)*
  - Loose mix collected during production
    - *4 cylinders re-heated and compacted by MnDOT*
    - *4 specimens compacted on site by contractor*
  - *Loose mix collection site marked. Field cores taken 1-2 days after initial collection.*

MnDOT DCT Implementation Aging Evaluation Study



MnDOT DCT Fracture Energy Provisional Performance Specifications

Table DCT-1 Minimum Average Fracture Energy Mixture Design Requirements for Wearing Course*	
Traffic Level	Fracture Energy
Traffic Level 2-3 / PG XX-34	450 J/m^2
Traffic Level 4-5 / PGXX-34	500 J/m^2

Table 2360-9 Allowable Differences between Contractor and Department Test Results*	
Item	Allowable Difference
DCT - Fracture Energy (J/m^2)	90
*Test a minimum of six (6) DCT test specimens according to ASTM D7313-13 MnDOT Modified revision dated September 1, 2015 to determine the average fracture energy of the submitted mix design (see MnDOT Modified for requirements of when greater than 6 specimens are to be tested).	

Table DCT-2 Minimum Average Fracture Energy Mixture Production Requirements for Wearing Course*	
Traffic Level / PG Grade	Fracture Energy (J/m^2)
Traffic Level 2-3 / PG XX-34	400
Traffic Level 4-5 / PGXX-34	450

Implementation of Performance Specification

3. Determine sensitivity of fracture energy to thermal cracking performance (2013)

4. Specification refinement efforts (specimen conditioning, practicality revisions etc.) (2014-16)

2. Pilot Implementation (2013)

5. Round-robin Testing (2014-16)

Implementation of Performance-based Specification (MnDOT)

1. Regional Validation of Performance Specifications (2011-2016)

Communications and Training

Summary

- With current evolution of asphalt mixtures (additives, recycling, production technologies) volumetric measures are no longer sufficient for controlling performance
- Fracture energy based performance tests (DCT, SCB) have shown very promising results
- Use of these tests in performance based specifications (as well as or balanced mix designs) are starting to become popular
- Implementation of performance test requires strong partnerships (agency, industry and researchers)
- MnDOT specification development: local validation, specification refinement, round-robin testing, training and communications

Currently Ongoing Efforts

- Minnesota DOT:
  - Continued training and adoption
  - Extending DCT specifications to address reflective cracking in asphalt overlays
- National Level:
  - Pooled Fund Study (NCAT, MnROAD partnership)
  - Several agencies are working on adoption efforts (Wisconsin, Illinois etc.)
  - NCHRP 09-57 succession study
- Lot of work is going on, stay tuned!

Thank you for your attention!

Acknowledgement:

DEPARTMENT OF TRANSPORTATION

Questions / Comments?

Contact: eshan.dave@unh.edu

Challenges with Current (QA) Specifications

- Risk on part of agency since performance is not ensured
  - In general QA specs work well because spec limits are based on historic data
- Low incentive for innovation on part of material producers since the requirements are not tied to performance
- As material sources change the limits prescribed in specs need to be revised
- As manufacture and construction technology changes the specifications need to be revised
  - Warm mix, High RAP, Newer plants and pavers
- Restricts innovation and out of box thinking

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*

Overview

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

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?

Testing Matrix

- Age Conditioning

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

- Test Temperature Study:

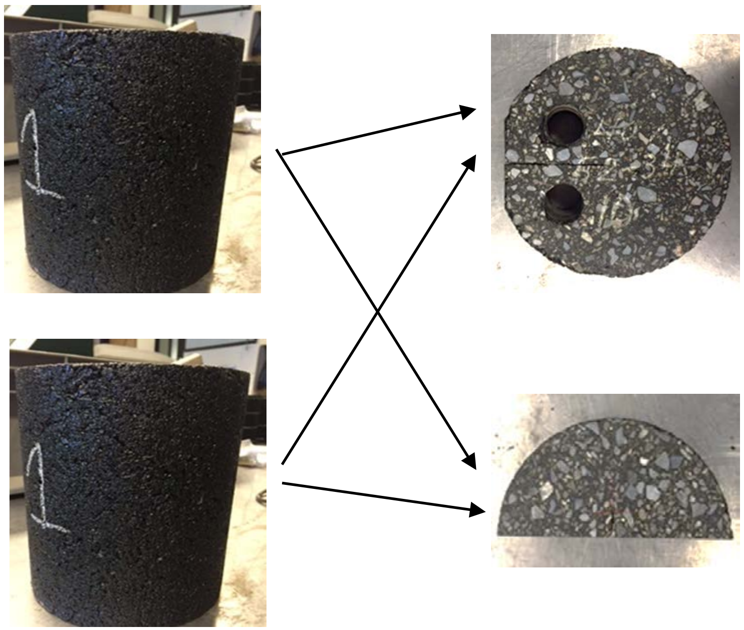
Mix	PG	RAP
Virginia	76-22	0%
	70-22	20%
	64-22	40%
Vermont	52-34	20%
	52-34	40%

- 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
  - <u>Current study: 0, 14 and 21 days</u>
- 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 Distribution

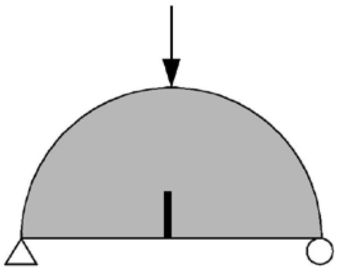
NH 0% RAP			NH 30% RAP			NY 0% RAP			NY 30% RAP		
Short-term aged			Short-term aged			Short-term aged			Short-term aged		
Discs	AV	test	Discs	AV	test	Discs	AV	test	Discs	AV	test
1.A	6.6%	SCB	1.A	6.6%	DCT	1.A	6.2%	SCB	1.A	6.4%	DCT
1.B	6.5%	DCT	1.B	6.6%	SCB	1.B	6.3%	DCT	1.B	7.1%	DCT
1.C	5.7%	Extra	1.C	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



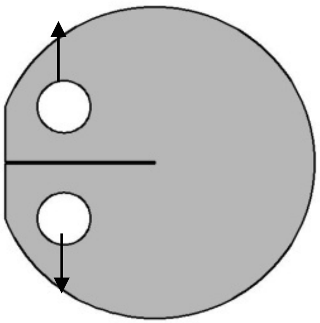
NH 0% RAP			NH 30% RAP			NY 0% RAP			NY 30% RAP		
21 days aged			21 days aged			21 days aged			21 days aged		
Discs	AV	test	Discs	AV	test	Discs	AV	test	Discs	AV	test
1.A	6.5%	DCT	1.A	6.9%	SCB	1.A	6.8%	DCT	1.A	6.8%	DCT
1.B	6.1%	SCB	1.B	7.0%	Extra	1.B	7.4%	SCB	1.B	7.4%	DCT
1.C	6.0%	Extra	1.C	6.6%	DCT	1.C	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

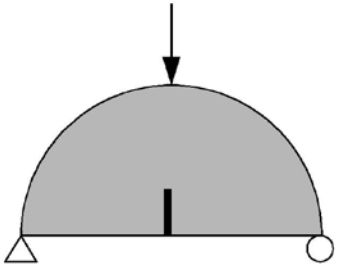


SCB: 25ºC

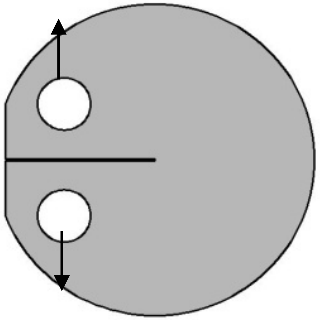


DCT: -12 or -18ºC

- 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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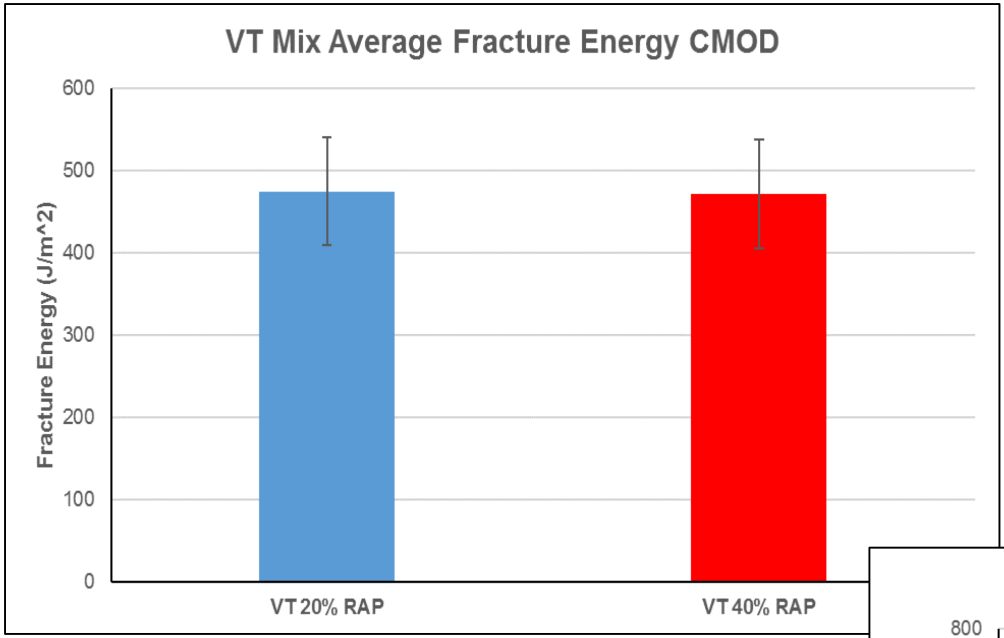
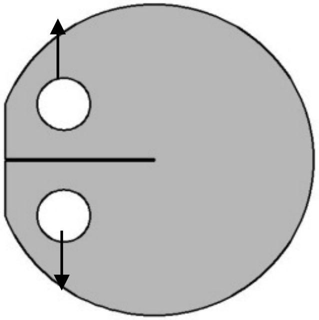
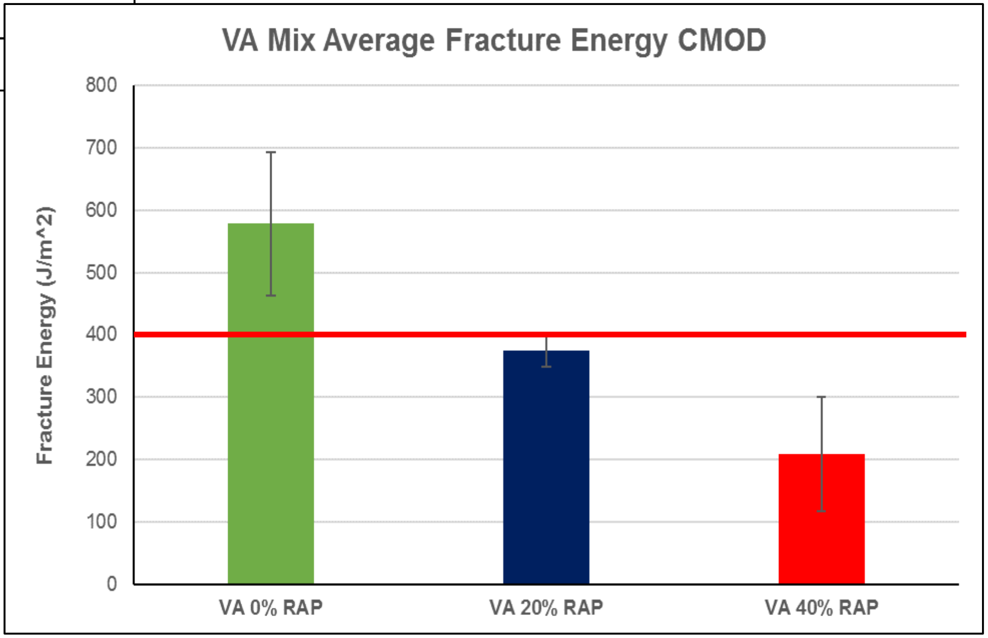
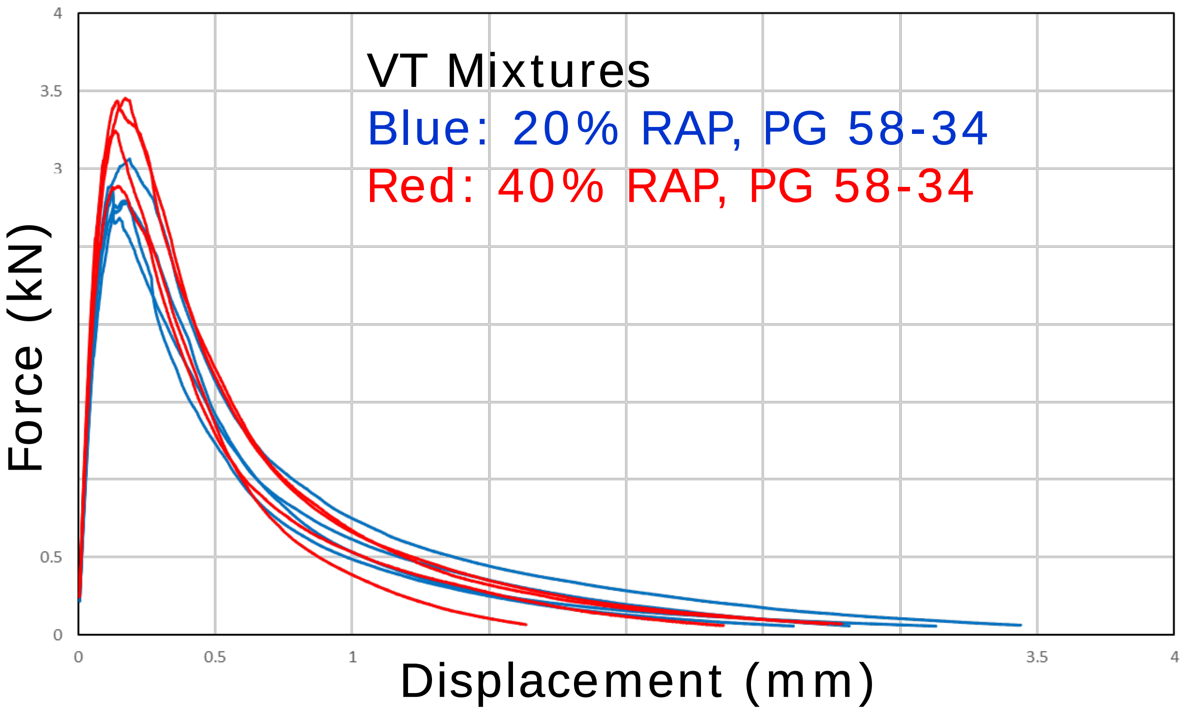
Temperature Study: Low Temperature Performance



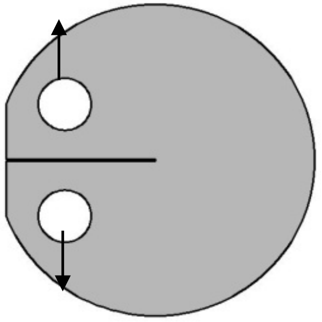


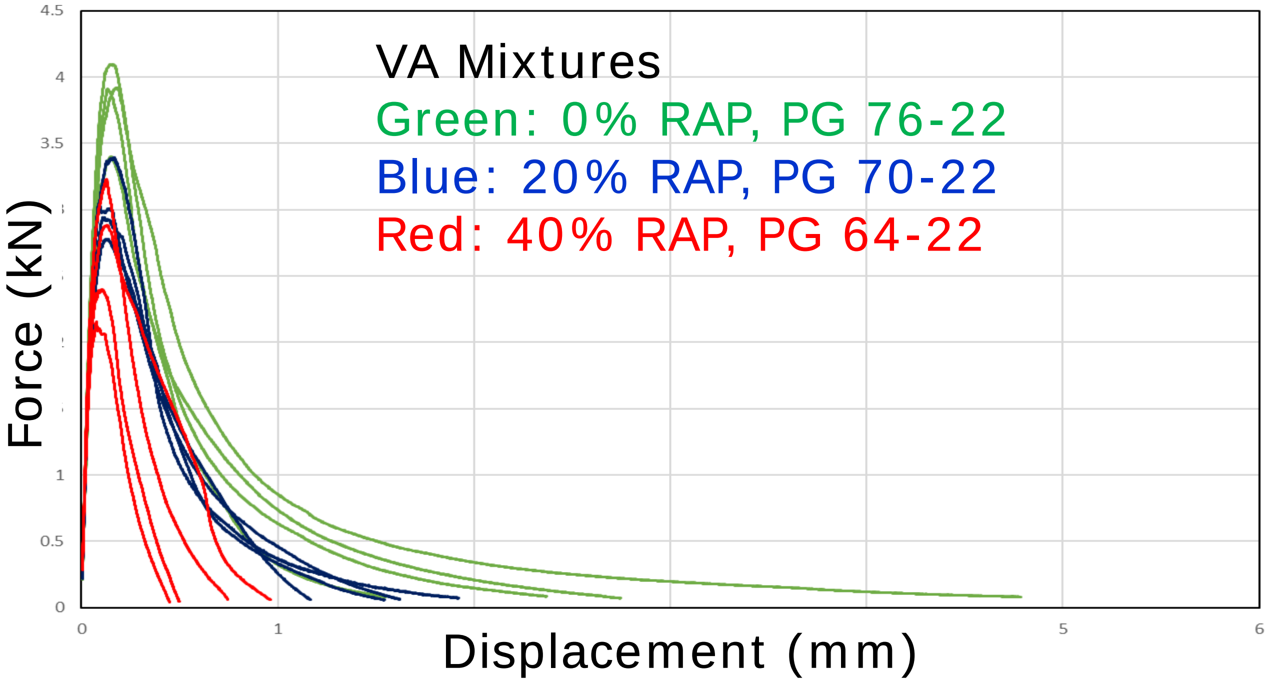


- Minimal difference between VT 20% and 40% RAP mixtures
- Substantial difference between VA mixtures



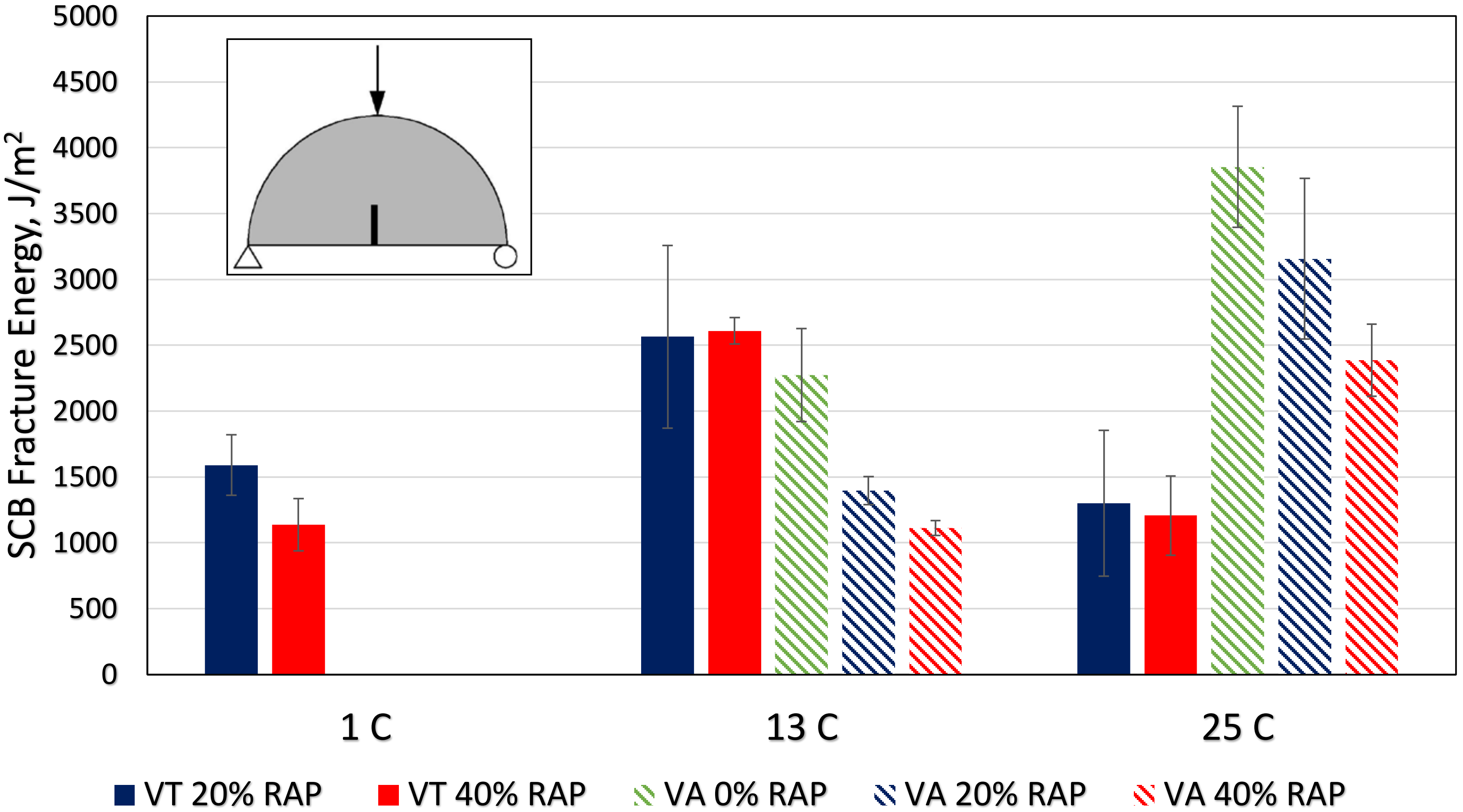
VT Mixtures
Blue: 20% RAP, PG 58-34
Red: 40% RAP, PG 58-34
Force (kN)
Displacement (mm)



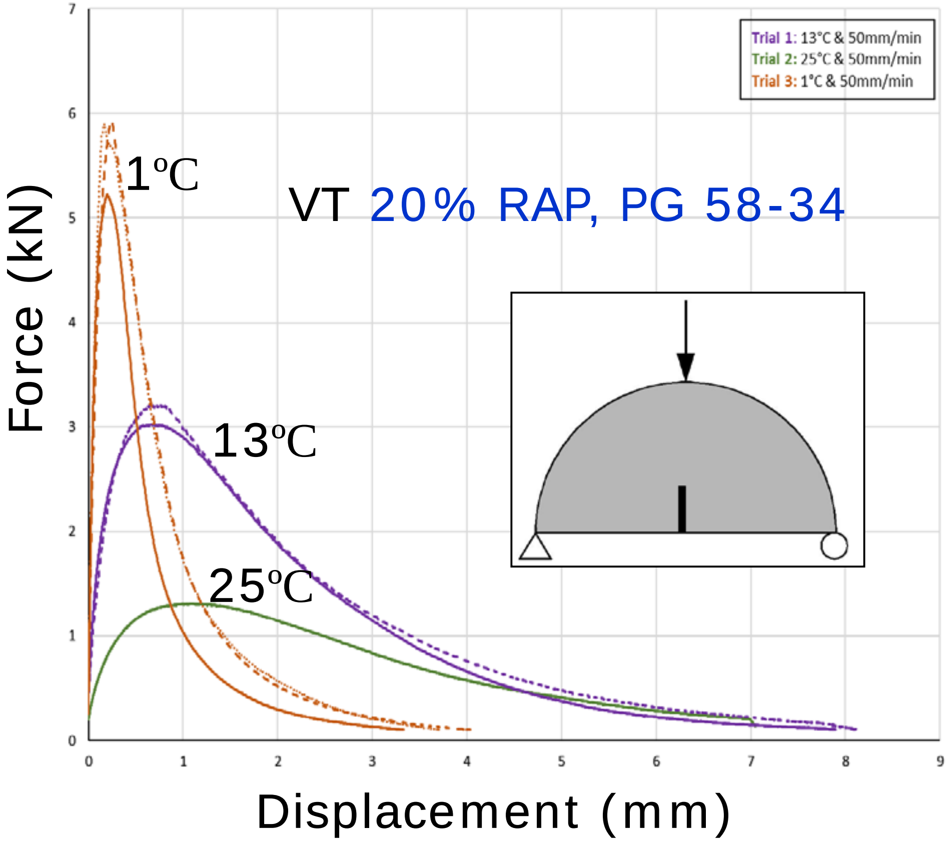


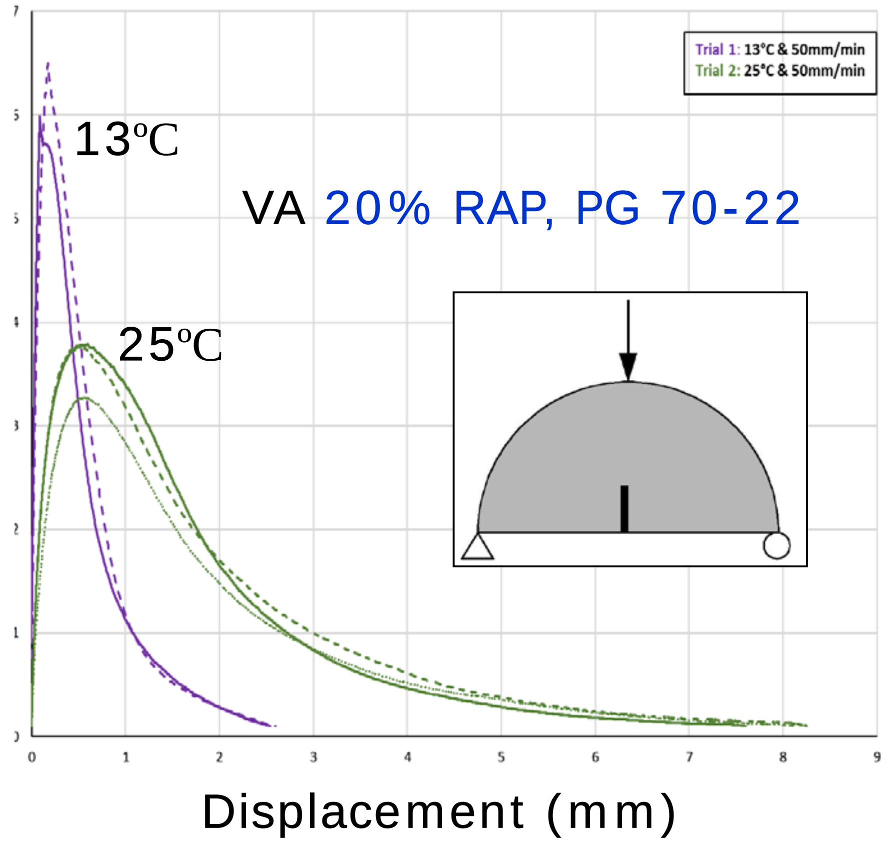
VA Mixtures
Green: 0% RAP, PG 76-22
Blue: 20% RAP, PG 70-22
Red: 40% RAP, PG 64-22
Force (kN)
Displacement (mm)

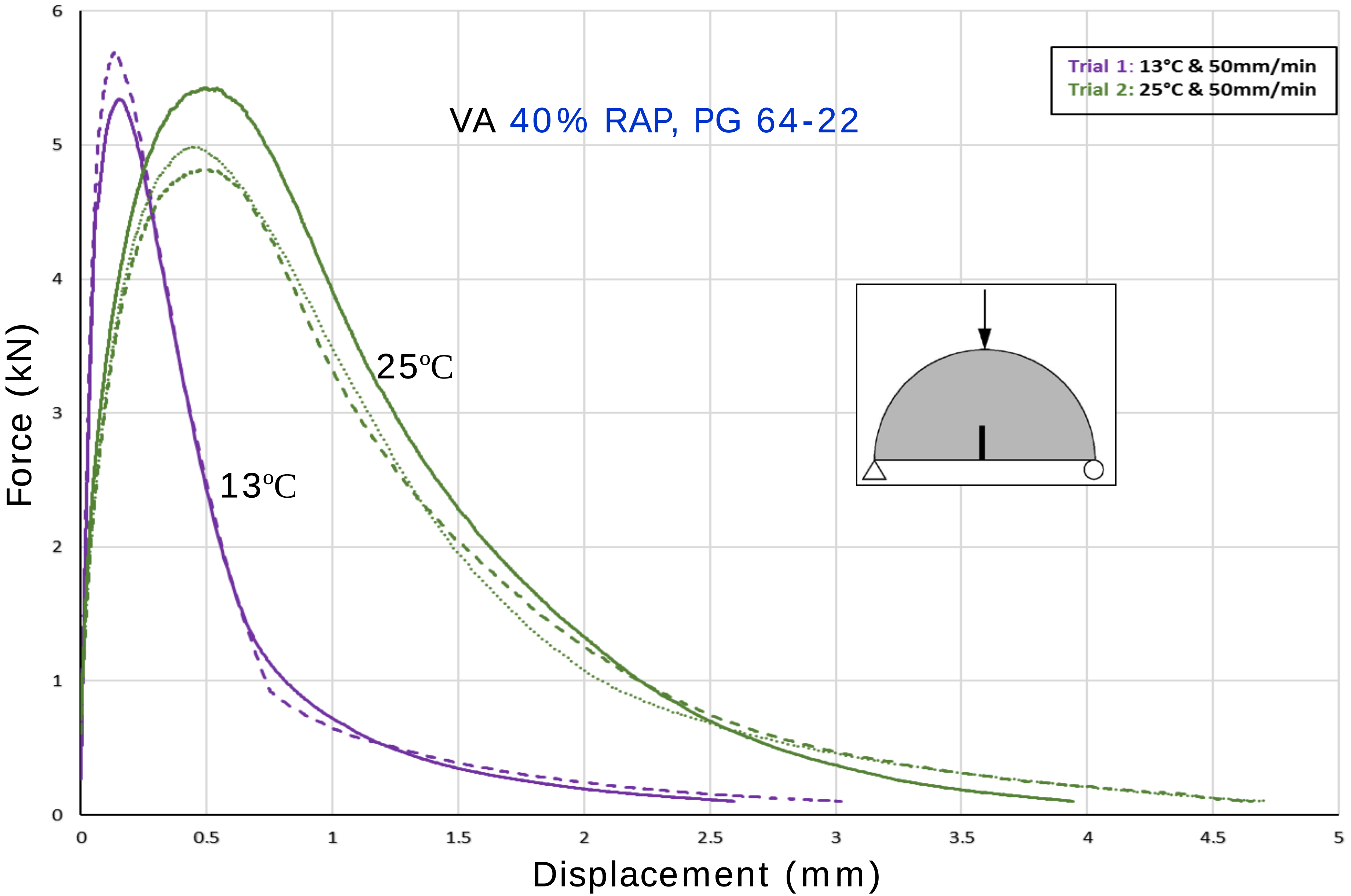
Effect of Temperature on SCB Results



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
25ºC
13ºC
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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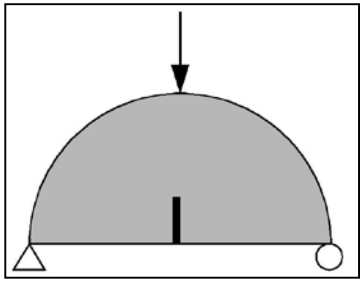
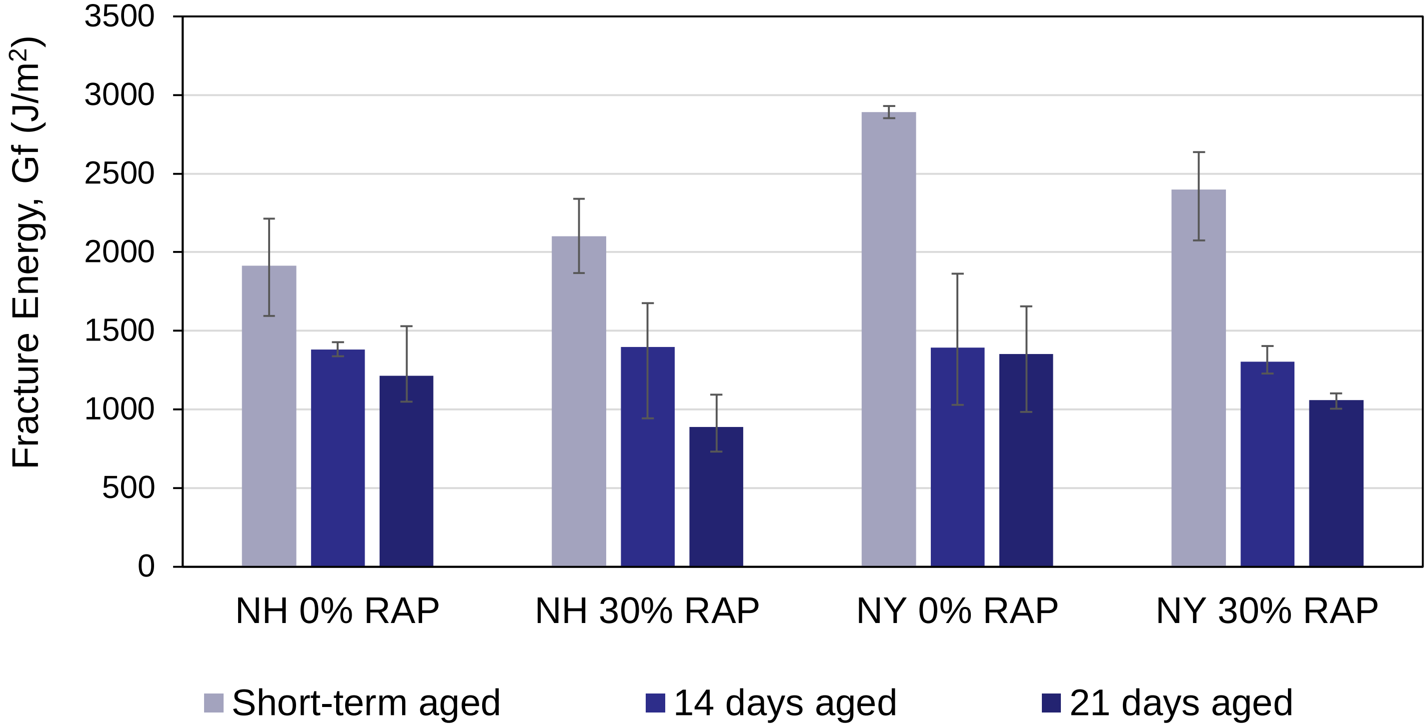
Aging Study Results

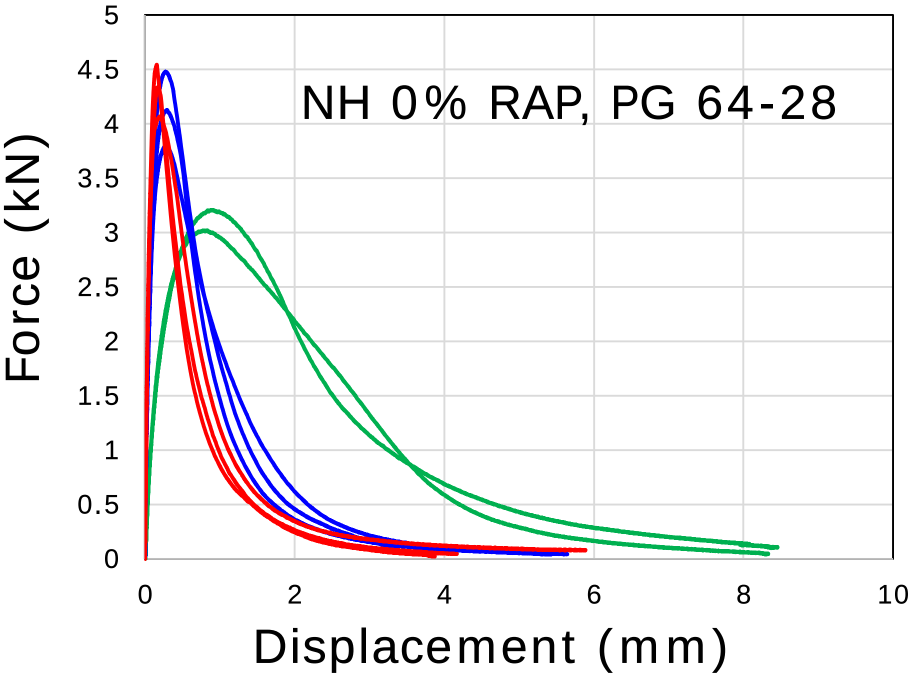
- SCB Fracture Energy at Intermediate Temperature

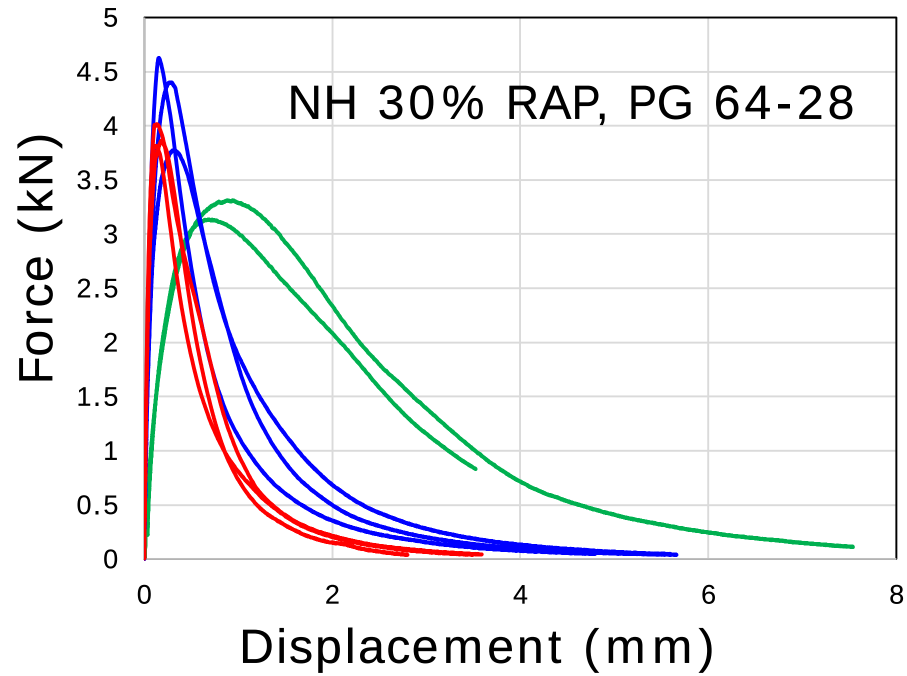




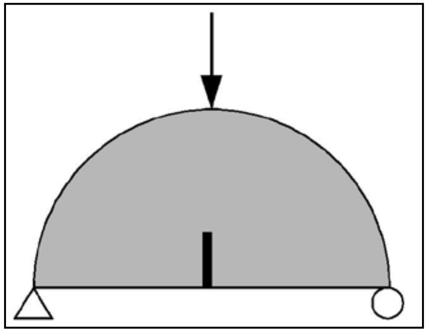
- Drop in fracture energy with increasing aging levels
- Extent of drop is not consistent with RAP amount

Effect of Aging on Fracture Behavior

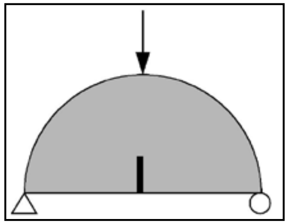




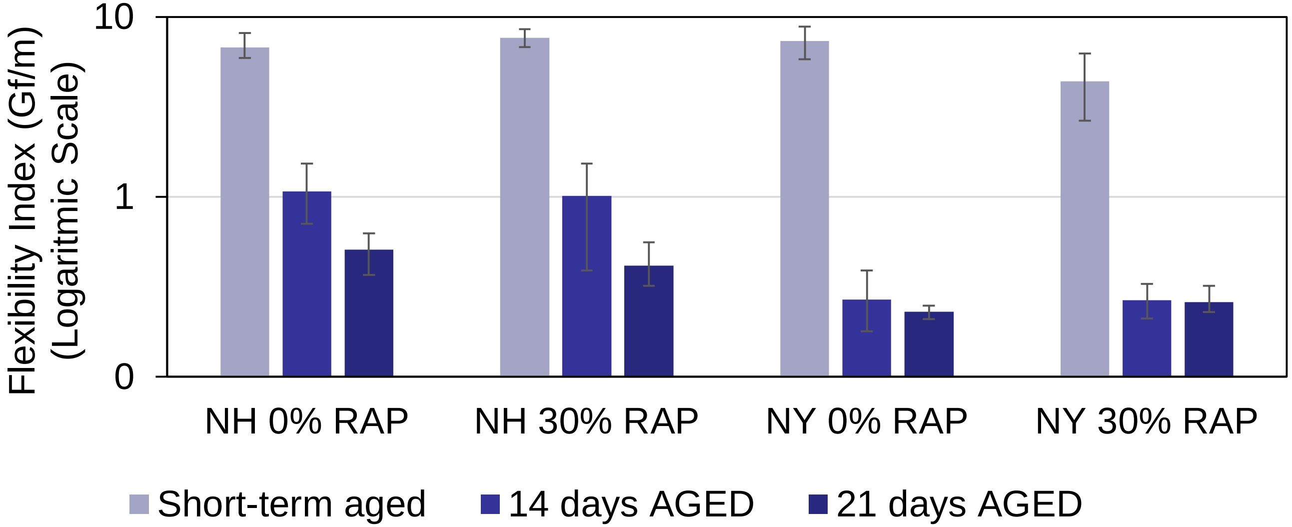
Green: Short-term aged
Blue: 14 days at 95 deg. C
Red: 21 days at 95 deg. C

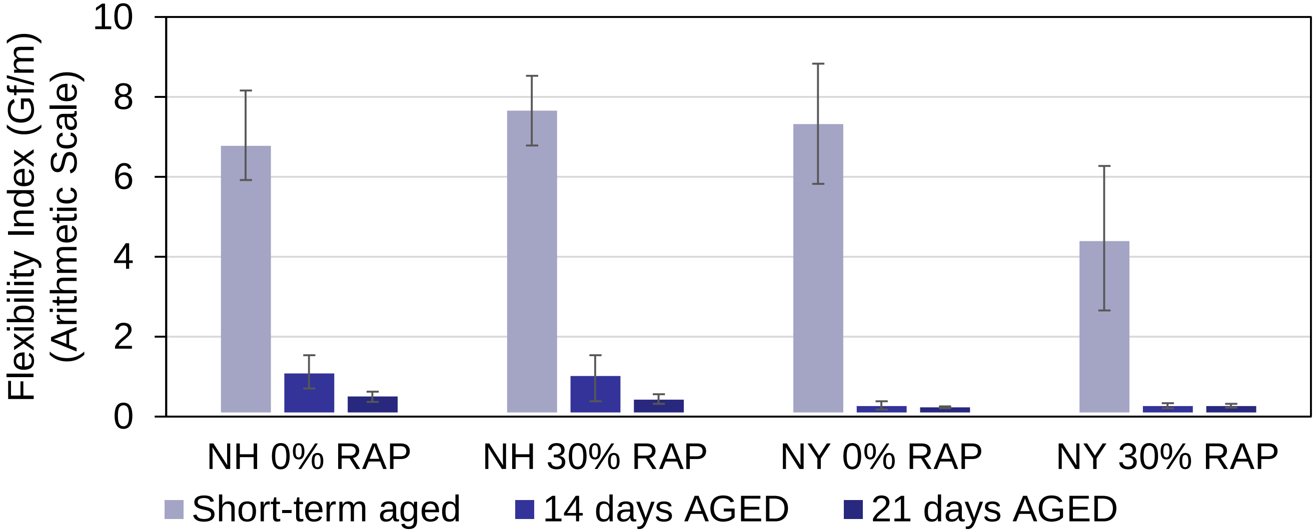


Aging Study Results



- SCB Flexibility Index at Intermediate Temperature





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