How Does Silo Storage Time Impact Asphalt Pavement Performance and Durability?

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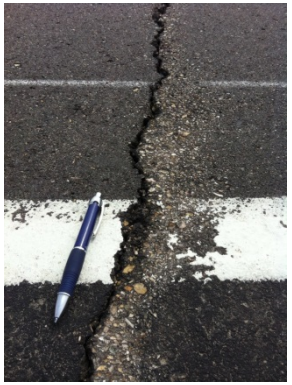
Overview

- Silo Storage Study
  - Objectives
  - Mix Types
  - Research Approach – Laboratory Performance Tests
  - Results for binder and mixture tests
- Fracture Testing
  - Background
  - Effect of Aging on Fracture
  - Fracture Testing of Silo Storage Mixture
  - Results and Discussion
- Summary

Silo Storage Study

- Hot mix stored in silos
- Elevated temperatures to keep mix workable
  - May remain in silo for as long as 24 hours
- Possible Effects
  - Aging
  - Continued blending of recycled and virgin binders
  - Performance impacts



Acknowledgments

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- UNH Hamel Center for Undergrad Research
- Research Partners
  - University of New Hampshire
  - MTE Services
  - Rutgers University
  - North Carolina State University
  - University of Massachusetts Dartmouth

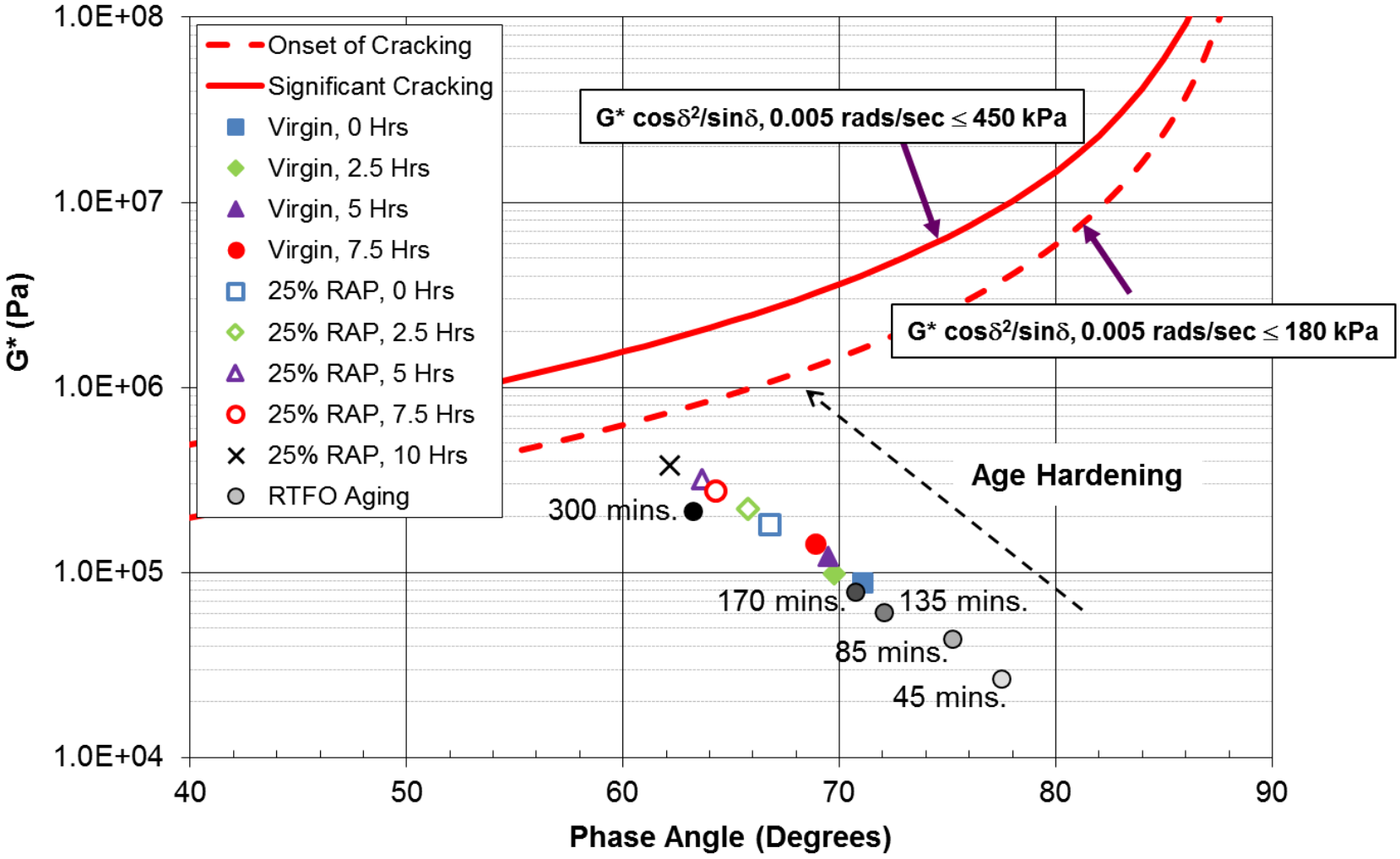
Mixtures for Silo Storage Evaluation

- Virgin mixture
  - PG 64-22, 5.4% AC
  - 12.5 mm NMAS
  - 7.0 ± 0.5% air voids
  - 0, 2.5, 5, 7.5 hour storage times
- 25% RAP mixture
  - PG 64-28
  - 12.5 mm NMAS
  - 6.0 ± 0.5% air voids
  - 0, 2.5, 5, 7.5, 10 hour storage times
- Mixture discharge temperatures: ~175^{o}C (350^{o}F)
- For each mix and storage type samples compacted at plant and (after reheating) compacted in lab

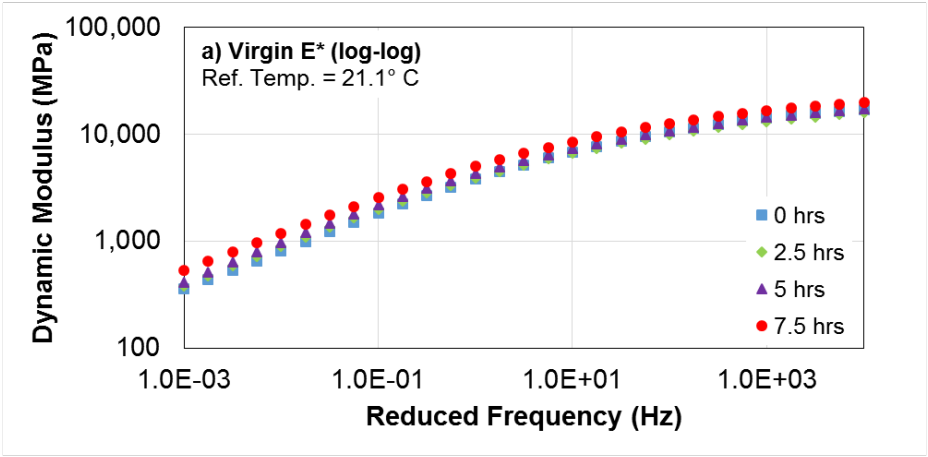
Research Approach

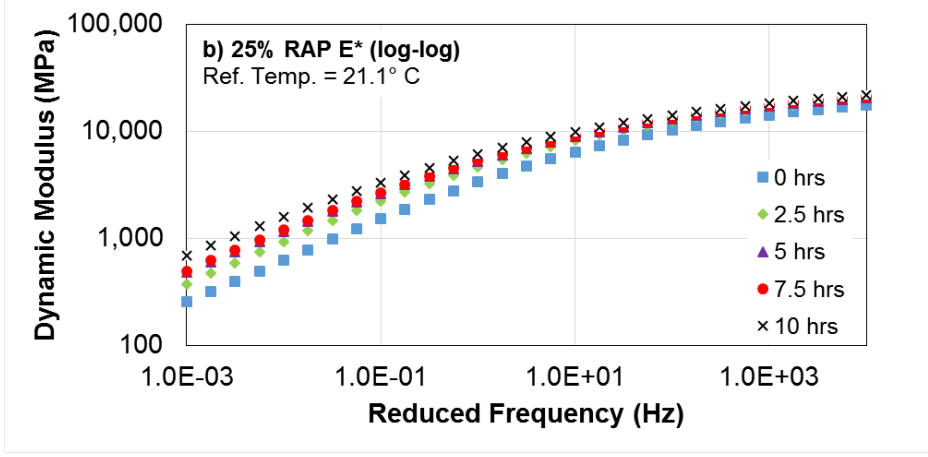
- Testing of Extracted and Recovered Binder
  - DSR and BBR Testing
  - RTFO Aged Binder
- Mixture Testing
  - TSRST
  - *Dynamic Modulus and S-VECD Fatigue Testing*
  - *Disk-shaped Compact Tension Test*
- Analysis
  - Binder: Critical cracking temperature, CAM model rheological indices, black space
  - Mixture: Black space, Layered viscoelastic continuum damage analysis (LVECD), fracture data (energy, peak loads, stiffness and softening slopes)

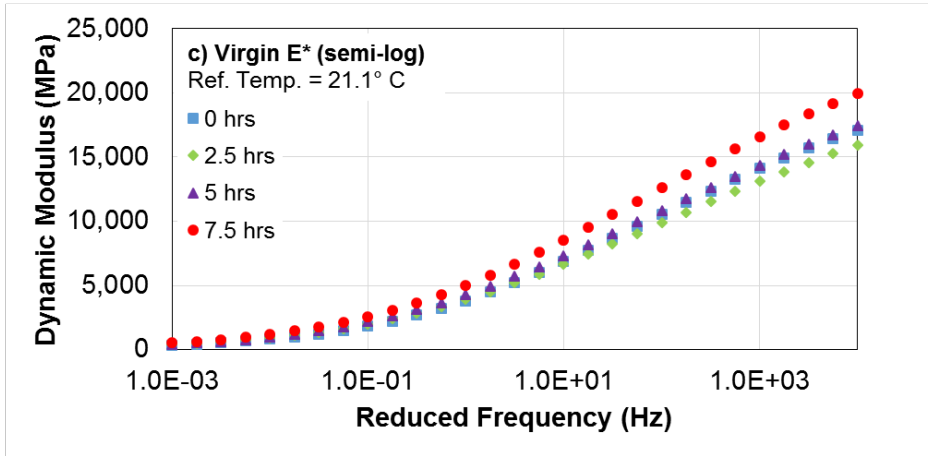
Binder: Black Space

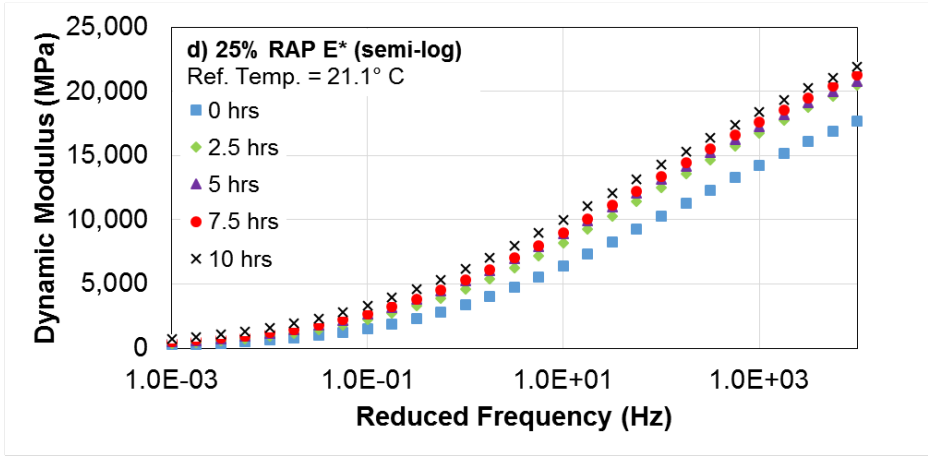


Dynamic Modulus Master Curves

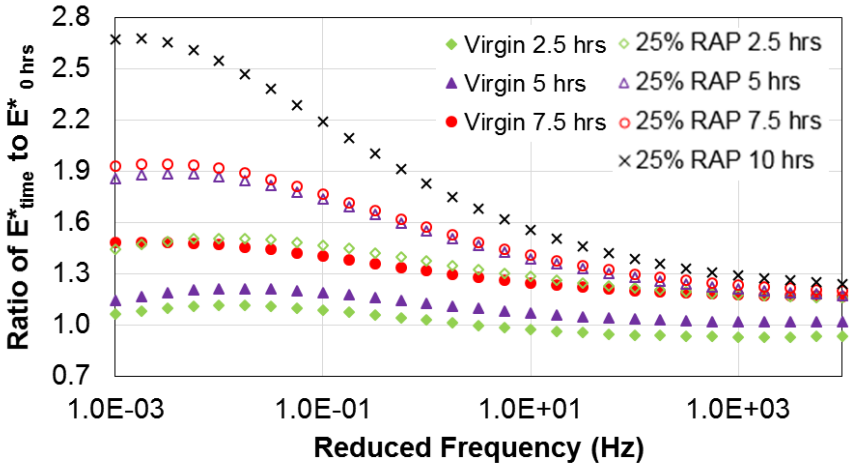


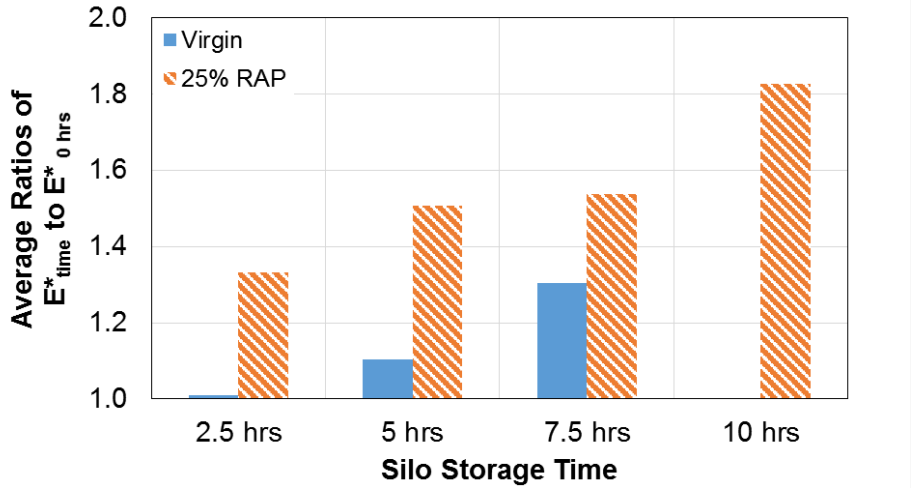




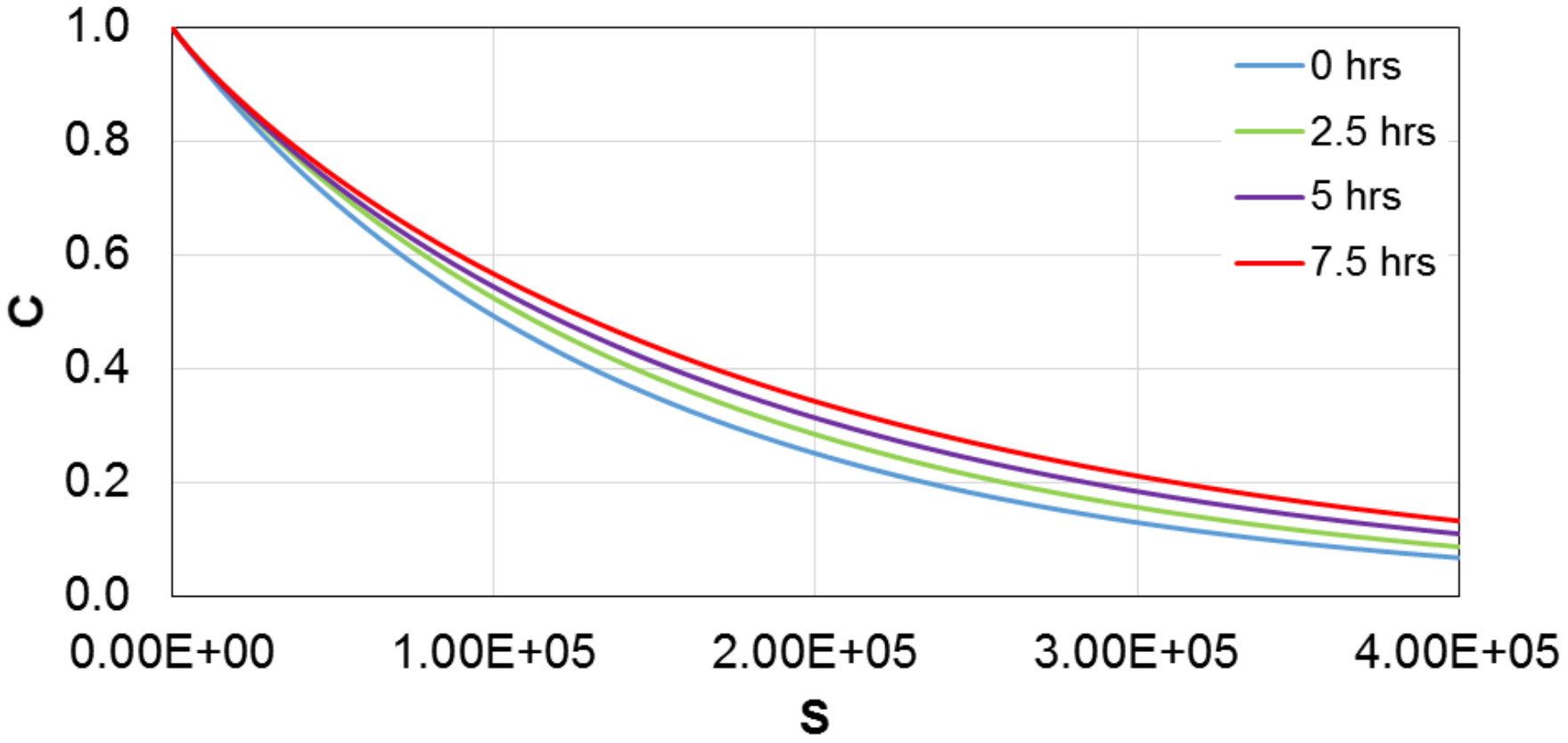


Dynamic Modulus Ratios





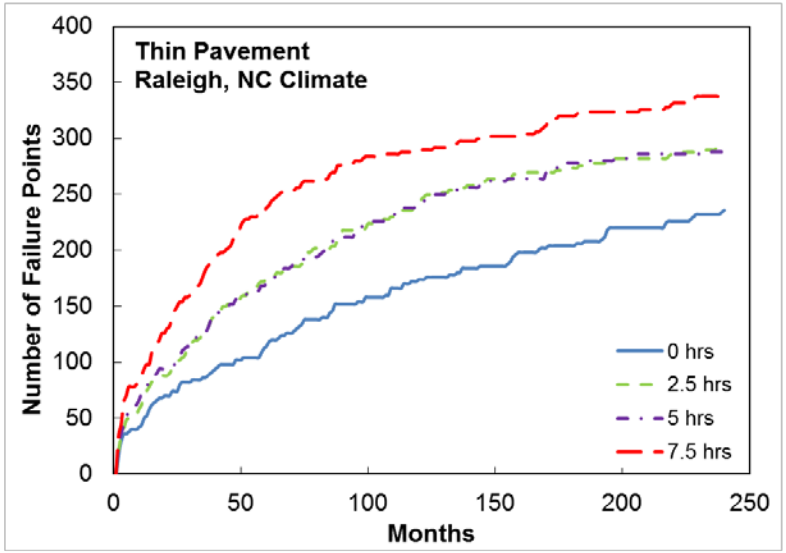
Fatigue: C-S (Damage Characteristic Curves)

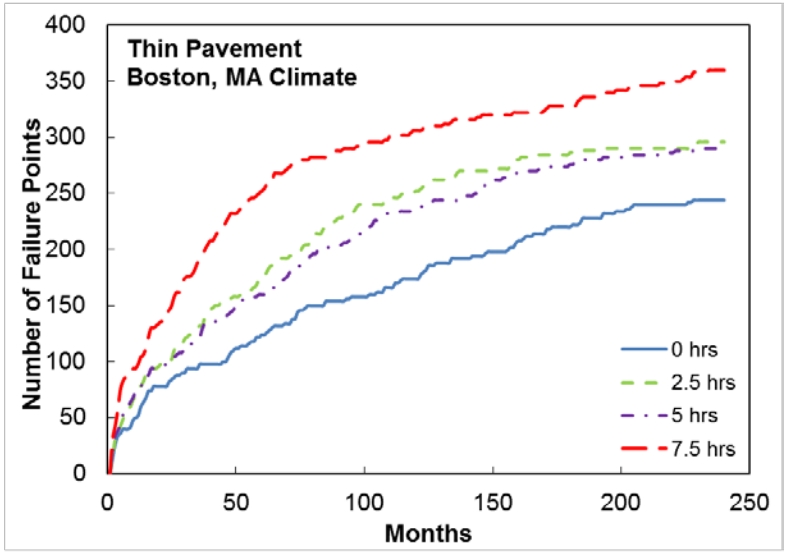


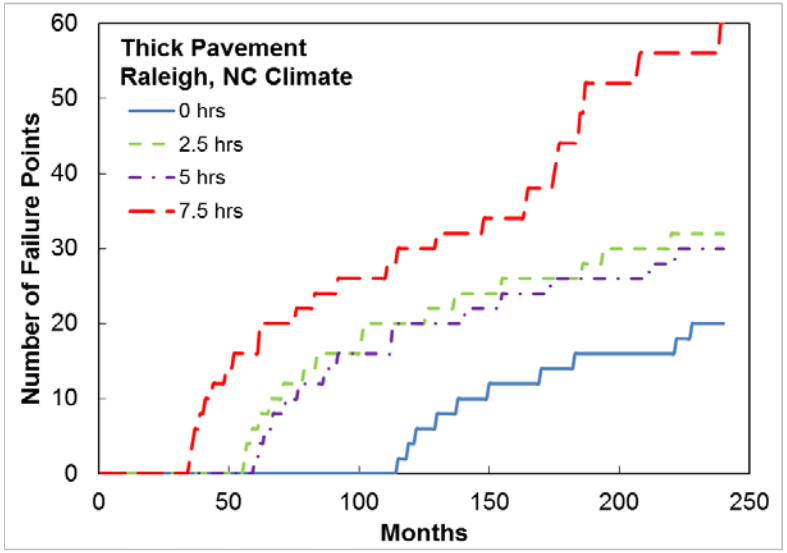
C: Pseudo-stiffness

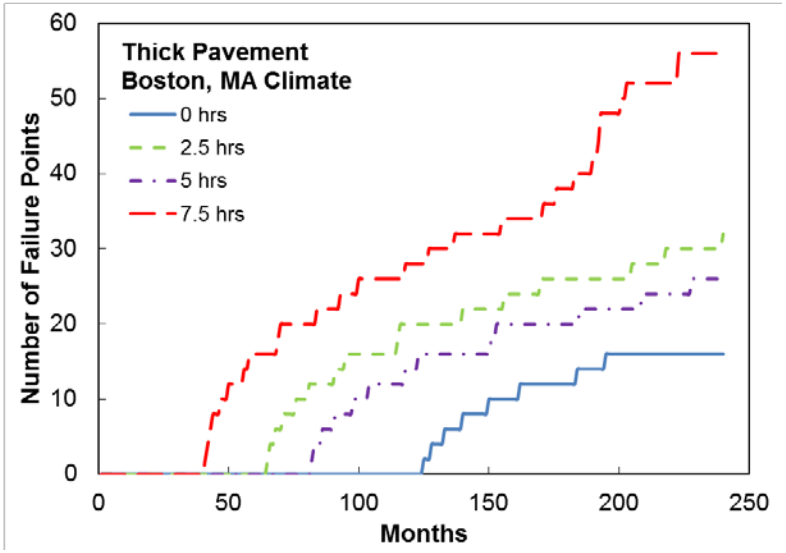
S: Damage parameter

LVECD Pavement Life Evaluation

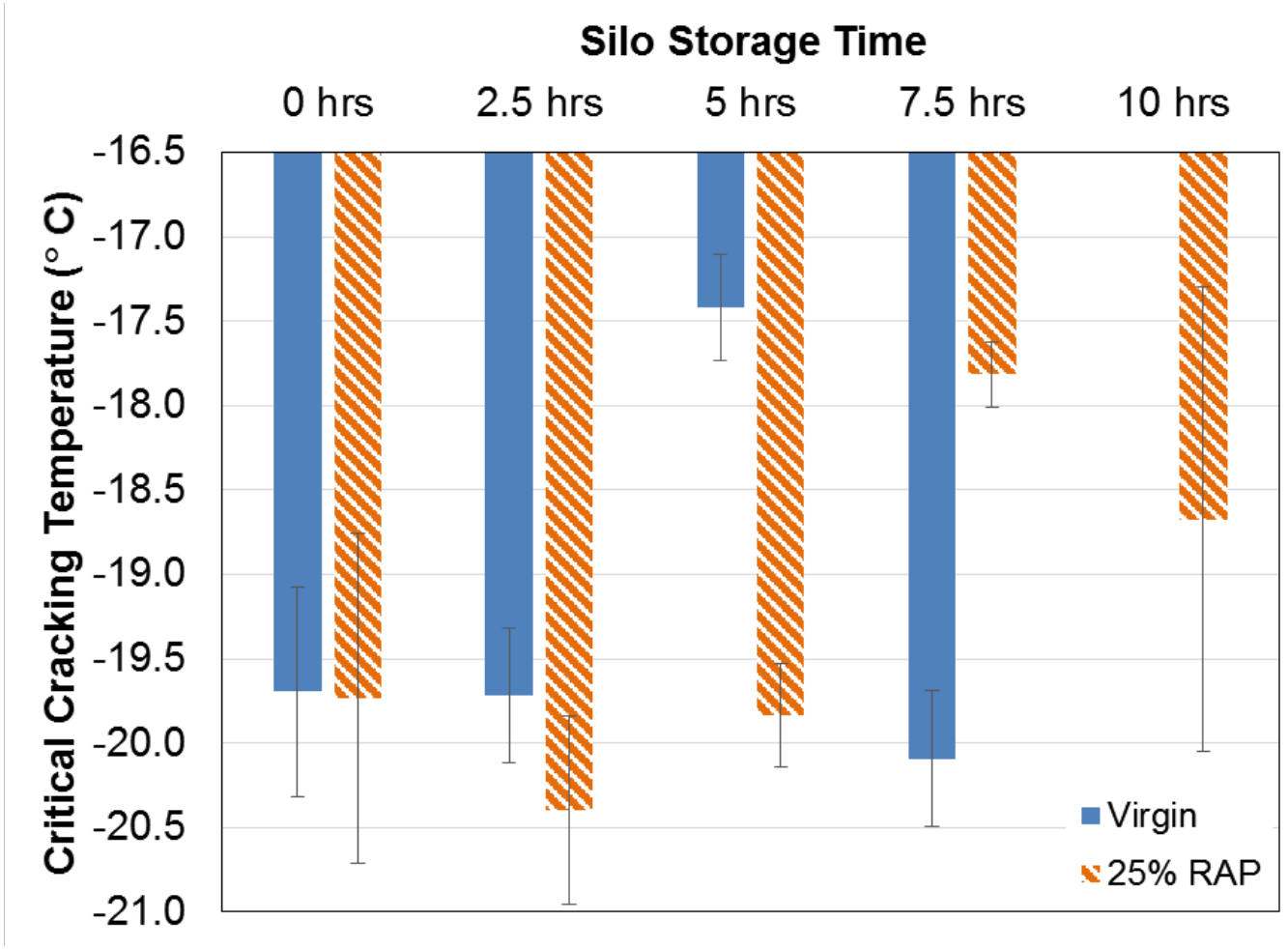






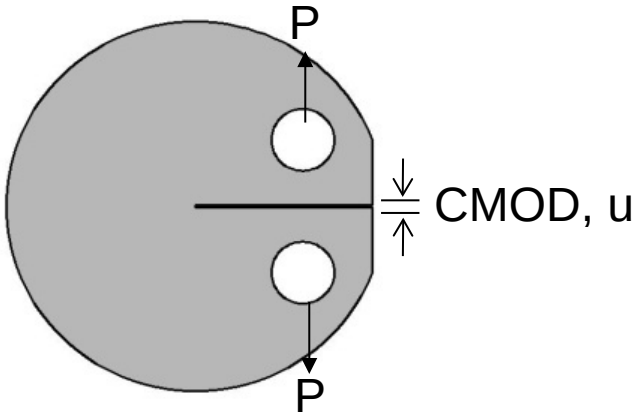


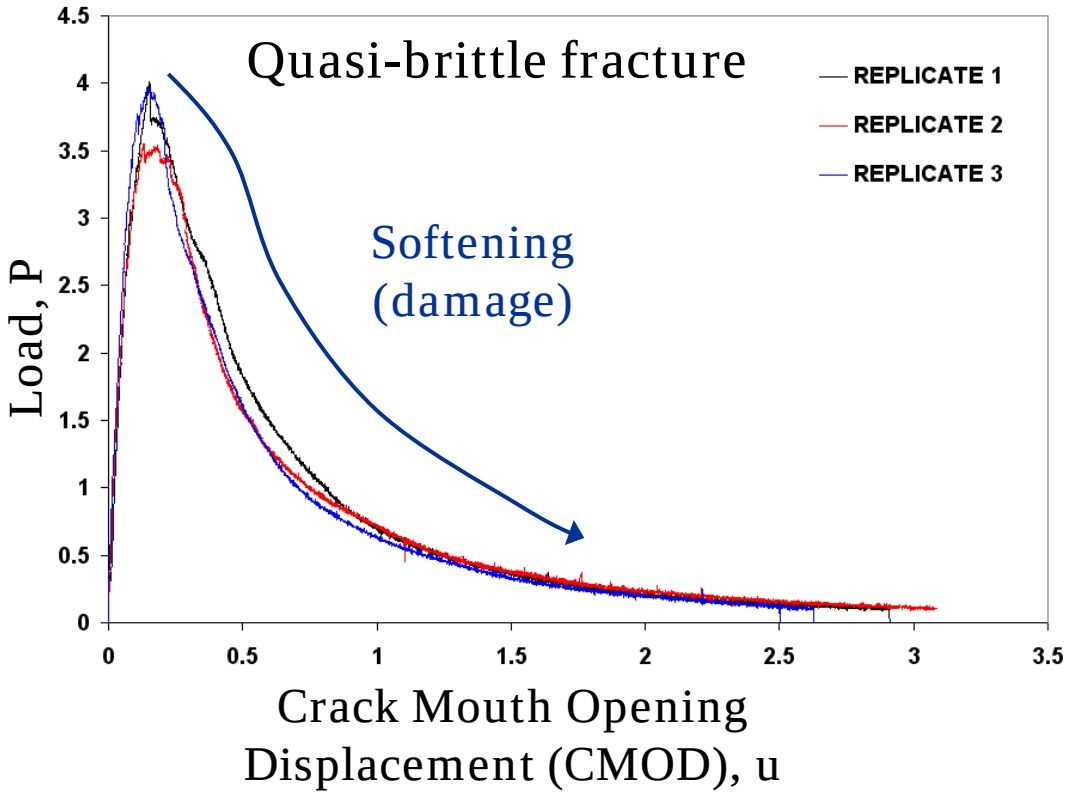
TSRST


Silo Storage Time
0 hrs
2.5 hrs
5 hrs
7.5 hrs
10 hrs
Critical Cracking Temperature (° C)
-16.5
-17.0
-17.5
-18.0
-18.5
-19.0
-19.5
-20.0
-20.5
-21.0
Virgin
25% RAP

Disk-Shaped Compact Tension, DCT Test

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





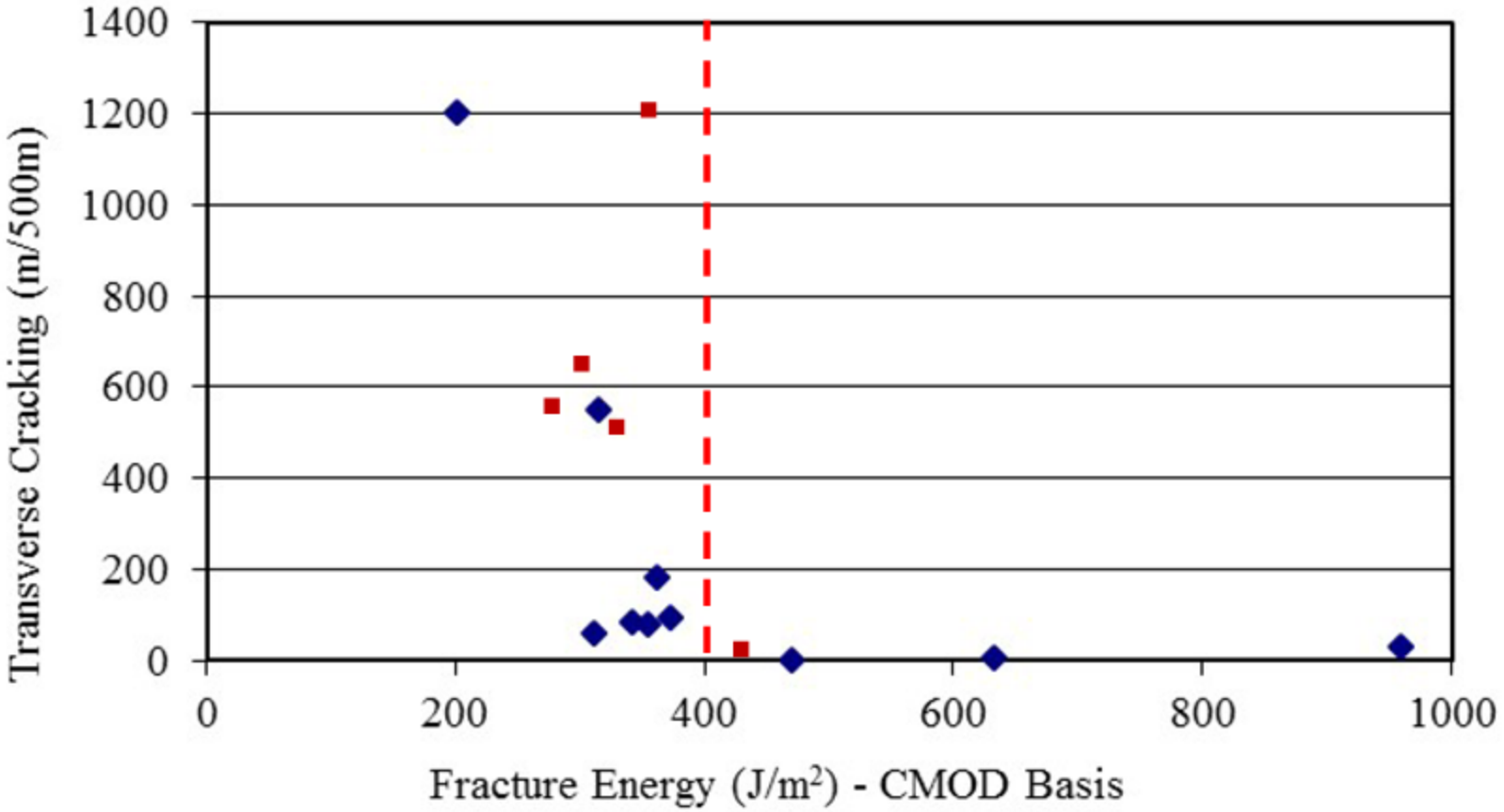
DCT Specimen Preparation

- Specimens made from 6 inch gyratory/core
- Cut into 50 mm Disc
- Specimen marking
- Flat face cut
  - Face needed for Knife Edges
- Loading holes cored
- Notch cut by band saw
- Knife edges glued

DCT Procedure

- Cooled to 10 degrees above 98% reliability PGLT
  - PGLT = -28 → -18° C
- Test conducted to achieve constant crack opening rate

Fracture Energy Basis: TPF-5(080) Low Temperature Pooled Fund Study



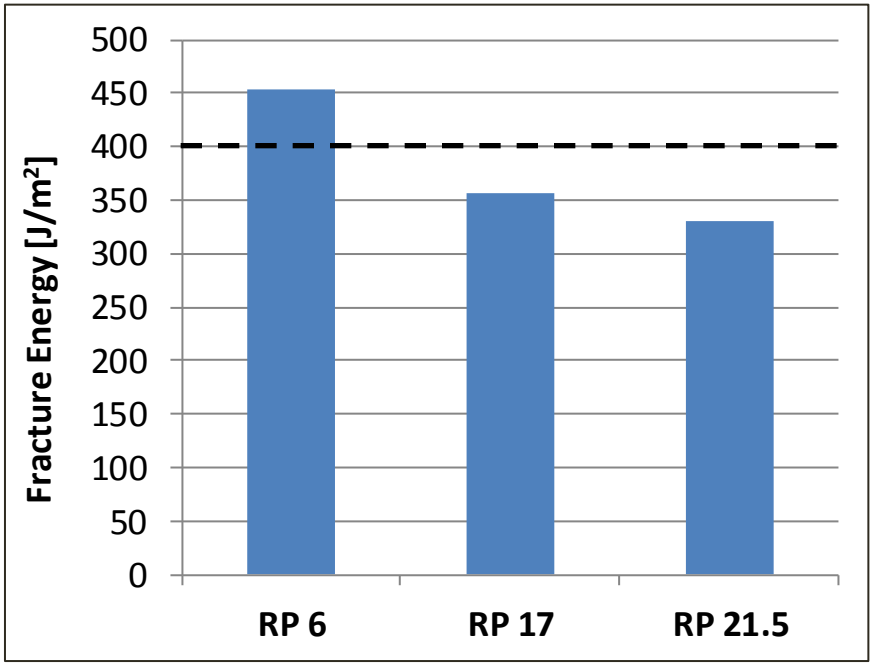
MnDOT Continued Validation: TH371 Sections

Field Cores (TH371)

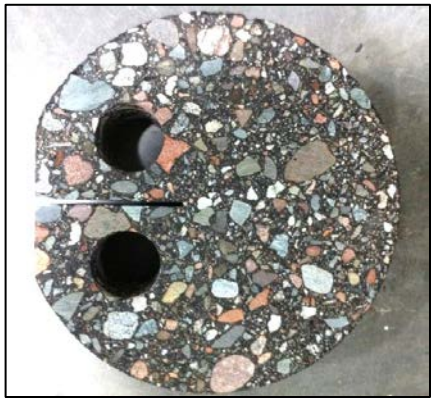
RP6: Good performing section (2005 construction)

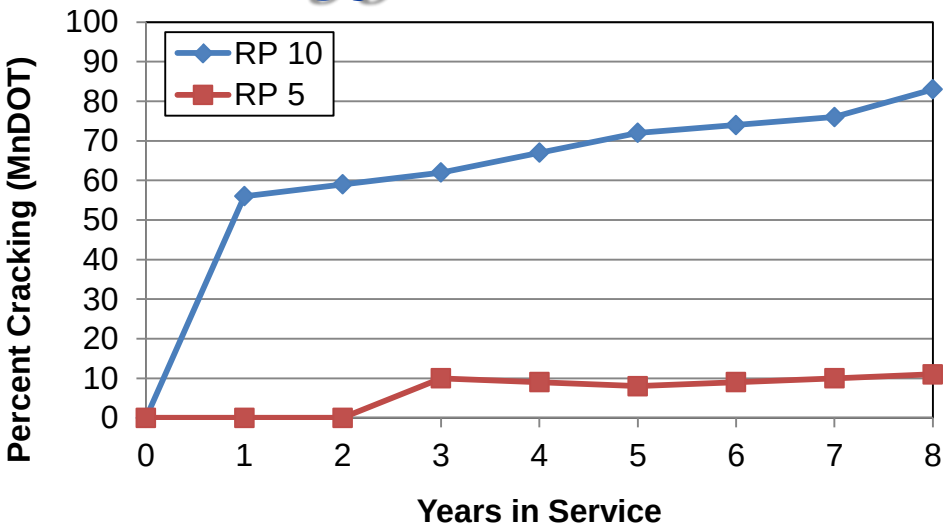
RP17/21.5: Poor performing section (2004 construction)

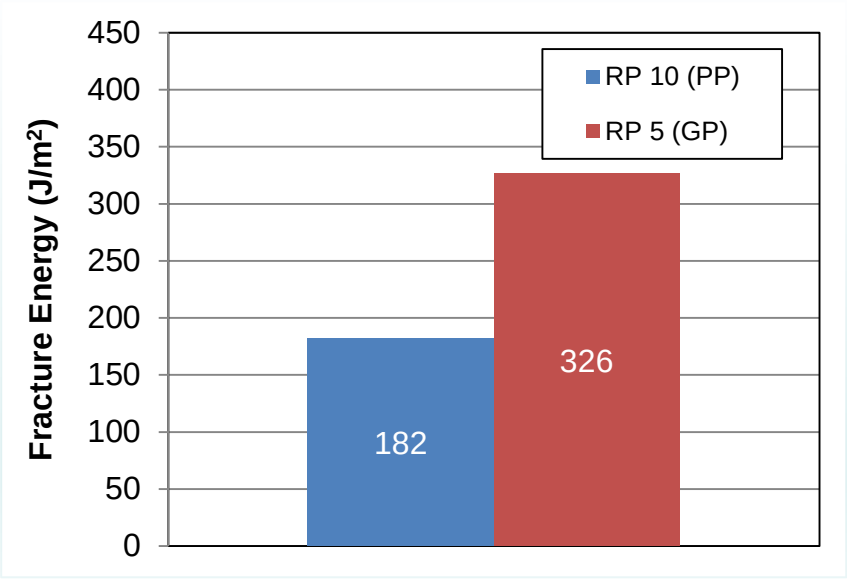
RP	North Bound Crack Count	South Bound Crack Count	Fracture Energy [J/m^2]
6	3	4	453.44
17	12	8	356.18
21.5	10	57	330.59



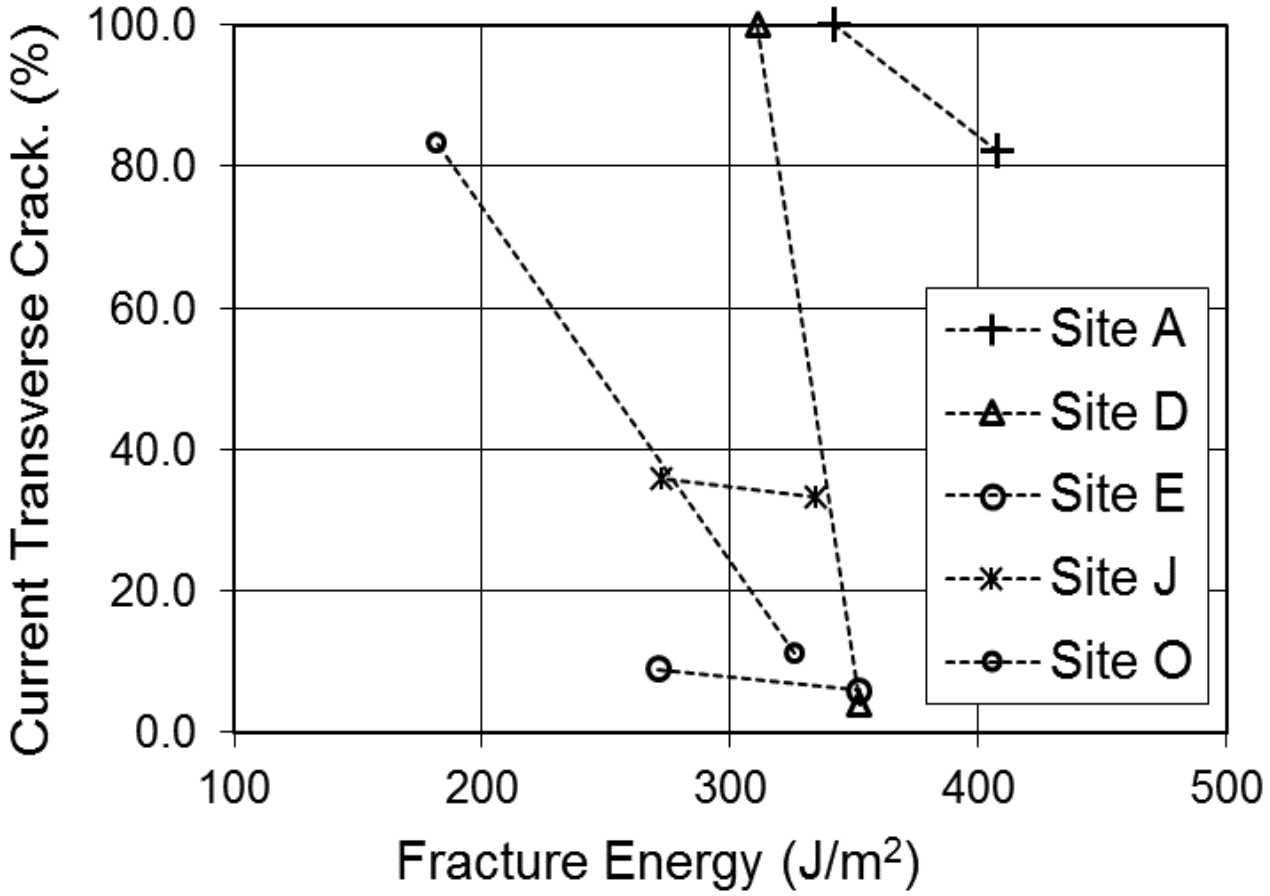
TH113 Cracking Performance vs. Fracture Energy







Field Core Results from MnDOT Lab Performance Study

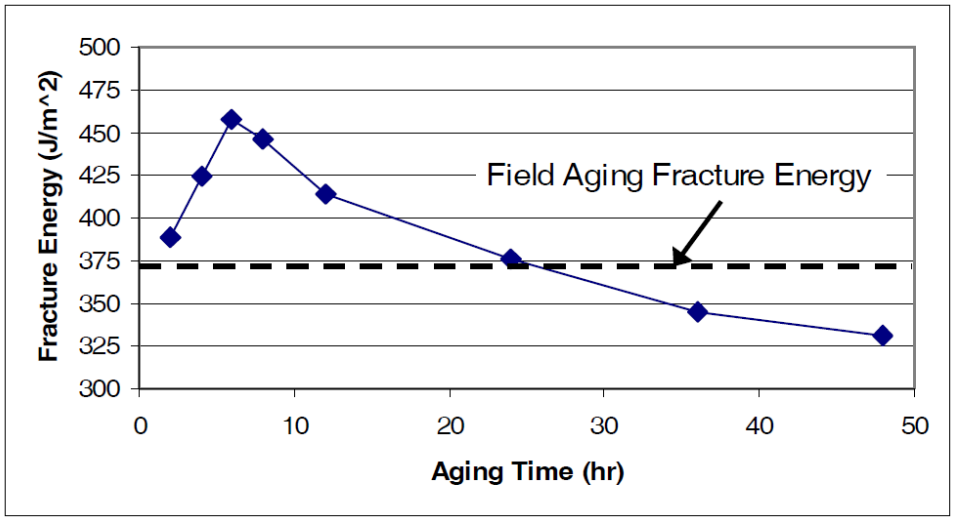


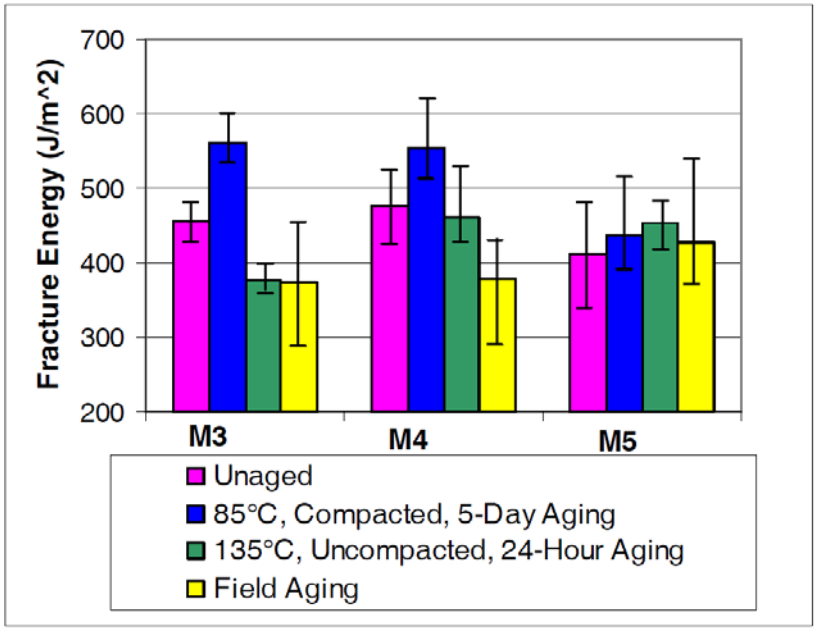
DCT Spec. Implementation

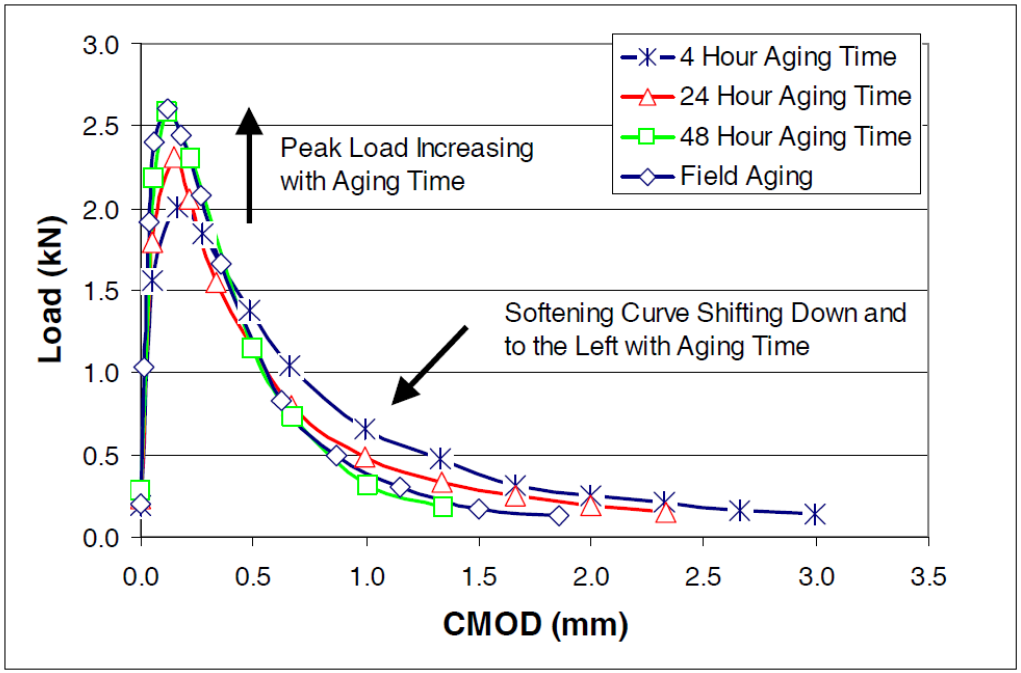
- DCT based specifications are currently being implemented:
  - Minnesota DOT
  - Wisconsin DOT
  - Chicago DOT (ASTM version)
  - Illinois Tollways (ASTM version)

	ASTM D7313-13	MnDOT Modified	WisDOT Modified
Specimen Prep	Minor Differences		
Test Equipment	No Difference		
Specimen Conditioning: Aging	N/A	AASHTO R30 (oven aging)	
Specimen Conditioning: Temperature	8 - 16 hr @ test temp. ± 0.2°C	Specimen core temperature monitored using dummy specimens	Initial Cond.: 8 - 12 hr @ -12°C± 5°C Final Cond.: 1.5±0.5 hr @ test temp.
Data Analysis	No Difference		
Test Temperature	Recommendation: PGLT + 10°C No requirement	98% Reliability Low Temperature + 10°C (Use LTPPBind 3.1 software)	10±0.5°C warmer than WisDOT plan specified lower temperature grade.

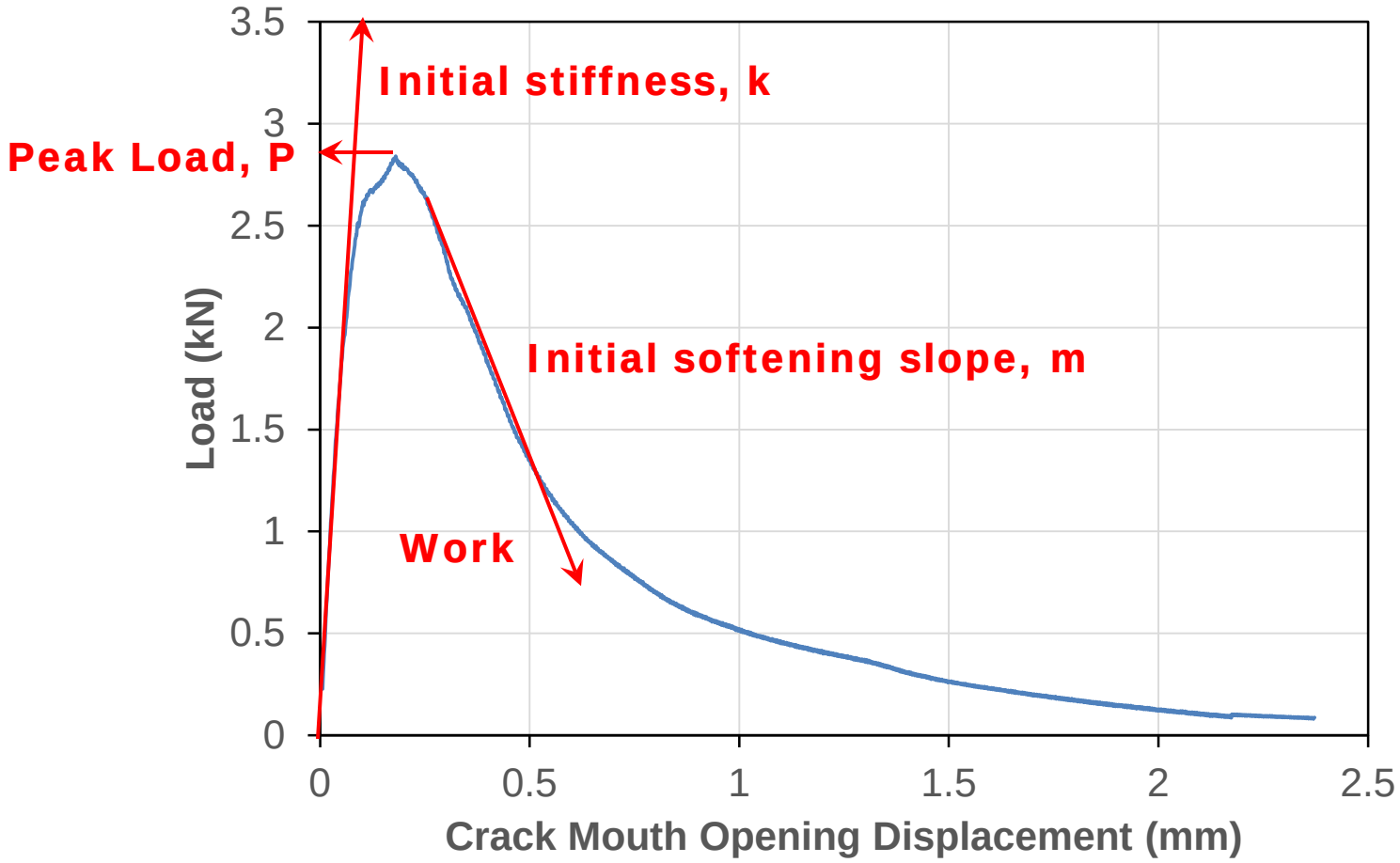
Effects of Aging on Fracture (Braham et al., 2009)





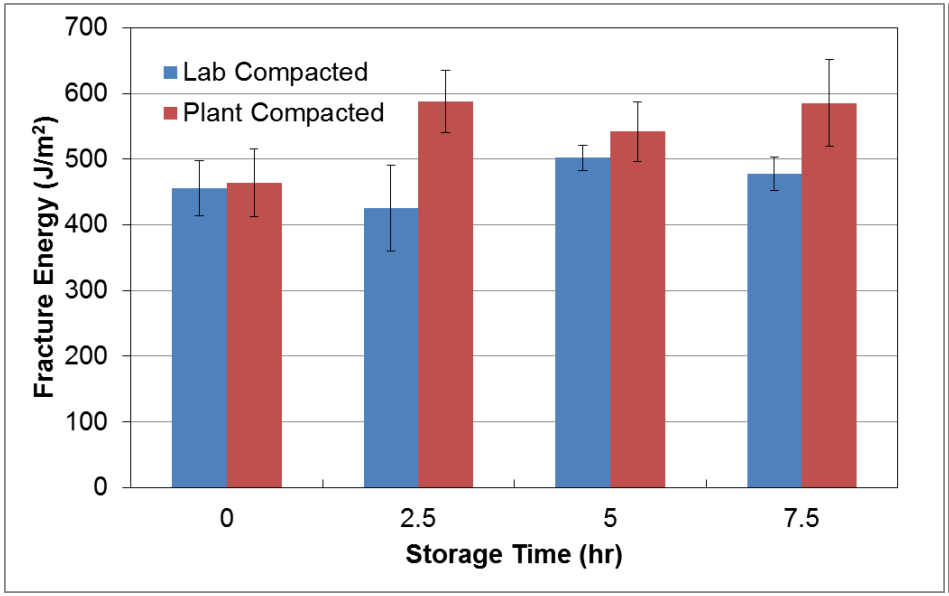


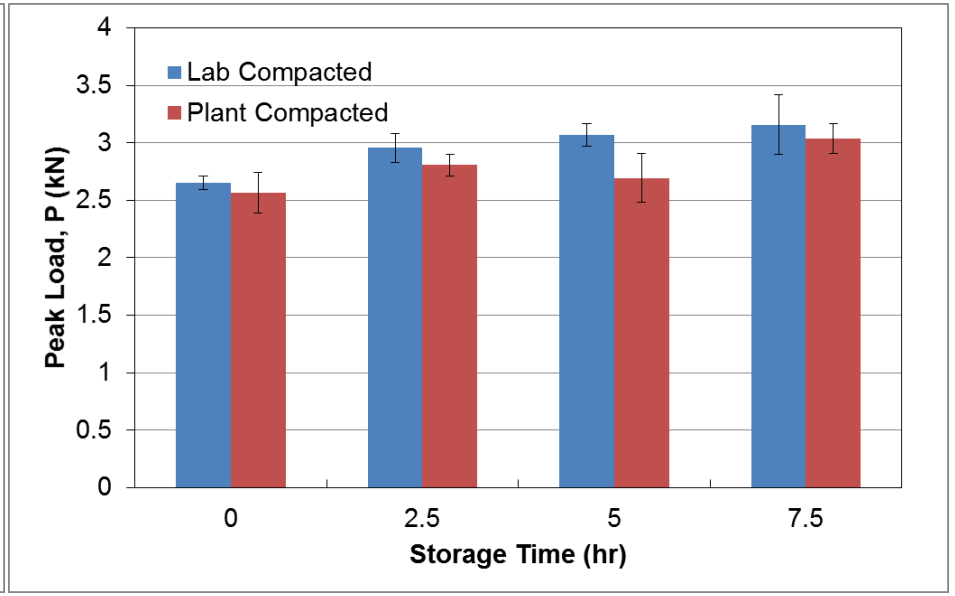
Fracture Data Analysis

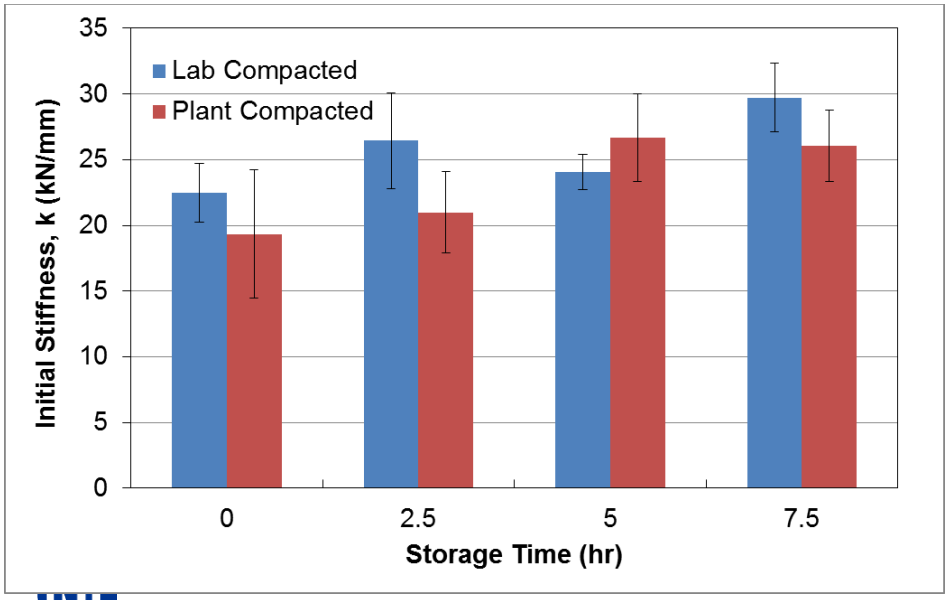


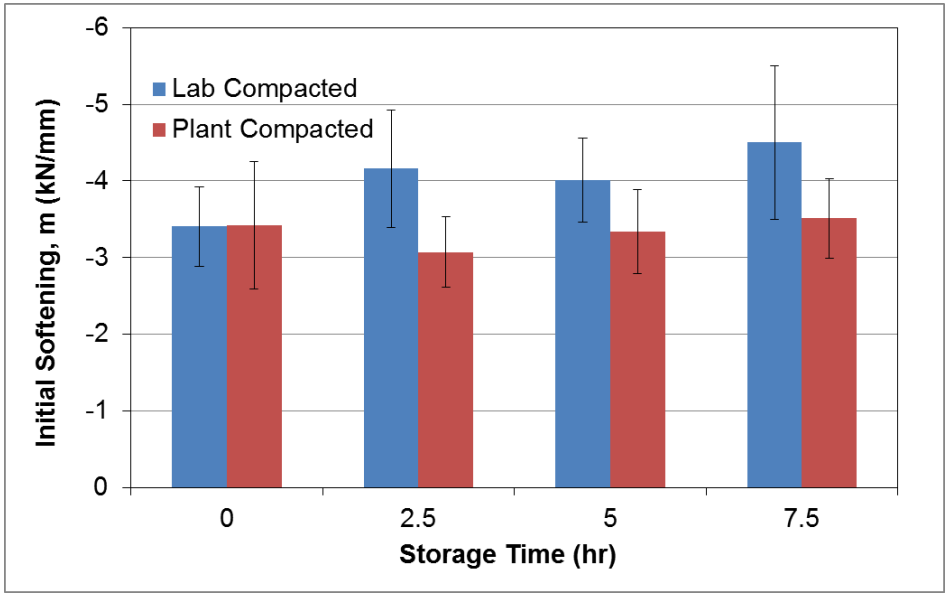
Fracture Energy, G_f = Work / Fractured Surface Area

Results for Silo Storage Study: Virgin Mix Only



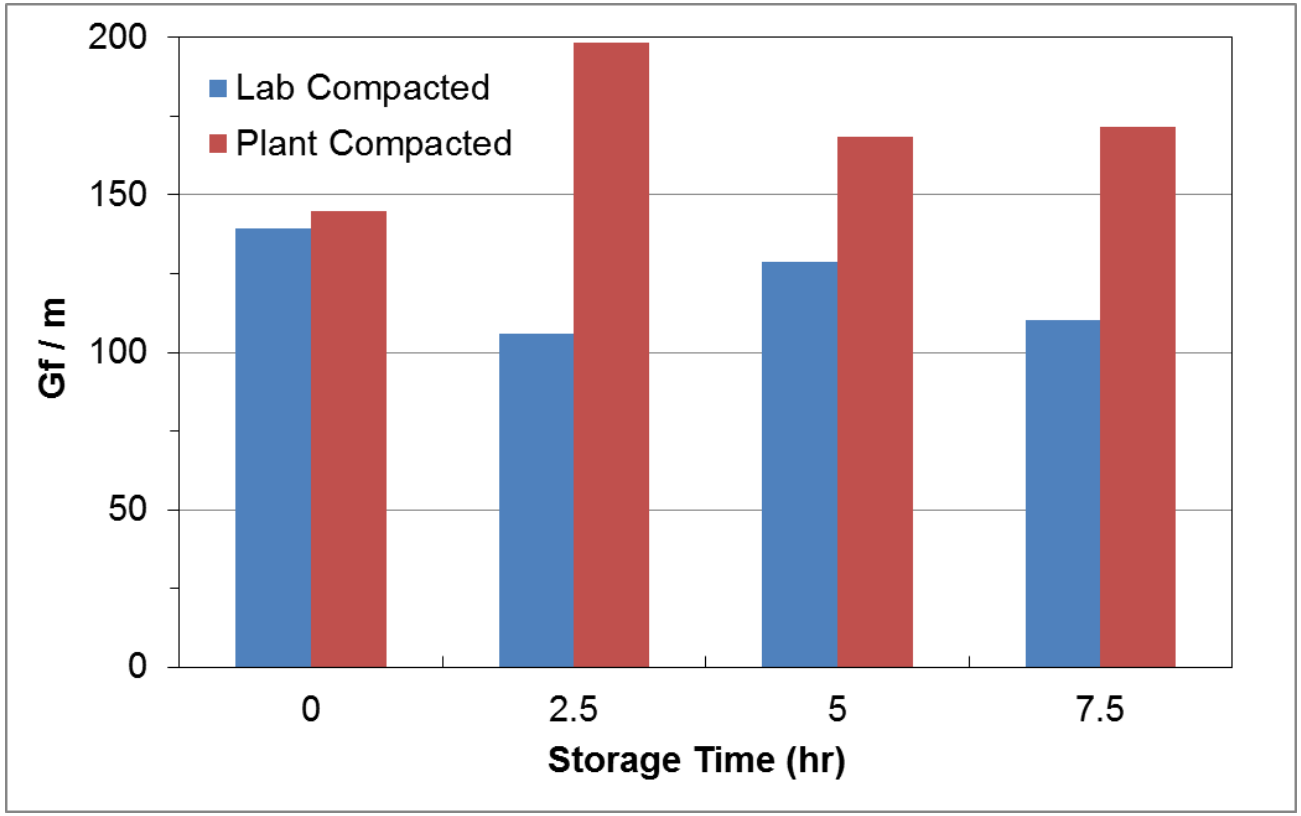






Results from Silo Storage Study

- Air Voids:
  - Plant Compacted: 8.5 +/- 0.3%
  - Lab Compacted: 6.9 +/- 0.3%

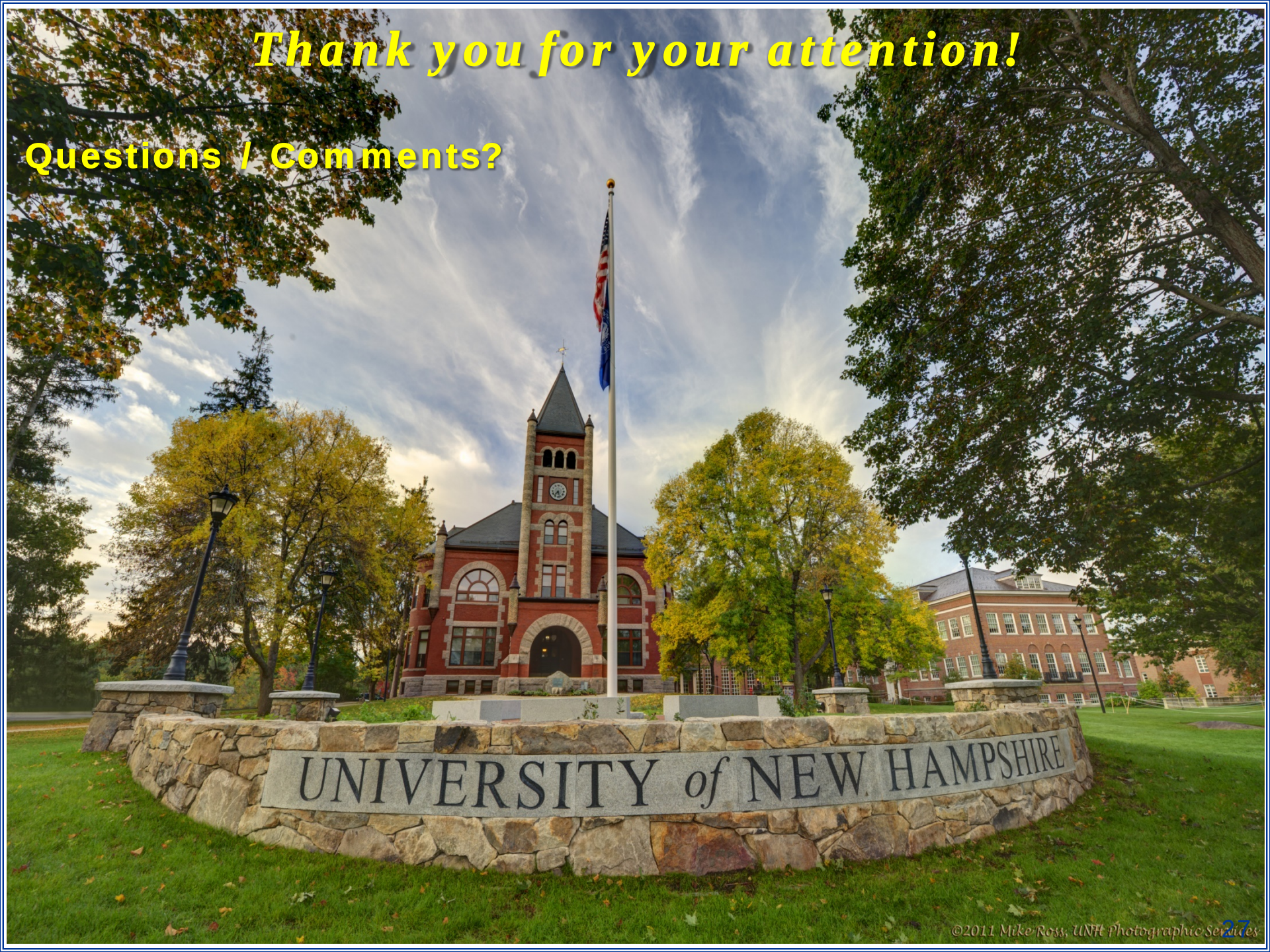


Summary

- Binder results
  - Increase in both high and low grades with longer silo storage times
    - *Larger increases for the high temperatures and in the RAP mixtures*
  - Recovered binders showed a clear change in rheological indices (CAM model) and in the Glover-Rowe parameter as silo storage time increases
    - *Both virgin and RAP mixtures experienced this aging, but the RAP mixture seemed to show larger changes.*
  - RTFO aging of the virgin binder showed that current laboratory conditioning times do not necessarily simulate asphalt plant production

Summary (cont.)

- Increase in dynamic modulus (stiffness) for both virgin and RAP mixtures
  - Difference was statistically significant at a storage time of 7.5 hour
  - RAP material experienced a greater increase in stiffness with storage time
- 7.5 hour stored virgin mixture was much more susceptible to fatigue cracking than the 0 hour mix
  - 2.5 and 5 hour mixtures were similar
- Trends for TSRST results are not consistent but in general up to 2.5 hour silo storage time there seems to be minimal to no change
- DCT testing provided insight into changes to mixture's mechanical response at low temperatures
  - Tests in virgin mixtures did not show detrimental effects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Questions / Comments?
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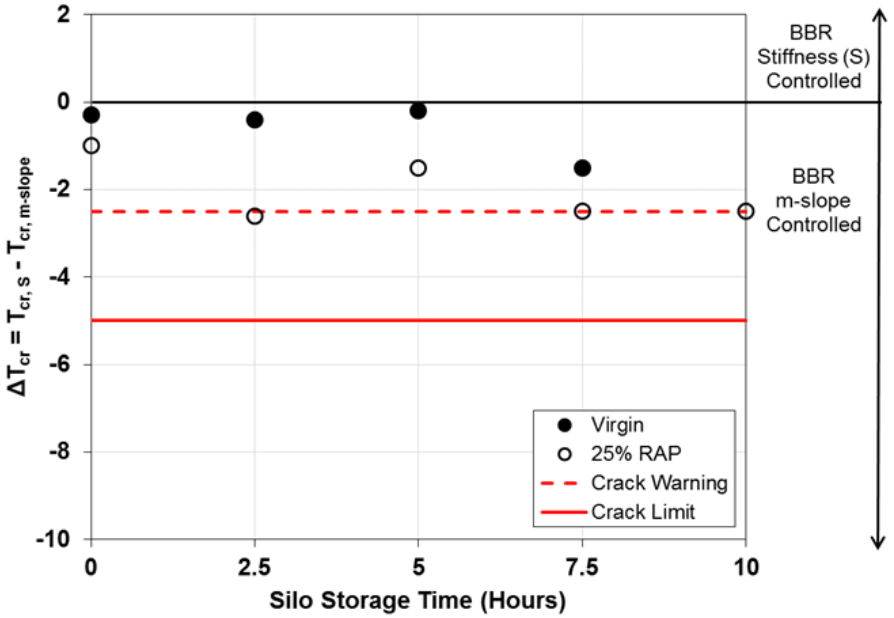
Binder Low Temperature Testing (BBR): PG Grading, ΔT_{cr}

Virgin Mix					
Silo Storage Time (Hrs)	Performance Grade (°C)				
	High Temp (RTFO)	Intermediate Temp	Low Temperature		
			Stiffness (S)	m-slope	BBR ΔT_{crit}
0 Hrs	72.1	22.7	-25.1	-24.8	-0.3
2.5 Hrs	73.8	23.3	-25.0	-24.6	-0.4
5 Hrs	73.4	24.1	-24.9	-24.7	-0.2
7.5 Hrs	75.5	24.1	-25.1	-23.6	-1.5

25% RAP Mix					
Silo Storage Time (Hrs)	Performance Grade (°C)				
	High Temp (RTFO)	Intermediate Temp	Low Temperature		
			Stiffness (S)	m-slope	BBR ΔT_{crit}
0 Hrs	73.9	24.6	-25.9	-24.9	-1.0
2.5 Hrs	76.2	22.6	-25.4	-22.8	-2.6
5 Hrs	77.9	24.5	-24.9	-23.4	-1.5
7.5 Hrs	77.3	23.6	-25.2	-22.7	-2.5
10 Hrs	80.0	24.1	-24.8	-22.3	-2.5



Binder: CAM Model Rheological Indices