Selection of a Critical Aging Protocol for NCAT Top-Down Cracking Experiment

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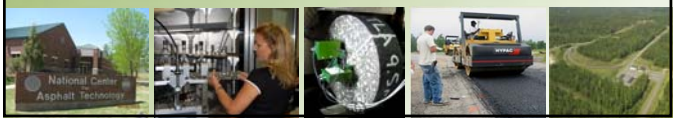


Presentation Outline

- Background
- Objectives
- Methodology
  - Critical field aging condition
  - Representative laboratory aging protocols
- Test Results
- Summary

NCAT/MnROAD Cracking Experiments

- Sponsored by 9 state DOTs and FHWA
- Objective: validate laboratory cracking tests by establishing correlations between the test results and measured cracking in real pavements using real loading conditions
  - Relatability to field performance
  - Practicality for mix design and quality assurance testing
  - Ability to accommodate recycled materials, new and future additives, and mix combinations
- NCAT focus on top-down cracking
- MnROAD focus on low-temperature cracking

Top-Down Cracking Experiment

- Seven test sections
  - Common pavement structure
  - HiMA mixtures for intermediate and base layers
  - Surface mixtures with varying cracking potential
- Field performance monitoring
  - August 2015 to present
  - 9.7 million ESALs as of November 1

Surface Layer	1.5"
Intermediate Layer	2.25"
Base Layer	2.25"
Granular base	6"
Stiff track subgrade	infinite

Top-Down Cracking Experiment

- Laboratory testing plan
  - 2 specimen types: LMLC and PMLC
  - 2 aging conditions: unaged and aged
  - 8 cracking tests

Which aging protocol to use?

Energy Ratio | OT-TX | OT-NCAT | IFIT | SCB-J_c | N_{Rex} Factor / IDEAL-CT | Cantabro | Cyclic Fatigue (S-VECD)

Laboratory Aging Protocols

- AASHTO R 30: 5 days at 85°C on compacted specimens
  - Developed in pre-SHRP study
  - Expected to simulate field aging over 7 to 10 years of service
  - Recent studies: not severe enough
- Alternative: loose mix aging prior to compaction
  - More significant due to increased exposure to oxygen and temperature
  - 8 to 24 hours at 135°C, 5 days (or longer) at 95°C
  - *Correlated with field aging?*
  - *Appropriate for top-down cracking?*

Objectives

- Identify a critical field aging condition where top-down cracking starts to develop
- Select a representative laboratory aging protocol to age asphalt mixtures for the NCAT top-down cracking experiment

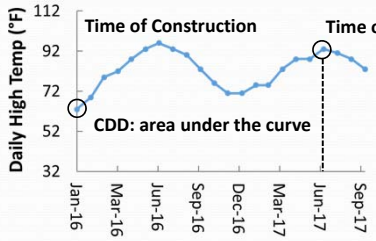
How to quantify field aging?

Time

Temperature

Cumulative Degree-Days (CDD)

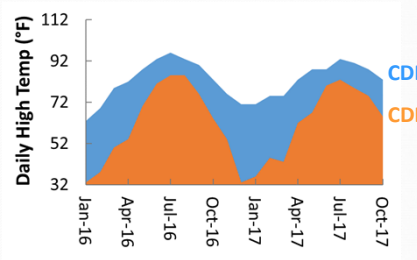
- Defined as the sum of the daily high temperature above freezing for all the days being considered from the time of construction to the time of coring (NCHRP report 815)



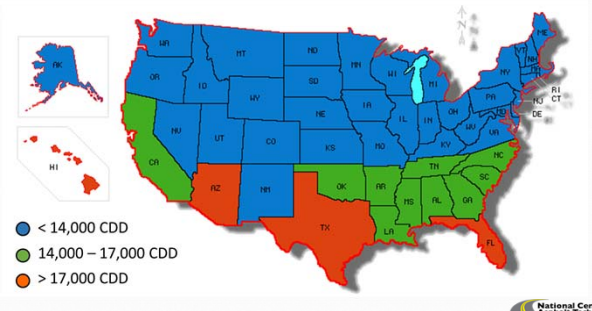
Example: Pavement in Jacksonville, FL

Cumulative Degree-Days (CDD)

- Blue: pavement in Jacksonville, FL
- Orange: pavement in Detroit, MI



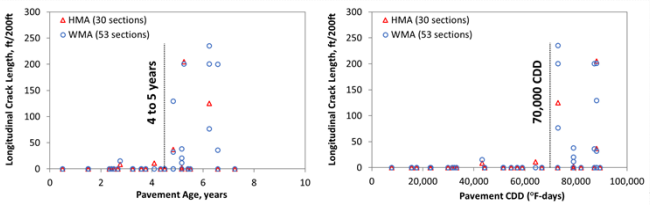
2016 US CDD Map*



**CDD calculated using state capital cities*

NCHRP 9-49A Cracking Data

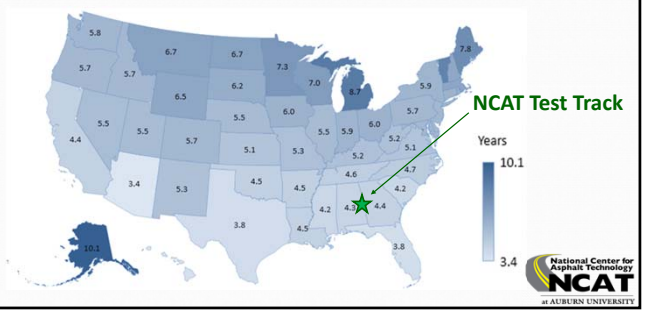
- Monitoring of 30 HMA and 53 WMA pavement sections
- Wheel-path longitudinal cracks started to develop after 4 to 5 years



(Data from NCHRP Report 843)

Preliminary Critical Field Aging

- Number of years required to reach 70,000 CDD

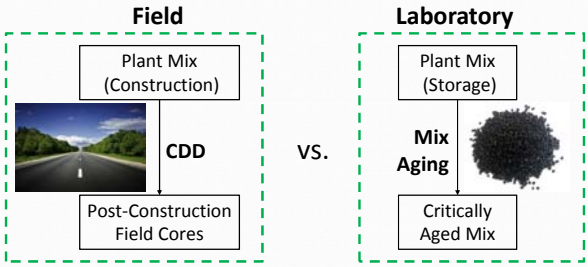


Which laboratory aging protocol to use?

Selection of Pavement Sections

Mixture ID	Construction Time	Pavement Age	CDD	Mixture
9-47A Michigan	07/2010	6 years	48,000	52-34 + 17% RAP
9-47A Washington	04/2010	6 years	80,000	64-28 + 20% RAP
Test Track S9(s)	07/2009	7 years	114,000	76-22(SBS) + 0% RAP
Test Track W4	09/2006	10 years	157,000	67-22 + 20% RAP
Test Track E6	04/2000	15 years	235,000	67-22 + 0% RAP

Research Methodology



Sampling of Field Cores

Extract asphalt binders from the top 1” layer

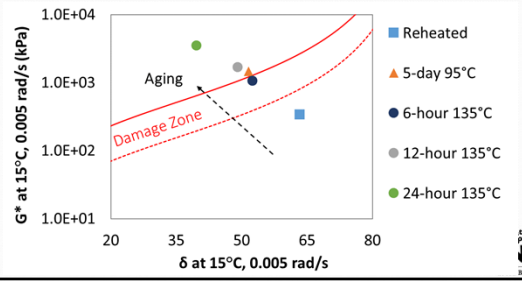
Laboratory Testing Plan

- 4 loose mix aging protocols
  - 5 days at 95°C
  - 6 hours at 135°C
  - 12 hours at 135°C
  - 24 hours at 135°C
- Tested as extracted and recovered
- Continuous performance grade – DSR, BBR, Delta T_c
- DSR frequency sweep – Glover-Rowe parameter
- FTIR – carbonyl area

Comparison of Aging Protocols

6h@135°C ≤ 5d@95°C < 12h@135°C < 24h@135°C

Example: NCHRP 9-47A WA Project



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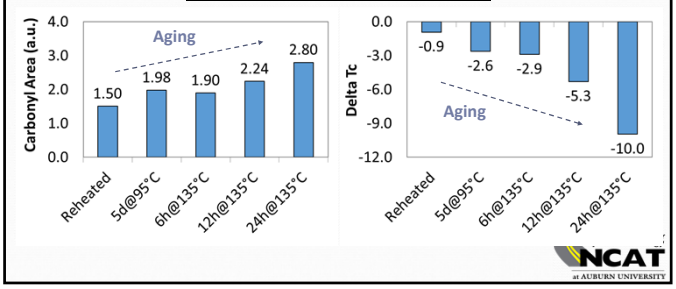
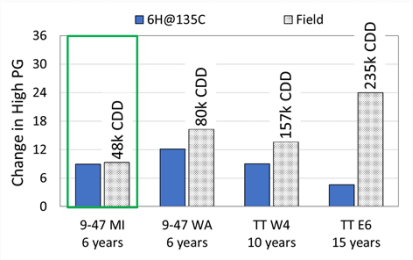


Laboratory Aging versus Field Aging

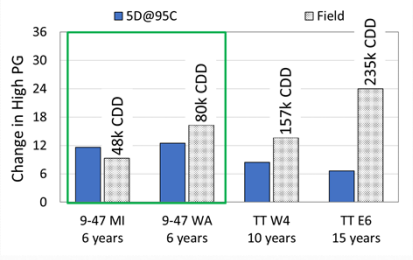
- Example: 6 hours at 135°C



6h@135°C ≈ 48k CDD

Laboratory Aging versus Field Aging

- Example: 5 days at 95°C



48k CDD < 5d@95°C < 80k CDD

Laboratory Aging versus Field Aging

Aging Protocol	Representative CDD Range
6 hours at 135°C	Approximately 48,000 CDD
5 days at 95°C	48,000 to 80,000 CDD
12 hours at 135°C	80,000 to 135,000 CDD
24 hours at 135°C	> 235,000 CDD

Preliminary critical field aging of 70,000 CDD

Alternative Aging Protocol at 135°C

- 6h@135°C ≤ 5d@95°C < 12h@135°C < 24h@135°C
- Equivalent aging time at 135°C
  - FTIR CA: fast-rate constant-rate oxidation kinetic model
  - G-R parameter: log-linear interpolation
  - PG: linear interpolation

Binder Property	Equivalent Aging Time (hours)
FTIR CA	7.5 (SD = 1.9)
G-R parameter	8.1 (SD = 1.4)
High-Temperature PG	7.6 (SD = 2.0)
Low-Temperature PG	7.1 (SD = 2.3)

Average: 7.6 hours

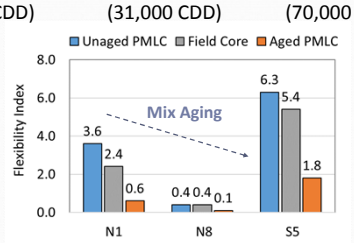
Top-Down Cracking Experiment

- LMLC specimen: 4 hours at 135°C + 8 hours at 135°C
- PMLC specimen: reheating + 8 hours at 135°C
- Validation of selected aging protocol (3 mixes)
  - Unaged plant mix
  - Critically aged plant mix ⇨
  - Field cores (2 to 4 years)

I-FIT
DSR
BBR
FTIR

Preliminary Validation Results

- I-FIT results
  - Unaged PMLC > 2-year field core > critically aged PMLC
    (0 CDD) (31,000 CDD) (70,000 CDD)



- Similar trends observed for DSR, BBR, FTIR results

Summary

- Preliminary critical field aging: 70,000 CDD
  - Top-down cracking starts to develop
- Representative loose mix aging protocols
  - 5 days at 95°C
  - 8 hours at 135°C (more practical)
- NCAT top-down cracking experiment
  - LMLC specimen: 4 hours at 135°C + 8 hours at 135°C
  - PMLC specimen: reheating + 8 hours at 135°C
  - Validated by preliminary field aging data

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Questions?

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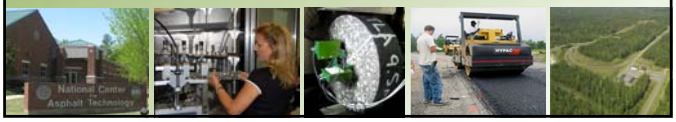

$$CA = CA_0 + k_c t + M(1 - e^{-k_f t}) \quad (5)$$

Where:

CA_0 = CA of asphalt binder extracted from the reheated mix;
t = aging time at 135°C;
k_c, k_f, and M = model coefficients.

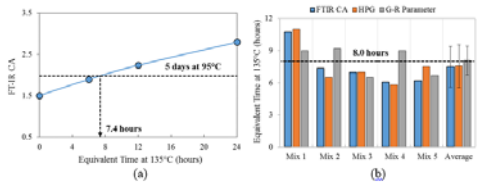

FIGURE 10 Determination of Equivalent Aging Time at 135°C: (a) Example of Mix 2 FI-IR *CA* Results, (b) Summary of All Results