Asphalt Performance Testing and Specification Development

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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

![Field Cracking Image]

![Voids in Mineral Aggregate Image]

![Recycled Asphalt Content Image]
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

- Load
- CMOD
- Crack formation
- Onset of damage
- Damage Zone
- Crack Mouth Opening Displacement (CMOD)
- Quasi-brittle fracture
- Softening
- Work of Fracture
- Load

Cracking

Displacement (CMOD)
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)
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,** $FI$:

$$FI = \frac{G_f}{m}$$
Specimen Preparations

Gyratory Specimen

50 mm (2 inch) Disk

Core loading holes

Notched

Cut disk into two halves

Notched

DCT

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
  - Extensive evaluation of performance tests (binder and mixtures)
  - 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)

<table>
<thead>
<tr>
<th>Limits</th>
<th>Project Criticality / Traffic Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High (&gt; 30M ESALs)</td>
</tr>
<tr>
<td>DCT Fracture Energy (J/m²)</td>
<td>690</td>
</tr>
<tr>
<td>IlliTC Cracking Prediction (m/km)</td>
<td>&lt; 4</td>
</tr>
</tbody>
</table>
MnDOT Implementation of Performance Specification


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

2. Pilot Implementation (2013)


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

Communication 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

1. Regional Validation of Performance Specifications (2011-2016)
2. Pilot Implementation (2013)
4. Specification refinement efforts (specimen conditioning, practicality revisions etc.) (2014-present)

Communications and Training
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 \( G_{f} > 400 \text{ J/m}^2 \)
- 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
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/m² (if actual is 375 J/m² is it too low?)

- **Approach:**
  - Simulate different combinations of climates, mixes, pavement structures with different fracture energies using *IlliTC*

<table>
<thead>
<tr>
<th>Asphalt Mix</th>
<th>PG28R</th>
<th>PG28R</th>
<th>PG34R</th>
<th>PG34</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pavement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture Energies Corresponding to Thermal Cracking Performance Levels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Damage (ND)</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
<td>≥425</td>
</tr>
<tr>
<td>Damaged (D)</td>
<td>450</td>
<td>425-450</td>
<td>375-450</td>
<td>300-375</td>
</tr>
<tr>
<td>Cracked (C)</td>
<td>≤425</td>
<td>≤400</td>
<td>≤350</td>
<td>No data</td>
</tr>
</tbody>
</table>

Variation of fracture energy by 25 J/m² might be sufficient in changing the thermal cracking performance of the pavement.
Implementation of Performance Specification

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

2. Pilot Implementation (2013)


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


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

Fracture Energy J/m²

<table>
<thead>
<tr>
<th>Condition</th>
<th>Fracture Energy (J/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Room Temp. to Test Temp.</td>
<td>350 ± 10</td>
</tr>
<tr>
<td>Ramp (0.33 °C/min)</td>
<td>380 ± 15</td>
</tr>
<tr>
<td>9 hr. Soak</td>
<td>320 ± 12</td>
</tr>
</tbody>
</table>
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

Average Fracture Energies: All Projects with XX-28 Binder

Average Fracture Energy: All Projects with XX-34 Binder
**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

Fracture Energy (J/m²)

<table>
<thead>
<tr>
<th>Location</th>
<th>Mix Design</th>
<th>No-Reheat</th>
<th>Reheats</th>
<th>Field Cores</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH 59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 59 N. D.L.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSAH 133</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 61 Little Marais</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 61 Lutsen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 65</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 86</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSAH 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TH 59 Roundabout PG 64-34
TH 59 N. D.L. PG 58-28
CSAH 133 PG 58-34
TH 61 Little Marais PG 58-34
TH 61 Lutsen PG 58-28
TH 11 PG 58-28
TH 65 PG 58-28
TH 29 PG 58-34
TH 62 PG 58-34
TH 86 PG 64-28
CSAH 3 PG 58-28

Lab Performance Testing, Eshan Dave, PAPA 01/18/2017
### Table DCT-1
**Minimum Average Fracture Energy Mixture Design Requirements for Wearing Course***

<table>
<thead>
<tr>
<th>Traffic Level</th>
<th>Fracture Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Level 2-3/PG XX-34</td>
<td>450 J/m²</td>
</tr>
<tr>
<td>Traffic Level 4-5/PGXX-34</td>
<td>500 J/m²</td>
</tr>
</tbody>
</table>

### Table 2360-9
**Allowable Differences between Contractor and Department Test Results***

<table>
<thead>
<tr>
<th>Item</th>
<th>Allowable Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCT - Fracture Energy (J/m²)</td>
<td>90</td>
</tr>
</tbody>
</table>

*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***

<table>
<thead>
<tr>
<th>Traffic Level/PG Grade</th>
<th>Fracture Energy (J/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Level 2-3/PG XX-34</td>
<td>400</td>
</tr>
<tr>
<td>Traffic Level 4-5/PGXX-34</td>
<td>450</td>
</tr>
</tbody>
</table>
Implementation of Performance Specification

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

2. Pilot Implementation (2013)


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


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!

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**

<table>
<thead>
<tr>
<th>Mix</th>
<th>PG</th>
<th>RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
<td>PG 64-22</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30%</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>PG 64-28</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30%</td>
</tr>
</tbody>
</table>

**Test Temperature Study:**

<table>
<thead>
<tr>
<th>Mix</th>
<th>PG</th>
<th>RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virginia</td>
<td>76-22</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>70-22</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>64-22</td>
<td>40%</td>
</tr>
<tr>
<td>Vermont</td>
<td>52-34</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>52-34</td>
<td>40%</td>
</tr>
</tbody>
</table>

- Short Term Aging: Plant Production
- Long Term Aging: NCHRP 09-54
- Long term oven aging of loose mix
  - Aging Temperature = 95 °C
  - 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 1°C
  - DCT: PG LT + 10 °C
- All tests on plant mixed, plant compacted samples
### Specimen Distribution

<table>
<thead>
<tr>
<th>NH 0% RAP</th>
<th>NH 30% RAP</th>
<th>NY 0% RAP</th>
<th>NY 30% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short-term aged</strong></td>
<td><strong>Short-term aged</strong></td>
<td><strong>Short-term aged</strong></td>
<td><strong>Short-term aged</strong></td>
</tr>
<tr>
<td>Discs</td>
<td>AV test</td>
<td>Discs</td>
<td>AV test</td>
</tr>
<tr>
<td>1.A</td>
<td>6.6% SCB</td>
<td>1.A</td>
<td>6.6% DCT</td>
</tr>
<tr>
<td>1.B</td>
<td>6.5% DCT</td>
<td>1.B</td>
<td>6.6% SCB</td>
</tr>
<tr>
<td>2.A</td>
<td>6.5% SCB</td>
<td>2.A</td>
<td>6.6% SCB</td>
</tr>
<tr>
<td>2.B</td>
<td>6.3% DCT</td>
<td>2.B</td>
<td>6.8% DCT</td>
</tr>
<tr>
<td>2.C</td>
<td>5.8% DCT</td>
<td>2.C</td>
<td>6.5% DCT</td>
</tr>
<tr>
<td><strong>14 days aged</strong></td>
<td><strong>14 days aged</strong></td>
<td><strong>14 days aged</strong></td>
<td><strong>14 days aged</strong></td>
</tr>
<tr>
<td>Discs</td>
<td>AV test</td>
<td>Discs</td>
<td>AV test</td>
</tr>
<tr>
<td>1.A</td>
<td>5.5% Extra</td>
<td>1.A</td>
<td>7.9% Extra</td>
</tr>
<tr>
<td>1.B</td>
<td>5.6% DCT</td>
<td>1.B</td>
<td>7.4% SCB</td>
</tr>
<tr>
<td>2.B</td>
<td>6.5% SCB</td>
<td>2.B</td>
<td>7.2% DCT</td>
</tr>
<tr>
<td>2.C</td>
<td>6.3% DCT</td>
<td>2.C</td>
<td>6.9% DCT</td>
</tr>
<tr>
<td><strong>21 days aged</strong></td>
<td><strong>21 days aged</strong></td>
<td><strong>21 days aged</strong></td>
<td><strong>21 days aged</strong></td>
</tr>
<tr>
<td>Discs</td>
<td>AV test</td>
<td>Discs</td>
<td>AV test</td>
</tr>
<tr>
<td>1.A</td>
<td>6.5% DCT</td>
<td>1.A</td>
<td>7.9% SCB</td>
</tr>
<tr>
<td>1.B</td>
<td>6.6% SCB</td>
<td>1.B</td>
<td>7.0% Extra</td>
</tr>
<tr>
<td>2.A</td>
<td>6.5% DCT</td>
<td>2.A</td>
<td>6.7% SCB</td>
</tr>
<tr>
<td>2.B</td>
<td>6.4% DCT</td>
<td>2.B</td>
<td>6.6% DCT</td>
</tr>
<tr>
<td>2.C</td>
<td>6.3% SCB</td>
<td>2.C</td>
<td>6.4% DCT</td>
</tr>
</tbody>
</table>

### NH 0% RAP

<table>
<thead>
<tr>
<th>Discs</th>
<th>AV test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.A</td>
<td>6.5% DCT</td>
</tr>
<tr>
<td>1.B</td>
<td>6.1% SCB</td>
</tr>
<tr>
<td>1.C</td>
<td>6.0% Extra</td>
</tr>
<tr>
<td>2.A</td>
<td>6.5% DCT</td>
</tr>
<tr>
<td>2.B</td>
<td>6.4% DCT</td>
</tr>
<tr>
<td>2.C</td>
<td>6.3% SCB</td>
</tr>
</tbody>
</table>

### NH 30% RAP

<table>
<thead>
<tr>
<th>Discs</th>
<th>AV test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.A</td>
<td>6.9% SCB</td>
</tr>
<tr>
<td>1.B</td>
<td>7.0% Extra</td>
</tr>
<tr>
<td>1.C</td>
<td>6.6% DCT</td>
</tr>
<tr>
<td>2.A</td>
<td>6.7% SCB</td>
</tr>
<tr>
<td>2.B</td>
<td>6.6% DCT</td>
</tr>
<tr>
<td>2.C</td>
<td>6.4% DCT</td>
</tr>
</tbody>
</table>

### NY 0% RAP

<table>
<thead>
<tr>
<th>Discs</th>
<th>AV test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.A</td>
<td>6.8% DCT</td>
</tr>
<tr>
<td>1.B</td>
<td>7.4% SCB</td>
</tr>
<tr>
<td>1.C</td>
<td>6.3% Extra</td>
</tr>
<tr>
<td>2.A</td>
<td>6.5% DCT</td>
</tr>
<tr>
<td>2.B</td>
<td>6.8% DCT</td>
</tr>
<tr>
<td>2.C</td>
<td>6.6% SCB</td>
</tr>
</tbody>
</table>

### NY 30% RAP

<table>
<thead>
<tr>
<th>Discs</th>
<th>AV test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.A</td>
<td>6.8% DCT</td>
</tr>
<tr>
<td>1.B</td>
<td>7.4% SCB</td>
</tr>
<tr>
<td>1.C</td>
<td>7.0% SCB</td>
</tr>
<tr>
<td>2.A</td>
<td>7.2% SCB</td>
</tr>
<tr>
<td>2.B</td>
<td>7.5% DCT</td>
</tr>
<tr>
<td>2.C</td>
<td>6.7% Extra</td>
</tr>
</tbody>
</table>
**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

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

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SCB: 25ºC

DCT: -12 or -18ºC

SCB: 25, 13 and 1ºC

DCT: -12 or -18ºC
Overview

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

VA Mixtures
Green: 0% RAP, PG 76-22
Blue: 20% RAP, PG 70-22
Red: 40% RAP, PG 64-22
Effect of Temperature on SCB Results

![Graph showing the effect of temperature on SCB fracture energy]
Effect of Temperature on Fracture Behavior at Intermediate Temperatures

Force (kN)

Displacement (mm)

1°C
VT 20% RAP, PG 58-34

13°C

25°C

13°C
VA 20% RAP, PG 70-22

25°C
VA 40% RAP, PG 64-22

Trial 1: 13°C & 50mm/min
Trial 2: 25°C & 50mm/min

Force (kN) vs. Displacement (mm)
Overview

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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

![Chart showing SCB Flexibility Index at Intermediate Temperature](chart.png)
Overview

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