Evaluation of Cracking Resistance and Durability of 100% Reclaimed Asphalt Pavement Mixtures

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100,000,000 Tons

2.7 Million Miles

93% Asphalt

Reclaimed Asphalt Pavement (RAP)

100% RECYCLABLE

Base
Sub-base
Shoulders
Landfill

Introduction
Research Objectives
Methodology
Binder Tests
Mixtures Tests
Conclusions
2000 Lane Miles Resurfacing per Year \times 2.25 \text{ inch Average Milling Depth} \rightarrow 1.8 \text{ Million Tons RAP}

- 450,000 Tons (25\%)
- 400,000 Tons Not Used

- 2000 Lane Miles Resurfacing per Year
- 2.25 inch Average Milling Depth
- 1.8 Million Tons RAP

- Introduction
- Research Objectives
- Methodology
  - Binder Tests
  - Mixtures Tests
- Conclusions
The average RAP content is under 25%
Why?

**Lack of Confidence**

Need for More Effective Design and Performance Verification Procedures High RAP Content Mixtures
Zaumanis, Mallick, & Frank (2014)
Premature cracking is a result of insufficient design, fast aging, and cracking resistance. This diagram illustrates the factors contributing to premature cracking.
Asphalt Aging:
Asphalt hardens and gets brittle and prone to cracking due to weathering and construction heating

Rejuvenation:
Adding a recycling agent (rejuvenator) to aged asphalt to cure aging and restore its original properties

- Effective rejuvenation has a major role in successful recycling
Recycled Binder Durability

![Graph showing pavement condition index (PCI) vs. pavement life (years) with recycling indicated]
How to verify effectiveness of rejuvenation?

- **Current practice:**

  Viscosity or penetration or performance grade requirements

  FDOT: Pen. : 40 – 80 dmm ; Viscosity @ 160 ° C : 5000 – 15000 Poises

![Diagram showing the process of rejuvenation with Virgin Binder, Aging, RAP Binder, Rejuvenation, and Recycled Binder.]

- **Durability**
- **Cracking Resistance**

**Introduction**

**Research Objectives**

**Methodology**

**Binder Tests**

**Mixtures Tests**

**Conclusions**
Research Objectives:

Evaluate Cracking Resistance and Durability of 100% RAP mixtures

- Compare the cracking resistance of several samples of recycled binder and mixture to that of non-recycled samples
- Monitor changes in the cracking resistance over the life of the pavement
- Investigate the effect of rejuvenators on crackling resistance and durability
## Methodology:

<table>
<thead>
<tr>
<th></th>
<th>Cracking Resistance</th>
<th>Aging</th>
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<tr>
<td><strong>Binder</strong></td>
<td>Bending Bean Rheometer (BBR)</td>
<td>Pressure Aging Vessel (PAV)</td>
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<tr>
<td><strong>Mixture</strong></td>
<td>Texas Overlay Test</td>
<td>Accelerated Pavement Weathering System (APWS)</td>
</tr>
</tbody>
</table>
Methodology

Superpave Performance Grade (PG) System

Construction
Rutting
Fatigue
Cracking

[RV]
[DSR]

Age
Aging
PAV
RTFO Aging
### Performance Graded Asphalt Binder Specification (from AASHTO MP 1)

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<th>PG 48</th>
<th>PG 52</th>
<th>PG 58</th>
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**Introduction**

- **Research Objectives**

- **Methodology**

- **Binder Tests**

- **Mixtures Tests**

- **Conclusions**

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**Florida: PG 67-22**
Bending Beam Rheometer (BBR)

Introduction

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Bending Beam Rheometer (BBR)

Parameters

Creep Stiffness (S)
- The stiffness at 60 second
- Indicate the amount of thermal stresses
- PG requirement: $S \leq 300$ Mpa

Stress Relaxation Parameter (m-value)
- The slope of master stiffness curve at 60 s
- Indicates the ability to relax stresses
- PG requirement: $m\text{-value} \geq 3.00$
Pressure Aging Vessel (PAV)

- Simulates long-term aging of the binder using heat and pressure
- Temperature: 90, 100, or 110 °C
- Pressure: 2.1 Mpa
- Time: 20 hours
- Simulate 7-10 years in service aging
Texas Overlay Test

- Evaluates the susceptibility of asphalt mixtures to fatigue and reflective cracking
- Applies repeated tension loads to the specimen to simulate repeated opening and closing of pavement joints and cracks due to temperature variations and traffic loading
- Designed by Texas Department of Transportation
Asphalt Pavement Weathering System (APWS)

- Accelerated pavement weathering
- Simulates natural pavement weathering (top to down) with parameters such as moisture (rain), UV (sunshine) and temperature
- Incorporates full-depth samples
Binder Tests

- **Aging (PAV):**
  - Standard: 20 hours (Plus RTFO)
  - Extended: 60 hours

- **Virgin Binder: Two samples PG 67-22**
  - True High Temperature Grade: Binder 1: 68.36 °C; Binder 1: 71.63°C

- **Rejuvenators:**
  - **HPE:** Heavy Paraffinic Distilled Solvent Extract
  - **CWE:** Water-based Emulsion From Wax Free Naphthenic Crude With Residue Content Of 60%
# Binder Tests

## Softening Curves

**Graph:**

- **Y-axis:** High Temperature Grade
- **X-axis:** Rejuvenator Dosage

Legend:
- Binder1 + HPE
- Binder1 + CWE
- Binder2 + HPE
- Binder2 + CWE

**Data Points:**

- Binder1 + HPE:
  - 10%: 78
  - 12%: 76
  - 14%: 74
  - 16%: 72
  - 18%: 70

- Binder1 + CWE:
  - 20%: 68

- Binder2 + HPE:
  - 22%: 76

- Binder2 + CWE:
  - 24%: 74
  - 26%: 72
  - 28%: 70
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**Binder Tests**

The graph shows the comparison of creep stiffness and m-value for different binders under standard and extended aging conditions.

- **Creep Stiffness (Mpa)**
  - **Binder1** shows a significantly higher creep stiffness compared to extended aging.
  - **Binder1+HPE** and **Binder1+CWE** exhibit lower creep stiffness than **Binder1**
  - **Binder2** and its modified versions (HPE and CWE) show intermediate creep stiffness.

- **m-value**
  - **Binder1** and **Binder1+HPE** have lower m-values compared to extended aging.
  - **Binder1+CWE** and **Binder2** show higher m-values than extended aging.
  - **Binder2+HPE** and **Binder2+CWE** have intermediate m-values.

**Methodology**

The datasets were obtained through binder tests and mixtures tests, which were conducted under controlled aging conditions.
Discussions:

- Recycled samples had significantly lower creep stiffness than virgin binders. Also the m-value was generally higher for recycled samples.

- By increasing the aging from the standard to the extended aging, the stiffness of all samples increased and their m-value dropped.

- Even after 60 hours of PAV aging, the stiffness of recycled binders was lower than the stiffness limit for PG67-22 ($S \leq 300$ MPa at $-12^\circ$C). However, in most cases the m-values were too low and did not meet the requirement ($m \geq 0.300$ at $-12^\circ$C)

- Both Rejuvenators enhanced the cracking resistance as characterized by a lower creep stiffness and higher m-value.
Mixture Tests

- Texas Overlay Test for:
  - Recycled and new mixture
  - Before and after APWS aging
- Two recycled mixtures and two Control (new) mixtures
- APWS aging for 3000 and 6000 hours
- A 3,000-hour APWS exposure simulates the aging that occurs in the field in 7 to 10 years
Sample Preparation

Recycled Mixtures

- Two recycled samples (CWE and HPE)
- RAP obtained from a hot in-place recycling project in Florida, USA
- Rap binder recovered to characterize and establish softening curves
- The same rejuvenators used for binder test used for rejuvenating the RAP
- 3% screening sand
Sample Preparation

Control Mixtures

- Control I:
  - Aggregate extracted from the RAP using ignition oven
  - Mixed with PG 67-22 virgin binder with a binder content similar to the RAP (6.3%)

- Control II: Mixtures commonly used in Florida

- All pills prepared using Gyratory Compactor with 50 gyrations
<table>
<thead>
<tr>
<th>Mixture</th>
<th>Replicate</th>
<th>Starting Load, kN</th>
<th>Final Load, kN</th>
<th>Decline in Load, %</th>
<th>Cycles to Failure</th>
<th>Average Number of Cycles to Failure (ANCF)</th>
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Results

\[ y = -0.013x + 71 \]

\[ y = -0.06x + 240 \]

\[ y = -0.06x + 285 \]
The Average Number of Cycles to Failure (ANCF) was considered an indication of susceptibility of mixtures to fatigue and reflective cracking.

Both recycled samples performed much better than both control samples at the initial stage (before aging). Their ANCF was significantly higher, meaning that they had much better cracking resistance.

The ANCF decreases with increased APWS aging time.

The rate of decrease in the ANCF with APWS time was considerably faster for recycled mixtures than for the control I.

However, even at the end of 3,000 hours, recycled samples had an equally good or better resistance to cracking when compared with un-aged control samples.
Discussions - Continued

- The recycled samples which were rejuvenated by CWE were found to have a better performance than those rejuvenated by HPE

- Limitations:
  - The variability of Texas Overlay Test results
  - The variability of the air voids between the control and recycled samples
  - The relatively small size of this experiment.
Conclusions

- Generally, recycled binders had significantly better cracking resistance than virgin binders. This fact was observed in both binder and mixture testing. This observation confirms that a properly recycled pavement can be even more resistant to cracking than a new pavement.

- In the binder testing, no consistent trend was observed in comparing the rate of decrease in cracking resistance of rejuvenated and virgin binders due to aging.

- The cracking resistance of recycled samples dropped faster. But because of the significant difference in the initial values, even after aging recycled samples had a better cracking resistance.

- The cracking resistance of recycled mixtures was affected by the type of rejuvenator.
Thank You