IMPACT OF POLYMER MODIFIED BINDERS ON THE DSR CREEP PROPERTIES OF HMA MIXTURES

by Gerald Reinke & Stacy Glidden
Outline

• MOTIVATION to develop a mechanistic test for HMA
• Sample Preparation & Test Description
• Rutting Prediction Results (MN & ALF)
• Results compared to SST testing
• Impact of Binder, Modifier & Gradation
Outline

- **MOTIVATION** to develop a mechanistic test for HMA
  - Sample Preparation & Test Description
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  - Results compared to SST testing
  - Impact of Binder, Modifier & Gradation
• Work on mechanistic test not finalized at the end of SHRP research program
• SST equipment and FSCH & RSCH tests were available, test methods and analysis procedures to predict rutting not well defined
• Equipment was expensive, few units available
• Agencies & contractors were interested in answers to short term questions regarding relative performance of mixes
Perception among user agencies and suppliers that SHRP PG grading system did not adequately identify the performance benefits of polymers or other additives in binders

Reasons for perception

- SHRP binder tests seemed to correlate to mix performance for conventional binders
- SHRP PG grading system did not provide tests capable of identifying superior performing binders in HMA
One response was the implementation of SHRP Plus binder specifications

- Forced suppliers to provide binders with a known performance history
  - Elastic Recovery (@ various temperatures & values)
  - Force Ductility (@ various temperatures & values)
  - Toughness & Tenacity (various results)
- In effect the binder specification became a surrogate mixture performance specification
- Lack of correlation to mix performance has not deterred use
  - Obvious need for some mechanistic solution
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A 1 SECOND STRESS IS APPLIED FOLLOWED BY A 9 SECOND RECOVERY PERIOD

Idea for dynamic mixture test based on the procedure developed for binder cumulative strain test plus the test procedure employed in SST RSCH mix test
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Idea for dynamic mixture test based on the procedure developed for binder cumulative strain test plus the test procedure employed in SST RSCH mix test
CUMULATIVE CREEP TEST RESULTS, RTFO, 58°C, 300 Pa STRESS

COMPARISON OF CYCLE 1 FOR CREEP AND RECOVERY TEST

PG 64-34 RTFO RESIDUE @ 58°C
PG 58-28 RTFO RESIDUE @ 58°C
CUMULATIVE CREEP TEST RESULTS, RTFO, 58°C, 300 Pa STRESS

COMPARISON OF CYCLE 1-5 FOR CREEP AND RECOVERY TEST

PG 64-34 RTFO RESIDUE, 58°C
PG 58-28 RTFO RESIDUE, 58°C
CUMULATIVE CREEP TEST RESULTS, RTFO, 58°C, 300 Pa STRESS

- PG 58-28 RTFO RESIDUE @ 58°C
- PG 64-34, RTFO RESIDUE @ 58°C
- PG 70-28 RTFO RESIDUE @ 58°C
Sample Preparation

50 mm
Sample Preparation & Test

- Sample Size
  - 6 mm x 12 mm x 50 mm
  - 10 mm x 12 mm x 50 mm
Sample Preparation & Test

- Dynamic Creep & Recovery Test
  - 10 Second Cycles
  - 1 Second Stress
  - 9 Seconds Recovery
- Static Creep Test
  - Stress Applied Until Failure
MNROAD CELL 3, A1, 15kPA, 58°C

CONSTANT STRESS IS APPLIED MATERIAL STRAINS UNTIL IT FAILS
REPEATED CYCLES OF 1 SEC STRESS FOLLOWED BY 9 SEC RECOVERY ARE APPLIED. STRAIN GRADUALLY DEVELOPS UNTIL SPECIMEN FAILS.
CELL 18, MNROAD 1992 MIX, 58° C, 15 KPA CREEP RECOVERY

TIME TO 5% STRAIN = 2561 SEC

STRAIN @ 2000 sec (200 CYCLES) = 4.3061%

FLOWNUMBER = 5291 s @ 9.09% STRAIN

TIME TO 5% STRAIN = 2561 SEC

STRAIN @ 2000 sec (200 CYCLES) = 4.3061%

TYPICAL FLOW FAILURE CURVE
REGION LABELS FOLLOWING WITCZAK

SECONDARY FLOW

TERTIARY FLOW

FAILRE REGION

LINEAR RATE OF DEFORMATION DEVELOPMENT

PRIMARY FLOW
CELL 18, MNROAD 1992 MIX, 58° C, 15 KPA CREEP RECOVERY

ANALYSIS OF 200 TH CYCLE

Discrete retardation spectrum
J0: 2.8609E-6 m^2/N
n0: 2.013E7 Pa.s
J1: 6.9100E-8 m^2/N
t1: 0.1793 s
J2: 3.624E-12 m^2/N
t2: 5.211E-3 s
J3: 1.7712E-8 m^2/N
t3: 0.02193 s
J4: 9.0565E-9 m^2/N
t4: 0.02447 s
J5: 2.7283E-9 m^2/N
t5: 0.05063 s
J6: 1.0542E-8 m^2/N
t6: 0.03351 s
Je: 1.091E-7 m^2/N
standard error: 0.1475
End condition: Max. iterations exceeded
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<table>
<thead>
<tr>
<th>CELL #</th>
<th>MIX TYPE &amp; BINDER</th>
<th>AVE RUT DEPTH AUG 2000, mm</th>
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</thead>
<tbody>
<tr>
<td>CELL 3</td>
<td>50 BLOW MARSHALL, 120/150</td>
<td>6.21</td>
</tr>
<tr>
<td>CELL 4</td>
<td>GYRATORY DESIGN, 120/150</td>
<td>9.60</td>
</tr>
<tr>
<td>CELL 17</td>
<td>75 BLOW MARSHALL, AC-20</td>
<td>5.15</td>
</tr>
<tr>
<td>CELL 18</td>
<td>50 BLOW MARSHALL, AC-20</td>
<td>5.96</td>
</tr>
</tbody>
</table>
MNROAD 1992 MIX RUT DEPTH VS. FLOWNUMBER
FROM REPEATED CREEP RECOVERY TEST
1 SEC CREEP LOAD, 9 SEC RECOVERY, 58° C, 15 KPA

Log10(Y) = 1.76279 - 0.000222104X
EMS = 0.00134741
R² = 0.954
MN Road Testing

MNROAD 1992 MIX RUT DEPTH VS. % STRAIN
AFTER 200 CYCLES OF CREEP RECOVERY
1 SEC CREEP LOAD, 9 SEC RECOVERY

TESTING PERFORMED AT 58° C, 15 KPA STRESS

Y = -18.8522 + 4.20718X
EMS = 0.0421179
R² = 0.993
<table>
<thead>
<tr>
<th>LANE #</th>
<th>BINDER</th>
<th>1994 Rut, mm</th>
<th>Rutting @ 2730 wheel passes</th>
<th>Wheel passes to 15 mm rut depth</th>
<th>Rutting @ 10,000 wheel passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>AC-10, 58-28</td>
<td>27</td>
<td>23.2</td>
<td>946</td>
<td>39.3</td>
</tr>
<tr>
<td>7</td>
<td>STYRELF 82-22</td>
<td>18</td>
<td>8</td>
<td>5.55 E4</td>
<td>12</td>
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<tr>
<td>8</td>
<td>NOVAPHALT, 76-22</td>
<td>9</td>
<td>3.5</td>
<td>1.75 E6</td>
<td>4.4</td>
</tr>
<tr>
<td>9</td>
<td>AC-5, 52-34</td>
<td>22</td>
<td>37.4</td>
<td>340</td>
<td>48.1</td>
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<tr>
<td>10</td>
<td>AC-20, 64-22</td>
<td>36</td>
<td>20.1</td>
<td>980</td>
<td>36.3</td>
</tr>
</tbody>
</table>
FHWA ALF Testing

Testing done at 58°C & 68 kPa

AC-5, 52-34
AC-10, 58-28
AC-20, 64-22
Testing done at 58°C & 68 kPa
FHWA ALF Testing

WHEEL PASSES TO 15 mm RUT DEPTH AS FUNCTION OF MIX PERMANENT STRAIN @ 10 TEST CYCLES

Log10(Y) = 4.55548 - 1.79247Log10(X)
EMS = 0.282642
R² = 0.913

WHEEL PASSES TO 15 mm RUT DEPTH

MIX PERMANENT STRAIN @ 10 CYCLES

58° C, 68 KPa STRESS
FHWA ALF Testing

ALF RUT DEPTH AFTER 2730 WHEEL PASSES
AS FUNCTION OF MIX $\eta_0$ @ 10 CYCLES, 58° C, 68 KPa

Log10(Y) = 1.46273 - 0.00728786X
EMS = 0.00883108
$R^2 = 0.961$

FHWA ALF Testing
FHWA ALF Testing

RUT DEPTH AT 10,000 WHEEL PASSES AS FUNCTION OF % STRAIN AT 10 CYCLES

\[ Y = 19.7709 + 22.4448 \log_{10}(X) \]

EMS = 5.34864

\[ R^2 = 0.989 \]

RUT DEPTH AT 10,000 WHEEL PASSES AS FUNCTION OF % STRAIN AT 10 CYCLES

FHWA ALF Testing

Y = 19.7709 + 22.4448Log10(X)
EMS = 5.34864
R² = 0.989
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Y = -3.15098 + 4.45102X
EMS = 0.129343
R² = 0.941

SUPERPAVE MIX - COMPARE SST TO DSR DYNAMIC CREEP RESULTS
SMA MIX - COMPARE SST TO DSR DYNAMIC CREEP RESULTS

\[ Y = -1.89171 + 5.41742X \]
\[ \text{EMS} = 1.79875 \]
\[ R^2 = 0.897 \]
COMPARISON OF SMA MIXES USING MODIFIED BINDERS
PG 67-22, PG 76-22 USING REATIVE ETHYLENE TERPOLYMER & PG 76-22 USING SBS
BASED ON STRAIN FROM RSCH TEST USING SST
AND STRAIN FROM DSR DYNAMIC CREEP TEST

50th DSR Cycle  
5th DSR Cycle  
SST SMA PERM STRAIN

Permanent % Strain DSR DYNAMIC CREEP
CORRELATION BETWEEN MIX STRAIN AT VARIOUS TEST CYCLES AS A FUNCTION OF BINDER CUMULATIVE % STRAIN

MIX % STRAIN AT VARIOUS TEST CYCLES
68 kPa STRESS, 64° C TEST TEMP

100TH MIX TEST CYCLE; R²=0.908
5TH MIX TEST CYCLE; R²=0.943
200TH MIX CYCLE; R²=0.951

PG 67-22
PG 76-22 RET
PG 76-22 SBS
PG 67-22

MIX % STRAIN AT VARIOUS TEST CYCLES
68 kPa STRESS, 64° C TEST TEMP

BINDER CUMULATIVE STRAIN @ 100 CYCLES

PG 67-22
PG 76-22 RET
PG 76-22 SBS
PG 67-22
PG 76-22 RET
PG 76-22 SBS
PG 67-22
PG 76-22 RET
PG 76-22 SBS
PG 67-22
RELATIONSHIP BETWEEN TIME TO 5% STRAIN FOR MIX USING DSR DYNAMIC CREEP TEST AS A FUNCTION OF BINDER CUMULATIVE % STRAIN

\[ Y = 3.064 \times 10^7 \times (X^{-1.395}) \]

Coefficient of Determination: 0.9894

PG 67-22

PG 76-22 RE’ PG 64-22 BASE

PG 76-22 SBS

PG 76-22 RET

PG 67-22
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MIXTURE STATIC CREEP TEST COMPARISON
ALL MIXES USED THE SAME AGGREGATE

COMPARISON OF STATIC CREEP TEST RESULTS USING AN APPLIED STRESS OF 50 kPa AT 67°C
STRESS IS APPLIED UNTIL SPECIMEN FAILS IN TERTIARY FLOW
TORSIONAL FLOWTIME TO FAILURE OF MIX, 67° C, 50 KPa CORRELATED TO CUMULATIVE STRAIN OF RTFO RESIDUE DETERMINED AT 67° C & 50 Pa STRESS

Log10(Y) = 4.75718 - 1.01992Log10(X)
EMS = 0.0127014
R² = 0.958
FLOW TIME TO FAILURE CORRELATED TO SHRP STIFFNESS

Log\(_{10}(Y) = 0.825992 + 1.69477\log_{10}(X)\)
EMS = 0.115605
\(R^2 = 0.619\)
RELATIONSHIP OF $G'/\sin(\delta)$ TO THE PHASE ANGLE OF THE BINDER DETERMINED AT 64°C & 10 RAD/SEC

Log10($Y$) = 2.26676 - 0.0207382X
EMS = 0.0267549
$R^2 = 0.591$
RELATIONSHIP BETWEEN CUMULATIVE STRAIN RESULTS AND BINDER PHASE ANGLE DETERMINED FROM SHRP TEST AT 64° C AND 10 RAD/SEC

Log10(Y) = -0.606195 + 0.0552516X
EMS = 0.0288422
R² = 0.905
CORRELATION BETWEEN MIX FLOW TIME TO FAILURE AND THE CUMULATIVE % STRAIN OF THE BINDER

\[ Y = 1065 \times \exp(-0.001382 \times X) \]

Coefficient of Determination : 0.8340

Intersection of tangents occurs at approximately 1215 % strain which calculates to a 200 sec flow time.
Comparison of 2 aggregate structures with 3 binders

- Mix types
  - e-3
    - 75 gyration @ $N_{\text{design}}$
    - 1 to < 3 million ESAL’s
  - PG 58-28, PG 64-34, PG 70-28; 6.0% binder content
  - E-10
    - 100 Gyrations @ $N_{\text{design}}$
    - 3 to < 10 million ESAL’s
    - PG 58-28, PG 70-28; 5.4% binder content
CUMULATIVE CREEP TEST RESULTS, RTFO, 58°C, 300 Pa STRESS

- PG 58-28 RTFO RESIDUE @ 58°C
- PG 64-34, RTFO RESIDUE @ 58°C
- PG 70-28 RTFO RESIDUE @ 58°C
MATHY PARKING LOT 70-28 UNAGED, A-2, E-10, 3.5AV, 68 KPA, 58°C, CUM CRT

- MATHY PARKING LOT 70-28 UNAGED, A-2, E-10, 3.5AV, 68 KPA, 58°C,
- MATHY PARKING LOT, 58-28 UNAGED B12, E-3, 3.6AV, 68 KPA, 58°C,
- MATHY PARKING LOT, 58-28 UNAGED D2, E-10, 3.5AV, 68 KPA, 58°C,
- MATHY PARKING LOT, 64-34 UNAGED B2, E-3, 3.5AV, 68 KPA, 58°C,
- MATHY PARKING LOT, 70-28 UNAGED 1C2, E-3, 3.5AV, 68 KPA, 58°C,
DSR Repeated Creep-Recovery Test
68 KPA, 58°C

% Strain at 30th Cycle

- MPL 58-28, E-3: 2.79
- MPL 58-28, E-10: 1.24
- MPL 64-34, E-3: 0.40
- MPL 70-28, E-3: 0.42
- MPL 70-28, E-10: 0.42
- STH72 64-34, E-1: 2.72
- USH35&54, 58-28, E-3: 8.51

1 sample, others broke before 30th cycle

3.5% AV
DSR Repeated Creep-Recovery Test
68 KPA, 58°C

% Strain at 30th Cycle

1 sample, others broke before 30th cycle

MPL 58-28, E-3
MPL 58-28, E-10
MPL 64-34, E-3
MPL 70-28, E-3
MPL 70-28, E-10
STH72 64-34, E-1
USH35&54, 58-28, E-3

3.5% AV
7.0% AV

MTE
Recommendations

- Use 10 mm thick slices to minimize testing variability
- Test should be conducted at the appropriate climatic temperature, not the PG Grade temperature
- Use 68 kPa stress level whenever possible, lower stress levels can be used but relationship to 68 kPa results is not known
- Dynamic creep testing should be used, especially for polymer modified mixes
Conclusions

• The DSR dynamic creep test can identify performance differences between
  – Aggregate structure
  – Mix type
  – Binder grades
  – Impact of polymer or other additives (fillers/fibers)
  – Service temperature variations

• The DSR dynamic creep test correlates well to the rutting behavior in the field for the two test road projects investigated (MNROAD & ALF)
CONCLUSION

- The DSR dynamic creep test results correlate well to SST RSCH results for the project investigated.
- Testing of field cores yields lower response values than testing lab specimens.
  - Due in part to differences in air voids.
- DSR creep testing of SMA mixes not yet as robust as testing of Superpave mixes.
  - Due to aggregate skeleton.
  - Inability to apply confining pressure.
CONCLUSION

• THE BINDER CUMULATIVE STRAIN RESULTS WERE PREDICTIVE OF DSR CREEP RESULTS FOR MIXTURES

– BINDER CUMULATIVE STRAINS BELOW 1500% MEASURED AT THE CLIMATE TEMPERATURE USING 300 Pa OF STRESS RESULTED IN MIXES WITH IMPROVED DYNAMIC CREEP TEST RESULTS COMPARED TO CONTROL BINDERS

– IT IS SUGGESTED TO USE A BINDER STRAIN OF \(< 2000\%\) AS A STARTING POINT TO BEGIN EVALUATING THE IMPACT OF BINDER STRAIN ON MIX PERFORMANCE
TO BE CONSIDERED

• The DSR dynamic creep test is suitable as a mix design tool, however more study needs to be conducted to determine appropriate response levels for field performance
  – Select a test response and monitor the field rutting behavior of mix
    • Time to 5% strain
    • Compliance or % strain at 100 or 200 seconds
    • Zero shear viscosity of mix at 100 or 200 cycles
    • Flownumber to tertiary failure
TO BE CONSIDERED

- The DSR dynamic creep test is suitable as a HMA QC tool. Volumetric QC specimens could be prepared for creep testing within a 6 hr time period
  - Creep response data available on the same day as mix laydown. Match with mix design values
  - Field lab installation is feasible, although most logically used on major projects
  - Equipment cost, including saws, is approximately $75,000
ACKNOWLEDGEMENTS

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Samples and Rutting Data

Kevin Stuart, FHWA
ALF Samples
END

If you were unable to obtain a CD copy and would like one, I can be reached at: greinke@mathy.com