Warm mix study with the use of wax modified asphalt binders

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Objectives

- To investigate the effect on rheology and performance of various warm mix additives with various was additives
Materials tested

0 Lion Oil PG 64-22
1 Romanta Normal Montan
2 Romanta Asphaltan A
3 Romanta Asphaltan B
4 Licomont BS 100
5 Sasobit
6 Luxco Pitch # 2
7 Alphamin GHP
8 Strohmeyer and Arpe Montan LGE
9 Astra Wax 3816D Microcrystalline

9 - Waxes
Test program

- Binder
  - M320 – Table 1 and 2
  - Binder master curves – BBR and DSR
  - BBR tests at different aging conditions (0, 2, 4, 8, 16 and 32 days)
  - MSCR

- Mixture
  - Mix BBR tests – 2 temperatures for limited mastercurves
  - Repeated creep tests
  - Fatigue – monotonic tests and repeated load
  - Master curves
Mix stiffness in BBR

- Tested BBR beams at varying ageing
- Analysis extended to use 1000 second data
- Removed early part of test data to avoid effects of non-instantaneous startup
Binder test data
PG grading – AASHTO M320
Viscosity changes

- Lion Oil PG 64-22
- Romania Normal Montan
- Romania Asphalitan A
- Romania Asphalitan B
- Licomont BS 100
- Sasobit
- Luxco Pitch #2
- Alphamin GHP
- Strohmeyer and Arpe Montan LGE
- Astra Wax 38/60 Microcrystalline

Viscosity at 135 °C, Pa.s

Viscosity Reduction, %
Binder – 0 day tests

- **RHEOLOGY ANALYSIS** in Abatech RHEA Software
- **RHEOLOGY OBSERVATIONS**
  - 6 (Luxco Pitch # 2) – has lower G* mastercurve
  - Significant difference in G* at lower end of frequency range
  - $\delta$ with various binders show some type of network at low frequencies, more significant in 2 (Romanta Asphaltan A), 3 (Romanta Asphaltan B), 4 (Licomont BS 100), 5 (Sasobit) and 7 (Alphamin GHP)
  - Judging from $\delta$ (*at low temp/high freq.*)
    - 6 (Luxco Pitch # 2) appears to have best relaxation properties
    - 9 (Astra Wax 3816D Microcrystalline) has worse relaxation properties
Master curve $E^*$, $T_{\text{ref}} = 25^\circ\text{C}$
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LOG-LINEAR SCALE

Frequency, rads/sec
Binder 1 – 0 days

Sample ID: B1-0-DSR BBR

Dynamic Mastercurve Tref = 25°C

1 Romanta Normal Montan

Legend
- Observed Data Points
- Computed Discrete Spectrum
- Complex Modulus
- Fitted Complex Modulus
- Phase Angle
- Fitted Phase Angle

Frequency, rad/sec

G', P'

Phase Angle, deg.
Binder 2 – 0 days

Sample ID: B2-0-DSR BBR

Dynamic Mastercurve Tref = 25°C

2 Romanta Asphalt A

Legend
- Observed Data Points
- Computed Discrete Spectrum
  - $g_i$, $1/\lambda_i$
  - Complex Modulus
  - Phase Angle
  - Fitted Complex Modulus
  - Fitted Phase Angle

Frequency, rad/sec

$G$, Pa

Phase Angle, deg.
Binder 3 – 0 days

Sample ID: b3-0-DSR BBR

Dynamic Mastercurve $T_{ref} = 25^\circ C$

3 Romanta Asphalt B

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Legend:
- Observed Data Points
- Complex Modulus
- Phase Angle
- Computed Discrete Spectrum
- $g_i, 1/\lambda_i$
- Fitted Complex Modulus
- Fitted Phase Angle

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Frequency, rad/sec

$G'$, $P_a$

Phase Angle, deg.
Binder 4 – 0 days
Binder 5 – 0 days

Dynamic Mastercurve $T_{ref} = 25^\circ C$

**Legend**
- Observed Data Points
- Computed Discrete Spectrum
  - $g_i$, $1/\lambda_i$
  - Complex Modulus
  - Phase Angle
- Fitted Complex Modulus
- Fitted Phase Angle
Binder 6 – 0 days

Sample ID: B6-0-DSR BBR
Dynamic Mastercurve Tref = 25°C

6 Luxco Pitch # 2
Binder 7 - 0 days

Sample ID: B7-0-DSR BBR

Dynamic Mastercurve Tref = 25°C

7 Alphamin GHP

Legend
- Observed Data Points
- Computed Discrete Spectrum
- Complex Modulus
- Fitted Complex Modulus
- Phase Angle
- Fitted Phase Angle
Binder 8 - 0 days

Sample ID: B8-0-DSR BBR

Dynamic Mastercurve Tref = 25°C

8 Strohmeyer and Arpe Montan LGE

Legend
- Observed Data Points
- Computed Discrete Spectrum
- Complex Modulus
- Fitted Complex Modulus
- Phase Angle
- Fitted Phase Angle

Frequency, rad/sec
Binder 9 - 0 days

Sample ID: b9-0-DSR BBR

Dynamic Mastercurve Tref = 25°C

9 Astra Wax 3816D Microcrystalline
Jnr

- Tests conducted at three temperatures
  - 58, 64, 70°C
- Jnr evaluated at 3.2 kPa and 4 (1/kPa)
- Elastic recovery – v. high for some products at low stress levels
- Certain products are more stress dependent than conventional binders
2 - % Recovery 58 to 64°C
Recovery – near grade temp

- Lion Oil PG 64-22
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- Romanta Asphalt B
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- Sasobit
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- Alphamin GHP
- Strohmeyer and Arpe Montan LGE
- Astra Wax 3816D Microcrystalline

% Recovery vs. Jnr 1/kPa
Jnr at 64°C

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Jnr – near grade temperature

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Stress kPa vs. Jnr 1/kPa
Jnr versus % recovery

% recovery

Jnr, 1/kPa

Elastic

Non-Elastic
PG grades – M320 Table 3
Difference in performance

- Binders grade different in Jr evaluation
- Can be as much ½ PG grade
- Early products that show network - 2 effected from 5
  - 2 (Romanta Asphaltan A)
  - 3 (Romanta Asphaltan B)
  - 4 (Licomont BS 100)
  - 5 (Sasobit)
  - 7 (Alphamin GHP)
- Suggests importance of Jr evaluation

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<td>8</td>
<td>2.31</td>
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<tr>
<td>9</td>
<td>0.16</td>
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Aged tests - binder
PG64-22 – aging to 32 days

-18°C

Stiffness, MPa

Time, seconds
Binder BBR S(t) at -12°C

Binder BBR Stiffness, -12°C, t = 60 seconds

Aging Time, days

Stiffness, MPa

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Binder BBR $S(t)$ at $-18^\circ C$
BBR data

- Aging data showed that the -18°C gave significantly more variability when compared to the -12°C data.
Mix test data
Mix BBR Data

- Data processed to produce equal-log scale representation with approximate linear double of scale
- Several cases exist which colder temperature is less stiff than matching warm temperature data
Removal of early BBR data

- Data before 8-seconds is removed from analysis in similar manner to binder BBR data
- Shows fitted (polynomial) approach versus direct calculation
- Data before t=8 seconds is less reliable

![Graph showing stiffness vs. time with data point corresponding to 8 seconds highlighted.](image-url)
Material 5 - Day 16

![Graph showing material properties over time. The graph plots stress (S(t), MPa) against time (t, seconds). There are different markers for different materials, with labels for each set of data points. The x-axis represents time in seconds, ranging from 0.1 to 1000, and the y-axis represents stress in MPa, ranging from 1000 to 100,000.]
Re-tests of Mix Beams

- Testing of beams before and after annealing
- Annealing conducted at 64\(^\circ\)C overnight
- 64\(^\circ\)C chosen since it represents day at likely high-pavement temperature
1 - PG64-22 - retests
5 - Sasobit - retests
9 - Astra Wax
Results from retesting

- In all cases healing overnight increased the stiffness of the mastercurve.
- Most significantly – it resulted in the BBR stiffness of the -18°C isotherm being greater than the -12°C isotherm – as expected!
- The “healing” is more significant for the -18°C isotherm.
Repeated creep torsion bar

- Tests at two stress levels
  - 34 and 68 kPa
- Temperature = 64°C
- 5 replicates - used results of middle 3
- Analysis of various parameters
Repeated load tests

- Concept used in early 1990’s with cyclic deformation tests
- Based on same concept as used for fatigue analysis
- Very easy to use to limit test time - stop test at say 5% less than max
Jnr Grade vs. Repeated Creep

\[ y = 9 \times 10^{-7}x^{4.6648} \]
\[ R^2 = 0.7589 \]

\[ y = 6 \times 10^{-9}x^{5.1932} \]
\[ R^2 = 0.7633 \]

\[ y = 6 \times 10^{-9}x^{5.4748} \]
\[ R^2 = 0.8031 \]
Jnr at 64°C vs. Repeated Creep

Flow Number (modified)

1/slope

min dy/dx

y = 467.69x^{-0.5795}
R^2 = 0.743

y = 302.97x^{-0.6394}
R^2 = 0.734

y = 112.64x^{-0.6689}
R^2 = 0.7603
Fatigue

- Work conducted by MTE Services, Inc
- Monotonic loading test
- Sand cylinders repeated loading
Monotonic tests

![Bar chart showing relative area value for 3% Wax Blends](chart.png)
Monotonic tests

ADDED SOME 1% Wax Blends

- control
- Montan
- Asphalt A
- Asphalt B
- Licomont BS 100
- Sasobit
- Luxco Pitch
- Alphamin
- Montan LGE
- Astra 3816

AREA UNDER MONOTONIC TEST CURVE AT PEAK VALUE
AREA 1% BLENDS
Sand Cylinder Fatigue

Tests at 600, 1000 and 1800 Microstrain

Generally all modifiers give poorer performance but difference is very small compared to other materials and typical “noise” in fatigue sets.
Master curves on sand-mix
Merged MasterCurve Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0° #1
Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7.1% AV, -30 to 60.0°
Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7.1% AV, -30 to 60.0°
Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7.1% AV, -30 to 60.0°
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G* (\(\omega\)) [Pa]
Summary – Binder tests

- Significant differences in PG grades with different modifiers
  - All had some loss of performance at low end of specification
- Master curves show different structures in binder – note low strain level
- Jnr – results show that binder is stress sensitive
  - Wax products generally vary more with stress level
  - Have apparently good behavior at low stress levels
  - As stress level increases performance drops
  - The wax materials are a non-elastic modifier
    - Note \( \delta \) can confuse the analysis such as used in some specifications
- Aging of BBR binder beams over extended time shows significant change in properties
  - Data at -12C was more in line with that expected
  - Data at -18C appears to be confounded
Summary – mix tests

- **BBR**
  - Avoid using early part of isotherm
  - Issues with -18C data after extended aging
  - Some damage/healing evident in data
  - Annealing at 64C showed that rankings could be restored to that expected
  - -18C is poorer than -12C data

- **Repeated creep**
  - Data lines up with Jnr results
  - Some suggestions for data analysis

- **Fatigue**
  - Monotonic tests show difference in performance
  - Preliminary – 1% and 3% wax show some different results
  - Repeated loading shows again significant differences – all waxes generally give lower performance but difference is small

- **Master curves**
  - Differences evident in G* master curves
  - Should be able to look at these combined with BBR master curves
What to do

- More work with 1% wax content
- Some additional analysis of data
  - Maybe combine $G^*$ and $S(t)$ master curves for mix to look at trends – do they match binder?
- DTT with notched specimens
- Develop report
Questions, comments and discussion – please !!??