Laboratory Mixing and Compaction Temperatures for Asphalt Binders

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• NCHRP 9-39
  – Dr. Randy West
• Bob McGennis, HollyFrontier Refining
• Member Companies of the Asphalt Institute
  – Technical Advisory Committee
Lab Mixing and Compaction Temperatures

• Background
  – MS-2
    • Recommended laboratory mixing and compaction temperature ranges for Marshall mix design based on viscosity (Saybolt Furol) as early as 1962
      – Changed to absolute and kinematic viscosity in 1974
      – 170 ± 20 centistokes for mixing
      – 280 ± 30 centistokes for compaction
  – Purpose
    • normalize the effect of asphalt binder stiffness on mixture volumetric properties
      – Aggregate packing and available void space

Lab Mixing and Compaction Temperatures

• Background
  – Modified Asphalt Binders in the Superpave Mix Design System
    • Adopted old (Marshall) standard in 1993
      – 0.17 ± 0.02 Pa-s (mixing)
      – 0.28 ± 0.02 Pa-s (compaction)
    • Manufacturer’s recommendation for modified asphalt binders
Lab Mixing and Compaction Temperatures

- Background
  - Modified Asphalt Binders in the Superpave Mix Design System
    - Produced lower air voids, higher density
      - Shear compaction with fixed angle, pressure
        » Not affected by mix stiffness (i.e., not significantly affected by temperature)
  - Short-term Mix Conditioning
    - Four hours at 135°C or two hours at compaction temperature
    - Different absorption?

NCHRP 9-39: Mixing & Compaction Temperatures

- Diagram showing viscosity (Pa.s) vs. temperature (°C) with compaction and mixing ranges indicated.
Background

• The Asphalt Institute equiviscous concept works well for unmodified, unfilled binders
• For most modified binders, the equiviscous concept results in excessive mixing and compaction temperatures:
  – Emission concerns
  – Binder degradation concerns
• Most specifying agencies have relied on binder suppliers to recommend appropriate temperatures.
  – No consensus exists on how that should be done

Does Temperature Matter?

• The literature indicates that…
  – SGC compaction process is insensitive to binder stiffness
    • the compactor operates in a constant strain mode
    • Therefore, compaction temperature has a negligible effect on volumetric properties.
  – Mechanical tests on HMA are affected by mixing and compaction temperatures
Lab Mixing and Compaction Temperatures

• NCHRP 9-10
  – Mixing and Compaction Temperatures for Modified Asphalt Binders
  – Task 9
    • High concern by SHA's
    • Unwilling to have to rely on manufacturer recommendations
    • Objective: Recommend new procedure
    • AAPT 2001 Paper – Zero Shear Viscosity
      – Khatri, Bahia, and Hanson

Research on Lab Mixing and Compaction Temperatures

• NCHRP 9-39, Procedure for Determining Mixing and Compaction Temperatures of Asphalt Binders in Hot Mix Asphalt
  – Purpose
    • Identify or develop a simple, rapid, and accurate laboratory procedure for determining the mixing and compaction temperatures of asphalt binder
NCHRP 9-39

• Candidate Methods for Determining Laboratory Mixing and Compaction Temperatures
  – Steady Shear Flow (SSF) method
    • Reinke
  – Phase Angle method
    • Casola

Laboratory Mixing and Compaction Temperatures

• Steady Shear Flow Test (Reinke)
  – Uses DSR
    • High shear stress sweep
      – 50 to 1000 Pa
      – 8 total data points
    • Multiple temperatures
      – 88°C to 112°C
    • Parallel Plate
      – 25 mm plates
      – 0.5 mm gap
Laboratory Mixing and Compaction Temperatures

- Steady Shear Flow (SSF) Test
  - Procedure
    - Start at 88°C, 50 Pa
    - 10-minute conditioning at each temperature
    - Conduct constant shear until steady state is achieved at each shear stress level
      - 12 second data sampling period
      - Steady state is achieved when three consecutive sampling periods generate viscosity values within 2%
      - 12 minute maximum time at any stress level
    - Repeat until maximum shear stress is conducted
    - Increment temperature by 6°C and repeat

SSF Procedure:
PG 64-34 (SBS-modified)
Steady Shear Flow Method

- Mixing Temperature
  \[ \text{Viscosity}_{\text{SS1000Pa}} = 0.17 \pm 0.02 \text{ Pa}\cdot\text{s} \]

- Compaction Temperature
  \[ \text{Viscosity}_{\text{SS1000Pa}} = 0.35 \pm 0.03 \text{ Pa}\cdot\text{s} \]

SSF Procedure:
PG 64-34 (SBS-modified)

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<th>Viscosity, Pa·s</th>
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<td>58</td>
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<td>0.1</td>
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Mixing Range
Compaction Range

SSF 153°C mixing 143°C comp.
RV 195°C mixing 185°C comp.
NCHRP 9-39

• Determining the Laboratory Mixing and Compaction Temperature of Asphalt Binder Using a Dynamic Shear Rheometer (Casola)
  – DSR Mastercurve
    • 25 mm parallel plate
    • Minimum of three test temperatures
      – Reference temperature = 80°C
    • 31 frequencies
      – 0.1 to 100 rad/s
  – Determine frequency (at T<sub>ref</sub>) where phase angle (δ) equals 86 degrees

<table>
<thead>
<tr>
<th>Test Temperature, °C</th>
<th>PG 64</th>
<th>PG 70</th>
<th>PG 76</th>
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<tr>
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</table>

May be required to achieve a phase angle of 75 degrees
May be required to achieve a phase angle of 88 degrees
• Mixing Temperature
  – Mixing Temperature (°F) = $325\omega^{-0.0135}$

• Compaction Temperature
  – Compaction Temperature (°F) = $300\omega^{-0.012}$

These relationships are purely empirical
NCHRP 9-39: Recommendations

• Option of Steady Shear Flow or Phase Angle Methods
  – Both methods provide reasonable mixing and compaction temperatures (i.e. generally consistent with field experience) for modified and unmodified binders
  – Both are simple, use existing equipment, and take less than one hour of hands free operation.
    • For highly modified binders, an environmental temperature chamber or Peltier plate is needed.

• Option of Steady Shear Flow or Phase Angle Methods
  – Both methods will provide similar results for most modified binders.
    • The SSF method will yield lower mixing and compaction temperatures than the Phase Angle Method for lower PG grades.
      – Differences of 7°C for mixing temperature and 10°C for compaction temperature may be observed.
AI Guidance Document

- For unmodified\textsuperscript{1} asphalt binders…
  - laboratory mixing and compaction temperature may be determined using:
    1. the rotational viscosity procedure (AASHTO T316) at two test temperatures; or
    2. the rotational viscosity procedure at 135°C in combination with the dynamic shear rheometer procedure (AASHTO T315) at a single test temperature

\textsuperscript{1} Also identified as: (a) AASHTO M320 asphalt binders that have a useful temperature interval (UTI) of < 92 degrees; or (b) AASHTO MP19 asphalt binders with an “S” designation
AI Guidance Document

• For modified asphalt binders...
  – laboratory mixing and compaction temperature may be determined using:
    (1) the DSR Phase Angle Procedure; or
    (2) the DSR Steady Shear Flow Procedure, as recommended by NCHRP Report 648.

In addition, the recommendation of the supplier may be used, as many suppliers have determined mixing and compaction temperatures for their individual products that have proven to be appropriate.

2 Also identified as: (a) AASHTO M320 asphalt binders that have a useful temperature interval (UTI) of ≥ 92 degrees; or (b) AASHTO MP19 asphalt binders with an “H”, “V”, or “E” designation

Lab Mixing and Compaction Temperatures: Caveats

• Regardless of the selected procedure, recommend that laboratory mixing temperatures do not exceed 177°C (350°F).

• Not applicable to asphalt binders that have been modified with ground tire rubber (GTR)
  – The NCHRP 9-39 research did not evaluate GTR-modified asphalt binders
  – Unknown how the recommended procedures will work with this class of modified asphalt binder.
  – Refer to other existing practices for GTR-modified asphalt binders.
Project Mixing and Compaction Temperatures

- Laboratory mixing and compaction temperatures
  - intended for determining design volumetric properties of the asphalt mixture
  - not intended to represent actual mixing and compaction temperatures at the project level.

- Project-level mixing and compaction temperatures
  - Mixing temperature
    • can best be defined as the temperature at which the aggregate can be sufficiently and uniformly coated.
    • As with the lab temperatures, the mixing temperature should not exceed 177°C (350°F).
  - Compaction temperature
    • usually in the range of 135-155°C (275-310°F)
    • based solely on the ability of the compaction equipment available for the project to achieve adequate in-place density.
More Information?

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Thanks!