asphalt institute

Laboratory Mixing and Compaction Temperatures for Asphalt Binders

Mike Anderson

North Central Asphalt User Producer Group Meeting
15 February 2012
Indianapolis, IN

Acknowledgments

asphalt institute

- DTFH61-08-H-00030
  - Cooperative Agreement between the FHWA and the Asphalt Institute
- NCHRP 9-10
  - Dr. Hussain Bahia
- 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 Marshall Mix Design System
    - Produced higher air voids, lower density
      - Impact compaction with fixed energy input
        - » Affected by mix stiffness = *ƒ* (temperature/binder stiffness)
    - Should optimum asphalt binder content be adjusted?
      - Volume of asphalt for durability shouldn't be affected by binder stiffness
      - Higher asphalt binder content may be unnecessary

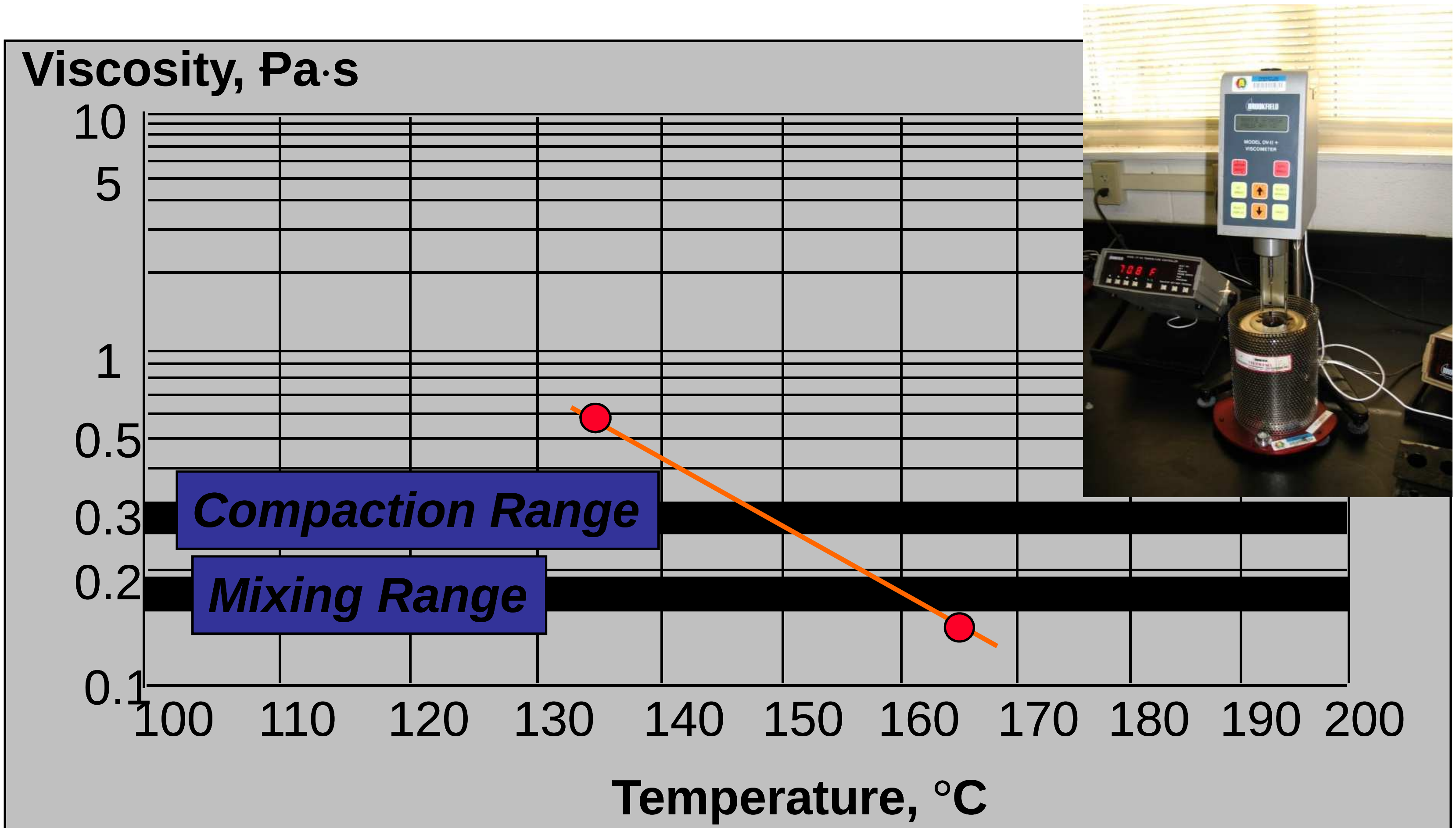
Lab Mixing and Compaction Temperatures

- 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℃ or two hours at compaction temperature
      - Different absorption?

NCHRP 9-39:
Mixing & Compaction Temperatures



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
      - Khatri, Bahia, and Hanson

NCHRP 9-10 Approach

- Zero Shear Viscosity (ZSV)
  - Believed to be related to rutting
    - European research
  - Accounts for effects of shear rate dependence
    - Simulates low shear in SGC

NCHRP 9-10: Determining ZSV

- Rotational Viscosity
  - 3 Temperatures
    - 105, 135, 165 used in research
  - Multiple shear rates
    - Typically 6.8 s^{-1} (20 rpm)
- Cross-Williamson Model
  - Excel spreadsheet using SOLVER function
    - multiple iterations
  - Executed at each temperature to determine ZSV

NCHRP 9-10: Determining Temperatures

- Plot ZSV vs. Temperature
  - Determine Mixing Temperature
    - ZSV = 3 Pa-s
  - Determine Compaction Temperature
    - ZSV = 6 Pa-s

NCHRP 9-10: Mixing and Compaction Temperatures

asphalt institute

- PG 76-22 (SBS)

– Conventional	202C	185C
– ZSV	165C	157C

- PG 76-22 (LDPE)

– Conventional	192C	176C
– ZSV	163C	155C

NCHRP 9-10: Determining Temperatures (Simplified)

- Simplified Procedure
  - Perform Rotational Viscosity Testing
    - 6.8 s^{-1} (20 RPM for Spindle 27)
    - Two temperatures
      - 135°C and ??
  - Determine Mixing and Compaction Temperatures
    - Mixing Temperature at which Viscosity = 0.75 Pa-s
    - Compaction Temperature at which Viscosity = 1.4 Pa-s

Research on Lab Mixing and Compaction Temperatures

asphalt institute

- 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 Report 648

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

asphalt institute

- Steady Shear Flow Test (Reinke)
  - Uses DSR
    - High shear stress sweep
      - 50 to 1000 Pa
      - 5 data points per log decade
        - » 8 total data points
    - Multiple temperatures
      - 88℃ to 112℃
    - Parallel Plate
      - 25-mm plates
      - 0.5 mm gap

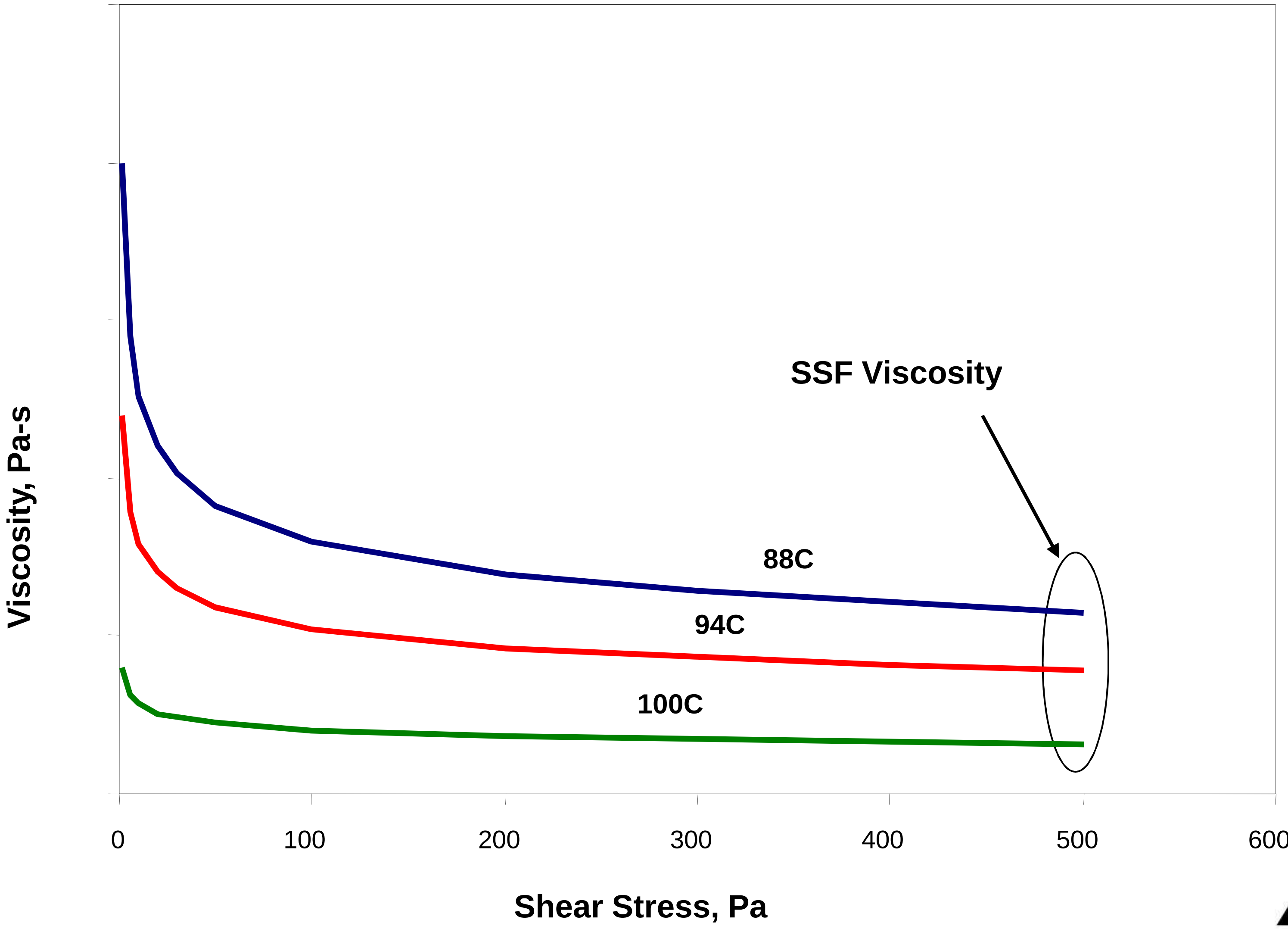
Laboratory Mixing and Compaction Temperatures

asphalt institute

- Steady Shear Flow (SSF) Test
  - Procedure
    - Start at 88℃, 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℃ and repeat

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

asphalt institute



Steady Shear Flow Method

- Mixing Temperature

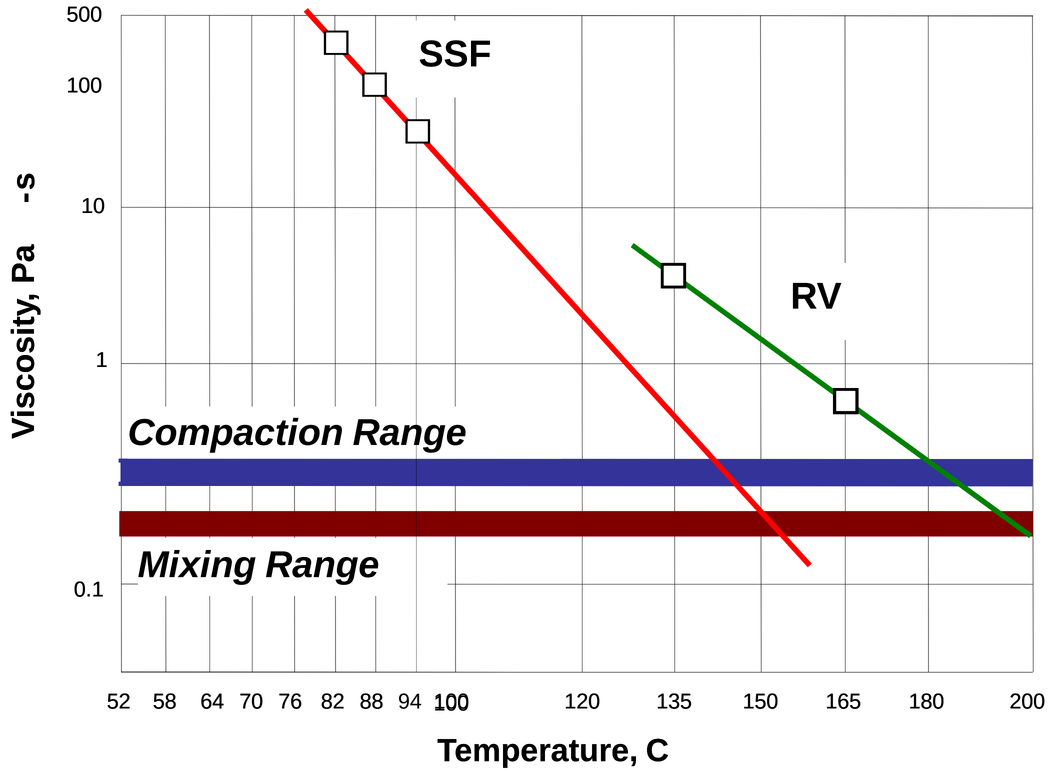
  $\text{Viscosity}_{SS1000Pa} = 0.17 \pm 0.02$ Pa·s

- Compaction Temperature

  $\text{Viscosity}_{SS1000Pa} = 0.35 \pm 0.03$ Pa·s

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

asphalt institute



SSF 153C mixing 143C comp.

RV 195C mixing 185C comp.

NCHRP 9-39

- Determining the Laboratory Mixing and Compaction Temperature of Asphalt Binder Using a Dynamic Shear Rheometer: The Casola Method
  - DSR Mastercurve
    - 25-mm parallel plate
    - Minimum of three test temperatures
      - Reference temperature = 80℃
    - 31 frequencies
      - 0.1 to 100 rad/s
  - Determine frequency (at T_{ref}) where phase angle (δ) equals 86 degrees

Table 1: Recommended Testing Temperatures (from Draft Test Procedure)

NCHRP 9-39

Test Temperature, ºC	High Temperature Grade (M320 Table 1)		
	PG 64	PG 70	PG 76
50	xx	xx	
60	X	xx	xx
70	X	X	xx
80	X	X	X
90	xxx	X	X
100		xxx	X
110		xxx	xxx
120			xxx
130			xxx

xx	May be required to achieve a phase angle of 75 degrees
xxx	May be required to achieve a phase angle of 88 degrees

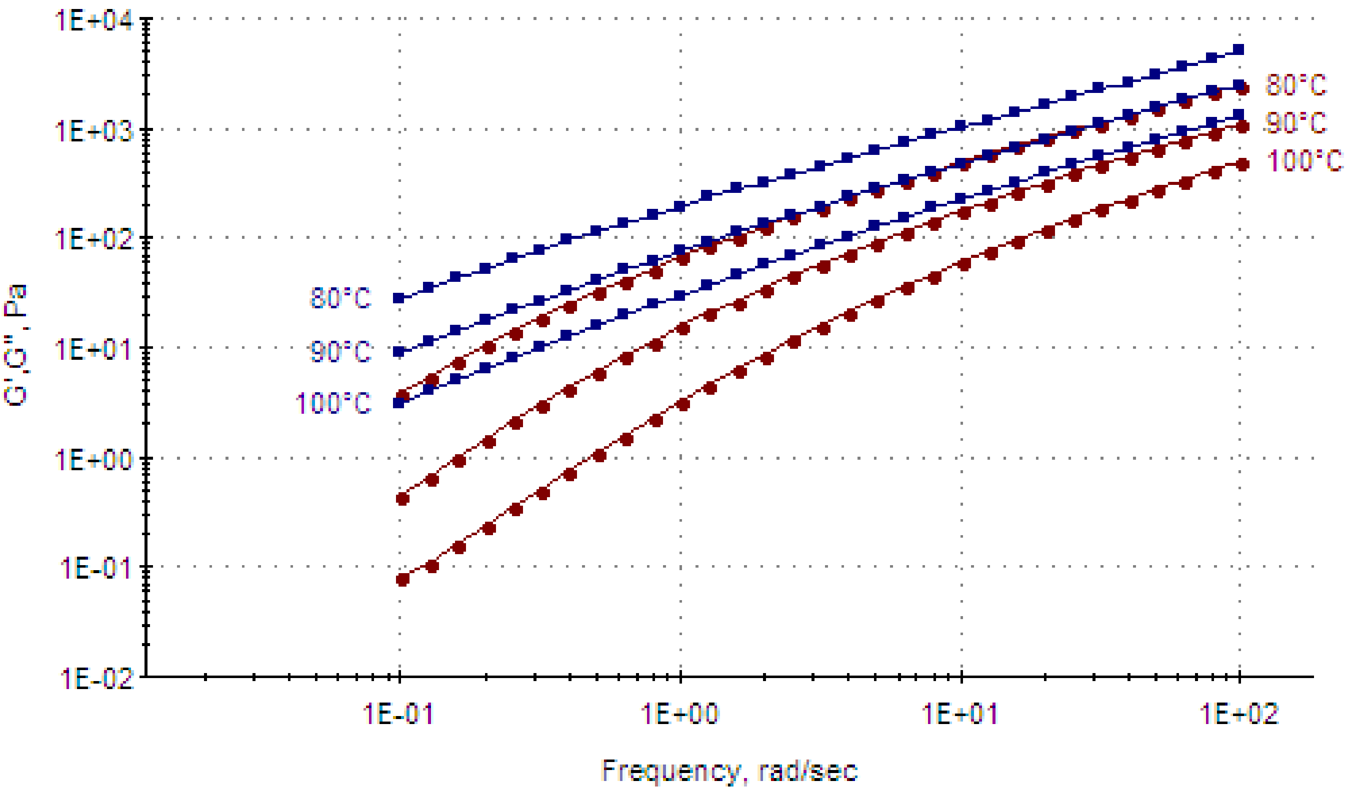
NCHRP 9-39

- Mixing Temperature
  - Mixing Temperature (°F) = $325\ \omega^{-0.0135}$
- Compaction Temperature
  - Compaction Temperature (°F) = $300\ \omega^{-0.012}$

These relationships are purely empirical

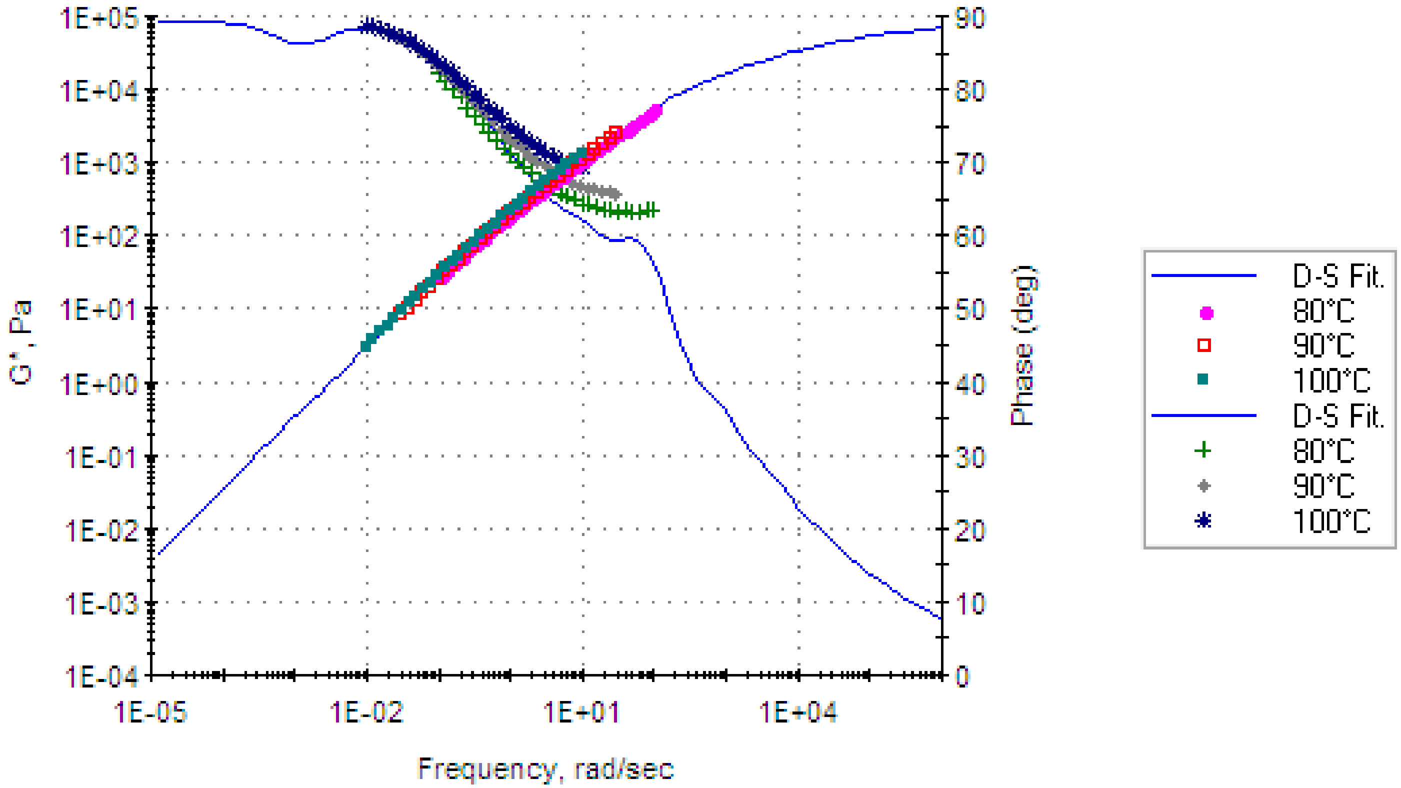
NCHRP 9-39 Phase Angle Method: Isotherms (PG 76-28)

asphalt institute



NCHRP 9-39 Phase Angle Method: MasterCurve (PG 76-28)

asphalt institute



NCHRP 9-39 Phase Angle Method: MasterCurve (PG 76-28)

G(t)	3.85E+02
J(t)	1.02E-03
m(ω)	9.39E-01
G*(ω)	1.41E+01
d(ω)	86.02
G'(ω)	9.74E-01
G"(ω)	1.40E+01
G*/sin(δ)	1.41E+01
J*(ω)	7.12E-02
J'(ω)	4.93E-03
J"(ω)	7.10E-02
Eta'(ω)	2.92E+02
ω	0.048 rad/s

Mixing Temperature

339°F

170°C

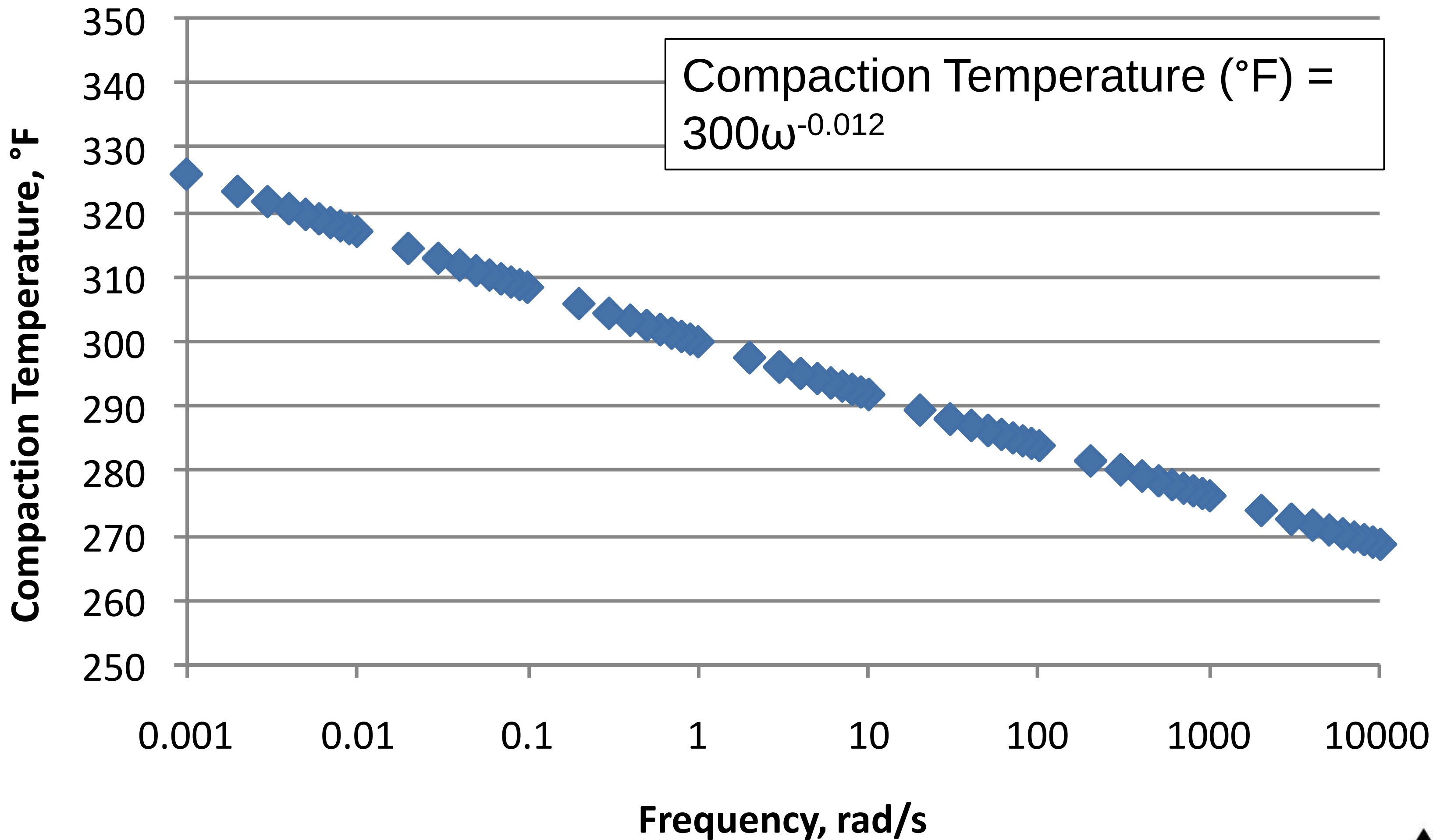
Compaction Temperature

311°F

155°C

NCHRP 9-39 Phase Angle Method

asphalt institute



NCHRP 9-39: Recommendations

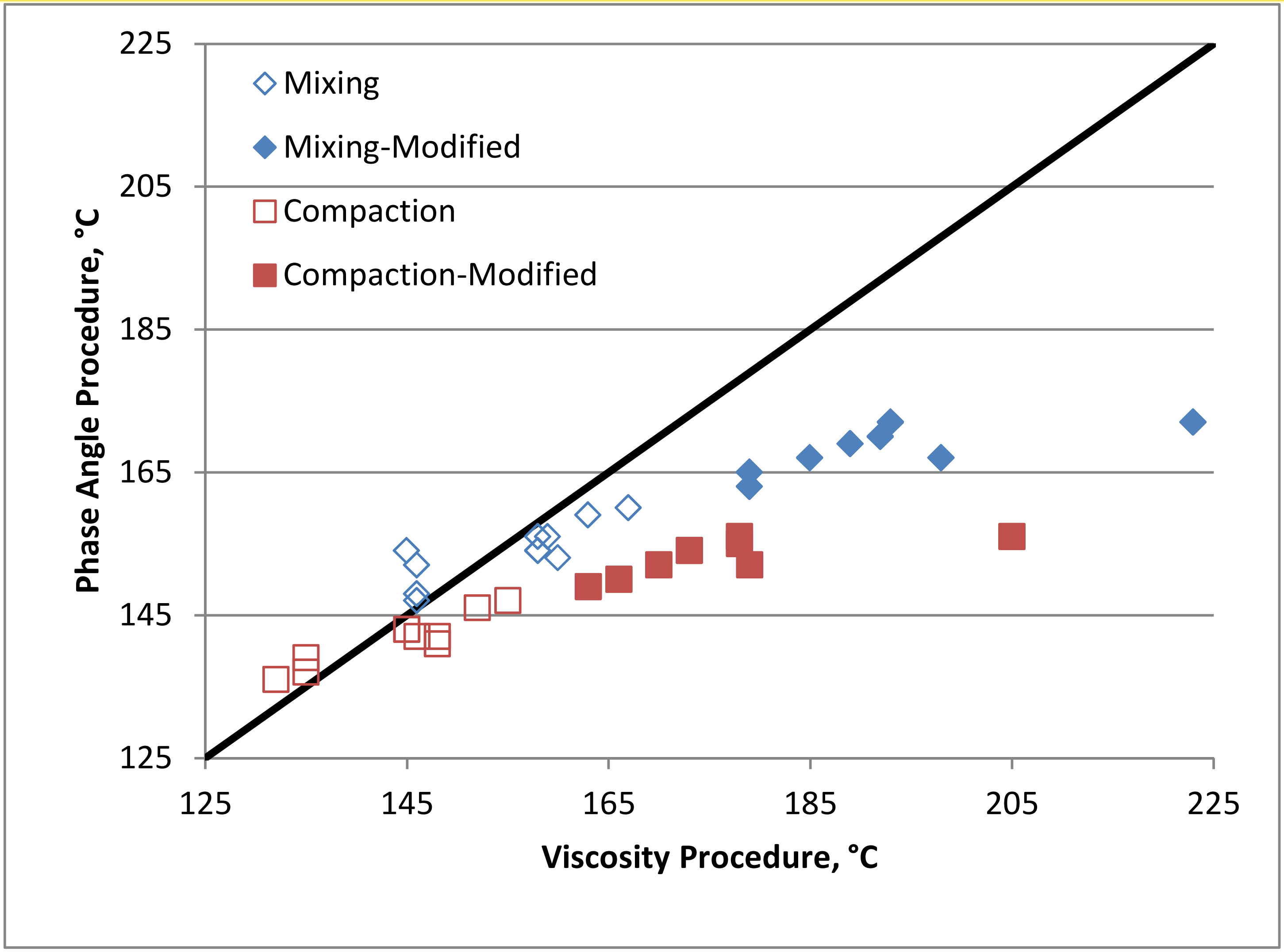
- Option of Steady Shear Flow or Phase Angle Methods
  - Both methods provide reasonable mixing and compaction temperatures (i.e. generally consistent with field experience) for modified and unmodified binders
  - Both are simple, use existing equipment, and take less than one hour of hands free operation.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

NCHRP 9-39: Recommendations

- 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℃ for mixing temperature and 10℃ for compaction temperature may be observed.

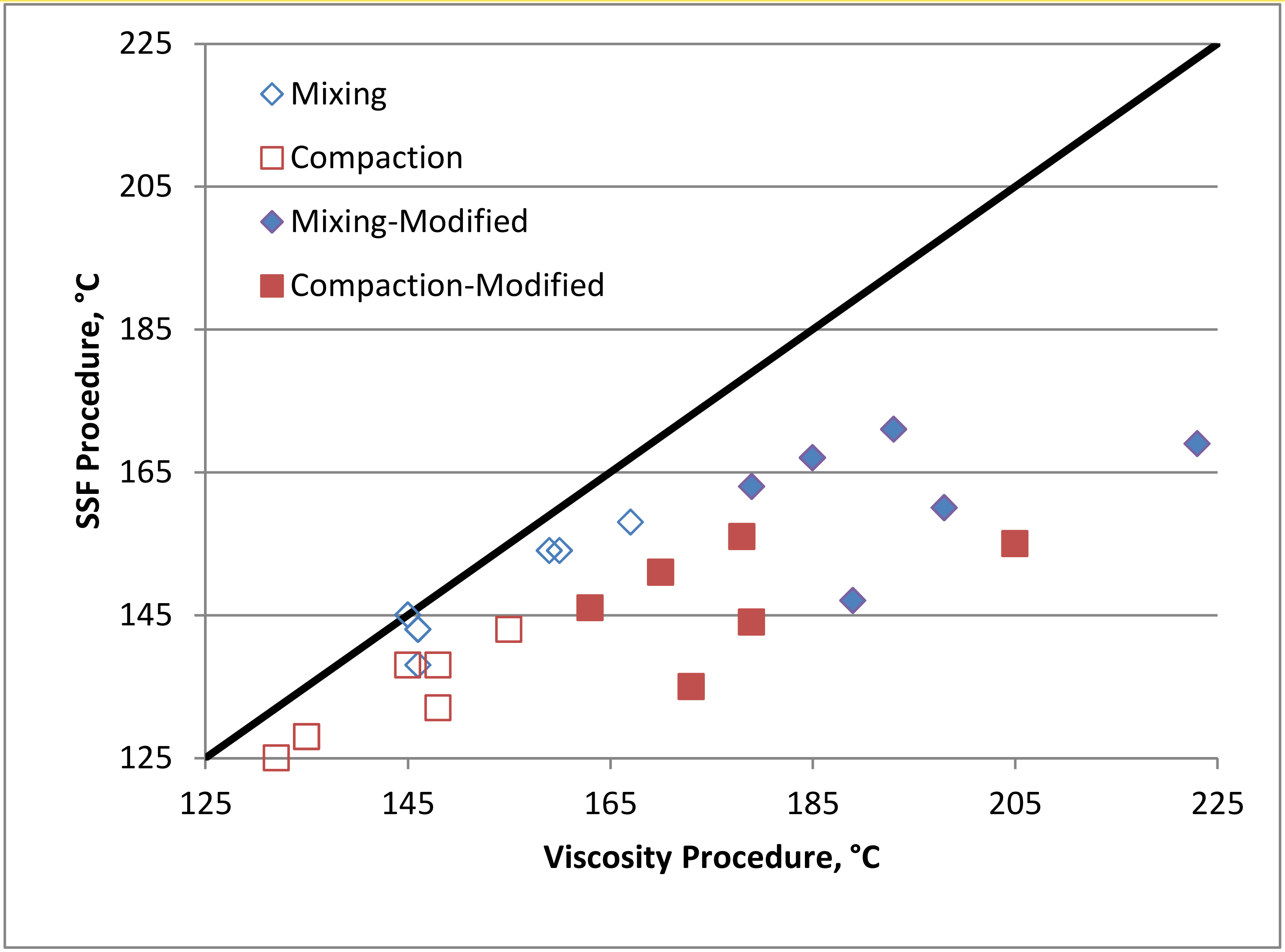
NCHRP 9-39 Data Comparison
(with added binders)

asphalt institute



NCHRP 9-39 Data Comparison
(with added binders)

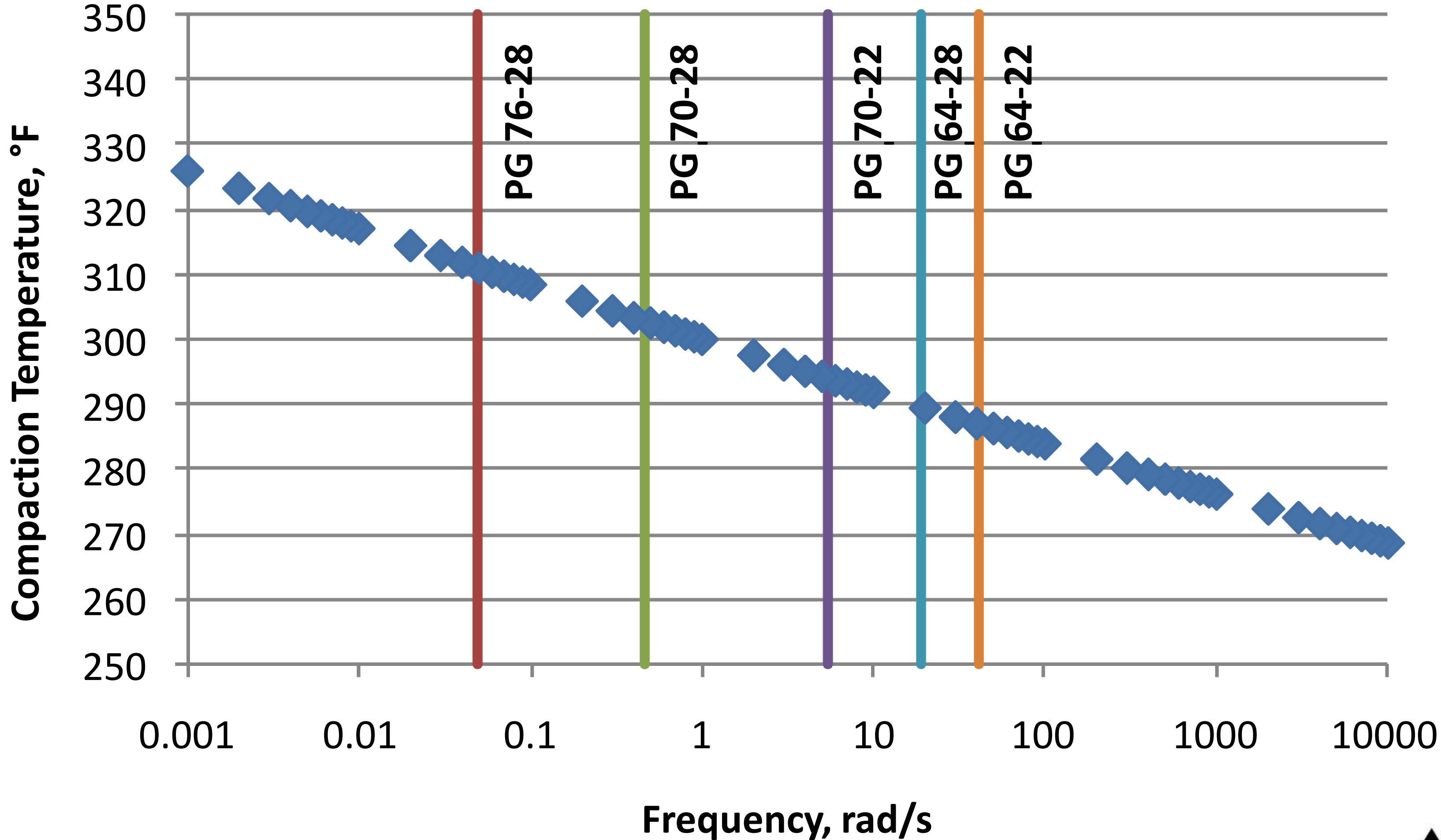
asphalt institute



NCHRP 9-39 Phase Angle Method: Calculated Temperatures

	ω (δ=86°)	Mixing Temperature	Compaction Temperature
PG 64-22	41	309°F (154°C)	287°F (142°C)
PG 64-28	19	312°F (156°C)	290°F (143°C)
PG 70-22	5.5	318°F (159°C)	294°F (146°C)
PG 70-28	0.47	328°F (165°C)	303°F (150°C)
PG 76-28	0.048	339°F (170°C)	311°F (155°C)

NCHRP 9-39 Phase Angle Method



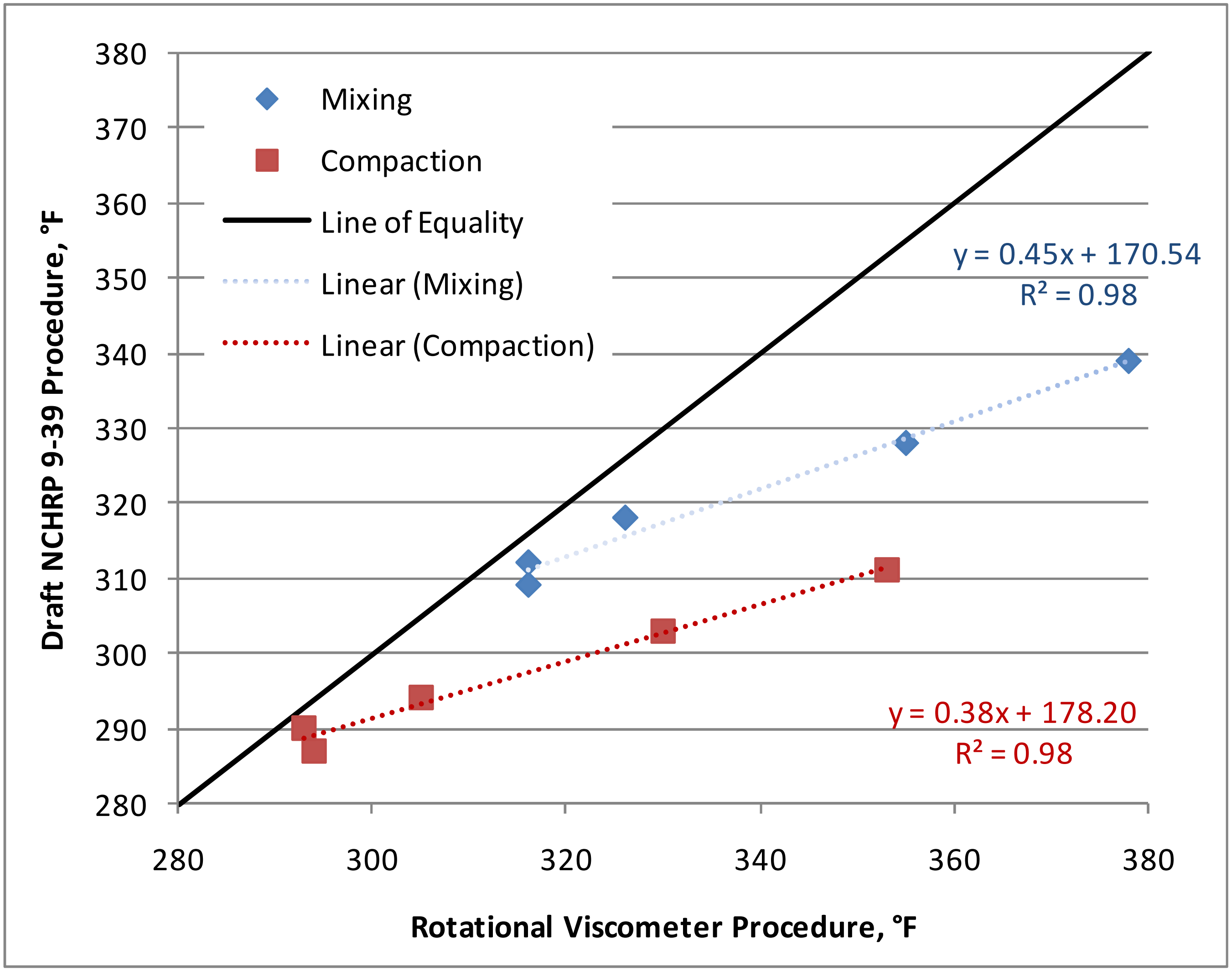
Standard Mixing and Compaction Temperatures

asphalt institute

	Rotational Viscosity (Pa-s)		Mixing Temperature, °F		Compaction Temperature, °F	
	135°C	165°C	Range	Midpoint	Range	Midpoint
PG 64-22	0.445	0.130	311-322	316	289-298	294
PG 64-28	0.430	0.130	310-322	316	288-298	293
PG 70-22	0.620	0.160	321-332	326	301-309	305
PG 70-28	1.047	0.282	349-361	355	325-335	330
PG 76-28	2.082	0.475	372-385	378	348-358	353

Comparison

asphalt institute



Comparison of Mixing and Compaction Temps

asphalt institute

Grade	NCHRP 9-39 via AI M	NCHRP 9-39 via AI C	Holly Method M	Holly Method C	ASTM D2493 via AI M	ASTM D2493 via AI C
PG 64-22	309	287	311	289	316	294
PG 64-28	312	290	309	288	316	293
PG 70-22	318	294	327	307	326	305
PG 70-28+	328	303	325	304	355	330
PG 76-28	339	311	336	313	378	353

NCHRP 9-39 via NMDOT

318 294

NCHRP 9-39 Phase Angle Method: Summary

- Need testing script to run multiple frequencies, temperatures
- Testing time
  - 40 minutes per temperature
    - Not considering conditioning time

NCHRP 9-39 Phase Angle Method: Summary

- Data Issues
  - May need to truncate data for mastercurve
    - Requires some judgment
  - 80°C may be too high for unmodified PG 64 or softer

AI Guidance Document

- For unmodified[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℃ in combination with the dynamic shear rheometer procedure (AASHTO T315) at a single test temperature

[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[2] 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 Mixing and Compaction Temperatures

asphalt institute

- 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℃ (350℉).
  - Compaction temperature
    - usually in the range of 135-155℃ (275-310℉)
    - based solely on the ability of the compaction equipment available for the project to achieve adequate in-place density.

More Information?

Contact:

Mike Anderson
Asphalt Institute
859-288-4984
manderson@asphaltinstitute.org

Thanks!