Recent National Research on Asphalt Binders:
Findings and Implementation

Mike Anderson, Asphalt Institute

November 16, 2022

2022 Annual Meeting – Raleigh, North Carolina

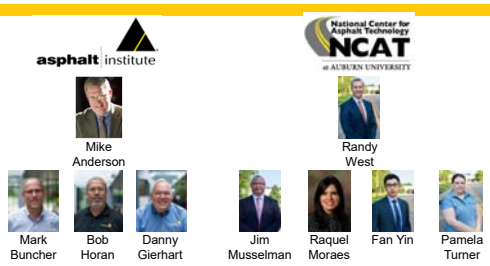
Acknowledgments

- National Cooperative Highway Research Program (NCHRP)
  - 20-44(19) Project Panel
    - **Ed Harrigan, NCHRP Program Officer**
    - Roberto Barcena, NCHRP Program Officer
- Research Teams for NCHRP Projects 09-52, 09-54, 09-56A, 09-59, 09-60, and 09-61
- Member Companies of the Asphalt Institute

Disclaimer

This investigation is being sponsored by TRB under the NCHRP Program. Data reported are work in progress. Contents of this research may have not been reviewed by the project panel of NCHRP, nor do they constitute a standard, specification, or regulation.

NCHRP 20-44(19) Research Implementation Team



NCHRP 20-44(19)

- "Implementation of Proposed AASHTO Standards for Asphalt Binders and Mixtures"
- Project Objectives
  - Facilitate actions needed to assure the timely adoption by the AASHTO Committee on Materials and Pavements (COMP) of the proposed AASHTO standards produced in the following NCHRP Projects:
    - **09-52, 09-54, 09-56A, 09-59, 09-60,** and **09-61**
    - others later designated by NCHRP

Asphalt Binder Research

- **NCHRP 09-59**
  - Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
- **NCHRP 09-60**
  - Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
- **NCHRP 09-61**
  - Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures

NCHRP 09-59

Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Don Christensen (PI, AAT) and Nam Tran (NCAT)
  - Objectives
    - determine asphalt binder properties that are significant indicators of the fatigue performance of asphalt mixtures
    - identify or develop a practical, implementable binder test (or tests) to measure properties that are significant indicators of mixture fatigue performance for use in a performance-related binder purchase specification such as AASHTO M 320 and M 332
  - NCHRP Report 982
    Relationships Between the Fatigue Properties of Asphalt Binders and the Fatigue Performance of Asphalt Mixtures

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Recommendations
    - The current intermediate binder specification parameter, G*sin δ, should be replaced by the Glover-Rowe parameter (GRP) determined at a frequency of 10 rad/s. The maximum allowable value for GRP after 20-hour PAV aging should be 5,000 kPa.
    - GRP = $G^*(\cos\delta)^2 / (\sin\delta)$

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Recommendations
    - The binder fatigue specification should include an allowable range for the Christensen-Anderson R-value of from 1.5 to 2.5, after 20-hour PAV aging.
    - The R-value should be calculated using the following equation:

$$R = log(2)\frac{log(S/3{,}000)}{log(1-m)}$$

Where

R = Christensen-Anderson R (rheologic index)
S = BBR creep stiffness at 60 seconds, MPa
m = BBR m-value at 60 seconds

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance

t Time (s)	P Force (mN)	d Deflection (mm)	Measured Stiffness (MPa)	Estimated Stiffness (MPa)	Difference (%)	m-value	R-value
8.0	978	0.228	346	346	0.000	0.282	1.96
15.0	977	0.273	289	288	-0.346	0.306	1.93
30.0	976	0.341	231	231	0.000	0.332	1.91
60.0	976	0.433	182	182	0.000	0.357	1.91
120.0	975	0.560	140	141	0.714	0.383	1.91
240.0	974	0.734	107	107	0.000	0.409	1.91

$$R = \log(2) * \frac{\log\left(\frac{S}{3000}\right)}{\log(1-m)} = \quad 0.30 * \frac{log\left(\frac{182}{3000}\right)}{log(1-0.357)} = 1.91$$

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Recommendations
    - The current intermediate test temperatures in AASHTO M 320 and M 332 should be replaced by temperatures based on the low PG of the asphalt binder instead of the current temperatures which use the average of the High and Low PG temperatures plus 4°C.

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Recommendations

Low PG	Intermediate Test Temperature, °C
-10	29
-16	27
-22	25
-28	22
-34	19

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Expected Impacts
    - GRP is determined using T 315 on PAV-aged material at the same loading frequency (10 rad/s). No (or minimal) impact on lab operations expected.

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Expected Impacts
    - The impact of the change to GRP will more significantly affect asphalt binders with lower phase angles, causing them to fail the specification criterion that they may have previously passed.

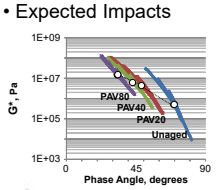
NCHRP 09-59

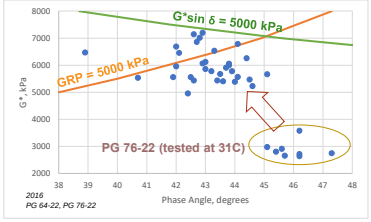
- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Expected Impacts

G* (kPa)/δ (degrees)	GRP, kPa			G*sin δ, kPa		
	8000	7000	6000	8000	7000	6000
40	7303	6391	5478	5142	4500	3857
42	6603	5777	4952	5353	4684	4015
45	5657	4950	4243	5657	4950	4243
47	5088	4452	3816	5851	5119	4388
50	4315	3776	3236	6128	5362	4596

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Expected Impacts





NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Expected Impacts

High PG	PG 52						PG 58					PG 64						PG 70					PG 76				
Low PG	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34
≤ 5000 kPa	DSR G*sin δ (Dynamic Shear Rheometer), AASHTO T 315																												
	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16	34	31	28	25	22	19	37	34	31	28	25
	29	27	25	22	19			27	25	22	19		29	27	25	22	19		29	27	25	22	19		29	27	25	22	19

Testing at Warmer Temperature

Testing at Colder Temperature

NCHRP 09-59

- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Expected Impacts
    - The estimated impact on lab operations should be very low as the principal findings from the research include:
      - calculating a new parameter from the standard AASHTO T 315 (DSR) test for use in M 320 and M 332;
      - calculating a new parameter from the standard AASHTO T 313 (BBR) test for use in M 320 and M 332;
      - changing the intermediate test temperature in for use in M 320 and M 332 for PAV DSR testing; and
      - incorporating new specification criteria for BBR testing.

Asphalt Binder Specification Objectives

- **NCHRP 09-59 Objectives**
  - determine asphalt binder properties that are significant indicators of the **fatigue** performance of asphalt mixtures
  - identify or develop a practical, implementable binder test (or tests) to measure properties that are significant indicators of mixture fatigue performance for use in a performance-related binder purchase specification such as AASHTO M 320 and M 332
- **NCHRP 09-60 Objectives**
  - propose changes to the current performance-graded (PG) asphalt binder specifications, tests, and practices to remedy gaps and shortcomings related to the premature loss of asphalt pavement **durability in the form of cracking and raveling**.

NCHRP 09-60

Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Research Team
    - Jean-Pascal Planche (PI, WRI), Michael D. Elwardany (WRI), Donald Christensen (AAT), Gayle King (Consultant), Carolina Rodezno (NCAT),and Snehalata Huzurbazar (Consultant/Statistician)

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Objectives
    - propose changes to the current performance-graded (PG) asphalt binder specifications, tests, and practices to remedy gaps and shortcomings related to the premature loss of asphalt pavement durability in the form of cracking and raveling.
  - Status
    - The draft final report for Phases I and II will be published in conjunction with that for the prospective Phase III.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations
    - Recommend adding ΔT_c to AASHTO M 320 and M 332 as a specification parameter.
      - Relates to the relaxation properties of unmodified binders and generally relates to the colloidal structure of the asphalt binder.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations
    - The use of ΔT_c alone can underestimate the performance of some complex binders such as polymer modified asphalt (PMA) binders
      - Due to an inability to capture failure properties outside the linear viscoelastic (LVE) domain such as strength/strain tolerance of PMAs.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations
    - To capture strength/strain tolerance, it is recommended to use the Asphalt Binder Cracking Device (ABCD) to determine the critical cracking temperature, T_{cr}
      - AASHTO T 387, Determining the Cracking Temperature of Asphalt Binder Using the Asphalt Binder Cracking Device (ABCD)

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations
    - T_{cr} is used with the temperature at which BBR Stiffness at 60 seconds of loading is equal to the specification value of 300 MPa ($T_{c,S}$)
    - A new parameter, ΔT_f is determined as the difference between $T_{c,S}$ and T_{cr}
      - Higher values of ΔT_f are associated with better asphalt binder strength/strain tolerance relative to its stiffness.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations
    - New revised specification:
      - Uses standard RTFO/PAV20 aging
      - Uses BBR data to determine $T_{c,S}$, $T_{c,m}$ and ΔT_c.
      - Uses ABCD to calculate T_{cr}

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations

$\Delta T_c < -6°C$	FAIL
$\Delta T_c > -2°C$	PASS
$-6°C < \Delta T_c < -2°C$	TBD

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations

$-6°C < \Delta T_c < -2°C$ TBD

ABCD test is used to determine T_{cr} and, subsequently, ΔT_f.

NCHRP 09-60

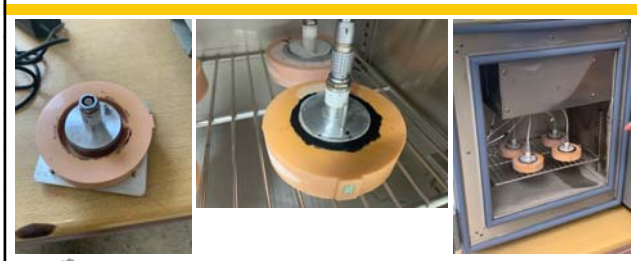
- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Recommendations

    $-6°C < \Delta T_c < -2°C$ TBD

    ABCD test is used to determine T_{cr} and, subsequently, ΔT_f.

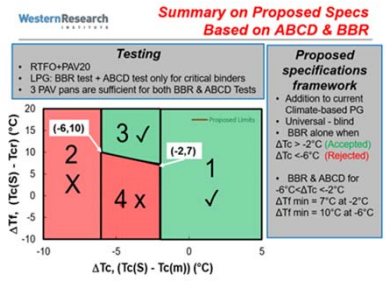
    For PAV20 asphalt binders, ΔT_f must be greater than a specified value from 7 to 10°C as a function of the ΔT_c value to meet the specification.

AASHTO T 387



Photos taken at Ohio DOT Office of Materials Management

NCHRP 09-60



NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Expected Impacts
    - The determination of ΔT_c requires testing at two or more BBR temperatures. This may be an operational challenge for user agencies who are most often just verifying the grade of the asphalt binder.

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Expected Impacts
    - The determination of ΔT_f requires the use of the ABCD test to first determine T_{cr}.
    - Estimated equipment cost is likely to be in the range of $40,000 to $50,000.

NCHRP 09-60

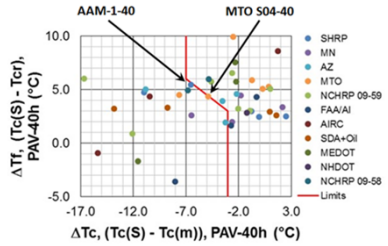
- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Expected Impacts
    - The use of the ABCD test with BBR testing means that 1-2 additional pans of PAV-aged asphalt binder may be needed.

NCHRP 09-60

- Expected Impacts
  - The use of ΔT_f in the manner proposed – as an additional test when routine testing indicates that the specification is not met – is similar to the way in which the Direct Tension test can be used in AASHTO M 320 Table 1.
    - Footnote g in AASHTO M 320 Table 1

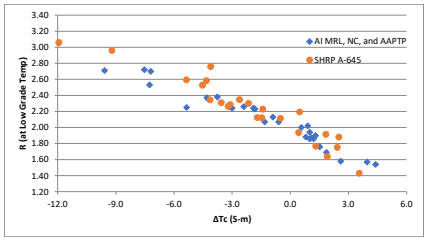
NCHRP 09-60

- Expected Impacts



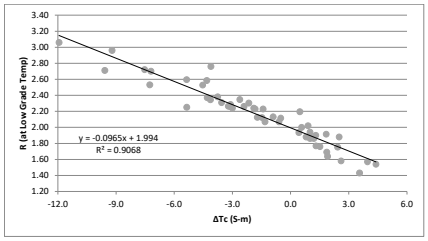
NCHRP 09-59 and NCHRP 09-60

- Relationship between **R** (09-59) and **ΔTc** (09-60)

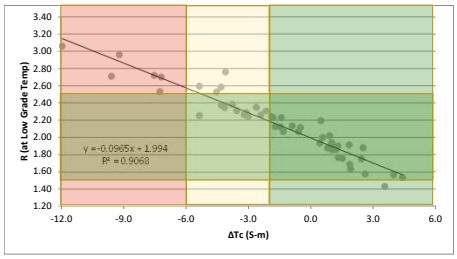


NCHRP 09-59 and NCHRP 09-60

- Relationship between **R** (09-59) and **ΔTc** (09-60)



NCHRP 09-59 and NCHRP 09-60



NCHRP 09-61

Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Research Team
    - Ramon Bonaquist (PI, AAT), Jeramie J. Adams (WRI), and David A. Anderson (Consultant)

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Objectives
    - develop practical laboratory aging methods to accurately simulate the short-term (from production to placement) and long-term (in-service) aging of asphalt binders.
    - determine the relationship between different methods of laboratory aging of asphalt binders and the actual aging that occurs during mixture production, transport, and placement as well as during the service life of the pavement structure.
  - NCHRP Report 967
    Asphalt Binder Aging Methods to Accurately Reflect Mixture Aging

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Key Findings/Recommendations
    - The recommendation for short-term conditioning of asphalt binders is to continue to use AASHTO T 240
      - Film thickness and its renewal during the test depend on the consistency of the asphalt binder, but…
      - The properties of residue from AASHTO T 240 agree reasonably well with the properties of asphalt binder recovered from mixtures subjected to short-term conditioning in accordance with NCHRP 09-52

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Key Findings/Recommendations
    - The recommendation for long-term conditioning of asphalt binders is that changing the operating parameters of the PAV (AASHTO R 28) can produce residue that reasonably simulates near-surface aging after 10 years in-service.
      - Changes will generally require thinner films and high temperatures in the PAV.

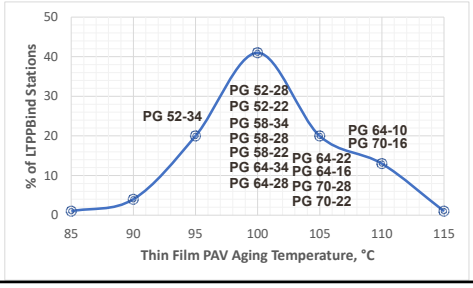
NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Key Findings/Recommendations
    - Use PAV procedure with the standard 20-hr aging at 2.1 MPa pressure but only 12.5 grams of asphalt binder in the pan (instead of 50 grams)
      - Calibrated results to the properties of recovered asphalt binders from 26 LTPP pavement sections where original binder and cores from 8 to 16 years in-service were available.
    - PAV temperature needed depends on the average of the 98 percent reliability high and low pavement temperature.

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Recommendations
    - Continue to use RTFO for short-term aging of asphalt binders
    - If 20-hour PAV is to be used then no changes recommended
    - If longer aging simulation is required then instead of 40-hour PAV using 50 grams of asphalt binder at 90, 100, or 110°C use 20-hour PAV with 12.5 grams of asphalt binder at varying temperature based on high and low pavement temperature.

NCHRP 09-61



NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Expected Impacts
    - No impact on lab operations for agency and industry labs for short-term aging
      - Continue to use RTFO procedure
      - Labs that experience asphalt binder loss during the conduct of AASHTO T 240 may need to consider changes in technique and/or training to minimize the occurrence of binder loss during the procedure.

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Expected Impacts
    - Depending on level of long-term aging desired, the PAV procedure could have an impact on lab operations.
      - The use of extended aging (40 hours in the standard PAV) impacts operations by requiring twice as long before aged residue can be obtained for intermediate and low temperature asphalt binder properties.
      - The reduction in film thickness in the pans from 3.1 millimeters (50 grams of asphalt binder) to 0.8 millimeters (12.5 grams of asphalt binder) allows the conditioning to be conducted using the standard time (20 hours) while still producing residue that has the same properties as the extended aging time (40 hours).

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Expected Impacts
    - The challenge with using thinner films is maintaining a consistent film thickness.
      - Requires very level pans that are not warped.
      - Operationally could pose a significant challenge for labs to routinely ensure levelness.
      - An extra levelling step conducted at a higher temperature under inert atmosphere may be needed for some modified asphalt binders.

NCHRP 09-61

- Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
  - Expected Impacts
    - The last recommended change was to use a varying PAV temperature as a function of the high and low PG temperature of the asphalt binder.
    - The recommended temperatures are 85-115°C in 5°C increments based on the asphalt binder PG.

Future Performance-Graded (PG) Asphalt Binder Specifications

Conceptual PG Asphalt Binder Specification (Standard PAV)

Performance Grade	PG 64						PG 70					
	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40
Average 7-day max pavement design temp, °C	<64						<70					
Design low pavement temperature, °C	>-10	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40
Tests on Residue from Pressure Aging Vessel (R 28)												
PAV aging temperature, °C	100						100 (110)					
Dynamic shear, T 315 G* (cos δ)² / sin δ maximum value 5,000 kPa, at 10 rad/s and test temperature, °C	29	27	25	22	19	17	29	27	25	22	19	17
Creep stiffness, T 313 Stiffness, maximum value 300 Mpa m-value, minimum value 0.30, at 60 sec and test temperature, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30
Creep stiffness, T313 R=log(2) log(S/3,000)/log(1-m) at 60 sec and specified test temperature minimum / maximum	1.50/2.50											
ΔT_c $T_{c,S} - T$	≥ -2.0[m]											
ΔT_f[m] $T_{c,S} - T_{cr}$	$\Delta T_{f,min} = \frac{22 - 3 * \Delta T_c}{4}$											

[m] If ΔT_c is greater than or equal to -2.0 then the determination of ΔT_f is not required. If ΔT_c is between -2.0 and -6.0 then ΔT_f may be determined. In that case, if ΔT_f exceeds the minimum value the sample is considered to meet the ΔT_c requirement.

National Research on Asphalt Binders

- **NCHRP 09-59**
  - Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
    - Recommend Glover-Rowe Parameter (GRP) on PAV-aged Asphalt Binder instead of G*sin δ
      - $G^*\cos^2\delta/\sin\delta \leq 5000$ kPa at 10 rad/s and intermediate temperature
    - Recommend R-value calculated from BBR data as additional parameter for durability
      - $1.50 \leq R \leq 2.50$
    - Recommend intermediate temperatures to be based only on low temperature grade rather than as a function of high and low temperatures

National Research on Asphalt Binders

- **NCHRP 09-60**
  - Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
    - Recommend using ΔT_c as added parameter for durability, relaxation
      - ΔT_c minimum of -6°C
        - $\Delta T_c < -2$°C requires passing value of ΔT_f to qualify
        - Similar to Footnote g in AASHTO M 320 Table 1
      - ΔT_f determined using T_{cr} from ABCD and $T_{c,S}$ from BBR

National Research on Asphalt Binders

- **NCHRP 09-61**
  - Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures
    - No change in RTFO procedure
      - Note elevation change in new version of AASHTO T 240
    - No change in PAV procedure for standard long-term aging
    - If considering extended aging (to simulate 40-hour PAV), use…
      - Thinner film in PAV pan (12.5 grams)
      - 20 hours, 2.1 MPa air pressure
      - Revised temperature based on average of 98% high and low PG
        - 5°C increments

Thanks!

- Questions or Comments?

Mike Anderson
manderson@asphaltinstitute.org
859.288.4984 office
502.641.2262 cell