Project No. 20-44(19)

Implementation of Proposed AASHTO Standards for Asphalt Binders and Mixtures

FINAL REPORT

Prepared for the

National Cooperative Highway Research Program (NCHRP)
Transportation Research Board
of
The National Academies of Sciences, Engineering, and Medicine

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May 4, 2023

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DISCLAIMER

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ABSTRACT

This report documents the results of a study to evaluate six NCHRP research projects with the goal of assisting the AASHTO Committee on Materials and Pavements (COMP) in understanding the principal research findings and proposed AASHTO standards produced in NCHRP Projects 09-52, 09-54, 09-56A, 09-59, 09-60, and 09-61. By understanding the technical basis supporting the research findings and proposed standards, identifying potential gaps in research that could affect implementation, and assessing the impact of the adoption of the research findings and standards on user agency and industry lab operations, the information provided in this report has facilitated, and can continue to facilitate, implementation of the proposed new and revised standards as desired by the AASHTO COMP Technical Subcommittees.

CHAPTER 1 BACKGROUND

The objective of the NCHRP 20-44(19) research implementation project was to facilitate actions needed to assure the timely adoption by the AASHTO Committee on Materials and Pavements (COMP) of the proposed AASHTO standards produced in NCHRP Projects 09-52, 09-54, 09-56A, 09-59, 09-60, 09-61, and others later designated by NCHRP.

Research Implementation Project Tasks

The following tasks were identified to assist in achieving the project objective:

- Task 1 Conduct an independent assessment of the technical basis for the proposed new and revised AASHTO standards.
- Task 2 Identify gaps in supporting data that must be addressed before the proposed standards are submitted to COMP.
- Task 3 Identify and resolve any conflicts between the requirements of the various standards.
- Task 4 Assess the impact of the standard's adoption on state DOT and industry operations.
- Task 5 Submit a consolidated, coordinated report to COMP Technical Subcommittees 2b, 2c, and 2d that provides the proposed standards from the five projects with supporting commentary. Conduct a webinar to brief the subcommittees on the proposals. Attend the annual COMP meeting and make a presentation to each subcommittee on the relevant proposed standards. If requested, brief industry groups (e.g., the National Asphalt Pavement Association and the Asphalt Institute) on the proposals and their potential impacts on industry operations.
- Task 6 Provide technical support to COMP Technical Subcommittees 2b, 2c, and 2d during their review and balloting process. Assist the subcommittees to resolve negatives and obtain any needed information from the research contractors.
- Task 7 Submit a final report that documents results, summarizes findings, draws conclusions, and presents the Task 5 consolidated report as amended by Task 6. An appendix to the report shall include electronic files of all data used in the project and the results of the analyses conducted with the data.

Research Implementation Team Members

The NCHRP 20-44(19) Research Implementation Team included members from the Asphalt Institute and the National Center for Asphalt Technology (NCAT). Mike Anderson was the Principal Investigator for the project and served as leader of the Asphalt Institute team. Randy West was leader of the NCAT team. Team members are shown in **FIGURE 1**.

FIGURE 1. NCHRP 20-44(19) Research Implementation Team Members

Research Implementation Project Budget and Timeline

The NCHRP 20-44(19) Research Implementation Project was initiated in May 2020 with an expected duration of 24 months, ending in May 2022. The project was extended six months to allow for review of the NCHRP 09-56A draft final report (which wasn't available to the team until June 2022) and attend/present at the first in-person annual meeting of the AASHTO Committee on Materials and Pavements (COMP) since August 2019.

The budget for the project is shown in **TABLE 1**.

TABLE 1. NCHRP 20-44(19) Budget

Project Activity	Cost, $
Labor	
Asphalt Institute	60,138
National Center for Asphalt Technology	51,128
SUBTOTAL	111,266
Travel	
Asphalt Institute	
Project Team Meeting (AI-NCAT)	3,200
AASHTO COMP Annual Meeting(s)	2,700
National Center for Asphalt Technology	
AASHTO COMP Annual Meeting(s)	2,700
SUBTOTAL	8,600
TOTAL	**119,866**

CHAPTER 2 FINDINGS

Research Projects Evaluated by the NCHRP 20-44(19) Team

TABLE 2 shows the NCHRP projects evaluated by the NCHRP 20-44(19) Research Implementation Team and the assigned leaders of the working group. The leaders were responsible for coordinating the review of each project although any of the team members could also provide input.

TABLE 2. NCHRP Projects Evaluated and Working Group Assignments

NCHRP Project No.	Title	Research Implementation Team Working Group Leaders
09-52	Short-Term Laboratory Conditioning of Asphalt Mixtures	Randy West (Lead) and Jim Musselman
09-54	Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction	Fan Yin (Lead) and Raquel Moraes
09-56A	Identifying Influences on and Minimizing the Variability of Ignition Furnace Correction Factors	Danny Gierhart (Lead) and Bob Horan
09-59	Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance	Mike Anderson (Lead) and Mark Buncher
09-60	Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications	Mike Anderson (Lead) and Mark Buncher
09-61	Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures	Raquel Moraes (Lead) and Pamela Turner

The Research Implementation Team evaluated each of the projects using the guidance in Tasks 1-4 and developed a Consolidated Technical Report in July 2021. The Consolidated Technical Report was revised in October 2022 after the draft final report from the NCHRP 09-56A project was made available and evaluated. The Revised Consolidated Technical Report is included as an Appendix.

The detailed evaluation for each research project is shown in the Revised Consolidated Technical Report. Shown in the following is a summary of the research projects and status of implementation of the research findings.

NCHRP 09-52 Short-Term Laboratory Conditioning of Asphalt Mixtures

The objectives of the project were to:

1. Develop a laboratory short-term aging protocol for loose mix prior to compaction to simulate the aging and asphalt absorption of an asphalt mixture as it is produced in a plant and then loaded into a truck for transport.
2. Develop a laboratory long-term aging protocol to simulate the aging of the asphalt mixture through its initial period of performance.
3. Determine the effects of the following variables on aging: WMA technology, aggregate asphalt absorption, plant temperature, plant type, presence of recycled materials, and asphalt source.

The research was led by Principal Investigator David Newcomb (Texas A&M Transportation Institute) and generated two NCHRP Reports. In NCHRP Report 815, the research team recommended changes to the short-term oven aging procedure (STOA) in *AASHTO R 30* to include:

- fixing the compaction temperatures at 116°C (240°F) for WMA and at 135°C (275°F) for HMA.
- conditioning the sample for 2 hours at the compaction temperature regardless of whether the sample is being prepared for volumetric mix design or performance testing.

In NCHRP Report 919, the follow-up research indicated that the long-term oven aging (LTOA) procedure in *AASHTO R 30* – aging of compacted specimens for 5 days at 85°C (185°F) in a forced draft oven – only simulated approximately 1-2 years in service. The research recommended replacing the current LTOA procedure in AASHTO R 30 with aging of loose mix under the same conditions – 5 days at 85°C (185°F) in a forced draft oven – before compaction for performance testing. This level of aging – using loose mix – was expected to simulate 7-14 years in service depending on the climate in which the mix was placed.

Implementation Activities

The NCHRP 20-44(19) Research Implementation Team worked with a Task Force from Technical Subcommittees 2c and 2d to revise *AASHTO R 30*. The revised version of the practice was approved by AASHTO and was published in August 2022 with the following changes:

- the compaction temperature is established as 116°C (240°F) for WMA and at 135°C (275°F) for HMA, regardless of the PG of the asphalt binder used.
- the loose mix sample is to be conditioned in a forced draft oven 2 hours at the appropriate compaction temperature regardless of whether the sample is being prepared for volumetric mix design or performance testing.

The LTOA procedure was left unchanged, recognizing that a future new standard may be needed to incorporate the findings from NCHRP Report 919 as well as the research from the NCHRP 09-54 project which was specifically focused on long-term conditioning of asphalt mixtures.

NCHRP 09-54 Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction

The objectives of the project were to develop a calibrated and validated procedure to simulate the long-term aging of asphalt mixtures for performance testing and prediction.

The research was led by Principal Investigator Richard Kim (North Carolina State University) and generated NCHRP Report 871 and NCHRP Report 973. The latter report addressed some areas for future research identified by the research team and refined some of the models developed in the former report but did not substantially change procedures and conclusions. Based on their work, the NCHRP 09-54 research team recommended changes to the long-term oven aging procedure (LTOA) for asphalt mixtures. It was envisioned that the new procedures would replace the LTOA procedure in *AASHTO R 30.*

The research team provided a draft standard practice for long-term conditioning of asphalt mixtures based on the depth from the surface of the asphalt mixture, climate in which the asphalt mixture would be expected to perform and the number of years of aging desired to be simulated.

Implementation Activities

The NCHRP 20-44(19) Research Implementation Team is continuing to work with a Task Force from Technical Subcommittee 2c to determine how best to incorporate procedures for long-term conditioning of asphalt mixtures. The current thinking is that the practice should be a stand-alone practice for long-term conditioning, removing any reference to LTOA from *AASHTO R 30* and creating a new standard practice including different long-term conditioning procedures. Conditioning procedures that may be included will be:

- compacted asphalt mixture specimens conditioned for 5 days at 85°C (185°F) in a forced draft oven before performance testing (original SHRP research procedure currently in *AASHTO R 30*).
- loose asphalt mixture samples conditioned for 5 days at 85°C (185°F) in a forced draft oven before compaction for performance testing (from NCHRP Report 919).
- loose asphalt mixture samples conditioned at 95°C (185°F) in a forced draft oven for a variable number of days – based on expected climate, depth from surface, and simulated aging desired – before compaction for performance testing (from NCHRP Report 871 and NCHRP Report 973).
- loose asphalt mixture samples conditioned for 20 hours in a forced draft oven at a variable temperature from 100-120°C (212-248°F) based on expected climate, before compaction for performance testing (from recent research by Texas A&M University).
- loose asphalt mixture samples conditioned for 8 hours at 135°C (275°F) in a forced draft oven before compaction for performance testing (from recent research by the National Center for Asphalt Technology).

The Climatic Aging Index (CAI) approach from the NCHRP 09-54 research, which uses the Enhanced Integration Climatic Model (EICM) for calculating the hourly pavement temperature as a required input, is the most comprehensive and flexible of the long-term conditioning procedures discussed above. However, its complexity means that it may not be selected for routine use. The researchers' decision to create maps of the United States showing oven aging duration at varying depths and aging times is a needed simplification.

NCHRP 09-56A Identifying Influences on and Minimizing the Variability of Ignition Furnace Correction Factors

The objectives of the research were to:

1. evaluate the effect of reducing the test temperature of *AASHTO T 308* method from 1000°F to 800°F.
2. determine the variability of asphalt content and aggregate correction factors of asphalt mixes containing high percentages of recycled asphalt materials (RAM) compared to those with virgin binder and aggregate only.
3. conduct an interlaboratory study that includes virgin mixes and mixes with high percentages of RAM to establish a revised precision statement for the AASHTO test procedure.

The research was led by Principal Investigator Carolina Rodezno (National Center for Asphalt Technology) and generated NCHRP Report 847 (for NCHRP 09-56) with publication of the final report for NCHRP 09-56A still pending as of this report.

Based on their work, the NCHRP 09-56A research team recommended changes to the asphalt ignition oven procedure, *AASHTO T 308*, as follows:
- Reduce the operating temperature of the ignition oven from 1000°C to 800C.
- Replace the current precision statement with a revised precision statement developed using a variety of asphalt mixtures that included virgin and recycled mixes, with different aggregates sources and nominal maximum aggregate sizes.

The basic changes recommended for *AASHTO T 308* include (1) changes in the recommended test temperature; and (2) a revised precision statement for asphalt content determination. This revised *AASHTO T 308* procedure is recommended for agencies that may deal with asphalt mixes containing with high recycled content materials and aggregates with high loss mass during ignition test. For agencies that do not deal with these two issues, the current precision statement may be adequate.

Implementation Activities

Since the draft final report was just made available in June 2022 and the final report publication is still pending there has been no effort to revise the *AASHTO T 308* standard. Recommended revisions will be shared with Technical Subcommittee 2c when the final report is published.

NCHRP 09-59 Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance

The objectives of this research were to:

1. determine asphalt binder properties that are significant indicators of the fatigue performance of asphalt mixtures.
2. 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*.
3. propose necessary changes to existing AASHTO specifications to incorporate the identified binder properties and their specification limits.
4. validate the binder fatigue properties, test(s), and changes to existing and/or proposed AASHTO test methods and specifications with data from field projects, accelerated loading facilities, or both, supplemented, as necessary, with data from additional laboratory-prepared specimens.

The research was led by Principal Investigator Don Christensen (Advanced Asphalt Technologies) and generated NCHRP Report 982. Based on the work of the research team, the following recommendations were made for revision to *AASHTO M 320* and *AASHTO M 332*:

- The current intermediate test temperatures in *AASHTO M 320* and *AASHTO 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.
- The current intermediate binder specification parameter, G*sin δ, should be replaced by the Glover-Rowe parameter (GRP = $G^*\cos^2\delta / \sin\delta$) determined at a frequency of 10 rad/s. The maximum allowable value for GRP after standard PAV aging (20 hours) should be 5,000 kPa.
- The binder fatigue specification should include an allowable range for the Christensen-Anderson R-value of from 1.5 to 2.5, after standard PAV aging. The R-value should be calculated using BBR test data and 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

Implementation Activities

The NCHRP 20-44(19) Research Implementation Team has presented the findings and recommendations of the research to AASHTO COMP Technical Subcommittee 2b. Presentations have also been made in various other industry meetings as discussed later. The Research Implementation Team has evaluated the research and potential impacts of changing the PG Asphalt Binder Specification and has the following assessment:

- New Intermediate Temperature Parameter, GRP, to Replace Existing Parameter, G*sin δ
  - The change from G*sin δ to the Glover-Rowe Parameter (GRP) – given as $G^*(\cos\delta)^2/\sin\delta$ – will have essentially no impact on lab operations since the test is the same, even if the calculations are different.
  - The GRP is more impacted by aging and a decrease in phase angle (δ) than the G*sin δ parameter, indicating better sensitivity to relaxation properties.

  - The change to GRP will accomplish what the most recent change to the PG specification sought to do (allowing G*sin δ values as high as 6000 kPa if the phase angle was 42 degrees or higher) – not reject asphalt binders with high stiffness but good relaxation properties, as demonstrated by higher values of δ – while also capturing the expected poorer performance of asphalt binders with low phase angles.
  - The variability of GRP is expected to be higher than the variability of G*sin δ due to the variability in δ appearing in three places in the GRP compared to one place in the G*sin δ parameter. The effect of this higher variability could be mitigated by allowing a higher specification value (e.g., 6,000 kPa instead of 5,000 kPa) so as not to unduly impact asphalt binders considered acceptable by the current specification.
- New Parameter for Durability, R
  - The R-value is an easy addition to *AASHTO M 320* and *AASHTO M 332* and will have essentially no impact on lab operations since it is calculated from BBR data used to grade the asphalt binder.
  - The variability appears reasonable.
  - R is highly correlated with ΔT_c. R values of 2.50, the recommended maximum allowable limit, correlate with ΔT_c values of approximately -5°C.
  - To minimize calculation errors, R should be calculated from BBR tests conducted at the Low PG test temperature (i.e., -12°C for a -22 grade).
- Revised Intermediate Temperatures Based on Low PG Instead of as a Function of the Average of the High and Low PG
  - The Research Implementation Team understands the rationale for the recommendation but believes that the basis for this recommendation does not appear to be as strongly supported by the research as the other recommendations.
  - The impact of changing intermediate test temperature can be significant – negatively impacting many asphalt binders that currently meet the PG specification.
  - In the opinion of the Principal Investigator of this report more evaluation will be needed on a national scale to evaluate the effects of changing intermediate test temperature on current asphalt binders.

AASHTO COMP Technical Subcommittee 2b should decide if they are ready for changes to be made to *AASHTO M 320* and *AASHTO M 332* based on this research or if they want to wait to process the recommendations in conjunction with those from the NCHRP 09-60 project when it is completed.

NCHRP 09-60 Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications

The objectives of the research were to 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.

The research was led by Principal Investigator Jean-Pascal Planche (Western Research Institute). Phases 1 and 2 have been completed and a draft final report prepared. The project is expected to be extended into Phase 3 with a full final report available after completion.

The draft final report includes the following recommendations for revision to *AASHTO M 320* and *AASHTO M 332*:

- The research team recommends adding ΔT_c to *AASHTO M 320* and *AASHTO M 332* as a specification parameter. The parameter relates to the relaxation properties of unmodified binders and generally relates to the colloidal structure of the asphalt binder. For asphalt binders that have been aged using the standard

PAV procedure (20 hours), the minimum allowable value of ΔT_c is -2°C to meet the proposed specification without further testing. Asphalt binders with a value of ΔT_c less than -6°C fail to meet the proposed specification (no qualification testing allowed).

- The researchers further recommend that a new parameter, ΔT_f, and criterion be used as a qualification for asphalt binders with ΔT_c values between -2 and -6°C.
  - The ΔT_f parameter is determined using $T_{c,S}$ from BBR testing and T_{cr} from ABCD testing (*AASHTO T 387*)

Implementation Activities

Although there are recommendations from Phases 1 and 2, it is possible that parameters and specification values may change after Phase 3 is complete. At this time it seems premature to suggest that the recommendations should be implemented by AASHTO COMP.

The Research Implementation Team has evaluated the research and potential impacts of changing the PG Asphalt Binder Specification and has the following assessment:

- Agencies and industry are familiar with the ΔT_c parameter. It is easy to calculate from standard BBR test data.
- The BBR test has relatively low variability meaning that ΔT_c should be expected to be reasonably repeatable, albeit slightly more variable than standard BBR test results since two temperature sets of data are used to determine ΔT_c values.
- The greatest impact on lab operations is that to determine ΔT_c a lab will have to perform BBR tests at passing and failing temperatures for every sample, not just those when continuous grading is desired. Throughput can be alleviated by having multiple BBRs set at different test temperatures.
- The proposed specification limit of -2°C, *without additional qualification testing required*, is very restrictive. The Research Implementation Team estimates that almost half of all asphalt binders will have ΔT_c values below -2°C, meaning that qualification testing using the ABCD equipment will be required in many instances.
  - Preliminary analysis suggests that many unmodified asphalt binders will not meet the proposed ΔT_f criterion that would allow an asphalt binder with a ΔT_c value between -2°C and -6°C to qualify per the specification. In other words, many unmodified asphalt binders in current use will fail to meet the specification.
- The ABCD equipment will be an added piece of equipment needed to be purchased for most labs. Estimated cost is in the range of $40,000 to $50,000.
- The ABCD test requires more asphalt binder than is generated from a standard 1-2 PAV pans of aged material. Additional RTFO and PAV aged binder will be needed to perform the test.
- The principal purpose for the ΔT_f parameter (and the ABCD test) appears to be to qualify modified asphalt binders that may have lower ΔT_c values, but which are expected to have good strain tolerance to resist cracking.
  - The Research Implementation Team would consider if another, simpler test/parameter might be used to indicate sufficient elasticity (e.g., MSCR Recovery) without needing to buy new equipment and perform an additional test requiring additional aged asphalt binder.

NCHRP 09-61 Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures

The objective of this research was to develop practical laboratory aging methods to accurately simulate the short-term (from production to placement) and long-term (in-service) aging of asphalt binders. The research will 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.

The research was led by Principal Investigator Ramon Bonaquist (Advanced Asphalt Technologies and generated NCHRP Report 967. Based on the work of the research team, the following recommendations were made:

- The current short-term conditioning procedure for asphalt binders, *AASHTO T 240*, reasonably simulates the properties of asphalt binder recovered from mixtures which were short-term conditioned in accordance with the recommendations from NCHRP 09-52 (as described in NCHRP Report 815). It should continue to be used in its current form.
- If users are satisfied with the aging simulated by the current long-term conditioning procedure (standard PAV procedure in *AASHTO R 28*) then no changes are required.
- If users want to produce residue that simulates near-surface aging after 10 years in-service then the procedure can be changed to a longer time (40 hours) with the same operating parameters (film thickness, pressure) or to keep the same time (20 hours) and pressure but change the film thickness to use 12.5 grams of asphalt binder in the pan (instead of 50 grams).
  - The conditioning temperature may also change to better reflect the aging as a function of the average of the High and Low PG. *AASHTO M 320* and *AASHTO M 332* would change to reflect those potentially different temperatures. Conditioning temperature would be between 85°C and 115°C in 5°C increments depending on the PG of the asphalt binder. An estimated 81% of all binder grades would require conditioning temperatures of 95, 100, or 105°C.

Implementation Activities

The Research Implementation Team has evaluated the research and potential impacts of changing the PG Asphalt Binder Specification and has the following assessment:

- The findings of the research support the assertion expressed by others that the standard PAV procedure in *AASHTO R 28* (20 hours, 2.1 MPa air pressure, 90-110°C temperature dependent on grade, 50 grams of asphalt binder in the PAV pan) does not simulate the long-term aging expected when it was developed during SHRP. The expectation was that the standard PAV aging procedure would produce residue with "…physical or chemical properties of asphalt binders after 5 to 10 years of in-service aging in the field." (*AASHTO R 28* Section 5.1). This research suggests that more severe conditioning – using 40 hours of PAV conditioning under standard conditions may be more appropriate to simulate that level of aging.
  - If more severe conditioning is desired to better replicate the properties of asphalt binders after approximately 10 years in-service, then the criteria for the intermediate and low temperature parameters will need to be evaluated to ensure that PG asphalt binders that have been successfully performing do not get excluded due to a change in conditioning without a corresponding change in criteria. This should be a national research effort as an NCHRP project.
- Laboratory operations – agency and industry – will be significantly affected by doubling the PAV aging time, effectively slowing the determination of grade by a full day.
- The proposal to achieve more severely conditioned residue by maintaining 20 hours of conditioning in the PAV at the same pressure with thinner films of asphalt binder (12.5 grams of asphalt binder to produce a 0.8 mm film thickness) alleviates the time concern of extended aging but adds complexity in

ensuring level film thickness. However, the use of thinner films also means that more pans will be needed to generate the same volume of aged residue. More pans used means that more PAV space may be needed. More PAV equipment may be needed to accommodate the new procedure. This is particularly true when considering that PAV conditioning temperatures may be different for different PG binders. In short, lab operations will still be impacted when using the thinner films, possibly as much as if 40 hours of conditioning were used.

- The use of one piece of equipment for short-term conditioning (static) and long-term conditioning is appealing, but as noted by the researchers, will first need development by equipment manufacturers. Implementation of this combined conditioning procedure would be at least several years in the future.

CHAPTER 3 CONCLUSIONS

Presentations and Technical Support to AASHTO COMP Technical Subcommittees

The NCHRP 20-44(19) Research Implementation Team made presentations to the AASHTO COMP Technical Subcommittees and provided technical support in understanding the potential changes to standards. In addition, the Research Implementation Team members presented at various conferences and meetings on the outcomes of the research.

The efforts are described below:

- NCHRP 09-52 and NCHRP 09-54 projects
  - The Research Implementation Team worked with a Task Force from Technical Subcommittee 2d to revise *AASHTO R 30* for short-term aging of asphalt mixtures. The revised version of *AASHTO R 30* was published in August 2022.
  - The Research Implementation Team is currently working with a Task Force from Technical Subcommittee 2c to develop a separate practice for long-term aging of asphalt mixtures.
  - The Research Implementation Team presented an overview of the research on short- and long-term aging at the August 2022 meeting of Technical Subcommittee 2c.
  - The Research Implementation Team presented an overview of the research on short- and long-term aging at the March 2022 meeting of the New Jersey Asphalt Paving Conference.
- NCHRP 09-56A project
  - The draft final report for the project was just made available to the Research Implementation Team in June 2022. No presentations have been made. Technical support will be available to Technical Subcommittee 2c as they seek to revise *AASHTO T 308*.
- NCHRP 09-59, NCHRP 09-60, and NCHRP 09-61 projects
  - The Research Implementation Team presented findings and evaluation of the three asphalt binder research projects at the Technical Subcommittee 2b meetings in January 2021, August 2021, and August 2022.
  - The Research Implementation Team presented findings and evaluation of the three asphalt binder research projects at the Technical Advisory Committee meetings of the Asphalt Institute in 2021 and 2022.
  - A webinar was presented for user agencies only in May 2022. Thirty-four individuals representing 17 user agencies attended the session. It is recorded and available through the Asphalt Institute Adobe Connect system.
    - https://asphaltinstitute.adobeconnect.com/pgxd01xsky8z/.
    - Enter **Binder22AI** as the passcode when requested.
  - A webinar on the same content was presented to AI members in June 2022.
  - In addition to the presentations listed above, the Research Implementation Team presented findings and evaluation of the three asphalt binder research projects at the following technical meetings:
    - Northeast Asphalt User Producer Group (NEAUPG) Binder Committee – October 2021
    - FHWA Pavement and Materials Technical Feedback Group – November 2021
    - Southeast Asphalt User Producer Group (SEAUPG) – November 2021
    - Pacific Coast Conference on Asphalt Specifications (PCCAS) Binder Committee – January 2022
    - Mid-Atlantic Quality Assurance Workshop – February 2022
    - New Jersey Asphalt Paving Conference – March 2022

Challenges Experienced in the Research Implementation Project

When the NCHRP 20-44(19) project was initiated in May 2020 only two of the six projects had published final reports – the NCHRP 09-52 (and its follow up project 09-52A) and NCHRP 09-54 (through Phases 1 and 2) projects. The NCHRP 09-56 project also had a published final report, but it was not initially identified as one of the six projects to be evaluated. **TABLE 3** shows the publication dates of the reports for each of the projects.

TABLE 3. Final Reports for the Six Evaluated NCHRP Projects

NCHRP Project No.	Title	NCHRP Report No.	Publication Date
09-52	Short-Term Laboratory Conditioning of Asphalt Mixtures	815 (09-52) 919 (09-52A)	2015 2019
09-54	Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction	871 (09-54) 973 (09-52A)	2018 2021[a]
09-56A	Identifying Influences on and Minimizing the Variability of Ignition Furnace Correction Factors	847 (09-56) TBD (09-56A)	2017 pending
09-59	Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance	982	2022[b]
09-60	Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications	TBD	pending
09-61	Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures	967	2021[c]

[a] Published in November 2021
[b] Published in February 2022
[c] Published in June 2021

Draft final reports are not available to the industry. Without a final report it is difficult to get input from the industry regarding the research findings. The information they (industry partners) have is usually based only on presentations from the research team.

It is also difficult to assist the AASHTO COMP Technical Subcommittees in implementation of changes to AASHTO standards when a final published report is not available. The concern is that a parameter or specification limit could change from the draft report as the research team continues evaluation and progress towards publication of a final report. The cautious approach would be to wait for the final report to be published, then consider any recommended changes to standards through formation of a task force within the Technical Subcommittee of interest.

APPENDIX A

Revised Consolidated Technical Report (January 2023)

Project No. 20-44(19)

Implementation of Proposed AASHTO Standards for Asphalt Binders and Mixtures

CONSOLIDATED TECHNICAL REPORT

Prepared for the

National Cooperative Highway Research Program (NCHRP)
Transportation Research Board
of
The National Academies of Sciences, Engineering, and Medicine

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Objective

The objective of the NCHRP 20-44(19) research implementation project is to facilitate actions needed to assure the timely adoption by the AASHTO Committee on Materials and Pavements (COMP) of the proposed AASHTO standards produced in NCHRP Projects 09-52, 09-54, 09-56A, 09-59, 09-60, 09-61, and others later designated by NCHRP.

This ***Consolidated Technical Report*** is intended to provide an overview of the six NCHRP projects by:

- assessing the technical basis for any new or revised AASHTO standards proposed in the research project.
- identifying the gaps in supporting data that must be addressed before the proposed standards are submitted to COMP.
- identifying and resolving any conflicts between the requirements of the various standards.
- assessing the impact of the standard's adoption on state DOT and industry operations.

The research implementation team will use this Consolidated Technical Report to provide commentary and technical support to the appropriate AASHTO COMP Technical Subcommittees.

NCHRP 09-52 Short-Term Laboratory Conditioning of Asphalt Mixtures

NCHRP 09-52 Project Objectives

The objectives of the project were to:

1. Develop a laboratory short-term aging protocol for loose mix prior to compaction to simulate the aging and asphalt absorption of an asphalt mixture as it is produced in a plant and then loaded into a truck for transport.
2. Develop a laboratory long-term aging protocol to simulate the aging of the asphalt mixture through its initial period of performance.
3. Determine the effects of the following variables on aging: WMA technology, aggregate asphalt absorption, plant temperature, plant type, presence of recycled materials, and asphalt source.

NCHRP 09-52 Project Team

- Texas A&M Transportation Institute
  - David Newcomb (PI), Amy Epps Martin, Fan Yin (now NCAT), Edith Arambula, Eun Sug Park, Arif Chowdhury
- National Center for Asphalt Technology (NCAT)
  - Ray Brown, Carolina Rodezno, Nam Tran
- University of California Pavement Research Center
  - Erdem Coleri, David Jones, John T. Harvey, James M. Signore

NCHRP 09-52 Project Status

The project was completed on August 31, 2015, and published as NCHRP Report 815, Short-Term Laboratory Conditioning of Asphalt Mixtures. A follow-up project, NCHRP Project 09-52A, "Short-Term Laboratory Conditioning of Asphalt Mixtures: Field Verification", conducted an extended field verification of the proposed changes to *AASHTO R 30*, *Mixture Conditioning of Hot Mix Asphalt (HMA)*, that were originally recommended in NCHRP Report 815. The 09-52A project final report was published as NCHRP Report 919, Field Verification of Proposed Changes to the AASHTO R 30 Procedures for Laboratory Conditioning of Asphalt Mixtures.

Key Findings and Conclusions

- The correlation between Lab-Mixed, Lab-Compacted (LMLC) and Plant-Mixed, Plant-Compacted (PMPC) specimens indicated that the selected short-term oven aging (STOA) protocols used on LMLC specimens – 2 hours at 135°C (275°F) for HMA and 2 hours at 116°C (240°F) for WMA were able to accurately simulate the amount of aging (based on mixture stiffness and binder characteristics), and to a lesser extent, absorbed binder (based on volumetrics) that occurs during production at an asphalt plant.
- The recommended changes to STOA in *AASHTO R 30* resulting from this project include:
  - fixing the compaction temperatures at 116°C (240°F) for WMA and at 135°C (275°F) for HMA; and
  - conditioning the sample for 2 hours at the compaction temperature regardless of whether the sample is being prepared for volumetric mix design or performance testing.

- Cumulative degree-days (CDD) was proposed as a metric to quantify field aging and was able to account for the differences in construction dates and climates for various field sites.
- Based on the mixture stiffness results, the laboratory STOA protocol of 2 hours at 135°C (275°F) on loose HMA plus long-term oven aging (LTOA) protocols of either 2 weeks at 60°C (140°F) or 5 days at 85°C (185°F) on compacted specimens were able to produce mixture aging equivalent to an average of 9,100 and 16,000 CDD, respectively, in the field.
  - For the LTOA protocol of 2 weeks at 60°C (140°F), the CDD value of 9,100 corresponds to approximately 7 months in-service (warmer climates) and 12 months in-service (colder climates).
  - For the LTOA protocol of 5 days at 85°C (185°F), the CDD value of 16,00 corresponds to approximately 11 months in-service (warmer climates) and 22 months in-service (colder climates).
- Due to the findings reported in NCHRP Report 815, there were no recommended changes to the LTOA procedure in *AASHTO R 30*.
- Field verification of the proposed changes to the *AASHTO R 30* Procedure for laboratory conditioning of asphalt mixtures was conducted in the follow-up NCHRP 09-52A project. The key finding from that work, as reported in NCHRP Report 919, is that the current LTOA procedure in *AASHTO R 30* is not realistic simulating only 1-2 years of service.
  - The research suggests replacing the aging of a compacted specimen with aging of loose mix under the same conditions – 5 days at 85°C (185°F) before compaction for performance testing.
  - This level of aging – using loose mix – was expected to simulate 7-10 years in-service (warmer climates) and 12-14 years in-service (colder climates) based on stiffness measurements.

Additional Research Identified by the Research Team in NCHRP 09-52 and 09-52A

- This study focused on mixture stiffness and rutting resistance to discriminate asphalt mixtures with different short-term aging characteristics. Testing was conducted at one set of temperatures for each test for most of the data. Additional mixture properties such as moisture susceptibility, fatigue cracking resistance, and thermal cracking resistance need to be considered for further validation and to examine how aging affects the long-term cold-temperature behavior of asphalt mixtures to quantify possible embrittlement with time.
- Differences in volumetric properties were observed for mixtures using highly absorptive aggregates when comparing LMLC specimens with the laboratory STOA protocols of 2 hours at 275°F for HMA and 2 hours at 240°F for WMA and the corresponding PMPC specimens. Therefore, the proposed STOA may not be fully applicable to highly absorptive aggregates, and additional STOA protocols should be explored in future research for achieving equivalent volumetric properties.
- Based on the limited amount of resilient modulus results for Indiana and Florida, LMLC specimens prepared using different LTOA protocols – 3 days at 185°F (85°C) and 2 weeks at 140°F (60°C) – produced equivalent levels of mixture aging. The 3-day LTOA protocol might be more practical for simulating field aging in colder climates. Therefore, there is a need to further explore the LTOA protocol of 3 days at 185°F (85°C) based on additional mixture results.
- Recommendations
  - Refine the relationship of the global aging model to climate.
  - Find a better means to characterize asphalt binder aging to differentiate asphalt sources.
  - Conduct a study on the impacts of aging on the fracture resistance of asphalt mixtures.

Proposed New and Revised Standards Resulting from the NCHRP 09-52 Project

New Standard: "Recommended Practice for Conducting Plant Aging Studies"

- Scope
  - The recommended practice provides a basic structure for conducting studies of plant aging effects on asphalt mixtures.

Revision to AASHTO R 30-02, Standard Practice for Mixture Conditioning of Hot Mix Asphalt

- Scope
  - Recommendation to fix the compaction temperatures at 116°C (240°F) for WMA and at 135°C (275°F) for HMA.
  - Recommendation to condition samples for 2 hours at the compaction temperature - regardless of whether the sample is being prepared for volumetric mix design or performance testing.

Interactions with Other Standards

Below is a list of AASHTO standards that have included *AASHTO R 30* as a referenced document and specifically cited the short-term mixture conditioning procedure in *AASHTO R 30*. Standards noted with an asterisk (*) sign in front of the designation number are those that contain sentences or phrases providing conflicting directions on the short-term aging of asphalt mixtures compared to the proposed aging procedure in NCHRP Project 09-52.

- *AASHTO R 46-08, Designing Stone Matrix Asphalt (SMA)*
- *AASHTO R 83-17*, *Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)*
- **AASHTO T 209-20, Theoretical Maximum Specific Gravity (Gmm) and Density of Hot Mix Asphalt (HMA)*
  - Note 5 – Short-term conditioning at the specified temperature is especially important when absorptive aggregates are used.
- **AASHTO T 320-07, Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures Using the Superpave Shear Tester (SST)*
  - Section 6.2.3: After mixing, condition the asphalt mixture for 4.0 ± 0.1 h at 135 ± 5°C in accordance with "Short-Term Conditioning for Mixture Mechanical Property Testing," *R 30*.
- **AASHTO T 342-11, Determining Dynamic Modulus of Hot Mix Asphalt (HMA)*
  - Section 9.2: Laboratory-prepared mixtures shall be temperature conditioned in accordance with the 4-h short-term oven conditioning procedure in *R 30*.
- **AASHTO T 378-17, Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)*
  - Appendix X2.2.1 Perform *Short-term Conditioning for Mixture Mechanical Property Testing* for the test specimens in accordance with *R 30* using the criteria listed in Table X2.1
- *AASHTO PP 76-13, Troubleshooting Asphalt Specimen Volumetric Differences between Superpave Gyratory Compactors (SCGs) Used in the Design and the Field Management of Superpave Mixtures*
  - Figure 1 – Superpave Gyratory Compactor (SGC) Evaluation Form
- *AASHTO PP 77-14*, *Materials Selection and Mixture Design of Permeable Friction Courses*
- **AASHTO TP 107-18*, *Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests*

- Section 9.2: Aging – Laboratory prepared mixtures shall be temperature- conditioned in accordance with the 4-h, short-term oven-conditioning procedure outlined in *R 30*.

Although NCHRP 09-52 and 09-52A addressed long-term conditioning procedures, it is expected that the recommendations on long term conditioning will principally come from the NCHRP 09-54 project.

Impact of NCHRP 09-52 Recommendations on Lab Operations (Agency and Industry)

With respect to short-term mixture conditioning, the recommendations change the conditioning temperatures from "the mixture's specified compaction temperature" by fixing the compaction temperatures for WMA at 240°F (116°C) and HMA at 275°F (135°C), respectively, and requiring the samples to be conditioned for 2 hours at that temperature. Standardizing the temperatures will likely simplify laboratory operations.

Unanswered Questions and Concerns that Could Affect Adoption of NCHRP 09-52 Recommendations

- Standardizing the compaction temperatures for unmodified mixtures could have an impact on volumetric properties if highly absorptive aggregates are used, and existing compaction temperatures are significantly greater than 116°C (240°F) and 135°C (275°F).
- The proposed changes only apply to unmodified mixes. For mixtures with modified binders, the agency needs to consider supplier's recommendations for establishing a compaction (and conditioning) temperature.
- The LTOA aging protocol evaluate in NCHRP Report 815 estimate the pavement in-service time to reach its initial period of performance, either 9,100 or 16,000 CDD, depending on the protocol used. These methods represent 7 or 11 months in warmer climates or 12 or 22 months in colder climates, again depending on the protocol used. There is a need to develop a protocol which represents a longer period beyond its initial performance. The latter is the focus of the NCHRP 09-54 research. In addition, the findings in NCHRP Report 919 suggest an alternate method using loose mix aging at 85°C for 5 days to simulate 7-10 years (warmer climates) or 12-14 years (colder climates)
- Cumulative degree-days (32°F [0°C] base) was proposed as a metric to quantify field aging and was able to account for the differences in construction dates and climates for various field sites. However, this method is based on air temperatures, and does not consider other factors that contribute to aging such as solar radiation and wind speed. There is a need to evaluate the use of CDD based on pavement temperature to include these other factors.
- Additional guidance on establishing the appropriate compaction (and STOA) temperature for mixtures with modified binders should be included in *AASHTO R 30*.
- If agencies have been using compaction temperatures that are significantly greater than 116°C (240°F) and 135°C (275°F) – for WMA and HMA, respectively – with absorptive materials, guidance may need to be provided regarding the potential impact on mixture volumetrics.

NCHRP 20-44(19) Research Implementation Activities – NCHRP 09-52

The NCHRP 20-44(19) Research Implementation Team worked with a task force in AASHTO COMP TS 2d to recommend changes to *AASHTO R 30*. The focus for this revision was on short-term conditioning of mixtures. Long-term conditioning of mixture specimens for use in performance-related testing will be addressed later and will consider the findings of the NCHRP 09-54 research.

The NCHRP 20-44(19) Team provided a redlined version of *AASHTO R 30* to the Task Force that incorporated the recommendations from NCHRP Report 815. Key changes are noted below:

- Title and Scope
  - Changed "HMA" to "Asphalt Mixtures" in title and in document.
    - New changes include references to both HMA and WMA.
  - Reduced types of conditioning from three to two.
    - Eliminated short-term conditioning for mixture and mechanical property testing.
- Section 2 – Referenced Documents and Section 3 – Summary of Practice
  - Eliminated reference to AASHTO PP 3, Preparing Hot Mix Asphalt (HMA) Specimens by Means of the Rolling Wheel Compactor
    - This is an expired standard that is not in use.
  - Added a reference to AASHTO R 68, Preparation of Asphalt Mixtures by Means of the Marshall Apparatus
  - Standardized conditioning temperatures
    - WMA 116°C
    - HMA 135°C
- Section 4 – Significance and Use
  - Language changed to reflect only two types of conditioning.
    - Short-Term Conditioning
    - Long-Term Conditioning
  - Changed the estimated aging that occurs from long-term conditioning from "7 – 10 years" to "the first 1 – 3 years."
- Section 7 – Mixture Conditioning Procedures
  - Changed "Mixture Conditioning for Volumetric Mix Design" to "Short-Term Mixture Conditioning"
  - Standardized conditioning temperatures
    - 116 ± 3°C for WMA
    - 135 ± 3°C for HMA
  - Conditioning temperature was previously based on compaction temperature that was determined from asphalt binder viscosity.
- Section 7.2 – Short-Term Conditioning for Mixture Mechanical Property Testing
  - Deleted
    - Long-term conditioning now references short-term conditioning.
- Section 7.3 – Long-Term Conditioning for Mixture Mechanical Property Testing
  - Title changed to "Long-Term Mixture Conditioning."
  - References short-term conditioning.
  - Eliminated reference to *AASHTO PP 3* (Rolling Wheel Compactor)
  - Other organizational changes made (not related to technical content)

The revised version of *AASHTO R 30* was published in the 2022 edition of the AASHTO standards.

During the Task Force discussions there were a couple of key questions/issues that affected *AASHTO R 30*. These are noted below.

Compaction Temperature and Conditioning Temperature/Time and Effects on Volumetric Properties

One important question is the compaction of the loose asphalt mix for purposes of determining the volumetric properties. For Short-Term Mixture Conditioning (two hours at the standardized conditioning temperature), should the loose mix be:

- placed in the compaction mold and compacted immediately after the two-hour conditioning period without adjusting the asphalt mixture temperature to the compaction temperature; or
- transferred to another oven operating at the compaction temperature for a short time, such as 30 minutes, after the two-hour conditioning period to bring the mixture to the appropriate compaction temperature before loading in the compaction mold and compacted; or
- transferred to another oven operating at the compaction temperature for a short time, such as 30 minutes, before the end of the two-hour conditioning period such that the total time in the oven at the conditioning and compaction temperature is two hours.

The same issue/questions above were identified in the Superpave Mix Design procedure when short-term conditioning was to be conducted for four hours at 135°C. The NCHRP 09-09 research project, "Refinement of the Superpave Gyratory Compaction Procedure", considered short-term conditioning of mixtures for use in mix design. An executive summary of the NCHRP 09-09 research is provided in NCHRP Research Results Digest 237 (1999). One of the outcomes of the research was a recommendation to simplify the short-term mixture conditioning procedure by changing the conditioning time to two hours and changing the conditioning temperature to the compaction temperature. This solved the logistical issue of needing two ovens at multiple temperatures (135°C and compaction temperature) and the question of whether to condition the mix for the full four hours at 135°C before switching to the oven operating at the compaction temperature or whether to use the last 30-40 minutes of the conditioning period at the different (i.e., compaction) temperature. The changes to *AASHTO R 30* recommended by the NCHRP 09-52 researchers bring a return to those questions.

If a change to a standardized conditioning time and temperature is desired, then the simplest solution is to condition the mix at the standardized temperature (135°C for HMA and 116°C for WMA) for two hours and then immediately load and compact specimens in the gyratory compactor to determine volumetric properties.

In assessing the potential impact of that approach, it should be considered that the compaction temperature of modified asphalt binders (except GTR-modified asphalt binders) will most likely not exceed 160°C if using one of the two proposed methods for determining lab mixing and compaction temperatures from NCHRP Report 648 (the final report of the NCHRP 09-39 research project). On the other end of the spectrum, it is unlikely that an unmodified asphalt binder with a low high temperature grade (e.g., PG 52) would have an equiviscous compaction temperature lower than 125°C. Thus, the most likely effect of using a standardized compaction temperature that is the same as the conditioning temperature (135°C for HMA) is to result in a compaction temperature that is 25°C lower to 10°C higher than the current practice.

Previous research has indicated that the volumetric properties of specimens compacted in the gyratory compactor are much less influenced by compaction temperature than the volumetric properties of specimens compacted using the Marshall hammer. As such, the use of a simple solution – conditioning and compacting at the same temperature – should resolve the operational issues without unduly affecting the volumetric properties of the specimen. The negative to the simple approach is that it ignores the concept of equiviscous compaction temperatures, which may be difficult for some users to accept.

Effect of Changing Short-Term Mix Conditioning for Performance-Related Tests

In changing *AASHTO R 30* to eliminate *Section 7.2, Short-Term Conditioning for Mixture Mechanical Property Testing*, the idea was that specimens prepared for mixture performance-related tests would be subject to long-term conditioning. However, some performance-related tests, such as the Hamburg Wheel Tracking test (HWTT) are intended to be performed when the mixture is in its most critical state – after production and placement. The AASHTO TS 2d Task Force raised concerns regarding the impact of changing conditioning times from four to two hours on HWTT results.

To address the concern, the NCHRP 20-44(19) Team reviewed findings from NCHRP Project 09-49 (Evaluation of the Moisture Susceptibility of WMA Technologies - which made the original recommendation to shorten the conditioning time from four to two hours and fix the compaction temperatures) as well as additional work by the Texas DOT. The NCHRP 09-49 results were more focused on dry resilient modulus, however, the TxDOT data showed a definite increase with HWTT rutting when the conditioning time was reduced from four to two hours. Based on this data, it does appear the change could have an impact if specification requirements were developed based on four hours of conditioning rather than two.

The NCHRP 20-44(19) Team then further reviewed the NCHRP 09-52 results. The researchers used two-hour conditioned lab mixed lab compacted (LMLC) samples and compared them with plant mixed lab compacted (PMLC) samples which had been sampled and compacted immediately following production. The comparison was based on the following measured properties: G_{mm}, P_{ba}, Resilient Modulus (M_R), Dynamic Modulus (E*), HWTT Rut depth at 5000 cycles, HWTT RRP (Rutting Resistance Parameter), High and Low temperature PG grading, and FTIR Carbonyl Area. The findings indicated a generally good correlation between two-hour conditioned samples and post-production samples, except for the HWTT rut depth. The HWTT rut depth results showed greater rutting with the two-hour conditioned samples, which would indicate that two hours of conditioning is not adequate. Although the researchers noted that the higher rutting on the lab conditioned samples was possibly due to stripping, they did not offer an explanation on why the lab tests would have more stripping that the companion plant mix samples.

In summary, the NCHRP 20-44(19) Team believes that a change in conditioning time could have an impact on the lab performance of current mixes. With the HWTT being used by a growing number of DOTs, the change to two hours conditioning could invalidate much of the historical database of results and the associated criterion (based on four hours of loose mix conditioning).

After discussion, it was decided to advance the revised version of AASHTO *R 30* with the changes as discussed previously, including the deletion of the Section 7.2 (Short-Term Conditioning for Mechanical Property Testing) – which requires four hours of conditioning.

Long-Term Conditioning in AASHTO R 30

Despite the issues discussed above, the changes to *AASHTO R 30* for short-term mix conditioning are relatively easy to adopt – once the few issues/questions are resolved. Changing the long-term conditioning procedure from the current practice of aging compacted mix specimens for five days at 85°C to loose mix aging at 95°C for a number of days based on climate, depth, and simulated age (as recommended from the NCHRP 09-54 research) is more complicated. The NCHRP 20-44(19) Team suggested to the *AASHTO R 30* Task Force that it might be best to move long-term conditioning procedure to a separate standard.

NCHRP 09-54 Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction

NCHRP 09-54 Project Objectives

The objectives of the project were to develop a calibrated and validated procedure to simulate the long-term aging of asphalt mixtures for performance testing and prediction.

NCHRP 09-54 Project Team

- North Carolina State University
  - Richard Kim (PI), Cassie Castorena, Michael Elwardany, Farhad Yousefi Rad
- Arizona State University
  - Shane Underwood, Akshay Gundla, Padmini Gudipudi
- Western Research Institute
  - Mike Farrar, Ronald Glaser

NCHRP 09-54 Project Status

The project report for Phases I and II has been published as NCHRP Report 871, Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction. The project report for Phase III has been published as NCHRP Report 973, Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction: Phase III Results.

Key Findings and Conclusions

- The sensitivity of the mechanical properties of asphalt mixtures to asphalt binder oxidation was determined.
- Two reliable chemical and rheological aging index properties (AIPs) were identified to track the oxidation levels of field-aged and laboratory-aged asphalt binders and mixtures.
- Loose mixture aging at 95°C was selected as the optimum long-term aging condition for performance testing and prediction of asphalt mixtures.
- A kinetics-derived climatic aging index (CAI) was developed to prescribe laboratory aging durations to match in-situ aging and predict the evolution of oxidative aging in asphalt pavements. The CAI was simplified and recalibrated using RAP, WMA, and PMA to yield the aging durations as a function of hourly pavement temperature history and depth offering reasonable accuracy to match field aging levels.
- Preliminary findings from the pavement aging model (PAM) highlight the need to consider both traffic and thermal loading in pavement performance simulations and demonstrate the impact of aging on the deterioration of pavement performance.
- A methodology that allows estimating the inputs to the PAM using RTFO and 40 hours of PAV instead of loose mixture aging was developed.

Additional Research Identified by the Research Team in NCHRP 09-54

- Development of a diffusion model to couple with the proposed kinetics model is needed to improve prediction of changes in the rheological and chemical properties of asphalt binders with field aging within existing pavement performance prediction frameworks.
- Calibration of the combined kinetics-diffusion model is needed to facilitate the prediction of asphalt binder properties during mix production and pavement in-service life, considering adjustments in field aging for different air voids and pavement depths.
- Integration of the kinetics-diffusion model into pavement performance prediction frameworks is needed by linking predicted changes in asphalt binder properties with field and laboratory aging to changes in performance properties of asphalt mixtures.
- Evaluation of the effects of polymer modified asphalt and RAP on the relationship between laboratory and field aging using a broader set of materials and field conditions is needed.

Note that the follow up research in Phase III, reported in NCHRP Report 973, addressed thee above items and added the following suggestion for additional research:

- More RAP field sections (with component materials and field cores preferably obtained at multiple long-term field aging durations) are needed to thoroughly investigate the effect of RAP blending, the age level of RAP, sources of RAP, and RAP content.
  - The field sections used were mainly from two climatic conditions and aged for only 4 years.

The researchers noted that RAP sections are complex to model in consideration of the effects of oxidative aging and the assumption of 100% blending between RAP and virgin asphalt binders.

Proposed New and Revised Standards Resulting from the NCHRP 09-54 Project

"Standard Method of Test for Long-Term Conditioning of Hot Mix Asphalt (HMA) for Performance Testing "

- Scope
  - Replacement of the current long-term mixture aging procedure in *AASHTO R 30*

Interactions with Other Standards

Below provides a list of AASHTO standards that have included *AASHTO R 30* as a referenced document and specifically cited the long-term mixture conditioning procedure in *AASHTO R 30*. Standards noted with an asterisk (*) sign in front of the designation number are those that contain sentences or phrases providing conflicting directions on the long-term aging of asphalt mixtures compared to the proposed aging procedure in NCHRP Project 09-54.

- *AASHTO R 15-18, Standard Practice for Evaluation of Asphalt Additives and Modifiers*
- **AASHTO R 83-17, Standard Practice for Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)*
  - Section 9.4.1: If it is desired to simulate long-term aging, condition the SGC specimen in accordance with *R 30.*
- **AASHTO PP 95-18 (2020)*, *Proposed Standard Practice for Preparation of Indirect Tension Performance Test Specimens*

  - Section 10.3.1: If it is desired to simulate long-term aging, condition the gyratory specimen in accordance with Sections 7.3.4 through 7.3.6 of *R 30.*
- *AASHTO PP 99-19*, *Standard Practice for Preparation of Small Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC) or Field Cores*
- *AASHTO TP 124-20*, *Standard Method of Test for Determining the Fracture Potential of Asphalt Mixtures Using the Illinois Flexibility Index Test (I-FIT)*

Impact of NCHRP 09-54 Recommendations on Lab Operations (Agency and Industry)

- By its nature, the use of long-term conditioning in a laboratory will slow the specimen preparation and testing process. In the current form of *AASHTO R 30* this can mean that the specimen is compacted after short-term conditioning but is then subjected to five days of conditioning at 85°C. The proposed revision from the NCHRP 09-52A project was to perform short-term conditioning on the loose mix followed immediately by five days of long-term loose mix conditioning at 85°C after which the specimen is compacted and prepared for testing.
  - In either case, performance test specimens would not be tested for at least six days (five days to age plus at least one day to compact/cool and prep test specimens) making the use of long-term conditioning useful only for laboratory mix design and forensic analysis. The process is simply too slow for use in a routine QA environment.
- The proposed procedure in NCHRP Report 871 and NCHRP Report 973 allows for great flexibility in considering different climates, simulated age, and depth of mixture. This is useful for design-build projects and experimental pavement sections but is too cumbersome for routine use in a laboratory.
  - The researchers simplified the process by calculating the Climatic Aging Index (CAI) at various locations in the United States. The CAI values represent the required duration (days) in an oven operating at 95°C that is needed to match the field aging for a given pavement temperature history and depth. The result was the production of nine maps of the US with aging times as a function of depth from the surface (6, 20, and 50 mm) and years of aging simulated (4, 8, and 16 years).
  - Even this simplification will need simplification as conditions can change significantly within a state based on project location and desired conditions. For example, the range of aging duration in Florida possible based on the maps can be as little as 2 days (mixture that is 50 mm from the surface near Jacksonville, simulating 4 years of aging) to as many as 37 days (mixture that is 6 mm from the surface near Miami, simulating 4 years of aging).
  - Given the variety of climatic conditions in the United States, the use of a standard practice (5 days at 85°C) seems unlikely. More likely, individual states will have to establish their own conditions.
- Although seemingly minor, the draft practice requires that technicians “Apportion the short-term aged loose mixture into several pans such that each pan has a relatively thin layer of loose mix, approximately equal to the mixture NMAS.” This is typically a thinner layer than is specified in *AASHTO R 30* (which requires a layer of 25-50 mm), meaning that for surface mixtures the lab will be using at least twice the number of pans for long-term conditioning than was used for short-term conditioning and possibly many more since specimens compacted for use in performance testing (e.g., AMPT dynamic modulus) are often much larger than volumetric specimens. This could lead to issues with oven space, requiring additional equipment.
- Another minor operational point is that labs will need to schedule the production of asphalt mixture subjected to long-term conditioning to avoid weekends, holidays, and other lab shutdown periods. For example, mixes subjected to five days of long-term conditioning probably should not be prepared on a Monday or Tuesday unless the lab is prepared to complete testing on the weekend.

Unanswered Questions and Concerns that Could Affect Adoption of NCHRP 09-54 Recommendations

- The project recommends loose mix aging at 95°C as the long-term conditioning protocol for asphalt mixtures. The duration of aging required to simulate in-situ aging of asphalt pavements vary from days to weeks, which may not be practical for routine use in mix design.
- Specific comments to Chapter 5 of NCHRP Report 871
  - Equation 1 should be revised to include *CAI* for clarity and consistency with the equation notes provided.

$$t_{oven} = \sum_{i=1}^{N} DA\exp(-E_a / RT_i) / 24 \quad (1)$$

where

t_{oven}	=	required oven aging duration at 95°C to reflect field aging (days);
CAI	=	climatic aging index;
D	=	depth correction factor;
A	=	*frequency (pre-exponential) factor;*
E_a	=	activation energy;
R	=	universal gas constant, or ideal gas constant;
T_i	=	pavement temperature obtained from the EICM at the depth of interest at the hour of interest, i (Kelvin);

  - Agency and industry personnel may not be familiar with the Enhanced Integration Climatic Model (EICM) for calculating the hourly pavement temperature, which is a required input for the determination of *CAI* and t_{oven} in Equation 1.
  - To facilitate the implementation of the proposed long-term aged procedure, additional aging duration maps may need to be developed for target field aging durations other than 4, 8, and 16 years.
  - Additional instructions need to be provided after Step 8.2.6 as to how the loose mix should be handled for reheating prior to compaction.
- The selection of 95°C for oven aging was based on laboratory test results showing that aging at 135°C reduces the dynamic modulus and fatigue resistance of asphalt mixtures, as well as literature that indicates chemical changes occurring at temperatures above 100°C due to disruption of polar molecular associations and sulfoxide decomposition. It should be noted that the sensitivity of sulfoxides to thermal decomposition is not identical for all asphalt binders. Existing literature has also recognized the importance of asphalt component compatibility on its oxidative age hardening behavior. In addition, the project evaluated three asphalt binders (i.e., ALF-SBS, SHRP AAD, and SHRP AAG binders) in the experiment to select the laboratory aging temperature, which may not be sufficient to reach a conclusion considering the wide variety of aging behaviors of asphalt from different crude sources and refining processes.

NCHRP 20-44(19) Research Implementation Activities – NCHRP 09-54

As of this report, the NCHRP 20-44(19) team is working with a task force initiated by AASHTO COMP Technical Subcommittee 2c to address the long-term conditioning of asphalt mixtures for performance testing. The most likely course of action is that Section 7.2 will be removed from *AASHTO R 30,* and a new proposed practice will be developed entitled “Long-Term Laboratory Conditioning of Asphalt Mixtures.”

The approach being considered by the Task Force for the new proposed practice is to provide multiple procedures for long-term conditioning based on the NCHRP 09-52, 09-52A, and 09-54 projects, as well as other significant projects, including the original research during SHRP. The proposed methods are as follows:

Method A – Conditioning of Compacted Specimens at 85°C

- According to NCHRP Report 815 and NCHRP Report 919, this original procedure from SHRP is expected to simulate approximately 23,000 cumulative degree days (CDD) of field aging for surface asphalt mixtures, which corresponds to 1 to 2 years of field aging for warmer climates and 2 to 3 years of field aging for colder climates.
- Compacted test specimens are placed in the conditioning oven for 120 ± 0.5 hours at a temperature of 85 ± 3°C. After cooling the specimen is removed from the oven and then prepared (cut/trimmed) for performance testing.

Method B – Conditioning of Loose Mixture at 85°C

According to NCHRP Report 919, this procedure is expected to simulate approximately 134,000 cumulative degree days (CDD) of field aging for surface asphalt mixtures, which corresponds to 7-10 years of field aging for warmer climates and 12-14 years of field aging for colder climates. This procedure involves the following steps:

- Place the loose mixture in a pan and spread it to an even thickness of 25-50 mm.
- Place the mixture and pan in the conditioning oven for 120 ± 0.5 h at a temperature of 85 ± 3°C.
- Stir the mixture at periodic intervals (TBD) to maintain uniform conditioning.
- After 120 ± 0.5 h, remove the mixture from the conditioning oven.
- Follow one of two procedures:
  - Place the mixture immediately in an oven at the desired compaction temperature and heat until the mixture reaches the appropriate temperature. Once the temperature is achieved in the mixture sample, remove it from the oven, load it in the mold, and compact following appropriate compaction procedures to achieve a specimen with the desired dimensions and percentage of air voids.
  - Allow the mixture to cool to room temperature. The long-term-conditioned loose mixture sample is now ready to be tested (e.g., theoretical maximum specific gravity determination) or to be heated to an appropriate temperature for compaction.

Method C – Conditioning of Loose Mixture at 95°C

This long-term conditioning procedure developed by the NCHRP 09-54 project and reported in NCHRP Report 871 and NCHRP Report 973 applies to laboratory-prepared asphalt mixtures that have been subjected to the short-term conditioning procedure described in Section 7.1 of *AASHTO R 30* and plant-mixed asphalt mixtures. It is not applicable to compacted roadway specimens. This procedure involves the following steps:

- Determine the required long-term conditioning duration that reflects the desired field aging in terms of age, climate, and depth using the Climatic Aging Index Equation or Laboratory Aging Duration Maps.
- Break down any large chunks of asphalt mixtures, taking care to avoid fracturing the aggregate, so that the clusters of the fine aggregate portion are not larger than the nominal maximum aggregate size (NMAS).

  - This step needs to be performed shortly after short-term aging of laboratory-prepared mixture samples or appropriate reheating of plant-mixed mixture samples to ensure that the asphalt mixture is sufficiently soft to be separated into pans for oven aging.
  - If an asphalt mixture sample is not sufficiently soft to be separated manually, then place it in a pan and warm it in an oven until it can be separated as described.
- Apportion the short-term aged loose mixture sample into one or more pans such that each pan has a relatively thin layer of loose mix, approximately equal to the NMAS of the asphalt mixture sample.
- Place the pan(s) in a forced-draft oven at 95°C ± 3°C for the duration determined mathematically by equation or visually by use of aging duration maps.
  - If multiple pans are used for an asphalt mixture sample, then place the pans on different shelves so that they are arranged vertically within the oven as much as possible. Ensure that adjacent pans do not overlap.
- Rotate the pan(s) to different shelves at four evenly spaced time intervals during the long-term conditioning period so that each pan has similar exposure to heat and air flow at different locations within the oven.
- After long-term conditioning, remove the pan(s) from the oven and combine any pans containing the same asphalt mixture sample to produce a single homogeneous asphalt mixture sample that has been subjected to long-term conditioning.
- Follow one of two procedures:
  - Place the mixture sample immediately in an oven at the desired compaction temperature and heat until the mixture reaches the appropriate temperature. Once the temperature is achieved in the mixture sample, remove it from the oven, load it in the mold, and compact following appropriate compaction procedures to achieve a specimen with the desired dimensions and percentage of air voids.
  - Allow the mixture sample to cool to room temperature. The long-term-conditioned loose mixture sample is now ready to be tested (e.g., theoretical maximum specific gravity determination) or to be heated to an appropriate temperature for compaction.

Method D – Conditioning of Loose Mixture at 100 to 125°C

This long-term conditioning procedure developed by Zhou at Texas A&M University applies to laboratory-prepared asphalt mixtures that have been subjected to the short-term conditioning procedure described in Section 7.1 of *AASHTO R 30* and plant-mixed asphalt mixtures. It is not applicable to compacted roadway specimens. The procedure is expected to yield an approximately equivalent level of asphalt aging as loose mixture conditioning for 6 days at 95°C per Method C. This procedure involves the following steps:

- Break down any large chunks of asphalt mixtures, taking care to avoid fracturing the aggregate, so that the clusters of the fine aggregate portion are not larger than the nominal maximum aggregate size (NMAS).
  - This step needs to be performed shortly after short-term aging of laboratory-prepared mixture samples or appropriate reheating of plant-mixed mixture samples to ensure that the asphalt mixture is sufficiently soft to be separated into pans for oven aging.
  - If an asphalt mixture sample is not sufficiently soft to be separated manually, then place it in a pan and warm it in an oven until it can be separated as described.
- Place the loose asphalt mixture sample in one or more pans, and spread to an even thickness ranging between 25 and 50 mm.
- Place the pan(s) in the conditioning oven for 20 ± 0.5 h at a temperature between 100 and 125°C that corresponds to the anticipated project location using an aging map.
- Stir the mixture periodically at intervals TBD to maintain uniform conditioning.
- After 20 ± 0.5 h, remove the pan(s) from the conditioning oven.

- Follow one of two procedures:
  - Place the mixture sample immediately in an oven at the desired compaction temperature and heat until the mixture reaches the appropriate temperature. Once the temperature is achieved in the mixture sample, remove it from the oven, load it in the mold, and compact following appropriate compaction procedures to achieve a specimen with the desired dimensions and percentage of air voids.
  - Allow the mixture sample to cool to room temperature. The long-term-conditioned loose mixture sample is now ready to be tested (e.g., theoretical maximum specific gravity determination) or to be heated to an appropriate temperature for compaction.

Method E – Conditioning of Loose Mixture at 135°C

This long-term conditioning procedure developed by the National Center for Asphalt Technology (NCAT) applies to laboratory-prepared asphalt mixtures that have been subjected to the short-term conditioning procedure described in Section 7.1 of *AASHTO R 30* and plant-mixed asphalt mixtures. It is not applicable to compacted roadway specimens. The procedure is expected to simulate approximately 85,000 cumulative degree days (CDD) of field aging for surface asphalt mixtures, which corresponds to 5 to 7 years of field aging for warmer climates and 8 to 10 years of field aging for colder climates. This procedure involves the following steps:

- Break down any large chunks of asphalt mixtures, taking care to avoid fracturing the aggregate, so that the clusters of the fine aggregate portion are not larger than the nominal maximum aggregate size (NMAS).
  - This step needs to be performed shortly after short-term aging of laboratory-prepared mixture samples or appropriate reheating of plant-mixed mixture samples to ensure that the asphalt mixture is sufficiently soft to be separated into pans for oven aging.
  - If an asphalt mixture sample is not sufficiently soft to be separated manually, then place it in a pan and warm it in an oven until it can be separated as described.
- Place the asphalt mixture sample in one or more pans, spreading the asphalt mixture in each pan to an even thickness at the NMAS of the mixture.
- Place the pan(s) in the conditioning oven for 8 ± 0.5 h at 135 ± 3°C.
- After 8 ± 0.5 h, remove the pan(s) from the conditioning oven and combine any pans containing the same asphalt mixture sample to produce a single homogeneous asphalt mixture sample that has been subjected to long-term conditioning.
- Follow one of two procedures:
  - Place the mixture sample immediately in an oven at the desired compaction temperature and heat until the mixture reaches the appropriate temperature. Once the temperature is achieved in the mixture sample, remove it from the oven, load it in the mold, and compact following appropriate compaction procedures to achieve a specimen with the desired dimensions and percentage of air voids.
  - Allow the mixture sample to cool to room temperature. The long-term-conditioned loose mixture sample is now ready to be tested (e.g., theoretical maximum specific gravity determination) or to be heated to an appropriate temperature for compaction.

NCHRP 09-56A Identifying Influences on and Minimizing the Variability of Ignition Furnace Correction Factors

NCHRP 09-56A Project Objectives

The objectives of the research were to:

1. evaluate the effect of reducing the test temperature of *AASHTO T 308* method from 1000°F to 800°F.
2. determine the variability of asphalt content and aggregate correction factors of asphalt mixes containing high percentages of recycled asphalt materials (RAM) compared to those with virgin binder and aggregate only.
3. conduct an interlaboratory study that includes virgin mixes and mixes with high percentages of RAM to establish a revised precision statement for the AASHTO test procedure.

NCHRP 09-56A Project Team

- National Center for Asphalt Technology
  - Carolina Rodezno (PI)

NCHRP 09-56A Project Status

The NCHRP 09-56 research findings are discussed in NCHRP Report 847, Variability of Ignition Furnace Correction Factors. The NCHRP 09-56A project was significantly delayed, but now complete, having been slowed by the global health situation. NCHRP has received the draft final report, but the final report has not yet been published. It is anticipated to be released sometime in 2023.

Key Findings and Conclusions

Key conclusions and findings from the NCHRP 09-56 research are described in NCHRP Report 847 and are shown below as they relate to the objectives of the NCHRP 09-56A project.

- The primary factors affecting asphalt and aggregate correction factors determined by *AASHTO T 308* are furnace type and test temperature. Conducting the test at 800°F appears to substantially reduce the magnitude and standard deviation of the correction factors for asphalt mixtures that do not contain lime.
- Sharing correction factors among different ignition furnaces appears acceptable for low correction factor aggregates (0.1% or less) but is problematic for aggregates with correction factors of 1.0 or greater.
- The precision estimates in *AASHTO T 308* appear applicable only to mixtures with low correction factor aggregates.
- A key product of the NCHRP 09-56 research is a proposed Standard Practice for Installation, Operation, and Maintenance of Ignition Furnaces. This was published as *AASHTO R 96* in 2019.
  - After reviewing the experimental data, the NCHRP project panel concluded that development of a verification procedure to identify causes for non-comparing, statistically different, or biased test results from ignition furnaces was premature. This led to the decision to continue with the project in NCHRP 09-56A with the intent of conducting an interlaboratory study in accordance with ASTM E691 as the basis for development of a robust, definitive verification procedure.

Key conclusions and recommendations from the NCHRP 09-56A research include:

- Ignition test results conducted with virgin mixes that utilized aggregates with both low and high mass loss confirmed that reducing the test temperature from 1000°F to 800°F resulted in a lower correction factor.
- The average standard deviation of tests conducted at 1000°F (unaged and aged) was 0.099, while the standard deviation of tests conducted at 800°F was 0.070. The difference in variance for most samples was not statistically significant.
- Centrifuge extraction results in general yielded lower asphalt contents than the actual values. This trend was more pronounced for mixes with aggregates with higher water absorption.
- Ignition tests (at 800°F) and centrifuge extractions conducted using simulated RAP suggested that for the evaluation of actual RAP materials, no test would consistently yield asphalt content results closer to the actual values, and that the results tend to be mix dependent.
- For recycled materials, centrifuge extraction results showed higher variability than ignition results for five out of seven materials.
- For mixes with high RAM contents (with one exception) the ignition tests conducted at 800°F yielded positive CFs that ranged from 0 to 0.37, indicating that even with mixes with high mass loss aggregates, results were less than 0.5.
- A revised precision statement was developed with the inclusion of a wide set of mixes that included virgin and recycled mixes, with different aggregates sources and nominal maximum aggregate sizes. The repeatability and reproducibility standard deviation of each individual mix type suggested that virgin mixes and recycled mixes do not require different precision statements.
- Since a new burning profile for IR irradiation-type furnaces was developed and used in this study, users of the Troxler units will be required to input and test the profile with their units before implementation of the revised procedure and precision statement.
- The results obtained in this study suggest that the current limits placed on aggregate gradation changes after ignition test conducted at 800°F seem acceptable for tests conducted on virgin and high RAM mixtures. Therefore, no changes to the current requirement are recommended.
- The basic changes recommended for *AASHTO T 308* include (1) changes in the recommended test temperature; and (2) a revised precision statement for asphalt content determination. This revised *AASHTO T 308* procedure is recommended for agencies that may deal with asphalt mixes containing with high recycled content materials and aggregates with high loss mass during ignition test. For agencies that do not deal with these two issues, the current precision statement may be adequate.

Additional Research Identified by the Research Team in NCHRP 09-56A

- Although the study included a wide range of aggregate and recycled materials, an evaluation with additional mixtures and RAP and RAS sources could be conducted in the future to refine the proposed precision statement.
- Although not highlighted as such, the draft report indicates that correction factors may be needed for centrifuge extractions for mixes with higher absorption, which may require additional research.

Proposed New and Revised Standards Resulting from the NCHRP 09-56A Project

Revisions to *AASHTO T 308, Determining the Asphalt Binder Content of Asphalt Mixtures by the Ignition Method* include the following:

- Proposed major changes (all proposed changes shown in separate Standard markup):
  - Reduce the test temperature from 1000°F to 800°F
  - Add mass requirements for recycled materials

- Add new burn profile for IR irradiation-type furnaces that would be equivalent to running tests at 800°F
- Add new values for precision and bias statement
- In Annex A, add significant verbiage pertaining to mixes with RAP and/or RAS

Interactions with Other Standards

Shown below is a list of AASHTO standards that have included *AASHTO T 308* as a referenced document. The likely changes to *AASHTO T 308* are not expected to impact any of these standards.

- *AASHTO M 156-13 (2017)*, *Requirements for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures*
- *AASHTO M 323-13*, *Superpave Volumetric Mix Design*
- *AASHTO R 96-19*, *Installation, Operation, and Maintenance of Ignition Furnaces*
- *AASHTO T 30-19*, *Mechanical Analysis of Extracted Aggregate*
- *AASHTO T240-13 (2017)*, *Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin Film Oven Test)*
- *AASHTO T 313-19*, *Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)*
- *AASHTO T 362-17*, *Quantitative Determination of the Percentage of Lime in Asphalt Mixtures*
- *AASHTO PP 78-17 (2020)*, *Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in Asphalt Mixtures*
- *AASHTO PP 86-20*, *Emulsified Asphalt Content of Cold Recycled Mixture Designs*
- *AASHTO PP 94-18 (2020)*, *Determining Optimum Asphalt Content of Cold Recycled Mixture with Foamed Asphalt*

Impact of NCHRP 09-56A Recommendations on Lab Operations (Agency and Industry)

- The NCHRP 09-56A recommendations should have negligible impact on daily lab operations. For the most common ignition oven types, 800°F would be input into the ignition oven rather than the current 1000°F. For IR irradiation-type ovens, a new burning profile would need to be programmed by local laboratory personnel one time. Afterward, all tests would simply use the new profile. Troxler's instructions for programming the new profile are included in the NCHRP 09-56A draft report.
- *AASHTO T 308* has always indicated that correction factors are required for each individual ignition furnace. The practice of sharing correction factors between ignition furnaces has never been allowed by the test procedure, although some agencies allow the practice. The lower ignition furnace set temperature typically results in lower correction factors (less than 0.50 in the tests on mixes using RAM in this study), therefore mitigating to some degree the variability introduced by sharing the same correction factor between multiple ovens for the same mix. The variability of the asphalt content test results for the high RAM mixes was similar to the one for virgin mixes in this study.
- Larger RAS samples than indicated in Table 2 may not completely ignite the asphalt during testing. Reducing the test size in the baskets may allow complete ignition. The way the *AASHTO T 308* revisions are currently proposed in 09-56A, there is no option to increase the test temperature back to 1000°F.

Unanswered Questions and Concerns that Could Affect Adoption of NCHRP 09-56A Recommendations

There appears to be little cause for concern regarding the adoption of the new, lower ignition furnace set temperature proposed in the draft report for NCHRP 09-56A. The report indicates that lowering the test temperature of *AASHTO T 308* method from 1000°F to 800°F will lower correction factors, resulting in lower variability, and still provide a complete burn of the binder.

Note 4 from the proposed revision of *AASHTO T 308* indicates larger RAS samples than indicated in Table 2 may not completely ignite the asphalt during testing. While technicians can reduce the testing size of the sample in an attempt to provide a complete burn, the proposed revision does not mention or allow a return to the 1000°F test temperature in these type situations. This caveat should be added to the proposed *AASHTO T 308* standard.

Table 2 gives minimum masses for RAP (identical to the virgin minimum mass requirements by NMAS), but gives a mass *range* for RAS, not a minimum mass as the table's column heading indicates. There will likely be concern about incomplete burns for RAP mixes. It should be noted that the study's harshest test was a 9.5mm mix with a 0.46 recycled binder ratio and it experienced no reported incomplete burn problems (the other five mixes in the study would appear to be less harsh, with larger NMAS and lower recycled binder ratios, as low as 0.31). In the specific case of RAS, an upper limit is desirable to mitigate incomplete burn issues caused by too much RAS. In the study, there was only one test mix that included RAS (20% RAP and 5% RAS for a recycled binder ratio of 0.36).

The study did not specifically research the effect on correction factors of hydrated lime in asphalt mixtures. There was some supposition in the report about the effect of lime. While there are unanswered questions about the effect of lime on correction factors at the proposed new temperature, the same questions exist for the current temperature of 1000°F. Therefore, the lime question should not affect the adoption of the proposed new test temperature of 800°F. However, future research is needed to answer this question.

NCHRP 20-44(19) Research Implementation Activities – NCHRP 09-56A

The NCHRP 20-44(19) Team has prepared a prepared a PowerPoint presentation discussing the NCHRP 09-56 and 09-56A research. Proposed changes to *AASHTO T 308* include the NCHRP 09-56 and 09-56A findings. There is a revised precision statement and a change to the test temperature from 1000°F to 800°F. *AASHTO R 96, Standard Practice for Installation, Operation, and Maintenance of Ignition Furnaces*, is not expected to change except for references to the test temperature.

A proposed revised version of *AASHTO T 308* is included in the draft final report. The NCHRP 20-44(19) Team will be prepared to brief Technical Subcommittee 2c on the changes and assist with the balloting of the revised standard.

NCHRP 09-59 Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance

NCHRP 09-59 Project Objectives

The objectives of this research were to:

1. determine asphalt binder properties that are significant indicators of the fatigue performance of asphalt mixtures.
2. 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*.
3. propose necessary changes to existing AASHTO specifications to incorporate the identified binder properties and their specification limits.
4. validate the binder fatigue properties, test(s), and changes to existing and/or proposed AASHTO test methods and specifications with data from field projects, accelerated loading facilities, or both, supplemented, as necessary, with data from additional laboratory-prepared specimens.

NCHRP 09-59 Project Team

- Advanced Asphalt Technologies
  - Don Christensen (PI)
- National Center for Asphalt Technology
  - Nam Tran

NCHRP 09-59 Project Status

The NCHRP 09-59 research findings were submitted in a draft final report completed in June 2019. The final report was published in 2022 as NCHRP Report 982, Relationships Between the Fatigue Properties of Asphalt Binders and the Fatigue Performance of Asphalt Mixtures.

Key Findings and Conclusions (excerpted from NCHRP Report 982)

- Although the fatigue life of an asphalt pavement depends upon many factors, the factors that can be addressed as part of a binder fatigue specification are applied binder strain, binder failure strain and the fatigue exponent. Fatigue life increases with decreasing applied binder strain relative to failure strain and increasing fatigue exponent.
  - Binder failure strain is primarily a function of binder modulus, with failure strain decreasing dramatically with increasing modulus.
  - The fatigue exponent for an asphalt mixture is inversely related to the binder phase angle.
- For polymer-modified binders, the phase angle value used for calculating the fatigue exponent is not the measured value, but the value calculated using the Christensen-Anderson rheological model and the R-value calculated at a modulus value above 10 MPa.
- A binder's failure strain under fatigue loading and a given set of conditions can be calculated and is called the fatigue strain capacity (FSC). It appears to be reasonably close to direct measurements of binder failure strain such as the direct tension test.

- The FSC of a binder is an important factor in determining fatigue performance and is a good basis for a specification test.
- The current intermediate temperature binder specification parameter, G* sin δ is only moderately correlated to binder FSC.
- The Glover-Rowe parameter (GRP) correlates much better to FSC and is a good indicator of binder failure strain under a given set of conditions.
- For thin pavements, high R-values can result in very poor fatigue performance at low temperatures. For thick pavements, low R-values can result in poor fatigue performance. For optimum pavement fatigue performance, both very low and very high R-values should be avoided, although the relative performance of binders with high R-values appears to be much worse than that for binders with low R-values.
- The current practice of determining binder fatigue test temperature is not consistently tied to average pavement temperatures for a range of climates. The intermediate test temperature in AASHTO M320 and M 332 is too high for grades PG 70-XX and higher, and too low for grades PG 58-XX and lower.
- Grade adjustments for traffic volume and speed can result in elevated binder fatigue test temperatures unless addressed properly by local agencies. Selecting binders with low-temperature PG grades that do not meet the requirements for the local climate can also elevate the binder fatigue test temperature.
- Several field validation sites and FHWA ALF fatigue data show reasonably good correlations between GRP and fatigue performance.
  - Although the correlations with G* sin δ are also good in some cases, GRP appears to relate better overall to fatigue performance.
- Using the proposed binder fatigue test temperatures, a reasonable and effective maximum value for GRP after RTFOT/20-hour PAV aging is 5,000 kPa at 10 rad/s.
  - For RTFOT/40hour PAV aging this limit should be raised to 8,000 kPa at 10 rad/s.
- A reasonable and effective range for R-value for binders aged using RTFOT/20-hour PAV aging is from1.50 to 2.50.
  - For RTFOT/40-hour PAV aging this range should be shifted to from 2.00 to 3.20. 12.
- It is possible that the extended loose-mix aging procedure used in NCHRP 09-59 resulted in an unrealistic loss of fatigue and fracture performance for some or all the polymer modified binders included in the study. If so, this would affect the applicability of some of the findings of this study to polymer-modified binders and would also question the advisability of adopting extended loose-mix aging for widespread use in asphalt concrete mix design and analysis. Of particular concern in this context is whether the same maximum R-value should apply to both non-modified and polymer-modified binders, or if the maximum value of R should be increased or eliminated for polymer-modified binders.
- Research recommendations are:
  - 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.
  - The current intermediate binder specification parameter, G*sin δ, should be replaced by the Glover-Rowe parameter (GRP = $G^*\cos^2\delta$ / sin δ) determined at a frequency of 10 rad/s. The maximum allowable value for GRP after RTFOT/20-hour PAV aging should be 5,000 kPa.
  - The binder fatigue specification should include an allowable range for the Christensen-Anderson R-value of from 1.5 to 2.5, after RTFOT/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

- The proposed maximum value for GRP and range for R-value given above should be considered tentative. Final values should be based on review and comment of the proposed specification by pavement engineers and researchers and collection of additional data on a wide range of binders.

Additional Research Identified by the Research Team in NCHRP 09-59

- One important consideration is whether the precision of R is adequate for a specification involving both a minimum and maximum value. If the precision is not good enough, a specification using only a maximum value of R should be implemented.
- A second issue is whether the same maximum R-value should apply to both non-modified and polymer-modified binders or if the maximum value of R should be increased for polymer-modified binders.
- There are suitable alternatives to R-value for use in an improved binder fatigue specification. These include ΔT_c and BBR stiffness at m=0.3. Some additional work would be needed to develop recommendations for specification values for either of these parameters.
- The findings, conclusions and recommendations of this project should be reevaluated after the conclusion of the NCHRP 09-60 project.

Proposed New and Revised Standards Resulting from the NCHRP 09-59 Project

- *AASHTO M 320*, *Specification for Performance-Graded Asphalt Binder*
  - Changes to Table 1 and Table 2 for testing of PAV-aged residue to replace the G*sin δ parameter with the GRP ($G^*\cos^2\delta/\sin\delta$). Added minimum/maximum R-values calculated from BBR testing as shown in the sample below:

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[a]	<64						<70					
Design low pavement temperature, °C[a]	>−10	>−16	>−22	>−28	>−34	>−40	>−10	>−16	>−22	>−28	>−34	>−40
Tests on Original Binder												
Flash point temperature, T 48, Min., °C	230											
Viscosity, T 316:[b] Maximum value of 3 Pa-s at test temperature, °C	135											
Dynamic shear, T 315:[d] G*/sin δ,[d] minimum value 1.00 kPa, at 10 rad/s and test temperature, °C	64						70					
Tests on Residue from Rolling Thin Film Oven (T 240)												
Mass change,[e] maximum, %	1.00											
Dynamic shear, T315:[e] G*/sin δ,[d] minimum value 2.20 kPa, at 10 rad/s and test temperature, °C	64						70					
Tests on Residue from Pressure Aging Vessel (R 28)												
PAV aging temperature, °C[f]	100						100 (110)					
Dynamic shear, T 315: G* (cos δ)² / sin δ,[d] maximum value 5,000 kPa, at 10 rad/s and test temperature, °C[g,h]	29	27	25	22	19	17	29	27	25	22	19	17
Creep stiffness, T 313:[i] 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											

- Changed the PAV DSR test temperature to be based only on low temperature PG instead of the current practice of using the average of the High PG and Low PG and adding 4°C.
- Revised *Footnote d* in Table 1 and Table 2 indicating that $G^{*}\cos^{2}\delta/\sin\delta$ is representative of intermediate temperature stiffness instead of $G^{*}\sin\delta$.
- Renumbered *Footnote g* in Table 1 and Table 2 to *Footnote i* to allow for additional Footnotes as described below. Added verbiage indicating that the R-value requirement must be satisfied in both cases.
- Added *Footnote g* in Table 1 and Table 2 indicating that the PAV DSR test temperature should be lowered 3°C for locations along the Pacific Coast of the US and Canada.
- Added *Footnote h* in Table 1 and Table 2 cautioning that increasing the low temperature PG above what is required for the climate will increase the intermediate test temperature and could result in reduced fatigue performance in addition to increased susceptibility to low temperature cracking. It is also noted that increasing pavement thickness will help improve fatigue performance.

- *AASHTO M 332*, *Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test*
  - Same changes to Table 1 as were made in *AASHTO M 320* Tables 1 and 2 as shown in the sample below:

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[b]	<64						<70					
Design low pavement temperature, °C[b]	>−10	>−16	>−22	>−28	>−34	>−40	>−10	>−16	>−22	>−28	>−34	>−40
Tests on Original Binder												
Flash point temperature, T 48, Min., °C	230											
Viscosity, T 316:[c] Maximum value of 3 Pa-s at test temperature, °C	135											
Dynamic shear, T 315:[d] G*/sin δ,[e] minimum value 1.00 kPa, at 10 rad/s and Test Temperature, °C	64						70					
Tests on Residue from Rolling Thin Film Oven (T 240)												
Mass change,[f] maximum, %	1.00											
MSCR, T350: Standard traffic "S" $J_{nr3.2}$, max 4.5 kPa^{-1} J_{nrdiff}, max, 75 % Test Temperature, °C	64						70					
MSCR, T350: Standard traffic "S" $J_{nr3.2}$, max 2.0 kPa^{-1} J_{nrdiff}, max, 75 % Test Temperature, °C	64						70					
MSCR, T350: Standard traffic "S" $J_{nr3.2}$, max 1.0 kPa^{-1} J_{nrdiff}, max, 75 % Test Temperature, °C	64						70					
MSCR, T350: Standard traffic "S" $J_{nr3.2}$, max 0.5 kPa^{-1} J_{nrdiff}, max, 75 % Test Temperature, °C	64						70					
Tests on Residue from Pressure Aging Vessel (R 28)												
PAV aging temperature, °C[g]	100						100 (110)					
Dynamic shear, T 315: "S" $G^* (\cos \delta)^2 / \sin \delta$,[e] maximum value 5,000 kPa, at 10 rad/s and Test Temperature, °C[h,i]	29	27	25	22	19	17	29	27	25	22	19	17
Dynamic shear, T 315: "H," "V," "E" $G^* (\cos \delta)^2 / \sin \delta$,[e] maximum value 6,000 kPa, at 10 rad/s and Test Temperature, °C[h,i]	29	27	25	22	19	17	29	27	25	22	19	17
Creep stiffness, T 313:[j] 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 temperature minimum / maximum	1.50 / 2.50											
Direct tension, T 314[i,j]												

- Same changes to the Footnotes as were made in *AASHTO M 320* Tables 1 and 2.

- *AASHTO R 29, Practice for Grading or Verifying the Performance Grade (PG) of an Asphalt Binder*
  - Changed Section 6.8 to provide starting test temperatures based on low temperature PG and reflecting the determination of the GRP ($G^*\cos^2 \delta/\sin \delta$) instead of $G^*\sin \delta$.
  - Added a new section after Section 6.11 to discuss calculation of R-value.
  - Changed Section 7.8 to show a different starting test temperature for the example asphalt binder (PG 64-40) and changed the parameter from $G^*\sin \delta$ to $G^*\cos^2 \delta/\sin \delta$.
  - Added verbiage to Section 7.9 about calculating R-value and noting acceptable values.
- *AASHTO T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)*
  - Changes were made in the draft final report to an earlier version of the standard, *T 313-12 (2016)*, so the changes will need to be reviewed to see how they fit in the latest version, *T 313-19*.
  - Changed Figure 4 (Typical Test Report) showing an added column for R-value at each of the loading times.

  - Added a new section after Section 14.3.7 to indicate that the report data should show R-value calculated to the nearest 0.1 (note that the example in Figure 4 shows R-value to the nearest 0.01).
  - Added a line in Table 1 to show that the precision estimates for R-value have not yet been determined.
  - Added a section in Annex A to show the calculation of R-value.
- *AASHTO T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)*
  - No changes were made by the NCHRP 09-59 researchers to *AASHTO T 315*, but a brief review indicates that some will be needed to accommodate the change from G*sin δ to G*cos² δ/sin δ.
    - Tables 2 and 3 reference G* sin δ in determining appropriate target shear strain and target shear stress.
    - Section 13.4.7 should be changed from G*sin δ to G*cos² δ/sin δ.
    - Table 4 (Precision Estimates) will need to change showing that the precision for G*cos² δ/sin δ has not yet been determined.
      - Since AASHTO re:source collects data on G* and δ after PAV aging, it should be possible to calculate G*cos² δ/sin δ from past proficiency sample programs and determine an estimate of precision.

Interactions with Other Standards

Although many AASHTO standards may reference the revised standards noted above (*M 320, M 332, R 29, T 313,* and *T 315*) it is unlikely that they will need to be significantly changed, with a few exceptions.

- *AASHTO M 323-13, Superpave Volumetric Mix Design*
  - Appendices X1 and X2 providing blending procedures for RAP and references the determination of T_{int} using G*sin δ.
- *AASHTO MP 46-20, Specification for Balanced Mix Design*
  - References the use of intermediate temperature using the average of the High PG and Low PG. The proposed revisions in *M 320* are based only on Low PG grade.

Impact of NCHRP 09-59 Recommendations on Lab Operations (Agency and Industry)

- 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 *AASHTO M 320* and *AASHTO M 332*.
  - calculating a new parameter from the standard *AASHTO T 313* (BBR) test for use in *AASHTO M 320* and *AASHTO M 332*.
  - changing the intermediate test temperature in for use in *AASHTO M 320* and *AASHTO M 332* for PAV DSR testing.
  - incorporating new specification criteria for BBR testing.
- DSR manufacturers will need to re-write testing scripts to calculate the new G*cos² δ/sin δ parameter, but otherwise the test operation will stay the same as is currently performed in *AASHTO T 315*.
  - Temperature sweep testing, used to determine the continuous grade temperature, can still proceed at 3°C intervals for PAV DSR. However, if the low temperature grade of the asphalt binder is a -10, -16, or -40, then the test temperatures will not match the test temperatures in *AASHTO M 320* and *AASHTO M 332*. Interpolation could be used, but most likely a user agency would want to see the value at the actual test temperature prescribed in *AASHTO M 320* or *AASHTO M 332* – meaning an additional single-point test would be needed. The solution would be for the DSR manufacturer to write

a script ignoring a constant temperature interval and incorporating the test temperatures shown in *AASHTO M 320* and *AASHTO M 332*.

- BBR manufacturers will need to re-configure the test report format to calculate R-value and show it at each of the loading times.

Unanswered Questions and Concerns that Could Affect Adoption of NCHRP 09-59 Recommendations

- More analysis is needed to ascertain how the change to the proposed parameters coupled with the change in test temperature may impact the specification compliance of current asphalt binders.
- If a user agency is using grade bumping in *AASHTO M 320* for modified asphalt binders and not basing the intermediate test temperature on the base, unmodified asphalt binder grade, then the recommended change may result in testing being conducted at a lower intermediate temperature. This could have an impact on the ability of the modified asphalt binder to meet the specification value.
- As proposed, the R-value is easily calculated from BBR data. To standardize this calculation, it would be beneficial to indicate that the calculation shall be performed using BBR data at the low PG temperature. Values of R may change slightly at different test temperatures. As noted, the sensitivity of R is unknown at this time and may not be suitable for use in a specification.

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One significant change could be the test temperature used by the technician for grade verification. The change to a single temperature based on the low PG of the asphalt binder means that a simplified chart can be used for determining intermediate test temperature. Test temperatures for some common grades in *AASHTO M 320* are shown in **TABLE A1** below.

TABLE A1. Intermediate Test Temperature after RTFO/PAV20 Aging

Asphalt Binder Grade	AASHTO M320 PAV DSR Temperature	NCHRP 09-59 Proposed PAV DSR Temperature	Difference (Current– Proposed Practice)
PG 52-28	16	22	+6
PG 52-34	13	19	+6
PG 58-22	22	25	+3
PG 58-28	19	22	+3
PG 58-34	16	19	+3
PG 64-16	28	27	-1
PG 64-22	25	25	0
PG 64-28	22	22	0
PG 64-34	19	19	0
PG 70-10	34	29	-5
PG 70-16	31	27	-4
PG 70-22	28	25	-3
PG 70-28	25	22	-3
PG 76-16	34	27	-7
PG 76-22	31	25	-6
PG 76-28	28	22	-6
PG 82-22	34	25	-9

The use of the GRP will also weight more significantly the phase angle (δ) of the asphalt binder than the current G*sin δ parameter, generally favoring asphalt binders that have a higher phase angle and disfavoring those binders with a lower phase angle. This rectifies a problem that has been seen with the G*sin δ parameter in which the opposite is true. It also lines up with changes in *AASHTO M320* and *AASHTO M 332* (S grades) which allows a G*sin δ value greater than 5000 kPa and less than 6000 kPa if the phase angle is 42 degrees or greater.

FIGURE A1 shows the impact of the coefficient on the intermediate binder property over a limited range of phase angle seen for asphalt binders at intermediate temperatures after RTFO/PAV20 aging.

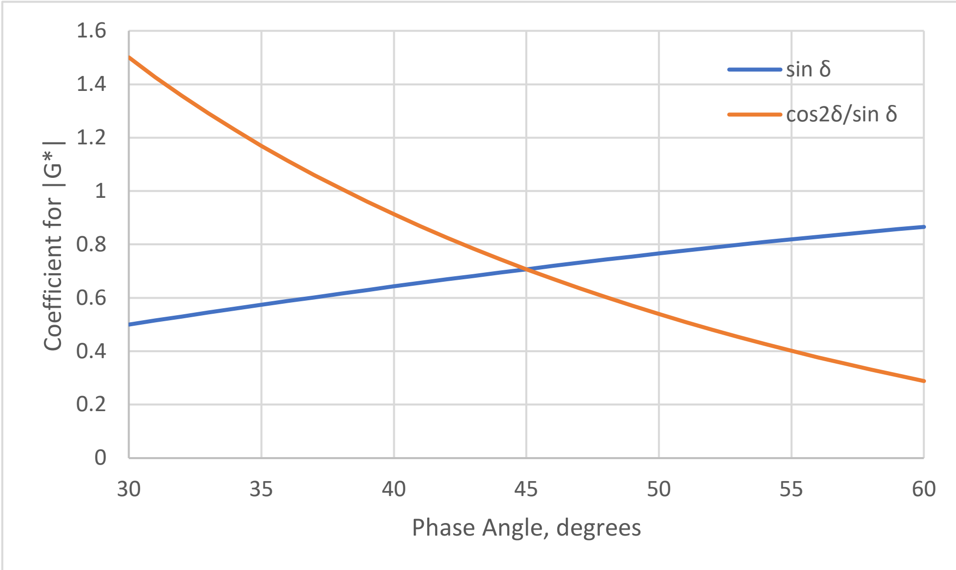

FIGURE A1. Coefficient of Intermediate Binder Parameter as a Function of Phase Angle

As can be seen in **FIGURE A1**, the coefficients move in different directions as a function of phase angle. As an asphalt binder ages, stiffness (G*) increases and relaxation (in the form of phase angle or δ) decreases. Because the coefficient decreases for the G*sin δ parameter as phase angle decreases, the impact of aging is somewhat mitigated. This is not true for the GRP ($G^*\cos^2 \delta/\sin \delta$) where the coefficient increases significantly as phase angle decreases – leading to a more rapid failure of the specification criterion as the asphalt binder ages.

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. This can be seen in **FIGURE A2** showing the ratio of the GRP coefficient to G* ($\cos^2\delta/\sin \delta$) to the *AASHTO M 320* coefficient to G* (sin δ).

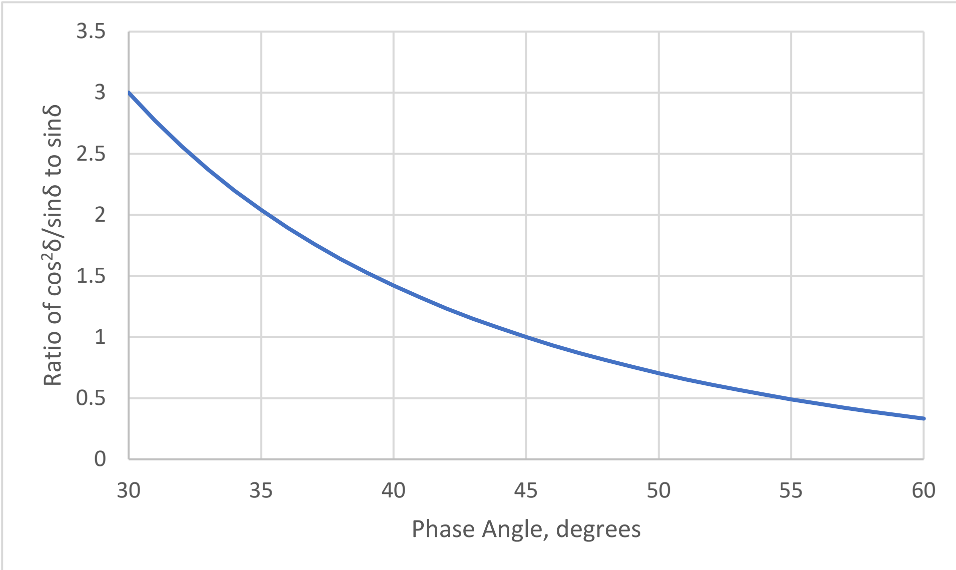

FIGURE A2. Effect of Coefficient of Intermediate Binder Parameter at the Same G* as a Function of Phase Angle

As shown in **FIGURE A2**, at a binder phase angle of 45 degrees, the two parameters will produce the same coefficient to G*. At a phase angle of 40 degrees, the GRP parameter will be 1.42 times greater than the G*sin δ parameter for the same value of G*. At phase angle of 50 degrees, the GRP parameter will be 0.7 times that of the G*sin δ parameter for the same value of G*.

Another question from the research recommendations is how the R-value can be used to address cracking and how it is related to ΔT_c as suggested by the researchers.

FIGURE A3 shows data from 52 unmodified asphalt binders including the SHRP MRL asphalt binders and other asphalt binders in SHRP Report A-645 as well as unmodified asphalt binders that had been aged for longer than the standard PAV aging time of 20 hours (as reported in the AAPTP 06-01 Final Report). This data set binders from locations across the US and Canada in relatively current production as well as past production.

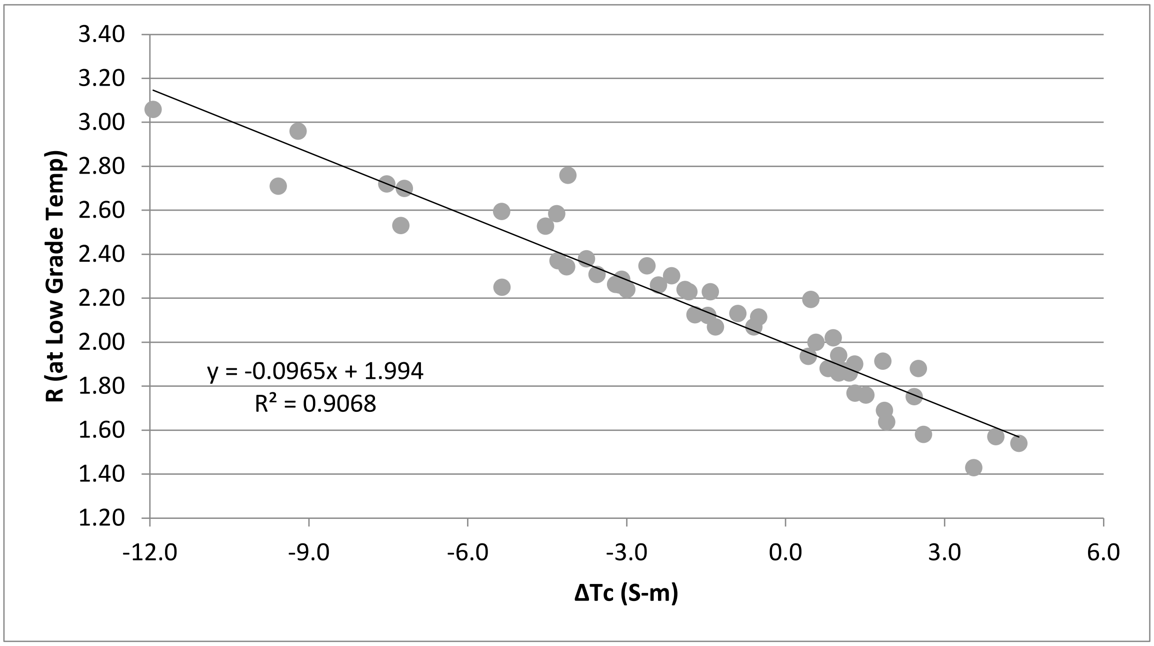

FIGURE A3. Relationship Between R Value and ΔT_c for Selected Unmodified Asphalt Binders

As shown in **FIGURE A3**, for the unmodified asphalt binders in this set of data the R-value is strongly related to the ΔT_c value – as expected since S and m-value are used to calculate each parameter. The proposed R-value specification limit of 2.5 is correlated to a ΔT_c value of -5.2°C. This is similar to the value suggested by other researchers and user agencies who are considering the use of ΔT_c value in their specifications.

One of the concerns expressed with the use of ΔT_c as a specification parameter is that polymer modified asphalt binders might have values of ΔT_c that are lower than the proposed specification. The same concern was expressed with the use of R value. **FIGURE A4** shows data mined from 34 modified asphalt binders used in the NCHRP 09-10 research project evaluating a broad variety of asphalt modification.

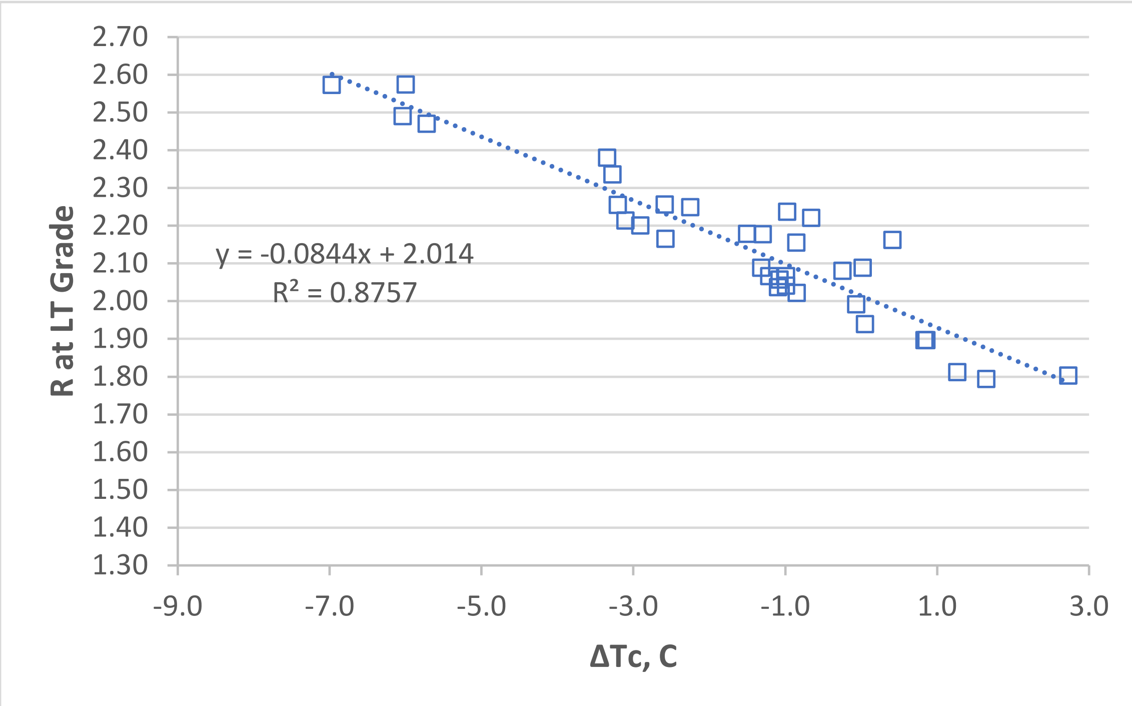

FIGURE A4. Relationship Between R Value and ΔT_c for Modified Asphalt Binders from the NCHRP 09-10 Research Project

As with the data shown in **FIGURE A3** for unmodified asphalt binders, the data shown in **FIGURE A4** for modified asphalt binders indicates that the R-value is strongly related to the ΔT_c value. For this data set, the proposed R-value specification limit of 2.5 is correlated to a ΔT_c value of -5.8°C. This is similar to the value from the data in FIGURE 3, suggesting that the relationship between R and ΔT_c should generally be the same whether the asphalt binder is unmodified or modified (at least using the types of modification and base asphalt binders studied in the NCHRP 09-10 research project). For the unmodified asphalt binder data set, a ΔT_c value of 0.0 corresponds to an R-value of 1.99. For the modified binder data set, a ΔT_c value of 0.0 corresponds to an R-value of 2.01.

It should also be noted that only two of the 34 modified asphalt binders in **FIGURE A4** exceeded an R-value of 2.50 – 6% of the evaluated materials. By comparison, ten of the 52 unmodified asphalt binders in **FIGURE A3** exceeded an R-value of 2.50 – 19% of the evaluated materials. If we remove those unmodified asphalt binders in **FIGURE A3** that were aged longer than PAV20, the percentage of evaluated materials that exceeded an R-value of 2.50 decreases to 15% (7 of 46).

Based on the data in **FIGURE A3** and **FIGURE A4**, two main conclusions can be made:

- R-value is strongly related to ΔT_c and could be used instead of ΔT_c in a specification if desired.
- Modified asphalt binders from the NCHRP 09-10 data set do not appear more likely to fail the proposed R-value or ΔT_c criteria than unmodified asphalt binders.

The findings suggest that the research recommendation to use R-value as a parameter in conjunction with the Glover-Rowe Parameter (GRP) to address cracking appears reasonable as R-value appears to directly relate to ΔT_c.

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 Project Objectives

The objectives of the research were to 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 Project Team

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NCHRP 09-60 Project Status

NCHRP has received the draft final report for Phase II. Work on Phase III is expected to begin in 2023.

Key Findings and Conclusions

- The research team recommends adding ΔT_c to *AASHTO M 320* and *M 332* as a specification parameter. The parameter relates to the relaxation properties of unmodified binders and generally relates to the colloidal structure of the asphalt binder.
- 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.
- To capture strength/strain tolerance, it is recommended to use the Asphalt Binder Cracking Device (ABCD) in *AASHTO T 387* to determine the critical cracking temperature, T_{cr}.
- The T_{cr} determined from *AASHTO T 387* is used with the temperature at which BBR Stiffness at 60 seconds of loading is equal to the specification value of 300 MPa. This temperature is referred to as $T_{c,S}$.
- A new parameter, ΔT_f is proposed 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.
- The proposed specification:
  - Uses standard RTFO/PAV20 aging
  - Uses BBR data to determine $T_{c,S}$, $T_{c,m}$ and ΔT_c.

- If ΔT_c values are less than -6°C, then the asphalt binder fails to meet the specification.
- If ΔT_c values are greater than -2°C, then the asphalt binder meets the specification.
- If ΔT_c values are less than or equal to -2°C and greater than or equal to -6°C, then the ABCD test is used to determine T_{cr} and, subsequently, ΔT_f.
  - In this instance, the 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.

- The proposed specification is summarized in **FIGURE A5** from the June 2020 workshop presenting the initial findings of the NCHRP 09-60 project.

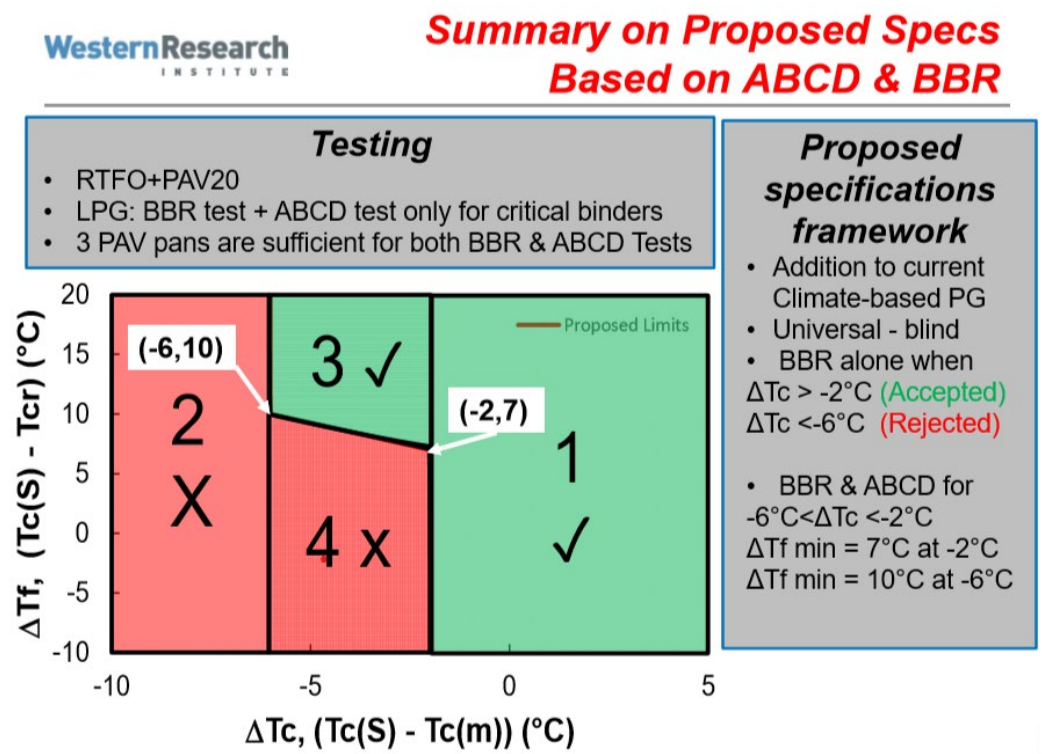

FIGURE A5. Summary of Proposed Specification from NCHRP 09-60

- If PAV40 is used instead of PAV20, the limits for ΔT_c and ΔT_f change as follows:
  - If ΔT_c values are less than -7°C, then the asphalt binder fails to meet the specification.
  - If ΔT_c values are greater than -3°C, then the asphalt binder meets the specification.
  - If ΔT_c values are less than or equal to -3°C and greater than or equal to -7°C, then the ABCD test is used to determine T_{cr} and, subsequently, ΔT_f.
    - In this instance, the ΔT_f must be greater than a specified value from 3 to 6°C as a function of the ΔT_c value to meet the specification.

Additional Research Identified by the Research Team in NCHRP 09-60

The biggest need identified by the research team was the need to conduct validation testing for the specification. Other needs are discussed below.

Proposed New and Revised Standards Resulting from the NCHRP 09-60 Project

The draft final report does not currently list any changes to the AASHTO standards, but changes are expected to the following standards:

- *AASHTO M 320, Specification for Performance-Graded Asphalt Binder*
- *AASHTO M 332, Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test*
- *AASHTO T 387, Determining the Cracking Temperature of Asphalt Binder Using the Asphalt Binder Cracking Device (ABCD)*
- *AASHTO R 29, Practice for Grading or Verifying the Performance Grade (PG) of an Asphalt Binder*
- *AASHTO PP xx, Characterizing the Relaxation Behavior of Asphalt Binders Using the Delta Tc (ΔTc) Parameter*

In addition, a new standard practice may be needed to illustrate the calculation of ΔT_f.

Interactions with Other Standards

As is the case with the NCHRP 09-59 research many AASHTO standards may reference the revised standards noted above (*M 320, M 332, R 29,* and *T 387*) it is unlikely that they will need to be significantly changed, with a few exceptions. One example is *AASHTO M 323* which includes an Annex on RAP blending.

Impact of NCHRP 09-60 Recommendations on Lab Operations (Agency and Industry)

- 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.
- The determination of ΔT_f requires the use of the ABCD test to first determine T_{cr}. The ABCD equipment is not widely available commercially at this time. Estimated equipment cost is likely to be in the range of $40,000 to $50,000.
- The use of the ABCD test with BBR testing means that 1-2 additional pans of PAV-aged asphalt binder may be needed.
- It is unknown how many asphalt binders would have ΔT_c values between -2 and -6°C and would therefore need to potentially qualify in the specification by using the additional ABCD testing and subsequent T_{cr} and ΔT_f calculations.
  - One of the concerns expressed with using ΔT_c only is that some polymer modified asphalt binders might exhibit lower values of ΔT_c and would therefore be disadvantaged in a specification using that parameter. The use of ΔT_f may help account for the increased strain tolerance and strength of polymer modified asphalt binders, but at the cost of having to perform testing that many unmodified asphalt binders may not need.
  - Based on the analysis in **FIGURE A3** and **FIGURE A4**, it appears that as many as 40-50% of asphalt binders would have ΔT_c values after PAV aging less than -2°C, meaning that many asphalt binders will then need qualification using the ΔTf approach (and ABCD test). It would seem to be confirmed by the NCHRP 09-59 research (NCHRP Report 982) which makes the following statement in setting a specification limit for the GRP:

> “One approach is to calculate the equivalent values to the current limit on $|G^*| \sin \delta$ of 5,000 kPa. However, this equivalency will depend on the R-

value of the binder; if selecting 2.2 as a typical R-value for a PAV-aged binder, the equivalent value of the GRP would be 5,300 kPa."

- Looking at the relationship between R and ΔT_c, it appears that an R value of 2.2 (identified as "typical") would correspond to a ΔT_c value of -2.1°C (unmodified) to -2.2°C (modified) – meaning about half of all asphalt binders should be above that value and about half below.
- The lower end of the specification limit is set so that asphalt binders that have a ΔT_c value lower than -6°C will fail without the opportunity for qualification. This appears to be reasonable and in general conformity with the NCHRP 09-59 recommendations. A ΔT_c value of -6°C in **FIGURE A3** and **FIGURE A4** corresponds roughly to an R value of 2.57 (unmodified asphalt binders) or 2.52 (modified asphalt binders). The maximum acceptable value recommended by the NCHRP 09-59 research was 2.50.

Unanswered Questions and Concerns that Could Affect Adoption of NCHRP 09-60 Recommendations

The following recommendations and issues were identified by participants and the research team during the June 2020 workshop.

- Limited field performance data was used to select test methods and threshold values. An expanded validation effort is needed to assure the AASHTO Subcommittee on Materials and other industry stakeholders that the proposed specification criteria are implementable and that they can indeed prevent premature age-induced surface damage.
- The primary tasks under a validation research project would include:
  - Conduct an ILS on ΔT_c and ΔT_f parameters.
  - Conduct an ILS on the ABCD test (*AASHTO T 387*)
  - Evaluate the effects of thermal history on test results.
  - Refine the minimum S value based on m=0.3 criteria.
  - Evaluate the effects of climate vs. low temperature PG grade on the proposed specification limits.
  - Combine S, m-value, and fracture to create a single low-temperature PG grade parameter.
  - Refine 20- and 40-hour PAV conditioning requirements for determining the ΔT_c and ΔT_f parameters coordinating with the 9-61 project.
  - Conduct further validation testing on an expanded list of materials used in the research with known specific problematic asphalt materials.
    - Conduct mixture verification crack testing to validate cracking potentials.
  - Develop AASHTO standard specification and test documents based on the results from the ILS and validation efforts.
  - Develop a detailed field validation program to be carried out by highway agencies through regional pooled fund efforts.

The NCHRP 09-60 research project may continue this work in a Phase III if approved by the project panel.

NCHRP 20-44(19) Research Implementation Activities – NCHRP 09-60

The NCHRP 20-44(19) Team believes that one key impediment to implementation is that more analysis is needed to ascertain how the proposed parameters may impact the specification compliance of current asphalt binders.

As noted by one user, if the recommendations of the NCHRP 09-60 research are adopted in *AASHTO M 320* and *AASHTO M 332* there will be some additional revisions needed to the ABCD test procedure (*AASHTO T 387*) to better address the verification of the strain gauges and temperature sensor. Section 9 of the standard notes that verification of the calibration shall be "…at least every six months and when measurements are suspect." More guidance should be provided regarding how to verify the calibration of the equipment.

The same user suggested that it might be worth considering whether three samples can be used to determine the ABCD Cracking Temperature (T_{cr}) instead of four samples. The question is whether the precision would be significantly different (i.e., worse) than what is currently reported in Section 17 Table 1 of *AASHTO T 387*. The advantage of reducing the number of test samples is that the amount of aged asphalt binder needed is reduced by approximately 15 grams. With extended aging (40-hour PAV) and other potential changes to the PAV procedure (*AASHTO R 28*) based on the findings of the NCHRP 09-61 research, reducing the amount of aged asphalt binder needed could be operationally important.

Even if the reduction in number of test samples does not significantly affect the precision, the use of the ABCD Cracking Temperature (T_{cr}) in the proposed specification could pose a problem with variability. For example, the published single-operator precision (d2s) in *AASHTO T 387* is approximately 2.7°C. This is just one of the two parameters needed to calculate ΔT_f.

As shown in **FIGURE A5**, the line of acceptability for ΔT_f as a function of ΔT_c goes from +7 at a ΔT_c value of -2 to +10 at a ΔT_c value of -6. Even without a change in the precision resulting from lowering the number of test specimens used from four to three, the range of ΔT_f is 3°C (+10 to +7) – which is almost the same as the single operator precision (2.7°C). The same is true for the specification using PAV40, where the line of acceptability for ΔT_f as a function of ΔT_c goes from +3 at a ΔT_c value of -3 to +6 at a ΔT_c value of -7.

When considering the expected variability in $T_{c,S}$ and adding that to the variability in T_{cr}, the variability in ΔT_f could be significant. If the differentiation between the performance of materials is not significant (which can be determined from a review of the draft final report), it might be better to simply specify a minimum ΔT_f value for asphalt binders with ΔT_c values between -2 and -6. While such a change will not fix the variability issue, it may make the adoption of the concept a little easier.

A review of the data from Figures 104 and 105 in as well as the data in Appendix H (Binder Test Data Summary) in the draft final report provides 32 binders with ΔT_c and ΔT_f values – all aged using PAV40. This data is segregated into modified and unmodified asphalt binders in **TABLE A2** and **TABLE A3**.

TABLE A2. Binder Test Data after RTFO/PAV40 Aging – Modified Asphalt Binder Samples

Binder Code	PG Grade	Identification	Laboratory Conditioning	Tc(S), °C	Tc(m), °C	ΔTc, °C	S(m=0.3), MPa	Tcr, °C	ΔTf, °C
59 B03-40	PG 76-22	SBS-modified	RTFOT+PAV40	-25.1	-22.5	-2.6	237	-31.6	6.5
59 B02-40	PG 76-34	SBS-modified	RTFOT+PAV40	-40.2	-23.5	-16.7	47	-46.2	6.0
59 B15-40	PG 58-34	Terpolymer-modified	RTFOT+PAV40	-32.8	-33.8	1.0	247	-38.9	6.1
59 B05-40	PG 76-28	SBR-modified	RTFOT+PAV40	-27.3	-22.7	**-4.6**	174	-33.0	**5.7**
MN1-2-40	PG 64-34	Terpolymer-modified	RTFOT+PAV40	-33.7	-31.9	-1.8	197	-38.2	4.5
MTO S10-40	PG 64-34	SBS-modified	RTFOT+PAV40	-38.7	-32.2	**-6.5**	105	-46.3	**7.6**
MTO S12-40	PG 64-34	Elvaloy	RTFOT+PAV40	-36.9	-37.2	0.3	261	-42.3	5.4
MTO S13-40	PG 76-40	SBS-modified	RTFOT+PAV40	-40.6	-38.1	-2.5	191	-50.6	10.0
MTO S14-40	PG 64-34	Triblock SBS-modified	RTFOT+PAV40	-38.1	-37.4	-0.7	230	-44.0	5.9
MTO S01-40	PG 64-34	Terpolymer	RTFOT+PAV40	-33.8	-34.6	0.8	318	-39.8	6.0
Biophalt-40	PG 76-28	Biophalt	RTFOT+PAV40	-28.9	-30.7	1.8	406	-39.3	10.4
ME2-40	PG 70-28	Maine Portland	RTFOT+PAV40	-33.7	-22.2	-11.5	83	-32.1	-1.6
ME3-40	PG 76-28	Maine Presque Isle	RTFOT+PAV40	-29.8	-27.5	-2.3	193	-37.4	7.6

TABLE A3. Binder Test Data after RTFO/PAV40 Aging – Unmodified Asphalt Binder Samples

Binder Code	PG Grade	Identification	Laboratory Conditioning	Tc(S), °C	Tc(m), °C	ΔTc, °C	S(m=0.3), MPa	Tcr, °C	ΔTf, °C
59 B14-40	PG 58-22	Contains REOB	RTFOT+PAV40	-27.4	-26.5	-0.9	235	-30.4	3.0
SHRP AAA-1-40	PG 58-28	Lloydminster crude	RTFOT+PAV40	-32.4	-32.4	0.0	271	-34.9	2.5
SHRP AAK-1-40	PG 64-22	Boscan crude	RTFOT+PAV40	-25.8	-25.0	-0.8	252	-28.8	3.0
SHRP AAM-1-40	PG 64-16	W. TX intermediate	RTFOT+PAV40	-25.0	-18.5	**-6.5**	116	-30.5	**5.5**
SHRP ABA-1-40	PG 64-22	W. TX Int. Oxidized	RTFOT+PAV40	-32.8	-21.8	-11.0	79	-37.6	4.8
AZ1-1-40	PG 76-16	W. Tx Int. Blend	RTFOT+PAV40	-26.4	-15.6	-10.8	86	-31.5	5.1
AZ1-2-40	PG 76-22	Venezuelan	RTFOT+PAV40	-24.9	-22.7	-2.2	232	-29.5	4.6
AZ1-3-40	PG 76-16	Rocky Mountain blend	RTFOT+PAV40	-20.1	-16.5	**-3.5**	206	-24.0	**3.9**
AZ1-4-40	PG 76-16	Canadian blend	RTFOT+PAV40	-18.6	-15.4	**-3.3**	188	-20.6	**2.0**
59 B12-40	PG 76-22	Oxidized	RTFOT+PAV40	-26.5	-14.4	-12.1	101	-27.4	0.9
59 P-40	PG 70-22	Oxidized	RTFOT+PAV40	-25.6	-23.6	-2.0	221	-28.8	3.2
MN1-3-40	PG 58-28	Canadian blend	RTFOT+PAV40	-29.7	-27.1	-2.6	176	-31.7	2.0
MN1-4-40	PG 58-28	Contains REOB	RTFOT+PAV40	-34.3	-27.8	**-6.5**	109	-36.9	**2.6**
MN1-5-40	PG 58-28	Venezuelan Blend	RTFOT+PAV40	-26.6	-28.8	2.2	369	-32.1	5.5
MTO S15-40	PG 58-28	Contains REOB	RTFOT+PAV40	-37.2	-29.6	-7.6	114	-41.7	4.5
MTO S04-40	PG 64-34	Contains REOB	RTFOT+PAV40	-36.8	-31.9	**-4.9**	137	-41.2	**4.4**
Visbroken-40	PG 64-16	Visbroken	RTFOT+PAV40	-24.4	-9.0	-15.4	60	-23.4	-1.0
SDA -A-40	PG 58-16	Solvent Deasphalted blend	RTFOT+PAV40	-20.9	-22.5	1.6	364	-25.2	4.3
ME1-40	PG 64-28	Maine Island Falls	RTFOT+PAV40	-28.7	-26.5	-2.2	176	-34.5	5.8

In **TABLE A2** and **TABLE A3**, lines shaded in red are samples that would fail the ΔT_c criterion for asphalt binders aged using PAV40 (< -7.0°C). Unshaded lines are samples that would pass the ΔT_c criterion for asphalt binders aged using PAV40 (> -3.0°C). Lines shaded in yellow would fall between the passing and failing ΔT_c values and would be subjected to further testing using the ABCD test to determine T_{cr}. The value of T_{cr} is used with the $T_{c,S}$ from BBR testing to determine the ΔT_f value. If the ΔT_f value is above the line bounded by points (-3, 3) and (-7, 6) – where the points have the form of (ΔT_c, ΔT_f) – then the sample would meet the specification.

Of the 13 modified asphalt binder samples in **TABLE A2**:

- Nine samples pass the ΔT_c criterion (> -3.0°C) and would require no additional testing.
- Two samples fail the ΔT_c criterion (< -7.0°C) and would require no additional testing.
- Two samples fall between the ΔT_c values of -3.0 and -7.0°C and require determination of ΔT_f value to meet the specification.
    - Both modified asphalt binders had ΔT_f values that would be above the line, indicating sufficient strain tolerance to help resist any potential issues with relaxation properties.

Of the 19 unmodified asphalt binder samples in **TABLE A3**:

- Nine samples pass the ΔT_c criterion (> -3.0°C) and would require no additional testing.

- Five samples fail the ΔT_c criterion (< -7.0°C) and would require no additional testing.
- Five samples fall between the ΔT_c values of -3.0 and -7.0°C and require determination of ΔT_f value to meet the specification.
  - Of the five samples only the AZ1-3-40 sample (PG 76-16 Rocky Mountain Blend) would pass the criterion.
  - Two samples – MN1-4-40 (PG 58-28 with REOB) and AZ1-4-40 (PG 76-16 Canadian Blend) – failed with ΔT_f values less than the minimum of +3°C.
  - Two samples – MTO S04-40 (PG 64-34 with REOB) and AAM-1-40 (PG 64-16 West TX Intermediate) – were borderline, sitting right on the line as shown in **FIGURE A6** below (Figure 105 from the draft final report with annotations added).

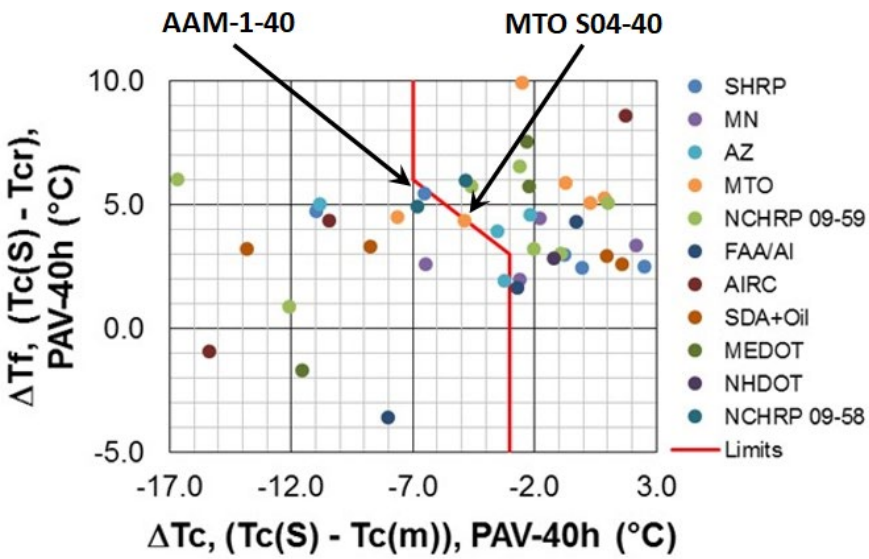

FIGURE A6. NCHRP 09-60 Asphalt Binders with 40-Hour PAV Aging

To summarize, of the 32 asphalt binders (modified and unmodified) in **TABLE A2** and **TABLE A3**:

- approximately 50% (eighteen asphalt binders) would meet the ΔT_c criterion (> -3.0°C) and would require no additional testing.
- approximately 25% (seven asphalt binders) would fail the ΔT_c criterion (< -7.0°C) and thus would require no additional testing.
- approximately 25% (seven asphalt binders) would fall between the ΔT_c values of -3.0 and -7.0°C and require determination of ΔT_f value using the ABCD test to evaluate if they meet the specification.

Of the seven asphalt binders that would require determination of ΔT_f value using the ABCD test to evaluate if they meet the specification:

- both modified asphalt binders would have sufficiently high ΔT_f values that would be above the line (as shown in **FIGURE A6**), indicating that they would meet the specification requirements.
- only one of the five unmodified asphalt binders would have sufficiently high ΔT_f values that would be above the line (as shown in **FIGURE A6**), indicating that they would meet the specification requirements.

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 states "If the creep stiffness is below 300 MPa the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value requirement must be satisfied in both cases."

In reality, *Footnote g* was rarely employed for a few reasons:

(1) The Direct Tension test was cumbersome to execute properly and had higher-than-desirable variability.

(2) The condition where m-value met the requirement, but S failed the requirement only occurred for S-controlled asphalt binders, or those that we now would see as having positive ΔT_c values. Asphalt binders supplied for conformance to *AASHTO M 320* were more often m-controlled, or those that we now would see as having negative ΔT_c values.

(3) If an asphalt binder failed the maximum 300 MPa requirement at a given temperature it still could be sold as an asphalt binder with a higher low temperature PG. In other words, if the sample failed S at -18°C but passed m-value, rather than running the Direct Tension test and possibly selling the asphalt binder as a PG xx-28, it could just be sold as a PG xx-22. In some cases, the additional testing might be beneficial, but often it was just avoided.

Although Statement (1) above is likely still a fair statement for the ABCD test, Statements (2) and (3) are different. The use of ΔT_c as a criterion means that the specification is identifying m-controlled asphalt binders, which are more common. Also, ΔT_c is a temperature-independent parameter – meaning that there is no recourse to sell an asphalt binder with a failing ΔT_c value as a different grade.

One option is to include the use of ΔT_f in the manner proposed in the specification – as an additional test that may be used to qualify an asphalt binder when routine testing indicates that the specification is not met. This could allow some unmodified asphalt binders like the AZ1-3-40 sample (PG 76-16 Rocky Mountain Blend) in **TABLE A3** to be used with a ΔT_c value less than -3.0°C. Another option would be to use a surrogate for strain tolerance from another test using existing equipment, like the DSR, rather than using ΔT_f. If a surrogate test could be correlated, at least directionally, with ΔT_f as an indicator of polymer modification and strain tolerance, then it could be an alternative option to alleviate the need for additional testing by suppliers of modified asphalt binders. Thus, modified asphalt binders that have ΔT_c values between -3.0 and -7.0°C could be used if they meet another minimum requirement that indicates sufficient polymer modification.

NCHRP 09-61 Short- and Long-Term Binder Aging Methods to Accurately Reflect Aging in Asphalt Mixtures

NCHRP 09-61 Project Objectives

The objective of this research was to develop practical laboratory aging methods to accurately simulate the short-term (from production to placement) and long-term (in-service) aging of asphalt binders. The research will 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 09-61 Project Team

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- Western Research Institute
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NCHRP 09-61 Project Status

The final report has been published as NCHRP Report 967, Asphalt Binder Aging Methods to Accurately Reflect Mixture Aging.

Key Findings and Conclusions

- The recommendation for short-term conditioning of asphalt binders is to continue to use *AASHTO T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film. Oven Test)*.
  - The research team found that although the film thickness and its renewal during the test depend on the consistency of the asphalt binder, properties of residue from *AASHTO T 240* agree reasonably well with the properties of asphalt binder recovered from mixtures which were short-term conditioned in accordance with the recommendations from NCHRP 09-52 (as described in NCHRP Report 815).
  - A survey of agency technicians during the project resulted in a report that approximately 4% of asphalt binders creep from the container during *AASHTO T 240*. Surprisingly, the binder loss issue was reported for both neat and modified asphalt binders. Some states report no loss, while neighboring states report high percentages. This led the research team to believe that equipment and technique need evaluation rather than a wholesale replacement of *AASHTO T 240*.
- 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.
  - The researchers used a 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) and calibrated the 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. The findings of that calibration indicate that the PAV

temperature to use depends on the average of the 98 percent reliability high and low pavement temperature from LTPPBind3.1.
  - The researchers recognized two main problems with implementing the change in PAV conditions (temperature and film thickness).
    - The PAV pan must be very level. The current tolerance is not acceptable. To maintain even film thickness, the pan must be level within about 0.00045 mm/mm. This is very difficult to achieve with current PAV designs. In the project, the research technician spent hours leveling the rack for each run using a precision machinists' level. The researchers do not believe this is acceptable for a production test method. To implement the recommendations more practically, the research team believes it will be necessary to have PAVs with automatic leveling control.
    - When using the recommended temperatures in a sensitivity study, the researchers found that some modified binders do not completely cover the pan. Based on this, the researchers believe that a levelling step at a higher temperature under inert atmosphere needs to be added.
- The researchers found that residue from static conditioning of 12.5 g of binder in a PAV pan in an oven also reasonably reproduced the properties of binder recovered from short-term conditioned loose mix. Thus, it seems possible that the same equipment can be used for short- and long-term conditioning.
- Using the same film thickness and pans for short- and long-term conditioning offers the potential to simplify laboratory conditioning. A very reasonable approach is to short-term condition the binder in the PAV in the pans used for the long-term procedure at low-pressure at 163 °C. Conditioning the thin film under a low pressure above atmospheric would eliminate the laboratory elevation effect that is known to be an issue with *AASHTO T 240*. Upon completion of the short-term conditioning, one pan would be removed, cooled, weighed for mass change determination, and the residue tested for high pavement temperature rheological properties. The temperature would be reduced to the long-term conditioning temperature, the pressure increased to 2.1 MPa, and the binder further conditioned for 20 hours.
  - This approach has some advantages including:
    - it removes the viscosity-dependent film renewal associated with *AASHTO T 240*.
    - it removes the laboratory elevation effect associated with *AASHTO T 240*.
    - it eliminates binder transfer loss between short- and long-term conditioning.
    - it improves the uniformity of the thin film for the subsequent long-term conditioning due to the higher temperature used for the short-term conditioning.
  - Despite the promise of the potential approach, the research team does not recommend adoption as an AASHTO standard until there is prototype equipment available. Prototype equipment should have:
    - a level pan system (current ovens used for short-term conditioning have shelves that warp as the oven heats, so leveling the pan is very difficult).
    - accurate temperature control from 80 to 170°C.
    - accurate pressure control at both low pressure and 2.1 MPa.
    - the potential ability to introduce air and an inert gas depending on how well modified binders will achieve a level film thickness at 163°C.

Additional Research Identified by the Research Team in NCHRP 09-61 (from NCHRP Report 967)

- To effectively use thin film (0.8 mm) conditioning in practice requires modification of current PAV equipment to meet the stricter levelness requirement of 0.025 degrees needed to form and condition 0.8-mm thin films. This will require collaboration between engineers and technicians using the equipment and equipment manufacturers.
  - The process used in NCHRP Project 09-29 to develop the Asphalt Mixture Performance Tester where manufacturers were involved early in the process is an example of how collaboration during equipment specification development can lead to innovative equipment meeting the needs of the end-

user. Manufacturers should be encouraged to develop innovative systems that meet the levelness requirement. Modified equipment from various manufacturers should then be assessed to confirm compliance with the levelness requirement and evaluate the time and effort required to level the pans.

- A new vacuum oven is needed to use 20-hour, 0.8-mm thin film conditioning to produce residue for the 40-hour ΔT_c criterion. This oven is needed to quickly form uniform thin films for many modified binders and to degas the stiffer residue to form acceptable specimens for DSR and BBR testing. The development of vacuum ovens will also require collaboration between engineers and technicians using the equipment and equipment manufacturers.
- Additional development work is also needed to better define the conditions needed for forming uniform 0.8-mm thin films of RTFOT residue for modified binders. The fact that some heavily modified binders do not form a film that completely covers the pan was identified late in the research; therefore, only limited effort could be expended on standardizing film formation. The conditions that were determined – temperature of 135°C, vacuum cycle nitrogen purging, and duration of up to 30 minutes – were found to be reasonable for the binders tested. However, other conditions, such as higher temperature for a shorter time may also be acceptable and require less time and effort.
- Implementation of the suggestions in the proposed *AASHTO Practice, 0.8-mm Static Film Short- and Long-Term Conditioning of Asphalt Binder*, will require the development of a new oven with accurate temperature and pressure control for performing the short-term conditioning. If properly designed, this oven could also be used to degas PAV residue after conditioning. Again, effective development of this oven will also require collaboration between engineers and technicians who use the equipment and equipment manufacturers.
- Implementation of the suggestions in the proposed *AASHTO Practice, 0.8-mm Static Film Short- and Long-Term Conditioning of Asphalt Binder* will require additional research to define appropriate specification criteria for the performance grading specifications, *AASHTO M 320* and *AASHTO M 332*. Using 12.5 g, 20-hr, 2.1 MPa long-term conditioning and the climate-based temperatures developed in NCHRP Project 09-61 will produce residue with properties similar to binder from the top 1 in of pavement aged 10 years in service. This residue, however, is significantly more aged than that obtained from the standard 50.0 g, 20-hr, 2.1 MPa PAV conditioning. Combining the increased aging with the current grading criteria results in changes of one to two grade levels. Additional research using pavement sections with documented performance is needed to determine if these grade changes are justified or if the criteria should be adjusted to accurately capture actual performance.

Proposed New and Revised Standards Resulting from the NCHRP 09-61 Project

- Revisions to AASHTO R 28, Accelerated Aging of Asphalt Binder Using a Pressure Aging Vessel (PAV)
  - Addition of Appendix X1
  - Addresses modifications to equipment and procedures needed to use 0.8-mm films in long term conditioning.
- Proposed new standard practice, 0.8-mm Static Film Short- and Long-Term Conditioning of Asphalt Binder
  - Discusses procedure to combine short-and long-term conditioning using the same pans and sample.

Interactions with Other Standards

Below provides a list of AASHTO standards that will likely be impacted by changes to *AASHTO R 28*.

- *AASHTO M 320, Specification for Performance-Graded Asphalt Binder*

- *AASHTO M 332, Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test*
- *AASHTO R 29, Practice for Grading or Verifying the Performance Grade (PG) of an Asphalt Binder*
- *AASHTO PP xx, Characterizing the Relaxation Behavior of Asphalt Binders Using the Delta Tc (ΔTc) Parameter*

Impact of NCHRP 09-61 Recommendations on Lab Operations (Agency and Industry)

- If the recommendation for short-term conditioning of asphalt binders is to continue to use *AASHTO T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film. Oven Test)*, then there should be no impact on lab operations for agency and industry labs. 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. The researchers found this to be reported as an infrequent occurrence (approximately 4% of asphalt binders).
- The long-term conditioning procedure using the PAV (*AASHTO R 28*) could have a greater impact on lab operations. The use of extended aging – such as 40 hours in the standard PAV – obviously 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 1 millimeter (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). This significantly improves lab operations.
- Unfortunately, the researchers indicated that the challenge with using thinner films is maintaining a consistent film thickness. This requires very level pans that are not warped. Operationally this could pose a significant challenge for labs to routinely ensure levelness. The other impact of conditioning less asphalt binder in a thinner film is that the researchers found that some modified asphalt binders did not initially flow to fill the pan at a uniform thickness. This could lead to the addition of an extra levelling step conducted at a higher temperature under inert atmosphere for those asphalt binders.
- The last recommended change was to use a varying PAV temperature as a function of the intermediate temperature of the asphalt binder. The recommended temperatures are 85-115°C in 5°C increments based on the asphalt binder PG. This change may have some impact on operations. In current practice, a PG 58-28 asphalt binder sample could be subjected to long-term conditioning in the same PAV run as a PG 64-22 asphalt binder since both would be conditioned at 100°C. In the proposed practice, a PG 58-28 would be conditioned at 100°C, but a PG 64-22 asphalt binder would be conditioned at 105°C. This could result in the lab needing to have additional PAV equipment to accommodate the increased operating temperatures. Education would also be needed so that the technician understood the appropriate temperature for conditioning.

Unanswered Questions and Concerns that Could Affect Adoption of NCHRP 09-61 Recommendations

The research team properly identified some of the concerns with the results and procedures that could implementation.

NCHRP 20-44(19) Research Implementation Activities – NCHRP 09-61

Based on the findings from the research, if current performance grading requirements are used then there are no significant changes needed for short-term conditioning of asphalt binders. *AASHTO T 240*, *Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film. Oven Test)*, can continue to be used.

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. The researchers found this to be reported as an infrequent occurrence (approximately 4% of asphalt binders).

The NCHRP 09-59 research presented findings and recommendations principally based on the standard 20-hour PAV aging, but also provided some suggestions for criteria if longer aging (i.e., 40-hour PAV) is used. The NCHRP 09-60 research presented findings that were based on the standard 20-hour PAV procedure but also conducted testing on samples after 40-hour PAV aging and provided some suggestions for criteria. As such, neither research project relies on changes to *AASHTO R 28* to implement their findings and recommendations. Thus, the findings and recommendations from the NCHRP 09-61 project can be independently evaluated, while understanding that any changes that are implemented may impact the implementation of the NCHRP 09-59 and 09-60 products.

The principal finding from the research regarding PAV aging (*AASHTO R 28*) is that reducing the film thickness of the asphalt binder in the PAV pan from 3.1 millimeters (50 grams of asphalt binder) to 1 millimeter (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). Although not required in either NCHRP 09-59 or 09-60, the researchers recognize that agencies wishing to use the ΔT_c parameter as a way of characterizing the durability cracking potential of an asphalt binder may want to use extended aging and could benefit from the ability to conduct a standard 20-hour procedure with a thinner film thickness instead of a procedure lasting twice as long.

Using thinner films in the PAV pan and standard test conditions, results were calibrated 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. The findings of that calibration indicate that the PAV temperature to use depends on the average of the 98 percent reliability high and low pavement temperature from LTPPBind3.1. **TABLE A4** below is taken from NCHRP Report 967 which shows the recommended temperatures.

TABLE A4. NCHRP 09-61 Draft Final Report: Recommended 12.5 g, 20-hr PAV Conditioning Temperatures for Performance Grading

Average of 98 % Reliability High and Low Pavement Temp., °C	Calculated PAV Temp., ºC	Recommended PAV Temp., ºC	% of LTPPBind 3.1 Stations	PG Grade Based on Environment
-6[1]	84.4	85	1	PG 40-52; PG 46-52; PG 40-46
-3[1]	86.6			
0[1]	88.9	90	4	PG 52-52; PG 46-46; PG 40-40; PG 46-40; PG 52-46; PG 40-34
3	91.1			
6	93.4	95	20	PG 58-46; PG 52-40; PG 46-34; PG 40-28 PG 58-40; PG 52-34; PG 46-28; PG 40-22
9	95.7			
12	97.9	100	41	PG 64-40; PG 58-34; PG 52-28; PG 46-22; PG 40-16 PG 64-34; PG 58-28: PG 52-22; PG 46-16; PG 40-10 PG 64-28; PG 58-22; PG 52-16; PG 46-10
15	100.2			
18	102.5			
21	104.8	105	20	PG 70-28; PG 64-22; PG 58-16; PG 52-10 PG 70-22; PG 64-16; PG 58-10
24	107.1			
27	109.3	110	13	PG 70-16; PG 64-10; PG 70-10
30	111.6			
33[1]	115.0	115	1	PG 76-10

[1] Outside range of data used in calibration.
Gray shaded cells indicate standard PAV aging temperatures per *AASHTO M 320* and *M 332*.

The final recommendation from the research provides a procedure for aging an asphalt binder through short- and long-term conditioning such that it simulates near-surface aging after approximately 10 years. This procedure is more challenging and would represent a change in how asphalt binders are currently graded. With this level of aging changes in criteria for intermediate and low temperatures would need to be re-evaluated and compared to performance.