asphalt institute

Evolution of Asphalt Binder Specifications

Mike Anderson, Asphalt Institute

SEAUPG Annual Meeting
November 19-21, 2024
Mobile, AL

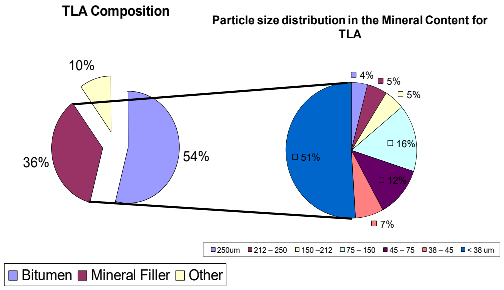
Asphalt Types

- Natural Asphalt Deposits
  - Lake asphalt
    - Trinidad
    - Bermudez
  - Rock asphalt
    - Natural asphalt

Acknowledgments

- Strategic Highway Research Program Research Teams
- National Cooperative Highway Research Program (NCHRP)
  - 20-44(19) Project Panel and Program Officers
- Research Teams for NCHRP Projects 09-59 and 09-60
- FHWA Cooperative Agreement 693JJ32350026
  - Development & Deployment of Innovative Asphalt Pavement Technologies
- Member Companies of the Asphalt Institute

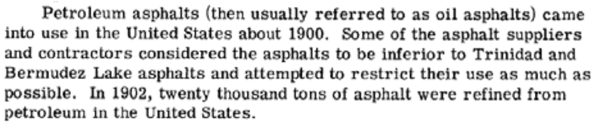
Trinidad Lake Asphalt



Interested in Early Testing and Specifications?

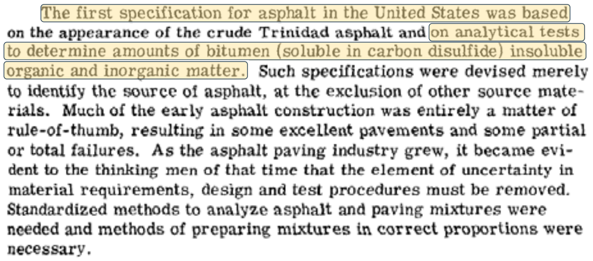
- “History of the Development of Asphalt Testing Apparatus and Asphalt Specifications”
  - Woodrow Halstead and J. York Welborn
  - <u>Proceedings</u> of the Association of Asphalt Paving Technologists, 1974
  - 50th Anniversary Volume

- “History of the Development of Asphalt Testing Apparatus and Asphalt Specifications”



Petroleum asphalts (then usually referred to as oil asphalts) came into use in the United States about 1900. Some of the asphalt suppliers and contractors considered the asphalts to be inferior to Trinidad and Bermudez Lake asphalts and attempted to restrict their use as much as possible. In 1902, twenty thousand tons of asphalt were refined from petroleum in the United States.

- “History of the Development of Asphalt Testing Apparatus and Asphalt Specifications”



The first specification for asphalt in the United States was based on the appearance of the crude Trinidad asphalt and on analytical tests to determine amounts of bitumen (soluble in carbon disulfide) insoluble organic and inorganic matter. Such specifications were devised merely to identify the source of asphalt, at the exclusion of other source materials. Much of the early asphalt construction was entirely a matter of rule-of-thumb, resulting in some excellent pavements and some partial or total failures. As the asphalt paving industry grew, it became evident to the thinking men of that time that the element of uncertainty in material requirements, design and test procedures must be removed. Standardized methods to analyze asphalt and paving mixtures were needed and methods of preparing mixtures in correct proportions were necessary.

- “History of the Development of Asphalt Testing Apparatus and Asphalt Specifications”
  - Bulletin 691 “Typical Specifications for Bituminous Road Materials”
    - Published in 1918
    - Prevost Hubbard and Charles Reeve (Office of Public Roads and Rural Engineering)
    - Purpose was to provide engineers with information to:
      - Secure a suitable grade of material
      - Insure reasonable uniformity of supply
      - Sufficiently identify the material by type

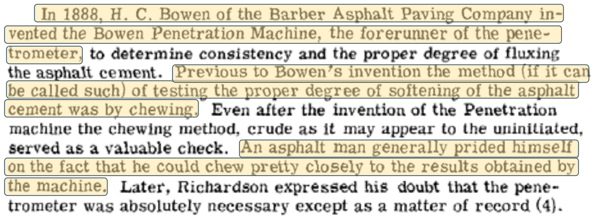
Solubility

- Procedure
  - ASTM D2042 (AASHTO T44)
- Purpose
  - Measure of the purity of the asphalt binder
    - Portion of the asphalt binder that is soluble in carbon disulfide (trichloroethylene) represents the active cementing constituents
    - Inert components—such as salts, free carbon, or non-organic contaminants—are insoluble

Bulletin 691 “Typical Specifications for Bituminous Road Materials”

Category	Penetration	Use
OA-1, Oil Asphalt for Construction	120-150	Macadam, Northern States
OA-2	90-120	Macadam, Middle States
OA-3	80-90	Macadam, Southern States Bituminous Conc. (1 size stone), Northern States
OA-4	70-80	Bituminous Conc. (1 size stone), Southern States Bituminous Conc. (graded), Northern States
OA-5	60-70	Bituminous Conc. (graded, coarse), Southern States Bituminous Conc. (graded, fine), Northern States
OA-6	50-60	Bituminous Conc. (graded, fine), Southern States Sheet Asphalt, Northern States
OA-7	40-50	Sheet Asphalt, Southern States or Northern States for very heavy traffic

- “History of the Development of Asphalt Testing Apparatus and Asphalt Specifications”



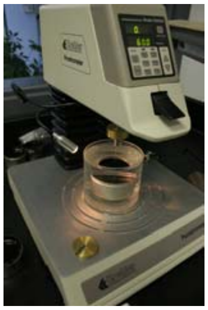
In 1888, H. C. Bowen of the Barber Asphalt Paving Company invented the Bowen Penetration Machine, the forerunner of the penetrometer, to determine consistency and the proper degree of fluxing the asphalt cement. Previous to Bowen’s invention the method (if it can be called such) of testing the proper degree of softening of the asphalt cement was by chewing. Even after the invention of the Penetration machine the chewing method, crude as it may appear to the uninitiated, served as a valuable check. An asphalt man generally prided himself on the fact that he could chew pretty closely to the results obtained by the machine. Later, Richardson expressed his doubt that the penetrometer was absolutely necessary except as a matter of record (4).

Bulletin 691 “Typical Specifications for Bituminous Road Materials”

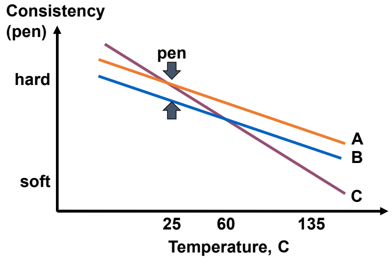
- Specification Tests for OA-1 to OA-7 Asphalt
  - Specific Gravity 25/25 C (77/77 F)
  - Flash Point, C (F)
  - Melting Point, C (F)
  - Penetration, 25C (77F)
  - Loss at 163C (325F)
    - Penetration of residue, 25C (77F)
  - Total Bitumen (Soluble in carbon disulfide)
    - Organic matter insoluble

Penetration

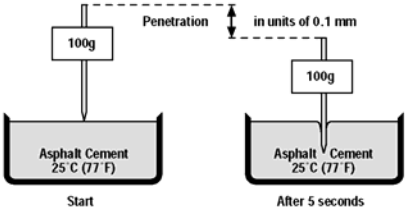
- Penetration
  - ASTM D5 (AASHTO T49)
    - One of oldest asphalt tests
  - Standard needle allowed to penetrate into sample under specified loading conditions
    - 25°C – 100 grams, 5 seconds
    - 0°C – 200 grams, 60 seconds
    - 46°C – 50 grams, 5 seconds
  - Depth of penetration is recorded in 0.1-mm units (dmm)
  - Three penetration readings per test



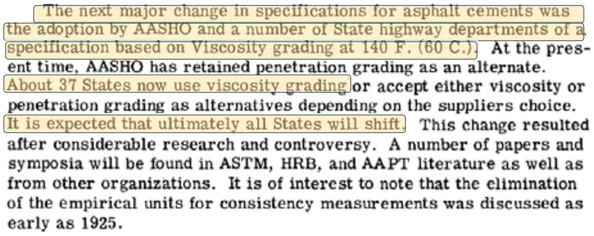
Penetration Grading



Penetration



- "History of the Development of Asphalt Testing Apparatus and Asphalt Specifications"



The next major change in specifications for asphalt cements was the adoption by AASHO and a number of State highway departments of a specification based on Viscosity grading at 140 F. (60 C.). At the present time, AASHO has retained penetration grading as an alternate. About 37 States now use viscosity grading or accept either viscosity or penetration grading as alternatives depending on the suppliers choice. It is expected that ultimately all States will shift. This change resulted after considerable research and controversy. A number of papers and symposia will be found in ASTM, HRB, and AAPT literature as well as from other organizations. It is of interest to note that the elimination of the empirical units for consistency measurements was discussed as early as 1925.

Penetration Graded Asphalt

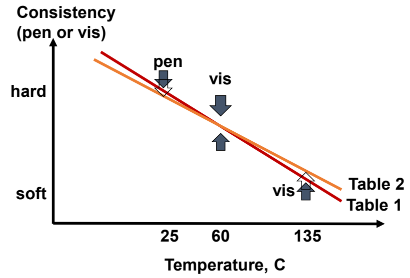
Test On Original Asphalt	120-150	85-100
Penetration, 25°C (77°F), dmm	120 min.	85 min.
(100 g - 5 sec)	150 max.	100 max.
Flash Point, COC, °C (°F), min.	219 (425)	232 (450)
Ductility, 25°C (77°F), cm, min.	100	100
Solubility in Trichloroethylene, %min.	99.0	99.0
Tests On Aged Asphalt (TFOT)		
Loss on heating, % maximum	1.3	1.0
Percent of original penetration, min.	46	50
Ductility of residue, cm, minimum	100	75

Viscosity

Specifications: Asphalt Cement

- Viscosity Graded Asphalt (AC)
  - ASTM D3381 (AASHTO M226)
    - Tables 1 and 2
  - Most commonly used (pre-SHRP) classification system in US
  - Based on Viscosity
    - Measure of the resistance of a material to flow
    - Absolute viscosity at 60°C (140°F)
    - Kinematic viscosity at 135°C (275°F)

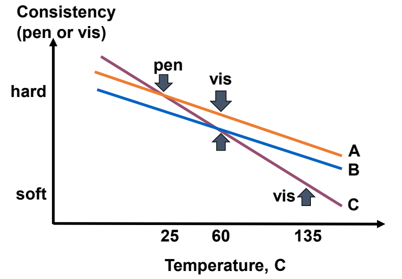
Viscosity Grading: Table 1 and Table 2



Viscosity Graded Asphalt (AC) Table 1

Test	AC-10	AC-20
Viscosity, 60°C (140°F), poises	1000 ± 200	2000 ± 400
Viscosity, 135°C (275°F), Cs, min.	150	210
Penetration, 25°C (77°F), dmm, min.	70	40
Flash Point, COC, °C (°F), min.	220 (425)	230 (450)
Solubility in Trichloroethylene, % min.	99.0	99.0
Test on residue from TFOT:		
Loss on heating, % max. (optional)		
Viscosity, 60°C (140°F), poises, max.	5000	10000
Ductility, 25°C (77°F), cm, min.	50	20

Viscosity Grading



Viscosity Graded Asphalt (AC) Table 2

Test	AC-10	AC-20
Viscosity, 60°C (140°F), poises	1000 ± 200	2000 ± 400
Viscosity, 135°C (275°F), Cs, min.	250	300
Penetration, 25°C (77°F), dmm, min.	80	60
Flash Point, COC, °C (°F), min.	220 (425)	230 (450)
Solubility in Trichloroethylene, % min.	99.0	99.0
Test on residue from TFOT:		
Loss on heating, % max. (optional)		
Viscosity, 60°C (140°F), poises, max.	5000	10000
Ductility, 25°C (77°F), cm, min.	75	50

Specifications: Asphalt Cement

- Viscosity Graded After Aging (AR)
  - ASTM D3381 (AASHTO M226) Table 3
  - AR = "Aged Residue"
  - Primarily used in Western US
  - Attempts to identify material characteristics after HMA production and laydown
  - Rolling Thin Film Oven (RTFO)
    - AASHTO T240
    - Simulates aging during mixing in HMA facility

Viscosity Graded Asphalt (AR)

Test On Residue From RTFO	AR-4000	AR-8000
Viscosity, 60°C (140°F), poises	4000 ± 1000	8000 ± 2000
Viscosity, 135°C (275°F), Cs-min.	275	400
Penetration, 25°C (77°F), dmm, min.	25	20
Percent of original penetration, min.	45	50
Ductility, 25°C (77°F), cm-minimum	75	75
Tests On Original Asphalt		
Flash Point, COC, °C (°F), minimum	225 (440)	230 (450)
Solubility in Trichloroethylene, %min.	99.0	99.0

What Do We Want From an Asphalt Binder Specification?

- SHRP-90-007, The SHRP Asphalt Research Program: 1990 Strategic Planning Document
  - The SHRP asphalt program was originally designed to develop specifications that addressed six pavement performance factors: **permanent deformation (rutting); fatigue cracking; low-temperature (thermal) cracking**; moisture sensitivity; aging; and adhesion.
    - Aging was not considered a distress, per se, but was considered important so that the asphalt binder could be tested in a state approximating that which would be attained after a period of time in service.

Problems with Previous Systems

- Penetration
  - empirical measure of viscous and elastic effects
- Viscosity
  - viscous effects only
- No Low Temperature Properties Measured
- Problems Characterizing Modified Asphalt Binders
  - Specification proliferation
- Long Term Aging not Considered

What Do We Want From an Asphalt Binder Specification?

- The asphalt binder needs to minimize its contribution to any distress
- Other factors than asphalt binder properties can lead to distress
  - Aggregate properties
  - Aggregate proportion
  - Volumetric properties
  - Effective asphalt binder content
  - Production in the mixing plant
  - Laydown and compaction
  - Thickness design
  - Drainage

What Do We Want From an Asphalt Binder Specification?

- SHRP-90-007, The SHRP Asphalt Research Program: 1990 Strategic Planning Document
  - The SHRP asphalt program was based on the premise that **asphalt pavement performance is significantly influenced by the properties of the asphalt binder.**
    - The mix designer must select an asphalt binder having properties that meet required minimum performance levels in order for the asphalt pavement to perform as expected for both its present and future environment and traffic loading conditions.

High Temperature Asphalt Pavement Behavior

- **Rutting and depressions**
- **Depends on…**
  - Asphalt binder (some)
  - Mineral aggregate (some)
  - Volumetric proportioning (some)

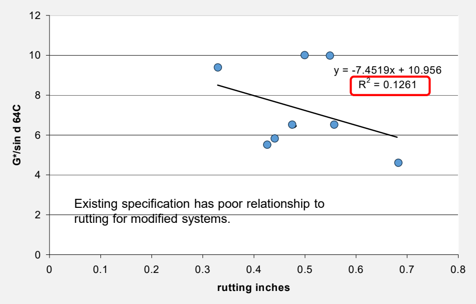
Depression on parking apron

Rutting in wheel path on TW, caused from instable surface mix.

Performance-Related Requirements in PG Binder Specification (AASHTO M320)

- Shearing resistance to resist traffic loads
    - Upper specification temperature
    - G*/sin δ ≥ 1.00 kPa Tank
    - G*/sin δ ≥ 2.20 kPa RTFO residue

Relationship between G*/ sin δ and ALF rutting

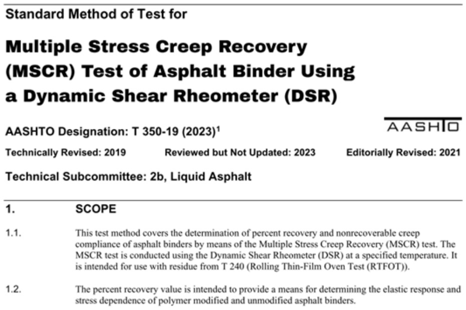


Existing specification has poor relationship to rutting for modified systems.

Shortcomings of G*/sin δ

- G*/sin δ as a High Temperature Parameter
    - Properties determined in Linear Viscoelastic (LVE) region
        - No damage behavior
            - Rutting is a non-linear failure
            - Polymer-modified systems engaged in non-linear region
        - Characterizes stiffness
            - Related to rutting

Addressing Asphalt Binder Contribution to Rutting: MSCR



Standard Method of Test for

Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

AASHTO Designation: T 350-19 (2023)[1]

AASHTO

Technically Revised: 2019 Reviewed but Not Updated: 2023 Editorially Revised: 2021

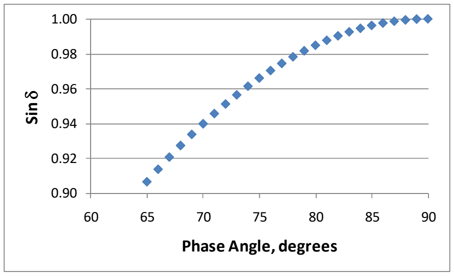
Technical Subcommittee: 2b, Liquid Asphalt

1. SCOPE

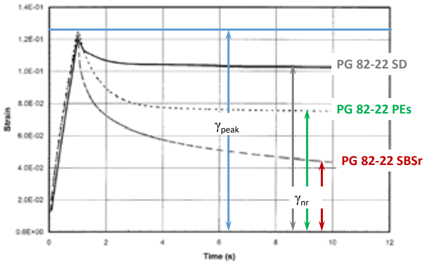
1.1. This test method covers the determination of percent recovery and nonrecoverable creep compliance of asphalt binders by means of the Multiple Stress Creep Recovery (MSCR) test. The MSCR test is conducted using the Dynamic Shear Rheometer (DSR) at a specified temperature. It is intended for use with residue from T 240 (Rolling Thin-Film Oven Test (RTFOT)).

1.2. The percent recovery value is intended to provide a means for determining the elastic response and stress dependence of polymer modified and unmodified asphalt binders.

Effect of Phase Angle



NCHRP 9-10 Binders: Response in MSCR



J_{nr} = 0.35 kPa^{-1}
Rec = 16%

J_{nr} = 0.25 kPa^{-1}
Rec = 40%

J_{nr} = 0.15 kPa^{-1}
Rec = 64%

Figure 2.30 Creep and recovery of the first cycle for three PG 82 binders at 1 s loading and 9 s recovery (70°C, 300 Pa).

Excerpt from NCHRP Report 459, *Characterization of Modified Asphalt Binders in Superpave Mix Design*

PG Grading System Using MSCR (AASHTO M332)

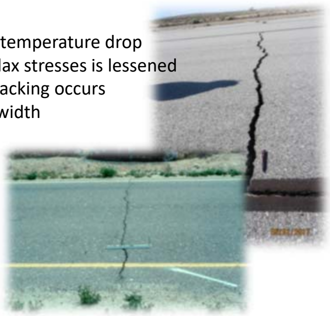
- PG 64 (Standard, Heavy, Very Heavy, Extreme) based on traffic
  - PG 64**S**-xx $J_{nr3.2} \leq 4.5$ kPa^{-1} $J_{nr,diff} \leq 75\%$
  - PG 64**H**-xx $J_{nr3.2} \leq 2.0$ kPa^{-1} $J_{nr,diff} \leq 75\%$
  - PG 64**V**-xx $J_{nr3.2} \leq 1.0$ kPa^{-1} $J_{nr,diff} \leq 75\%$
  - PG 64**E**-xx $J_{nr3.2} \leq 0.5$ kPa^{-1} n/a

Low Temperature Cracking in Mix Design

- Recommended Tests and Conditions
  - NCHRP Report 673
    - Research also has shown that thermal cracking performance of asphalt mixtures is most strongly affected by the asphalt binder properties.
      - As long as the asphalt binder that is used in the mixture has the appropriate low temperature properties for the expected use, the expectation for conventional asphalt mixtures will be that they will have adequate laboratory thermal cracking performance.
        - Maximum Stiffness at 60 seconds of 300 MPa at LT Grade + 10°C
        - Minimum m-value at 60 seconds of 0.300 at LT Grade + 10°C

Linear coefficient of thermal expansion for asphalt binder is on average about 17 times greater than the coefficient of thermal expansion for aggregate

Low Temperature Asphalt Pavement Behavior



- **Thermal cracks**
  - Internal stresses induced by rapid temperature drop
  - If binder is too brittle, ability to relax stresses is lessened
  - When stresses exceed strength, cracking occurs
    - Transverse, equal spacing, full width
    - a.k.a. low-temp. cracking
- **Depends on…**
  - ➢ Asphalt binder (lots)
  - ➢ Mineral aggregate (little)
  - ➢ Volumetric proportioning (some)

Fatigue Cracking

- Fatigue Cracks (load-associated)
  - Bottom-up cracking
  - “Alligator” cracking
- Depends on…
  - Asphalt binder (some)
  - Mineral aggregate (some)
  - Volumetric proportioning (some)
  - Other non-material factors (some)

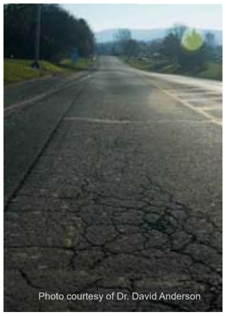
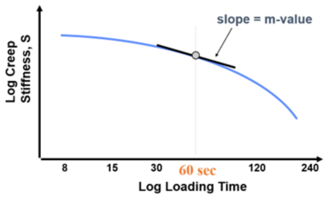


Photo courtesy of Dr. David Anderson

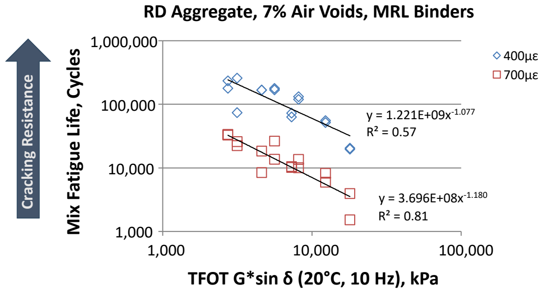
Low Temperature Behavior of Asphalt Binders



Zube and Skog: “Final Report on the Zaca-Wigmore Asphalt Test Road”

- 1969 AAPT Paper
- Relevance to PG Specification
  - From SHRP Report A-367 (Pages 36-37):
    - “At the suggestion of the A-003A researchers, and in light of an **evaluation of the fatigue performance in field trials such as Zaca-Wigmore** (figure 2.22), the fatigue criterion was changed to reflect the energy dissipated per load cycle. Dissipated energy in a dynamic shear test is appropriately **calculated as G*sin δ** (Ferry 1980).”

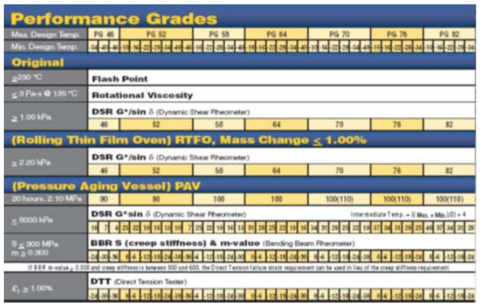
SHRP A-388: Fatigue of Asphalt Mixtures



NCHRP 09-59

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

AASHTO M320



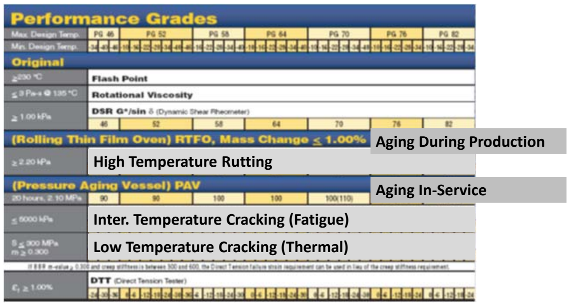
Performance Grades

Max. Design Temp.	PG 46	PG 52	PG 58	PG 64	PG 70	PG 76	PG 82
Min. Design Temp.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Original							
≥230 °C	Flash Point						
≤ 3 Pa·s @ 135 °C	Rotational Viscosity						
≥ 1.00 kPa	DSR G*/sin δ (Dynamic Shear Rheometer)						
	46	52	58	64	70	76	82
(Rolling Thin Film Oven) RTFO, Mass Change ≤ 1.00%							
≥ 2.20 kPa	DSR G*/sin δ (Dynamic Shear Rheometer)						
	46	52	58	64	70	76	82
(Pressure Aging Vessel) PAV							
20 hours, 2.10 MPa	90	90	100	100	100(110)	100(110)	100(110)
≤ 5000 kPa	DSR G*sin δ (Dynamic Shear Rheometer) Intermediate Temp. = [(Max. + Min.)/2] + 4						
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S ≤ 300 MPa m ≥ 0.300	BBR S (creep stiffness) & m-value (Bending Beam Rheometer)						
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
If BBR m-value ≥ 0.300 and creep stiffness is between 300 and 600, the Direct Tension failure strain requirement can be used in lieu of the creep stiffness requirement.							
ε_f ≥ 1.00%	DTT (Direct Tension Tester)						
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NCHRP 09-59

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

AASHTO M320



Performance Grades

Original

Flash Point

Rotational Viscosity

DSR G*/sin δ (Dynamic Shear Rheometer)

(Rolling Thin Film Oven) RTFO, Mass Change ≤ 1.00%

Aging During Production

High Temperature Rutting

(Pressure Aging Vessel) PAV

Aging In-Service

Inter. Temperature Cracking (Fatigue)

Low Temperature Cracking (Thermal)

DTT (Direct Tension Tester)

Asphalt Binder Specification Objectives

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

How Asphalt Pavements Behave with Aging

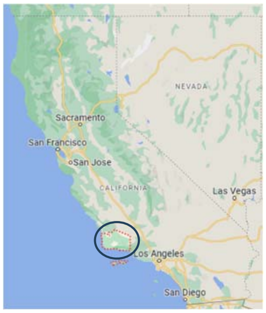
- Durability Cracks (not load-associated)
  - Mixture is brittle
  - Random, wandering cracking
  - Longitudinal
- Depends on…
  - Asphalt binder (some)
  - Mineral aggregate (little)
  - Volumetric proportioning (some)

NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Jean-Pascal Planche (PI, WRI), Michael D. Elwardany (WRI), Donald Christensen (AAT), Gayle King (Consultant), Carolina Rodezno (NCAT),and Snehalata Huzurbazar (Consultant/Statistician)
  - Objectives
    - propose changes to the current performance-graded (PG) asphalt binder specifications, tests, and practices to remedy gaps and shortcomings related to the premature loss of asphalt pavement durability in the form of cracking and raveling.
  - Status
    - The draft final report for Phases I and II will be published in conjunction with Phase III.

Zube and Skog:
"Final Report on the Zaca-Wigmore Asphalt Test Road"

- Two main types of failure during service life were encountered on the project
  - Fatigue Cracking
    - Most prevalent
    - Related to recovered asphalt binder consistency (i.e., stiffness)
  - Block Cracking with Raveling
    - Most prevalent in the passing lane
    - Gain in shear susceptibility during weathering
    - Drop in ductility (i.e., viscoelastic behavior) during service life



NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Key Findings
    - Recommend adding ΔT_c to AASHTO M 320 and M 332 as a specification parameter.
      - $\Delta T_c = T_{c,S} - T_{c,m}$
      - 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.

$T_{c,S}$ = Temperature at which BBR Stiffness at 60 seconds is exactly equal to 300 MPa
$T_{c,m}$ = Temperature at which BBR m-value at 60 seconds is exactly equal to 0.300

NCHRP 09-59

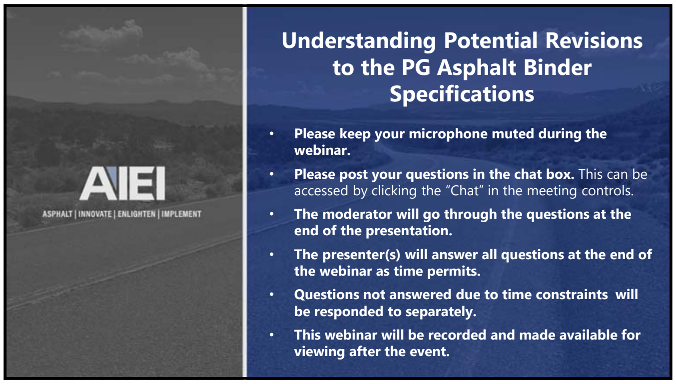
- Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance
  - Recommendations
    - The binder fatigue specification should include an allowable range for the Christensen-Anderson R-value of from 1.5 to 2.5, after 20-hour PAV aging.
    - The R-value should be calculated using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

$$R = log(2)\frac{log(S/3.000)}{log(1-m)}$$

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

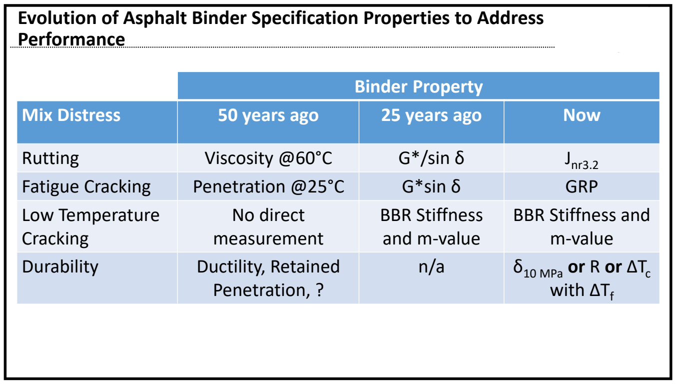
NCHRP 09-60

- Addressing Impacts of Changes in Asphalt Binder Formulation and Manufacture on Pavement Performance through Changes in Asphalt Binder Specifications
  - Key Findings
    - To capture strength/strain tolerance, it is recommended to use the Asphalt Binder Cracking Device (ABCD) to determine the critical cracking temperature, T_{cr}
      - AASHTO T 387, Determining the Cracking Temperature of Asphalt Binder Using the Asphalt Binder Cracking Device (ABCD)
    - A new parameter, ΔT_f is determined as the difference between $T_{c,S}$ and T_{cr}
      - Higher values of ΔT_f are associated with better asphalt binder strength/strain tolerance relative to its stiffness.



Understanding Potential Revisions to the PG Asphalt Binder Specifications

- **Please keep your microphone muted during the webinar.**
- **Please post your questions in the chat box.** This can be accessed by clicking the "Chat" in the meeting controls.
- **The moderator will go through the questions at the end of the presentation.**
- **The presenter(s) will answer all questions at the end of the webinar as time permits.**
- **Questions not answered due to time constraints will be responded to separately.**
- **This webinar will be recorded and made available for viewing after the event.**



Evolution of Asphalt Binder Specification Properties to Address Performance

	Binder Property		
Mix Distress	50 years ago	25 years ago	Now
Rutting	Viscosity @60°C	G*/sin δ	$J_{nr3.2}$
Fatigue Cracking	Penetration @25°C	G*sin δ	GRP
Low Temperature Cracking	No direct measurement	BBR Stiffness and m-value	BBR Stiffness and m-value
Durability	Ductility, Retained Penetration, ?	n/a	$\delta_{10\ MPa}$ **or** R **or** ΔT_c with ΔT_f

Thanks!

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