

COMMITTEE ON MATERIALS AND PAVEMENTS

Meeting (Annual or Mid-Year)

Annual

Date

Wednesday, August 7th

Scheduled Time

1:00 PM – 3:00 PM

Technical Subcommittee & Name

Technical Subcommittee 2b, “Liquid Asphalts”

Chair Name and (State)

Joe DeVol (Washington State)

Vice Chair Name and (State)

Barry Paye (Wisconsin)

Research Liaison Name and (State)

I. Introduction and Housekeeping

II. Call to Order and Opening Remarks

A. Brief Summary of Activities

1. Joe DeVol has graciously agreed to be the Chair of Technical Committee 2b. Thanks so much for helping us out.
2. Discuss Chairmanship Succession Planning.

III. Roll Call of Voting Members

Present	Member Name	State	Present	Member Name	State
<input type="checkbox"/>	DeVol, Joe (360) 709-5421 DeVolJ@wsdot.wa.gov	WA	<input type="checkbox"/>	Metcalfe, Ross Oak 406-444-9201 rmetcalfe@mt.gov	MT
<input type="checkbox"/>	Paye, Barry C 608-246-7945 barry.paye@dot.wi.gov	WI	<input type="checkbox"/>	Tedford, Darin P (775) 888-7784 dtedford@dot.nv.gov	NV
<input type="checkbox"/>	George, P. E., Scott W. 334-206-2220 georges@dot.state.al.us	AL	<input type="checkbox"/>	Dusseault, Chuck R. (603) 271-3151 chuck.dusseault@dot.nh.gov	NH
<input type="checkbox"/>	Sandoval-Gil, Jesus A (602) 712-2592 jsandoval-gil@azdot.gov	AZ	<input type="checkbox"/>	Thielke, Russell (518) 457-4585 Russell.Thielke@dot.ny.gov	NY
<input type="checkbox"/>	Wieden, Craig (303) 398-6501 craig.wieden@state.co.us	CO	<input type="checkbox"/>	Peoples, Chris A (919) 329-4000 cpeoples@ncdot.gov	NC
<input type="checkbox"/>	Lauzon, Robert G 8602580312 robert.lauzon@ct.gov	CT	<input type="checkbox"/>	Biehl, Eric R (614) 275-1380 eric.biehl@dot.ohio.gov	OH
<input type="checkbox"/>	Khan, Wasi U 202-671-2316 wasi.khan@dc.gov	DC	<input type="checkbox"/>	Romero, Matt (405) 522-4918 mromero@odot.org	OK
<input type="checkbox"/>	Wu, Peter 404-608-4840 pwu@dot.ga.gov	GA	<input type="checkbox"/>	Ramirez, Timothy (717) 783-6602 tramirez@pa.gov	PA
<input type="checkbox"/>	Joaquin, Anita L. (808) 832-3405 anita.joaquin@hawaii.gov	HI	<input type="checkbox"/>	Byrne, Michael P (401) 222-2524 x4135 michael.byrne@dot.ri.gov	RI

Present	Member Name	State	Present	Member Name	State
<input type="checkbox"/>	Trepanier, Jim (217) 782-9607 james.trepanier@illinois.gov	IL	<input type="checkbox"/>	Egan, Brian (615) 350-4101 brian.egan@tn.gov	TN
<input type="checkbox"/>	Barezinsky, Richard A (785) 368-6521 rick.barezinsky@ks.gov	KS	<input type="checkbox"/>	Nussbaum, L. Scott (801) 726-9065 snussbaum@utah.gov	UT?
<input type="checkbox"/>	Myers, Allen H 502-564-3160 allen.myers@ky.gov	KY	<input type="checkbox"/>	Gagulic, Mladen (802) 828-6405 mladen.gagulic@vermont.gov	VT
<input type="checkbox"/>	Davis, Jason 225-248-4106 jason.davis@la.gov	LLA	<input type="checkbox"/>	Crandol, Robert Wilson 8043283137 robert.crandol@vdot.virginia.gov	VA
<input type="checkbox"/>	Bradbury, Rick L (207) 624-3482 Richard.Bradbury@maine.gov	ME	<input type="checkbox"/>	Farley, Paul M (304) 558-7491 paul.m.farley@wv.gov	WV
<input type="checkbox"/>	Barot, Sejal 443-572-5037 sbarot@sha.state.md.us	MD	<input type="checkbox"/>	Lane, Becca 416 235 3512 Becca.Lane@ontario.ca	ON MOT
<input type="checkbox"/>	Grieco, John E 857-368-3410 John.Grieco@dot.state.ma.us	MA	<input type="checkbox"/>		

Quorum Rules Met?

Annual Meeting: Simple majority of voting members (☐y/ ☐n) | Mid-Year Meeting: Voting members present (☐y/ ☐n)

A. Review of Membership (*New members, exiting members, etc.*)

- Chris Peoples has accepted a new position in NCDOT. Is there a successor for Chris from North Carolina that would want to be a voting member of this subcommittee?

IV. Approval of Technical Subcommittee Minutes

2019 Mid-year Meeting Minutes distributed as **Attachment A** of this Agenda.

V. Old Business

A. T 240 – NCHRP Project 20-07 Task 400 – Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder Report (See **Attachment B**)

- The states most likely to be affected were split 50/50 on whether to change the standard or for each state to determine how to implement the results.

B. COMP Ballot Items (*Include any ASTM changes/equivalencies, including ASTM standards' revision years.*)

All COMP Ballot Items were handled at the Mid-Year Meeting.

COMP Ballot #	Standard	Results (neg/affirm)	Comments/Negatives	Action

C. Technical Subcommittee Ballots

TS Ballot #19-01	Standard	Results (neg/affirm)	Comments/Negatives	Action
Item 1	T 111 This ballot item is a result of comments by Ontario in the reconfirmation ballot. (Page 8 of the Midyear Minutes) Several items in this standard have been updated.	2/23	(GA) 5.1. remove the quotation marks at the end of the third sentence.	Editorial
			(RI) Section 5.1 – Change "assure" to "ensure".	Editorial
			(OH) Sections 3.1 and 5.1 end in a quotation although there is no beginning quotation. -Sections 6.1 and 6.3: Assuming Fahrenheit units are not needed. -Section 6.6: Agree with whoever commented about removing the section. Could be a note though.	Editorial
			(WI) Negative 3.1 & Note need some formatting cleanup. There is an " at the end of the note that needs to be deleted. Same with section 5 formatting and " at the end of 5.1. Is the proposal to keep 6.6, or delete it? I am confused.	Sent back to Ontario so they may contact WI for discussion and resolution. 3.1 and 5.1 are Editorial
			(PA) Negative with comments: 1) Negative is due to Section 2.2 and the addition of ASTM Standards D402, D1856, D2172, D5404, and D6997. The first reason for this negative is that the standard does not reference any of these added ASTM standards in the body or any other Section of the standard. The second reason for this negative is that there are equivalent AASHTO Standards listed in Section 2.1 for some of the added ASTM Negative Standards. If there are equivalent AASHTO Standards, the AASHTO Standards are to be referenced in the body of the standard and used, not the ASTM standards. Other editorial comments: 2) In Section 1.1, 3 rd line, revise from "back asphalts, other synthetic" to "back asphalts, and other synthetic". 3) In Section 1.1, add a period at the end. 4) In Section 3.1, the "Note" needs a number. 5) In Section 3.1, Note, 2nd sentence (or 2nd paragraph?), revise from "are partially soluble, form conglomerates or gels" to "are partially soluble and form conglomerates or gels" for better readability and clarity. 6) In Section 5.1, delete the closing quote symbol (") at end of section as there is no opening quote symbol within this section. 7) In Section 6.1, 1 st line, revise from "empty crucible (Mc) .It is" to "empty crucible (Mc). It is" (i.e., place the empty space after the period not before the period). 8) In Section 6.1, 2nd line, revise from "crucible to be kept" to "crucible be kept".	Sent back to Ontario so they may contact PA for discussion and resolution.

C. Technical Subcommittee Ballots

TS Ballot #19-01	Standard	Results (neg/affirm)	Comments/Negatives	Action
			9) In Section 6.5, revise from "Return the crucible containing residue in the muffle furnace" to "Repeat placing the crucible containing residue in the muffle furnace" for better readability.	
Item 2	T 315 This ballot item comes from the work of Task Force 16-C (Page 9 of the Mid-year Minutes). TF 16-C was reviewing the contradictory statements in Section 12.1 and X1.8.1 regarding the linear region in T 315.	0/25	No Comments received.	Motion to send to COMP Ballot
Item 3	M 332 This ballot item is to resolve a negative vote from the COMP ballot. During the Mid-year meeting it was determined to remove the confusing language from footnote g in the Table 1. (Page 4 of the Mid-year Minutes)	0/25	No Comments received.	Motion to send to COMP Ballot
Item 4	T 383 This ballot item includes several minor word revisions as well as clarification on the 3 plate versus 1 plate procedure. (Page 6 of the	0/25	(PA) Affirmative with comments: 1) In Section 3.1.2, 1 st line, revise from "is applied to a steel plate" to either "is applied to a metal plate" or "is applied to a steel or aluminum plate" so that it agrees with the Section 6.1.3 text "steel or aluminum plates". 2) In Section 3.1.2, should this section make reference to the fact that the process of 3 applications per plate is done on a total of 3 plates or done on the same plate 3 times? Perhaps revise from "The amount of asphalt	Determine which comments are editorial and address as needed. For technical comments – a decision will need to be made either to move forward to a COMP Ballot with the standard as voted on in the TS ballot with editorials included as appropriate or to hold over for another year. The only other thing you could do would be to

C. Technical Subcommittee Ballots

TS Ballot #19-01	Standard	Results (neg/affirm)	Comments/Negatives	Action
	Mid-year Minutes)		<p>mixture retained is recorded after the three application cycles" to "The average amount of asphalt mixture retained is recorded after three replicates of the test procedure."</p> <p>3) In Section 5.1.4, removing the SI units for the sieve size seems odd as other sections, including Sections 5.1.2, 5.1.3, and 5.1.5 include the SI units with U.S. customary units in parenthesis. Suggest keeping both the SI unit with U.S. customary unit in parenthesis for the sieve size in Section 5.1.4.</p> <p>4) In Section 6.1.2, at end, revise from the period to a semi-colon for consistency with the end of the other subsections within Section 6.1.</p> <p>5) In Section 6.1.3, it specifies a steel or aluminum plate "with a textured surface that simulates the inside of a typical truck bed..." but also specifies that "Each plate shall be machined flat to a tolerance of +/-0.1mm (+/- 0.0005 in) in any direction". This seems to be contradictory. Also, how would one verify that the plate texture is similar to a truck bed? Should a procedure be specified for texturing a machined plate (e.g., using a wire brush or wire wheel)?</p> <p>6) In Sections 6.1.3 and 6.3.13, is it required to have three separate plates, or could the same plate be used to repeat Sections 6.3.1 to 6.3.12 subject to cleaning the metal plate each time? For better efficiency, three different metal plates are ideal to perform each replicate simultaneously, but I am not seeing that three different metal plates would be necessary unless the three different plates are to simulate three different truck bed textures as the texturing specified in Section 6.1.3 would likely be slightly different on each of three metal plates. If the same metal plate could be used, I suggest allowing that option in Sections 6.1.3, 6.3.13, and 6.3.14.</p> <p>7) In Section 6.3.3, suggest formatting the "Note:" as a separate paragraph with a Note # as is normally done with Notes.</p> <p>8) In Section 7.1.2, why are three metal plates specified? The Section 7.3 procedure does not specify to perform the procedure on three different plates or to average the results from three different plates.</p> <p>9) In Section 7.1.2, it specifies three steel or aluminum plates "with a textured surface that simulates the inside of a typical truck bed..." but also specifies that "Each plate shall be</p>	<p>have a TS floor ballot at the meeting but if the changes are complex then it would be better to have another TS ballot next year to address the new issues raised.</p> <ol style="list-style-type: none"> 1) Changed to metal 2) Editorial – no change made. Section 3 is a high level look, where the details are contained later in the process. 3) 2mm added back in 4) Semi-colon added 5) Comment on flatness was to avoid questions about warped plates. Since release agents are used on many surfaces, any further definition of “similar to a truck bed” would be beyond the detail of this procedure. 6) 3 plates are required to have triplicate testing, as required in other ASTM and AASHTO Standards. Using 1 plate and doing it from start to finish 3 times would take a significant amount of time. 7) The word note is deleted, and the process is added a full sentence. The same applies to number 10. 8) 3 plates are required to have triplicate testing, as required in other ASTM and AASHTO Standards. Using 1 plate and having to do it from start to finish 3 times would take a significant amount of time. 9) See response in 5. 10) See response in 7

C. Technical Subcommittee Ballots

TS Ballot #19-01	Standard	Results (neg/affirm)	Comments/Negatives	Action
			<p>machined flat to a tolerance of +/-0.1mm (+/- 0.0005 in) in any direction". This seems to be contradictory. Also, how would one verify that the plate texture is similar to a truck bed? Should a procedure be specified for texturing a machined plate (e.g., using a wire brush or wire wheel)?</p> <p>10) In Section 7.3.2, suggest formatting the "Note:" as a separate paragraph with a Note # as is normally done with Notes.</p>	
			<p>(MT) It appears there is a "note" included within sections 6.3.3 and 7.3.2 (same information). The note gives direction on how to apply the ARA so that "the surface is evenly coated." It seems like this is mandatory information and therefore the word "Note" should be removed. If this is not mandatory information the note should be separate, however I don't see any alternatives to the direction given to ensure the surface is evenly coated.</p>	<p>This comment is Technical if found valid.</p> <p>Response – Note is removed, suggest voice vote at the meeting to move to COMP.</p>
			<p>(AZ) In subsection 6.1.3 for the plates, the proposed flatness tolerance is an extremely tight machining tolerance. Is there a particular rationale for requiring such a strict tolerance?</p>	<p>Good question</p> <p>NTPEP testing labs have gone to a tight tolerance to reduce industry debate.</p>
			<p>(ON) Section 1.2: Replace "In-pound units" with "other units".</p> <p>Section 2.3: Do not put the hyperlink, just the title of the method.</p> <p>Section 3.1.1 mentions "opacity". Should it be replaced by "discoloration" which is used several times in the document?</p> <p>Section 5.1. 4: Leave dimensions in SI units as per section 1.2.</p> <p>Section 6.1.2: a) Clarify the weight requirements. The weight can be interpreted as 6.8 Kg± 0.14 Kg or 6.8 Kg± 0.45 Kg</p> <p>b) Is the bucket's footprint a square or a circle?</p> <p>c) Instead of defining a "Unit Weight Bucket" maybe define a weight which can be a bucket with a square footprint (?? mm X ?? mm) or ?? mm diameter filled with (any) sand to a total mass of 6.8 Kg± 0.14 Kg or 6.8 Kg± 0.45 Kg.</p>	<p>Some of these questions are technical in nature. The comments are editorial.</p> <p>1.2 – In-pound is used to match other standards.</p> <p>2.3 – Link deleted</p> <p>3.1.1 – Changed to discoloration</p> <p>5.1.4 – Edit made to include both.</p> <p>6.1.2 – Richard/Dawn – should we change the 2nd measure to 0.14 kg to match? Do we want to change to a footprint size of x number of square inches, or do we keep with the unit weight bucket?</p>
			<p>(TN) Comments: Editorial – The sections "Apparatus" and "Materials" need to be removed from Sections 5,6 and 7 and be their own sections as shown in the AASHTO "Model Standard" Guidelines.</p> <p>- Section 5.1.4 are we requiring the use of a no. 10 sieve 8 in. in diameter OR a sieve size such that no material is lost during washing.</p>	<p>Good comment but not editorial this change would be Technical.</p> <p>- Wouldn't moving this add to the confusion as each section is a different test procedure. I get what the AASHTO guide is going for,</p>

C. Technical Subcommittee Ballots

TS Ballot #19-01	Standard	Results (neg/affirm)	Comments/Negatives	Action
			- Section 6.1.3- the flatness tolerances for the steel or aluminum plate, to the flatness of +or- 0.1mm, seems excessive to measure. No truck bed is ever going to be this precise.	<p>but it would be more confusing to the user.</p> <ul style="list-style-type: none"> - A #10 sieve is suggested to support the filter, but allow it to drain. The test lab has found that this works best, so it is what is specified. - Flatness need is for test repeatability between labs, not to match field conditions.

D. Reconfirmation Ballots

Reconf. Ballot #	Standard	Results (neg/affirm)	Comments/Negatives	Action

E. Task Force Reports

Task Force #	Title	Members	Status/Update
16-A	TFO/PAV Pan Warping	DE-Karl Zipf, AI-Mike Anderson, AASHTO Re:source-Maria Knake, Dave Anderson	Dave Anderson will provide an update.
17-01	Re-write T 228	AASHTO Re:source-Maria Knake, MT-Leslie White, AASHTO Consultant-Georgene Geary	See Email from Maria - Attachment C (I think this task force should merge into the TFASH and this standard should be one of the first to undergo harmonization.)
17-02	Use of ΔT_c Practice	AL - Lyndi, NC-Chris Peoples, ON-Anne Holt, FL-Tim Ruelke; ME-Rick Bradbury, TX-Brett Haggerty, AI-Bob Horan, NH-Denis Boisvert, FHWA-Jack Youtchef, ETG-Matt Corrigan	A draft practice was sent out to the Task Force and a web meeting was held. See Attachment D .
19-01	DSR-PAV Variability	WS-Barry Paye, WA-Joe DeVol, and TN-Matt Chandler	A web meeting was held with the TF. Draft redlined standards were submitted to the TS in June. See Attachment E . (Mid-Year Minutes Attachment D is the presentation given at mid-year.)

VI. New Business

A. AASHTO re:source/CCRL/NTPEP (Observations from assessments, as applicable.)

- B. Task Force for Asphalt Standards Harmonization (TFASH)
 - 1. Update from last meeting. (Maria Knake) (See **Attachment F**) – request for AASHTO members
 - 2. Possible Standards to start Harmonization
 - a. T 228 & ASTM D70 (See Task Force 17-01). See **Attachment C**.
 - b. Standards that Maria and Dave Anderson have been working on:
 - i. BBR
 - ii. DSR
 - iii. PAV
 - c. PG Tire Rubber-Modified Asphalt Specification, ASTM Subcommittee D04.40 (Contact Doug Carlson) Email from Maria – **Attachment G**
- C. Presentation by Industry/Academia
 - 1. Update on Task Force item 19-01 - Scott Veglahn
 - 2. AMAP - Skip Paul
- D. Revisions/Work on Standards for Coming Year
 - 1. Draft rubber binder test standard for concentric cylinder (cup and bob) - Matt Corrigan
 - 2. Draft for high RBR binder blends NCHRP 9-58 – Matt Corrigan
- E. Review of Stewardship List
See **Attachment H** for steward list as it currently stands – there are some areas for volunteer opportunities.
- F. Proposed New Standards
- G. NCHRP Issues
- H. Correspondence, Calls, Meetings
- I. Proposed New Task Forces (*Include list of volunteers to lead and/or join TF.*)
- J. New TS Ballots
 - 1.

VII. Open Discussion

- A.
- B.

VIII. Adjourn

TS Meeting Summary

Meeting Summary		
Items Approved by the TS for Ballot (<i>Include reconfirmations.</i>)		
Standard Designation	Summary of Changes Proposed	Ballot Type
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
		<input type="checkbox"/> TS <input type="checkbox"/> COMP <input type="checkbox"/> CONCURRENT
New Task Forces Formed		
Task Force Name	Summary of Task	TF Member Names and (States)
Research Proposals (<i>Include number/title/states interested.</i>)		
Other Action Items		



COMMITTEE ON MATERIALS & PAVEMENTS

2018 - 2019 Mid Year Meeting (*Webinar*)

Wednesday, January 23, 2019

2:30 – 4:30 PM EST

Minutes

TECHNICAL SECTION 2b

Liquid Asphalts

I. Introduction and Housekeeping (*AASHTO Liaison*)

II. Call to Order and Opening Remarks

A. Summary of activities

B. Looking for a new Chair for TS 2b.

Lyndi is leaving 2b because of a change in her position at ALDOT. Please reach out to Lyndi, Barry, or Casey! We are very eager to hear from you!

III. Roll Call

Voting states present: AL, WI, AZ, CO, CT, GA, KS, IL, LA, ME, MD, MT, NV, NY, OH, TN, UT, VT, WV.

Attendance as registered via email:

Last Name	First Name	Email Address
Akisetty	Chandra	cakisetty@sha.state.md.us
Aschenbrener	Tim	timothy.aschenbrener@dot.gov
Barezinsky	Rick	rick.barezinsky@ks.gov
Biehl	Eric	eric.biehl@dot.ohio.gov
Blackburn	Lyndi	blackburnl@dot.state.al.us
Bradbury	Rick	richard.bradbury@maine.gov
Burch	Paul	pburch@azdot.gov
Carlson	Eliana	eliana.carlson@ct.gov
Clawson	Chad	cclawson@ashto.org
Corrigan	Matthew	matthew.corrigan@dot.gov
Crane	John	JEJCrane@gmail.com
Davis	Jason	jason.davis@la.gov
Davis	Steve	davissj@wsdot.wa.gov
DeVol	Joe	devolj@wsdot.wa.gov
Doran	Michael	michael.doran@tn.gov
Egan	Brian	Brian.Egan@tn.gov
Garrison	Miles	miles.garrison@txdot.gov
Greutert	Timothy	timothy.greutert@dot.ca.gov
Hemsley	Mike	mike.hemsley@ptsilab.com
Kelly	Michael	Michael.Kelly@dot.ny.gov
Kennedy	Kevin	kennedyk@michigan.gov
Kim	Sungho	sungho.kim@vdot.virginia.gov
Knake	Maria	mknake@ashtoresource.org
Kriz	Pavel	pavel.kriz@esso.ca
Lawrence	Bill	BillLawrence@utah.gov
Metcalfe	Oak	rmetcalfe@mt.gov
Morse	Kelly	Kelly.Morse@illinois.gov
Motamed	Arash	arash.motamed@txdot.gov
Nener-Plante	Derek	derek.nener-plante@maine.gov
Nussbaum	Scott	snussbaum@utah.gov
PAN	CHANGLIN	cpan@dot.nv.gov
Paye	Barry	barry.paye@dot.wi.gov
Sade	Ben	bsade@ashtoresource.org
Salomon	Delmar	delmar@technopave.com
Schwartz	Aaron	aaron.schwartz@vermont.gov
Short	Temple	shorttk@scdot.org
Sirianni	Jonathan	jsirianni@ashto.org
Stanford	Michael	michael.stanford@state.co.us
Tedford	Darin	dtedford@dot.nv.gov

Thielke	Russell	Russell.Thielke@dot.ny.gov
Trautman	Brett	Brett.Trautman@modot.mo.gov
Trepanier	Jim	james.trepanier@illinois.gov
Turgeon	Curt	curt.turgeon@state.mn.us
Walbeck	Travis	travis.b.walbeck@wv.gov
Wieden	Craig	craig.wieden@state.co.us
Wilson	Craig	cwilson@azdot.gov
Wu	Peter	pwu@dot.ga.gov
Syslo	Mick	mick.syslo@nebraska.gov
Zwanka	Merrill	zwankame@scdot.org

IV. Approval of Technical Subcommittee Minutes

- A. 2018 Annual Meeting Minutes distributed with the COMP ballot and the Mid-year agenda.
Motion to approve meeting minutes - MT; second by OH; meeting minutes approved as distributed.

V. Old Business

- A. COMP Ballot Items (Including any ASTM Changes/equivalencies)

All Items passed.

1. **Item No. 13** - COMP Ballot to update the precision estimates in **T 313, "Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)"**. See pages 3-4 of the meeting minutes.

Georgia Department of Transportation (Monica L. Flournoy) (mflournoy@dot.ga.gov)

Affirmative

The slope (m-value) should be 6.0 not 5.8 on Table 1.

Values in the Table were correct as voted on in the TS ballot before the COMP ballot.

2. **Item No. 14** - COMP Ballot to update the precision estimates in **T 315, "Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)"**. See pages 3-6 of the meeting minutes.

Illinois Department of Transportation (Brian Pfeifer) (brian.pfeifer@illinois.gov)

Affirmative

After comparing IDOT lab values vs. our producer's qualification sample results, we have some concerns with the multi-laboratory precision values. Due to the tightening of the ranges, some results for ODSR and RTFO DSR results may fall out of the multi-laboratory ranges but not enough to be of major concern. Conversely, the PAV DSR would fall out of the significantly lowered range frequently. The problem with the use of proficiency sample results for statistical analysis for P&B is that proficiency samples are intended to provide an ideal situation for labs and technicians to demonstrate competencies and consistencies by the control of the samples and timing of delivery. This controlled process removes all the normal day-to-day, lab to lab potentials for differences in results. Routine samples tested at Agency and producer's labs may be tested at vastly different times of the material's life and/or handling conditions. These uncontrolled variables need to be considered when developing the P&B as they are used to verify data/result compliance between laboratories.

Pennsylvania Department of Transportation (Timothy L Ramirez) (tramirez@pa.gov)

Affirmative

Editorial comments:

- 1) In Table caption, revise from "Table 1" to "Table 4".
- 2) For each Note, revise the Note numbers from "Note 1" to "Note 29" and from "Note 2" to "Note 30".
- 3) In Section 1.1 Bias, revise from Section "1.1" to "14.2".

The information presented in the ballot was a cut and paste of the page in the standard showing revisions to the table and when pasting to a new document the numbering system is reset. Therefore, the Table, Note, and Section numbers all reverted to 1. The numbering system will be correct in the published standard.

3. **Item No. 15** - COMP Ballot to update the precision estimates in **T 316, "Viscosity Determination of Asphalt Binder Using Rotational Viscometer"**. See pages 3-7 of the meeting minutes.
Illinois Department of Transportation (Brian Pfeifer) (brian.pfeifer@illinois.gov)

Affirmative

Upon comparison of IDOT lab data vs. producer's qualification sample results, the rotational viscometer multi-laboratory results varied by greater than the newly revised 10.5% range. The problem with the use of proficiency sample results for statistical analysis for P&B is that proficiency samples are intended to provide an ideal situation for labs and technicians to demonstrate competencies and consistencies by the control of the samples and timing of delivery. This controlled process removes all the normal day-to-day, lab to lab potentials for differences in results. Routine samples tested at Agency and producer's labs may be tested at vastly different times of the material's life and/or handling conditions. These uncontrolled variables need to be considered when developing the P&B as they are used to verify data/result compliance between laboratories.

Pennsylvania Department of Transportation (Timothy L Ramirez) (tramirez@pa.gov)

Affirmative

Editorial comments:

- 1) For each Note, revise the Note numbers from "Note 1" to "Note 2" and from "Note 2" to "Note 3".
 - 2) In Section 1.1 Bias, revise from Section "1.1" to "15.2".
- See comment above for Item 14 concerning this issue. The numbering system will be correct in the published standard.

4. **Item No. 16** - COMP Ballot to add precision estimates to **T 350, "Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)"**. See pages 8-9 of the meeting minutes.

California Department of Transportation (Daniel Speer) (dan.speer@dot.ca.gov)

Affirmative

The attached document for revisions to AASHTO T 350 does not show the recommended revisions to the standard. However, the Technical Subcommittee's meeting minutes provide the recommended revisions. Approval is recommended for the revisions to the standard and the addition of precision estimates as approved by the Technical Subcommittee.

This item was to *add* (not update) precision statements.

Pennsylvania Department of Transportation (Timothy L Ramirez) (tramirez@pa.gov)

Affirmative

Editorial comments:

- 1) In Note 1, line 2, revise from "AASHTO re: source" to "AASHTO re:source" (i.e., delete space between ":" and "s").
- 2) In Note 2, 2nd & 3rd lines, revise from "results of 1.20 kPa-1 and 1.300 kPa-1" to "results of 1.2 kPa-1 and 1.3 kPa-1" as T 350, Section 9.1.5 indicates to report Nonrecoverable Creep Compliance at 0.1 kPa to "two significant digits".
- 3) In Note 2, 4th & 5th lines, revise from "1.20 kPa-1 and 1.30 kPa-1" to "1.2 kPa-1 and 1.3 kPa-1" as T 350, Section 9.1.5 indicates to report Nonrecoverable Creep Compliance at 0.1 kPa to "two significant digits".

These editorial comments will be reviewed and corrections if necessary will be made prior to publication.

5. **Item No. 17** - COMP ballot to revise M 332. Delete the Jnr Diff requirement for Extremely Heavy Traffic Binders in **M 332, "Specification for Performance-Graded Asphalt Binder using Multiple Stress Creep Recovery"**. See page 10 of meeting minutes.

Arkansas Department of Transportation (Michael C Benson) (michael.benson@ardot.gov)

Affirmative

Table 1, footnote g appears to cover not only waiving the Jnr diff for binders with Jnr3.2 values & 0.5 kPa-1, but also direction on the use of Jnr3.2 values. Consideration should be made to include these as two separate footnotes rather than combined as indicated.

Indiana Department of Transportation (Matthew Beeson) (mbeeson@indot.in.gov)

Affirmative

Comments on new superscript "g":g The Jnr diff requirement shall not apply to asphalt binders having a Jnr3.2 value of 0.5 kPa-1 or lower at the selected test temperature. Waiving Jnr diff is intended for binders with Jnr less than 0.5. -Second sentence conflicts with the first. First sentence says Jnr diff shall not apply. Second sentence just says "is intended" to not apply. Recommend deleting second sentence. For each grade the Jnr requirement is a maximum value.- Superscript "g" is next to Jnr diff in the table. This sentence applies to Jnr. Recommend a separate letter for this sentence or move the "g" to the end of "MSCR, T 350" so it applies to all. A binder that has a Jnr of 0.4 may be supplied as a E grade, and may also be supplied as a V, H, or S grade as well.-Same statement on location of superscript as above.

North Carolina Department of Transportation (Christopher A Peoples) (cpeoples@ncdot.gov)

Negative

More clarification is needed for the last line of note g: "A binder that has a Jnr of 0.4 may be supplied as an E grade, and may also be supplied as a V, H, or S as well". The assumption is that Jnr is Jnr 3.2. Is this saying if a binder is anything other than the maximum jnr for an E designation it can be used for anything? Shouldn't Jnr diff come into play still?

Are there suggestions on how to make this clearer without changing the intent? Should the standard just be balloted with the removal of the text beyond the first sentence of the footnote? MT: would it be appropriate to have the additional sentences in a note rather than in a footnote?

WA: dealing with it from Jnr is one thing but going into grades is where it may get confusing.

Post meeting: North Carolina agreed to withdraw its negative provided the standard would go back to ballot this year to delete the additional sentences beyond the first sentence in footnote g. See **Attachment A** for the proposed ballot item for 2019.

Standard will be published as voted in the 2018 COMP ballot.

Pennsylvania Department of Transportation (Timothy L Ramirez) (tramirez@pa.gov)

Affirmative

Comments:

- 1) Table 1, footnote g, we do not know how much of an affect this will have on what is supplied for "S", "H", and "V" grades.
- 2) In Table 1, footnote g, it is strongly recommended to delete the extra sentences added to this footnote for this COMP ballot (i.e., delete the 2nd, 3rd, and 4th sentences of footnote g). These extra sentences were **very close to being a negative vote** for me, but I think it is important to address the Jnr difference issue in this standard. The 2nd sentence is same as 1st sentence, so it is not needed. The 3rd sentence, related to maximum value, is also not needed as the Table 1 requirements already specify Jnr is a maximum value. The 4th sentence should not be permitted as it mentions "E" grades, but the footnote g is not included in Table 1 for "E" grades since the Jnr diff requirement is deleted from Table 1 for

the "E" grades. Also, regarding the 4th sentence, it is really not needed for the other "S", "H" and "V" grades as any result less than the maximum Jnr specified will meet the Table 1 requirements.

Texas Department of Transportation (Miles Ralph Garrison) (miles.garrison@txdot.gov)

Affirmative

The main thing here is relaxing the Jnr difference for the grades with very low Jnr. I agree with this change; we've seen that some of our more heavily modified materials tend to have higher Jnr difference, and one concern I had with this spec was that the 75% max might not always have been reasonable for those grades. We don't currently use this spec, but it's still a good change. If we were using this spec, we would always use the same PAV temperature of 100°C, but this is consistent with other AASHTO PG specs, so no objection to that.

6. **Item No. 18** - COMP Ballot to revise T 383. This includes minor revisions and picture upgrades for **T 383, "Evaluation of Asphalt Release Agents (ARAs)"**. See page 10 of meeting minutes.

Pennsylvania Department of Transportation (Timothy L Ramirez) (tramirez@pa.gov)

Affirmative

Comment:

- 1) In Section 3.1.3 and at end of 1st line, revise from "plates" to "plate" as there is only one metal plate used.
- 2) In Section 3.1.3, 4th line, revise from "each metal plate" to "the metal plate" as there is only one metal plate used in the procedure, not multiple plates.
- 3) In Section 7.2.1, end of 2nd line, delete one of the two periods (revise from "." to ".").
- 4) In Section 7.3.11, the procedure is to be repeated until the percent of retained binder is greater than 10.0%. We have not run this test, but will there ever be occasions when the 10.0% retained binder requirement cannot be reached or it will take a high number of repeats to reach this limit?
- 5) In Section 9.1.2, revise from "each metal plate" to "the metal plate" as there is only one metal plate used in the procedure, not multiple plates.
- 6) In Section 9.1.3, revise from "each metal plate" to "the metal plate" as there is only one metal plate used in the procedure, not multiple plates.

7. **Item No. 19** - CONCURRENT Ballot to adopt TP 092, **"Determining the Cracking Temperature of Asphalt Binder Using the Asphalt Binder Cracking Device (ABCD)"** to a full standard. See page 12 of the meeting minutes

Texas Department of Transportation (Miles Ralph Garrison) (miles.garrison@txdot.gov)

Affirmative

Specimen molds: is the 40 shore hardness a minimum or a maximum? Is there an acceptable range? I'm not sure the reference to 10W30 motor oil is useful; not everyone is familiar enough with motor oil to know what that means. The parenthetical is a better description of the consistency, so we should just use that. For cleanup, I have had good results with a lot of different tests using Teflon spatulas to chip or scrape off asphalt with little risk of damaging metal molds or machined parts. Specimen molds: is the 40 shore hardness a minimum or a maximum? Is there an acceptable range? I'm not sure the reference to 10W30 motor oil is useful; not everyone is familiar enough with motor oil to know what that means. The parenthetical is a better description of the consistency, so we should just use that. For cleanup, I have had good results with a lot of different tests using Teflon spatulas to chip or scrape off asphalt with little risk of damaging metal molds or machined parts.

[Lyndi will reach out to a state that is actually running this test. Eric Biehl \(OH\) volunteered to investigate this comment and be a steward for this standard.](#)

B. TS Ballot TS 2b 18-03

All items passed but Chair found PA's negative on Item 2 persuasive therefore this item was not included in the COMP ballot.

1. Ballot Item - **Revise T 383 with minor changes and updated pictures.** Refer to the document comments for clarification on new pictures versus pictures being deleted.

Georgia Department of Transportation (Peter Wu) (pwu@dot.ga.gov)

Affirmative

First two photos do not have a identification such as Figure 1, etc. The third photo is marked as figure 1.

New York State Department of Transportation (Don Streeter) (donald.streeter@dot.ny.gov)

Affirmative

First 2 pictures after 5.3.14 do not have figure numbers or captions. Need to delete or add figure numbers and captions. If add figure numbers and captions, will need to check and update all Figure numbers and references to them.

6.1.2 - 2nd line - delete extra "." from (0..3 lb), should be (0.3 lb)

Pennsylvania Department of Transportation (Timothy Ramirez) (tramirez@pa.gov)

Affirmative with comments:

- 1) In Section 3.1.2, the proposed changes to the Summary of Test Method do not agree with the Section 6 procedure. The proposed revisions in Section 3.1.2, 1st line "applied to each of 3 steel plates that have" and in Section 3.1.2, 2nd line "Each plate is tilted" indicates multiple plates are involved, but in Section 6.1.3, only "one 16-gauge steel or aluminum plate" is required. Recommend revising Section 3.1.2 completely to read "In the Mixture Slide Test, a metal plate is initially treated with the ARA. A sample of HMA is applied to the treated metal plate and the metal plate is tilted to allow the HMA to slide free. The amount of retained HMA on the plate is recorded. The application of HMA, tilting of the plate, and recording the amount of retained HMA on the plate is repeated two additional times. The degree of adhesion to the metal plate is determined by gain in weight from the three HMA application cycles."
- 2) In Section 3.1.3, the proposed revision in the 1st line, "metal plates", and the proposed revision in the 4th line, "to each metal plate" does not agree with the Section 7 procedure. These proposed revisions indicate multiple plates are involved but, in Section 7.1.2, only "one 16-gauge steel or aluminum plate" is required. It is recommended that the proposed revisions in 1st line and 4th line, NOT be implemented.
- 3) In Section 7.2.1, end of 2nd line, delete one of the two periods (revise from ".." to ".").
- 4) In Section 8.1, end of 2nd line, revise from semi-colon (";") to period (".").
- 5) In Section 9.1.2, due to the reason in comment 1) above, it is recommended not to implement any of the proposed changes in this Section.
- 6) In Section 9.1.3, due to the reason in comment 2) above, it is recommended not to implement any of the proposed changes in this Section.

Questions were raised on whether 3 plates are used, and the test is run 3 separate times or is the test run 3 separate times on the same plate. It's a small distinction with big impact. This issue was deemed technical in content and will be balloted this year with the clarification on using one plate 3 times or running 3 tests on 3 plates. The standard will be published this year as balloted in this COMP ballot.

Tennessee Department of Transportation (Brian Egan) (brian.egan@tn.gov)

Affirmative

Editorial comments- The standard appears to be a hybrid of SI units and English units with random consistency. Suggest that the standard be made consistent with English units included consistently in parenthesis.- Section 5.2.1.1 and 6.2.1.1, -should reference Table 4 instead of Table 3 -Section

5.2.1.2 - suggest allowing PG 64-22 and other "non-modified" asphalt binders representative of the DOT's binders used- Section 5.2.1.4 and 6.2.1.4 - suggest adding "or R 68 Section 4.4" for Marshall sample preparation- Section 5.3.15- Will there be limits established to "define" "Slight", "moderate" and "severe" stripping in addition to visual determinations?

2. Ballot to Delete T 228, "Specific Gravity of Semi-Solid Asphalt Materials"

Pennsylvania Department of Transportation (Timothy L Ramirez) (tramirez@pa.gov)

Negative

Negative with comments:

- 1) Negative is due to several of the AASHTO exceptions not included in the most recent ASTM D70-18. The AASHTO exceptions not included in ASTM D70-18 are listed below. Some of the AASHTO exceptions may no longer be relevant or significant, but I felt obligated to identify which exceptions are not included before voting in the affirmative to delete T 228.
- 2) AASHTO exception "1." deals with replacement of ASTM references with AASHTO references. One of two replacements is AASHTO R 66 for ASTM D140. When AASHTO R 66 was AASHTO T 40, it was equivalent to ASTM D140, but now AASHTO R 66 is no longer equivalent to ASTM D140. I presume it is no longer equivalent due to significant differences. If most are using AASHTO R 66 for sampling asphalt materials, will this conflict with ASTM D70 due to any of the significant differences? The other replacement is for AASHTO T 295 for ASTM D3142, but T 295 is equivalent to ASTM D3142 so this replacement is not an issue.
- 3) AASHTO exception "2." and "4." deal with adding reference to AASHTO M 231 (Weighing Devices). M 231 does not have any referenced ASTM standard equivalent. ASTM D70-18, Section 6.4 Balance, does not reference any standard specification for a balance. Is the text within ASTM D70, Section 6.4 acceptable for specifying a suitable balance (weighing device)?
- 4) AASHTO exception "3." is in regards to ASTM D70, Note 2 with the AASHTO exception reading "The terms "relative density" and "specific gravity" are used interchangeably in this standard." and the ASTM D70-18, Section 3.1.2, Note 2 text reading "Relative density is also described as specific gravity." which is the same exact text used in ASTM D70-08, Note 2 in which the AASHTO exception was written to revise. So not all of the AASHTO exceptions are included in ASTM D70-18.
- 5) AASHTO exception "5." is included in ASTM D70-18, Section 10.1.1 except for the text "at test temperature".
- 6) AASHTO exception "6." included "or hot plate" which is not included in ASTM D70-18, Section 11.1.1. Are some still using hot plates?
- 7) AASHTO exception "7." is included in ASTM D70-18, Section 11.1.3 except for the text "at the test temperature".
- 8) AASHTO exception "8.", Precision Estimates for "Asphalt" are different than the Precision Estimates for "Asphalt" in ASTM D70-18 (e.g., Single-Operator Precision Estimate at 15.6°C in AASHTO = 0.0032 vs. ASTM = 0.0032 and Multilaboratory Precision Estimate at 15.6°C in AASHTO = 0.0051 vs. ASTM = 0.0068). ASTM D70-18 also allows a "pooled values" precision as noted in Table 1 and in Section 14. These "pooled values" precision estimates are not the same as the T 228 "Asphalt" precision estimates and will this cause confusion as to which precision estimates are to be used for PG Asphalt Binders? In addition, the ASTM D70-18, does not include any indication of the basis or data used to develop/determine the precision estimates. T 228 indicates precision estimates are based on the analysis of test results from eight pairs of AMRL proficiency samples and includes the types of PG binder grades that were included in the analysis and indicates analysis is contained in "NCHRP Project No. 9-26, Phase 3". So again, not all AASHTO exceptions seem to be included in ASTM D70-18. Since the ASTM D70-18 does not indicate basis of the Precision Estimates in the standard, it cannot be determined if the ASTM D70-18 Precision Estimates are newer or more recent than those in AASHTO T 228.

This negative was found by the Chair to be persuasive so this item to delete T 228 was not included in the COMP ballot.

Maria Knake (Re:source): PA's comments can be included in another ballot through ASTM to increase harmonization efforts. The Chair recommends that T 228 be kept as an AASHTO standard until the issues have been resolved.

C. Reconfirmation Ballots

Everything passed with no negatives.

1. R 029-15 "Grading or Verifying the Performance Grade (PG) Asphalt Binder"
2. T 049-15, "Penetration of Bituminous Materials" – ASTM D5/D5M-13
3. T 111-11 (2015), "Mineral Matter or Ash in Asphalt Materials"

New York State Department of Transportation (Donald Streeter) (donald.streeter@dot.ny.gov)

Affirmative

T111 does not specify the concentration of the ammonium carbonate solution. Recommend using language similar to that used in T 164 appendix A - specify the ammonium carbonate solution as "saturated"

Ontario Ministry of Transportation (Becca Lane) (becca.lane@ontario.ca)

Affirmative

- Section 1 Scope Subsection 1.1 : Consider replacing " in solid, semisolid and liquid asphalt" with "of bulk and recovered asphalt binders, distillation residues of emulsified and cut-back asphalts, other synthetic or naturally occurring asphaltic materials"
- Section 2: If the change is adopted for the scope, the test methods from the following list will be required:
 - ASTM D1856-09 Standard Test Method for Recovery of Asphalt from Solution by Abson Method
 - ASTM D2172-17 Standard Test Methods for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
 - ASTM D5404-12 Standard Practice for Recovery of Asphalt from Solution Using the Rotary Evaporator
 - ASTM D6997 - 12 Standard Test Method for Distillation of Emulsified Asphalt
 - ASTM D402- 14 Standard Test Method for Distillation of Cutback Asphalt
 - AASHTO T 164-14 Standard Method of Test for Quantitative Extraction and Recovery of Asphalt Binder from Hot Mix Asphalt (HMA)
 - AASHTO T 319-15 Standard Method of Test for Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures
 - AASHTO T59-16 Standard Method of Test for Testing Emulsified Asphalt
 - AASHTO T78-15 Standard Method of Test for Cutback Asphaltic Products
- Section 3, Subsection 3.1: Consider the integration of a note : "For recovered binder from asphalt mixtures , the ash content may include fine mineral materials not retained on the filters or other equipment prior to the recovery process"
- Section 3, Subsection 3.2: Consider the integration of a note: "Some compounds contained in asphaltic materials are partially soluble , form conglomerates or gels when in contact with solvent, resulting in clogging of filters used in the solubility method. In such cases the ash method is preferred"
- Section 5: Consider the following change: Since the materials are defined in the scope of the methods and should not contain water remove "If the sample contains more than 2.0 percent water, it shall be dehydrated by distillation in accordance with ASTM D95, before testing." and replace with "If the sample is not fluid, heat the sample with care to prevent local overheating until it has become sufficiently fluid to pour, occasionally stirring the sample to aid heat transfer and to assure uniformity. Avoid the entrapment of air." Remove the "a temperature

below the volatilization temperature of the asphalt” and replace with “at $100 \pm 10^{\circ}\text{C}$ ($212 \pm 18^{\circ}\text{F}$).”

Ontario has volunteered to review and revise as necessary this standard. New York’s comment will also be addressed. If you disagree or have anything to add please get in touch with ON!

4. T 201-15, “Kinematic Viscosity of Asphalts (Bitumens)” ASTM D2170/D2170M-10
5. T 202-15, “Viscosity of Asphalts by Vacuum Capillary Viscometer” ASTM D2171/D2171M- 10
6. TP 113-15, “Determination of Asphalt Binder Resistance to Ductile Failure Using Double-Edge-Notched Tension (DENT) Test”
7. TP 127-17, “Determining the Fracture Energy Density of Asphalt Binder Using the Binder Fracture Energy (BFE) Test”

D. Task Force Reports

Task Force 16-A:

Review the options available and write a procedure for checking TFO/PAV pans for excessive warping. Members: Delaware (Karl Zipf), Asphalt Institute (Mike Anderson), and AMRL (Maria Knake). Dave Anderson is working on a method for checking pan warping. An update was given at the Annual meeting.

Dave Anderson has an apparatus that was built and has a working group of volunteers who will be participating in a round robin.

Task Force 16-C:

Review contradictory statements in Section 12.1 and X1.8.1 regarding the linear region in T315 and consider revision to current guidance in standard. Members: Asphalt Institute (Mike Anderson), Virginia (Bill Bailey), Nevada (Charlie Pan), John D’Angelo (Consultant), Kathy Sokol.

Post meeting Charlie (NV) proposed correction language to T 315 to resolve this conflict. Other members of the task force agreed with the proposal. This standard with the revised language will be submitted for a TS ballot.

Task Force 17-A:

Precision and bias for T 350. Multiple Stress Creep Recovery and several other standards (T 240, Rolling Thin Film Oven Test; T 313, Bending Beam Rheometer; T 315, Dynamic Shear Rheometer; T 316, Rotational Viscosity). Members: Joe DeVol (WA) will lead the effort. Matthew Corrigan (FHWA), Bob Horan (Asphalt Institute), John Malusky (AASHTO re:source), Maria Knake (AASHTO), Bill Bailey (VA), and Lyndi Blackburn (AL).

COMP Ballot items for all except T 240.

Sunset this TF. T240 will continue to be worked on separately.

Task Force 17-01:

This task force was formed to re-write T 228 which is currently a “C” standard. Task Force members are Leslie White (Montana), Maria Knake (AASHTO), and Georgene Geary (AASHTO Consultant).

See TS Ballot with Pennsylvania Negative. This ballot is being harmonized with D 70 to remember to check on the status of this effort.

Task Force 17-02:

This task force was formed to look at developing a new standard for long term aging, the determination of ΔT_c and a practice explaining how to use ΔT_c . Task Force members are Lyndi Blackburn (AL), Chris Peoples (NC), Anne Holt (ON), Tim Ruelke (FL), Rick Bradbury (ME), Brett Haggerty (TX), Bob Horan (Asphalt Institute), Denis Boisvert (NH), Jack Youtchef (FHWA), and Matt Corrigan (ETG liaison).

VI. New Business

A. Research Proposals

1. Accepting research proposals that will be covered at the annual meeting.

B. AASHTO Re:source/CCRL/NTPEP - Observations from Assessments, as applicable?

1. NTPEP is getting an asphalt binder group together. There needs to be buy-in from all of the regions to make it a truly national proposal.
2. The RNS submitted by the TS regarding the issues of mercury in-glass thermometers was accepted for 20-07 funding. So, this work is underway.

C. NCHRP Issues

NCHRP Project 20-07 / Task 400 – Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder

Report (**Attachment B**) is complete and was forwarded to the TS. The Chair sent the report out to the folks with the Rocky Mountain User Producer Group and to the WAQTC.

Both groups are looking into the report and will get back to Lyndi – these groups are most likely to be impacted by elevation. The researcher makes 2 recommendations for implementation: 1) don't modify T240 and the effect of ILS will be accounted for in the statistical analysis. Each state would need to adopt their own dispute resolution procedures. 2) Modify T240 and include the adjustments for differences in elevation. (details are in the attachment).

If your state has an opinion on this or has questions, please email Lyndi and Barry. If there are a lot of questions we could have a conference call to try to answer/resolve some of them.

D. Correspondence, calls, meetings

- Development of AASHTO/ASTM Harmonization Task Force for Asphalt
Maria Knake
Minutes of Initial meeting are included as **Attachment C**.
This effort has worked really well on the cement side. The process for developing the harmonization TF in cement was shared along with lessons learned. The group is looking for technical experts to help with this effort (email Maria, Casey, or Lyndi if you want to get involved!)
- Email from Karl Zipf concerning R92
One of Karl's suppliers pointed out on the new R-92, 4.2 and 7.3.1 that the equation of the curve is missing from the standard.
The equation is missing! There will be a ballot coming out with this resolution.
This item was resolved after the meeting – the document in the Materials Library had the equation and was correct. The document supplied to Karl via email was incorrect.

E. Presentation by Industry/Academia

- Dr. Pavel Kriz with ExxonMobil
Asphalt Institute task force on improving a highly variable DSR test performed at intermediate temperature on PAV residue. Specifically looking into the test standard documented in AASHTO T315 and the validity of specification limits of 5000 kPa and of 6000 kPa documented in M320 and M332, respectively.
Dr. Pavel Kriz presented this work and the presentation is included as **Attachment D**. A Task Force was formed with the following members: WS, WA, TN.

F. Revisions/Work on Standards for Coming Year

Chair will send these standards out to states for review.

1. R 028-12(2016), "Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)" - CO

2. T 314-12(2016), "Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)" - MA
3. TP 101-12(2018), "Estimating Fatigue Resistance of Asphalt Binders Using the Linear Amplitude Sweep" – Must Drop Category
4. TP 113-15(2019), "Determination of Asphalt Binder Resistance to Ductile Failure Using Double-Edge-Notched Tension (DENT) Test" - ON
5. TP 122-16(2018), "Determination of Performance Grade of Physically Aged Asphalt Binder Using Extended Bending Beam Rheometer (EBBR) Method"
6. TP 123-16(2018), "Measuring Asphalt Binder Yield Energy and Elastic Recovery Using the Dynamic Shear Rheometer"
7. TP 127-17(2019), "Determining the Fracture Energy Density of Asphalt Binder Using the Binder Fracture Energy (BFE) Test" – FL

G. Proposed New Standards

1. Permission forms for drawings/photos

H. Proposed New Task Forces

Task Force 19-01:

WS (Barry Paye), WA (Joe DeVol), and TN (Matt Chandler) volunteered to be members of this task force. This TF is formed to examine the short term/long term effects of the proposal by the AI Task Force looking at the DSR-PAV variability and considering the possibility of adding a phase angle limit in M 320 and M 332.

I. New TS Ballots?

- Determination of REOB using XRF – submitted by Terry Arnold, FHWA Turner Fairbank
- M332 to delete confusing language in footnote g
- T 383 clarification (3 plate vs 1 plate)
- T 111 after ON submits revisions
- Potential ballot for T 228 (depending on ongoing work)
- T 240 may have a ballot depending on how states feel about results of elevation
- T 315 with language as proposed by the Task Force to resolve the existing conflict.

J. Technical Subcommittee membership

VII. Open Discussion

None

VIII. Adjourn

Attachments:

- A** – M 332 Proposed ballot item to delete confusing footnote g language.
B – NCHRP Project 20-07 / Task 400 – Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder Report.
C – Minutes of Initial meeting for the development of an AASHTO/ASTM Harmonization Task Force for Asphalt.
D – Presentation by Dr. Pavel Kriz

Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test

AASHTO Designation: M 332-18¹

Technical Section: 2b, Liquid Asphalt

Release: Group 3 (August)



**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Table 1—Performance-Graded Asphalt Binder Specification^a

Performance Grade	PG 46			PG 52							PG 58				
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40
Average 7-day max pavement design temp, °C ^b	<46			<52							<58				
Min pavement design temp, °C ^b	>-34	>-40	>-46	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40
Original Binder															
Flash point temp, T 48, min °C	230														
Viscosity, T 316: ^c max 3 Pa•s, test temp, °C	135														
Dynamic shear, T 315: ^d G*/sinδ, min 1.00 kPa ^e test temp @ 10 rad/s, °C	46			52							58				
Rolling Thin-Film Oven Residue (T 240)															
Mass change, max, percent ^f	1.00														
MSCR, T 350: Standard Traffic “S” <i>J</i> _{nr3.2} , max 4.5 kPa ⁻¹ <i>J</i> _{nr diff} , max 75% ^g test temp, °C	46			52							58				
MSCR, T 350: Heavy Traffic “H” <i>J</i> _{nr3.2} , max 2.0 kPa ⁻¹ <i>J</i> _{nr diff} , max 75% ^g test temp, °C	46			52							58				
MSCR, T 350: Very Heavy Traffic “V” <i>J</i> _{nr3.2} , max 1.0 kPa ⁻¹ <i>J</i> _{nr diff} , max 75% ^g test temp, °C	46			52							58				
MSCR, T 350: Extremely Heavy Traffic “E” <i>J</i> _{nr3.2} , max 0.5 kPa ⁻¹ test temp, °C	46			52							58				
Pressurized Aging Vessel Residue (R 28)															
PAV aging temp, °C ^{h-}	90			90							100				
Dynamic shear, T 315: “S” G* sinδ, max 5000 kPa ^e test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13
Dynamic shear, T 315: “H,” “V,” “E” G* sinδ, max 6000 kPa ^e test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13
Creep stiffness, T 313: ⁱ⁻ <i>S</i> , max 300 MPa <i>m</i> -value, min 0.300 test temp @ 60 s, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30
Direct tension, T 314: ⁱ⁻ Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30

^a MSCR testing on RTFO residue should be performed at the PG grade based on the environmental high pavement temperature. Grade bumping is accomplished by requiring a lower J_{nr} value while testing at the environmental temperature.

^b Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35, excluding the provisions for “grade bumping.”

^c This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^d For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

^e G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

^f The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^g The $J_{nr diff}$ requirement shall not apply to asphalt binders having a $J_{nr3.2}$ value of 0.5 kPa⁻¹ or lower at the selected test temperature. Waiving $J_{nr diff}$ is intended for binders with J_{nr} less than 0.5. For each grade the J_{nr} requirement is a maximum value. A binder that has a J_{nr} of 0.4 may be supplied as a E grade, and may also be supplied as a V, H, or S grade as well.

^{h-} The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

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.

Continued on next page.

Table 1—Performance-Graded Asphalt Binder Specification^a (Continued)

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					
Min pavement design temp, °C ^b	>−10	>−16	>−22	>−28	>−34	>−40	>−10	>−16	>−22	>−28	>−34	>−40
Original Binder												
Flash point temp, T 48, min °C	230											
Viscosity, T 316: ^c max 3 Pa•s, test temp, °C	135											
Dynamic shear, T 315: ^d G*/sinδ, min 1.00 kPa ^e test temp @ 10 rad/s, °C	64						70					
Rolling Thin-Film Oven Residue (T 240)												
Mass change, max, percent ^f	1.00											
MSCR, T 350: Standard Traffic “S” <i>J</i> _{nr3.2} , max 4.5 kPa ^{−1} <i>J</i> _{nr diff} , max 75% ^g test temp, °C	64						70					
MSCR, T 350: Heavy Traffic “H” <i>J</i> _{nr3.2} , max 2.0 kPa ^{−1} <i>J</i> _{nr diff} , max 75% ^g test temp, °C	64						70					
MSCR, T 350: Very Heavy Traffic “V” <i>J</i> _{nr3.2} , max 1.0 kPa ^{−1} <i>J</i> _{nr diff} , max 75% ^g test temp, °C	64						70					
MSCR, T 350: Extremely Heavy Traffic “E” <i>J</i> _{nr3.2} , max 0.5 kPa ^{−1} test temp, °C	64						70					
Pressurized Aging Vessel Residue (R 28)												
PAV aging temp, °C ^h	100						100 (110)					
Dynamic shear, T 315: “S” G* sinδ, max 5000 kPa ^e test temp @ 10 rad/s, °C	31	28	25	22	19	16	34	31	28	25	22	19
Dynamic shear, T 315: “H,” “V,” “E” G* sinδ, max 6000 kPa ^e test temp @ 10 rad/s, °C	31	28	25	22	19	16	34	31	28	25	22	19
Creep stiffness, T 313: ⁱ <i>S</i> , max 300 MPa <i>m</i> -value, min 0.300 test temp @ 60 s, °C	0	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	−30
Direct tension, T 314: ⁱ Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	0	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	−30

^a MSCR test on RTFO residue should be performed at the PG grade based on the environmental high pavement temperature. Grade bumping is accomplished by requiring a lower J_{nr} value while testing at the environmental temperature.

^b Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35, excluding the provisions for “grade bumping.”

^c This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^d For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

^e G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

^f The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^g The $J_{nr diff}$ requirement shall not apply to asphalt binders having a $J_{nr3.2}$ value of 0.5 kPa^{−1} or lower at the selected test temperature. Waiving $J_{nr diff}$ is intended for binders with J_{nr} less than 0.5. For each grade the J_{nr} requirement is a maximum value. A binder that has a J_{nr} of 0.4 may be supplied as a E grade, and may also be supplied as a V, H, or S grade as well.

^h The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

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.

Continued on next page.

Table 1—Performance-Graded Asphalt Binder Specification^a (Continued)

Performance Grade	PG 76					PG 82				
	10	16	22	28	34	10	16	22	28	34
Average 7-day max pavement design temp, °C ^b	<76					<82				
Min pavement design temp, °C ^b	>−10	>−16	>−22	>−28	>−34	>−10	>−16	>−22	>−28	>−34
Original Binder										
Flash point temp, T 48, min°C	230									
Viscosity, T 316: ^c max 3 Pa•s, test temp, °C	135									
Dynamic shear, T 315: ^d G*/sin δ, min 1.00 kPa ^e test temp @ 10 rad/s, °C	76					82				
Rolling Thin-Film Oven Residue (T 240)										
Mass change, max, percent ^f	1.00									
MSCR, T 350: Standard Traffic “S” <i>J</i> _{nr3.2} , max 4.5 kPa ^{−1} <i>J</i> _{nr diff} , max 75% ^g test temp, °C	76					82				
MSCR, T 350: Heavy Traffic “H” <i>J</i> _{nr3.2} , max 2.0 kPa ^{−1} <i>J</i> _{nr diff} , max 75% ^g test temp, °C	76					82				
MSCR, T 350: Very Heavy Traffic “V” <i>J</i> _{nr3.2} , max 1.0 kPa ^{−1} <i>J</i> _{nr diff} , max 75% ^g test temp, °C	76					82				
MSCR, T 350: Extremely Heavy Traffic “E” <i>J</i> _{nr3.2} , max 0.5 kPa ^{−1} test temp, °C	76					82				
Pressurized Aging Vessel Residue (R 28)										
PAV aging temp, °C ^h	100 (110)					100 (110)				
Dynamic shear, T 315: “S” G* sinδ, max 5000 kPa ^e test temp @ 10 rad/s, °C	37	34	31	28	25	40	37	34	31	28
Dynamic shear, T 315: “H,” “V,” “E” G* sinδ, max 6000 kPa ^e test temp @ 10 rad/s, °C	37	34	31	28	25	40	37	34	31	28
Creep stiffness, T 313: ⁱ <i>S</i> , max 300 MPa <i>m</i> -value, min 0.300 test temp @ 60 s, °C	0	−6	−12	−18	−24	0	−6	−12	−18	−24
Direct tension, T 314: ^j Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	0	−6	−12	−18	−24	0	−6	−12	−18	−24

^a MSCR test on RTFO residue should be performed at the PG grade based on the environmental high pavement temperature. Grade bumping is accomplished by requiring a lower J_{nr} value while testing at the environmental temperature.

^b Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35, excluding the provisions for “grade bumping.”

^c This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^d For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

^e G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

^f The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^g The $J_{nr diff}$ requirement shall not apply to asphalt binders having a $J_{nr3.2}$ value of 0.5 kPa^{−1} or lower at the selected test temperature. Waiving $J_{nr diff}$ is intended for binders with J_{nr} less than 0.5. For each grade the J_{nr} requirement is a maximum value. A binder that has a J_{nr} of 0.4 may be supplied as a E grade, and may also be supplied as a V, H, or S grade as well.

^h The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

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.

**NCHRP Project 20-07 / Task 400
Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder**

Revised Final Report

**Prepared for
National Cooperative Highway Research Program
Transportation Research Board**

of

The National Academies of Sciences, Engineering and Medicine

**TRANSPORTATION RESEARCH BOARD OF
THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING
AND MEDICINE
PRIVILEGED DOCUMENT**

This document, not released for publication, is furnished only for review to members of or participants in the work of CRP. This document is to be regarded as fully privileged and dissemination of the information included herein must be approved by CRP

by

**Advanced Asphalt Technologies, LLC
40 Commerce Circle
Kearneysville, WV 25430
December, 2018**

Permission to use any unoriginal material has been obtained from all copyright holders as needed.

Acknowledgement of Sponsorship

This work was sponsored by the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine.

Disclaimer

This is an uncorrected draft as submitted by the contractor. The opinions and conclusions expressed or implied herein are those of the contractor. They are not necessarily those of the Transportation Research Board, the Academies, or the program sponsors.

Table of Contents

Table of Contents.....	i
Table of Figures	iii
Table of Tables.....	iv
ABSTRACT.....	V
SUMMARY.....	1
CHAPTER 1 BACKGROUND.....	3
Problem.....	3
Rolling Thin Film Oven Test (RTFOT) Conditioning	3
Expected Elevation Effects.....	4
Observed Elevation Effects	5
Objective and Scope	5
CHAPTER 2 RESEARCH APPROACH.....	6
Introduction.....	6
Analysis of Available Data.....	6
Data Sources	6
Elevation Versus Barometric Pressure.....	6
Statistical Analysis.....	7
Engineering Analysis	13
RTFOT Conditioning Time Experiment	15
Methods to Account for the Elevation Effect	15
Effect of Binder Properties on Elevation Effect.....	15
Vary RTFOT Operating Parameters With Elevation.....	15
Theoretical Estimate of Additional RTFOT Conditioning Time.....	19
Experimental Design	20
Background	20
Basic Experimental Design	21
Binders	21
Laboratory Testing	21
CHAPTER 3 FINDINGS AND APPLICATION.....	24
Introduction.....	24
Analysis of Rheological Property Data	24
Graphical Analysis	24

Statistical Analysis	24
Outlier Analysis.....	25
Initial Linear Regression Analysis	26
Optimization.....	27
Final Linear Regression Analysis.....	27
Analysis of Mass Change Data	29
Graphical Analysis	29
Statistical Analysis	29
Application	31
CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS.....	32
Conclusions.....	32
Recommendations for Implementation	32
No Modification of AASHTO T 240	32
Interlaboratory Studies	32
Recommendation for Binder Acceptance	32
Modification of AASHTO T 240.....	33
REFERENCES.....	34
APPENDIX A BINDER GRADING DATA.....	35
APPENDIX B LABORATORY INSTRUCTIONS	37
APPENDIX C RECOMMENDED MODIFICATION TO AASHTO T 240	40

Table of Figures

Figure 1. Results From the SHRP Volatilization Experiment.	4
Figure 2. Reported Barometric Pressure for Reported Elevations.	7
Figure 3. Effect of Elevation on Properties for WCTG Binder 552.	11
Figure 4. Effect of Elevation on Properties for AASHTO Resource Binder 235/236.	12
Figure 5. Engineering Significance of Elevation Effect on AASHTO M 320 High Temperature Performance Grade Criterion.	13
Figure 6. Engineering Significance of Elevation Effect on AASHTO M 332 High Temperature Performance Grade Criteria.	14
Figure 7. Relationship Between 135 °C Viscosity and Elevation Effect.	16
Figure 8. Preliminary RTFOT Conditioning Time Study Results.	18
Figure 9. Graphical Representation of the Experimental Design.	23
Figure 10. Example Graphical Analysis of Rheological Properties.	25
Figure 11. Residuals After Optimization.	28
Figure 12. Mass Change Versus Elevation for Binder B2 and Binder B3.	30
Figure 13. Comparison of Measured and Fitted Mass Change Data for Binders B2 and B3.	31

Table of Tables

Table 1. Summary of Statistical Analysis of Available Data with Outliers Removed.	9
Table 2. Summary of Significant Elevation Effects.....	10
Table 3. Summary of $G^*/\sin\delta$ Elevation Effects from Various Studies.	10
Table 4. Summary of Elevation Effect by AASHTO M 332 Traffic Level.....	14
Table 5. Summary of Preliminary RTFOT Conditioning Time Study Results.....	17
Table 6. Estimate of Additional Conditioning Time for AASHTO Resource Binders.....	19
Table 7. Estimated Equivalent RTFOT Conditioning Times Using Carbonyl Model.....	20
Table 8. Participating Laboratories, Elevations, and RTFOT Conditioning Times.....	22
Table 9. Binders Used in RTFOT Conditioning Time Experiment.	23
Table 10. Rheological Property Outliers.....	26
Table 11. Summary of Initial Linear Regression.....	26
Table 12. Summary of Elevation Adjustment Time Optimization.	27
Table 13. Summary of Final Linear Regression.	29
Table 14. Summary of Mass Change Model.....	30

Abstract

This report documents research conducted to investigate the effect of elevation on the properties of residue and mass change measurements from AASHTO T 240. The research included: (1) evaluation of proficiency sample test results to determine the magnitude and significance of the elevation effect, (2) identification and assessment of methods to minimize the elevation effect, (3) design and execution of a laboratory experiment to adjust the conditioning time in AASHTO T 240 as a function of elevation to minimize the elevation effect, and (4) recommendation of modifications to AASHTO T 240 to implement the findings of the research. The primary conclusion drawn from the research is laboratory elevation affects both the rheological properties of the residue and the mass change for asphalt binders conditioned in accordance with AASHTO T 240. It is possible to approximately account for the effect of elevation by increasing the conditioning time as a function of elevation and applying a mass change adjustment.

SUMMARY

Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder

This report documents research conducted by the National Cooperative Highway Research Program to investigate the effect of elevation on the properties of residue and mass change measurements from AASHTO T 240, *Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)*. For tests on AASHTO T 240 residue, laboratories at higher elevations report lower AASHTO M 320 $G^*/\sin\delta$ values, lower AASHTO M 332 recovery values, and higher AASHTO M 332 nonrecoverable compliance (J_{NR}) values compared to laboratories at lower elevation. The prevailing theory is that the lower oxygen content per unit volume of air available at higher elevations results in reduced oxidative aging of the asphalt binder during AASHTO T 240 conditioning. This elevation effect can lead to poor reproducibility between laboratories at different elevations and different conclusions being drawn concerning the acceptability of the same binder under AASHTO M 320 and AASHTO M 332 when tested at different elevations.

The research documented in this report included: (1) evaluation of proficiency sample test results obtained from the Western Cooperative Testing Group and AASHTO re:source to determine the magnitude and significance of the elevation effect, (2) identification and assessment of methods to minimize the elevation effect, (3) design and execution of a laboratory experiment to adjust the conditioning time in AASHTO T 240 as a function of elevation to minimize the elevation effect, and (4) recommendation of modifications to AASHTO T 240 to implement the findings of the research.

The primary conclusion drawn from analysis of the proficiency sample data and the experiment conducted in this project is laboratory elevation affects both the rheological properties of the residue and the mass change for asphalt binders conditioned in accordance with AASHTO T 240. It is possible to approximately account for the effect of elevation on the rheological properties of the residue by increasing the conditioning one minute for every 1,000 ft increase in elevation. When this conditioning time adjustment is applied, 0.006 percent should be added to the resulting mass change for every 1,000 increase in elevation.

The research produced two recommendations. First to address poor reproducibility between laboratories at different elevations in interlaboratory studies, it was recommended that the statistical analysis of the interlaboratory study data should consider the elevation effect. This can be accomplished by regressing the data against elevation. If the elevation effect is significant, then the standardized residuals (residuals divided by the standard deviation of the residuals) should be used to rate the performance of each laboratory on the same scale that is currently used based on standard deviation. If the elevation effect is not significant, then the analysis can be performed in the usual manner using the standard deviation to rate the performance of each laboratory. Second to address the possibility of different conclusions being drawn concerning the acceptability of the same binder under AASHTO M 320 and AASHTO M 332 when tested at different elevations, it was recommended that when a producer's laboratory is 1,000 ft or more below the elevation of the acceptance laboratory, agencies should consider directing the producer to use the conditioning time and mass change adjustments developed in this study. For this application, the conditioning time in the

producer's laboratory at a lower elevation should be decreased by one minute for every 1,000 ft rounded to the nearest minute, and the resulting mass change should be decreased by 0.006 percent for every 1,000 ft.

CHAPTER 1

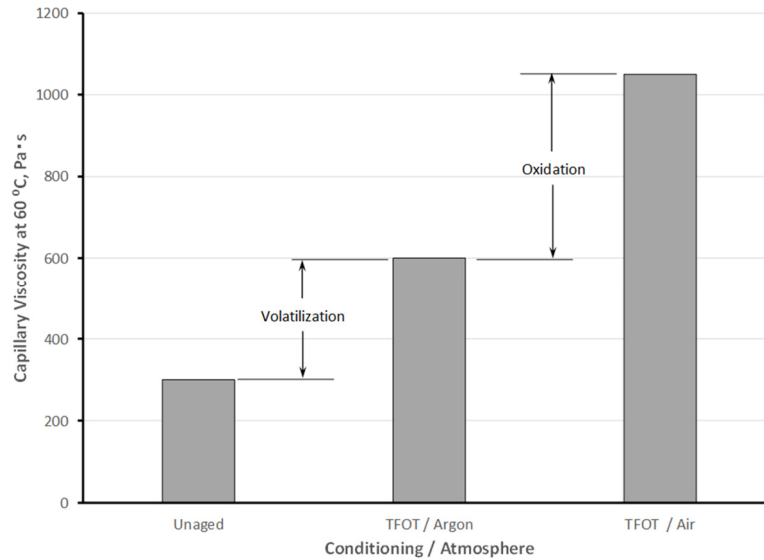
Background

Problem

To simulate the aging that occurs during construction, the specifications for performance graded (PG) asphalt binder, AASHTO M 320, *Standard Specification for Performance-Graded Asphalt Binder*, and AASHTO M 332, *Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test*, include criteria for tests on residue from AASHTO T 240, *Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)*. For tests on AASHTO T 240 residue, laboratories at higher elevations report lower AASHTO M 320 $G^*/\sin\delta$ values, lower AASHTO M 332 recovery values, and higher AASHTO M 332 nonrecoverable compliance (J_{NR}) values compared to laboratories at lower elevation. The prevailing theory is that the lower oxygen content per unit volume of air available at higher elevations results in reduced oxidative aging of the asphalt binder during AASHTO T 240 conditioning. This elevation effect can lead to poor reproducibility between laboratories at different elevations and different conclusions being drawn concerning the acceptability of the same binder under AASHTO M 320 and AASHTO M 332 when tested at different elevations. A recent study by the Modified Asphalt Research Center at the University of Wisconsin-Madison reviewed data from the Western Cooperative Testing Group interlaboratory testing and concluded that the rheological properties of residue from AASHTO T 240 were affected by elevation and that AASHTO T 240 needed refinement to take laboratory elevation into account (Velasquez, et. al., 2013).

Rolling Thin Film Oven Test (RTFOT) Conditioning

During AASHTO T 240 conditioning, two processes change the properties of asphalt binders: (1) volatile loss, and (2) oxidation (Anderson et al., 1994). Both processes increase the stiffness of asphalt binders. Figure 1 shows the results of a volatilization experiment for binder AAK-1 conducted during the Strategic Highway Research Program (SHRP) where short-term conditioning was conducted in a Thin Film Oven modified to use different gases (Anderson et al., 1994). Results should be similar for the RTFOT. As labelled on the figure, the difference between unaged and Argon is the increase in viscosity caused by volatilization. And the difference between Argon and Air is the increase in viscosity caused by oxidation. This figure shows both processes are important. The relative contribution of volatilization and oxidation is probably binder dependent.



Source of Data: Anderson, et al., 1994

Figure 1. Results From the SHRP Volatilization Experiment.

Expected Elevation Effects

Atmospheric pressure, which is the force per unit area exerted against a surface by the weight of the air above that surface, decreases with increasing elevation. Equation 1 is the well accepted relationship first published in 1963 for the variation in atmospheric pressure with elevation (Manual of Barometry, 1963). Over the range of elevations of interest for this project, atmospheric pressure, as affected by elevation, varies from about 101.3 kPa (760 mm Hg) at sea level to about 78.2 kPa (609.6 mm Hg) at an elevation of 7,000 ft.

$$p_h = p_o \times (1 - 2.256 \times 10^{-5} \times h)^{5.256} \quad (1)$$

where:

- p_h = air pressure (kPa) at elevation h
- p_o = atmospheric pressure at sea level, 101.325 kPa
- h = elevation above sea level (m)

Equation 1 can be approximated with a linear relationship with an error of no more than 0.66 percent from sea level to 7,000 feet. Based on the linear approximation, atmospheric pressure change is approximately 0.36 kPa per 100 ft (2.8 mm Hg per 100 ft). The typical range in atmospheric pressure expected from daily and seasonal weather changes at any elevation is approximately ± 12.5 mm Hg (Weather Underground, 2017), which is approximately equal to a change in elevation of about ± 450 ft.

The composition of air remains constant up to an elevation of 10 km (33,000 ft) (The Engineering ToolBox, 2016). Therefore, over the range of elevations of interest for this project, the volume composition of air is approximately 78 percent nitrogen, 21 percent oxygen, and 1 percent other gases.

Differences in atmospheric pressure have the potential to affect both volatilization and oxidation. As the atmospheric pressure decreases, the temperature where volatile components are vaporized will decrease, which will increase volatile loss producing a stiffer residue. This effect is captured in the temperature corrections for AASHTO T 48, *Standard Method of Test for Flash and Fire Points by Cleveland Open Cup*, and AASHTO T 78, *Standard Method of Test for Distillation of Cutback Asphalt Products*.

The effect of atmospheric pressure on the concentration of oxygen molecules in the atmosphere, which affects oxidation, is explained by the Ideal Gas Law, Equation 2. For the same volume of air at the same temperature, there are fewer air molecules as the elevation increases and therefore, fewer oxygen molecules available for oxidation. At an elevation of 7,000 ft, atmospheric pressure is approximately 78 percent of that at sea level, so the number of oxygen molecules available for oxidation is 78 percent of that at sea level.

$$pV = nRT \quad (2)$$

where:

p = absolute pressure, N/m²

V = volume, m³

n = number of moles of gas

R = universal gas constant = 8.3145 J/mol K

T = absolute temperature, °K

Observed Elevation Effects

The effect of elevation on the properties of RTFOT residue has been evaluated independently at the Colorado State University (CSU) (Wang, 2013) and the Modified Asphalt Research Center (MARC) (Velasquez, et al., 2013) using data from the Western Cooperative Testing Group (WCTG). These studies concluded that the stiffness of RTFOT residue decreased with increasing elevation, suggesting that the oxidation effect described above is dominant. Neither study included an analysis of mass change measurements. The rates of change in $G^*/\sin\delta$ reported in the two reports range from -0.016 kPa/1,000 ft to -0.108 kPa/1,000 ft; the upper and lower range differ by a factor 6.8. This may be due to several factors including: (1) differences in the oxidation rate for various binders, (2) differences in volatilization for the various binders, (3) between laboratory differences in RTFOT equipment and procedures, and (4) between laboratory differences in dynamic shear rheometer testing. Using the average rate of -0.053 kPa/1,000 ft reported in the MARC study, an elevation difference of 4,000 ft corresponds to an error of approximately 10 percent of the RTFOT $G^*/\sin\delta$ pass/fail criterion of 2.20 kPa. Considering that the range of elevations for laboratories in the United States may be as much as 7,000 ft, the elevation effect appears to be a significant component of the variation of results between laboratories, and for binders produced near the specification limit, may result in different conclusions concerning the acceptability of the binder being drawn by two laboratories at different elevations.

Objective and Scope

AASHTO Technical Subcommittee 2b endorsed this research to further study the effect of elevation on the properties of residue from AASHTO T 240. The objectives of the project were: (1) to confirm or refute previous studies showing an elevation effect on properties of residue from AASHTO T 240, and if there is an elevation effect and it is of engineering significance, then (2) to improve the AASHTO T 240 procedure to minimize differences in physical properties of AASHTO T 240 residue obtained at different elevations. The elevation effect was confirmed through rigorous analysis of data from proficiency sample programs conducted by the WCTG and AASHTO re:source. A laboratory study was then conducted to adjust for the elevation effect by varying the conditioning time as a function of elevation.

CHAPTER 2

Research Approach

Introduction

The research was conducted in two sequential phases. The first phase was a statistical and engineering evaluation of data from proficiency sample programs conducted by the WCTG and AASHTO re:source. This evaluation confirmed that elevation significantly affected the properties of residue from AASHTO T 240. Based on this finding a laboratory study aimed at adjusting for the elevation effect by varying the conditioning time as a function of elevation was designed and executed. This chapter describes the methodology used in the two phases.

Analysis of Available Data

Data Sources

Two independent sets of data measured on RTFOT residue by laboratories at different elevations were used in the statistical analysis:

- **Western Cooperative Testing Group (WCTG) Data.** This data set included data from 11 binders tested by the WCTG. Ten of the 11 binders were modified binders. For this data set, one sample for each of the 11 binders was tested by approximately 40 different laboratories yielding 441 observations. The reported elevation for the laboratories ranged from 12 to 6,720 ft above sea level. The distribution of laboratories was relatively uniform over this elevation range.
- **AASHTO re:source Proficiency Sample Data.** This data set included data from four binders included in the AASHTO re:source proficiency sample testing: Sample 235/236, Sample 239/240, Sample 241/242, and Sample 245/246. Samples 235/236 and 239/240 were neat binders while samples 241/243 and 245/246 were modified binders. This data set included replicate test data from approximately 213 laboratories yielding 1,700 observations. The reported elevation for the laboratories ranged from 0 to 6,295 ft above sea level. This data set is weighted toward laboratories at lower elevation. Approximately 68 percent of the laboratories included in this data set are at elevations below 1,000 ft.

Elevation Versus Barometric Pressure

An important consideration in this project was whether to use elevation or barometric pressure as the basis for evaluating differences in the properties of RTFOT residue and for developing improvements to AASHTO T 240. As discussed above, atmospheric pressure varies with elevation and weather, although the variation caused by weather is significantly smaller. When reporting proficiency sample results, AASHTO re:source and WCTG also collect data on the elevation of the laboratory and the barometric pressure at the time of testing. However, apparently there is confusion amongst participating laboratories over the reporting of barometric pressure data. Some laboratories report barometric pressure corrected to sea level, most likely either from a local weather service or a barometer that corrects to sea level, while other laboratories report the actual barometric pressure at their elevation. This is shown graphically in Figure 2 using data reported for one of the WCTG samples. Plotting the reported barometric pressure as a

function of the reported elevation produces two distinct sets of data. The first set, which varies around the mean atmospheric pressure at sea level of 101.3 kPa, are laboratories reporting barometric pressure corrected to sea level. The second set, which varies around the line representing Equation 1, are laboratories reporting the barometric pressure at their elevation. The second set of data accurately reflect the atmospheric pressure at the elevation of the test. The incorrect reporting of barometric pressure was likely a factor in the MARC elevation study which showed significantly less explained variance when the data were regressed against reported barometric pressure compared to when the data were regressed against reported elevation (Velasquez, et al., 2013).

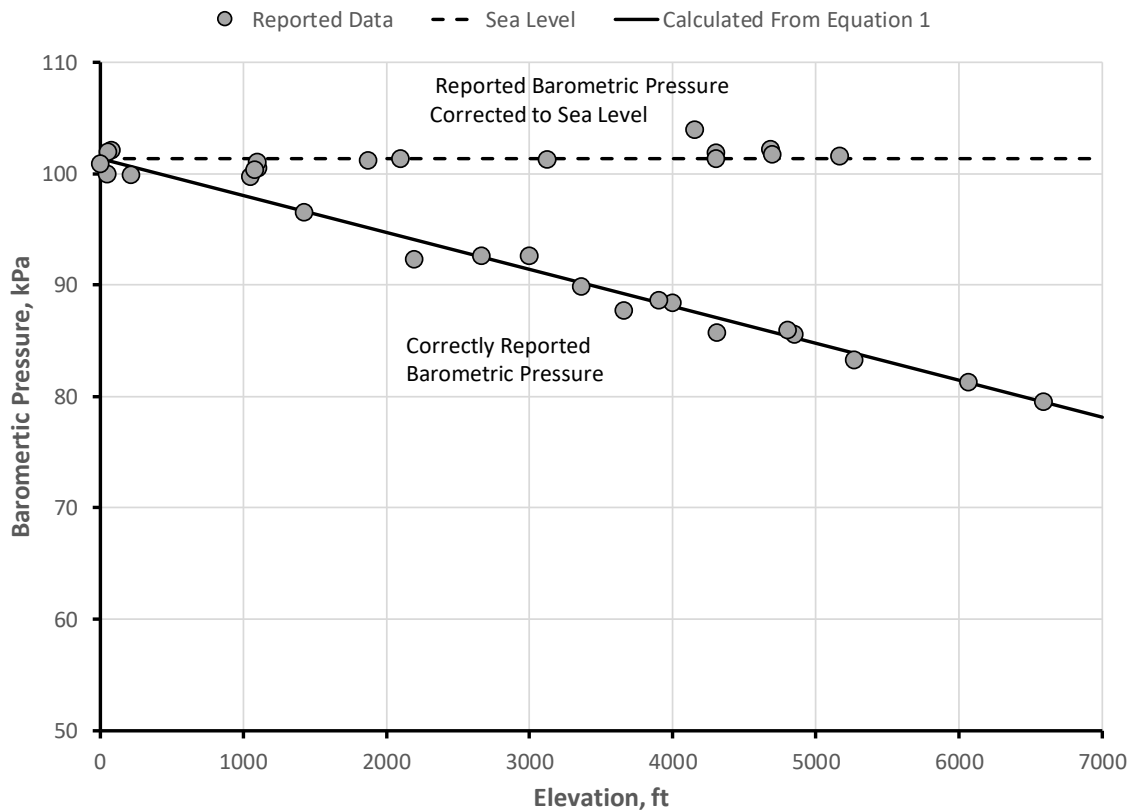


Figure 2. Reported Barometric Pressure for Reported Elevations.

For the analyses conducted during this project and for the improvements to AASHTO T 240 that will be recommended by this project, elevation was selected as the basis for the following reasons:

1. The lack of standardization in the reporting of barometric pressure by laboratories performing materials testing.
2. The pressure changes associated with weather are small compared to the range of elevations for laboratories in the United States; approximately ± 1.7 kPa for weather variations versus approximately 22 kPa for a 7,000 ft elevation difference.
3. The reported elevation for a laboratory is easily verified using on-line mapping tools.

Statistical Analysis

Elevation and six test properties were included in the data for both data sets. The test properties were: (1) Original $G^*/\sin\delta$, (2) RTFOT $G^*/\sin\delta$, (3) Aging Index (ratio of RTFOT $G^*/\sin\delta$ to Original $G^*/\sin\delta$),

(4) Mass Change, (5) RTFOT nonrecoverable compliance, J_{NR} , and (6) RTFOT percent recovery, R . Graphical and statistical analyses were performed separately on each data set for each of the six test properties. The graphical analysis included the preparation of plots as a function of elevation to identify trends in the data and the presence of potential outliers. The statistical analysis included a systemic identification of outliers followed by linear regression analysis. Dummy variables were used to allow the intercept and the slope of the relationship between the property of the RTFOT residue and elevation to vary for the different binders. To identify outliers, linear regression models with different intercepts and different slopes for each binder were prepared and observations with standardized residuals having absolute value greater than 2.5 were flagged as outliers. The final regression analysis was then conducted on the data set after removing the outliers.

Table 1 summarizes the results of the statistical analysis. Linear regression models including the specific binder and elevation as predictors explain 82 to 99 percent of the variance in the data sets. The major difference between this analysis for the WCTG data set and the analyses reported earlier by other researchers is this analysis collectively considers the trends in the data for all binders in the WCTG data set, where earlier analyses by other researchers treated each binder separately. The larger population used in this analysis, approximately 440 compared to approximately 40 used in earlier analyses by other researchers, improves the sensitivity of the statistical analysis. The AASHTO re:source data set includes even more observations. The same conclusions were reached for both data sets.

Table 1 shows there is no elevation effect for the original $G^*/\sin\delta$; however, the elevation effect is statistically significant for all the properties measured after RTFOT conditioning. Further, the elevation effect is binder dependent except for mass change.

Table 2 summarizes the slopes for the elevation effects. These slopes give the change in the respective property per 1,000 ft increase in elevation. The elevation effects for $G^*/\sin\delta$, Aging Index, mass change, and J_{NR} are rational and consistent between the two data sets. RTFOT $G^*/\sin\delta$ and Aging Index, decrease with increasing elevation while J_{NR} increases with increasing elevation due to the pressure dependency of the oxidation reaction. Mass change becomes increasingly negative with elevation due to the greater volatile loss that occurs due to the lower atmospheric pressure at higher elevations. The results for R show positive and negative slopes which may be the result of the effect of changes in oxidation on the polymers in the various modified binders. Note that the three neat binders and nine of the polymer modified binders have negative slope for R resulting in less recovery with increasing elevation which is expected based on the J_{NR} slopes. However, three of the polymer modified binders show an increase in recovery with elevation while the J_{NR} for these binders decreases with elevation.

Figures 3 and 4 show examples of the elevation effects for two of the 15 binders that were analyzed. These binders have slopes near the middle of the ranges in Table 2. The data in these figures have the outliers removed. Figure 3 shows the effects for binder 552 from the WCTG data set which is a polymer modified binder. Figure 4 shows the effects for binder 235/236 from the AASHTO re:source data set which is a neat binder.

Table 3 summarizes and compares the range of the elevation effects for RTFOT $G^*/\sin\delta$ data for the data sets analyzed in this project and those reported in earlier research. Note that different binders were analyzed in this study and the MARC study. The specific binders used in the CSU study were not identified. All three studies concluded that the elevation effect is significant, and Table 3 shows the elevation effect is binder specific, and that there is reasonable agreement from the three studies for the range of the elevation effect.

Table 1. Summary of Statistical Analysis of Available Data with Outliers Removed.

Data Set	Parameter	Observations		Significant Effects			Adj R ² , %	Conclusion
		Total	Outliers Removed	Elev.	Unequal Intercepts	Unequal Slopes		
WCTG	Original G*/sinδ	440	440	No	NA*	NA*	NA*	Elevation effect not significant
	RTFOT G*/sinδ	441	427	Yes	Yes	Yes	93.7	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	Aging Index	440	427	Yes	Yes	Yes	82.4	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	Mass Change	427	402	Yes	Yes	No	90.1	Significant elevation effect. Use model with unequal intercepts and equal slope
	J _{NR}	407	376	Yes	Yes	Yes	96.6	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	% R	400	353	Yes	Yes	Yes	99.0	Significant elevation effect. Use model with unequal intercepts and unequal slopes
AASHTO Resource	Original G*/sinδ	1674	1674	No	NA	NA	NA	Elevation effect not significant
	RTFOT G*/sinδ	1674	1635	Yes	Yes	Yes	92.7	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	Aging Index	1672	1601	Yes	Yes	Yes	89.0	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	Mass Change	1700	1593	Yes	Yes	No	93.8	Significant elevation effect. Use model with unequal intercepts and equal slope
	J _{NR}	1420	1363	Yes	Yes	Yes	82.4	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	% R	1418	1349	Yes	Yes	Yes	98.6	Significant elevation effect. Use model with unequal intercepts and unequal slopes

*NA denotes not applicable

Table 2. Summary of Significant Elevation Effects.

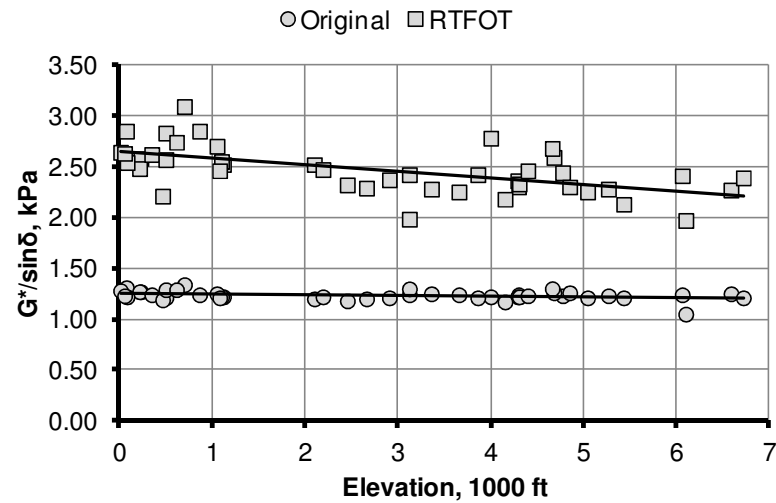
Data Set	Binder	Type*	RTFOT G*/sinδ, kPa/1,000 ft	Aging Index	Mass Change, %/1,000 ft	J _{NR} , kPa ⁻¹ /1,000 ft	% R, %/ 1,000 ft
WCTG	551	P	-0.0615	-0.0354	-0.0033	0.0333	-0.059
	552	P	-0.0641	-0.0427		0.0432	-0.269
	553	P	-0.0239	-0.0146		0.0394	-0.432
	554	P	-0.0173	-0.0136		0.0677	-0.677
	555	N	-0.1149	-0.0740		0.0927	-0.119
	556	P	-0.0496	-0.0251		0.0027	0.010
	557	P	-0.0914	-0.0442		0.0204	-0.546
	560	P	-0.0477	-0.0271		0.0416	-0.415
	561	P	-0.0477	-0.0379		0.0593	-0.282
	562	P	-0.0701	-0.0609		0.0249	0.720
	563	P	-0.0448	-0.0147		0.0076	-0.413
AASHTO Resource	235/236	N	-0.0613	-0.0374	-0.0059	0.0384	-0.094
	239/240	N	-0.0806	-0.0412		0.0470	-0.032
	241/242	P	-0.0302	-0.0233		-0.0002	0.519
	245/246	P	-0.0257	-0.0188		0.0236	-0.300

* N denotes neat binder, P denotes polymer modified binder

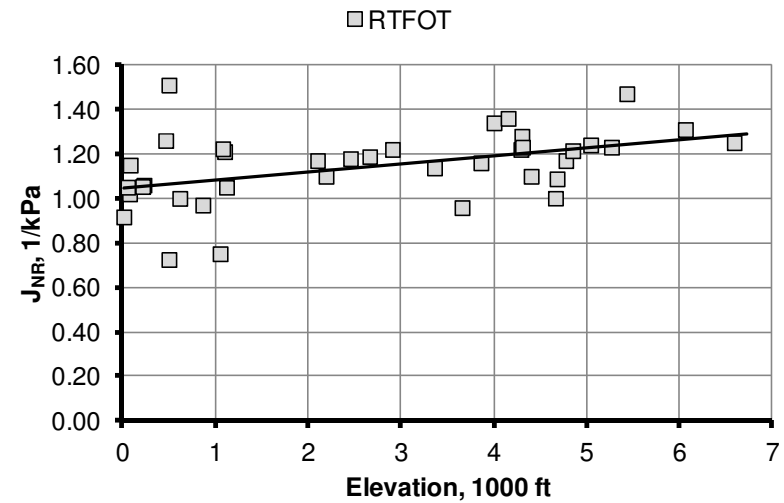
Table 3. Summary of G*/sinδ Elevation Effects from Various Studies.

Study	CSU	MARC	NCHRP 20-7 Task 400	
Source	Unspecified WCTG	WCTG Samples 519 to 532	WCTG Samples 551 to 557 and 560 to 563	AASHTO Samples 235/235, 239/240, 241/242, and 245/246
Binders	7	14	11	4
Smallest Effect, kPa/1000 ft	NS*	NS*	-0.024	-0.026
Largest Effect, kPa/1000 ft	-0.083	-0.108	-0.115	-0.081

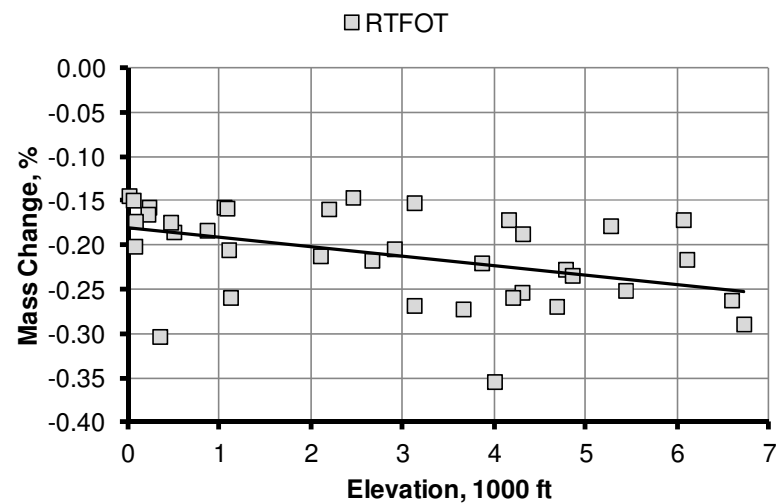
* NS denotes not significant



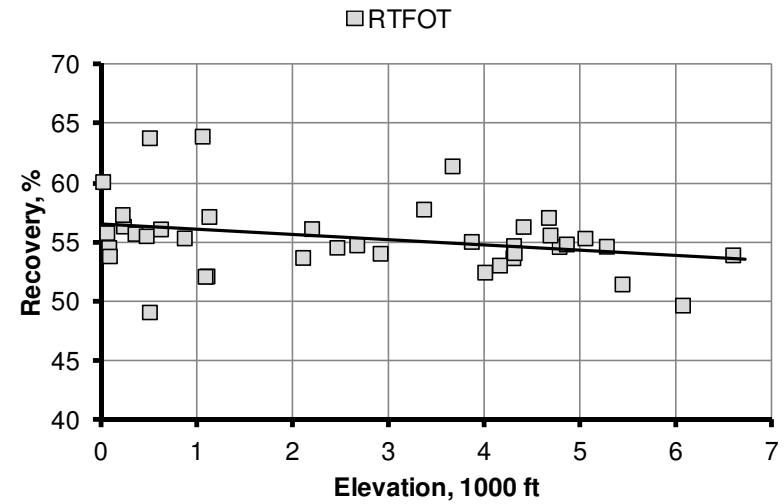
a. Original and RTFOT $G^*/\sin\delta$.



b. J_{NR} .

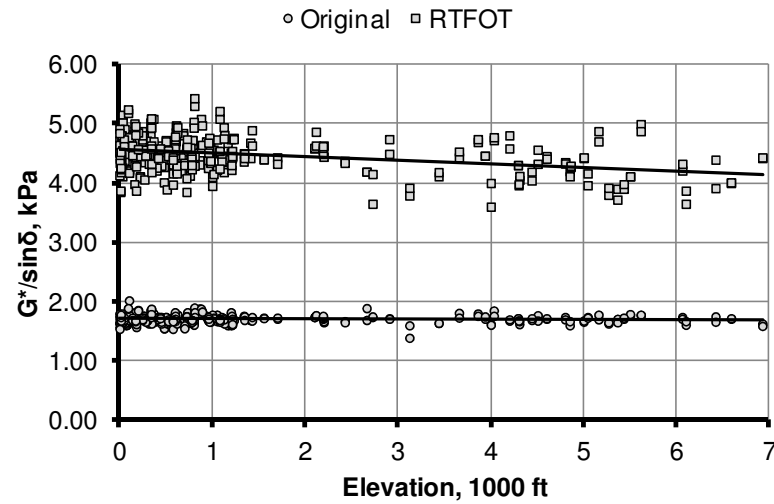


c. Mass Change.

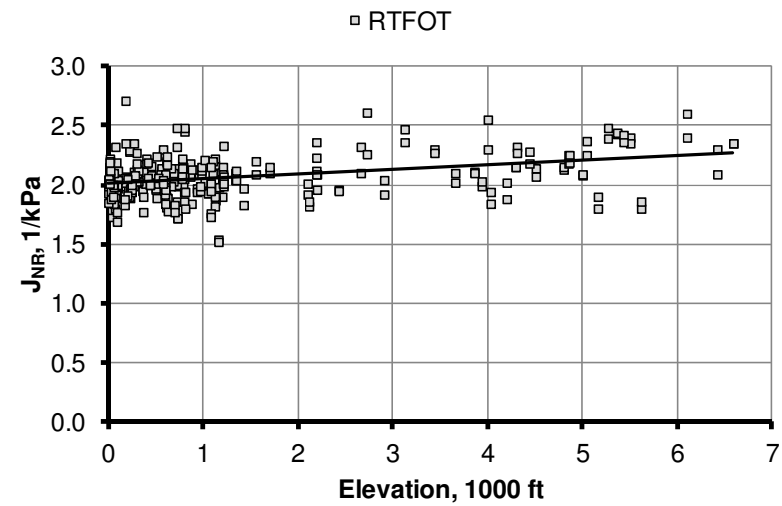


d. %R.

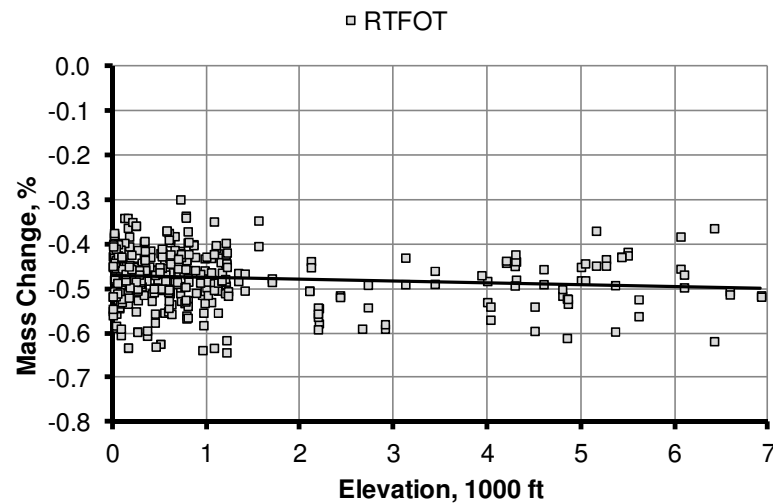
Figure 3. Effect of Elevation on Properties for WCTG Binder 552.



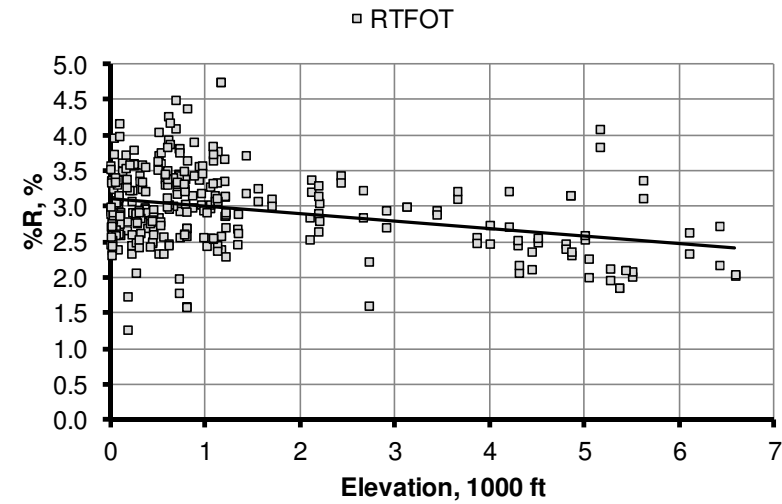
a. Original and RTFOT $G^*/\sin\delta$.



b. J_{NR} .



c. Mass Change.



d. %R.

Figure 4. Effect of Elevation on Properties for AASHTO Resource Binder 235/236.

Engineering Analysis

The analysis presented above showed elevation has a statistically significant effect on data collected after RTFOT conditioning and the effect is rational based on engineering principles. The analyses presented below used the range of the slopes obtained from the statistical analysis to quantify the engineering significance of the elevation effect on AASHTO M 320 and AASHTO M 332 specification criteria.

Figure 5 shows the potential effect of elevation on RTFOT residue $G^*/\sin\delta$ expressed as a percentage of the AASHTO M 320 criterion of 2.20 kPa. The shaded area shows the range of the effect for the 15 binders that were analyzed. At an elevation difference of 4,000 ft, the difference can be as high as 21 percent of 2.20 kPa or 0.46 kPa. This difference has engineering significance. A binder with an acceptable RTFOT $G^*/\sin\delta$ of 2.50 kPa when tested at sea level may have an unacceptable RTFOT $G^*/\sin\delta$ when tested at an elevation of 4,000 ft or higher.

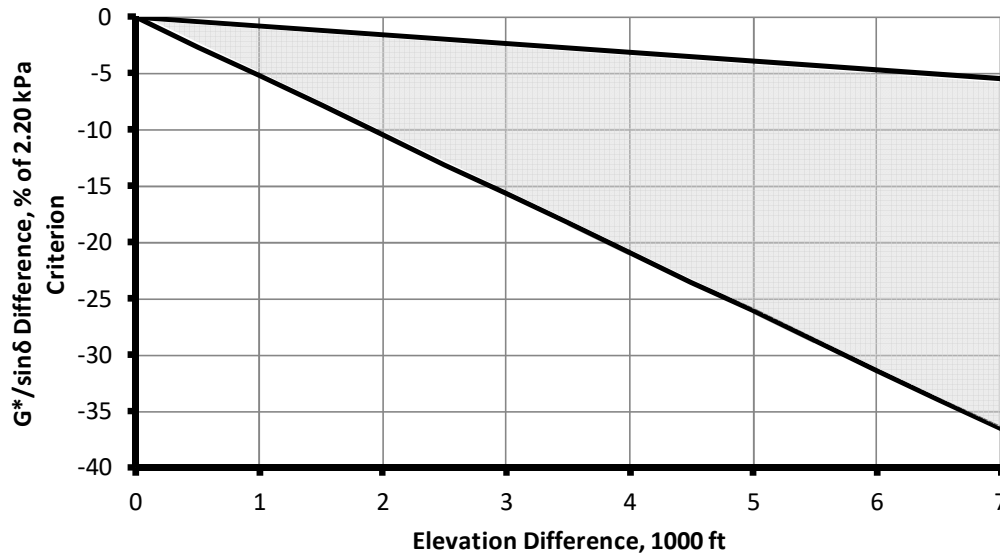


Figure 5. Engineering Significance of Elevation Effect on AASHTO M 320 High Temperature Performance Grade Criterion.

A similar analysis for the AASHTO M 332 high temperature performance grade criteria is somewhat more complicated because the criteria are a function of traffic level as given below:

- $\leq 4.5 \text{ kPa}^{-1}$ for standard traffic
- $\leq 2.0 \text{ kPa}^{-1}$ for heavy traffic
- $\leq 1.0 \text{ kPa}^{-1}$ for very heavy traffic
- $\leq 0.5 \text{ kPa}^{-1}$ for extremely heavy traffic

Also, it appears based on the 15 binders analyzed, that the elevation effect is less for binders meeting higher traffic levels. Table 4 summarizes the range of the elevation effect on J_{NR} for binders meeting different AASHTO M 332 traffic levels. Note that AASHTO re:source proficiency sample binder 245/246 was not included in this analysis because the J_{NR} data for this sample was collected at 12 °C above the pavement temperatures where the binder would be normally be used.

Table 4. Summary of Elevation Effect by AASHTO M 332 Traffic Level.

AASHTO M 332 Traffic Level	Number of Binders	Elevation Effect, kPa-1/1,000 ft	
		Minimum	Maximum
S	4	0.0384	0.0927
H	5	0.0249	0.0677
V	2	0.0006	0.0432
E	2	0.0027	0.0076

Figure 6 shows the potential effect of elevation on RTFOT residue J_{NR} expressed as a percentage of the AASHTO M 332 criteria for the appropriate traffic level for the binder. The shaded area shows the range of the effect for the 13 binders included in the analysis. At an elevation difference of 4,000 ft, the difference can be as high as 17 percent. Although somewhat less than that for $G^*/\sin\delta$, the elevation effect is still significant. A V grade binder with an acceptable J_{NR} of 0.85 kPa⁻¹ when tested at sea level may have an unacceptable J_{NR} when tested at an elevation of 4,000 ft or higher.

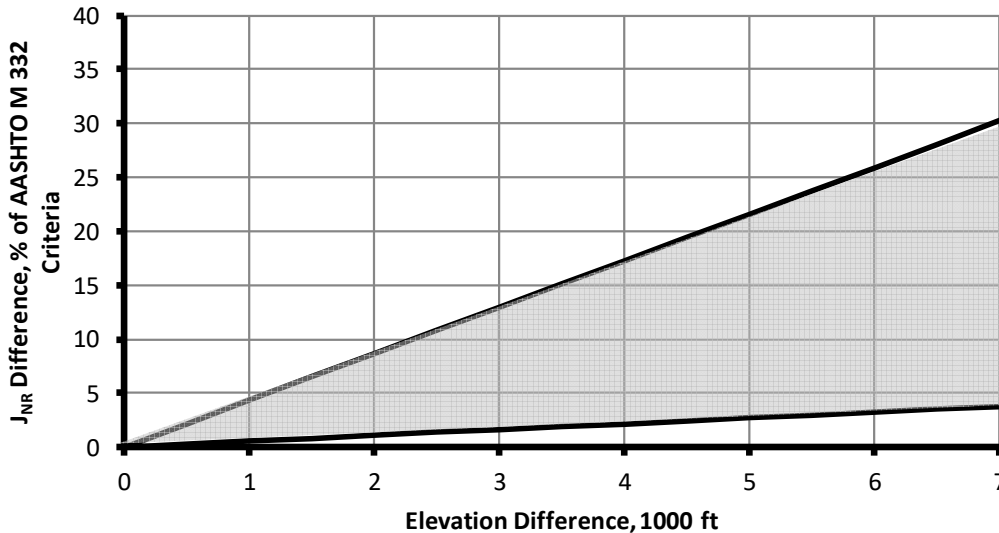


Figure 6. Engineering Significance of Elevation Effect on AASHTO M 332 High Temperature Performance Grade Criteria.

The last specification criteria that was considered was the mass change. Both AASHTO M 320 and AASHTO M 332 limit the mass change from RTFOT conditioning to one percent. The statistical analysis showed the mass change is increasingly negative with a slope ranging from -0.0033 percent per 1,000 ft for the WCTG data set to -0.0060 percent per 1,000 ft for the AASHTO re:source data set. The larger slope from the AASHTO re:source data set yields a difference of -0.042 percent for a 7,000 ft elevation difference. The binders in the data sets analyzed had average mass change ranging from +0.036 to -0.820 percent. Over this range, the elevation effect is not important; however, it may be larger and could be significant for binders that have mass change near the lower limit of -1.000 percent.

RTFOT Conditioning Time Experiment

Methods to Account for the Elevation Effect

The statistical analysis showed that laboratory elevation significantly affects properties measured after RTFOT conditioning, and the engineering analysis showed that the elevation effect is of engineering significance. When conducting interlaboratory or proficiency studies, the elevation effect should be included in the statistical analysis. AASHTO resource, WCTG, and organizations performing interlaboratory studies that include tests on RTFOT residue should consider this additional step when performing data analysis.

For acceptance testing, data from laboratories at different elevations will not generally be available for a specific binder. In this case it is necessary to account for the elevation effect. Three methods to account for the elevation effect were considered:

1. Conduct RTFOT conditioning at a constant pressure.
2. Relate the elevation effect to properties measured on the binder before RTFOT conditioning.
3. Vary the operating parameters of the RTFOT with elevation.

Conducting the RTFOT conditioning at a constant pressure, while technically the most prudent approach, was not pursued because this approach would require significant modification of existing RTFOT equipment. The other two methods were evaluated as discussed below.

Effect of Binder Properties on Elevation Effect

An evaluation was conducted to determine if the binder specific elevation effect for $G^*/\sin\delta$ could be predicted from other properties measured on the original binder during AASHTO M 320 and M 332 testing. The properties that were analyzed included:

1. Rotational viscosity at 135 °C,
2. Original G^* ,
3. Original δ ,
4. Original $G^*/\sin\delta$,
5. Mass change.

The only property that was related to the elevation effect was the 135 °C viscosity as shown in Figure 7. Other properties showed much poorer correlation with the elevation effect. Including other properties with the 135 °C viscosity did not result in significant improvement. The relationship shown in Figure 7 indicates that the sensitivity to elevation decreases with increasing viscosity, which may be the result of stiffer binders aging less during RTFOT conditioning. The relationship in Figure 7 is not sufficiently accurate to adjust tests on RTFOT residue to a common elevation.

Vary RTFOT Operating Parameters With Elevation

Consideration was given to varying three operational parameters for the RTFOT with elevation to account for the elevation effect: (1) test duration, (2) test temperature, and (3) air flow rate. Air flow rate was rejected based on research performed in developing the Modified Rotating German Flask which showed varying air flow had a large effect on mass change with relatively little effect on the stiffness of the conditioned binder (Robertson, et. al., 2001). Test duration was selected over temperature because it will be easier to implement in practice, and initial estimates of additional time based on analysis of data from NCHRP Project 9-36 for the Stirred Air Flow Test were reasonable at about 10 minutes for an elevation of 7,000 ft (Anderson and Bonaquist, 2012).

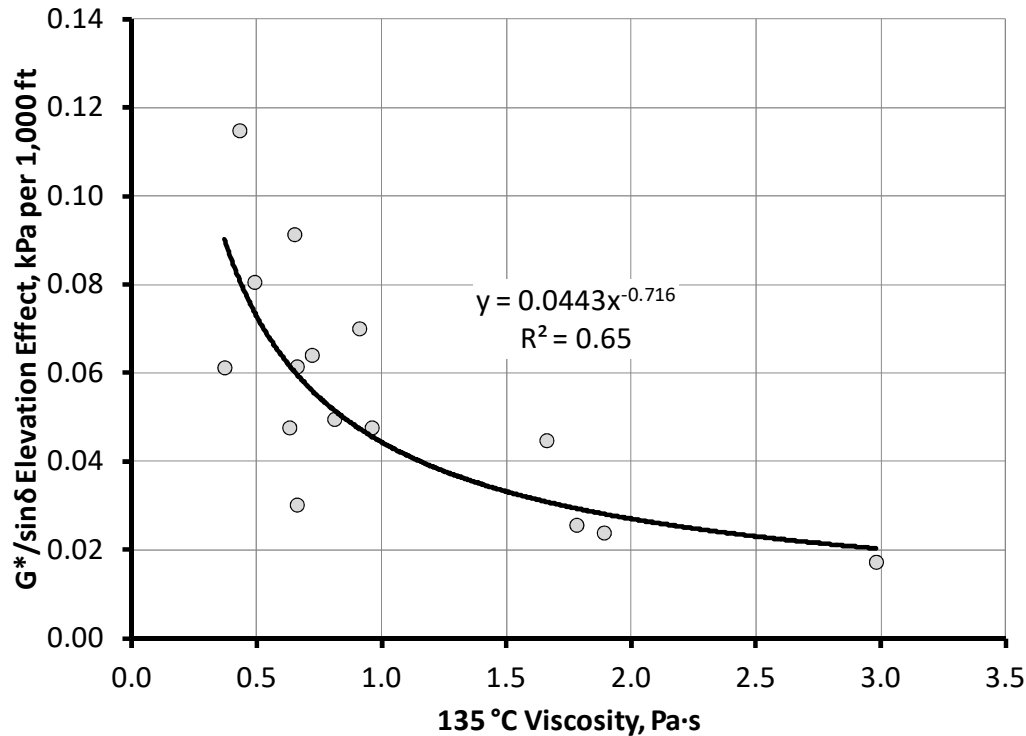


Figure 7. Relationship Between 135 °C Viscosity and Elevation Effect.

A preliminary investigation of the effect of increased RTFOT conditioning time on AASHTO M 320 and M 332 specification properties was conducted early in the project in Advanced Asphalt Technologies, LLC's (AAT's) laboratory which is at an elevation of 552 ft. The hypothesis underlying this work was that binders that are more sensitive to the effect of elevation on their properties would also have properties that are more sensitive to the effect of RTFOT conditioning time. AASHTO M 320 and M 332 specification properties for the four AASHTO re:source proficiency sample binders were measured after conditioning the binders in the RTFOT for 85, 95, 105, and 115 minutes. Replicate tests were conducted for each binder. The results are summarized in Table 5 and presented graphically in Figure 8. Figure 8 includes best fit linear regression lines which show that the RTFOT time effect is approximately linear over the range of conditioning times included in the experiment.

Table 6 summarizes the slopes as a function of RTFOT conditioning time for $G^*/\sin\delta$ and J_{NR} for the binders tested. These slopes are a measure of the sensitivity of the specification properties to conditioning time. Table 6 also includes the slopes of the elevation effect for these binders from Table 2. The ratio of the slopes gives the additional RTFOT conditioning times to provide approximately equivalent rheological properties, which are also summarized in Table 6. Excluding binder 241/242 which had minimal sensitivity of J_{NR} to elevation, the time ranges from 1.4 to 2.4 minutes per 1,000 ft with an average of 1.9. Additional conditioning times to adjust for elevation appear to be somewhat longer for J_{NR} compared to $G^*/\sin\delta$.

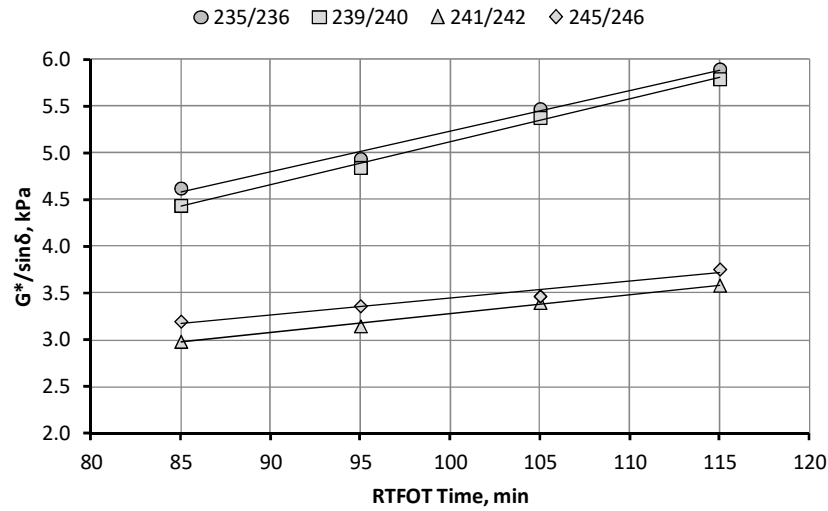
Note that the range of the $G^*/\sin\delta$ effect included in this experiment was from -0.026 to 0.081 kPa/1,000 ft which covered approximately 70 percent of the range of elevation effects summarized in Table 3 from this study and previous studies. The RTFOT time study confirms that those binders that are more sensitive to the elevation effect are also more sensitive to conditioning time. The elevation effect for $G^*/\sin\delta$ in Table 6 varies by a factor of 3, while the estimate of additional conditioning time varies by a factor of only 1.3.

Table 5. Summary of Preliminary RTFOT Conditioning Time Study Results.

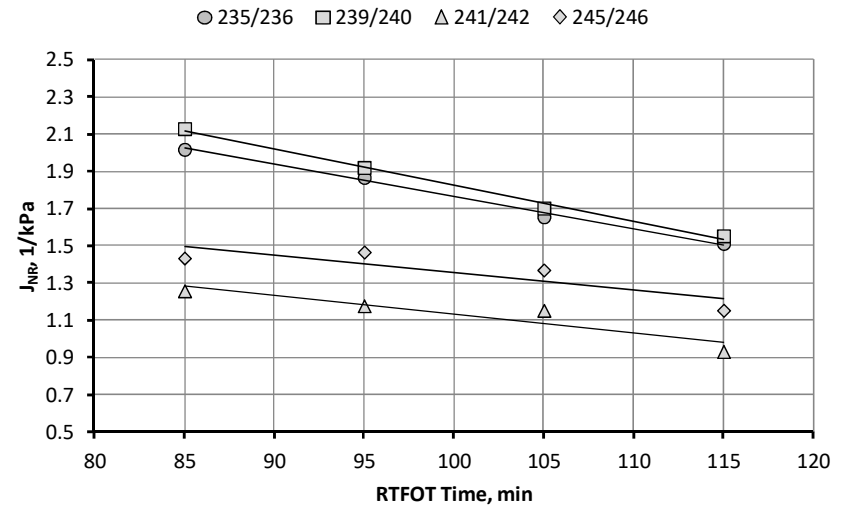
Sample Pairs (Odd/Even)	Time, min	Temp, °C	G*/sinδ, kPa			J _{NR} , 1/kPa			%R, %			Mass Change, %		
			Odd	Even	Avg	Odd	Even	Avg	Odd	Even	Avg	Odd	Even	Avg
235/236	0	58	1.92	1.76	1.84	NT*	NT*	NT*	NT*	NT*	NT*	NA**	NA**	NA**
	85	58	4.44	4.81	4.63	2.15	1.89	2.02	1.2	3.3	2.2	-0.422	-0.438	-0.430
	95	58	4.74	5.14	4.94	1.99	1.74	1.87	1.4	3.9	2.7	-0.460	-0.490	-0.475
	105	58	5.21	5.74	5.48	1.78	1.53	1.66	1.9	4.7	3.3	-0.501	-0.521	-0.511
	115	58	5.63	6.17	5.90	1.64	1.38	1.51	2.3	5.8	4.0	-0.542	-0.525	-0.534
239/240	0	58	1.67	1.88	1.78	NT*	NT*	NT*	NT*	NT*	NT*	NA**	NA**	NA**
	85	58	4.65	4.23	4.44	1.96	2.30	2.13	2.9	1.0	2.0	0.024	0.021	0.023
	95	58	5.13	4.56	4.85	1.73	2.11	1.92	3.7	1.4	2.5	0.026	0.024	0.025
	105	58	5.64	5.12	5.38	1.53	1.88	1.70	4.5	1.8	3.1	0.027	0.025	0.026
	115	58	6.23	5.36	5.80	1.34	1.77	1.55	5.7	2.1	3.9	0.029	0.030	0.029
241/242	0	64	1.51	1.42	1.47	NT*	NT*	NT*	NT*	NT*	NT*	NA**	NA**	NA**
	85	64	3.15	2.82	2.99	1.20	1.31	1.26	47.2	48.8	48.0	-0.329	-0.304	-0.317
	95	64	3.25	3.05	3.15	1.07	1.29	1.18	50.4	47.7	49.1	-0.336	-0.335	-0.336
	105	64	3.50	3.30	3.40	1.04	1.27	1.15	49.0	50.8	49.9	-0.333	-0.348	-0.341
	115	64	3.71	3.46	3.59	0.89	0.98	0.93	52.4	51.7	52.1	-0.403	-0.366	-0.385
245/246	0	76	1.69	1.74	1.72	NT*	NT*	NT*	NT*	NT*	NT*	NA**	NA**	NA**
	85	76	3.20	3.20	3.20	1.40	1.47	1.43	36.2	35.3	35.7	-0.060	-0.059	-0.060
	95	76	3.42	3.31	3.37	1.38	1.55	1.47	36.8	32.1	34.4	-0.070	-0.062	-0.066
	105	76	3.47	3.47	3.47	1.41	1.33	1.37	34.9	33.5	34.2	-0.087	-0.065	-0.076
	115	76	3.80	3.72	3.76	1.08	1.22	1.15	40.7	37.4	39.0	-0.080	-0.049	-0.065

* NT denotes not tested

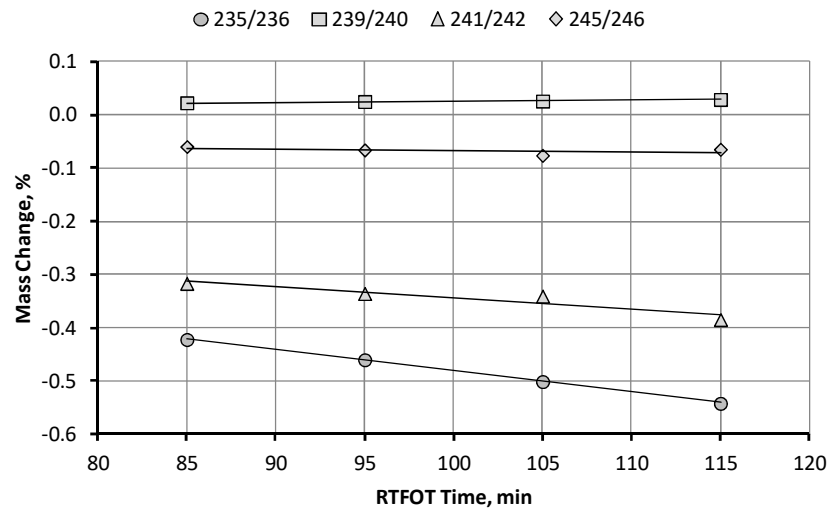
**NA denotes not applicable



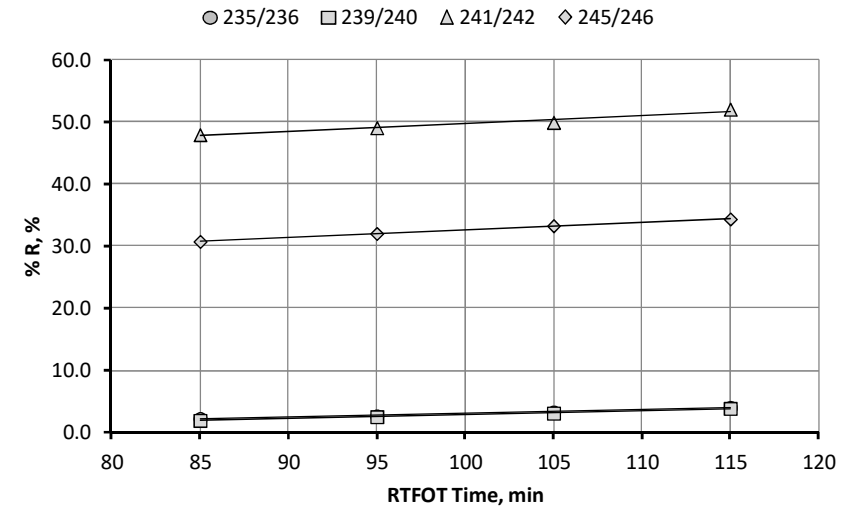
a. $G^*/\sin\delta$.



b. J_{NR} .



c. Mass Change.



d. %R.

Figure 8. Preliminary RTFOT Conditioning Time Study Results.

Table 6. Estimate of Additional Conditioning Time for AASHTO Resource Binders.

Binder	$\Delta G^*/\sin\delta$, kPa/min	$\Delta G^*/\sin\delta$, kPa/1,000 ft	Additional Conditioning Time, Min/1,000 ft	ΔJ_{NR} , kPa ⁻¹ /min	ΔJ_{NR} , kPa ⁻¹ /1,000 ft	Additional Conditioning Time, Min/1,000 ft
235/236	0.0468	-0.0645	1.4	-0.01728	0.0384	2.2
239/240	0.0460	-0.0806	1.8	-0.01946	0.0470	2.4
241/242	0.0217	-0.0296	1.4	-0.01002	0.0006	0.1
245/246	0.0172	-0.0257	1.5	-0.00939	0.0217	2.3

Theoretical Estimate of Additional RTFOT Conditioning Time

A second estimate of the additional RTFOT conditioning time needed at higher elevations was conducted using the kinetic model for carbonyl formation developed by Liu, et. al. (Liu, et. al., 1996) and given in Equation 3. This model only addresses the oxidation effect which is apparently the dominant effect based on the statistical analyses presented earlier.

$$r_{CA} = Ap^{\alpha}e^{\left(\frac{-E}{RT}\right)} \quad (3)$$

where:

r_{CA} = carbonyl formation rate

p = oxygen pressure

T = temperature

R = universal gas constant

A , α , and E are binder dependent fitting constants

Assuming that the rheological properties of a binder depend on the total amount of carbonyl formed, the time required to obtain equal amounts of carbonyl at two elevations when the conditioning is done at the same temperature is given by:

$$(r_{CA})_1 t_1 = (r_{CA})_2 t_2 \quad (4)$$

where:

$(r_{CA})_1$ = carbonyl formation rate at elevation 1

$(r_{CA})_2$ = carbonyl formation rate at elevation 2

t_1 = conditioning time at elevation 1

t_2 = conditioning time at elevation 2

Substituting Equation 3 for r_{CA} in Equation 4 yields:

$$\left[Ap_1^{\alpha}e^{\left(\frac{-E}{RT}\right)} \right] t_1 = \left[Ap_2^{\alpha}e^{\left(\frac{-E}{RT}\right)} \right] t_2 \quad (5)$$

Recalling temperature is constant and for a given binder and A , E , and α are constants, then solving for t_2 yields:

$$t_2 = t_1 \left(\frac{p_1}{p_2} \right)^{\alpha} \quad (6)$$

The ratio of the pressure at elevation h to the pressure at sea level can be determined from Equation 1 resulting in Equation 7

$$\frac{p_0}{p_h} = (1 - 2.526 \times 10^{-5} \times h)^{-5.256} \quad (7)$$

where:

p_h = air pressure (kPa) at elevation h

p_0 = atmospheric pressure at sea level, 101.325 kPa

h = elevation above sea level (m)

Substituting Equation 7 into Equation 6, and using the standard RTFOT condition time of 85 min and sea level as the basis yields the equivalent RTFOT conditioning time at elevation h :

$$t_h = 85 \times (1 - 2.526 \times 10^{-5} \times h)^{-(5.256\alpha)} \quad (8)$$

For 10 different binders, Lui, et al. reported that α varies from 0.25 to 0.61. Table 7 summarizes the range of additional RTFOT conditioning times based on this analysis. Table 7 also shows the time estimated from the testing conducted on the four AASHTO re:source binders during this project. The experimental data are in reasonable agreement with the theoretical analysis from the carbonyl model providing further evidence of the reasonableness of the additional time estimates.

Table 7. Estimated Equivalent RTFOT Conditioning Times Using Carbonyl Model.

Elevation, Ft	Equivalent RTFOT Conditioning Time, min								Experimental
	$\alpha = 0.25$	$\alpha = 0.30$	$\alpha = 0.35$	$\alpha = 0.40$	$\alpha = 0.45$	$\alpha = 0.50$	$\alpha = 0.55$	$\alpha = 0.60$	
0	85	85	85	85	85	85	85	85	85
1000	86	86	86	86	87	87	87	87	87
2000	87	87	87	88	88	89	89	89	89
3000	88	88	89	89	90	90	91	92	91
4000	89	89	90	91	92	92	93	94	93
5000	89	90	91	92	93	94	95	96	95
6000	90	92	93	94	95	96	97	99	96
7000	91	93	94	96	97	98	100	101	98

Experimental Design

Background

The main RTFOT conditioning time experiment was designed to verify the RTFOT conditioning times as a function of elevation presented in Table 7. The experiment was based on the following important considerations from the work described above:

1. The effect of elevation on the properties of RTFOT residue is approximately linear over the range of elevations of laboratories in the United States. For a linear elevation effect, it is important to include laboratories at high and low elevations.
2. The additional RTFOT conditioning time to account for the elevation effect is estimated to be approximately 1.9 min/1,000 ft.
3. The effect of RTFOT conditioning time on the properties of RTFOT residue is approximately linear over the range of conditioning times that will be used in the experiment. This allows testing in each laboratory to be conducted at two conditioning times with results at other conditioning times interpolated with a high level of confidence.

4. The elevation effect is binder specific, with higher viscosity binders generally showing a smaller elevation effect. The experiment must include a range of neat and modified binders with different 135 °C viscosities.

The design of the experiment also considered the following information on the reported repeatability and reproducibility of dynamic shear rheometer (DSR) measurements, and general principles of experimental design:

1. Replication was included by testing in multiple laboratories at similar elevations rather than multiple tests within a single laboratory at a given elevation.
2. The multi-laboratory coefficient of variation in AASHTO T 315 for $G^*/\sin\delta$ for tests on original binder is 6.8 percent compared to 7.8 percent for tests on RTFOT residue. This shows that a significant amount of the variability in tests on RTFOT residue is the result of differences in equipment and laboratory procedures associated with the dynamic shear rheometer measurements rather than the RTFOT conditioning. Therefore, to reduce one component of variability, all physical property measurements were made in one laboratory.
3. Detailed instructions regarding the performance of the RTFOT conditioning were given to the participating laboratories to reduce variability caused by between laboratory differences in the RTFOT conditioning.

Basic Experimental Design

The experiment design uses laboratories at different elevations to condition the binders in the RTFOT. Twenty-five laboratories agreed to perform the RTFOT conditioning. Table 8 summarizes the participating laboratories and their elevations. Table 8 also presents the target conditioning time based on 85 minutes plus 1.9 min/1000 ft elevation rounded to the nearest minute. The experiment design requires each laboratory to condition each binder at the two times listed in the last two columns of Table 8, measure the mass change, and return the conditioned binder to AAT's laboratory for rheological property measurements. The RTFOT time difference of 10 minutes produces a significant difference in the properties measured on RTFOT residue. Figure 9 is a graphical representation of the basic experiment design. The limits shown in Figure 9 are the RTFOT conditioning times that will be used in each laboratory.

Binders

The available funding allowed a total of 8 binders to be included in the experiment. Table 9 shows continuous grading data for the binders included in the experiment. Detailed binder grading data are presented in Appendix A. These binders were selected based on the analysis of the WCTG and AASHTO re:source samples to: (1) cover a wide range of performance grades, (2) include neat and polymer modified binders, (3) exhibit a range of volatile loss, and (4) cover a range of elevation effects. Volatile loss is expected to increase with increasing low temperature grade. The selected binders include low temperature grades of -22, -28, and -34. The analysis of the WCTG and AASHTO re:source data showed that the viscosity of the binder influences the elevation effect with high viscosity, modified binders showing much lower sensitivity to elevation. The selected binders include neat and polymer modified binders at each low temperature grade to provide a range of viscosities.

Laboratory Testing

The analysis presented in Chapter 3 used AASHTO M 320 and M 332 specification properties measured on RTFOT residue. The properties that were measured included: (1) $G^*/\sin\delta$, (2) J_{NR} , (3) % R, and (4) Mass Change. In addition, 135 and 163 °C viscosity data were collected to evaluate the effect of viscosity at the RTFOT conditioning temperature on the elevation effect.

Each laboratory conditioned four bottles for each of the binders in the RTFOT using the two conditioning times listed in Table 8 for the elevation of their laboratory. Two of the bottles were used to measure and report mass change. The residue from the other two bottles was combined and returned to AAT for the rheological testing. Appendix B presents detailed instructions provided to the laboratories performing the RTFOT conditioning. The conditioning required each laboratory to make eight RTFOT runs; two binders were conditioned during each run of the RTFOT. For 8 binders conditioned in 25 laboratories at two conditioning times, the experiment provided 400 mass change measurements and 400 RTFOT residue samples for rheological testing and analysis.

Table 8. Participating Laboratories, Elevations, and RTFOT Conditioning Times.

Laboratory	Elevation, ft	RTFOT Conditioning Times, min		
		Target	Low	High
L1	79	85	80	90
L2	224	85	80	90
L3	517	86	81	91
L4	552	86	81	91
L5	574	86	81	91
L6	622	86	81	91
L7	715	86	81	91
L8	764	86	81	91
L9	938	87	82	92
L10	971	87	82	92
L11	1100	87	82	92
L12	2000	89	84	94
L13	2001	89	84	94
L14	2516	90	85	95
L15	3123	91	86	96
L16	3256	91	86	96
L17	4030	93	88	98
L18	4307	93	88	98
L19	4334	93	88	98
L20	4700	94	89	99
L21	5050	95	90	100
L22	5164	95	90	100
L23	5254	95	90	100
L24	6182	97	92	102
L25	7174	99	94	104

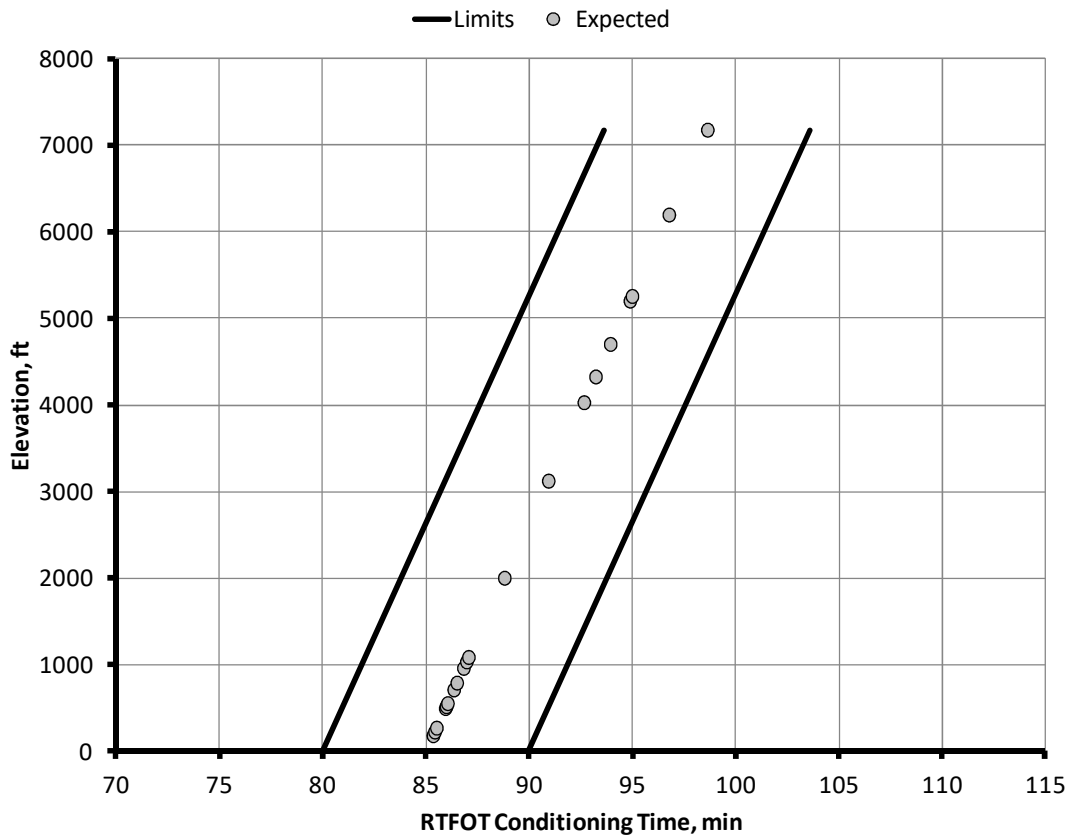


Figure 9. Graphical Representation of the Experimental Design.

Table 9. Binders Used in RTFOT Conditioning Time Experiment.

Binder	Type	135 °C Viscosity, Pa·s	Continuous Performance Grade Temperature, °C			
			High	Intermediate	Low	ΔT_c
B1	Neat	0.461	68.4	23.0	-25.5	+0.5
B2	Polymer	1.134	77.8	20.5	-26.3	-1.6
B3	Neat	0.282	60.5	16.7	-30.3	+1.0
B4	Neat	0.442	65.3	14.8	-30.8	-0.3
B5	Polymer	2.505	82.7	17.5	-30.0	+0.2
B6	Neat	0.217	54.9	11.0	-35.1	+2.1
B7	Polymer	0.583	64.0	9.4	-36.8	-0.7
B8	Polymer	1.248	72.4	11.6	-35.2	-1.2

CHAPTER 3

Findings and Application

Introduction

All participating laboratories performed the RTFOT conditioning, reported the mass change and returned the RTFOT residue for testing. Different analyses were performed on the mass change and rheological data. As discussed in Chapter 2, the experiment was designed to verify that the effect of elevation on the rheological properties of RTFOT residue could be minimized by increasing the RTFOT conditioning time as a function of elevation. Therefore, the analysis of the rheological data was aimed at confirming that there is no elevation effect when the RTFOT conditioning time is adjusted as a function of elevation. On the other hand, the analysis of the mass change data was directed at determining an average mass change adjustment as a function of elevation for the adjusted RTFOT conditioning time determined from analysis of the rheological data. These two analyses are presented below.

Analysis of Rheological Property Data

Graphical Analysis

The rheological property analysis was conducted on the specification properties after RTFOT conditioning: $G^*/\sin\delta$ for AASHTO M 320 and J_{NR} and %R for AASHTO M 332. These properties were plotted as a function of elevation to identify trends in the data and potential outliers. Figure 10 shows the variation of the specification rheological properties as a function of elevation for binders B4 and B5. B4 is a neat binder while B5 is a polymer modified binder with very high recovery. In this figure, the interpolated value at the target RTFOT conditioning time from Table 8 is plotted as a function of elevation. Recall that the conditioning times for the laboratories were adjusted 1.9 min per 1,000 ft of elevation. This adjustment was based on the analysis described earlier for the WCTG and AASHTO re:source proficiency data. These figures show the presence of outliers. The figures also suggest that the estimated conditioning time increase of 1.9 min per 1,000 ft of elevation over compensates for the elevation effect. $G^*/\sin\delta$ appears to increase with elevation, while J_{NR} appears to decrease. The effect of elevation on %R is mixed. By using RTFOT conditioning times of ± 5 min of the target the experiment was designed to allow adjustment of the conditioning time function as discussed in the next section.

Statistical Analysis

The statistical analysis of the rheological property data was conducted in four steps. The first step was an outlier analysis like that described earlier in the analysis of the WCTG and AASHTO re:source proficiency data. This was followed by a linear regression analysis to confirm the trends from the graphical analysis that the RTFOT conditioning time increase of 1.9 min per 1,000 ft of elevation overcompensates for the elevation effect. The third step was an optimization to adjust the conditioning time increase. The optimization was performed on the combined data for the three specification properties: $G^*/\sin\delta$, J_{NR} , and %R. The final step was regression analysis using the average conditioning time increase from the optimization to confirm that specification properties were not significantly affected by elevation. The sections below describe details of these four steps.

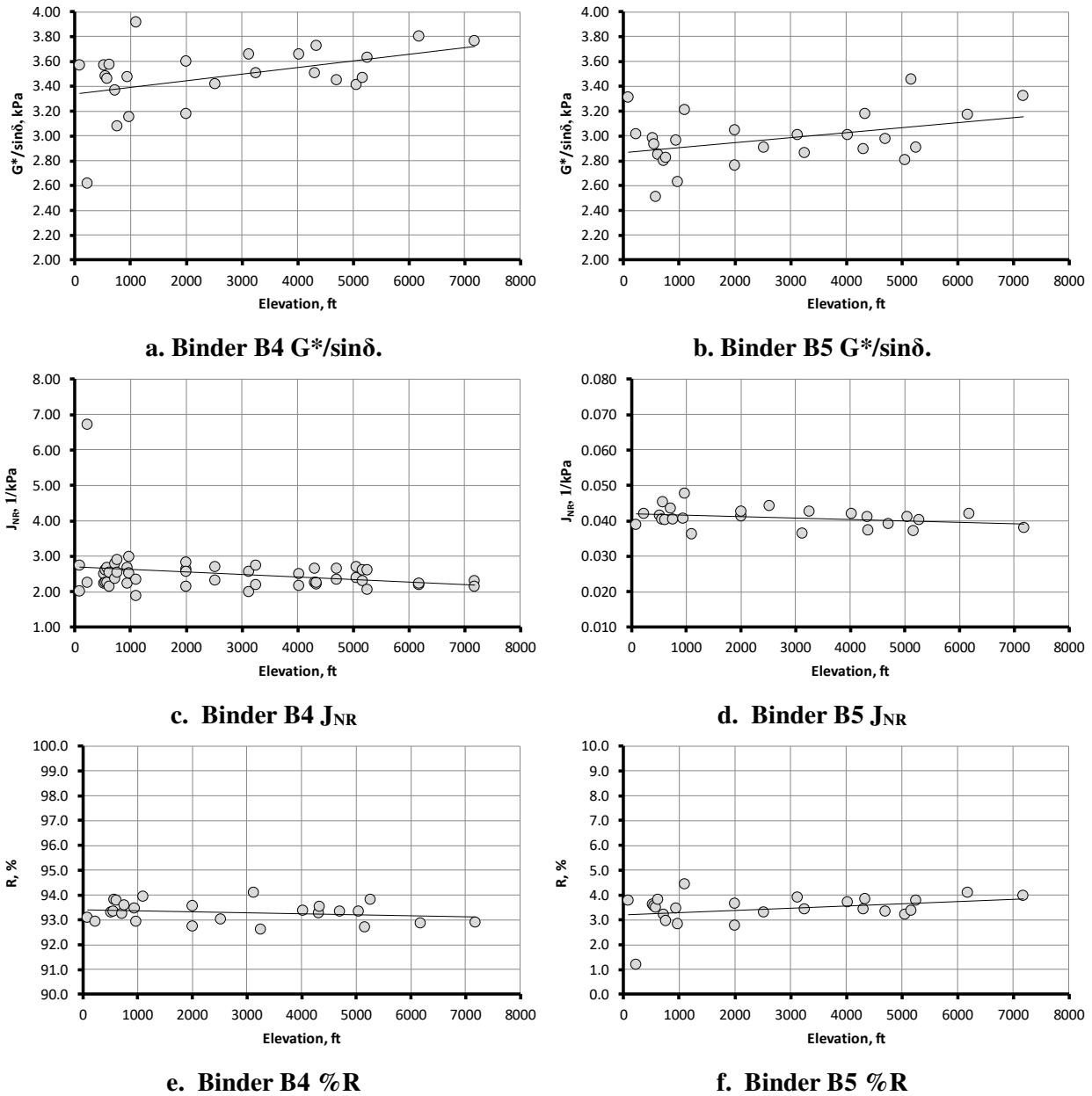


Figure 10. Example Graphical Analysis of Rheological Properties.

Outlier Analysis

Outliers were identified using an approach like that described earlier for the analysis of the WCTG and AASHTO re:source proficiency data. For each combination of specification property and binder (24 total), the average and standard deviation were calculated. Outliers were identified as varying from the average by more than 2.5 standard deviations. Table 9 identifies the specific results that were identified as outliers. Additionally, Lab 10 did not return the residue for binder B1 because of a testing error.

Table 10. Rheological Property Outliers.

Item	$G^*/\sin\delta$	J_{NR}	% R
Total Observations	200	200	200
Outliers	B1 Lab 1	B1 Lab 1	B1 Lab 1
	B2 Lab 1	B1 Lab 6	B2 Lab 1
	B3 Lab 2	B2 Lab 1	B3 Lab 2
	B4 Lab 2	B3 Lab 2	B4 Lab 2
	B6 Lab 5	B4 Lab 2	B6 Lab 5
	B7 Lab 5	B6 Lab 5	B7 Lab 8
	B8 Lab 5	B7 Lab 5	B8 Lab 5
	B8 Lab 16	B8 Lab 5	
		B8 Lab 16	
Residue Not Returned	B1 Lab 10	B1 Lab 10	B1 Lab 10
Analyzed	191	190	192

Initial Linear Regression Analysis

An initial regression analysis was conducted for the three rheological specification properties. Only the modified binder data were used in the evaluation of %R. This analysis used the interpolated value at the target RTFOT conditioning time from Table 8 and the outliers and missing data listed in Table 10 were removed. In this analysis dummy variables were used to allow the slope and the intercept to vary for the binders. The results of these analyses are summarized in Table 11. This analysis found the intercepts to be different for the different binders for the three specification properties. The analysis also found elevation was a significant factor, and the elevation effect was the same for all binders. Although the elevation effect is small for all properties, it may be of engineering significance considering the elevation range of US laboratories of approximately 7,000 ft. The slopes from the regression analysis, positive for $G^*/\sin\delta$ and %R, and negative for J_{NR} , indicate the target elevation adjustment time of 1.9 min/1,000 ft overcompensates for the effect of elevation on RTFOT residue.

Table 11. Summary of Initial Linear Regression.

Item	$G^*/\sin\delta$	J_{NR}	% R
Total Observations	200	200	100
Outliers/Missing Data	9	10	3
Adjusted R ²	0.939	0.994	0.992
Elevation Slope	0.0358 kPa/1000ft	-0.0155 1/kPa/1000 ft	0.1816 %/1000ft
B1 Intercept	3.75 kPa	2.58 1/kPa	NC*
B2 Intercept	2.55 kPa	0.40 1/kPa	51.1 %
B3 Intercept	3.64 kPa	2.66 1/kPa	NC*
B4 Intercept	3.42 kPa	2.47 1/kPa	NC*
B5 Intercept	2.88 kPa	0.08 1/kPa	92.8 %
B6 Intercept	3.47 kPa	2.74 1/kPa	NC*
B7 Intercept	4.30 kPa	0.27 1/kPa	70.0 %
B8 Intercept	4.39 kPa	0.10 1/kPa	83.7 %

* NC denotes not included in the regression analysis

Optimization

The experiment was designed to allow the initial estimate of the elevation adjustment time to be improved using data collected in the experiment. Each laboratory conditioned the binders using two conditioning times that were ± 5 min from the target conditioning time for that elevation. The preliminary RTFOT conditioning time experiment showed the rheological properties vary linearly with conditioning time; therefore, linear interpolation between the two conditioning times can be used calculate the rheological properties for various elevation adjustment times between about 0.6 to 3.4 min/1,000 ft. The optimization was performed using the Solver function in Excel. A spreadsheet was developed to minimize the sum of the errors squared between the interpolated property for each binder in each laboratory and the average interpolated property for that binder from all laboratories. The spreadsheet included $G^*/\sin\delta$ and J_{NR} for all binders and %R for the modified binders. The spreadsheet allowed the elevation time adjustment for the interpolation to vary between 0.6 and 3.4 min/1,000 ft. Table 12 summarizes the results from the optimization. Figure 11 shows the residuals after the optimization confirming that the residuals do not depend on the elevation. The average elevation adjustment time from the optimization considering the three rheological properties is 1.05 min/1,000 ft.

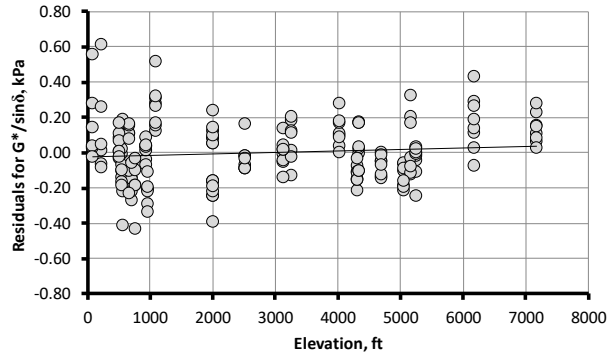
Table 12. Summary of Elevation Adjustment Time Optimization.

Item	$G^*/\sin\delta$	J_{NR}	% R
B1 Average	3.88 kPa	2.52 1/kPa	NC*
B2 Average	2.66 kPa	0.35 1/kPa	52.2 %
B3 Average	3.76 kPa	2.60 1/kPa	NC*
B4 Average	3.55 kPa	2.40 1/kPa	NC*
B5 Average	3.00 kPa	0.04 1/kPa	93.3 %
B6 Average	3.60 kPa	2.67 1/kPa	NC*
B7 Average	4.42 kPa	0.22 1/kPa	70.6 %
B8 Average	4.50 kPa	0.06 1/kPa	84.2 %
Optimum Elevation Adjustment Time	1.05 min/1,000 ft		
Total Observations	300		
Outliers/Missing Data	22		

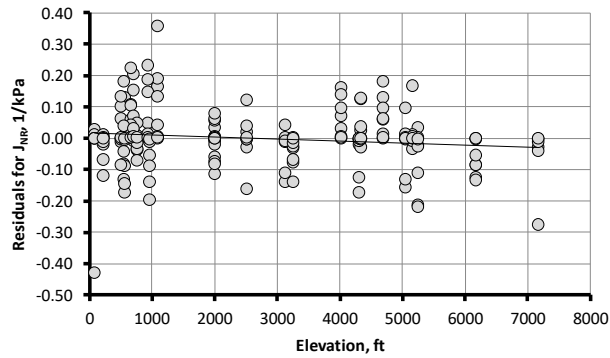
* NC denotes not included in the optimization

Final Linear Regression Analysis

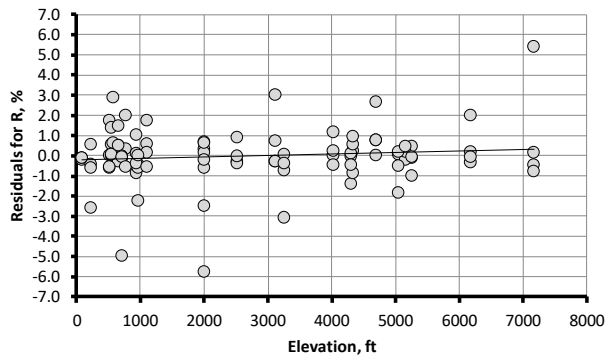
The linear regression analysis was repeated using the average elevation adjustment time of 1.05 min/1,000 ft to confirm that the measured rheological properties were not affected by elevation. The results are summarized in Table 13. These results confirm that there is not an elevation effect using an elevation adjustment time of 1.05 min/1,000 ft.



a. $G^*/\sin\delta$ Residuals



b. J_{NR} Residuals



c. %R Residuals

Figure 11. Residuals After Optimization.

Table 13. Summary of Final Linear Regression.

Item	$G^*/\sin\delta$	J_{NR}	% R
Total Observations	200	200	100
Outliers/Missing Data	9	10	3
Adjusted R^2	0.926	0.994	0.991
Elevation Slope	Not Significant	Not Significant	Not Significant
B1 Intercept	3.85 kPa	2.54 1/kPa	NC*
B2 Intercept	2.64 kPa	0.36 1/kPa	52.1 %
B3 Intercept	3.74 kPa	2.61 1/kPa	NC*
B4 Intercept	3.52 kPa	2.42 1/kPa	NC*
B5 Intercept	2.97 kPa	0.05 1/kPa	93.2 %
B6 Intercept	3.57 kPa	2.68 1/kPa	NC
B7 Intercept	4.39 kPa	0.24 1/kPa	70.5 %
B8 Intercept	4.48 kPa	0.07 1/kPa	84.1 %

* NC denotes not included in the regression analysis

Analysis of Mass Change Data

Graphical Analysis

The mass change data were analyzed to determine an average mass change adjustment as a function of elevation for the final elevation adjustment time of 1.05 min/1,000 ft. The interpolated mass change for each binder was plotted as a function of elevation to identify trends in the data. Figure 12 shows the mass change variation with elevation for binders B2 and B3. B2 is a polymer modified binder with low mass change, while B3 is a neat binder with high mass change. The trend for both binders is greater mass loss with increasing elevation. This figure also shows the presence of outliers.

Statistical Analysis

The statistical analysis of the mass change data followed the approach described earlier for the analysis of WCTG and AASHTO re:source proficiency sample data. Linear regression equations for mass change as a function of elevation were developed for mass change interpolated for the elevation adjustment time of 1.05 min/1,000 ft elevation. Dummy variables were included in the regression analysis to allow the slope and intercept of the mass change as a function of elevation to vary for the eight binders. Outliers were identified by fitting regression models with different intercepts and different slopes for each binder and observations with standardized residuals having absolute value greater than 2.5 were flagged as outliers. The final regression analysis was then conducted on the data set after removing the outliers.

Table 14 summarizes the results of the statistical analysis. A linear regression model with binder specific intercepts, but a common elevation slope has an explained variance of 93.1 percent. The elevation slope of -0.0062 %/1,000 ft can be used to adjust the mass loss measured in laboratories at different elevations to a common elevation. The elevation effect in this model is somewhat larger than that reported in Chapter 2 for the WCTG and AASHTO re:source proficiency sample data because this model also includes the effect of increasing RTFOT conditioning time with elevation. For an elevation difference of 7,000 ft, the mass change difference is -0.043 percent. Figure 12 compares the measured data to the regression model for binders B2 and B3 which have the smallest and largest mass changes in the data set. Although the elevation effect is significant, the most significant factor affecting the mass change is the binder.

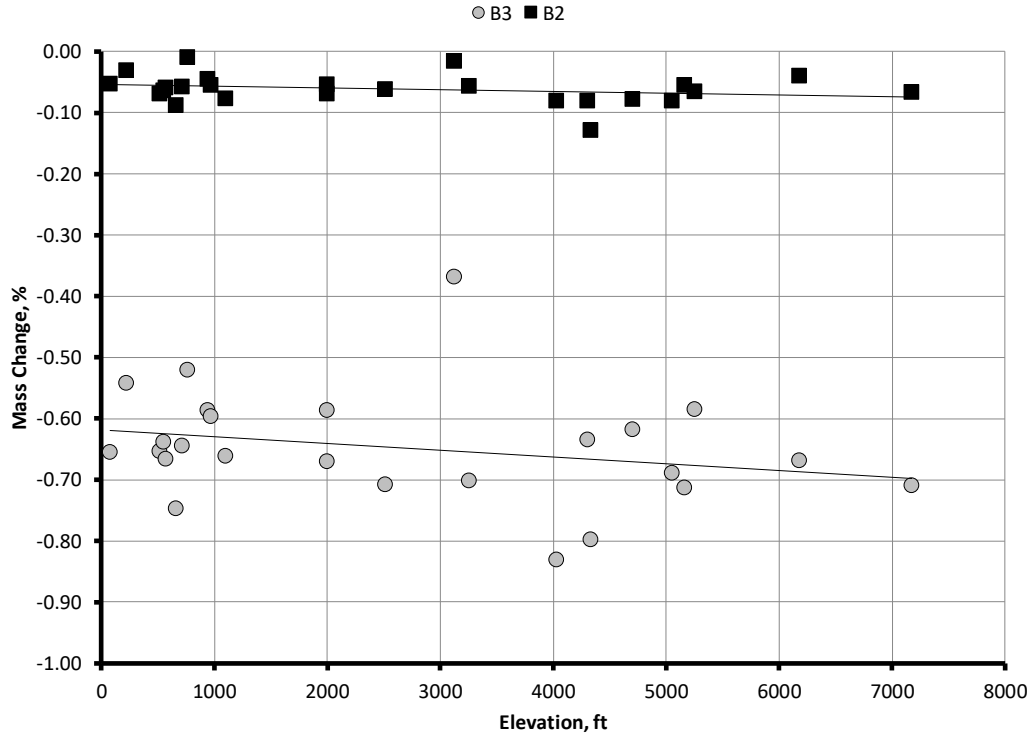


Figure 12. Mass Change Versus Elevation for Binder B2 and Binder B3.

Table 14. Summary of Mass Change Model.

Property	Value
Total Observations	200
Outliers and Missing Data	6
Adjusted R ²	0.931
Elevation, %/1000 ft	-0.0062
B1 Intercept, %	-0.137
B2 Intercept, %	-0.045
B3 Intercept, %	-0.652
B4 Intercept, %	-0.094
B5 Intercept, %	-0.108
B6 Intercept, %	-0.280
B7 Intercept, %	-0.477
B8 Intercept, %	-0.467

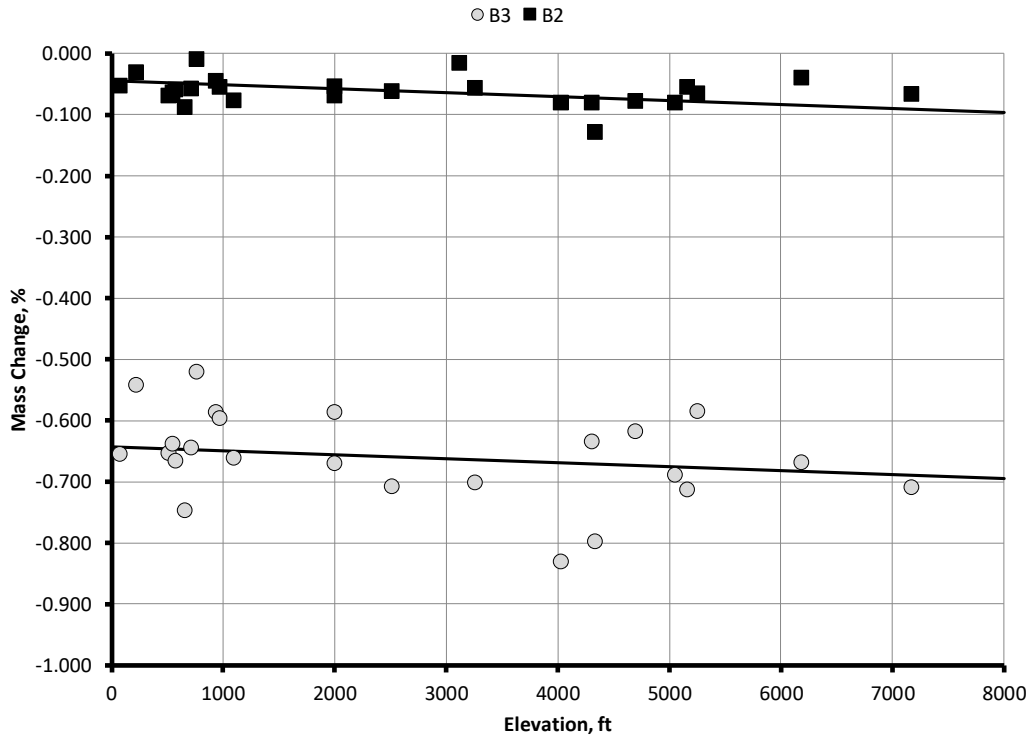


Figure 13. Comparison of Measured and Fitted Mass Change Data for Binders B2 and B3.

Application

Application of the statistical models developed from the experimental work completed in this project is straightforward. To provide approximately equivalent rheological properties, the RTFOT conditioning time should be increased one minute for every 1,000 ft increase in elevation. When this RTFOT conditioning time adjustment is applied, 0.006 percent should be added to the resulting mass change for every 1,000 increase in elevation.

CHAPTER 4

Conclusions and Recommendations

Conclusions

The primary conclusion drawn from analysis of proficiency sample data from WCTG and AASHTO re:source, and the experiment conducted in this project is laboratory elevation affects both the rheological properties of the residue and the mass change for asphalt binders conditioned in accordance with AASHTO T 240. It is possible to approximately account for the effect of elevation on the rheological properties of the residue by increasing the conditioning one minute for every 1,000 ft increase in elevation. When this conditioning time adjustment is applied 0.006 percent should be added to the resulting mass change for every 1,000 increase in elevation.

Recommendations for Implementation

The sections below describe two approaches for implementing the findings of this study. The first approach recommends not modifying AASHTO T 240. If this approach is adopted, then the effect of elevation on interlaboratory results should be accounted for in the statistical analysis of the data. Also, to address potential differences in specification properties due to elevation differences, agencies should adopt a dispute resolution procedure that includes the adjustments to AASHTO T 240 developed in this study. The second approach is to modify AASHTO T 240 to include the adjustments developed in this study. Additional details for these approaches are presented below.

No Modification of AASHTO T 240

Interlaboratory Studies

If AASHTO T 240 is not modified to account for the elevation effect, then the statistical analysis of data from interlaboratory studies should be adjusted to account for the effect of elevation on the rheological properties of the residue and the mass change for asphalt binder conditioned in accordance with AASHTO T 240. The approach used in this project to investigate the effect of elevation is recommended. First the data should be regressed against elevation. If the elevation effect is significant, then the standardized residuals (residuals divided by the standard deviation of the residuals) should be used to rate the performance of each laboratory on the same scale that is currently used based on standard deviation. If the elevation effect is not significant, then the analysis can be performed in the usual manner using the standard deviation to rate the performance of each laboratory. Implementation of this recommendation requires accurate data on the elevation of each laboratory, which can be readily obtained from on-line map services. Although the analysis can be done using barometric pressure or elevation, elevation is recommended due to the confusion associated with reporting barometric pressure that was discussed in Chapter 2.

Recommendation for Binder Acceptance

If AASHTO T 240 is not modified to account for the elevation effect, then it is possible that laboratories at different elevations may reach different conclusions concerning the acceptance of an asphalt binder. Agencies performing acceptance testing at higher elevations should modify their dispute resolution

procedures to include retesting using adjusted RTFOT conditioning times and mass change based on the findings from this study. One possible approach is provided below:

When the supplier's laboratory is at an elevation of 1,000 ft or more below the Department's laboratory and there is a difference in acceptance results that may be due to the elevation difference, the Department will retest the binder using a modified RTFOT conditioning time that adds one minute for each 1,000 ft difference in elevation rounded to the nearest minute. When using this modified RTFOT conditioning time, 0.006 percent will be added to the resulting mass change for each additional minute of RTFOT conditioning time. The elevation of the supplier's and Department's laboratory will be determined using an on-line mapping service.

Modification of AASHTO T 240

This section presents the modifications to AASHTO T 240 required to implement the findings of this study. The modifications use an elevation of 500 ft as the basis for adjusting the RTFOT conditioning time and mass change measurements. The modifications are based on increasing the RTFOT conditioning time 1 minute per 1,000 ft increase in elevation rounded to the nearest minute and adding 0.006 percent to the measured mass change for each minute of RTFOT conditioning time greater than 85 minutes. Appendix C details the required modifications.

REFERENCES

- Anderson, D.A. and Bonaquist, R.F., "Investigation of Short-Term Laboratory Aging of Neat and Modified Asphalt Binders," NCHRP Report 709, National Cooperative Highway Research Program, Washington, D.C., 2012.
- Anderson, D.A., Christensen, D.W., Bahia, H.U., Dongre, R., Sharma, M.G., Antle, C.E., and Button, J., "Binder Characterization and Evaluation Volume 3: Physical Characterization," SHRP-A-369, Strategic Highway Research Program, National Research Council, Washington, DC, 1994.
- "Manual of Barometry", (WBAN), Vol 1, First Edition, U.S. Dept of Commerce, Weather Bureau, Washington, D.C., 1963.
- Liu, M.; Lunsford, K. M.; Davison, R. R.; Glover, C. J.; Bullin, J. A." The Kinetics of Carbonyl Formation in Asphalt," American Institute of Chemical Engineers Journal, Volume 42, 1996.
- Robertson, R. E., J. F. Branthaver, P. M. Harnsberger, J. C. Petersen, S. M. Dorrence, J. F. McKay, T. F. Turner, A. T. Pauli, S.-C. Huang, J.-D. Huh, J.E. Tauer, K. P. Thomas, D. A. Netzel, F. P. Miknis, T. Williams, J.J. Duvall, F.A. Barbour, C. Wright, S.L. Salmans and A.F. Hansert, "Fundamental Properties of Asphalts and Modified Asphalts, Volume II: Final Report, New Methods," FHWA-RD-99-213. U.S. Department of Transportation, Federal Highway Administration, McLean, VA., 2001.
- The Engineering ToolBox, http://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html, 2016.
- Velasquez, R., Swiertz, D., and Bahia, H., "Effect of Laboratory Elevation on Binder Aging using the Rolling Thin Film Oven (RTFO)," Modified Asphalt Research Center (MARC) University of Wisconsin-Madison, January, 2013.
- Wang, H., "Effects of Laboratory Elevation on Rolling Thin Film Oven Test Results," Masters of Science Thesis, Colorado State University, 2013.
- Weather Underground, https://www.wunderground.com/resources/pressure_records.asp, 2017

APPENDIX A

Binder Grading Data

Table A1. Binder Performance Grading Data.

Condition	Property	Method	Temp, °C	Binder							
				B1	B2	B3	B4	B5	B6	B7	B8
Original	Viscosity, Pa·s	AASHTO T 316	135	0.461	1.134	0.282	0.442	2.505	0.217	0.583	1.248
			52						1.44		
			58			1.36			0.683		
	G*/sinδ, kPa	AASHTO T 315	64	1.73		0.642	1.16			1.07	
			70	0.823			0.597			0.627	1.40
			76		1.18						0.907
			82		0.676			1.18			
			88					0.821			
			52						3.49		
			58			3.50			1.64		
RTFOT Residue	G*/sinδ, kPa	AASHTO T 315	64	3.99		1.59	3.28			3.98	
			70	1.82			1.68			2.19	2.67
			76		2.74						1.64
			82		1.53			2.30			
			88					1.59			
			7							6660	
			10						5640	4640	6010
			13				6170		3880		4230
PAV Residue	G*·sinδ, MPa	AASHTO T 315	16			5440	4320	5960			
			19		5960	3770		4150			
			22	5640	4220						
			25	3920							
			-12	197	149						
			-18	406	305	223	195	238			
			-24			478	433	478	262	194	228
			-30						557	408	462
	Creep Stffness, MPa	AASHTO T 313	-12	0.343	0.336						
			-18	0.281	0.287	0.337	0.329	0.325			
			-24			0.273	0.270	0.261	0.337	0.327	0.311
			-30						0.270	0.272	0.258
	m-value	AASHTO T 313	-12	0.343	0.336						
			-18	0.281	0.287	0.337	0.329	0.325			
			-24			0.273	0.270	0.261	0.337	0.327	0.311
			-30						0.270	0.272	0.258

APPENDIX B

Laboratory Instructions

Introduction

Thank you for agreeing to participate in the Rolling Thin Film Oven Test (RTFOT) Elevation Experiment being conducted as part of NCHRP Project 20-07 / Task 400, Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder. The objective of this experiment is to determine the feasibility of adjusting the RTFOT conditioning time to account for the decreased aging that occurs during RTFOT conditioning at higher elevations. Through an analysis of AASHTO Resource and Western Cooperative Testing Group (WCTG) proficiency sample data, we confirmed that there is an elevation effect and for some binders the effect is large enough to result in different conclusions being drawn concerning the acceptability of the same binder under AASHTO M 320 and AASHTO M 332 when tested at different elevations. You are one of 25 laboratories that have agreed to participate in this experiment. The range of elevations for the laboratories vary from approximately 200 ft to 7000 ft.

The RTFOT Elevation Experiment includes conditioning eight binders in 20 laboratories at different elevations. Each laboratory will condition each binder at two different conditioning times based on the elevation of the laboratory. Since only high temperature properties will be measured, each laboratory will condition four bottles of each binder resulting in a total of eight runs of the RTFOT; four runs at each of two condition times. For each binder, each laboratory will measure and report the mass change using two bottles and return the residue from the other two bottles to Advanced Asphalt Technologies, LLC for rheological testing. Using a single laboratory for rheological testing will reduce testing error caused by differences in testing equipment and procedures in different laboratories.

The requirements given in AASHTO T 240, *Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)* will be followed. Please review AASHTO T 240 prior to performing the requested work. Detailed instructions are provided below.

Samples and Containers

You have received 16 tins containing binder. There are eight binder samples labeled B1 through B8 and for each binder sample you have received two tins with binder. The performance grade for each of the binder samples are listed below. You also received 16 marked tins to return the conditioned binder. The tins are marked LXX-BY-ZZ where XX is your laboratory number, Y is the binder number, and ZZ is the conditioning time.

Sample ID	Performance Grade	Type
B-1	PG 64-22	Neat
B-2	PG 76-22	Polymer
B-3	PG 58-28	Neat
B-4	PG 64-28	Neat
B-5	PG 76-28	Polymer
B-6	PG 52-34	Neat
B-7	PG 58-34	Polymer
B-8	PG 64-34	Polymer

Preparation of Oven

Prepare the oven in accordance with Section 6 of AASHTO T 240. Please ensure that the nozzle for the air flow is positioned at the center of the opening in the mouth of the bottle to ensure proper air flow.

Procedure

Condition the binders and measure the mass change in accordance with Section 7 of AASHTO T 240 with the following exceptions:

4. Condition each of the 8 binders using the two conditioning times assigned to your laboratory. These times are different from the standard condition time of 85 minutes.
5. Condition 4 bottles of each binder for each conditioning time. Use 2 of the bottles for each binder to measure and record the mass change. Transfer the contents for the 2 bottles not used for the mass change measurement into the appropriately marked container.
6. Condition two binders during each run of the RTFOT. A total of 8 RTFOT runs will be required.

When removing the bottles from the RTFOT alternate between the two binders and complete the removal and transfer of the residue to the appropriate container within the 5 minutes specified in Section 7.7 of AASHTO T 240. First, remove the bottles that will be used for mass change. Next, remove and drain, one at a time, the bottles that will be used for physical property measurements in the following order: One bottle from binder A, two bottles from binder B, and the last bottle from binder A.

Reporting and Shipping

Report the mass change measured for each binder for each conditioning time using the table below.

Binder	Condition Time of __ Minutes			Conditioning Time of __ Minutes		
	Bottle 1	Bottle 2	Average	Bottle 1	Bottle 2	Average
B-1						
B-2						
B-3						
B-4						
B-5						
B-6						
B-7						
B-8						

Return the 16 containers of RTFOT residue via FedEx Ground using the box and return shipping label provided to:

Ramon Bonaquist
Advanced Asphalt Technologies, LLC
40 Commerce Circle
Kearneysville, WV 25430
(681)-252-3329

Questions:

If any of these instructions are not clear or you require additional information, please contact:

Ramon Bonaquist
Phone: 681-252-3329
Mobile: 703-999-8365
e-mail: aatt@erols.com

APPENDIX C

Recommended Modification to AASHTO T 240

Introduction

This appendix presents the changes to AASHTO T 240 needed to implement the RTFOT conditioning time and mass change adjustments developed in this project. The changes are presented below and refer to the sections in AASHTO T 240-13 (2017). New text is shown in **bold**.

Recommended Changes to AASHTO T 240-13 (2017)

1. Scope
No change required.
2. Referenced Documents
In Section 2.3 add an appropriate reference to this document when it is published.
3. Summary of Test Method
No change required.
4. Significance and Use
No change required.
5. Apparatus
No change required.
6. Preparation of Oven
No change required
7. Procedure
Modify Section 7.6 as to read:
*7.6 With the oven at operating temperature and the airflow set at 4000 ± 300 ml/min, arrange the containers holding the asphalt binder in the carriage so that the carriage is balanced. Fill any unused spaces in the carriage with empty containers. Close the door and rotate the carriage assemble at a rate of 15 ± 0.2 r/min. Maintain the glass containers in the oven with the air flowing and the carriage rotating **for duration listed in Table 1 based on the elevation of the laboratory**. The test temperature of $163 \pm 1.0^{\circ}\text{C}$ ($325 \pm 1.8^{\circ}\text{F}$) shall be reached within the first 10 min – otherwise discontinue the test.*

Table 1 – Conditioning Time

<i>Elevation, Ft</i>	<i>Conditioning Time, min</i>
0 – 999	85
1,000 – 1,999	86
2,000 – 2,999	87
3,000 – 3,999	88
4,000 – 4,999	89
5,000 – 5,999	90
6,000 – 6,999	91
7,000 – 7,999	92

Modify Section 7.9 to add a new Section 7.9.1 as follows:

7.9.1 Calculate the mass change using the following equation. The mass change may be negative (mass loss) or positive (mass gain)

$$\text{mass change, \%} = \frac{(B - A)}{B} \times 100\% + F$$

where:

A = mass of binder plus container before conditioning, g

B = mass of binder plus container after conditioning, g

F = mass change correction factor from Table 2

Table 2 – Mass Change Correction Factor

<i>Conditioning Time, min</i>	<i>F</i>
85	0.000
86	+0.006
87	+0.012
88	+0.018
89	+0.024
90	+0.030
91	+0.036
92	+0.042

Renumber current Section 7.9.1 as **Section 7.9.2**.

8. Report

No change required

9. Precision and Bias

Relabel Table 1 as Table 3; relabel Table 2 as Table 4; relabel Table 3 as Table 5

10. Keywords

No change required

Appendix

No change required

Development of AASHTO / ASTM Harmonization Group for Asphalt

Meeting Minutes

January 8, 2019

Introduction of Attendees:

Name	Organization / Affiliation	Present?
Allen Myers	Kentucky Transportation Cabinet, Chair of COMP TS 2c	X
Amir Gotalipour	Engineering Software Consultants / FHWA / Mobile Asphalt Testing Trailer/ Chair of D04.44	X
Ashley Wiand	ASTM International (on her honeymoon!)	
Barry Paye	Wisconsin DOT, Vice Chair of COMP TS 2b	X
Becky McDaniel	Technical Director North Central Superpave Center, Purdue Chair, ASTM Committee D04 on Road and Paving Materials, ASTM Board of Directors	X
Bob Kluttz	Kraton Polymers, Chair of Subcommittee D04.40, Asphalt Specifications, FHWA ETG on asphalt	X
Brian Johnson	AASHTO, Manager of Laboratory Assessment Program, Liaison for COMP, ASTM member	X
Brian Pfeifer	Illinois DOT, Chair of COMP TS 2a	X
Casey Soneira	AASHTO, AASHTO Liaison for COMP	X
Curt Turgeon	Minnesota DOT, Vice Chair of COMP	X
Don Streeter	New York DOT, member of COMP and JAAHTG	X
Evan Rothblatt	ASTM International	X
Frank Fee	Frank Fee, LLC Chair of Subcommittee D04.93, Strategic Planning, TRB AFK10	X
Glenn Page	AASHTO, Associate Program Director for Project Delivery	X
John Staton	Michigan DOT, Current Chair of COMP TS 3a	
Lyndi Blackburn	Alabama DOT, Chair of COMP TS 2b	X
Maria Knake	AASHTO, Liaison for COMP, ASTM Member	X
Mark Felag	Rhode Island DOT, former Chair of COMP TS 3a	X
Moe Jamshidi	Nebraska DOT, Chair of COMP	X
Oak Metcalfe	Montana Department of Transportation, Chair of COM TS 2d	X
Payman Pirzadeh	Imperial Oil, ASTM Member, Interested member from Industry	X
Steven Lenker	AASHTO re:source / CCRL	

Discussion of the Cement Harmonization Task Force in AASHTO/ASTM that has already been successful

- Articles on JAAHTG provided by Mark Felag
Mark Felag shared some articles on the work done by the Joint AASHTO-ASTM Harmonization Task Group (JAAHTG) and the work that this group has done. These articles were sent to the group by Maria prior to the meeting. They include a lot of details on the start of the group and the work that they have done in the past.

Brief history Cement Harmonization Task Group (Mark Felag or Don Streeter)

Mark Felag briefly discussed the history behind the task group:

- For many years there had been differences that existed between the AASHTO and ASTM versions of the cement standards. Discussions would come up again every four years (during publication time for AASHTO), but neither party wanted to change their standards.
- Eventually Mark believed that the differences could be resolved, but that it would not work with an attitude of “you change yours to meet ours.” The differences between the standards would need to be carefully reviewed and discussed.
- The group started with the sole purpose of harmonizing 1 standard that had 5 major differences (AASHTO M 85 and ASTM C 150). The goal of harmonization was to make the two standards identical.
- The task group worked so well that in 2009 they expanded the focus of the group to include other standards for harmonization.

Lesson Learned

- Mark went on to briefly discuss some of the things that they have learned over the years that are critical to the success of the group.
- In the JAAHTG there are two co-chairs that work closely with the chairs of the Technical Subcommittee and Subcommittee within AASHTO and ASTM, respectively.
- Standards are balloted at the subcommittee level in both AASHTO and ASTM and then the group coordinates when the standards are published so that they are released around the same time.
- A good secretary that is committed to this substantial effort is needed to keep track of action items, take good notes, and track the progress of the work.
- It is important for the group to have a list and prioritize the standards where harmonization is needed.

What has worked well / Recommendations for Replicating Effort in asphalt standards (Don Streeter)

- Don Streeter has served as the AASHTO co-chair of the JAAHTG for about 8 years. He shared his thoughts on best practices for a harmonization group such as this one.
 - 6-8 people are needed from AASHTO and ASTM each.
 - Have two co-chairs of the group, one from the AASHTO side, one from ASTM

- Have a dedicated coordinator/secretary that will schedule the next meeting and send out meeting minutes.
- The other members should be technical experts that can assist with research needs, drafting standards
- Part of the agenda for each meeting should be an update from both AASHTO and ASTM on any meetings that took place since the last call, other updates or news from each side. A typical agenda for JAAHTG starts with approval of the minutes, and then report on AASHTO 3a mid-year meeting, report on ASTM subcommittee meeting, etc.
- When standards go to ballot it is important that both ballots in AASHTO and ASTM clearly define the work that was done jointly, including rationale behind the change, any research or data available to support the change, etc. The rationale should clearly state that both AASHTO and ASTM have worked on and have agreed upon these changes as part of the rationale.
- There should be a structured meeting agenda for each meeting. The JAAHTG met every 4-8 weeks.
- Prioritize the standards that will be harmonized and keep a running tally of the work being done.
- Take votes on changes within the task group first until you get the nays ironed out.
- Once the item goes to ballot with one group, the task force should meet again to iron out any negatives received before the item goes to ballot with the other group. Somebody should be responsible for placing an administrative negative on ballots that go through both groups to ensure that the ballot can be held back if there is an issue with the ballot from the other group and to ensure that publication can happen around the same time.
- Don reiterated that it is important to build consensus amongst all of the task group members.
- Members should keep open minds regarding the changes to the standards and take a reasonable look at the science behind the rationale for changes.
- Co-chairs are responsible for facilitating the meetings, take turns with the AASHTO co-chair running one meeting and then the ASTM co-chair running the other.

Open discussion

- There was some discussion regarding vertical construction vs. horizontal construction differences that exist in the cement and concrete communities that don't exist with asphalt. Given that there is not this difference for asphalt, which asphalt standards are more prevalently used in the U.S.? The AASHTO Accreditation program has seen that it is about 50/50 for ASTM vs. AASHTO in asphalt standards. FAA requires ASTM D3666 and accompanying ASTM asphalt standards, and ASTM standards are also used internationally. **ACTION ITEM: AASHTO re:source will provide the group with specific data on how many labs are accredited for AASHTO versions of tests vs. the ASTM versions.**
- A point of clarification was made that the secretary does not do the bulk of the writing of the standards. The members (technical experts) do this work. The Secretary keeps the projects moving along, documents progress, and schedules meetings.

Can this effort be replicated on the asphalt side?

- Attendees present seemed to believe that this effort could be replicated and looked upon this effort positively

What are the Barriers to this Effort?

- What should be done about new standards and new technology that are brought to both groups?
 - This is a separate issue and should be discussed further with different set of people. Right now the MOU for AASHTO and ASTM states that if one group is working on developing a standard, then the other group cannot pursue that standard. There is currently no effective communication between AASHTO and ASTM when it comes to new test methods right now. The communication through this group could help to improve this, but decisions still need to be made on how to handle research work that is brought to both AASHTO and ASTM. **ACTION ITEM: Moe Jamshidi indicated that this topic will be discussed at the next COMP Steering Committee Meeting.** If changes are to be made to the current MOU, higher levels of management for both AASHTO and ASTM need to get involved.
- The focus of the group will be to harmonize existing similar standards.

Where should we start?

- It was suggested that AASHTO M 320 / ASTM D6373 (PGB spec) and AASHTO M 332 / ASTM D8259 (PGB spec with MSCR) specifications might be a good place to start.

Who should be involved?

- It was suggested that a link to the work done in TRB should be created as part of this harmonization effort as well.
- It would be helpful to have a list of who the chairs are for the AASHTO Technical Subcommittees and corresponding ASTM subcommittees. **ACTION ITEM: Maria will work on putting this together to share with the group.**
- The following people volunteered to be part of the Asphalt Standards Harmonization Task Group:
 - Amir Golalipour (FHWA- AASHTO and ASTM)
 - Bob Kluttz (ASTM)
 - Maria Knake (AASHTO)
 - Casey Soneira (AASHTO)
 - Payman Pirzadeh (ASTM)
 - Frank Fee (ASTM)
 - Lyndi Blackburn (AASHTO)
 - Barry Paye (AASHTO)
 - Ashley Wiand (ASTM- volunteered by Evan Rothblatt)

We will wait to finalize the members list until AASHTO and ASTM have a chance to recruit additional technical experts from their member ranks. Don Streeter reiterated

that the Chairs and Vice Chairs of JAAHTG did not do the bulk of the work and are not necessarily expected to be the co-chairs of the task group- rely on other members and technical experts to do that.

- What is the next step?
 - ACTION ITEM: Maria Knake will work on developing a first draft of a Charter for the task group and will send to the members for review by the end of January.

Running List of Open Action Items			
Action Item	Assigned To	Date Assigned	Status
AASHTO re:source will provide the group with specific data on how many labs are accredited for AASHTO versions of tests vs. the ASTM versions.	Maria Knake	1/8/19	just assigned
Moe Jamshidi indicated that this topic [what to do when standards/research come to both AASHTO and ASTM] will be discussed at the next COMP Steering Committee Meeting.	Moe Jamshidi	1/8/19	just assigned
Maria Knake will work on developing a first draft of a Charter for the task group and will send to the members for review by the end of January.	Maria Knake	1/8/19	just assigned

Asphalt Institute DSR-PAV TF Outcome Report to AASHTO COMP TS 2b

January 23, 2018

Pavel Kriz (Imperial Oil/ExxonMobil)

Gerry Reinke (Mathy)

Mike Anderson (Asphalt Institute)



- Lead ExxonMobil Asphalt Technical Organization in Americas
- Expertise in Asphalt Manufacturing, Modification, Testing and Characterization
- Master Black Belt in Lean Six Sigma

- BSc in Chemical Engineering, ICT Prague (2001)
- MSc in Petroleum Refining, ICT Prague (2003)
- Researcher, Crude Oil Rheology, DTU Denmark (2004)
- PhD in Asphalt Rheology, U of Calgary (2005-2009)
- Asphalt Lead Researcher, Imperial Oil/ExxonMobil (2009-2013)
- Asphalt Team Lead, Imperial Oil/ExxonMobil (2013-2017)

Background & Case for Action

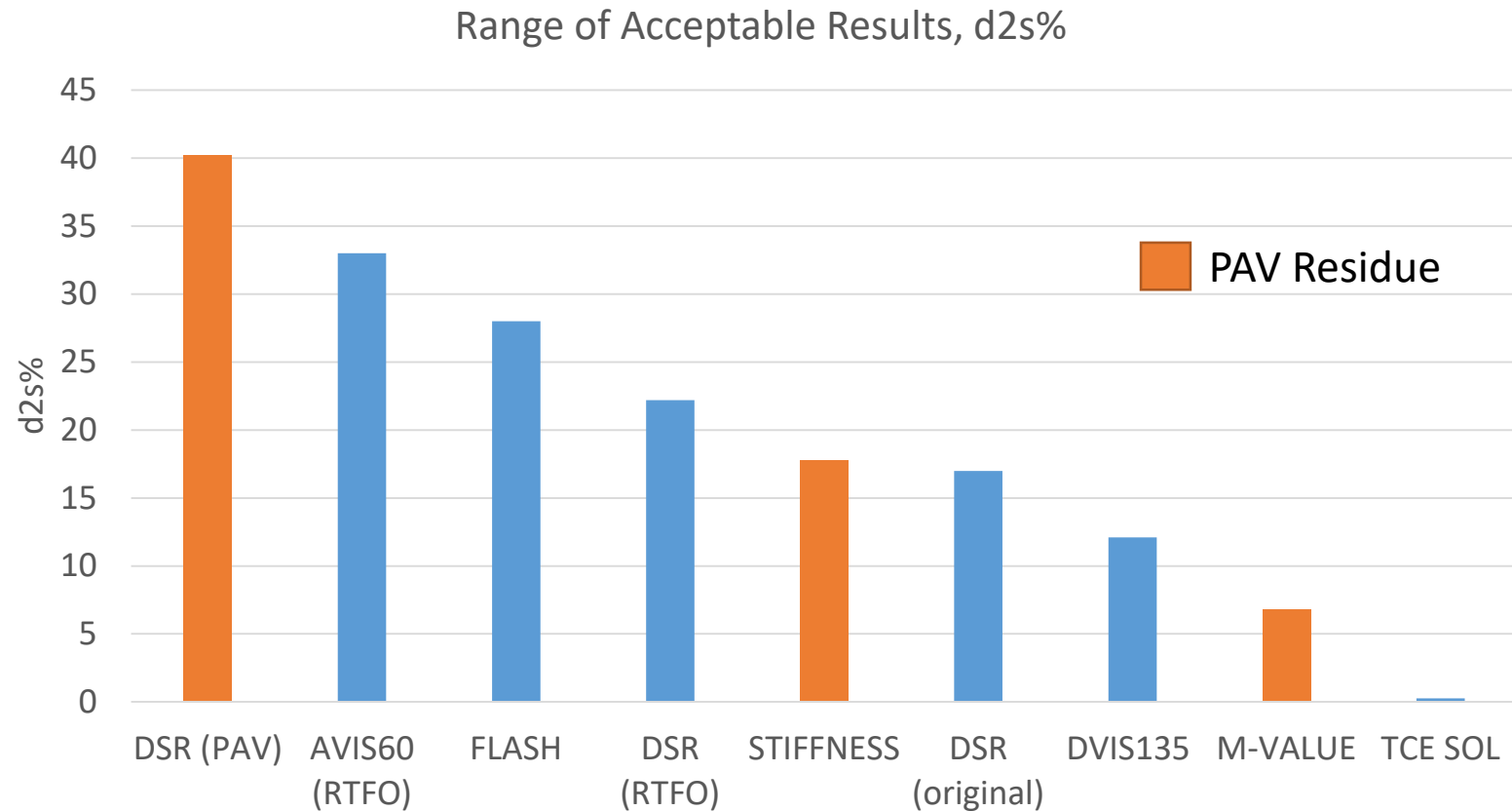
ATTACHMENT A

asphalt institute



ATTACHMENT D

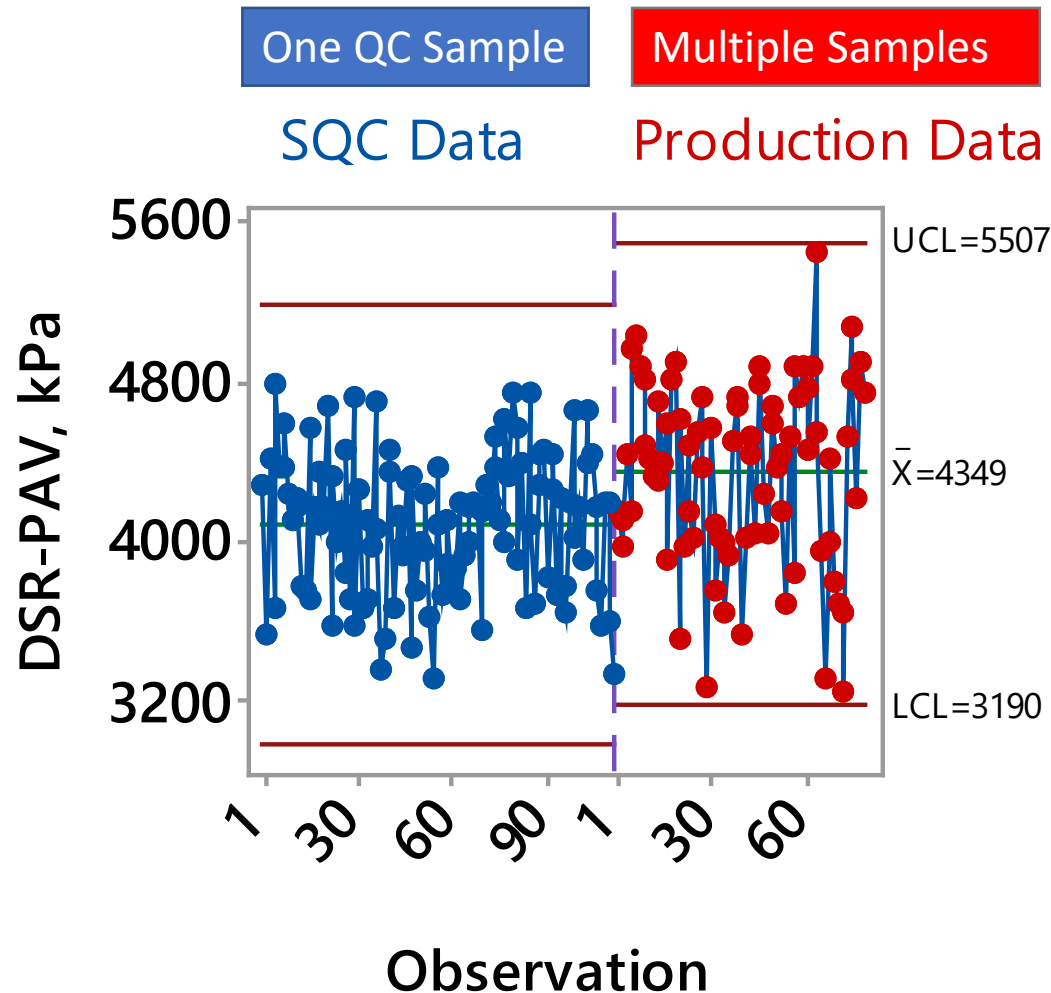
- DSR-PAV is (after DTT) the most variable test SuperPave™



Background & Case for Action



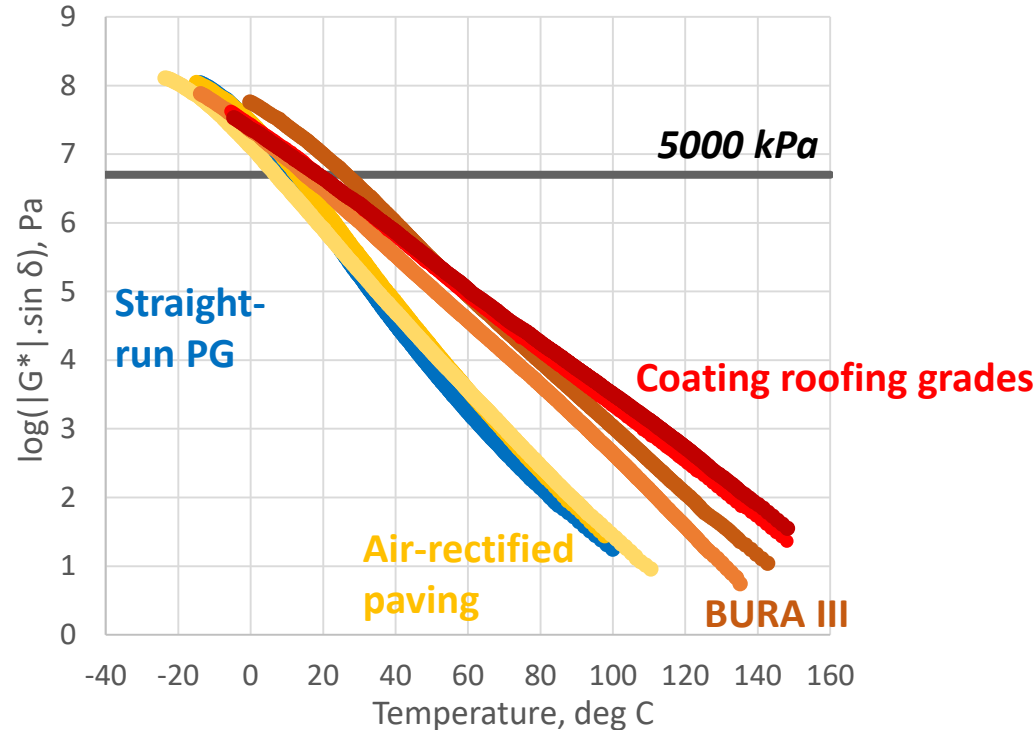
- High test variability = Inability to distinguish performance



Background & Case for Action



- DSR-PAV cannot discriminate poor performing binders, namely phase instable binders exhibiting high rates of cracking.



1. Modify T315 test protocol to reduce the test variability to acceptable level
2. Review scientific validity of DSR-PAV parameter $|G^*| \sin \delta$ to assess binder performance
3. Review ability of DSR-PAV test to discriminate poor performers

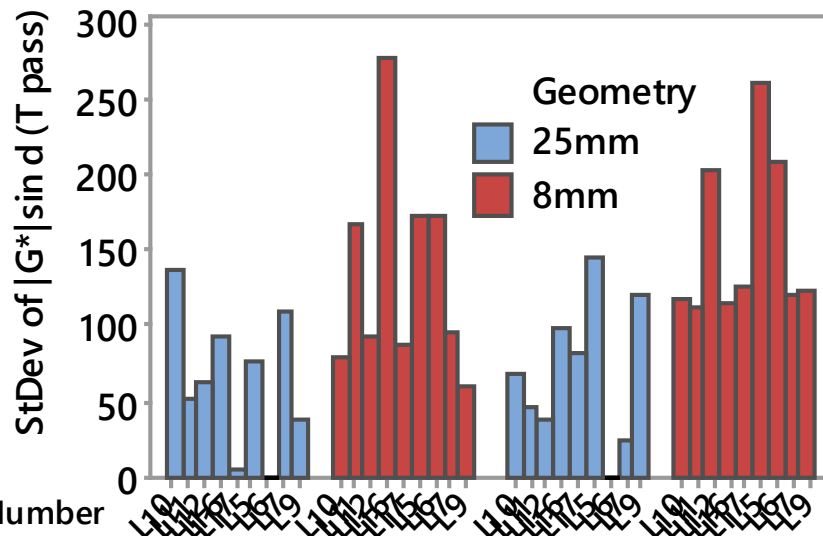
1. Two round robins (stage 1 – thermal equilibrium time) & (stage 2 – optimal plate size and strain level) were conducted to identify improvements to AASHTO T315.
2. $|G^*| \sin \delta$ was analyzed in terms of relationships among material functions in a complex plane
3. Set of approximately 40 binders with ranging crude origins & phase stability were prepared. The blends covered wide range (beyond typical grades) of grades and properties. Ability of DSR-PAV parameter to discriminate performance was tested

Findings 1: Test Setup

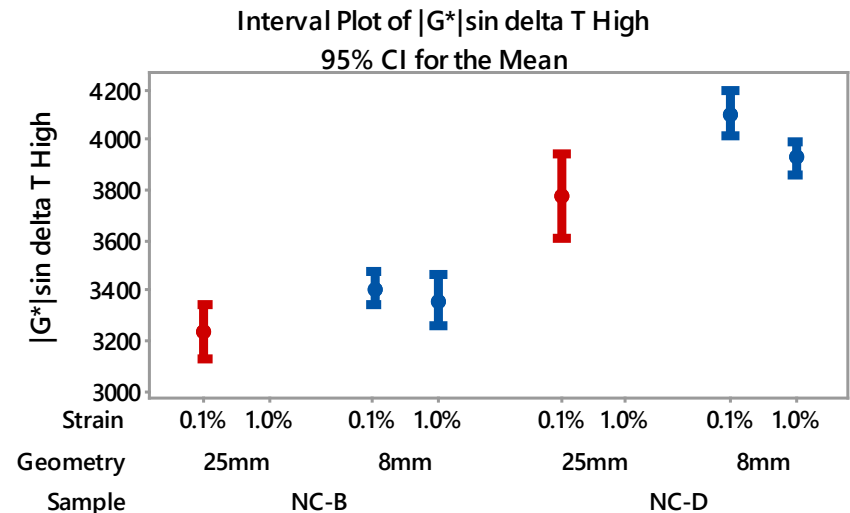


- Time to thermal equilibrium adequate
- 25mm PP improved inter-lab repeatability (precision)
- But provided poorer intra-lab accuracy

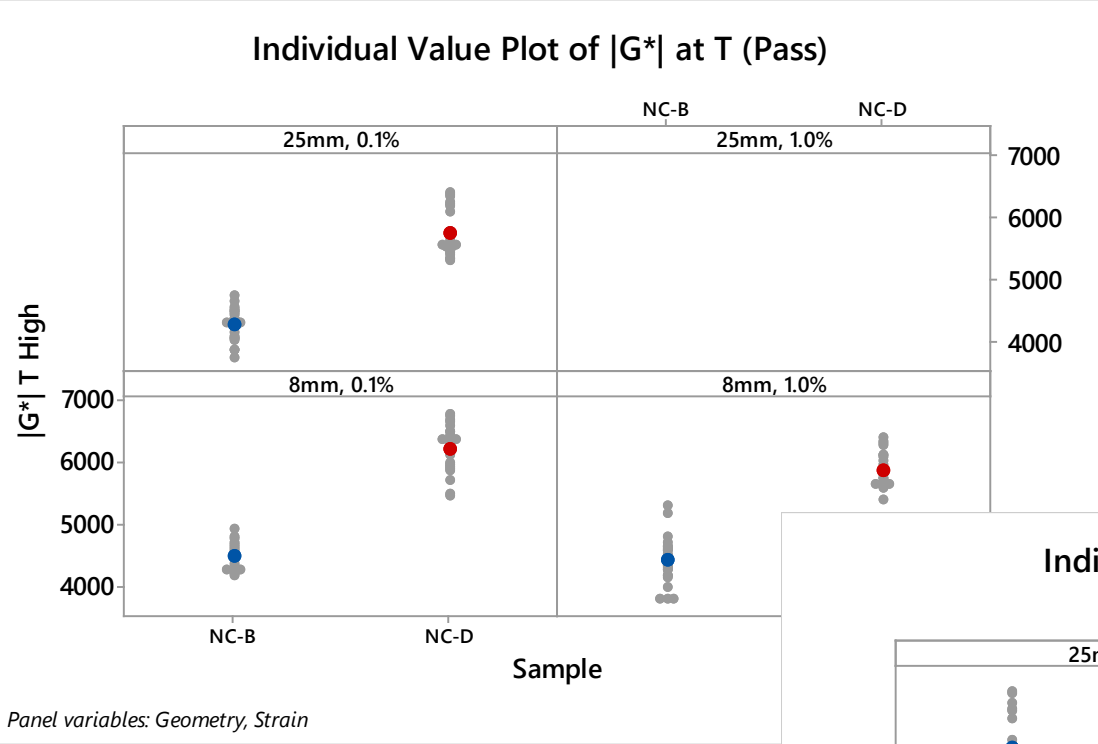
StDev in individual labs, lower=better



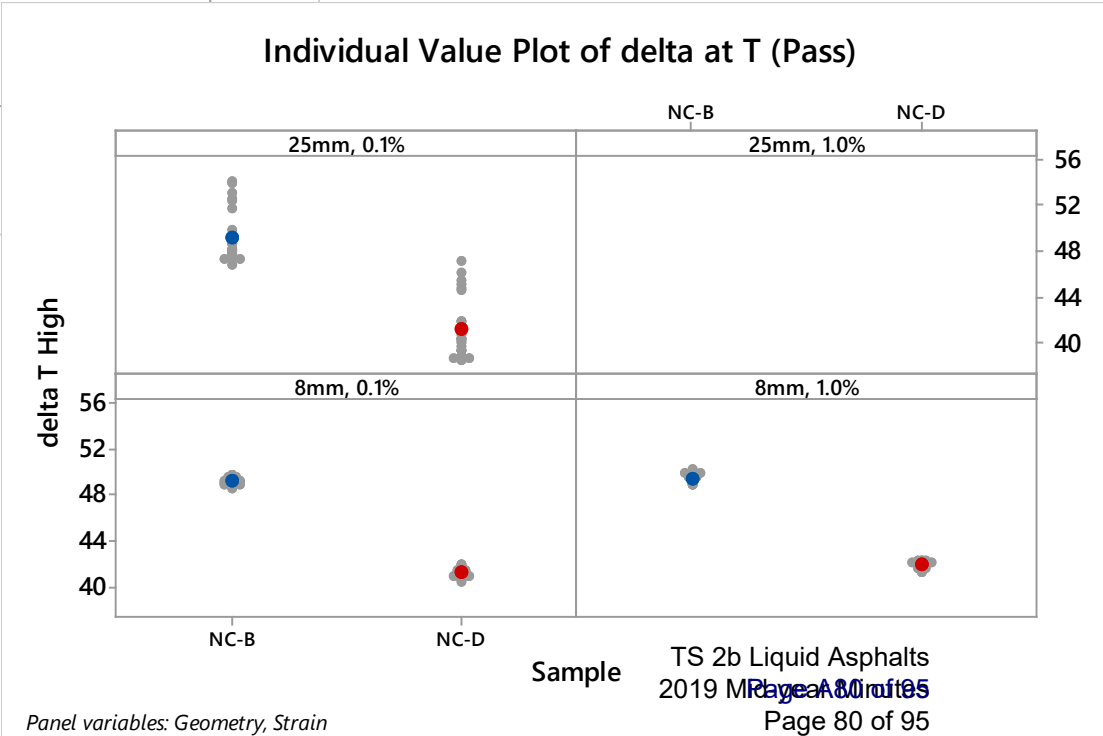
Dispersion all data/all labs, shorter=better



Phase Angle Discriminates Properties

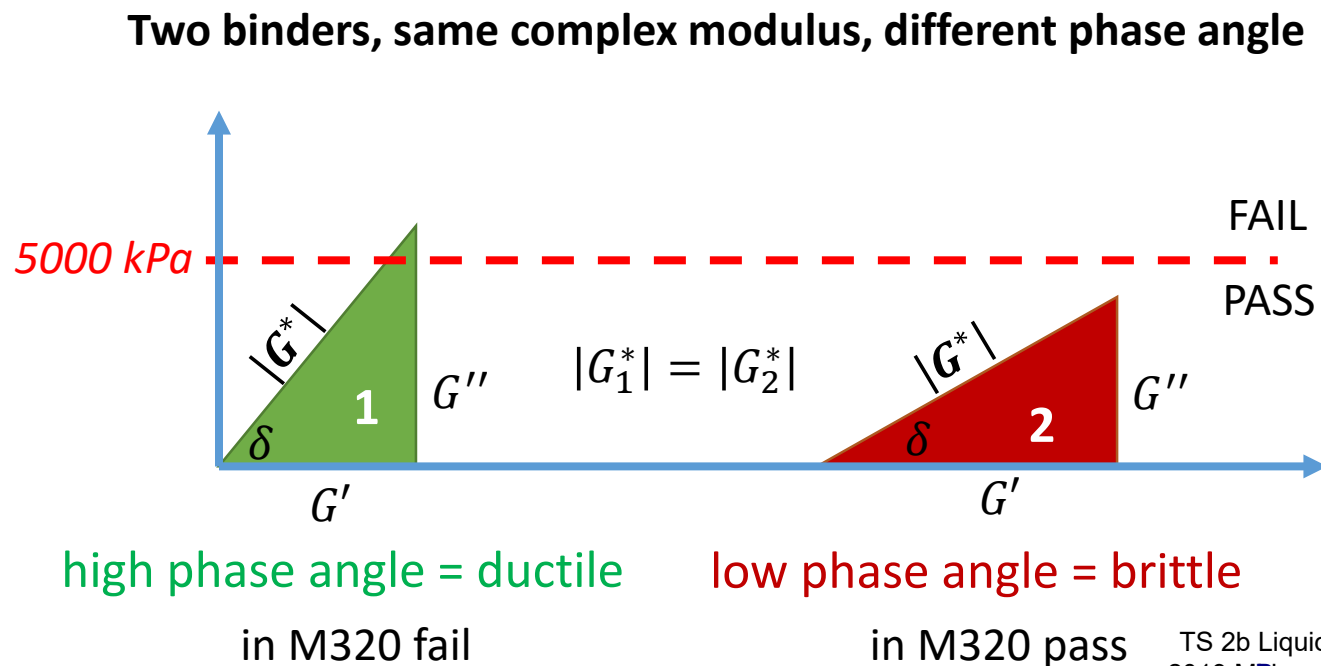


ATTACHMENT D



Findings 2: Science Behind DSR-PAV

- Limiting $|G^*| \sin \delta (= G'')$ to a maximum limit is benefiting low phase angle, i.e. **brittle** binders
- High quality **ductile** binders with high phase angle are disadvantaged.



Findings 3: DSR-PAV vs. Binder Performance

ATTACHMENT D

- Phase instability is demonstrated in more negative delta Tc, higher aging index and lower phase angle. It increases with oxidation/aging, addition of paraffinic wax and oil, REOB, incompatible asphaltenes etc.
- $|G^*| \sin \delta$ parameter was found not to correlate with binder phase instability, in contrary **all samples passed $|G^*| \sin \delta$ limit of 5000 kPa**

Phase Angle vs. Aging Rate

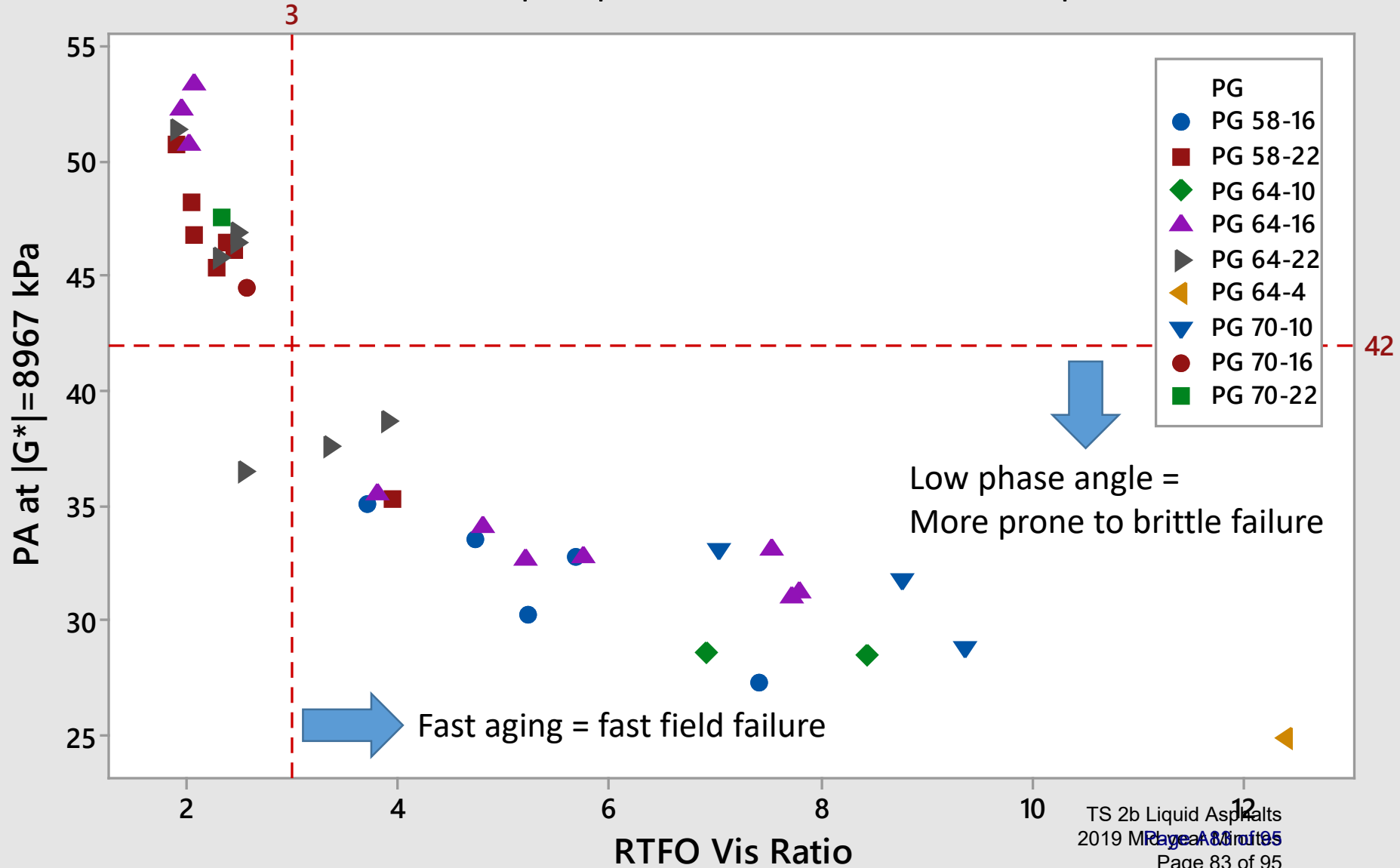
ATTACHMENT A

asphalt institute



ATTACHMENT D

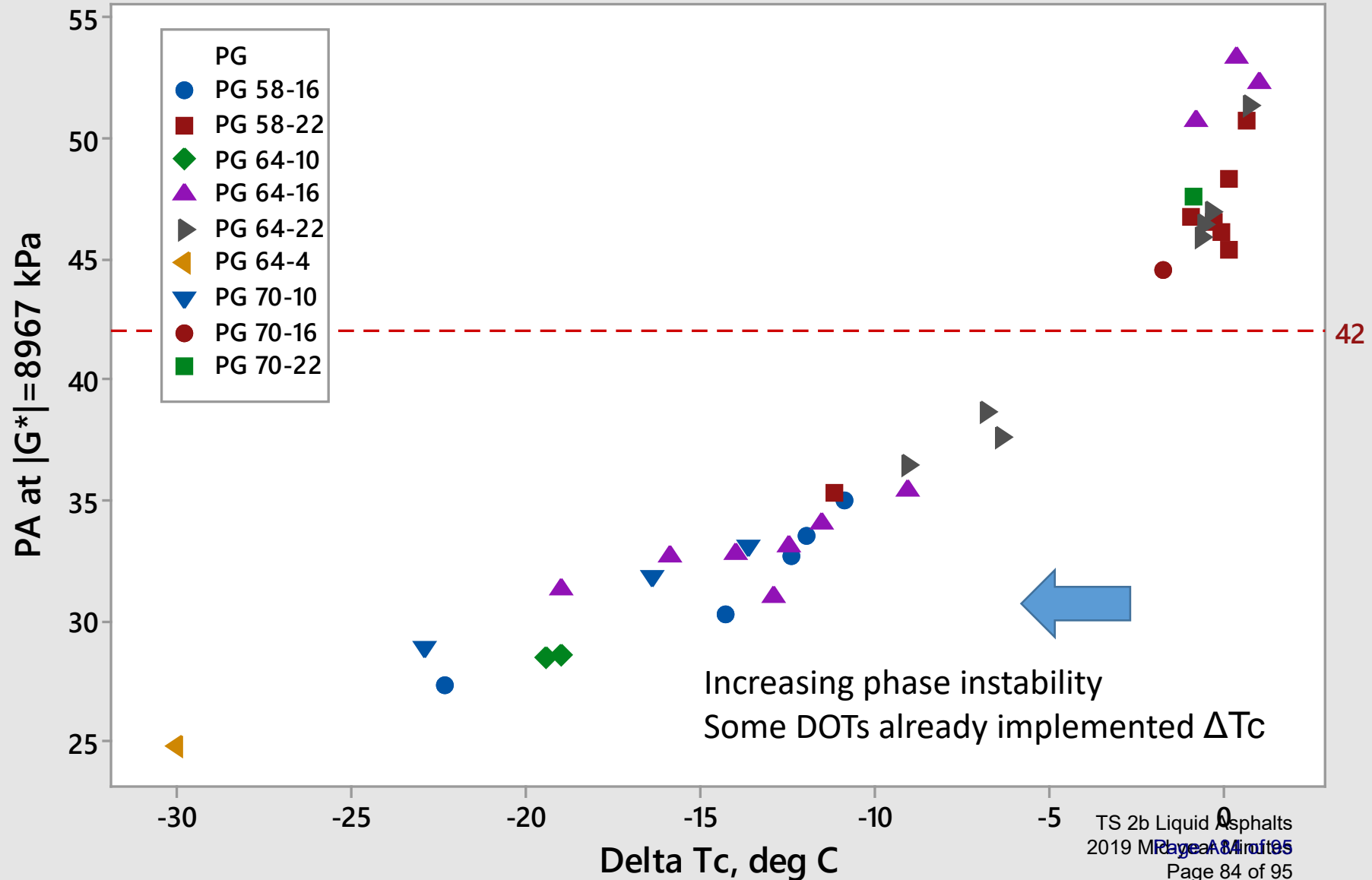
- All samples passed DSR-PAV for their respective PG



Phase Angle vs. delta Tc (relaxation)

- All samples passed DSR-PAV for their respective PG

ATTACHMENT D



- Do not alter current AASHTO T315 test protocol
- Support phase angle minimum limit at constant complex modulus value to replace $|G^*| \sin \delta$.
 - This approach utilizes correct science
 - Discriminates poor performers
 - Is practical – uses existing test protocol, labs are familiar with testing & historical data for comparison & validation exist. Best “speed to market” vs. other proposals

AI TAC supports changes to AASHTO M320 and M332 (S-grade) to allow binders with DSR-PAV $|G^*| \sin \delta$ parameter between 5001 - 6000 kPa (as for H, V, E grades), if their phase angle at the intermediate PG temperature is higher than 42 degrees to rectify an impact of a highly variable DSR-PAV test.

AI TAC supports industry efforts to replace $|G^*| \sin \delta$ parameter with a more repeatable and scientifically correct parameter

This proposal was reviewed at Dec 2018 ETG Meeting

THANK YOU!

Appendix

ATTACHMENT A



ATTACHMENT D

Supporting Data Objective 1

ATTACHMENT A

asphalt | institute 

ATTACHMENT D

Thermal Equilibrium

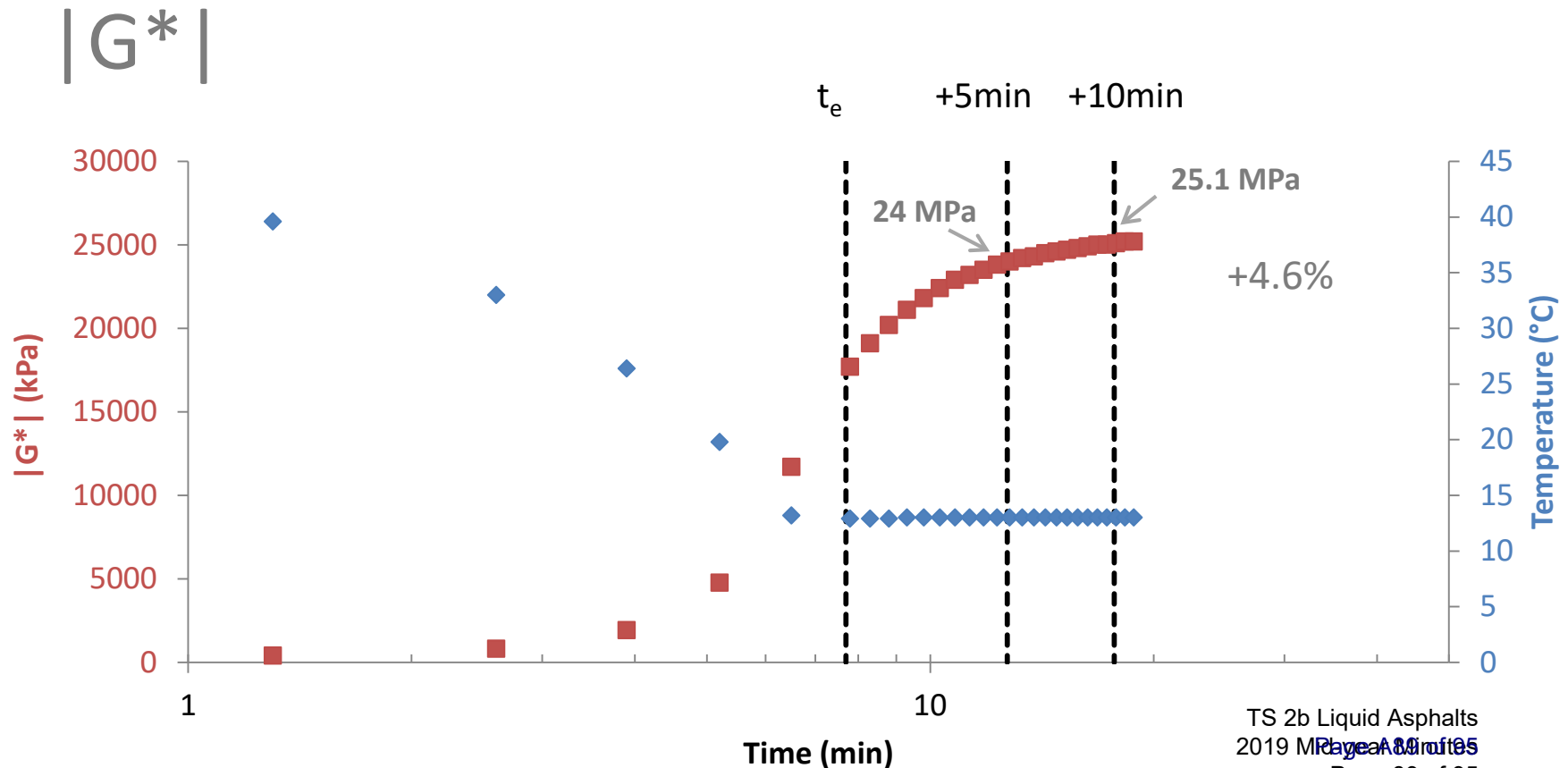
ATTACHMENT A

asphalt institute



ATTACHMENT D

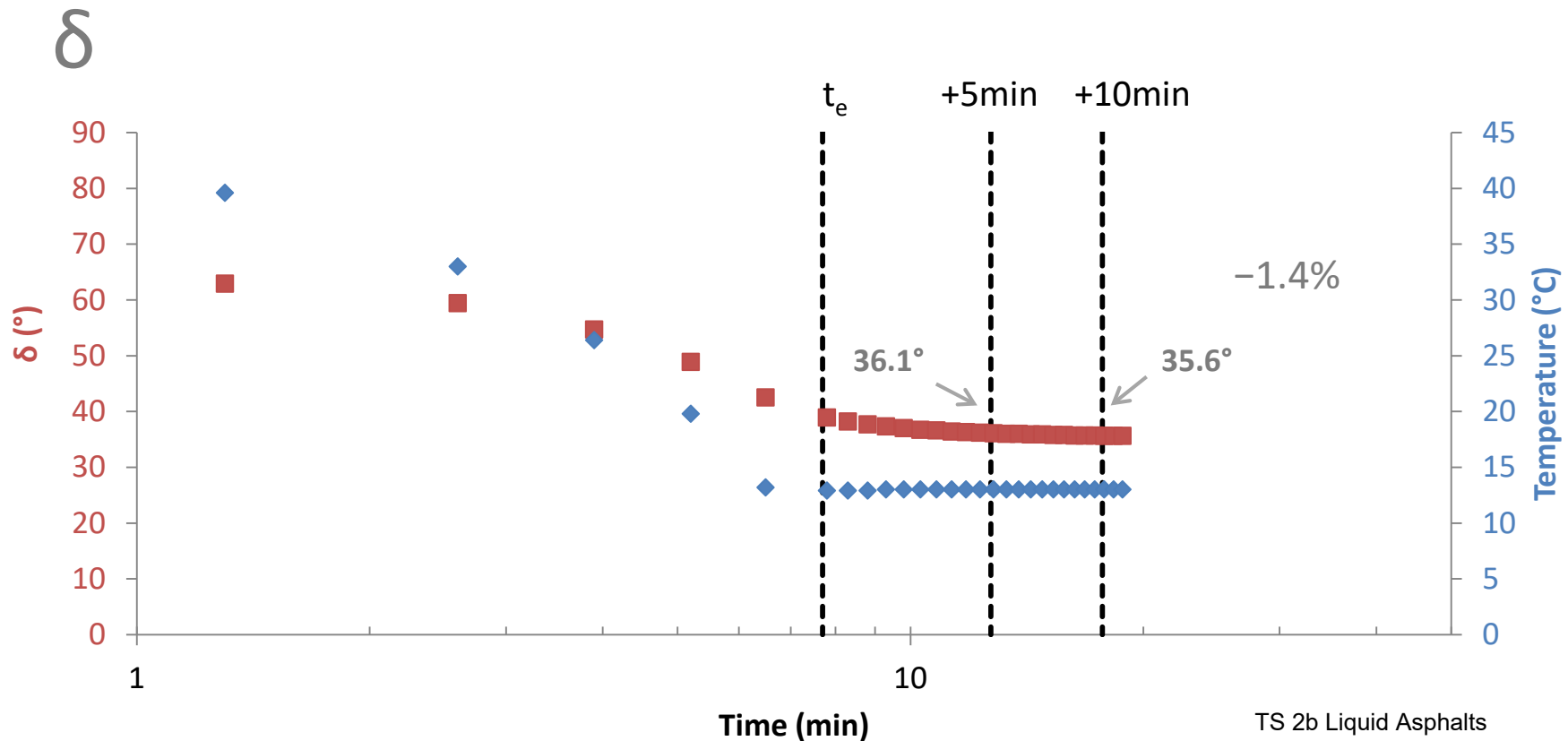
1. Thermal Equilibrium is not a significant factor in DSR-PAV variability, however DSR manufacturers should further research it



Thermal Equilibrium



1. Thermal Equilibrium is not a significant factor in DSR-PAV variability, however DSR manufacturers should further research it



Thermal Equilibrium

ATTACHMENT A

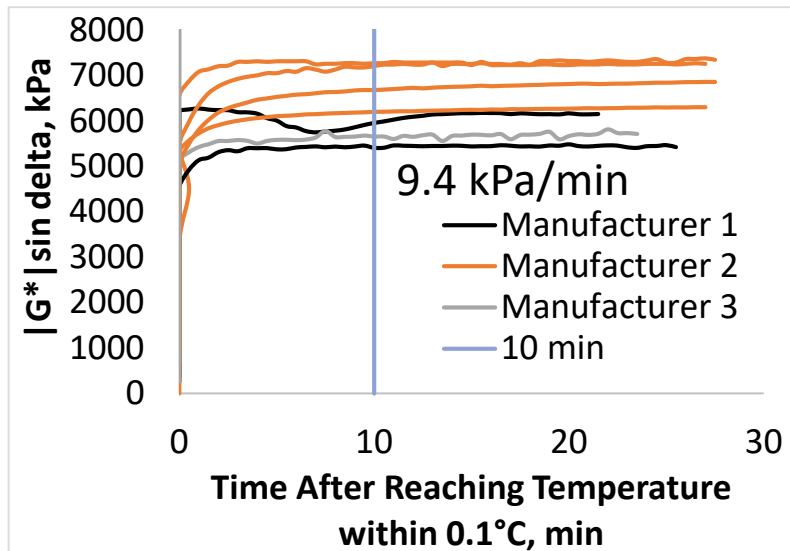
asphalt institute



ATTACHMENT D

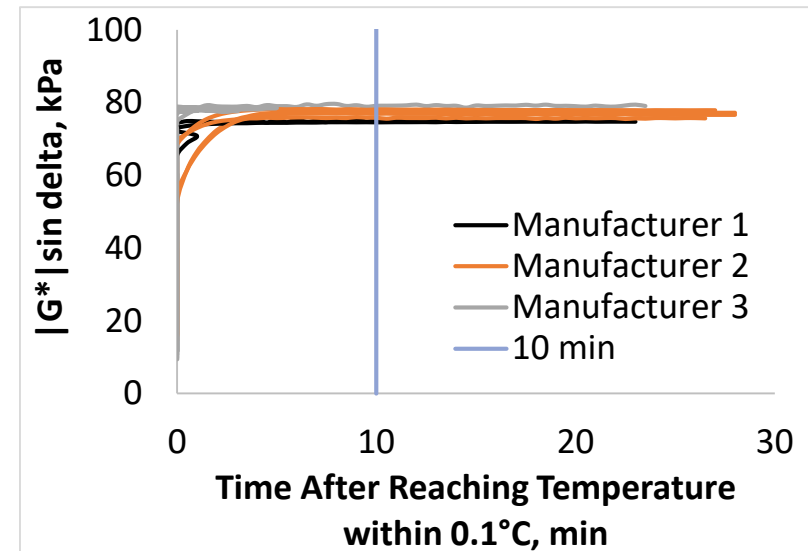
1. Thermal Equilibrium is not a significant factor in DSR-PAV variability, however DSR manufacturers should further research it

NC-D Asphalt



19 °C

Cannon Standard



13 °C

Supporting Data Objective 2

ATTACHMENT A

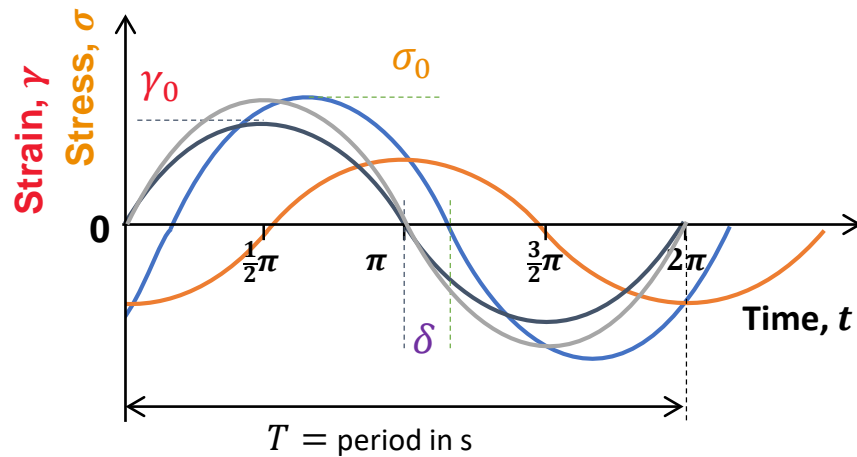
asphalt | institute 

ATTACHMENT D

Complex, Storage & Loss Moduli

ATTACHMENT A

asphalt institute



$$\omega = \frac{2\pi}{T} = 2\pi f \text{ (analogous to } \dot{\gamma} \text{)}$$

$$\sigma = \sigma_0 \sin(\omega t + \delta)$$

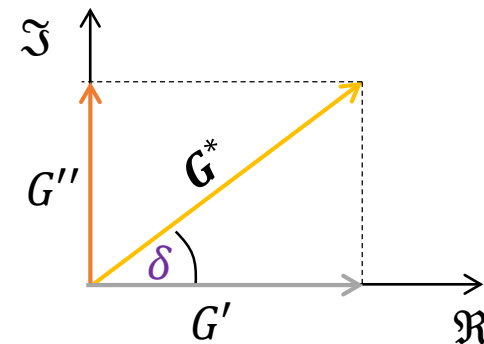
$$\sigma = \underbrace{\sigma_0 \cos \delta \sin \omega t}_{\sigma \text{ in phase with } \gamma} + \underbrace{\sigma_0 \sin \delta \cos \omega t}_{\sigma \text{ out of phase with } \gamma}$$

$$\sigma = \gamma_0 \left[\underbrace{\left(\frac{\sigma_0}{\gamma_0} \right) \cos \delta \sin \omega t}_{G'} + \underbrace{\left(\frac{\sigma_0}{\gamma_0} \right) \sin \delta \cos \omega t}_{G''} \right]$$

Representation in Complex Plane

ATTACHMENT D

(σ out of phase γ)
viscous



(σ in phase with γ)
elastic

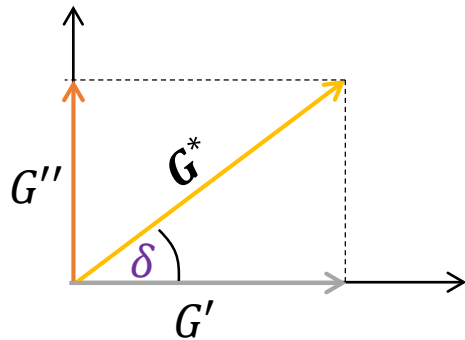
$$G^* = G' + iG''$$

$$|G^*| = \sqrt{G'^2 + G''^2} = \frac{\sigma_0}{\gamma_0}$$

$$\tan \delta = G''/G'$$

symbol	modulus	energy	response
G'	storage	stored	elastic
G''	loss	dissipated	viscous

Science Behind DSR-PAV

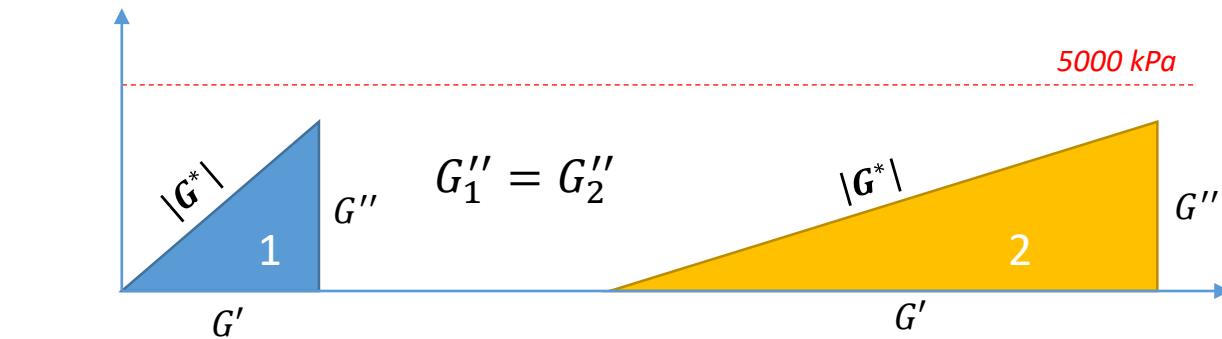


$$G^* = G' + iG''$$

$$|G^*| = \sqrt{G'^2 + G''^2} = \frac{\sigma_0}{\gamma_0}$$

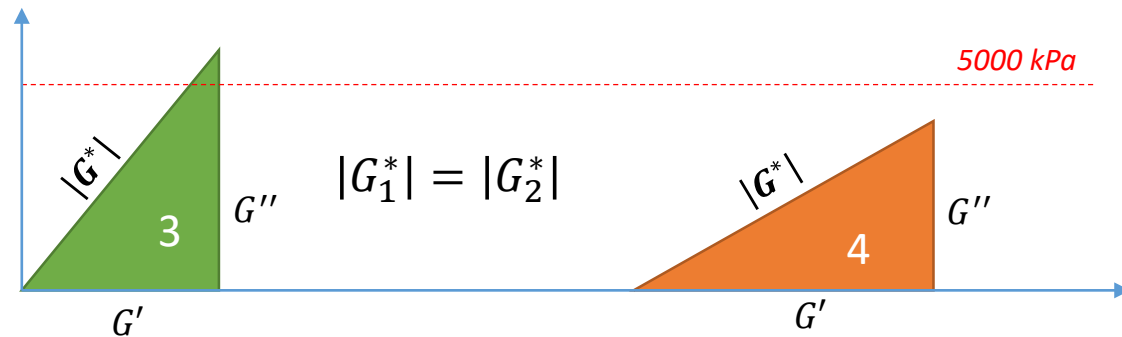
$$\tan \delta = G''/G'$$

$$|G^*| \cdot \sin \delta = |G^*| \frac{G''}{|G^*|} = G''$$



high phase angle = ductile

low phase angle = brittle

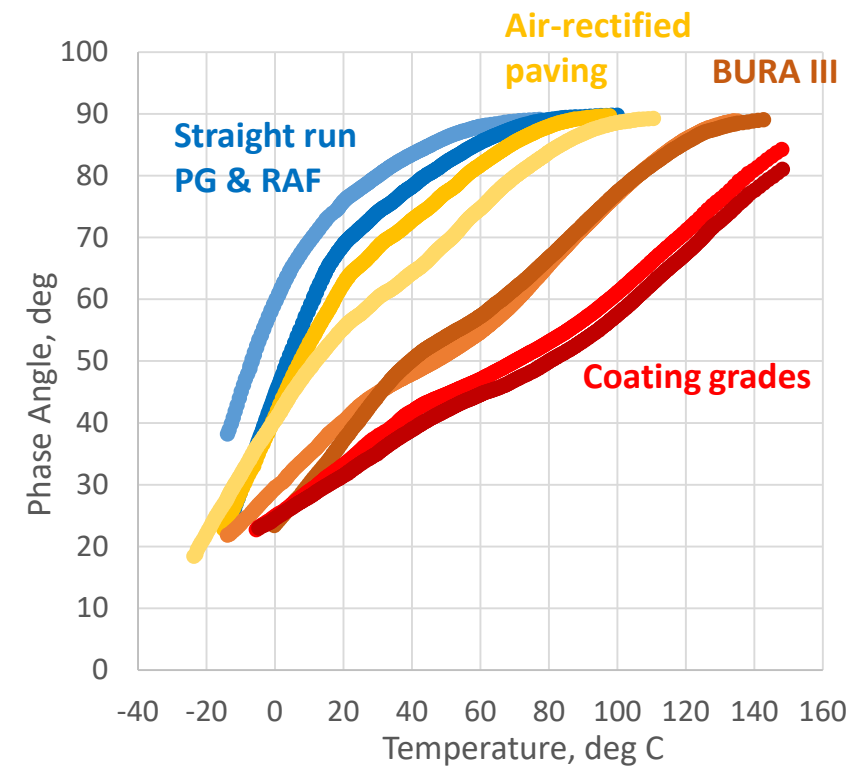
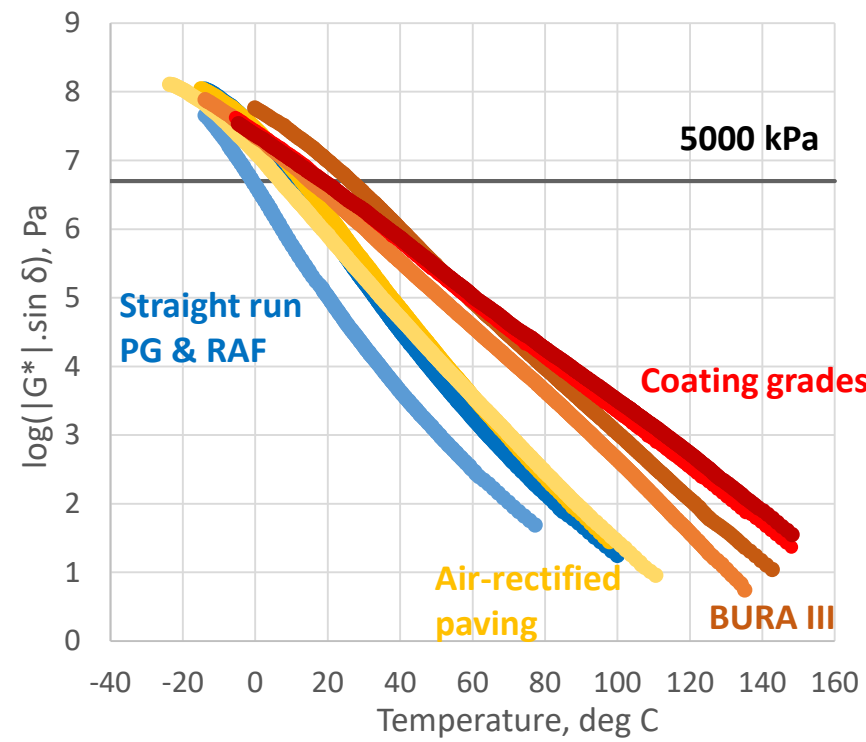


high phase angle = ductile

low phase angle = brittle



- Two asphalts (PG 64 & PG 46) were oxidized to variety of products ranging from 1 PG stiffer paving grade to roofing coating grades
- Phase angle offers clear differentiation between these binders



**NCHRP Project 20-07 / Task 400
Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder**

Revised Final Report

**Prepared for
National Cooperative Highway Research Program
Transportation Research Board**

of

The National Academies of Sciences, Engineering and Medicine

**TRANSPORTATION RESEARCH BOARD OF
THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING
AND MEDICINE
PRIVILEGED DOCUMENT**

This document, not released for publication, is furnished only for review to members of or participants in the work of CRP. This document is to be regarded as fully privileged and dissemination of the information included herein must be approved by CRP

by

**Advanced Asphalt Technologies, LLC
40 Commerce Circle
Kearneysville, WV 25430
December, 2018**

Permission to use any unoriginal material has been obtained from all copyright holders as needed.

Acknowledgement of Sponsorship

This work was sponsored by the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine.

Disclaimer

This is an uncorrected draft as submitted by the contractor. The opinions and conclusions expressed or implied herein are those of the contractor. They are not necessarily those of the Transportation Research Board, the Academies, or the program sponsors.

Table of Contents

Table of Contents.....	i
Table of Figures	iii
Table of Tables.....	iv
ABSTRACT.....	V
SUMMARY.....	1
CHAPTER 1 BACKGROUND.....	3
Problem.....	3
Rolling Thin Film Oven Test (RTFOT) Conditioning	3
Expected Elevation Effects.....	4
Observed Elevation Effects	5
Objective and Scope	5
CHAPTER 2 RESEARCH APPROACH.....	6
Introduction.....	6
Analysis of Available Data.....	6
Data Sources	6
Elevation Versus Barometric Pressure.....	6
Statistical Analysis.....	7
Engineering Analysis	13
RTFOT Conditioning Time Experiment	15
Methods to Account for the Elevation Effect	15
Effect of Binder Properties on Elevation Effect.....	15
Vary RTFOT Operating Parameters With Elevation.....	15
Theoretical Estimate of Additional RTFOT Conditioning Time.....	19
Experimental Design	20
Background	20
Basic Experimental Design	21
Binders	21
Laboratory Testing	21
CHAPTER 3 FINDINGS AND APPLICATION.....	24
Introduction.....	24
Analysis of Rheological Property Data	24
Graphical Analysis	24

Statistical Analysis 24

 Outlier Analysis..... 25

 Initial Linear Regression Analysis 26

 Optimization..... 27

 Final Linear Regression Analysis..... 27

Analysis of Mass Change Data 29

 Graphical Analysis 29

 Statistical Analysis 29

Application 31

CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS..... 32

Conclusions..... 32

Recommendations for Implementation 32

 No Modification of AASHTO T 240 32

 Interlaboratory Studies 32

 Recommendation for Binder Acceptance 32

 Modification of AASHTO T 240..... 33

REFERENCES..... 34

APPENDIX A BINDER GRADING DATA..... 35

APPENDIX B LABORATORY INSTRUCTIONS 37

APPENDIX C RECOMMENDED MODIFICATION TO AASHTO T 240 40

Table of Figures

Figure 1. Results From the SHRP Volatilization Experiment.	4
Figure 2. Reported Barometric Pressure for Reported Elevations.	7
Figure 3. Effect of Elevation on Properties for WCTG Binder 552.	11
Figure 4. Effect of Elevation on Properties for AASHTO Resource Binder 235/236.	12
Figure 5. Engineering Significance of Elevation Effect on AASHTO M 320 High Temperature Performance Grade Criterion.	13
Figure 6. Engineering Significance of Elevation Effect on AASHTO M 332 High Temperature Performance Grade Criteria.	14
Figure 7. Relationship Between 135 °C Viscosity and Elevation Effect.	16
Figure 8. Preliminary RTFOT Conditioning Time Study Results.	18
Figure 9. Graphical Representation of the Experimental Design.	23
Figure 10. Example Graphical Analysis of Rheological Properties.	25
Figure 11. Residuals After Optimization.	28
Figure 12. Mass Change Versus Elevation for Binder B2 and Binder B3.	30
Figure 13. Comparison of Measured and Fitted Mass Change Data for Binders B2 and B3.	31

Table of Tables

Table 1. Summary of Statistical Analysis of Available Data with Outliers Removed.	9
Table 2. Summary of Significant Elevation Effects.....	10
Table 3. Summary of $G^*/\sin\delta$ Elevation Effects from Various Studies.	10
Table 4. Summary of Elevation Effect by AASHTO M 332 Traffic Level.....	14
Table 5. Summary of Preliminary RTFOT Conditioning Time Study Results.....	17
Table 6. Estimate of Additional Conditioning Time for AASHTO Resource Binders.....	19
Table 7. Estimated Equivalent RTFOT Conditioning Times Using Carbonyl Model.....	20
Table 8. Participating Laboratories, Elevations, and RTFOT Conditioning Times.....	22
Table 9. Binders Used in RTFOT Conditioning Time Experiment.	23
Table 10. Rheological Property Outliers.....	26
Table 11. Summary of Initial Linear Regression.....	26
Table 12. Summary of Elevation Adjustment Time Optimization.	27
Table 13. Summary of Final Linear Regression.	29
Table 14. Summary of Mass Change Model.....	30

Abstract

This report documents research conducted to investigate the effect of elevation on the properties of residue and mass change measurements from AASHTO T 240. The research included: (1) evaluation of proficiency sample test results to determine the magnitude and significance of the elevation effect, (2) identification and assessment of methods to minimize the elevation effect, (3) design and execution of a laboratory experiment to adjust the conditioning time in AASHTO T 240 as a function of elevation to minimize the elevation effect, and (4) recommendation of modifications to AASHTO T 240 to implement the findings of the research. The primary conclusion drawn from the research is laboratory elevation affects both the rheological properties of the residue and the mass change for asphalt binders conditioned in accordance with AASHTO T 240. It is possible to approximately account for the effect of elevation by increasing the conditioning time as a function of elevation and applying a mass change adjustment.

S U M M A R Y

Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder

This report documents research conducted by the National Cooperative Highway Research Program to investigate the effect of elevation on the properties of residue and mass change measurements from AASHTO T 240, *Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)*. For tests on AASHTO T 240 residue, laboratories at higher elevations report lower AASHTO M 320 $G^*/\sin\delta$ values, lower AASHTO M 332 recovery values, and higher AASHTO M 332 nonrecoverable compliance (J_{NR}) values compared to laboratories at lower elevation. The prevailing theory is that the lower oxygen content per unit volume of air available at higher elevations results in reduced oxidative aging of the asphalt binder during AASHTO T 240 conditioning. This elevation effect can lead to poor reproducibility between laboratories at different elevations and different conclusions being drawn concerning the acceptability of the same binder under AASHTO M 320 and AASHTO M 332 when tested at different elevations.

The research documented in this report included: (1) evaluation of proficiency sample test results obtained from the Western Cooperative Testing Group and AASHTO re:source to determine the magnitude and significance of the elevation effect, (2) identification and assessment of methods to minimize the elevation effect, (3) design and execution of a laboratory experiment to adjust the conditioning time in AASHTO T 240 as a function of elevation to minimize the elevation effect, and (4) recommendation of modifications to AASHTO T 240 to implement the findings of the research.

The primary conclusion drawn from analysis of the proficiency sample data and the experiment conducted in this project is laboratory elevation affects both the rheological properties of the residue and the mass change for asphalt binders conditioned in accordance with AASHTO T 240. It is possible to approximately account for the effect of elevation on the rheological properties of the residue by increasing the conditioning one minute for every 1,000 ft increase in elevation. When this conditioning time adjustment is applied, 0.006 percent should be added to the resulting mass change for every 1,000 increase in elevation.

The research produced two recommendations. First to address poor reproducibility between laboratories at different elevations in interlaboratory studies, it was recommended that the statistical analysis of the interlaboratory study data should consider the elevation effect. This can be accomplished by regressing the data against elevation. If the elevation effect is significant, then the standardized residuals (residuals divided by the standard deviation of the residuals) should be used to rate the performance of each laboratory on the same scale that is currently used based on standard deviation. If the elevation effect is not significant, then the analysis can be performed in the usual manner using the standard deviation to rate the performance of each laboratory. Second to address the possibility of different conclusions being drawn concerning the acceptability of the same binder under AASHTO M 320 and AASHTO M 332 when tested at different elevations, it was recommended that when a producer's laboratory is 1,000 ft or more below the elevation of the acceptance laboratory, agencies should consider directing the producer to use the conditioning time and mass change adjustments developed in this study. For this application, the conditioning time in the

producer's laboratory at a lower elevation should be decreased by one minute for every 1,000 ft rounded to the nearest minute, and the resulting mass change should be decreased by 0.006 percent for every 1,000 ft.

CHAPTER 1

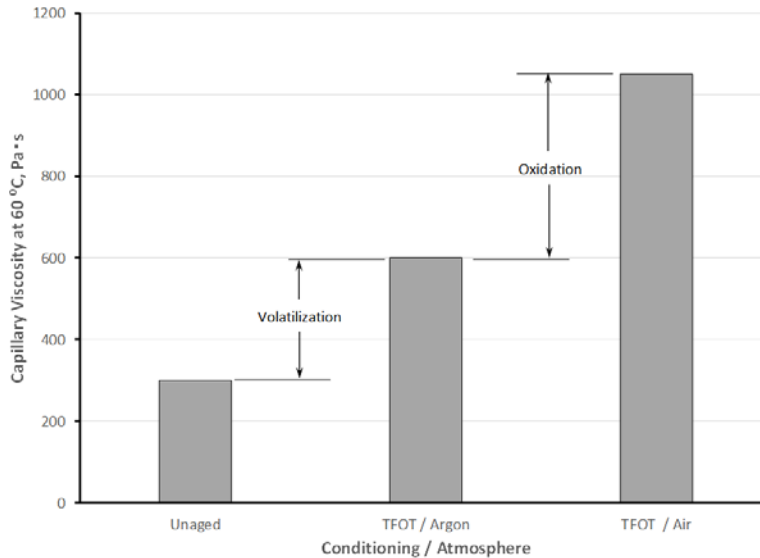
Background

Problem

To simulate the aging that occurs during construction, the specifications for performance graded (PG) asphalt binder, AASHTO M 320, *Standard Specification for Performance-Graded Asphalt Binder*, and AASHTO M 332, *Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test*, include criteria for tests on residue from AASHTO T 240, *Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)*. For tests on AASHTO T 240 residue, laboratories at higher elevations report lower AASHTO M 320 $G^*/\sin\delta$ values, lower AASHTO M 332 recovery values, and higher AASHTO M 332 nonrecoverable compliance (J_{NR}) values compared to laboratories at lower elevation. The prevailing theory is that the lower oxygen content per unit volume of air available at higher elevations results in reduced oxidative aging of the asphalt binder during AASHTO T 240 conditioning. This elevation effect can lead to poor reproducibility between laboratories at different elevations and different conclusions being drawn concerning the acceptability of the same binder under AASHTO M 320 and AASHTO M 332 when tested at different elevations. A recent study by the Modified Asphalt Research Center at the University of Wisconsin-Madison reviewed data from the Western Cooperative Testing Group interlaboratory testing and concluded that the rheological properties of residue from AASHTO T 240 were affected by elevation and that AASHTO T 240 needed refinement to take laboratory elevation into account (Velasquez, et. al., 2013).

Rolling Thin Film Oven Test (RTFOT) Conditioning

During AASHTO T 240 conditioning, two processes change the properties of asphalt binders: (1) volatile loss, and (2) oxidation (Anderson et al., 1994). Both processes increase the stiffness of asphalt binders. Figure 1 shows the results of a volatilization experiment for binder AAK-1 conducted during the Strategic Highway Research Program (SHRP) where short-term conditioning was conducted in a Thin Film Oven modified to use different gases (Anderson et al., 1994). Results should be similar for the RTFOT. As labelled on the figure, the difference between unaged and Argon is the increase in viscosity caused by volatilization. And the difference between Argon and Air is the increase in viscosity caused by oxidation. This figure shows both processes are important. The relative contribution of volatilization and oxidation is probably binder dependent.



Source of Data: Anderson, et al., 1994

Figure 1. Results From the SHRP Volatilization Experiment.

Expected Elevation Effects

Atmospheric pressure, which is the force per unit area exerted against a surface by the weight of the air above that surface, decreases with increasing elevation. Equation 1 is the well accepted relationship first published in 1963 for the variation in atmospheric pressure with elevation (Manual of Barometry, 1963). Over the range of elevations of interest for this project, atmospheric pressure, as affected by elevation, varies from about 101.3 kPa (760 mm Hg) at sea level to about 78.2 kPa (609.6 mm Hg) at an elevation of 7,000 ft.

$$p_h = p_o \times (1 - 2.256 \times 10^{-5} \times h)^{5.256} \quad (1)$$

where:

- p_h = air pressure (kPa) at elevation h
- p_o = atmospheric pressure at sea level, 101.325 kPa
- h = elevation above sea level (m)

Equation 1 can be approximated with a linear relationship with an error of no more than 0.66 percent from sea level to 7,000 feet. Based on the linear approximation, atmospheric pressure change is approximately 0.36 kPa per 100 ft (2.8 mm Hg per 100 ft). The typical range in atmospheric pressure expected from daily and seasonal weather changes at any elevation is approximately ± 12.5 mm Hg (Weather Underground, 2017), which is approximately equal to a change in elevation of about ± 450 ft.

The composition of air remains constant up to an elevation of 10 km (33,000 ft) (The Engineering ToolBox, 2016). Therefore, over the range of elevations of interest for this project, the volume composition of air is approximately 78 percent nitrogen, 21 percent oxygen, and 1 percent other gases.

Differences in atmospheric pressure have the potential to affect both volatilization and oxidation. As the atmospheric pressure decreases, the temperature where volatile components are vaporized will decrease, which will increase volatile loss producing a stiffer residue. This effect is captured in the temperature corrections for AASHTO T 48, *Standard Method of Test for Flash and Fire Points by Cleveland Open Cup*, and AASHTO T 78, *Standard Method of Test for Distillation of Cutback Asphalt Products*.

The effect of atmospheric pressure on the concentration of oxygen molecules in the atmosphere, which affects oxidation, is explained by the Ideal Gas Law, Equation 2. For the same volume of air at the same temperature, there are fewer air molecules as the elevation increases and therefore, fewer oxygen molecules available for oxidation. At an elevation of 7,000 ft, atmospheric pressure is approximately 78 percent of that at sea level, so the number of oxygen molecules available for oxidation is 78 percent of that at sea level.

$$pV = nRT \quad (2)$$

where:

p = absolute pressure, N/m²

V = volume, m³

n = number of moles of gas

R = universal gas constant = 8.3145 J/mol K

T = absolute temperature, °K

Observed Elevation Effects

The effect of elevation on the properties of RTFOT residue has been evaluated independently at the Colorado State University (CSU) (Wang, 2013) and the Modified Asphalt Research Center (MARC) (Velasquez, et al., 2013) using data from the Western Cooperative Testing Group (WCTG). These studies concluded that the stiffness of RTFOT residue decreased with increasing elevation, suggesting that the oxidation effect described above is dominant. Neither study included an analysis of mass change measurements. The rates of change in $G^*/\sin\delta$ reported in the two reports range from -0.016 kPa/1,000 ft to -0.108 kPa/1,000 ft; the upper and lower range differ by a factor 6.8. This may be due to several factors including: (1) differences in the oxidation rate for various binders, (2) differences in volatilization for the various binders, (3) between laboratory differences in RTFOT equipment and procedures, and (4) between laboratory differences in dynamic shear rheometer testing. Using the average rate of -0.053 kPa/1,000 ft reported in the MARC study, an elevation difference of 4,000 ft corresponds to an error of approximately 10 percent of the RTFOT $G^*/\sin\delta$ pass/fail criterion of 2.20 kPa. Considering that the range of elevations for laboratories in the United States may be as much as 7,000 ft, the elevation effect appears to be a significant component of the variation of results between laboratories, and for binders produced near the specification limit, may result in different conclusions concerning the acceptability of the binder being drawn by two laboratories at different elevations.

Objective and Scope

AASHTO Technical Subcommittee 2b endorsed this research to further study the effect of elevation on the properties of residue from AASHTO T 240. The objectives of the project were: (1) to confirm or refute previous studies showing an elevation effect on properties of residue from AASHTO T 240, and if there is an elevation effect and it is of engineering significance, then (2) to improve the AASHTO T 240 procedure to minimize differences in physical properties of AASHTO T 240 residue obtained at different elevations. The elevation effect was confirmed through rigorous analysis of data from proficiency sample programs conducted by the WCTG and AASHTO re:source. A laboratory study was then conducted to adjust for the elevation effect by varying the conditioning time as a function of elevation.

CHAPTER 2

Research Approach

Introduction

The research was conducted in two sequential phases. The first phase was a statistical and engineering evaluation of data from proficiency sample programs conducted by the WCTG and AASHTO re:source. This evaluation confirmed that elevation significantly affected the properties of residue from AASHTO T 240. Based on this finding a laboratory study aimed at adjusting for the elevation effect by varying the conditioning time as a function of elevation was designed and executed. This chapter describes the methodology used in the two phases.

Analysis of Available Data

Data Sources

Two independent sets of data measured on RTFOT residue by laboratories at different elevations were used in the statistical analysis:

- **Western Cooperative Testing Group (WCTG) Data.** This data set included data from 11 binders tested by the WCTG. Ten of the 11 binders were modified binders. For this data set, one sample for each of the 11 binders was tested by approximately 40 different laboratories yielding 441 observations. The reported elevation for the laboratories ranged from 12 to 6,720 ft above sea level. The distribution of laboratories was relatively uniform over this elevation range.
- **AASHTO re:source Proficiency Sample Data.** This data set included data from four binders included in the AASHTO re:source proficiency sample testing: Sample 235/236, Sample 239/240, Sample 241/242, and Sample 245/246. Samples 235/236 and 239/240 were neat binders while samples 241/243 and 245/246 were modified binders. This data set included replicate test data from approximately 213 laboratories yielding 1,700 observations. The reported elevation for the laboratories ranged from 0 to 6,295 ft above sea level. This data set is weighted toward laboratories at lower elevation. Approximately 68 percent of the laboratories included in this data set are at elevations below 1,000 ft.

Elevation Versus Barometric Pressure

An important consideration in this project was whether to use elevation or barometric pressure as the basis for evaluating differences in the properties of RTFOT residue and for developing improvements to AASHTO T 240. As discussed above, atmospheric pressure varies with elevation and weather, although the variation caused by weather is significantly smaller. When reporting proficiency sample results, AASHTO re:source and WCTG also collect data on the elevation of the laboratory and the barometric pressure at the time of testing. However, apparently there is confusion amongst participating laboratories over the reporting of barometric pressure data. Some laboratories report barometric pressure corrected to sea level, most likely either from a local weather service or a barometer that corrects to sea level, while other laboratories report the actual barometric pressure at their elevation. This is shown graphically in Figure 2 using data reported for one of the WCTG samples. Plotting the reported barometric pressure as a

function of the reported elevation produces two distinct sets of data. The first set, which varies around the mean atmospheric pressure at sea level of 101.3 kPa, are laboratories reporting barometric pressure corrected to sea level. The second set, which varies around the line representing Equation 1, are laboratories reporting the barometric pressure at their elevation. The second set of data accurately reflect the atmospheric pressure at the elevation of the test. The incorrect reporting of barometric pressure was likely a factor in the MARC elevation study which showed significantly less explained variance when the data were regressed against reported barometric pressure compared to when the data were regressed against reported elevation (Velasquez, et al., 2013).

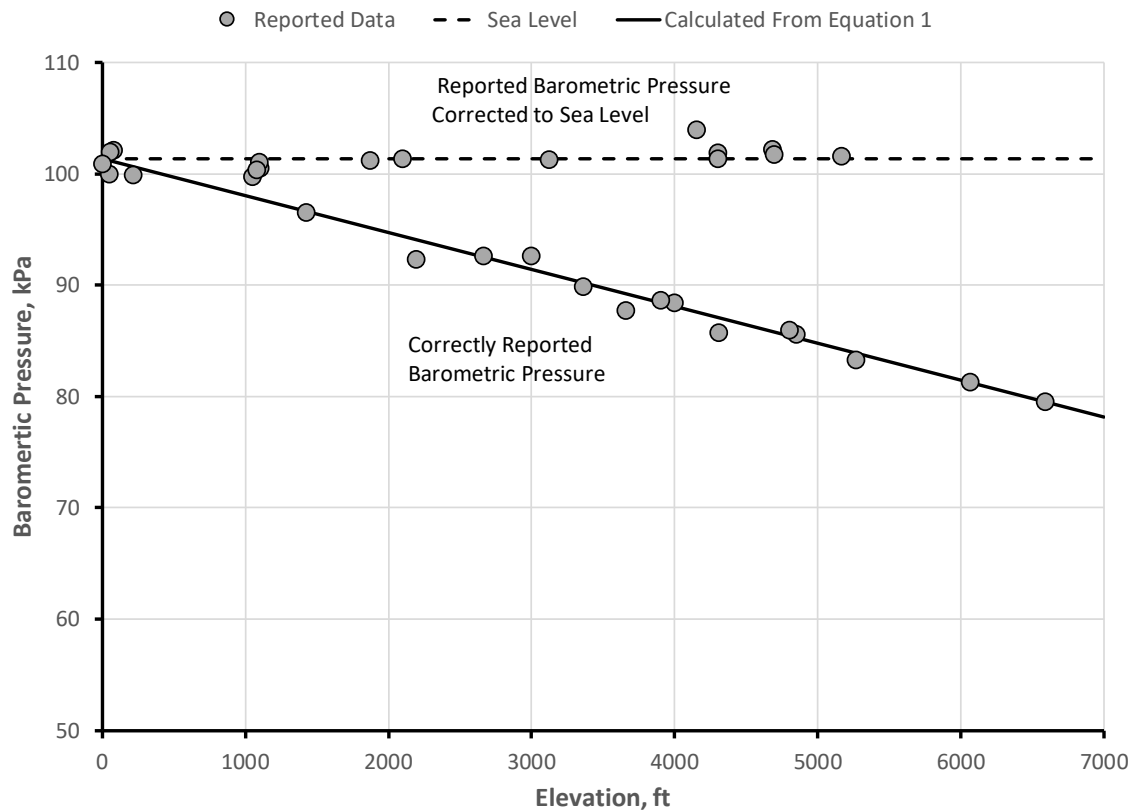


Figure 2. Reported Barometric Pressure for Reported Elevations.

For the analyses conducted during this project and for the improvements to AASHTO T 240 that will be recommended by this project, elevation was selected as the basis for the following reasons:

1. The lack of standardization in the reporting of barometric pressure by laboratories performing materials testing.
2. The pressure changes associated with weather are small compared to the range of elevations for laboratories in the United States; approximately ± 1.7 kPa for weather variations versus approximately 22 kPa for a 7,000 ft elevation difference.
3. The reported elevation for a laboratory is easily verified using on-line mapping tools.

Statistical Analysis

Elevation and six test properties were included in the data for both data sets. The test properties were: (1) Original $G^*/\sin\delta$, (2) RTFOT $G^*/\sin\delta$, (3) Aging Index (ratio of RTFOT $G^*/\sin\delta$ to Original $G^*/\sin\delta$),

(4) Mass Change, (5) RTFOT nonrecoverable compliance, J_{NR} , and (6) RTFOT percent recovery, R . Graphical and statistical analyses were performed separately on each data set for each of the six test properties. The graphical analysis included the preparation of plots as a function of elevation to identify trends in the data and the presence of potential outliers. The statistical analysis included a systemic identification of outliers followed by linear regression analysis. Dummy variables were used to allow the intercept and the slope of the relationship between the property of the RTFOT residue and elevation to vary for the different binders. To identify outliers, linear regression models with different intercepts and different slopes for each binder were prepared and observations with standardized residuals having absolute value greater than 2.5 were flagged as outliers. The final regression analysis was then conducted on the data set after removing the outliers.

Table 1 summarizes the results of the statistical analysis. Linear regression models including the specific binder and elevation as predictors explain 82 to 99 percent of the variance in the data sets. The major difference between this analysis for the WCTG data set and the analyses reported earlier by other researchers is this analysis collectively considers the trends in the data for all binders in the WCTG data set, where earlier analyses by other researchers treated each binder separately. The larger population used in this analysis, approximately 440 compared to approximately 40 used in earlier analyses by other researchers, improves the sensitivity of the statistical analysis. The AASHTO re:source data set includes even more observations. The same conclusions were reached for both data sets.

Table 1 shows there is no elevation effect for the original $G^*/\sin\delta$; however, the elevation effect is statistically significant for all the properties measured after RTFOT conditioning. Further, the elevation effect is binder dependent except for mass change.

Table 2 summarizes the slopes for the elevation effects. These slopes give the change in the respective property per 1,000 ft increase in elevation. The elevation effects for $G^*/\sin\delta$, Aging Index, mass change, and J_{NR} are rational and consistent between the two data sets. RTFOT $G^*/\sin\delta$ and Aging Index, decrease with increasing elevation while J_{NR} increases with increasing elevation due to the pressure dependency of the oxidation reaction. Mass change becomes increasingly negative with elevation due to the greater volatile loss that occurs due to the lower atmospheric pressure at higher elevations. The results for R show positive and negative slopes which may be the result of the effect of changes in oxidation on the polymers in the various modified binders. Note that the three neat binders and nine of the polymer modified binders have negative slope for R resulting in less recovery with increasing elevation which is expected based on the J_{NR} slopes. However, three of the polymer modified binders show an increase in recovery with elevation while the J_{NR} for these binders decreases with elevation.

Figures 3 and 4 show examples of the elevation effects for two of the 15 binders that were analyzed. These binders have slopes near the middle of the ranges in Table 2. The data in these figures have the outliers removed. Figure 3 shows the effects for binder 552 from the WCTG data set which is a polymer modified binder. Figure 4 shows the effects for binder 235/236 from the AASHTO re:source data set which is a neat binder.

Table 3 summarizes and compares the range of the elevation effects for RTFOT $G^*/\sin\delta$ data for the data sets analyzed in this project and those reported in earlier research. Note that different binders were analyzed in this study and the MARC study. The specific binders used in the CSU study were not identified. All three studies concluded that the elevation effect is significant, and Table 3 shows the elevation effect is binder specific, and that there is reasonable agreement from the three studies for the range of the elevation effect.

Table 1. Summary of Statistical Analysis of Available Data with Outliers Removed.

Data Set	Parameter	Observations		Significant Effects			Adj R ² , %	Conclusion
		Total	Outliers Removed	Elev.	Unequal Intercepts	Unequal Slopes		
WCTG	Original G*/sinδ	440	440	No	NA*	NA*	NA*	Elevation effect not significant
	RTFOT G*/sinδ	441	427	Yes	Yes	Yes	93.7	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	Aging Index	440	427	Yes	Yes	Yes	82.4	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	Mass Change	427	402	Yes	Yes	No	90.1	Significant elevation effect. Use model with unequal intercepts and equal slope
	J _{NR}	407	376	Yes	Yes	Yes	96.6	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	% R	400	353	Yes	Yes	Yes	99.0	Significant elevation effect. Use model with unequal intercepts and unequal slopes
AASHTO Resource	Original G*/sinδ	1674	1674	No	NA	NA	NA	Elevation effect not significant
	RTFOT G*/sinδ	1674	1635	Yes	Yes	Yes	92.7	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	Aging Index	1672	1601	Yes	Yes	Yes	89.0	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	Mass Change	1700	1593	Yes	Yes	No	93.8	Significant elevation effect. Use model with unequal intercepts and equal slope
	J _{NR}	1420	1363	Yes	Yes	Yes	82.4	Significant elevation effect. Use model with unequal intercepts and unequal slopes
	% R	1418	1349	Yes	Yes	Yes	98.6	Significant elevation effect. Use model with unequal intercepts and unequal slopes

*NA denotes not applicable

Table 2. Summary of Significant Elevation Effects.

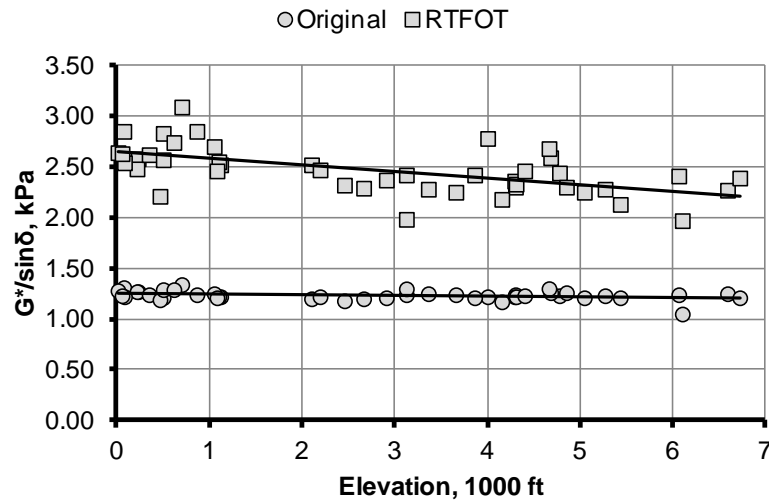
Data Set	Binder	Type*	RTFOT G*/sinδ, kPa/1,000 ft	Aging Index	Mass Change, %/1,000 ft	J _{NR} , kPa ⁻¹ /1,000 ft	% R, %/ 1,000 ft
WCTG	551	P	-0.0615	-0.0354	-0.0033	0.0333	-0.059
	552	P	-0.0641	-0.0427		0.0432	-0.269
	553	P	-0.0239	-0.0146		0.0394	-0.432
	554	P	-0.0173	-0.0136		0.0677	-0.677
	555	N	-0.1149	-0.0740		0.0927	-0.119
	556	P	-0.0496	-0.0251		0.0027	0.010
	557	P	-0.0914	-0.0442		0.0204	-0.546
	560	P	-0.0477	-0.0271		0.0416	-0.415
	561	P	-0.0477	-0.0379		0.0593	-0.282
	562	P	-0.0701	-0.0609		0.0249	0.720
	563	P	-0.0448	-0.0147		0.0076	-0.413
AASHTO Resource	235/236	N	-0.0613	-0.0374	-0.0059	0.0384	-0.094
	239/240	N	-0.0806	-0.0412		0.0470	-0.032
	241/242	P	-0.0302	-0.0233		-0.0002	0.519
	245/246	P	-0.0257	-0.0188		0.0236	-0.300

* N denotes neat binder, P denotes polymer modified binder

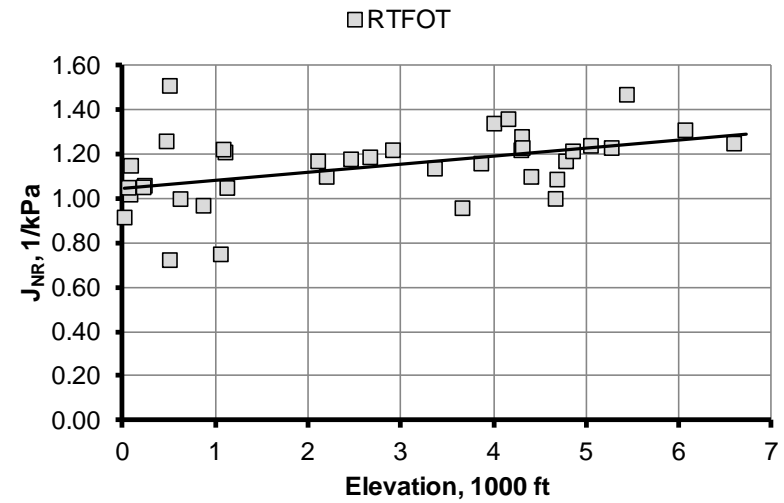
Table 3. Summary of G*/sinδ Elevation Effects from Various Studies.

Study	CSU	MARC	NCHRP 20-7 Task 400	
Source	Unspecified WCTG	WCTG Samples 519 to 532	WCTG Samples 551to 557 and 560 to 563	AASHTO Samples 235/235, 239/240, 241/242, and 245/246
Binders	7	14	11	4
Smallest Effect, kPa/1000 ft	NS*	NS*	-0.024	-0.026
Largest Effect, kPa/1000 ft	-0.083	-0.108	-0.115	-0.081

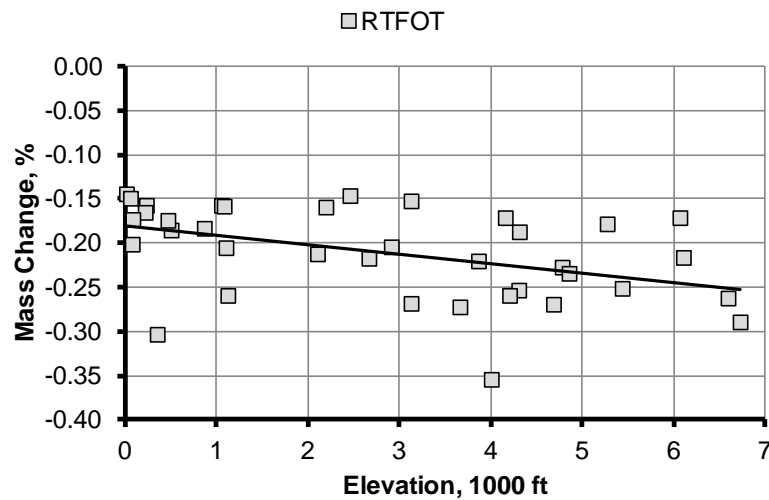
* NS denotes not significant



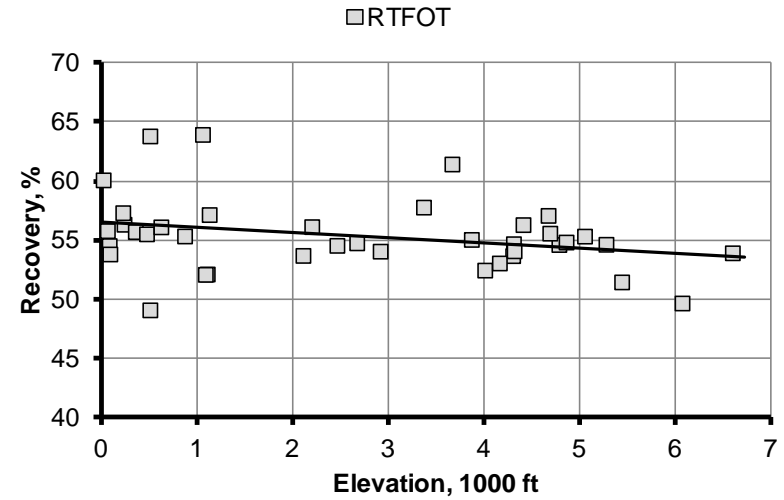
a. Original and RTFOT $G^*/\sin\delta$.



b. J_{NR} .

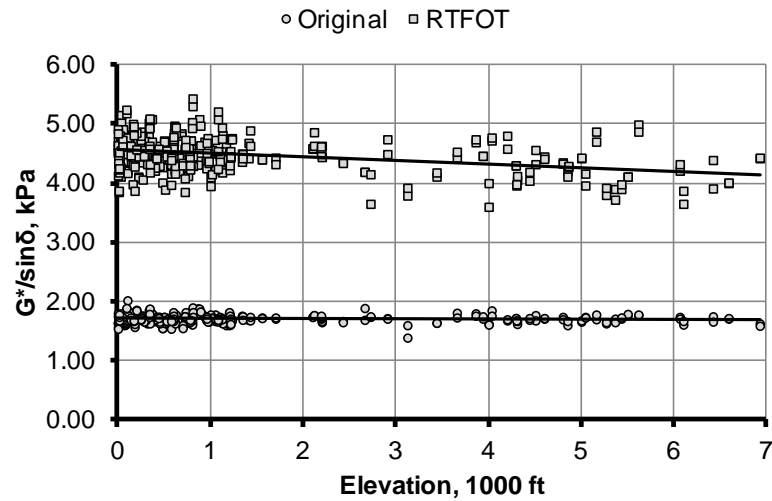


c. Mass Change.

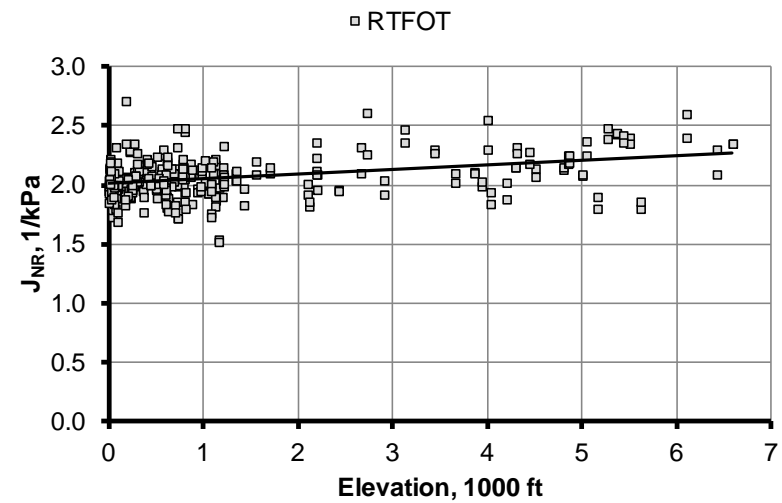


d. %R.

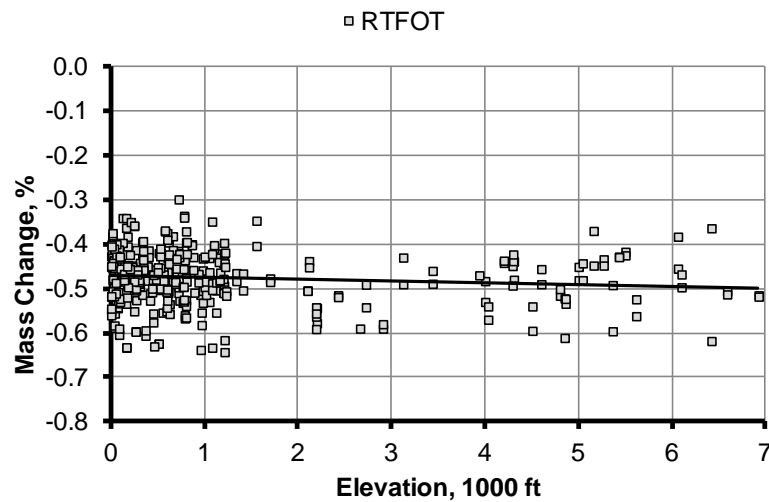
Figure 3. Effect of Elevation on Properties for WCTG Binder 552.



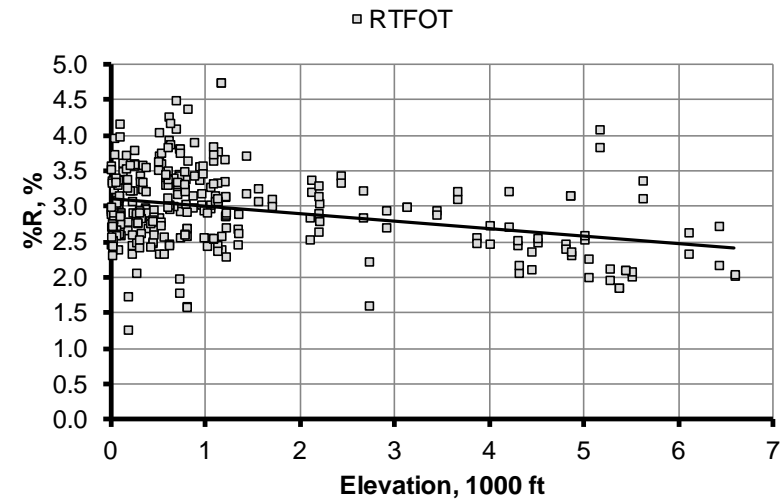
a. Original and RTFOT $G^*/\sin\delta$.



b. J_{NR} .



c. Mass Change.



d. %R.

Figure 4. Effect of Elevation on Properties for AASHTO Resource Binder 235/236.

Engineering Analysis

The analysis presented above showed elevation has a statistically significant effect on data collected after RTFOT conditioning and the effect is rational based on engineering principles. The analyses presented below used the range of the slopes obtained from the statistical analysis to quantify the engineering significance of the elevation effect on AASHTO M 320 and AASHTO M 332 specification criteria.

Figure 5 shows the potential effect of elevation on RTFOT residue $G^*/\sin\delta$ expressed as a percentage of the AASHTO M 320 criterion of 2.20 kPa. The shaded area shows the range of the effect for the 15 binders that were analyzed. At an elevation difference of 4,000 ft, the difference can be as high as 21 percent of 2.20 kPa or 0.46 kPa. This difference has engineering significance. A binder with an acceptable RTFOT $G^*/\sin\delta$ of 2.50 kPa when tested at sea level may have an unacceptable RTFOT $G^*/\sin\delta$ when tested at an elevation of 4,000 ft or higher.

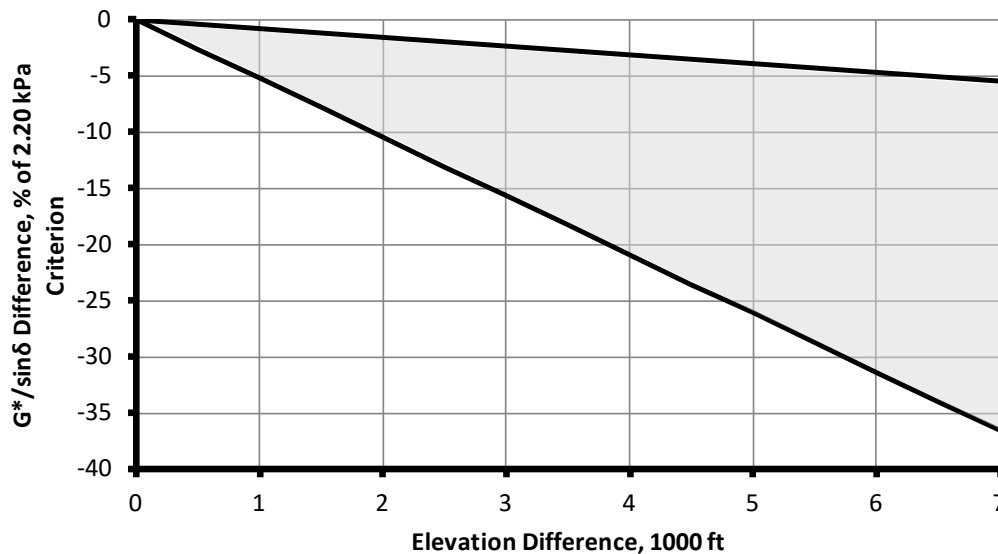


Figure 5. Engineering Significance of Elevation Effect on AASHTO M 320 High Temperature Performance Grade Criterion.

A similar analysis for the AASHTO M 332 high temperature performance grade criteria is somewhat more complicated because the criteria are a function of traffic level as given below:

- $\leq 4.5 \text{ kPa}^{-1}$ for standard traffic
- $\leq 2.0 \text{ kPa}^{-1}$ for heavy traffic
- $\leq 1.0 \text{ kPa}^{-1}$ for very heavy traffic
- $\leq 0.5 \text{ kPa}^{-1}$ for extremely heavy traffic

Also, it appears based on the 15 binders analyzed, that the elevation effect is less for binders meeting higher traffic levels. Table 4 summarizes the range of the elevation effect on J_{NR} for binders meeting different AASHTO M 332 traffic levels. Note that AASHTO re:source proficiency sample binder 245/246 was not included in this analysis because the J_{NR} data for this sample was collected at 12 °C above the pavement temperatures where the binder would be normally be used.

Table 4. Summary of Elevation Effect by AASHTO M 332 Traffic Level.

AASHTO M 332 Traffic Level	Number of Binders	Elevation Effect, kPa-1/1,000 ft	
		Minimum	Maximum
S	4	0.0384	0.0927
H	5	0.0249	0.0677
V	2	0.0006	0.0432
E	2	0.0027	0.0076

Figure 6 shows the potential effect of elevation on RTFOT residue J_{NR} expressed as a percentage of the AASHTO M 332 criteria for the appropriate traffic level for the binder. The shaded area shows the range of the effect for the 13 binders included in the analysis. At an elevation difference of 4,000 ft, the difference can be as high as 17 percent. Although somewhat less than that for $G^*/\sin\delta$, the elevation effect is still significant. A V grade binder with an acceptable J_{NR} of 0.85 kPa^{-1} when tested at sea level may have an unacceptable J_{NR} when tested at an elevation of 4,000 ft or higher.

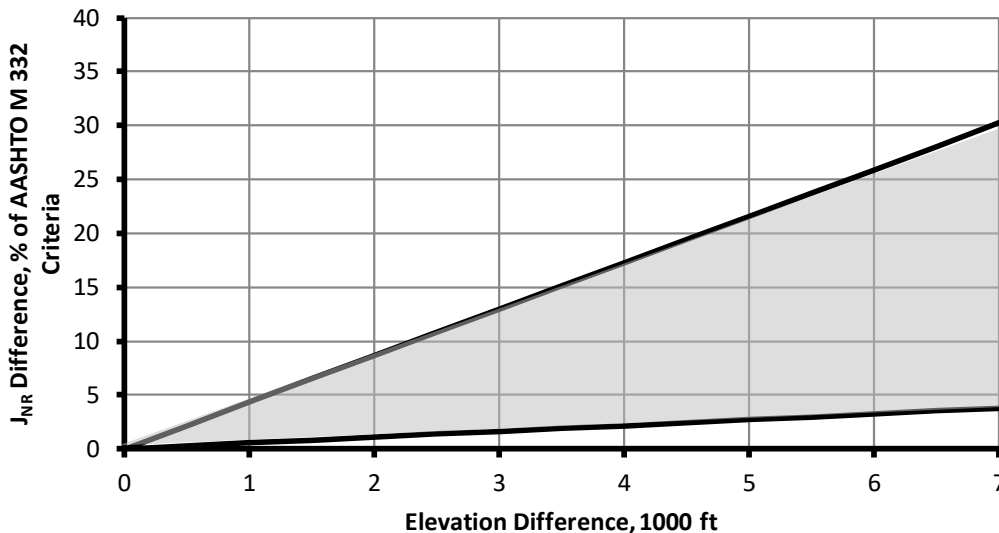


Figure 6. Engineering Significance of Elevation Effect on AASHTO M 332 High Temperature Performance Grade Criteria.

The last specification criteria that was considered was the mass change. Both AASHTO M 320 and AASHTO M 332 limit the mass change from RTFOT conditioning to one percent. The statistical analysis showed the mass change is increasingly negative with a slope ranging from -0.0033 percent per 1,000 ft for the WCTG data set to -0.0060 percent per 1,000 ft for the AASHTO re:source data set. The larger slope from the AASHTO re:source data set yields a difference of -0.042 percent for a 7,000 ft elevation difference. The binders in the data sets analyzed had average mass change ranging from +0.036 to -0.820 percent. Over this range, the elevation effect is not important; however, it may be larger and could be significant for binders that have mass change near the lower limit of -1.000 percent.

RTFOT Conditioning Time Experiment

Methods to Account for the Elevation Effect

The statistical analysis showed that laboratory elevation significantly affects properties measured after RTFOT conditioning, and the engineering analysis showed that the elevation effect is of engineering significance. When conducting interlaboratory or proficiency studies, the elevation effect should be included in the statistical analysis. AASHTO resource, WCTG, and organizations performing interlaboratory studies that include tests on RTFOT residue should consider this additional step when performing data analysis.

For acceptance testing, data from laboratories at different elevations will not generally be available for a specific binder. In this case it is necessary to account for the elevation effect. Three methods to account for the elevation effect were considered:

1. Conduct RTFOT conditioning at a constant pressure.
 2. Relate the elevation effect to properties measured on the binder before RTFOT conditioning.
 3. Vary the operating parameters of the RTFOT with elevation.
- Conducting the RTFOT conditioning at a constant pressure, while technically the most prudent approach, was not pursued because this approach would require significant modification of existing RTFOT equipment. The other two methods were evaluated as discussed below.

Effect of Binder Properties on Elevation Effect

An evaluation was conducted to determine if the binder specific elevation effect for $G^*/\sin\delta$ could be predicted from other properties measured on the original binder during AASHTO M 320 and M 332 testing. The properties that were analyzed included:

1. Rotational viscosity at 135 °C,
2. Original G^* ,
3. Original δ ,
4. Original $G^*/\sin\delta$,
5. Mass change.

The only property that was related to the elevation effect was the 135 °C viscosity as shown in Figure 7. Other properties showed much poorer correlation with the elevation effect. Including other properties with the 135 °C viscosity did not result in significant improvement. The relationship shown in Figure 7 indicates that the sensitivity to elevation decreases with increasing viscosity, which may be the result of stiffer binders aging less during RTFOT conditioning. The relationship in Figure 7 is not sufficiently accurate to adjust tests on RTFOT residue to a common elevation.

Vary RTFOT Operating Parameters With Elevation

Consideration was given to varying three operational parameters for the RTFOT with elevation to account for the elevation effect: (1) test duration, (2) test temperature, and (3) air flow rate. Air flow rate was rejected based on research performed in developing the Modified Rotating German Flask which showed varying air flow had a large effect on mass change with relatively little effect on the stiffness of the conditioned binder (Robertson, et. al., 2001). Test duration was selected over temperature because it will be easier to implement in practice, and initial estimates of additional time based on analysis of data from NCHRP Project 9-36 for the Stirred Air Flow Test were reasonable at about 10 minutes for an elevation of 7,000 ft (Anderson and Bonaquist, 2012).

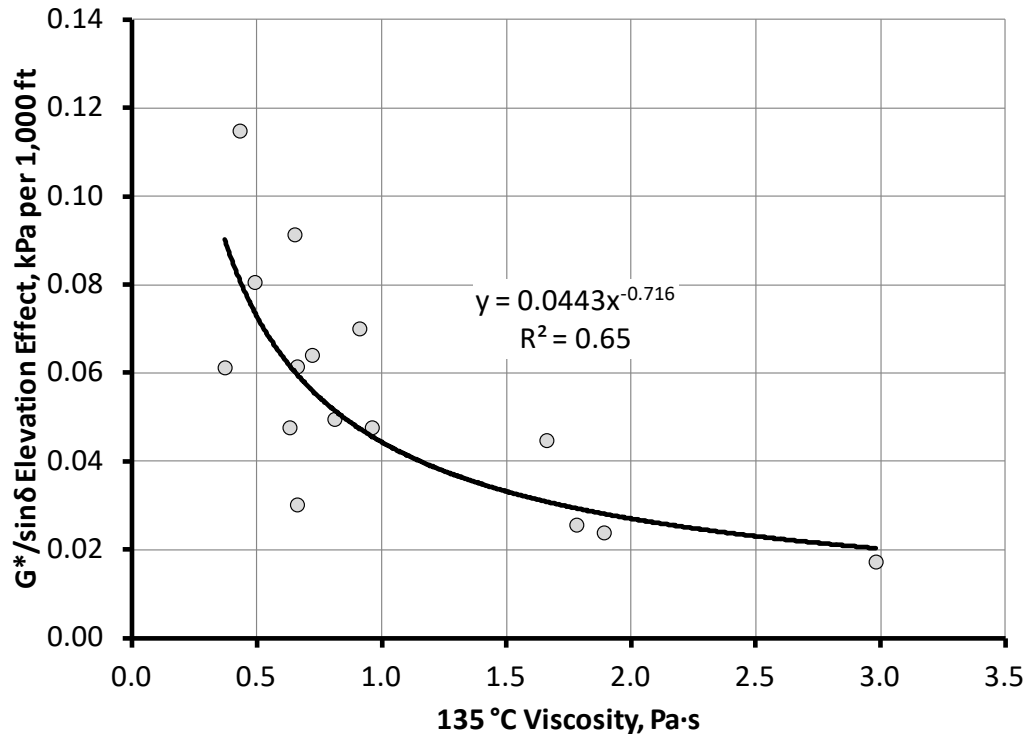


Figure 7. Relationship Between 135 °C Viscosity and Elevation Effect.

A preliminary investigation of the effect of increased RTFOT conditioning time on AASHTO M 320 and M 332 specification properties was conducted early in the project in Advanced Asphalt Technologies, LLC's (AAT's) laboratory which is at an elevation of 552 ft. The hypothesis underlying this work was that binders that are more sensitive to the effect of elevation on their properties would also have properties that are more sensitive to the effect of RTFOT conditioning time. AASHTO M 320 and M 332 specification properties for the four AASHTO re:source proficiency sample binders were measured after conditioning the binders in the RTFOT for 85, 95, 105, and 115 minutes. Replicate tests were conducted for each binder. The results are summarized in Table 5 and presented graphically in Figure 8. Figure 8 includes best fit linear regression lines which show that the RTFOT time effect is approximately linear over the range of conditioning times included in the experiment.

Table 6 summarizes the slopes as a function of RTFOT conditioning time for $G^*/\sin\delta$ and J_{NR} for the binders tested. These slopes are a measure of the sensitivity of the specification properties to conditioning time. Table 6 also includes the slopes of the elevation effect for these binders from Table 2. The ratio of the slopes gives the additional RTFOT conditioning times to provide approximately equivalent rheological properties, which are also summarized in Table 6. Excluding binder 241/242 which had minimal sensitivity of J_{NR} to elevation, the time ranges from 1.4 to 2.4 minutes per 1,000 ft with an average of 1.9. Additional conditioning times to adjust for elevation appear to be somewhat longer for J_{NR} compared to $G^*/\sin\delta$.

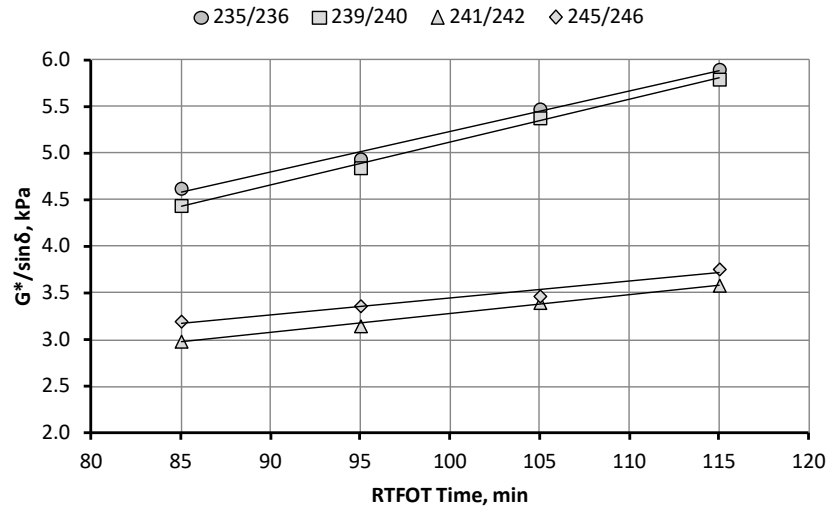
Note that the range of the $G^*/\sin\delta$ effect included in this experiment was from -0.026 to 0.081 kPa/1,000 ft which covered approximately 70 percent of the range of elevation effects summarized in Table 3 from this study and previous studies. The RTFOT time study confirms that those binders that are more sensitive to the elevation effect are also more sensitive to conditioning time. The elevation effect for $G^*/\sin\delta$ in Table 6 varies by a factor of 3, while the estimate of additional conditioning time varies by a factor of only 1.3.

Table 5. Summary of Preliminary RTFOT Conditioning Time Study Results.

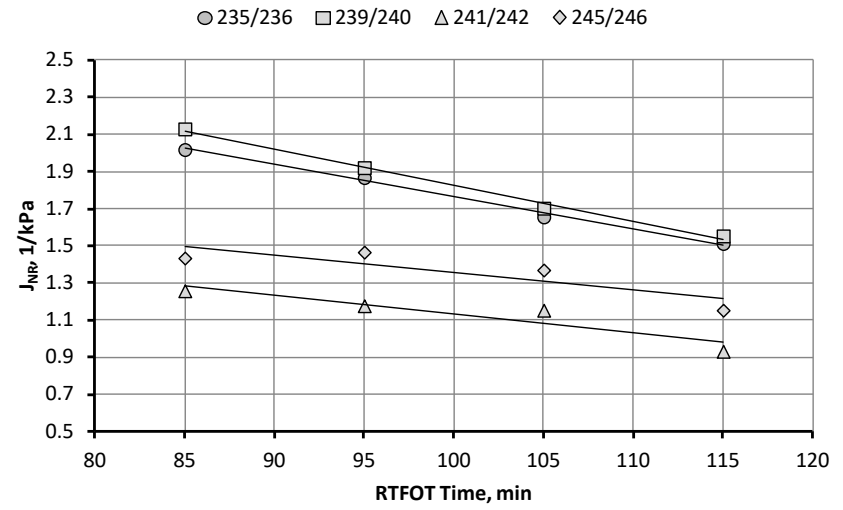
Sample Pairs (Odd/Even)	Time, min	Temp, °C	G*/sinδ, kPa			J _{NR} , 1/kPa			%R, %			Mass Change, %			Aging Index		
			Odd	Even	Avg	Odd	Even	Avg	Odd	Even	Avg	Odd	Even	Avg	Odd	Even	Avg
235/236	0	58	1.92	1.76	1.84	NT*	NT*	NT*	NT*	NT*	NT*	NA**	NA**	NA**	NA**	NA**	NA**
	85	58	4.44	4.81	4.63	2.15	1.89	2.02	1.2	3.3	2.2	-0.422	-0.438	-0.430	2.31	2.73	2.52
	95	58	4.74	5.14	4.94	1.99	1.74	1.87	1.4	3.9	2.7	-0.460	-0.490	-0.475	2.47	2.92	2.69
	105	58	5.21	5.74	5.48	1.78	1.53	1.66	1.9	4.7	3.3	-0.501	-0.521	-0.511	2.71	3.26	2.99
	115	58	5.63	6.17	5.90	1.64	1.38	1.51	2.3	5.8	4.0	-0.542	-0.525	-0.534	2.93	3.51	3.22
239/240	0	58	1.67	1.88	1.78	NT*	NT*	NT*	NT*	NT*	NT*	NA**	NA**	NA**	NA**	NA**	NA**
	85	58	4.65	4.23	4.44	1.96	2.30	2.13	2.9	1.0	2.0	0.024	0.021	0.023	2.78	2.25	2.52
	95	58	5.13	4.56	4.85	1.73	2.11	1.92	3.7	1.4	2.5	0.026	0.024	0.025	3.07	2.43	2.75
	105	58	5.64	5.12	5.38	1.53	1.88	1.70	4.5	1.8	3.1	0.027	0.025	0.026	3.38	2.72	3.05
	115	58	6.23	5.36	5.80	1.34	1.77	1.55	5.7	2.1	3.9	0.029	0.030	0.029	3.73	2.85	3.29
241/242	0	64	1.51	1.42	1.47	NT*	NT*	NT*	NT*	NT*	NT*	NA**	NA**	NA**	NA**	NA**	NA**
	85	64	3.15	2.82	2.99	1.20	1.31	1.26	47.2	48.8	48.0	-0.329	-0.304	-0.317	2.09	1.99	2.04
	95	64	3.25	3.05	3.15	1.07	1.29	1.18	50.4	47.7	49.1	-0.336	-0.335	-0.336	2.15	2.15	2.15
	105	64	3.50	3.30	3.40	1.04	1.27	1.15	49.0	50.8	49.9	-0.333	-0.348	-0.341	2.32	2.32	2.32
	115	64	3.71	3.46	3.59	0.89	0.98	0.93	52.4	51.7	52.1	-0.403	-0.366	-0.385	2.46	2.44	2.45
245/246	0	76	1.69	1.74	1.72	NT*	NT*	NT*	NT*	NT*	NT*	NA**	NA**	NA**	NA**	NA**	NA**
	85	76	3.20	3.20	3.20	1.40	1.47	1.43	36.2	35.3	35.7	-0.060	-0.059	-0.060	1.89	1.84	1.87
	95	76	3.42	3.31	3.37	1.38	1.55	1.47	36.8	32.1	34.4	-0.070	-0.062	-0.066	2.02	1.90	1.96
	105	76	3.47	3.47	3.47	1.41	1.33	1.37	34.9	33.5	34.2	-0.087	-0.065	-0.076	2.05	1.99	2.02
	115	76	3.80	3.72	3.76	1.08	1.22	1.15	40.7	37.4	39.0	-0.080	-0.049	-0.065	2.25	2.14	2.19

* NT denotes not tested

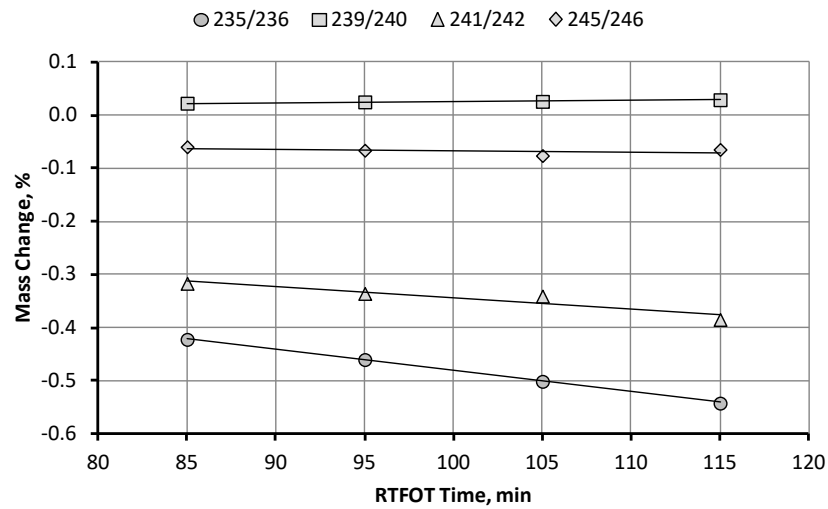
**NA denotes not applicable



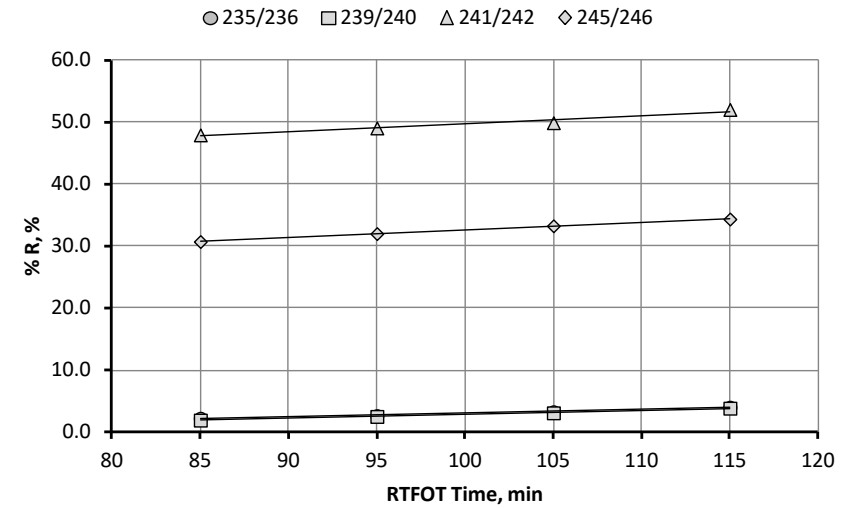
a. $G^*/\sin\delta$.



b. J_{NR} .



c. Mass Change.



d. %R.

Figure 8. Preliminary RTFOT Conditioning Time Study Results.

Table 6. Estimate of Additional Conditioning Time for AASHTO Resource Binders.

Binder	$\Delta G^*/\sin\delta$, kPa/min	$\Delta G^*/\sin\delta$, kPa/1,000 ft	Additional Conditioning Time, Min/1,000 ft	ΔJ_{NR} , kPa ⁻¹ /min	ΔJ_{NR} , kPa ⁻¹ /1,000 ft	Additional Conditioning Time, Min/1,000 ft
235/236	0.0468	-0.0645	1.4	-0.01728	0.0384	2.2
239/240	0.0460	-0.0806	1.8	-0.01946	0.0470	2.4
241/242	0.0217	-0.0296	1.4	-0.01002	0.0006	0.1
245/246	0.0172	-0.0257	1.5	-0.00939	0.0217	2.3

Theoretical Estimate of Additional RTFOT Conditioning Time

A second estimate of the additional RTFOT conditioning time needed at higher elevations was conducted using the kinetic model for carbonyl formation developed by Liu, et. al. (Liu, et. al., 1996) and given in Equation 3. This model only addresses the oxidation effect which is apparently the dominant effect based on the statistical analyses presented earlier.

$$r_{CA} = Ap^{\alpha}e^{\left(\frac{-E}{RT}\right)} \quad (3)$$

where:

r_{CA} = carbonyl formation rate

p = oxygen pressure

T = temperature

R = universal gas constant

A , α , and E are binder dependent fitting constants

Assuming that the rheological properties of a binder depend on the total amount of carbonyl formed, the time required to obtain equal amounts of carbonyl at two elevations when the conditioning is done at the same temperature is given by:

$$(r_{CA})_1 t_1 = (r_{CA})_2 t_2 \quad (4)$$

where:

$(r_{CA})_1$ = carbonyl formation rate at elevation 1

$(r_{CA})_2$ = carbonyl formation rate at elevation 2

t_1 = conditioning time at elevation 1

t_2 = conditioning time at elevation 2

Substituting Equation 3 for r_{CA} in Equation 4 yields:

$$\left[Ap_1^{\alpha} e^{\left(\frac{-E}{RT}\right)} \right] t_1 = \left[Ap_2^{\alpha} e^{\left(\frac{-E}{RT}\right)} \right] t_2 \quad (5)$$

Recalling temperature is constant and for a given binder and A , E , and α are constants, then solving for t_2 yields:

$$t_2 = t_1 \left(\frac{p_1}{p_2} \right)^{\alpha} \quad (6)$$

The ratio of the pressure at elevation h to the pressure at sea level can be determined from Equation 1 resulting in Equation 7

$$\frac{p_0}{p_h} = (1 - 2.526 \times 10^{-5} \times h)^{-5.256} \quad (7)$$

where:

p_h = air pressure (kPa) at elevation h

p_o = atmospheric pressure at sea level, 101.325 kPa

h = elevation above sea level (m)

Substituting Equation 7 into Equation 6, and using the standard RTFOT condition time of 85 min and sea level as the basis yields the equivalent RTFOT conditioning time at elevation h :

$$t_h = 85 \times (1 - 2.526 \times 10^{-5} \times h)^{-(5.256\alpha)} \quad (8)$$

For 10 different binders, Lui, et al. reported that α varies from 0.25 to 0.61. Table 7 summarizes the range of additional RTFOT conditioning times based on this analysis. Table 7 also shows the time estimated from the testing conducted on the four AASHTO re:source binders during this project. The experimental data are in reasonable agreement with the theoretical analysis from the carbonyl model providing further evidence of the reasonableness of the additional time estimates.

Table 7. Estimated Equivalent RTFOT Conditioning Times Using Carbonyl Model.

Elevation, Ft	Equivalent RTFOT Conditioning Time, min								Experimental
	$\alpha =$ 0.25	$\alpha =$ 0.30	$\alpha =$ 0.35	$\alpha =$ 0.40	$\alpha =$ 0.45	$\alpha =$ 0.50	$\alpha =$ 0.55	$\alpha =$ 0.60	
0	85	85	85	85	85	85	85	85	85
1000	86	86	86	86	87	87	87	87	87
2000	87	87	87	88	88	89	89	89	89
3000	88	88	89	89	90	90	91	92	91
4000	89	89	90	91	92	92	93	94	93
5000	89	90	91	92	93	94	95	96	95
6000	90	92	93	94	95	96	97	99	96
7000	91	93	94	96	97	98	100	101	98

Experimental Design

Background

The main RTFOT conditioning time experiment was designed to verify the RTFOT conditioning times as a function of elevation presented in Table 7. The experiment was based on the following important considerations from the work described above:

1. The effect of elevation on the properties of RTFOT residue is approximately linear over the range of elevations of laboratories in the United States. For a linear elevation effect, it is important to include laboratories at high and low elevations.
2. The additional RTFOT conditioning time to account for the elevation effect is estimated to be approximately 1.9 min/1,000 ft.
3. The effect of RTFOT conditioning time on the properties of RTFOT residue is approximately linear over the range of conditioning times that will be used in the experiment. This allows testing in each laboratory to be conducted at two conditioning times with results at other conditioning times interpolated with a high level of confidence.

4. The elevation effect is binder specific, with higher viscosity binders generally showing a smaller elevation effect. The experiment must include a range of neat and modified binders with different 135 °C viscosities.

The design of the experiment also considered the following information on the reported repeatability and reproducibility of dynamic shear rheometer (DSR) measurements, and general principles of experimental design:

1. Replication was included by testing in multiple laboratories at similar elevations rather than multiple tests within a single laboratory at a given elevation.
2. The multi-laboratory coefficient of variation in AASHTO T 315 for $G^*/\sin\delta$ for tests on original binder is 6.8 percent compared to 7.8 percent for tests on RTFOT residue. This shows that a significant amount of the variability in tests on RTFOT residue is the result of differences in equipment and laboratory procedures associated with the dynamic shear rheometer measurements rather than the RTFOT conditioning. Therefore, to reduce one component of variability, all physical property measurements were made in one laboratory.
3. Detailed instructions regarding the performance of the RTFOT conditioning were given to the participating laboratories to reduce variability caused by between laboratory differences in the RTFOT conditioning.

Basic Experimental Design

The experiment design uses laboratories at different elevations to condition the binders in the RTFOT. Twenty-five laboratories agreed to perform the RTFOT conditioning. Table 8 summarizes the participating laboratories and their elevations. Table 8 also presents the target conditioning time based on 85 minutes plus 1.9 min/1000 ft elevation rounded to the nearest minute. The experiment design requires each laboratory to condition each binder at the two times listed in the last two columns of Table 8, measure the mass change, and return the conditioned binder to AAT's laboratory for rheological property measurements. The RTFOT time difference of 10 minutes produces a significant difference in the properties measured on RTFOT residue. Figure 9 is a graphical representation of the basic experiment design. The limits shown in Figure 9 are the RTFOT conditioning times that will be used in each laboratory.

Binders

The available funding allowed a total of 8 binders to be included in the experiment. Table 9 shows continuous grading data for the binders included in the experiment. Detailed binder grading data are presented in Appendix A. These binders were selected based on the analysis of the WCTG and AASHTO re:source samples to: (1) cover a wide range of performance grades, (2) include neat and polymer modified binders, (3) exhibit a range of volatile loss, and (4) cover a range of elevation effects. Volatile loss is expected to increase with increasing low temperature grade. The selected binders include low temperature grades of -22, -28, and -34. The analysis of the WCTG and AASHTO re:source data showed that the viscosity of the binder influences the elevation effect with high viscosity, modified binders showing much lower sensitivity to elevation. The selected binders include neat and polymer modified binders at each low temperature grade to provide a range of viscosities.

Laboratory Testing

The analysis presented in Chapter 3 used AASHTO M 320 and M 332 specification properties measured on RTFOT residue. The properties that were measured included: (1) $G^*/\sin\delta$, (2) J_{NR} , (3) % R, and (4) Mass Change. In addition, 135 and 163 °C viscosity data were collected to evaluate the effect of viscosity at the RTFOT conditioning temperature on the elevation effect.

Each laboratory conditioned four bottles for each of the binders in the RTFOT using the two conditioning times listed in Table 8 for the elevation of their laboratory. Two of the bottles were used to measure and report mass change. The residue from the other two bottles was combined and returned to AAT for the rheological testing. Appendix B presents detailed instructions provided to the laboratories performing the RTFOT conditioning. The conditioning required each laboratory to make eight RTFOT runs; two binders were conditioned during each run of the RTFOT. For 8 binders conditioned in 25 laboratories at two conditioning times, the experiment provided 400 mass change measurements and 400 RTFOT residue samples for rheological testing and analysis.

Table 8. Participating Laboratories, Elevations, and RTFOT Conditioning Times.

Laboratory	Elevation, ft	RTFOT Conditioning Times, min		
		Target	Low	High
L1	79	85	80	90
L2	224	85	80	90
L3	517	86	81	91
L4	552	86	81	91
L5	574	86	81	91
L6	622	86	81	91
L7	715	86	81	91
L8	764	86	81	91
L9	938	87	82	92
L10	971	87	82	92
L11	1100	87	82	92
L12	2000	89	84	94
L13	2001	89	84	94
L14	2516	90	85	95
L15	3123	91	86	96
L16	3256	91	86	96
L17	4030	93	88	98
L18	4307	93	88	98
L19	4334	93	88	98
L20	4700	94	89	99
L21	5050	95	90	100
L22	5164	95	90	100
L23	5254	95	90	100
L24	6182	97	92	102
L25	7174	99	94	104

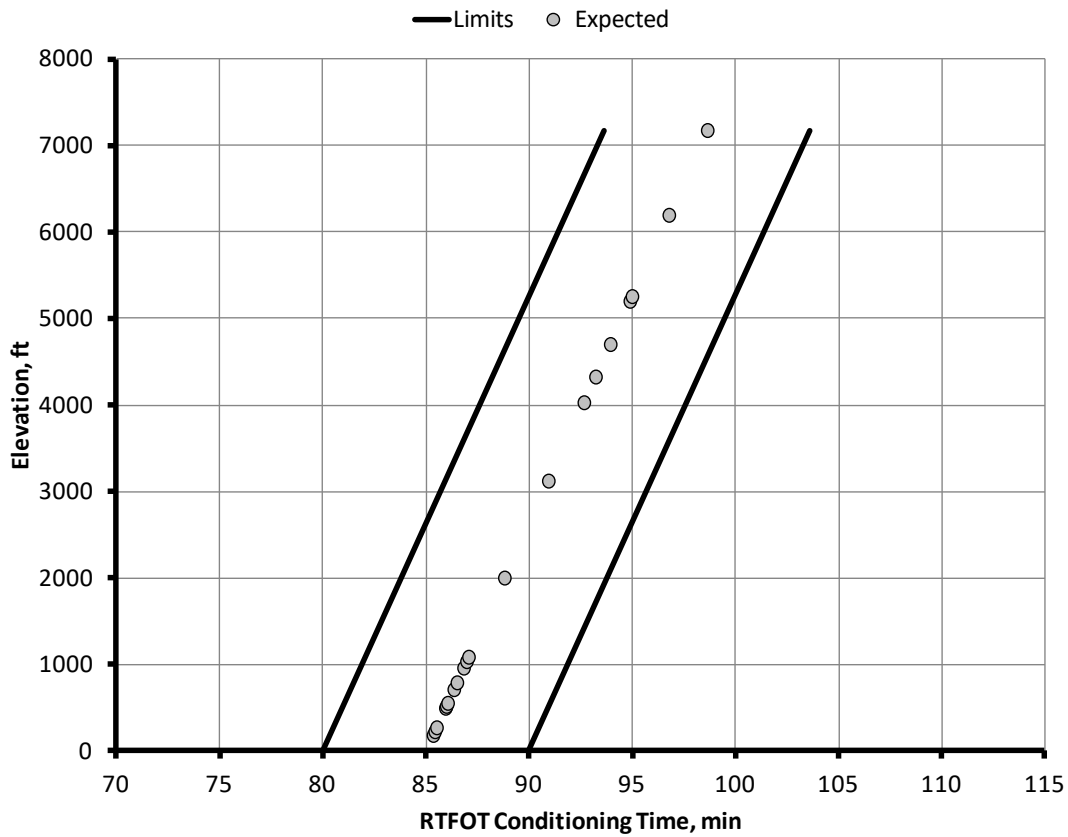


Figure 9. Graphical Representation of the Experimental Design.

Table 9. Binders Used in RTFOT Conditioning Time Experiment.

Binder	Type	135 °C Viscosity, Pa·s	Continuous Performance Grade Temperature, °C			
			High	Intermediate	Low	ΔT_c
B1	Neat	0.461	68.4	23.0	-25.5	+0.5
B2	Polymer	1.134	77.8	20.5	-26.3	-1.6
B3	Neat	0.282	60.5	16.7	-30.3	+1.0
B4	Neat	0.442	65.3	14.8	-30.8	-0.3
B5	Polymer	2.505	82.7	17.5	-30.0	+0.2
B6	Neat	0.217	54.9	11.0	-35.1	+2.1
B7	Polymer	0.583	64.0	9.4	-36.8	-0.7
B8	Polymer	1.248	72.4	11.6	-35.2	-1.2

CHAPTER 3

Findings and Application

Introduction

All participating laboratories performed the RTFOT conditioning, reported the mass change and returned the RTFOT residue for testing. Different analyses were performed on the mass change and rheological data. As discussed in Chapter 2, the experiment was designed to verify that the effect of elevation on the rheological properties of RTFOT residue could be minimized by increasing the RTFOT conditioning time as a function of elevation. Therefore, the analysis of the rheological data was aimed at confirming that there is no elevation effect when the RTFOT conditioning time is adjusted as a function of elevation. On the other hand, the analysis of the mass change data was directed at determining an average mass change adjustment as a function of elevation for the adjusted RTFOT conditioning time determined from analysis of the rheological data. These two analyses are presented below.

Analysis of Rheological Property Data

Graphical Analysis

The rheological property analysis was conducted on the specification properties after RTFOT conditioning: $G^*/\sin\delta$ for AASHTO M 320 and J_{NR} and %R for AASHTO M 332. These properties were plotted as a function of elevation to identify trends in the data and potential outliers. Figure 10 shows the variation of the specification rheological properties as a function of elevation for binders B4 and B5. B4 is a neat binder while B5 is a polymer modified binder with very high recovery. In this figure, the interpolated value at the target RTFOT conditioning time from Table 8 is plotted as a function of elevation. Recall that the conditioning times for the laboratories were adjusted 1.9 min per 1,000 ft of elevation. This adjustment was based on the analysis described earlier for the WCTG and AASHTO re:source proficiency data. These figures show the presence of outliers. The figures also suggest that the estimated conditioning time increase of 1.9 min per 1,000 ft of elevation over compensates for the elevation effect. $G^*/\sin\delta$ appears to increase with elevation, while J_{NR} appears to decrease. The effect of elevation on %R is mixed. By using RTFOT conditioning times of ± 5 min of the target the experiment was designed to allow adjustment of the conditioning time function as discussed in the next section.

Statistical Analysis

The statistical analysis of the rheological property data was conducted in four steps. The first step was an outlier analysis like that described earlier in the analysis of the WCTG and AASHTO re:source proficiency data. This was followed by a linear regression analysis to confirm the trends from the graphical analysis that the RTFOT conditioning time increase of 1.9 min per 1,000 ft of elevation overcompensates for the elevation effect. The third step was an optimization to adjust the conditioning time increase. The optimization was performed on the combined data for the three specification properties: $G^*/\sin\delta$, J_{NR} , and %R. The final step was regression analysis using the average conditioning time increase from the optimization to confirm that specification properties were not significantly affected by elevation. The sections below describe details of these four steps.

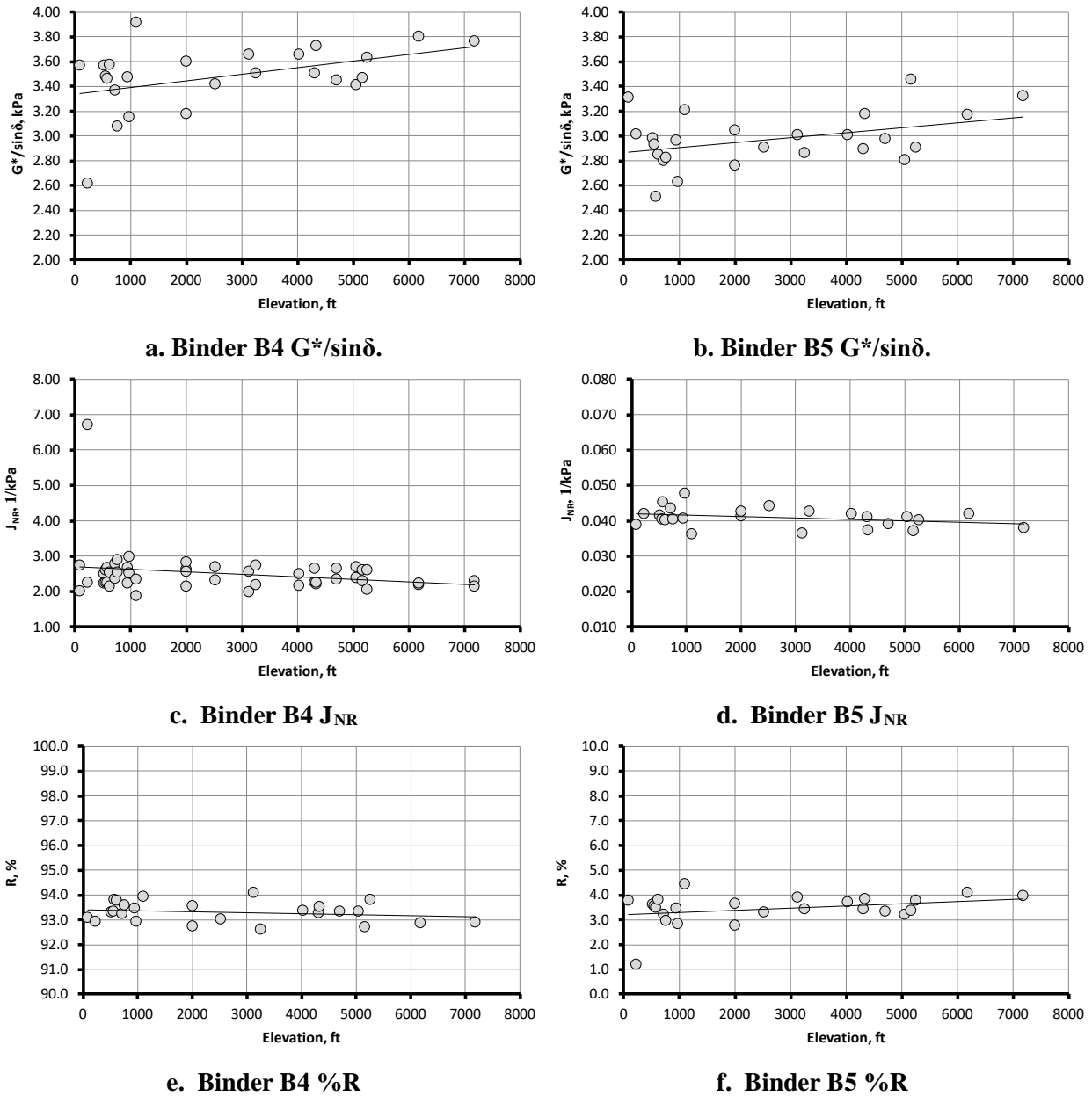


Figure 10. Example Graphical Analysis of Rheological Properties.

Outlier Analysis

Outliers were identified using an approach like that described earlier for the analysis of the WCTG and AASHTO re:source proficiency data. For each combination of specification property and binder (24 total), the average and standard deviation were calculated. Outliers were identified as varying from the average by more than 2.5 standard deviations. Table 9 identifies the specific results that were identified as outliers. Additionally, Lab 10 did not return the residue for binder B1 because of a testing error.

Table 10. Rheological Property Outliers.

Item	$G^*/\sin\delta$	J_{NR}	% R
Total Observations	200	200	200
Outliers	B1 Lab 1	B1 Lab 1	B1 Lab 1
	B2 Lab 1	B1 Lab 6	B2 Lab 1
	B3 Lab 2	B2 Lab 1	B3 Lab 2
	B4 Lab 2	B3 Lab 2	B4 Lab 2
	B6 Lab 5	B4 Lab 2	B6 Lab 5
	B7 Lab 5	B6 Lab 5	B7 Lab 8
	B8 Lab 5	B7 Lab 5	B8 Lab 5
	B8 Lab 16	B8 Lab 5	
		B8 Lab 16	
Residue Not Returned	B1 Lab 10	B1 Lab 10	B1 Lab 10
Analyzed	191	190	192

Initial Linear Regression Analysis

An initial regression analysis was conducted for the three rheological specification properties. Only the modified binder data were used in the evaluation of %R. This analysis used the interpolated value at the target RTFOT conditioning time from Table 8 and the outliers and missing data listed in Table 10 were removed. In this analysis dummy variables were used to allow the slope and the intercept to vary for the binders. The results of these analyses are summarized in Table 11. This analysis found the intercepts to be different for the different binders for the three specification properties. The analysis also found elevation was a significant factor, and the elevation effect was the same for all binders. Although the elevation effect is small for all properties, it may be of engineering significance considering the elevation range of US laboratories of approximately 7,000 ft. The slopes from the regression analysis, positive for $G^*/\sin\delta$ and %R, and negative for J_{NR} , indicate the target elevation adjustment time of 1.9 min/1,000 ft overcompensates for the effect of elevation on RTFOT residue.

Table 11. Summary of Initial Linear Regression.

Item	$G^*/\sin\delta$	J_{NR}	% R
Total Observations	200	200	100
Outliers/Missing Data	9	10	3
Adjusted R ²	0.939	0.994	0.992
Elevation Slope	0.0358 kPa/1000ft	-0.0155 1/kPa/1000 ft	0.1816 %/1000ft
B1 Intercept	3.75 kPa	2.58 1/kPa	NC*
B2 Intercept	2.55 kPa	0.40 1/kPa	51.1 %
B3 Intercept	3.64 kPa	2.66 1/kPa	NC*
B4 Intercept	3.42 kPa	2.47 1/kPa	NC*
B5 Intercept	2.88 kPa	0.08 1/kPa	92.8 %
B6 Intercept	3.47 kPa	2.74 1/kPa	NC*
B7 Intercept	4.30 kPa	0.27 1/kPa	70.0 %
B8 Intercept	4.39 kPa	0.10 1/kPa	83.7 %

* NC denotes not included in the regression analysis

Optimization

The experiment was designed to allow the initial estimate of the elevation adjustment time to be improved using data collected in the experiment. Each laboratory conditioned the binders using two conditioning times that were ± 5 min from the target conditioning time for that elevation. The preliminary RTFOT conditioning time experiment showed the rheological properties vary linearly with conditioning time; therefore, linear interpolation between the two conditioning times can be used calculate the rheological properties for various elevation adjustment times between about 0.6 to 3.4 min/1,000 ft. The optimization was performed using the Solver function in Excel. A spreadsheet was developed to minimize the sum of the errors squared between the interpolated property for each binder in each laboratory and the average interpolated property for that binder from all laboratories. The spreadsheet included $G^*/\sin\delta$ and J_{NR} for all binders and %R for the modified binders. The spreadsheet allowed the elevation time adjustment for the interpolation to vary between 0.6 and 3.4 min/1,000 ft. Table 12 summarizes the results from the optimization. Figure 11 shows the residuals after the optimization confirming that the residuals do not depend on the elevation. The average elevation adjustment time from the optimization considering the three rheological properties is 1.05 min/1,000 ft.

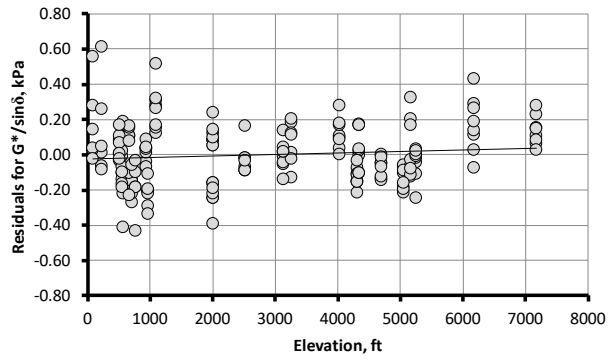
Table 12. Summary of Elevation Adjustment Time Optimization.

Item	$G^*/\sin\delta$	J_{NR}	% R
B1 Average	3.88 kPa	2.52 1/kPa	NC*
B2 Average	2.66 kPa	0.35 1/kPa	52.2 %
B3 Average	3.76 kPa	2.60 1/kPa	NC*
B4 Average	3.55 kPa	2.40 1/kPa	NC*
B5 Average	3.00 kPa	0.04 1/kPa	93.3 %
B6 Average	3.60 kPa	2.67 1/kPa	NC*
B7 Average	4.42 kPa	0.22 1/kPa	70.6 %
B8 Average	4.50 kPa	0.06 1/kPa	84.2 %
Optimum Elevation Adjustment Time	1.05 min/1,000 ft		
Total Observations	300		
Outliers/Missing Data	22		

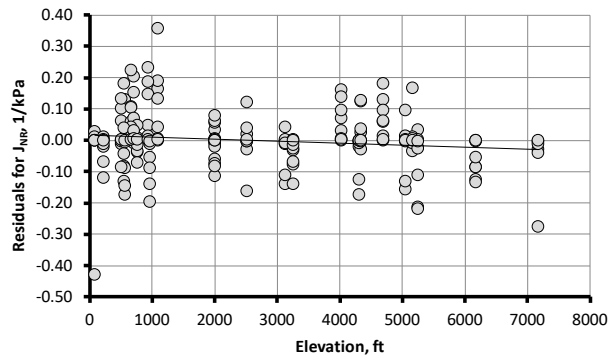
* NC denotes not included in the optimization

Final Linear Regression Analysis

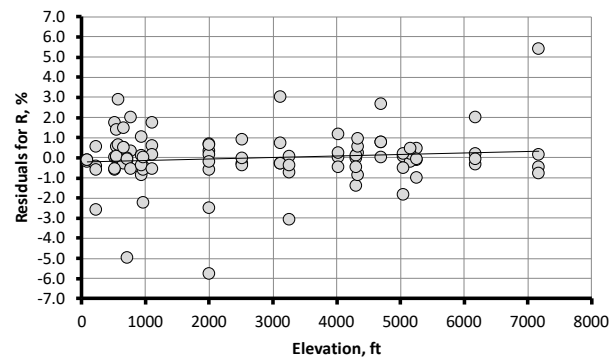
The linear regression analysis was repeated using the average elevation adjustment time of 1.05 min/1,000 ft to confirm that the measured rheological properties were not affected by elevation. The results are summarized in Table 13. These results confirm that there is not an elevation effect using an elevation adjustment time of 1.05 min/1,000 ft.



a. $G^*/\sin\delta$ Residuals



b. J_{NR} Residuals



c. %R Residuals

Figure 11. Residuals After Optimization.

Table 13. Summary of Final Linear Regression.

Item	$G^*/\sin\delta$	J_{NR}	% R
Total Observations	200	200	100
Outliers/Missing Data	9	10	3
Adjusted R^2	0.926	0.994	0.991
Elevation Slope	Not Significant	Not Significant	Not Significant
B1 Intercept	3.85 kPa	2.54 1/kPa	NC*
B2 Intercept	2.64 kPa	0.36 1/kPa	52.1 %
B3 Intercept	3.74 kPa	2.61 1/kPa	NC*
B4 Intercept	3.52 kPa	2.42 1/kPa	NC*
B5 Intercept	2.97 kPa	0.05 1/kPa	93.2 %
B6 Intercept	3.57 kPa	2.68 1/kPa	NC
B7 Intercept	4.39 kPa	0.24 1/kPa	70.5 %
B8 Intercept	4.48 kPa	0.07 1/kPa	84.1 %

* NC denotes not included in the regression analysis

Analysis of Mass Change Data

Graphical Analysis

The mass change data were analyzed to determine an average mass change adjustment as a function of elevation for the final elevation adjustment time of 1.05 min/1,000 ft. The interpolated mass change for each binder was plotted as a function of elevation to identify trends in the data. Figure 12 shows the mass change variation with elevation for binders B2 and B3. B2 is a polymer modified binder with low mass change, while B3 is a neat binder with high mass change. The trend for both binders is greater mass loss with increasing elevation. This figure also shows the presence of outliers.

Statistical Analysis

The statistical analysis of the mass change data followed the approach described earlier for the analysis of WCTG and AASHTO re:source proficiency sample data. Linear regression equations for mass change as a function of elevation were developed for mass change interpolated for the elevation adjustment time of 1.05 min/1,000 ft elevation. Dummy variables were included in the regression analysis to allow the slope and intercept of the mass change as a function of elevation to vary for the eight binders. Outliers were identified by fitting regression models with different intercepts and different slopes for each binder and observations with standardized residuals having absolute value greater than 2.5 were flagged as outliers. The final regression analysis was then conducted on the data set after removing the outliers.

Table 14 summarizes the results of the statistical analysis. A linear regression model with binder specific intercepts, but a common elevation slope has an explained variance of 93.1 percent. The elevation slope of -0.0062 %/1,000 ft can be used to adjust the mass loss measured in laboratories at different elevations to a common elevation. The elevation effect in this model is somewhat larger than that reported in Chapter 2 for the WCTG and AASHTO re:source proficiency sample data because this model also includes the effect of increasing RTFOT conditioning time with elevation. For an elevation difference of 7,000 ft, the mass change difference is -0.043 percent. Figure 12 compares the measured data to the regression model for binders B2 and B3 which have the smallest and largest mass changes in the data set. Although the elevation effect is significant, the most significant factor affecting the mass change is the binder.

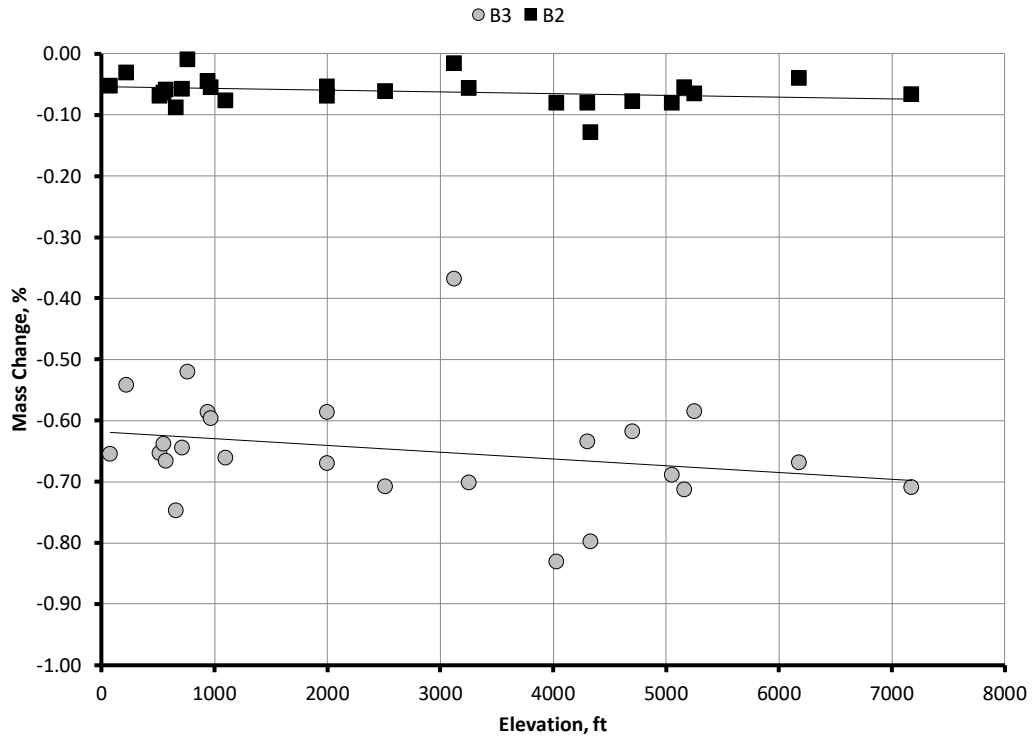


Figure 12. Mass Change Versus Elevation for Binder B2 and Binder B3.

Table 14. Summary of Mass Change Model.

Property	Value
Total Observations	200
Outliers and Missing Data	6
Adjusted R ²	0.931
Elevation, %/1000 ft	-0.0062
B1 Intercept, %	-0.137
B2 Intercept, %	-0.045
B3 Intercept, %	-0.652
B4 Intercept, %	-0.094
B5 Intercept, %	-0.108
B6 Intercept, %	-0.280
B7 Intercept, %	-0.477
B8 Intercept, %	-0.467

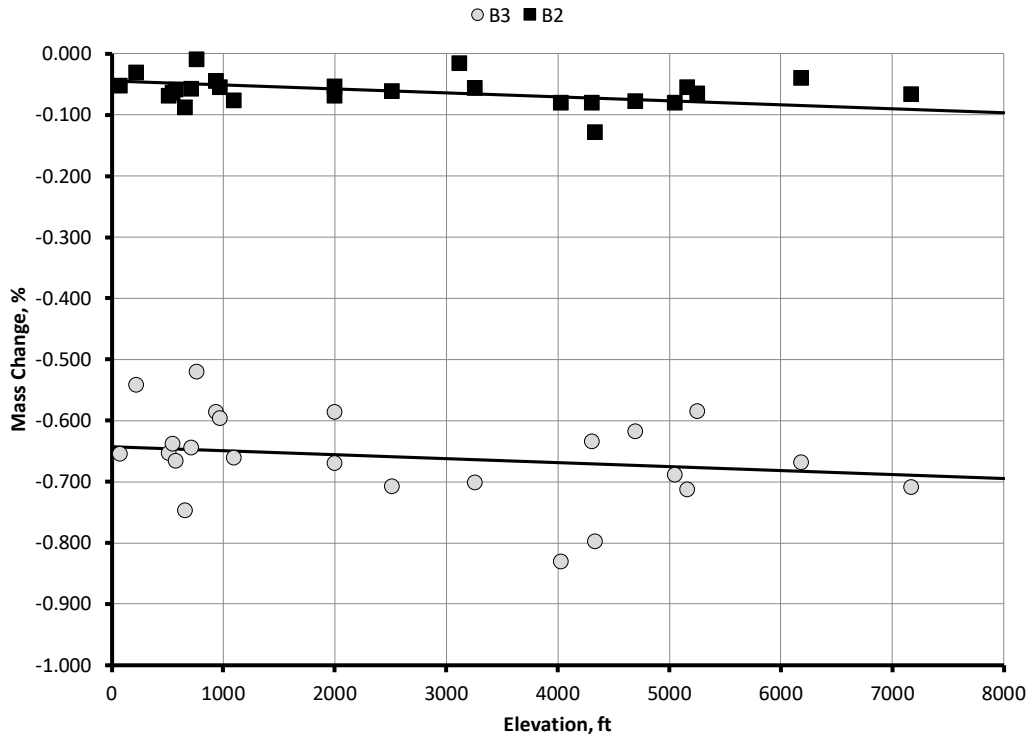


Figure 13. Comparison of Measured and Fitted Mass Change Data for Binders B2 and B3.

Application

Application of the statistical models developed from the experimental work completed in this project is straightforward. To provide approximately equivalent rheological properties, the RTFOT conditioning time should be increased one minute for every 1,000 ft increase in elevation. When this RTFOT conditioning time adjustment is applied, 0.006 percent should be added to the resulting mass change for every 1,000 increase in elevation.

CHAPTER 4

Conclusions and Recommendations

Conclusions

The primary conclusion drawn from analysis of proficiency sample data from WCTG and AASHTO re:source, and the experiment conducted in this project is laboratory elevation affects both the rheological properties of the residue and the mass change for asphalt binders conditioned in accordance with AASHTO T 240. It is possible to approximately account for the effect of elevation on the rheological properties of the residue by increasing the conditioning one minute for every 1,000 ft increase in elevation. When this conditioning time adjustment is applied 0.006 percent should be added to the resulting mass change for every 1,000 increase in elevation.

Recommendations for Implementation

The sections below describe two approaches for implementing the findings of this study. The first approach recommends not modifying AASHTO T 240. If this approach is adopted, then the effect of elevation on interlaboratory results should be accounted for in the statistical analysis of the data. Also, to address potential differences in specification properties due to elevation differences, agencies should adopt a dispute resolution procedure that includes the adjustments to AASHTO T 240 developed in this study. The second approach is to modify AASHTO T 240 to include the adjustments developed in this study. Additional details for these approaches are presented below.

No Modification of AASHTO T 240

Interlaboratory Studies

If AASHTO T 240 is not modified to account for the elevation effect, then the statistical analysis of data from interlaboratory studies should be adjusted to account for the effect of elevation on the rheological properties of the residue and the mass change for asphalt binder conditioned in accordance with AASHTO T 240. The approach used in this project to investigate the effect of elevation is recommended. First the data should be regressed against elevation. If the elevation effect is significant, then the standardized residuals (residuals divided by the standard deviation of the residuals) should be used to rate the performance of each laboratory on the same scale that is currently used based on standard deviation. If the elevation effect is not significant, then the analysis can be performed in the usual manner using the standard deviation to rate the performance of each laboratory. Implementation of this recommendation requires accurate data on the elevation of each laboratory, which can be readily obtained from on-line map services. Although the analysis can be done using barometric pressure or elevation, elevation is recommended due to the confusion associated with reporting barometric pressure that was discussed in Chapter 2.

Recommendation for Binder Acceptance

If AASHTO T 240 is not modified to account for the elevation effect, then it is possible that laboratories at different elevations may reach different conclusions concerning the acceptance of an asphalt binder. Agencies performing acceptance testing at higher elevations should modify their dispute resolution

procedures to include retesting using adjusted RTFOT conditioning times and mass change based on the findings from this study. One possible approach is provided below:

When the supplier's laboratory is at an elevation of 1,000 ft or more below the Department's laboratory and there is a difference in acceptance results that may be due to the elevation difference, the Department will retest the binder using a modified RTFOT conditioning time that adds one minute for each 1,000 ft difference in elevation rounded to the nearest minute. When using this modified RTFOT conditioning time, 0.006 percent will be added to the resulting mass change for each additional minute of RTFOT conditioning time. The elevation of the supplier's and Department's laboratory will be determined using an on-line mapping service.

Modification of AASHTO T 240

This section presents the modifications to AASHTO T 240 required to implement the findings of this study. The modifications use an elevation of 500 ft as the basis for adjusting the RTFOT conditioning time and mass change measurements. The modifications are based on increasing the RTFOT conditioning time 1 minute per 1,000 ft increase in elevation rounded to the nearest minute and adding 0.006 percent to the measured mass change for each minute of RTFOT conditioning time greater than 85 minutes. Appendix C details the required modifications.

REFERENCES

- Anderson, D.A. and Bonaquist, R.F., "Investigation of Short-Term Laboratory Aging of Neat and Modified Asphalt Binders," NCHRP Report 709, National Cooperative Highway Research Program, Washington, D.C., 2012.
- Anderson, D.A., Christensen, D.W., Bahia, H.U., Dongre, R., Sharma, M.G., Antle, C.E., and Button, J., "Binder Characterization and Evaluation Volume 3: Physical Characterization," SHRP-A-369, Strategic Highway Research Program, National Research Council, Washington, DC, 1994.
- "Manual of Barometry", (WBAN), Vol 1, First Edition, U.S. Dept of Commerce, Weather Bureau, Washington, D.C., 1963.
- Liu, M.; Lunsford, K. M.; Davison, R. R.; Glover, C. J.; Bullin, J. A." The Kinetics of Carbonyl Formation in Asphalt," American Institute of Chemical Engineers Journal, Volume 42, 1996.
- Robertson, R. E., J. F. Branthaver, P. M. Harnsberger, J. C. Petersen, S. M. Dorrence, J. F. McKay, T. F. Turner, A. T. Pauli, S.-C. Huang, J.-D. Huh, J.E. Tauer, K. P. Thomas, D. A. Netzel, F. P. Miknis, T. Williams, J.J. Duvall, F.A. Barbour, C. Wright, S.L. Salmans and A.F. Hansert, "Fundamental Properties of Asphalts and Modified Asphalts, Volume II: Final Report, New Methods," FHWA-RD-99-213. U.S. Department of Transportation, Federal Highway Administration, McLean, VA., 2001.
- The Engineering ToolBox, http://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html, 2016.
- Velasquez, R., Swiertz, D., and Bahia, H., "Effect of Laboratory Elevation on Binder Aging using the Rolling Thin Film Oven (RTFO)," Modified Asphalt Research Center (MARC) University of Wisconsin-Madison, January, 2013.
- Wang, H., "Effects of Laboratory Elevation on Rolling Thin Film Oven Test Results," Masters of Science Thesis, Colorado State University, 2013.
- Weather Underground, https://www.wunderground.com/resources/pressure_records.asp, 2017

APPENDIX A

Binder Grading Data

Table A1. Binder Performance Grading Data.

Condition	Property	Method	Temp, °C	Binder							
				B1	B2	B3	B4	B5	B6	B7	B8
Original	Viscosity, Pa·s	AASHTO T 316	135	0.461	1.134	0.282	0.442	2.505	0.217	0.583	1.248
			52						1.44		
			58			1.36			0.683		
			64	1.73		0.642	1.16			1.07	
	G*/sinδ, kPa	AASHTO T 315	70	0.823			0.597			0.627	1.40
			76		1.18						0.907
			82		0.676			1.18			
			88					0.821			
RTFOT Residue	G*/sinδ, kPa	AASHTO T 315	52						3.49		
			58			3.50			1.64		
			64	3.99		1.59	3.28			3.98	
			70	1.82			1.68			2.19	2.67
			76		2.74						1.64
			82		1.53			2.30			
			88					1.59			
PAV Residue	G*·sinδ, MPa	AASHTO T 315	7							6660	
			10						5640	4640	6010
			13				6170		3880		4230
			16			5440	4320	5960			
			19		5960	3770		4150			
			22	5640	4220						
			25	3920							
	Creep Stffness, MPa	AASHTO T 313	-12	197	149						
			-18	406	305	223	195	238			
			-24			478	433	478	262	194	228
			-30						557	408	462
	m-value	AASHTO T 313	-12	0.343	0.336						
			-18	0.281	0.287	0.337	0.329	0.325			
			-24			0.273	0.270	0.261	0.337	0.327	0.311
			-30						0.270	0.272	0.258

APPENDIX B

Laboratory Instructions

Introduction

Thank you for agreeing to participate in the Rolling Thin Film Oven Test (RTFOT) Elevation Experiment being conducted as part of NCHRP Project 20-07 / Task 400, Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder. The objective of this experiment is to determine the feasibility of adjusting the RTFOT conditioning time to account for the decreased aging that occurs during RTFOT conditioning at higher elevations. Through an analysis of AASHTO Resource and Western Cooperative Testing Group (WCTG) proficiency sample data, we confirmed that there is an elevation effect and for some binders the effect is large enough to result in different conclusions being drawn concerning the acceptability of the same binder under AASHTO M 320 and AASHTO M 332 when tested at different elevations. You are one of 25 laboratories that have agreed to participate in this experiment. The range of elevations for the laboratories vary from approximately 200 ft to 7000 ft.

The RTFOT Elevation Experiment includes conditioning eight binders in 20 laboratories at different elevations. Each laboratory will condition each binder at two different conditioning times based on the elevation of the laboratory. Since only high temperature properties will be measured, each laboratory will condition four bottles of each binder resulting in a total of eight runs of the RTFOT; four runs at each of two condition times. For each binder, each laboratory will measure and report the mass change using two bottles and return the residue from the other two bottles to Advanced Asphalt Technologies, LLC for rheological testing. Using a single laboratory for rheological testing will reduce testing error caused by differences in testing equipment and procedures in different laboratories.

The requirements given in AASHTO T 240, *Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)* will be followed. Please review AASHTO T 240 prior to performing the requested work. Detailed instructions are provided below.

Samples and Containers

You have received 16 tins containing binder. There are eight binder samples labeled B1 through B8 and for each binder sample you have received two tins with binder. The performance grade for each of the binder samples are listed below. You also received 16 marked tins to return the conditioned binder. The tins are marked LXX-BY-ZZ where XX is your laboratory number, Y is the binder number, and ZZ is the conditioning time.

Sample ID	Performance Grade	Type
B-1	PG 64-22	Neat
B-2	PG 76-22	Polymer
B-3	PG 58-28	Neat
B-4	PG 64-28	Neat
B-5	PG 76-28	Polymer
B-6	PG 52-34	Neat
B-7	PG 58-34	Polymer
B-8	PG 64-34	Polymer

Preparation of Oven

Prepare the oven in accordance with Section 6 of AASHTO T 240. Please ensure that the nozzle for the air flow is positioned at the center of the opening in the mouth of the bottle to ensure proper air flow.

Procedure

Condition the binders and measure the mass change in accordance with Section 7 of AASHTO T 240 with the following exceptions:

- Condition each of the 8 binders using the two conditioning times assigned to your laboratory. These times are different from the standard condition time of 85 minutes.
- Condition 4 bottles of each binder for each conditioning time. Use 2 of the bottles for each binder to measure and record the mass change. Transfer the contents for the 2 bottles not used for the mass change measurement into the appropriately marked container.
- Condition two binders during each run of the RTFOT. A total of 8 RTFOT runs will be required.

When removing the bottles from the RTFOT alternate between the two binders and complete the removal and transfer of the residue to the appropriate container within the 5 minutes specified in Section 7.7 of AASHTO T 240. First, remove the bottles that will be used for mass change. Next, remove and drain, one at a time, the bottles that will be used for physical property measurements in the following order: One bottle from binder A, two bottles from binder B, and the last bottle from binder A.

Reporting and Shipping

Report the mass change measured for each binder for each conditioning time using the table below.

Binder	Condition Time of __ Minutes			Conditioning Time of __ Minutes		
	Bottle 1	Bottle 2	Average	Bottle 1	Bottle 2	Average
B-1						
B-2						
B-3						
B-4						
B-5						
B-6						
B-7						
B-8						

Return the 16 containers of RTFOT residue via FedEx Ground using the box and return shipping label provided to:

Ramon Bonaquist
Advanced Asphalt Technologies, LLC
40 Commerce Circle
Kearneysville, WV 25430
(681)-252-3329

Questions:

If any of these instructions are not clear or you require additional information, please contact:

Ramon Bonaquist
Phone: 681-252-3329
Mobile: 703-999-8365
e-mail: aatt@erols.com

APPENDIX C

Recommended Modification to AASHTO T 240

Introduction

This appendix presents the changes to AASHTO T 240 needed to implement the RTFOT conditioning time and mass change adjustments developed in this project. The changes are presented below and refer to the sections in AASHTO T 240-13 (2017). New text is shown in **bold**.

Recommended Changes to AASHTO T 240-13 (2017)

1. Scope
No change required.
2. Referenced Documents
In Section 2.3 add an appropriate reference to this document when it is published.
3. Summary of Test Method
No change required.
4. Significance and Use
No change required.
5. Apparatus
No change required.
6. Preparation of Oven
No change required
7. Procedure
Modify Section 7.6 as to read:
*7.6 With the oven at operating temperature and the airflow set at 4000 ± 300 ml/min, arrange the containers holding the asphalt binder in the carriage so that the carriage is balanced. Fill any unused spaces in the carriage with empty containers. Close the door and rotate the carriage assemble at a rate of 15 ± 0.2 r/min. Maintain the glass containers in the oven with the air flowing and the carriage rotating **for duration listed in Table 1 based on the elevation of the laboratory**. The test temperature of $163 \pm 1.0^{\circ}\text{C}$ ($325 \pm 1.8^{\circ}\text{F}$) shall be reached within the first 10 min – otherwise discontinue the test.*

Table 1 – Conditioning Time

<i>Elevation, Ft</i>	<i>Conditioning Time, min</i>
<i>0 – 999</i>	<i>85</i>
<i>1,000 – 1,999</i>	<i>86</i>
<i>2,000 – 2,999</i>	<i>87</i>
<i>3,000 – 3,999</i>	<i>88</i>
<i>4,000 – 4,999</i>	<i>89</i>
<i>5,000 – 5,999</i>	<i>90</i>
<i>6,000 – 6,999</i>	<i>91</i>
<i>7,000 – 7,999</i>	<i>92</i>

Modify Section 7.9 to add a new Section 7.9.1 as follows:

7.9.1 Calculate the mass change using the following equation. The mass change may be negative (mass loss) or positive (mass gain)

$$\text{mass change, \%} = \frac{(B - A)}{(A - C)} \times 100\% + F$$

where:

A = mass of binder plus container before conditioning, g

B = mass of binder plus container after conditioning, g

C = mass of container, g

F = mass change correction factor from Table 2

Table 2 – Mass Change Correction Factor

<i>Conditioning Time, min</i>	<i>F</i>
<i>85</i>	<i>0.000</i>
<i>86</i>	<i>+0.006</i>
<i>87</i>	<i>+0.012</i>
<i>88</i>	<i>+0.018</i>
<i>89</i>	<i>+0.024</i>
<i>90</i>	<i>+0.030</i>
<i>91</i>	<i>+0.036</i>
<i>92</i>	<i>+0.042</i>

Renumber current Section 7.9.1 as **Section 7.9.2**.

8. Report

No change required

9. Precision and Bias

Relabel Table 1 as Table 3; relabel Table 2 as Table 4; relabel Table 3 as Table 5

10. Keywords

No change required

Appendix

No change required

From: [Maria Knake](#)
To: [Metcalf, Oak](#); [Blackburn, Lyndi](#); [DeVol, Joe](#); [Paye, Barry - DOT](#); [Geary, Georgene](#); [Soneira, Casey](#)
Subject: ASTM D70 Ballot
Date: Friday, June 21, 2019 2:35:45 PM
Attachments: [image001.png](#)
[image002.png](#)
[image003.png](#)
[image004.png](#)
[t 228 T228-09.pdf](#)
[D70 Ballot.doc](#)
[D70-08.19119.pdf](#)

Hello Oak, 2b Leadership, Georgene, and Casey:

As you may recall, over the last couple of years we have discussed whether a “C” standard is needed for ASTM T 228. At first glance, the differences between AASHTO and ASTM (D70) are numerous. However, after taking a closer look, the standards are pretty similar. We decided to go to ASTM and ask if they would make changes to bring the standards in alignment. I happen to be the technical contact in ASTM for D70, so this was an easy conversation. I had been working on some other revisions to D70 to bring it conformance with ASTM policy. Those changes have been finalized and published, so I am ready to tackle this as a harmonization issue at this point. I have reviewed the most recent version of D70 and have made changes to bring it in alignment with T228. I have included three documents 1) My proposed ballot for ASTM D70 2) T228 list of differences with my comments on those differences 3) The 2008 version of D70, which is the version that T228 refers to. It is necessary to refer to this when comparing to the current version of D70.

I would like your feedback on D70 before I send this to ballot. If you would like to wait until after the COMP meeting in August, that is fine. I just wanted to get this out on the table and make good on my promise to follow through with this.

The standards are not very off now, so I think this will be an easy review. I did incorporate many of Oak’s suggestions into previous D70 ballots, so the standards are fairly well harmonized at this point.

After I send this to ballot at ASTM I will continue to keep you informed of progress, including negatives received, etc. Once D70 is published, it is completely up to TS 2b to decide what to do with T228. Georgene might have some recommendations on how to proceed.

Thank you for your time.

Have a great weekend,

-Maria

Maria Knake

Manager, Laboratory Assessment Program



Email: mknake@ashtoresource.org

Direct: 240-436-4804

Cell: 240-772-0031

Main: 240-436-4900

Website: www.ashtoresource.org

AASHTO re:source (formerly AMRL)

4441 Buckeystown Pike

Suite A

Frederick, MD 21704

This document is not an ASTM standard; it is under consideration within an ASTM technical committee but has not received all approvals required to become an ASTM standard. You agree not to reproduce or circulate or quote, in whole or in part, this document outside of ASTM Committee/Society activities, or submit it to any other organization or standards bodies (whether national, international, or other) except with the approval of the Chairman of the Committee having jurisdiction and the written authorization of the President of the Society. If you do not agree with these conditions please immediately destroy all copies of the document. Copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. All Rights Reserved.



Designation: D70 – 18a

Date: June 2018
To: Subcommittee D04.47
Tech Contact: Maria Knake
Work Item #: WK68775
Ballot Action: Revision to ASTM D70

Rationale: The purpose of this ballot is to address differences between the AASHTO version (T 228) of this test procedure and the ASTM version. The AASHTO version is a “C” standard that lists differences between the AASHTO version and the ASTM version. This work has been discussed with AASHTO COMP Technical Subcommittee 2b, and they have suggested that changes be made to the ASTM version to harmonize the standards.

Standard Test Method for Density of Semi-Solid Asphalt Binder (Pycnometer Method)¹

This standard is issued under the fixed designation D70; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope *

1.1 This test method covers the determination of the relative density and density of semi-solid asphalt binder by use of a pycnometer.

NOTE 1—An alternate method for determining the density of asphalt binder is Test Method D3289. For materials which are too fluid for use of this test method, use Test Method D3142/D3142M.

NOTE 2—This test method may also be used for the determination of the relative density and density of soft tar pitches.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 **Warning**—Mercury has been designated by the United States Environmental Protection Agency (EPA) and many state agencies as a hazardous material that can cause central nervous system, kidney, and liver damage. Mercury, or its vapor, may be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury-containing products. See the applicable product Material Safety Data Sheet (MSDS) or Safety Data Sheet (SDS) for details and the EPA’s website (www.epa.gov/mercury/faq.htm) for additional information. Users should be aware that selling mercury, mercury-containing products, or both, in your state may be prohibited by state law.

1.4 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

¹ This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.47 on Miscellaneous Asphalt Tests.

Current edition approved Dec. 1, 2018. Published December 2018. Originally approved in 1920. Last previous edition approved in 2018 as D70 – 18. DOI: 10.1520/D0070-18A.

*A Summary of Changes section appears at the end of this standard.



2. Referenced Documents

2.1 *ASTM Standards:*²

C670

D140/D140M

D3142/D3142M

D3289

D3666

D4311/D4311M

E1

E77

E563

E644

E879

E1137/E1137M

2.2 *Other:*

CRC Handbook of Chemistry and Physics

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *density*—the mass per unit volume of a material.

3.1.2 *relative density*—the ratio of the mass of a given volume of a material to the mass of the same volume of water at the same temperature (see **Note 3**).

NOTE 3—Relative density is also described as specific gravity.

4. Summary of Test Method

4.1 The sample is placed in a standardized pycnometer. The pycnometer and sample are weighed, then the remaining volume is filled with water. The filled pycnometer is brought to the test temperature and weighed. The density of the sample is calculated from its mass and the mass of water displaced by the sample in the filled pycnometer.

5. Significance and Use

5.1 Values of density are used for converting volumes to units of mass, and for correcting measured volumes from the temperature of measurement to a standard temperature using Practice **D4311/D4311M**.

5.2 The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of Specification **D3666** are generally considered capable of competent and objective testing, sampling, inspection, etc. Users of this standard are cautioned that compliance with Specification **D3666** alone does not completely ensure reliable results. Reliable results depend on many factors; following the suggestions of Specification **D3666** or some similar acceptable guideline provides a means of evaluation and controlling some of these factors.

6. Apparatus

6.1 *Pycnometer*, glass, consisting of a cylindrical or conical vessel carefully ground to receive an accurately fitting glass stopper 22 to 26 mm [0.9 to 1.0 in.] in diameter. The stopper shall be provided with a hole 1.0 to 2.0 mm [0.04 to 0.08 in.] in

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



diameter, centrally located in reference to the vertical axis. The top surface of the stopper shall be substantially plane and have no chips, and the lower surface shall be concave to allow all air to escape through the bore. The height of the concave section shall be 4.0 to 18.0 mm [0.16 to 0.71 in.] at the center. The stoppered pycnometer shall have a capacity of 24 to 30 mL [0.95 to 1.18 in.] and shall weigh not more than 40 g [1.4 oz]. Suitable pycnometers are illustrated in Fig. 1.

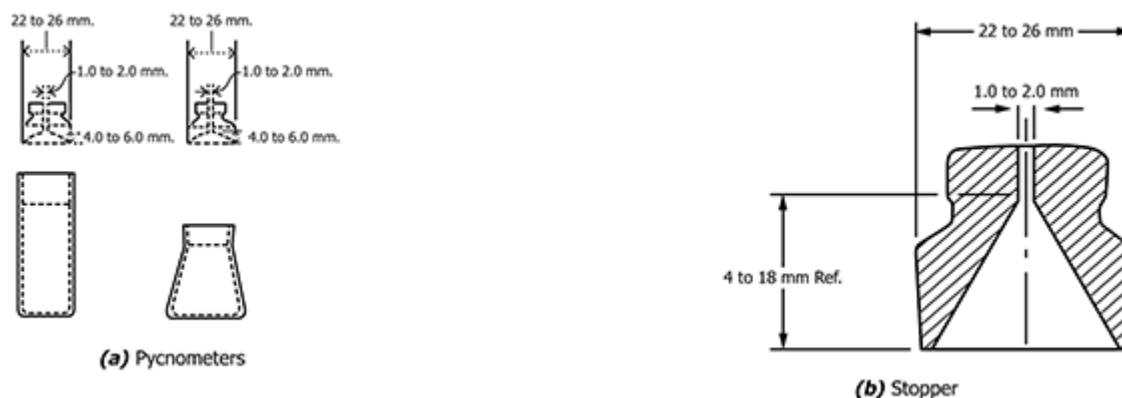


FIG. 1 Suitable Pycnometers and Stopper

6.2 *Water Bath*, constant-temperature, capable of maintaining the temperature within 0.1 °C [0.2 °F] of the test temperature. The water bath shall be equipped with a thermometer as described in 6.3.

6.3 *Thermometer*—The thermometer shall be one of the following:

6.3.1 A liquid-in-glass partial immersion thermometer of suitable range with subdivisions and maximum scale error of 0.1 °C [0.2 °F] which conforms to the requirements of Specification E1. Calibrate the thermometer in accordance with one of the methods in Test Method E77 or verify its original calibration at the ice point (Notes 4 and 5). A thermometer commonly used is an ASTM 63C.

NOTE 4—Practice E563 provides instructions on the preparation and use of an ice-point bath as a reference temperature.

NOTE 5—If the thermometer does not read 0.0 ± 0.1 °C [32.0 ± 0.2 °F] at the ice point, then the thermometer should be recalibrated.

6.3.2 A platinum resistance thermometer (PRT) with sensor which conforms to the requirements of Specification E1137/E1137M. The thermometer shall be calibrated annually as a single unit and have a 3- or 4-wire connection configuration. The sensing element shall be immersed to the depth specified by the manufacturer. Calibrate the PRT system (sensor and readout) in accordance with Test Methods E644 or verify its original calibration at the ice point (Notes 4 and 5). Corrections shall be applied to ensure accurate measurements within 0.1 °C [0.2 °F].

6.3.3 A thermistor thermometer with sensor which conforms to the requirements of Specification E879, calibrated annually as a single unit. The sensing element of the thermistor shall be completely immersed. Calibrate the thermistor thermometer system (sensor and readout) in accordance with Test Methods E644 or verify its original calibration at the ice point (Notes 4 and 5). Corrections shall be applied to ensure accurate measurements within 0.1 °C [0.2 °F].

6.4 *Balance*, capable of making the required measurements to an accuracy of at least 0.001 g [0.00001 oz].

6.5 *Beaker*, 600-mL [20-fluid oz] or larger Griffin low-form beaker.

6.6 *Tongs or Clean Nitrile (or Similar) Gloves*, for placing and removing the pycnometer from the beaker.

7. Materials

7.1 *Water*—Boiled and cooled distilled or deionized water, free of visual contaminants. Water greater than three days post boiling and cooling shall not be used (Note 7).

NOTE 6—Water should be discarded or re-boiled if bubbles are seen in the pycnometer during testing.

NOTE 7—As an alternative to using heat, a vacuum source to pull a negative pressure until the water boils without heat may be used. In this case, the water does not have to be cooled before use.

8. Sampling

8.1 Take samples in accordance with Practice D140/D140M. The sample shall be free of foreign substances.

8.2 Thoroughly mix the sample before removing a representative portion for testing.



9. Preparation of Apparatus

9.1 Partially fill a 600-mL [20-fluid oz] or larger Griffin low-form beaker with freshly boiled and cooled distilled or deionized water to a level that will allow the top of the pycnometer to be immersed to a depth of not less than 40 mm [1.6 in.].

9.2 Partially immerse the beaker in the water bath to a depth sufficient to allow the bottom of the beaker to be immersed to a depth of not less than 100 mm [3.9 in.], while the top of the beaker is above the water level of the bath. Utilize some method to ensure that the beaker does not tip over, while making sure that circulation of the water in the conditioning bath around the beaker is not restricted.

9.3 Maintain the temperature of the water bath within 0.1 °C [0.2 °F] of the test temperature as determined by the thermometer described in 6.3.

10. Standardization of Pycnometer

10.1 Perform each of the following steps for each test temperature at which the pycnometer will be used, handling the pycnometer only with tongs or gloves as described in 6.6:

10.1.1 Thoroughly clean, dry, and weigh the pycnometer to the nearest 0.001 g [0.00001 oz]. Designate this mass as *A*.

10.1.2 Remove the beaker from the water bath, if necessary. Fill the pycnometer with freshly boiled distilled or deionized water, placing the stopper loosely in the pycnometer. Place the pycnometer in the beaker and press the stopper firmly in place. Do not allow any air bubbles to remain in the pycnometer. Return the beaker to the water bath if previously removed.

10.1.3 Allow the pycnometer to remain in the water for a period of not less than 30 min. The water bath must be maintained within 0.1 °C [0.2 °F] of the test temperature as determined by the thermometer described in 6.3 during this time period. Remove the pycnometer and immediately dry the top of the stopper with one stroke of a dry towel (Note 8), then quickly dry the remaining outside area of the pycnometer and weigh to the nearest 0.001 g [0.00001 oz]. Designate the mass of the pycnometer plus water as *B*.

NOTE 8—Do not re-dry the top of the stopper even if a small droplet of water forms as a result of expansion. If the top is dried at the instant of removing the pycnometer from the water, the proper mass of the contents at the test temperature will be recorded. If moisture condenses on the pycnometer during weighing, quickly re-dry the outside of the pycnometer (excluding the top) before recording the mass.

11. Procedure

11.1 Perform each of the following steps, handling the pycnometer only with tongs or gloves as described in 6.6:

11.1.1 *Preparation of Sample*—Heat the sample with care, stirring to prevent local overheating, until the sample has become sufficiently fluid to pour. In no case should the temperature be raised to more than 55 °C [131 °F] above the expected softening point for tar, or to more than 110 °C [230 °F] above the expected softening point for asphalt. Do not heat for more than 60 min over a flame or hot plate or more than 120 min in an oven, and avoid incorporating air bubbles into the sample.

11.1.2 Pour enough sample into the clean, dry, warmed pycnometer to fill it about three-fourths of its capacity. Take precautions to keep the material from touching the sides of the pycnometer above the final level and prevent the inclusion of air bubbles (Note 9). Allow the pycnometer and its contents to cool to ambient temperature for a period of not less than 40 min and weigh with the stopper to the nearest 0.001 g [0.00001 oz]. Designate the mass of the pycnometer plus sample as *C*. The pycnometer shall be handled with only tongs or gloves during this entire process.

NOTE 9—If any air bubbles are inadvertently entrained, remove by brushing the surface of the asphalt in the pycnometer with a high “soft” flame of a Bunsen burner or torch. To avoid overheating, do not allow the flame to remain in contact with the asphalt more than a few seconds at any one time.

11.1.3 Remove the beaker from the water bath, if necessary. Fill the pycnometer containing the sample with freshly boiled distilled or deionized water, placing the stopper loosely in the pycnometer. Do not allow any air bubbles to remain in the pycnometer. Place the pycnometer in the beaker and press the stopper firmly in place. Return the beaker to the water bath if previously removed.

11.1.4 Allow the pycnometer to remain in the water bath for a period of not less than 30 min. Remove the pycnometer from the bath. Dry and weigh using the same technique and timing as that employed in 10.1.3. Designate this mass of pycnometer plus sample plus water as *D*.

12. Calculation

12.1 Calculate the relative density to the nearest 0.001 as follows:

$$\text{relative density} = (C - A) / [(B - A) - (D - C)] \quad (1)$$



where:

- A = mass of pycnometer (plus stopper),
 B = mass of pycnometer filled with water,
 C = mass of pycnometer partially filled with asphalt, and
 D = mass of pycnometer plus asphalt plus water.

12.2 Calculate density to the nearest 0.001 as follows:

$$\text{Density} = \text{relative density} \times W_T \quad (2)$$

where:

W_T = density of water at the test temperature (Note 10).

NOTE 10—Density of water from CRC Handbook of Chemistry and Physics:

Temperature °C [°F]	Density of Water kg/m ³ (kg/L)	[Density of Water lb/ft ³ (lb/gal)]
15.6 [60.1]	999.0 (0.9990)	[62.37 (8.337)]
25.0 [77]	997.0 (0.9970)	[62.24 (8.321)]

13. Report

13.1 Report density to the nearest 1 kg/m³ (0.001 kg/L) [0.05 lb/ft³ (0.001 lb/gal)] and the test temperature.

14. Precision and Bias

14.1 *Single-Operator Precision*—The single-operator pooled standard deviation for the relative density (specific gravity) of semi-solid bituminous materials has been found to be 0.0013 at 15.6 °C and 0.00082 at 25.0 °C (see Table 1). Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than the following values (see Note 11):

Test Temperature, °C [°F]	Density, kg/m ³ (kg/L)
15.6 [60.1]	3.7 (0.0037)
25.0 [77]	2.3 (0.0023)

TABLE 1 Precision of Relative Density Data for Semi-Solid Bituminous Materials

	Temperature °C [°F]	Single-Operator			Multilaboratory		
		Degrees of Freedom	(1S)	(D2S)	Degrees of Freedom	(1S)	(D2S)
Asphalt	15.6 [60.1]	54	0.0011	0.0032	24	0.0018	0.0051
	25.0 [77]	54	0.00080	0.0023	24	0.0024	0.0068
Soft tar pitch	15.6 [60.1]	72	0.0013	0.0038	27	0.0029	0.0083
	25.0 [77]	72	0.00083	0.0023	27	0.0017	0.0048
Pooled values	15.6 [60.1]	114	0.0013	0.0037	51	0.0024	0.0068
	25.0 [77]	114	0.00082	0.0023	51	0.0019	0.0053

14.2 *Multilaboratory Precision*—The multilaboratory pooled standard deviation for the relative density (specific gravity) of semi-solid bituminous materials has been found to be 0.0024 at 15.6 °C and 0.0019 at 25.0 °C (see Table 1). Therefore, results of two properly conducted tests by two laboratories on samples of the same material should not differ by more than the following values (see Note 11):



Test Temperature, °C [°F]	Density, kg/m ³ (kg/L)
15.6 [60.1]	6.8 (0.0068)
25.0 [77]	5.4 (0.0054)

NOTE 11—These number represent, respectively, the (1S) and (D2S) limits as described in Practice C670.

14.3 *Bias*—No information can be presented on the bias of the procedure in this test method for measuring density because no material having an accepted reference value is available.

15. Keywords

15.1 density; pycnometer; relative density; specific gravity

SUMMARY OF CHANGES

Committee D04 has identified the location of selected changes to this standard since the last issue (D70 – 18) that may impact the use of this standard. (Approved Dec. 1, 2018.)

- (1) Added new Note 2 and renumbered remaining notes.
- (2) Moved the contents of Note 7 into the body of the standard as mandatory language.

Committee D04 has identified the location of selected changes to this standard since the last issue (D70 – 17) that may impact the use of this standard. (Approved Apr. 1, 2018.)

- (1) Term ‘bituminous materials’ changed to ‘asphalt binder’ in Section 1.
- (2) SI units changed to combined SI/inch-pound units throughout.
- (3) Specifications D3666 and E879 added to Section 2.
- (4) Added new subsections 1.4 and 5.2.
- (5) Thermometer requirements updated in 6.3.2 and 6.3.3.
- (6) Wording updated throughout to specify that the pycnometer is to be handled with tongs or gloves at all times.

Committee D04 has identified the location of selected changes to this standard since the last issue (D70 – 09) that may impact the use of this standard. (Approved Dec. 15, 2017.)

- (1) Term ‘asphalt cement’ changed to ‘asphalt’ in 1.1.
- (2) Units changed to SI only in 1.2.
- (3) Mercury caveat moved to Section 1.
- (4) Term ‘calibrate’ changed to ‘standardize’ throughout.
- (5) Thermometer wording changed to be more specific in 6.3.
- (6) Requirements for water updated in 7.1.
- (7) Note 7 added to indicate that water can be boiled by applying negative pressure until it boils.
- (8) Rubber-covered tongs added to the apparatus in 6.6.
- (9) Maximum preheat time changed from 60 min to 120 min in 11.1.
- (10) ASTM standards E77, E563, E644, and E1137/E1137M added to Section 2.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; http://www.copyright.com/



Designation: D 70 – 08

Standard Test Method for Density of Semi-Solid Bituminous Materials (Pycnometer Method)¹

This standard is issued under the fixed designation D 70; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers the determination of the relative density and density of semi-solid bituminous materials, asphalt cements, and soft tar pitches by use of a pycnometer.

NOTE 1—An alternate method for determining the density of semi-solid and solid bituminous materials is Test Method D 3289. For materials which are too fluid for use of this test method, use Test Method D 3142.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

D 140 Practice for Sampling Bituminous Materials

D 3142 Test Method for Specific Gravity, API Gravity, or Density of Cutback Asphalts by Hydrometer Method

D 3289 Test Method for Density of Semi-Solid and Solid Bituminous Materials (Nickel Crucible Method)

D 4311 Practice for Determining Asphalt Volume Correction to a Base Temperature

E 1 Specification for ASTM Liquid-in-Glass Thermometers

2.2 Other:

CRC Handbook of Chemistry and Physics

¹ This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.47 on Miscellaneous Asphalt Tests.

Current edition approved Jan. 1, 2008. Published January 2008. Originally approved in 1920. Last previous edition approved in 2003 as D 70 – 03.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *density*—the mass per unit volume of a material.

3.1.2 *relative density*—the ratio of the mass of a given volume of a material to the mass of the same volume of water at the same temperature (see Note 2).

NOTE 2—Relative density is also described as specific gravity.

4. Summary of Test Method

4.1 The sample is placed in a calibrated pycnometer. The pycnometer and sample are weighed, then the remaining volume is filled with water. The filled pycnometer is brought to the test temperature, and weighed. The density of the sample is calculated from its mass and the mass of water displaced by the sample in the filled pycnometer.

5. Significance and Use

5.1 Values of density are used for converting volumes to units of mass, and for correcting measured volumes from the temperature of measurement to a standard temperature using Practice D 4311.

6. Apparatus

6.1 *Pycnometer*, glass, consisting of a cylindrical or conical vessel carefully ground to receive an accurately fitting glass stopper 22 to 26 mm in diameter. The stopper shall be provided with a hole 1.0 to 2.0 mm in diameter, centrally located in reference to the vertical axis. The top surface of the stopper shall be substantially plane and have no chips, and the lower surface shall be concave to allow all air to escape through the bore. The height of the concave section shall be 4.0 to 18.0 mm at the center. The stoppered pycnometer shall have a capacity of 24 to 30 mL and shall weigh not more than 40 g. Suitable pycnometers are illustrated in Fig. 1.

6.2 *Water Bath*, constant-temperature, capable of maintaining the temperature within 0.1°C (0.2°F) of the test temperature.

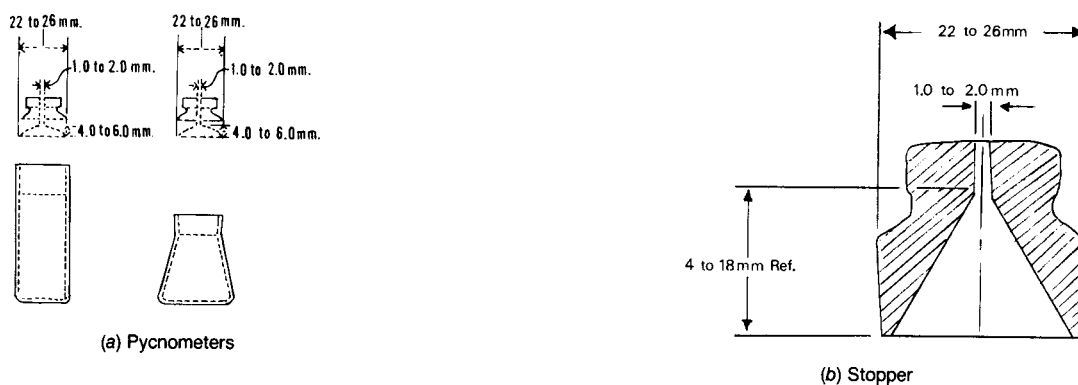


FIG. 1 Suitable Pycnometers and Stopper

6.3 *Thermometric device*, calibrated liquid in glass, total immersion type, of suitable range with graduations at least every 0.1°C (0.2°F) and a maximum scale error of 0.1°C (0.2°F) as prescribed in Specification E 1. Thermometer commonly used is ASTM 63°C (63°F). Any other thermometric device of equal accuracy may be used.

6.4 *Balance*, capable of making the required measurements to an accuracy of at least 0.001g.

6.5 *Beaker*, 600 mL or larger Griffin low-form beaker.

7. Materials

7.1 *Water*—Freshly boiled and cooled distilled or deionized water.

8. Hazards

8.1 **Warning:** Mercury has been designated by the United States Environmental Protection Agency (EPA) and many state agencies as a hazardous material that can cause central nervous system, kidney and liver damage. Mercury, or its vapor, may be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury containing products. See the applicable product Material Safety Data Sheet (MSDS) for details and EPA's website—www.epa.gov/mercury/faq.htm—for additional information. Users should be aware that selling mercury, mercury containing products, or both, into your state may be prohibited by state law.

9. Sampling

9.1 Take samples in accordance with Practice D 140. The sample shall be free of foreign substances.

9.2 Thoroughly mix the sample before removing a representative portion for testing.

10. Preparation of Apparatus

10.1 Partially fill a 600-mL or larger Griffin low-form beaker with freshly boiled and cooled distilled or deionized water to a level that will allow the top of the pycnometer to be immersed to a depth of not less than 40 mm.

10.2 Partially immerse the beaker in the water bath to a depth sufficient to allow the bottom of the beaker to be immersed to a depth of not less than 100 mm, while the top of the beaker is above the water level of the bath. Utilize some method to ensure that the beaker does not tip over, while

making sure that circulation of the water in the conditioning bath around the beaker is not restricted.

10.3 Maintain the temperature of the water bath within 0.1°C (0.2°F) of the test temperature.

11. Calibration of Pycnometer

11.1 Thoroughly clean, dry, and weigh the pycnometer to the nearest 0.001 g. Designate this mass as *A*.

11.2 Remove the beaker from the water bath if necessary. Fill the pycnometer with freshly boiled distilled or deionized water, placing the stopper loosely in the pycnometer. Place the pycnometer in the beaker and press the stopper firmly in place. Return the beaker to the water bath if previously removed.

NOTE 3—Calibration must be done at the test temperature. A pycnometer calibrated at one temperature cannot be used at a different temperature without recalibration at that temperature.

11.3 Allow the pycnometer to remain in the water for a period of not less than 30 min. Remove the pycnometer, immediately dry the top of the stopper with one stroke of a dry towel (Note 4), then quickly dry the remaining outside area of the pycnometer and weigh to the nearest 0.001 g. Designate the mass of the pycnometer plus water as *B*.

NOTE 4—Do not redry the top of the stopper even if a small droplet of water forms as a result of expansion. If the top is dried at the instant of removing the pycnometer from the water, the proper mass of the contents at the test temperature will be recorded. If moisture condenses on the pycnometer during weighing, quickly redry the outside of the pycnometer (excluding the top) before recording the mass.

12. Procedure

12.1 *Preparation of Sample*—Heat the sample with care, stirring to prevent local overheating, until the sample has become sufficiently fluid to pour. In no case should the temperature be raised to more than 55°C (131°F) above the expected softening point for tar, or to more than 110°C (230°F) above the expected softening point for asphalt. Do not heat for more than 60 min, and avoid incorporating air bubbles into the sample.

12.2 Pour enough sample into the clean, dry, warmed pycnometer to fill it about three fourths of its capacity. Take precautions to keep the material from touching the sides of the pycnometer above the final level and prevent the inclusion of air bubbles (Note 5). Allow the pycnometer and its contents to

cool to ambient temperature for a period of not less than 40 min and weigh with the stopper to the nearest 0.001 g. Designate the mass of the pycnometer plus sample as *C*.

NOTE 5—If any air bubbles are inadvertently occluded, remove by brushing the surface of the asphalt in the pycnometer with a high “soft” flame of a bunsen burner or torch. To avoid overheating, do not allow the flame to remain in contact with the asphalt more than a few seconds at any one time.

12.3 Remove the beaker from the water bath if necessary. Fill the pycnometer containing the asphalt with freshly boiled distilled or deionized water, placing the stopper loosely in the pycnometer. Do not allow any air bubbles to remain in the pycnometer. Place the pycnometer in the beaker and press the stopper firmly in place. Return the beaker to the water bath if previously removed.

12.4 Allow the pycnometer to remain in the water bath for a period of not less than 30 min. Remove the pycnometer from the bath. Dry and weigh using the same technique and timing as that employed in 11.3. Designate this mass of pycnometer plus sample plus water as *D*.

13. Calculation

13.1 Calculate the relative density to the nearest 0.001 as follows:

$$\text{relative density} = (C - A) / [(B - A) - (D - C)] \quad (1)$$

where:

A = mass of pycnometer (plus stopper),

B = mass of pycnometer filled with water,

C = mass of pycnometer partially filled with asphalt, and

D = mass of pycnometer plus asphalt plus water.

13.2 Calculate density to the nearest 0.001 as follows:

$$\text{Density} = \text{relative density} \times W_T \quad (2)$$

where:

W_T = density of water at the test temperature (Note 6).

NOTE 6—Density of water from **CRC Handbook of Chemistry and Physics**:

Temperature, °C	Density of Water, kg/m ³ (kg/L)
15.0	999.1 (0.9991)
25.0	997.0 (0.9970)

14. Report

14.1 Report density to the nearest 1 kg/m³(0.001 kg/L) and the test temperature.

15. Precision and Bias

15.1 *Single Operator Precision*—The single-operator standard deviation for the relative density of semi-solid bituminous materials has been found to be 0.0013 at 15.6°C (60°F) and 0.00082 at 25.0°C (77°F). Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than the following values (see Note 7):

Test Temperature, °C	Density, kg/m ³ (kg/L)
15.0	3.5 (0.0035)
25.0	2.3 (0.0023)

15.2 *Multilaboratory Precision*—The multilaboratory standard deviation for the relative density of semi-solid bituminous materials has been found to be 0.0024 at 15.6°C and 0.0019 at 25.0°C. Therefore, results of two properly conducted tests by two laboratories on samples of the same material should not differ by more than the following values (see Note 6):

Test Temperature, °C	Density, kg/m ³ (kg/L)
15.0	6.7 (0.0067)
25.0	5.3 (0.0053)

NOTE 7—These number represent, respectively, the (1S) and (D2S) limits as described in Practice C 670.

15.3 *Bias*—No information can be presented on the bias of the procedure in this test method for measuring density because no material having an accepted reference value is available.

16. Keywords

16.1 density; pycnometer; relative density; specific gravity

TABLE 1 Precision of Relative Density Data for Semi-Solid Bituminous Materials

	Temperature °C	Single-Operator			Multilaboratory		
		Degrees of Freedom	(1S)	(D2S)	Degrees of Freedom	(1S)	(D2S)
Asphalt	15.6	54	0.0011	0.0032	24	0.0018	0.0051
	25.0	54	0.00080	0.0023	24	0.0024	0.0068
Soft tar pitch	15.6	72	0.0013	0.0038	27	0.0029	0.0083
	25.0	72	0.00083	0.0023	27	0.0017	0.0048
Pooled values	15.6	114	0.0013	0.0035	51	0.0024	0.0067
	25.0	114	0.00082	0.0023	51	0.0019	0.0053

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).

Standard Method of Test for Specific Gravity of Semi-Solid Asphalt Materials

AASHTO Designation: T 228-09 (2013)

Technical Section: 2b, Liquid Asphalt

ASTM Designation: D70-08



**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Specific Gravity of Semi-Solid Asphalt Materials

AASHTO Designation: T 228-09 (2013)



Technical Section: 2b, Liquid Asphalt

ASTM Designation: D70-08

AASHTO T 228-09 (2013) is identical to ASTM D70-08 except for the following provisions:

1. Replace all references to the ASTM standards listed in the following table with the corresponding AASHTO standards:

<i>Referenced Standards</i>	
ASTM	AASHTO
D140	R 66
D3142	T 295

This change probably not necessary to make in D70 but let me know if you disagree.

2. Add the following to Section 2:
 2.3 *AASHTO Standard:*
 M 231, Weighing Devices Used in the Testing of Materials Same with this one
3. Add the following sentence to Note 2: Note 3 of this version already addresses this point.
 The terms “relative density” and “specific gravity” are used interchangeably in this standard.
4. Replace Section 6.4 with the following:
 6.4 *Balance*—conforming to the requirements of M 231, Class B. Necessary?
5. Replace Section 11.2 with the following: Added statement about air bubbles. The rest is already addressed
 11.2 Fill the pycnometer with freshly boiled distilled or deionized water at test temperature and place the stopper in the pycnometer. Do not allow any air bubbles to remain in the pycnometer. Place the filled pycnometer in the beaker.
6. Replace the last sentence in Section 12.1 with the following:
 “Do not heat for more than 60 min over a flame or hot plate or for more than 2 h in an oven, and avoid incorporating air bubbles in the sample.” Change made.
7. Replace Section 12.3 with the following:
 12.3 Fill the pycnometer with freshly boiled distilled or deionized water at the test temperature and place the stopper in the pycnometer. Do not allow any air bubbles to remain in the pycnometer. Place the filled pycnometer in the beaker. No significant difference now.
8. Replace Section 15 with the following: Section is now 11.1.3
15. Precision and Bias
 15.1 *Precision*—Criteria for judging the acceptability of the relative density results obtained by this method are given in Table 1.
 15.1.1 *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 1 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the

The only difference now is that the ASTM version also has pooled values. Ok to keep as-is?

same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results exceeds the values given in Table 1, Column 3.

15.1.2 *Multilaboratory Precision (Reproducibility)*—The figures in Column 4 of Table 1 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results exceeds the values given in Table 1, Column 5.

Table 1—Precision Estimates

Condition	Single-Operator		Multilaboratory	
	Standard Deviation (1s) ^a	Acceptable Range of Two Results (d2s) ^a	Standard Deviation (1s) ^a	Acceptable Range of Two Results (d2s) ^a
Asphalt:				
Specific Gravity (15.6°C)	0.0011	0.0032	0.0018	0.0051
Specific Gravity (25°C)	0.0008 ^b	0.0021 ^b	0.0013 ^b	0.0035 ^b
Soft Tar Pitch:				
Specific Gravity (15.6°C)	0.0013	0.0038	0.0029	0.0083
Specific Gravity (25°C)	0.00083	0.0023	0.0017	0.0048

^a These values represent the 1s and d2s limits described in ASTM Practice C670.

^b The precision estimates denoted by the superscript “b” are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 104 to 121 laboratories for each of the eight pairs of samples. The analysis included four binder grades: PG 52-34, PG 64-16, PG 64-22, and PG 70-22. Average specific gravities in the analysis ranged from 1.0058 to 1.0428. The details of this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Note: Values in Table 1 not marked with a superscript “b” are precision estimates retained from ASTM D70-03, Section 14, Table 1. These values were not part of the scope of the AMRL research activities described with the superscript “b.”

15.2 *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

Standard Practice for

Characterizing the Relaxation
Behavior of Asphalt Binders Using
the Delta T_c (ΔT_c) Parameter

Commented [FHWA1]: Suggest using subscript c throughout document ... since the verbalization of delta is the important aspect and not the verbalization of c. Ideally it would be "Delta T subscript c" verbalized but people are used to saying Delta T_c. It is more accurate to use T subscript c throughout the document.

Formatted: Subscript

AASHTO Designation: PP xx-19



American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Characterizing the Relaxation Behavior of Asphalt Binders Using the Delta T_c (ΔT_c) Parameter

AASHTO Designation: PP xx-19



1. SCOPE

1.1. This practice provides a means of evaluating the behavior of an asphalt binder at low temperature using the results (Stiffness and m-value) from the Bending Beam Rheometer (BBR) test to calculate a value (identified as Delta T_c or ΔT_c) that is indicative of the relaxation properties of the asphalt binder. This practice is primarily intended for use with residue generated after long-term conditioning with T-240 (Rolling Thin-Film Oven (RTFO)) and R 28 (Pressurized Aging Vessel (PAV)), but may also be used on recovered asphalt binder from asphalt mixture, reclaimed asphalt pavement (RAP), and ~~reeyeled~~ ~~reclaimed~~ asphalt shingles (RAS).

1.2. The behavior of an asphalt binder at low temperature can provide insight to the technologist indicating to what extent the asphalt binder exhibits adequate relaxation properties to minimize its contribution to non-load related, durability cracking in an asphalt pavement.

1.3. This practice may be used in conjunction with M 320, *Specification for Performance-Graded Asphalt Binder*, or M 332, *Performance-Graded Asphalt Binder Using the Multiple Stress Creep Recovery (MSCR) Test*.

1.4. The values stated in SI units are to be regarded as the standard.

1.5. *This standard does not purport to address all the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. AASHTO Standards:

- T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- T-240, Effect of Heat and Air on Moving Film of Asphalt (Rolling Thin-Film Oven Test)
- R 28, Accelerated Aging of Asphalt Binder Using Pressurized Aging Vessel (PAV)
- R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
- M-320, Performance-Graded Asphalt Binder
- M 332, Performance-Graded Asphalt Binder Using the Multiple Stress Creep Recovery (MSCR) Test
- PP 78, Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in Asphalt Mixtures

2.2. ASTM Standards:

Commented [FHWA2]: Suggest using subscript c throughout document ... since the verbalization of delta is the important aspect and not the verbalization of c. Ideally it would be "Delta T subscript c" verbalized but people are used to saying Delta T_c. It is more accurate to use T subscript c throughout the document.

Formatted: Subscript

Formatted: Subscript

Commented [FHWA3]: AASHTO PP 78 uses "reclaimed" for RAS. See referenced standards.

Commented [FHWA4]: Perhaps we can add the additional information provided regarding susceptibility to accelerated ageing that can be captured with this parameter. The rate of ageing or accelerated aging that is captured with this test is applicable to load related cracking as well. The need to capture aging and longer term specimen oven conditioning in all the cracking evaluations is needed since cracking becomes a larger concern later in the pavement life as it continues to age in place. I don't believe it is limited to non-load related cracking.

- D-8, Standard Terminology Relating to Materials for Roads and Pavements
- D-7643, Determining the Continuous Grading Temperatures and Continuous Grades for PG Graded Asphalt Binders

3. TERMINOLOGY

3.1. Definitions:

3.1.1. Definitions of terms used in this practice may be found in ASTM D-8, determined from common English usage, or combinations of both.

3.2. Definitions of Terms Specific to This Standard:

3.2.1. $T_{c,s}$ – the critical temperature at which the specification criterion is exactly met for BBR Stiffness $S(t)$ (300 MPa at 60 seconds of loading).

3.2.2. $T_{c,m}$ – the critical temperature at which the specification criterion is exactly met for BBR m-value (0.300 at 60 seconds of loading).

3.2.3. Delta T_c (ΔT_c) – the calculated difference between $T_{c,s}$ and $T_{c,m}$. It is related to the relaxation properties of the asphalt binder.

4. SUMMARY OF PRACTICE

4.1. This practice is used to evaluate the relaxation behavior of an asphalt binder using parameters obtained from the Bending Beam Rheometer (BBR) test at two or more temperatures to calculate a value for a parameter, ΔT_c .

4.2. The ΔT_c value may be determined on asphalt binders being evaluated for compliance with AASHTO M 320 or M 332. The ΔT_c value may be determined on asphalt binders recovered from asphalt mixture, pavement cores or slabs, reclaimed asphalt pavement (RAP), or reclaimed asphalt shingles (RAS).

5. SIGNIFICANCE AND USE

5.1. This practice is used to evaluate the behavior of an asphalt binder at low temperatures as an indication of the relaxation properties of the asphalt binder. Although the evaluation is conducted at low temperature, it is expected that the properties measured will be highly correlated with the relaxation properties of the asphalt binder at intermediate temperature. In either case, asphalt binders which exhibit poor relaxation properties are expected to be susceptible to non-load related, durability cracking in service.

6. APPARATUS

6.1. Use apparatus as specified in T 313, T 240, and R 28.

Commented [FHWA5]: Ensure definitions are consistent with regard to AI documents or the referenced ASTM standards. The first few rounds of ASTM standard ballots on this topic wasn't using commonly found terminology from other documents and generated negative ballot responses to revise the definitions.

Is there a need to add the references for these definitions? Correct me if I'm mistaken, but I don't believe these definitions are captured in ASTM D8 (reference in sect 3.1.1 above) since they are not used in multiple ASTM standards.

Do we need to included definitions for S and m-value here?

Also need to check terminology used in T313 and M320 to ensure consistency.

Commented [FHWA6]: need to include S as the parameter since it is used in the other standards as well as further down in this document.

Is this $S_m(t)$, $S(t)$, or just S ?

Formatted: Subscript

Commented [FHWA7]: This instance is correct. Uses reclaimed for RAS.

Commented [FHWA8]: see similar previous comment on limiting to non-load related cracking

7. PROCEDURE

7.1. Perform testing on the aged or recovered asphalt binder sample following the procedures in AASHTO T313.

7.1.1. For lab-aged asphalt binder that has not been recovered, start testing at a temperature appropriate for the expected low temperature grade.

7.1.1.1. If the grade of the asphalt binder is known, the starting test temperature is simply ten degrees warmer than the low temperature grade, as described in Section 7.9 of AASHTO R 29.

7.1.1.2. If the grade of the asphalt binder is unknown, select the starting test temperature following the procedure described in Section 6.9 of AASHTO R 29.

7.1.2. After obtaining values of **Stiffness** $S(t)$ and m -value at 60 seconds of loading – $S(60)$ and $m(60)$, respectively – choose a second test temperature based on the first $S(60)$ value so that when testing is completed the two $S(60)$ values will bracket the specification criterion of 300 MPa as described in AASHTO M 320 and M 332.

Note 1 – Usually the second test temperature based on the $S(60)$ result will be six (6) degrees warmer or colder than the first test temperature. Although it is possible to choose a second test temperature that is more than six degrees from the first test temperature, some error could be realized in the calculation of the critical temperature for BBR Stiffness ($T_{c,s}$) as a result of the assumption of a linear relationship between temperature and the logarithm of Stiffness. It is therefore recommended that the technician add testing at a third test temperature if the $S(60)$ result from the first test indicates that the second temperature should be more than twelve (12) degrees different from the first test temperature. The second and third test temperatures would then be used to determine $T_{c,s}$.

Note 2 – For many asphalt binders, the selection of two temperatures based on $S(60)$ values such that they bracket the specification value of 300 MPa in the calculation of $T_{c,s}$ will be sufficient to also provide m -values at the same temperatures that bracket the specification value of 0.300 in the calculation of $T_{c,m}$. If not, then the technician should consider adding a third test temperature. It is good practice to bracket the specification values and use interpolation to determine $T_{c,s}$ and $T_{c,m}$ instead of determining the values by extrapolation.

7.2. Calculation of Delta T_c (ΔT_c)

7.2.1. The parameter Delta T_c (ΔT_c) is determined as the difference between the critical temperature for BBR Stiffness ($T_{c,s}$) where the Stiffness at 60 seconds of loading is calculated to be exactly at the specification criterion of 300 MPa and the critical temperature for BBR m -value ($T_{c,m}$) where the m -value at 60 seconds of loading is calculated to be exactly at the specification criterion of 0.300. Calculations for determining $T_{c,s}$ and $T_{c,m}$ are shown in ASTM D7643 and are repeated below for reference. The calculation for determining ΔT_c is shown in Section 6.3 of ASTM D7643 and Section 7 of AASHTO PP 78 and is also repeated below for reference.

$$T_{c,s} = T_x + \left(\frac{(T_x - T_y) * (\text{Log } 300 - \text{Log } S_x)}{\text{Log } S_x - \text{Log } S_y} \right) - 10 \quad \text{Eq. 1}$$

$$T_{c,m} = T_x + \left(\frac{(T_x - T_y) * (0.300 - m_x)}{m_x - m_y} \right) - 10 \quad \text{Eq. 2}$$

Formatted: Subscript

Formatted: Subscript

$$\Delta T_c = T_{c,s} - T_{c,m}$$

Eq. 3

Where

$T_{c,s}$ = critical temperature where BBR Stiffness at 60 seconds loading = 300 MPa (reported to 0.1°C)

Commented [FHWA9]: already defined in definitions section. okay to duplicate here as long as they match up.

$T_{c,m}$ = critical temperature where BBR m-value at 60 seconds loading = 0.300 (reported to 0.1°C)

Commented [FHWA10]: already defined in definitions section. okay to duplicate here as long as they match up.

T_x, T_y = temperature at which the BBR test is performed

Commented [FHWA11]: should these be defined in the definitions section 3.1?

S_x, S_y = Stiffness at 60 seconds, measured at BBR test temperature T_x, T_y

Commented [FHWA12]: should these be defined in the definitions section 3.1?

m_x, m_y = m-value at 60 seconds, measured at BBR test temperature T_x, T_y

Note 3 – ΔT_c is typically reported to one decimal place (i.e., 0.1), but as it is a measure of the difference between two critical temperatures and is not a direct temperature measurement it should be considered as unitless. Thus “the ΔT_c of the asphalt binder was determined to be -4.2” is correct, but “the ΔT_c of the asphalt binder was determined to be -4.2 degrees” is not.

Commented [FHWA13]: This appears inconsistent with the Sections 7.2.3 and 7.2.4 below describing positive and negative values. Is this sentence or note needed?

7.2.1.1. For asphalt binders that have more negative ΔT_c values, usually lower than -6, users may find that it is necessary to perform testing at a warmer BBR test temperature so that m-value will be higher than the 0.300 specification.

Note 4 – Users evaluating asphalt binders having very low ΔT_c values (significantly lower than -6) may find it difficult to effectively test at temperatures that would allow for interpolation in calculating $T_{c,m}$. In these instances, the S values are low enough that they could result in the BBR test being considered invalid because the maximum deflection is reached during the test.

7.2.2. For ease in comparison of different values of ΔT_c , it is recommended that the conditioning of the asphalt binder be identified by an additional subscript as follows:

O Original, tank asphalt binder (not subjected to any conditioning)

R RTFO-aged asphalt binder

Pxx PAV-aged asphalt binder, where the “xx” represents the number of hours of PAV conditioning

Rec Recovered asphalt binder, not subjected to additional conditioning

Commented [FHWA14]: I really like this structure and use. Great!!

7.2.2.1. Thus, $\Delta T_{c,P40}$ would represent a ΔT_c value calculated from BBR data measured after the asphalt binder was subjected to conditioning in the PAV for 40 hours. The term $\Delta T_{c,Rec}$ would represent a ΔT_c value calculated from BBR data measured after recovery of the asphalt binder from a mixture sample, core/slab, RAP, or RAS.

7.2.2.2. Users may choose to skip the extra subscripts and simply describe the level of conditioning to which the asphalt binder was subjected. In the absence of a description or subscripts, it may be assumed that the asphalt binder was not recovered and was subjected to the standard long-term conditioning procedure (RTFO followed by 20-hours of PAV).

7.2.3. Asphalt binders having a ΔT_c value less than zero (negative numbers) are “m-controlled” for the given condition at which they are tested. This means that the temperature at which the m-value reaches 0.300 is warmer than the temperature at which the Stiffness reaches 300 MPa and is the controlling parameter for determining low temperature grade. The more negative the ΔT_c value, the more m-controlled the asphalt binder.

7.2.3.1. The more m-controlled the asphalt binder is, the more slowly it will relax stresses at a given stiffness than a less m-controlled asphalt binder. It is this slower relaxation of stresses that is believed to be related to non-load related, durability cracking.

Commented [FHWA15]: similar comment on limiting to non-load related durability cracking.

7.2.4. Asphalt binders having a ΔT_c value greater than zero (positive numbers) are “S-controlled” for the given condition at which they are tested. This means that the temperature at which the Stiffness reaches 300 MPa is warmer than the temperature at which the m-value reaches 0.300 and is the controlling parameter for determining low temperature grade. The more positive the ΔT_c value, the more S-controlled the asphalt binder.

Note 5 – Although it might seem that S-controlled asphalt binders (those with positive ΔT_c values) would be best for cracking, it is important to realize that stiffness matters as well as relaxation. A very stiff asphalt binder that relaxes well for its stiffness may still result in cracking in service.

7.3. *Impact of Aging and Increased Asphalt Binder Stiffness on Delta T_c (ΔT_c)*

Formatted: Subscript

7.3.1. The value of ΔT_c is affected by increased aging both in service ageing and ageing represented by oven conditioning. The ΔT_c values of asphalt binders subjected to 20 hours of conditioning in the PAV as described in AASHTO R 28 will be lower-more negative than the ΔT_c values of RTFO-aged asphalt binders. Similarly, the ΔT_c values of asphalt binders subjected to longer PAV conditioning times will be lower-more negative than the ΔT_c values of 20 hours of conditioning as described in AASHTO R 28.

Commented [FHWA16]: This addition, I feel helps support sections 7.2.2 and 8.1.4.

Note 6 – The standard PAV conditioning procedure described in AASHTO R 28 was intended to produce an asphalt binder with physical properties that simulated the properties of an asphalt binder after it had been in-service for a number of years. In validation efforts, the Strategic Highway Research Program (SHRP) researchers found that the amount of aging simulated could vary as a consequence of a number of potential factors such that PAV conditioning adequately simulated physical properties after four years in one location and eight years in another. In yet another site, the amount of aging in service after four years resulted in aged properties that exceeded those after standard PAV aging [1].

7.3.1.1. Users should consider if the standard PAV conditioning procedure is appropriate for the project conditions and intended simulation of physical properties or if a modified version of the standard PAV conditioning procedure (e.g., 40 hours) is more appropriate.

7.3.2. The value of ΔT_c is generally affected by increased asphaltenes, the consequence of which is greater high temperature stiffness in unmodified asphalt binders. As the high temperature grade of the unmodified asphalt binder increases for a given asphalt binder source the ΔT_c value will decrease. Thus, an unmodified PG 58-22 produced from a specific source (refinery and crude source/blend used) will typically have a higher value of ΔT_c after the same level of aging than an unmodified PG 64-16 produced from the same source.

7.4. *Determining Delta T_c (ΔT_c) of Asphalt Binders Recovered from RAP and RAS*

Formatted: Subscript

7.4.1. RAP is the reclaimed version of an asphalt mixture that had been in service for a number of years. As a result, the asphalt binder in the RAP has already been subjective to oxidative aging through time and is stiffer and more brittle than the original, unaged asphalt binder. Consequently, the RAP asphalt binder is expected to have relaxation properties that are more similar to those of longer-term aged asphalt binders. In many cases, the ΔT_c value of RAP asphalt binder will be much lower-more negative than a typical PAV-aged asphalt binder. In this case, the conditions described in Section 7.2.1.1 may apply.

Commented [FHWA17]: Suggest checking whole document again to ensure lower and higher are not used to describe the temperature.

7.4.2. RAS is the reclaimed version of roofing asphalt shingles that are either obtained as manufacturer's waste (from shingle production, not in-service on a roof) or post-consumer waste (shingles that had been in service

on a roof). The roofing asphalt binder that is used with shingles is, at the start of its life, an oxidized asphalt binder that is much stiffer than a paving grade asphalt binder. After being in service on a roof for a period of time, additional oxidation occurs that substantially affects the relaxation properties of the asphalt binder. RAS asphalt binder is expected to be much stiffer with much less relaxation than RAP asphalt binders or paving grade asphalt binders. The conditions described in Section 7.2.1.1 will apply.

Note 7 – The asphalt binder must first be recovered from the RAP or RAS before it can be tested to determine the value of ΔT_c . Many factors including the solvent used, choice of the extraction/recovery procedure, ability to effectively remove fines from the recovered asphalt binder, and skill of the technician may impact the properties of the recovered asphalt binder.

Note 8 – Linear blending equations may not work well when determining the ΔT_c of a blend of materials (e.g., RAP + RAS + virgin asphalt binder). As a measure of the relaxation properties, ΔT_c is a *shape* parameter (related to the shape of the mastercurve, or R-value) than an individual *point* parameter. Linear blending may work with point parameters but may not work as well with shape parameters.

7.5. ***Determining Delta T_c (ΔT_c) of Asphalt Binders Recovered from Pavement Cores/Slabs***

Formatted: Subscript

7.5.1. The procedure for conditioning the recovered asphalt binder from asphalt pavement cores/slabs will be dependent on the purpose of the testing. If the intent is to have an estimate of the properties of the asphalt binder as it exists, then no further conditioning is needed after recovery. If the core/slab is from a relatively young pavement and the purpose is to evaluate how the asphalt may be expected to behave as it ages, then the user could consider additional conditioning of the recovered asphalt binder before testing to determine ΔT_c .

Commented [FHWA18]: Excellent!!

7.6. ***Establishing Performance Criterion for Delta T_c (ΔT_c)***

Formatted: Subscript

7.6.1. Users will wish to establish an appropriate performance criterion based on their experience with the parameter and observed performance of asphalt mixtures. Initial relationships between data sets in the work done by Glover and his colleagues [2] and the AAPTP 06-01 project [3] suggest that the limiting value for cracking appeared to be -5. This is the limit that also is referenced in AASHTO PP 78 (Section 7.2.4 with Notes 7 and 8).

Commented [FHWA19]: Suggest adding reference to AI's State of Practice on REOB-VTA here as well because it provide additional valuable information pertinent to this subject.

Note 9 – The initial performance criterion described above by Glover et.al. was not based on any specific level of aging, but rather on the cracking that was observed in field sections. As of this time, the standard PAV procedure described in AASHTO R 28 (20 hours at 2.1 MPa and a temperature appropriate for the binder grade) is intended to "...simulate the in-service oxidative aging that occurs in asphalt binders during pavement service. Residue from this practice may be used to estimate the physical or chemical properties of asphalt binders after 5 to 10 years of in-service aging in the field."

8. **REPORT**

8.1. *Report the following information:*

8.1.1. Sample identification;

8.1.2. ΔT_c value, nearest 0.1;

8.1.3. Identification if the asphalt binder was recovered;

8.1.4. Level of conditioning (aging) of the asphalt binder.

9. PRECISION AND BIAS

9.1. *Precision* – The research required to develop precision estimates has not been conducted.

9.2. *Bias* – The research required to establish the bias has not been conducted.

10. KEYWORDS

10.1. Asphalt binders; Delta T_c (ΔT_c); Bending Beam Rheometer (BBR); critical temperature (T_c); viscoelastic behavior; relaxation.

Formatted: Subscript

11. REFERENCES

- [1] Anderson D.A., D.W. Christensen, H.U. Bahia, R. Dongre, M.G. Sharma, C.E. Antle, and J. Button. Binder Characterization and Evaluation, Volume 3: Physical Characterization, SHRP Report A-369, Strategic Highway Research Board, National Research Council, Washington, DC, 1994
- [2] Glover C.J., R.R. Davison, C.H. Domke, Y. Ruan, P. Juristyarini, D.B. Knorr, and S.H. Jung. "Development of a New Method for Assessing Asphalt Binder Durability with Field Evaluation", Federal Highway Administration and Texas Department of Transportation, Report # FHWA/TX-05/1872-2, 2005
- [3] Anderson R.M., G.N. King, D.I. Hanson, and P.B. Blankenship. "Evaluation of the Relationship between Asphalt Binder Properties and Non-Load Related Cracking", Asphalt Paving Technology, Volume 80, Association of Asphalt Paving Technologists, 2011

[Add AAPT paper.](#)

[Add AI State of Practice on REOB-VTAE](#)

Standard Specification for Performance-Graded Asphalt Binder

AASHTO Designation: M 320-17

Technical Subcommittee: 2b, Liquid Asphalt

Release: Group 3 (July)

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Specification for

Performance-Graded Asphalt Binder

AASHTO Designation: M 320-17



Technical Subcommittee: 2b, Liquid Asphalt

Release: Group 3 (July)

1. SCOPE

- 1.1. This specification covers asphalt binders graded by performance. Grading designations are related to the average seven-day maximum pavement design temperature and the minimum pavement design temperature. This specification contains Table 1 and Table 2. If no table is specified, the default is Table 1.
- 1.2. Table 2 incorporates R 49 for determining the critical low cracking temperature using a combination of T 313 and T 314 test procedures.
- Note 1**—For asphalt cements graded by viscosity at 60°C, see M 226.
- Note 2**—R 29 provides information for determining the performance grade of an asphalt binder.
- Note 3**—For specifying performance-graded asphalt binder using Multiple Stress Creep Recovery (MSCR), see M 332.

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
- M 226, Viscosity-Graded Asphalt Cement
 - M 323, Superpave Volumetric Mix Design
 - M 332, Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test
 - R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
 - R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
 - R 35, Superpave Volumetric Design for Asphalt Mixtures
 - R 49, Determination of Low-Temperature Performance Grade (PG) of Asphalt Binders
 - R 66, Sampling Asphalt Materials
 - T 44, Solubility of Bituminous Materials
 - T 48, Flash and Fire Points by Cleveland Open Cup
 - T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
 - T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
 - T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
 - T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
 - T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

2.2. *ASTM Standards:*

- D8, Standard Terminology Relating to Materials for Roads and Pavements
- D95, Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation
- D5546, Standard Test Method for Solubility of Asphalt Binders in Toluene by Centrifuge (withdrawn 2017)

3. TERMINOLOGY

3.1. *Definitions:*

3.1.1. Definitions for many terms common to asphalt binder are found in ASTM D8.

3.1.2. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of nonparticulate organic modifiers.

4. ORDERING INFORMATION

4.1. When ordering under this specification, include in the purchase order the performance grade (PG) of asphalt binder required and the table used (e.g., (1) M 320, PG 52-16, Table 1, or (2) M 320, PG 64-34, Table 2). If no table is specified, the default is Table 1.

4.2. Asphalt binder grades may be selected by following the procedures described in M 323 and R 35.

5. MATERIALS AND MANUFACTURE

5.1. Asphalt binder shall be prepared by the refining of crude petroleum by suitable methods, with or without the addition of modifiers.

5.2. Modifiers may be any organic material of suitable manufacture that is used in virgin or recycled condition and that is dissolved, dispersed, or reacted in asphalt binder to enhance its performance.

5.3. The asphalt binder shall be homogeneous, free from water and deleterious materials, and shall not foam when heated to 175°C.

5.4. The asphalt binder shall be at least 99.0 percent soluble as determined by T 44 or ASTM D5546.

5.5. This specification is not applicable for asphalt binders in which fibers or other discrete particles are larger than 250 µm in size.

5.6. The grades of asphalt binder shall conform to the requirements given in Table 1 or Table 2.

Note 4—Grades outside of Table 1 or Table 2 are sometimes specified. If grades are specified beyond those listed in Table 1 or Table 2, a high, low, and intermediate temperature shall be specified. The high and low temperature grade should be specified in 6°C increments for consistency with the PG grading system.

6. SAMPLING

6.1. The material shall be sampled in accordance with R 66.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

7. TEST METHODS

- 7.1. The properties outlined in Sections 5.3, 5.4, and 5.6 shall be determined in accordance with R 28, T 44 or ASTM D5546, T 48, ASTM D95, T 240, T 313, T 314, T 315, and T 316.

8. INSPECTION AND CERTIFICATION

- 8.1. Inspection and certification of the material shall be agreed on between the purchaser and the seller. Specific requirements shall be made part of the purchase contract. The seller shall provide material handling and storage procedures to the purchaser for each asphalt binder grade certified.

9. REJECTION AND RETESTING

- 9.1. If the results of any test do not conform to the requirements of this specification, retesting to determine conformity is performed as indicated in the purchase order or as otherwise agreed on between the purchaser and the seller.

10. KEYWORDS

- 10.1. Asphalt binder; asphalt cement; direct tension; flash point; modifier; performance specifications; pressure aging; rheology.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Table 1—Performance-Graded Asphalt Binder Specification

Performance Grade	PG 46			PG 52							PG 58					PG 64						
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40	
Average 7-day max pavement design temp, °C ^a	<46			<52							<58					<64						
Min pavement design temperature, °C ^a	>-34	>-40	>-46	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40	
Original Binder																						
Flash point temp, T 48, min °C	230																					
Viscosity, T 316: ^b max 3 Pa•s, test temp, °C	135																					
Dynamic shear, T 315: ^c G*/sinδ, ^d min 1.00 kPa test temp @ 10 rad/s, °C	46			52							58					64						
Rolling Thin-Film Oven Residue (T 240)																						
Mass change, ^e max, percent	1.00																					
Dynamic shear, T 315: G*/sinδ, ^d min 2.20 kPa test temp @ 10 rad/s, °C	46			52							58					64						
Pressurized Aging Vessel Residue (R 28)																						
PAV aging temperature, °C ^f	90 (100, 110)			90 (100, 110)							100 (110)					100 (110)						
Dynamic shear, T 315: G* sinδ, ^{d,g} max 5000 6000 kPa <u>δ, ^{d,g} min 42.0°</u> test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16	
Creep stiffness, T 313: ^{h,i} S, max 300 MPa m-value, min 0.300 test temp @ 60 s, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	
Direct tension, T 314: ^{h,i} Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	

^a Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35.

^b This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^c For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

^d G*/sinδ = high temperature stiffness, and G* sinδ = intermediate temperature stiffness, and δ = high or intermediate temperature phase angle.

^e The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^f The PAV aging temperature is based on anticipated climatic conditions and is one of three temperatures, 90°C for climates requiring PG 52-xx and below, 100°C for climates requiring PG 58-xx to PG 70-xx, or 110°C for climates requiring PG 76-xx and above. Normally the PAV aging temperature is specified based on the PG grade. However, when the binder is being used in a different climate due to grade bumping or need for softer binder due to blending, the PAV aging temperature may be specified as 100°C when used in climates requiring PG 58-xx to PG 70-xx, or 110°C when used in climates requiring PG 76-xx and above.

^g If the intermediate temperature stiffness, G* sinδ, is below 5000 kPa, the phase angle minimum limit is not required. If the intermediate temperature stiffness, G* sinδ, is between 5000 and 6000 kPa, the intermediate phase angle minimum limit is required.

^h 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.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Continued on next page.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Table 1—Performance-Graded Asphalt Binder Specification (*Continued*)

Performance Grade	PG 70						PG 76					PG 82				
	10	16	22	28	34	40	10	16	22	28	34	10	16	22	28	34
Average 7-day max pavement design temperature, °C ^a	<70						<76					<82				
Min pavement design temperature, °C ^a	>−10	>−16	>−22	>−28	>−34	>−40	>−10	>−16	>−22	>−28	>−34	>−10	>−16	>−22	>−28	>−34
Original Binder																
Flash point temp, T 48, min °C	230															
Viscosity, T 316: ^b max 3 Pa•s, test temp, °C	135															
Dynamic shear, T 315: ^c G*/sin δ, ^d min 1.00 kPa test temp @ 10 rad/s, °C	70						76					82				
Rolling Thin-Film Oven Residue (T 240)																
Mass change, ^e max, percent	1.00															
Dynamic shear, T 315: G*/sin δ, ^d min 2.20 kPa test temp @ 10 rad/s, °C	70						76					82				
Pressurized Aging Vessel Residue (R 28)																
PAV aging temperature, °C ^f	100 (110)						110 (100)					110 (100)				
<u>Dynamic shear, T 315:</u> <u>—G*·sinδ,^{d,g} max 6000 kPa</u> <u>δ,^{d,g} min 42.0°</u> <u>—test temp @ 10 rad/s, °C</u> <u>Dynamic shear, T 315:</u> <u>—G*·sin δ,^d max 5000 kPa</u> <u>—test temp @ 10 rad/s, °C</u>	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Creep stiffness, T 313: ^{g,h} S, max 300 MPa m-value, min 0.300 test temp @ 60 s, °C																
	0	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	0	−6	−12	−18	−24
Direct tension, T 314: ^{g,h} Failure strain, min 1.0% test temp @ 1.0 mm/min, °C																
	0	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	0	−6	−12	−18	−24

^a Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35.

^b This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^c For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sin δ at test temperatures where the asphalt is a Newtonian fluid.

^d G*/sin δ = high temperature stiffness, and G* sin δ = intermediate temperature stiffness, and δ = high or intermediate temperature phase angle.

^e The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^f The PAV aging temperature is based on anticipated climatic conditions and is one of three temperatures, 90°C for climates requiring PG 52-xx and below, 100°C for climates requiring PG 58-xx to PG 70-xx, or 110°C for climates requiring PG 76-xx and above. Normally the PAV aging temperature is specified based on the PG grade. However, when the binder is being used in a different climate due to grade bumping or need for softer binder due to blending, the PAV aging temperature may be specified as 100°C when used in climates requiring PG 58-xx to PG 70-xx, or 110°C when used in climates requiring PG 76-xx and above.

^g If the intermediate temperature stiffness, G* sin δ, is below 5000 kPa, the phase angle minimum limit is not required. If the intermediate temperature stiffness, G* sin δ, is between 5000 and 6000 kPa, the intermediate phase angle minimum limit is required.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

^h 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.

Table 2—Performance-Graded Asphalt Binder Specification Using Critical Cracking Temperature

Performance Grade	PG 46			PG 52							PG 58					PG 64					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day max pavement design temperature, °C ^a	<46			<52							<58					<64					
Min pavement design temperature, °C ^a	>−34	>−40	>−46	>−10	>−16	>−22	>−28	>−34	>−40	>−46	>−16	>−22	>−28	>−34	>−40	>−10	>−16	>−22	>−28	>−34	>−40
Original Binder																					
Flash point temp, T 48, min °C	230																				
Viscosity, T 316: ^b max 3 Pa·s, test temp, °C	135																				
Dynamic shear, T 315: ^c G*/sinδ ^d , min 1.00 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Rolling Thin-Film Oven Residue (T 240)																					
Mass change, ^e max, percent	1.00																				
Dynamic shear, T 315: G*/sinδ ^d , min 2.20 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Pressurized Aging Vessel Residue (R 28)																					
PAV aging temperature, °C ^f	90 (100, 110)			90 (100, 110)							100 (110)					100 (110)					
Dynamic shear, T 315: <u>G* sinδ, ^{d,g} max 6000 kPa</u> <u>δ, ^{d,g} min 42.0°</u> <u>test temp @ 10 rad/s, °C—G* sinδ^d, max 5000 kPa</u> <u>test temp @ 10 rad/s, °C</u>	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Critical low cracking temp, R 49: ^{g,h} Critical cracking temp determined by R 49, test temp, °C	−24	−30	−36	0	−6	−12	−18	−24	−30	−36	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	−30

^a Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35.

^b This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^c For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

^d G*/sinδ = high temperature stiffness, and G* sinδ = intermediate temperature stiffness, and δ = high or intermediate temperature phase angle.

^e The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^f The PAV aging temperature is based on anticipated climatic conditions and is one of three temperatures, 90°C for climates requiring PG 52-xx and below, 100°C for climates requiring PG 58-xx to PG 70-xx, or 110°C for climates requiring PG 76-xx and above. Normally the PAV aging temperature is specified based on the PG grade. However, when the binder is being used in a different climate due to grade bumping or need for softer binder due to blending, the PAV aging temperature may be specified as 100°C when used in climates requiring PG 58-xx to PG 70-xx, or 110°C when used in climates requiring PG 76-xx and above.

^g If the intermediate temperature stiffness, G* sinδ, is below 5000 kPa, the phase angle minimum limit is not required. If the intermediate temperature stiffness, G* sinδ, is between 5000 and 6000 kPa, the intermediate phase angle minimum limit is required.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

For verification of grade, at a minimum perform T 313 at the test temperature and at the test temperature minus 6°C and T 314 at the test temperature. Testing at additional temperatures for T 313 may be necessary if 300 MPa is not bracketed at the initial two test temperatures. Compare the failure stress from T 314 to the calculated induced thermal stress as per R 49. If the failure stress exceeds the induced thermal stress, the asphalt binder is deemed a “PASS” at the specification temperature.

Continued on next page.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Table 2—Performance-Graded Asphalt Binder Specification Using Critical Cracking Temperature (Continued)

Performance Grade	PG 70						PG 76					PG 82				
	10	16	22	28	34	40	10	16	22	28	34	10	16	22	28	34
Average 7-day max pavement design temperature, °C ^a	<70						<76					<82				
Min pavement design temperature, °C ^a	>−10	>−16	>−22	>−28	>−34	>−40	>−10	>−16	>−22	>−28	>−34	>−10	>−16	>−22	>−28	>−34
Original Binder																
Flash point temp, T 48, min °C	230															
Viscosity, T 316: ^b max 3 Pa•s, test temp, °C	135															
Dynamic shear, T 315: ^c G*/sinδ ^d , min 1.00 kPa test temp @ 10 rad/s, °C	70						76					82				
Rolling Thin-Film Oven Residue (T 240)																
Mass change, ^e max, percent	1.00															
Dynamic shear, T 315: G*/sinδ ^d , min 2.20 kPa test temp @ 10 rad/s, °C	70						76					82				
Pressurized Aging Vessel Residue (R 28)																
PAV aging temperature, °C ^f	100 (110)						110 (100)					110 (100)				
Dynamic shear, T 315: <u>G* sinδ^{d,g} max 6000 kPa</u> <u>δ^{d,g} min 42.0°</u> <u>test temp @ 10 rad/s, °C—G* sinδ^d, max 5000 kPa</u> <u>test temp @ 10 rad/s, °C</u>	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Critical low cracking temp, R 49: ^{g,h} Critical cracking temp determined by R 49, test temp, °C	0	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	0	−6	−12	−18	−24

^a Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35.

^b This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^c For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

^d G*/sinδ = high temperature stiffness, ~~and~~ G* sinδ = intermediate temperature stiffness, and δ = high or intermediate temperature phase angle.

^e The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^f The PAV aging temperature is based on anticipated climatic conditions and is one of three temperatures, 90°C for climates requiring PG 52-xx and below, 100°C for climates requiring PG 58-xx to PG 70-xx, or 110°C for climates requiring PG 76-xx and above. Normally the PAV aging temperature is specified based on the PG grade. However, when the binder is being used in a different climate due to grade bumping or need for softer binder due to blending, the PAV aging temperature may be specified as 100°C when used in climates requiring PG 58-xx to PG 70-xx, or 110°C when used in climates requiring PG 76-xx and above.

^g If the intermediate temperature stiffness, G* sinδ, is below 5000 kPa, the phase angle minimum limit is not required. If the intermediate temperature stiffness, G* sinδ, is between 5000 and 6000 kPa, the intermediate phase angle minimum limit is required.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

For verification of grade, at a minimum perform T 313 at the test temperature and at the test temperature minus 6°C and T 314 at the test temperature. Testing at additional temperatures for T 313 may be necessary if 300 MPa is not bracketed at the initial two test temperatures. Compare the failure stress from T 314 to the calculated induced thermal stress as per R 49. If the failure stress exceeds the induced thermal stress, the asphalt binder is deemed a “PASS” at the specification temperature.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Standard Specification for

Performance-Graded Asphalt
Binder Using Multiple Stress
Creep Recovery (MSCR) Test

AASHTO Designation: M 332-19¹

Technical Subcommittee: 2b, Liquid Asphalt

Release: Group 3 (July)



American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Standard Specification for

Performance-Graded Asphalt Binder Using
Multiple Stress Creep Recovery (MSCR) Test

AASHTO Designation: M 332-19¹



Technical Subcommittee: 2b, Liquid Asphalt

Release: Group 3 (July)

1. SCOPE

- 1.1. This specification covers asphalt binders graded by performance using the multiple stress creep recovery (MSCR) test. Grading designations are related to the average seven-day maximum pavement design temperature, minimum pavement design temperature, and traffic loading.
- 1.2. This specification incorporates T 350 for determining non-recoverable creep compliance, J_{nr} . “S,” “H,” “V,” or “E” designations must be specified for standard, high, very high, or extremely high traffic loading, respectively.
Note 1—For asphalt cements graded by viscosity at 60°C, see M 226.
Note 2—For performance-graded asphalt binder, see M 320.
- 1.3. To ensure that the asphalt binder exhibits elastic response, the specifying agency may require compliance with R 92.

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
- M 226, Viscosity-Graded Asphalt Cement
 - M 320, Performance-Graded Asphalt Binder
 - M 323, Superpave Volumetric Mix Design
 - R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
 - R 35, Superpave Volumetric Design for Asphalt Mixtures
 - R 66, Sampling Asphalt Materials
 - R 92, Evaluating the Elastic Behavior of Asphalt Binders Using the Multiple Stress Creep Recovery (MSCR) Test
 - T 44, Solubility of Bituminous Materials
 - T 48, Flash and Fire Points by Cleveland Open Cup
 - T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
 - T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
 - T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
 - T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer
- T 350, Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

2.2. *ASTM Standards:*

- D8, Standard Terminology Relating to Materials for Roads and Pavements
- D5546, Standard Test Method for Solubility of Asphalt Binders in Toluene by Centrifuge (withdrawn 2017)

3. TERMINOLOGY

3.1. *Definitions:*

3.1.1. Definitions for many terms common to asphalt binder are found in ASTM D8.

3.1.2. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of nonparticulate organic modifiers.

4. ORDERING INFORMATION

4.1. When ordering under this specification, include in the purchase order the performance grade (PG) of asphalt binder required including the designation for traffic loading (e.g., M 332, PG 64V-22).

4.1.1. If required to comply with the elastic response requirements in R 92, include reference to R 92 in the purchase order (e.g., M 332, PG 64V-22, R 92, Percent Recovery of X).

4.2. The required environmental asphalt binder grades may be selected by following the procedures described in M 323 and R 35, except do not use the “grade bumping” procedure in M 323. Select the environmentally appropriate high- and low-temperature grades and the appropriate “S,” “H,” “V,” or “E” grade for the expected traffic level and traffic load rate.

4.2.1. Standard Designation “S” in most typical situations will be for traffic levels fewer than 10 million Equivalent Single Axle Loads (ESALs) and more than the standard traffic speed (>70 km/h).

4.2.2. High Designation “H” in most situations will be for traffic levels of 10 to 30 million ESALs or slow-moving traffic (20 to 70 km/h).

4.2.3. Very High Designation “V” in most situations will be for traffic levels of greater than 30 million ESALs or standing traffic (<20 km/h).

4.2.4. Extremely High Designation “E” in most situations will be for traffic levels of greater than 30 million ESALs and standing traffic (<20 km/h) such as toll plazas or port facilities.

Note 3—“Grade bumping” is accomplished by using “H,” “V,” or “E” designations and not by increasing the PG high-temperature grade as recommended in M 323.

5. MATERIALS AND MANUFACTURE

5.1. Asphalt binder shall be prepared by the refining of crude petroleum by suitable methods, with or without the addition of modifiers.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

- 5.2. Modifiers may be any organic material of suitable manufacture that is used in virgin or recycled condition and that is dissolved, dispersed, or reacted in asphalt binder to enhance its performance.
- 5.3. The asphalt binder shall be homogeneous, free from water and deleterious materials, and shall not foam when heated to 175°C.
- 5.4. The asphalt binder shall be at least 99.0 percent soluble as determined by T 44 or ASTM D5546.
- 5.5. This specification is not applicable for asphalt binders in which fibers or other discrete particles are larger than 250 µm in size.
- 5.6. The grades of asphalt binder shall conform to the requirements given in Table 1.
- 5.7. If required to exhibit an elastic response, the asphalt binder shall conform to the requirements of R 92.

6. SAMPLING

- 6.1. The material shall be sampled in accordance with R 66.

7. TEST METHODS

- 7.1. The properties outlined in Sections 5.3, 5.4, and 5.6 shall be determined in accordance with R 28, T 44, or ASTM D5546, T 48, T 240, T 313, T 314, T 315, T316, and T 350.

8. INSPECTION AND CERTIFICATION

- 8.1. Inspection and certification of the material shall be agreed on between the purchaser and the seller. Specific requirements shall be part of the purchase contract. The seller shall provide material handling and storage procedures to the purchaser for each asphalt binder grade certified.

9. REJECTION AND RETESTING

- 9.1. If the results of any test do not conform to the requirements of this specification, retesting to determine conformity is performed as indicated in the purchase order or as otherwise agreed on between the purchaser and the seller.

10. KEYWORDS

- 10.1. Asphalt binder; asphalt cement; direct tension; flash point; modifier; multiple stress creep recovery (MSCR); performance specifications; pressure aging; rheology.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Table 1—Performance-Graded Asphalt Binder Specification^a

Performance Grade	PG 46			PG 52								PG 58				
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	
Average 7-day max pavement design temp, °C ^b	<46			<52								<58				
Min pavement design temp, °C ^b	>34	>40	>46	>10	>16	>22	>28	>34	>40	>46	>16	>22	>28	>34	>40	
Original Binder																
Flash point temp, T 48, min °C	230															
Viscosity, T 316: ^c max 3 Pa·s, test temp, °C	135															
Dynamic shear, T 315: ^d G*/sinδ, min 1.00 kPa ^e test temp @ 10 rad/s, °C	46			52								58				
Rolling Thin-Film Oven Residue (T 240)																
Mass change, max, percent ^f	1.00															
MSCR, T 350: Standard Traffic “S” J _{nr3,2} , max 4.5 kPa ⁻¹ J _{ardiff} , max 75% ^g test temp, °C	46			52								58				
MSCR, T 350: Heavy Traffic “H” J _{nr3,2} , max 2.0 kPa ⁻¹ J _{ardiff} , max 75% ^g test temp, °C	46			52								58				
MSCR, T 350: Very Heavy Traffic “V” J _{nr3,2} , max 1.0 kPa ⁻¹ J _{ardiff} , max 75% ^g test temp, °C	46			52								58				
MSCR, T 350: Extremely Heavy Traffic “E” J _{nr3,2} , max 0.5 kPa ⁻¹ test temp, °C	46			52								58				
Pressurized Aging Vessel Residue (R 28)																
PAV aging temp, °C ^h	90			90								100				
Dynamic shear, T 315: “S” <u>G* sinδ,^{i,j} max 6000 kPa</u> <u>δ,^{i,j} min 42.0°</u> <u>test temp @ 10 rad/s, °C—G* sinδ, max 5000 kPa^e</u> <u>test temp @ 10 rad/s, °C</u>	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	
Dynamic shear, T 315: “H,” “V,” “E” G* sinδ, max 6000 kPa ^e test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	
Creep stiffness, T 313: ^k S, max 300 MPa m-value, min 0.300 test temp @ 60 s, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	
Direct tension, T 314: ^l Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	

^a MSCR testing on RTFO residue should be performed at the PG grade based on the environmental high pavement temperature. Grade bumping is accomplished by requiring a lower J_{nr} value while testing at the environmental temperature.

^b Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35, excluding the provisions for "grade bumping."

^c This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^d For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of $G^*/\sin\delta$ at test temperatures where the asphalt is a Newtonian fluid.

^e $G^*/\sin\delta$ = high temperature stiffness, and $G^* \sin\delta$ = intermediate temperature stiffness, and δ = high or intermediate temperature phase angle.

^f The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^g The J_{rdiff} requirement shall not apply to asphalt binders having a $J_{nr,2}$ value of 0.5 kPa⁻¹ or lower at the selected test temperature. For each grade, the J_{nr} is a maximum value. A binder that has a J_{nr} of 0.4 may be supplied as an E grade, and may also be supplied as a V, H, or S grade as well.

^h The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

ⁱ If the intermediate temperature stiffness, $G^* \sin \delta$, is below 5000 kPa, the phase angle minimum limit is not required. If the intermediate temperature stiffness, $G^* \sin \delta$, is between 5000 and 6000 kPa, the intermediate phase angle minimum limit is required.

[#] 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.

Continued on next page.

Formatted: Font: 7 pt

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Table 1—Performance-Graded Asphalt Binder Specification^a (Continued)

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					
Min pavement design temp, °C ^b	>−10	>−16	>−22	>−28	>−34	>−40	>−10	>−16	>−22	>−28	>−34	>−40
Original Binder												
Flash point temp, T 48, min °C	230											
Viscosity, T 316: ^c max 3 Pa•s, test temp, °C	135											
Dynamic shear, T 315: ^d G*/sinδ, min 1.00 kPa ^e test temp @ 10 rad/s, °C	64						70					
Rolling Thin-Film Oven Residue (T 240)												
Mass change, max, percent ^f	1.00											
MSCR, T 350: Standard Traffic “S” $J_{nr/2}$, max 4.5 kPa ^{−1} $J_{nr,diff}$, max 75% ^g test temp, °C	64						70					
MSCR, T 350: Heavy Traffic “H” $J_{nr/2}$, max 2.0 kPa ^{−1} $J_{nr,diff}$, max 75% ^g test temp, °C	64						70					
MSCR, T 350: Very Heavy Traffic “V” $J_{nr/2}$, max 1.0 kPa ^{−1} $J_{nr,diff}$, max 75% ^g test temp, °C	64						70					
MSCR, T 350: Extremely Heavy Traffic “E” $J_{nr/2}$, max 0.5 kPa ^{−1} test temp, °C	64						70					
Pressurized Aging Vessel Residue (R 28)												
PAV aging temp, °C ^h	100						100 (110)					
Dynamic shear, T 315: “S” <u>$G^* \sin \delta$,^{c,f} max 6000 kPa</u> <u>δ,^{c,f} min 42.0°</u> <u>test temp @ 10 rad/s, °C—$G^* \sin \delta$, max 5000 kPa^e</u> <u>test temp @ 10 rad/s, °C</u>	31	28	25	22	19	16	34	31	28	25	22	19
Dynamic shear, T 315: “H,” “V,” “E” $G^* \sin \delta$, max 6000 kPa ^e test temp @ 10 rad/s, °C	31	28	25	22	19	16	34	31	28	25	22	19
Creep stiffness, T 313: ^f S , max 300 MPa m -value, min 0.300 test temp @ 60 s, °C	0	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	−30
Direct tension, T 314: ^g Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	0	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	−30

^a MSCR test on RTFO residue should be performed at the PG grade based on the environmental high pavement temperature. Grade bumping is accomplished by requiring a lower J_{nr} value while testing at the environmental temperature.

^b Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35, excluding the provisions for “grade bumping.”

^c This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^d For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of $G^*/\sin \delta$ at test temperatures where the asphalt is a Newtonian fluid.

^e $G^*/\sin \delta$ = high temperature stiffness, and $G^* \sin \delta$ = intermediate temperature stiffness, and δ = high or intermediate temperature phase angle.

^f The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^g The $J_{nr,diff}$ requirement shall not apply to asphalt binders having a $J_{nr,2}$ value of 0.5 kPa^{−1} or lower at the selected test temperature. For each grade, the J_{nr} is a maximum value. A binder that has a J_{nr} of 0.4 may be supplied as an E grade, and may also be supplied as a V, H, or S grade as well.

^h The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

ⁱ If the intermediate temperature stiffness, $G^* \sin \delta$, is below 5000 kPa, the phase angle minimum limit is not required. If the intermediate temperature stiffness, $G^* \sin \delta$, is between 5000 and 6000 kPa, the intermediate phase angle minimum limit is required.

[#] 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.

Continued on next page.

Formatted: Font: 7 pt

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Table 1—Performance-Graded Asphalt Binder Specification^a (Continued)

Performance Grade	PG 76					PG 82				
	10	16	22	28	34	10	16	22	28	34
Average 7-day max pavement design temp, °C ^b	<76					<82				
Min pavement design temp, °C ^b	>−10	>−16	>−22	>−28	>−34	>−10	>−16	>−22	>−28	>−34
Original Binder										
Flash point temp, T 48, min°C	230									
Viscosity, T 316: ^c max 3 Pa•s, test temp, °C	135									
Dynamic shear, T 315: ^d G*/sin δ, min 1.00 kPa ^e test temp @ 10 rad/s, °C	76					82				
Rolling Thin-Film Oven Residue (T 240)										
Mass change, max, percent ^f	1.00									
MSCR, T 350: Standard Traffic “S” J _{nr,3,2} , max 4.5 kPa ^{−1} J _{nr,diff} , max 75% ^g test temp, °C	76					82				
MSCR, T 350: Heavy Traffic “H” J _{nr,3,2} , max 2.0 kPa ^{−1} J _{nr,diff} , max 75% ^g test temp, °C	76					82				
MSCR, T 350: Very Heavy Traffic “V” J _{nr,3,2} , max 1.0 kPa ^{−1} J _{nr,diff} , max 75% ^g test temp, °C	76					82				
MSCR, T 350: Extremely Heavy Traffic “E” J _{nr,3,2} , max 0.5 kPa ^{−1} test temp, °C	76					82				
Pressurized Aging Vessel Residue (R 28)										
PAV aging temp, °C ^h	100 (110)					100 (110)				
Dynamic shear, T 315: “S” <u>G* sinδ, ^{c,f} max 6000 kPa</u> <u>δ, ^{c,f} min 42.0°</u> <u>test temp @ 10 rad/s, °C—G* sinδ, max</u> <u>5000 kPa^e</u> <u>test temp @ 10 rad/s, °C</u>	37	34	31	28	25	40	37	34	31	28
Dynamic shear, T 315: “H,” “V,” “E” G* sinδ, max 6000 kPa ^e test temp @ 10 rad/s, °C	37	34	31	28	25	40	37	34	31	28
Creep stiffness, T 313: ^g S, max 300 MPa m-value, min 0.300 test temp @ 60 s, °C	0	−6	−12	−18	−24	0	−6	−12	−18	−24
Direct tension, T 314: ^g Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	0	−6	−12	−18	−24	0	−6	−12	−18	−24

^a MSCR test on RTFO residue should be performed at the PG grade based on the environmental high pavement temperature. Grade bumping is accomplished by requiring a lower J_{nr} value while testing at the environmental temperature.

^b Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35, excluding the provisions for “grade bumping.”

^c This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

^d For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of $G^*/\sin \delta$ at test temperatures where the asphalt is a Newtonian fluid.

^e $G^*/\sin \delta$ = high temperature stiffness, and $G^* \sin \delta$ = intermediate temperature stiffness, and δ = high or intermediate temperature phase angle.

^f The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

^g The $J_{nr,diff}$ requirement shall not apply to asphalt binders having a $J_{nr,2}$ value of 0.5 kPa^{−1} or lower at the selected test temperature. For each grade, the J_{nr} is a maximum value. A binder that has a J_{nr} of 0.4 may be supplied as an E grade, and may also be supplied as a V, H, or S grade as well.

^h The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

¹ If the intermediate temperature stiffness, $G^* \sin \delta$, is below 5000 kPa, the phase angle minimum limit is not required. If the intermediate temperature stiffness, $G^* \sin \delta$, is between 5000 and 6000 kPa, the intermediate phase angle minimum limit is required.

² 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.

Formatted: Font: 7 pt

¹ Formerly AASHTO Provisional Standard MP 19. First published as a full standard in 2014.

Standard Method of Test for

Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

AASHTO Designation: T 315-19¹

Technical Subcommittee: 2b, Liquid Asphalt

Release: Group 3 (July)



American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

AASHTO Designation: T 315-19¹



Technical Subcommittee: 2b, Liquid Asphalt

Release: Group 3 (July)

1. SCOPE

- 1.1. This test method covers the determination of the dynamic shear modulus and phase angle of asphalt binder when tested in dynamic (oscillatory) shear using parallel plate test geometry. It is applicable to asphalt binders having dynamic shear modulus values in the range from 100 Pa to 10 MPa. This range in modulus is typically obtained between 6 and 88°C at an angular frequency of 10 rad/s. This test method is intended for determining the linear viscoelastic properties of asphalt binders as required for specification testing and is not intended as a comprehensive procedure for the full characterization of the viscoelastic properties of asphalt binder.
- 1.2. This standard is appropriate for unaged material or material aged in accordance with T 240 and R 28.
- 1.3. Particulate material in the asphalt binder is limited to particles with longest dimensions less than 250 μm .
- 1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
 - M 320, Performance-Graded Asphalt Binder
 - R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
 - R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
 - R 66, Sampling Asphalt Materials
 - T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
 - T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

- 2.2. *ASTM Standards:*
- C670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
 - D2170/D2170M, Standard Test Method for Kinematic Viscosity of Asphalts (Bitumens)
 - D2171/D2171M, Standard Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer
 - E1, Standard Specification for ASTM Liquid-in-Glass Thermometers
 - E77, Standard Test Method for Inspection and Verification of Thermometers
 - E563, Standard Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature
- 2.3. *Deutsche Industrie Norm (DIN) Standard:*
- 43760, Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors

3. TERMINOLOGY

- 3.1. *Definitions:*
- 3.1.1. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of nonparticulate organic modifiers.
- 3.2. *Descriptions of Terms Specific to This Standard:*
- 3.2.1. *annealing*—heating the binder until it is sufficiently fluid to remove the effects of steric hardening.
- 3.2.2. *calibration*—process of checking the accuracy and precision of a device using NIST-traceable standards and making adjustments to the device where necessary to correct its operation or precision and accuracy.
- 3.2.3. *complex shear modulus (G^*)*—ratio calculated by dividing the absolute value of the peak-to-peak shear stress, τ , by the absolute value of the peak-to-peak shear strain, γ .
- 3.2.4. *dummy test specimen*—a specimen formed between the dynamic shear rheometer (DSR) test plates from asphalt binder or other polymer to measure the temperature of the asphalt binder held between the plates. The dummy test specimen is used solely to determine temperature corrections.
- 3.2.5. *linear viscoelastic*—within the context of this specification refers to a region of behavior in which the dynamic shear modulus is independent of shear stress or strain.
- 3.2.6. *loading cycle*—a unit cycle of time for which the test sample is loaded at a selected frequency and stress or strain level.
- 3.2.7. *loss shear modulus (G'')*—the complex shear modulus multiplied by the sine of the phase angle expressed in degrees. It represents the component of the complex modulus that is a measure of the energy lost (dissipated during a loading cycle).
- 3.2.8. *molecular association*—a process where associations occur between asphalt binder molecules during storage at ambient temperature. Often called steric hardening in the asphalt literature, molecular associations can increase the dynamic shear modulus of asphalt binders. The amount of molecular association is asphalt specific and may be significant even after a few hours of storage.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

- 3.2.9. *oscillatory shear*—refers to a type of loading in which a shear stress or shear strain is applied to a test sample in an oscillatory manner such that the shear stress or strain varies in amplitude by about zero in a sinusoidal manner.
- 3.2.10. *parallel plate geometry*—refers to a testing geometry in which the test sample is sandwiched between two relatively rigid parallel plates and subjected to oscillatory shear.
- 3.2.11. *phase angle (δ)*—the angle in radians between a sinusoidally applied strain and the resultant sinusoidal stress in a controlled-strain testing mode, or between the applied stress and the resultant strain in a controlled-stress testing mode.
- 3.2.12. *portable thermometer*—an electronic device that consists of a temperature detector (probe containing a thermocouple or resistive element), required electronic circuitry, and readout system.
- 3.2.13. *reference thermometer*—a NIST–traceable liquid-in-glass or electronic thermometer that is used as a laboratory standard.
- 3.2.14. *steric hardening*—see molecular association.
- 3.2.15. *storage shear modulus (G')*—the complex shear modulus multiplied by the cosine of the phase angle expressed in degrees. It represents the in-phase component of the complex modulus that is a measure of the energy stored during a loading cycle.
- 3.2.16. *temperature correction*—difference in temperature between the temperature indicated by the DSR and the test specimen as measured by the portable thermometer inserted between the test plates.
- 3.2.17. *thermal equilibrium*—is reached when the temperature of the test specimen mounted between the test plates is constant with time.
- 3.2.18. *verification*—process of checking the accuracy of a device or its components against an internal laboratory standard. It is usually performed within the operating laboratory.

4. SUMMARY OF TEST METHOD

- 4.1. This standard contains the procedure used to measure the complex shear modulus (G^*) and phase angle (δ) of asphalt binders using a dynamic shear rheometer and parallel plate test geometry.
- 4.2. The standard is suitable for use when the dynamic shear modulus varies between 100 Pa and 10 MPa. This range in modulus is typically obtained between 6 and 88°C at an angular frequency of 10 rad/s, dependent on the grade, test temperature, and conditioning (aging) of the asphalt binder.
- 4.3. Test specimens 1 mm thick by 25 mm in diameter or 2 mm thick by 8 mm in diameter are formed between parallel metal plates. During testing, one of the parallel plates is oscillated with respect to the other at preselected frequencies and rotational deformation amplitudes (strain control) (or torque amplitudes [stress control]). The required stress or strain amplitude depends on the value of the complex shear modulus of the asphalt binder being tested. The required amplitudes have been selected to ensure that the measurements are within the region of linear behavior.
- 4.4. The test specimen is maintained at the test temperature to within $\pm 0.1^\circ\text{C}$ by positive heating and cooling of the upper and lower plates or by enclosing the upper and lower plates in a thermally controlled environment or test chamber.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

- 4.5. Oscillatory loading frequencies using this standard can range from 1 to 100 rad/s using a sinusoidal waveform. Specification testing is performed at a test frequency of 10 rad/s. The complex modulus (G^*) and phase angle (δ) are calculated automatically as part of the operation of the rheometer using proprietary computer software supplied by the equipment manufacturer.

5. SIGNIFICANCE AND USE

- 5.1. The test temperature for this test is related to the temperature experienced by the pavement in the geographical area for which the asphalt binder is intended to be used.
- 5.2. The complex shear modulus is an indicator of the stiffness or resistance of asphalt binder to deformation under load. The complex shear modulus and the phase angle define the resistance to shear deformation of the asphalt binder in the linear viscoelastic region.
- 5.3. The complex modulus and the phase angle are used to calculate performance-related criteria in accordance with M 320.

6. APPARATUS

- 6.1. *Dynamic Shear Rheometer (DSR) Test System*—Consisting of parallel metal plates, an environmental chamber, a loading device, and a control and data acquisition system.

- 6.1.1. *Test Plates*—Stainless steel or aluminum plates with smooth ground surfaces. One 8.00 ± 0.02 mm in diameter and one 25.00 ± 0.05 mm in diameter (Figure 1). The base plate in some rheometers is a flat plate. A raised portion, a minimum of 1.50 mm high, with the same radius as the upper plate is required. The raised portion makes it easier to trim the specimen and may improve test repeatability.

Note 1—To obtain correct data, the upper and lower plates should be concentric with each other. At present there is no suitable procedure for the user to check the concentricity except to visually observe whether or not the upper and lower plates are centered with respect to each other. The moveable plate should rotate without any observable horizontal or vertical wobble. This operation may be checked visually or with a dial gauge held in contact with the edge of the moveable plate while it is being rotated. There are two values that determine the operating behavior of a measuring system: centricity (horizontal wobble) and runout (vertical wobble). Typically, wobble can be detected if it is greater than ± 0.02 mm. For a new system, a wobble of ± 0.01 mm is typical. If the wobble grows to more than ± 0.02 mm with use, it is recommended that the instrument be serviced by the manufacturer.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

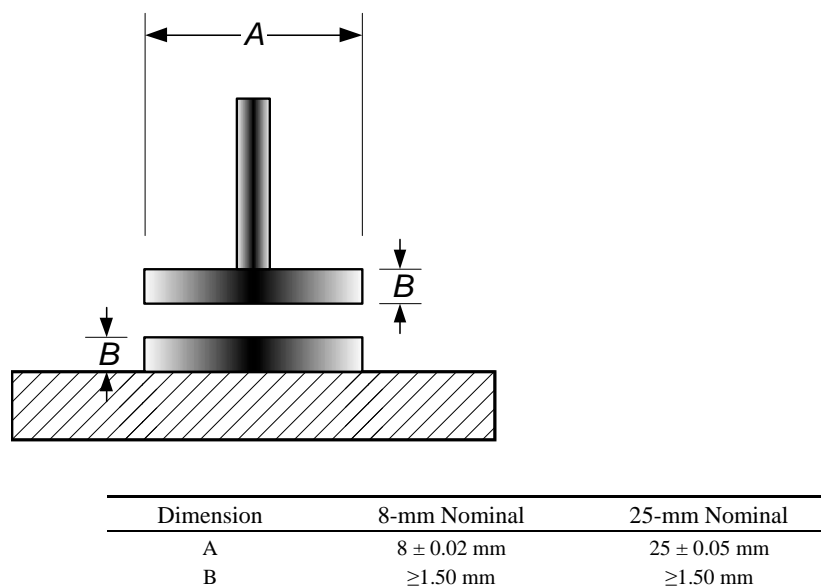


Figure 1—Plate Dimensions

6.1.2. *Environmental Chamber*—For controlling the test temperature, by heating or cooling (in steps or ramps), to maintain a constant specimen environment. The medium for heating and cooling the specimen in the environmental chamber shall not affect asphalt binder properties. The temperature in the chamber may be controlled by the circulation of fluid such as water, conditioned gas such as nitrogen, or by a suitable arrangement of solid-state Peltier elements surrounding the sample. When forced air is used, a suitable drier must be included to prevent condensation of moisture on the plates and fixtures and, if operating below freezing temperatures, the formation of ice. The environmental chamber and the temperature controller shall control the temperature of the specimen, including thermal gradients within the sample, to an accuracy of $\pm 0.1^\circ\text{C}$. The chamber shall completely enclose the top and the bottom plates to minimize thermal gradients.

Note 2—A circulating bath unit, separate from the DSR, that pumps the bath fluid through the test chamber may be required if a fluid medium is used. The flow rate of the bath media should not be modified once the temperature settings have been adjusted to the desired value. Media lines should be periodically inspected and cleaned or replaced if necessary to remove obstructions.

6.1.2.1. *Temperature Controller*—Capable of maintaining specimen temperatures within $\pm 0.1^\circ\text{C}$ for test temperatures ranging from 3 to 88°C .

6.1.2.2. *Internal Temperature Detector for the DSR*—A platinum resistance thermometer (PRT) mounted within the environmental chamber as an integral part of the DSR and in close proximity to the fixed plate, with a range of 3 to 88°C , and with a resolution of 0.1°C (see Note 3). This thermometer shall be used to control the temperature of the test specimen between the plates and shall provide a continuous readout of temperature during the mounting, conditioning, and testing of the specimen. The PRT shall be calibrated as an integral unit with its respective meter or electronic circuitry.

Note 3—PTRs meeting DIN Standard 43760 (Class A) or equal are recommended for this purpose.

6.1.3. *Loading Device*—Capable of applying a sinusoidal oscillatory load to the specimen at a frequency of 10.0 ± 0.1 rad/s. If frequencies other than 10 rad/s are used, the frequency shall be accurate to 1 percent. The loading device shall be capable of providing either a stress-controlled or strain-controlled load. If the load is strain controlled, the loading device shall apply a cyclic torque

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

sufficient to cause an angular rotational strain accurate to within 100 μ rad of the strain specified. If the load is stress controlled, the loading device shall apply a cyclic torque accurate to within 10 mN·m of the torque specified. Total system compliance at 100 N·m of torque shall be less than 2 mrad/N·m. The manufacturer of the device shall certify that the frequency, stress, and strain are controlled and measured with an accuracy of one percent or less in the range of this measurement.

- 6.1.4. *Control and Data Acquisition System*—Capable of providing a record of temperature, frequency, deflection angle, and torque. Devices used to measure these quantities shall meet the accuracy requirements specified in Table 1. In addition, the system shall calculate and record the shear stress, shear strain, complex shear modulus (G^*), and phase angle (δ). The system shall measure and record G^* , in the range of 100 Pa to 10 MPa, to an accuracy of 1.0 percent or less, and the phase angle, in the range of 0 to 90 degrees, to an accuracy of 0.1 degree.

Table 1—Control and Data Acquisition System Requirements

Property	Accuracy
Temperature	0.1°C
Frequency	1%
Torque	10 mN·m
Deflection angle	100 μ rad

- 6.2. *Specimen Mold (Optional)*—The overall dimensions of the silicone rubber mold for forming asphalt binder test specimens may vary but the thickness shall be greater than 5 mm. If the mold is a single sample mold, the following dimensions have been found suitable: For a 25-mm test plate with a 1-mm gap, a mold cavity approximately 18 mm in diameter and 2.0 mm deep. For an 8-mm test plate with a 2-mm gap, a mold cavity approximately 8 mm in diameter and 2.5 mm deep.
- 6.3. *Specimen Trimmer*—With a straightedge at least 4 mm wide.
- 6.4. *Wiping Material*—Clean cloth, paper towels, cotton swabs, or other suitable material as required for wiping the plates.
- 6.5. *Cleaning Solvents*—Mineral oil, citrus-based solvents, mineral spirits, toluene, or similar solvent as required for cleaning the plates. Acetone for removing the solvent residue from the surfaces of the plates is also necessary.
- 6.6. *Reference Thermometer*—Either NIST-traceable liquid-in-glass thermometer(s) or NIST-traceable electronic thermometric device(s). This temperature standard shall be used to standardize the portable thermometer (Section 9.3).
- 6.6.1. *Liquid-in-Glass Thermometer*—NIST-traceable thermometer(s) meeting the requirements of ASTM E1 with a suitable range and subdivisions of 0.1°C. The thermometer(s) shall be a partial immersion thermometer(s) within an ice point and standardized in accordance with ASTM E563.
- 6.6.1.1. *Optical Viewing Device (Optional)*—For use with liquid-in-glass thermometers that enhances readability and minimizes parallax when reading the liquid-in-glass reference thermometer.
- 6.6.2. *Electronic Thermometer*—Incorporating a resistive detector (Note 3) with an accuracy of $\pm 0.05^\circ\text{C}$ and a resolution of 0.01°C. The electronic thermometer shall be standardized at least once per year using a NIST-traceable reference standard in accordance with ASTM E77.
- 6.7. *Portable Thermometer*—A standardized portable thermometer consisting of a resistive detector, associated electronic circuitry, and digital readout. The thickness of the detector shall be no greater

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

than 2.0 mm such that it can be inserted between the test plates. The reference thermometer (see Section 6.6) may be used for this purpose if its detector fits within the dummy specimen as required by Section 9.4.1 or 9.4.2.

7. HAZARDS

- 7.1. Standard laboratory caution should be used in handling the hot asphalt binder when preparing test specimens.

8. PREPARATION OF APPARATUS

- 8.1. Prepare the apparatus for testing in accordance with the manufacturer's recommendations. Specific requirements will vary for different DSR models and manufacturers.
- 8.2. Inspect the surfaces of the test plates and discard any plates with jagged or rounded edges or deep scratches. Clean any asphalt binder residue from the plates with an organic solvent such as mineral oil, mineral spirits, a citrus-based solvent, or toluene. Remove any remaining solvent residue by wiping the surface of the plates with a cotton swab or a soft cloth dampened with acetone. If necessary, use a dry cotton swab or soft cloth to ensure that no moisture condenses on the plates.
- 8.3. Mount the cleaned and inspected test plates on the test fixtures and tighten firmly.
- 8.4. Select the testing temperature according to the grade of the asphalt binder or according to the preselected testing schedule (see Note 4). Allow the DSR to reach a stabilized temperature within $\pm 0.1^\circ\text{C}$ of the test temperature.

Note 4—M 320 and R 29 provide guidance on the selection of test temperatures.

- 8.5. With the test plates at the test temperature or the middle of the expected testing range, establish the zero gap level (1) by manually spinning the moveable plate, and while the moveable plate is spinning, close the gap until the removable plate touches the fixed plate (the zero gap is reached when the plate stops spinning completely), or (2) for rheometers with normal force transducers, by closing the gap and observing the normal force and after establishing contact between the plates, setting the zero gap at approximately zero normal force.

Note 5—The frame, detectors, and fixtures in the DSR change dimension with temperature causing the zero gap to change with changes in temperature. Adjustments in the gap are not necessary when measurements are made over a limited range of temperatures. The gap should be set at the test temperature or, when tests are to be conducted over a range of temperatures, the gap should be set at the middle of the expected range of test temperatures. For most instruments, no gap adjustment is needed as long as the test temperature is within $\pm 12^\circ\text{C}$ of the temperature at which the gap is set. If the instrument has thermal gap compensation, the gap may be set at the first test temperature instead of the middle of the range of test temperatures.

- 8.6. Once the zero gap is established as per Section 8.5, move the plates apart to approximately the test gap and preheat the plates. Preheating the plates promotes adhesion between the asphalt binder and the plates, especially at the intermediate grading temperatures.
- 8.7. To preheat 25-mm plates, bring the test plates to the test temperature or the lowest test temperature if testing is to be conducted at more than one temperature. To preheat 8-mm plates, bring the plates to between 34 and 46°C. Move the plates apart and establish a gap setting of 1.05 mm (for 25-mm diameter test specimens) or 2.10 mm (for 8-mm diameter test specimens).

Note 6—In order to obtain adequate adhesion between the asphalt binder and the test plates, the plates must be preheated. Preheating is especially critical when the silicone mold is used to prepare the asphalt binder for transfer to the test plates and when the testing is conducted with the

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

8-mm plates. When the direct placement method is used, as long as the test plates are immediately brought in contact with the asphalt binder, the heat carried with the asphalt binder improves adhesion. The preheating temperature needed for proper adhesion will depend on the grade and nature of the asphalt binder and the test temperature (8-mm or 25-mm plates). For some of the stiffer binder grades, especially those with high levels of modification, heating the plates to 46°C may not be sufficient to ensure proper adhesion of the asphalt binder to the test plates, especially if the silicone mold is used and the testing is conducted with 8-mm plates. For highly modified asphalt binders only, higher preheat temperatures may be used.

9. VERIFICATION AND CALIBRATION

9.1. Verify the DSR and its components at least every 6 months and when the DSR or plates are newly installed, when the DSR is moved to a new location, or when the accuracy of the DSR or any of its components is suspect. Four items require verification—the test plate diameter, DSR torque transducer, portable thermometer, and DSR test specimen temperature. Verify the DSR temperature transducer before verifying the torque transducer.

9.2. *Verification of Plate Diameter*—Measure the diameters to the nearest 0.01 mm. Maintain a log of the measured diameters as part of the laboratory quality control program so that the measurements are clearly identified with the specific plates. Enter the actual measured dimensions into the DSR software for use in calculations. If the top and bottom plates differ in diameter, enter the smaller of the two measured diameters.

Note 7—An error of ± 0.05 mm in the diameter of the plate results in a 0.8 percent error in the complex modulus for the 25-mm plate. For the 8-mm plate, errors in diameter of ± 0.01 , ± 0.02 , and ± 0.05 mm give respective errors in complex modulus of 0.5, 1.0, and 2.5 percent (see Figure 2).

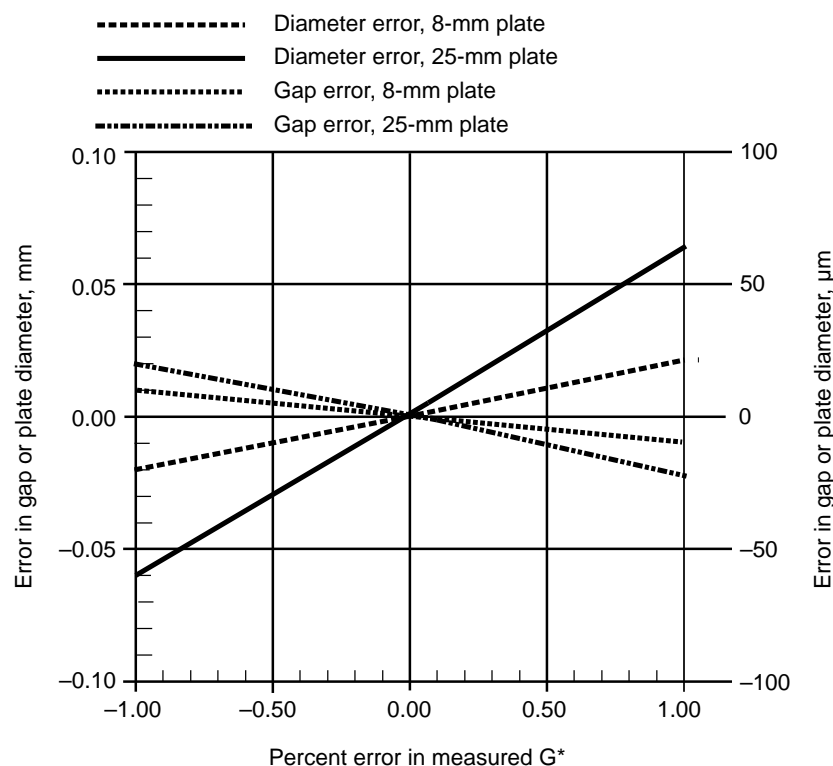


Figure 2—Effect of Error in Gap or Plate Diameter

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

- 9.3. *Verification of Portable Thermometer*—Verify the portable thermometer (used to measure the temperature between the test plates), using the laboratory reference thermometer. A portable thermometer shall be considered the combination of the meter (readout device) and the thermistor (temperature probe) as a single unit, and must be verified as such. If the reference thermometer (Section 6.6) is also used as a portable thermometer to measure the temperature between the test plates, it shall meet the requirements of Section 6.7.
- 9.3.1. *Recommended Verification Procedure*—Bring the reference thermometer into intimate contact with the detector from the portable thermometer and place them in a thermostatically controlled and stirred water bath (Note 8). Ensure that deionized water is used to prevent electrical conduction from occurring between the electrodes of the resistive temperature sensitive element. If deionized water is not available, encase the reference thermometer and detector of the portable thermometer in a waterproof plastic bag prior to placement in the bath. Obtain measurements at intervals of approximately 6°C over the range of test temperatures allowing the bath to reach thermal equilibrium at each temperature. If the readings of the portable thermometer and the reference thermometer differ by 0.1°C or more, record the difference at each temperature as a temperature correction, and maintain the corrections in a log as part of the laboratory quality control program.
- Note 8**—A recommended procedure for the high-temperature range is to use a stirred water bath that is controlled within $\pm 0.1^\circ\text{C}$ such as the viscosity bath used for ASTM D2170/D2170M or D2171/D2171M. For a low-temperature bath, an ice bath or controlled-temperature bath may be used. Bring the probe from the portable thermometer into contact with the reference thermometer, and hold the assembly in intimate contact. A rubber band works well for this purpose. Immerse the assembly in the water bath, and bring the water bath to thermal equilibrium. Record the temperature on each device when thermal equilibrium is reached.
- Note 9**—If the readings from the two devices differ by 0.5°C or more, the calibration or operation of the portable thermometer may be suspect, and it may need to be recalibrated or replaced. A continuing change in the temperature corrections with time may also make the portable thermometer suspect.
- 9.4. *Test Specimen Temperature Correction*—Thermal gradients within the rheometer can cause differences between the temperature of the test specimen and the temperature indicated by the DSR thermometer (also used to control the temperature of the DSR). The DSR thermometer shall be checked at an interval no greater than six months. When these differences are 0.1°C or greater, determine a temperature correction by using a thermal detector mounted in a silicone rubber wafer (Section 9.4.1) or by placing asphalt binder (dummy sample) between the plates and inserting the detector of the portable thermometer into the asphalt binder (Section 9.4.2).
- 9.4.1. *Method Using Silicone Rubber Wafer*—For the entire range of test temperatures, place the wafer between the 25-mm test plates, and close the gap to bring the wafer into contact with the upper and lower plate so that the silicone rubber makes complete contact with the surfaces of the upper and lower plates. If needed, apply a thin layer of petroleum grease or anti-seize compound (see Note 10) to completely fill any void space between the silicone rubber and the plates. Complete contact is needed to ensure proper heat transfer across the plates and silicone rubber wafer. Determine any needed temperature correction as per Section 9.4.3.
- Note 10**—Anti-seize compound available by that name at hardware and auto supply stores is much less apt to contaminate the circulating water than petroleum grease.
- Note 11**—The thickness of the silicone wafer should be measured with calipers to identify the actual thickness. The thickness can be used to set the gap for temperature.
- 9.4.2. *Method Using Dummy Test Specimen*—The dummy test specimen shall be formed from asphalt binder or other polymer that can be readily formed between the plates. Mount the dummy test specimen between the test plates, and insert the detector (probe) of the portable thermometer into the dummy test specimen. Close the gap to the test gap (1 mm for 25-mm plates and 2 mm for 8-mm plates) keeping the detector centered vertically and radially in the dummy test specimen.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

Heat the plates as needed to allow the dummy test specimen to completely fill the gap between the test plates. It is not necessary to trim the dummy test specimen but avoid excessive material around the edges of the plates. Determine any needed temperature correction as per Section 9.4.3.

Note 12—Silly putty can leave a residue of silicone oil on the surfaces of the plates, and for this reason, its use as a dummy specimen is not recommended.

- 9.4.3. *Determination of Temperature Correction*—Obtain simultaneous temperature measurements with the DSR thermometer and the portable thermometer at 6°C increments to cover the range of test temperatures. At each temperature increment, after thermal equilibrium has been reached, record the temperature indicated by the portable thermometer and the DSR thermometer to the nearest 0.1°C. Temperature equilibrium is reached when the temperature indicated by both the DSR thermometer and the portable thermometer do not vary by more than 0.1°C over a 5-min period. Obtain additional measurements to include the entire temperature range that will be used for measuring the dynamic shear modulus.
- 9.4.4. *Plot Correction Versus Specimen Temperature*—Using the data obtained in Section 9.4, prepare a plot of the difference between the two temperature measurements versus the temperature measured with the portable thermometer (Figure 3). This difference is the temperature correction that must be applied to the DSR temperature controller to obtain the desired temperature in the test specimen between the test plates. Report the temperature correction at the respective test temperature from the plot and report the test temperature between the plates as the test temperature. Alternatively, the instrument software may be written to incorporate these temperature corrections.

Note 13—The difference between the two temperature measurements may not be a constant for a given rheometer but may vary with differences between the test temperature and the ambient laboratory temperature as well as with fluctuations in ambient temperature. The difference between the two temperature measurements is caused in part by thermal gradients in the test specimen and fixtures.

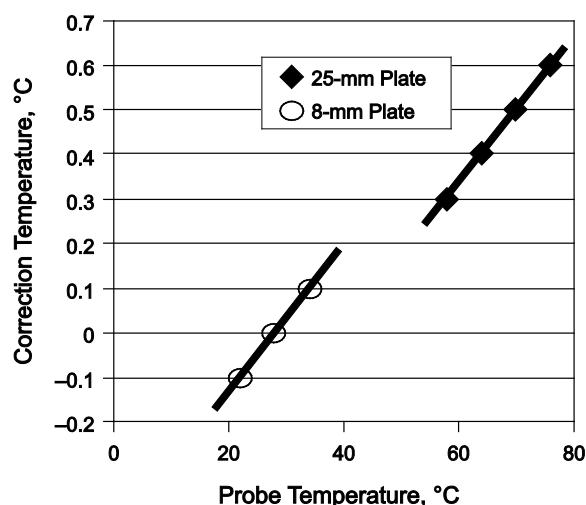


Figure 3—Determination of Temperature Correction

- 9.5. *Verification of DSR*—Verify the accuracy of the torque transducer and angular displacement transducer.

Note 14—A newly installed or reconditioned instrument should be verified on a weekly basis using the procedures in Section 9.5 until acceptable verification has been demonstrated. Maintaining the data in the form of a control chart where the verification measurements are plotted versus calendar date is recommended (see Appendix X2).

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

9.5.1. *Verification of Torque Transducer*—Verify the calibration of the torque transducer a minimum of once every six months using a reference fluid or manufacturer-supplied fixtures when the calibration of the torque transducer is suspect or when the dynamic viscosity, as measured for the reference fluid, indicates that the torque transducer is not in calibration.

9.5.1.1. *Verification of Torque Transducer with Reference Fluid*—The complex viscosity measured with the DSR shall be within 3 percent of the capillary viscosity as reported by the manufacturer of the reference fluid; otherwise, the calibration of the torque transducer shall be considered suspect. Calculate the complex viscosity as the complex modulus, G^* , divided by the angular frequency in rad/s. Recommended practice for using the reference fluid is given in Appendix X3.

$$\text{Percent Variance} = \left[\frac{(\eta_a - \eta_b)}{\eta_a} \right] \times 100 \quad (1)$$

where:

η_a = the standard capillary viscosity as reported by the supplier of the reference fluid; and

η_b = the measured viscosity as calculated from the complex modulus, G^* , divided by the angular frequency in rad/s.

Note 15—A suitable reference fluid is available from Cannon Instrument Company as Viscosity Standard Number N2700000SP. The viscosity of the standard is reported in mPa·s. Convert the viscosity measurements to mPa·s before calculating the percent variance.

9.5.1.2. *Verification of Torque Transducer with Fixtures*—Verify the calibration of the torque transducer using the manufacturer-supplied fixtures in accordance with the instructions supplied by the manufacturer. Suitable manufacturer-supplied fixtures are not widely available. If suitable fixtures are not available, this requirement shall be waived.

9.5.2. *Verification of Angular Displacement Transducer*—If manufacturer-supplied fixtures are available, verify the calibration every six months or when the calibration of the DSR is suspect. If suitable fixtures are not available, this requirement shall be waived.

9.5.3. If the DSR cannot be successfully verified according to Section 9.5, it shall not be used for testing in accordance with this standard until it has been successfully calibrated by the manufacturer or other qualified service personnel.

10. PREPARING SAMPLES AND TEST SPECIMENS

10.1. *Preparing Test Samples*—If unaged binder is to be tested, obtain test samples according to R 66.

10.1.1. *Degassing Prior to Testing*—If the asphalt binder is also being tested according to T 314 (DT) and has been conditioned according to T 240 (RTFO) and R 28 (PAV), degas the asphalt binder as described in R 28 prior to testing. Otherwise, degassing of the asphalt binder sample is not required.

10.1.2. Anneal the asphalt binder from which the test specimen is obtained by heating until sufficiently fluid to pour the required specimens. Annealing prior to testing removes reversible molecular associations (steric hardening) that occur during normal storage at ambient temperature. Avoid heating the binder samples above a temperature of 163°C; however, with some modified or heavily aged asphalt binders, pouring temperatures above 163°C may be required. Loosely cover the sample, and stir it occasionally during the heating process to ensure homogeneity and to remove air bubbles. Minimize the heating temperature and time to avoid hardening the sample.

Note 16—For neat asphalt binders, minimum pouring temperatures that produce a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Note 17—For PAV aged samples, asphalt binder may be placed in a vacuum oven set at a maximum of 175°C for 40 min. Due to the poor heat transfer in the vacuum oven, the asphalt binder will not be overheated.

10.1.3. Cold material from storage containers must be annealed prior to usage. Structure developed during storage can result in overestimating the modulus by as much as 50 percent.

10.2. *Preparing Test Specimens*—Zero the gap as specified in Section 8. Carefully clean and dry the surfaces of the test plates so that the specimen will adhere to both plates uniformly and strongly. Heat the chamber to 34 to 46°C when using the 8-mm specimens. Heat the chamber to the test temperature or the beginning of the range (Note 6) when using 25-mm specimens. This requirement is to preheat the upper and lower plates to allow specimen adhesion to both plates. Prepare a test specimen using one of the methods specified in Section 10.3.1, 10.3.2, or 10.3.3.

10.3. Transfer asphalt binder to one of the test plates through pouring (Section 10.3.1), direct transfer (Section 10.3.2), or by use of a silicone mold (Section 10.3.3). Use a sufficient amount of asphalt binder so that trimming is required.

Note 18—Direct transfer and pouring are the preferred methods because the test results are less likely to be influenced by steric hardening than with the silicone mold method. Direct transfer and direct pouring result in higher asphalt binder temperatures when the plates and asphalt binder are brought into contact, thereby improving adhesion. For this reason, it is also important to bring the asphalt binder and plates into contact promptly after pouring or direct transfer.

10.3.1. *Pouring*—Only when using rheometers that are designed for removal of the plates without affecting the zero setting, remove the removable plate and, while holding the sample container approximately 15 mm above the test plate surface, pour the asphalt binder in the center of the upper test plate continuously until it covers the entire plate except for an approximate 2-mm wide strip at the perimeter (Note 19). Wait only long enough for the specimen to stiffen, to prevent movement, and then mount the test plate in the rheometer for testing.

Note 19—An eye dropper or syringe may be used to transfer the hot asphalt binder to the plate.

10.3.2. *Direct Transfer*—Transfer the hot asphalt binder to one of the plates using a glass or metal rod, spatula, or similar tool. Immediately after transferring the hot asphalt binder to one of the plates, proceed to Section 10.4 to trim the specimen and form the bulge.

Note 20—A small, narrow stainless steel spatula of the type used to weigh powders on an analytical balance has been found suitable for transferring the asphalt hot binder. When using a rod, form the test specimen with a twisting motion, using a mass of sufficient size. The twisting motion seems to keep the mass on the rod in control. A 4- to 5-mm diameter rod is suitable. The glass rod technique is especially useful for the 8-mm plate.

10.3.3. *Silicone Mold*—Pour the hot asphalt binder into a silicone rubber mold that will form a pellet having dimensions as required in Section 6.2. Allow the silicone rubber mold to cool to room temperature. The molds shall be covered while cooling to eliminate contamination. The specimen may be mounted to either the upper or lower plate. To mount the specimen to the lower plate, remove the specimen from the mold and center the pellet on the lower plate of the DSR. To mount the specimen to the upper plate, center the specimen on the upper plate while it is still in the silicone rubber mold. Gently press the specimen to the upper plate and then carefully remove the silicone rubber mold leaving the specimen adhered to the upper plate. Complete all testing within 4 h of pouring the specimen into the silicone rubber mold.

10.3.3.1. The filled mold should be cooled at room temperature by placing the mold on a flat laboratory bench surface without chilling. Cooling to temperatures below room temperature results in an unknown thermal history that may affect the measured values of modulus and phase angle. Cooling may also result in the formation of moisture on the surface of the specimen that will interfere with adhesion of the specimen to the plates.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Note 21—Solvents should not be used to clean the silicone rubber molds. Wipe the molds with a clean cloth to remove any asphalt binder residue. With use, the molds will become stained from the asphalt binder, making it difficult to remove the binder from the mold. If sticking becomes a problem, discard the mold.

Note 22—Some binder grades cannot be removed from the silicone mold without cooling. Materials such as PG 52-34, PG 46-34, and some PG 58-34 grades do not lend themselves to being removed from the mold at ambient temperatures. If the binder specimen cannot be removed from the mold without cooling, the direct transfer or pouring method may be used, or the filled mold may be chilled in a freezer or refrigerator for a maximum of 10 min to facilitate demolding the specimen.

- 10.4. *Trimming Test Specimen*—Immediately after the specimen has been placed on one of the test plates as described above, move the test plates together until the gap between the plates equals the testing gap plus the gap closure required to create the bulge. (See Section 10.5 for gap closure required to create the bulge.) Trim excess binder by moving a heated trimming tool around the edges of the plates so that the asphalt binder is flush with the outer diameter of the plates.

Note 23—The trimming tool should be at a temperature that is sufficiently hot as to allow trimming but not excessively hot as to burn the edge of the specimen. The trimming tool should also not be excessively cool as to snag or damage the edge of the test specimen.

Note 24—The gap should be set at the starting test temperature (Section 11.1.1) or at the middle of the expected range of test temperatures (Section 11.1.2). See Note 5 for guidance on setting the gap. Typically, reliable test results may be obtained with a single sample using temperatures within 12°C of the temperature at which the gap is set.

- 10.5. *Creating Bulge*—Immediately after the trimming is complete, decrease the gap by the amount required to form a slight bulge at the outside face of the test specimen. The gap required to create a bulge is rheometer specific and depends on factors such as the design of the rheometer and the difference between the trimming temperature and test temperature. Recommended closure values for creating the gap are 0.05 mm for the 25-mm plate and 0.10 mm for the 8-mm plate. A recommended practice for verifying the gap closure required to produce an appropriate bulge is given in Appendixes X8, X9, and X10.

Note 25—The complex modulus is calculated with the assumption that the specimen diameter is equal to the plate diameter. If the asphalt binder forms a concave surface at its outer edges, this assumption will not be valid and the modulus will be underestimated. The calculated modulus is based on the radius of the plate raised to the fourth power. A slight bulge equal to approximately one quarter of the gap is recommended. A procedure for determining the closure required to form an acceptable gap is given in Appendixes X8, X9, and X10.

11. PROCEDURE

- 11.1. Bring the specimen to the test temperature $\pm 0.1^\circ\text{C}$. See Note 4.
- Note 26**—The gap should be set at the starting test temperature (Section 11.1.1) or at the middle of the expected range of test temperatures (Section 11.1.2). See Note 5 for guidance on setting the gap. Typically, reliable test results may be obtained with a single sample, in an 8-mm to 25-mm plate, using temperatures within 12°C of the temperature at which the gap is set.
- 11.1.1. When testing a binder for compliance with M 320, select the test temperature from the appropriate table in M 320.
- 11.1.2. When conducting a temperature sweep, start at a midrange test temperature and increase or decrease the test temperature to cover the desired range of test temperatures. (See Sections 6 and 7 in R 29.)

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

- 11.2. Set the temperature controller to the desired test temperature, including any offset as required by Section 9.4.4. Allow the temperature indicated by the RTD to come to the desired temperature. The test shall be started only after the temperature has remained at the desired temperature $\pm 0.1^\circ\text{C}$ for at least 10 min.

Note 27—It is impossible to specify a single equilibration time that is valid for DSRs produced by different manufacturers. The design (fluid bath or air oven) of the environmental control system and the starting temperature will dictate the time required to reach the test temperature. The method for determining the correct thermal equilibrium time is described in Appendix X12.

- 11.3. *Strain Control Mode*—When operating in a strain-controlled mode, determine the strain value according to the value of the complex modulus. Control the strain within 20 percent of the target value calculated by Equation 2.

$$\gamma, \text{ percent} = \frac{12.0}{(G^*)^{0.29}} \quad (2)$$

where:

γ = shear strain in percent, and

G^* = complex modulus in kPa.

- 11.3.1. When testing specimens for compliance with M 320, select an appropriate strain value from Table 2. Software is available with the dynamic shear rheometers that will control the strain automatically without control by the operator.

Table 2—Target Strain Values

Material	kPa	Strain, percent	
		Target Value	Range
Original binder	$1.0 G^*/\sin \delta$	12	9 to 15
RTFO residue	$2.2 G^*/\sin \delta$	10	8 to 12
PAV residue	5000-6000 $G^*\sin \delta$	1	0.8 to 1.2

- 11.4. *Stress Control Mode*—When operating in a stress-controlled mode, determine the stress level according to the value of the complex modulus. Control the stress within 20 percent of the target value calculated by Equation 3.

$$\tau = 12.0(G^*)^{0.71} \quad (3)$$

where:

τ = shear stress in kPa, and

G^* = complex modulus in kPa.

- 11.4.1. When testing specimens for compliance with M 320, select an appropriate stress level from Table 3. Software is available with the dynamic shear rheometers that will control the stress level automatically without control by the operator.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Table 3—Target Stress Levels

Material	kPa	Stress, kPa	
		Target Level	Range
Original binder	1.0 $G^*/\sin \delta$	0.12	0.09 to 0.15
RTFO residue	2.2 $G^*/\sin \delta$	0.22	0.18 to 0.26
PAV residue	50.0 $G^*/\sin \delta$	50.0	40.0 to 60.0

- 11.5. When the temperature has equilibrated, condition the specimen by applying the required strain for a recommended 10 cycles or a required range of 8 to 16 cycles at a frequency of 10 rad/s (see Note 28). Obtain a test measurement by recording data for an additional recommended 10 cycles or a range of 8 to 16 cycles. Reduce the data obtained for the second set of cycles to produce a value for the complex modulus and phase angle. Typically a Fast Fourier Transform (FFT) is used to reduce the data. Multiple measurements may be obtained to verify that the sample is properly prepared. Disbonding between the plates and the binder or fracture in the sample can result in a decrease in the modulus with repeat measurements. Some asphalt binders may exhibit a reduced modulus with continued application of shear stresses (multiple measurements). The data acquisition system automatically acquires and reduces the data when properly activated. When conducting tests at more than one frequency, start testing at the lowest frequency and increase to the highest frequency.

Note 28—The standard frequency of 10 rad/s is used when testing binder for compliance with M 320.

- 11.6. The data acquisition system specified in Section 6.1.4 automatically calculates G^* and δ from test data acquired when properly activated.
- 11.7. Initiate the testing immediately after preparing and trimming the specimen. The testing at subsequent temperatures should be done as quickly as possible to minimize the effect of molecular associations (steric hardening) that can cause an increase in modulus if the specimen is held in the rheometer for a prolonged period of time. When testing at multiple temperatures all testing should be completed within 4 h.

12. INTERPRETATION OF RESULTS

- 12.1. The dynamic modulus and phase angle depend on the magnitude of the shear strain; the modulus and phase angle for both unmodified and modified asphalt binder decrease with increasing shear strain as shown in Figure 4. A plot such as that shown in Figure 4 can be generated by gradually increasing the load or strain amplitude, thereby producing a strain sweep. It is not necessary to generate such sweeps during normal specification testing; however, such plots are useful for verifying the limits of the linear region.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

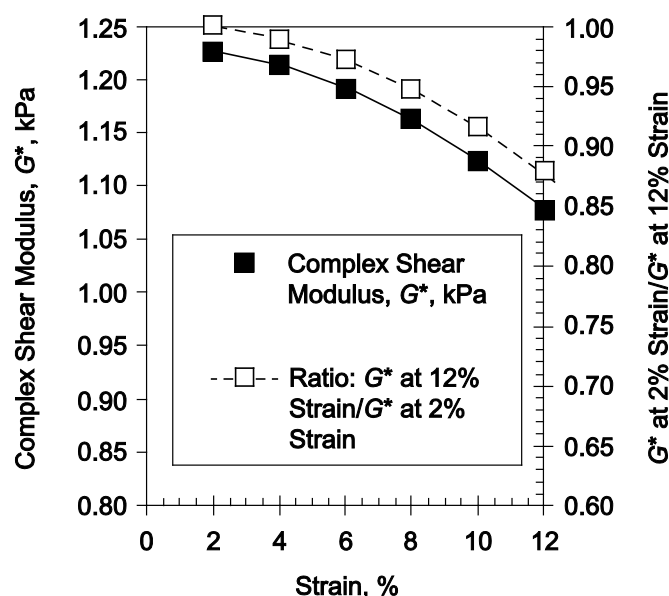


Figure 4—Example of Strain Sweep

- 12.2. A linear region may be defined at small strains where the modulus is relatively independent of shear strain. This region will vary with the magnitude of the complex modulus. The linear region is defined as the range in strains where the complex modulus is 95 percent or more of the zero-strain value.
- 12.3. The shear stress varies linearly from zero at the center of the plates to a maximum at the extremities of the plate perimeter. The shear stress is calculated from the applied or measured torque, measured or applied strain, and the geometry of the test specimen.

13. REPORT

- 13.1. A sample report format is given in Appendix X13. Provide a complete identification and description of the material tested including name, grade, and source.
- 13.2. Describe the instrument used for the test including the model number.
- 13.3. The strain and stress levels specified in Tables 2 and 3 have been selected to ensure a common reference point that has been shown to be within the linear region for neat and modified asphalt binders. Some systems may not be linear within this region. When this situation is observed, report the modulus at the recommended stress or strain levels but also report that the test conditions were outside the linear region.
- 13.4. *For each test, report the following:*
- 13.4.1. Test plate diameter, nearest 0.1 mm, and test gap, nearest 1 μm ;
 - 13.4.2. Test temperature, nearest 0.1°C;
 - 13.4.3. Test frequency, nearest 0.1 rad/s;
 - 13.4.4. Strain amplitude, nearest 0.01 percent, or torque, nearest $\text{mN}\cdot\text{m}$;

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

- 13.4.5. Complex modulus (G^*) for the 10 measurements, kPa to three significant figures;
- 13.4.6. Phase angle (δ) for the second 10 cycles, nearest 0.1 degrees; and
- 13.4.7. $G^*/\sin\delta$, nearest 0.01 kPa, or $G^*\sin\delta$, nearest whole number.

14. PRECISION AND BIAS

- 14.1. *Precision*—Criteria for judging the acceptability of dynamic shear results obtained by this method are given in Table 4.
- 14.1.1. *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 4 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 4, Column 3.
- 14.1.2. *Multilaboratory Precision (Reproducibility)*—The figures in Column 2 of Table 4 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 4, Column 3.

Table 4—Precision Estimates

Condition	Coefficient of Variation (1s)% ^a	Acceptable Range of Two Test Results (d2s)% ^a
<i>Single-Operator Precision:</i>		
Original Binder: $G^*/\sin\delta$ (kPa)	1.6	4.6
RTFO Residue: $G^*/\sin\delta$ (kPa)	2.5	7.2
PAV Residue: $G^*\sin\delta$ (kPa)	3.9	11.2
<i>Multilaboratory Precision:</i>		
Original Binder: $G^*/\sin\delta$ (kPa)	3.6	10.2
RTFO Residue: $G^*/\sin\delta$ (kPa)	5.9	16.8
PAV Residue: $G^*\sin\delta$ (kPa)	9.7	27.4

^aThese values represent the 1s% and d2s% limits described in ASTM C670.

<u>Condition</u>	<u>Coefficient of Variation (1s)^a</u>	<u>Acceptable Range of Two Test Results (d2s)^a</u>
<i>Single-Operator Precision:</i>		
<u>Original Binder: δ (°)</u>	<u>0.18</u>	<u>0.49</u>
<u>RTFO Residue: δ (°)</u>	<u>0.15</u>	<u>0.42</u>
<u>PAV Residue: δ (°)</u>	<u>0.09</u>	<u>0.25</u>
<i>Multilaboratory Precision:</i>		
<u>Original Binder: δ (°)</u>	<u>0.34</u>	<u>0.95</u>
<u>RTFO Residue: δ (°)</u>	<u>0.34</u>	<u>0.94</u>
<u>PAV Residue: δ (°)</u>	<u>0.76</u>	<u>2.11</u>

^aThese values represent the 1s and d2s limits described in ASTM C670.

Note 29—The precision estimates given in Table 4 are based on the analysis of test results from ten pairs of AASHTO re:source proficiency samples. The data analyzed consisted of results from 224 to 302 laboratories for each of the ten pairs of samples. The analysis included seven binder

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

grades: PG 58-28, PG 58-28 (modified), PG 64-22, PG 70-22, PG 70-28 (modified), PG 76-22 (modified), and PG 82-22 (modified). Average original binder results for $G^*/\sin\delta$ ranged from 1.196 kPa to 1.871 kPa. Average RTFO residue results for $G^*/\sin\delta$ ranged from 2.554 kPa to 5.385 kPa. Average PAV residue results for $G^*\cdot\sin\delta$ averaged from 901 kPa to 4744 kPa. The methods used for this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Note 30—As an example, two tests conducted on the same PAV residue yield results of 1200 kPa and 1300 kPa, respectively. The average of these two measurements is 1250 kPa. The acceptable range of results is then 11.2 percent of 1250 kPa or 140 kPa. As the difference between 1200 kPa and 1300 kPa is less than 140 kPa, the results are within the acceptable range.

- 14.2. *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

15. KEYWORDS

- 15.1. Dynamic shear rheometer; DSR; complex modulus; asphalt binder.

APPENDIXES

(Nonmandatory Information)

X1. TESTING FOR LINEARITY

- X1.1. *Scope:*
- X1.1.1. This procedure is used to determine whether an unaged asphalt binder exhibits linear or nonlinear behavior at the upper grading temperature, e.g., 52, 58, 64, 70, 76, or 82°C. The determination is based on the change in complex shear modulus at 10 rad/s when the strain is increased from 2 to 12 percent.
- X1.2. *Procedure:*
- X1.2.1. Verify the DSR and its components in accordance with Section 9 of this standard.
- X1.2.2. Prepare the DSR in accordance with Section 10 of this standard.
- X1.2.3. Prepare a test specimen for testing with 25-mm plates as per Section 11 of this standard. Select the test temperature as the upper grading temperature for the binder in question.
- X1.2.4. Determine the complex shear modulus at 2 and 12 percent strain following the test procedure described in Section 12 except as noted below. Always start with the lowest strain and proceed to the next larger strain.
- X1.3. *Strain Controlled Rheometers*—If the software provided with the DSR will automatically conduct tests at multiple strains, program the DSR to obtain the complex shear modulus at strains of 2, 4, 6, 8, 10, and 12 percent. If this automatic feature is not available, test by manually selecting strains of 2, 4, 6, 8, 10, and 12 percent strain.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

- X1.4. For stress-controlled rheometers, compute the starting stress based on the complex shear modulus, G^* , and shear stress, τ , as determined at the upper grading temperature during the grading of the binder. At this temperature the complex modulus, G^* , will be greater than or equal to 1.00 kPa and the shear stress, τ , will be between 0.090 and 0.150 kPa (see Table 2). Calculate the starting stress as $\tau / 6.00$ kPa. Increase the stress in five increments of $\tau / 6.00$ kPa.
- Note X1**—*Sample calculation:* Assume a PG 64-22 asphalt binder with $G^* = 1.29$ kPa at 64°C and $\tau = 0.135$ kPa. The starting stress will be $1.35\text{kPa}/6 = 0.225$ kPa. Test at 0.225, 0.450, 0.675, 0.900, 1.13, and 1.35 kPa, starting with 0.225 kPa.
- X1.5. *Plot of Complex Modulus Versus Strain*—Prepare a plot of complex shear modulus versus percent strain as shown in Figure 4. From the plot, determine the complex shear modulus at 2 and 12 percent strain.
- X1.6. *Calculations:*
- X1.6.1. Calculate the modulus ratio as the complex shear modulus at 12 percent strain divided by the complex shear modulus at 2 percent strain.
- X1.7. *Report:*
- X1.7.1. *Report the following:*
- X1.7.1.1. Complex shear modulus (G^*) to three significant figures;
- X1.7.1.2. Strain, nearest 0.1 percent;
- X1.7.1.3. Frequency, nearest 0.1 rad/s; and
- X1.7.1.4. The ratio calculated by dividing the modulus at 12 percent strain by the modulus at 2 percent strain.
- X1.8. *Data Interpretation:*
- X1.8.1. The measurement was performed in the nonlinear range of the material if the modulus ratio as calculated in Section X1.6.1 is <0.900 and linear if ≥ 0.900 . If the measurement was performed in the nonlinear range of the material, the results obtained under this standard will be considered as invalid for grading a binder according to M 320.

X2. CONTROL CHART

- X2.1. *Control Charts:*
- X2.1.1. Control charts are commonly used by various industries, including the highway construction industry, to control the quality of products. Control charts provide a means for organizing, maintaining, and interpreting test data. As such, control charts are an excellent means for organizing, maintaining, and interpreting DSR verification test data. Formal procedures based on statistical principles are used to develop control charts and the decision processes that are part of statistical quality control.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

A quality control chart is simply a graphical representation of test data versus time. By plotting laboratory measured values for the reference fluid in a control chart format, it is easy to see when:

- The measurements are well controlled and both the device and the operator are performing properly.
- The measurements are becoming more variable with time, possibly indicating a problem with the test equipment or the operator.
- The laboratory measurements for the fluid are, on the average above or below the target (reference fluid) value.

Many excellent software programs are available for generating and maintaining control charts. Some computer-based statistical analysis packages contain procedures that can be used to generate control charts. Spreadsheets such as Microsoft's Excel can also be used to generate control charts and, of course, control charts can be generated manually. (See Table X3.1 as an example.)

X2.2. *Care in Selecting Data:*

- X2.2.1. Data used to generate control charts should be obtained with care. The idea of randomness is important but need not become unnecessarily complicated. An example will show why a random sample is needed; a laboratory always measures the reference fluid at the start of the shift or workday. These measurements could be biased by start-up errors such as a lack of temperature stability when the device is first turned on. The random sample ensures that the measurement is representative of the process or the material being tested. Said another way, a random sample has an equal chance of being drawn as any other sample. A measurement or sample always taken at the start or end of the day, or just before coffee break, does not have this chance.

X3. EXAMPLE

- X3.1. The power of the control chart is illustrated in Table X3.1 using the verification data obtained for the DSR. Other DSR verification data suitable for a quality control chart presentation include measurements for determining the temperature correction, calibrating the electronic thermometer, and maintaining data from internally generated asphalt binder reference samples. For this example, the reported viscosity for the reference fluid is 271 Pa·s; hence, the calculated value for G^* is 2.71 kPa. This value for G^* is labeled as “ G^* from Reference Fluid” in Figure X3.1. The laboratory should obtain this value on average if there is no laboratory bias.

Table X3.1—Sample Test Data

Week	Measured G^* , kPa
1	2.83
2	2.82
3	2.77
4	2.72
5	2.69
6	2.72
7	2.77
8	2.75
9	2.71
10	2.82
11	2.66
12	2.69
13	2.75

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

14	2.69
15	2.73
16	2.77
17	2.72
18	2.67
19	2.66
20	2.78
21	2.74
22	2.69
Average	2.73
Std. Dev.	0.051
CV %	1.86

X3.2. *Comparison of 22-Week Laboratory Average for G^* with Value Calculated from Reference Fluid:*

X3.2.1. The 22-week average of the laboratory measurements is labeled as “22-Week Laboratory Average” in Figure X3.1. Over the 22 weeks for which measurements were made, the average was 2.73 kPa. This value compares favorably with the calculated reference value, 2.71 kPa, differing on the average by only 0.7 percent. There appears to be little laboratory bias in this data.

X3.3. *Comparison of CV of Laboratory Measurements with Round Robin CV:*

X3.3.1. From a previous round robin study, the within laboratory standard deviation (d1s) for the fluid was reported as 0.045 (CV = 1.67 percent). The 22-week standard deviation for the measured values of G^* is 0.051 (CV = 1.86 percent), as compared to 0.045 (CV = 1.67 percent) reported from the round robin. However, it should be pointed out that the 22-week CV, 1.86 percent, also includes day-to-day variability, a component of variability not included in the round-robin d1s value. Based on this information the variability of the laboratory measurements are acceptable.

X3.4. *Variability of Measured Values:*

X3.4.1. In Figure X3.1, the value of G^* calculated from the reference fluid is shown as a solid line. Also shown are two dotted lines that represent the G^* calculated from the reference fluid ± 2 d1s where d1s is the value from the round robin. The calculated reference value for the fluid is 2.71 kPa, and the standard deviation is 0.045. Thus, a deviation of 2 d1s gives values of:

$$2.71 \text{ kPa} \pm (2)(0.045) = 2.80 \text{ kPa}, 2.62 \text{ kPa} \quad (X3.1)$$

If the laboratory procedures are under control, the equipment is properly calibrated, and there is no laboratory bias, 95 percent of the measurements should fall within the limits 2.62 kPa and 2.80 kPa. Laboratory measurements outside this range are suspect, and the cause of the outlier should be investigated. The outlier may be the result of either testing variability or laboratory bias. The measurement from Week 10 in Figure X3.1 falls outside the ± 2 d1s limits and is cause for concern such that testing procedures and verification should be investigated.

If a measurement deviates from the target, in this case G^* from the reference fluid, by more than ± 3 d1s, corrective action should be initiated. The ± 3 d1s limits 99.7 percent of the measured values if the laboratory procedures are under control and the equipment is properly calibrated.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

X3.5. *Trends in Measured Value:*

X3.5.1. The control chart can also be used to identify unwanted trends in the data. For example, from Weeks 1 to 5, a steady decrease in the measured value is observed. This is cause for concern and the reason for the trend should be investigated. More sophisticated rules for analyzing trends in control charts can be found elsewhere.

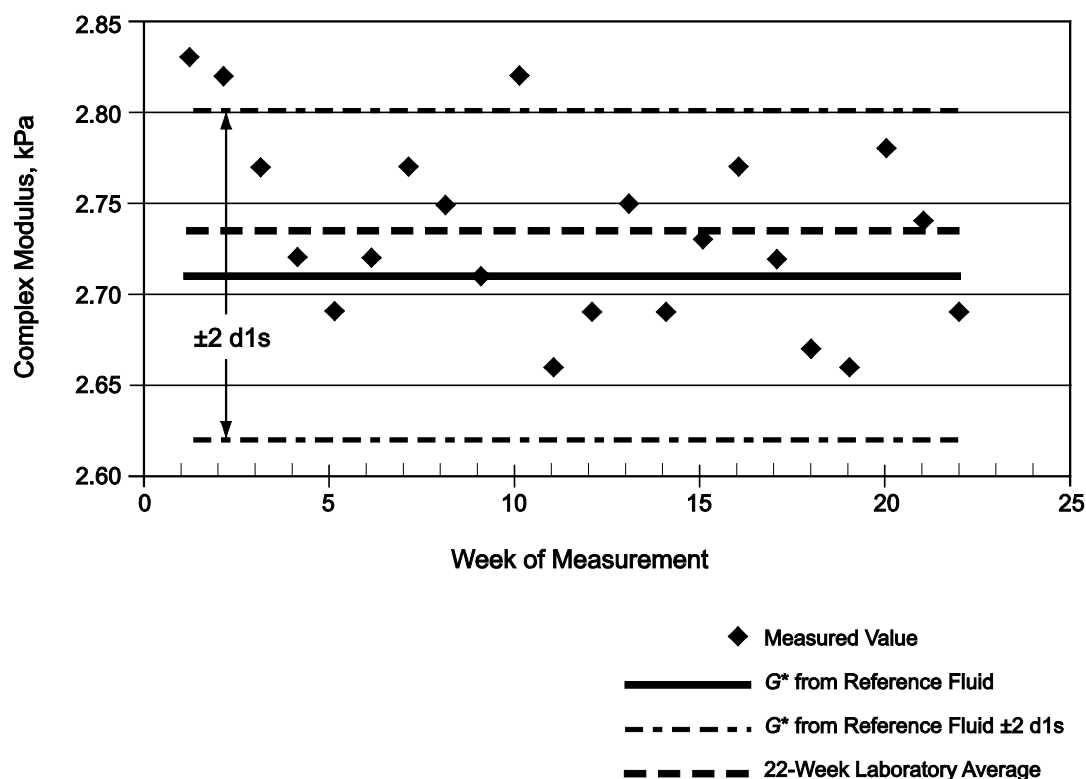


Figure X3.1—Control Chart

X4. USE OF REFERENCE FLUID

X4.1. *Source of Reference Fluid:*

X4.2. An organic polymer produced by Cannon Instrument Company as Viscosity Standard N2700000SP has been found suitable as reference fluid for verifying the calibration of the DSR. The viscosity of the fluid, as determined from NIST–traceable capillary viscosity measurements, is approximately 270 Pa·s at 64°C. However, the viscosity of the fluid varies from one lot to the next. The lot-specific viscosity is printed on the label of the bottle.

X5. CAUTIONS IN USING REFERENCE FLUID

X5.1. Some items of caution when using the reference fluid are:

- The fluid cannot be used to verify the accuracy of the phase angle measurement.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

- The fluid must not be heated as heating can degrade the fluid, causing a change in its viscosity.
- The fluid should be used for verification only after the DSR temperature measurements are verified.
- The fluid cannot be used to calibrate the torque transducer. The manufacturer or other qualified service personnel using a calibration device designed specifically for the rheometer should perform the calibration. These calibration devices are typically not available in operating laboratories.
- When tested at 10 rad/s, the reference fluid should be used only at 64°C and above. At lower temperatures, the fluid is viscoelastic; hence, the viscosity, η , reported on the certificate by Cannon will not match the complex viscosity $\eta^* = G^*/10$ rad/s determined from the measurement.
- Bubbles in the fluid will have a dramatic effect on the measured value of G^* . The fluid in the bottle should be free of bubbles and care must be taken not to introduce bubbles when preparing test specimens. Recommended procedures for preparing test specimens are given in Appendix X6.

X6. CALCULATION OF G^* FROM STEADY-STATE VISCOSITY MEASUREMENTS

X6.1. Among the different methods for converting between dynamic and steady-state viscosity of polymers, the most popular and most successful is the so-called Cox-Merz empirical rule. The rule leads, in simplified terms, to the following approximation.

$$\frac{G^*}{\omega} \sim \eta \quad (X6.1)$$

where:

- G^* = the complex modulus;
- ω = the angular frequency in radians/s; and
- η = the shear rate independent capillary viscosity as reported by the supplier of the reference fluid.

For this rule to apply the measurements must be in the viscous region where the phase angle approaches 90 degrees. The value of the complex modulus is then simply 10 times the value of the capillary viscosity. For example, if the capillary viscosity is 270,000 mPa·s the complex modulus is:

$$G^*, \text{ kPa} \approx (270,000 \text{ mPa} \cdot \text{s})(1 \text{ kPa}/1,000,000 \text{ mPa})(10 \text{ rad/s}) = 2.70 \text{ kPa} \cdot \text{rad} \quad (X6.2)$$

The reference fluid behaves as a viscous fluid at 64°C and above and provides very accurate estimates of G^* above 64°C. At temperatures below 58°C the fluid gives incorrect values for G^* with the error increasing as the temperature departs from 64°C. At 64°C and above G^* divided by the frequency in radians per second should be no more than 3 percent different than the viscosity printed on the bottle label. If this is the case, then the torque calibration should be considered suspect.

X7. METHODS FOR TRANSFERRING THE FLUID TO THE TEST PLATES

X7.1. Three different methods are recommended for transferring the fluid to the test plates:

X7.2. The glass rod method (Section X7.3), the spatula method (Section X7.4), and a direct method where a removable test plate is held in direct contact with the fluid in the bottle (Section X7.6).

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

X7.3. *Glass Rod Method (Figure X7.1):*

X7.3.1. In this method, a glass rod is inserted into the fluid and rotated (Step 1) while in the fluid. Continue rotating the rod, and pull it slowly from the fluid (Step 2) carrying a small mass of the fluid with the rod. Touch the mass to the plate (Step 3) to transfer the fluid to the plate. See Figure X7.1.



Figure X7.1—Using a Glass Rod to Place the Reference Fluid on the Plate

X7.4. *Spatula Method (Figure X7.2):*

X7.5. When carefully used, a spatula may be used to transfer the fluid. Special care must be taken not to trap air as the material is scooped from the bottle (Step 1). Smear the mass on the spatula onto the plate (Step 2) and cut the mass from the spatula by drawing the spatula across the edge of the plate (Step 3). This method appears to be the most difficult to implement and is the least recommended of the three methods.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.



Figure X7.2—Using a Spatula to Place the Reference Fluid on the Plate

- X7.6. *Direct Touch Method (Figure X7.3)*—If the rheometer is equipped with plates that may be removed and reinstalled without affecting the gap reference, remove one of the plates and touch the surface of the plate to the surface of the fluid in the bottle (Step 1). Pull the plate from the bottle, bringing a mass of the fluid along with the plate (Step 2). Invert the plate and allow the fluid to flow out into a mushroom shape (Step 3).

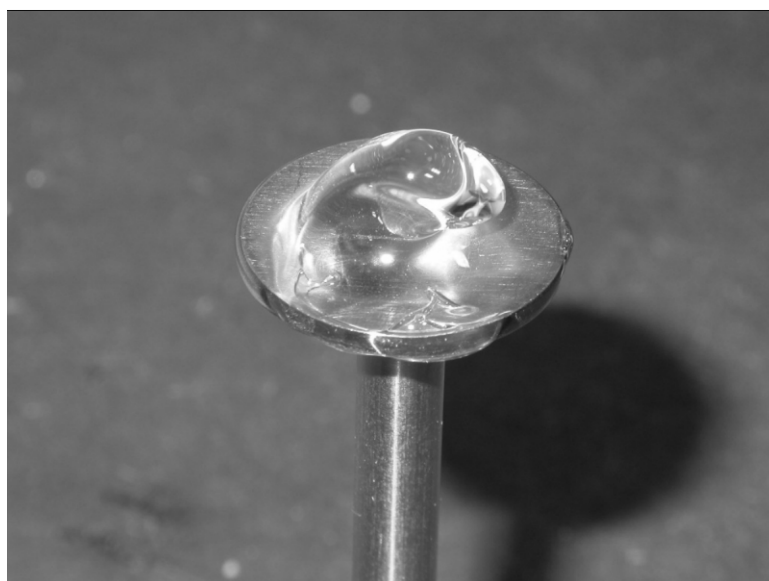


Figure X7.3—Direct Touch Method to Place the Reference Fluid on the Plate

Proceed immediately to Section 10.5 to trim the reference fluid specimen and form the bulge. Proceed with testing the reference fluid specimen as described in Section 11.

X8. SELECTION OF GAP CLOSURE TO OBTAIN BULGE

- X8.1. *Need for Accurate Measurement of Specimen Diameter:*

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

- X8.2. The accuracy of the DSR measurements depends on an accurate measurement of the diameter of the test specimen. The diameter of the test specimen is assumed to be equal to the diameter of the test plates. For this reason, the trimming of excess binder and the final closure of the gap to produce a slight bulge in the test specimen are critical steps in the DSR test procedure. When the gap is closed to its final dimension, the bulge must be of sufficient size to compensate for any shrinkage in the binder and consequently avoiding a concave surface as shown in Figure X8.1. The diameter of the test specimen in Figure X8.1 approaches d , rather than d' , the diameter of the plate. The modulus, G^* , is calculated according to the following equation:

$$|G^*| = \left(\frac{2h}{\pi r^4} \right) \left(\frac{\tau}{\Theta} \right) \quad (X8.1)$$

where:

- G^* = complex modulus;
- τ = torque applied to test specimen;
- h = thickness of test specimen;
- Θ = angular rotation, radians; and
- r = radius of test plate.

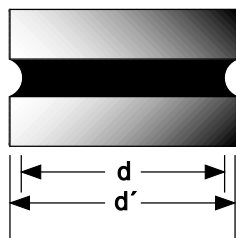


Figure X8.1—Concave Surface Resulting from Insufficient Closure after Trimming

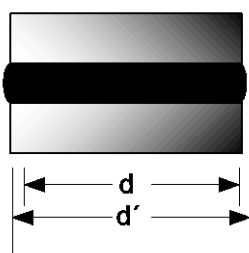


Figure X8.2—Proper Bulge

- X8.3. According to Equation X8.1, the modulus depends on the radius (or diameter) raised to the fourth power. Therefore, a small concavity in the outer surface of the test specimen, as shown in Figure X8.1, will have a large effect on the measured modulus because the actual specimen diameter will be less than the plate diameter. For a given amount of concavity, the effect on the measured modulus is greater for the 8-mm plate than the 25-mm plate. A more desirable result is a slight bulge as illustrated in Figure X8.2. Shear stresses are not transferred directly from the plate to the overhanging binder; therefore, the effect of a slight bulge on the measured modulus is much less than a slight concavity. It should be noted that errors in the diameter of the test specimen do not affect the measured values of the phase angle.

X9. RECOMMENDED GAP CLOSURE VALUES

- X9.1. Recommended values for the gap closure required to form a bulge at the test temperature similar to the bulge illustrated in Figure X8.2 are given in Section 10.5 as 50 μm and 100 μm for the 25-mm and 8-mm plates, respectively. Although these values may be appropriate for many rheometers, they may not be appropriate for all rheometers. The applicability of these values to a specific rheometer may be determined by preparing a test specimen using the recommended closure and observing the shape of the bulge after the final closure of the gap and after the test specimen is at the test temperature. If the recommended closure values do not give an appropriate bulge, the recommended closure values should be adjusted as appropriate.

Proper and improper bulges are shown in Figures X10.1 through X10.3. A magnifying glass is useful for examining the shape of the bulge. Regardless of the closure required to produce a desirable bulge, the actual gap should be used in the calculations.

X10. FACTORS AFFECTING BULGE DEVELOPMENT

- X10.1. A number of factors can affect the bulge formed at the test temperature. These include:

- The amount of closure used to create the bulge.
- The difference in temperature between the trimming temperature, the temperature at which the bulge is created, and the test temperature.
- Thermal expansion–contraction characteristics of the rheometer.
- Thermal contraction and expansion of the asphalt binder.

A concave surface is more likely to form at the intermediate temperatures, than at the upper test temperatures (8-mm plate rather than the 25-mm plate). In fact, at the higher test temperatures excessive material can be squeezed from the plates as shown in Figure X10.3. This situation should also be avoided and may require gap closures somewhat less than the recommended values.

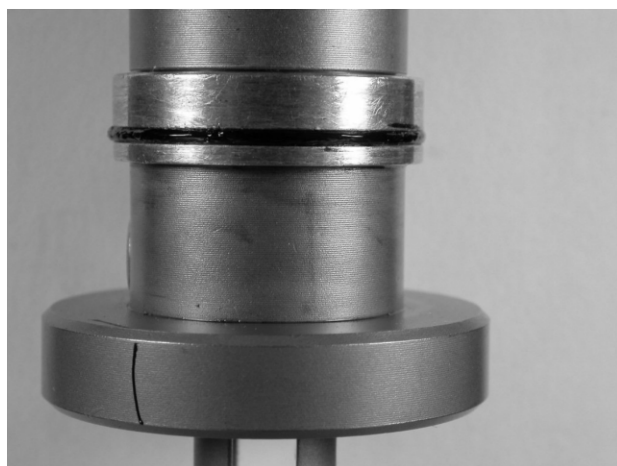


Figure X10.1—Good Bulge Size

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.



Figure X10.2—Concave Bulge



Figure X10.3—Oversized Bulge

X11. DETERMINATION OF TIME TO THERMAL EQUILIBRIUM

X11.1. *Reason for Determining Time Required to Obtain Thermal Equilibrium:*

X11.1.1. After the test specimen has been mounted in the DSR, it takes some time for the asphalt binder between the test plates to reach thermal equilibrium. Because of thermal gradients within the test plates and test specimen, it may take longer for the test specimen to come to thermal equilibrium than the time indicated by the DSR thermometer. Therefore, it is necessary to experimentally determine the time required for the test specimen to reach thermal equilibrium.

X11.1.2. The time required to obtain thermal equilibrium varies for different rheometers. Factors that affect the time required for thermal equilibrium include:

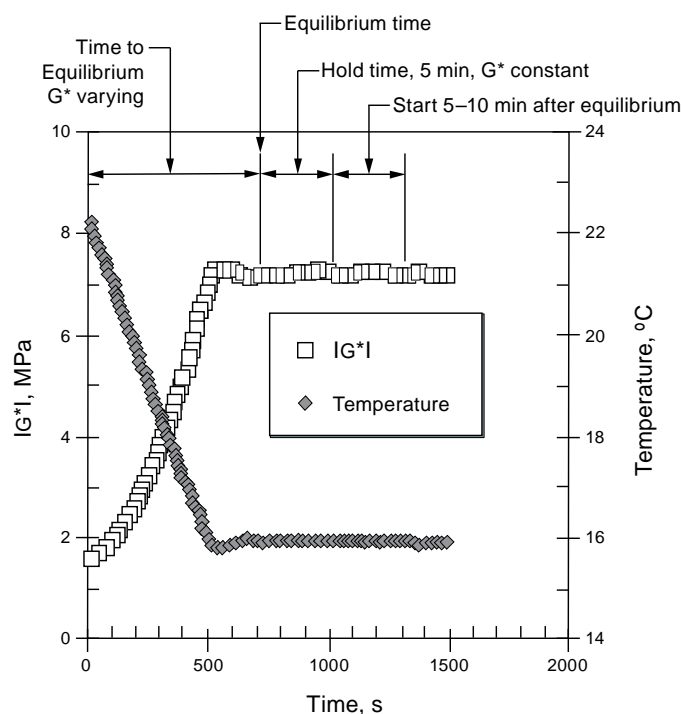
X11.1.3. Design of the rheometer and whether air or liquid is used as a heating/cooling medium;

Mid-production copy for standard development purposes only. Any other use is a violation of copyright. Do not remove this header and do not upload to the Materials Library.

- X11.1.4. Difference between ambient temperature and the test temperature, different when testing below room temperature, and above room temperature;
- X11.1.5. Difference in temperature between the trimming and test temperature; and
- X11.1.6. Plate size, different for the 8-mm and 25-mm plate.
- X11.2. It is not possible to specify a single time as the time required to obtain thermal equilibrium. For example, thermal equilibrium is reached much quicker with liquid-controlled rheometers than with air-cooled rheometer. This requires that the time to thermal equilibrium be established for individual rheometers, typical trimming and testing temperatures, and testing conditions.

X12. METHOD TO DETERMINE THE TIME REQUIRED TO OBTAIN THERMAL EQUILIBRIUM

- X12.1. A reliable estimate of the time required for thermal equilibrium can be obtained by monitoring the DSR temperature and the complex modulus of a sample mounted between the test plates. Because the modulus is highly sensitive to temperature, it is an excellent indicator of thermal equilibrium. The following procedure is recommended for establishing the time to thermal equilibrium:
- X12.2. Mount a binder sample in the DSR and trim in the usual manner. Create a bulge and bring the test chamber or fluid to the test temperature.
- X12.3. Operate the rheometer in a continuous mode at 10 rad/s using an unmodified asphalt binder—one that does not change modulus with repeated shearing. Use the smallest strain value that gives good measurement resolution.
- X12.4. Record the modulus at 30-s time intervals, and plot the modulus versus time (Figure X12.1).



Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

Figure X12.1—Determining Thermal Equilibrium Time

- X12.5. The time to reach thermal equilibrium is the time required to reach a constant modulus. Typically, this time will be greater than the time required to reach a constant reading on the DSR thermometer.
- X12.6. Because the time required to reach thermal equilibrium will vary with the test temperature and testing conditions, the time to thermal equilibrium should be established separately for both intermediate and high-temperature measurements. Once the time to thermal equilibrium has been established, it does not have to be repeated unless the test conditions change.

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

X13. SAMPLE REPORT

Header Information:

Item	Data Group 1	Item	Data Group 2
Operator's Name:	24 Alpha-Numeric	Date of Test (dd/mm/yy):	__/__/__
Test Specimen ID No.:	18 Alpha	Time of Test (hr:min):	__:__
Project ID No.:	12 Alpha-Numeric	DSR Manufacturer:	12 Alpha-Numeric
File Name:	12 Alpha-Numeric	DSR Model:	12 Alpha-Numeric
Test Plate Diameter, Nearest 0.01 mm:	00.00	DSR Serial Number or Other Identifying ID No.:	18 Alpha-Numeric
Test Frequency, rad/s:	0.00	Software Version:	12 Alpha-Numeric
Test Gap, 0.01 mm:	00.00		

Test Results for Grading (Use separate column for each test temperature):

Measurements	Data Group 3	Data Group 4	Data Group 5	Data Group 6
Test Specimen Temperature, 0.1°C	0.00	0.00	0.00	0.00
Temperature Correction at Test Temperature, 0.1°C	0.00	0.00	0.00	0.00
Stress Amplitude, kPa	0.00	0.00	0.00	0.00
Strain Amplitude, percent	0.00	0.00	0.00	0.00
Complex Modulus, G^* , kPa	0.00	0.00	0.00	0.00
Phase Angle, degrees	00.0	00.0	00.0	00.0
Complex Modulus/sin(Phase Angle)	0.00	0.00	0.00	0.00
Complex Modulus $\times \sin\delta$ (Phase Angle)	00.0	00.0	00.0	00.0
Comments generated by DSR software (Example: "This material passes.")				
At end of file, 276 alphanumeric field for operator comments and comments, if any, generated by DSR software.				

Test Results for Linearity Determination:

Measurements	Data Group 7					
Test Specimen Temperature, 0.1°C	0.00					
Temperature Correction at Test Temperature, 0.1°C	0.00					
	Data Group 8	Data Group 9	Data Group 10	Data Group 11	Data Group 12	Data Group 13
Measurements		0.00	0.00	0.00	0.00	0.00
Stress Amplitude, kPa	0.00	0.00	0.00	0.00	0.00	0.00
Strain Amplitude, percent	0.00	0.00	0.00	0.00	0.00	0.00
Complex Modulus, G^* , kPa	0.00	00.0	00.0	00.0	00.0	00.0
Phase Angle, degrees	00.0	00.0	00.0	00.0	00.0	00.0
At end of file, 276 alphanumeric field for operator comments and comments, if any, generated by DSR software.						

Mid-production copy for standard development purposes only. Any other use is a violation of copyright.
Do not remove this header and do not upload to the Materials Library.

X14. REFERENCES

- X14.1. Anderson, D. A. and M. Marasteanu. *Manual of Practice for Testing Asphalt Binders in Accordance with the Superpave PG Grading System*. The Pennsylvania Transportation Institute, The Pennsylvania State University, PTI 2K07, November 1999 (Revised February 2002).
- X14.2. Anderson, D. A., C. E. Antle, K. Knechtel, and Y. Liu. *Interlaboratory Test Program to Determine the Inter- and Intra-Laboratory Variability of the SHRP Asphalt Binder Tests*. FHWA, 1997.
- X14.3. Cox, W. P. and E. H. Merz. Correlation of Dynamic and Steady Flow Viscosities. *Journal of Polymer Science*, Vol. 28, 1958, pp. 619–622.
- X14.4. Wadsworth, H., ed. *Handbook of Statistical Methods for Engineers and Scientists*. McGraw-Hill, New York, NY, 1990.

¹ Formerly AASHTO Provisional Standard TP 5. First published as a full standard in 2002.

TFASH Meeting Minutes

May 15, 2019

Attendees:

AASHTO Membership			
Name	Organization / Company	Contact Information	Present?
Lyndi Blackburn	Alabama Department of Transportation	blackburnl@dot.state.al.us	X
Barry Paye	Wisconsin Department of Transportation	Barry.Paye@dot.wi.gov	X
Joe DeVol	Washington State Department of Transportation	DeVolJ@wsdot.wa.gov	

ASTM Membership			
Name	Organization / Company	Contact Information	Present?
Amir Golalipour	Engineering Software Consultants / Chair of ASTM D04.44	amir.golalipour.ctr@dot.gov	X
Bob Kluttz	Kraton Polymers / Chair of ASTM D04.40	bob.kluttz@kraton.com	X
Payman Pirzadeh	Imperial Oil	payman.pirzadeh@esso.ca	X
Frank Fee	Frank Fee, LLC	frank.fee@verizon.net	

Friends			
Name	Organization / Company	Contact Information	Present?
Maria Knake	AASHTO	mknake@ashtoresource.org	X
Casey Soneira	AASHTO	csoneira@ashto.org	X
Beck McDaniel	North Central Superpave Center	rsmcdani@purdue.edu	
David Mensching	FHWA	david.mensching@dot.gov	X
Ashley Wiand	ASTM	awiand@astm.org	
Joe Williams	AASHTO	jwilliams@ashtoresource.org	X

Others Present: Evan Rothblatt (ASTM), Mike Anderson (Asphalt Institute)

Review of Feedback Received on Draft Charter

- Comments received from members and friends on the first draft were discussed during the meeting. Action Item A draft Version 0.3 that incorporates changes recommended during today's meeting will be emailed out after the meeting concludes.

Establishing TFASH Chairs and Other Roles

- This topic was discussed briefly, and it was decided that an effort to recruit more members of TFASH should take place before selecting Chairs and filling other roles within TFASH.

Recruiting additional members

Additional members of TFASH are needed at this point, as there are vacancies on both sides, and there is not enough representation for asphalt mix and emulsions subcommittees. We will need to advertise and actively recruit additional members in order to ensure the success of TFASH. The following actions will be taken in order to start recruiting additional members.

- Lyndi will send an email to asphalt-related COMP Chairs and Vice Chairs to ask them to think about members of their subcommittees who may want to be a part of TFASH.
- Maria will talk to Casey Soneira about a time to present TFASH at the COMP meeting
- Maria will talk to Becky McDaniel and Ashley Wiand about discussing TFASH during the Exec meeting and Main meeting for ASTM Committee D04.

Priorities for TFASH

- The feedback received on which standards should be a priority for TFASH were briefly reviewed. The group decided that M320/D6373 (PG Binder Spec) and M332/D6373 (PG Binder with MSCR Spec) should be the first priorities of the group. These standards are “low-hanging fruit” that will allow TFASH to test the process we have put in place and make progress relatively quickly. In addition, because these standards are specs that are used for buying and selling of asphalt, they have a big impact on the industry.

Document Storage

- We need a place to store the charter, meeting minutes, and other relevant documents for TFASH. Maria will explore options. Ideas presented included: free Wordpress Site, Box, ASTM’s website, AASHTO re:source’s website.

Timing of Next Meeting

We need to recruit more members before TFASH can really gain momentum. For this reason, the next meeting will be in late August or early September after the AASHTO COMP meeting. Both groups will have had a meeting by then and can report on the activities of each.

Running Summary of Open Action Items			
Action Item	Assigned To	Date Assigned	Status
AASHTO re:source will provide the group with specific data on how many labs are accredited for AASHTO versions of tests vs. the ASTM versions.	Maria Knake	1/8/19	Joe Williams will send this out in May 2019
Maria and Joe Williams will work on Version 0.3 of Charter based on comments received during May 15, 2019 meeting	Maria Knake and Joe Williams	5/15/19	Just assigned
Send an email to Chairs and Vice Chairs of Group 2 Subcommittees (asphalt-related) in COMP to recruit additional members	Lyndi Blackburn	5/15/19	Complete
Maria will talk to Casey Soneira about a time during COMP to	Maria Knake	5/15/19	Just assigned

discuss TFASH and recruit members			
Maria will talk to Becky McDaniel and Ashley Wiand about discussing TFASH during D04 Exec and Main meetings in June	Maria Knake	5/15/19	Just assigned

Task Force on Asphalt Standards Harmonization (TFASH)
Charter
Version 0.12

Purpose

The Task Force on Asphalt Standards Harmonization (TFASH) will examine significant differences between the AASHTO and ASTM versions of asphalt-related standards that are published by both organizations. The task group will evaluate technical issues that exist in the standards and work together to develop consistent requirements that would meet the collective needs of asphalt producers, testing laboratories, specifiers, and owners. The Task Force will submit recommended changes to the appropriate AASHTO and ASTM subcommittees for consideration and ballot.

Background

Currently, both AASHTO and ASTM publish and maintain standards related to asphalt binder, asphalt emulsions, asphalt mixtures, and other asphalt pavement-related products. The divergence of asphalt specification requirements creates a burden for owners and specifiers, and creates logistical problems for asphalt producers. Producers and testing facilities must often meet varying technical requirements for customers in different states or for different applications, depending upon the standard specified. The TFASH was formed in January 2019 in order to bring representatives from both organizations together to develop consistent requirements that will simplify production and testing, lead to more uniform asphalt products, and facilitate effective commerce between buyers and sellers.

In development of the Task Force, the TFASH followed the model established by the Joint AASHTO-ASTM Harmonization Task Group (JAAHTG) on cement. This Task Force was formed by Mark Felag of the Rhode Island Department of Transportation, the former Chair of the AASHTO Committee on Materials and Pavements (COMP) Technical Subcommittee 3a on Cement (-formerly known as the AASHTO Subcommittee on Materials, Technical Section 3a) This cooperative effort between AASHTO Technical Subcommittee 3a and ASTM Committee C01 has been very successful over the years, and continues to establish consistent cement standards through consensus of the Task Group members.

Lyndi Blackburn	Not sure this information is necessary – suggest rewriting to say the task force is structured similar to previous successful task forces between AASHTO and ASTM.
-----------------	--

Scope

~~The~~ TFASH shall ~~focuses~~ its efforts on asphalt standards that fall under the jurisdiction of the AASHTO COMP Technical Subcommittees and ASTM Committee D04 on Road and Paving Materials as shown in Table 1 below. Only standards where similar published versions exist in both organizations will be evaluated by the Task Force.

Table 1: Relevant AASHTO COMP Technical Subcommittees and ASTM D04 Subcommittees

Relevant AASHTO COMP Technical Subcommittees	Relevant ASTM Committee D04 Subcommittees
2a, Emulsified Asphalt 2b, Liquid Asphalt 2c, Asphalt-Aggregate Mixtures 2d, Proportioning of Asphalt-Aggregate Mixtures	D04.20, Mechanical Tests of Asphalt Mixtures D04.21, Specific Gravity and Density of Asphalt Mixtures D04.22, Effect of Water and Other Elements on Asphalt Coated Aggregates D04.23, Plant-Mixed Surfaces and Bases D04.24, Asphalt Surface Treatments D04.25, Analysis of Asphalt Mixtures D04.26, Fundamental/Mechanistic Tests D04.40, Asphalt Specifications D04.41, Emulsified Asphalt Specifications D04.42, Emulsified Asphalt Test D04.44, Rheological Tests D04.46, Durability and Distillation Tests D04.47, Miscellaneous Asphalt Tests

Goals

The goal of the TFASH ~~goals are is to develop~~ ment of recommendations to present to the relevant subcommittees that harmonize testing methods that meet the collective needs of AASHTO members as well as ASTM users, general interest, and producer members. As such, the Task Force strives to develop recommendations on AASHTO and ASTM standards that:

1. ensure high-performing, durable, and long-lasting asphalt pavements;
2. provide a means to determine compliance to a procedure, process or of an asphalt product;
3. promote consistency and uniformity in asphalt materials;
4. use scientifically sound testing and sampling methodologies;
5. provide for the optimization of available natural resources and manufacturing technology and can accommodate various local and regional requirements;
6. ensure effective communication between buyers and sellers of asphalt products; and
7. promote fairness, equity, and practicality in asphalt test methods, practices, and specifications.

Frank Fee	Add: Provide a formal means for the exchange of current information (e.g. new standards, revisions, task group activities, etc.) for the corresponding subcommittees of each organization.
David Mensching	Regarding #2: How will this impact AASHTO re:source? Will it follow existing guidance in terms of when a laboratory can be assessed on a test method that has recently changed?
Jeff Withee	#2, something missing between “or” and “of.” Something is needed here. Should this be “property” or something similar?

Roles and Responsibilities

The TFASH is comprised of official members, friends, and officer positions as described below.

Members

Membership of the TFASH will consist of six AASHTO COMP members and six ASTM Committee D04 members. To ensure there are no conflicts of interest, AASHTO and ASTM staff may not act as members of the TFASH. Members are responsible for providing technical expertise, assisting with research needs, and drafting standards. Members may be asked to provide updates on recent meetings and other activities for the subcommittees in which they participate.

Lyndi Blackburn	Suggest setting a # for membership.
David Mensching	What if there aren't six of each? What if there is an imbalance of members from AASHTO or ASTM? Will the consensus process not proceed until there are 6 members from each group or at least a balance of members from each group?

Friends

Any person who ~~so desires is not interested or cannot serve as a member of the Task Force~~ may be a Friend of the TFASH. Friends ~~will be invited~~receive invitations to attend meetings, will receive notes and other updates on the work of the Task Force, and will be allowed to provide input. However, Friends will not be part of the consensus process outlined ~~above~~below. AASHTO and ASTM staff may be a Friend of the Task Force.

Lyndi Blackburn	This consensus process was not clear to me in the above part of the document – did you really mean below. – See Operational Guidelines.
David Mensching	Regarding Consensus: Does this mean friends need to leave the meeting? Or just friends are not involved in the voting?

Co-~~Chairman~~Chairmen

The TFASH will have two Co-Chairs, one from AASHTO and one from ASTM. Only official members of the Task Force can act as Co-Chairs. The Co-Chairmen of the TFASH will alternate responsibilities for leading Task Force meetings and facilitating fair and open discussion amongst all members. The Co-Chairmen are responsible for ensuring that consensus is reached amongst all members before recommendations to AASHTO and ASTM subcommittees are made. The Co-Chairmen will work with the Secretary to develop and approve an agenda for each meeting.

Secretary

The Secretary of the TFASH is responsible for tracking action items, maintaining meeting minutes, scheduling and coordinating Task Force meetings, making amendments to the Charter (with member consensus), tracking the progress of work underway, and with the permission of the Co-Chairman, sending recommended ballot items to the appropriate AASHTO and ASTM subcommittee chairs. The Secretary of the TFASH can be any Member or Friend.

Operational Guidelines

Meetings

At a minimum, the agenda for each meeting of the TFASH will include the following:

1. Call to Order

2. Attendance
3. Review of Membership
4. Approval of Previous Meeting Minutes
5. AASHTO COMP Updates
6. ASTM Committee D04 Updates
7. Review of Action Items from Previous Meeting
8. Old Business
9. New Business
10. Review of Standards Prioritization List
11. Review of New Action Items and Assignments
12. Date and Time for Next Meeting
13. Adjournment

David Mensching	Item 11: Would this be where the consensus procedure fits in?
-----------------	---

Consensus

In order to ensure that both the interests of AASHTO membership and ASTM membership are met, the TFASH will evaluate technical issues that exist in the standards and work together to develop consistent requirements. In doing so, input from both AASHTO and ASTM Task Force membership will be equally considered. A suggestion will not be submitted to the relevant AASHTO and ASTM subcommittees until 100% consensus amongst all Task Force members can be reached.

David Mensching	What about input from the friends? I understand friends will not have a role in consensus voting, but will their input be presented during the consensus process for review by the members? It is not clear to me here.
Jeff Withee	This is a pretty high bar which potentially allows one person out of twelve to stymie an otherwise overwhelming majority. Also, since each organization will presumably still have to approve of any TFASH proposed changes to their standards through their normal subcommittee balloting process, there will be an opportunity to reject any objectionable proposals. If you need to put a number on it, perhaps 75% is the more reasonable threshold. That will require at least half of one organization's members to support something even if the other organization's members unanimously support it. Conversely, at the 75% threshold, a simple majority (4) of either organization's members could prevent something from moving forward from the TFASH. Granted the actual consensus discussions will more likely be mixed support between all members of the TFASH (this comment is mainly a thought exercise on the potential consequences of a 100% support requirement to advance recommended changes.)

Ballot Rationale Statements

Any recommendations ~~that are sent to ballot as a result of the work of the TFASH~~ the appropriate AASHTO and ASTM subcommittees must include a detailed rationale statement. ~~The statement will clearly state for both the ASTM and AASHTO ballot that the work was done jointly.~~ The rationale will include the reason for the change, as well as any research or data to support the change. The rationale must clearly state that ~~both AASHTO and ASTM have worked on and have agreed upon these recommended changes~~ the work was done jointly by the Membership of TFASH.

Jeff Withee	I wouldn't think the change is "agreed upon" by either organization until their relevant subcommittee approves of the change through their normal ballot process.
-------------	---

Timing of Ballots

Once suggestions are submitted to the appropriate AASHTO and ASTM subcommittees, TFASH members will recommend a coordinated timing of ballots. Once ballot results are received from one group (AASHTO or ASTM), the task force will meet again to address any negatives received before the item goes to ballot with the other group.

Administrative Negatives

In order to ensure that a balloted change can be fully vetted according to the rules outlined above, one voting member of either AASHTO or ASTM, as applicable, will be assigned to place an administrative negative on the ballot item, if necessary. ~~The administrative negative is~~ ensures that even if no negatives are received on the ballot for one organization, ~~but negatives exist from the corresponding ballot of the other organization,~~ these negatives from the corresponding ballot from the other organization can be addressed by the Task Force and the change reballoted if necessary.

Prioritization

A running list of standards that fall into the defined scope of TFASH, as well as the AASHTO and ASTM subcommittees with jurisdiction of these standards, will be maintained by the Secretary. Priority ratings will be given to standards on the list, as assigned by TFASH members. The list will also serve as a record of work currently in progress and work already completed. The list will be reviewed at every meeting of the Task Force to determine if reprioritization of any standards is needed.

David Mensching	I take it that friends can provide their input to the prioritization but the assignment will ultimately fall on the members.
Jeff Withee	Will TFASH members also be tasked with gathering prioritization input from the respective ASTM or AASHTO subcommittees that they work with? The broader membership of those subcommittees likely has good insight into which standards differences are causing the most challenges, duplicative efforts, etc.

Frequency of Meetings

The TFASH will hold web meetings every other month in January, March, May, July, September, and November. The date and time of the next meeting will be discussed at the conclusion of each meeting. The Secretary will send a poll to the members with possible dates and times subsequent to each meeting, as necessary. A meeting invitation will be sent to all Members and Friends once scheduled. Additional web meetings will be scheduled as deemed necessary by TFASH members.

Lyndi Blackburn	Suggest quarterly- scheduling additional meetings is always doable but I think you will scare folks off if you start at every other month.
-----------------	--

Amendment

This Charter will be revised as necessary to ensure that it continues to meet the needs of the TFASH. Changes to the Charter must be approved by consensus of all current members.

Version History

Table 2: Version History of Charter Document

Version	Date	Author	Rationale
0.1	February 26, 2019	Maria Knake	First Draft
0.2	April 29, 2019	Maria Knake	Update with Comments from Members and Friends

AASHTO Designation	ASTM Designation	AASHTO Subcommittee	ASTM Subcommittee	Title	Ownership (Co-Owned or Individually Owned)
T 312	D6925	2d	D04.20	Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor	Individually Owned
T 312	D6925	2d	D04.20	Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor	Individually Owned
T 312	D6925	2d	D04.20	Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor	Individually Owned
T 166	D2726	2c	D04.21	Bulk Specific Gravity (Gmb) of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens	Individually Owned
T 209	D2031	2c	D04.21	Theoretical Maximum Specific Gravity (Gmm) and Density of Hot Mix Asphalt (HMA)	Individually Owned
R 66	D140	2a	D04.30	Sampling Asphalt Materials	Individually Owned
R 67	D5361	2c	D04.30	Sampling Asphalt Mixtures after Compaction (Obtaining Cores)	Individually Owned
T 168	D979	2c	D04.30	Sampling Bituminous Paving Mixtures	C-Standard
M 226	D3381	2b	D04.40	Viscosity-Graded Asphalt Cement	Individually Owned
M 320	D6373	2b	D04.40	Performance-Graded Asphalt Binder	Individually Owned
M 320	D6373	2b	D04.40	Performance-Graded Asphalt Binder	Individually Owned
M 320	D6373	2b	D04.40	Performance-Graded Asphalt Binder	Individually Owned
M 332	D8239	2b	D04.40	Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test	Individually Owned
M 332	D8239	2b	D04.40	Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test	Individually Owned
M 81	D2028	2a	D04.40	Cutback Asphalt (Rapid-Curing Type)	Individually Owned
M 82	D2027	2a	D04.40	Cutback Asphalt (Medium-Curing Type)	Individually Owned

R 49	D6816	2b	D04.44	Determination of Low-Temperature Performance Grade (PG) of Asphalt Binders	N/A
T 201	D2170	2b	D04.44	Kinematic Viscosity of Asphalts (Bitumens)	C-Standard
T 202	D2171	2b	D04.44	Viscosity of Asphalts by Vacuum Capillary Viscometer	C-Standard
T 301	D6084	2a	D04.44	Elastic Recovery Test of Asphalt Materials by Means of a Ductilometer	Individually Owned
T 313	D6648	2b	D04.44	Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)	Individually Owned
T 314	D6723	2b	D04.44	Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)	Individually Owned
T315	D7175	2b	D04.44	Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)	Individually Owned
T 315	D7175	2b	D04.44	Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)	Individually Owned
T 350	D7405	2b	D04.44	Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)	Individually Owned
T 49	D5	2b	D04.44	Penetration of Bituminous Materials	C-Standard
T 50	D139	2a	D04.44	Float Test for Bituminous Materials	C-Standard
T 51	D113	2b	D04.44	Ductility of Asphalt Materials	C-Standard
R 28	D6521	2b	D04.46	Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)	Individually Owned
T 179	D1754	2b	D04.46	Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)	Jointly Owned
T 240	D2872	2b	D04.46	Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)	Jointly Owned
T 78	D402	2a	D04.46	Distillation of Cutback Asphalt Products	Individually Owned
T 228	D70	2b	D04.47	Specific Gravity of Semi-Solid Asphalt Materials	C-Standard
T 295	D3142	2a	D04.47	Specific Gravity or API Gravity of Liquid Asphalts by Hydrometer Method	Jointly Owned
T 44	D2042	2b	D04.47	Solubility of Bituminous Materials	Jointly Owned

T 44	D2042	2b	D04.47	Solubility of Bituminous Materials	Jointly Owned
T 79	D3143	2a	D04.47	Flash Point with Tag Open-Cup Apparatus for Use with Material Having a Flash Point Less Than 93°C (200°F)	Individually Owned
T 316	D4402	2b	D08.03	Viscosity Determination of Asphalt Binder Using Rotational Viscometer	Individually Owned
T 53	D36	2b	D08.03	Softening Point of Bitumen (Ring-and-Ball Apparatus)	C-Standard

Bob's Priority	Suggested By	Member/Friend Comments
	Becky McDaniel	Widely Used
	David Mensching	Commonly Used Standard
	Maria Knake	Commonly Used
	Becky McDaniel	Widely Used
	Becky McDaniel	Widely Used
	David Mensching	Commonly Used Standard
	David Mensching	Commonly Used Standard
	David Mensching	Commonly Used Standard
4	Bob Kluttz	Not that commonly used in US paving
1	Bob Kluttz	Ready!
	David Mensching	Commonly Used Standard
	Maria Knake	Commonly Used Standard used for purchasing/selling, would have positive impact on industry to harmonize
1	Bob Kluttz	Ready!
	Maria Knake	Commonly Used Standard used for purchasing/selling, would have positive impact on industry to harmonize
4	Bob Kluttz	Low interest for me.
4	Bob Kluttz	Low interest for me.

4	Bob Kluttz	Standard not in common use
4	Bob Kluttz	Standard not in common use
4	Bob Kluttz	Standard not in common use
2	Bob Kluttz	Harmonizing would be really valueable as states are split on which standard they reference
3	Bob Kluttz	Huge standard, still being worked in ASTM, big project
4	Bob Kluttz	Standard not in common use
	Maria Knake	Arguably the most important test in PG testing.
3	Bob Kluttz	Huge standard, big project
2	Bob Kluttz	Priority for me, as we're also trying to harmonize with Eurobitume
4	Bob Kluttz	Standard in the middle of revision
4	Bob Kluttz	Low interest for me.
4	Bob Kluttz	Standard not in common use
3	Bob Kluttz	Still being worked in ASTM
4	Bob Kluttz	Standard not in common use
3	Bob Kluttz	Still being worked in ASTM
4	Bob Kluttz	Low interest for me.
4	Bob Kluttz	Low interest for me.
4	Bob Kluttz	Low interest for me.
3	Bob Kluttz	Standard in the middle of ASTM project to add toluene as solvent.

	Maria Knake	There has been a lot of discussion regarding this standard from AASHTO members and other industry reps, harmonization would be good for all users. ASTM version recently revised, on-going work on new solvents.
4	Bob Kluttz	Low interest for me.
3	Bob Kluttz	Standard needs work before harmonizing. Need to add shear rate report in lieu of spindle.
4	Bob Kluttz	Not that commonly used in US paving

Comments
R 92 contains information on determining elastic behavior, was removed from M332

The ASTM version of this standard is owned by the Roofing and Waterproofing Committee
The ASTM version of this standard is owned by the Roofing and Waterproofing Committee

AASHTO COMP SUBCOMMITTEES	
Subcommittee	Chair
2a Emulsified Asphalts	Brian Pfeifer
2b Liquid Asphalt	Lyndi Blackburn (soon to be Joe DeVol)
2c Asphalt-Aggregate Mixtures	Allen Myers
2d Asphalt-Aggregate Mixtures	Oak Metcalfe

ASTM COMMITTEE D04 SUBCOMMITTEES	
Subcommittee	Chair
D04.20 Mechanical Tests of Asphalt Mixtures	Richard Steger
D04.21 Specific Gravity and Density of Asphalt Mixtures	Dick Reaves
D04.22 Effect of Water and Other Elements on Asphalt Coated Aggregates	Brian Johnson
D04.23 Plant-Mixed Asphalt Surfaces and Bases	Kent Hansen
D04.24 Asphalt Surface Treatments	Guy Sisler
D04.25 Analysis of Asphalt Mixtures	Mohammad Louay
D04.26 Fundamental/Mechanistic Tests	Phil Blankenship
D04.27 Cold Mix Asphalts	Michael Pemberton
D04.30 Methods of Sampling	Terry Taulbee
D04.31 Calcium and Sodium Chlorides and Other Deicing Materials	Wilfrid Nixon
D04.32 Bridges and Structures	Ronald Watson
D04.33 Formed In-Place Sealants for Joints and Cracks in Pavements	Delmar Saloman
D04.34 Preformed Joint Fillers, Sealers and Sealing Systems	Ronald Watson
D04.38 Highway Traffic Control Materials	Jason Davis
D04.40 Asphalt Specifications	Bob Kluttz
D04.41 Emulsified Asphalt Specifications	Zineb Hafassa
D04.42 Emulsified Asphalt Test	Marla Kilburg
D04.43 Specifications and Test for Tar and Tar Products	Michael Goeller
D04.44 Rheological Tests	Amir Golalipour
D04.46 Durability and Distillation Tests	Kevin Hardin
D04.47 Miscellaneous Asphalt Tests	Felicia Reid (soon to be Payman Pirzadeh)
D04.50 Aggregate Specifications	Scott Woodard
D04.51 Aggregate Tests	Cecil Jones
D04.91 Terminology	Maria Knake
D04.93 Strategic Planning	Frank Fee
D04.94 Statistical Procedures and Evaluation of Data	Erv Dukatz
D04.95 Quality Control, Inspection and Testing Agencies	Dave Savage
D04.99 Sustainable Asphalt Pavement Materials and Construction	John Yzenas (soon to be Kelly Cook)

Vice Chair
Scott Nussbaum
Barry Paye
Rick Bradbury
Greg Milburn

Vice Chair
None
None
Andrew Laxroix
Frank Fee
John Malusky
Ali Regimand
Jason Bausano
Glenn Heilman
Brian Johnson
None
None
Michael Guymon
None
Philip Lancaster
Maria Knake
John Malusky
Stephanie Richards
None
Scott Veglahn
Maria Knake
Todd Dobbs
Jennifer Hanley
Patrick Jacomet
John Malusky
Stu Schwotzer
Don Powell
Glenn Waite
Frank Fee

From: [Maria Knake](#)
To: [DeVol, Joe](#); [Barry Paye](#); [Blackburn, Lyndi](#)
Cc: [Doug Carlson](#)
Subject: PG Tire Rubber-Modified Asphalt Spec
Date: Monday, June 17, 2019 1:52:04 PM
Attachments: [image001.png](#)
[image002.png](#)
[image003.png](#)
[image004.png](#)

Joe, Barry, and Lyndi:

ASTM Subcommittee D04.40 has been working on a PG Tire Rubber-Modified Asphalt Specification. A question came up at the meeting as to whether AASHTO already has such a spec. I do not believe that one exists. It was suggested that perhaps ASTM and AASHTO can collaborate on creating of this specification. Especially given some of our recent discussions, it seems appropriate and timely to see if there are an TS 2b COMP members who might be interested in working on the ASTM task group. If anybody from 2b is interested, they can contact Doug Carlson. I have included Doug on this email. DCarlson@libertytire.com

I joined the task group on the ASTM side specifically with state's interests in mind. Let me know how I can assist.

-Maria

Maria Knake

Manager, Laboratory Assessment Program



Email: mknake@ashtoresource.org

Direct: 240-436-4804

Cell: 240-772-0031

Main: 240-436-4900

Website: www.ashtoresource.org

AASHTO re:source (formerly AMRL)

4441 Buckeystown Pike

Suite A

Frederick, MD 21704

30-Jan-19

STATE	AASHTO	TYPE	RECONFIRM REQUIRED	TITLE	NOTES	ASTM INDEX	LATEST ASTM
OK	M 226-80 (2017)	A	2021	Viscosity Graded Asphalt Cement			
GA	M 320-17	A	2021	Performance Graded Asphalt Binder	Former MP1 & MP1a.		D 3381-09a
FWHA	M 332-18	A	2022	Performance Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR)	Former MP 19		D 6373-07e1
IN	R 15-00 (2017)	A	2021	Asphalt Additives and Modifiers			
CT	R 26-01 (2018)	A	2022	Certifying Suppliers of Performance Graded Asphalt Binders	Former PP26. Task Force to review and update.??		
CO	R 28-12 (2016)	A	2020	Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel	Former PP1.		D 6521-08
AZ	R 29-15	A	2019	Grading or Verifying the Performance Grade of an Asphalt Binder	Former PP6.		
TN	R 49-09 (2018)	A	2022	Determination of Low-Temperature Performance Grade (PG) of Asphalt Binders	Former PP 42 (Original adoption 2001.)		D 6816-02 (withdrawn)
FWHA	R 92-18	A	2022	Evaluating the Elastic Behavior of Asphalt Binders Using the MSCR Test	Former Appendix of M332		
HI	T 44-14 (2018)	B	2022	Solubility of Bituminous Materials	NH will look at update. ASTM is also looking to revise.	D 2042-01*	D 2042-09
WI	T 48-18	A	2022	Flash and Fire Points by Cleveland Open Cup	COMP Ballot 2017 to an "A" standard.	D 92-05a*	D 92-05a(2010)
IL	T 49-15	C	2019	Penetration of Bituminous Materials	Consider rewriting as an "A" standard.	D 5-06e1*	D 5-06e1
KS	T 51-09 (2018)	C	2022	Ductility of Bituminous Materials	Consider rewriting as an "A" standard based on T 300.	D 113-07*	D 113-07
ME	T 53-09 (2018)	C	2022	Softening Point of Bitumen (Ring-and-Ball)		D 36-06*	D 36-09
LA	T 102-09 (2018)	A	2022	Spot Test of Asphaltic Materials			
NH	T 111-11 (2015)	A	2019	Inorganic Matter or Ash in Bituminous Materials			
RI	T 179-05 (2018)	B	2022	Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)		D 1754-97(2002)	D 1754-09
VA	T 201-15	C	2019	Kinematic Viscosity of Asphalts (Bitumens)	Consider rewriting as an "A" standard	D 2170-07*	D 2170-10
AR	T 202-15	C	2019	Viscosity of Asphalts by Vacuum Capillary	Consider rewriting as an "A" standard.	D 2171-07*	D 2171-10
ID	T 228-09 (2018)	C	2022	Specific Gravity of Semi-Solid Bituminous Materials	2 pages of exceptions most have been incorporated into D70. Waiting to see if ASTM will incorporate all of the exceptions - Maria	D 70-08*	D 70-09e1
UT	T 240-13 (2017)	B	2021	Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)		D 2872-04*	D 2872-04
WV	T 313-12 (2016)	A	2020	Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)	Former TP1.		D 6648-08
MA	T 314-12 (2016)	A	2020	Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)	Former TP3.		D 6723-02 (withdrawn)
MD	T 315-12 (2016)	A	2020	Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)	Former TP5.		D 7175-08
NV	T 316-13 (2017)	A	2021	Viscosity Determination of Asphalt Binder Using Rotational Viscometer	Former TP48.		D 4402-06
SC	T 350-14 (2018)	A	2022	Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)	Former TP 70		D 7405-08a
KY	T 377-17	A	2021	Detecting the Presence of Phosphorus in Asphalt Binder	First published in 2009 - Concurrent Ballot 2016 to Full Standard- Former TP 78-09 (2013)		
TX/IL	T 383-18	A	2022	Evaluation of Asphalt Release Agents	First published in 2012 - Balloted to Full Standard 2017 - Former TP 102-12 (2015)		
OH	TP 92-14 (2018)	A	2019	Determining the Cracking Temperatures of Asphalt Binder Using the Asphalt Binder Cracking Device (ABCD)	First published in 2011-Balloted to Full Standard 2018 - to be published 2019 Former TP 92-14 (2018)		
	TP 101-12 (2018)	A	2019	Estimating Fatigue Resistance of Asphalt Binders Using the Linear Amplitude Sweep			
	TP 113-15	A	2017	Determination of Asphalt Binder Resistance to Ductile Failure Using Double-Edge-Notched Tension (DENT) Test	First published in 2012 -		
	TP 122-16 (2018)	A	2020	Determination of Performance Grade of Physically Aged Asphalt Binder Using Extended Bending Beam Rheometer	First published in 2015		
	TP 123-16 (2018)	A	2020	Measuring Asphalt Binder Yield Energy and Elastic Recovery Using the Dynamic Shear Rheometer	First published in 2016		
FL	TP 127-17	A	2019	Determining the Fracture Energy and Elastic Recovery Using the Dynamic Shear Rheometer	First published in 2016		
TX	MP 38-2018	A	2020	Performance Graded Asphalt Binder for Surface Treatments	First published in 2017		
					First published in 2018		

The following states are not assigned any standards:

DC NY
MT NM
NJ VT
AL

Eliminated Standards

	M 20-70 (2004)	A	2008	Penetration Graded Asphalt Cement	Deleted Nov. 2008		D 946-82(1999)
	T 47-98 (2002)	C	2006	Loss on Heating of Oil and Asphaltic Compounds	Deleted Nov. 2003	D 6-95 (2000)*	D 6-95 (2000)
	T 72-97 (2001)	C	2005	Saybolt Viscosity	Reassigned to ts 2a.	D 88-94 (1999)*	D 88-94 (1999)*
	T 73-03	C	2007	Flash Point by Pensky-Martens Closed Tester	Deleted Nov. 2003	D 93-02a	D 93-02a
	T 79-96 (2000)	A	2004	Flash Point with Tag Open-Cup Apparatus for Use with Material Having a Flash Less Than 93.3°C (200°F)	Reassigned to ts 2a.		
	T 229-97 (2000)	C	2004	Density of Solid Pitch and Asphalt (Displacement Method)	Deleted Nov. 2003	D 71-94 (1999)*	D 71-94 (1999)*
	MP 1a-04	A	Ext. 2005	Performance Graded Asphalt Binder	Deleted by SOM Ballot November 2004. Incorporated into M 320 as Table 2.		