The National Academies of
SCIENCES · ENGINEERING · MEDICINE

TRANSPORTATION RESEARCH BOARD

TRB Webinar: Innovations in Testing—Modified Binders Cracking Resistance

May 25, 2022

2:30- 4:00 PM Eastern

@NASEMTRB
#TRBwebinar

PDH Certification Information:

- 1.5 Professional Development Hours (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
- Questions? trbwebinar@nas.edu

#TRBwebinar

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

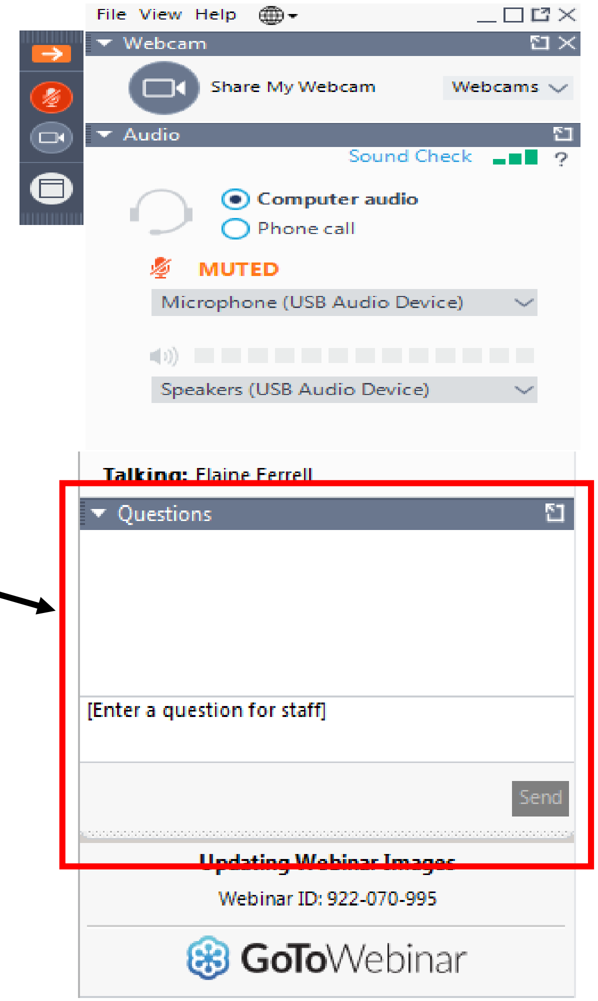
REGISTERED CONTINUING EDUCATION PROGRAM

Learning Objectives

- Use and apply emerging intermediate temperature tests to characterize the benefits of modified binders using existing laboratory equipment

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



#TRBwebinar

Dr. Amy Epps Martin
a-eppsmartin@tamu.edu

Dr. Ramez M. Hajj
rhajj@illinois.edu

Dr. Nazimuddin Wasiuddin
wasi@latech.edu

Dr. Enad Mahmoud
enad.mahmoud@txdot.

A new ductility test for asphalt binders considering a realistic triaxial stress state

Ramez Hajj, Ph.D.

Assistant Professor

University of Illinois at Urbana-Champaign

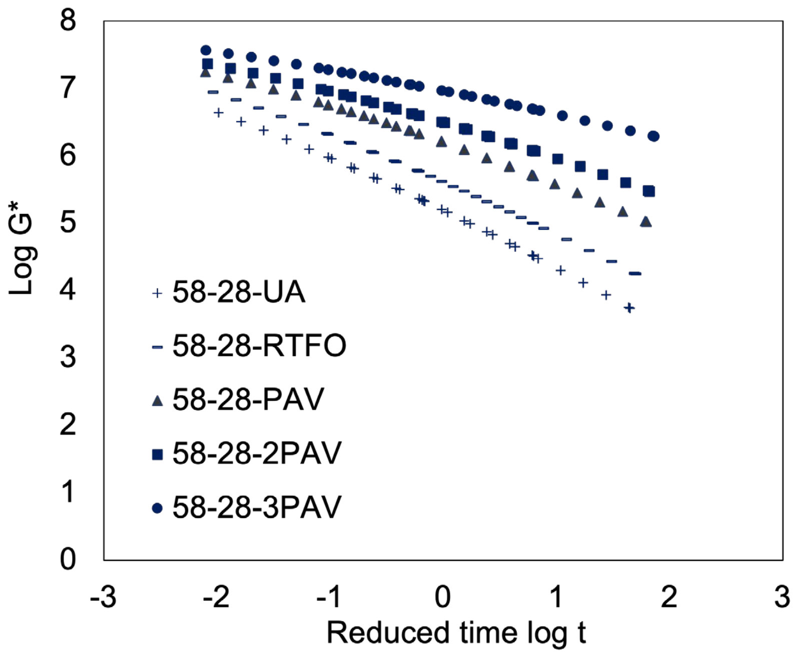
TRB Webinar 05/25/2022

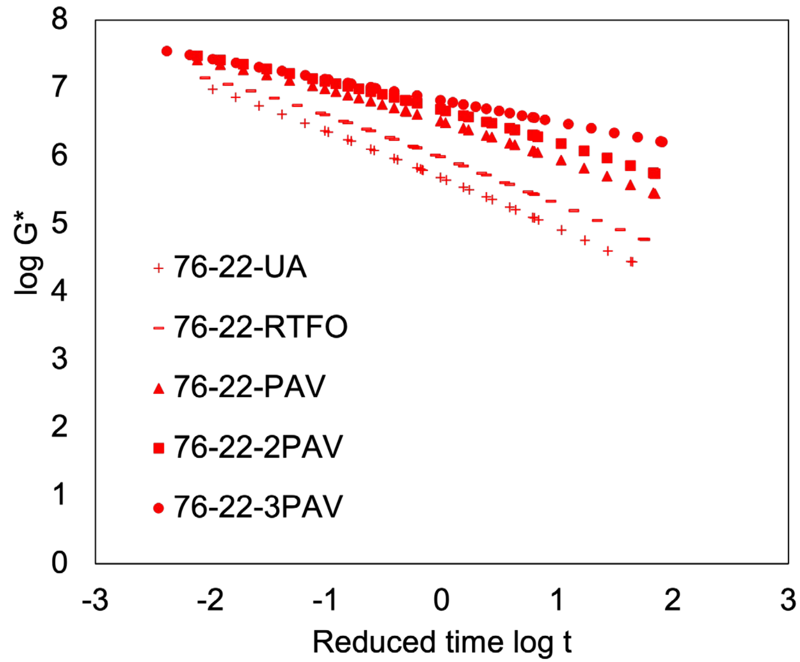
Disclaimer

- This presentation represents my views only; not the views of any sponsor or agency.

What we know

- Aging increases stiffness; modification often does too



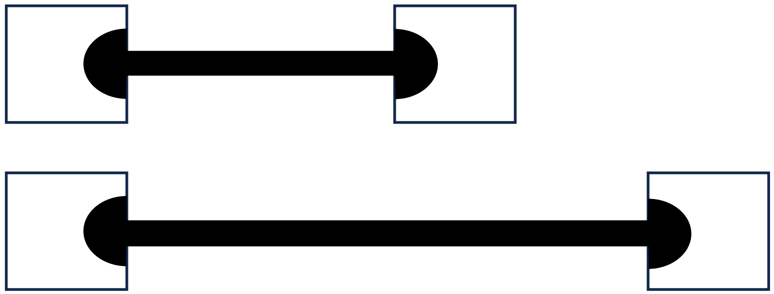


Polymer-modified asphalt cracking

- **Why do LVE cracking indicators not hold up for polymer modified asphalt?**
  - Block copolymers have a fundamentally different deformation mechanism
  - Polymer generally increases stiffness – can muddle LVE properties
  - Original studies linking binder ductility to asphalt field cracking are from the 1950s! This does not apply to today's binders.
  - We are using only linear viscoelastic behavior to link to nonlinear phenomena. We use MSCR at high temperature to predict plastic deformation for this reason.

The “old” ductility test

- Issues first noted by Saal (1955)
  - Large temperature rise during stretching and thixotropic effects from structural breakdown cast doubt on test’s significance
- Later, Tabatabaee et al. (2013) observed lack of correlation with cracking and issues capturing ductility of polymer-modified asphalt.

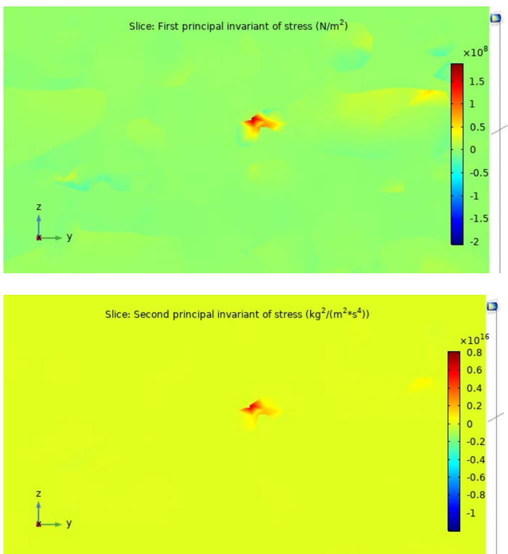


Importance of triaxiality

$$\text{Triaxiality} = \frac{\text{Hydrostatic Stress}}{\text{Von Mises Stress}}$$

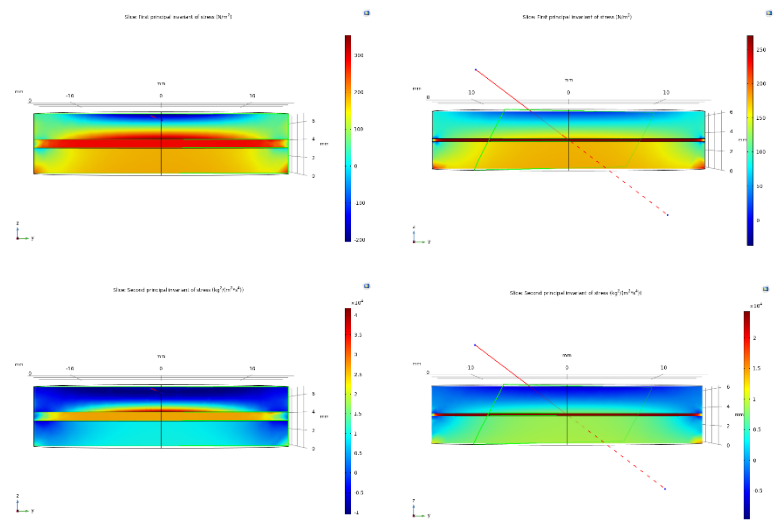
- Concept explored on and off for asphalt materials over the years
- Higher triaxiality leads to more brittle failure
- Observed in composites, etc. at interfaces between inclusions
- Review of polymer literature indicates that ductility tests <u>cannot</u> be considered accurate without considering stress state

Stress state observed in asphalt mixes



Aspect Ratio = 15

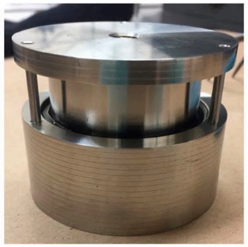
Aspect Ratio = 50

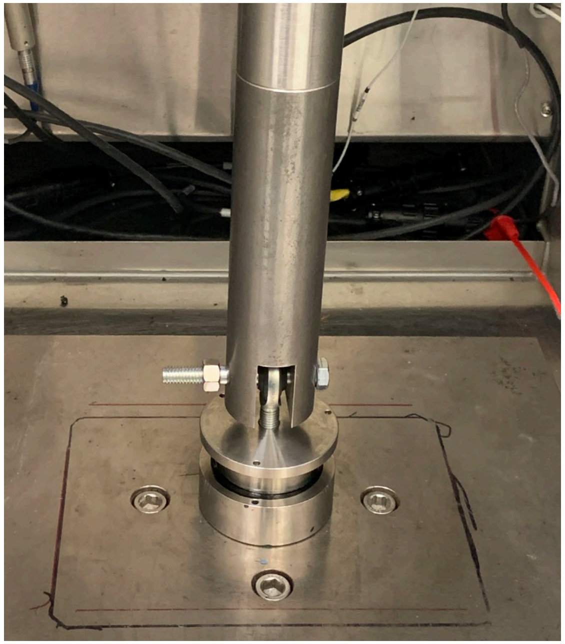


Alternative for ductility testing

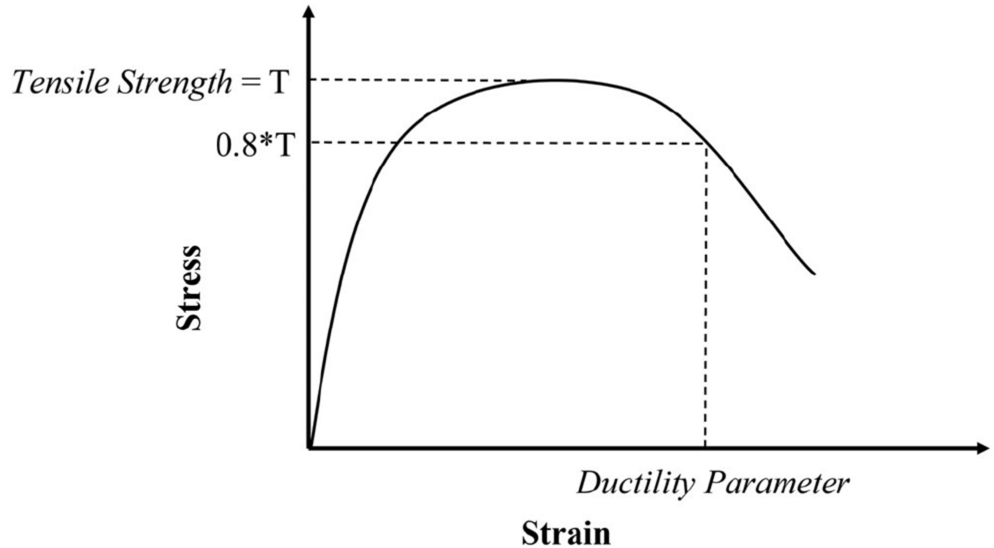
- Poker chip test



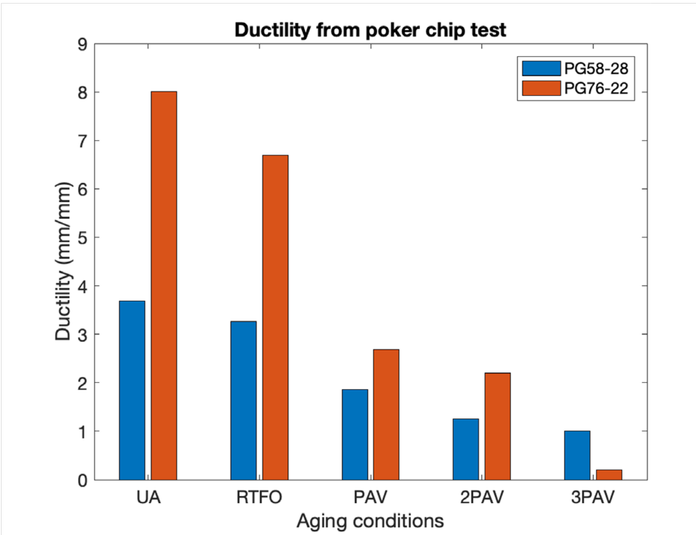




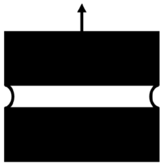
Typical Test Result



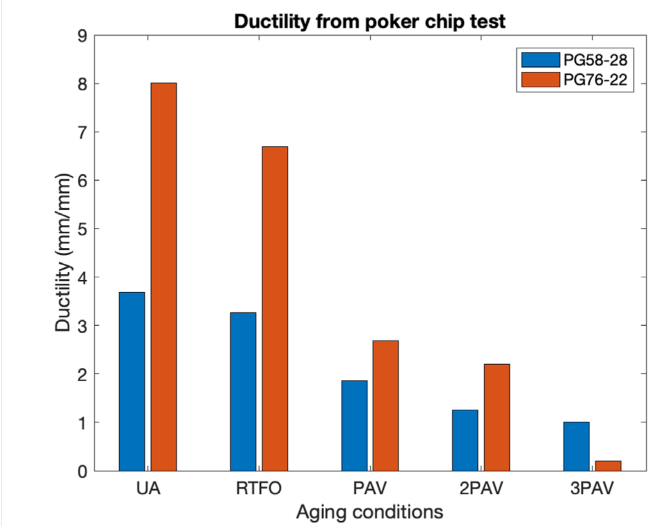
Modified vs. Unmodified



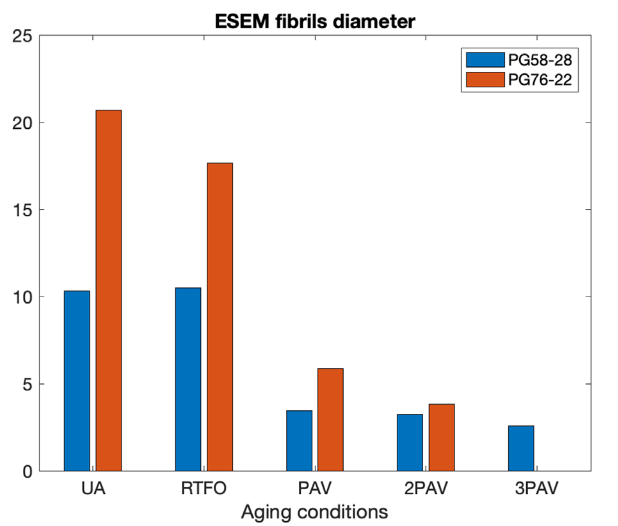
(a)



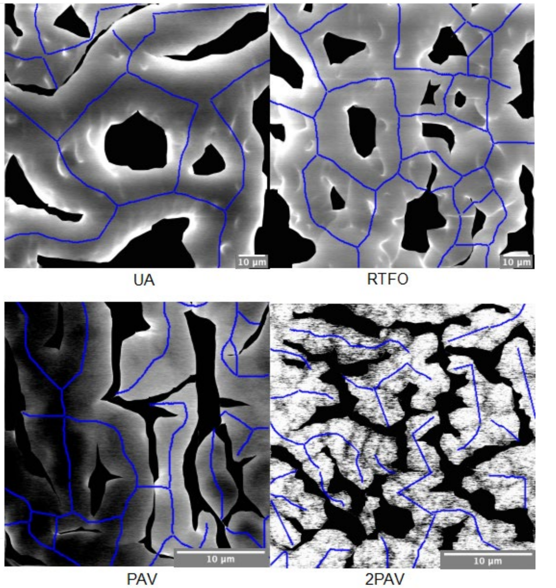
Modified vs. Unmodified



(a)

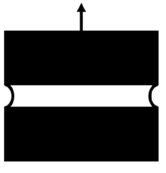


(b)



UA RTFO

PAV 2PAV

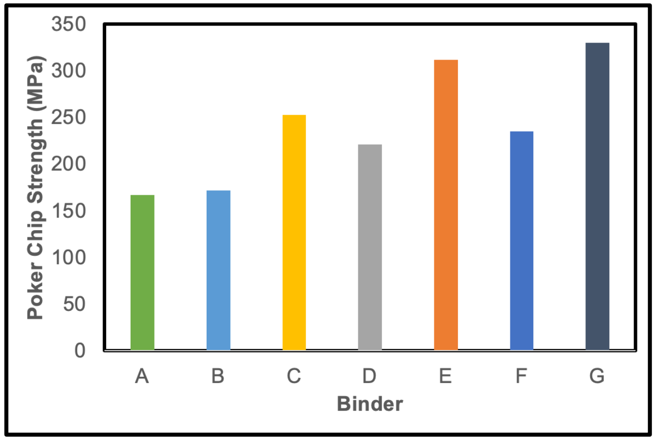


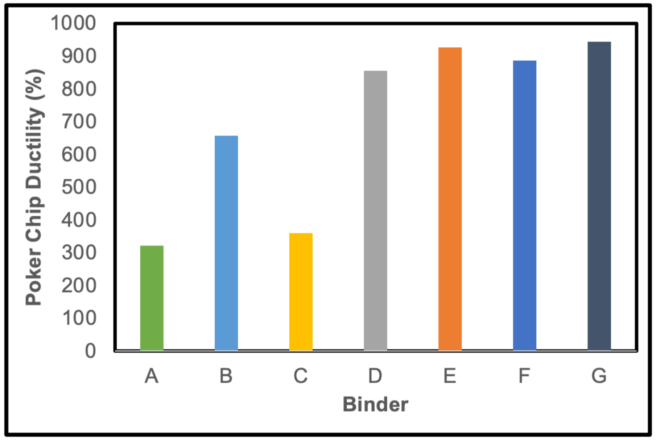
Another Example

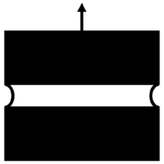
UTI ≥ 92 → Modified	
Symbol	Grade
A	PG 58-28
B	PG 64-28
C	PG 64-22
D	PG 70-28
E	PG 70-22
F	PG 76-28
G	PG 76-22

Another Example

UTI ≥ 92 → Modified	
Symbol	Grade
A	PG 58-28
B	PG 64-28
C	PG 64-22
D	PG 70-28
E	PG 70-22
F	PG 76-28
G	PG 76-22

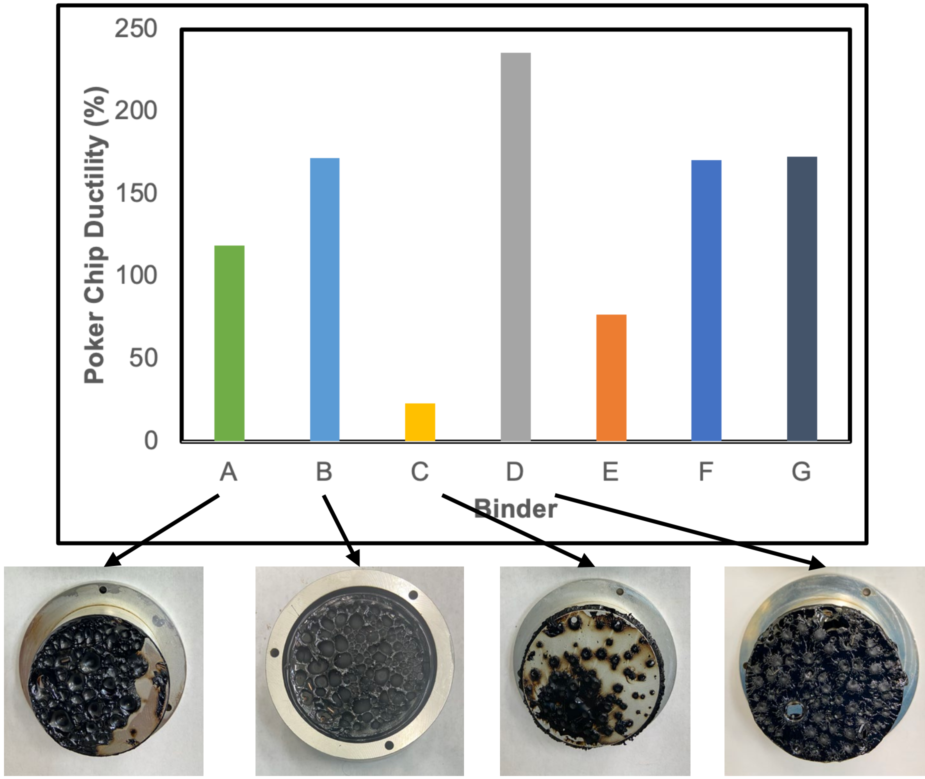






Low Temperature

UTI ≥ 92 → Modified	
Symbol	Grade
A	PG 58-28
B	PG 64-28
C	PG 64-22
D	PG 70-28
E	PG 70-22
F	PG 76-28
G	PG 76-22



However, PG is not always related

- Consider the same base binder, modified with two different polymers, same dosage (intermediate temp):

Binder 1 – PG 76-16

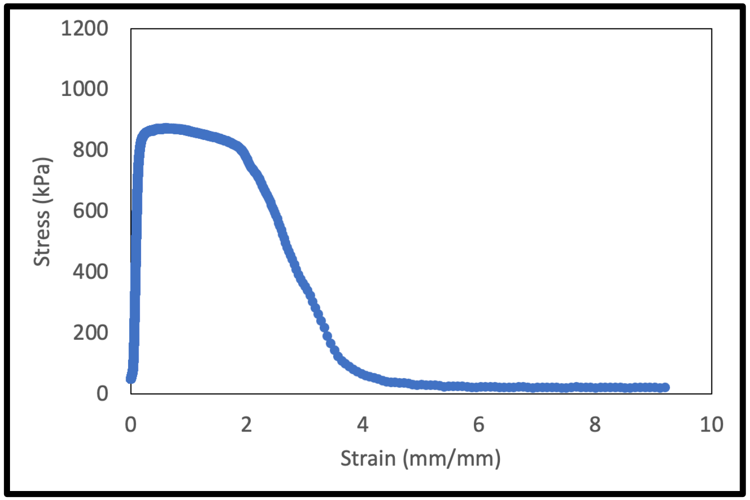
Binder 2 – PG 76-22

However, PG is <u>not</u> always related

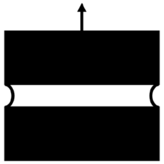
- Consider the same base binder, modified with two different polymers, same dosage (intermediate temp):

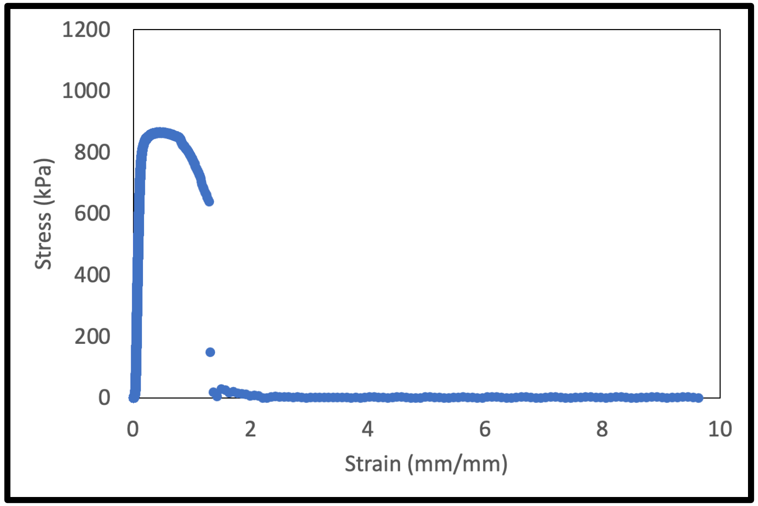
Binder 1 – PG 76-16

Binder 2 – PG 76-22



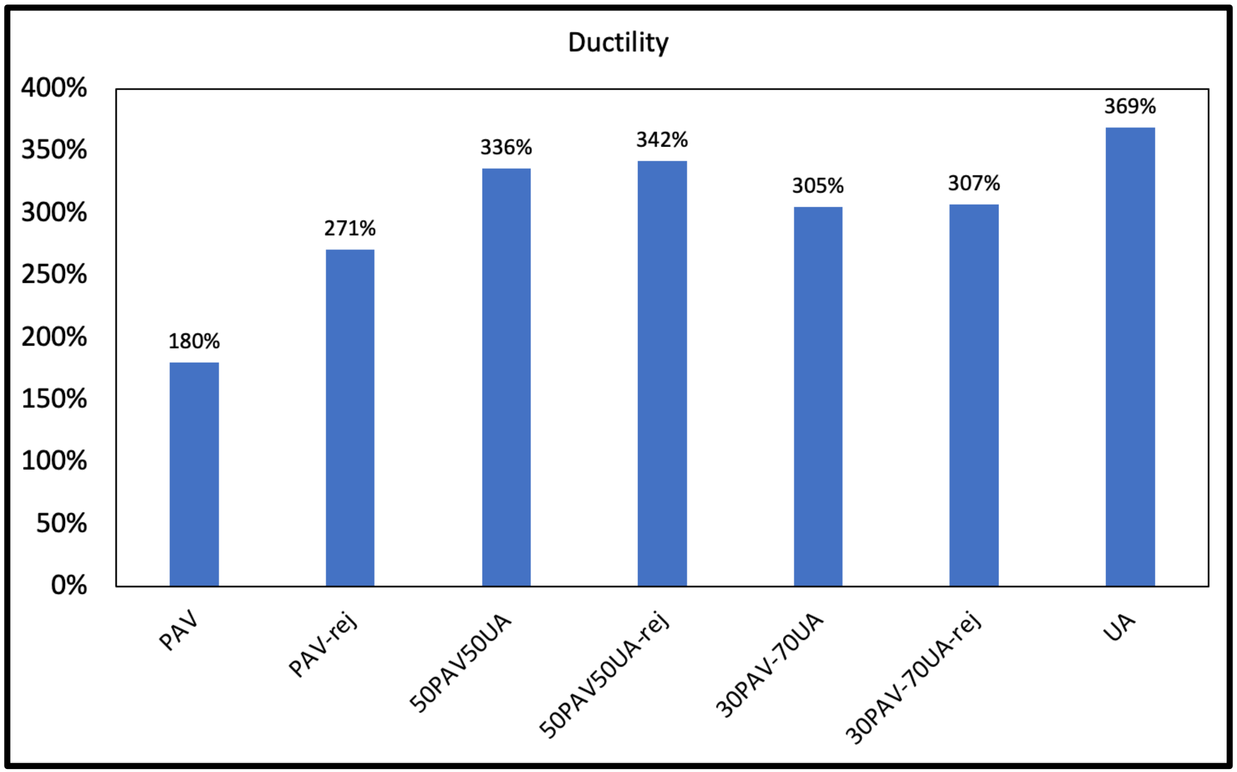
Average poker chip ductility = 297%

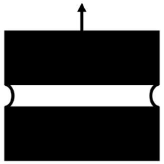




Average poker chip ductility = 115%

Effect of bio-oil rejuvenator





Conclusions

- Over the years, many LVE indicators have come and gone; aging is often used to justify them but fails to hold up for modified binders
- The traditional ductility test, and any test that does not consider stress state, are insufficient to characterize modified asphalt.
- Poker chip test is sensitive to a range of modifiers and is future proof due to its fundamental nature
- Poker chip test is easy to run, and data is easy to interpret

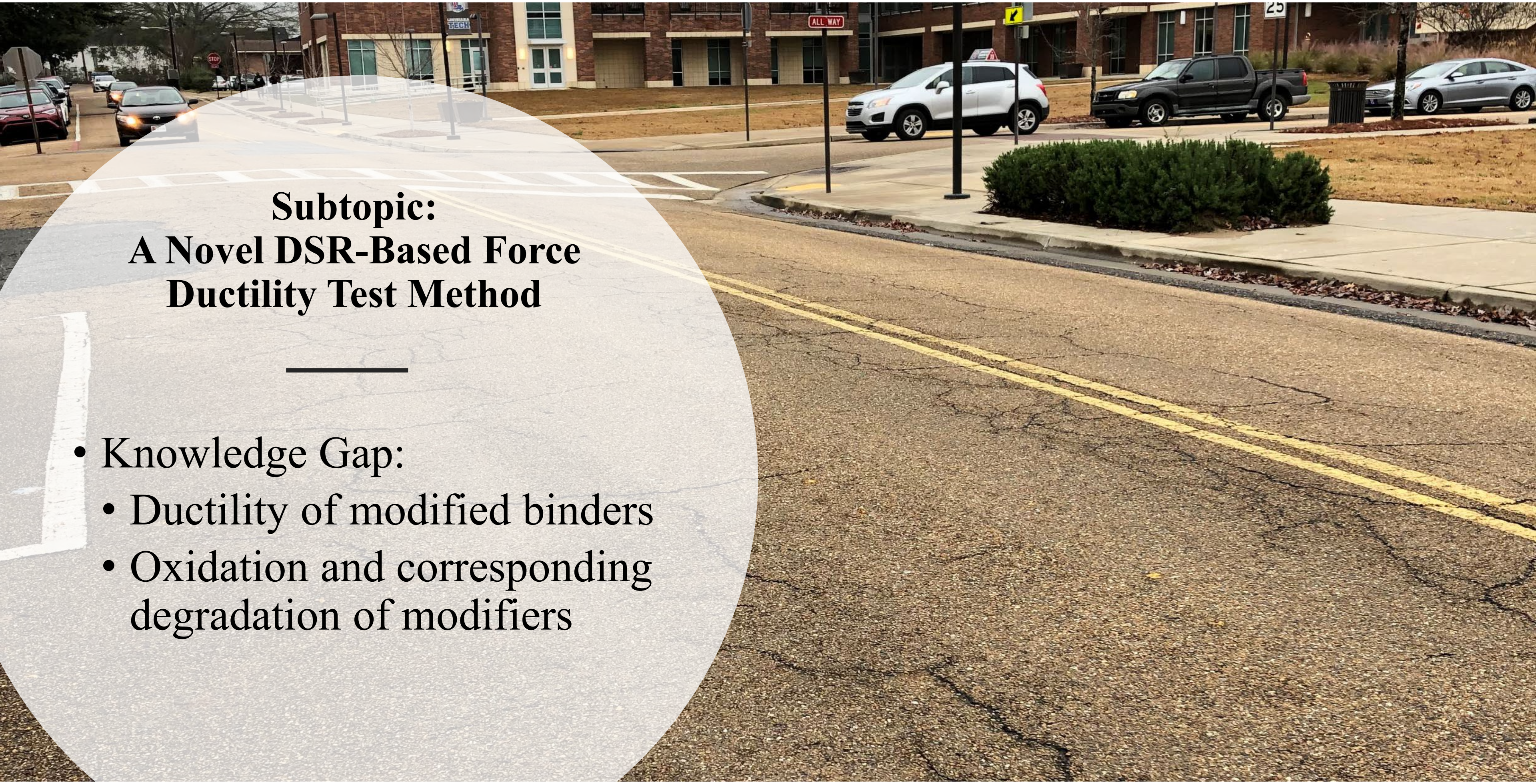
Acknowledgements

- Thank you to our sponsors- BASF SE and the Smart Transportation Infrastructure Initiative
- Thank you to my excellent students for their contributions- Yujia Lu, Renan Santos Maia, Babak Asadi, Abhilash Vyas, and Yudi Wang
- Thank you to Amit Bhasin and his research team for their contributions and continued collaboration

Questions?

TRB Webinar: Innovations in Testing—Modified Binders Cracking Resistance

N. “Wasi” Wasiuddin
Professor, Louisiana Tech University

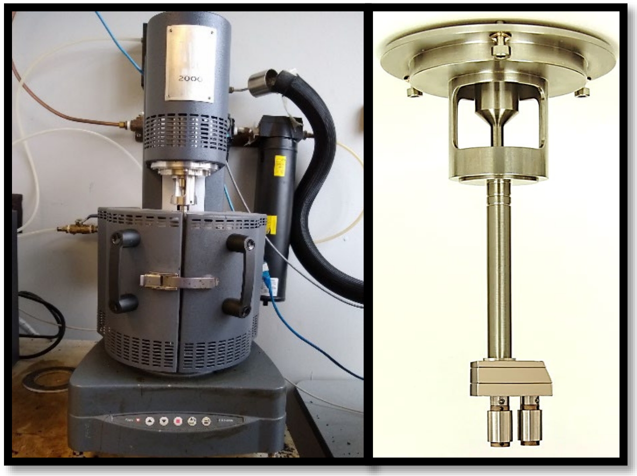


**Subtopic:
A Novel DSR-Based Force Ductility Test Method**

- Knowledge Gap:
  - Ductility of modified binders
  - Oxidation and corresponding degradation of modifiers

Advantages of using Sentmanat External Rheometer (SER) Fixture in DSR

- SER can be accommodated in currently used DSR models
- From one DSR mold sample more than 15 SER samples can be prepared
- Results more reflective of the material response
  - Length of the sample remains constant providing true strain
  - Cross sectional area of the sample is assumed not varying throughout the sample length proving true stress
- More precision and wider range in temperature and force



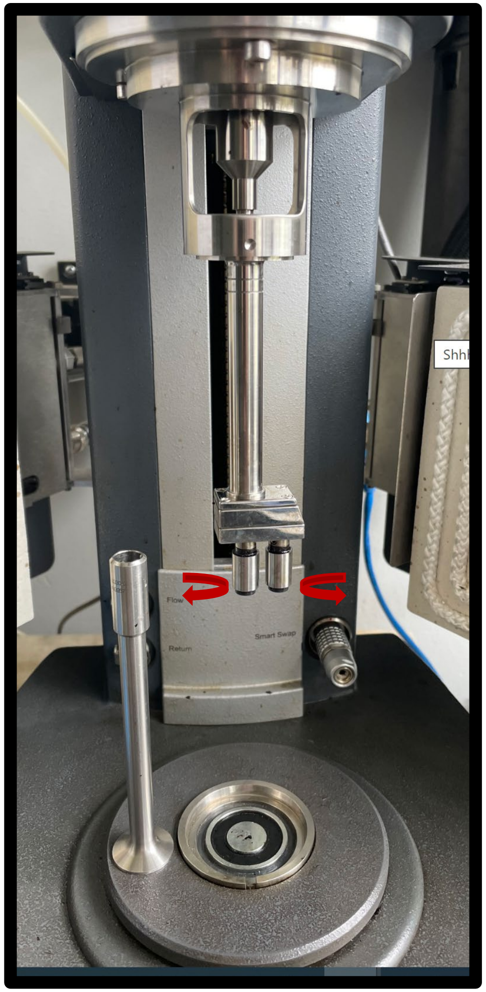
SER Fixture

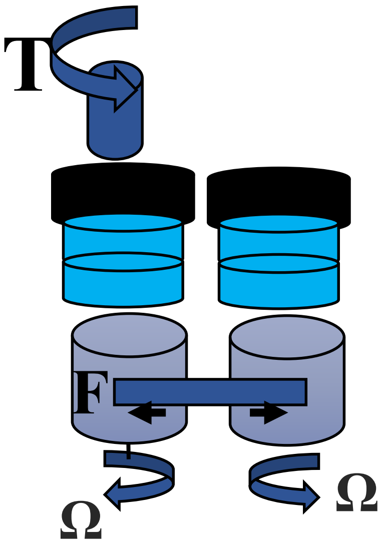
With This Test Method We Will:

- Compare the effectiveness of different types of modifications
- Investigate the F_2 value of stiffer binder due to aging
- Determine the degradation of modifiers due to aging
- Investigate the effect of UV aging on degradation of SBS

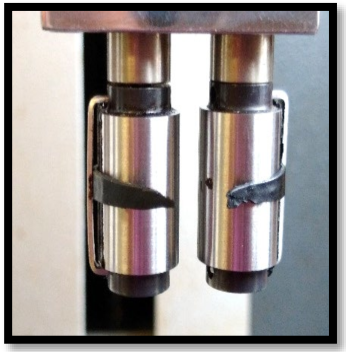
How It Works:

A Sentmanat Extensional Rheometer (SER) fixture was introduced for modified asphalt binder characterization





$L_o = 12.72\ mm$



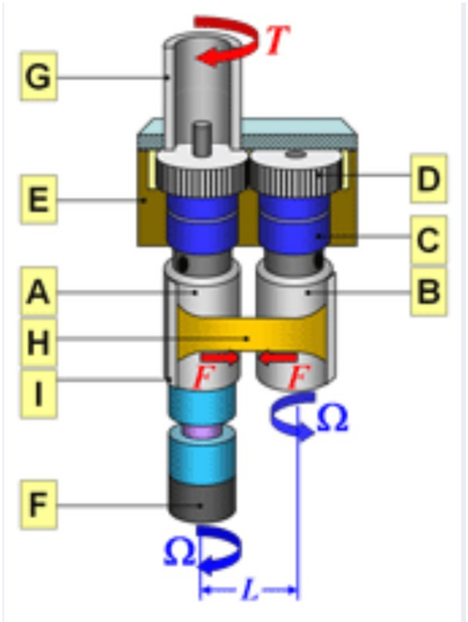
How It Works:

Hencky Strain Rate:

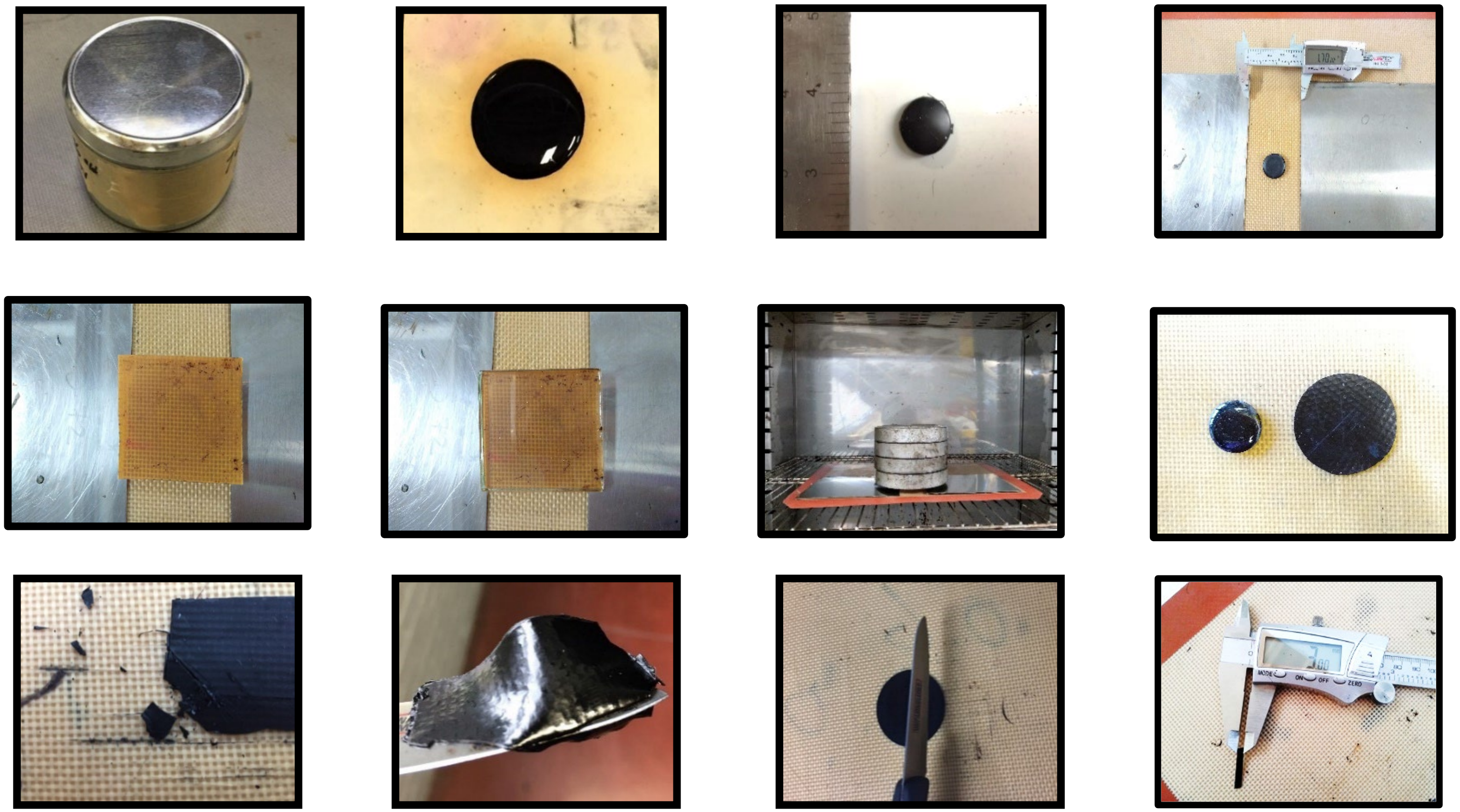
$$d\epsilon_H/dt = 2\ \Omega R/L_0$$

Instantaneous X-Sectional Area:

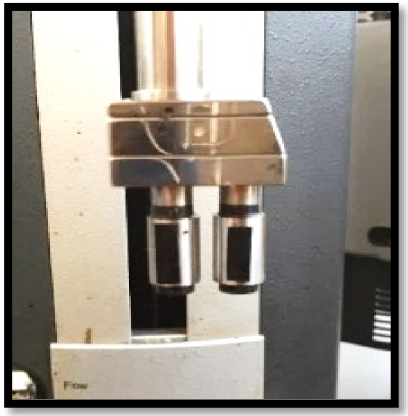
$$A(t) = A_0 \exp[-\ (d\epsilon_H/dt)\ t]$$

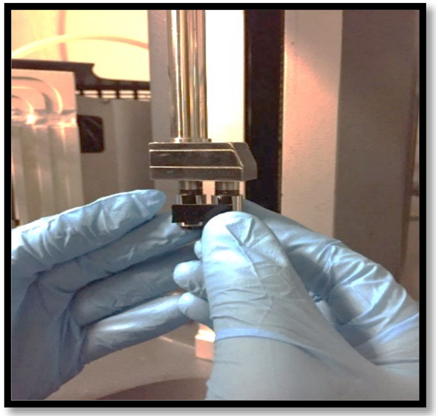


Sample Preparation:

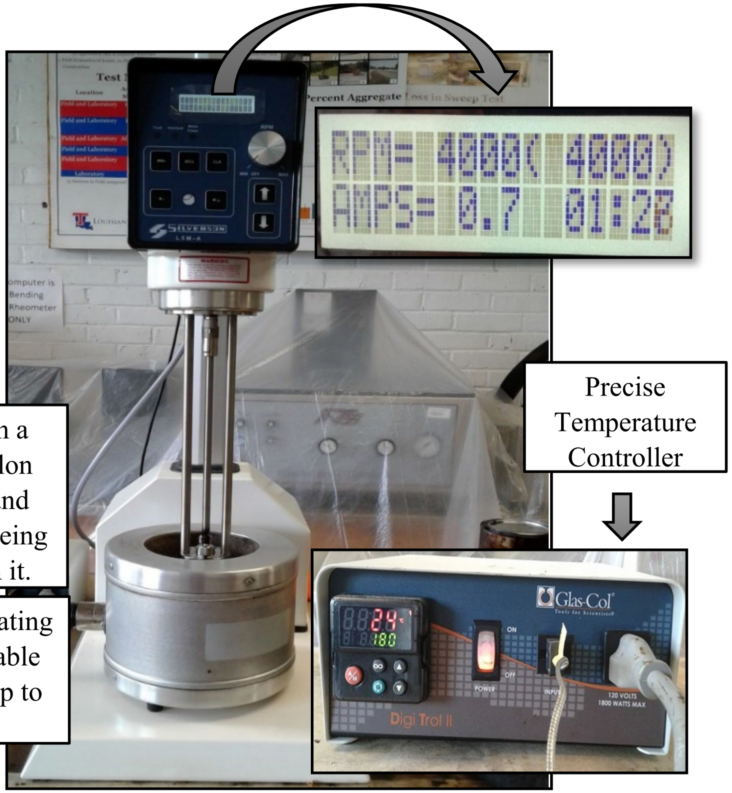


Sample Preparation:





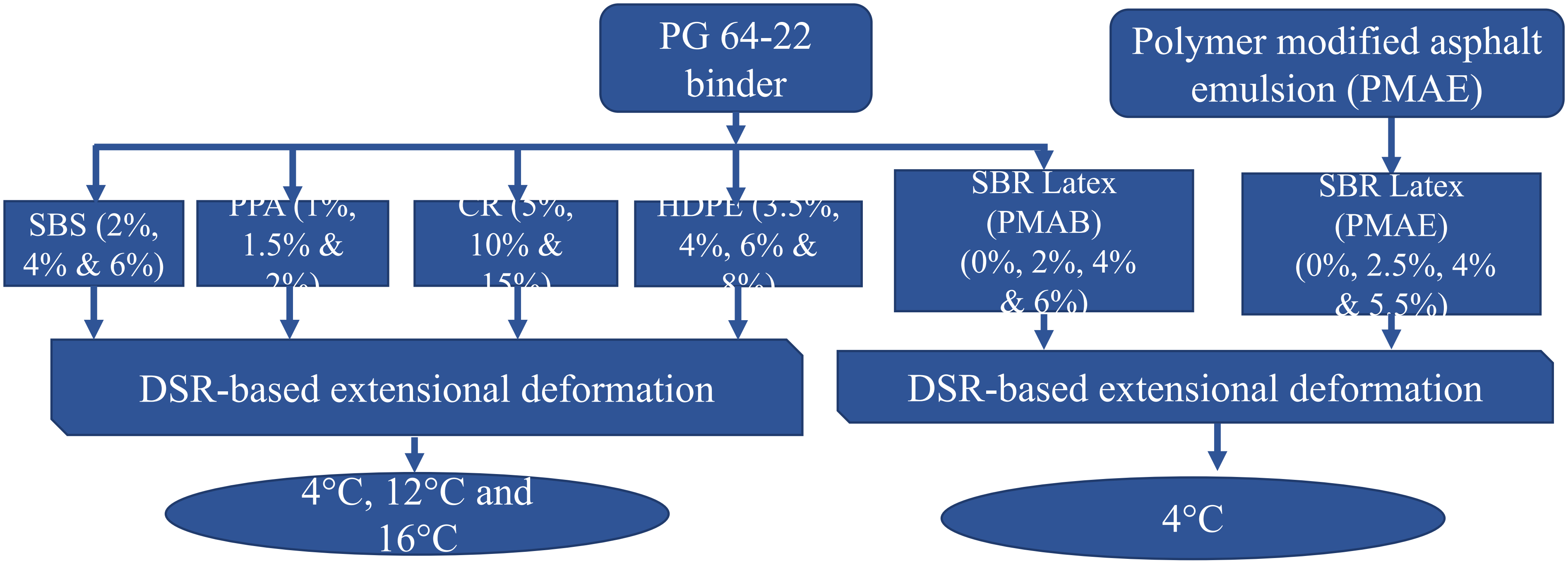
SBS Polymer



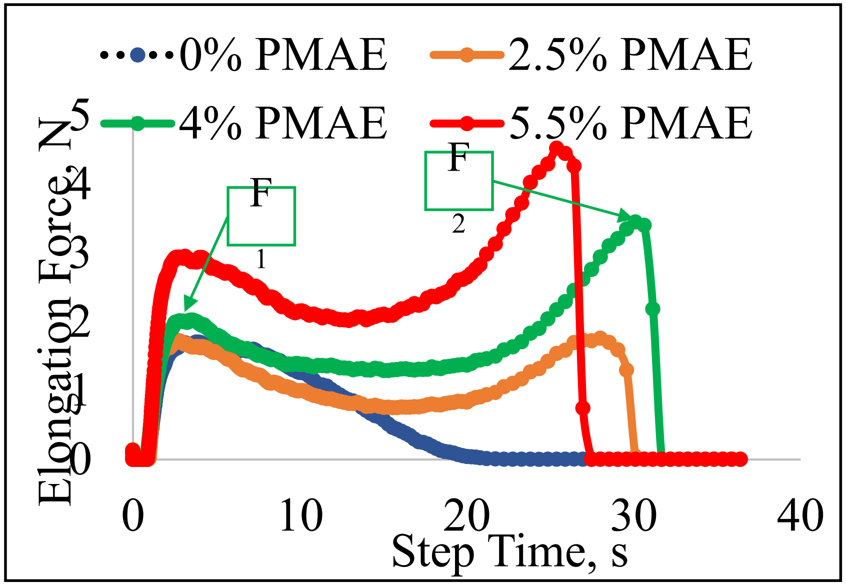
Mixing of SBS with asphalt binder by a hand drill

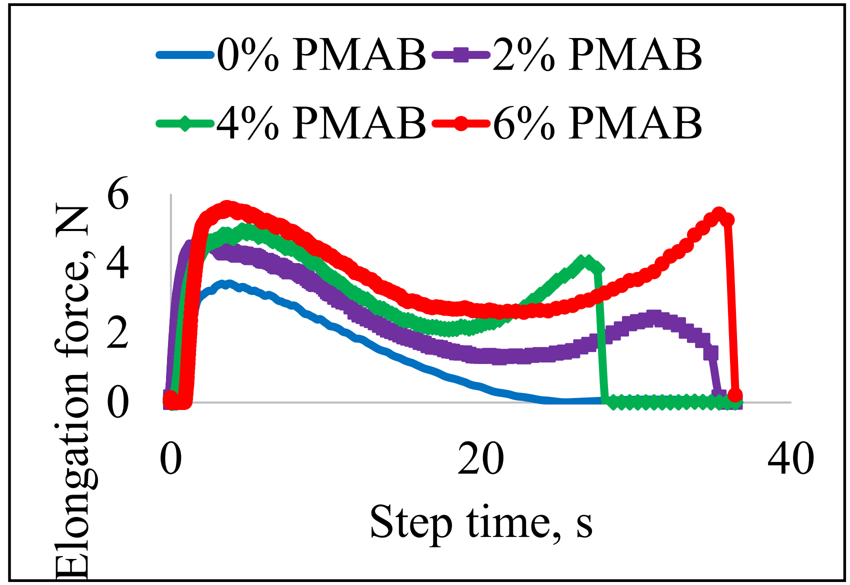
Mixing of Polymer with Binder by A High Shear Mixer

Test Factorial: Identification and Determination of Elastomeric Polymer Content

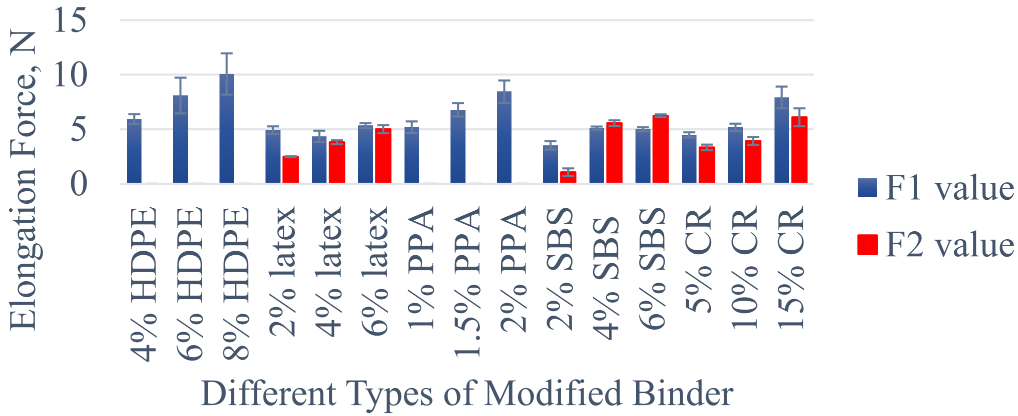


Elongation Force vs Step Time Curve Characterization

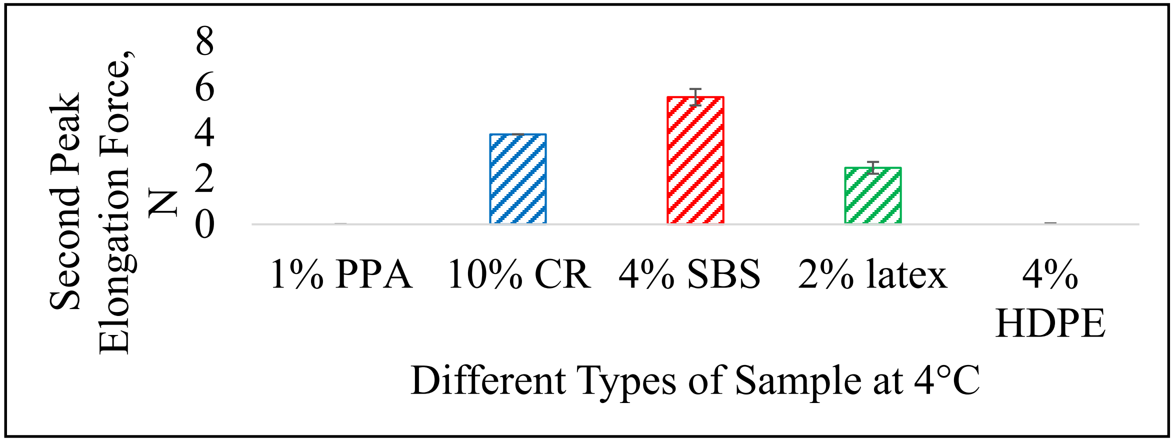




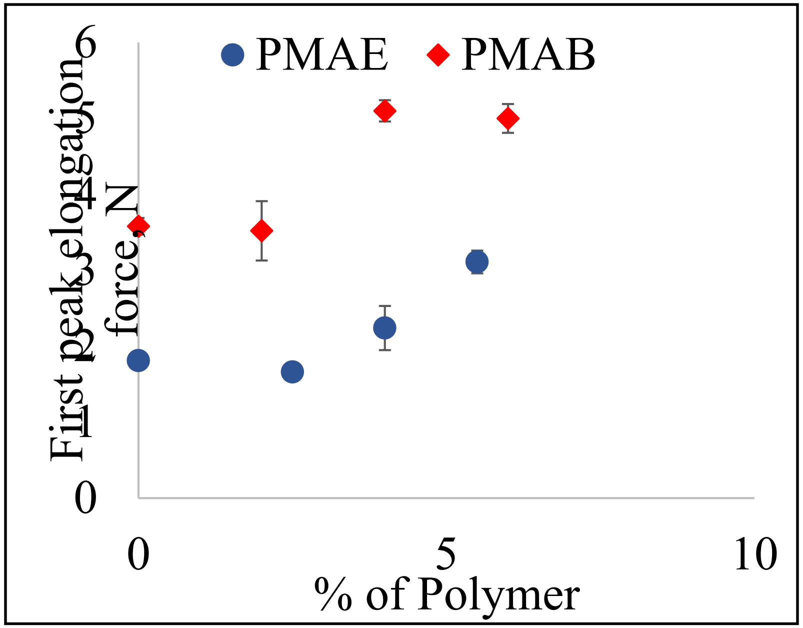
F_2 at Similar Stiffness

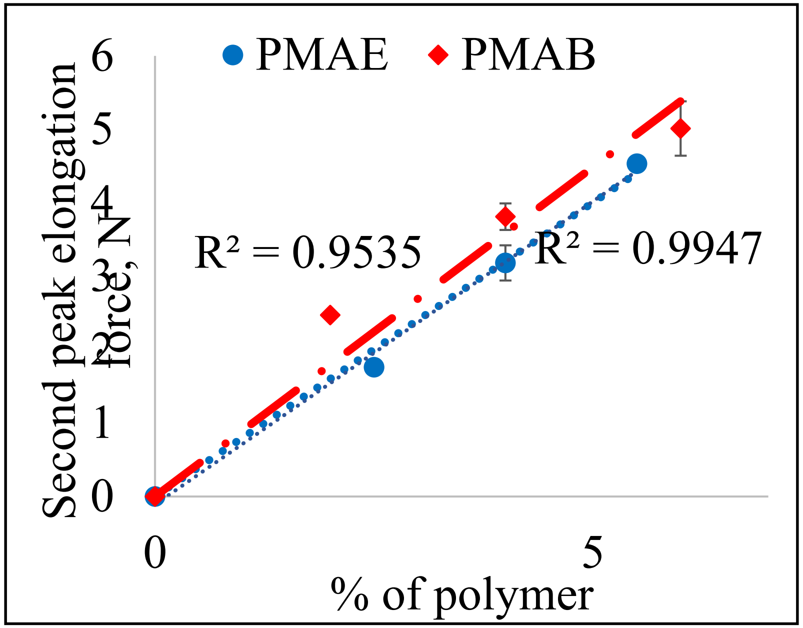


Modified Binder	F_1 value at 4°C
1% PPA	5.18
10% CR	5.17
4% SBS	5.1
2% latex	4.92
4% HDPE	4.93

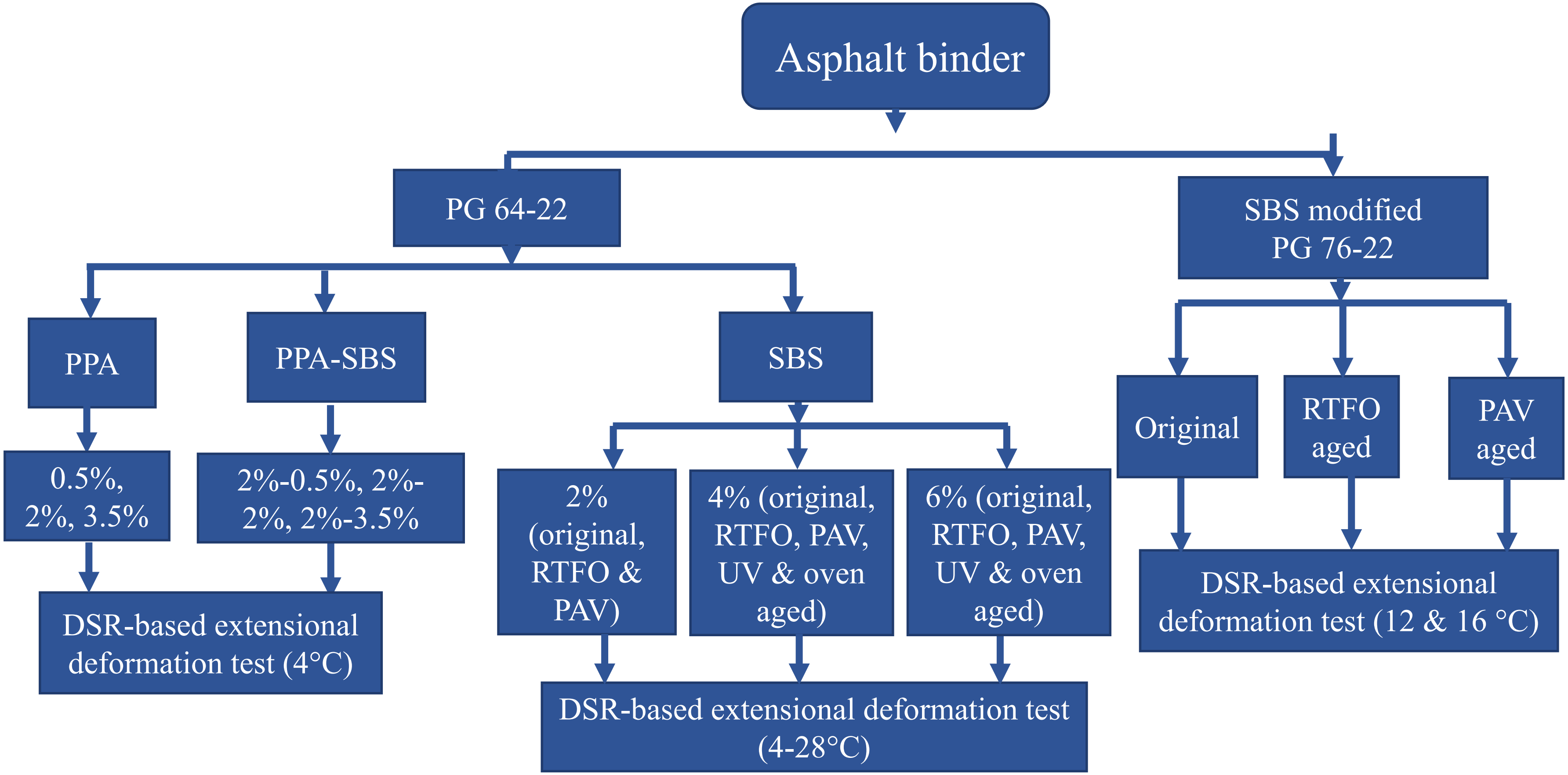


Elongation Force and Percent of Polymer

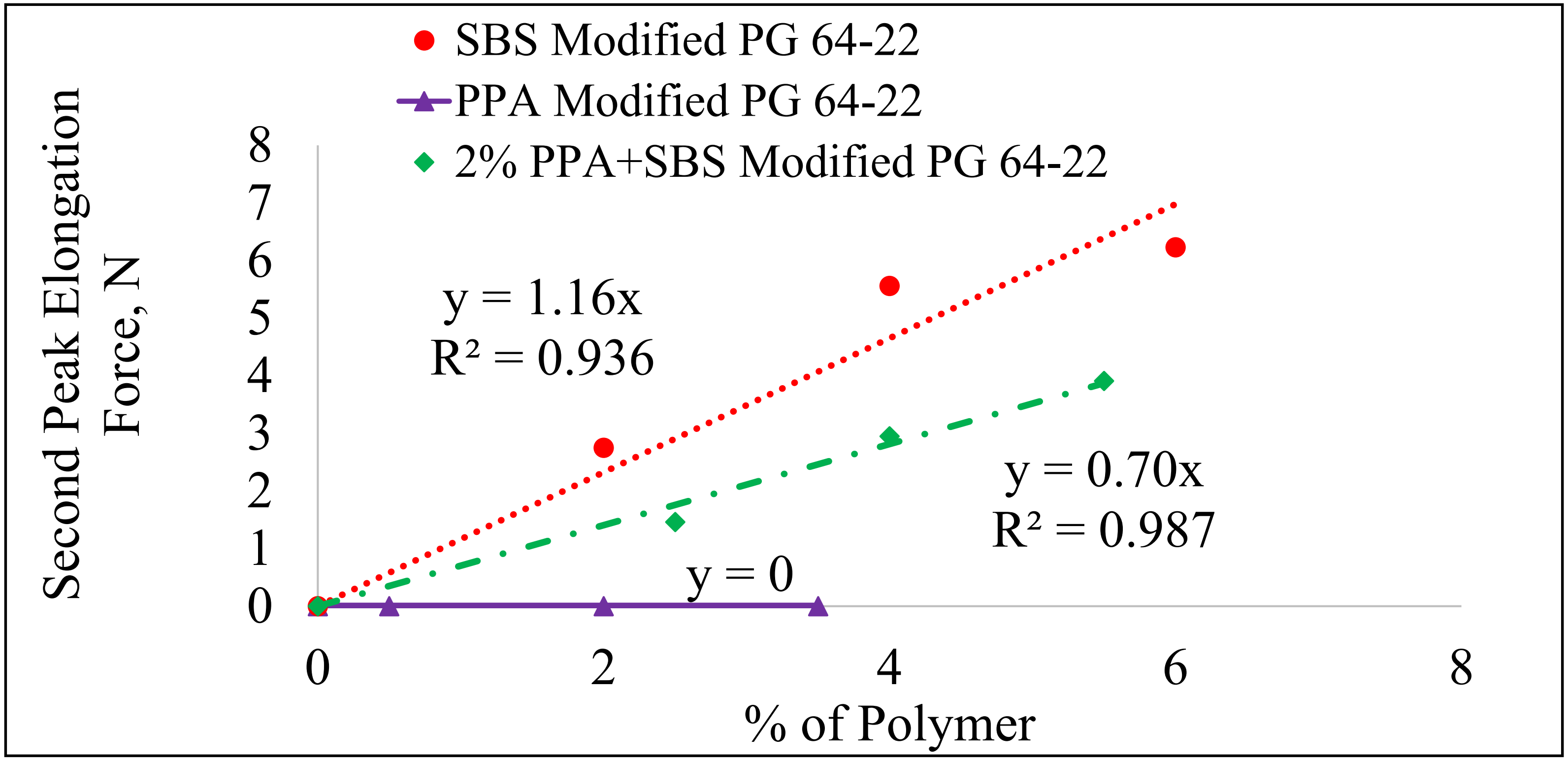




Test Factorial: Evaluating SBS Degradation due to Aging of Binder

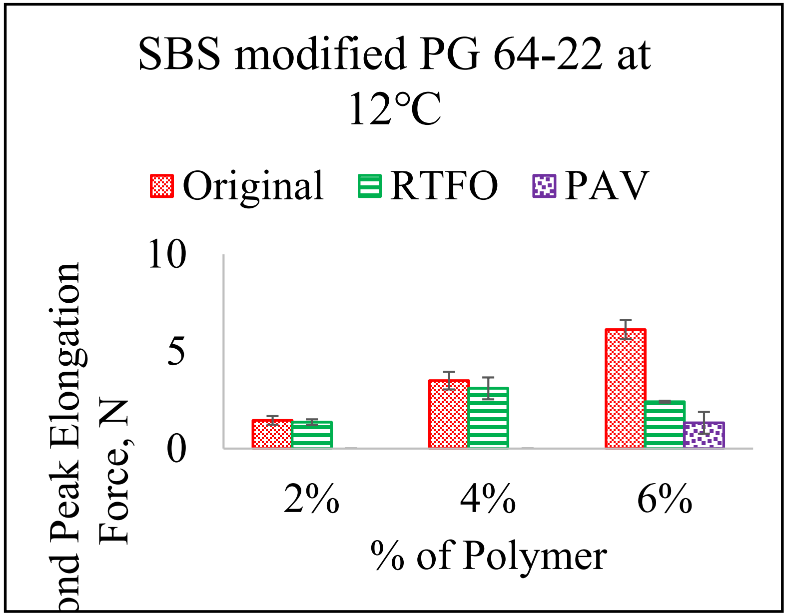


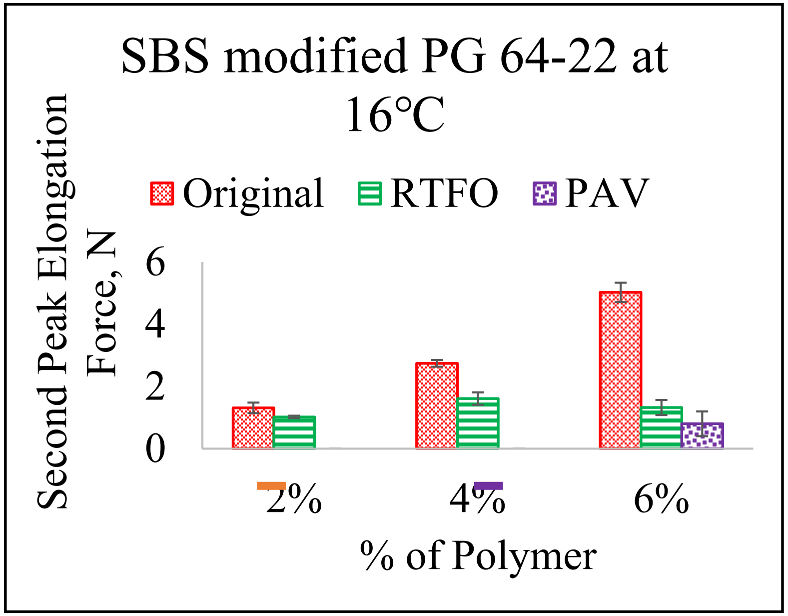
Second Peak Elongation Force vs. Percent of Polymer



Second Peak Elongation Force of Different Percent of Polymer

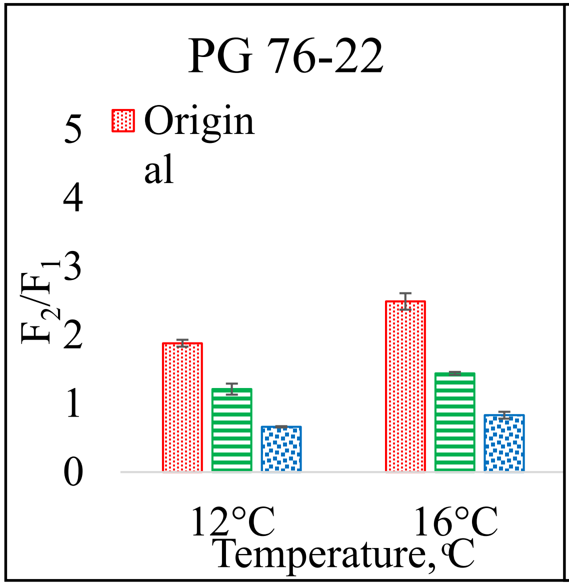
- High stiffness- sample breaks – no F_2
- Increasing of test temperature (up to 28°C).
- 7-60% reduction after RTFO aging
- 79-100% reduction after PAV aging

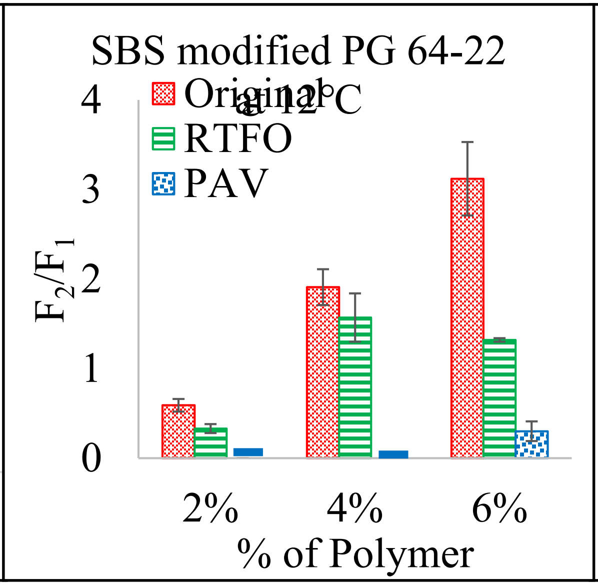


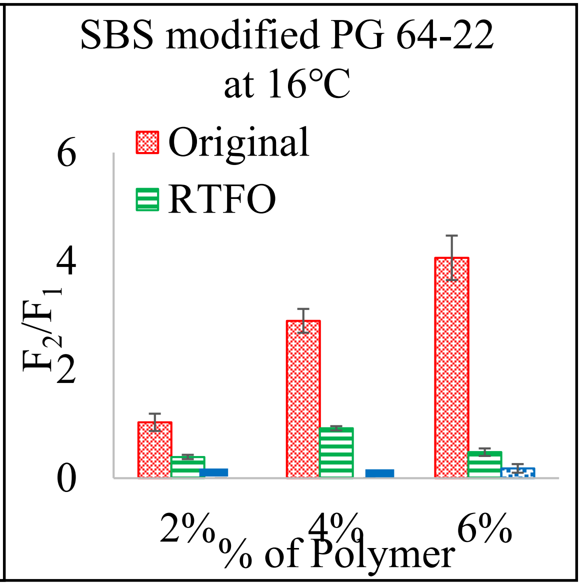


Second Peak Elongation Force over First Peak Elongation Force

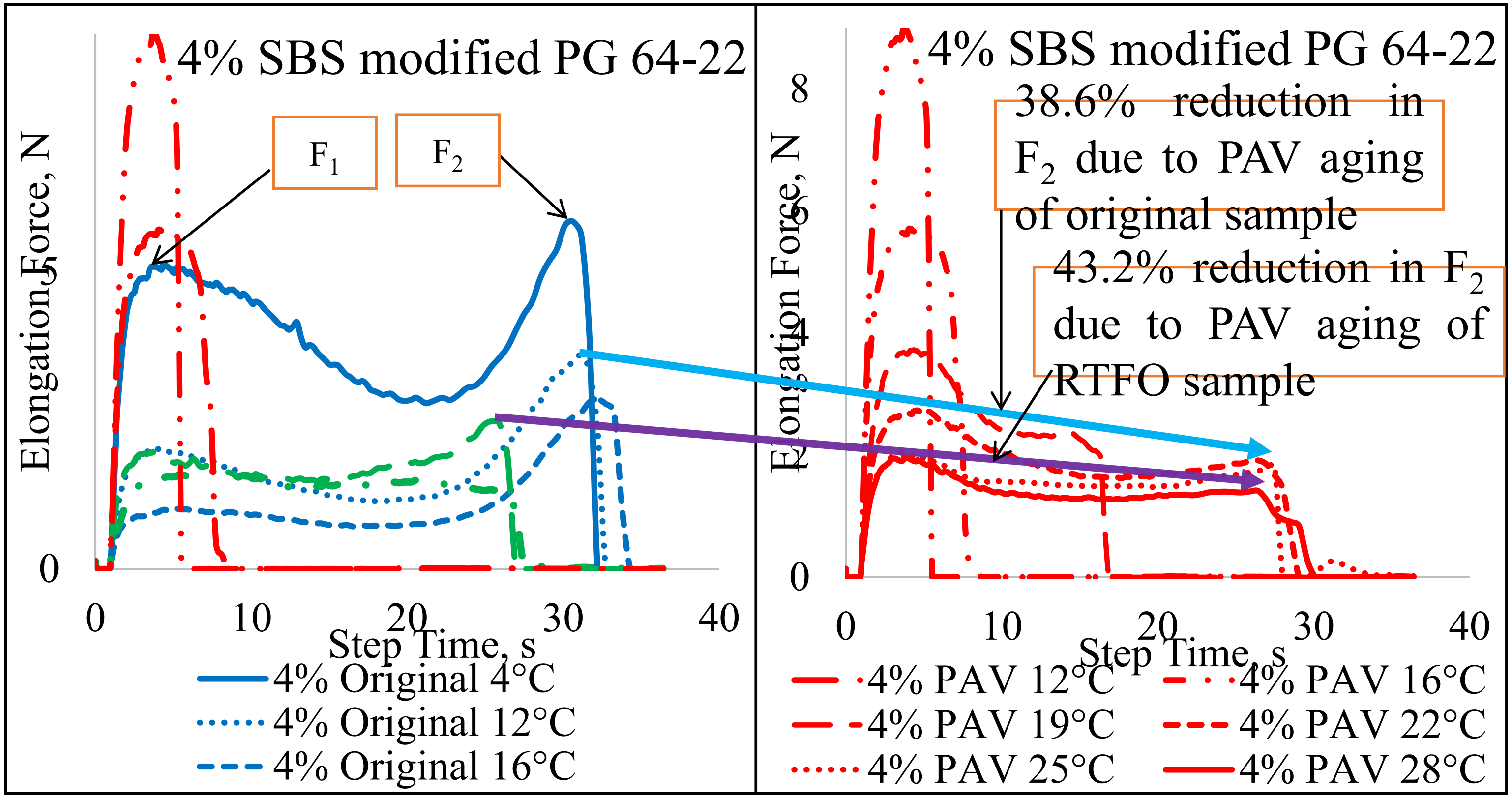
- 18-44% reduction after RTFO aging
- 65-100% reduction after PAV aging







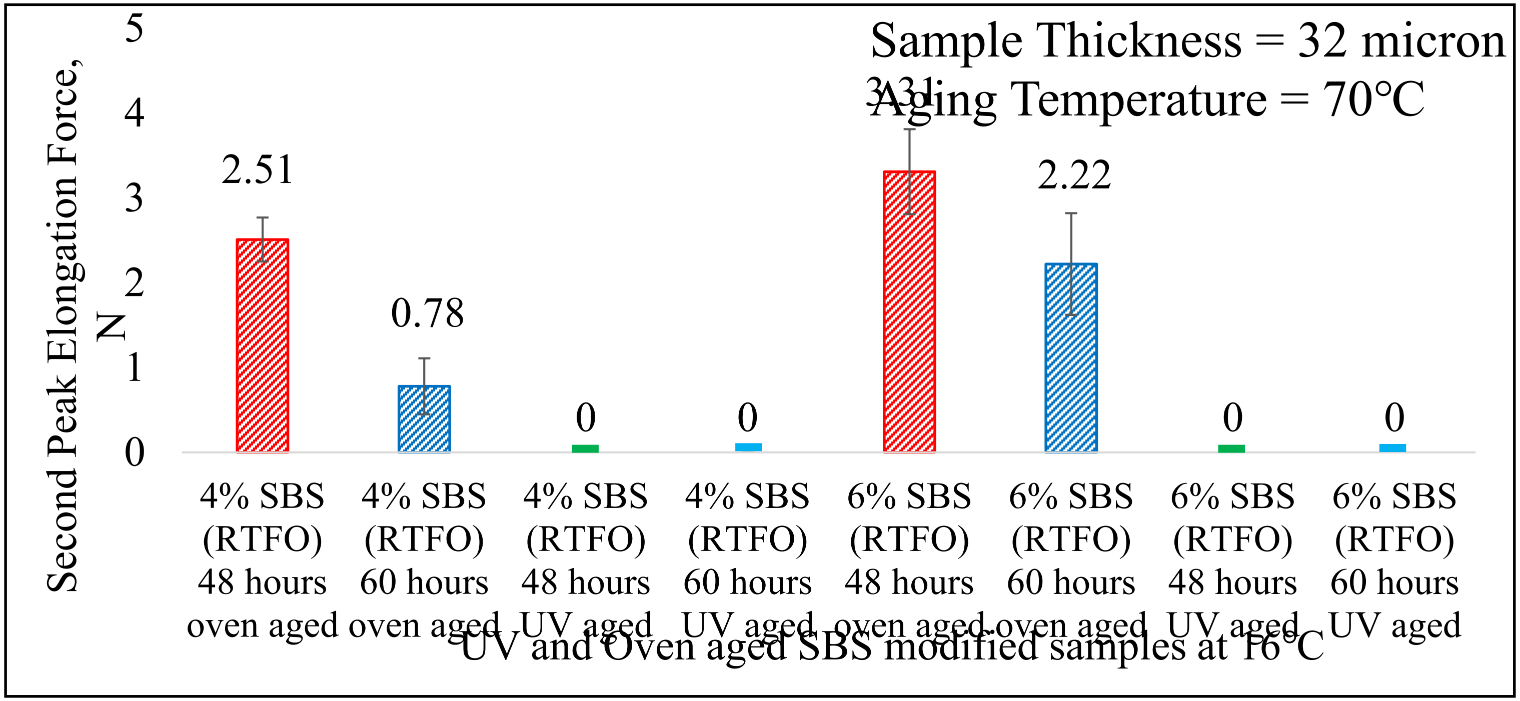
Understanding F_2 Value of Stiffer Binder



Second Peak Elongation Force of UV and Oven Aged Binder

- Oven aging: 40-78%
- UV aging: 100%

- UV A: 72mW/cm^2
- 32 μm film thickness



Test Factorial: SBS Degradation due to Aging of Asphalt Mixture

Type	Specified Sample	Duration of Aging	Test Temperature	No. of Sample
4% SBS Modified PG 64-22 binder	Original	-	4°C, 12°C & 16°C	3 replicates for a specific test temperature
Laboratory aged mixture	Aging at 85ºC temperature in forced draft oven	0 hour	4°C to 16°C at 4°C interval & 19°C to 28°C at 3°C interval	3 replicates for a specific test temperature
		4 hours		
		1 day		
		3 days		
		5 days		
	Aging at 135ºC temperature in forced draft oven	0 hour 4 hours 8 hours 12 hours 1 day	4°C to 16°C at 4°C interval & 19°C to 31°C at 3°C interval	3 replicates for a specific test temperature

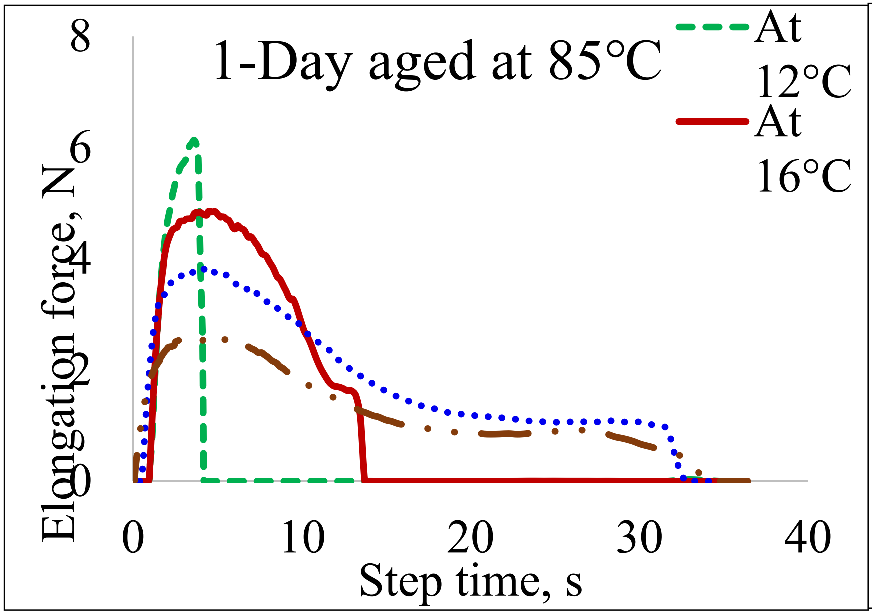
Laboratory Aged Asphalt Mixture

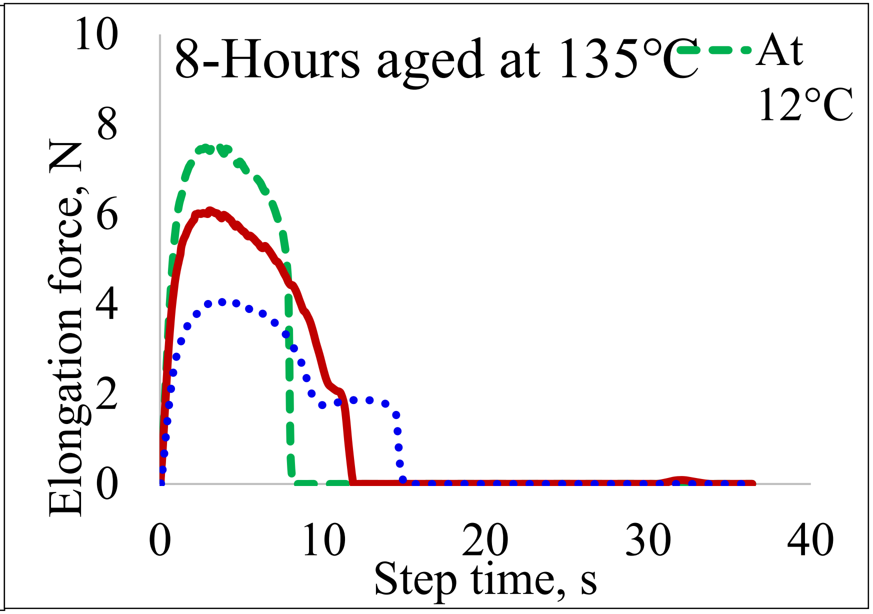
Collection of mixture in a bowl before aging started

Laboratory mixture aging at 85°C and 135°C

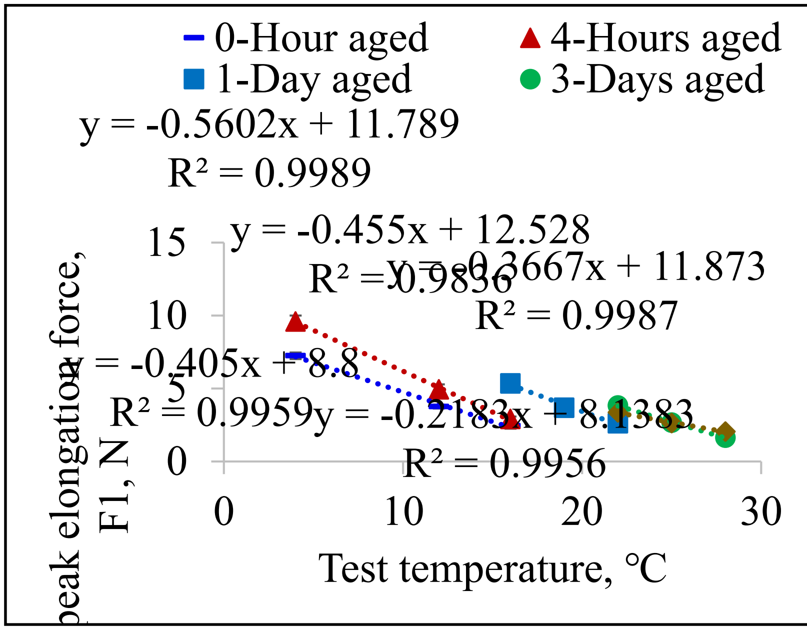
Asphalt binder extraction from loose mixture

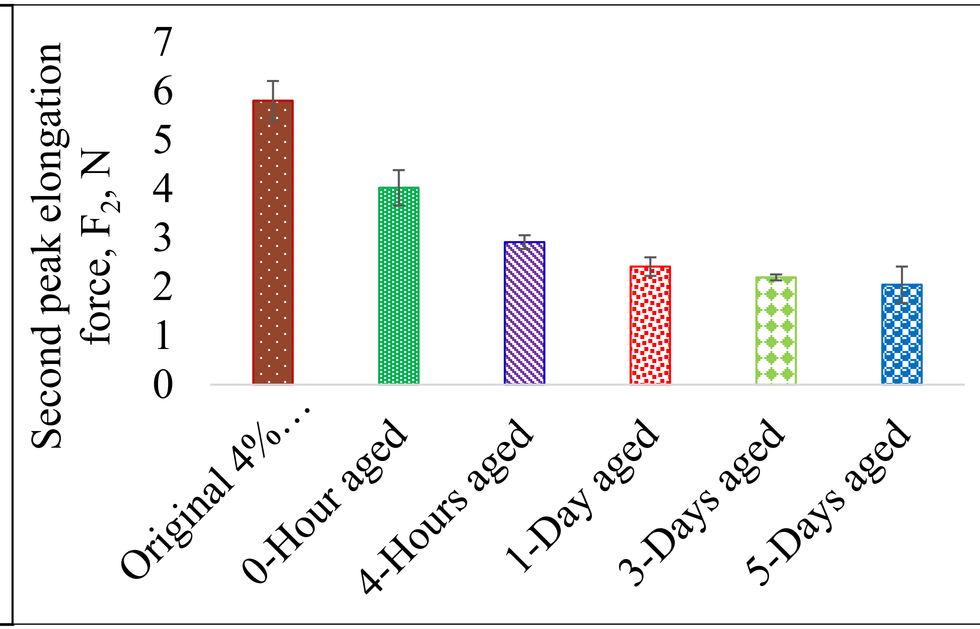
Elongation Force and Step Time Curve of Mixture Extracted Binder



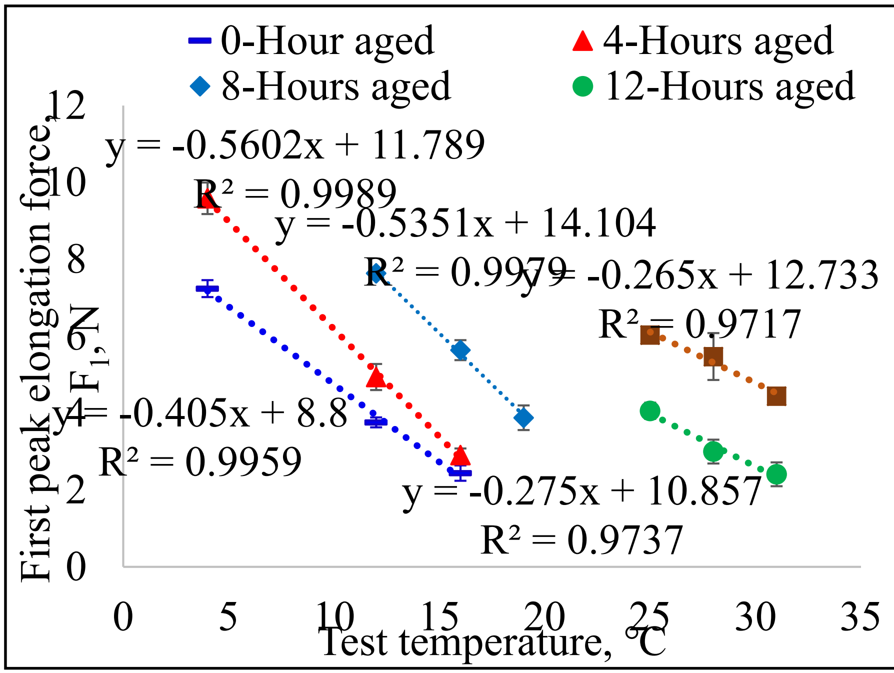


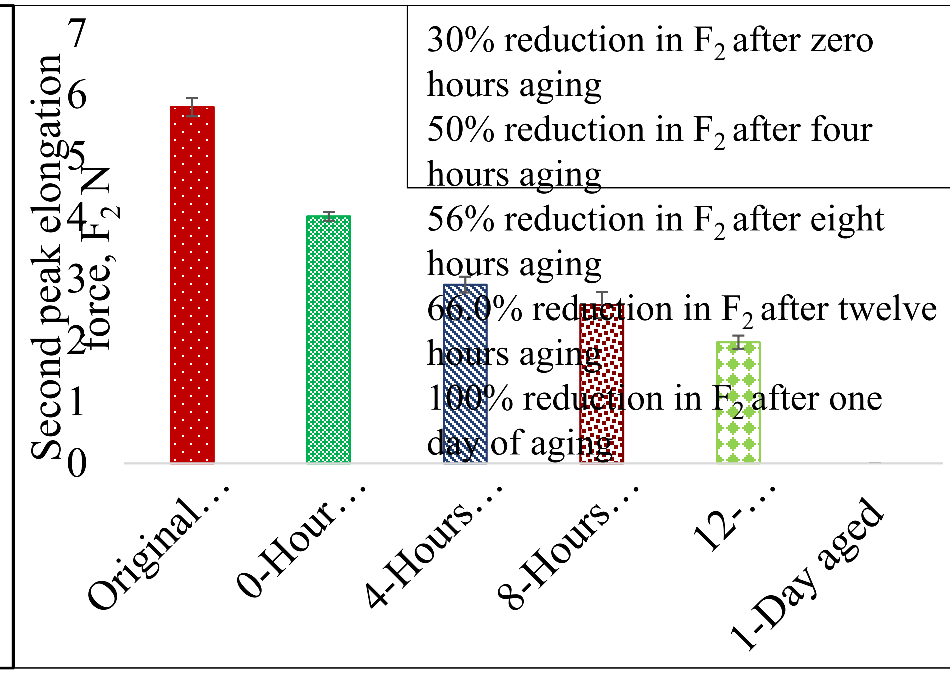
Laboratory Aged Mixture Extracted Binder at Equal Stiffness (Aged at 85°C)





Laboratory Aged Mixture Extracted Binder at Equal Stiffness (Aged at 135°C)





Remarks

- SBS modified binder is the most effective in force ductility
- F_1 has no linear correlation with percent of elastomeric polymer
- F_2 has linear correlation with percent of elastomeric polymer with $R^2 = 0.99$
- All the test temperatures used in this study exhibit reduction in F_2/F_1 due to RTFO aging, and further reduction is observed due to PAV aging
- UV aging degrades the SBS polymer completely
- 85°C mixture aging showed a 65% reduction; 135°C mixture aging showed a 100% reduction in F_2 value
- Mixture aging temperature has more influence than aging duration in SBS degradation
- F_2/F_1 is recommended as a polymer degradation parameter due to aging

Innovations in Testing—Modified Binders Cracking Resistance

State Perspective on Cracking Resistance of Modified Binders

MAY 25, 2022

ENAD MAHMOUD

DEPUTY DIRECTOR, MATERIALS AND TESTS DIVISION

TEXAS DEPARTMENT OF TRANSPORTATION

Outline

- Historical use of modified asphalt binders in Texas
- Research and specifications related to cracking resistance
    - Past
    - Present
    - Future

Outline

- Historical use of modified asphalt binders in Texas
- Research and specifications related to cracking resistance
    - Past
    - Present
    - Future

Historical Use of Modified Asphalt Binders

1960s 1970s 1980s 1990s 2000s 2010s 2020s

- HMA overlays on bridge decks needed more “flexible” mixes
- Experimented with SBR
- Success prompted the use of SBR modified binders

Historical Use of Modified Asphalt Binders

1960s 1970s 1980s 1990s 2000s 2010s 2020s

- AC-3 and AC-5 + 2% SBR for seal coats
- AC-5 and AC-10 + 2 to 3% SBR for HMA
- Developed FTIR based method to detect polymer content

Historical Use of Modified Asphalt Binders

1960s 1970s 1980s **1990s** 2000s 2010s 2020s

- SBR use was very common
- Other modifiers were introduced including SBS, EVA, Polyethylene
- SBS showed better performance
- Specs for AC-15P -30P for seal coats and -15P -30P -45P for HMA were added
- 1997 adopted PG + retained polymer specific tests

Historical Use of Modified Asphalt Binders

1960s 1970s 1980s 1990s **2000s** 2010s 2020s

- AC-xx- P or SBR or TR designations were used for chip seal binders
- Polymer designations for PG binders were removed BUT Elastic Recovery using ductilitometer was retained as a requirement to detect elastomers
- Research project on simple cracking test for binders ➔ (more later)
    - Charles Glover @Texas A&M
    - Developed surrogate DSR parameter for ductility
    - Worked very well for unmodified binders

Historical Use of Modified Asphalt Binders

1960s 1970s 1980s 1990s 2000s **2010s** 2020s

- Additional specs for softer xx-TR binders
- Multiple projects and specs looking beyond PG:
  - Ductilometer elastic recovery spec → MSCR elastic recovery spec
  - XRF → Screen and limit use of PPA and REOB
  - Investigated cracking tests → Tc, GR, Poker Chip

Outline

- Historical use of modified asphalt binders in Texas
- Research and specifications related to cracking resistance
    - Past
    - Present
    - Future

Cracking of Asphalt Binders – Past

"Indirect cracking" requirement via Elastic Recovery using Ductilometer

30% ER for UTI = 92
(e.g. PG64-28, 70-22)

50% ER for UTI = 98
(e.g. PG70-28, 76-22)

60% ER for UTI = 104
(e.g. PG76-28, 82-22)

Cracking of Asphalt Binders – Past

Research on surrogate for ductility

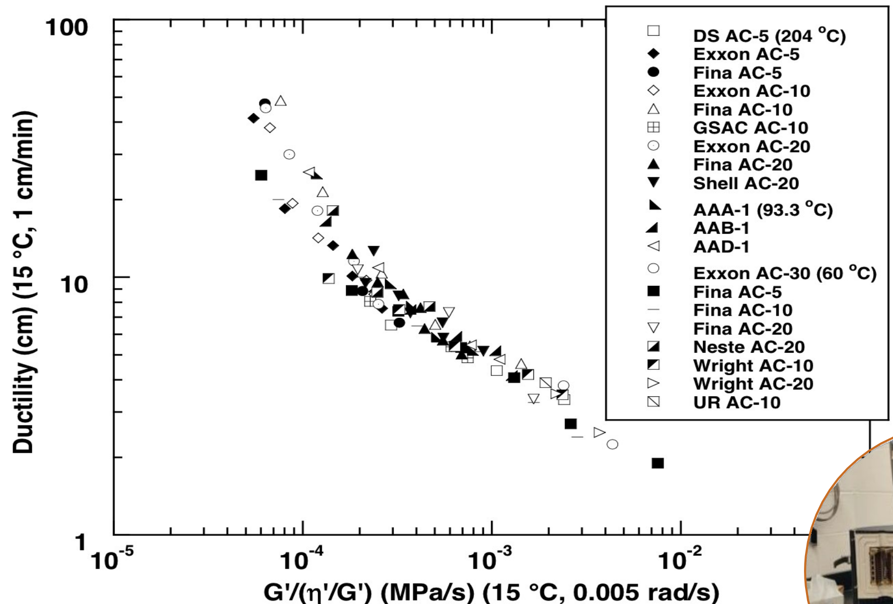
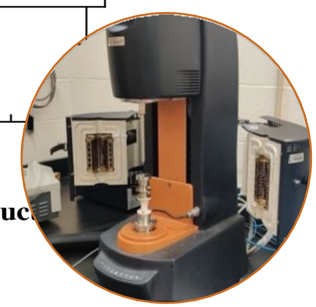


Figure 4-11. Ductility versus DSR Parameter G′/(η′/G′), All Duc



Source: Glover et al. (2005); research was done between 1998 -2002

Cracking of Asphalt Binders – Past

Research on surrogate for ductility

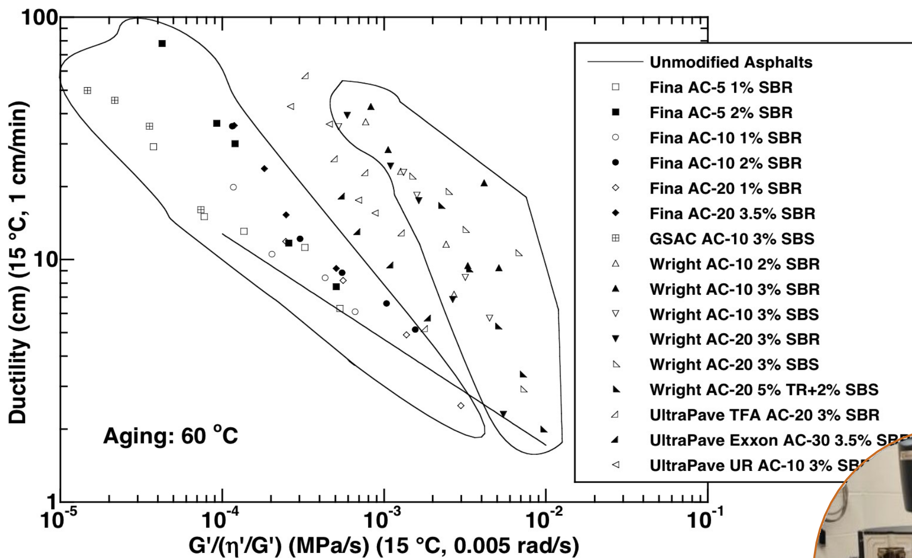
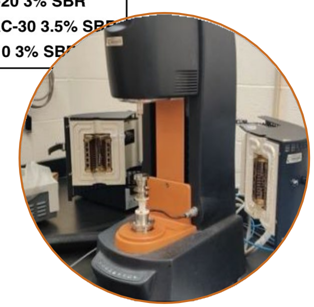


Figure 5-11. Ductility versus G′/(η′/G′) for Modified Asphalts.



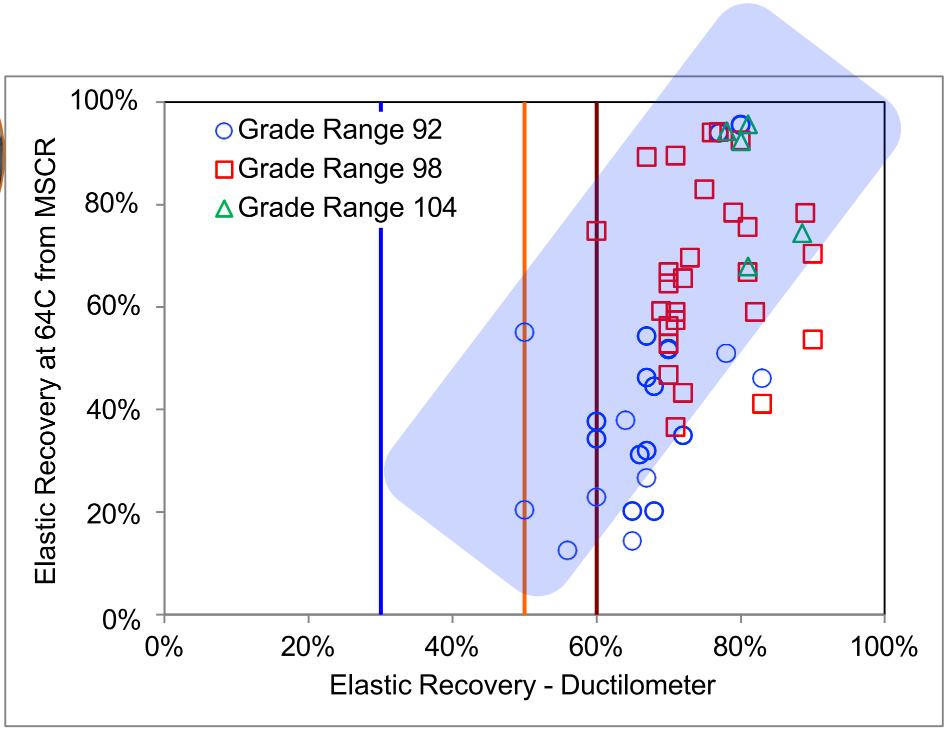
Source: Glover et al. (2005); research was done between 1998 -2002

Outline

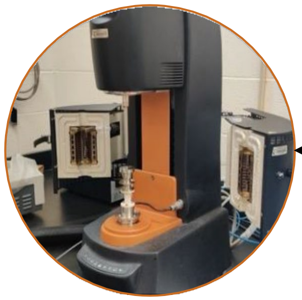
- Historical use of modified asphalt binders in Texas
- Research and specifications related to cracking resistance
  - Past
  - Present
  - Future

Cracking of Asphalt Binders – Present

“Indirect requirement” Ductilometer ➔ DSR



Cracking of Asphalt Binders – Present

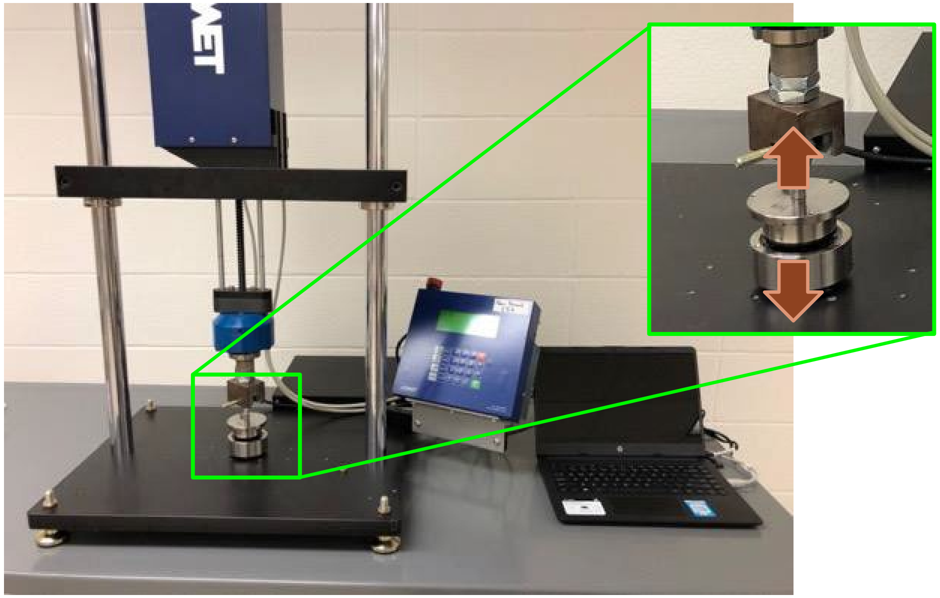


Property and Test Method	PG 58			PG 64				PG 70				PG 76				PG 82		
	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28
Average 7-day max pavement design temperature, °C[1]	58			64				70				76				82		
Min pavement design temperature, °C[1]	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28
Original Binder																		
Flash point, T 48, Min, °C	230																	
Viscosity, T 316[2, 3]: Max, 3.0 Pa·s, test temperature, °C	135																	
Dynamic shear, T 315[4]: G*/sin(δ), Min, 1.00 kPa, Max, 2.00 kPa[7], Test temperature @ 10 rad/sec., °C	58			64				70				76				82		
Elastic recovery, D6084, 50°F, % Min[8]	–	–	30	–	–	30	50	–	30	50	60	30	50	60	70	50	60	70
Rolling Thin-Film Oven (Tex-541-C)																		
Mass loss, Tex-541-C, Max, %	1.0																	
Dynamic shear, T 315: G*/sin(δ), Min, 2.20 kPa, Max, 5.00 kPa[7], Test temperature @ 10 rad/sec., °C	58			64				70				76				82		
MSCR, T350, Recovery, 0.1 kPa, High Temperature, % Min[8]	-	-	20	-	-	20	30	-	20	30	40	20	30	40	50	30	40	50
Pressure Aging Vessel (PAV) Residue (R 28)																		
PAV aging temperature, °C	100																	
Dynamic shear, T 315: G*/sin(δ), Max, 5000 kPa ...ture @ 10 rad/sec., °C	25	22	19	28	25	[illegible]												

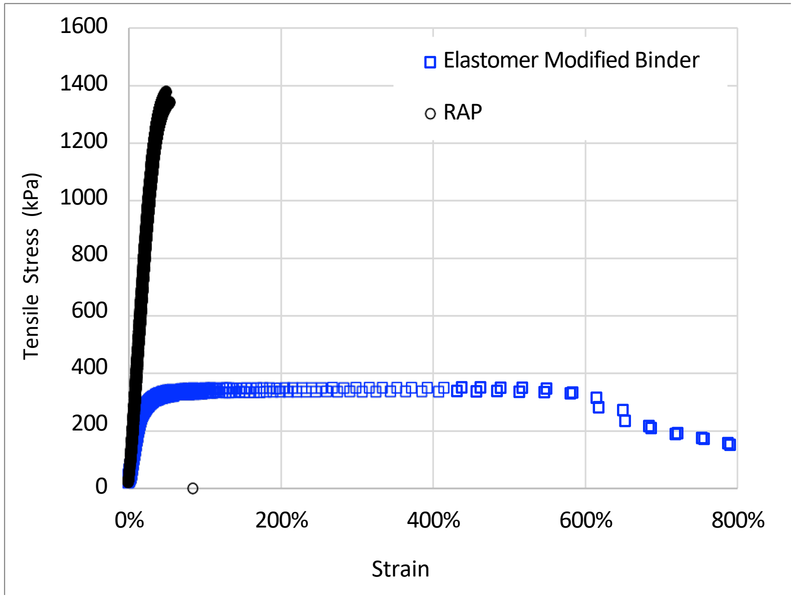
Outline

- Historical use of modified asphalt binders in Texas
- Research and specifications related to cracking resistance
  - Past
  - Present
  - Future

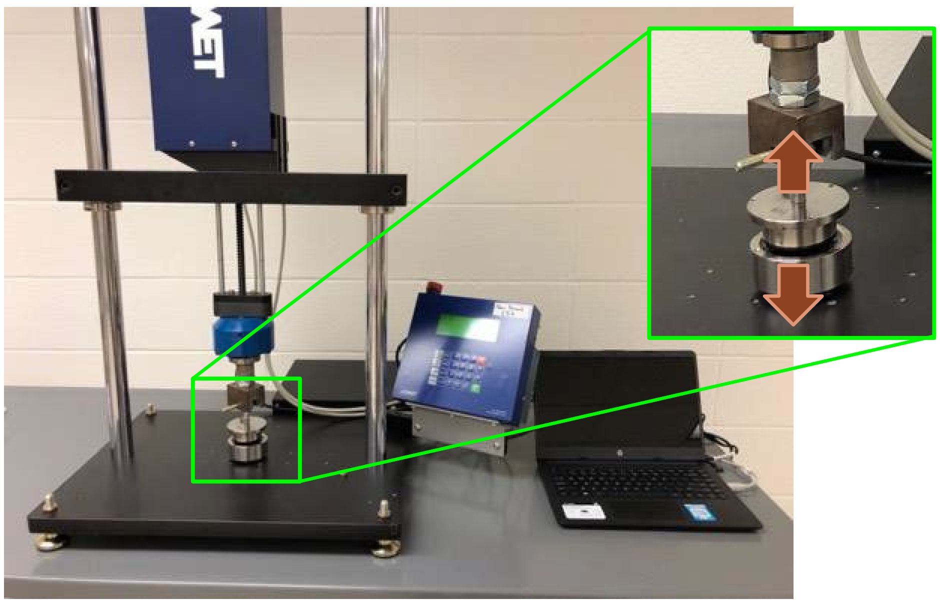
Cracking of Asphalt Binders – Future



Poker chip test ➔
Combine fundamental mechanics with simple test

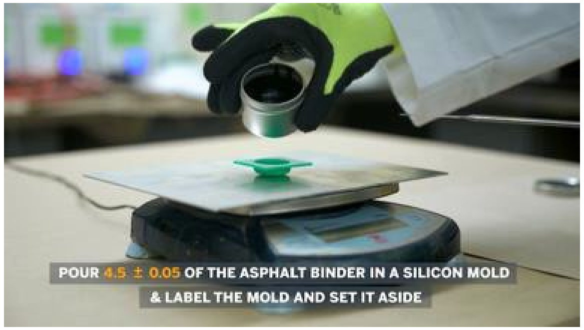


Cracking of Asphalt Binders – Future

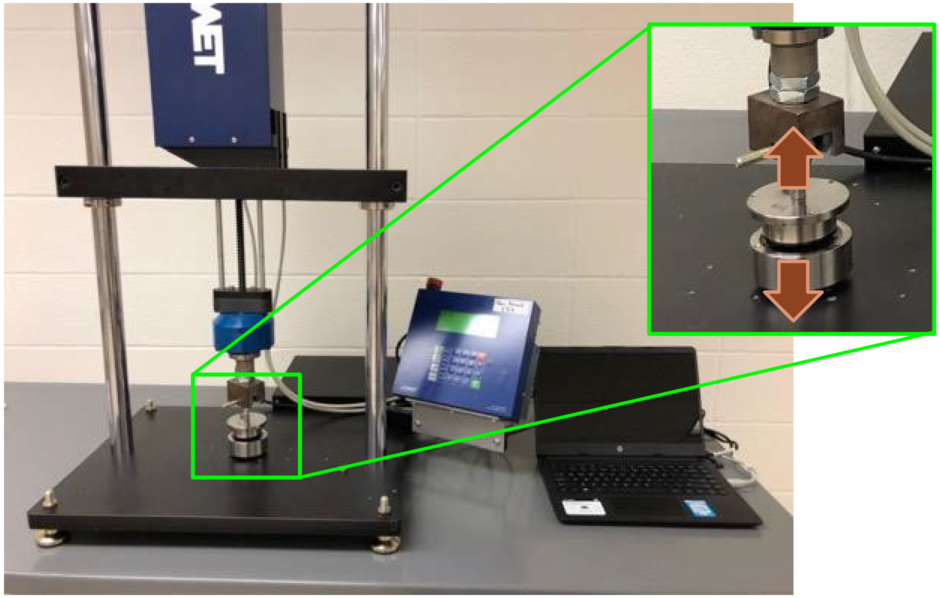


- Equipment
  - ✓ Low capital cost
  - ✓ Small footprint
  - ✓ Plug and play
- Sample
  - ✓ Easy to prepare and run
- Results
  - ✓ Easy to interpret
  - ✓ No special software
- Other
  - ✓ Induces failure
  - ✓ Repeatable

Cracking of Asphalt Binders – Future

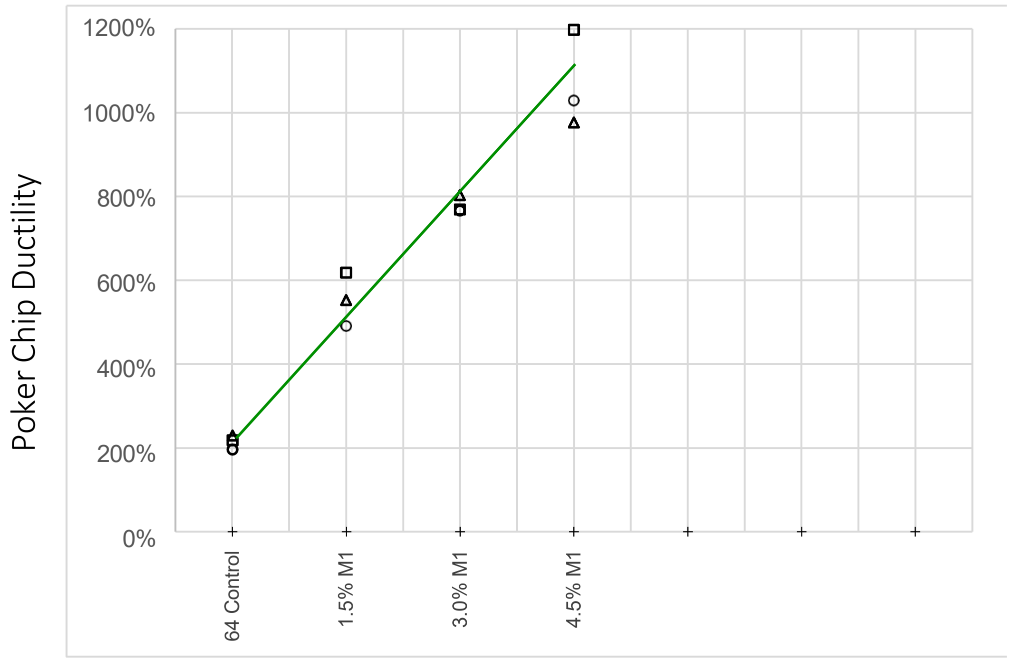


Cracking of Asphalt Binders – Future

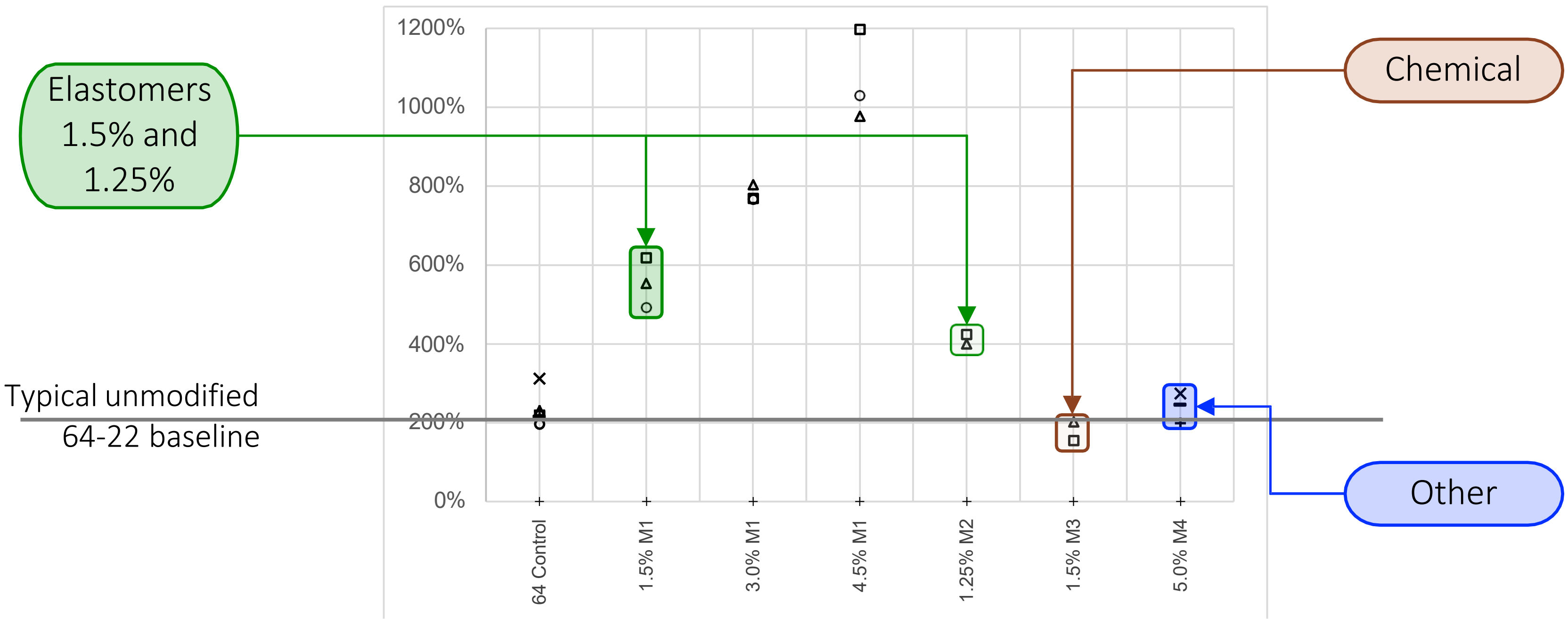


- Lab modified binders
- PG binders
- Field validation with cracking

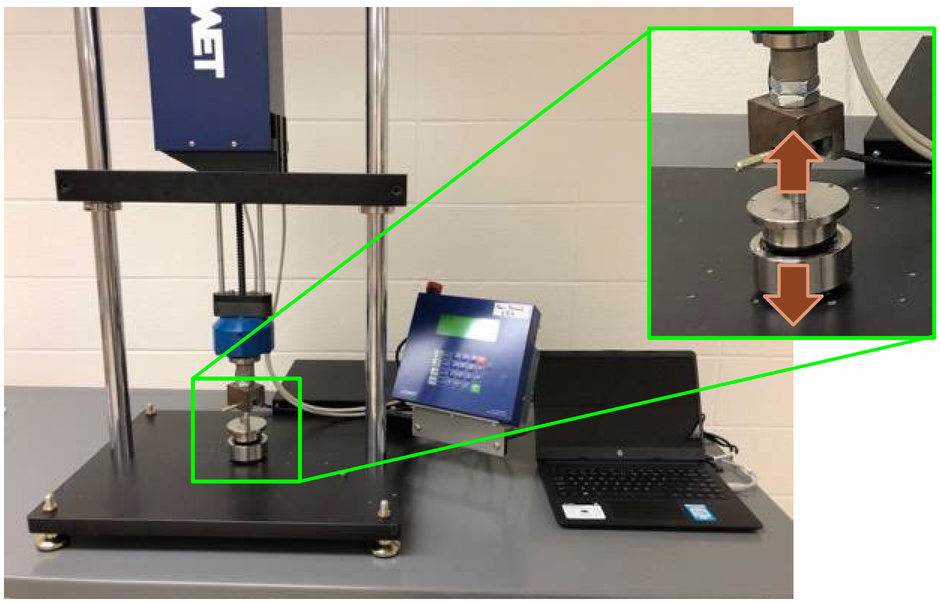
Cracking of Asphalt Binders – Future



Cracking of Asphalt Binders – Future

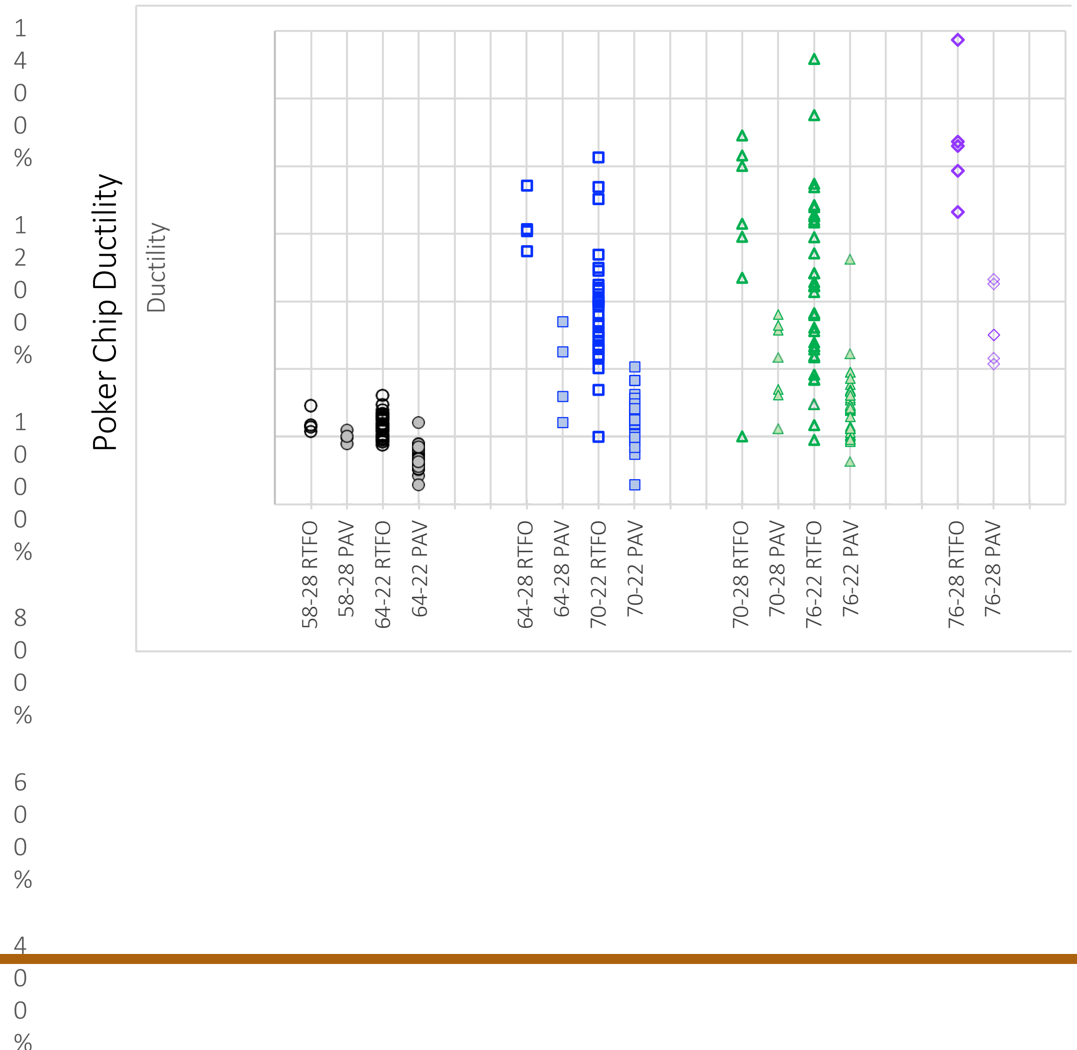


Cracking of Asphalt Binders – Future

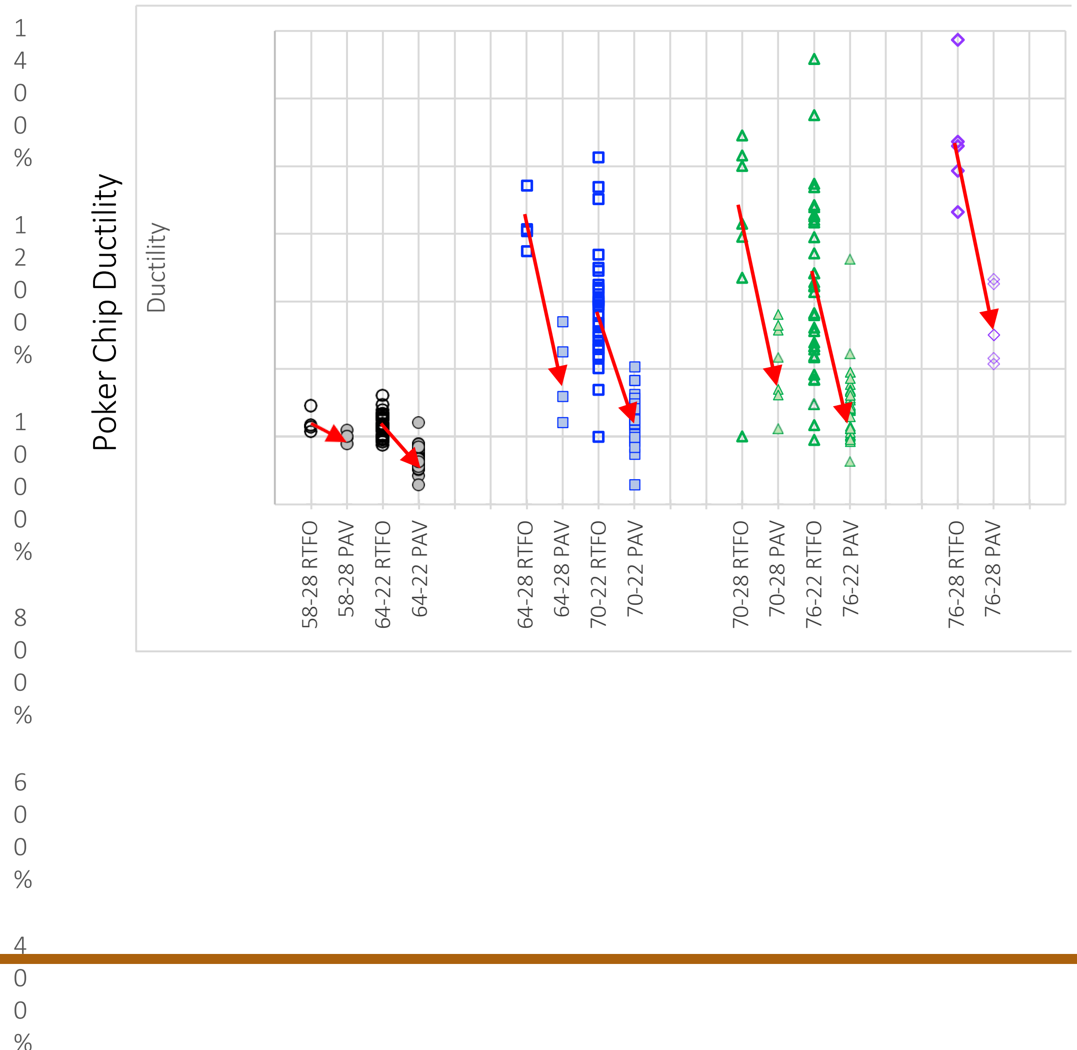


- Lab modified binders
- PG binders
- Field validation with cracking

Cracking of Asphalt Binders – Future

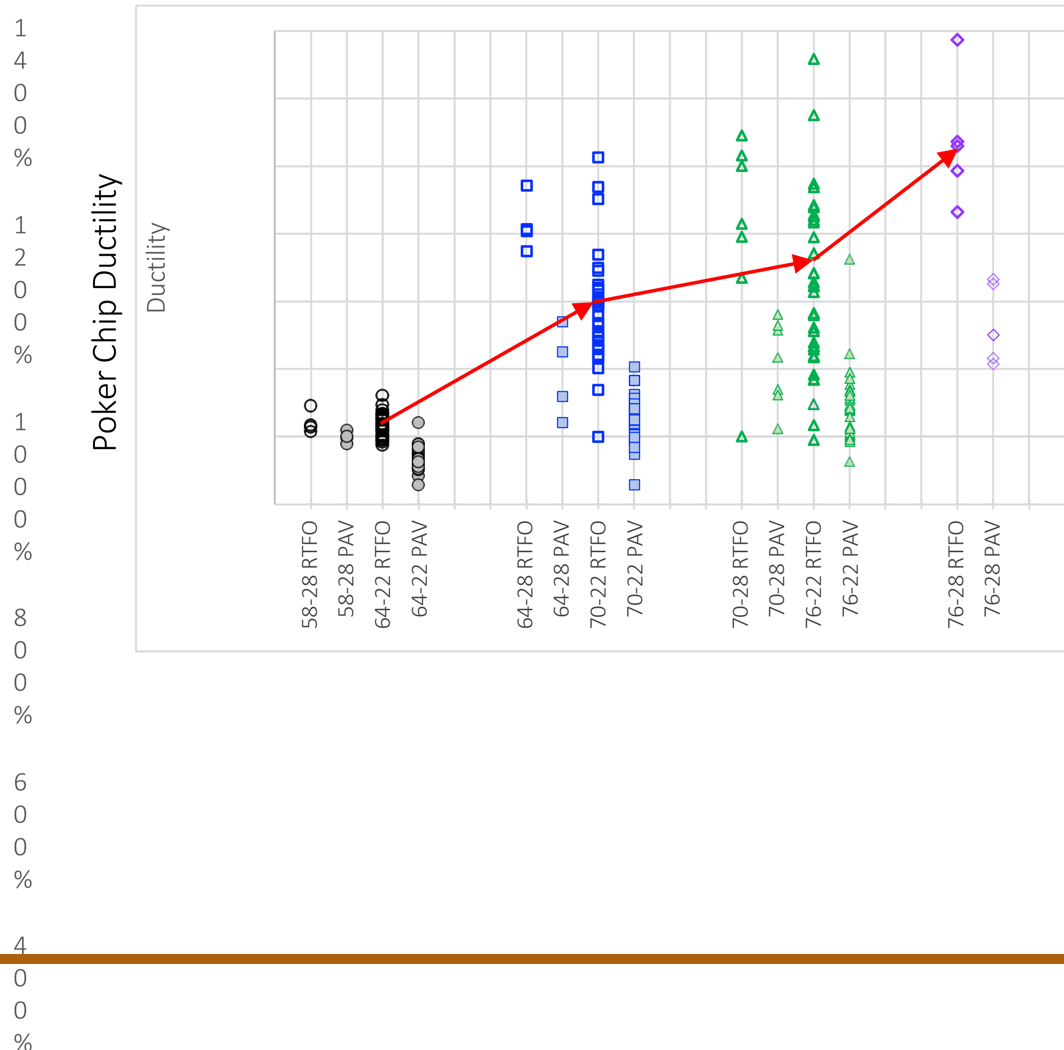


Cracking of Asphalt Binders – Future



- Effect of 20PAV aging

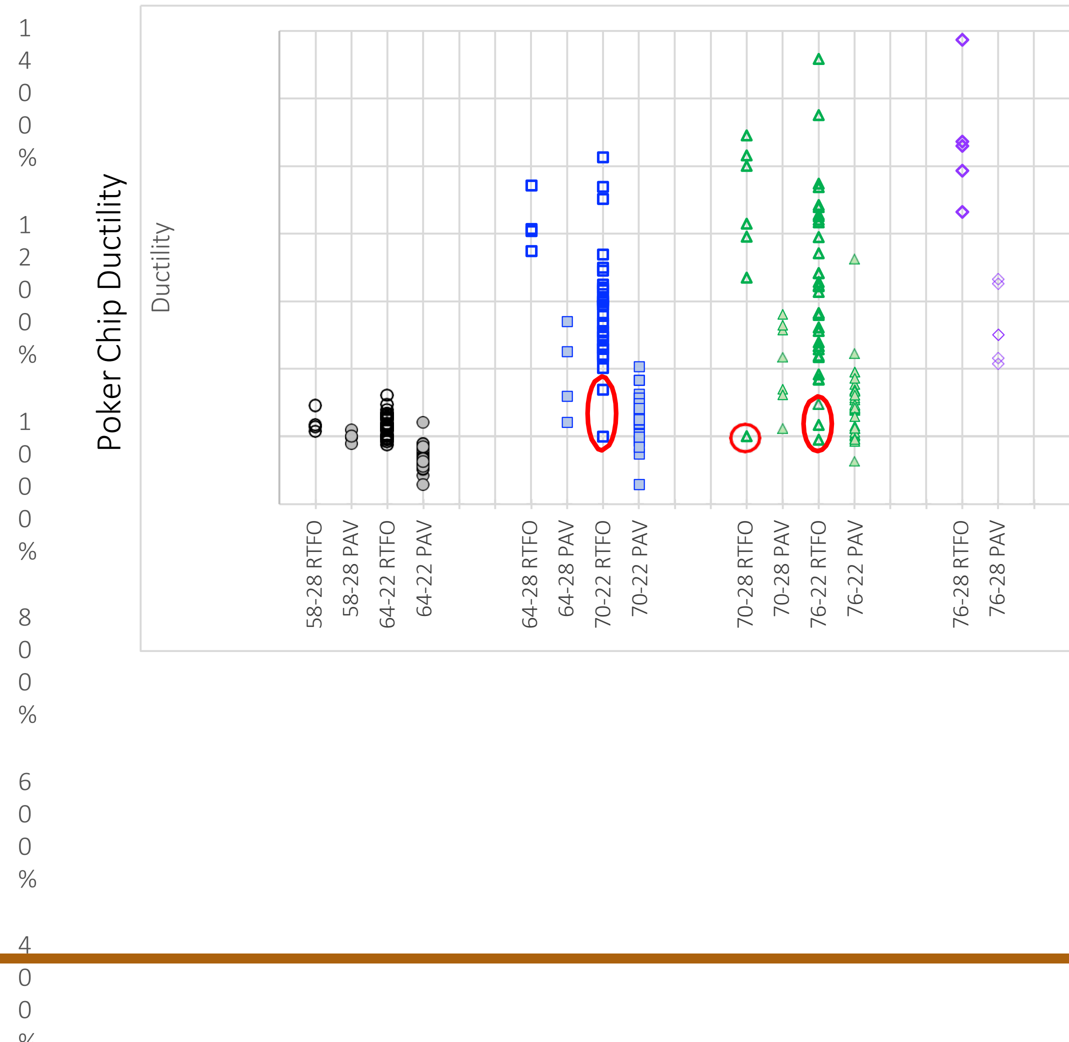
Cracking of Asphalt Binders – Future



- Effect of 20PAV aging

- Effect of polymer (RTFO)
  64-22 ➔
  70-22 ➔
  76-22 ➔
  76-28

Cracking of Asphalt Binders – Future

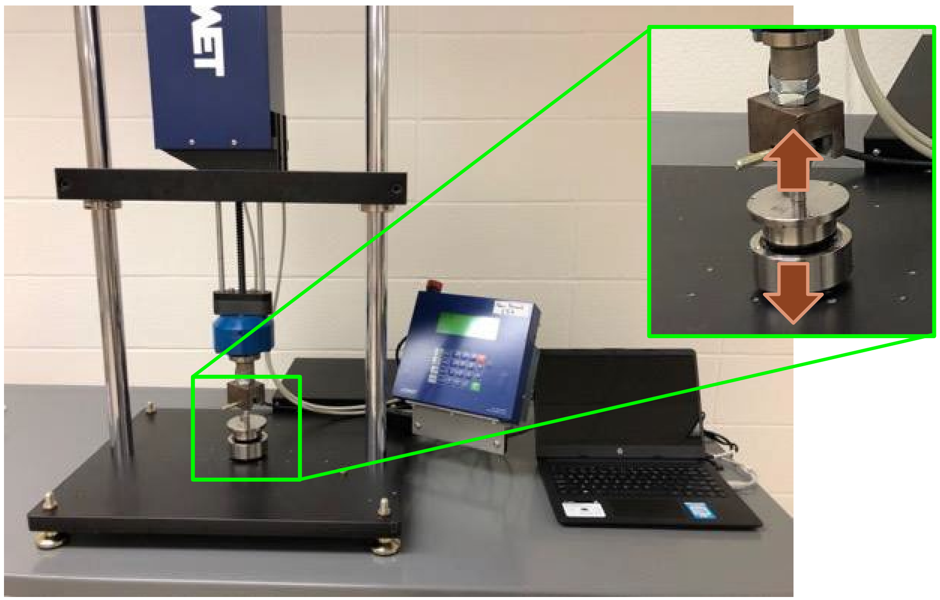


- Effect of 20PAV aging

- Effect of polymer (RTFO)
  64-22 ➔
  70-22 ➔
  76-22 ➔
  76-28

- Anomalous Binders with elastic recovery but low ductility

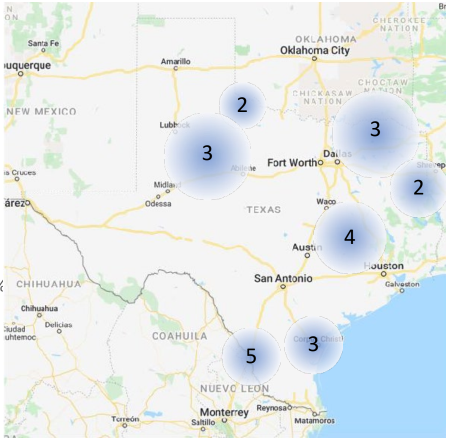
Cracking of Asphalt Binders – Future



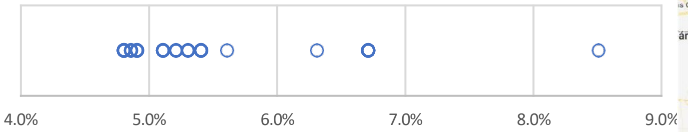
- Lab modified binders
- PG binders
- Field validation with cracking

Cracking of Asphalt Binders – Future

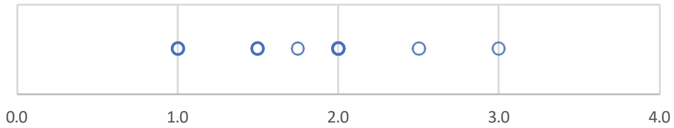
- Diverse locations / weather conditions



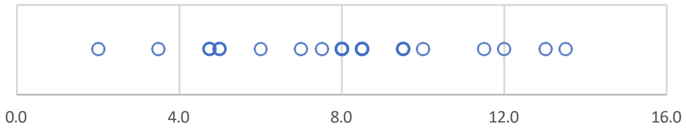
- Binder contents (%)



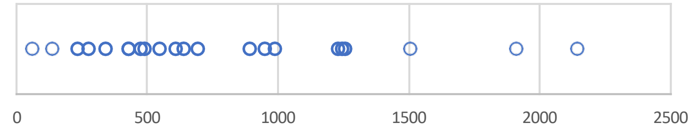
- Layer thickness (in)



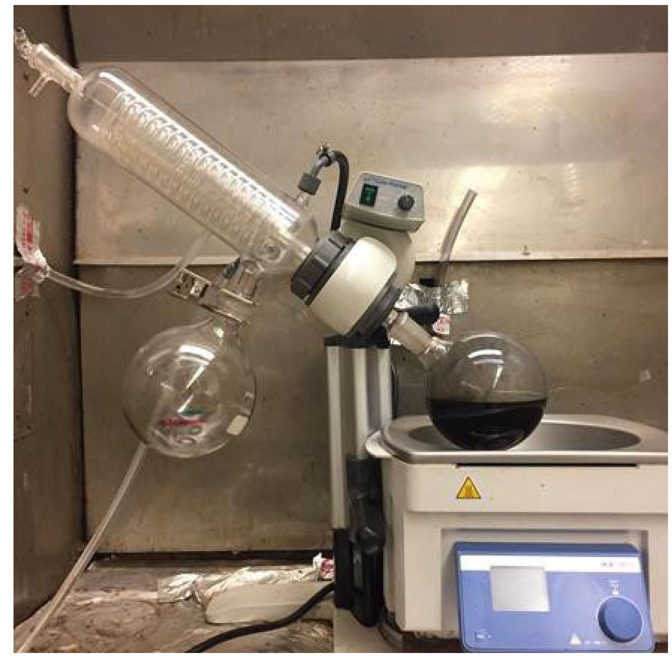
- Total HMA thickness (in)



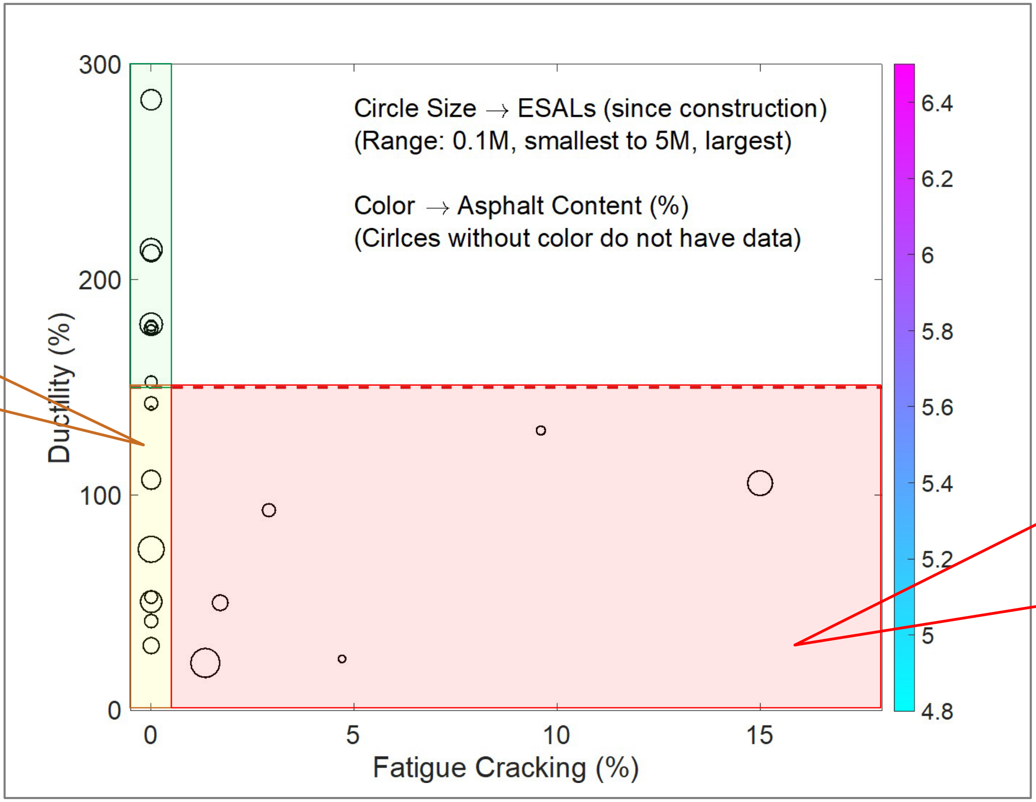
- Truck traffic



Cracking of Asphalt Binders – Future



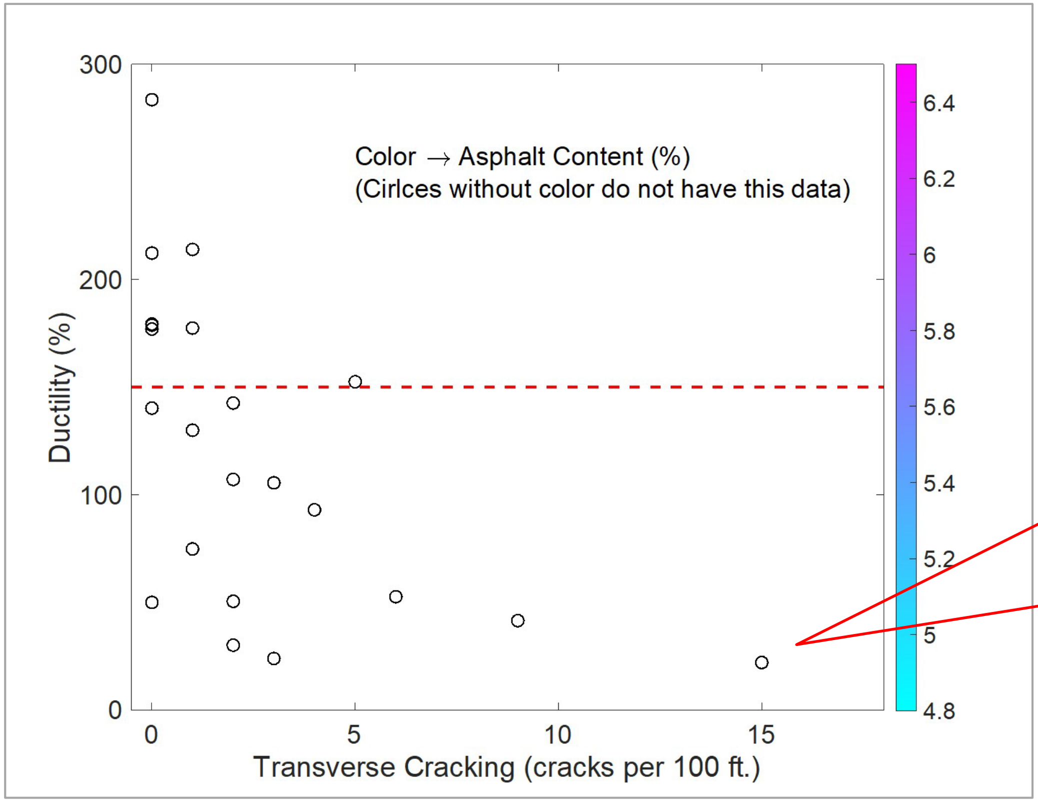
Cracking of Asphalt Binders – Future



These sections have low ductility but no surface cracking at the time of inspection

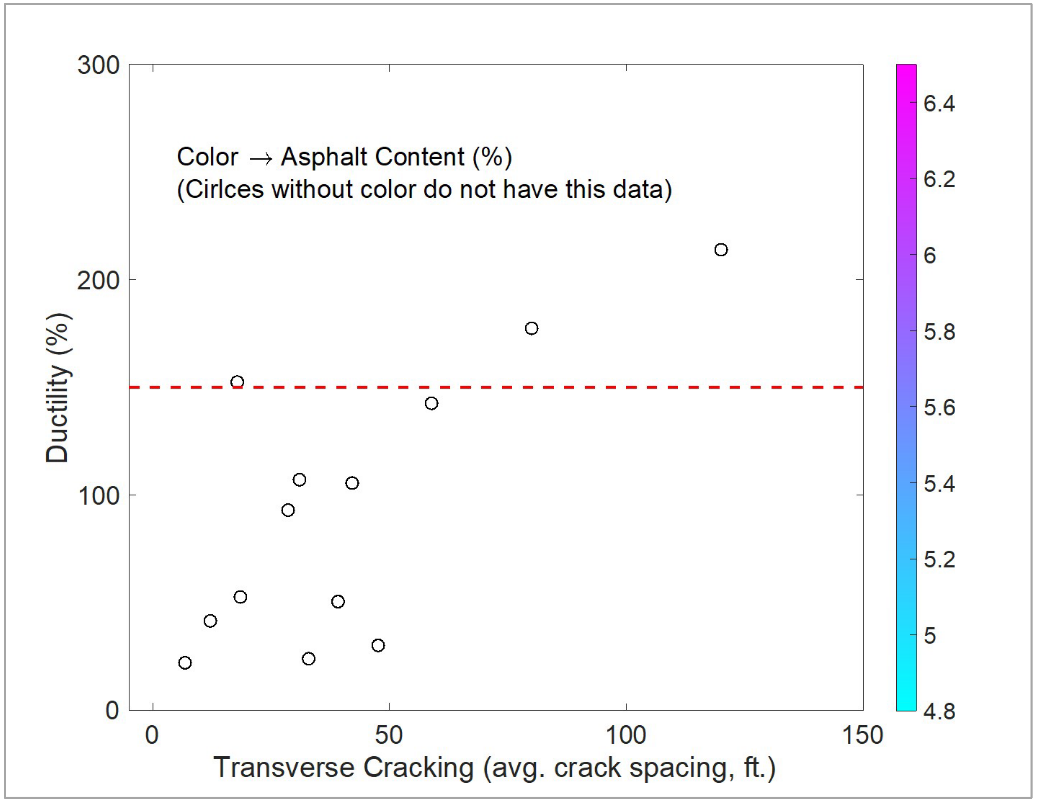
43% of sections with ductility < 150% showed signs of fatigue cracking on surface regardless of traffic volume, thickness, and binder content.

Cracking of Asphalt Binders – Future



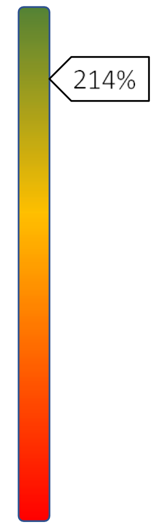
86% of sections that showed ductility < 150% showed some degree of transverse cracking.

Cracking of Asphalt Binders – Future



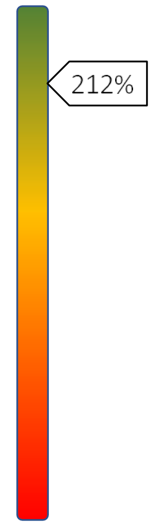
Cracking of Asphalt Binders – Future

#1: 7 years
Photo and coring from Oct. 2019



Poker Chip
Ductility

Cracking of Asphalt Binders – Future

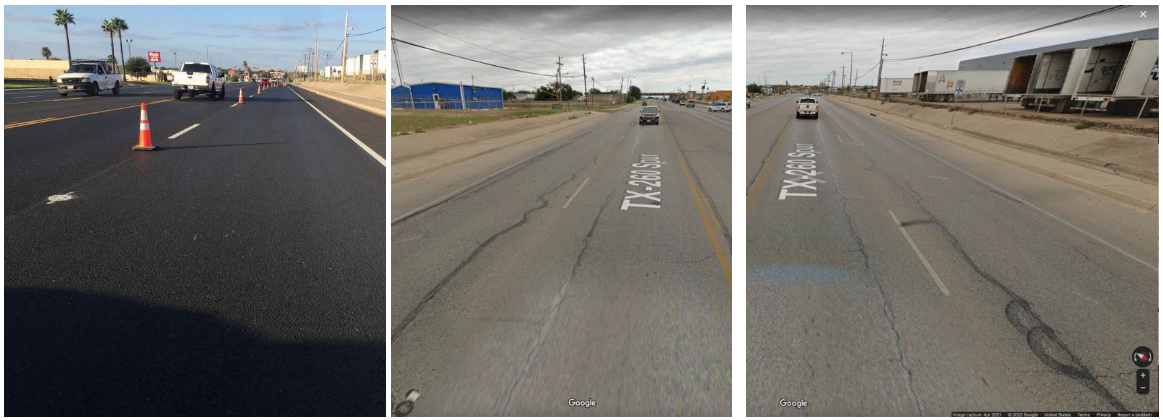


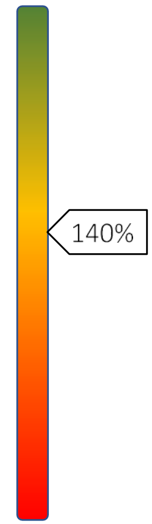
Poker Chip Ductility

#20: 7 years

Left – Photo and coring from Nov. 2021; Middle and Right – Google Street from Jan. 2019 and April 2021 showing no cracking over time

Cracking of Asphalt Binders – Future

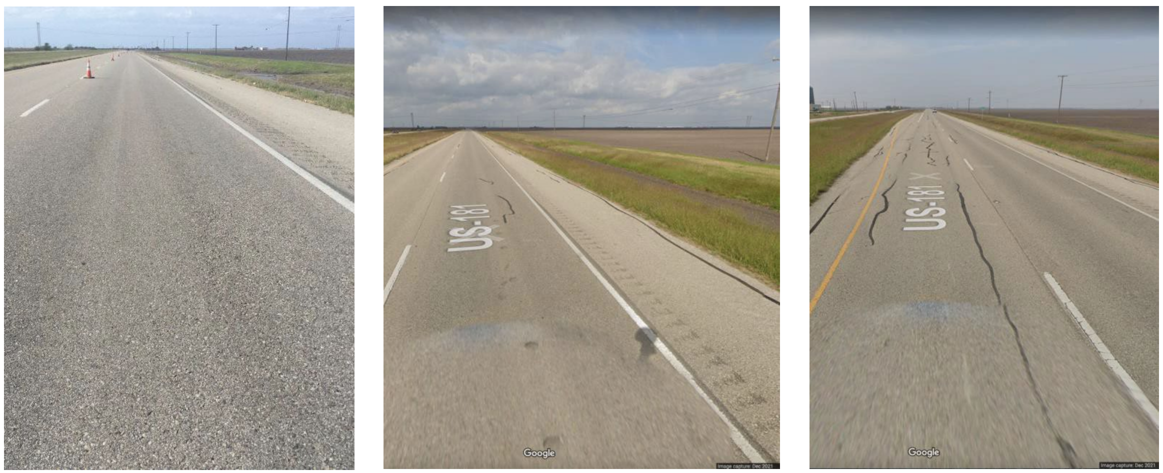


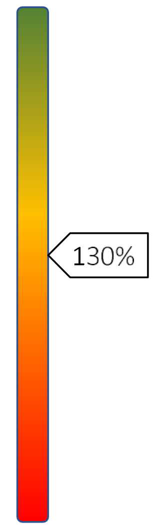


Poker Chip Ductility

#19: 7 years
Left – Photo and coring from Nov. 2021 after a recent overlay; Right – Google Street from April 2021 before the overlay showing cracking

Cracking of Asphalt Binders – Future





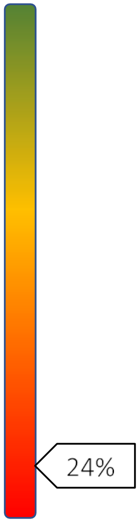
Poker Chip Ductility

#3: 6 years

Note: Left – Nov. 2019 during coring; Middle and Right – Google Street, Dec. 2021

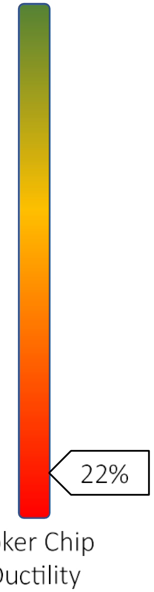
Cracking of Asphalt Binders – Future

#22: 9 years
Photo and coring from Nov. 2021



Poker Chip
Ductility

Cracking of Asphalt Binders – Future



#13: 7 years
Left – Photo and coring from March 2020 after a recent seal coat showing some bleed through cracks; Right – Google Street from April 2018 before seal coat showing cracks

Conclusions

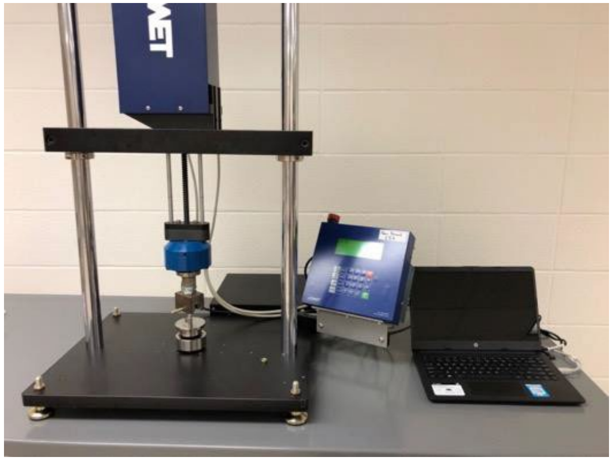
- One additional piece of equipment (≅ 15K)

+ Method ➔ Simple and repeatable

+ Equipment ➔ Low cost, small footprint, plug and play

+ Parameter ➔
    - mechanics based,
    - induces failure and not a stiffness index,
    - measured directly,
    - sensitive to elastomer content,
    - sensitive to aging

+ 87% of field sections had some form of cracking when ductility < 150%



Dr. Amy Epps Martin
a-eppsmartin@tamu.edu

TEXAS A&M UNIVERSITY
Engineering

Dr. Ramez M. Hajj
rhajj@illinois.edu

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Dr. Nazimuddin Wasiuddin
wasi@latech.edu

LOUISIANA TECH UNIVERSITY

Dr. Enad Mahmoud
enad.mahmoud@txdot.

Texas Department of Transportation

Other Events for You:

Consider Attending the 2022 TRANSED-DRT 2022 Virtual Conference

Registration is now open for the TRB Committee on Accessible Transportation and Mobility's **TRANSED-DRT 2022 Virtual conference.** Join us on September 12-16, 2022, to address the theme of "Inclusive Accessible and Sustainable Demand Response Transportation". The Conference aims to describe current global research, services to improve mobility and accessibility for individuals with disabilities and for older adults, and best practices in providing demand responsive transportation (paratransit). Access program highlights and register here. https://web.cvent.com/event/2452154a-17ea-464f-a191-12cc0b3284d1/websitePage:18647cf2-f444-46d9-8b37-39c723ad529e

TRB Weekly

The National Academies of
SCIENCES · ENGINEERING · MEDICINE
TRB
TRANSPORTATION RESEARCH BOARD

- Subscribe to the newsletter for the most recent TRB news & research

https://bit.ly/ResubscribeTRBWeekly

TRB’s Podcast!

- Have you heard TRB’s Transportation Explorers?
- Listen on our website or subscribe wherever you listen to podcasts!

#TRBExplorers

Get involved with TRB

- Receive emails about upcoming webinars: https://mailchi.mp/nas.edu/trbwebinars

- Find upcoming conferences: https://www.nationalacademies.org/trb/events

@NASEMTRB
@NASEMTRB
Transportation Research Board

#TRBWebinar

Get Involved with TRB

Getting involved is free!

Be a Friend of a Committee bit.ly/TRBcommittees

– Networking opportunities

– May provide a path to Standing Committee membership

Join a Standing Committee bit.ly/TRBstandingcommittee

Work with CRP https://bit.ly/TRB-crp

Update your information www.mytrb.org