Airfield Perspectives on the MSCR Asphalt Binder Grading System

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Ben C. Cox, PhD, PE
Senior Research Engineer, US Army Corps of Engineers, ERDC
601-634-2376, benjamin.c.cox@usace.army.mil

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Overview

- Objectives for this Multiple Stress Creep Recovery (MSCR) presentation:

  1. Explain what MSCR is – its attributes and potential benefits

  2. Describe who is using it

  3. Discuss implications for airfield applications

Motivations

- The multiple stress creep recovery (MSCR) grading system is gradually replacing the current PG system at the state DOT level

- While nationwide implementation is still some ways off, current implementation levels are widespread enough that it has become a factor for multiple airfield paving projects

- MSCR is sometimes misunderstood as a simple naming convention change due to over-simplification in elevator-pitch-level conversation

- In reality, MSCR captures certain asphalt behaviors better than PG

Standard Specifications and Test Methods

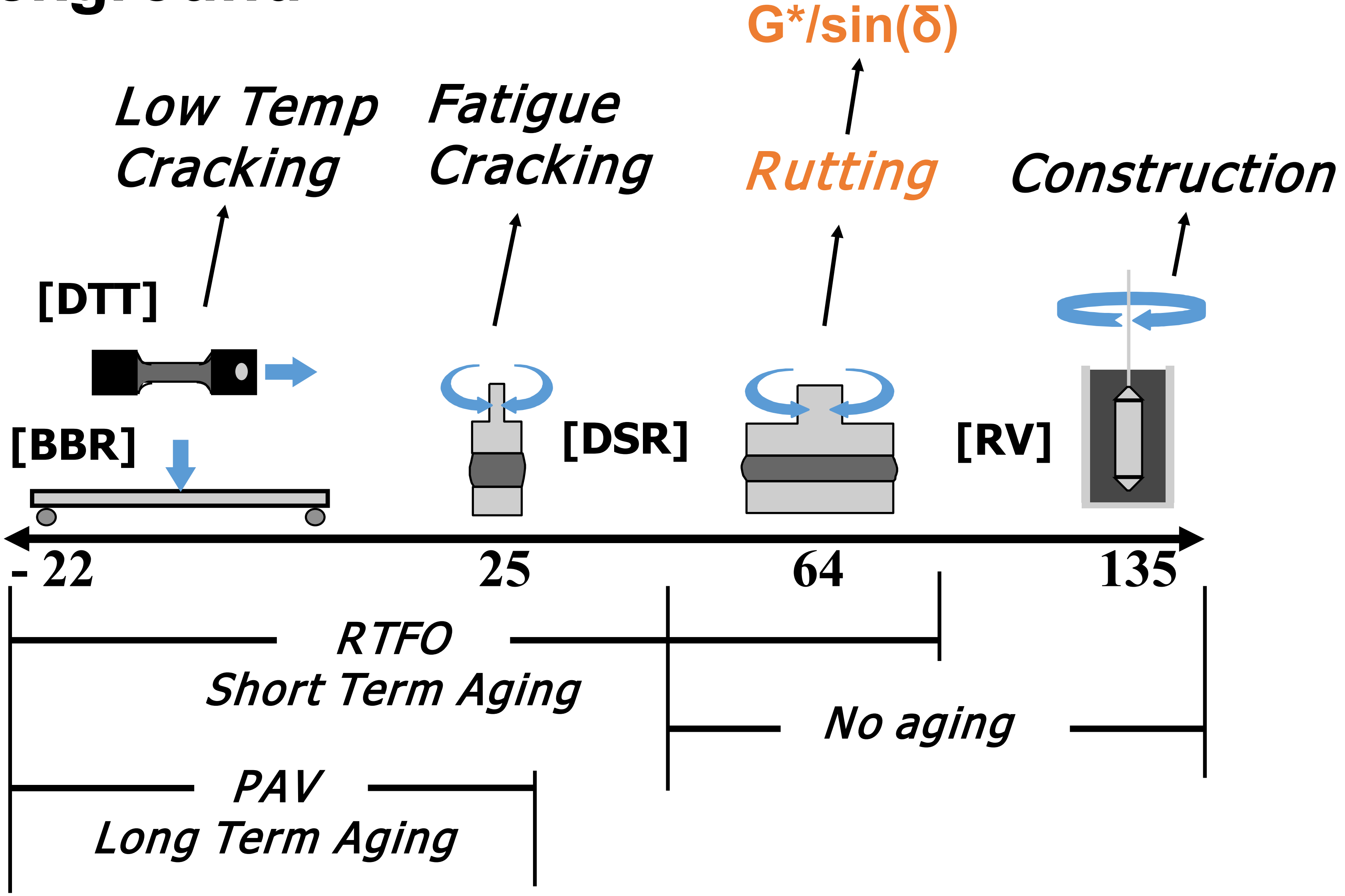
	AASHTO	ASTM
PG Grading System	M320	D6373
DSR Test	T315	D7175
PG+ Elastic Recovery Test	T301	D6084
MSCR Grading System	M332	D8239
MSCR Test	T350	D7405
MSCR Elastic Behavior	R92	n/a

Current UFC and UFGS Guidance

- UFC 3-250-03 (Section 2-3.1)
  - Specify PG wherever possible; otherwise, Pen grades are acceptable
  - States PG+ tests can be used to ensure polymer modification
  - Briefly mentions MSCR is “in the works”
- UFGS 32 12 15.13 (Section 2.4)
  - Specify PG binders wherever possible
  - Grade bump based on tire pressure
    (100-200 psi → +1 grade; +200 psi → +2 grades)
  - Use PG+ testing for polymer-modified binder (elastic recovery)
  - Nothing on MSCR

PG System – Background

- Introduced early 1990s
- Example: PG 64-22
- Dynamic Shear Rheometer (DSR) is used to characterize rutting



PG System – Background

- Rutting assessment developed primarily around
  (1) unmodified asphalts
  (2) G*/sin(δ)

- Based on performance-related properties that were intended to be blind to modification

- Works well for many cases (e.g. neat binders, moderate traffic), less adequate for accurately capturing modified binder performance

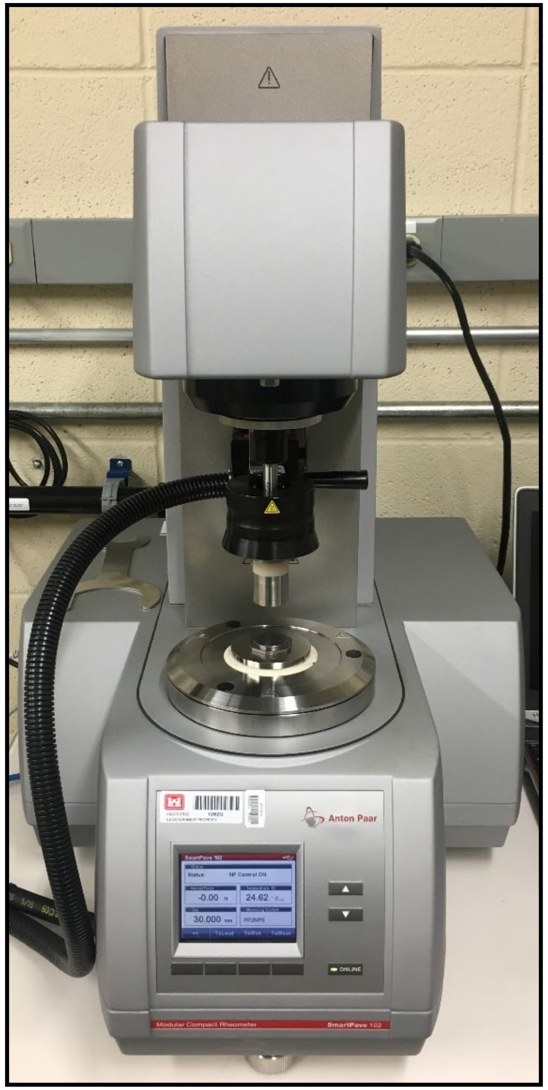
- Needed refinement for slow traffic, high traffic, heavy traffic – led to the simple fix of grade bumping

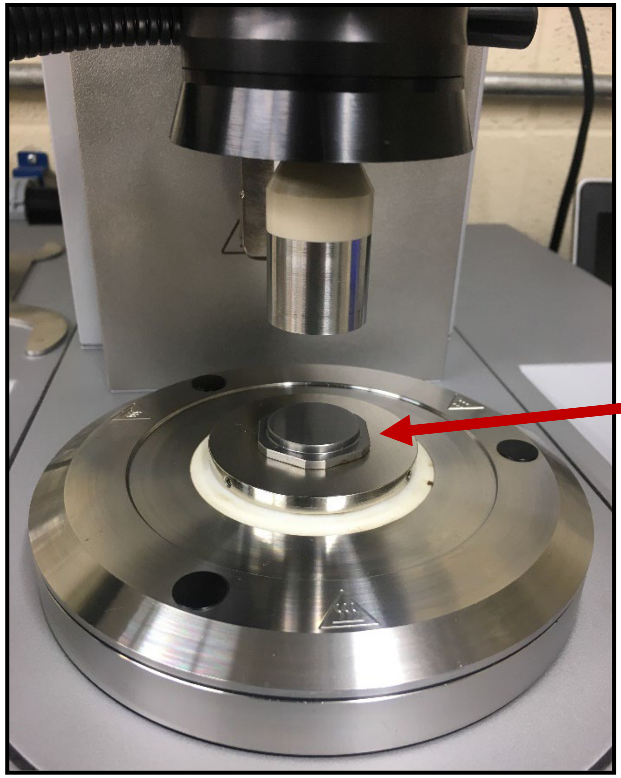
AASHTO M320 – PG Grading Chart

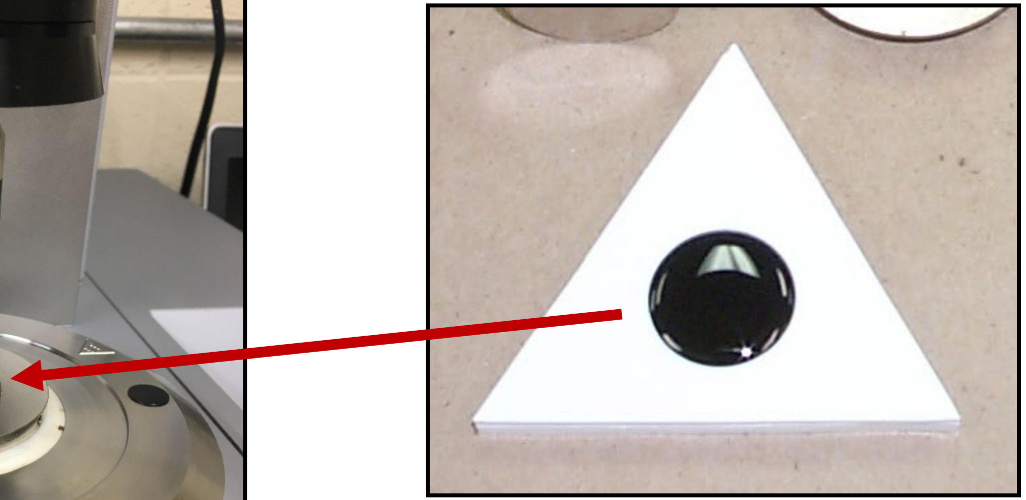
Performance Grades																																					
Max. Design Temp.	PG 46			PG 52							PG 58					PG 64						PG 70						PG 76					PG 82				
Min. Design Temp.	-34	-40	-46	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-10	-16	-22	-28	-34
Original																																					
≥230 °C	**Flash Point**																																				
≤ 3 Pa-s @ 135 °C	**Rotational Viscosity**																																				
≥ 1.00 kPa	**DSR G*/sin δ** (Dynamic Shear Rheometer)																																				
	46			52							58					64						70						76					82				
(Rolling Thin Film Oven) RTFO, Mass Change ≤ 1.00%																																					
≥ 2.20 kPa	**DSR G*/sin δ** (Dynamic Shear Rheometer)																																				
	46			52							58					64						70						76					82				
(Pressure Aging Vessel) PAV																																					
20 hours, 2.10 MPa	90			90							100					100						100(110)						100(110)					100(110)				
≤ 5000 kPa	**DSR G*sin δ** (Dynamic Shear Rheometer) — Intermediate Temp. = [(Max. + Min.)/2] + 4																																				
	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
S ≤ 300 MPa m ≥ 0.300	**BBR S (creep stiffness) & m-value** (Bending Beam Rheometer)																																				
	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24
	If BBR m-value ≥ 0.300 and creep stiffness is between 300 and 600, the Direct Tension failure strain requirement can be used in lieu of the creep stiffness requirement.																																				
$\varepsilon_f \geq 1.00\%$	**DTT** (Direct Tension Tester)																																				
	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24

(Asphalt Institute)

AASHTO M320 DSR





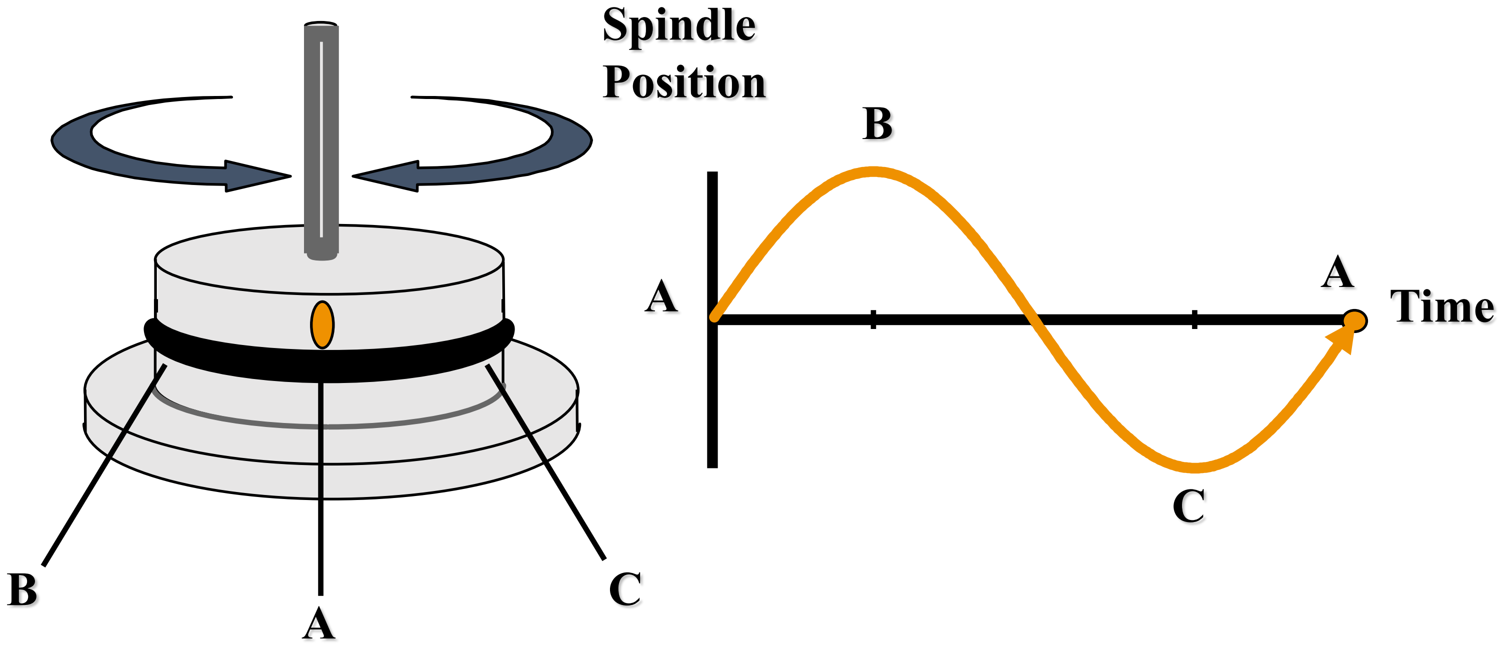


Binder sample is loaded onto 25 mm DSR plates for testing.

DSR testing is performed at a range of temperatures, normally 6 °C increments (e.g. 64, 70, 76 °C).

AASHTO M320 DSR Mechanics

Spindle oscillates from A to B to C to A



Test Outputs: complex modulus (G*), phase angle (δ)

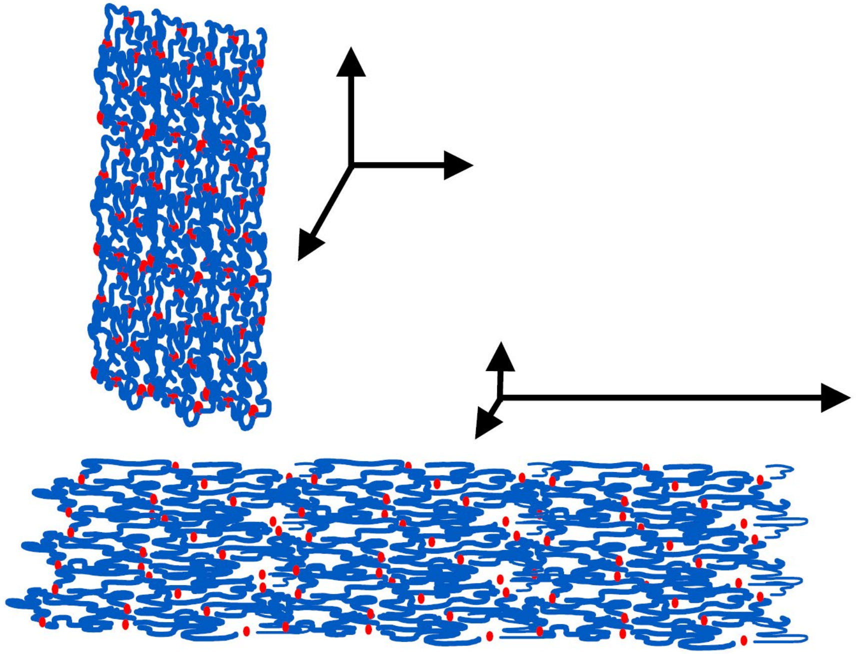
PG System – Concerns

- Grade bumping results in binders being tested at much higher temperatures than would be experienced in the field
- Not all binders exhibit the same temperature sensitivity so grade bumping is not representative of in-service performance
- Conventional DSR testing occurs in the LVE range (low stress/low strain), but damage (rutting/shear failure) does not; damage is a high stress/high strain phenomenon (non-linear)

PG System – Concerns

- Load response for a polymer-modified binder is driven by base binder, entanglement of polymer chains, and extent of polymer cross-linking

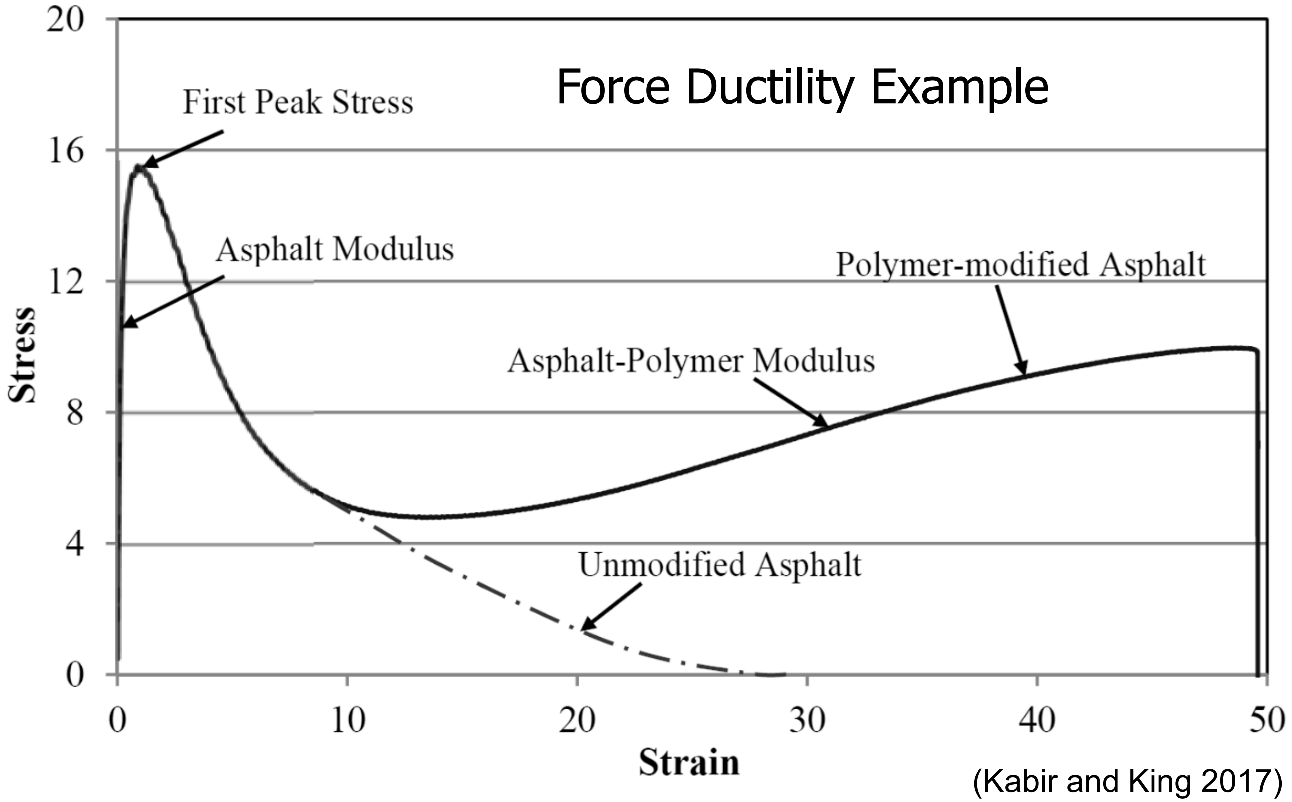
- Polymers increase PG grade but are treated like a filler (stiffens)



(D'Angelo et al. 2007)

PG System – Concerns

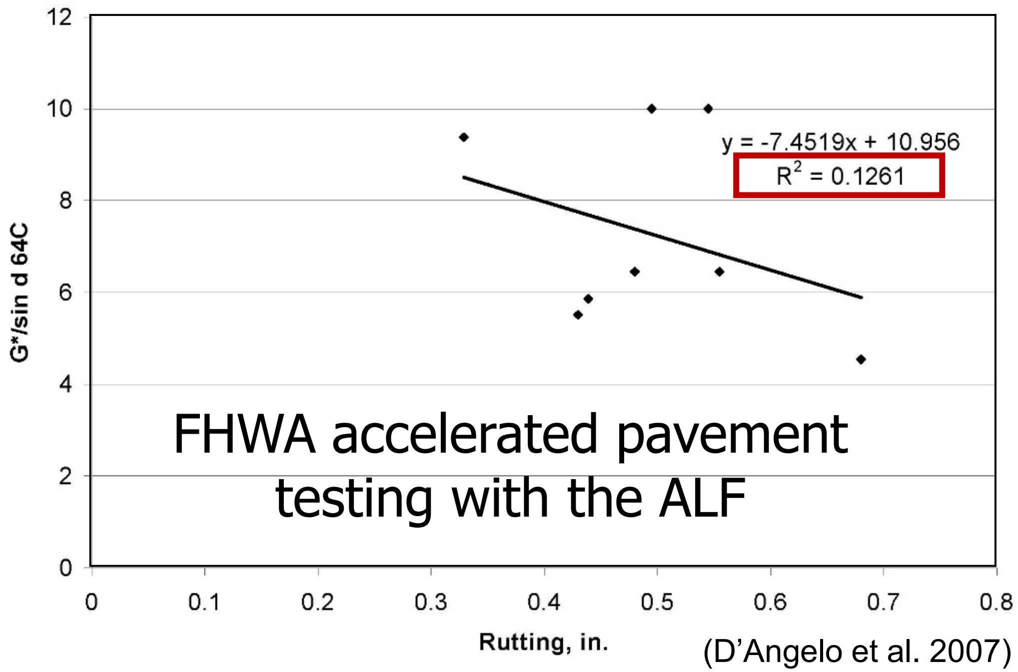
- Stress level in DSR testing is generally not sufficient to mobilize the polymer network structure of modified binders



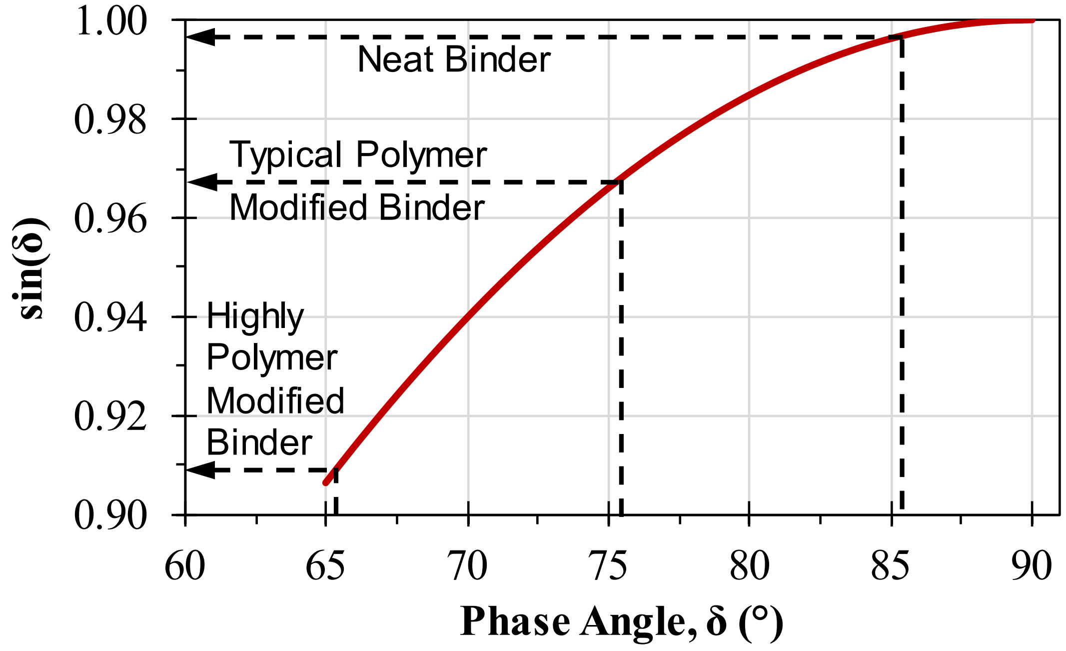
(Kabir and King 2017)

PG System – Concerns

- G*/sin(δ) does not necessarily correlate well to actual rutting
- G*/sin(δ) unable to adequately capture benefits of elastomeric modification b/c of δ's small impact on G*/sin(δ) – led to PG+ tests



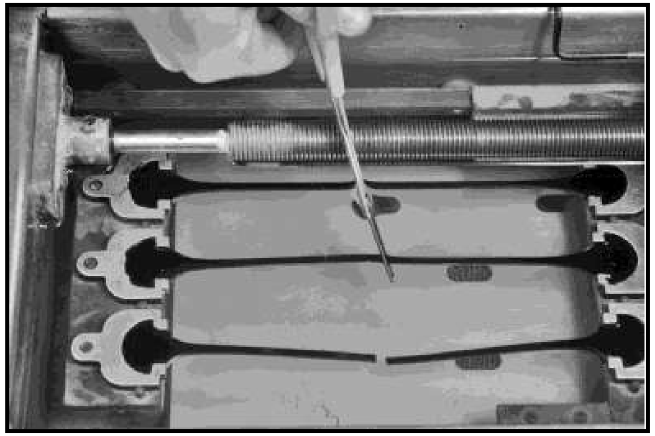
(D'Angelo et al. 2007)

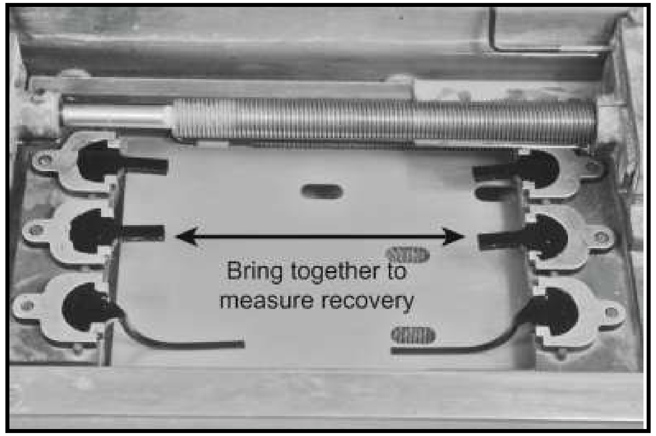


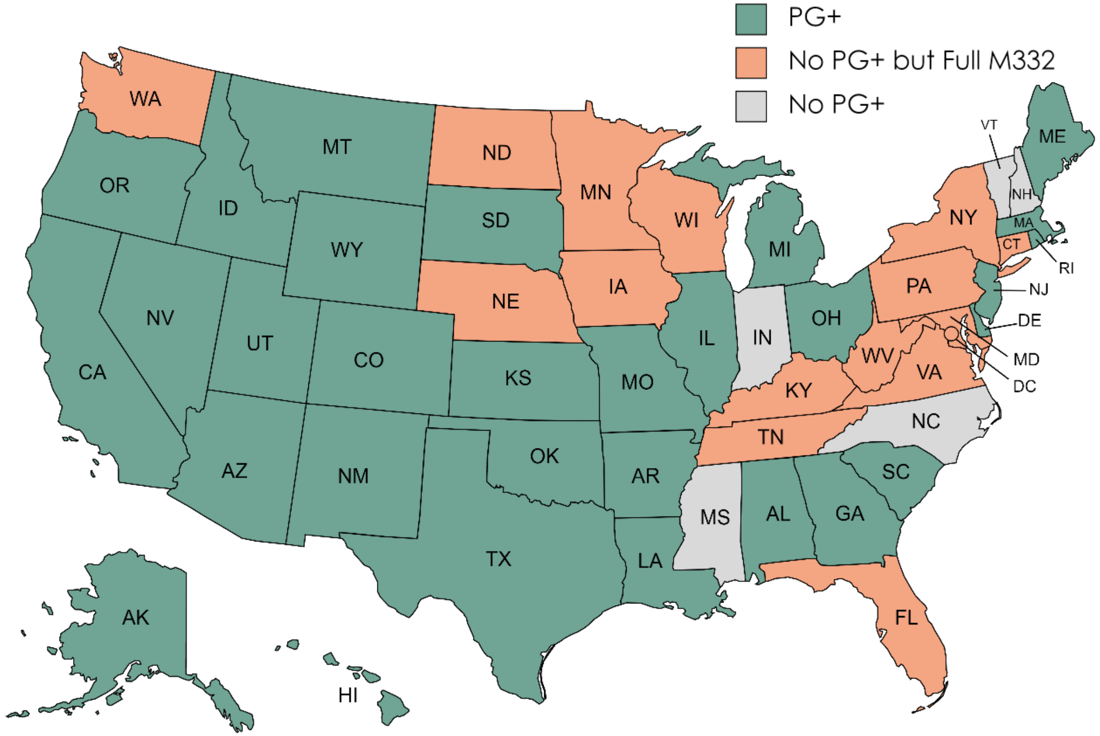
PG+ Tests

- Many utilize PG+ tests (elastic recovery is common – 18 states)
- Can be lengthy and/or complicated to run
- Better indication of polymer *presence* than *performance*

D6084 elastic recovery: ~4 hr to prepare and run test

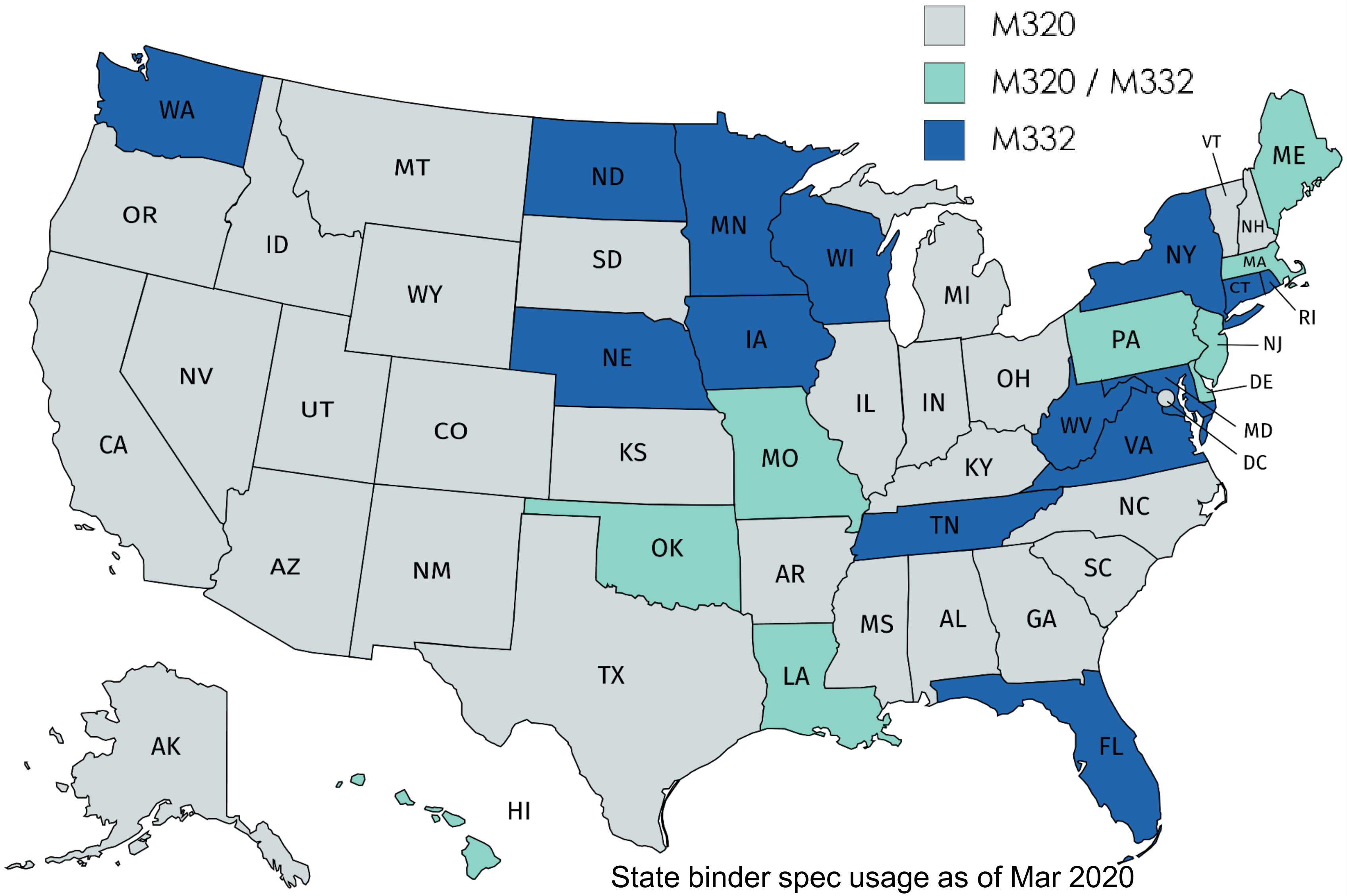






State of Practice – State Agencies (March 2020)

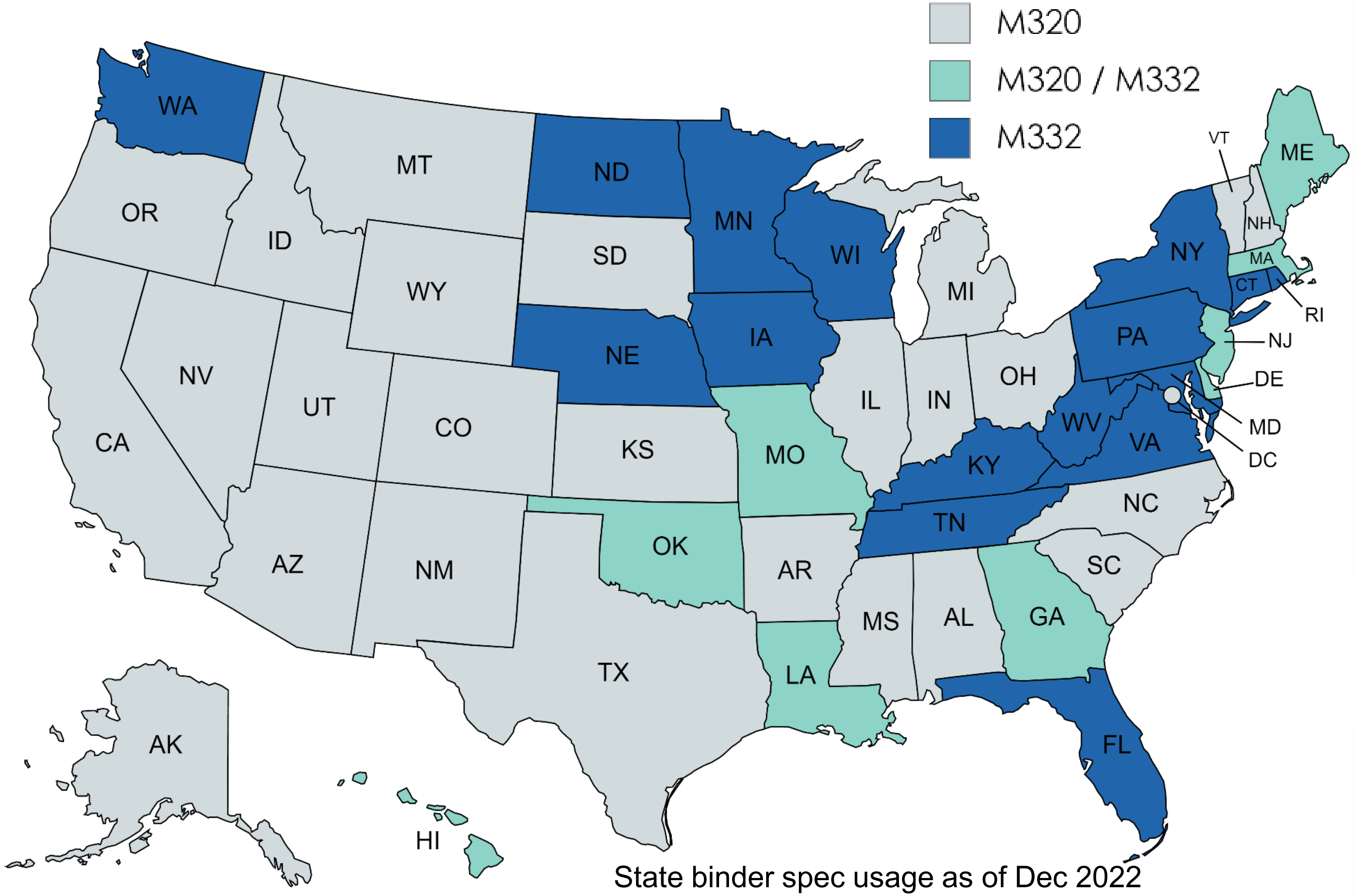
- 15 MSCR states
- 9 dual-use states
- General trend:
  3 states per year adopting MSCR



State binder spec usage as of Mar 2020

State of Practice – State Agencies (December 2022)

- 17 MSCR states
- 9 dual-use states
- Only 2 new states in over 2 years



State binder spec usage as of Dec 2022

AASHTO M332 – MSCR Grading Chart

- Test at climate temperature (no grade bumping)
- Example: PG 64E-22 (generally akin to PG 76-22)

S <10M ESALs and standard speed

H >10M ESALs or slow traffic

V >30M ESALs <u>or</u> standing traffic

E >30M ESALs <u>and</u> standing traffic

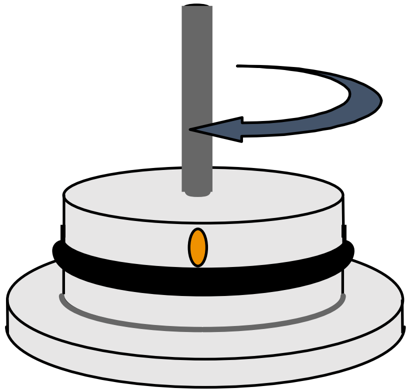
High PG	PG 52	PG 58	PG 64	PG 70	PG 76
Low PG	-10 | -16 | -22 | -28 | -34 | -40 | -46	-16 | -22 | -28 | -34 | -40	-10 | -16 | -22 | -28 | -34 | -40	-10 | -16 | -22 | -28 | -34 | -40	-10 | -16 | -22 | -28 | -34
Original NO CHANGE TO TESTING					
≥230 °C	**Flash Point,** AASHTO T 48				
≤ 3 Pa-s	**Rotational Viscosity** @ 135° C, AASHTO T 316				
≥ 1.00 kPa (S H V E)	**DSR G*/sin δ** (Dynamic Shear Rheometer), AASHTO T 315				
	52	58	64	70	76
RTFO (Rolling Thin Film Oven), AASHTO T 240					
≤ 1.00%	**Mass Change**				
≤ 4.5 kPa^{-1} S ≤ 2.0 kPa^{-1} H ≤ 1.0 kPa^{-1} V ≤ 0.5 kPa^{-1} E	**MSCR $J_{nr, 3.2}$** (Multiple Stress Creep-Recovery), AASHTO T 350				
	52	58	64	70	76
≤ 75% (S H V E)	**MSCR $J_{nr, Diff}$** (Multiple Stress Creep-Recovery), AASHTO T 350				
	52	58	64	70	76
PAV (Pressure Aging Vessel), AASHTO R28 NO CHANGE TO TESTING					
	90	100	100	100(110)	100(110)
≤ 5000 kPa S ≤ 6000 kPa H ≤ 6000 kPa V ≤ 6000 kPa E	**DSR G*sin δ** (Dynamic Shear Rheometer), AASHTO T 315				Intermediate Temp. = [(High PG + Low PG)/2] + 4
	25 | 22 | 19 | 16 | 13 | 10 | 7	25 | 22 | 19 | 16 | 13	31 | 28 | 25 | 22 | 19 | 16	34 | 31 | 28 | 25 | 22 | 19	37 | 34 | 31 | 28 | 25
S ≤ 300 MPa m ≥ 0.300	**BBR S (creep stiffness) & m-value** (Bending Beam Rheometer), AASHTO T 313				
	0 | -6 | -12 | -18 | -24 | -30 | -36	-6 | -12 | -18 | -24 | -30	0 | -6 | -12 | -18 | -24 | -30	0 | -6 | -12 | -18 | -24 | -30	0 | -6 | -12 | -18 | -24

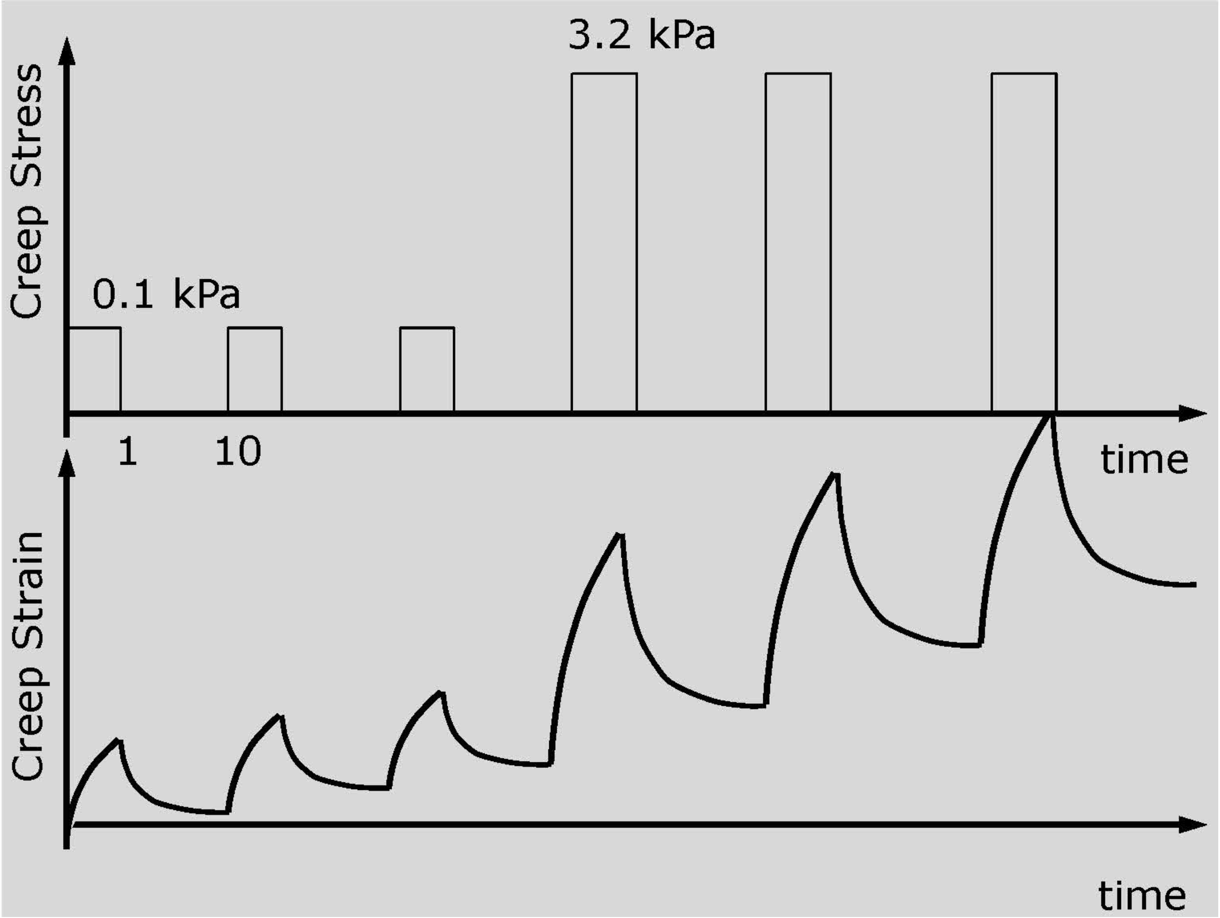
(Asphalt Institute)

AASHTO M332 (MSCR) DSR Mechanics

- Test at two stress levels 0.1 and 3.2 kPa

- 1 cycle = 1 sec creep loading then 9 sec recovery





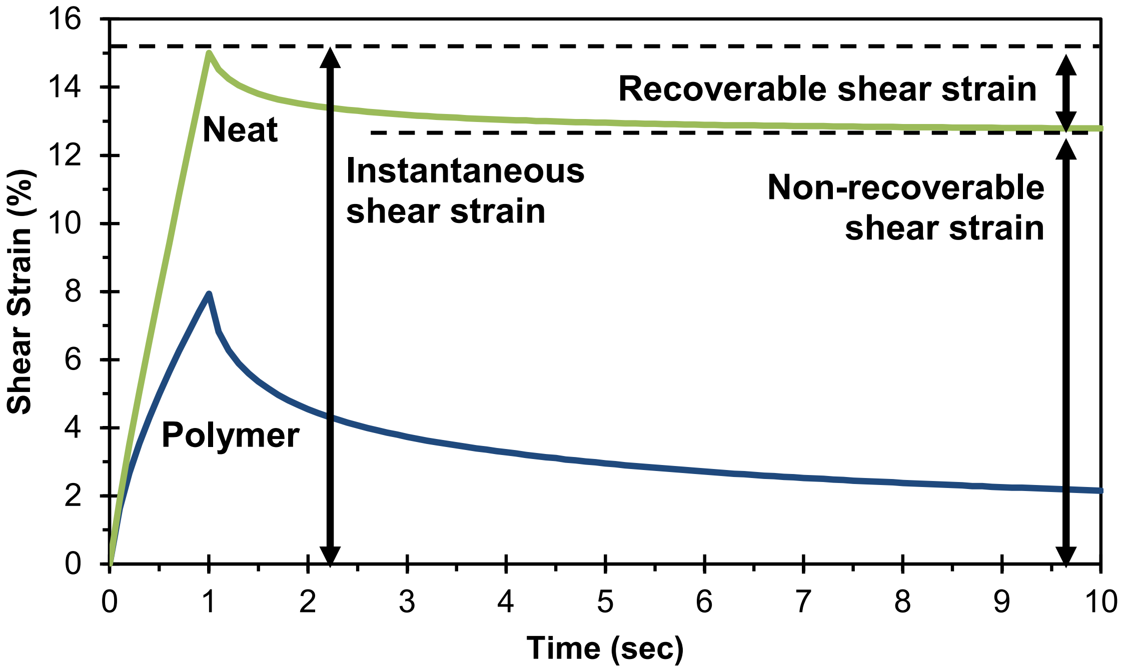
(D'Angelo and Dongre 2009)

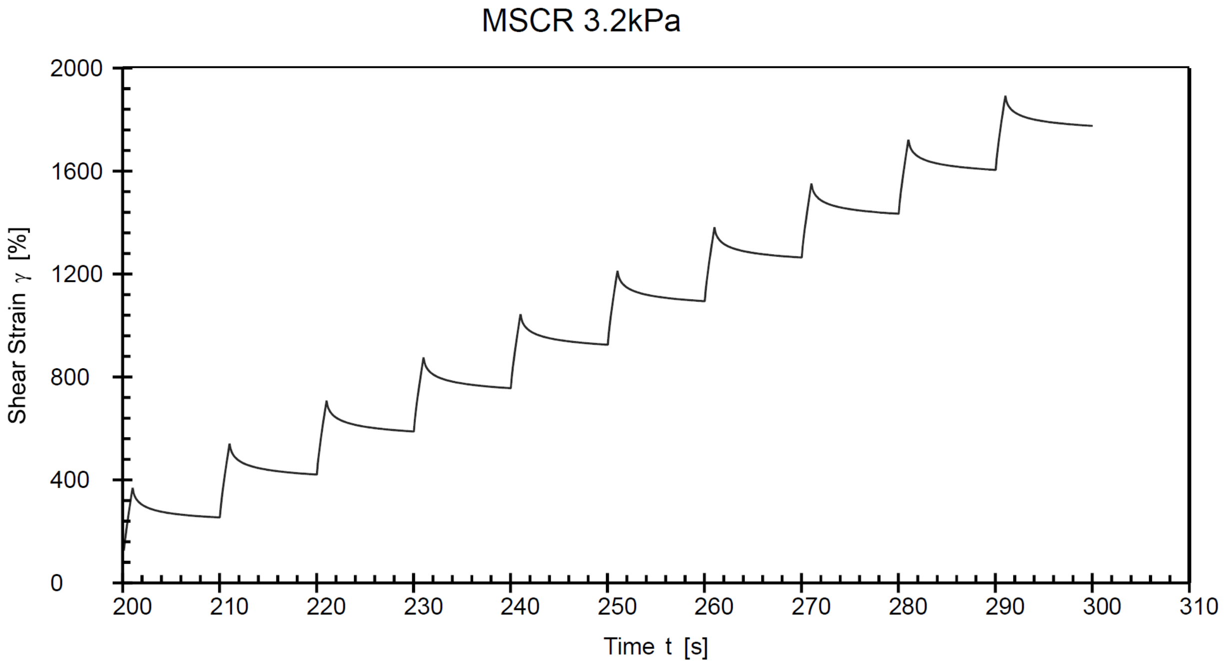
Test Outputs: non-recoverable creep compliance (J_{nr}), recovery (R)

AASHTO M332 (MSCR) DSR Mechanics

$$J_{nr} = \frac{\text{Non-recoverable (nr) shear strain}}{\text{Applied Shear Stress (0.1 or 3.2 kPa)}}$$

$$\%Rec = \frac{\text{Recoverable shear strain}}{\text{Instantaneous shear strain}}$$





MSCR System – Advantages w.r.t. PG System

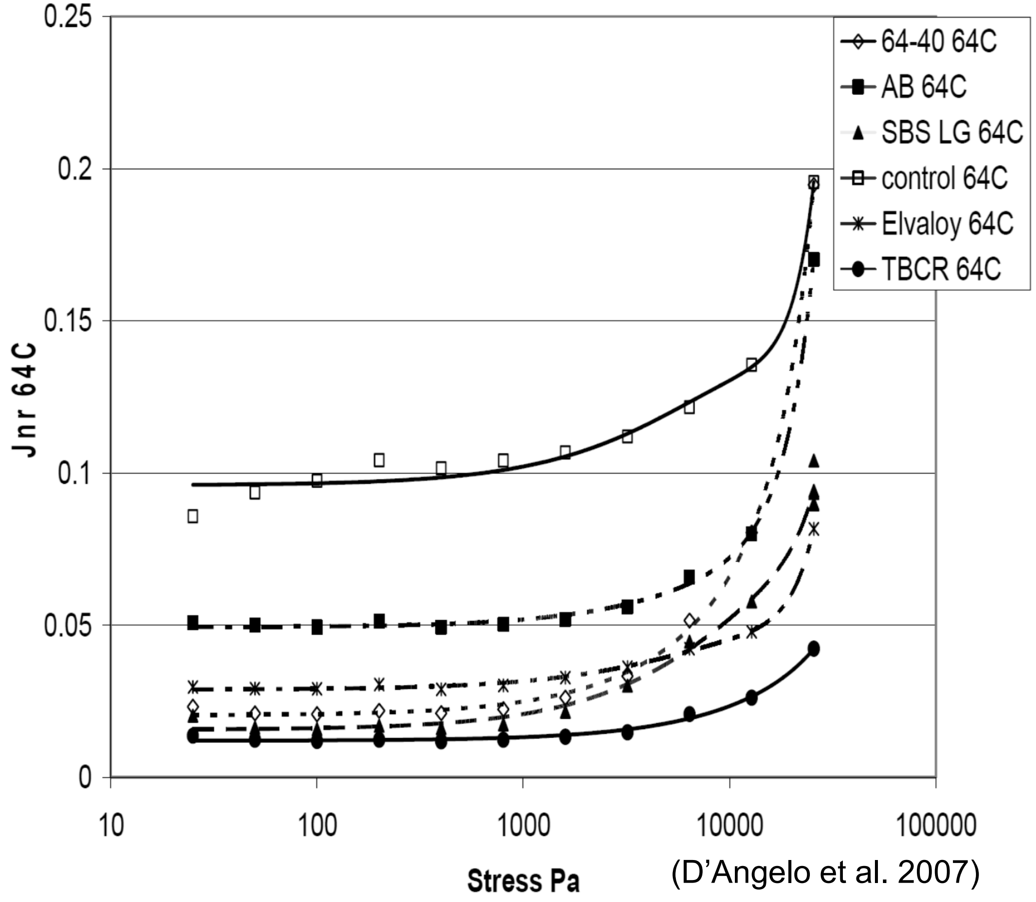
- Grade bumping is not necessary – all testing occurs at the anticipated in-service temperature – more representative

- J_{nr} better correlates to field rutting for <u>both</u> neat & modified binders

- %Recovery can replace other PG+ tests – faster/easier and does a better job of quantifying polymer modification

MSCR System – Advantages w.r.t. PG System

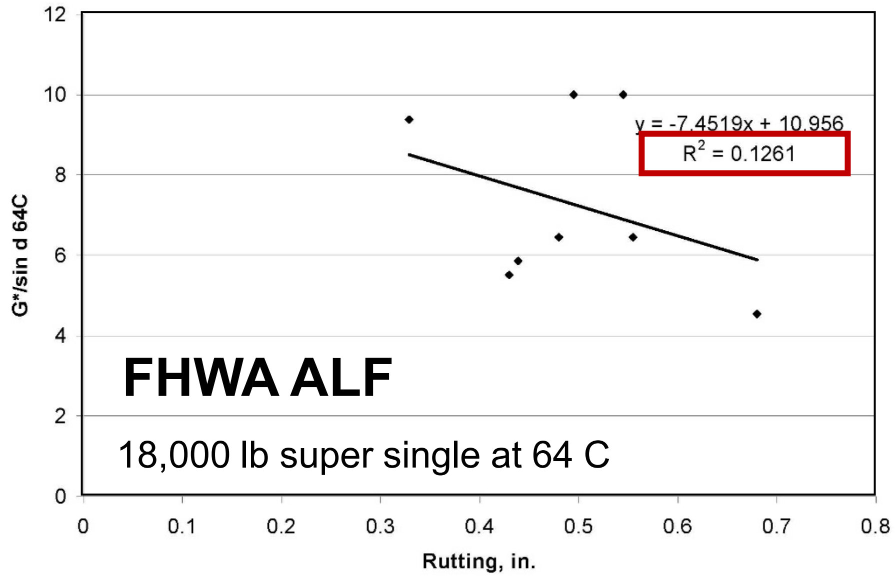
- Testing at higher stress level better characterizes polymer modification
- Testing at two stress levels provides stress sensitivity check ($J_{nr,diff}$)
- Polymer disentanglement is a contributing factor to stress sensitivity

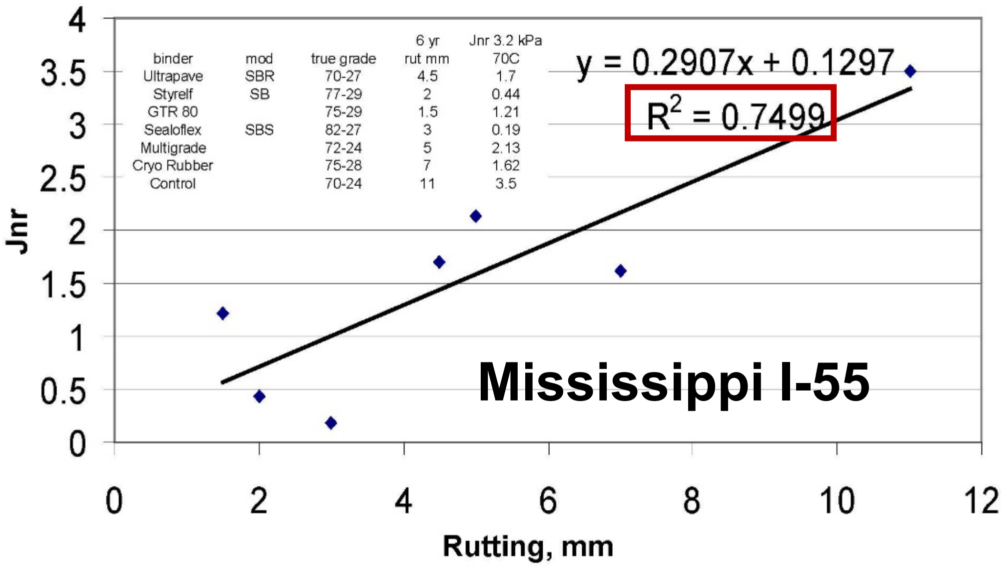


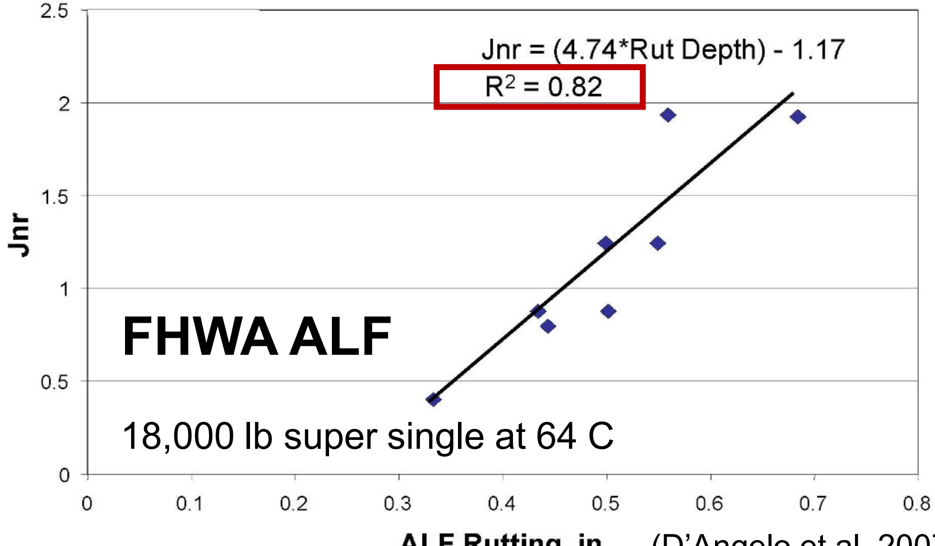
(D’Angelo et al. 2007)

J_{nr} vs G*/sin(δ)

- Multiple studies (lab, APT, interstate) have shown J_{nr} relates better to rutting than G*/sin(δ)
- R^2 of 0.75-0.82 (J_{nr}) vs. 0.13 (G*/sin(δ))







(D'Angelo et al. 2007)

MDOT Database

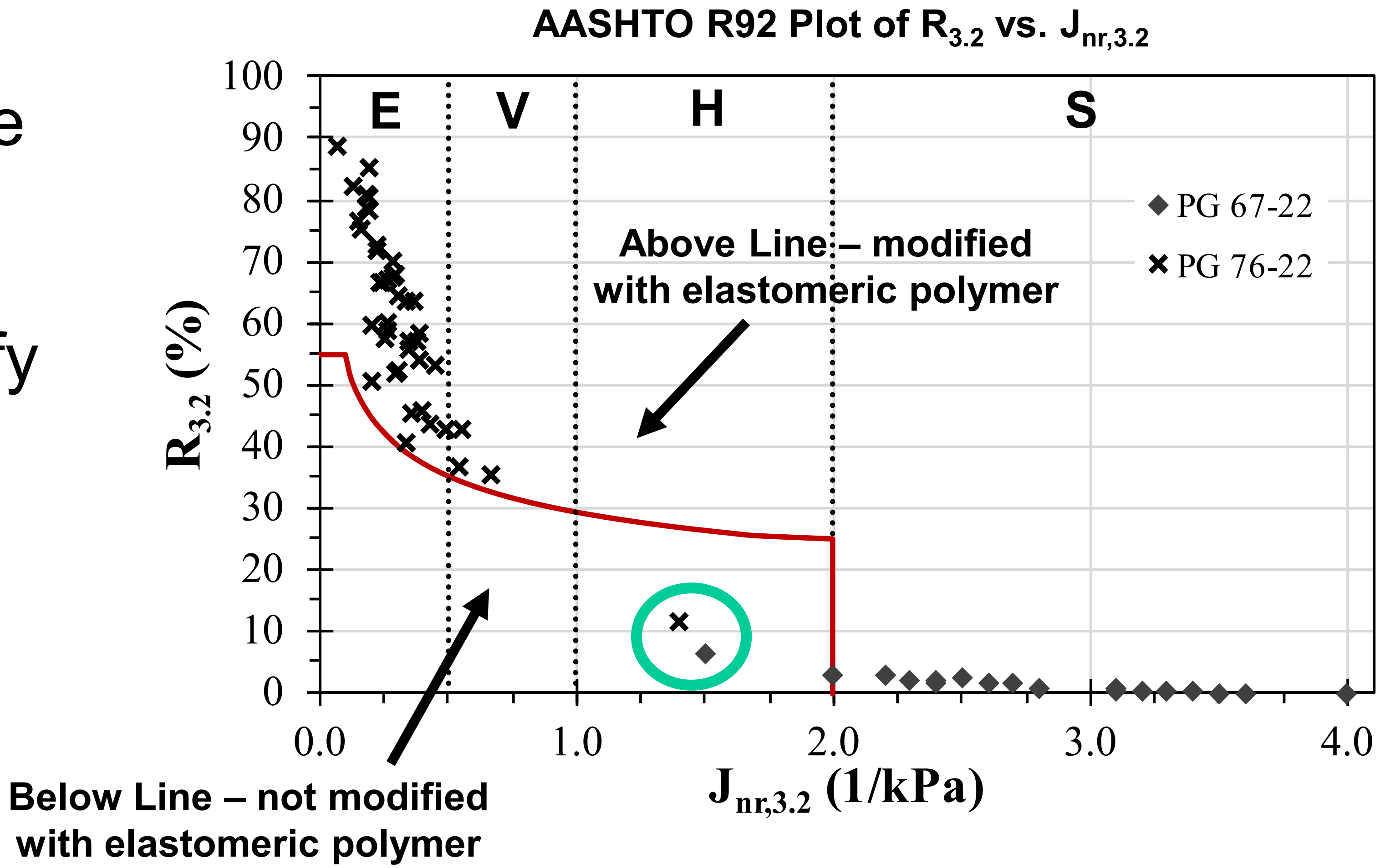
- Mississippi DOT has not yet implemented MSCR but has collected side-by-side data since 2011
- PG 76-22 MSCR grade varies – could be “H”, “V”, or “E”
- One implication is potentially better discrimination with MSCR

PG Grade	Binders Tested	MSCR Grade (tested at 67 C)			
		S	H	V	E
PG 67-22	23	22	1	---	---
PG 76-22	44	---	1	3	40

MDOT Database

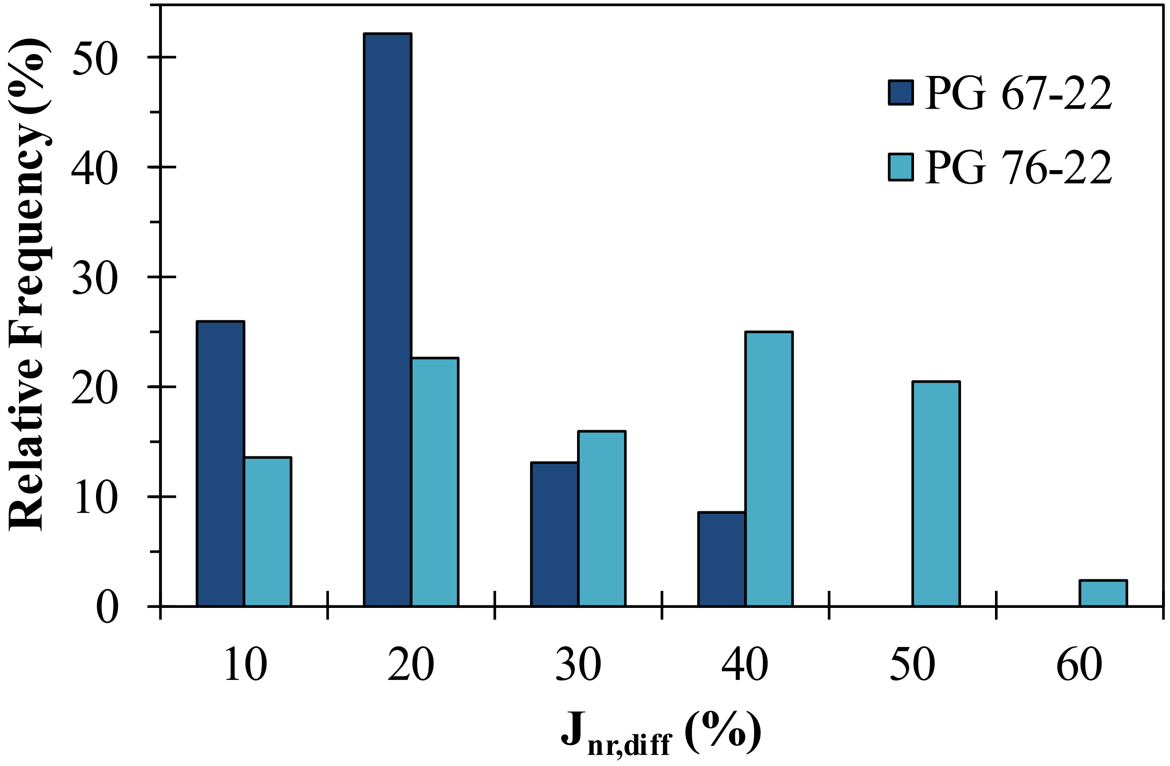
- Polymers often required for reasons other than reduced rutting (reduce cracking, raveling)

- J_{nr} alone cannot identify elastomeric polymers but $R_{3.2}$ can



MDOT Database

- $J_{nr,diff}$ is % difference between $J_{nr,0.1}$ and $J_{nr,3.2}$
- $J_{nr,diff}$ is stress sensitivity parameter
- MDOT data shows higher levels of stress sensitivity in PG 76-22 binders



- This is due to two-phase nature of polymer modified binders; they generally become non-linear above 0.8 kPa stress as polymer chains start to extend and disentangle

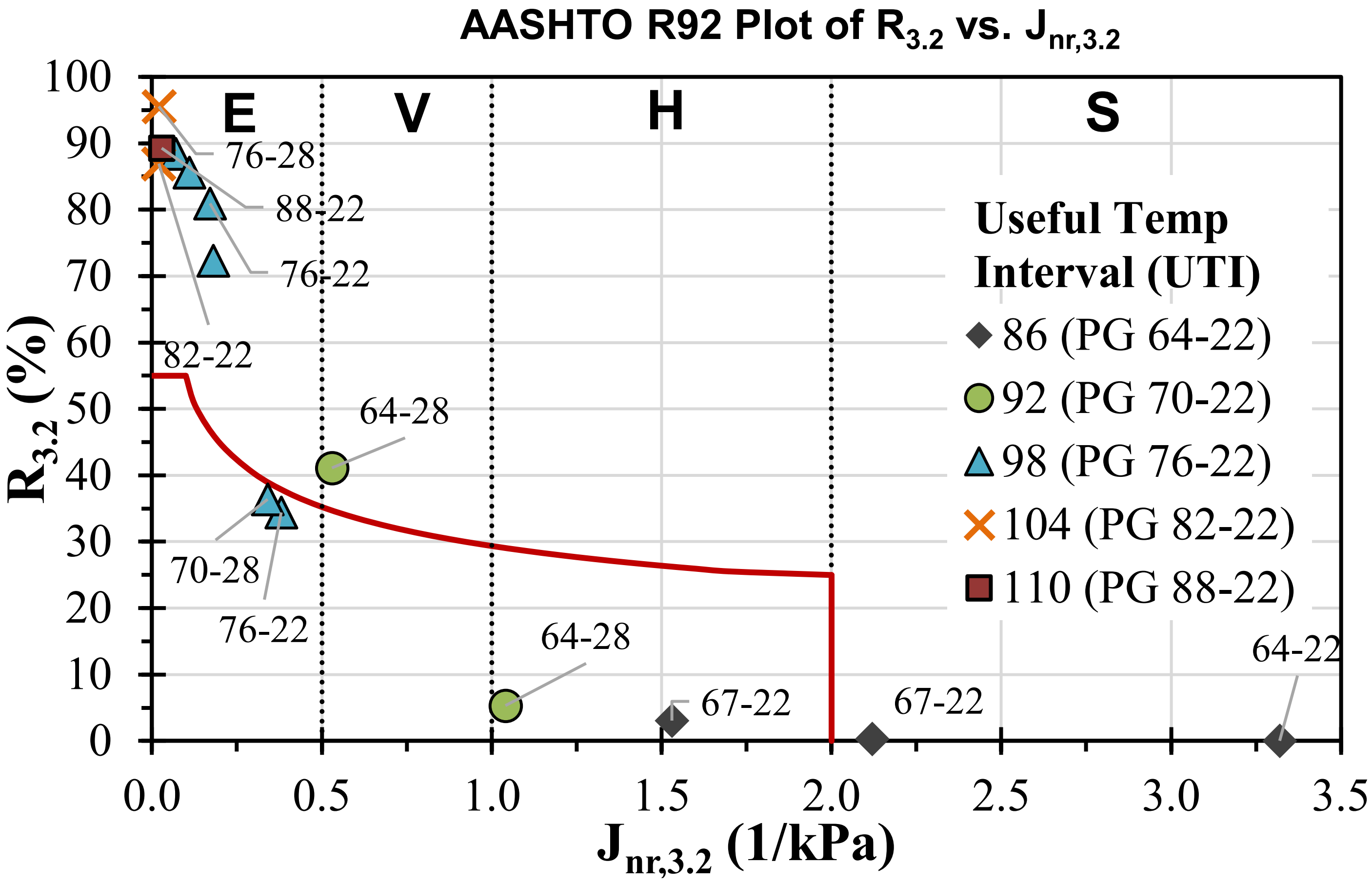
ERDC Testing

PG Grade	UTI	PG			MSCR				Notes
		δ (°)	G*/sin(δ) (kPa)	P/F Temp (°C)	$J_{nr,\ 3.2}$ (1/kPa)	$J_{nr,diff}$ (%)	$R_{3.2}$ (%)	Grade	
PG 64-22	86	83.4	3.12	66.8	3.3	15	0.0	S	---
PG 67-22	89	84.7	2.92	69.1	2.1	13	0.4	S	---
PG 67-22	89	78.2	3.97	71.9	1.5	29	3.1	H	---
PG 76-22	98	63.3	2.25	76.3	0.2	31	81	E	---
PG 76-22	98	73.1	3.33	80.0	0.4	39	34	E	---
PG 76-22	98	65.8	3.01	79.4	0.2	47	72	E	---
PG 82-22	104	61.3	2.39	95.1	0.0	70	87	E	---
PG 88-22	110	60.8	2.61	90.1	0.0	74	89	E	--
PG 64-28	92	77.4	3.77	68.5	1.0	36	5.3	H	---
PG 64-28	92	70.5	4.15	69.9	0.5	33	41	V	---
PG 70-28	98	73.5	3.07	73.2	0.3	38	36	E	---
PG 70-28	98	61.4	3.14	74.3	0.1	38	88	E	---
PG 70-28	98	61.5	2.47	71.4	0.1	86 (F)	86	E	---
PG 76-28	104	46.7	2.70	85.3	0.0	88 (F)	96	E	---
PG 70-22 (Bad)	92	---	---	---	1.4	49	1.4	H	3% SBS (not cross-linked)
PG 76-22 (Bad)	98	78.0	2.40	76.8	1.1	1283 (F)	1.1	H	6% polyethylene (LDPE)
PG 76-22 (Bad)	98	81.5	3.45	73.7	0.3	28	30	E	3% natural latex rubber

ERDC Results

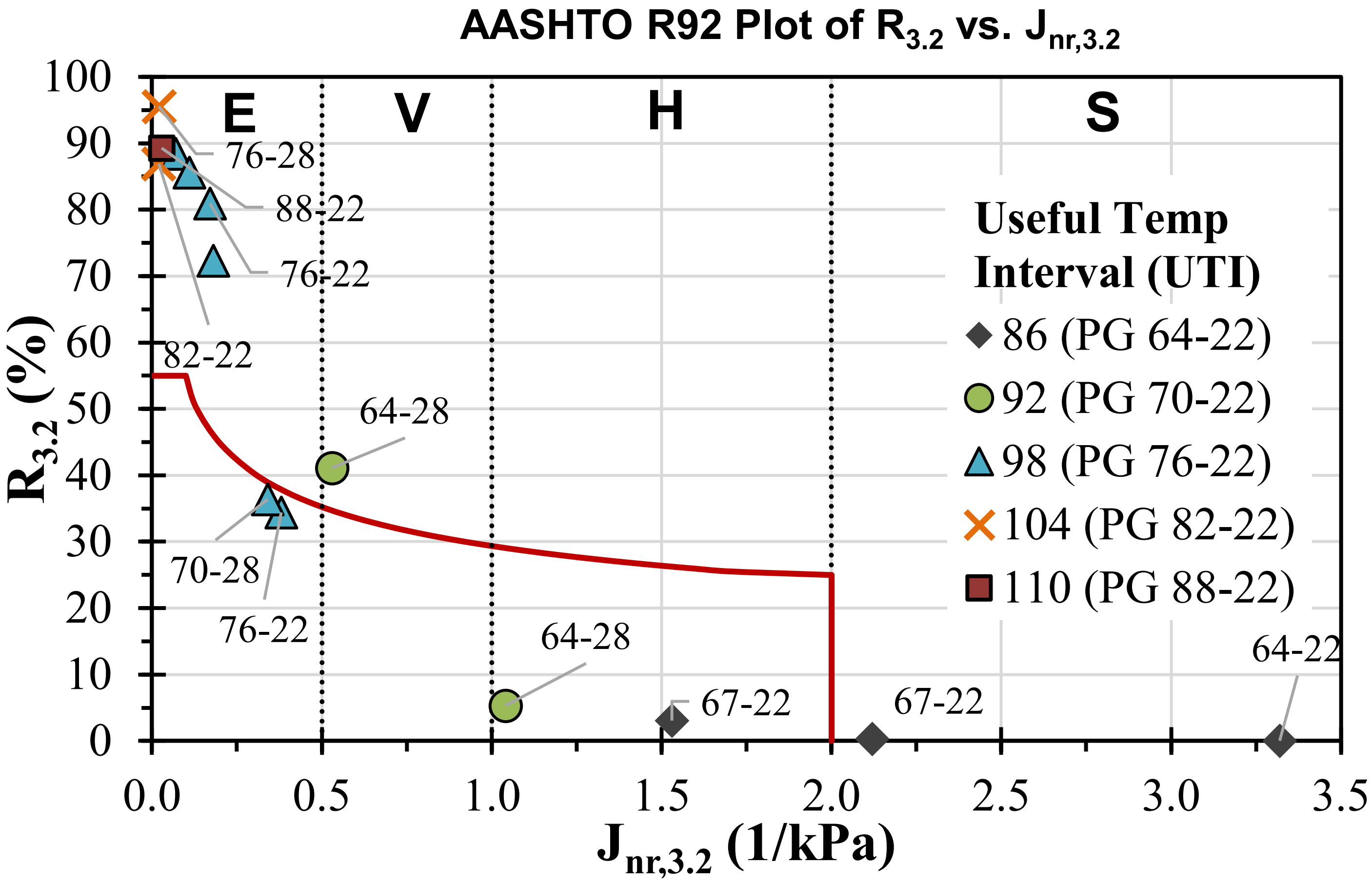
- The two PG 64-28s range from H to V and below to above recovery curve

- The UTI 98 binders are all E grades but there are two distinct groups; one is clearly set apart above recovery curve



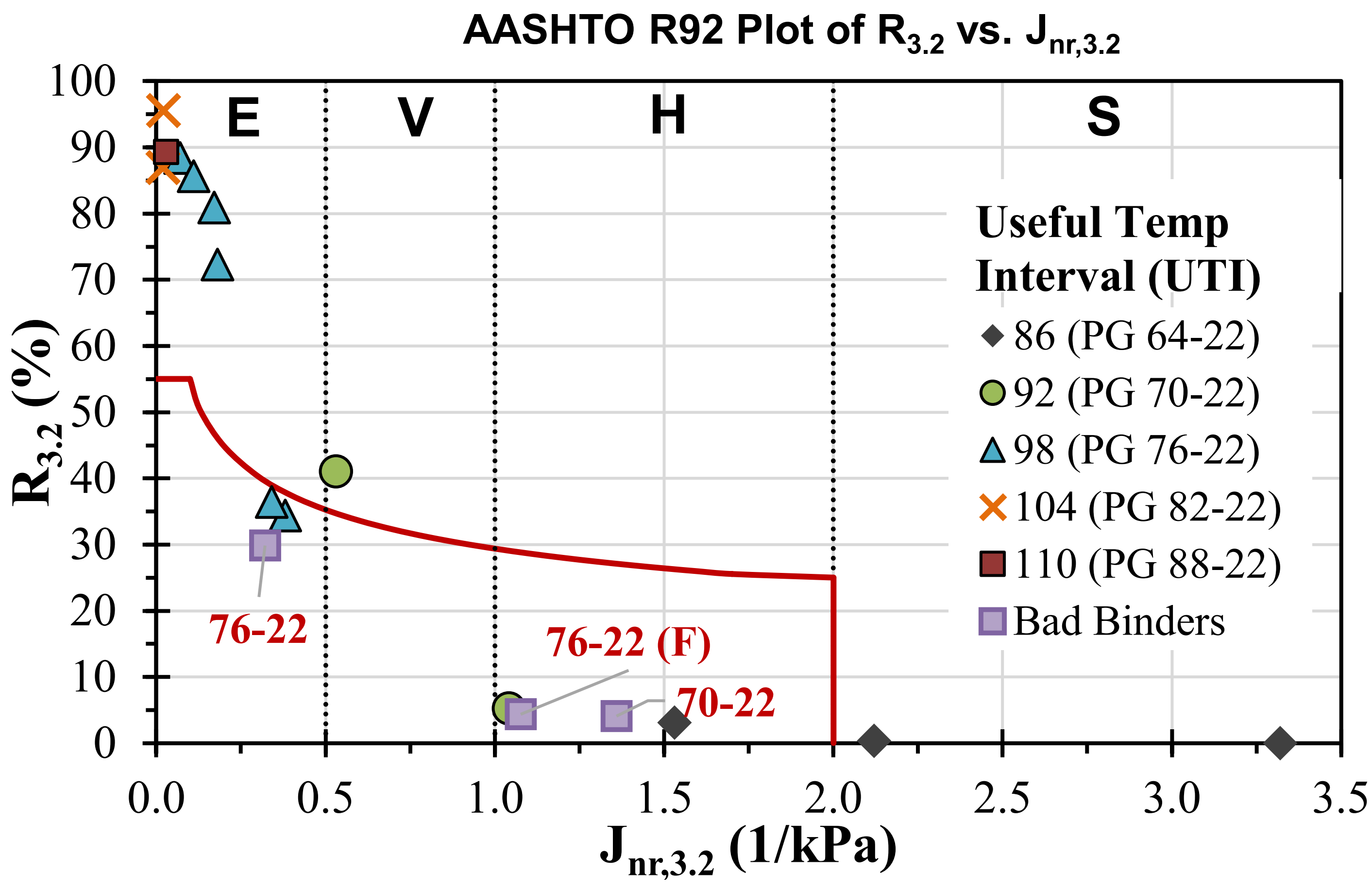
ERDC Results

- Higher-end airfield binders (PG 76-28, 82-22, 88-22) are far to the left of E band
- Not distinct from other E grades – potential drawback to current MSCR letter grades



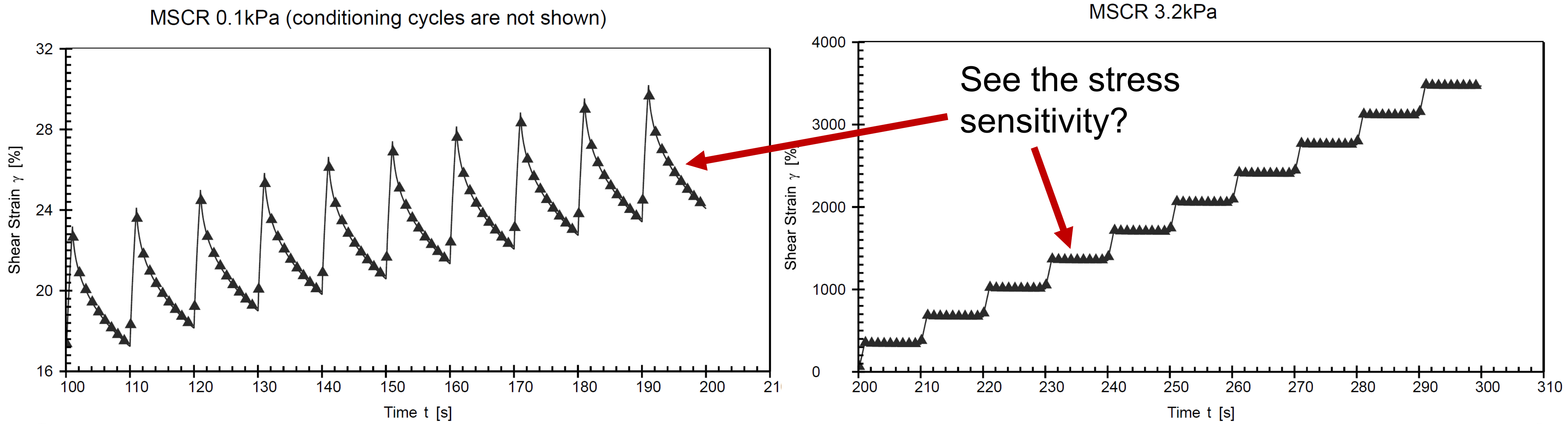
ERDC Results

- Custom-blend "bad" binders shown as reference
- PG 76-22 (3% SBS) was E grade but below curve (it was intentionally not cross-linked)
- PG 76-22 (F) (6% LDPE) was H grade, below curve
- PG 70-22 (3% natural latex rubber) was H grade, below curve



Stress Sensitivity Case

- PG 76-22 (PG 64-22 modified with LDPE)
- MSCR grades it a PG 64H-22, but…
- Fails $J_{nr,diff}$ criteria of <75% – $J_{nr,diff}$ was 1,283%
- This binder would not have been flagged with PG system



State DOT Examples for High Grades

Color-Code Legend
Conventional PG
Conventional MSCR
Non-conventional

- Additional letter grade
  - Iowa adopted an additional E+ grade ($J_{nr} < 0.5$, $R_{3.2} > 90\%$)
    64-22S, 64-22H, 64-22V, 64-22E, 64-22E+
- Combination PG grade bump and MSCR
  - Maine allows PG 64-28, PG 64E-28, and PG 70E-28
  - Rhode Island allows PG 64S-28, PG 64E-28, and PG 70E-34
- Combination PG grade bump, MSCR, additional letter grade
  - Virginia's HP binder is PG 76E-28 (HP) (tested at 76 C, $J_{nr} < 0.1$, $R_{3.2} > 90\%$)

Summary

- MSCR at higher stress levels is better related to rutting than PG and is also informative regarding stress sensitivity and elastic properties without the need for additional tests (i.e., PG+ tests)

- Some questions remain with regard to airfield implementation
  - MSCR system was developed around highway loadings…appropriate?
  - How should highly modified binders (e.g. PG 82-22, PG 88-22) be distinguished from other E grades like PG 76-22?
    - Add additional requirements?
    - “Grade bump” via increased stress level (e.g., 10 kPa as in Golalipour et al. 2017)? This likely requires research.

- Overall, MSCR has room for growth relative to PG and should be considered (dual spec at minimum to handle supply in MSCR states)

- Even if MSCR is not specified in full, replace elastic recovery with MSCR $R_{3.2}$ – simpler, quicker, easier, equipment more readily available, better discretion

Questions?

ERDC Asphalt Materials Research Lab

Ben Cox, Benjamin.C.Cox@usace.army.mil, 601-634-2376

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