Texas A&M Transportation Institute

Lives, Time and Resources

Characterizing the Effectiveness of Recycling Agents and their Evolution with Aging in Binders and Mixtures with High RAP and/or RAS Contents

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NCHRP 9-58: The Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios

TTI

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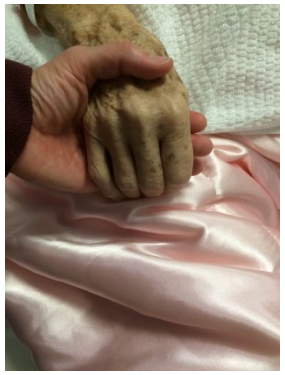
Motivation – High Recycled Binder Ratio (RBR)
Mitigation – Recycling Agent (RA)

BENEFITS

- ✓ Economic
- ✓ Environmental
- ✓ Engineering



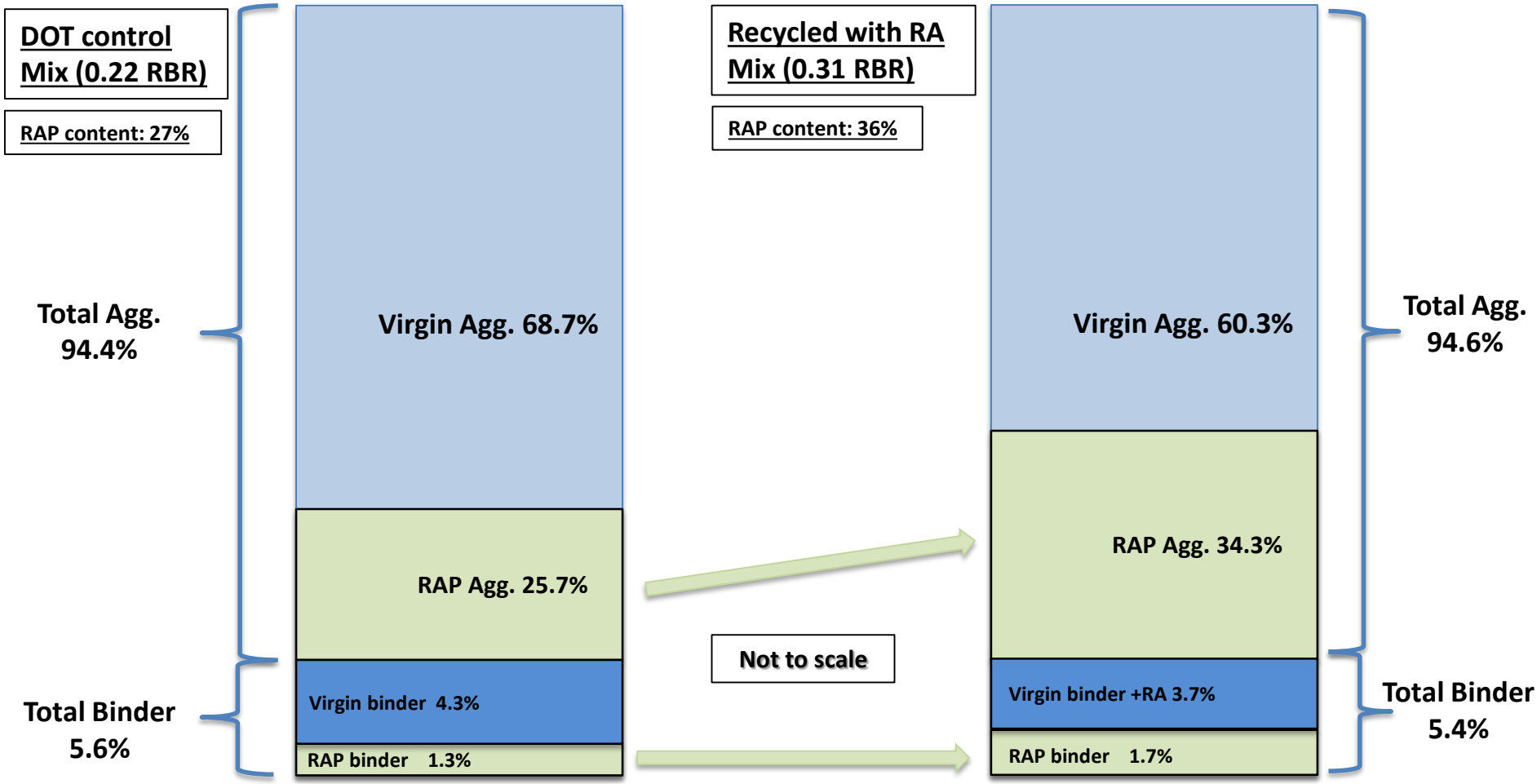
REMAINING ISSUES

? Engineering

- Embrittlement
- Aging
- Blending

- Mixture Performance

WI DOT & Recycled with RA



NCHRP 9-58 Research Plan

PHASE I

Identification of Gaps in Knowledge on RA Use with High RBRs

- **Task 1.** Gather Information
- **Task 2.** Design Laboratory Experiment
- **Task 3.** Document Results in First Interim Report

PHASE II

Investigation of Effectiveness of RAs in Restoring Binder Rheology, Development of Blending Protocol, and Associated Mixture Performance

- **Task 4.** Conduct Laboratory Experiment
- **Task 5.** Design Field Experiment and Document Results in Second Interim Report

PHASE III

Validation of RA Use in Mixtures with High RBRs

- **Task 6.** Conduct Field Experiment
- **Task 7.** Propose Revisions to AASHTO Specifications and Test Methods
- **Task 8.** Develop Training Materials and Best Practices and Deliver Workshop
- **Task 9.** Document Results in Final Report

Phase II Laboratory Tests – BINDER & MORTAR

- PG - BOTH

$$\Delta T_c = (T_S - T_m)$$

- Glover-Rowe

$$G\text{-}R = \frac{G^*(cos\delta)^2}{sin\delta}$$ @ 15 °C, 0.005 rad/sec

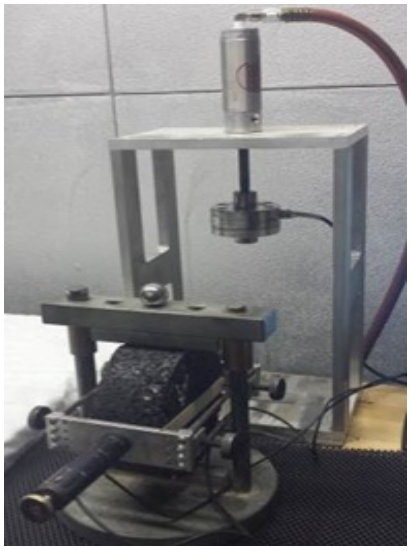
Rejuvenating Effectiveness

$$RE = \frac{(log\,G\text{–}R_{DOT\ Control} - log\,G\text{–}R_{Recycled})}{log\,G\text{–}R_{DOT\ Control}} * 100$$

- Carbonyl Area Growth by FT-IR

Phase II Laboratory Tests - MIXTURE

- Stiffness
  - M_R @ 25 °C
  - E*
- Cracking Resistance
  - FI by SCB
  - N_f by S-VECD
  - RI by UTSST



Phase II TX (Expanded) Materials

- **TX: PG 64-22 + 0.28 RBR (0.1 RAP+0.18 MWAS) + 2.7% Tall Oil T1 (Target=PG 70-22)**

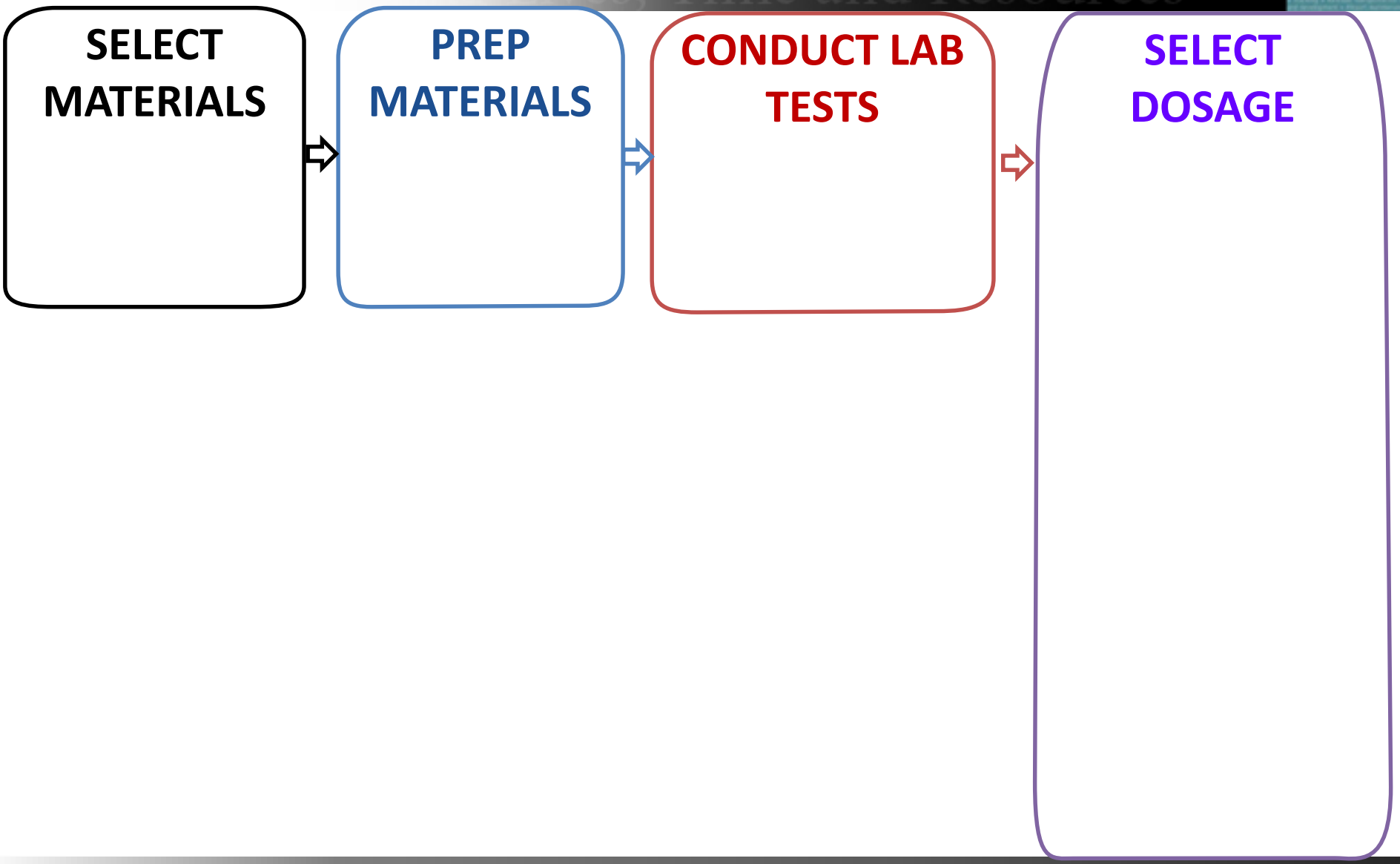
- **+ 0.4 RBR** w/RAP only, **0.5 RBR** balanced RAP/RAS
- **+ Aromatic Extract A1**
- **+ NH PG 64-28** & **NV PG 64-28P**
- **+ TX TOAS**

RECYCLING AGENT (RA) DOSAGE SELECTION METHOD

1 Restore PGL/Check PGH

2 Restore ΔT_c

3 Restore PGH


SELECT MATERIALS
PREP MATERIALS
CONDUCT LAB TESTS
SELECT DOSAGE

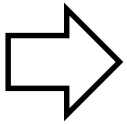
SELECT MATERIALS

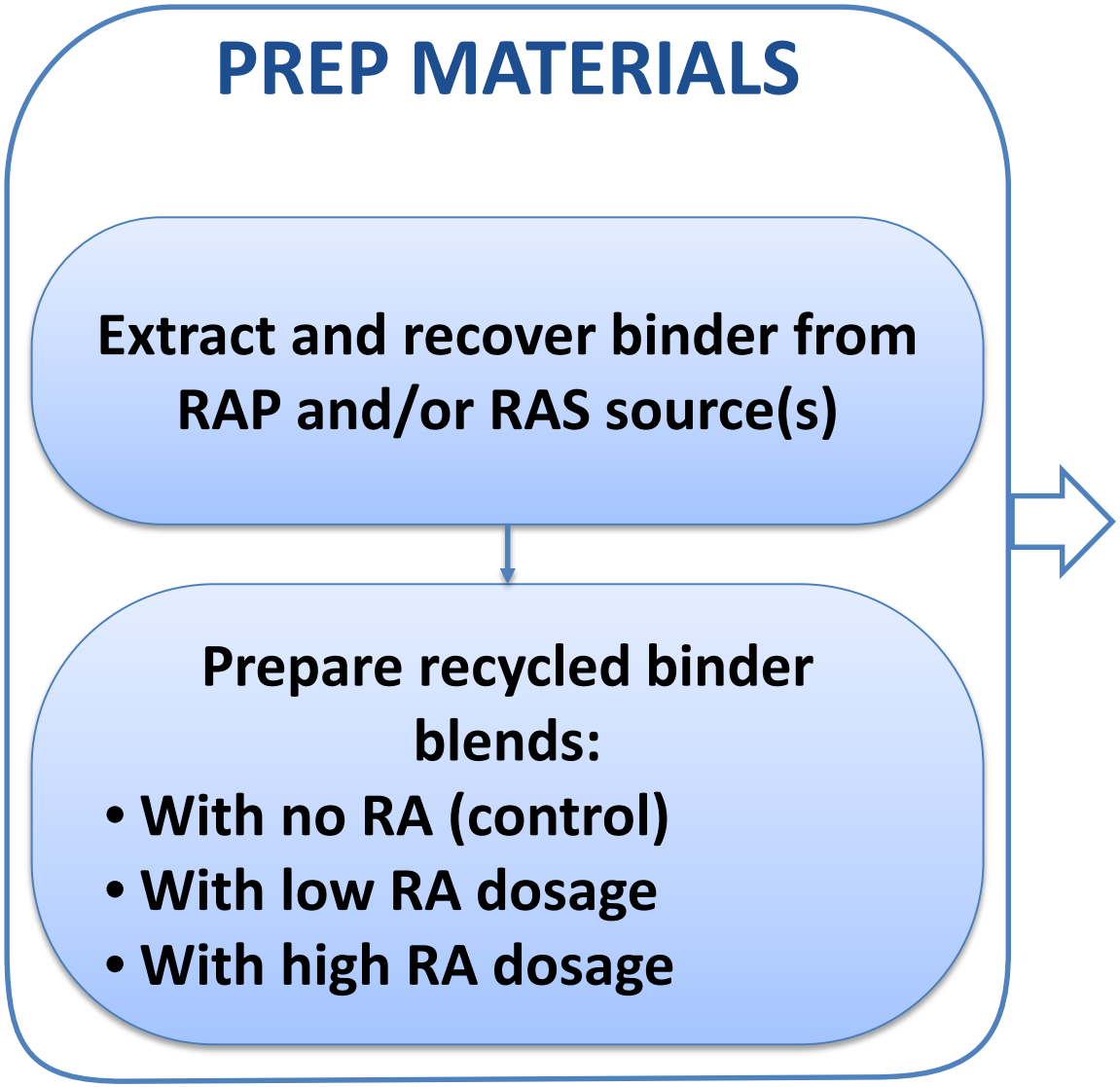
Target and base binder PG grade

RAP and/or RAS source(s)

Recycling Agent (RA)

RAP and/or RAS Recycled Binder Ratio (RAPBR/ RASBR)

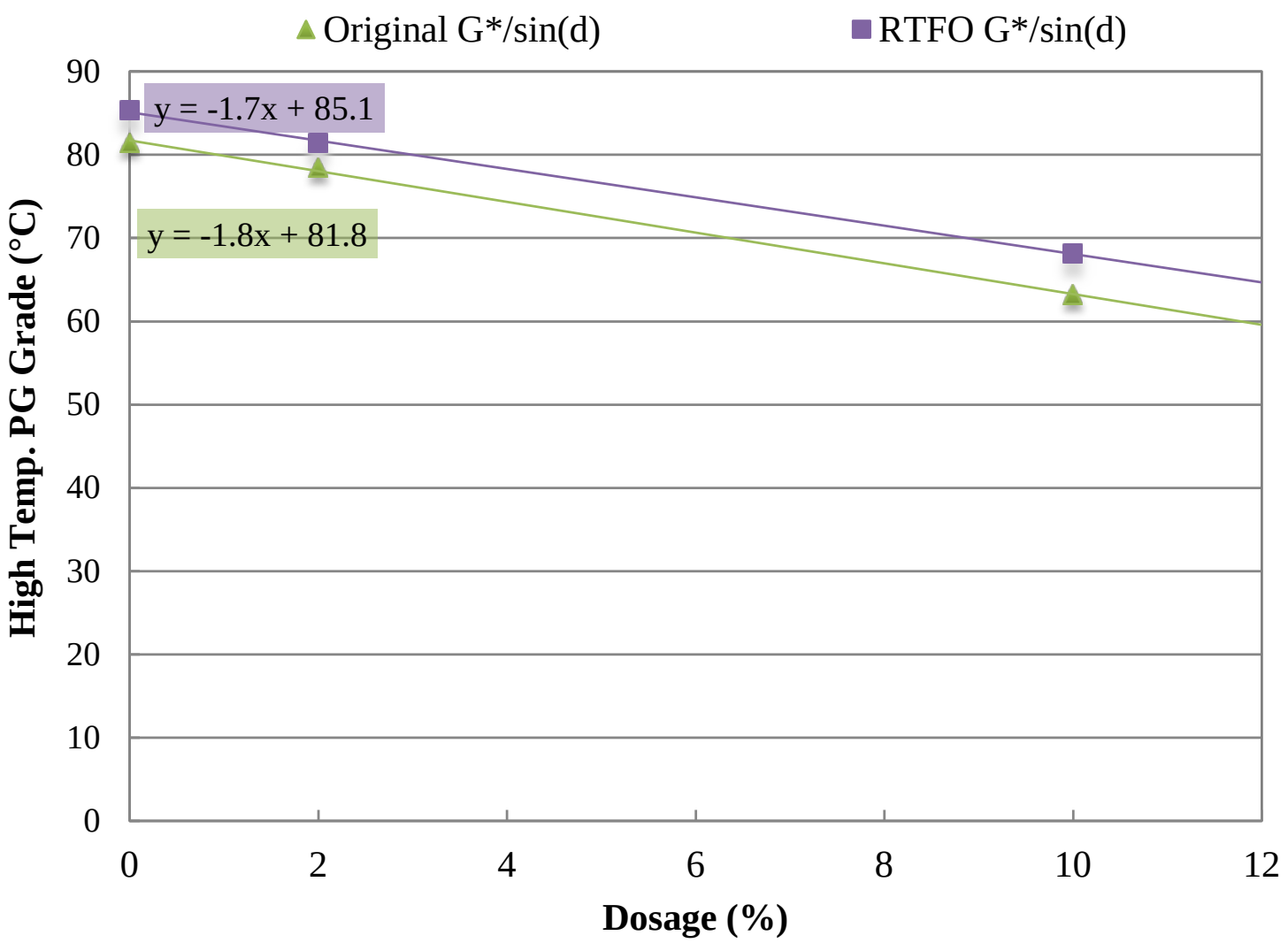



PREP MATERIALS
Extract and recover binder from RAP and/or RAS source(s)
Prepare recycled binder blends:
• With no RA (control)
• With low RA dosage
• With high RA dosage

CONDUCT LAB TESTS

Obtain high PG grade (PGH) and low PG grade (PGL) per AASHTO M320:

- Target binder
- Recycled binder blend with no RA (control)
- Recycled binder blend with low RA dosage
- Recycled binder blend with high RA dosage


0.3 RBR (PG 64-22 | 0.1 TxRAP | 0.2 TxMWAS | T1)
Original G*/sin(d)
RTFO G*/sin(d)
y = -1.7x + 85.1
y = -1.8x + 81.8
High Temp. PG Grade (°C)
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
Dosage (%)

SELECT DOSAGE

Plot original & RTFO PGH, S- & m-controlled PGL vs. RA dosage for all blends

↓

Establish linear regression equations

↓

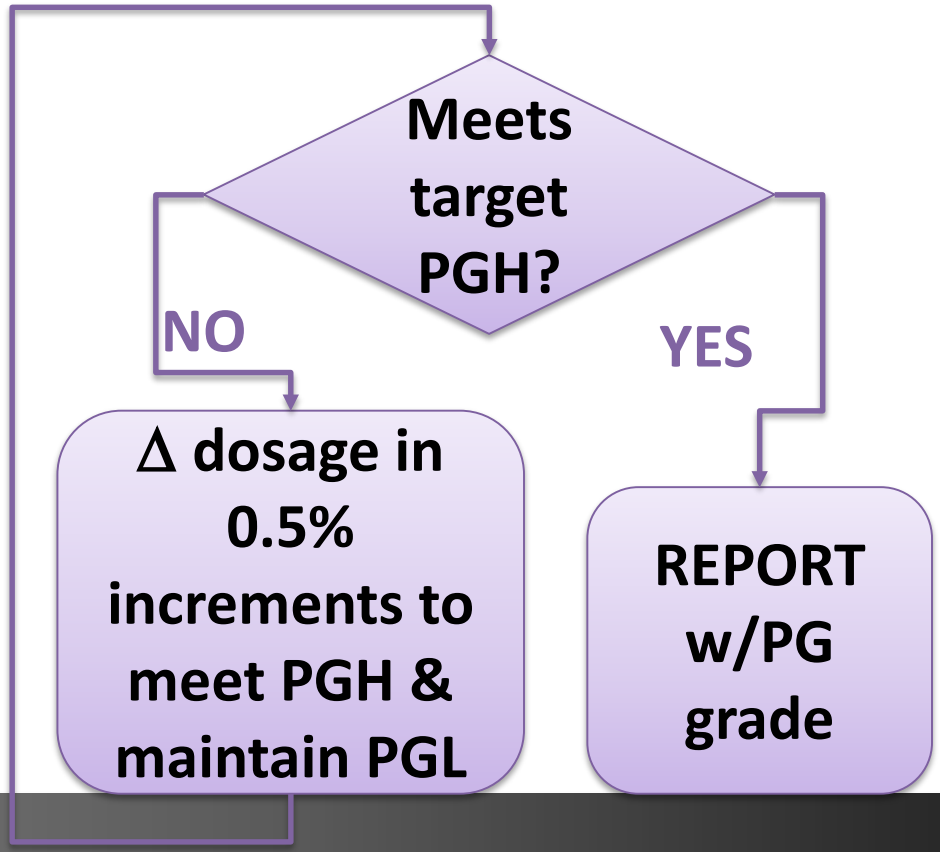
Select RA dosage in 0.5% increments to meet target binder PGL using warmer PGL regression line

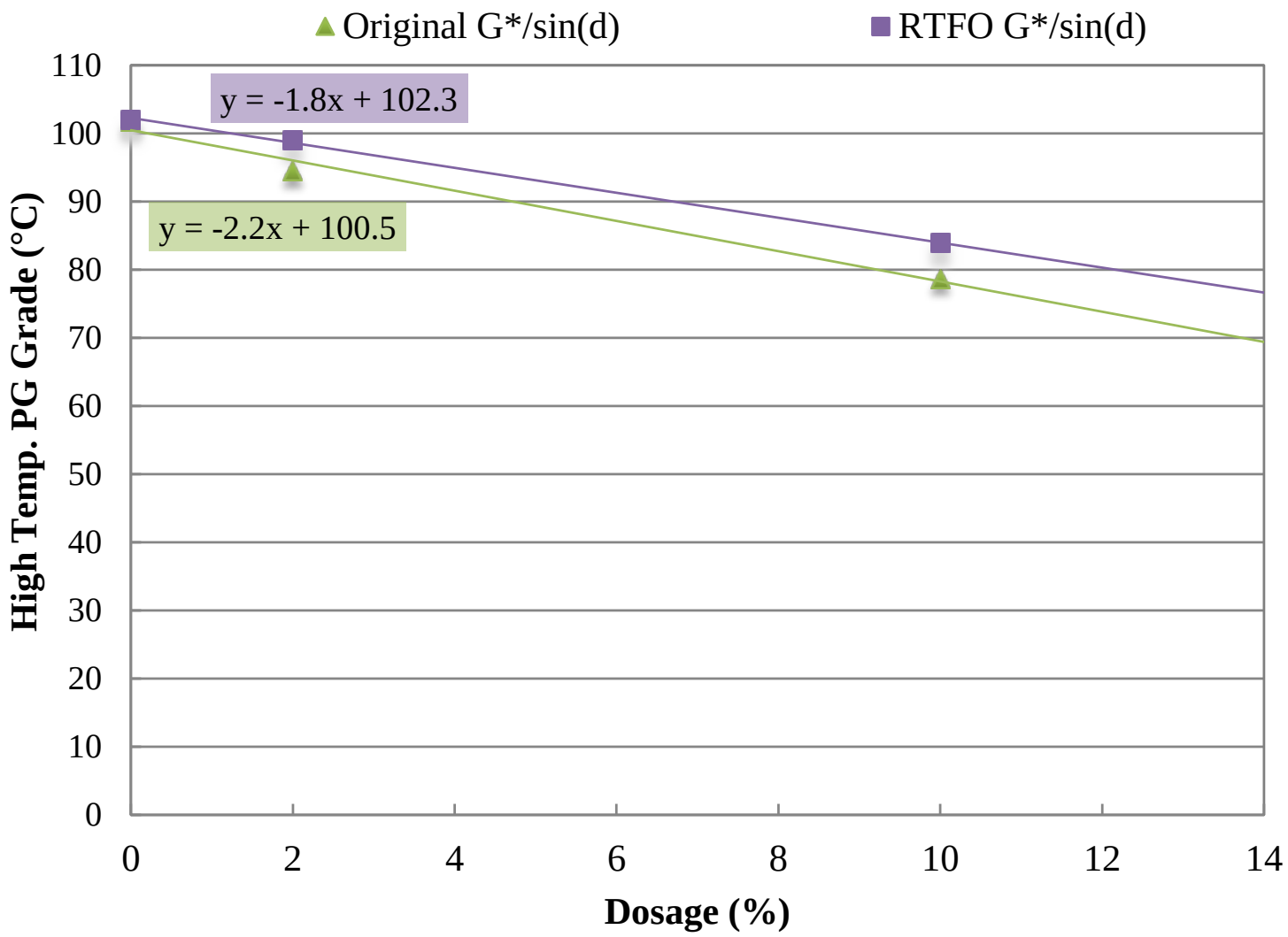
↓

Verify PGH of selected dosage vs. target binder PGH using colder PGH regression line

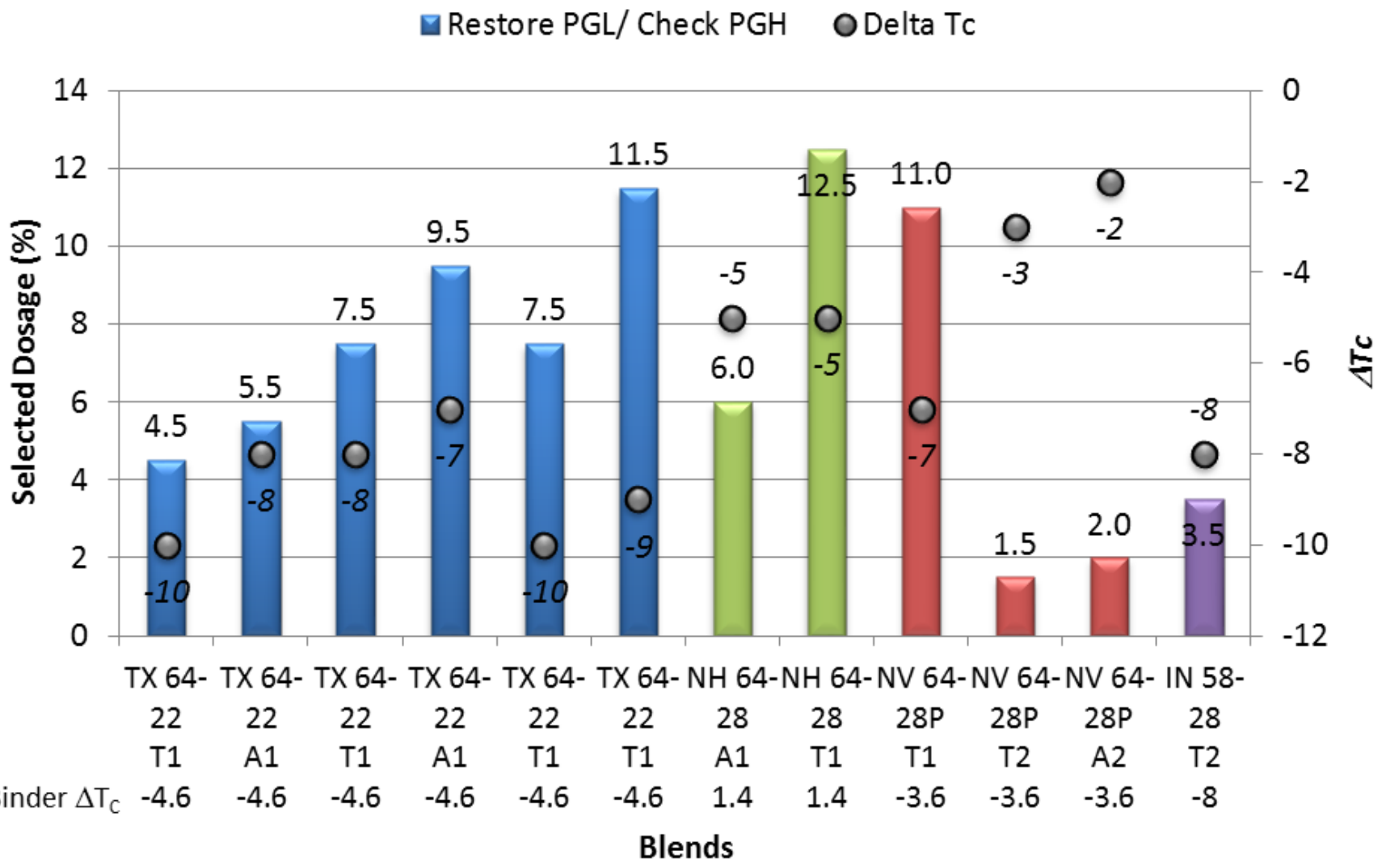
**For RAS mixtures, if dosage >5.5%, <u>replace</u> virgin binder with 50% RA and <u>add</u> other 50%.*

1 Restore PGL/Check PGH

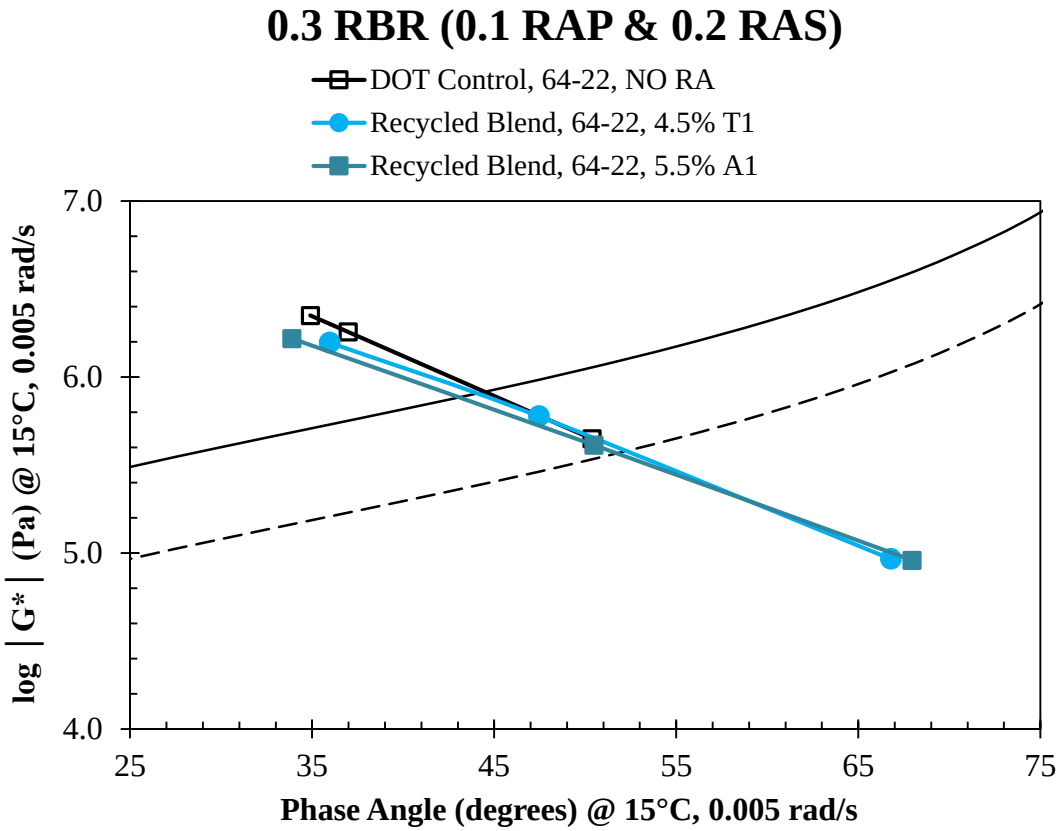



0.5 RBR (64-22 | 0.25 TxRAP | 0.25 TxTOAS | T1)
Original G*/sin(d)
RTFO G*/sin(d)
y = -1.8x + 102.3
y = -2.2x + 100.5
High Temp. PG Grade (°C)
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
Dosage (%)

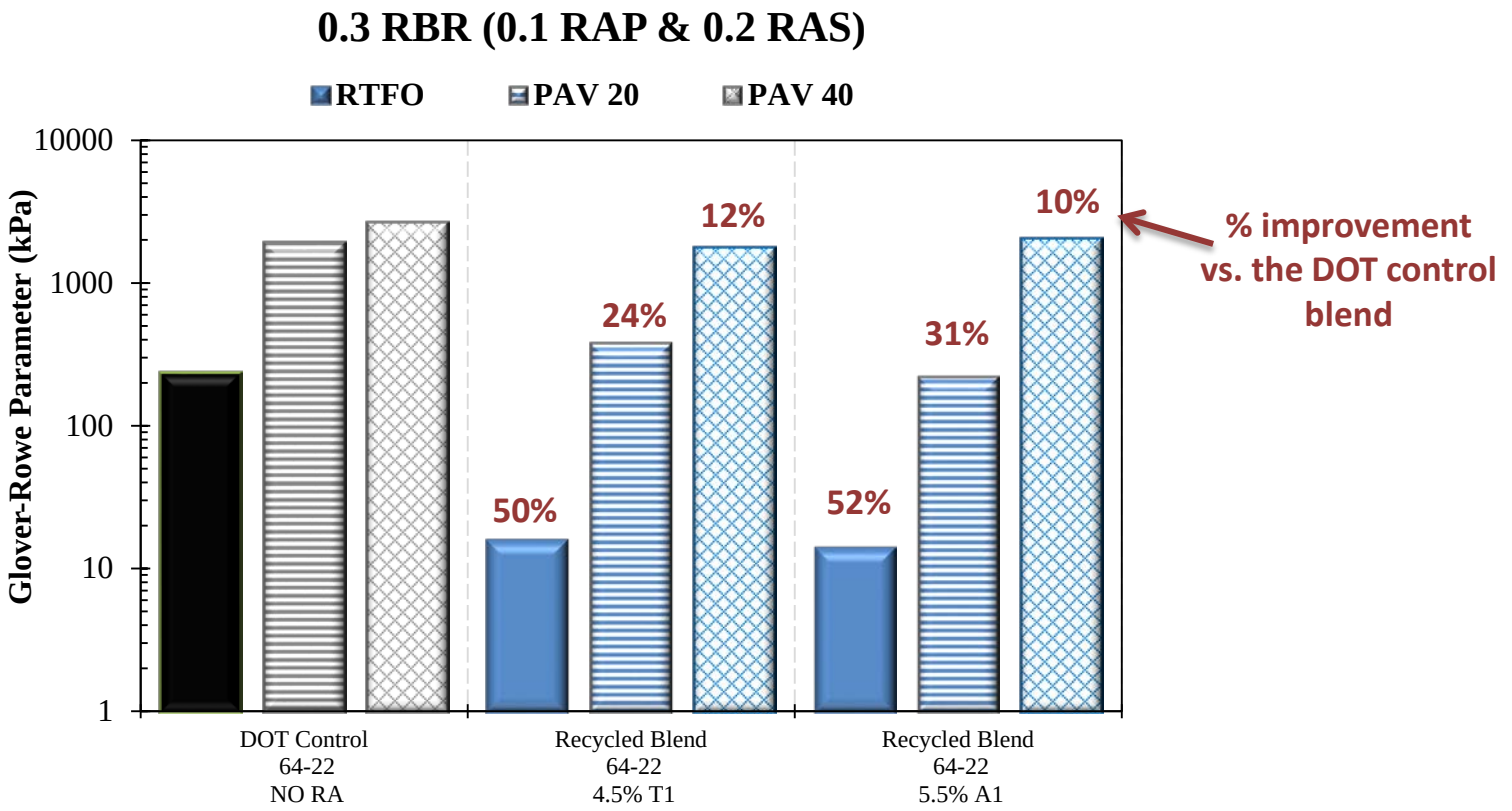
PHASE II DOSAGE SELECTION RESULTS



G-R Binder Black Space Diagram

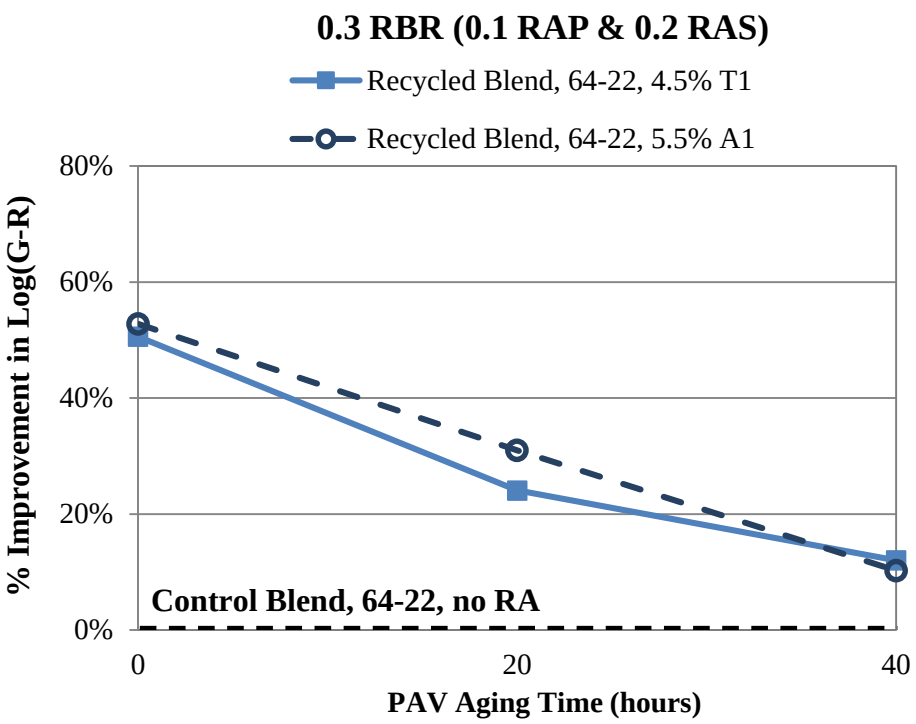


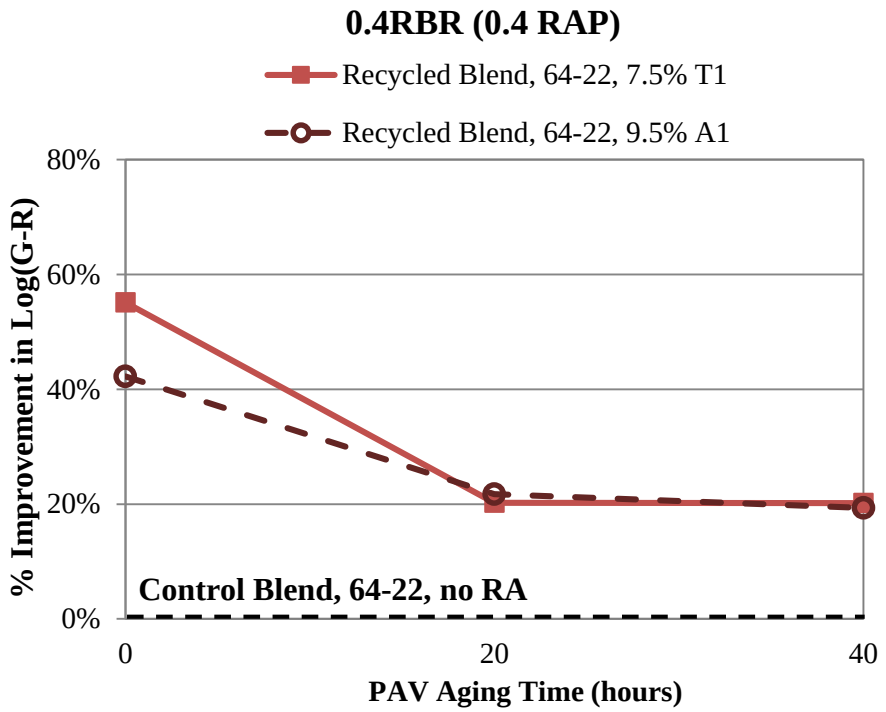
G-R Results w/Aging



Recycled Blends @ opt RA < DOT control Blend no RA

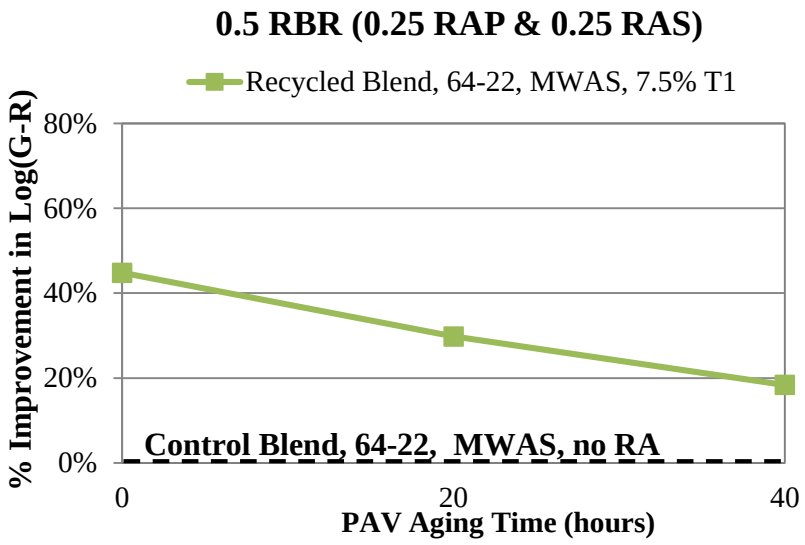
Binder RE Evolution with PAV Aging

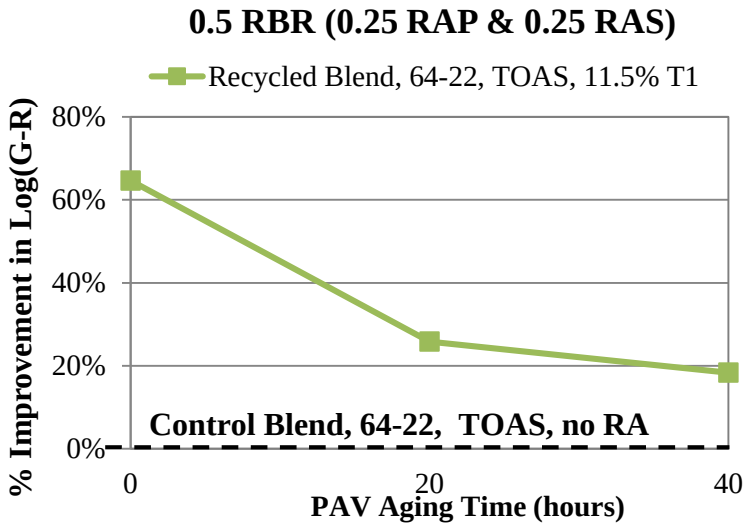


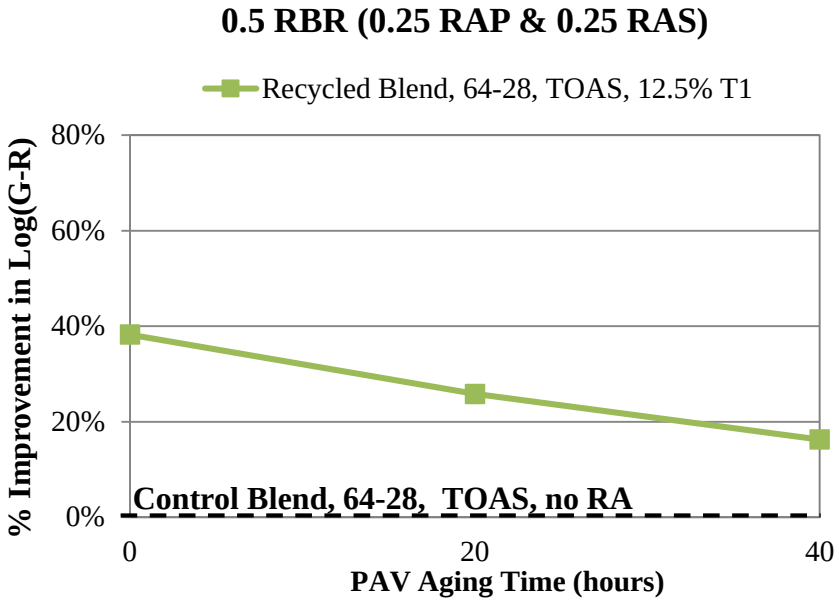


The “rejuvenating” effect of RA decreased with PAV aging

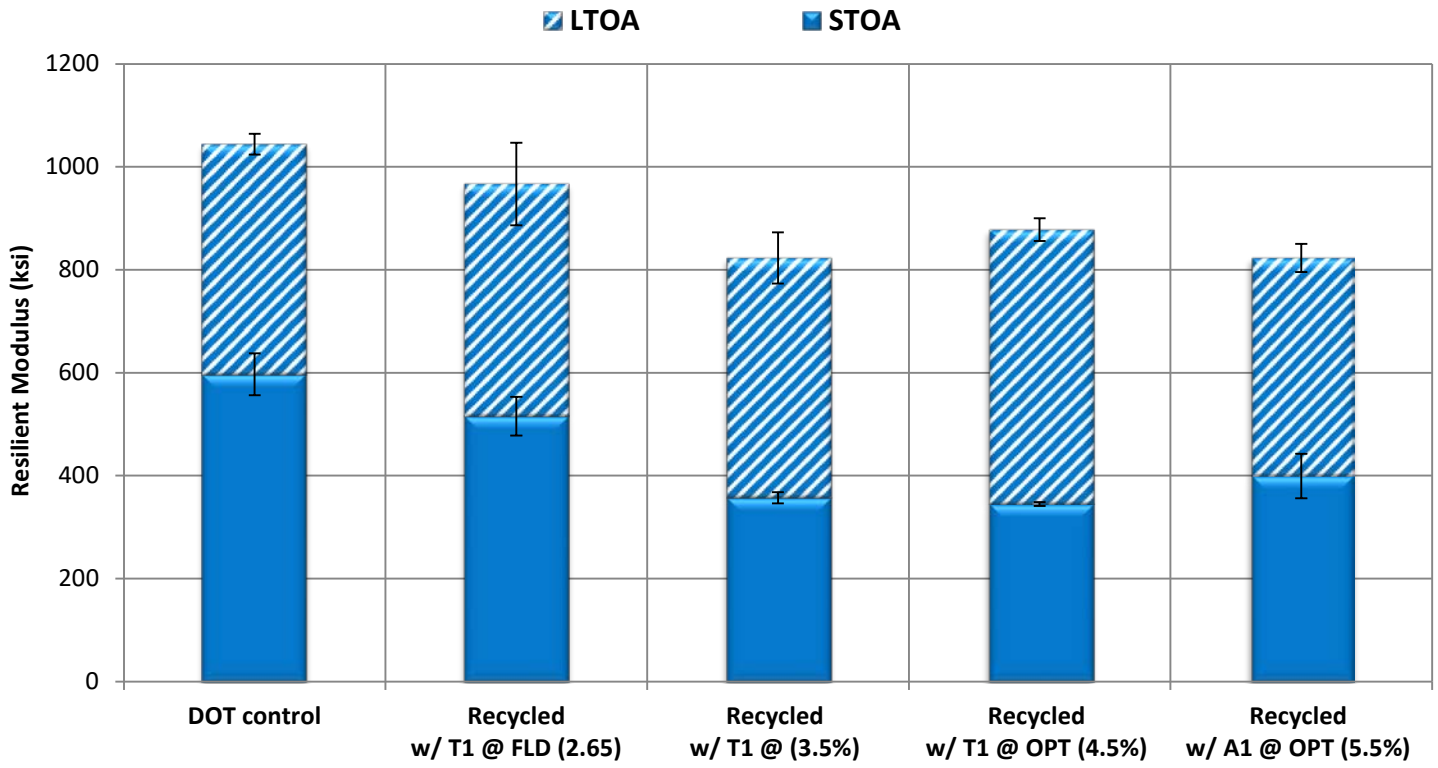
Binder RE Evolution with PAV Aging



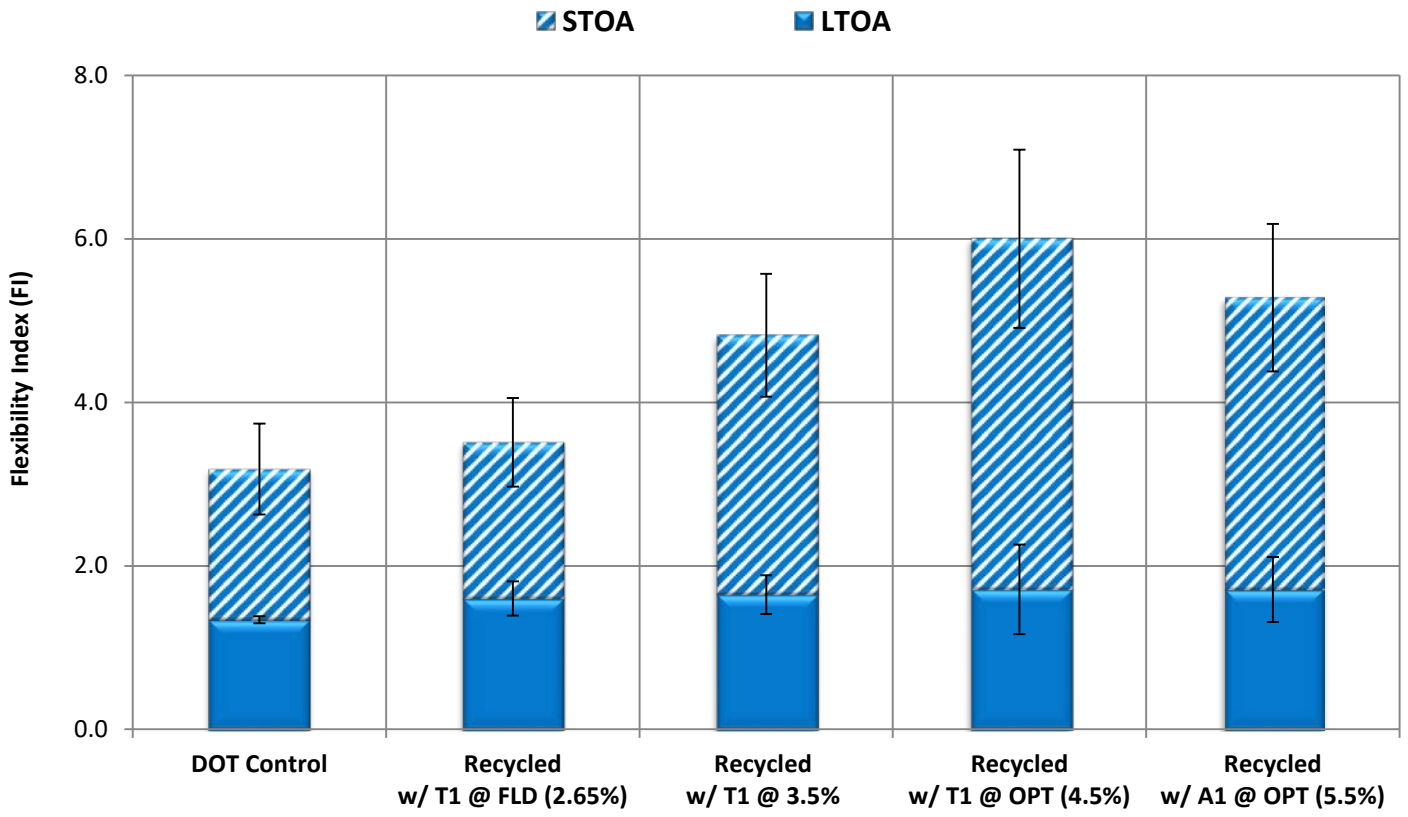




RA Dosage Selection – Mixture Validation - M_R



RA Dosage Selection – Mixture Validation - SCB

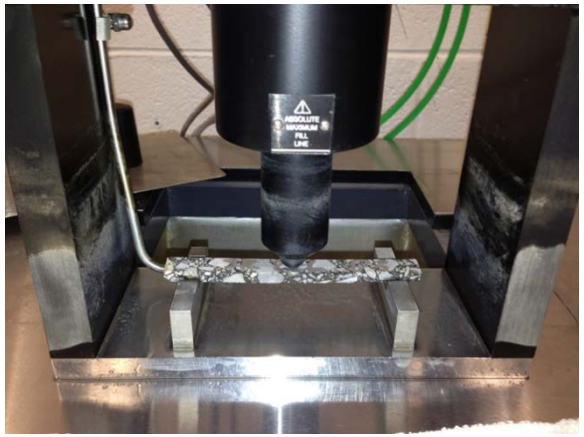


Phase IIB Materials

- **TX: PG 64-22 + 0.28 RBR (0.1 RAP+0.18 MWAS) + 2.7% Tall Oil T1 (Target=PG 70-22)**
- **+ Better Base Binder (less negative ΔT_c)**
- **+ Softer Base Binder**
- **+ Vegetable Oil V1, + Bio-Based Oil B**
- **+ 0.5 RBR** balanced RAP/RAS w/ **TX TOAS**
- Related Phase IIA results

Phase IIB

- RA Dosage Selection beyond restoring PGL/checking PGH by restoring ΔT_c to -5, restoring PGH
- + HWTT to preclude over-softening
- + BBR Sliver (AASHTO TP 125) for mixture Black Space
- + DSC (& UTSST) for onset of brittle behavior



SELECT DOSAGE

Plot original & RTFO PGH, S- & m-controlled PGL vs. RA dosage for all blends

↓

Establish linear regression equations

↓

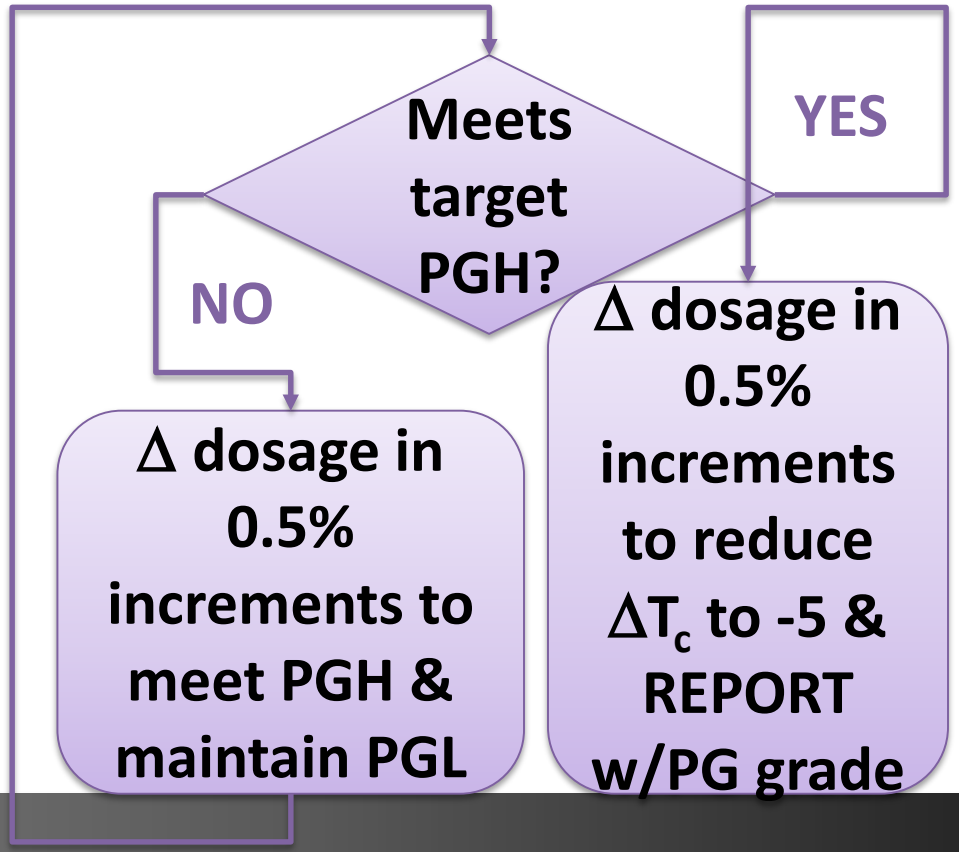
Select RA dosage in 0.5% increments to meet target binder PGL using warmer PGL regression line

↓

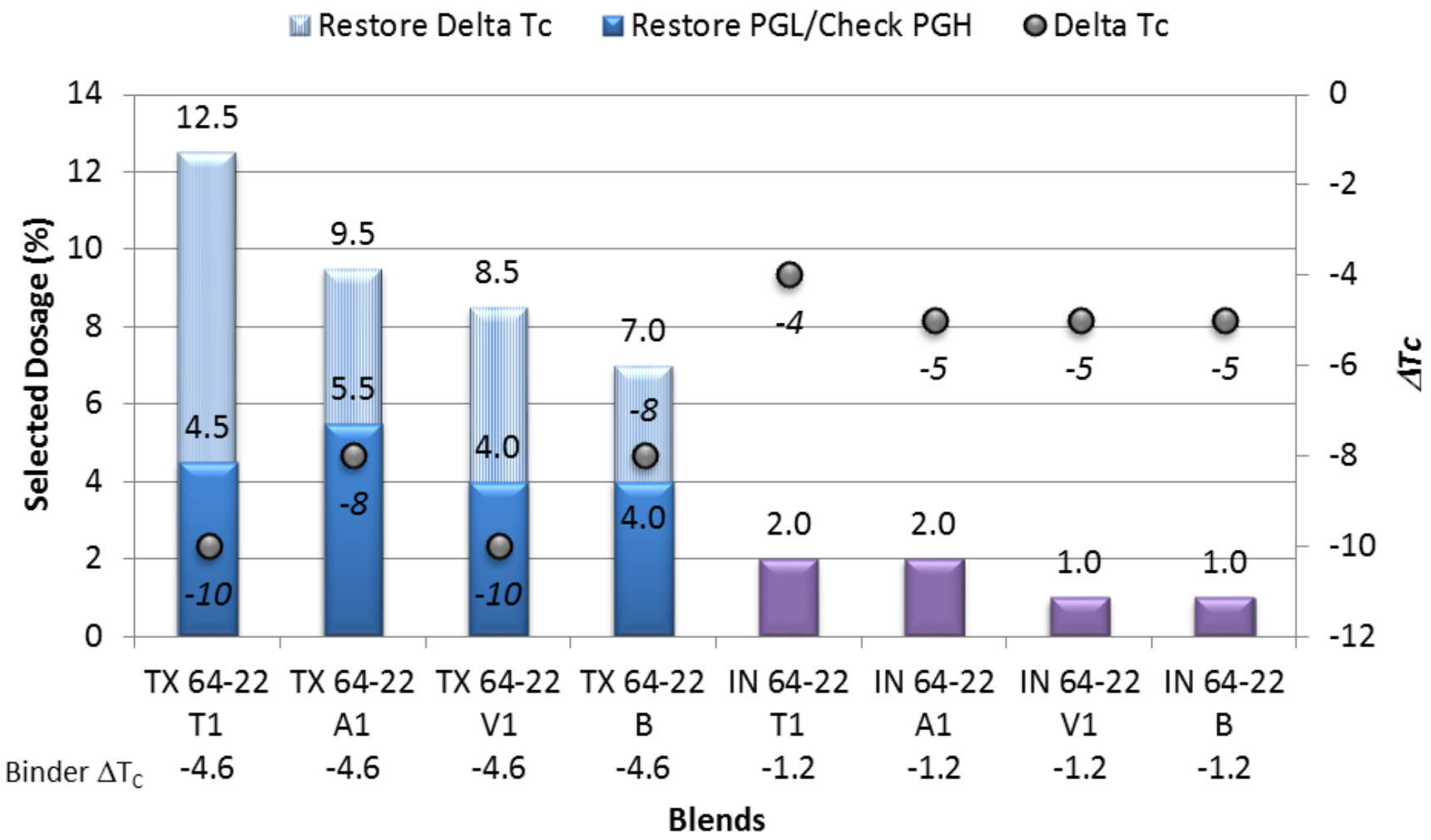
Verify PGH of selected dosage vs. target binder PGH using colder PGH regression line

**For RAS mixtures, if dosage >5.5%, <u>replace</u> virgin binder with 50% RA and <u>add</u> other 50%.*

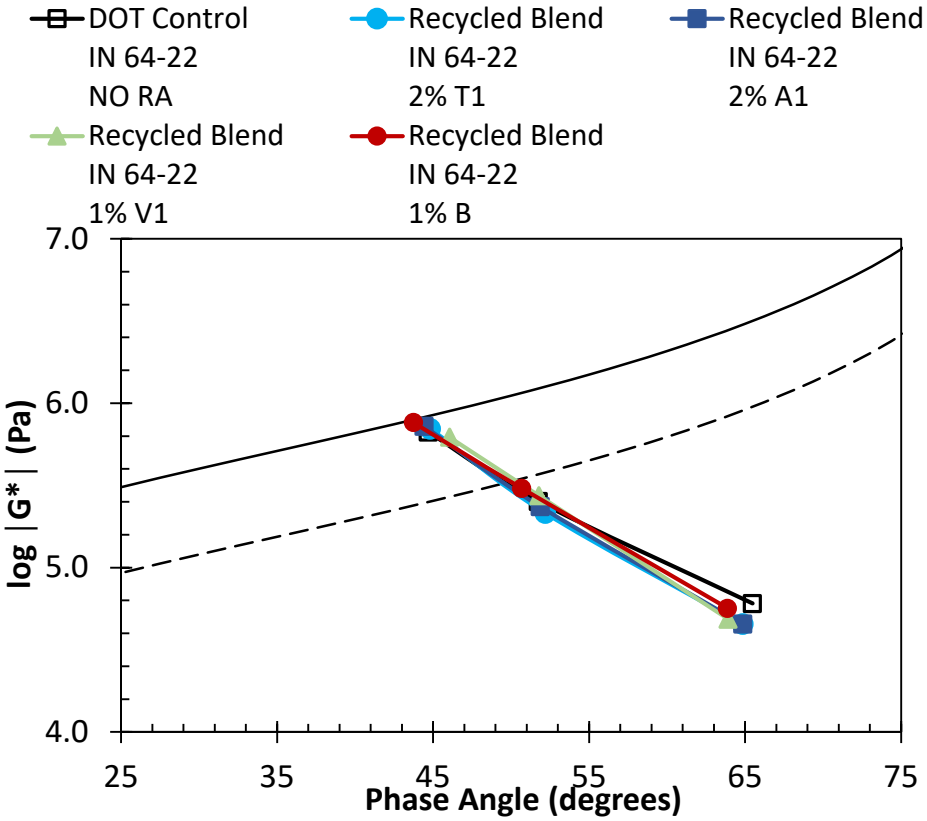
2 Restore ΔT_c

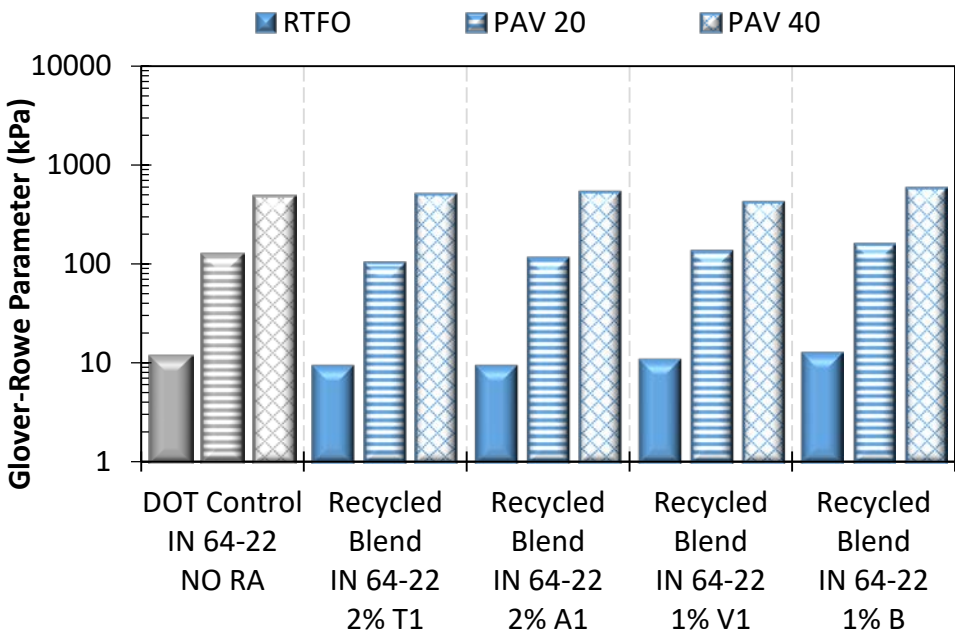


PHASE IIB DOSAGE SELECTION RESULTS
0.28 RBR (0.1 TX RAP + .18 TX MWAS)



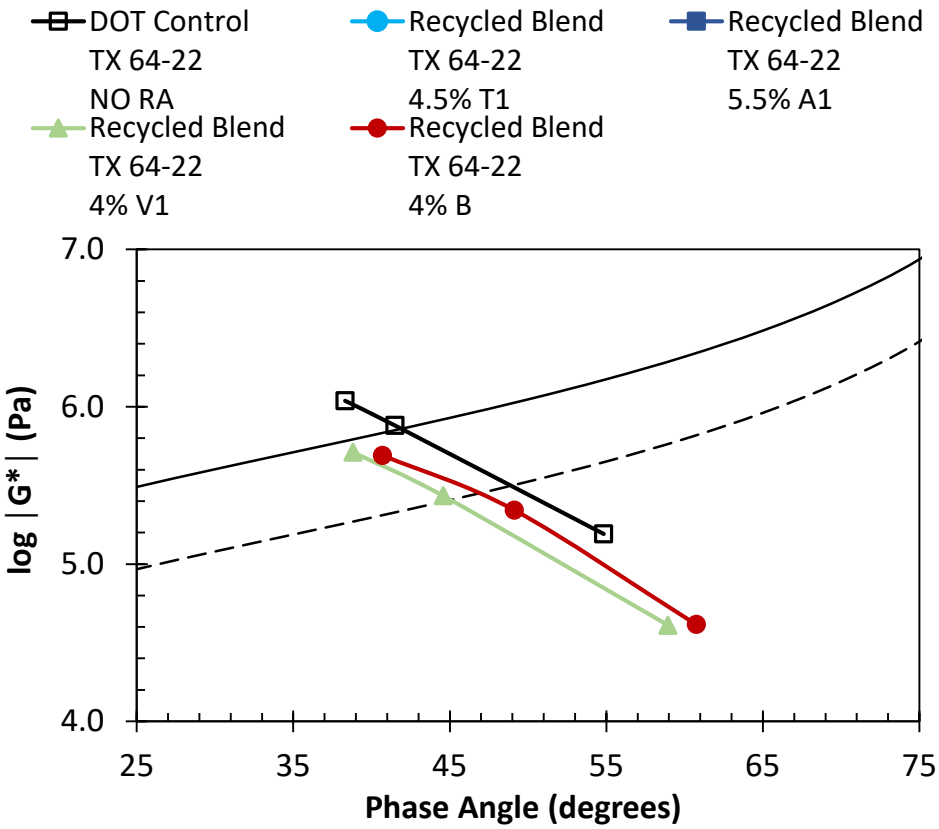
G-R Results @ 21°C – (0.28 RBR) Blends w/ IN PG 64-22 Restore PGL/Check PGH and Restore ΔT_c

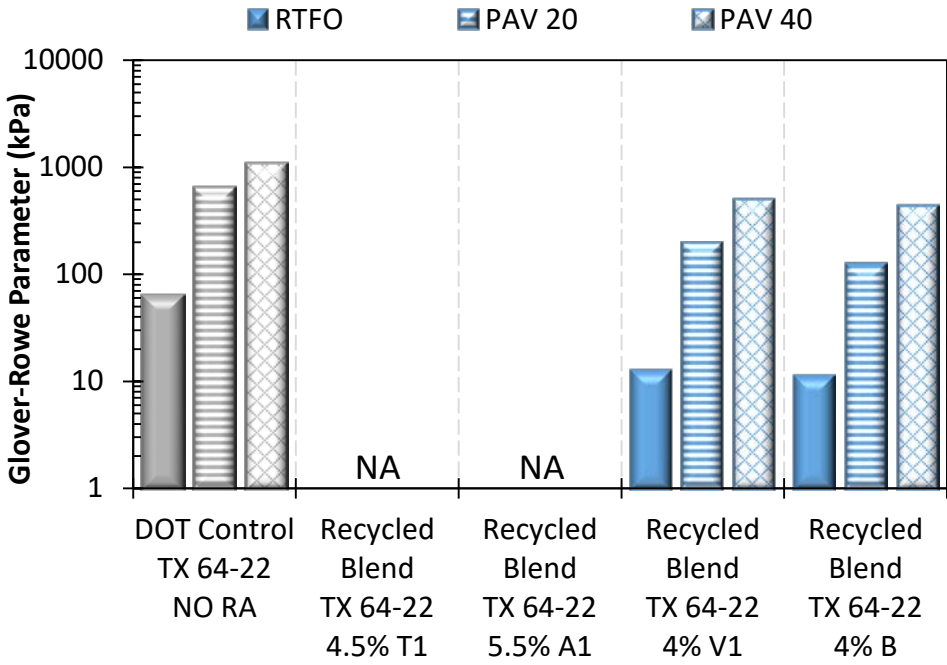




G-R @ T= 21°C, same thresholds
RAs may not be needed with 0.3 RBR and a better binder

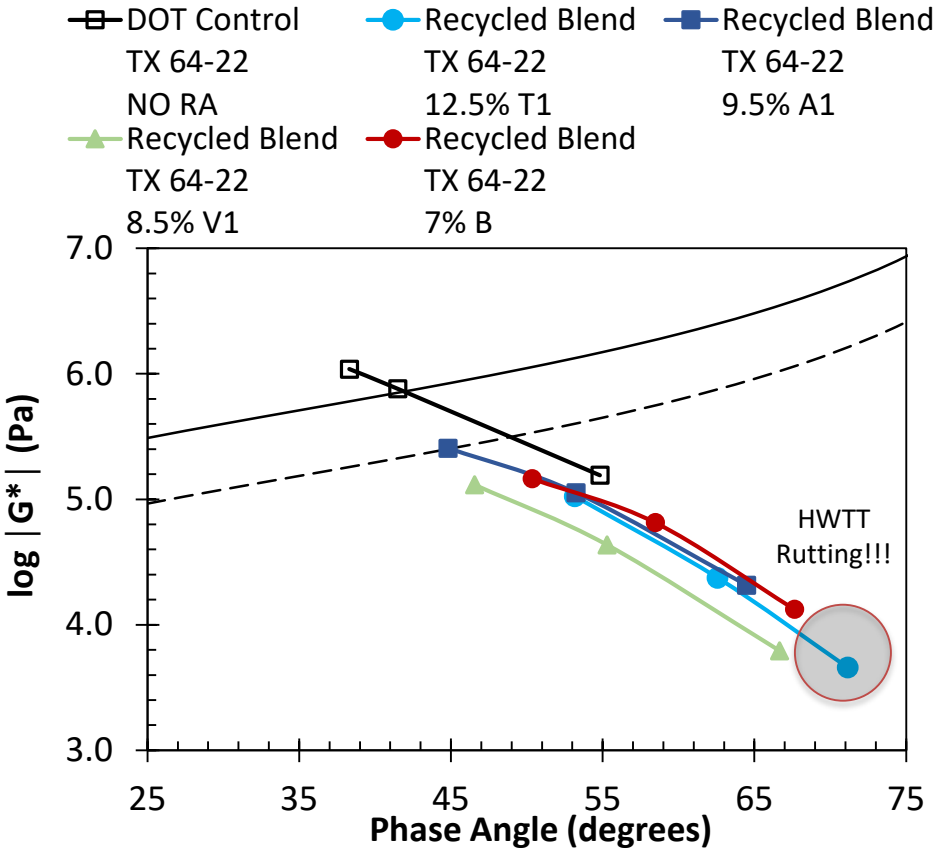
G-R Results @ 21°C – (0.28 RBR) Blends w/ TX PG 64-22 Restore PGL/Check PGH

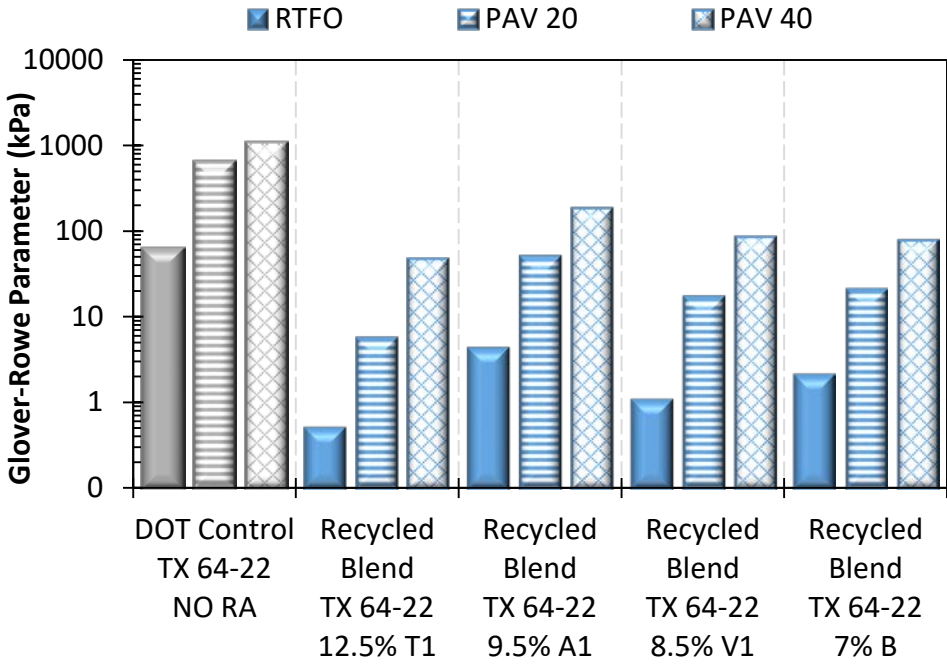




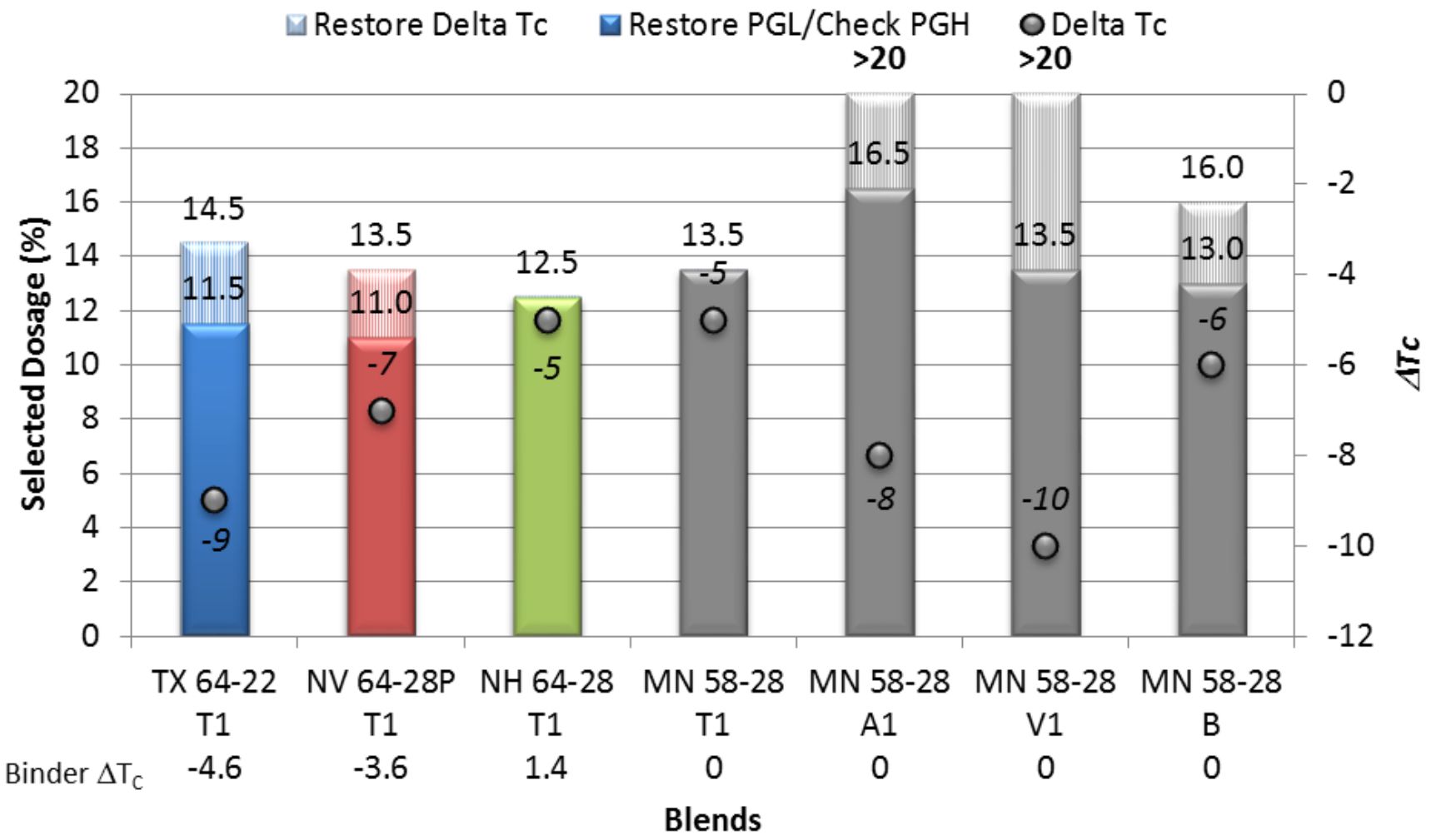
G-R @ T= 21°C, same thresholds
Control blend ages beyond the thresholds
RAs improve the blends

G-R Results @ 21°C – (0.28 RBR) Blends w/ TX PG 64-22 Restore ΔT_c





PHASE IIB DOSAGE SELECTION RESULTS
0.5 RBR (0.25 TX RAP + 0.25 TX TOAS)



SELECT DOSAGE

Plot original & RTFO PGH, S- & m-controlled PGL vs. RA dosage for all blends

↓

Establish linear regression equations

↓

Select RA dosage in 0.5% increments to restore PGH to minimum that meets target using colder PGH regression line

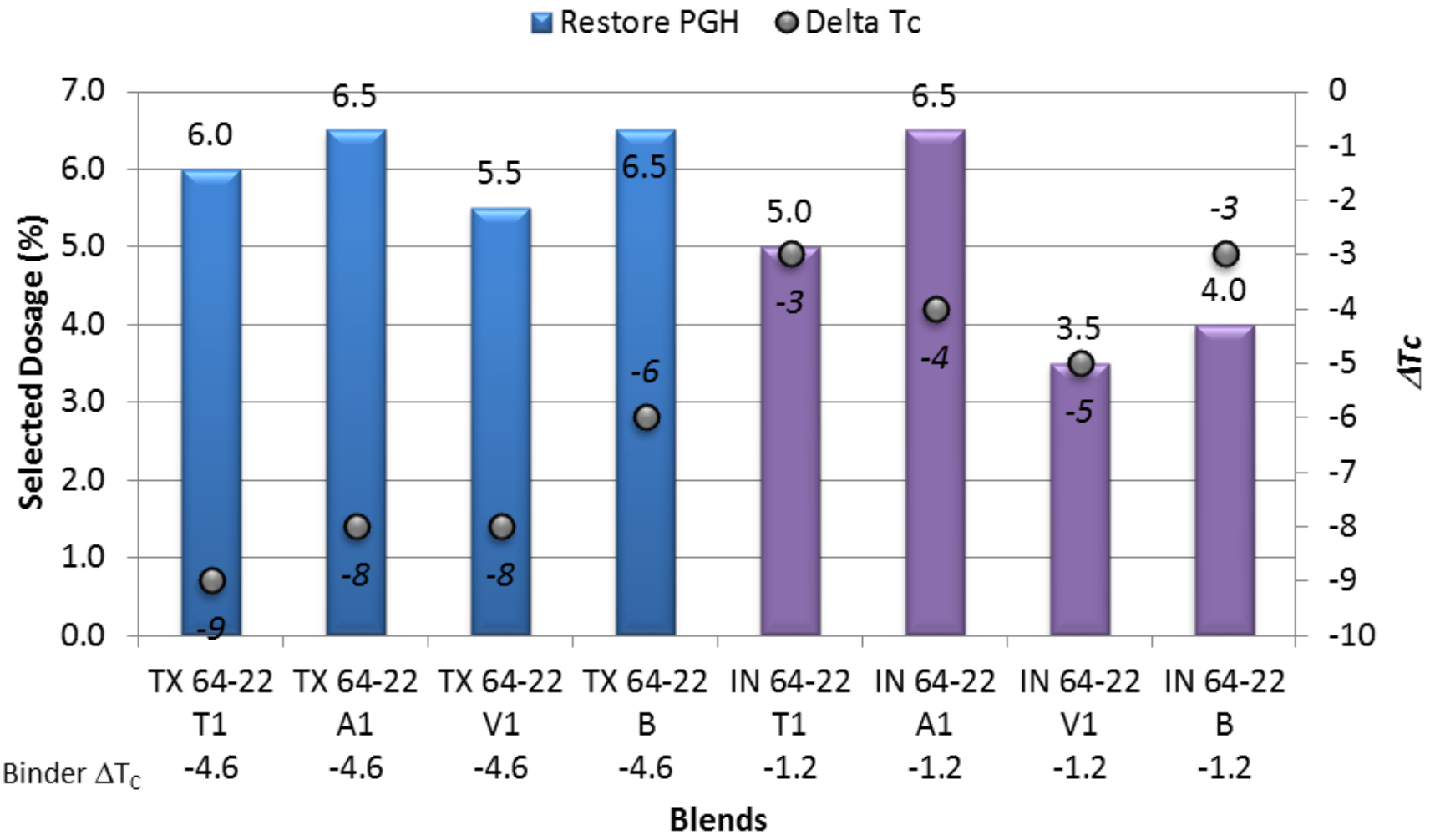
→

REPORT w/ PG grade & ΔT_c

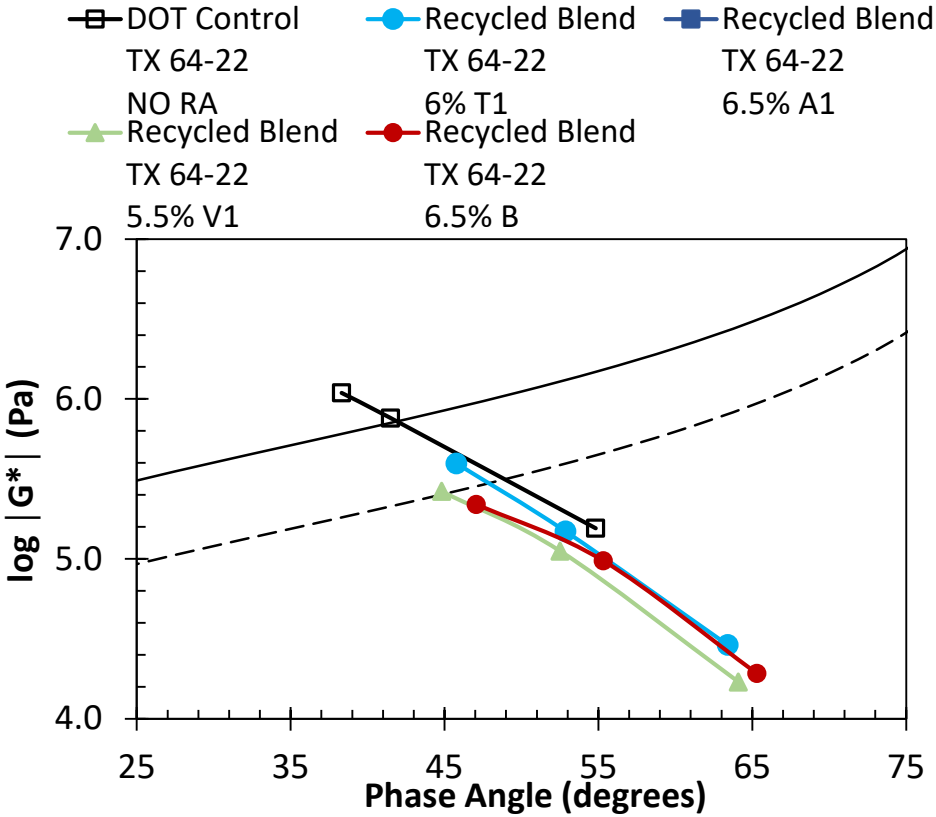
**For RAS mixtures, if dosage >5.5%, replace virgin binder with 50% RA and add other 50%.*

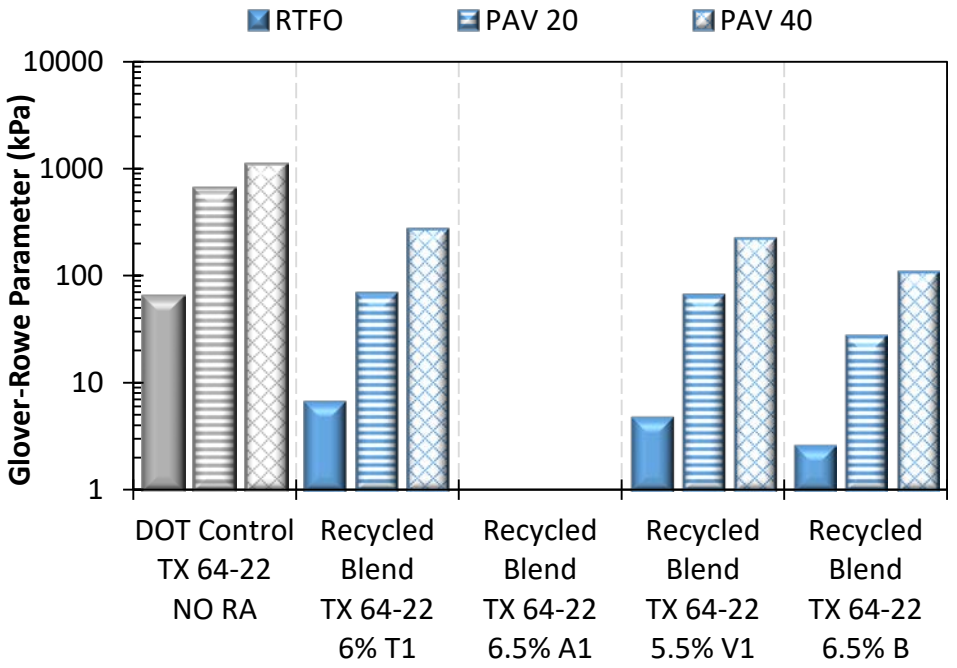
3 Restore PGH

PHASE IIB DOSAGE SELECTION RESULTS
0.28 RBR (0.1 TX RAP + .18 TX MWAS)

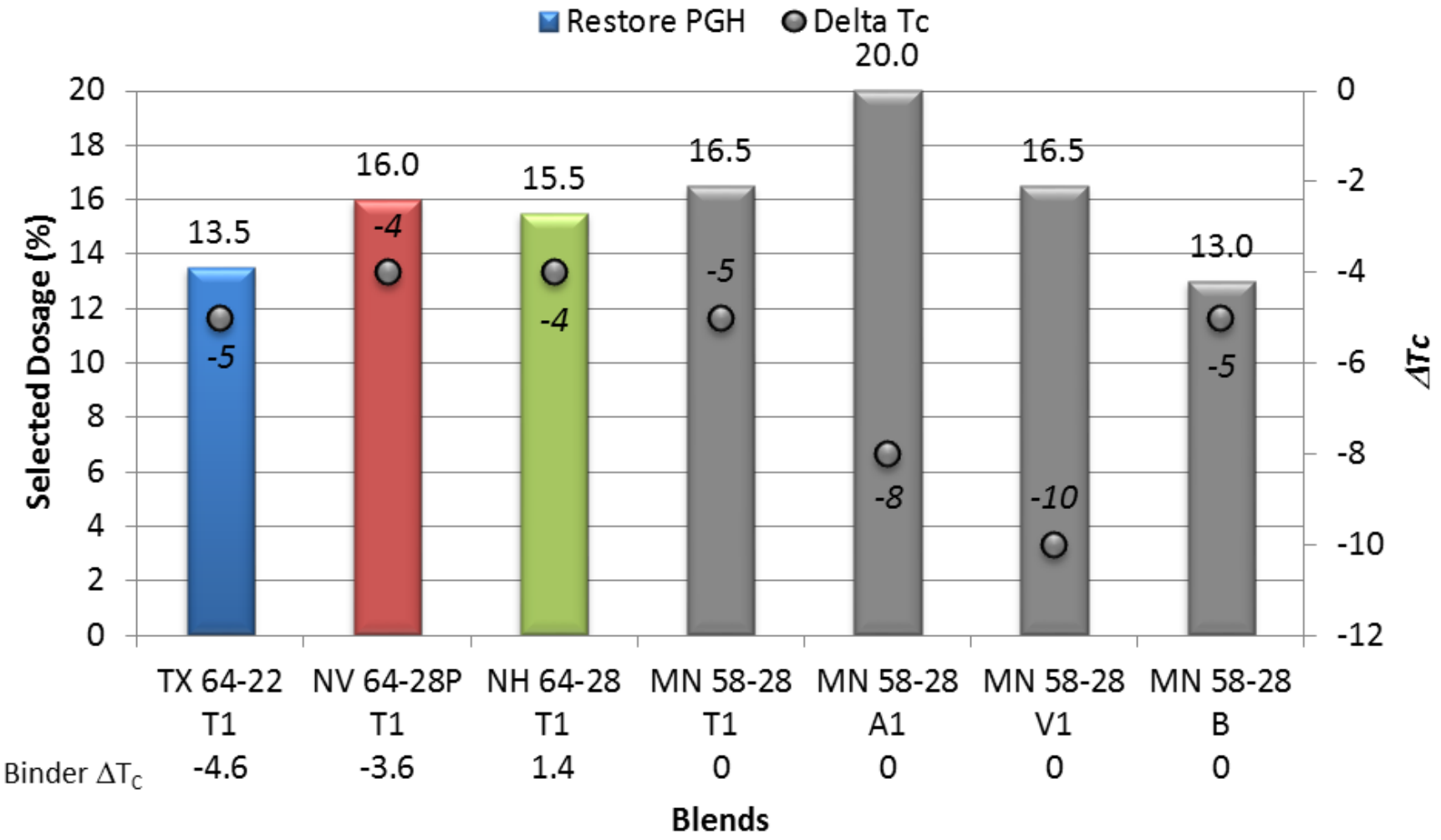


Estimated G-R @ 21°C
(0.28 RBR) Blends w/ TX PG 64-22
Restore PGH

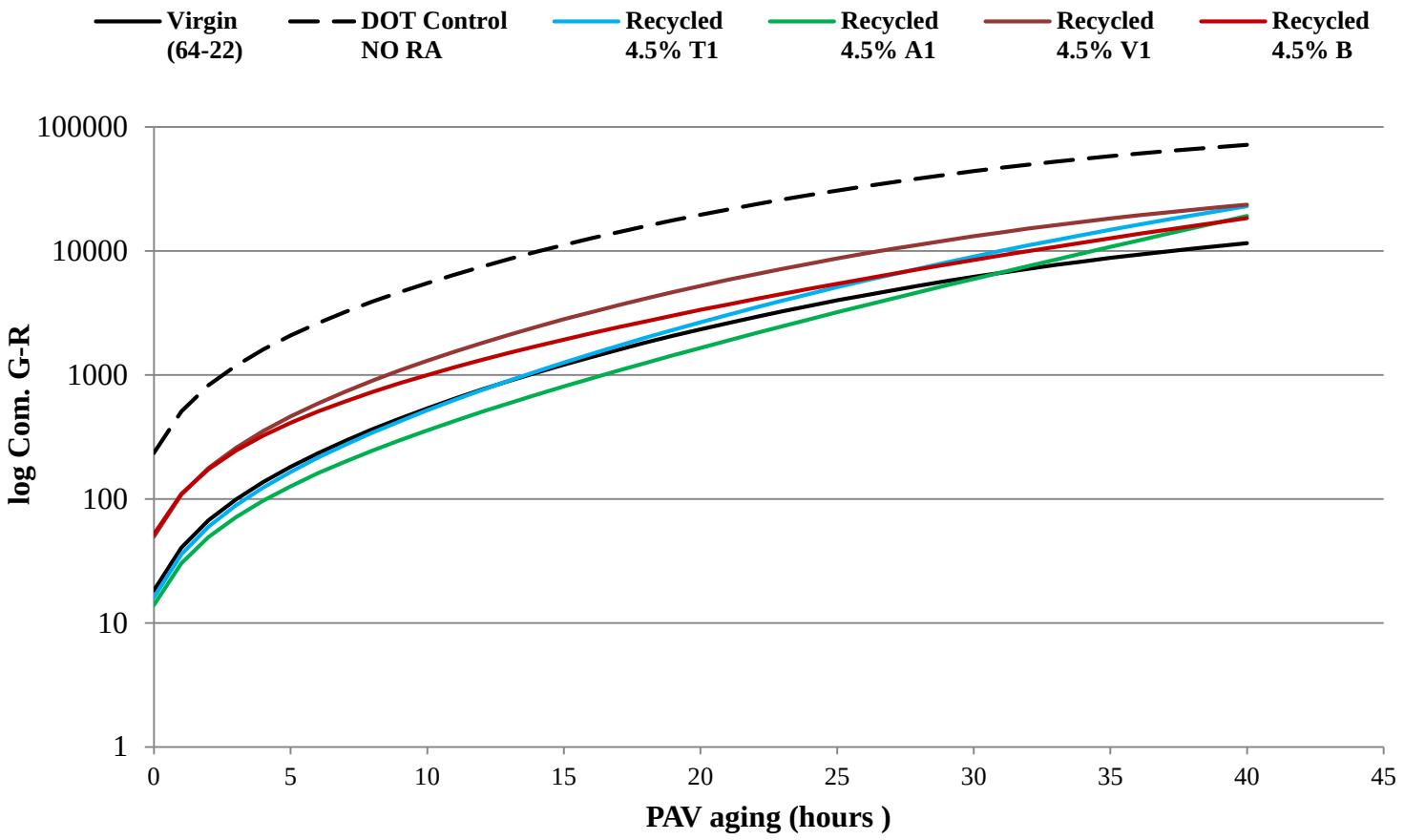




PHASE IIB DOSAGE SELECTION RESULTS
0.5 RBR (0.25 TX RAP + 0.25 TX TOAS)



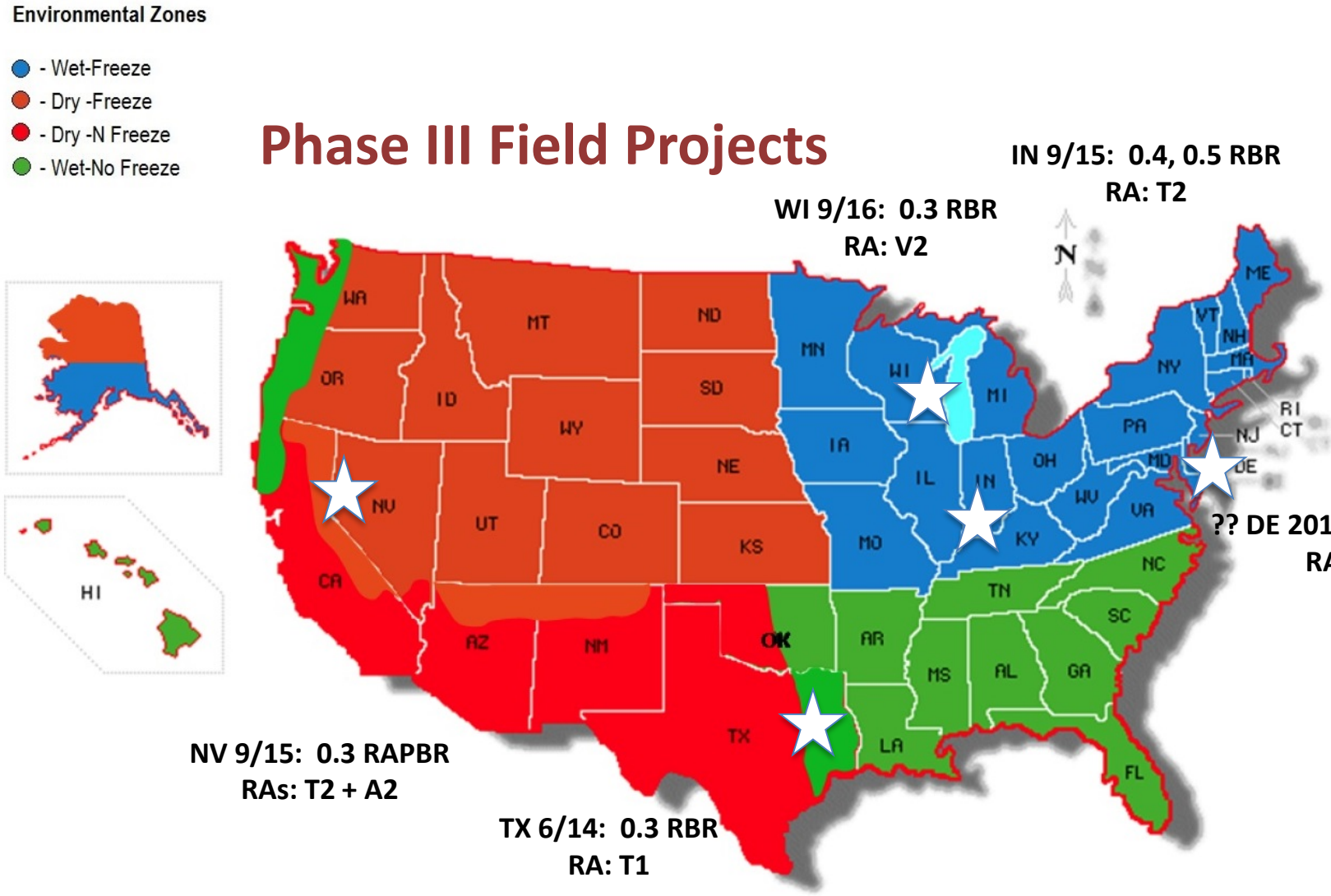
Cumulative G-R



Next Steps

- Finalize **RA Dosage Selection Method**
  - Consider **Incompatibility** by Chemical or Rheological Properties
- Complete **Aging Analysis** to explore oven vs PAV aging, chemical vs rheological properties
- Characterize **Mixtures**
  - Cracking Resistance – FI by SCB, N_f by S-VECD, RI by UTSST
  - Embrittlement - UTSST Viscous-Glassy Transition, Mixture Black Space with BBR Sliver and E*, ϕ
- Evaluate **Phase III Field Projects** to set thresholds for **Rejuvenating Effectiveness w/Aging**

Phase III Field Projects



IN 9/15: 0.4, 0.5 RBR
RA: T2

WI 9/16: 0.3 RBR
RA: V2

?? DE 2016: PG 64-28
RA: ??

NV 9/15: 0.3 RAPBR
RAs: T2 + A2

TX 6/14: 0.3 RBR
RA: T1

NV Field Project

Laboratory Mixtures (LMLC) & Field Mixtures (RPMLC, Cores)

	Binder		Mixture			
	Dosage Selection	RE & Evolution	HWTT	M_R & SCB (STOA & LTOA)	E* & UTSST (LTOA)	S-VECD (LTOA)
Target 64-28P	Mod Binder		√	√	√	√
Recycled (R) 64-28P (0.3 RAPBR)	–	–	√	√	√	√
(R) +T2@FLD (2%)	RA Type	√	√	√	√	√
(R) +A2@FLD (2%)	√	√	√	√	√	√
DOT Control 64-28P (0.15 RAPBR)	–	–	√	√	√	√

IN Field Project

Laboratory Mixtures (LMLC) & Field Mixtures (RPMLC, Cores)

	Binder		Mixture			
	Dosage Selection	RE & Evolution	HWTT	M_R & SCB (STOA & LTOA)	E* & UTSST (LTOA)	S-VECD (LTOA)
Target 64-22	–	–	–	–	–	–
DOT Control (58-28) (0.32 RBR) (0.25 RAP & 0.07 MWAS)	–	–	√	√	√	–
Recycled (58-28) (0.42 RBR) (0.14 RAP & 0.28 MWAS + T2 FLD (3%)	High RAS		√	√	√	√

WI Field Project

Laboratory Mixtures (LMLC) & Field Mixtures (RPMLC, Cores)

	Binder		Mixture		
	Dosage Selection	RE & Evolution	HWTT	M_R & SCB (STOA & LTOA)	E* & UTSST (LTOA)
DOT Control 58-28S (0.22 RAPBR)	–	–	√	√	√
Recycled 58-28S (0.3 RAPBR)	–	–	√	√	√
Recycled 52-34S (0.3 RAPBR)	–	√	√	√	√
Recycled 58-28S (0.3 RAPBR) + V2@FLD			√	√	√

Mod Binders

V Type

Contact

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