Texas A&M Transportation Institute

Lives, Time and Resources

Evaluating the Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios

46th Ohio Asphalt Paving Conference

February 3, 2021

MOTIVATION & CONCERN for High Recycled Binder Ratio (RBR) = High RAP and/or RAS

- OH in 2019
  - 19.4M tons HMA/WMA
  - 6.3M tons RAP
  - 12k tons RAS
- materials savings = $2.3M

- Workability
- Compaction

- Performance **w/Aging**

NCHRP 9-58 Objectives

- **High RBR** = 0.3 – 0.5
- Assess effectiveness of recycling agents at selected dose to
  - **partially restore binder rheology**
  - **improve mixture cracking performance** without adversely affecting rutting resistance
- Evaluate the **evolution of recycling agent effectiveness** with aging
- Recommend **evaluation tools**

9-58 Binder Blend Evaluation Tools

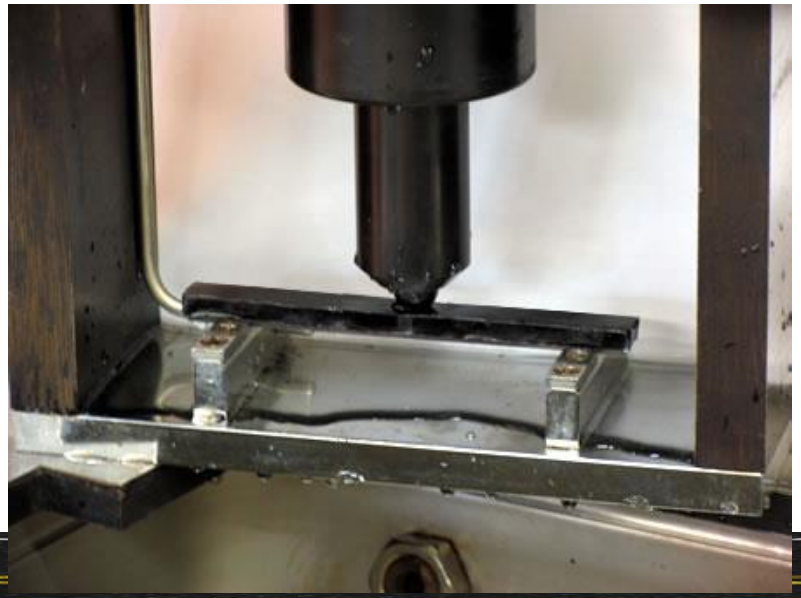
- **DSR** for PGH, G-R, $T_{\delta=45}$

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

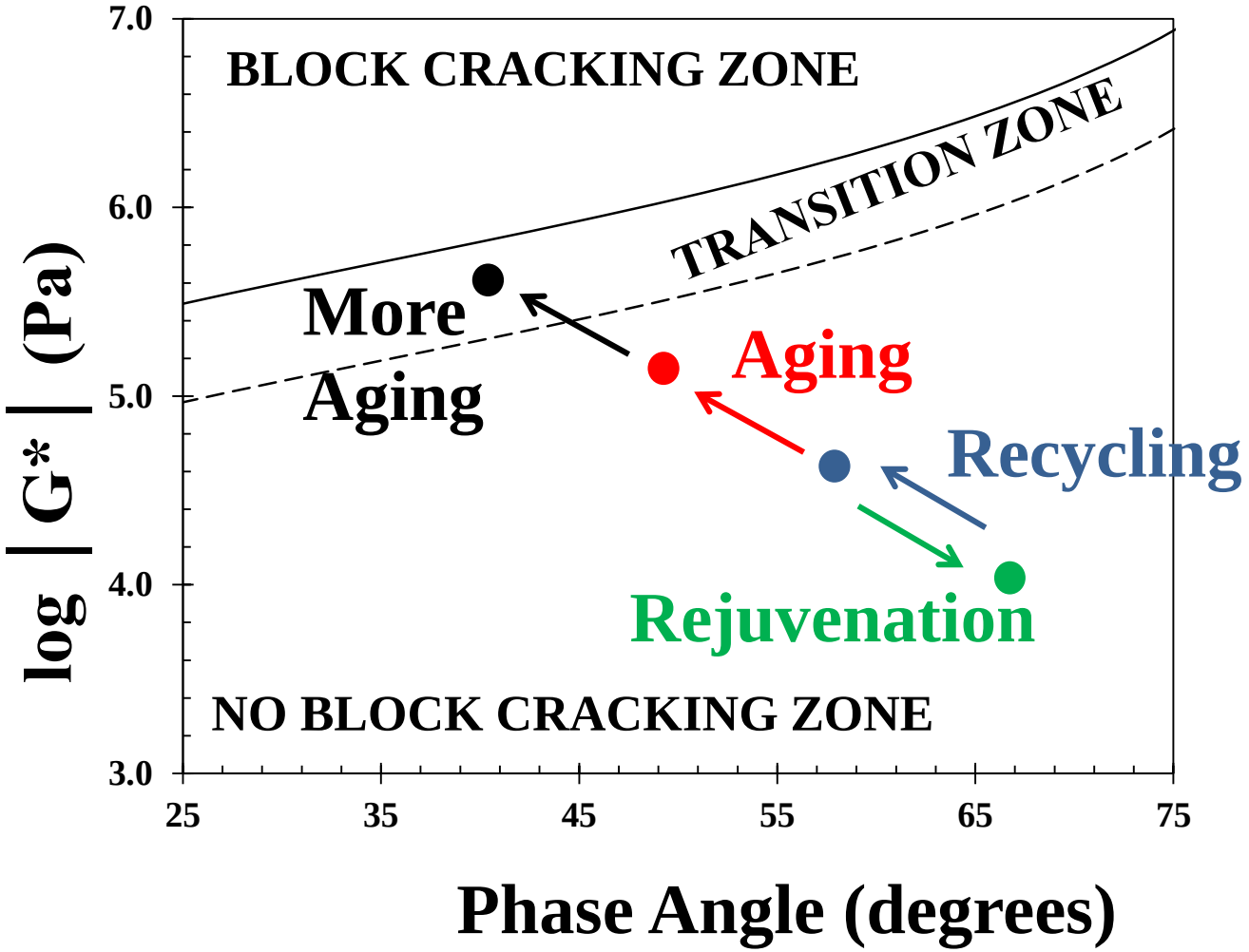
$T_{\delta=45°}$ for G'=G"@ 10 rad/sec

- **BBR** for ΔT_c

ΔT_c @ PAV20 = $T_S - T_m$



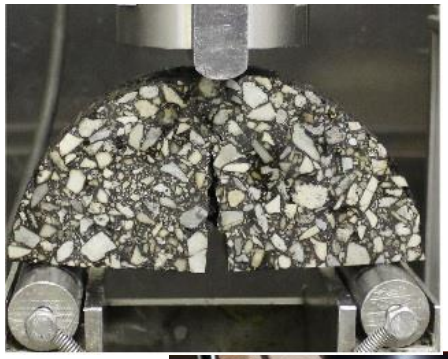
Black Space Evaluation with Aging/Recycling



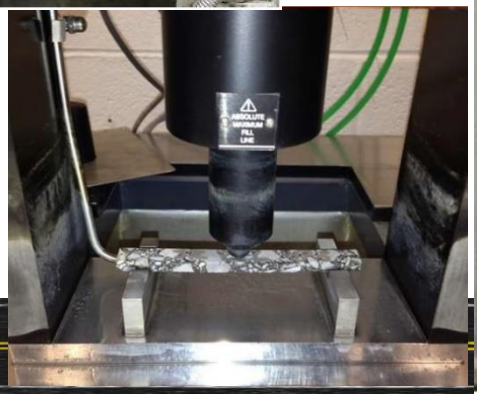
9-58 Mixture Evaluation Tools

- HWTT/APA for $N_{12.5}$

- E* for G-R_m @ 20°C, 5Hz
- I-FIT for FI



- BBR_m for S_m and m-$value_m$
- UTSST for CRI_{Env}



9-58 Materials

TX
NH
NV
IN
WI
DE

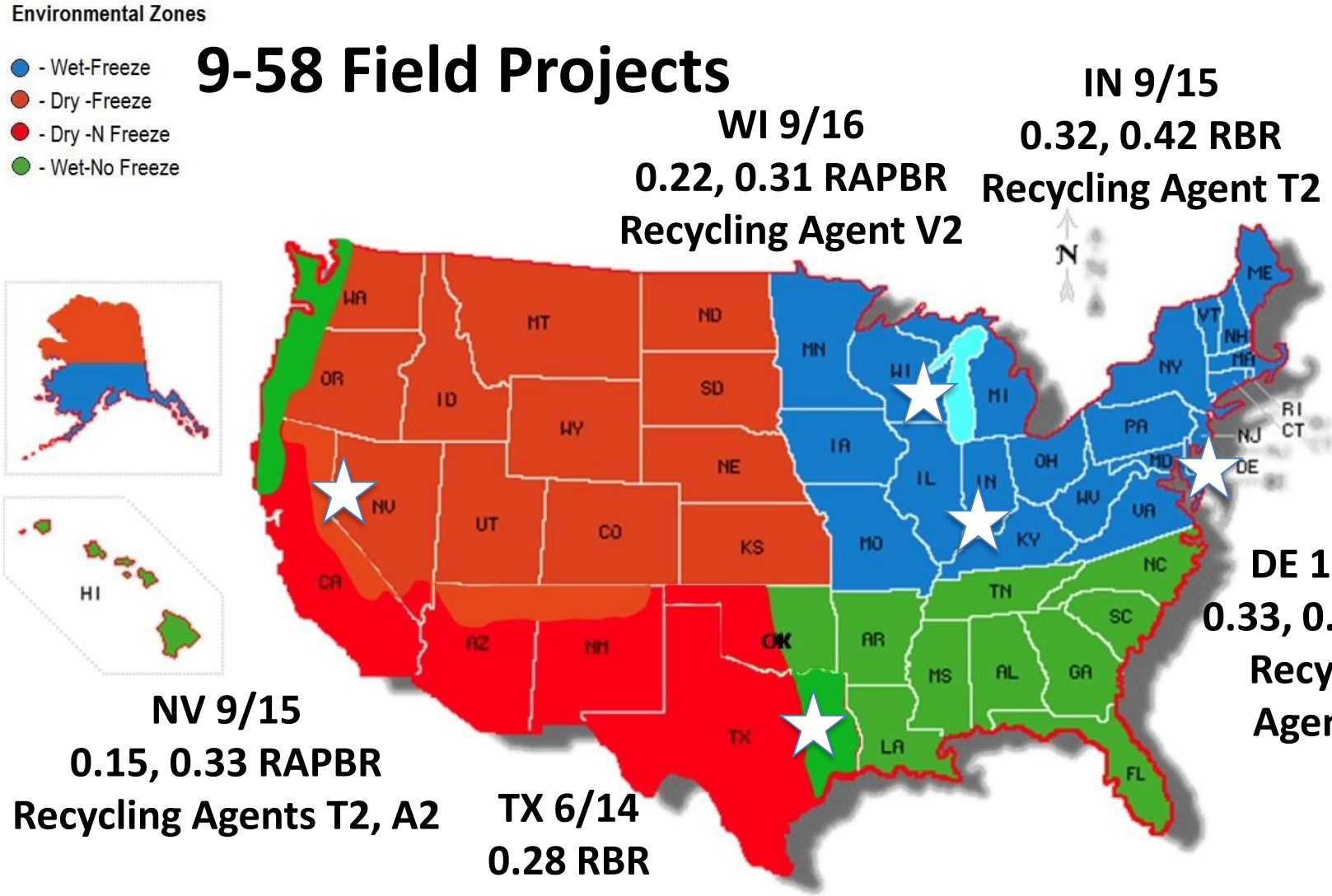
TX MWAS,
TOAS
CA TOAS
IN MWAS
DE MWAS

(ΔT_c)
TX PG 64-22 (-4.6), PG 70-22P (-4.9)
NH PG 64-28 (+1.4)
NV PG 64-28P (-3.6)
IN PG 64-22 (-1.2), PG 58-28 (-8.0)
MN PG 58-28 (0.0)
WI PG 58-28 (-3.4), PG 52-34 (+0.4)
DE PG 64-28 (+0.1)

A1, A2
P
T1, T2
V1, V2, V3
B1, B2

TX
NV
IN
WI
DE

9-58 Field Projects



WI 9/16
0.22, 0.31 RAPBR
Recycling Agent V2

IN 9/15
0.32, 0.42 RBR
Recycling Agent T2

DE 12/16
0.33, 0.41 RBR
Recycling Agent T2

NV 9/15
0.15, 0.33 RAPBR
Recycling Agents T2, A2

TX 6/14
0.28 RBR
Recycling Agent T1

Draft AASHTO Standard Practice for 0.3-0.5 RBR + Recycling Agent

- Component Materials Selection & Proportioning Guidelines
- Recycling Agent Dose Selection & Incorporation Methods
- Binder Blend Rheological Evaluation Tools
- Mixture Performance Evaluation Tools
- RAP Binder Availability Factor

Component Materials Selection & Proportioning

- **Base Binder**
  - PGH $\leq$ 64°C
  - ΔT_c @ PAV20 $\geq$ -3.5°C

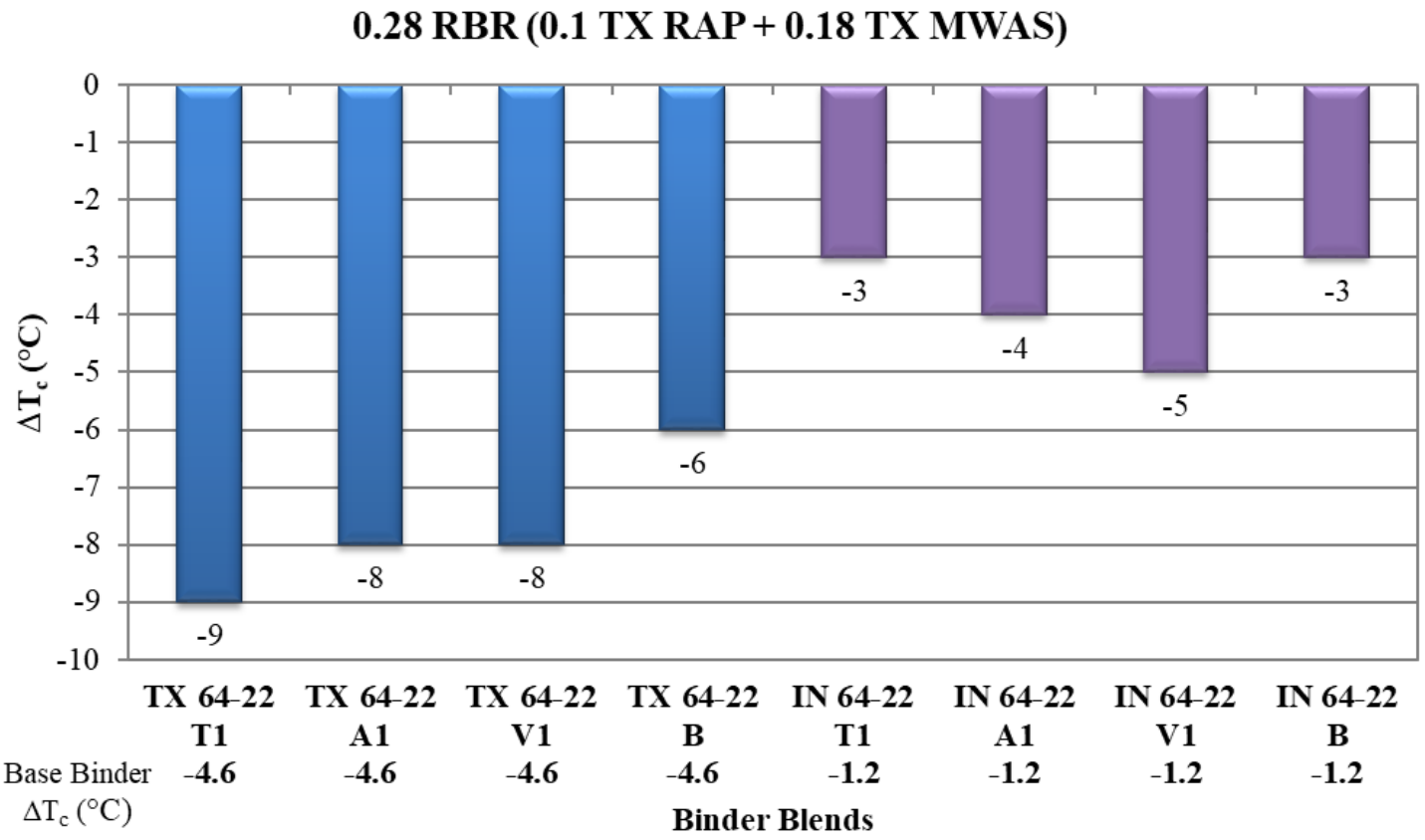
- **RAP**
  - PGH $\leq$ 100°C
  - ΔT_c @ PAV20 $\geq$ -7.5°C

- **RAS**
  - PGH $\leq$ 150°C

- **RBR $\leq$ 0.5**
  (RAP_{BR}+RAS_{BR})
- **$RAS_{BR} \leq 0.15$**

Component Materials Selection

(TX PG 64-22 w/ ΔT_c =-4.6, IN PG 64-22 w/ ΔT_c=-1.2)



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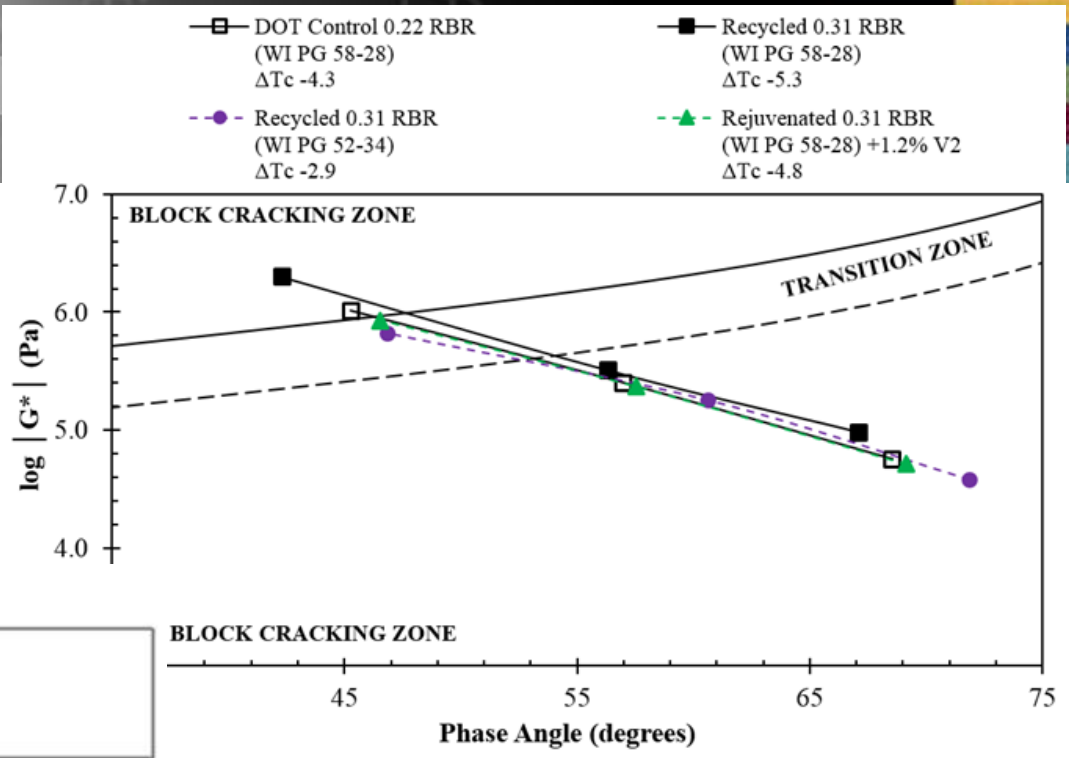
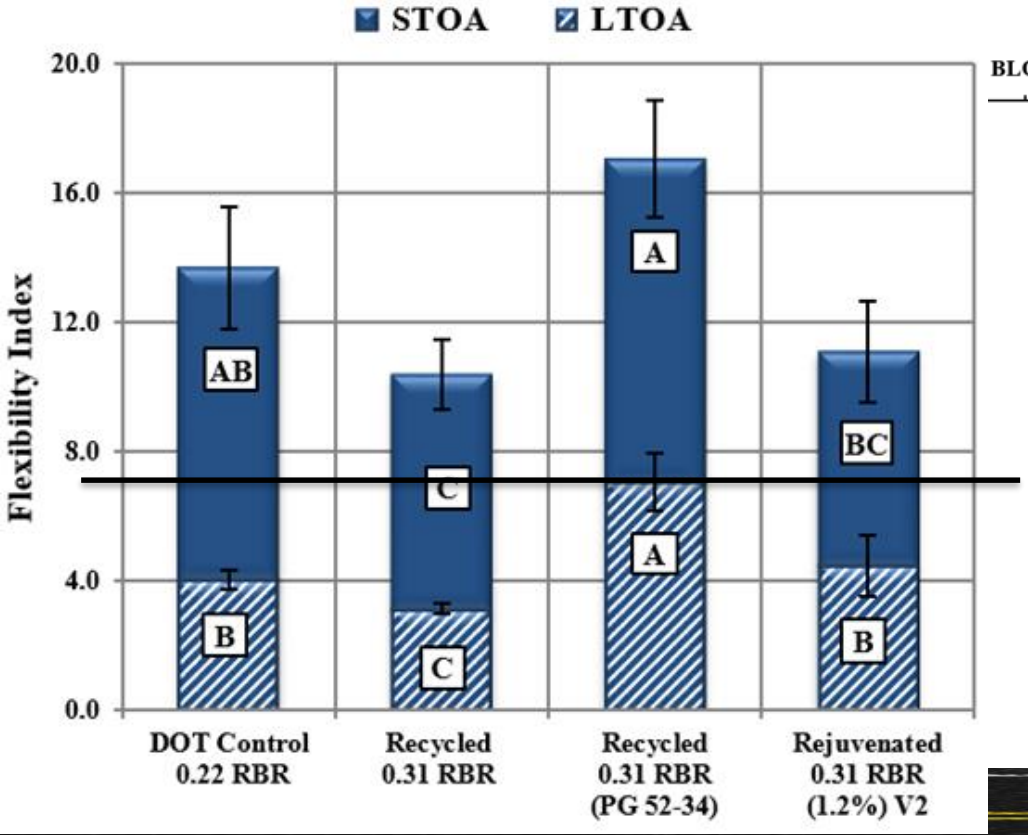
Component Materials Selection (WI PG 58-28, PG 52-34)





≥ 7 after STOA

Recycling Agent Dose Selection & Incorporation

- Match *Continuous* PGH = BALANCED

$$\%RA = (PGH_{Blend} - PGH_{Target}) \,/Slope\ Rate^{*}$$

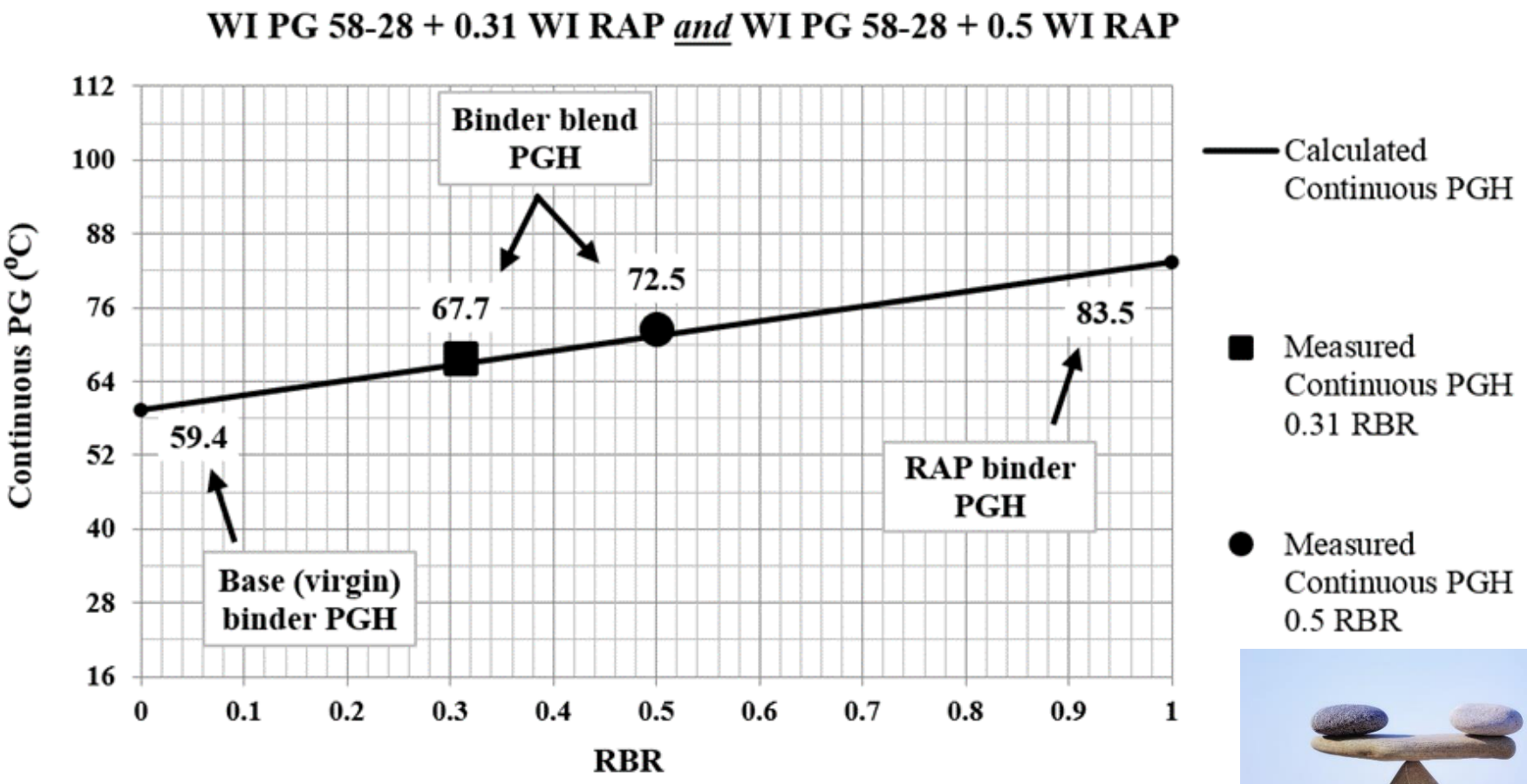
$$PGH_{Blend} = (RAP_{BR} \times PGH_{RAP}) + (RAS_{BR} \times PGH_{RAS}) + (BB_{BR} \times PGH_{Base})$$

*1.82 for tall oils, vegetable oils, bio-based oils, 1.38 for aromatic extracts

- **≤ Max without sacrificing rutting resistance & economical**
- Dose as % of total binder (base + recycled) by replacement

Materials Proportioning / Balance

$$PGH_{Blend} = (BB_{BR} \times PGH_{Base}) + (RAP_{BR} \times PGH_{RAP})$$



Materials Proportioning / Balance

$$PGH_{Blend} = (RAP_{BR} \times PGH_{RAP}) + (RAS_{BR} \times PGH_{RAS}) + (BB_{BR} \times PGH_{Base})$$

$$\%RA = (PGH_{Blend} - PGH_{Target}) \,/1.82$$

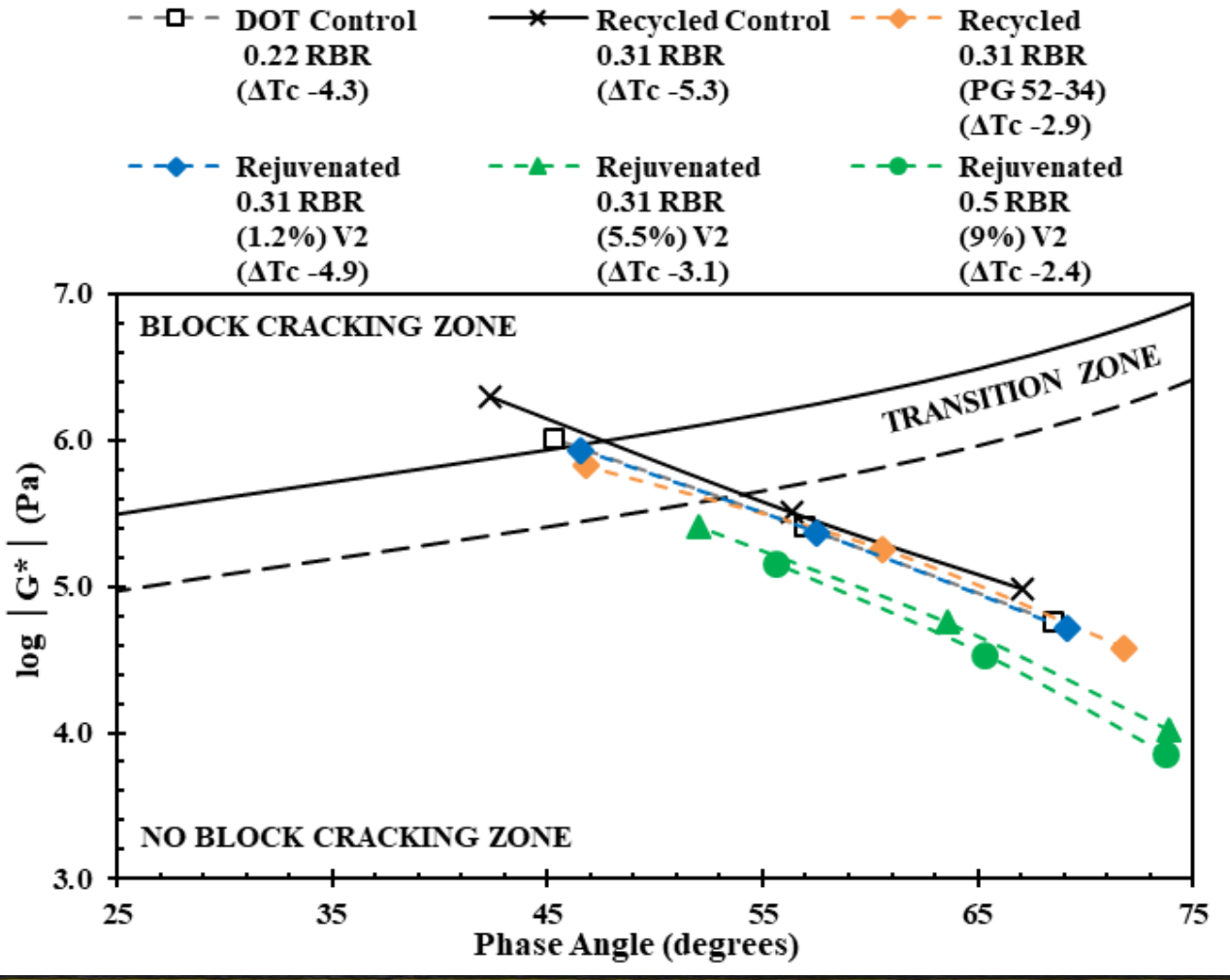
Base Binder	RAP	RAS	RA Dose	Comments
TX PG 64-22	0.25 TX RAP	0.25 TX TOAS	19.4	UNBALANCED Very High Dose
	0.4 TX RAP	0.1 TX TOAS	13.5	Δ RAP/RAS High Dose
	0.4 TX RAP	0.1 TX MWAS	10.9	Δ RAS Type High Dose
	0.4 NH RAP	0.1 TX MWAS	7.3	Δ RAP Type Marginal Dose
MN 58-28	0.4 NH RAP	0.1 TX MWAS	4.6	Δ Base Binder Acceptable Dose

Binder Blend Rheological Evaluation

T & Aging Conditions	Test	Parameter	Suggested Performance Threshold
T_{high} Unaged, Short-Term	DSR	PGH	Target Climate
T_{int} Track w/Aging	DSR	G-R	$\leq$ 180 kPa after 20-hr PAV $\leq$ 600 kPa after 40-hr PAV
	DSR	$T_{\delta=45°}$	$\leq$ 32° after 20-hr PAV $\leq$ 45° after 40-hr PAV
T_{low} Long-Term	BBR	ΔT_c	$\geq$ -5.0 after 20-hr PAV

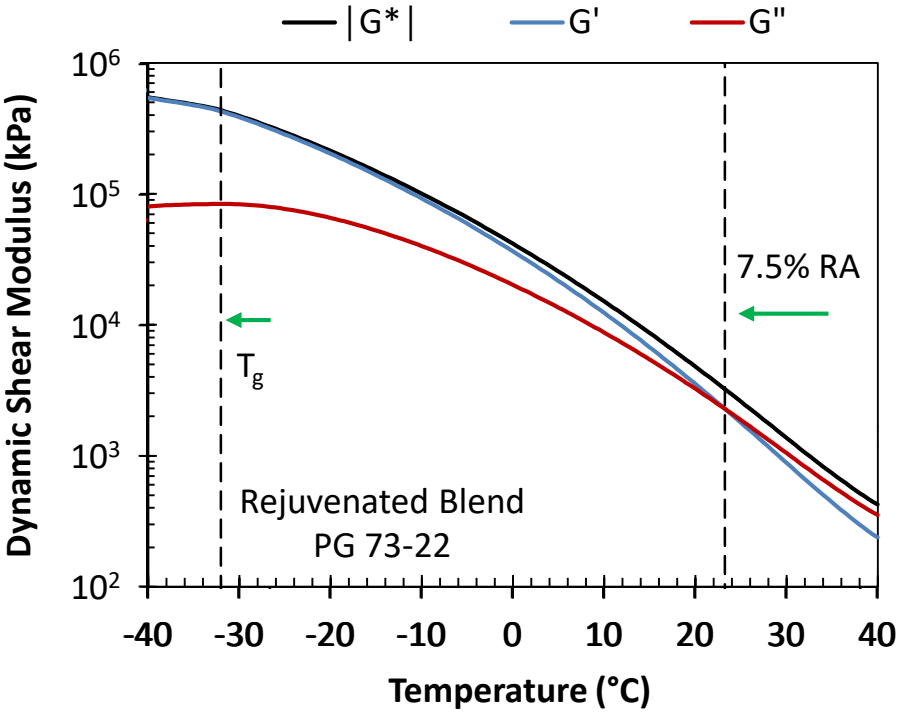
Short-Term Aging = RTFOT; Long-Term Aging = PAV @ 100°C

G-R Black Space (WI PG 58-28, PG 52-34)

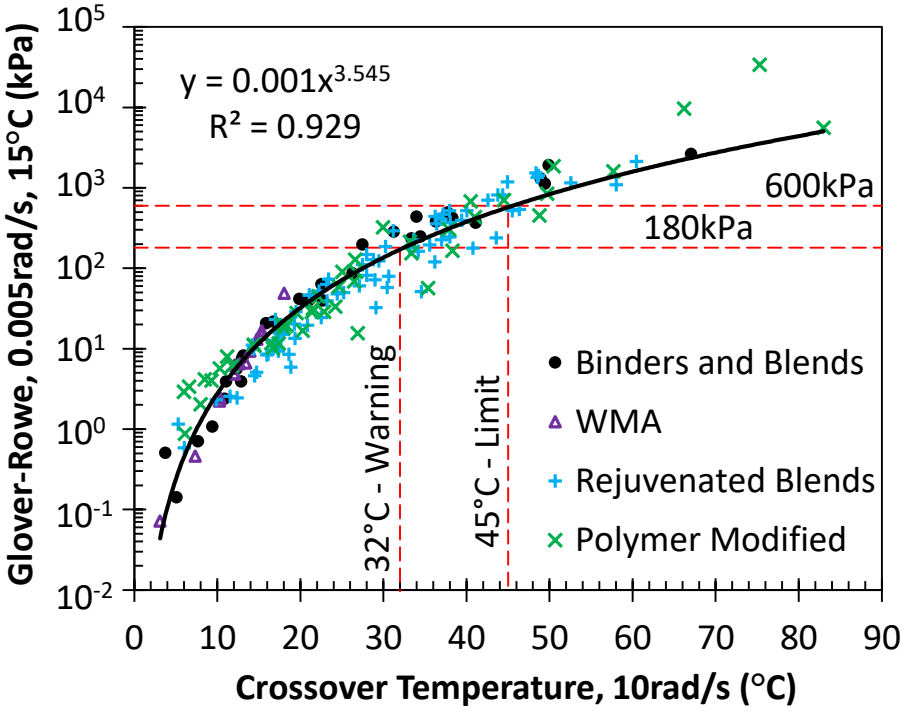


Crossover Temperature ($T_{\delta=45^\circ}$) @ 10 rad/sec

Determination by T Sweep



Preliminary Thresholds



Note: $T_{\delta=45^\circ}$ in this study was obtained from mastercurves and time-temperature superposition.

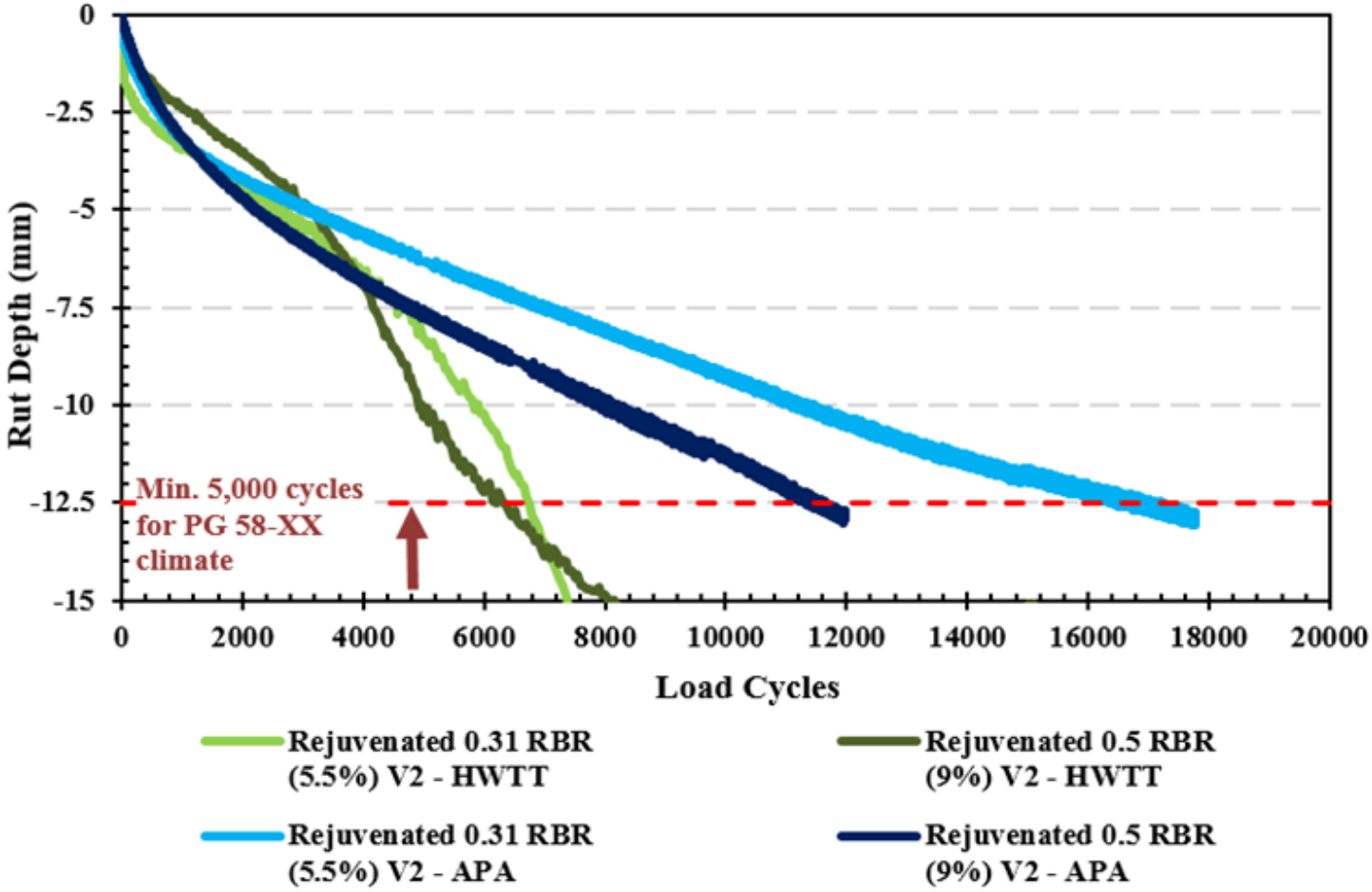
Mixture Performance Evaluation

T & Aging Conditions	Test	Parameter	Suggested Performance Threshold
T_{high} Short-Term	HWTT or APA	$N_{12.5}$	$\geq$ 5000 for PG 58-XX $\geq$ 7500 for PG 64-XX (cold) $\geq$ 10,000 for PG 64-XX (warm) $\geq$ 15,000 for PG 70-XX
T_{int} Track w/Aging & Short-Term	E*	G-R_m	$\leq$ 8000 MPa after STOA $\leq$ 19,000 MPa after LTOA
	I-FIT	FI	$\geq$ 7 after STOA
T_{low} Short- & Long-Term	BBR_m	S_m, m-$value_m$	$\leq$ Utah threshold after STOA
	UTSST	CRI_{Env}	$\geq$ 17 after LTOA

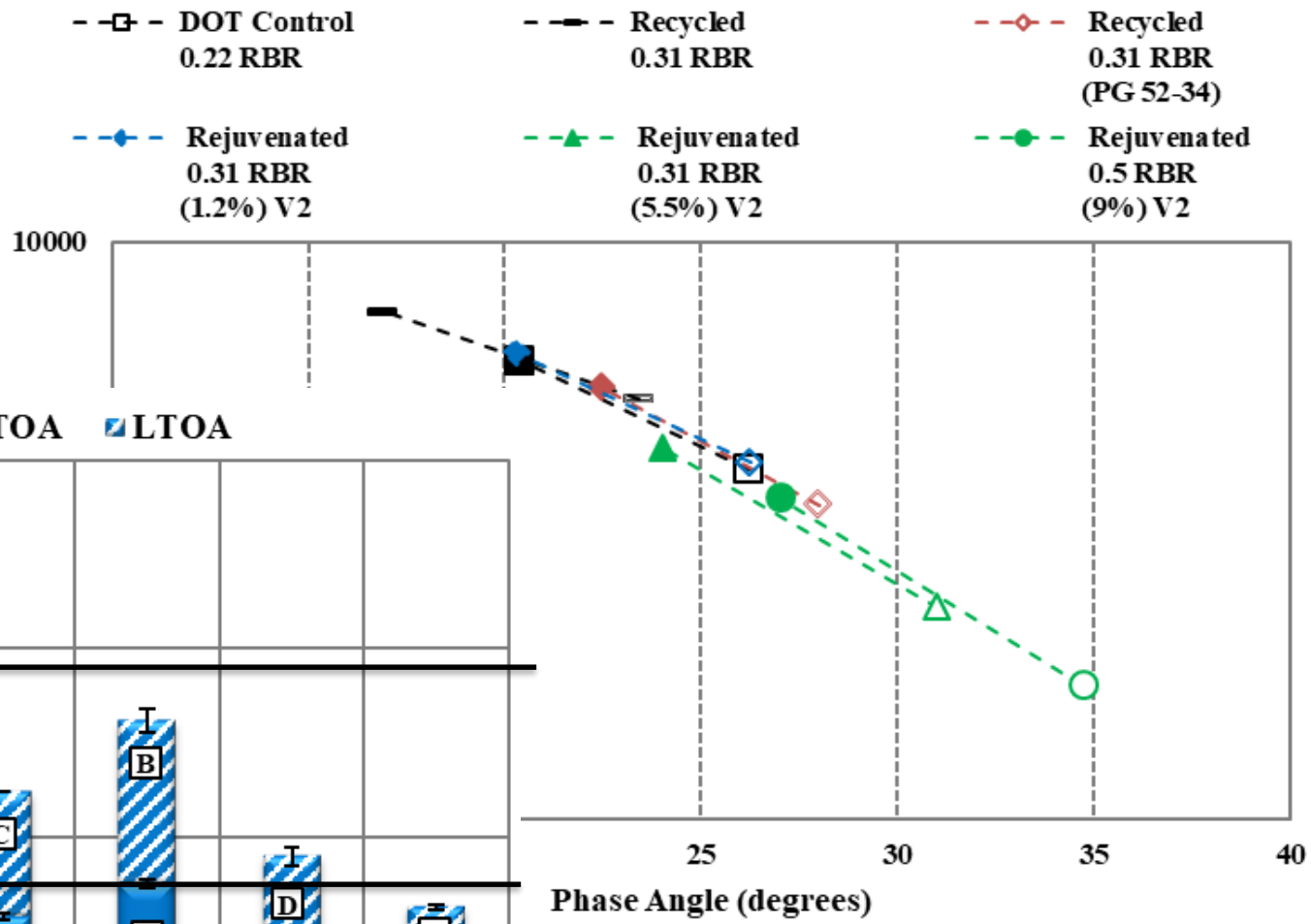
Short-Term Aging = STOA = 2hr @ 135˚C; Long-Term Aging = LTOA = 5d @ 85˚C

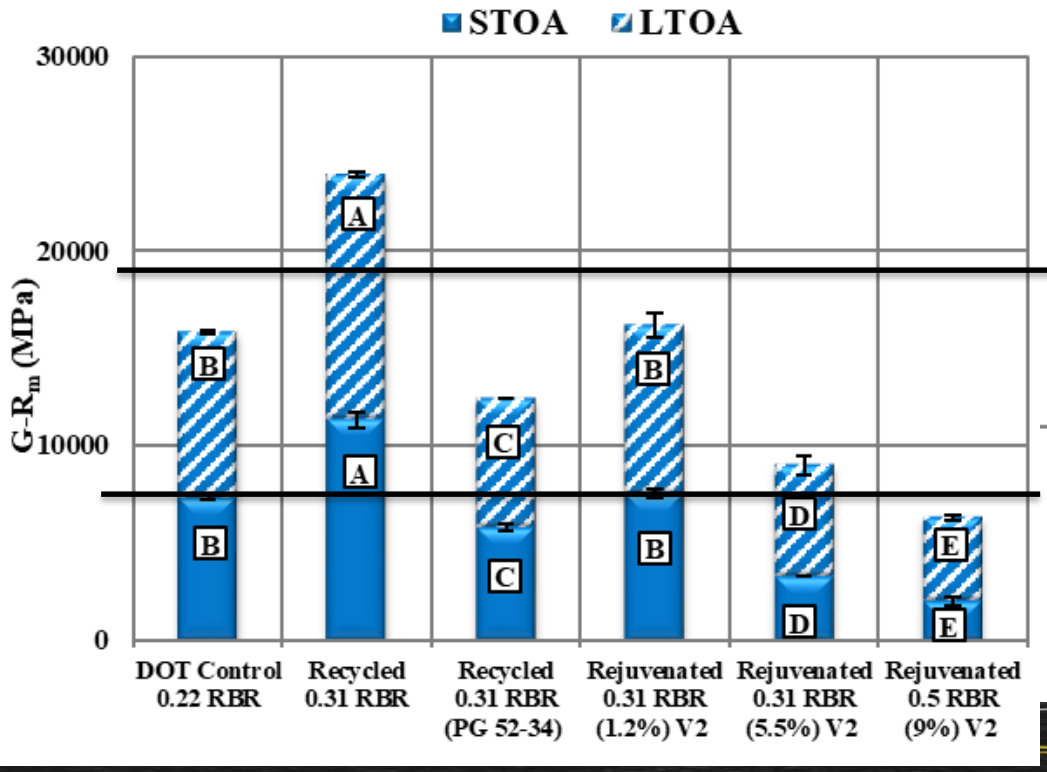
$N_{12.5}$ (WI PG 58-28)

≥ 5000 for PG 58-XX



$G\text{-}R_m$ Black Space WI PG 58-28, PG 52-34



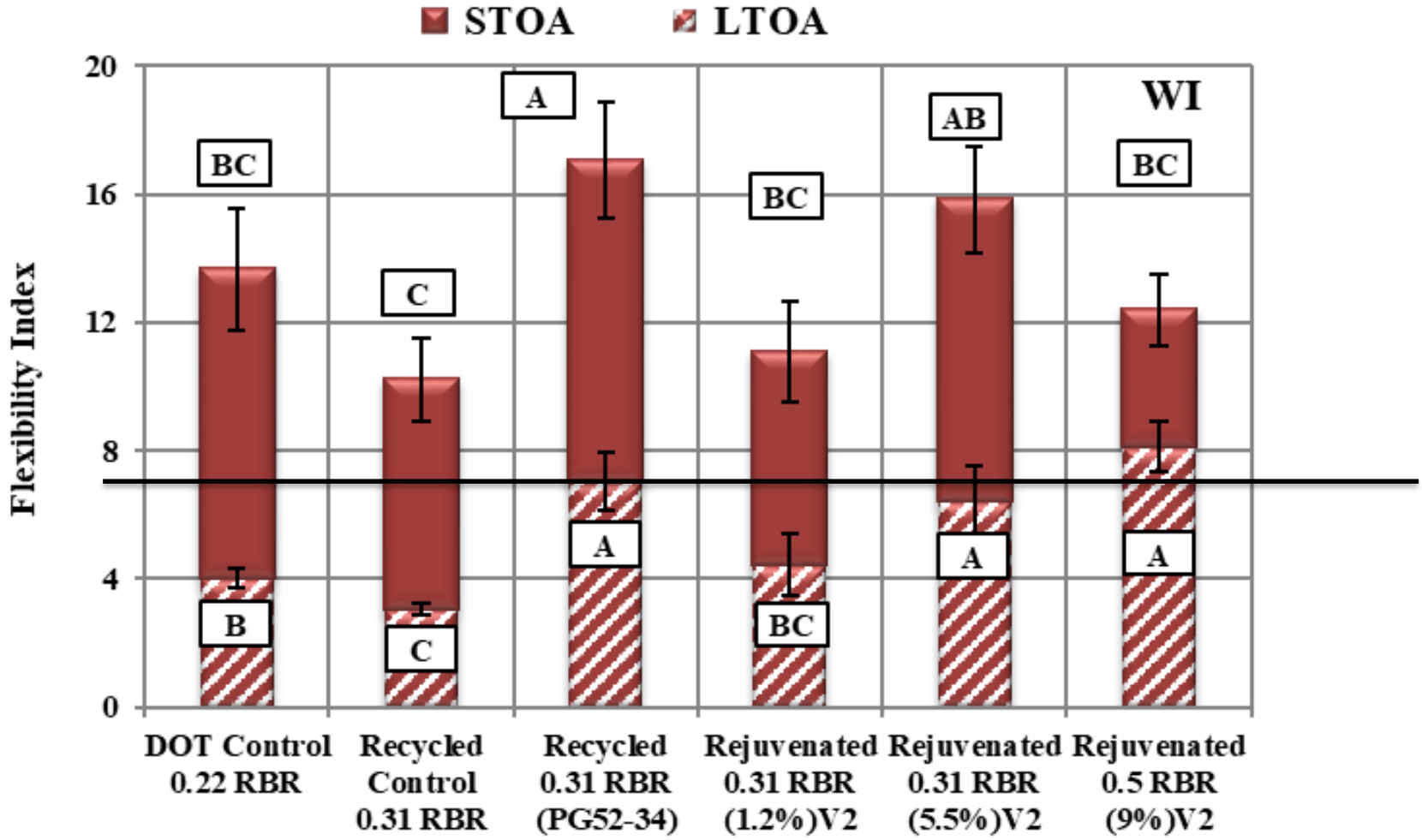


≤ 8000 MPa after STOA

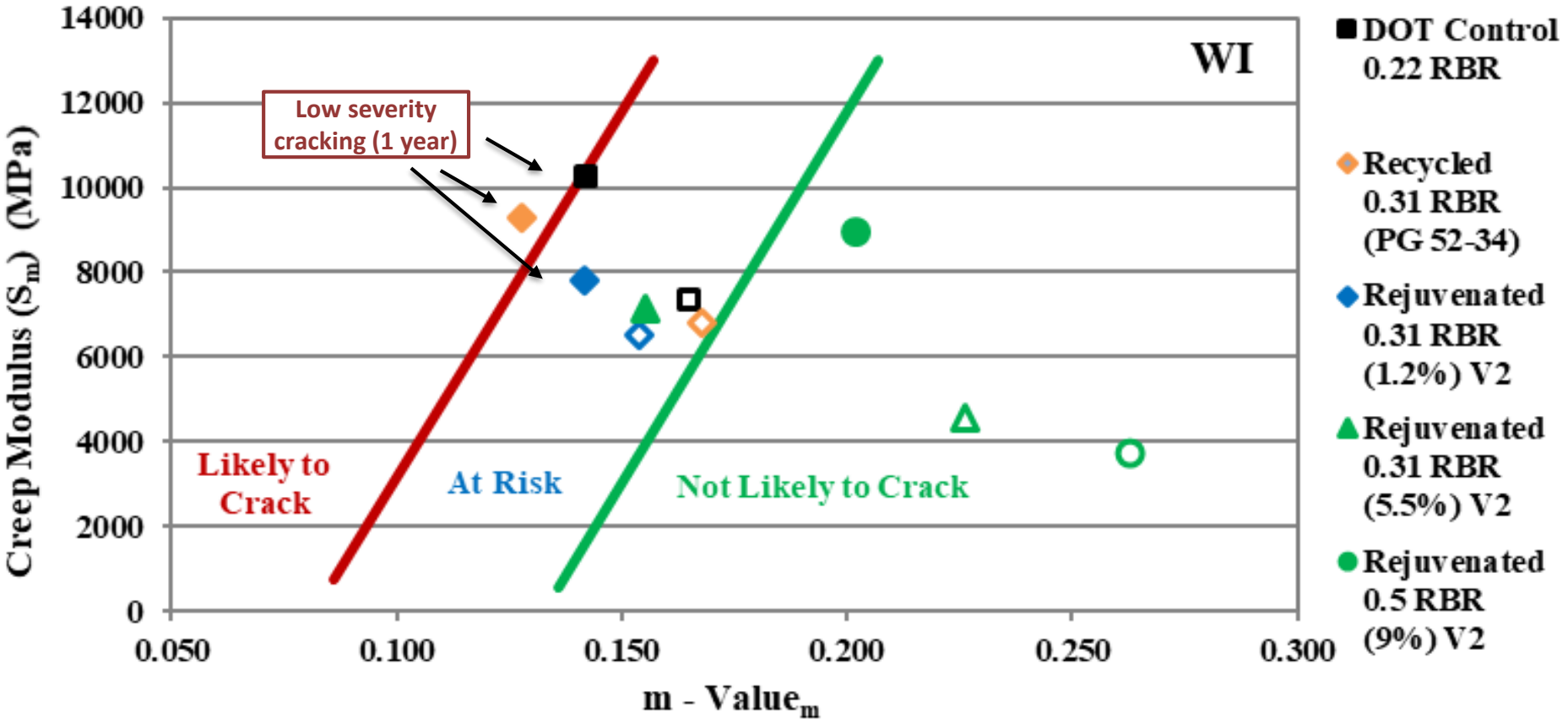
≤ 19,000 MPa after LTOA

FI (WI PG 58-28, PG 52-34)

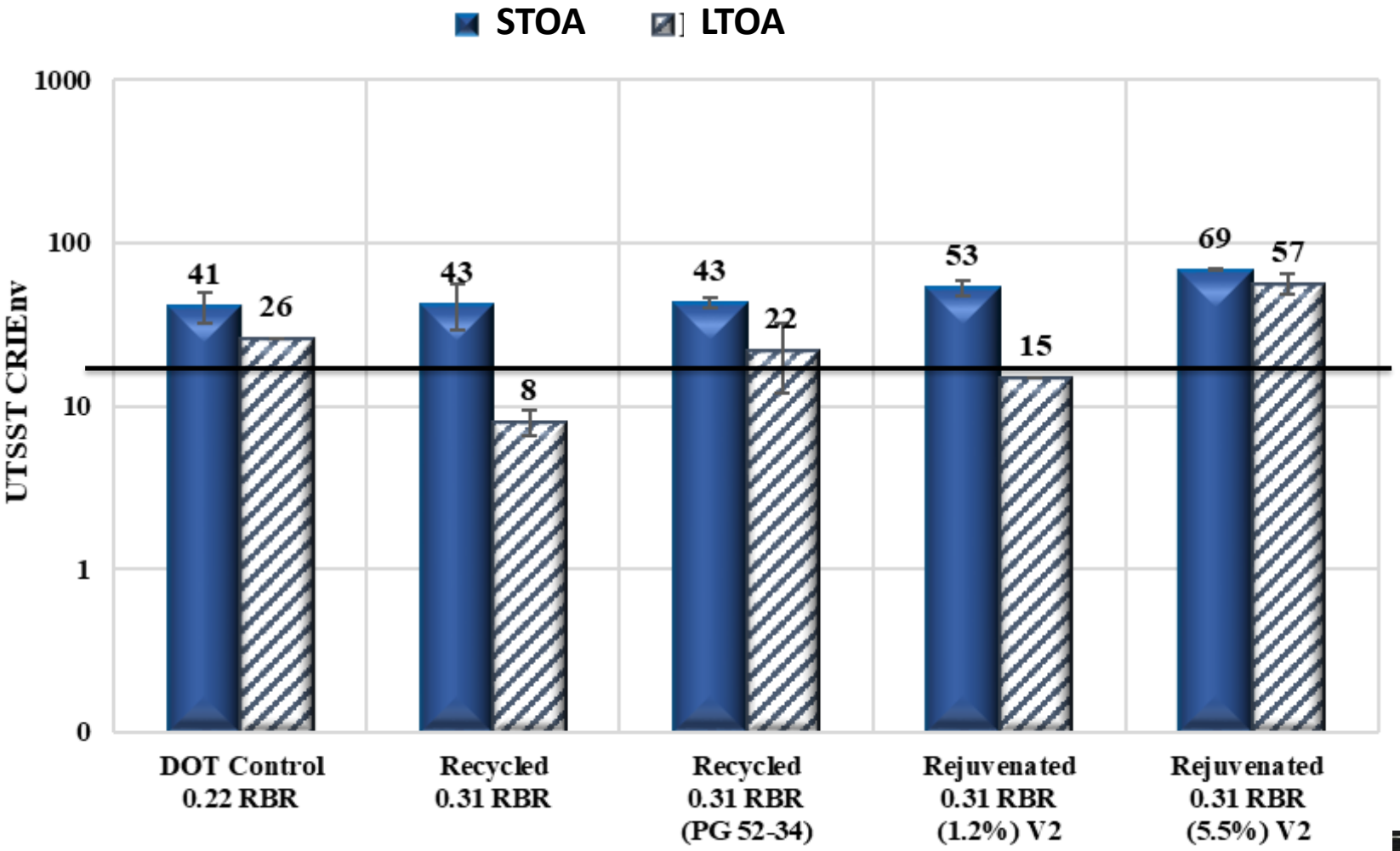
≥ 7 after STOA



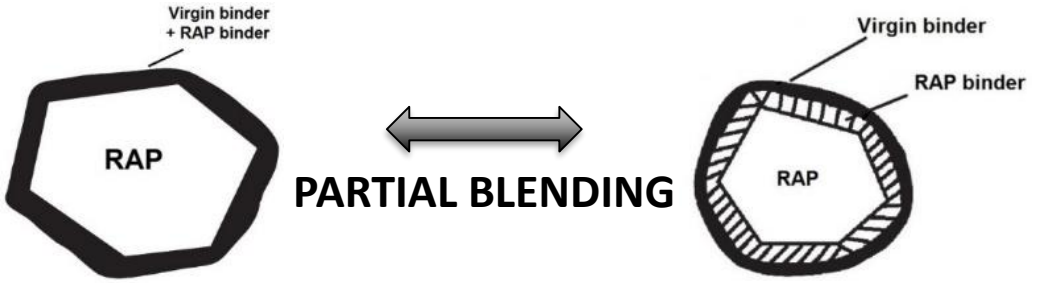
S_m, m-value$_m$ (WI PG 58-28, PG 52-34)



CRI_{Env} (WI PG 58-28, PG 52-34) ≥ 17 after LTOA



RAP Binder Availability



100% Available **0% Available**

Black Rock

- Binder Availability Factor (BAF)

  measured binder content of #4 fraction in RAP mixture as compared to that for virgin mixture

  $RAPBAF = -0.010\ x\ PGH_{RAP} + 1.771$ for 150°C mixing

- Degree of Activity (DoA)

  IDT TS of 100% RAP after 4hrs @ 140°C, 170°C & SGC compaction

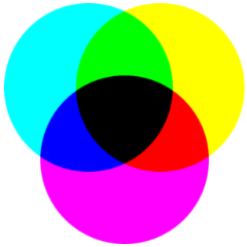
$$DoA\ (\%) = 100 \times \frac{TS\ (T)}{max\ TS}$$

RAP Binder Availability

	NCHRP 09-58 (BAF)	RILEM (DoA)	FHWA (DWT)
Advantages	Considers interaction of RAP & virgin materials	Requires only RAP	Requires only RAP
	Performance testing not required	Utilizes simple performance testing & relevant conditioning temperatures	Performance testing not required
		Captures effects of gradation & effective binder content	
Limitations	Requires ignition oven	Includes testing @ multiple temperatures	Requires SGC with modified control software
	Uses specific type & size of RAP & virgin materials	Requires comparison of results for multiple RAP sources	
	Only considers total binder content		No agreement with other methods

Additional Results

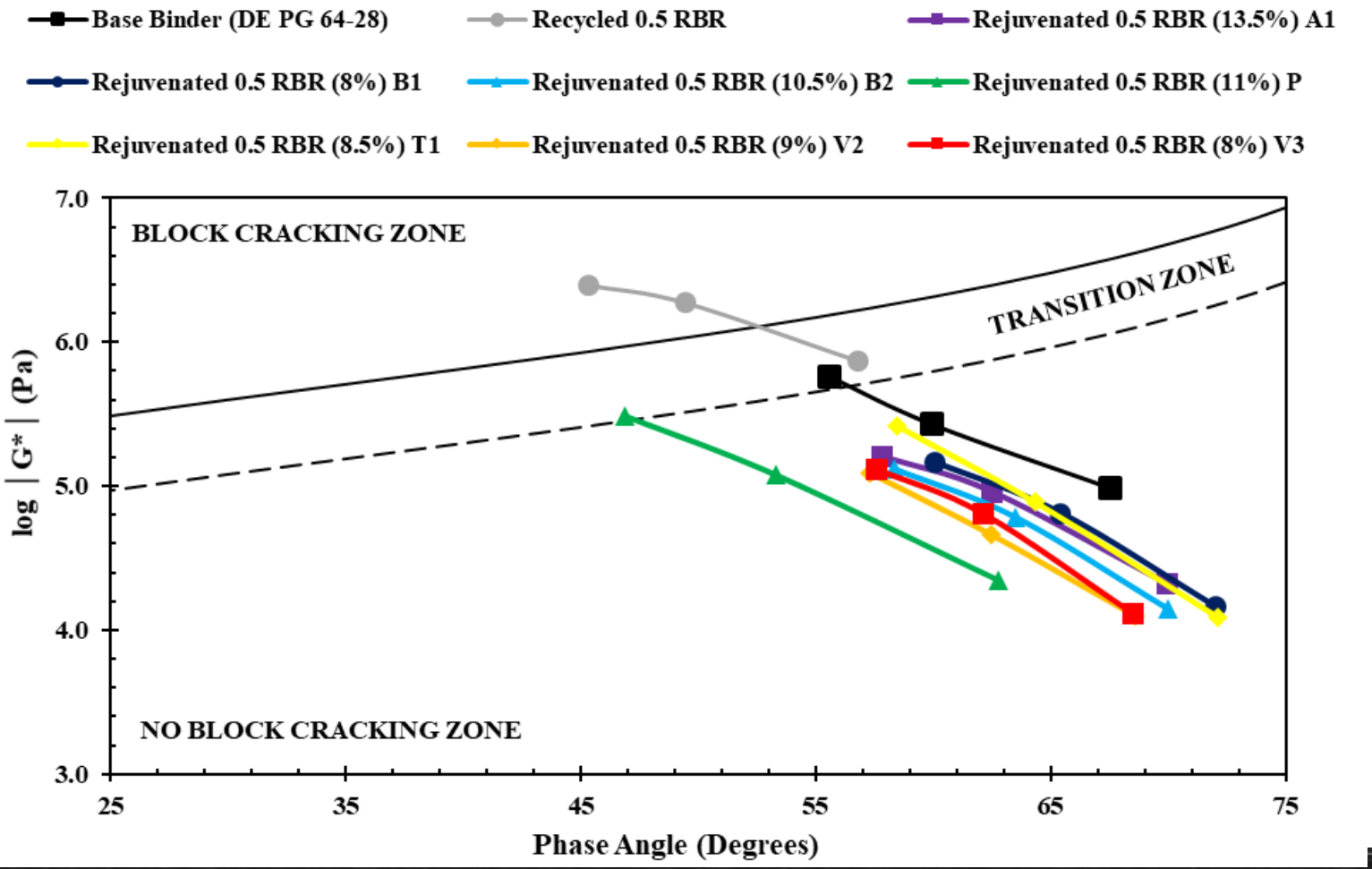
- Representative Binder Blending
  - **mortar results indicate complete blending "over" estimates both PGH & PGL**



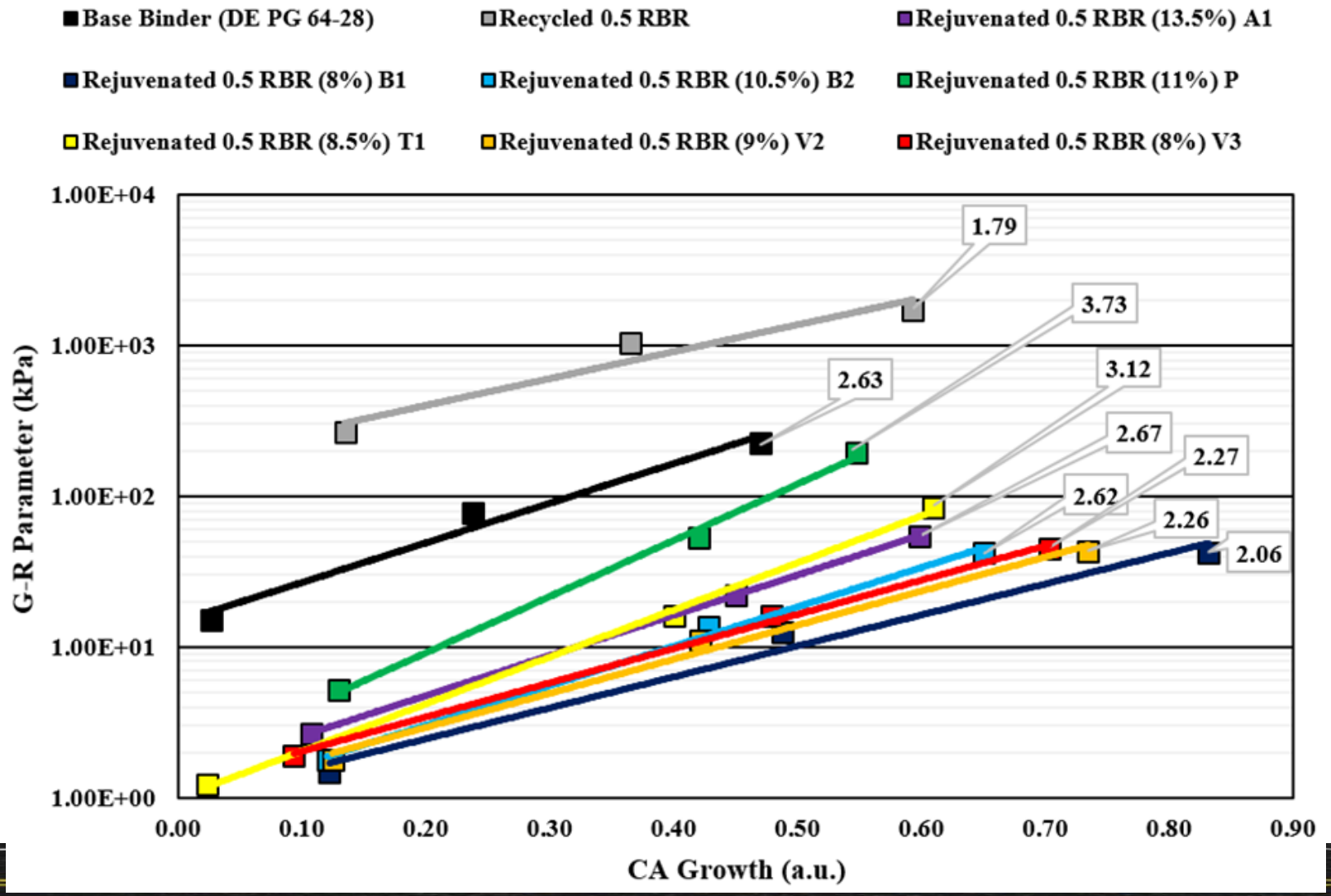
- Chemical Compatibility
  - **DSC results show recycling agents shift T_g colder**
  - **AFM results indicate recycling agents increase & aging decreases molecular mobility**
  - **FTIR results show carbonyl compounds in recycling agents that thus require the use of CA_g**

- Recycling Agent Classification/Effectiveness
  - Bulk
  - Microstructure

Recycling Agent Classification/Effectiveness

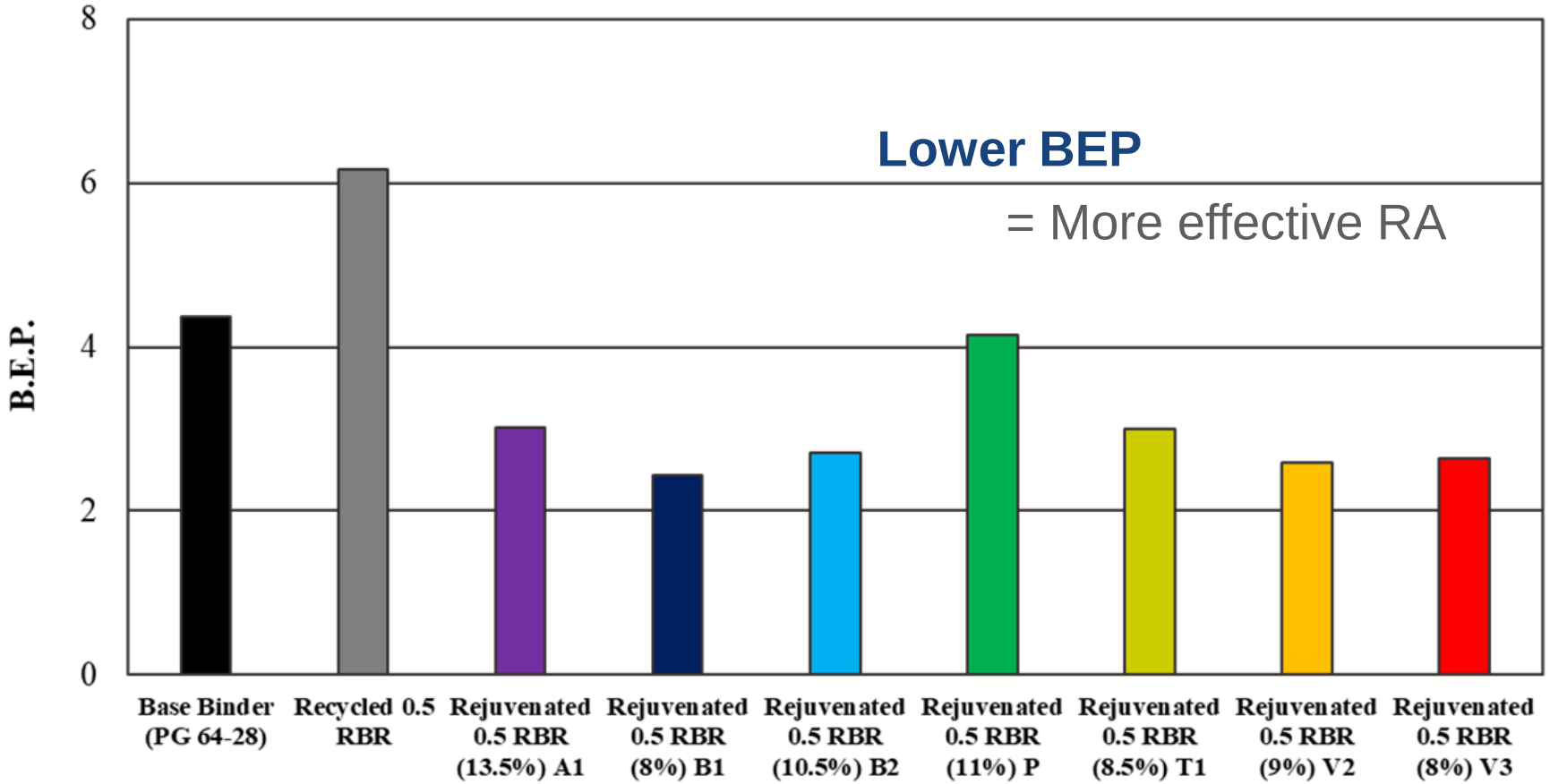


Recycling Agent Classification/Effectiveness

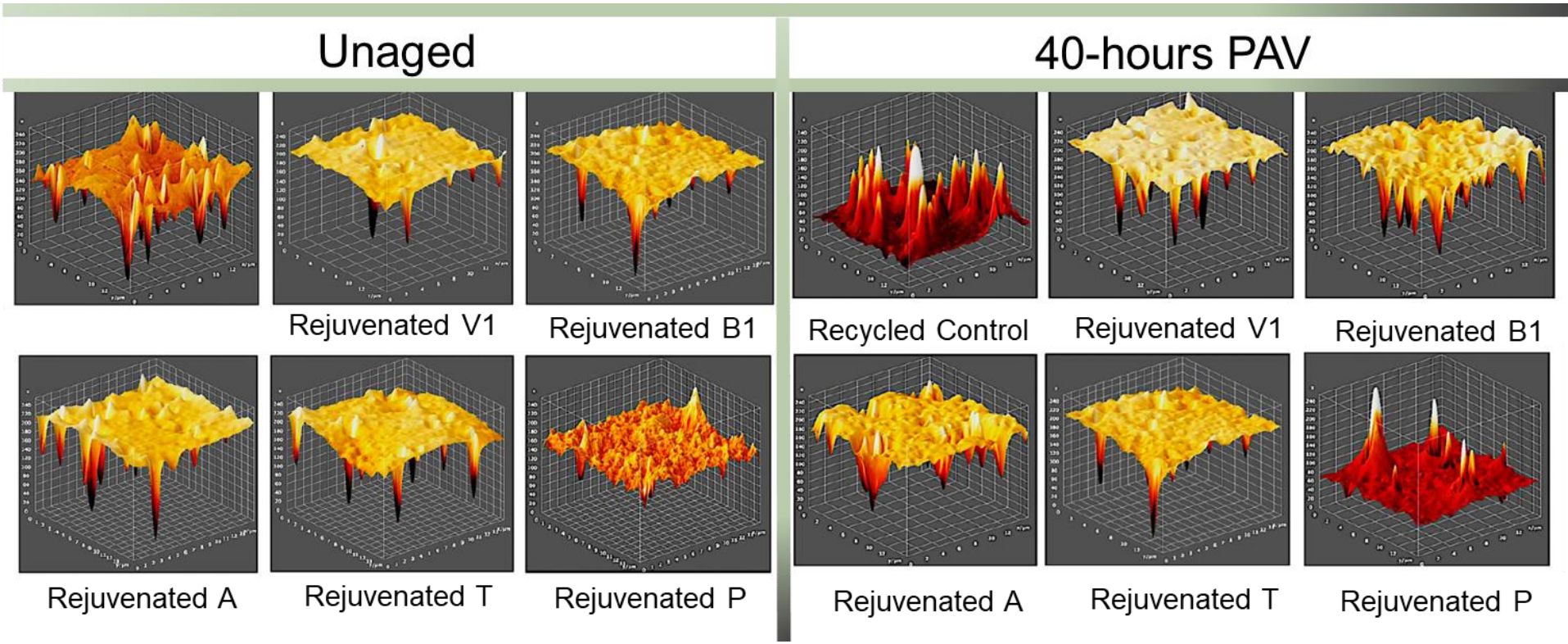


Recycling Agent Classification/Effectiveness

Binder Embrittlement Parameter (BEP) = $\text{Log}[(\text{G-R}_{\text{RTFO}}*\text{G-R}_{\text{PAV40}})*(\text{G-R/CA}_{\text{g}}\ \text{HS})^2]$

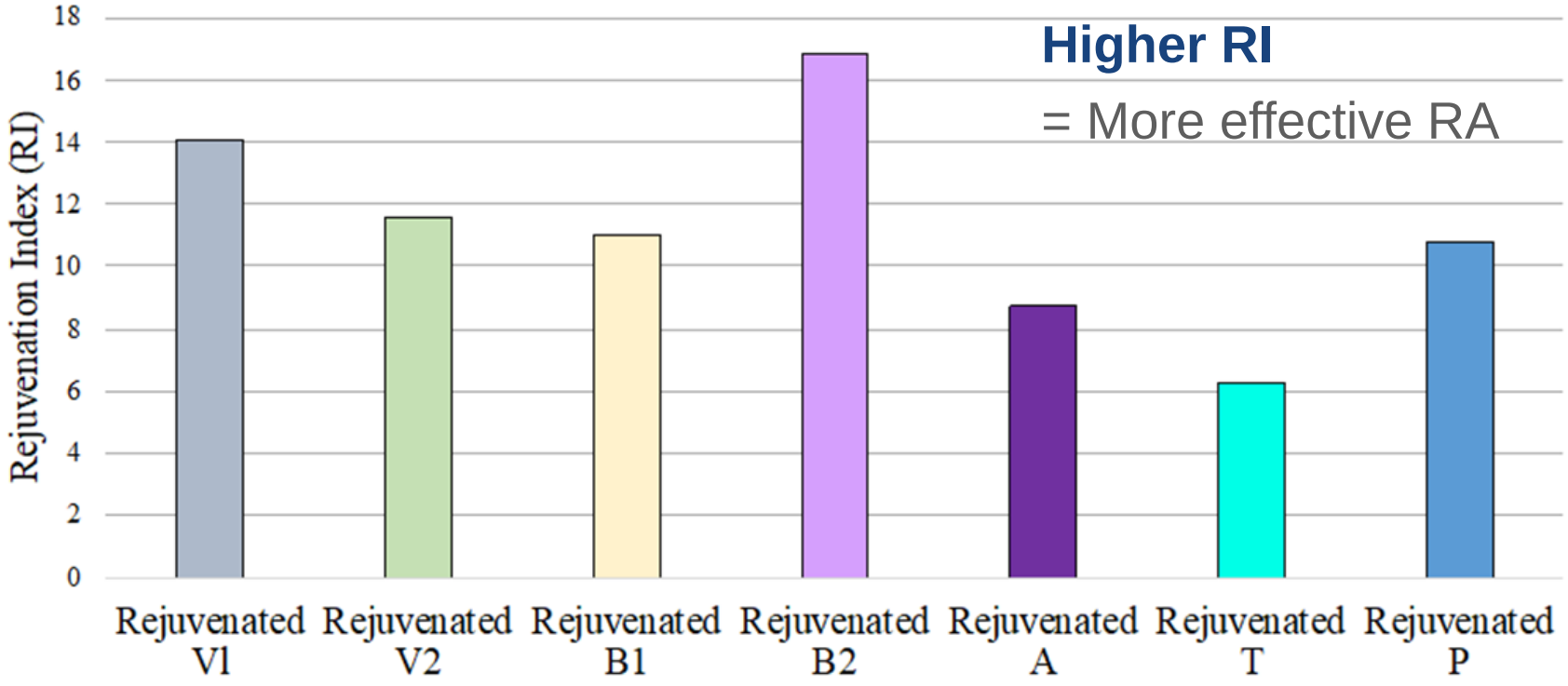


Recycling Agent Classification/Effectiveness - Microstructure



Recycling Agent Classification/Effectiveness

$$\text{Rejuvenation Index (RI)} = \frac{\int_0^{40} E_{RAP}(x)dx \,.\, \int_0^{40} WPT\ Energy_{RAP}(x)dx}{\int_0^{40} E_{Rej}(x)dx \,.\, \int_0^{40} WPT\ Energy_{Rej}(x)dx}$$



Recycling Agent Classification/Effectiveness

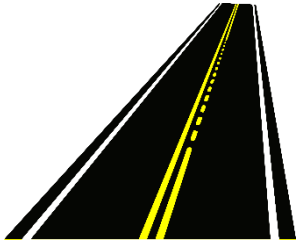
- Must utilize CA_g
- BEP captures oxidation & rheological stiffening, embrittlement
- RI captures aging resistance & roughness/inhomogeneity
- Recycling Agent Classification
  - P = only ***SOFTENER*** w/poor compatibility despite low CA_g
  - A = sufficient ***REPLENISHER*** for some combos @ higher dose
  - V & B = ***EMULSIFIER*** to compatabilize, oxidize but less rheological effect
  - T = ***EMULSIFIER*** that is more sensitive to aging, more volatile (early gen)
- Specifications for blends & characterization with aging needed

Implementation & Future Research

- TxDOT BMD with High RBR

- Capturing Durability of High RBR Mixtures (NCHRP 09-65)
  - Moisture Susceptibility
  - Aging

- Field Demonstration Projects with High Recycling Agent Dose



- NAPA Practical Guide

- Recycling Agent Classification

- Binder Availability & Blending

THANK YOU!

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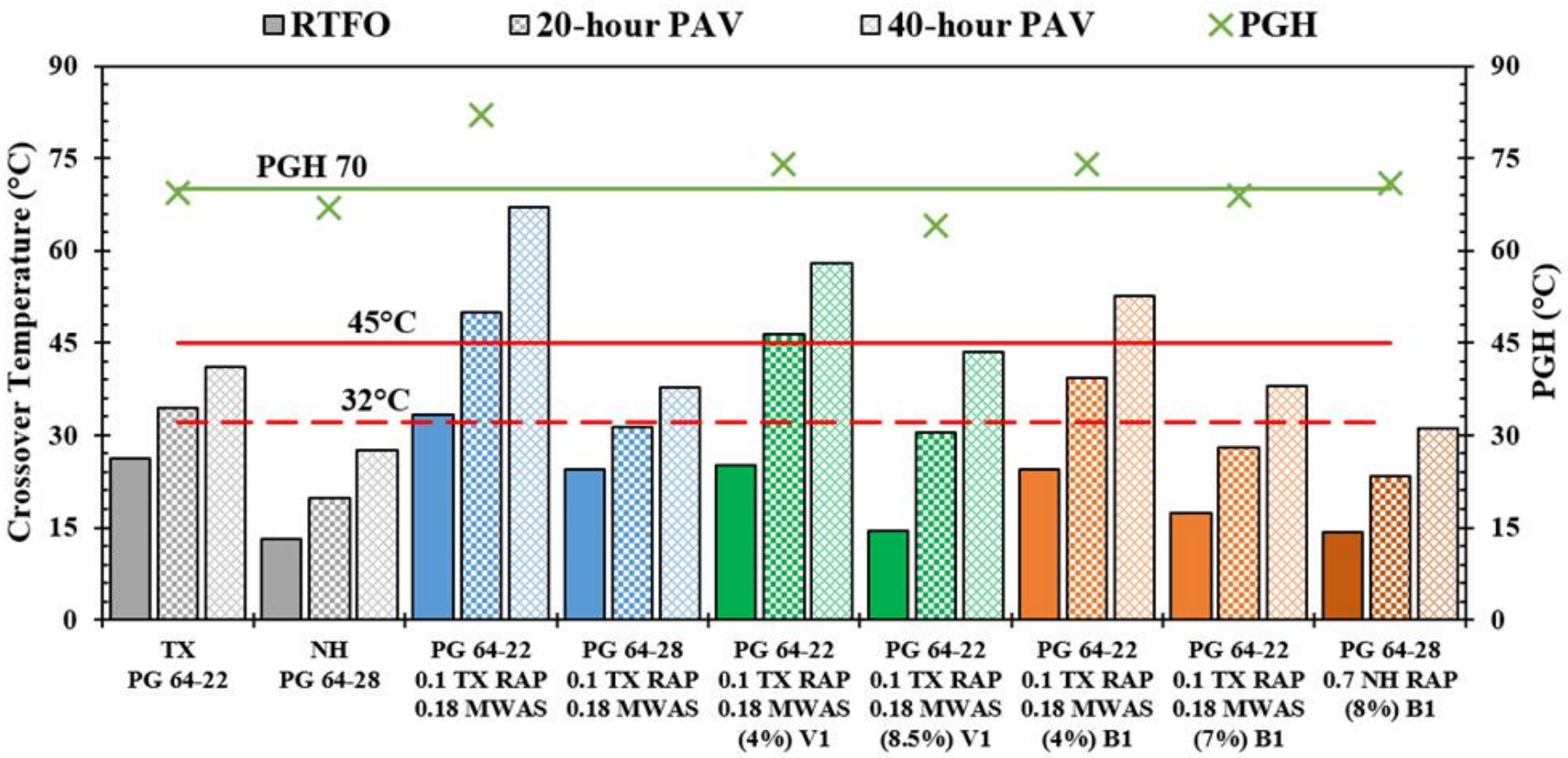
Acknowledgements

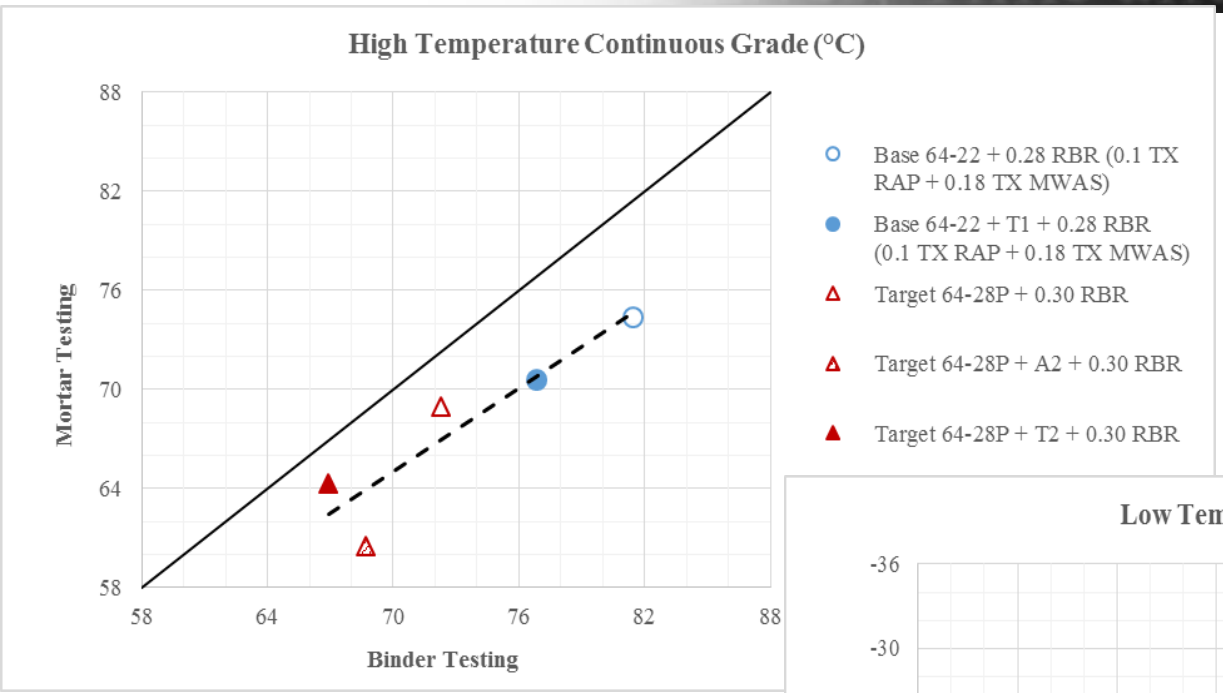
TTI, UNH, UNR, Gayle King

TX, NV, IN, WI, DE DOTs, APAs, & Contractors

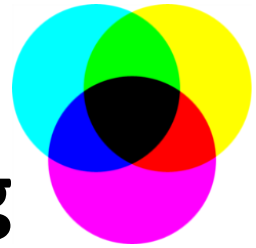
Recycling Agent Manufacturers

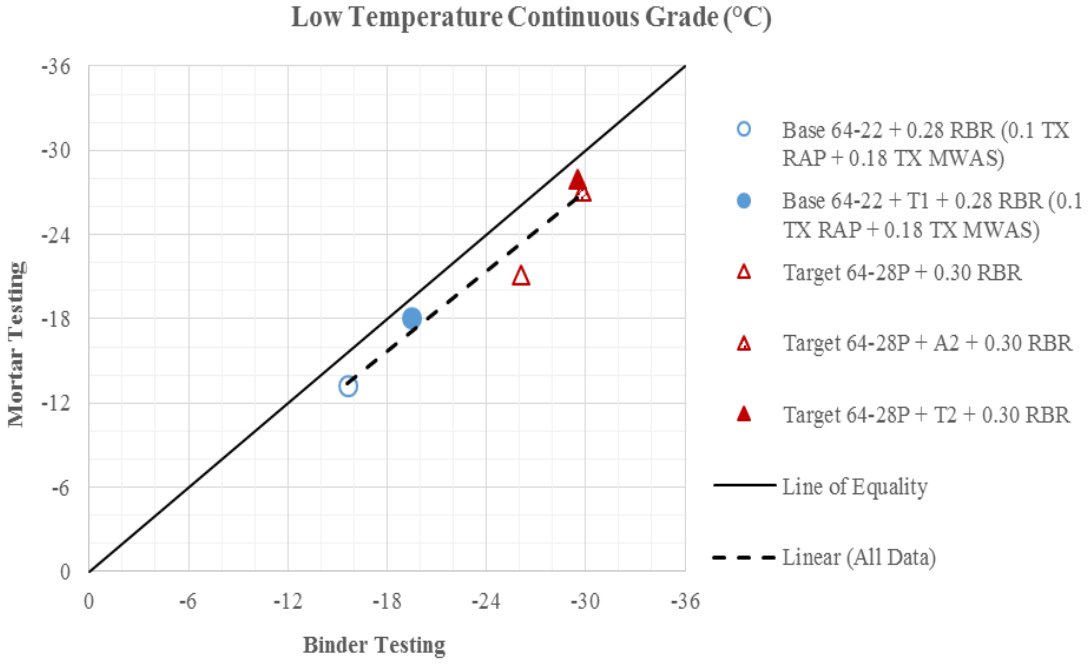
Crossover Temperature ($T_{\delta=45^\circ}$) @ 10 rad/sec (TX PG 64-22 w/ ΔT_c =-4.6, NH PG 64-28 w/ ΔT_c=+1.4)





Representative Binder Blending





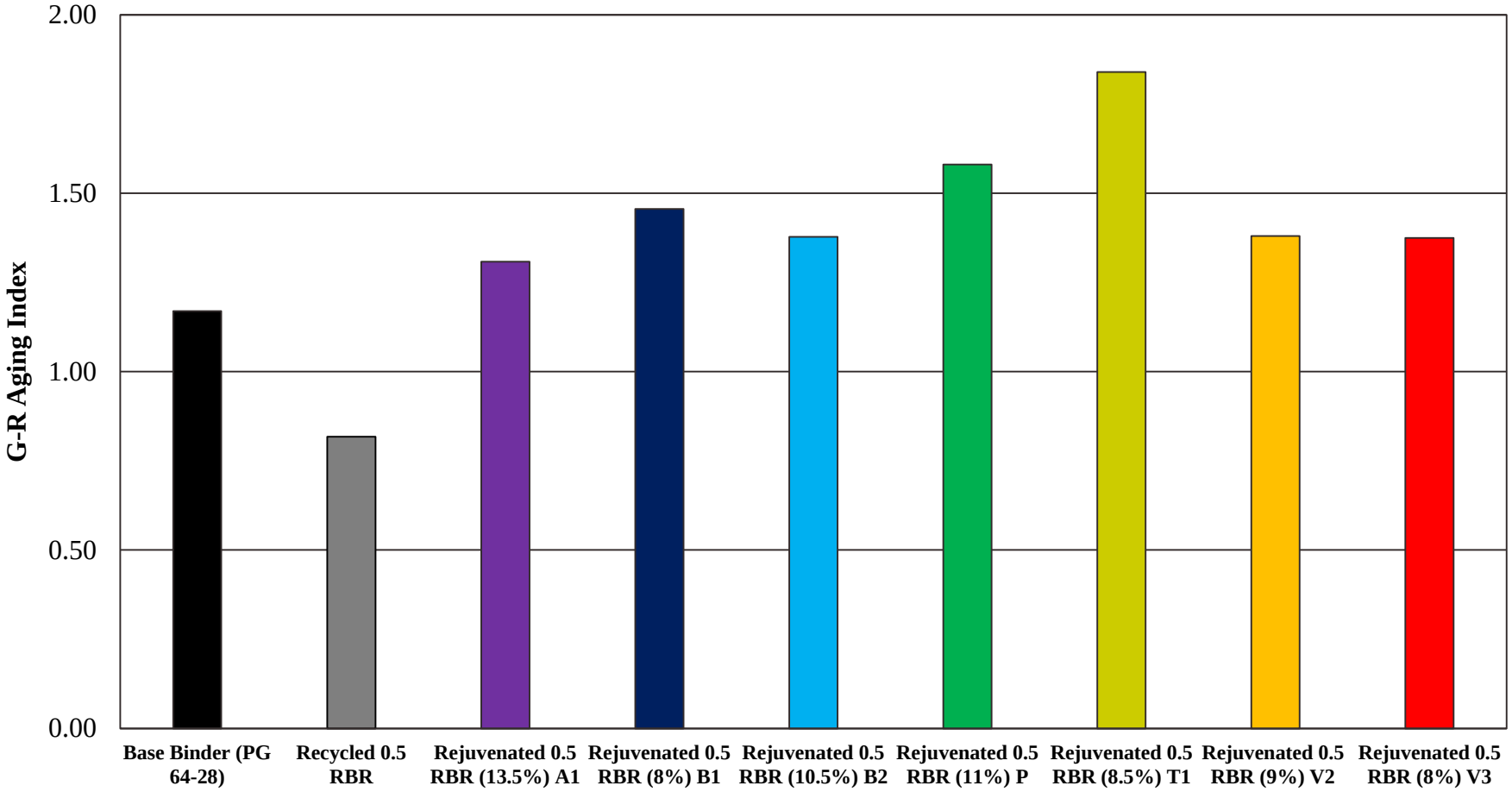
- RA reduces both PGH & PGL
- Complete blending **"over" estimates** both PGH & PGL

Chemical Compatibility

	Highlights	Tools/Partner
Rejuvenation	T_g Inflection & T_g End shift to **colder T**	Modulated DSC/WRI
	Strong RA-asphaltene polar interaction, **no breaking of agglomerates**	SAR-AD/WRI
	Some RA include carbonyl-containing chemical groups that *confound CA calculation*	FT-IR/TTI
	Microstructural changes suggest **increased molecular mobility**	AFM/TAMU Q
Aging	RA can experience chemical changes with aging	FT-IR/TTI
	Microstructural changes suggest **decreased molecular mobility**	AFM/TAMU Q

Black Space Evaluation with Aging/Recycling

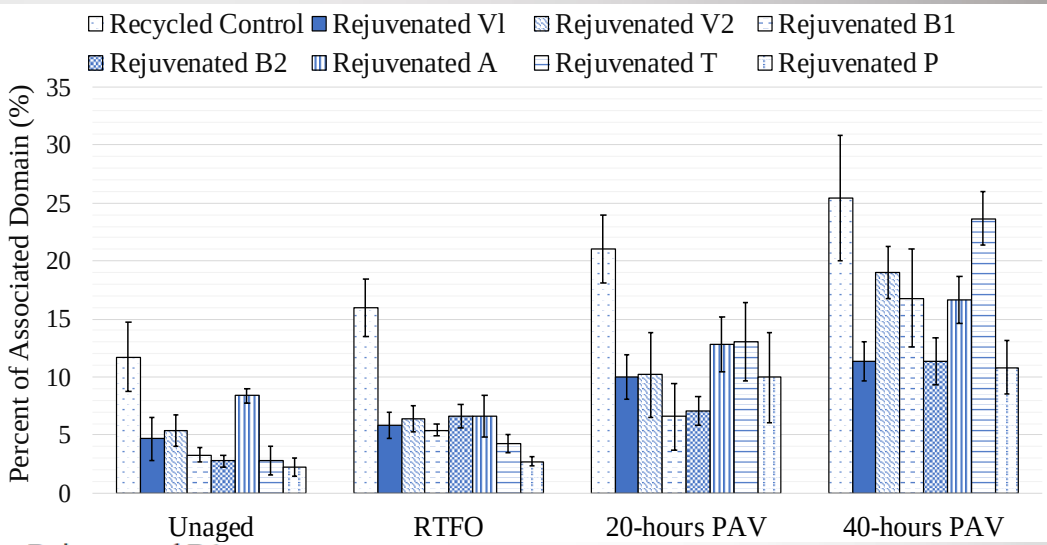
Aging Index = Log [G-R_{PAV40}/G-R_{RTFO}]

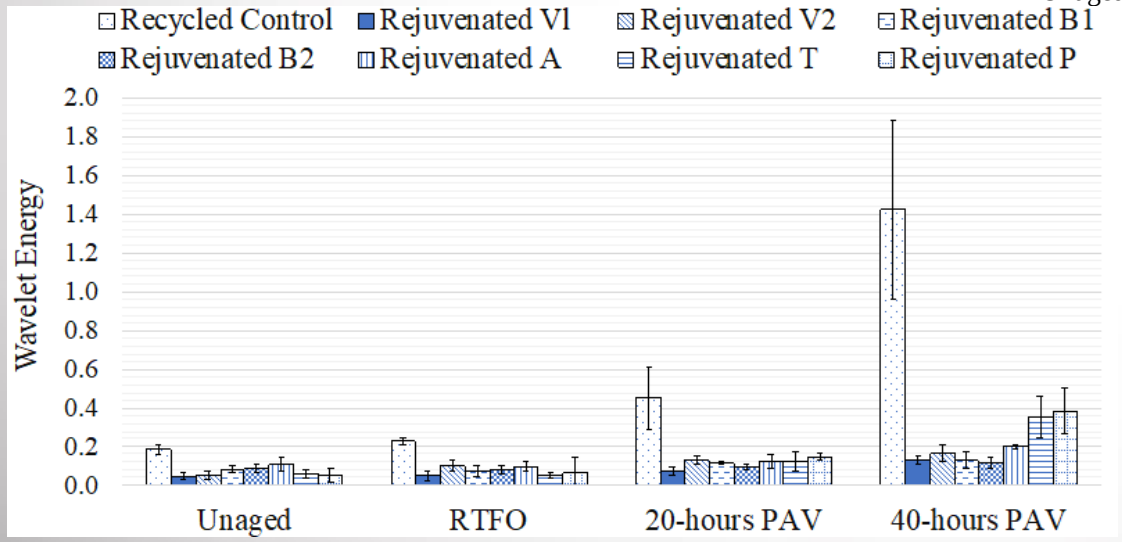


Microstructure Quantification

More %associations

= Less homogeneity

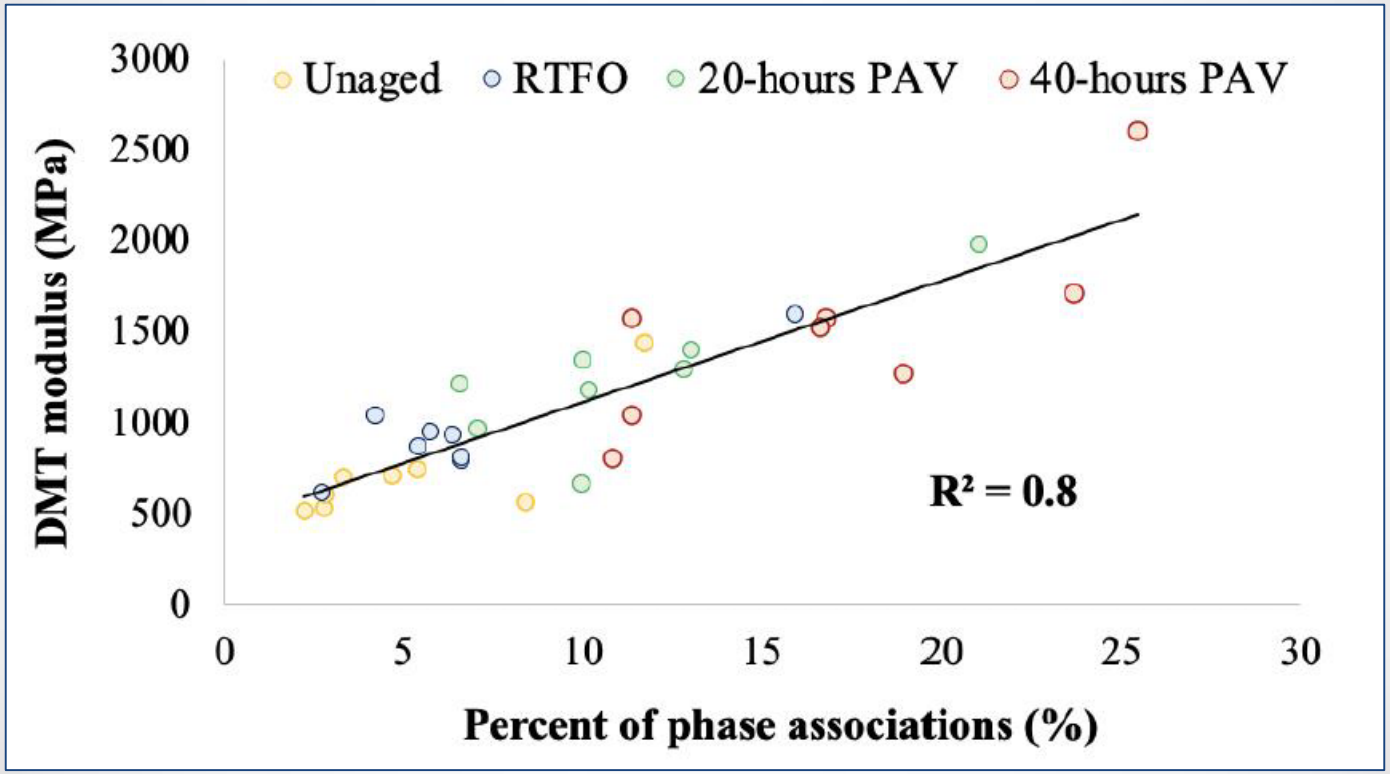




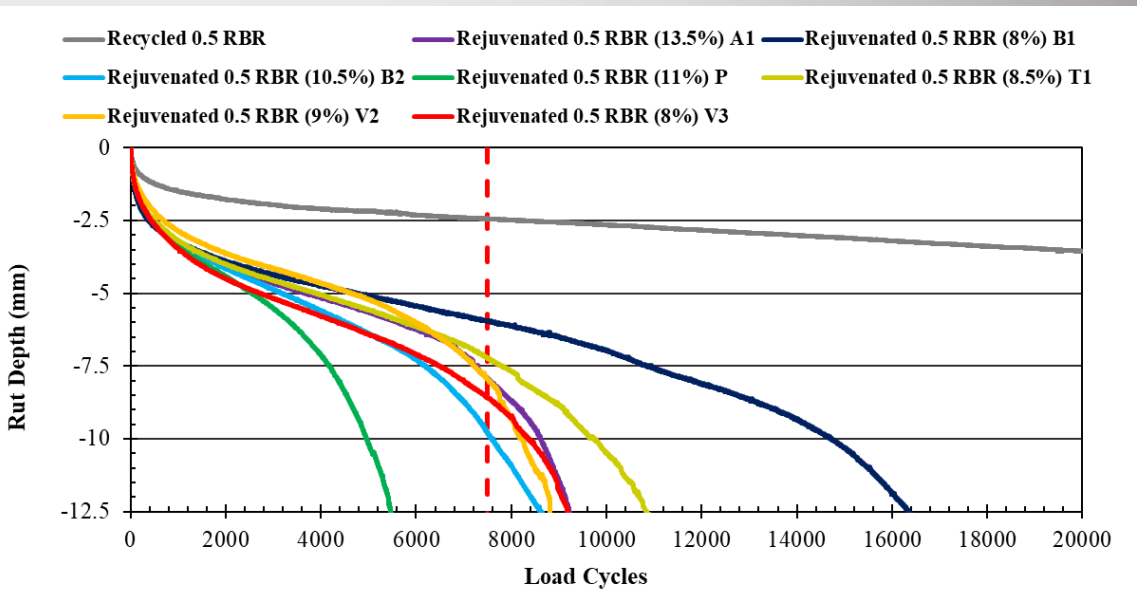
More energy

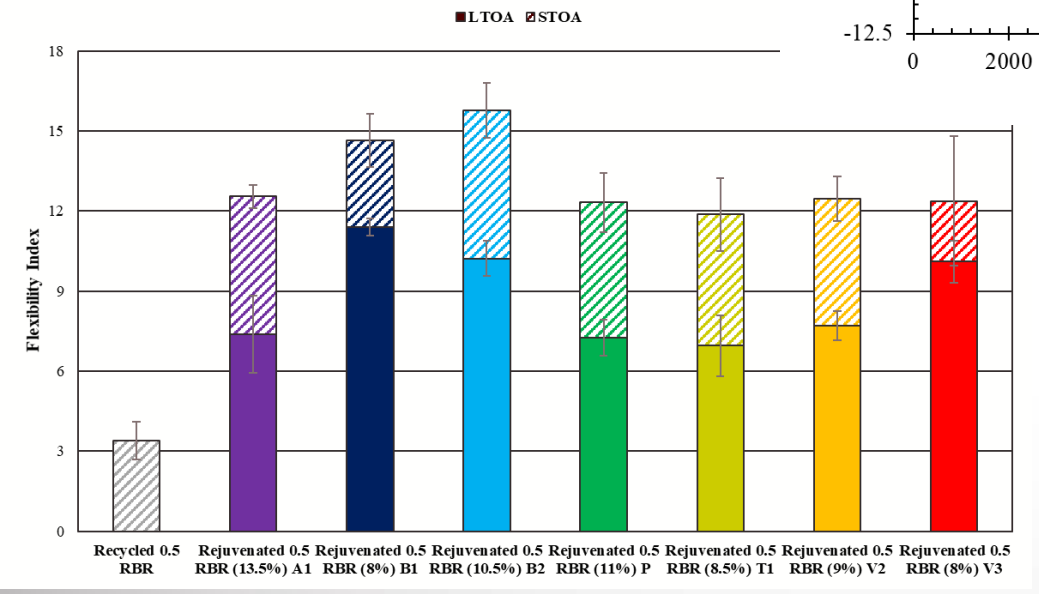
= More roughness

Microstructure & Nanomechanical Properties



MIXTURE PERFORMANCE





Literature Review

- Recycled binders partially available
  - binder content
  - source (aging)
  - %
  - virgin binder grade & recycling capacity
  - additive type, dose, & incorporation method
  - mixing temperature
  - storage time, temperature
  - gradation
- RAP binder more available

- Different methods to estimate recycled binder availability.

- RAP (32 refs): 16% to 96%

- RAS (4 refs): 36% to 61%

- RAP + RAS (6 refs): for 15% RAP + 5% RAS
  - RAP: 40-60%
  - RAS (MWAS): 20-40%
  - RAS (TOAS): <20%

Prepare Mixtures with SPECIFIC Virgin Materials, Determine Binder Content by Ignition Oven

NCHRP 09-58 (BAF)

Virgin Mixture

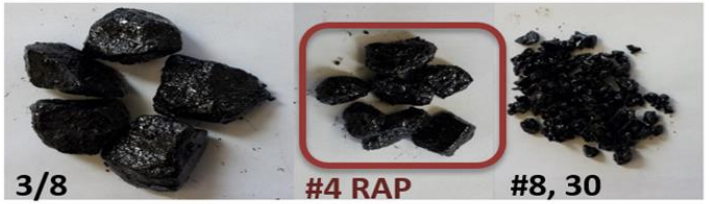
Mix virgin binder & aggregate

Sieve loose mixture

RAP Mixture

Mix virgin binder & aggregate + RAP

Sieve loose mixture



Determine P_b of material retained on No. 4 sieve using the ignition oven

Labeled as *Reference* P_b

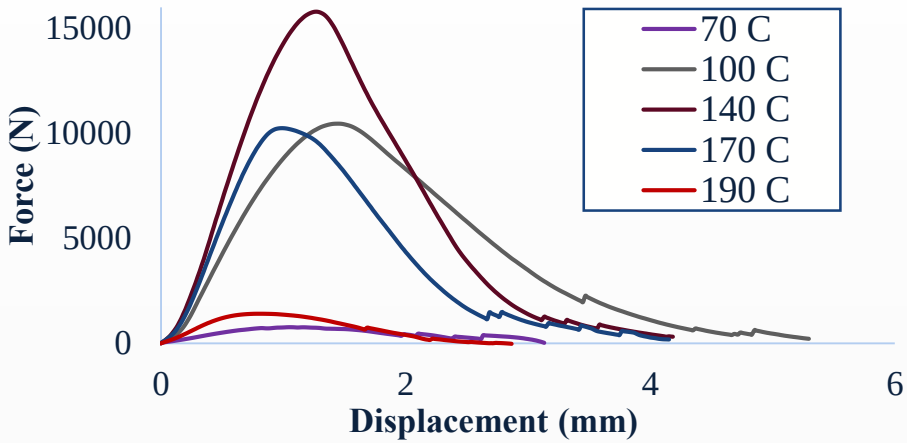
* constant for specific mixture

Labeled as *RAP'* P_b

* varies based on RAP source

RILEM (DoA)

Condition 100% RAP for 4hrs @
160°F, 212°F, 285°F, 340°F, 375°F;
Compact in SGC;
Test in Indirect Tension (S_T, CT_{Index})



$$DoA\ (\%) = 100 \times \frac{X_{RAP}(T, test)}{max\ X_{RAP}}$$

$X_{RAP} = S_T$ per Tex-226-F

OR

$= CT_{Index}$ per Tex-250-F