SELECTION & USE OF REJUVENATORS

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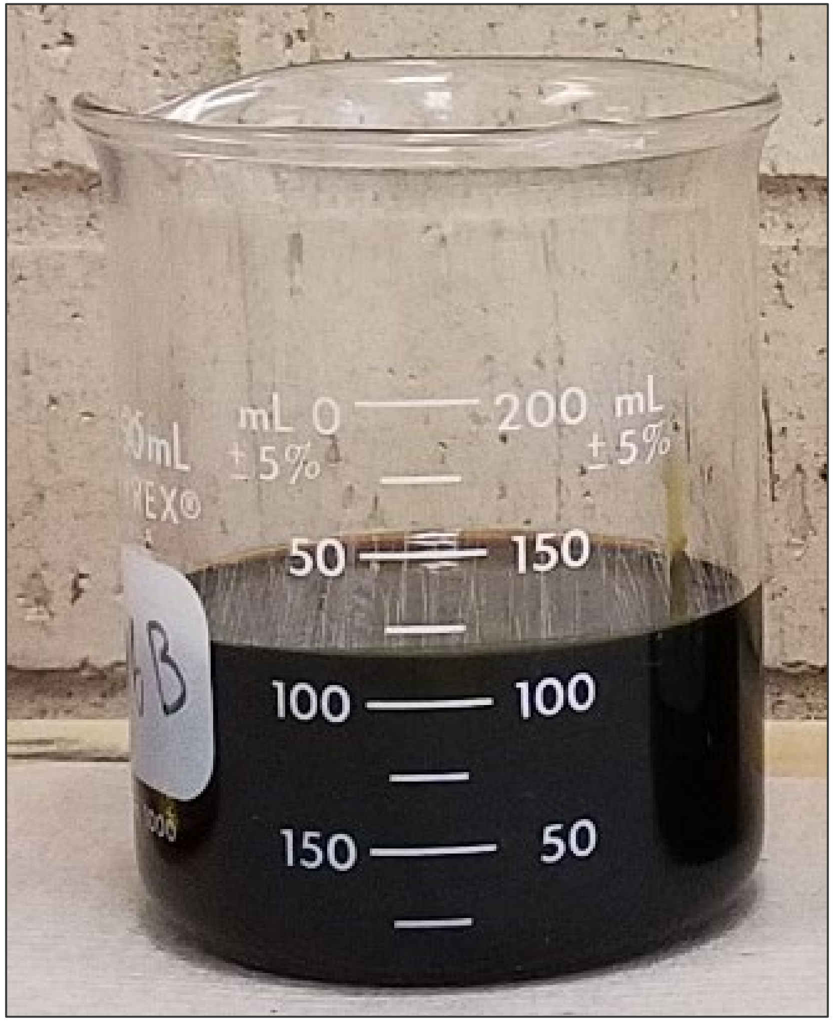
Rejuvenator

- Use in HMA
- Classification/Categorization
  - General
  - Specific: ASTM, NCAT, NE DOT, 09-58, Microstructural Analysis
- Evaluation Tools: 09-58, 09-65
- Remaining Challenges



REJUVENATORS = strategy to RAM or improve cracking performance

- **MOTIVATION**
- US in 2019
  - 422M tons HMA/WMA
  - 89M tons RAP
  - 0.9M tons RAS
- $3.3B = materials savings
- 59M yd^3 landfill space

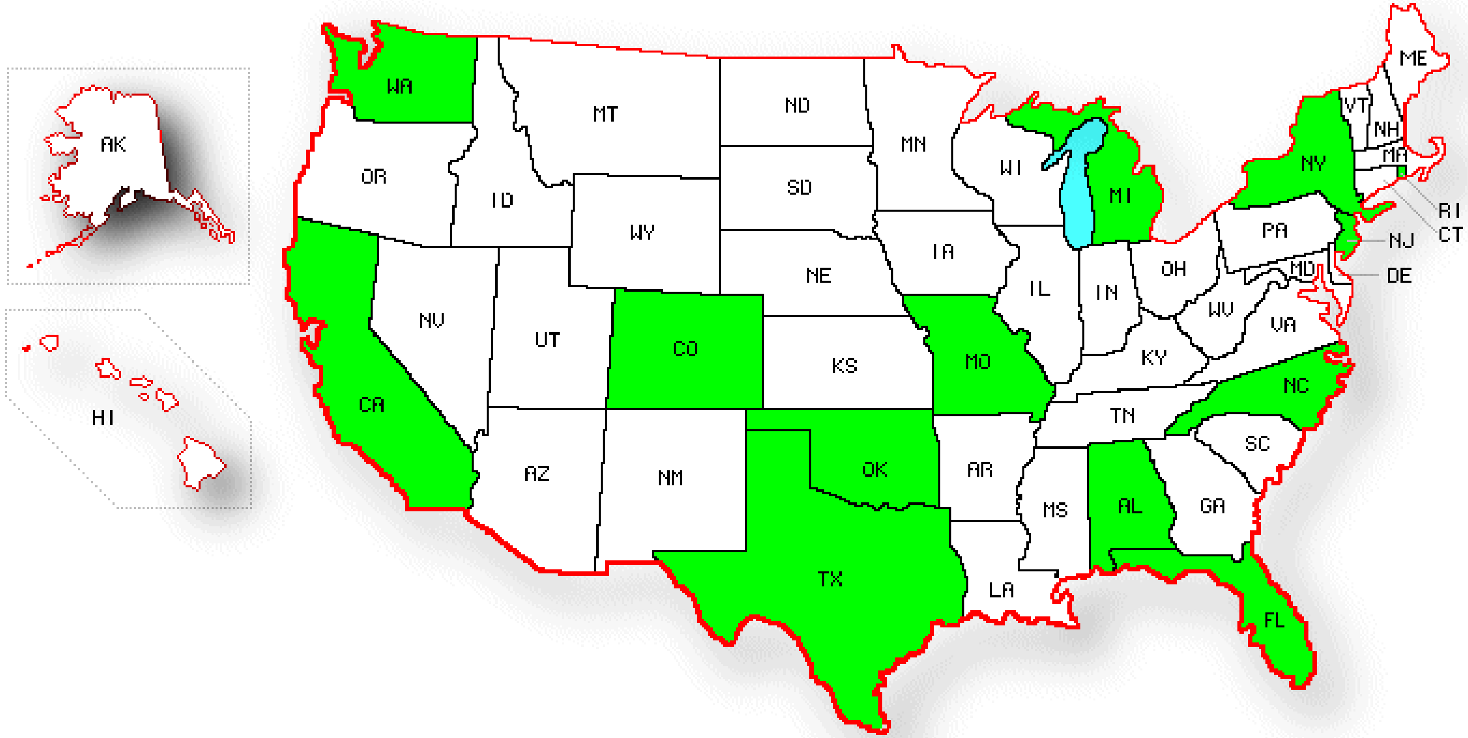
CONCERN

- Workability
- Compaction

- Performance **w/Aging**

Use in HMA

- Web Search of Specs, APL/QPL
- Known Research
- 13 States



Source: diymaps.net (c)

Terminology

- **RECYCLING AGENT**
  - Softener
    - reduce stiffness
  - **Rejuvenator**
    - reduce stiffness & brittleness
    - partially restore chemical balance
    - improve aging sensitivity
    - improve moisture susceptibility
- **GENERAL CLASSIFICATION**
  - Petroleum-Based
  - Bio-Based

ASTM D4552 – revised summer 2020

- **Viscosity @ 60C & Ratio after RTFOT**
- **FP**
- **Saturates* & Wt Change after RTFOT**

TABLE 1 Physical Properties of Hot-Mix Recycling Agents

Test	ASTM Test Method	RA 0 Min	RA 0 Max	RA 1 Min	RA 1 Max	RA 5 Min	RA 5 Max	RA 25 Min	RA 25 Max	RA 75 Min	RA 75 Max	RA 250 Min	RA 250 Max	RA 500 Min	RA 500 Max
Viscosity - 60 °C [140 °F], mm^2/s	D2170/D2170M	10	49	50	175	176	900	901	4500	4501	12 500	12 501	37 500	37 501	60 000
Flash Point, COC, °C [°F]	D92	219 [425]	. . .	219 [425]	. . .	219 [425]	. . .	219 [425]	. . .	219 [425]	. . .	219 [425]	. . .	219 [425]	. . .
Saturates, wt, %[A]	D2007	. . .	30	. . .	30	. . .	30	. . .	30	. . .	30	. . .	30	. . .	30
Tests on Residue from RTFO 163 °C [325 °F]	D2872														
Viscosity Ratio[B]	D2872	. . .	3	. . .	3	. . .	3	. . .	3	. . .	3	. . .	3	. . .	3
Wt Change, ±, %	D2872	. . .	4	. . .	4	. . .	4	. . .	4	. . .	4	. . .	4	. . .	4
Specific Gravity at 25 °C [77 °F]	D70 or D1298	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100

[A] The suitability of Test Method D2007 for measurement of saturates content and determination of compatibility of non-petroleum-based recycling agents has not been established. Additional testing may be required for assessment of the compatibility of non-petroleum-based recycling agents.

[B] $\text{Viscosity Ratio} = \frac{\text{Viscosity of residue from RTFO test at 60 °C [140 °F]}}{\text{Original viscosity at 60 °C [140 °F]}}$

GRADE for Bio-Based Rejuvenators (RA 0)

NCAT 2014

CATEGORY	EXAMPLES	DESCRIPTION	CONCERNS
Paraffinic Oils	Waste Engine Oil (WEO) Waste Engine Oil Bottoms (WEOB) Valero VP 165® Storbit®	Refined used lubricating oils	Environmental concerns with WEO & WEOB
Aromatic Extracts	Hydrolene® Reclamite® Cyclogen L® ValAro 130A®	Refined crude oil products with polar aromatic oil components	Potential health concerns
Napthenic Oils	SonneWarmix RJ™ Ergon HyPrene®	Engineered hydrocarbons for asphalt modification	
Triglycerides & Fatty Acids	Waste Vegetable Oil Waste Vegetable Grease Brown Grease Oleic Acid Hydrogreen®	Derived from cooking oils	Odor problems
Tall Oils	Sylvaroad™ RP1000	Paper industry byproducts Same chemical family as liquid antistrip agents and emulsifiers	

Table 1 Categories and examples of rejuvenators

NCAT, "NCAT Researchers Explore Multiple Uses of Rejuvenators," Asphalt Technology News 26 (1), p. 7-8, Spring 2014, 2014.

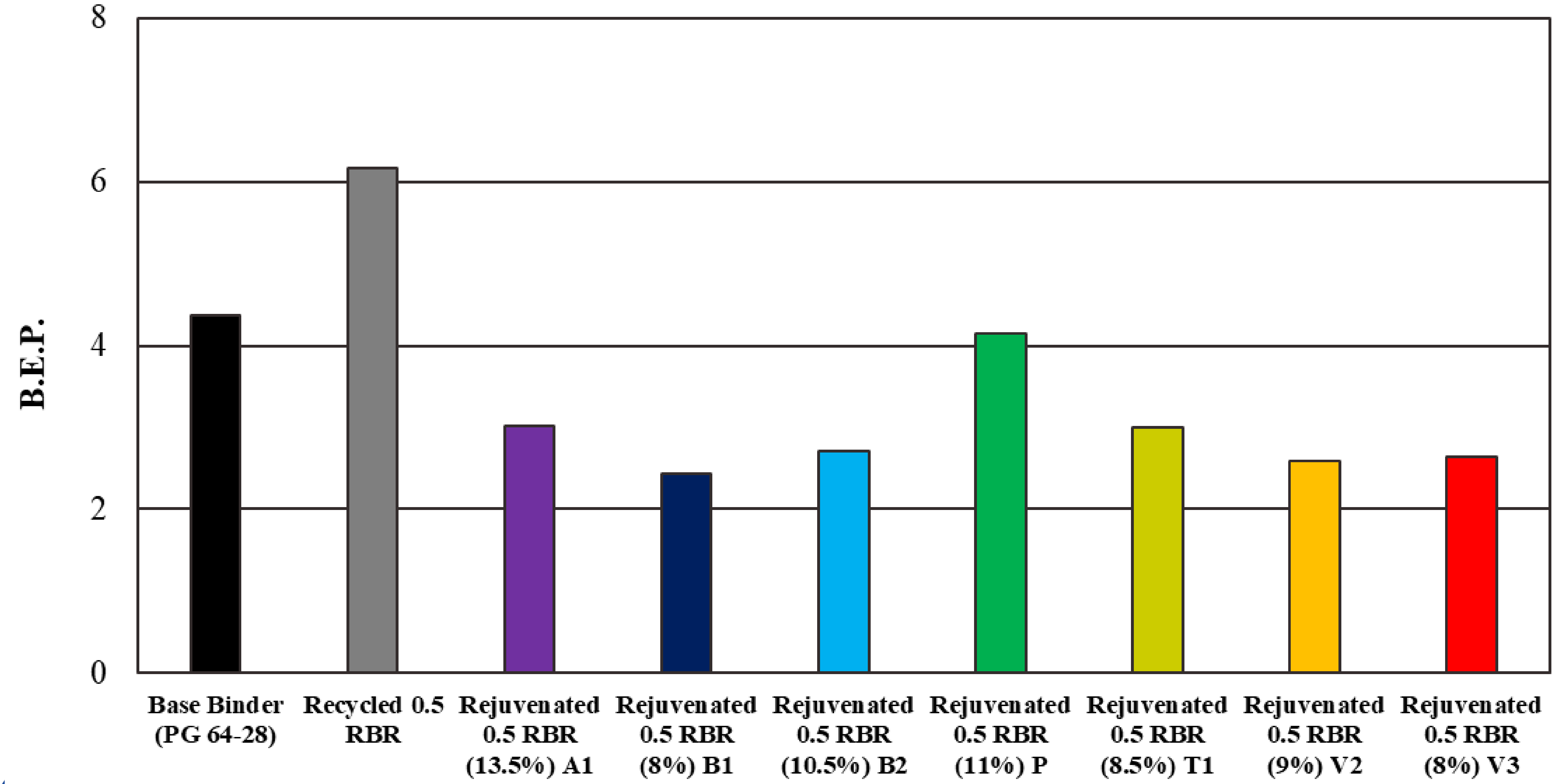
NE DOT

Class	Effectiveness (Benefits)					Cautionary (Limitations)		Advisory (Modifications)	
	PG	Prevent Rut @ T_{high}	Prevent Crack @ T_{int}	Prevent Crack @ T_{low}	CI	Moisture	Long-Term Aging	Improve Moisture Susceptibility	Improve Aging Resistance
I Paraffinic Oils	✓ **PGH**	✓		✓			X		X
II Aromatic Extracts	✓	✓	✓	✓ **w/aging**	✓				
III Napthenic Oils	✓	✓		✓			X		X
IV Triglycerides & Fatty Acids	✓	✓	✓	✓	✓	X	X	X	X
V Tall Oils	✓ **PGH**	✓	✓	✓	✓	X	X	X	X

Haghshenas, H.F., R. Rea, G. Reinke, and D. F. Haghshenas "Chemical Characterization of Recycling Agents," Journal of Materials in Civil Engineering 32 (5), 2020. + 3 Submitted Papers by Haghshenas et al.

NCHRP 09-58 (Bulk)

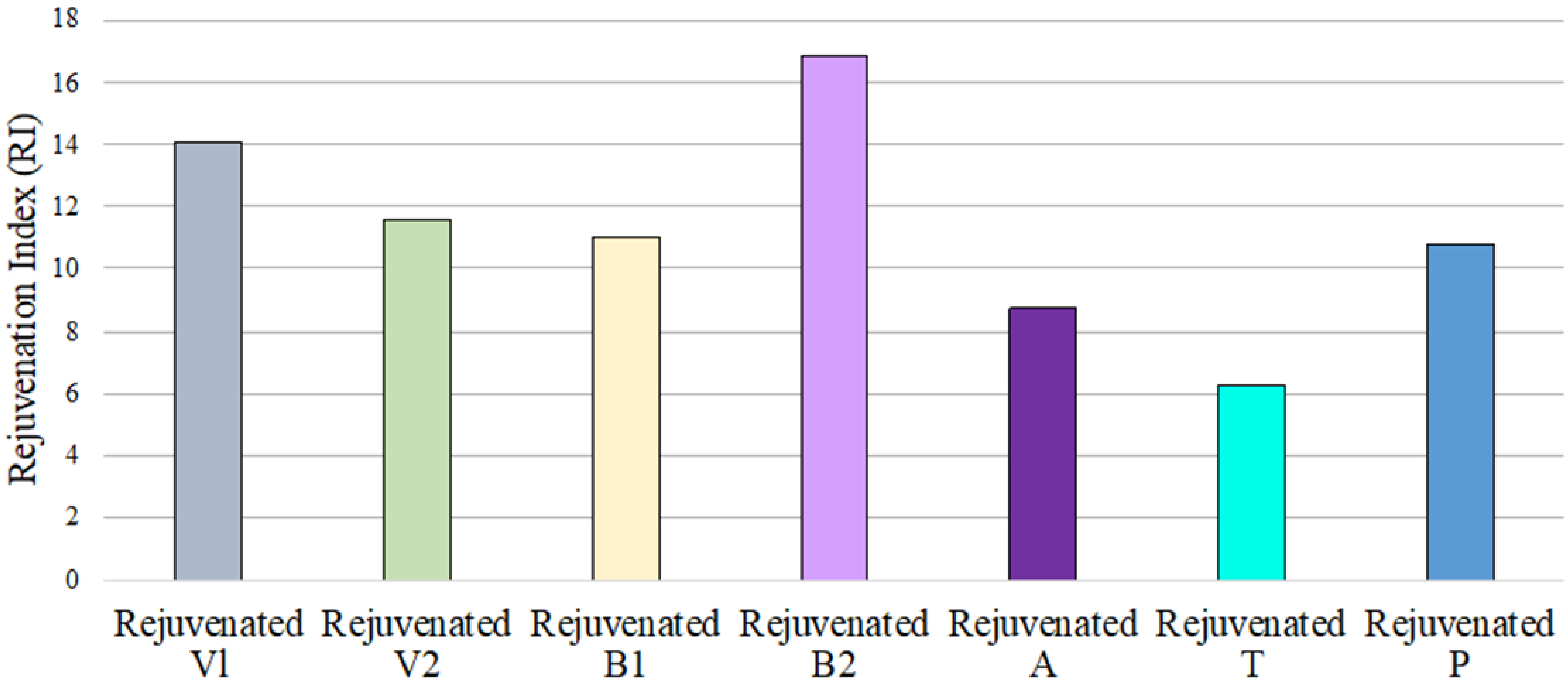
Lower BEP = More effective



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

Microstructural Analysis

Higher RI = More effective



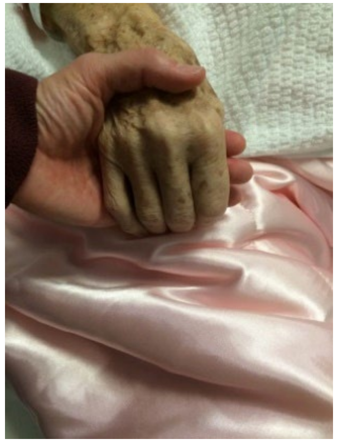
$$\text{Rejuvenation Index (RI)} = \frac{\int_0^{40} E_{RAP}(x)dx \, . \, \int_0^{40} WPT\ Energy_{RAP}(x)dx}{\int_0^{40} E_{Rej}(x)dx \, . \, \int_0^{40} WPT\ Energy_{Rej}(x)dx}$$

Classification/Categorization

- 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

NCHRP 09-58: Draft AASHTO Standard Practice for 0.3-0.5 RBR + Rejuvenator

- ❑ Component Materials Selection & Proportioning Guidelines



- ❑ Rejuvenator Dose Selection & Incorporation Methods (restore continuous PGH, replacement)
- ❑ Binder Blend Rheological Evaluation Tools
- ❑ Mixture Performance Evaluation Tools
- ❑ RAP Binder Availability Factor

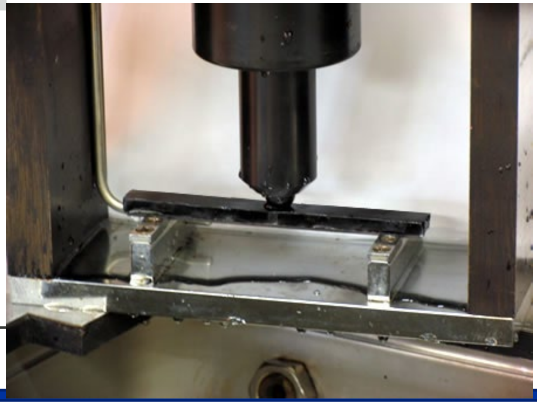
NCHRP 09-58: Component Materials Selection & Proportioning

- **Base Binder**
  - **PGH ≤ 64°C**
  - **ΔT_c @ PAV20 ≥ -3.5°C**
- **RAP**
  - **PGH ≤ 100°C**
  - **ΔT_c @ PAV20 ≥ -7.5°C**
- **RAS**
  - **PGH ≤ 150°C**

- **RBR ≤ 0.5**
  (RAP_{BR}+RAS_{BR})
- **RAS_{BR} ≤ 0.15**

NCHRP 09-58: Binder Blend 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



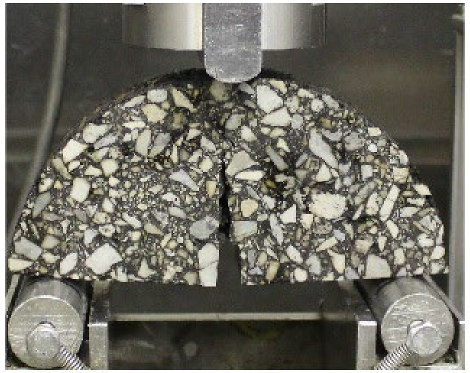
Short-Term Aging = RTFOT; Long-Term Aging = PAV @ 100°C

NCHRP 09-58: Mixture Evaluation

T & Aging Conditions	Test	Parameter	Suggested Performance Threshold
T_{high} Short-Term	HWTT or APA	$N_{12.5}$	≥ 5,000 for PG 58-XX ≥ 7,500 for PG 64-XX (cold) ≥ 10,000 for PG 64-XX (warm) ≥ 15,000 for PG 70-XX
T_{int} Track w/Aging & Short-Term	E*	$G\text{-}R_m$	≤ 8,000 MPa after STOA ≤ 19,000 MPa after LTOA
	I-FIT	FI	≥ 7 after STOA
T_{low} Short- & Long-Term	BBR_m	S_m, m-$value_m$	≤ Utah threshold after STOA
	UTSST	CRI_{Env}	≥ 17 after LTOA

Short-Term Aging = STOA = 2hr @ 135°C loose mix

Long-Term Aging = LTOA = 5d @ 85°C compacted specimen



NAPA QIP 131: Practical Guide for Using Recycling Agents in Asphalt Mixtures

Approach	Field Performance Risk	Mix Design Risk	Time and Equipment Needs	Cost	Binder Evaluation			Mixture Evaluation	
					Virgin	RAP and/or RAS	Blend	Rutting	Cracking
Simplest	Mod	High	Low	Low	No	No	No	Yes	Yes
Intermediate	Mod	Mod	Mod	Mod	Yes	Yes	No	Yes	Yes
Comprehensive	Low	Low	High	High	Yes	Yes	Yes	Yes	Yes

NCHRP 09-65: Revised Draft AASHTO Standard Practice to Capture Durability

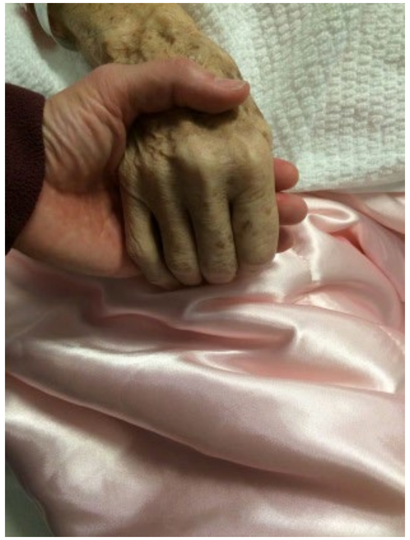
NCHRP 09-65

	Dry-Freeze	Wet-Freeze
Int Cracking	Shorter Mid-Term Critical Aging	Shorter Mid-Term Critical Aging
Low Cracking	Shorter Mid-Term Critical Aging after STOA	Shorter Mid-Term Critical Aging after STOA
Raveling	Conditioned (Shorter Mid-Term Aging + Moisture w/F/T) to Unconditioned	Conditioned (Shorter Mid-Term Aging + Moisture w/F/T) to Unconditioned
Moisture	after STOA, after Moisture w/F/T	after STOA, after Moisture w/F/T
Rutting	after STOA	after STOA

	Dry-No Freeze	Wet-No Freeze
Int Cracking	Longer Mid-Term Critical Aging after STOA	Longer Mid-Term Critical Aging after STOA
Raveling	Ratio (Conditioned/Unconditioned) Conditioned= Longer Mid-Term Aging	Ratio (Conditioned/Unconditioned) Conditioned= Longer Mid-Term Aging + Moisture w/out F/T
Moisture	after STOA	after STOA, after Moisture w/out F/T
Rutting	after STOA	after STOA

Remaining Challenges

- ❑Classification/Categorization = Selection



- ❑Effectiveness with Aging

- ❑Recycled Binder Availability (NCHRP 09-68)

Thank You!

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