Fundamentals of Recycling Agents

Faustina Keuliyan Rodriguez

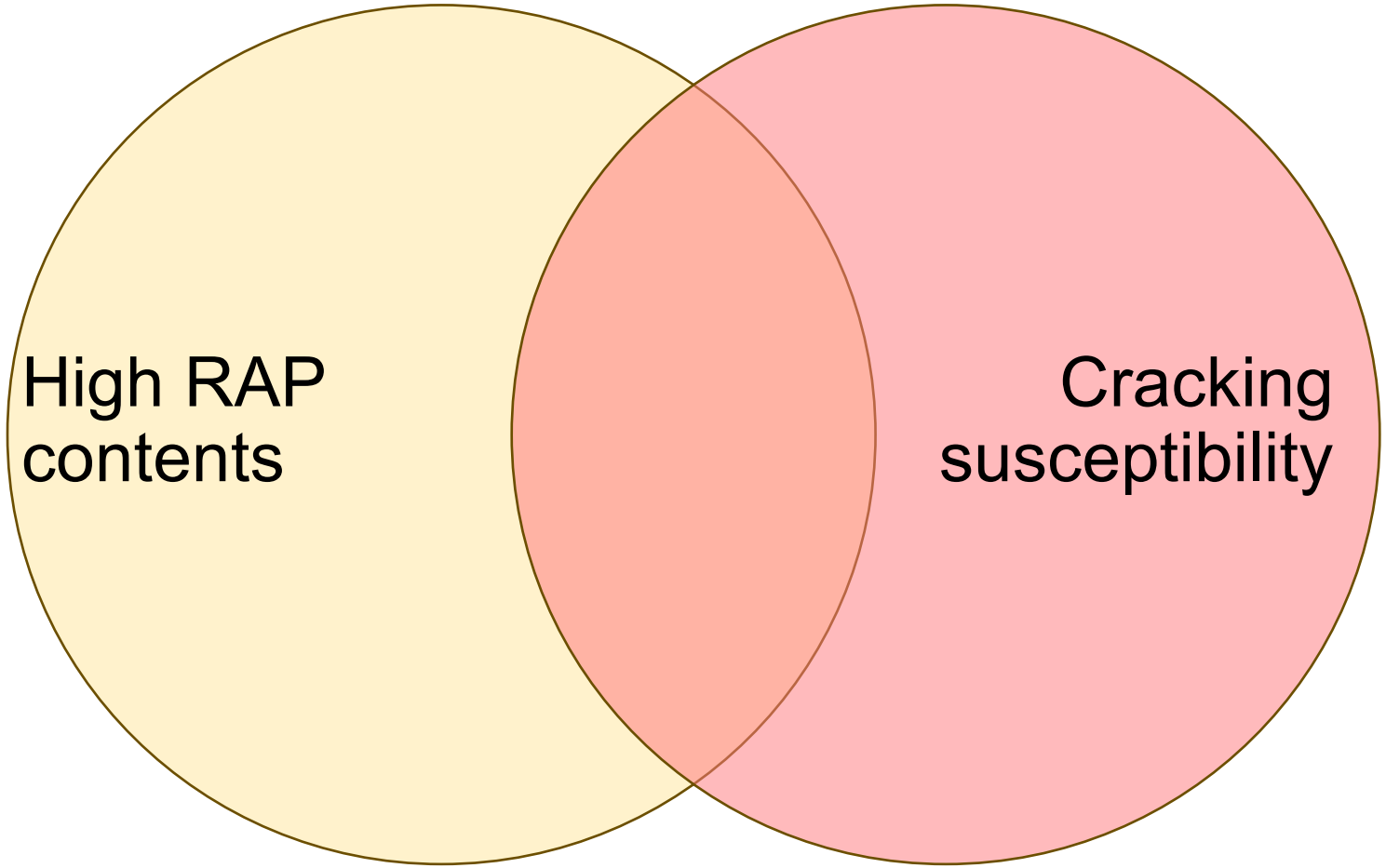
Heritage Research Group

The Heritage Group

Outline

- **Introduction**
- **Background**
  - Effects of aging on binder properties
  - Challenges with RAP containing mixtures
- **Recycling agents**
  - Classifications
  - Effects on rheological properties
- **Dosage selection and effectiveness**
- **Summary and resources**

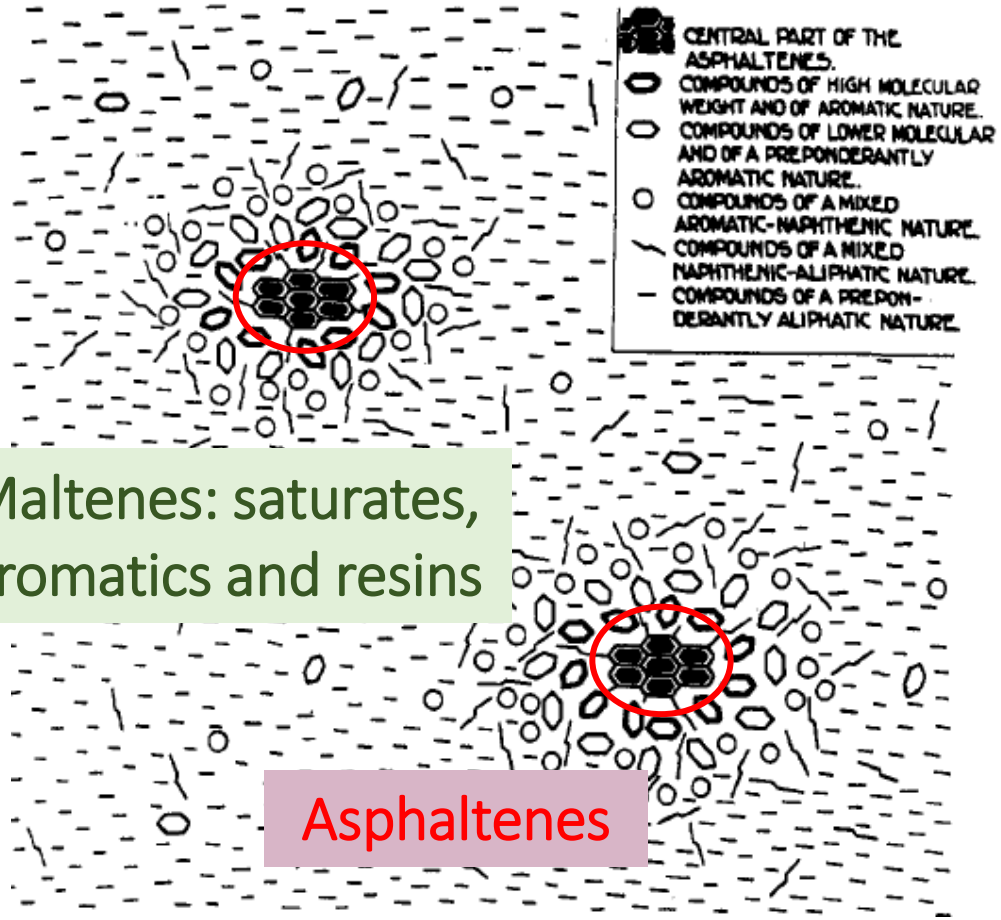
Introduction



Effect of aging on binder properties

- Binder properties depend on **source** and **refining process**
- This translates to CHEMICAL COMPOSITION

Colloidal model based on **four (SARA) fractions**:
Saturates, Aromatics, Resins and Asphaltenes



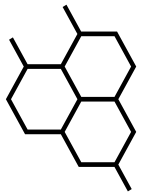
From (Pfeiffer, 1940)

What needs to be dispersed

Continuous phase

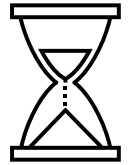
Effect of aging on binder properties

What causes aging?



OXYGEN

TEMPERATURE



TIME

LONG-TERM AGING: Field aging, occurs throughout entire service life

Due to exposure to atmospheric oxygen

Oxygen reacts with asphalt molecules causing an **increase in asphaltenes**

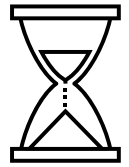
Asphaltenes start to agglomerate, molecules lose mobility

Formation of clusters leads to **worse dispersion** of asphaltenes in maltenes

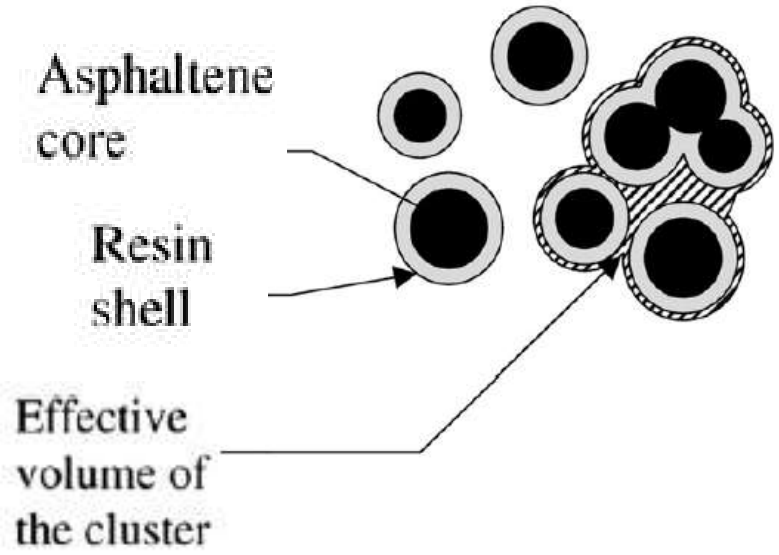
Effect of aging on binder properties

OXYGEN

TEMPERATURE



TIME



From (Lesueur, 2009)

As aging progresses, clusters become larger and more abundant

Asphalt molecules lose mobility

Binder becomes **stiffer and more brittle**, highly susceptible to cracking

Main concern with RAP

What's the **quality of the RAP binder** being added to the mix?

Premise of recycling agents

CHALLENGE: Addition of high amounts of RAP into mixtures while maintaining adequate pavement durability

The expected environmental and economic benefits of RAP usage should not be attained at the expense of performance properties

HOW DO WE MITIGATE THIS RISK?

RECYCLING AGENTS Restore the rheological properties of aged binders:

- Lower viscosity
- Lower stiffness and brittleness
- Increased ductility

What are recycling agents?

Chemical additives that reverse the impacts of oxidation on the rheology of binders

- Improve asphaltene to maltene ratio
- Reduce the size of asphaltene clusters
- Improve dispersion
- Restore molecular mobility

… but really what are they?

PETROLEUM-BASED ADDITIVES

- Aromatic extracts
- Paraffinic oils
- Naphthenic oils

BIO-BASED ADDITIVES

- Tall oils: by-product from paper processing (pines)
- Vegetable oils: e.g., cotton seed oil, soybean oil, palm oil

NO CONSENSUS ON CLASSIFICATION

ASTM D4552-20 earliest classification, revised in 2020 to include bio-based

Others: NCAT, Nebraska, Texas A&M

What to look for:

IMPROVEMENT IN RHEOLOGY OF RAP BINDER

Not only softer binder, improved relaxation properties, better cracking resistance

LONG-TERM PERFORMANCE

Aging stability, minimal loss in effectiveness over time

RA effects on rheology

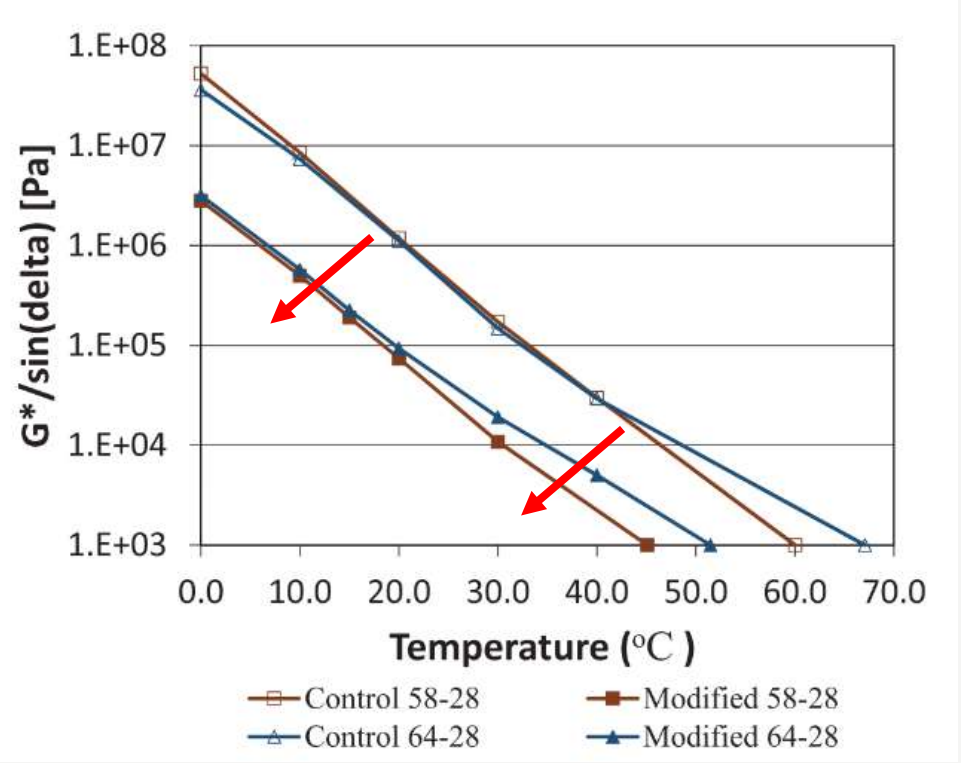
The rejuvenation process is expected to reverse the effects of oxidation on recycled binders:

At **high temperatures**

- Stiffness |G*| is reduced
- Phase angle (δ) increases

REDUCTION IN PGH

Could bring rutting concerns



From (Elkashef et.al, 2017)

RA effects on rheology

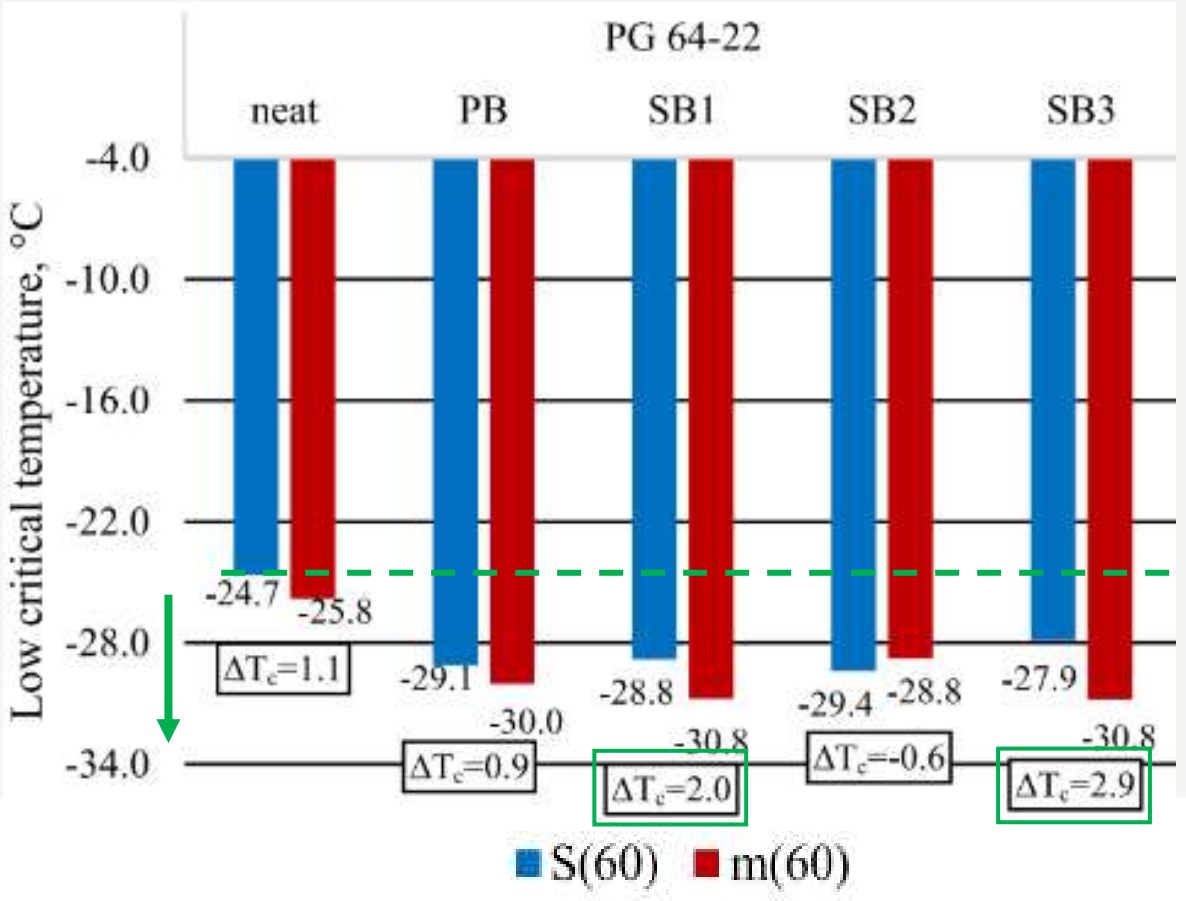
The rejuvenation process is expected to reverse the effects of oxidation on recycled binders:

At **low temperatures**

- Stiffness (S) is reduced
- m-value increases, improved binder relaxation
- ΔTc becomes more positive

REDUCTION IN PGL

INCREASE IN ΔTc (more positive)



From (Santos et.al, 2021)

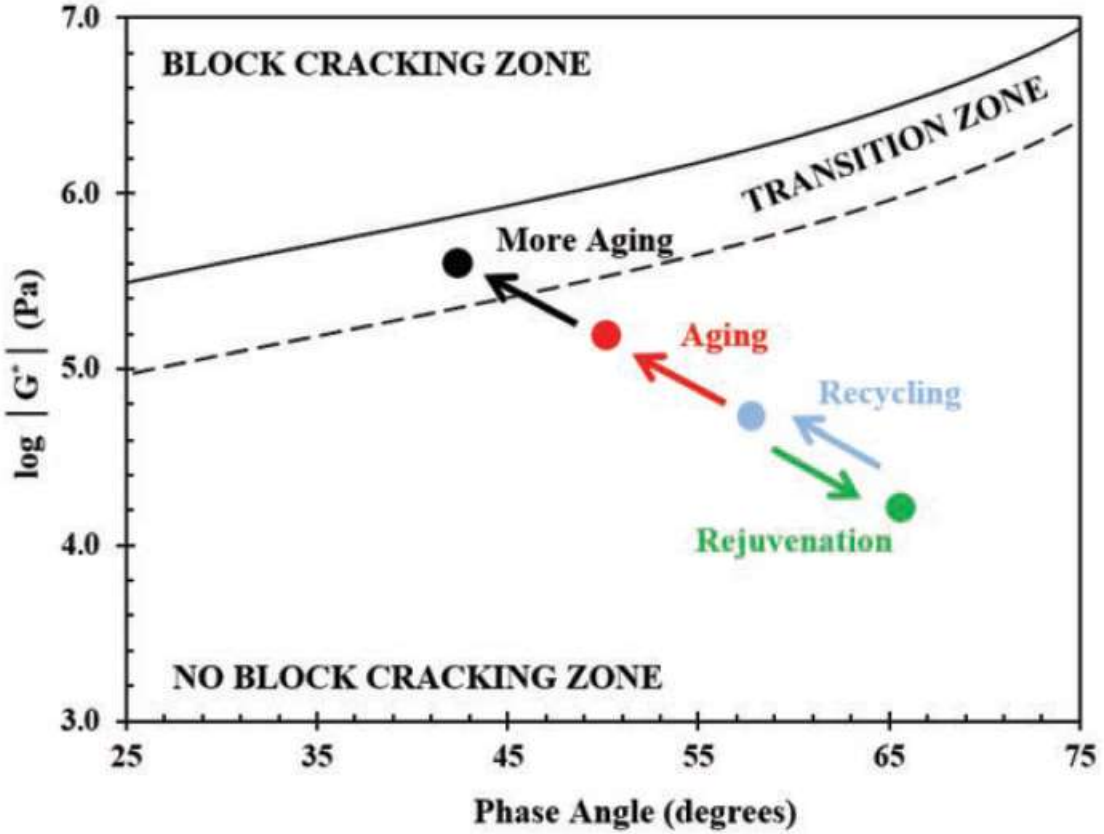
RA effects on rheology

The rejuvenation process is expected to reverse the effects of oxidation on recycled binders:

At **intermediate temperatures**

- G-R parameter is reduced
- Improved binder ductility
- Useful for aging susceptibility

$$G - R(@15℃, 0.05\,rad/s) = \frac{|G^*|\,(\cos\delta)^2}{\sin\delta}$$



From (NCHRP Report 927, 2020)

RA dosage selection

Improve recycled mixture's cracking resistance

Provide adequate rutting resistance

- Manufacturers provide **recommendations**
- **Need for a method to select/verify dosages** by agencies and contractors
- NCHRP 09-58 (2020) developed:

1	2	3
Restore low PG + verify high PG	**Achieve ΔTc= -5.0 °C after 20h PAV**	**Restore continuous PGH**

Method 1

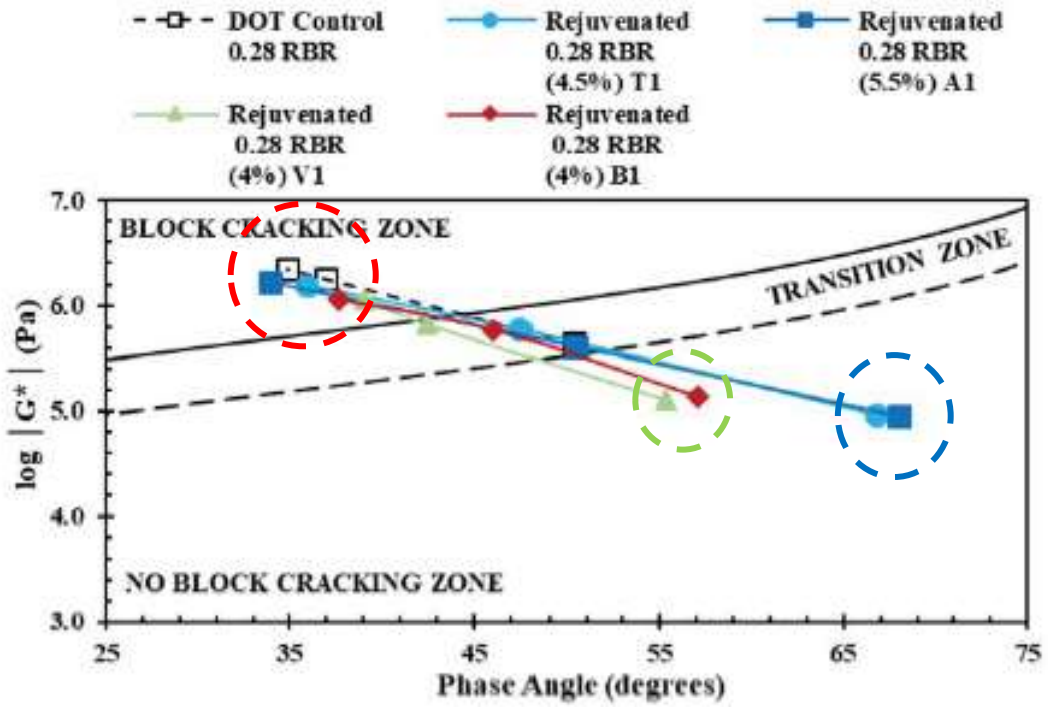
1 **Restore low PG + verify high PG**

2 Achieve ΔTc= -5.0 °C after 20h PAV

3 Restore continuous PGH

- Match the **PG low** of the **recycled blend** to that of the **target PG of the virgin binder** for the climate and traffic
- Verify PGH of the recycled blend and <u>increase</u> RA % if needed, while maintaining PGL

G-R parameter showed high aging susceptibility



From (NCHRP Report 927, 2020)

Method 2

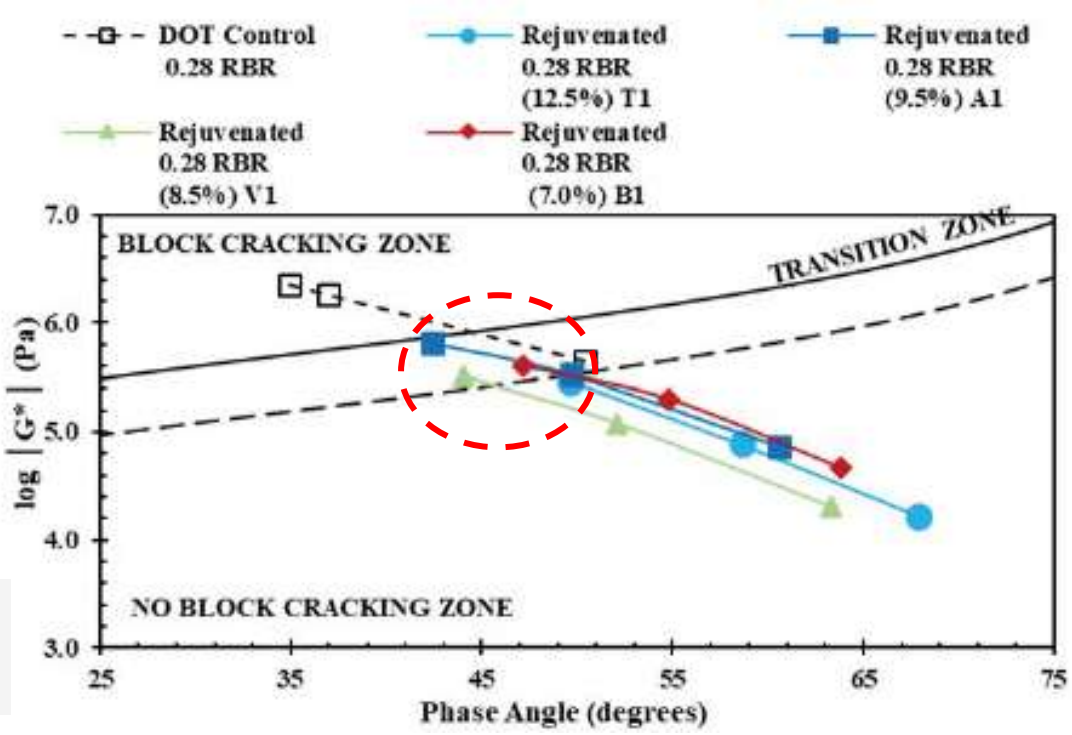
1 Restore low PG + verify high PG

2 **Achieve ΔTc= -5.0 °C after 20h PAV**

3 Restore continuous PGH

- Match ΔTc= -5.0 °C (or less negative) after 20h PAV for the recycled blend
- Higher RA dosages were needed for more negative ΔTc (of the base binders)
- High dosages can lead to rutting of the mix

Away from cracking zone – RA dosages 7.0 – 12.5%



From (NCHRP Report 927, 2020)

Method 3

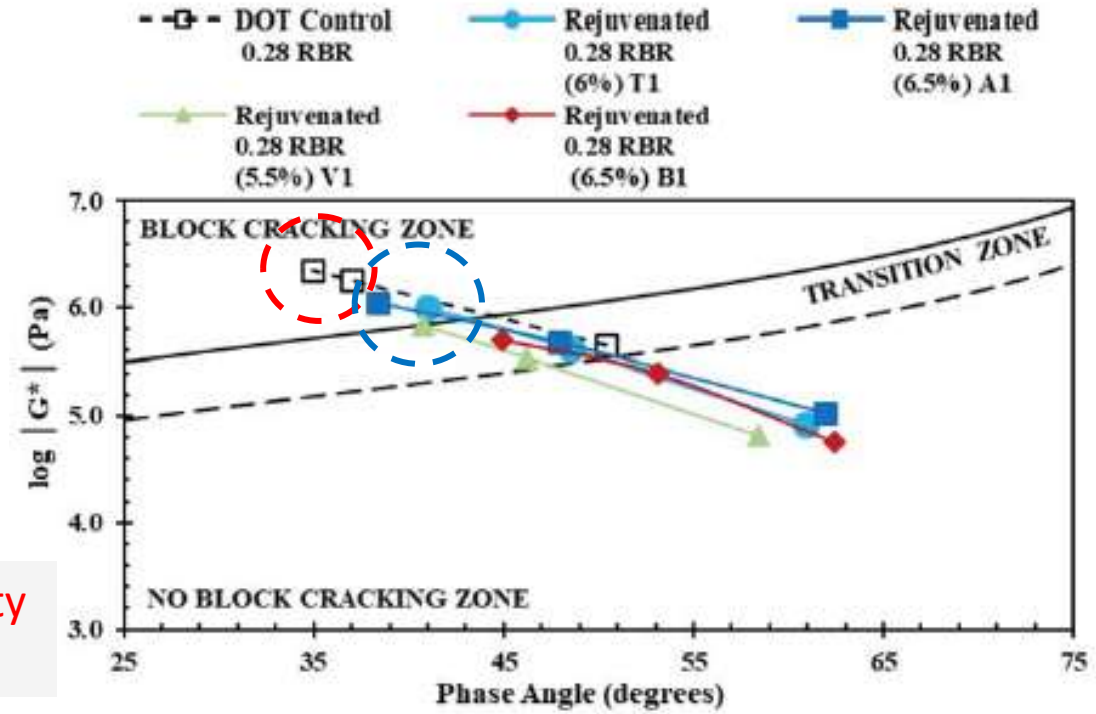
1 Restore low PG + verify high PG

2 Achieve ΔTc= -5.0 °C after 20h PAV

3 **Restore continuous PGH**

- Match **continuous high PG** of the target virgin binder
- Only based on DSR testing
- No rutting concerns, rejuvenated mixes performed better than control after 40h PAV

Better aging susceptibility
No rutting concerns



Method 3

1. Determine **PGH of base and recycled binders** per AASHTO M320
2. For the **selected RBR** and given base/recycled binders calculate **PGH of the blend**

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

RAP binder ratio (% by weight relative to total binder)

Continuous PGH of RAP binder

Base binder ratio (% by weight relative to total binder)

Continuous PGH of Base binder

Method 3

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

Continuous PGH of recycled blend

$$Recycling\ agent\ (\%) = \left(PGH_{Blend} - PGH_{Target}\right) / Slope\ Rate$$

Continuous PGH of target climate

SLOPE RATE: Reduction in PGH (°C) per 1% recycling agent

Tall oils Vegetable oils Reacted bio-based oils	Aromatic extracts (Petroleum based)
1.82 (from NCHRP 09-58)	**1.32** (from NCHRP 09-58)

RA Effectiveness

DISPERSION: uniform and homogeneous, ensure all RAP binder becomes useful for the recycled mixture

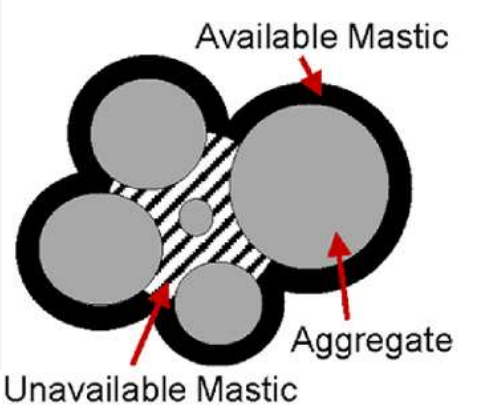
Depends on time, temperature, dosage, RA incorporation into mix

DIFFUSION: RA diffuses – passively - into the RAP binder

Depends on time, temperature, binder film thickness, formation of RAP clusters

COMPATIBILITY

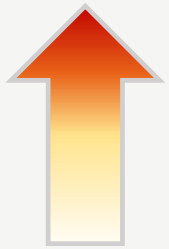
Depends on RA, type and age of RAP binder



(From Gulzar et al., 2023)

Mixing Characteristics

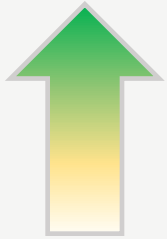
MIXING TEMPERATURE



Higher diffusion rates

Risk of aging

MIXING TIME



More dispersion, better uniformity

Limited by production times

Mixing Characteristics

ADDITION METHOD

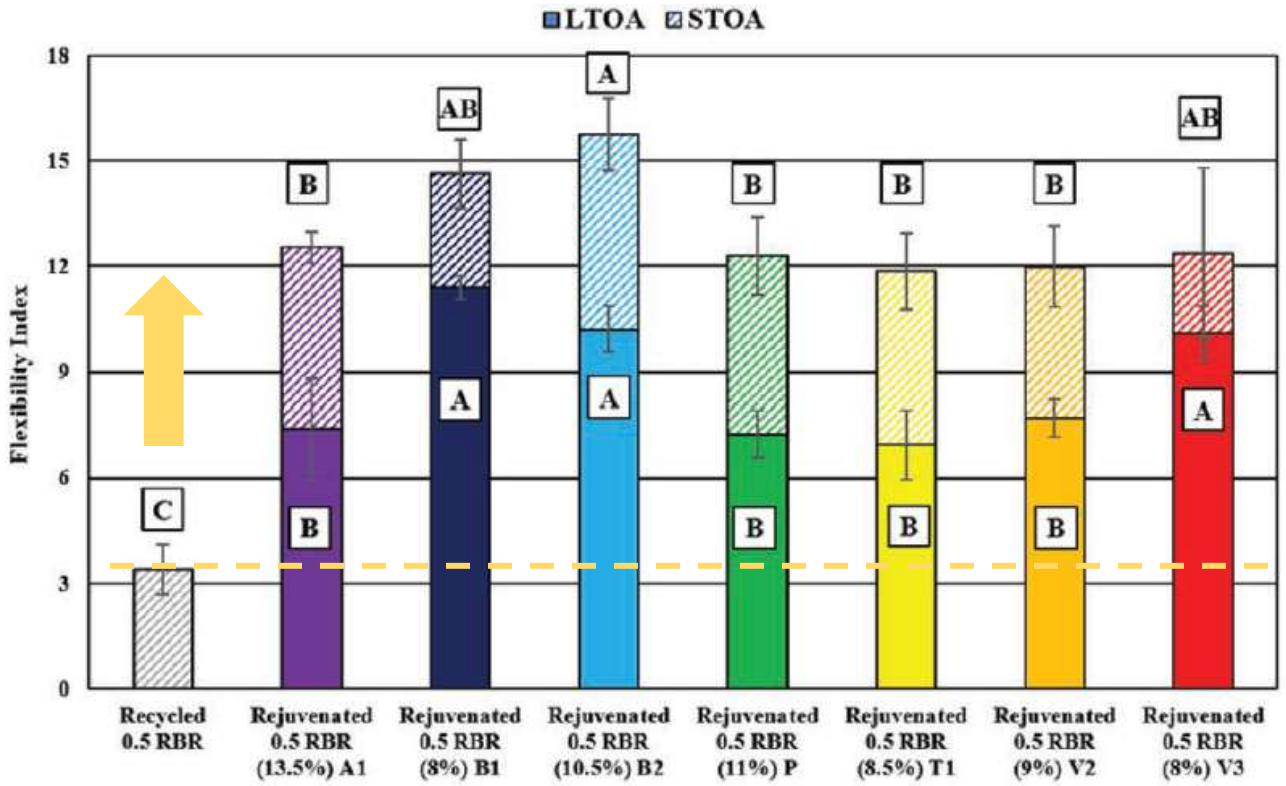
Depends on plant design

METHOD 1

METHOD 2

(From Gulzar et al., 2023)

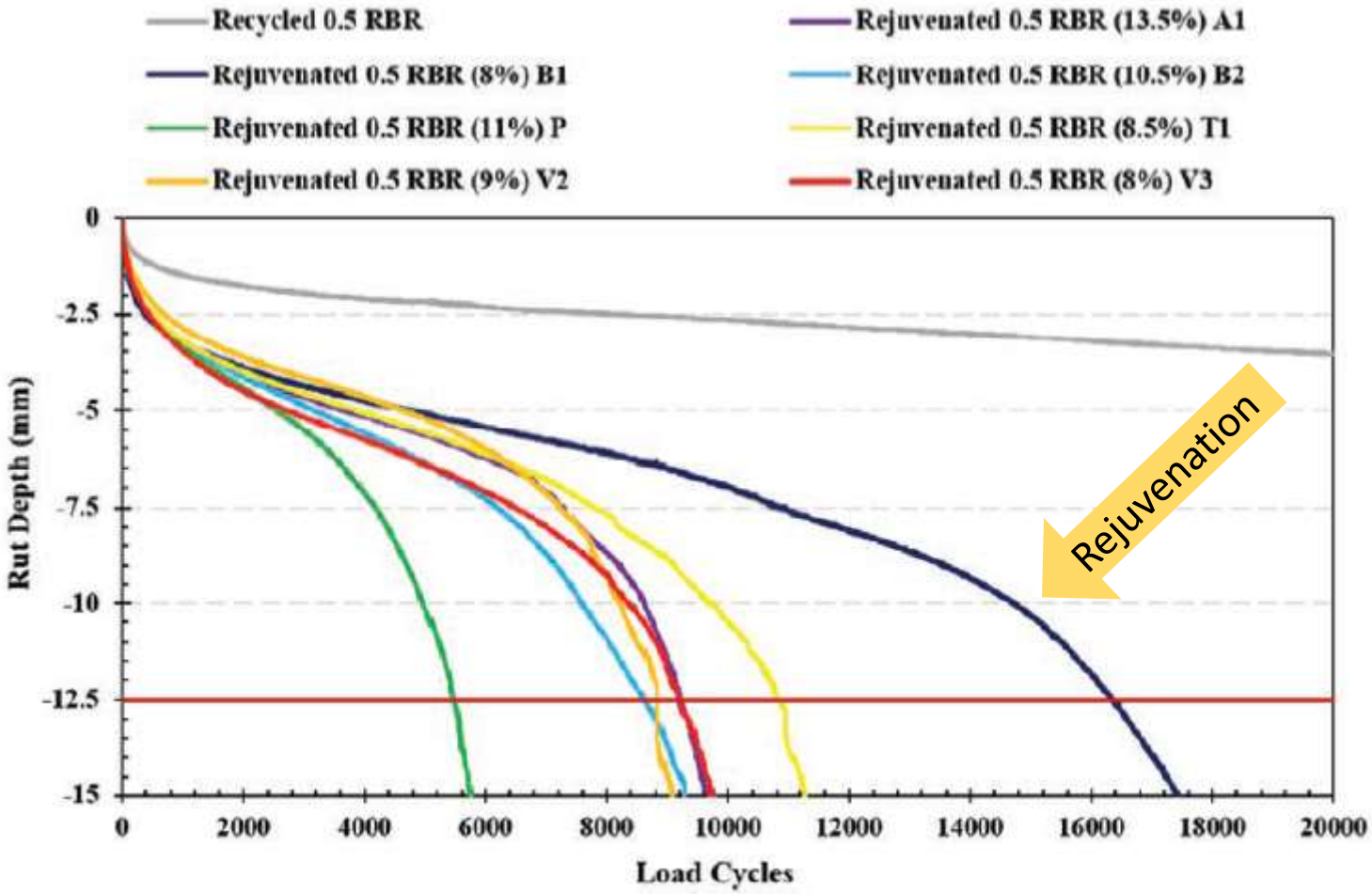
Mixture performance evaluation



Flexibility Index after short- and long-term aging
(From NCHRP 09-58)

- All rejuvenated mixtures performed **better than the control**
- **Reacted bio-based oils (B1 and B2) and vegetable oil (V3)** showed superior performance

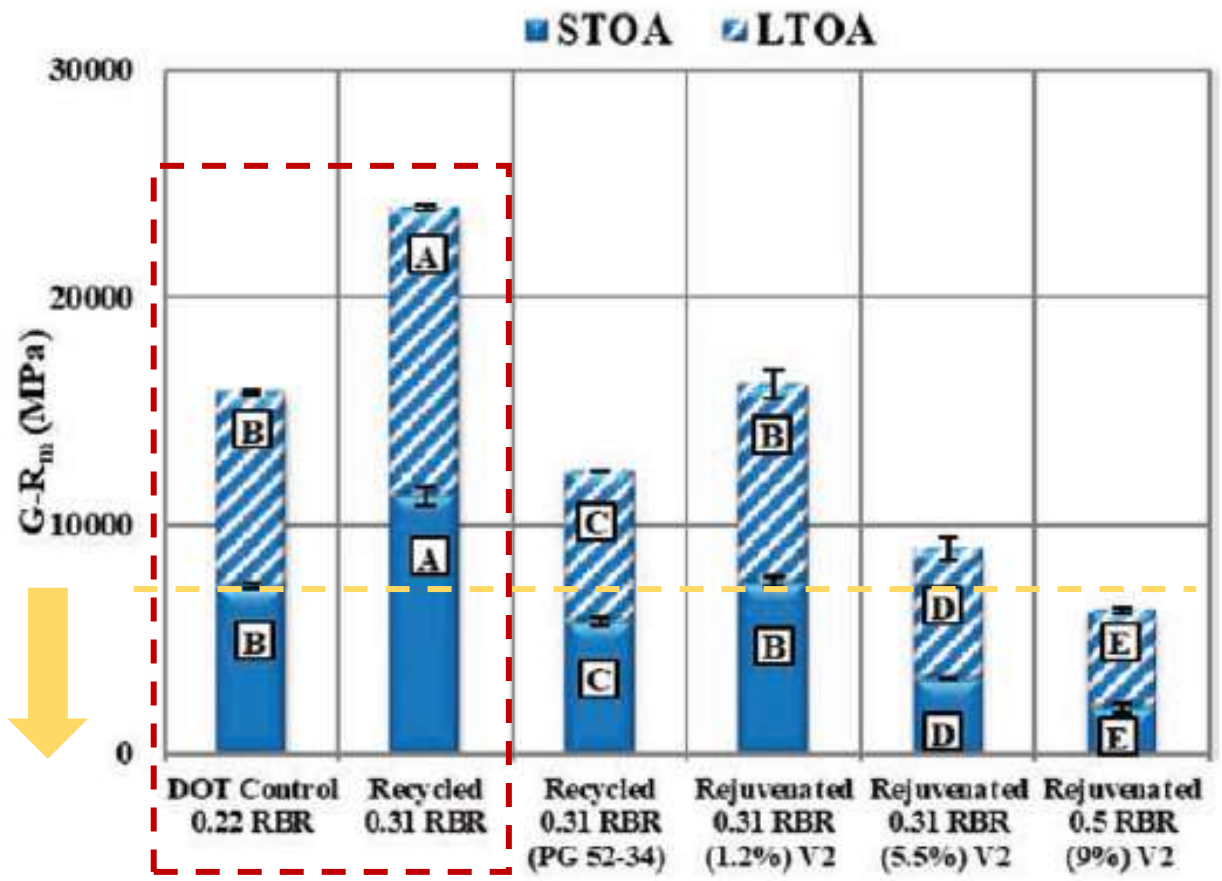
Mixture performance evaluation



(From NCHRP 09-58)

- Rejuvenated mixes showed worse rutting performance than the control
- **Paraffinic oil** showed poor rutting resistance while comparable cracking performance

Mixture performance evaluation



(From NCHRP 09-58)

- **Higher RBR** increased G-R parameter

$$G - R_m = \frac{|E^*|(\cos\varphi)^2}{\sin\varphi}$$

- Addition of **RAs allowed for higher RBR** and performed similarly to the control
- **Softer base binder** (PG 52-34) performed even better that the control

Summary

- Addition of RAP can compromise durability of mixtures due to the stiffness and brittleness of aged binders
- Recycling agents **facilitate the addition of RAP** by restoring the rheological properties of recycled binders
- No universal classification exists, origins include **petroleum-based and bio-based additives**
- Selection should consider **initial rheological properties** and **long-term effectiveness**
- RA dosage targeting **continuous high PG** improved cracking resistance without rutting concerns
- Mixing **time, temperature and addition** method affect RA effectiveness
- Evaluation of RAs should include **mixture performance properties**

Resources

NCHRP Report 927

Evaluating the Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios (2020)

DETAILS

282 pages | 8.5 x 11 | PAPERBACK

ISBN 978-0-309-48104-5 | DOI 10.17226/25749

VTRC 24-R3

Engineered Frameworks for Evaluating the Use of Recycling Agents in Surface Asphalt Mixtures for Virginia

https://vtrc.virginia.gov/media/vtrc/vtrc-pdf/vtrc-pdf/24-R3.pdf

Journal article: Literature review

Review

Towards sustainable roads: A State-of-the-art review on the use of recycling agents in recycled asphalt mixtures

Saqib Gulzar [a,*], Andrew Fried [a], Jaime Preciado [a], Cassie Castorena [a], Shane Underwood [a], Jhony Habbouche [b], Ilker Boz [b]

[a] North Carolina State University, 915 Partners Way, Raleigh, NC, 27695, USA
[b] Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA, 22903, USA

Thank you

Faustina Keuliyan Rodriguez
Pavement Research

fkeuliyanrodriguez@hrglab.com

Heritage Research Group