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Understanding Binder Blending and Diffusion in RAP Mixes

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Reclaimed Asphalt Pavement (RAP) Basics

100% recyclable

Environmental & economic incentives

Average RAP content in new mix increased from 15% to 20% between 2009 and 2018 (NAPA)

Incorporating RAP in new mix requires caution

- Manage stiffness of aged binder in RAP
- Ensure proper aggregate gradation and effective binder content
- Achieve proper cohesion between virgin and RAP binders, and adhesion to aggregate

How do we properly account for aged binder?

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Understanding RAP-Virgin Binder Blending

Step I : Understand blending between RAP and virgin binders

- Evaluate binder diffusion using change in viscosity

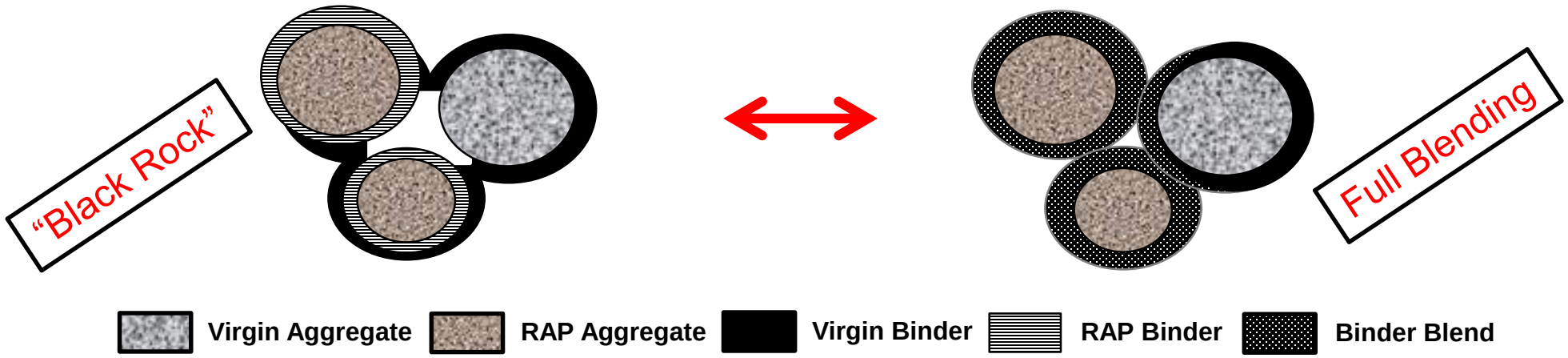
Step II: Demonstrate binder blending in mixtures

- Use findings to validate diffusion in mixtures
- Determine average diffusion distance / binder thickness

Step III: Understand impact of binder blending in practice

- Plant Trials / Field Validation

RAP Binder, a “black rock” or “binder blend component”?



Extent of blending is critically important for mixture rheological & failure properties

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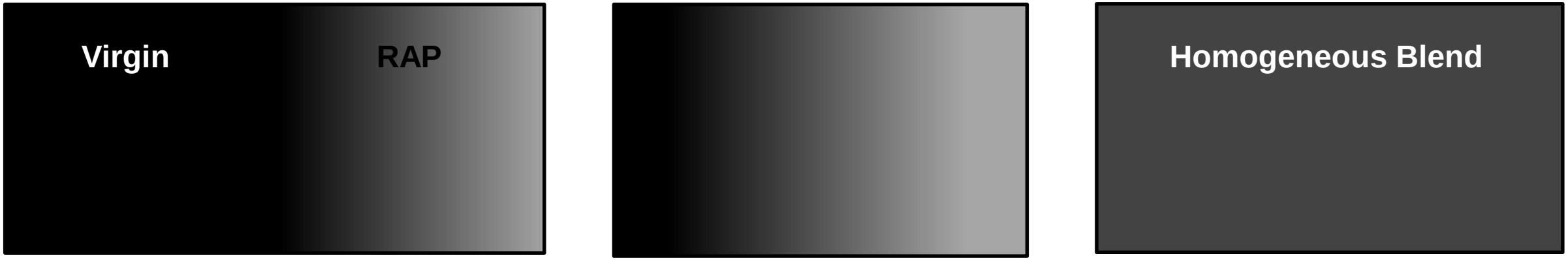
What is Diffusion?

- Migration of material in the direction of concentration gradient
- Moving from two separate liquids to one homogeneous blend



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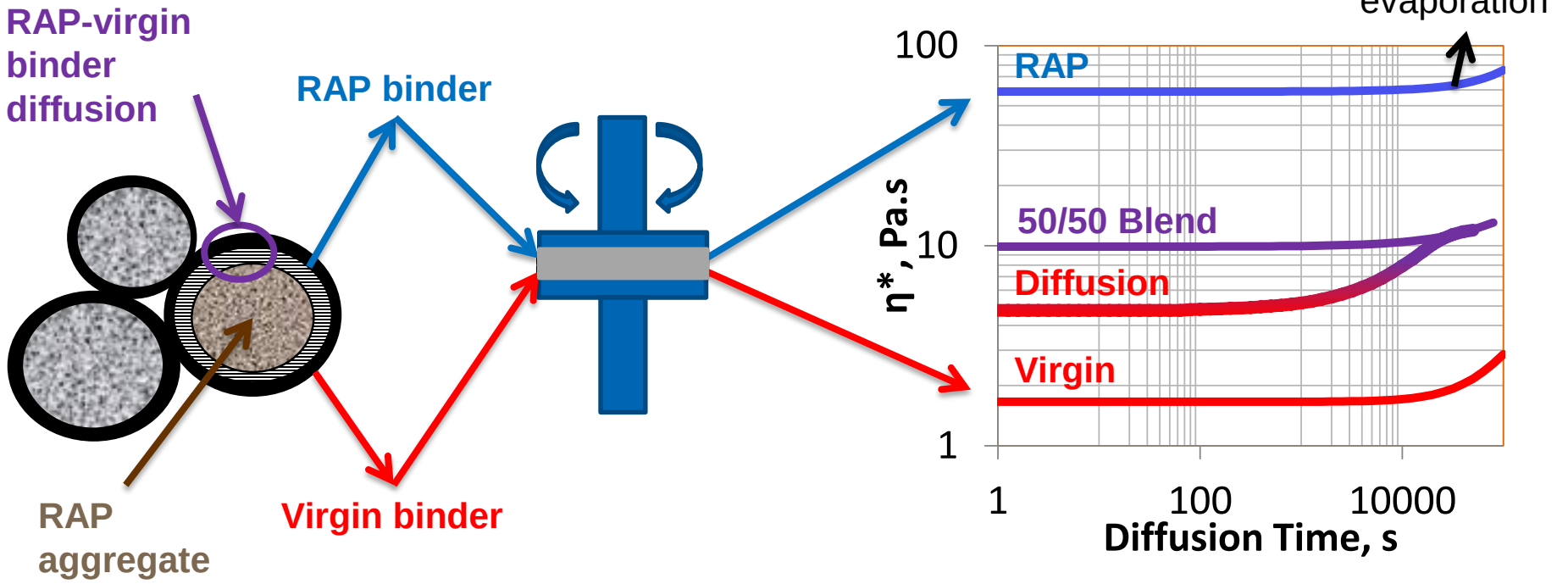
Step I: RAP-Virgin Binder Diffusion in Experiment

Diffusion in Mix

Test in Rheometer

Results

Results corrected for effects of oxidation & evaporation



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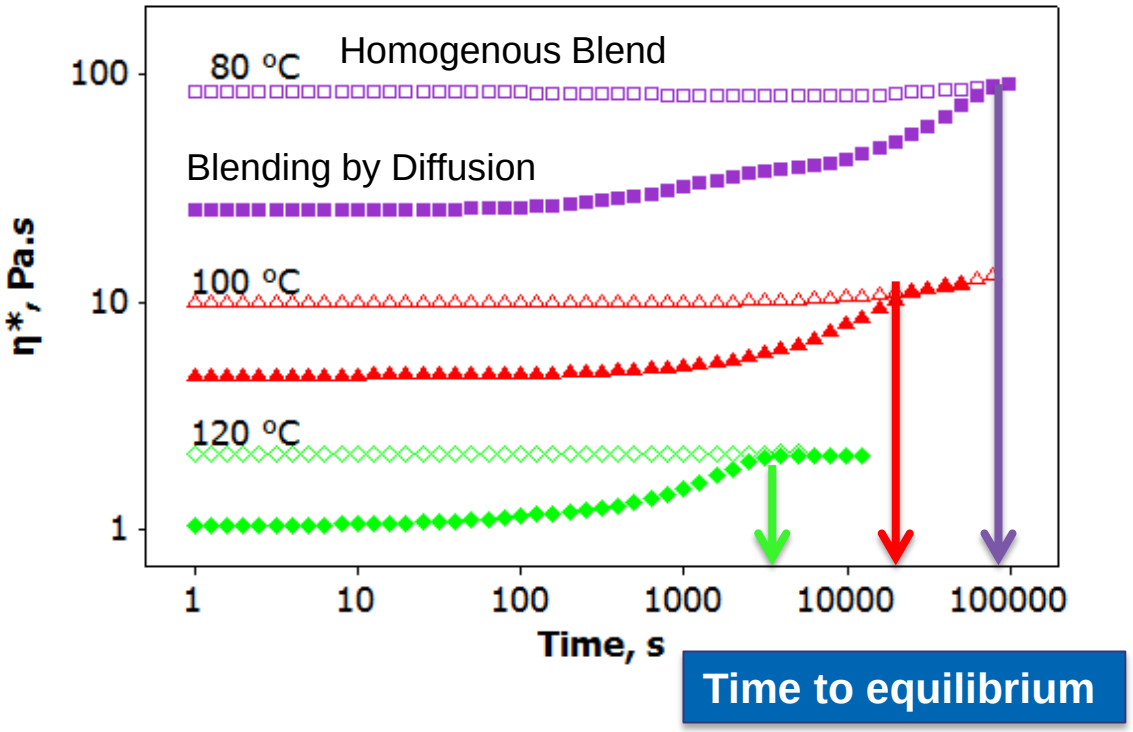
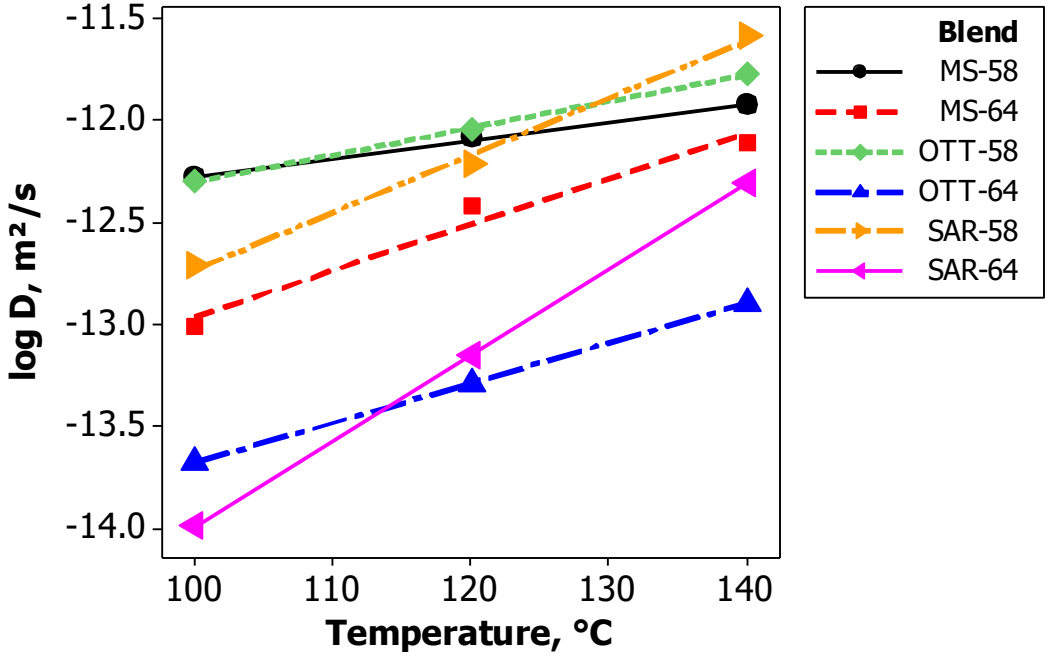
Diffusion is Faster at Higher Temperature

- Faster Brownian motion at higher temperature increases diffusion rate
- Log of diffusion coefficient increase linearly with temperature

Diffusion at Varying Temperature



Dependence of Diffusion Coefficient On T



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Key Learnings during Step 1

Binders behave like liquids & blend by diffusion

Diffusion rate increases with temperature

Binder Blending in Mix is More Complex

Film thickness & time at temperature define blending in the mix

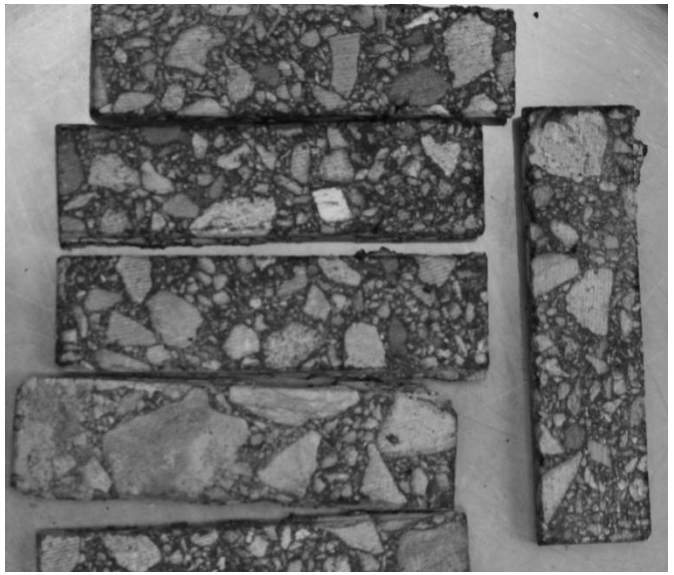
- Distribution of thicknesses exists
- Proper binder contact may not be reached by mixing

Understanding effective binder thickness in mix is essential

Step II: Evaluating Diffusion in Mix

Conditioning under N_2 atmosphere at three temperatures (90, 120, 150 °C)
DSR testing in torsion, 5-10 repeats per sample

MIX SAMPLE AFTER CUTTING



MIX SAMPLE AFTER 1H @ 90°C

TORSION TEST SETUP

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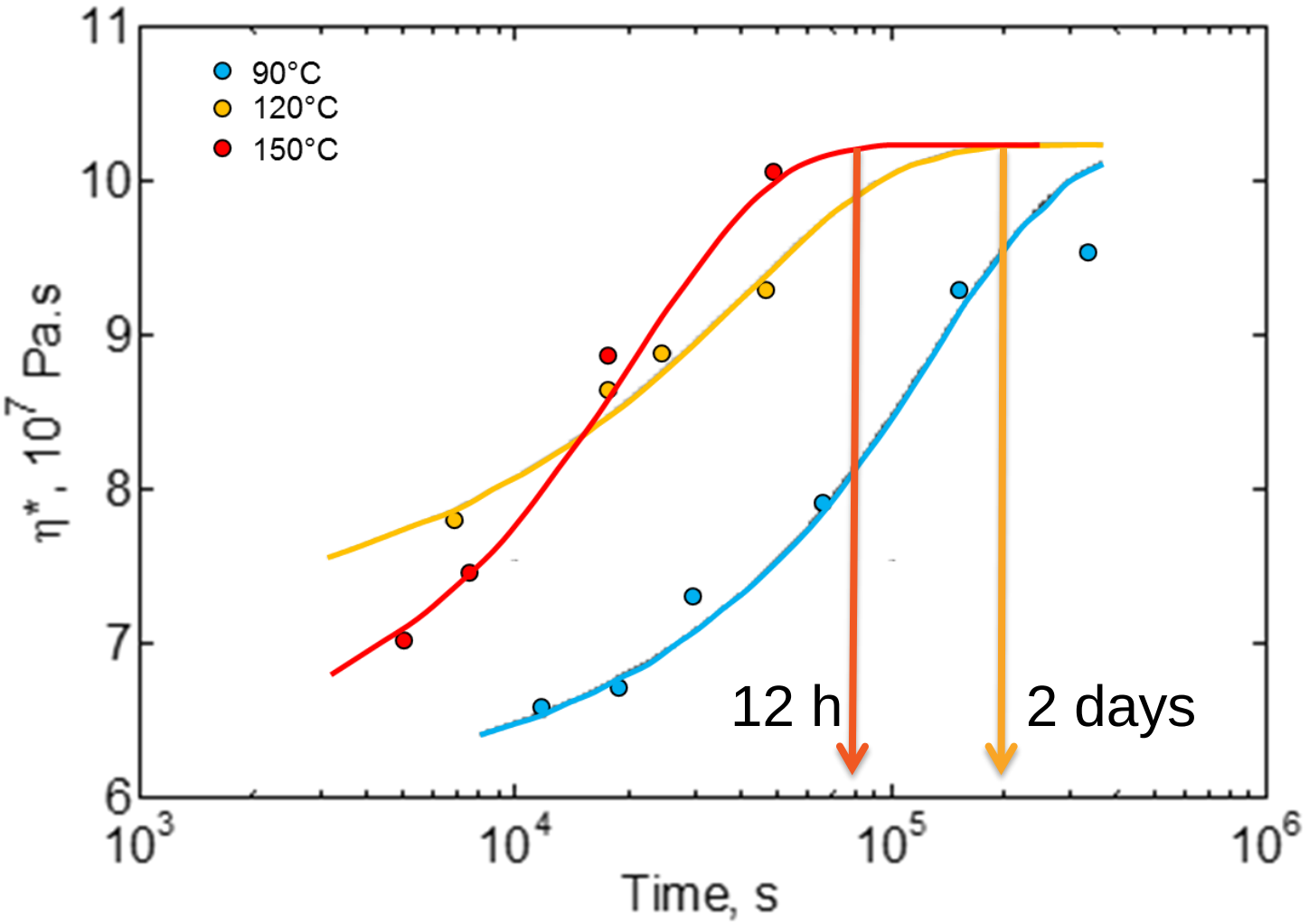
Binder Diffusion Model Tracks Mix Property Evolution



Diffusion distance = 800µm

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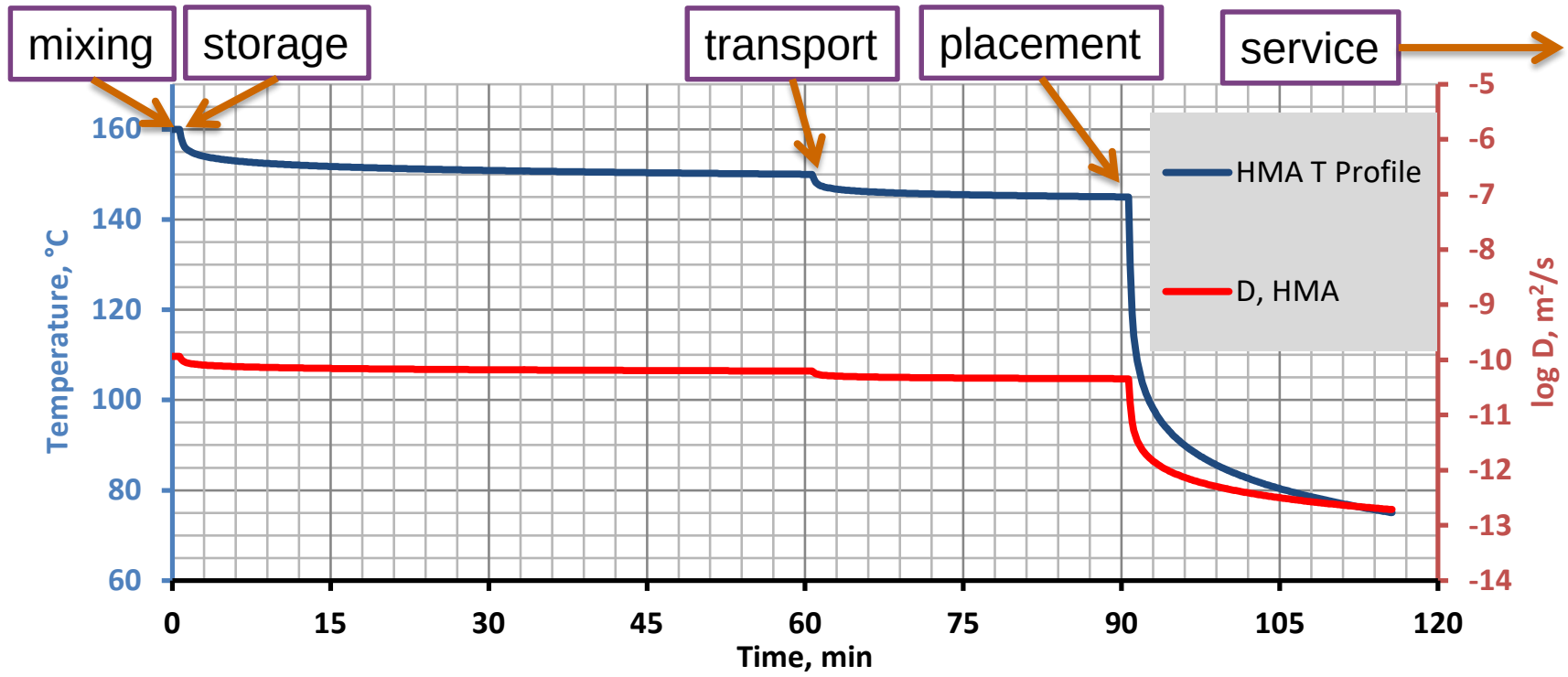
Simulating Diffusion Rate at Realistic Conditions

Diffusion coefficient decreases with mix cooling



Winter paving conditions?

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Key Learnings during Step 2

Binder film thickness & time at temperature are critical parameters

Diffusion may not be completed during mix production

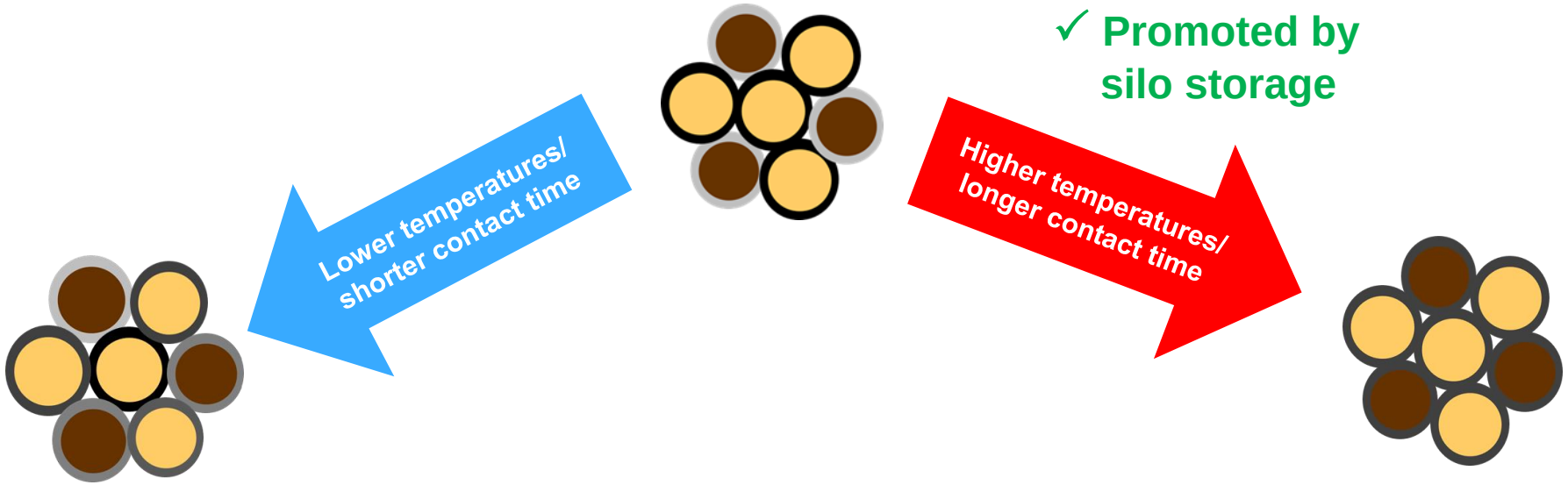
- Effective binder content may be lower than expected

Silo storage at higher temperature can assist diffusion

Step III: Plant Trail / Field Validation

Hypotheses for extended silo storage:

- Heat & time helps blending between virgin & RAP binders in plant HMA
- Improves cohesiveness of final blend & its performance



Less-uniform binder film
Lower effective binder content

Homogenous binder film
Higher effective binder content

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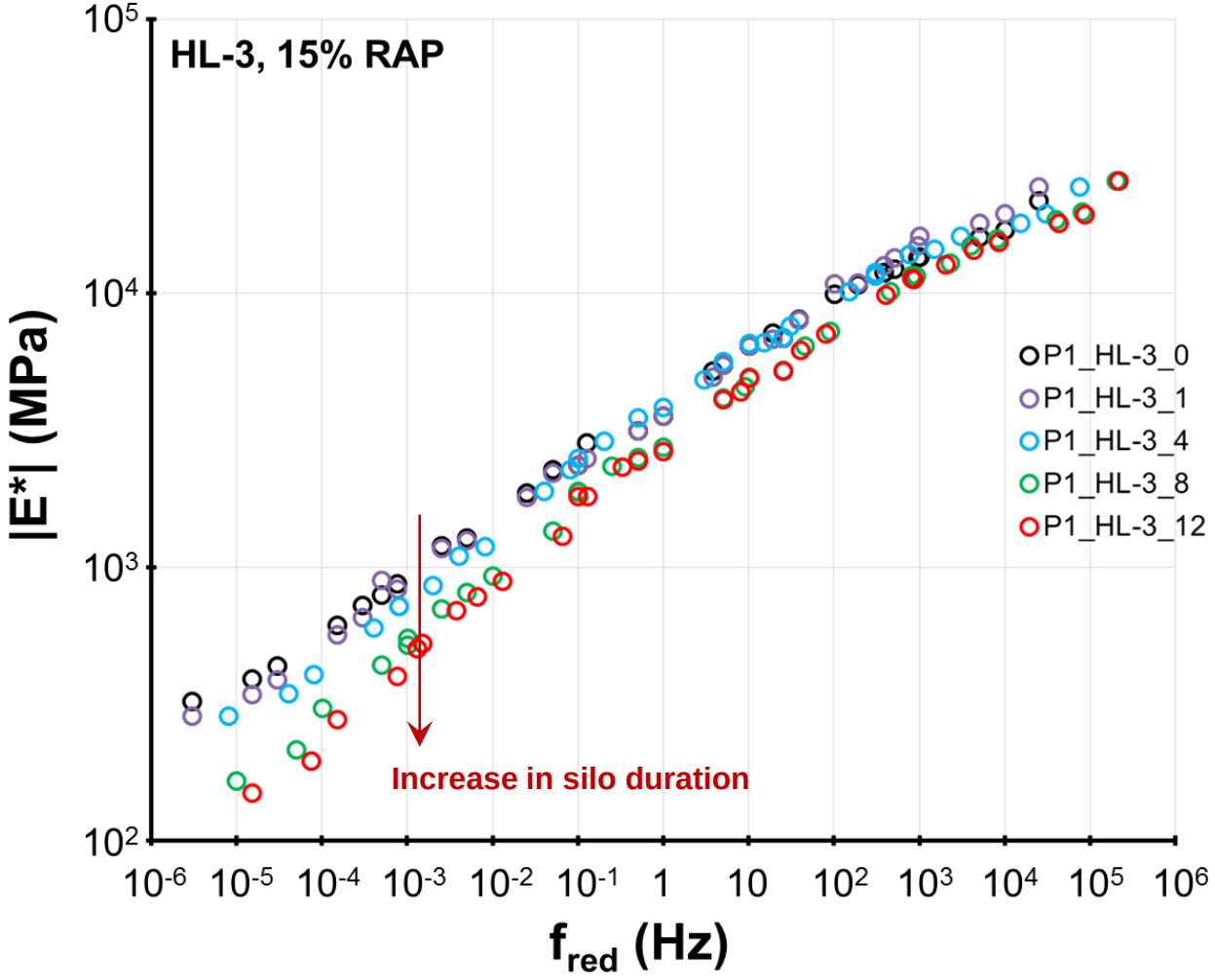
Asphalt Plants & Samples

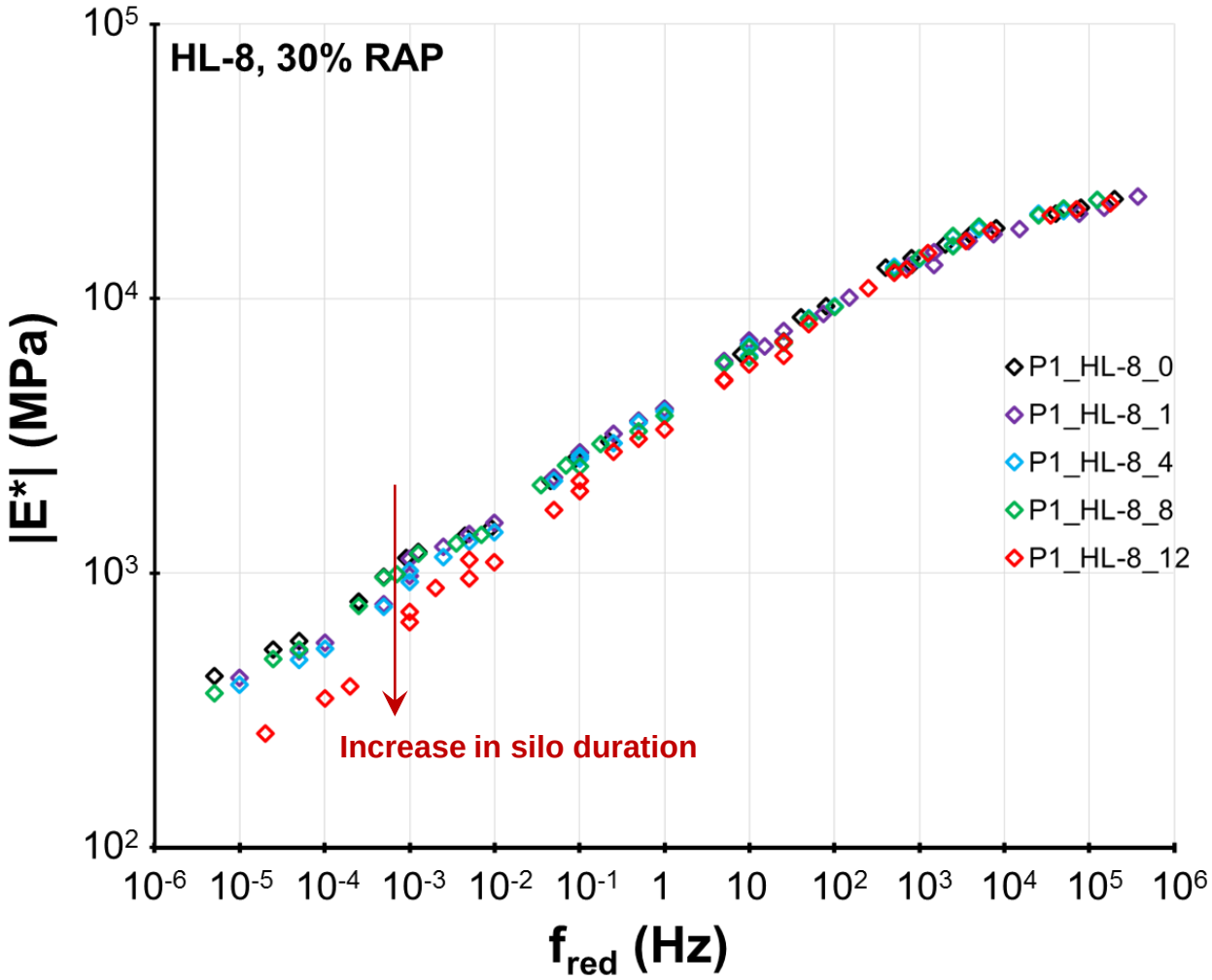
- Two HMA plants in Ontario, Canada, participated
- Mix samples collected at 0, 1, 4, 8, 12 hours of storage
  - 24-hour samples were also collected at Plant 2

Plant Operating Conditions & Mix Properties

Plant	**Plant 1**		**Plant 2**	
Asphalt Course	Surface (HL-3)	Base (HL-8)	Surface (HL-3)	Base (HL-8)
Production Temperature (°C)	**160**	**150-170**	**165**	**170-180**
Silo Temperature (°C)	140	140	147	147
Silo Status	**Off-loading**	**Off-loading**	**Stagnant**	**Stagnant**
Production Rate (tons/h)	**178**	**180**	**180**	**150**
Virgin Binder	PG 58-28	PG 52-34	PG 58-28	PG 52-34
AC Content (%)	5.0	4.7	5	4.7
RAP content (%)	15	30	20	40

Mix Modulus Evolves During Silo Storage





- Properties of mixes change with storage time counterintuitively, despite binder aging & absorption

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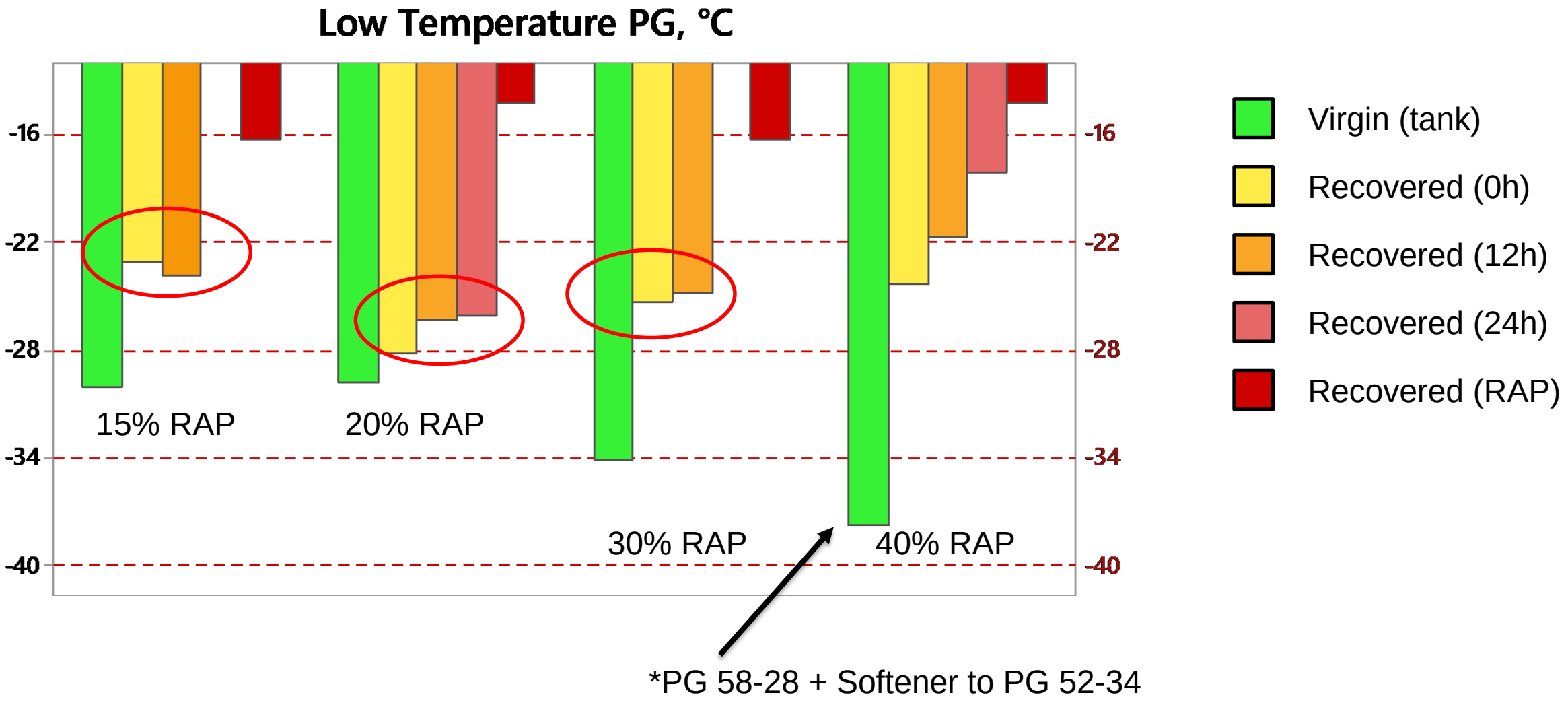
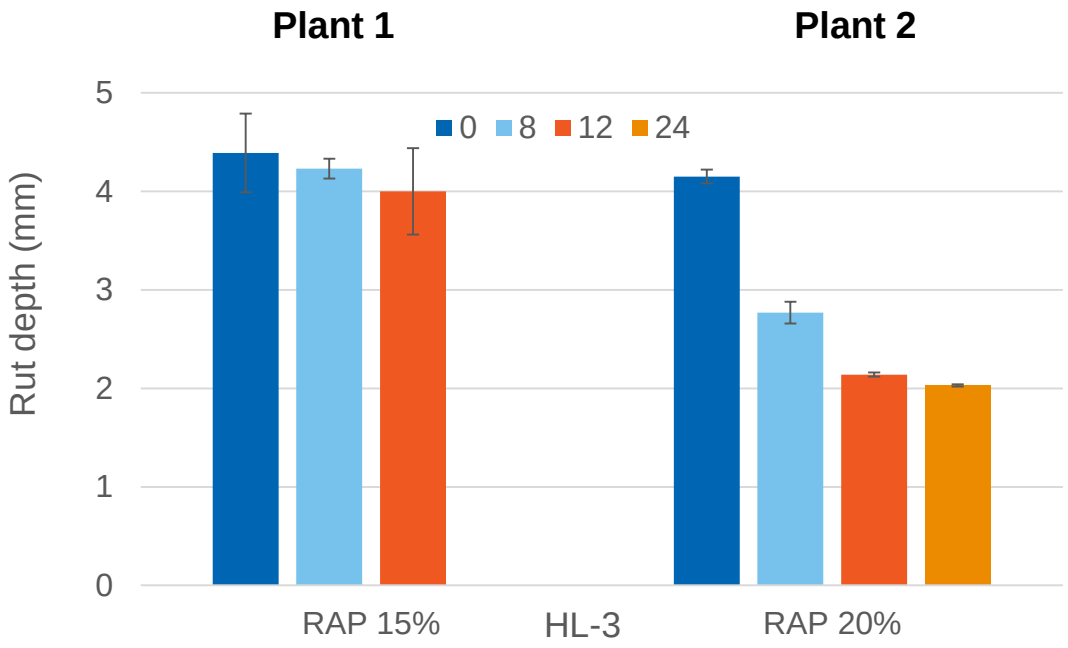
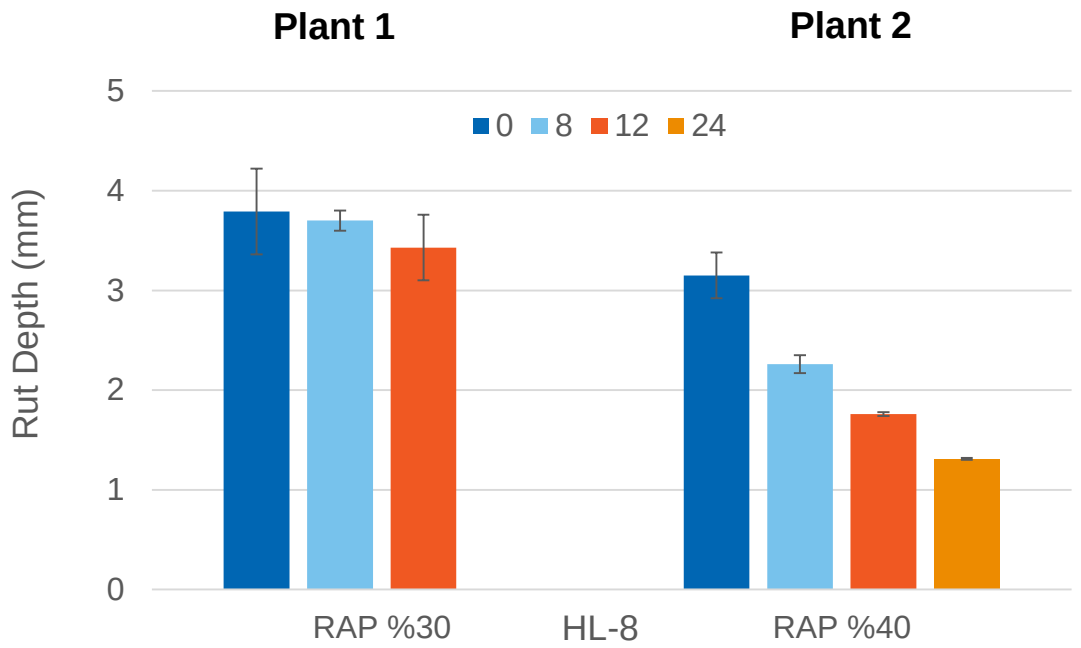
Binder Aging During Silo Storage not Significant*



Rutting Depth Reduced with Storage Time





Aging, absorption or diffusion?

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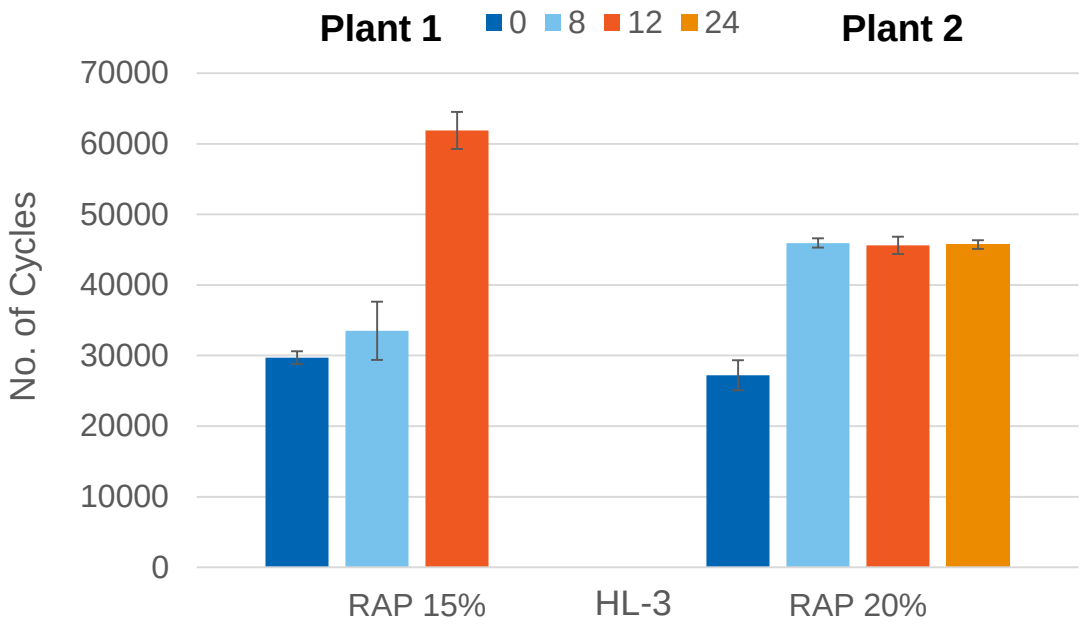
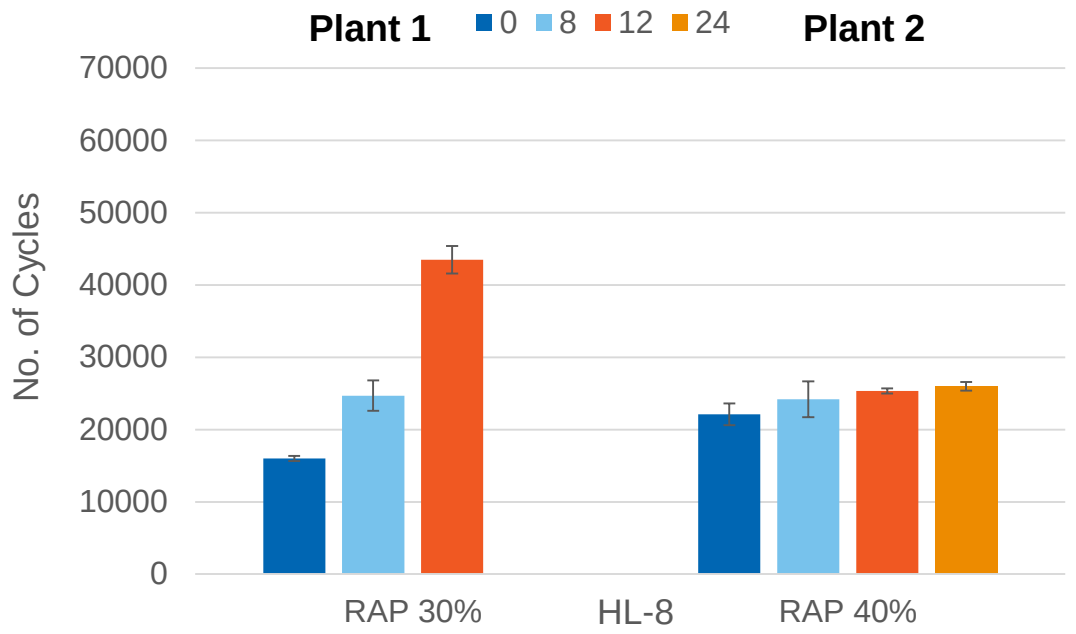
Fatigue Performance Improved with Storage Time





- Fatigue performance improves
- VMA slightly reduces & VFA slightly increases with storage time

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Key Learnings during Step III – Field Validation

Binder & mix properties evolve during silo storage

Binder diffusion is dominant factor in evolution of mix properties within 12 Hrs.

- Fatigue & rutting both improve as the binder film homogenizes

Caution must be exercised on binder chemistry

Binder softeners may increase binder aging during silo storage

RAP mixes evolve over time due to on-going RAP-virgin binder diffusion

Is RAP binder “a black rock” or “a binder blend component”?

…It depends, time & heat helps.

Thank you for your time!

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