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Asphalt Diffusion

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ETG – Baton Rouge
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Understand RAP-Virgin Binder Diffusion

Objective

- Understand diffusion between RAP and Virgin binder
- Understand impact of binder blending on rheological properties

Approach

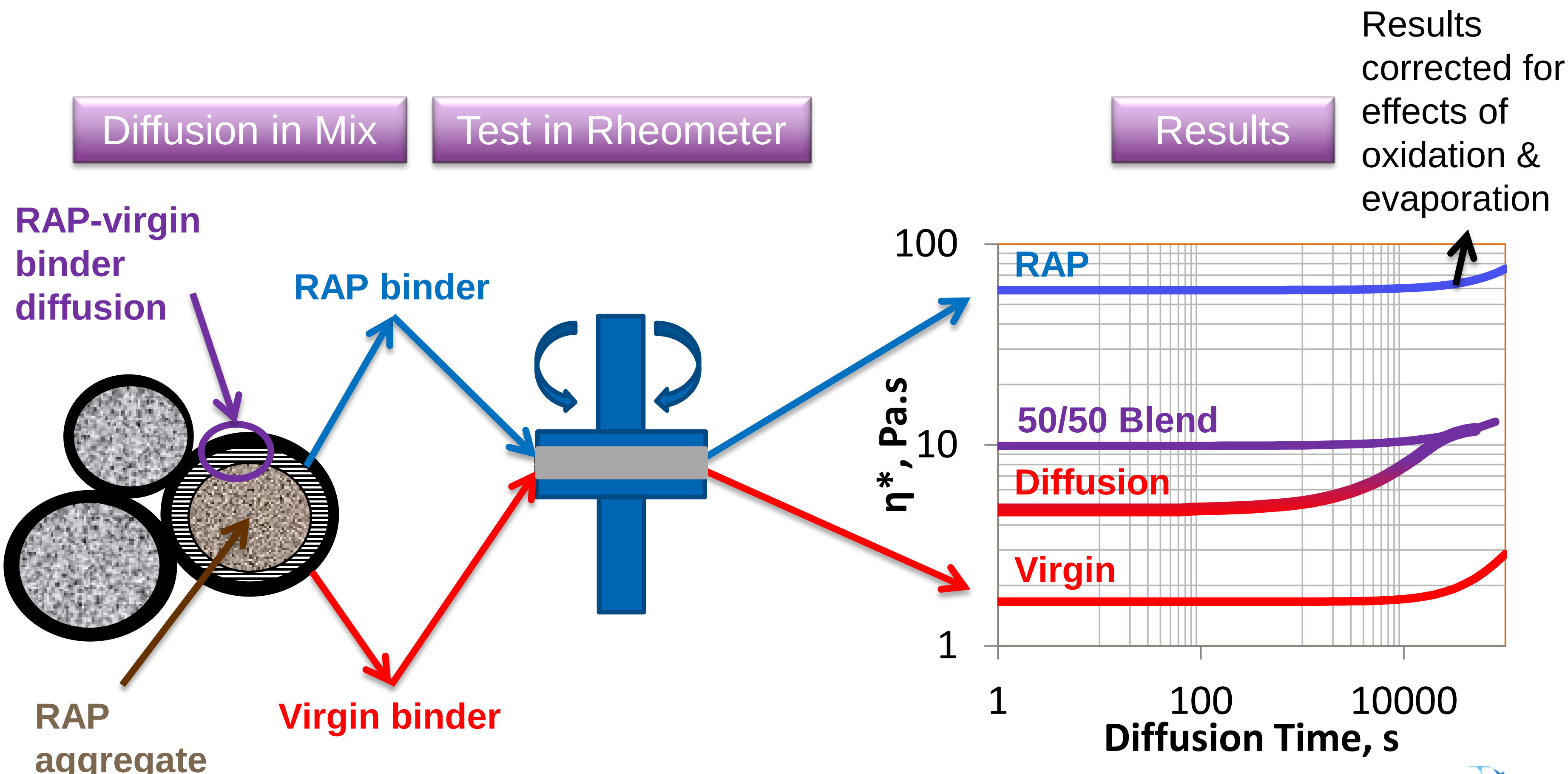
- Understand diffusion kinetics
- Verify the approach for asphalt mix
- Translate findings to mix production & paving conditions

Section 1

Binder Diffusion

RAP-Virgin Binder Diffusion Key to Performance

- Diffusion rate depends on molecular mobility → temperature & molecular structure



Diffusion Coefficient Calculated from Viscosity

$$\phi_{RAP}(y,t) = (1-\alpha)\left(1-\phi_0^{Virgin}\right) - \frac{2\left(1-\phi_0^{Virgin}\right)}{\pi}\sum_{n=1}^{\infty}\frac{\sin(n\pi\alpha)}{n}\cos\left(\frac{n\pi y}{L}\right)\exp\left\{-\left(\frac{n\pi}{L}\right)^2 Dt\right\}$$

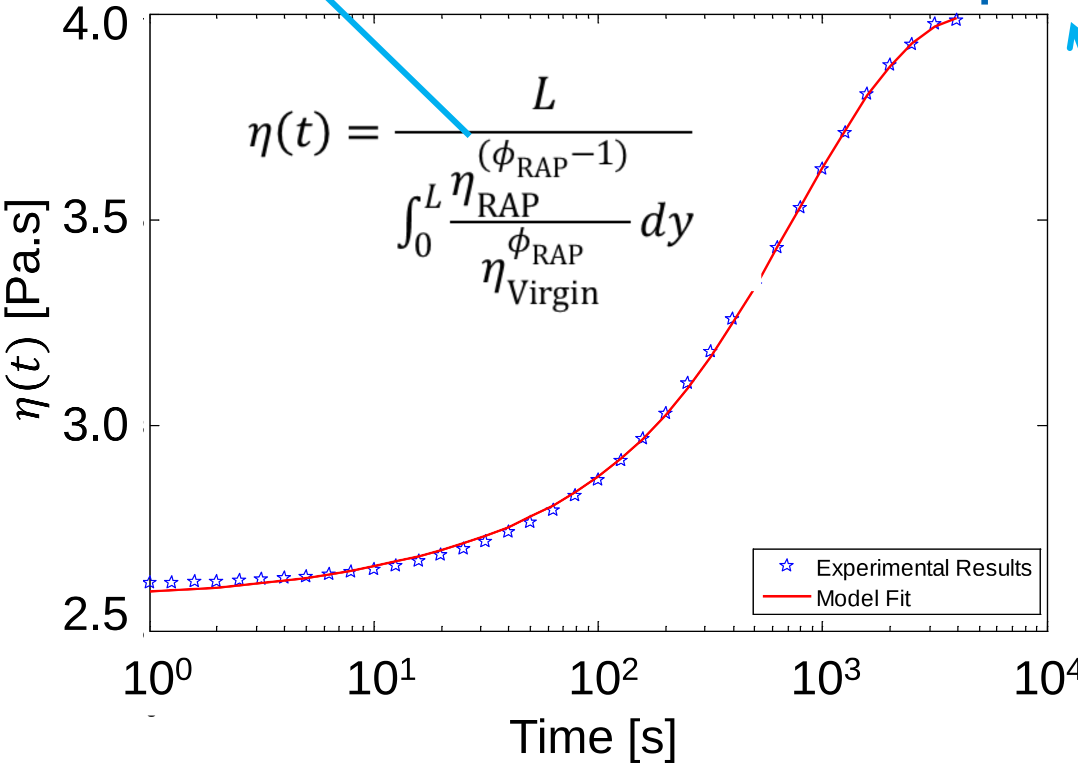
RAP conc. in distance y at time t

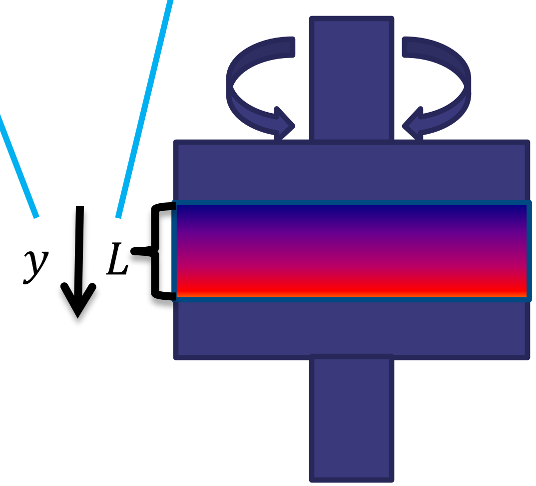
Average RAP conc. in the specimen

Distance from the top plate

Total sample thickness

Diffusion coefficient

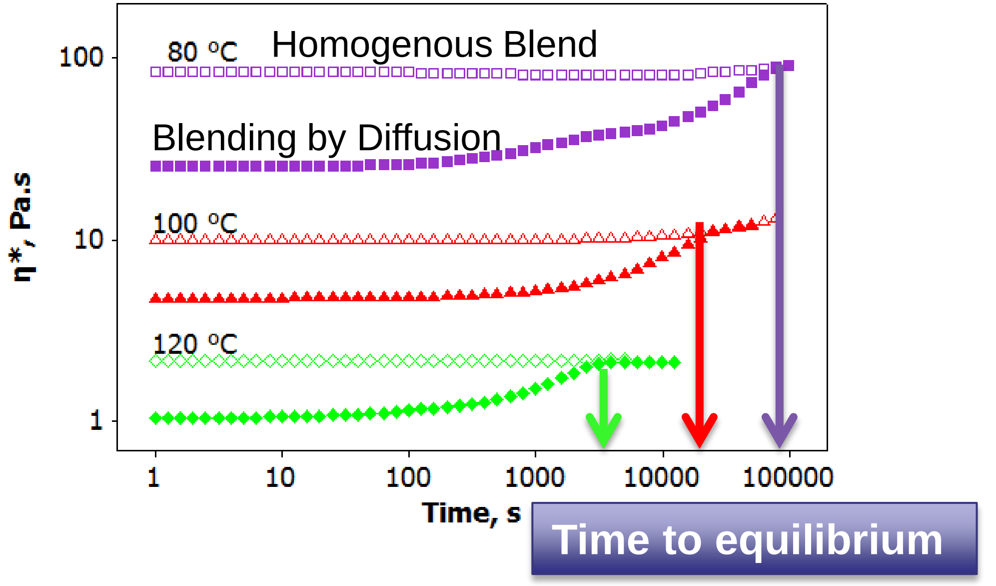




Diffusion is Faster at Higher Temperature

- Faster Brownian motion at higher temperature increases diffusion rate & reduces time to equilibrium (homogenous blend)

Diffusion at Varying Temperature



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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

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Section 2

Mix Diffusion

"Finding the Distance"

Specific Mixes Prepared to Study Diffusion

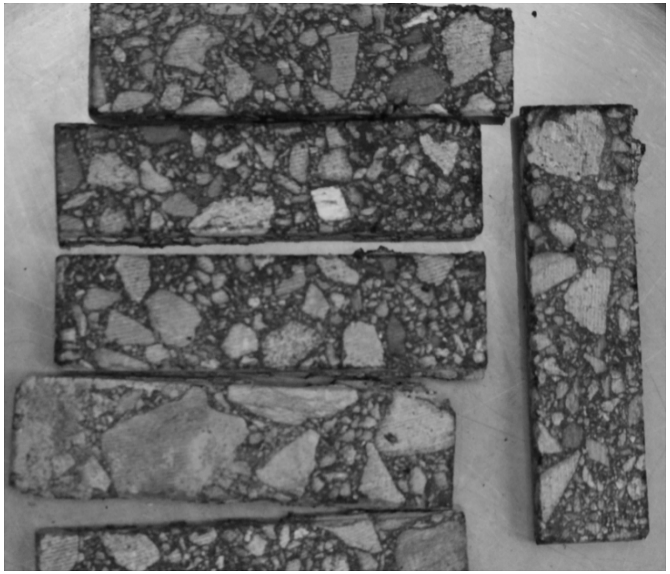
ID		Binder Added	Aggregate		RAP	Air Voids %
			Virgin	RAP		
AD	Asphalt Diffusion	Virgin	Same in all mixes	None	30%	3.5
BC	Blended Control	Lab Blend (Virgin+ RAP)	Same in all mixes	RAP aggregate	None	2.7

Superpave 12.5mm Mix Design (OPSS.MUNI 1151)

Mix Briquette Cut & Conditioned

Conditioning in N_2 purged PAV at constant temperature (90, 120, 150 °C) & variable time

MIX SAMPLE AFTER CUTTING

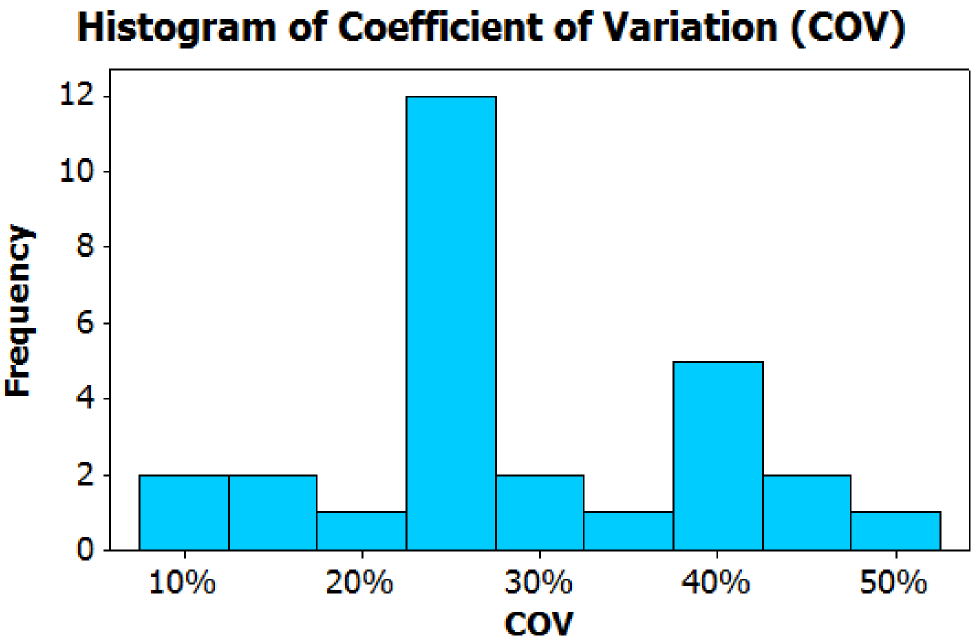


MIX SAMPLE AFTER 1H @ 90°C

Testing in DSR – High Variability is a Challenge

- Test in torsion, 10 rad/s, 20 °C, constant strain (LVE)
  - Small size specimen selected as a compromise to manage time & effort
  - Larger aggregate significantly contribute to variability
- 5-10 repeats, COV remained high

TORSION TEST SETUP



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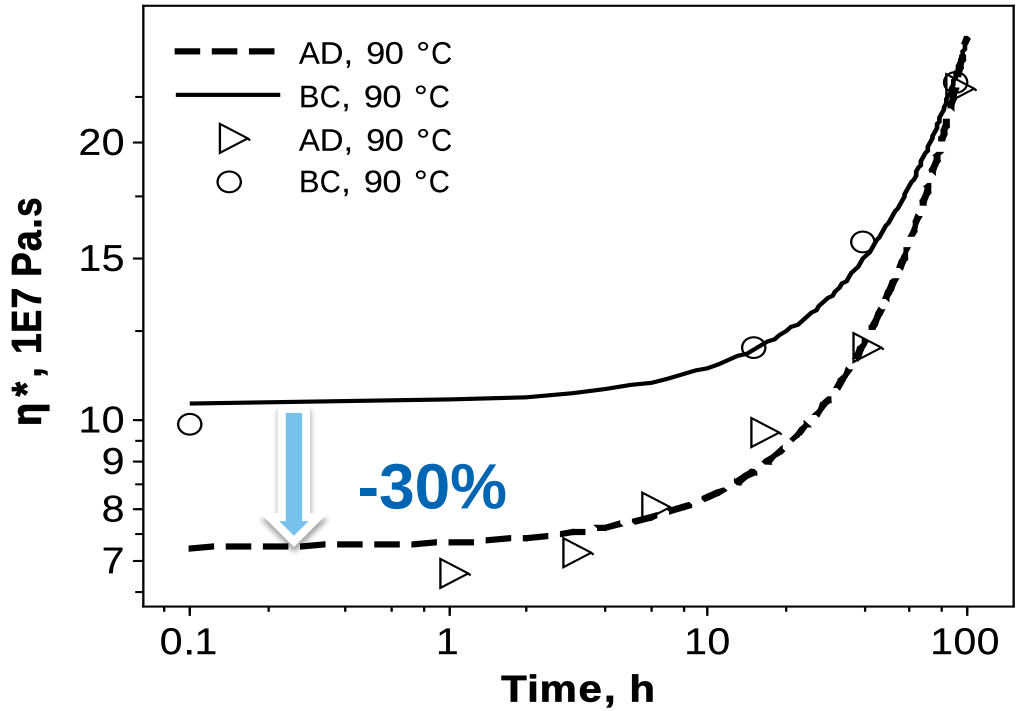
RAP Mix is Softer than Control (pre-blended binders)

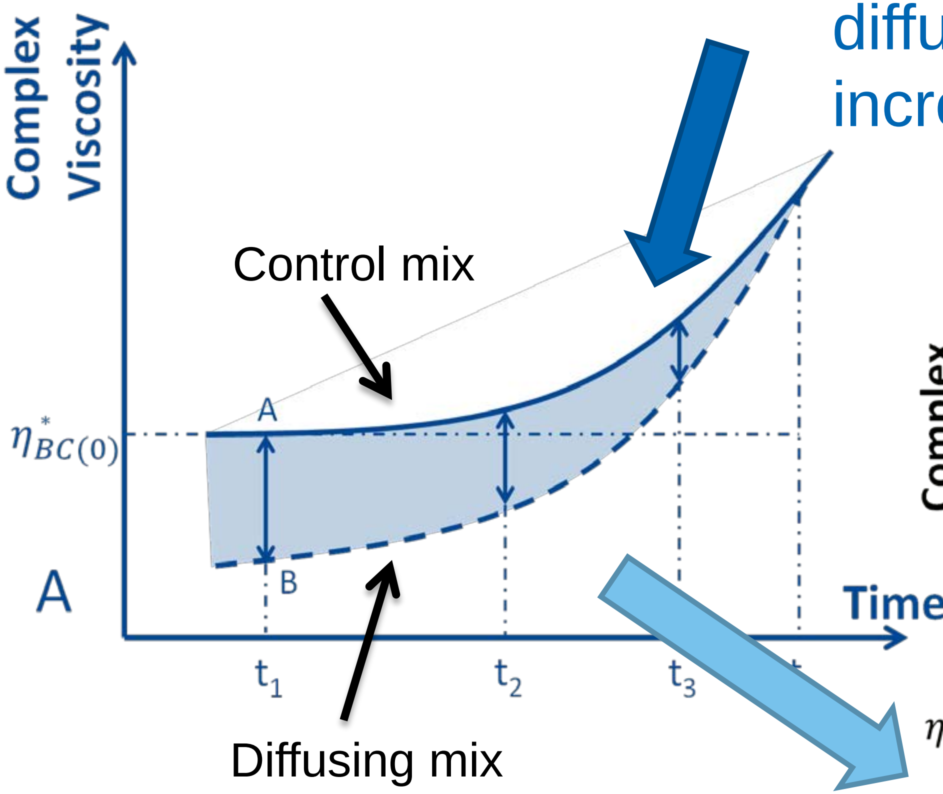
EXPERIMENTAL DATA FOR DIFFUSING (AD) & CONTROL MIX (BC)



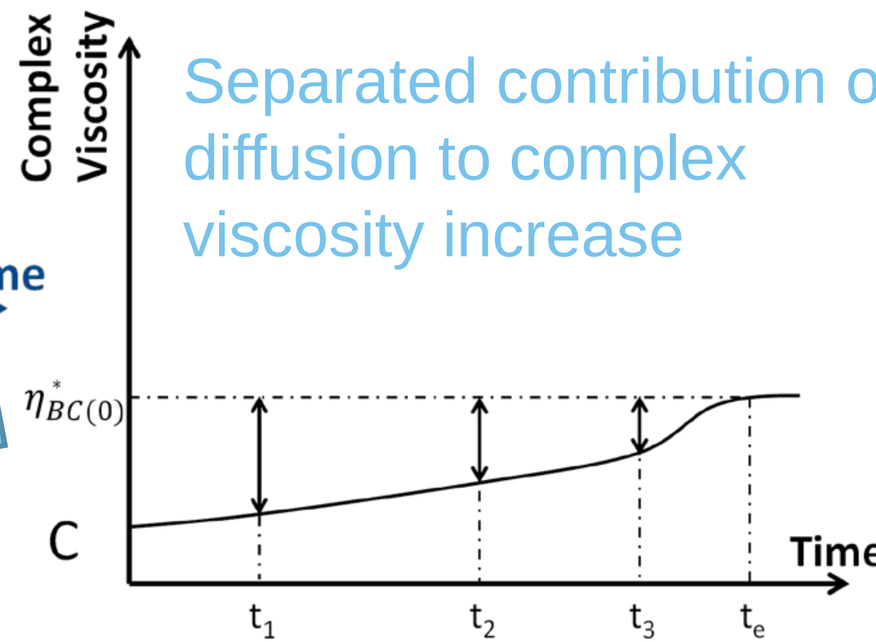
Significant hardening attributed to binder absorption & evaporation

Diffusion Only Partially Responsible for Mix Hardening

Shaded Area = Contribution of diffusion to complex viscosity increase



Separated contribution of diffusion to complex viscosity increase



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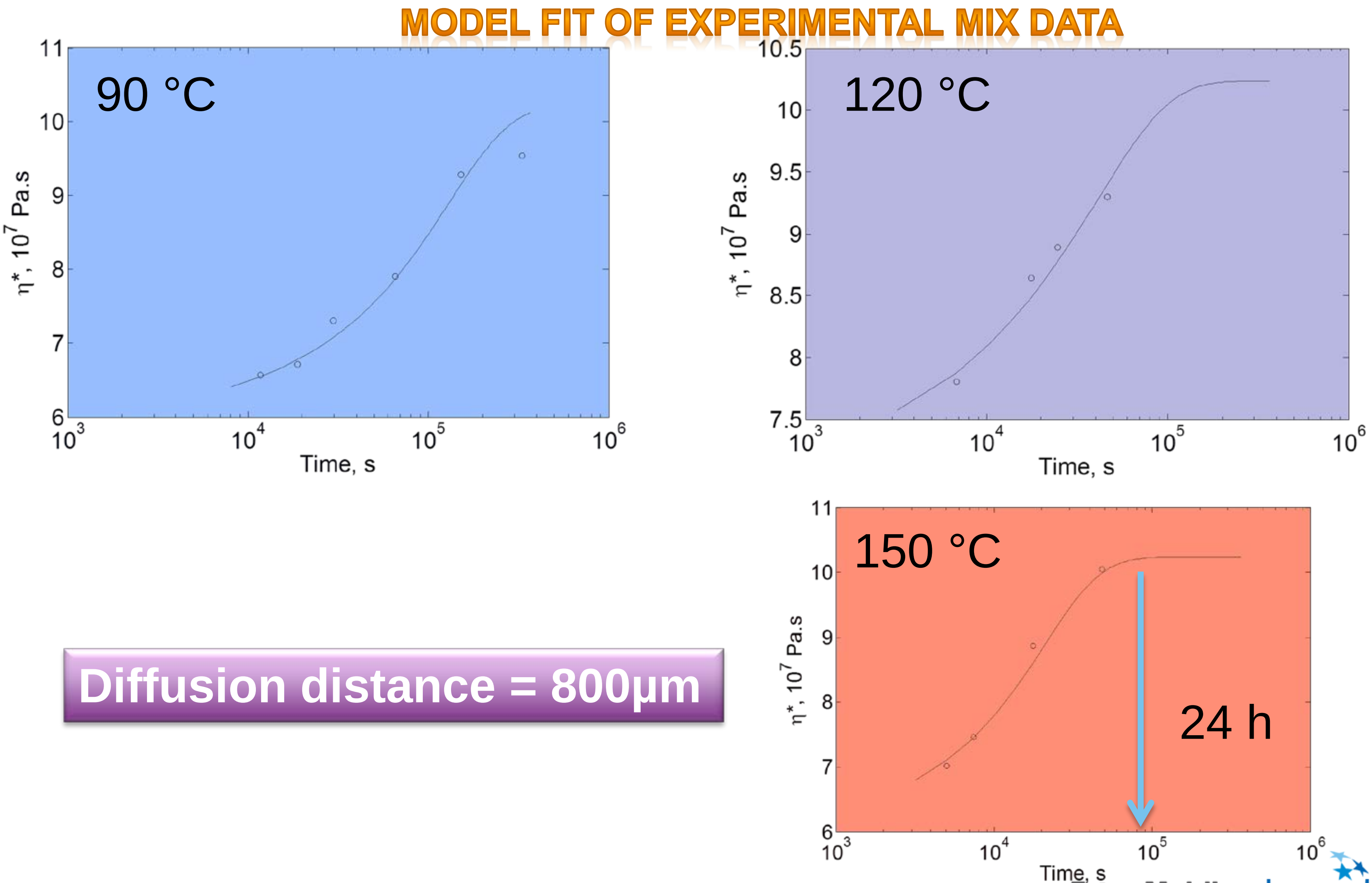
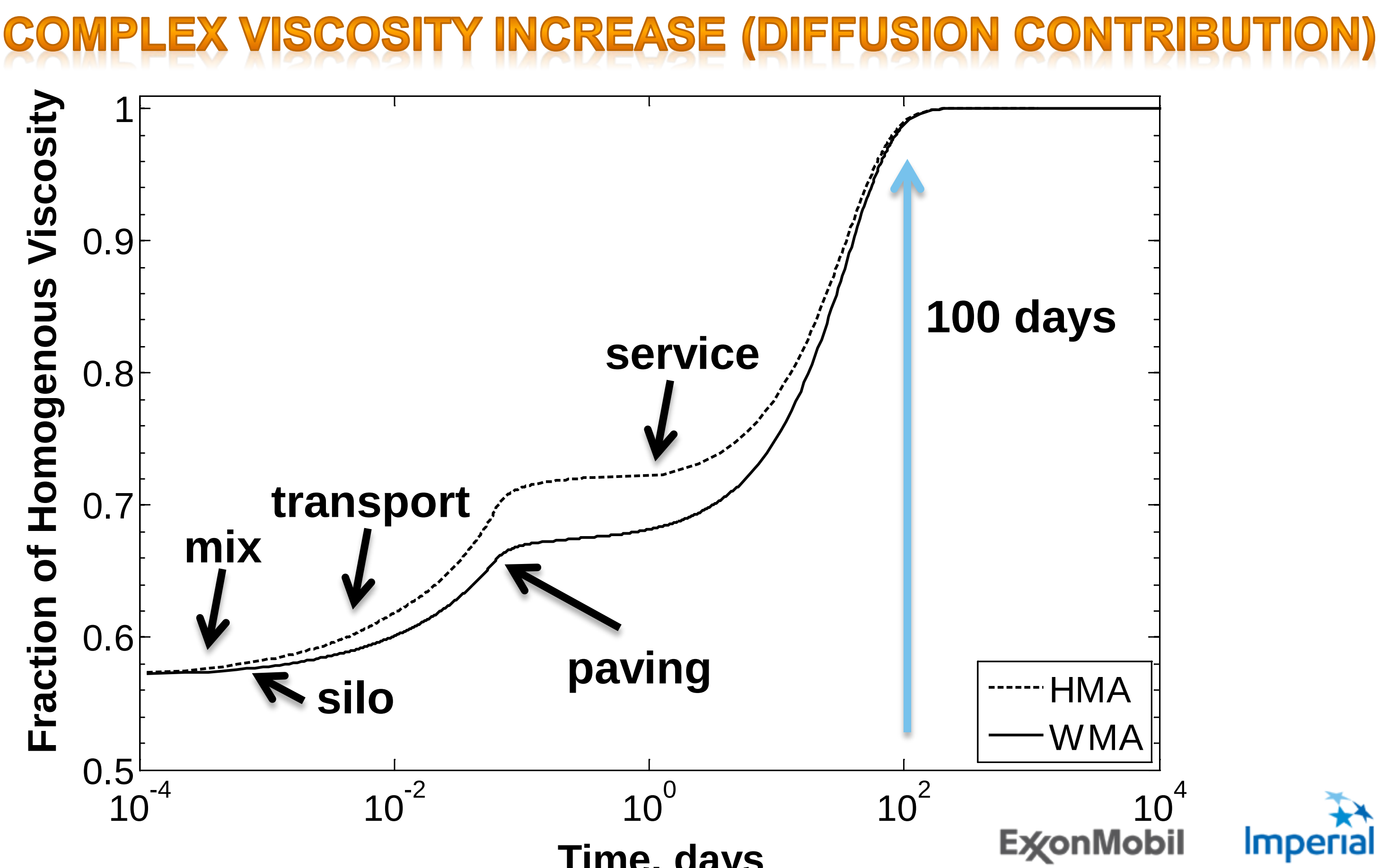
Binder Diffusion Model Fits Mix Data Well



Diffusion distance = 800µm

Diffusion = Lengthy Process at Mix/Pavement Temperatures

In realistic mix production & placement scenario incomplete blending results in lower complex viscosity



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Extent of Blending is Critical for RAP Mix Performance & Virgin PG Selection

Binder film thickness & time at temperature are critical parameters for diffusion in the asphalt mix

Diffusion may not be completed during mix production

- Effective binder viscosity is lower than expected (“lubrication”)

Silo storage at higher temperature can assist diffusion

Asphalt mix is a dynamic system

- Caution should be used during mix testing

Thank you

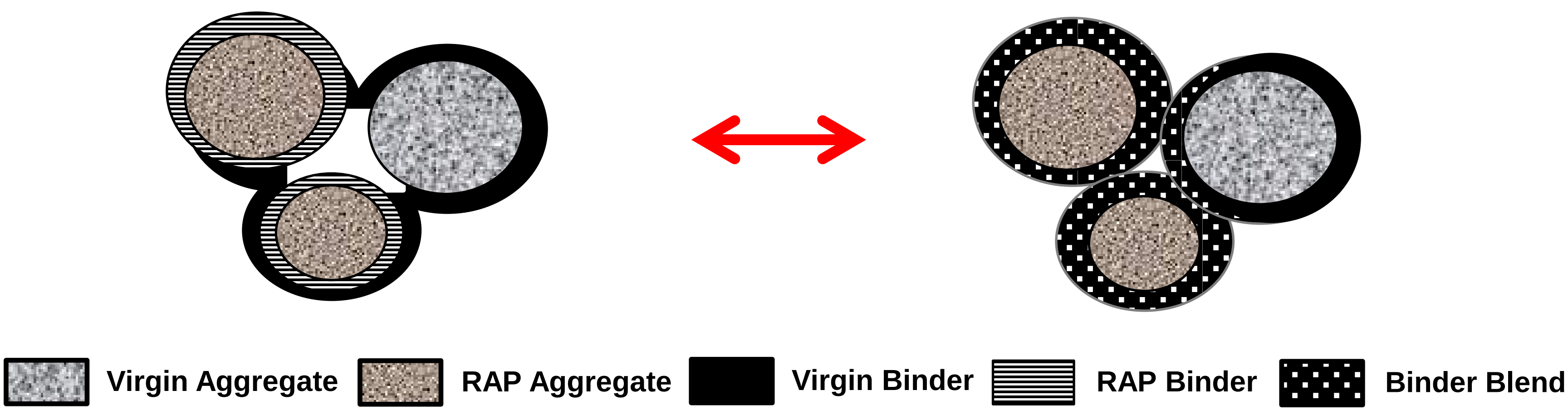
Appendix

Proper Binder Contact is Essential for Good Blending

Factors: Contact	Factors: Blending
RAP temperature	Diffusion rate (D(T))
Mixing energy/time	Film thickness (distance)
Virgin binder viscosity	Time

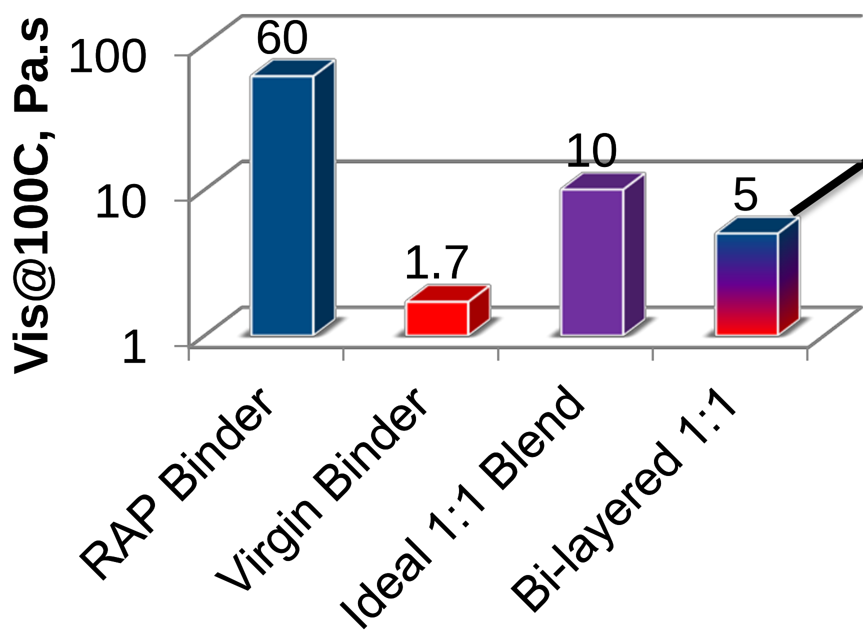
Poor contact
Poor blending

Good contact
Good blending

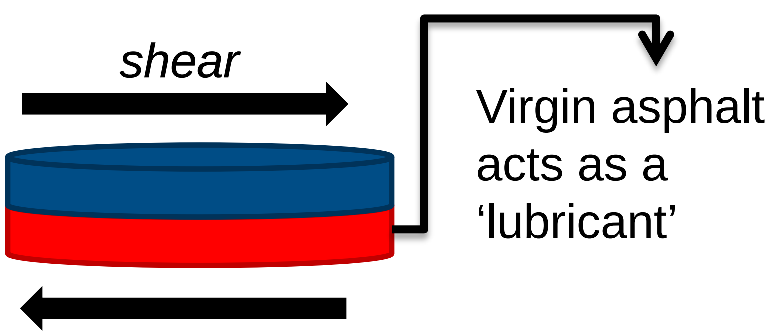


RAP-Virgin Binder Blending is Critical to Mix Rheology

Viscosity of two discrete layers of RAP & virgin binder is significantly lower than that of homogenous blend



Bi-layered sample viscosity is lower than that of homogenous blend

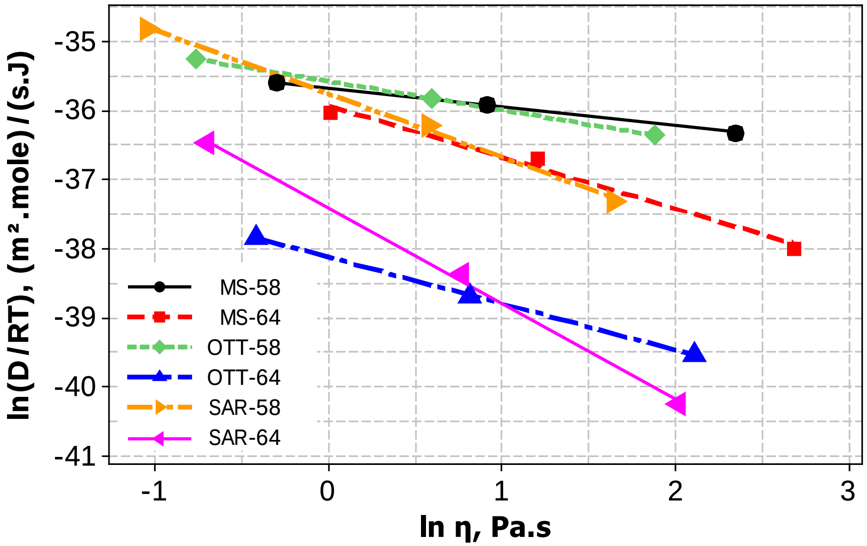


Diffusion Rate Can Be Estimated From Viscosity-Temperature Profile

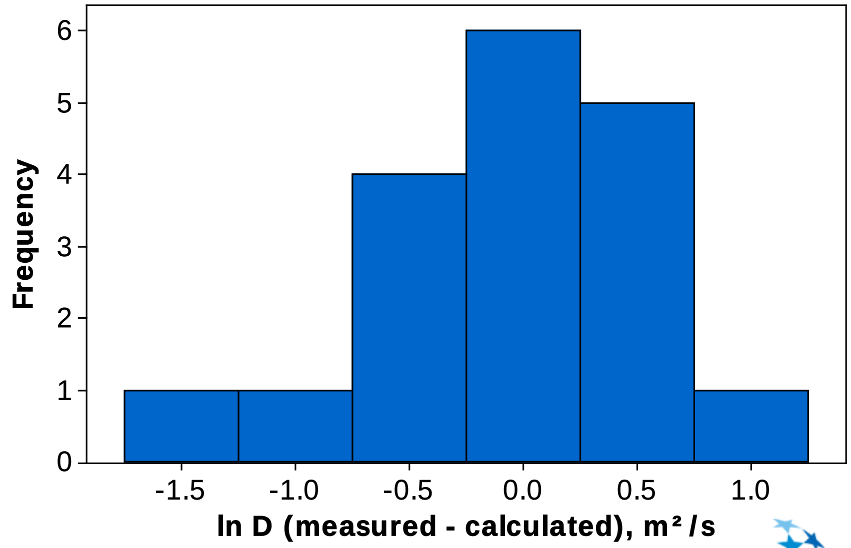
The free volume theory was used to relate diffusion coefficient to viscosity-temperature profile, $\eta(T)$

Relatively accurate estimations of diffusion coefficients are possible from Newtonian viscosity-temperature profiles (Brookfield at 100-140 °C)

Relation Between D and η



Histogram of D Estimates Residuals



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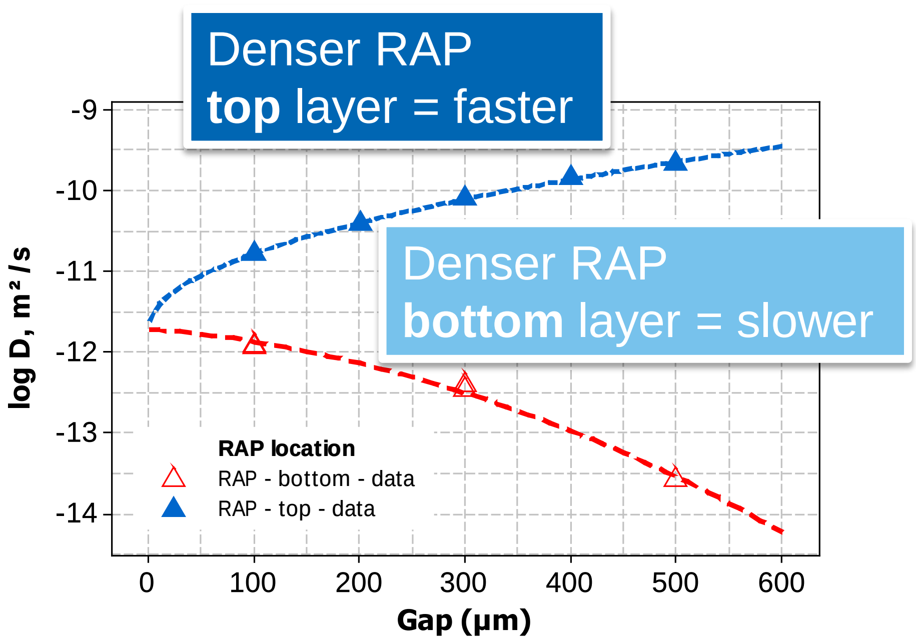
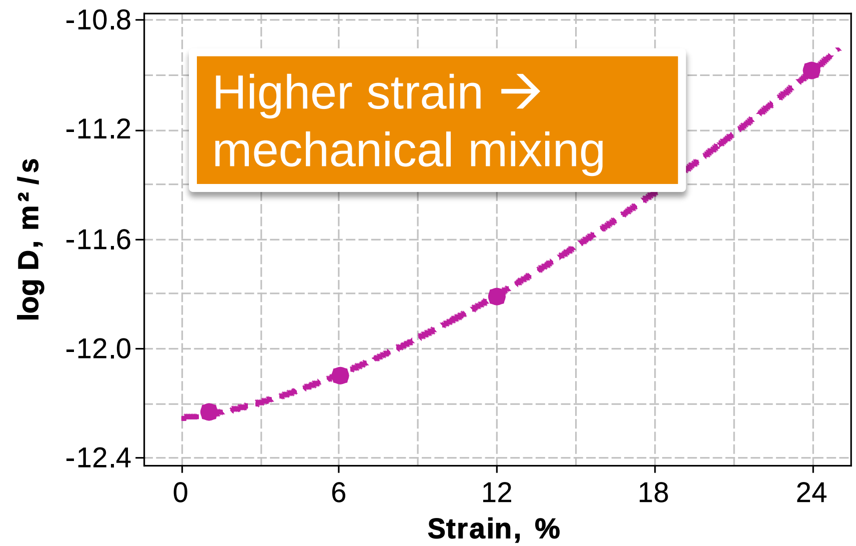
Experimental Results Sensitive to Test Setup

Density differences between binders impact diffusion rates
Higher test strains result in artificially higher diffusion rates

Effect of RAP Layer Position

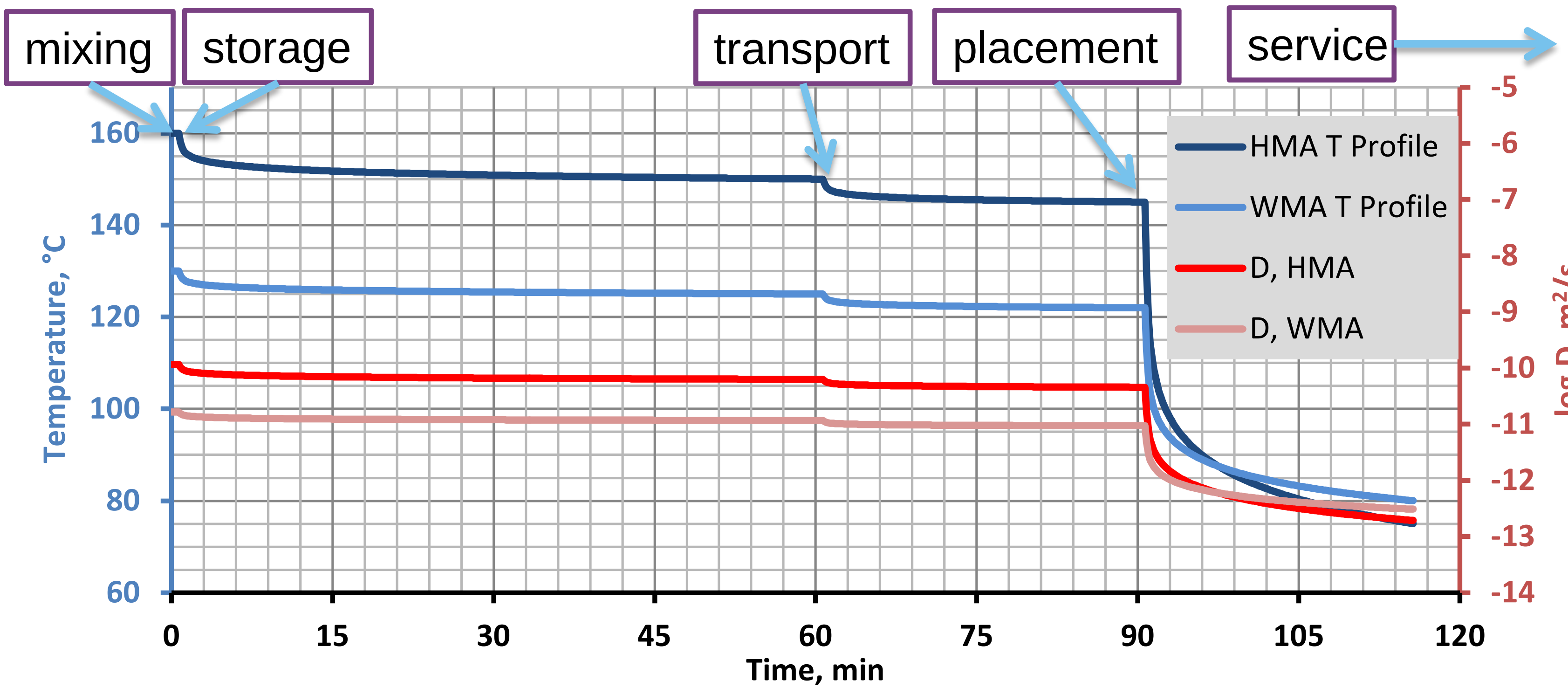


Effect of Test Strain on Diffusion Rate

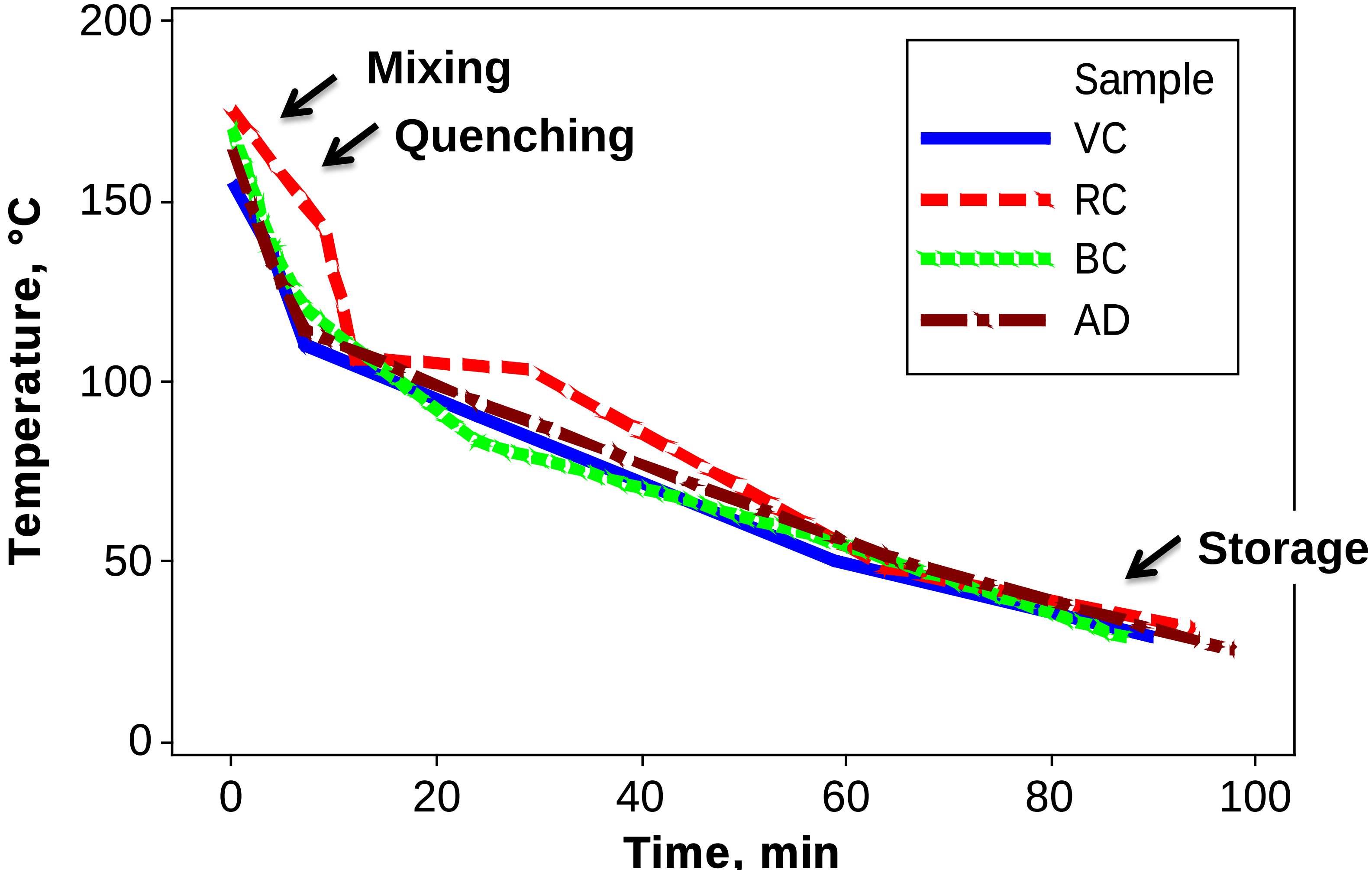


Simulating Diffusion Rate at Realistic Conditions

Diffusion coefficient decreases with mix cooling



Mix Temperature Profile Determined to Assess Extent of Diffusion Before Testing



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