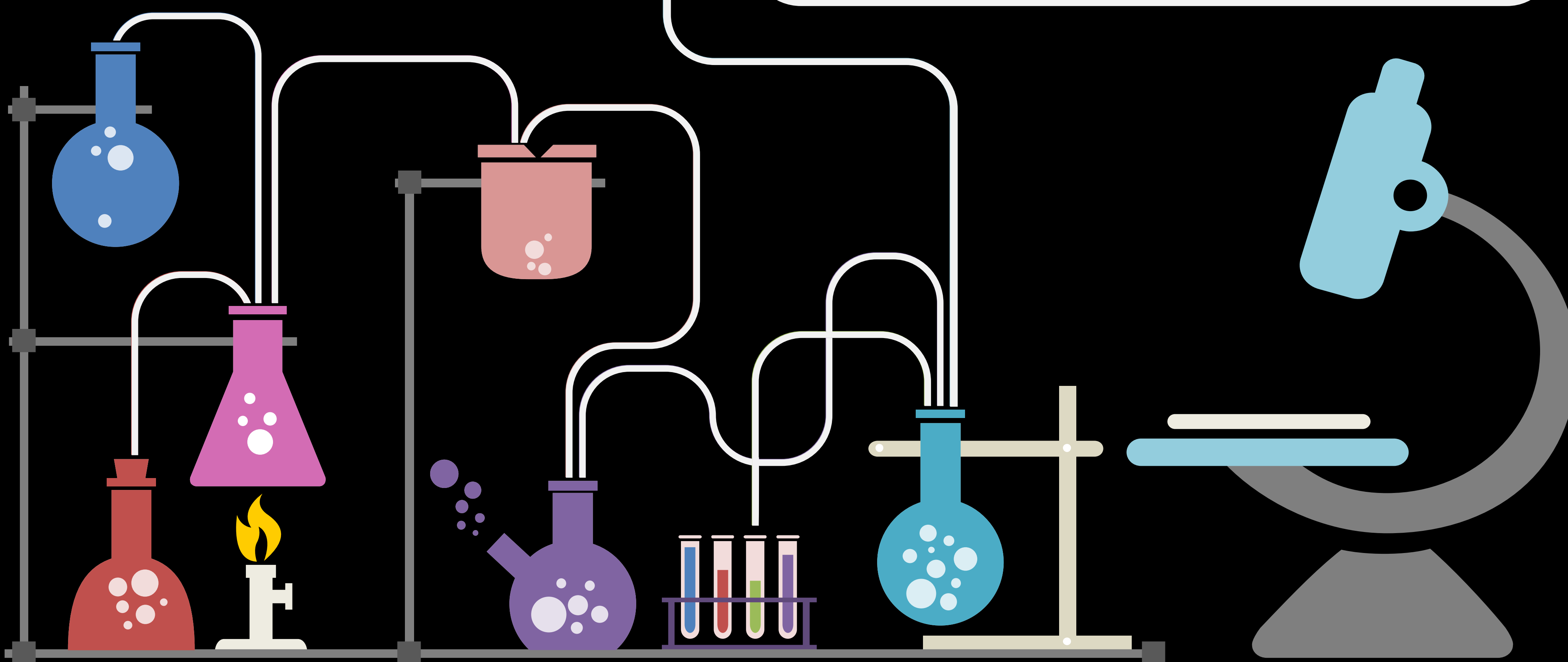
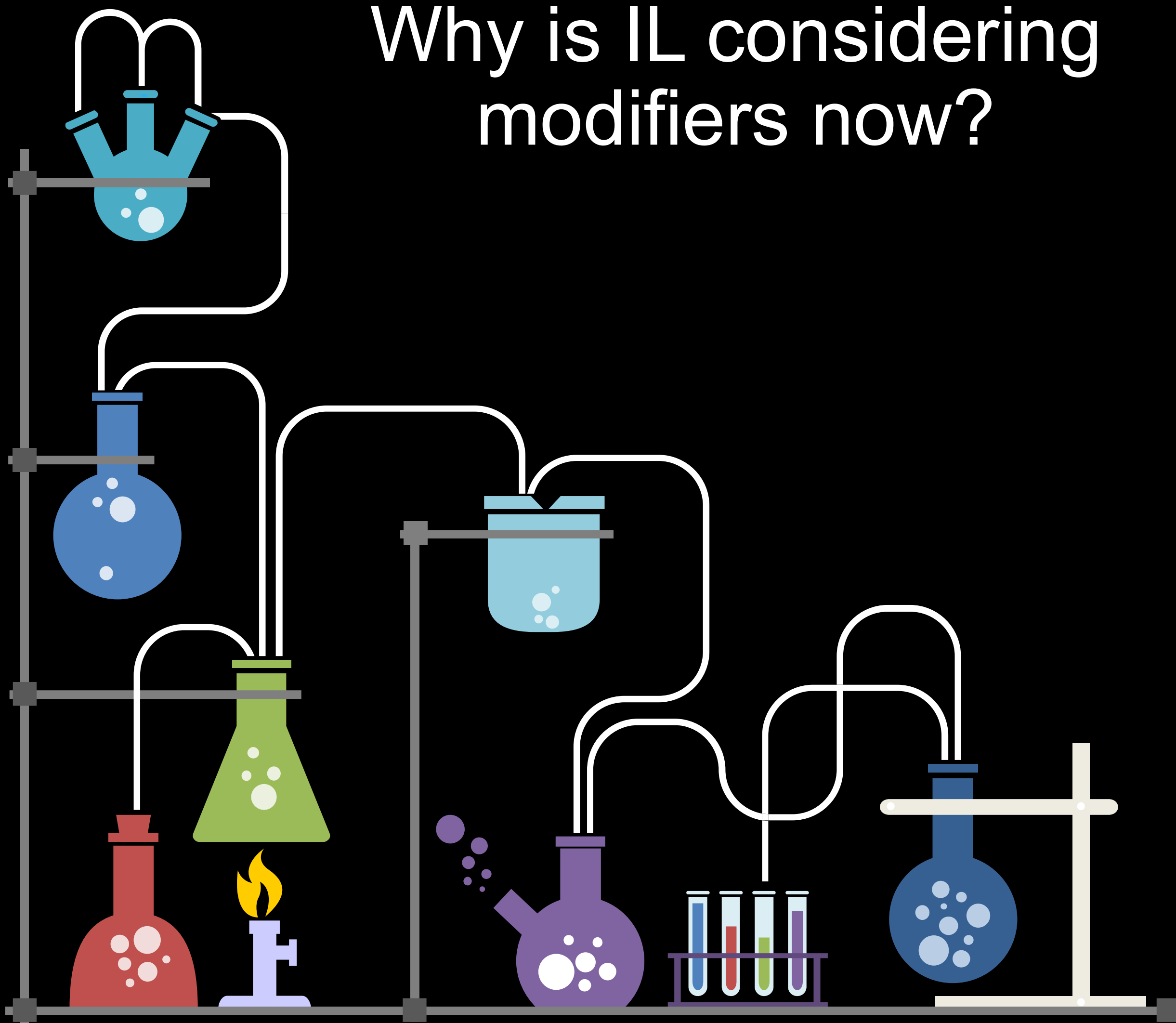
Illinois Department of Transportation

Asphalt Binder Modification



Why is IL considering modifiers now?



- ❖ Illinois does not currently allow modification other than polymer.
- ❖ Significant change in base binder used in IL from PG 64-22 to PG 58-28.
- ❖ Need for **economic & sustainable** alternatives to achieve softer PGs.
- ❖ Can those softer grades be achieved with softening agents without a compromise?

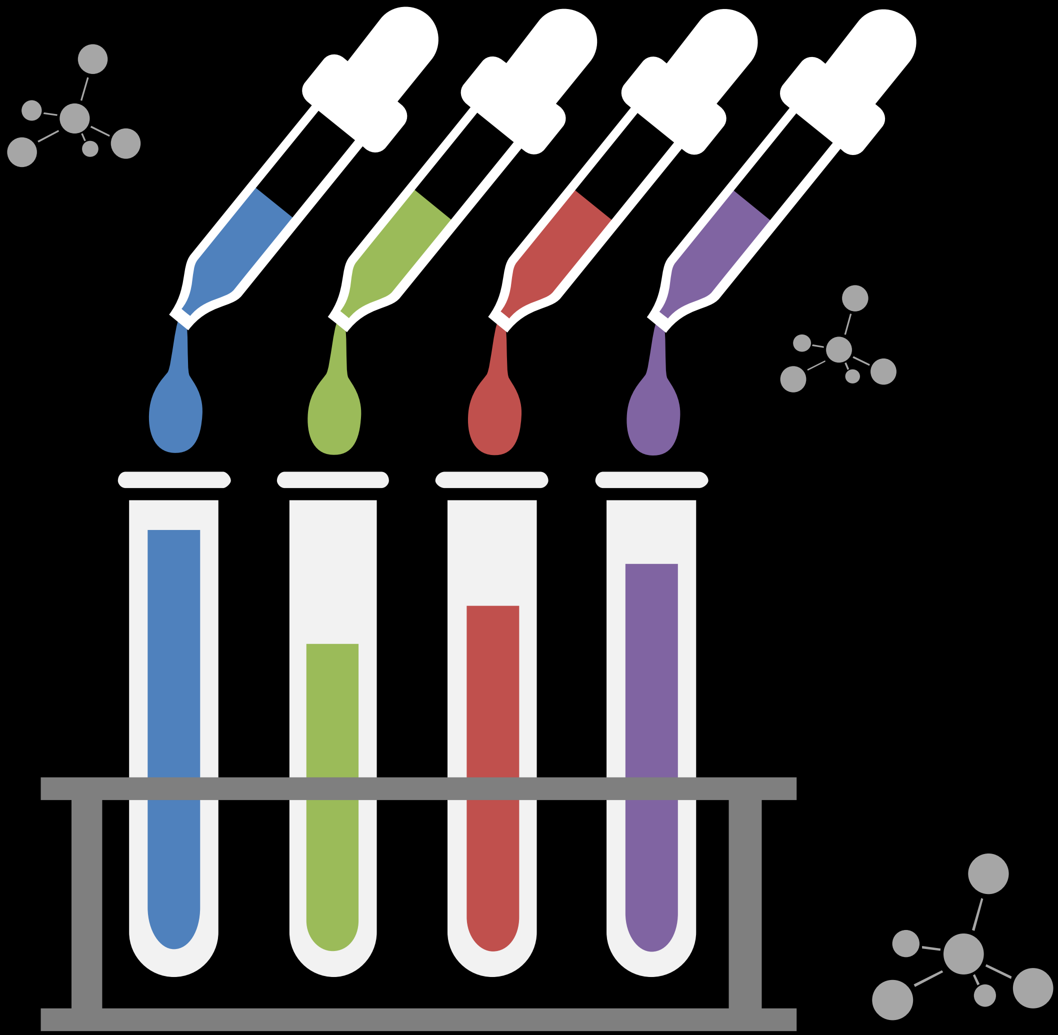
ICT Project
R27-196HS

"Rheology-Chemical Based Procedure to Evaluate Additives/Modifiers used in Asphalt Binders for Performance Enhancements"

Dr. BK Sharma

Dr. Hasan Ozer

Dr. Imad Al-Qadi



Binder Chemistry

Evaluating the effect of modifiers on the binder chemistry and performance

Long Term Aging

Developing an efficient long-term aging procedure for modified binders

Modifier Chemistry

Conduct thorough chemical characterization of modifier

Validation

Validate and fine-tune the preliminary thresholds established

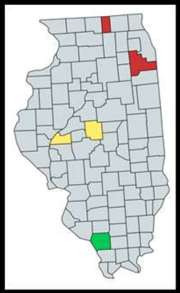
Rheology

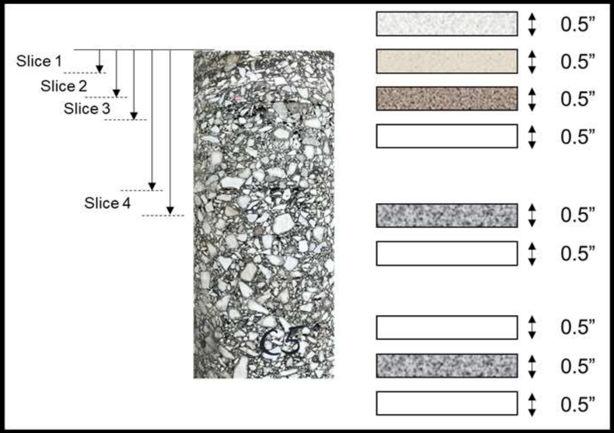
- FS (Gr, w_c, R-value)
- BBR (ΔT_c)
- LAS

Chemistry

- FTIR
- GPC
- TLC FID, SARAD
- Microscopy
- TGA/DSC

- 20-hr PAV
- 40-hr PAV
- 60-hr PAV
- Modified PAV to match real time aging





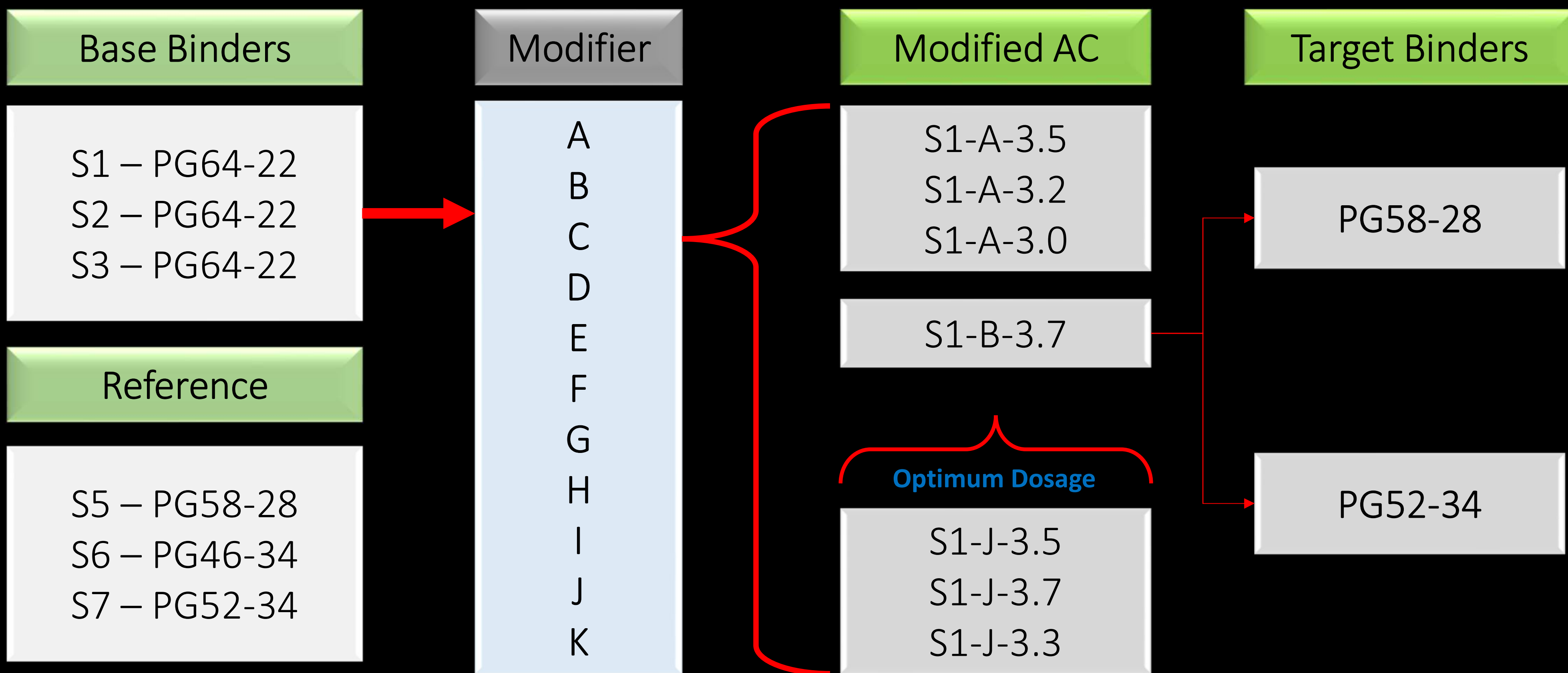
Long-Term Lab Aging

Modifiers

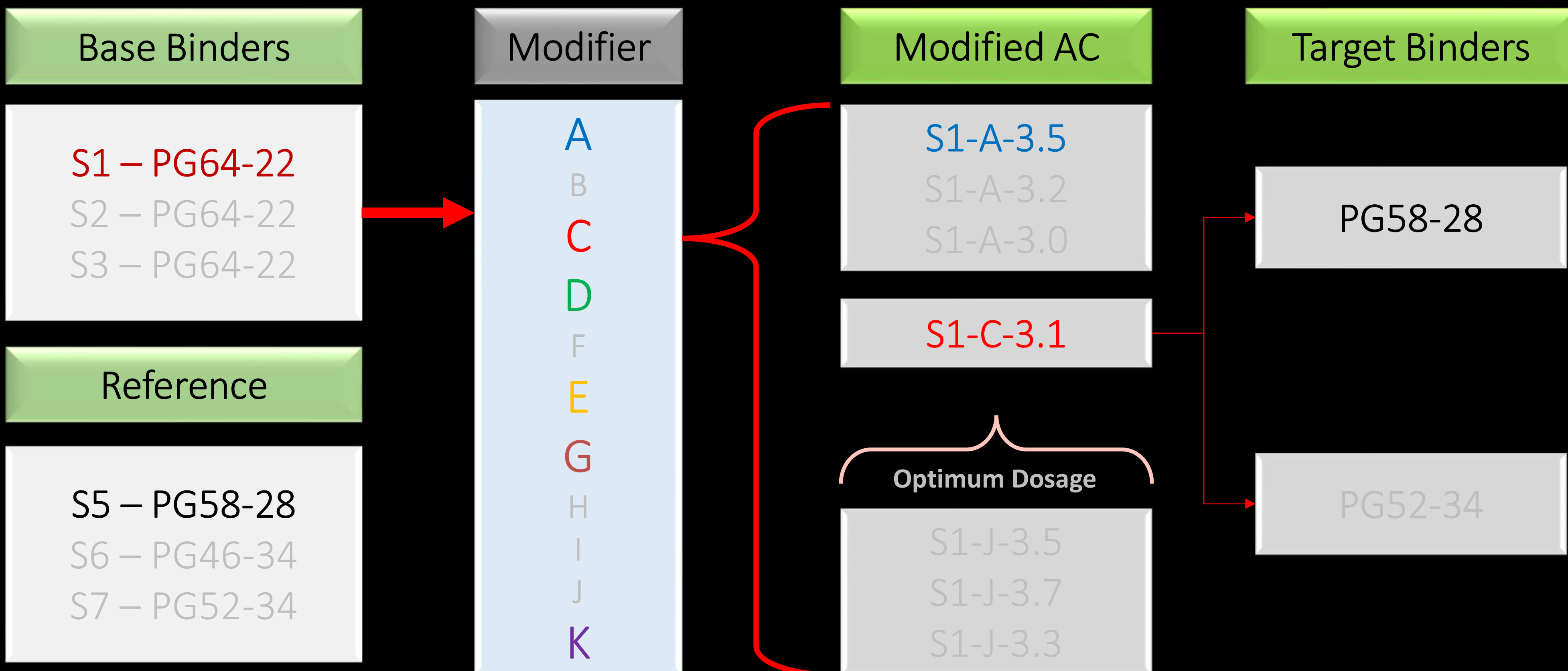
Modifier ID	Type
A	NA
B	Fatty acid derivatives
C	Fatty acid derivatives
D	Bio Oil Blend
E	Mod. Veg Oil
F	Mod. Veg Oil
G	Glycol Amine
H	Asphalt
I	Soybean Oil, Methyl ester
J	Vegetable oil
K	ReOB
L	NA

ID	Binder	Qty.
S1	PG 64-22	110 gal.
S2	PG 64-22	50 gal.
S3	PG 64-22	50 gal.
S5	PG 58-28	20 gal.
S6	PG 46-34	20 gal.
S7	PG 52-34	20 gal.
S8	PG58-28	4 gal.
S9	PG64-22	4 gal.

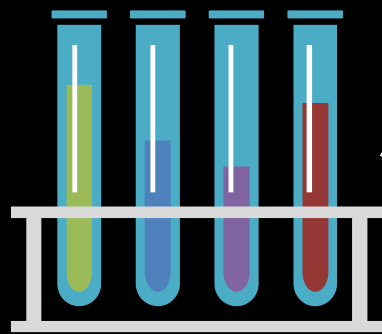
Binder Modification Matrix



Modifiers Tested

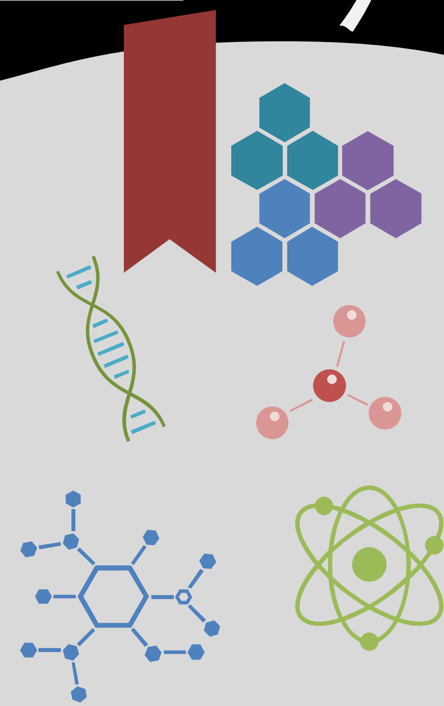


Binder Rheology



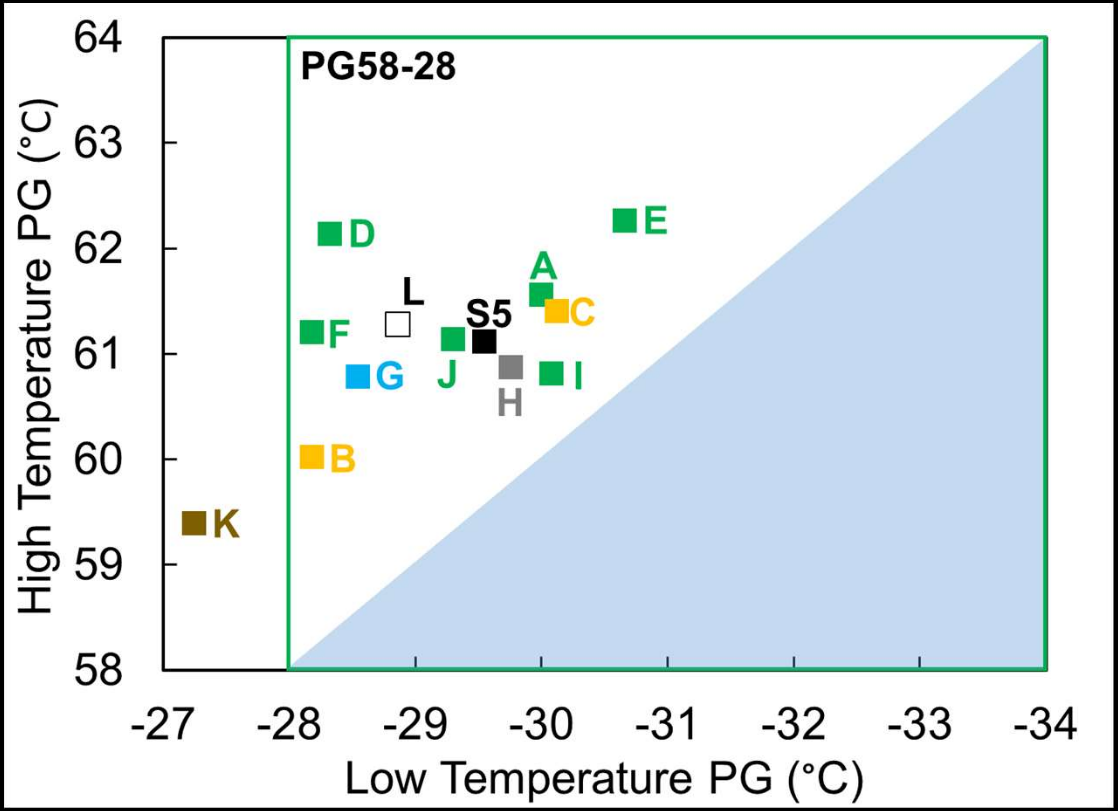
1. Base and Reference Binder
2. 11 Modified Binders
3. Optimum dosage
4. Source variability
5. Other softer PGs, 52-34

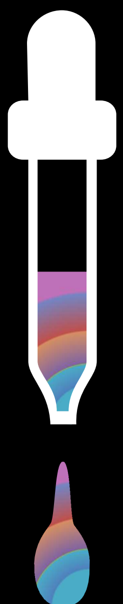
Select modifiers for select aging conditions



Superpave PG Grading

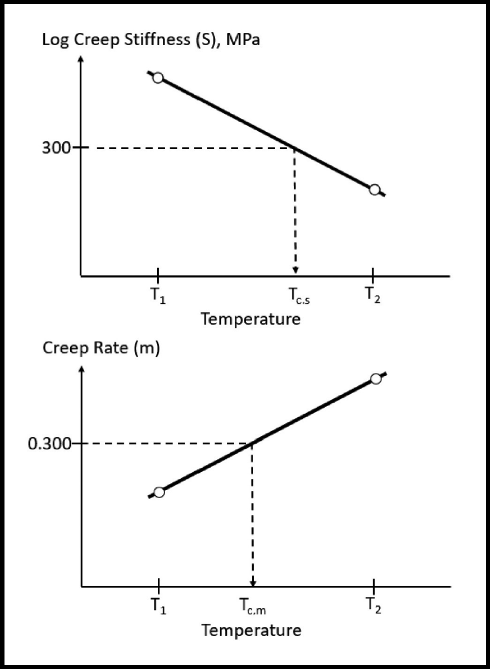
- S1 modified to 58-28s
- Modification concentrated to one region (right)
- Modifier K, ReOB failed to achieve 58-28 with S1
- During optimum dosage determination, modifiers will be selected to populate the left triangle.

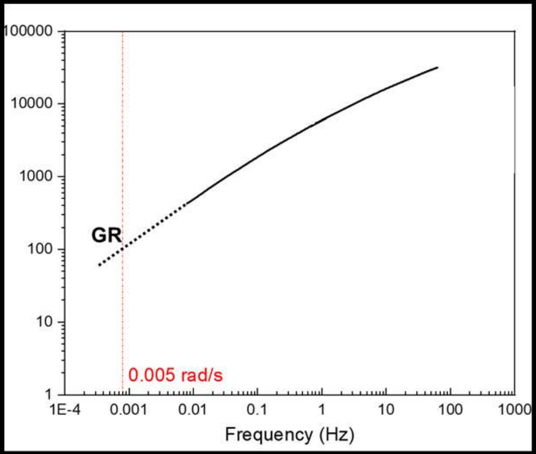




Rheological Work Summary

Small-strain parameters – Low temperature





Glover-Rowe (GR)

$$GR = \frac{G^* \times (\cos\delta)^2}{\sin\delta}$$

@ 0.005 rad/s

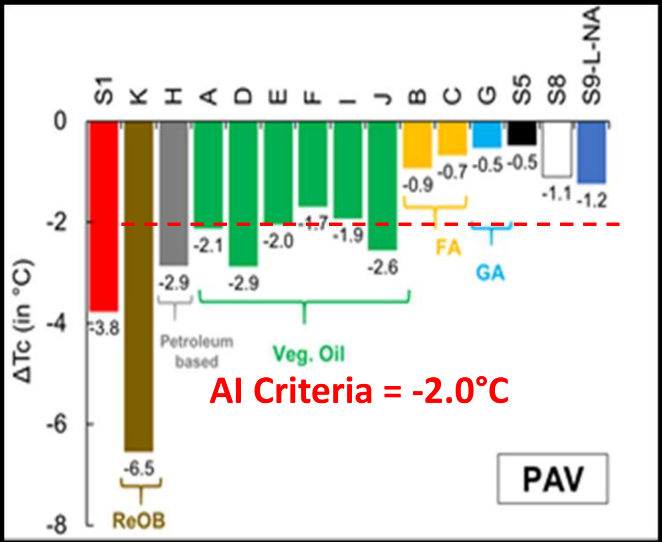
BBR: ΔTc

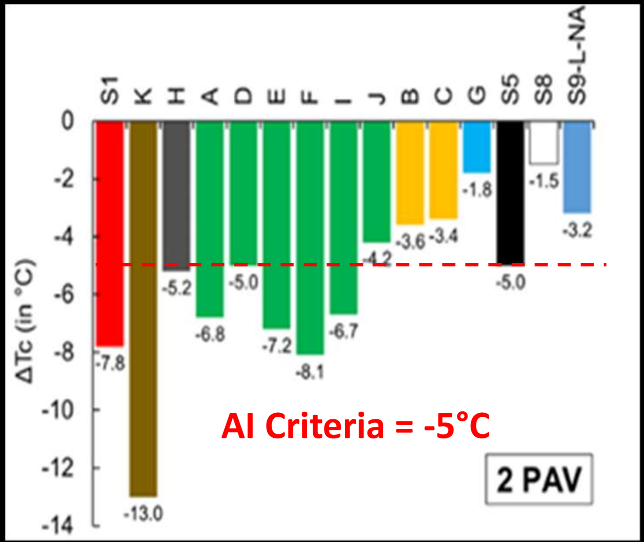
Relaxation under creep loading

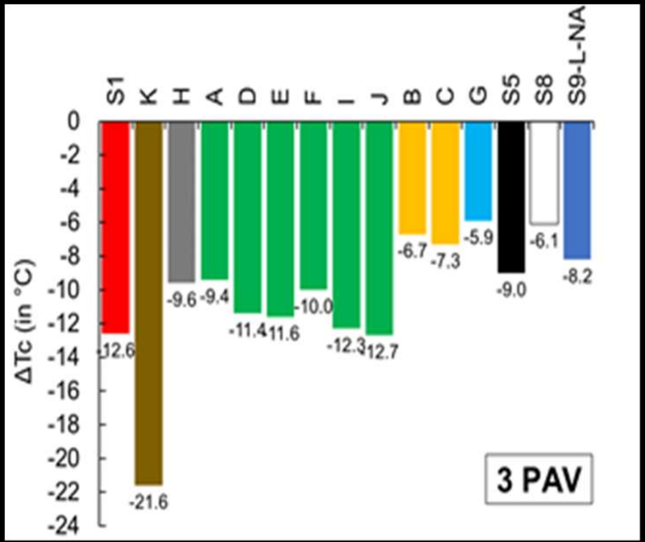
DSR:

Empirical relationship to ductility

BBR ΔT_c

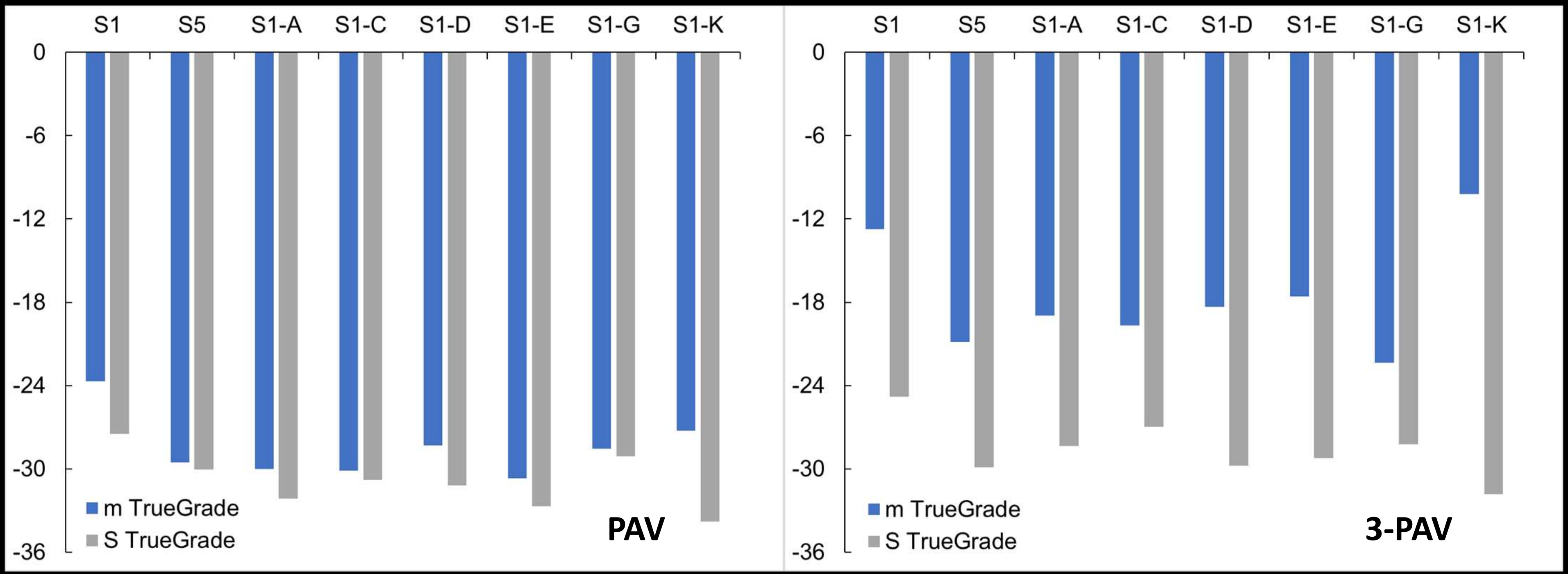






- ΔTc improved with modification except K
- Glycol amine and Fatty acid derivatives perform better using the ΔTc criteria than oil-based modifiers
- K is the worst performer
- Trends were more comparable for 2 & 3-PAV

m-value & Stiffness

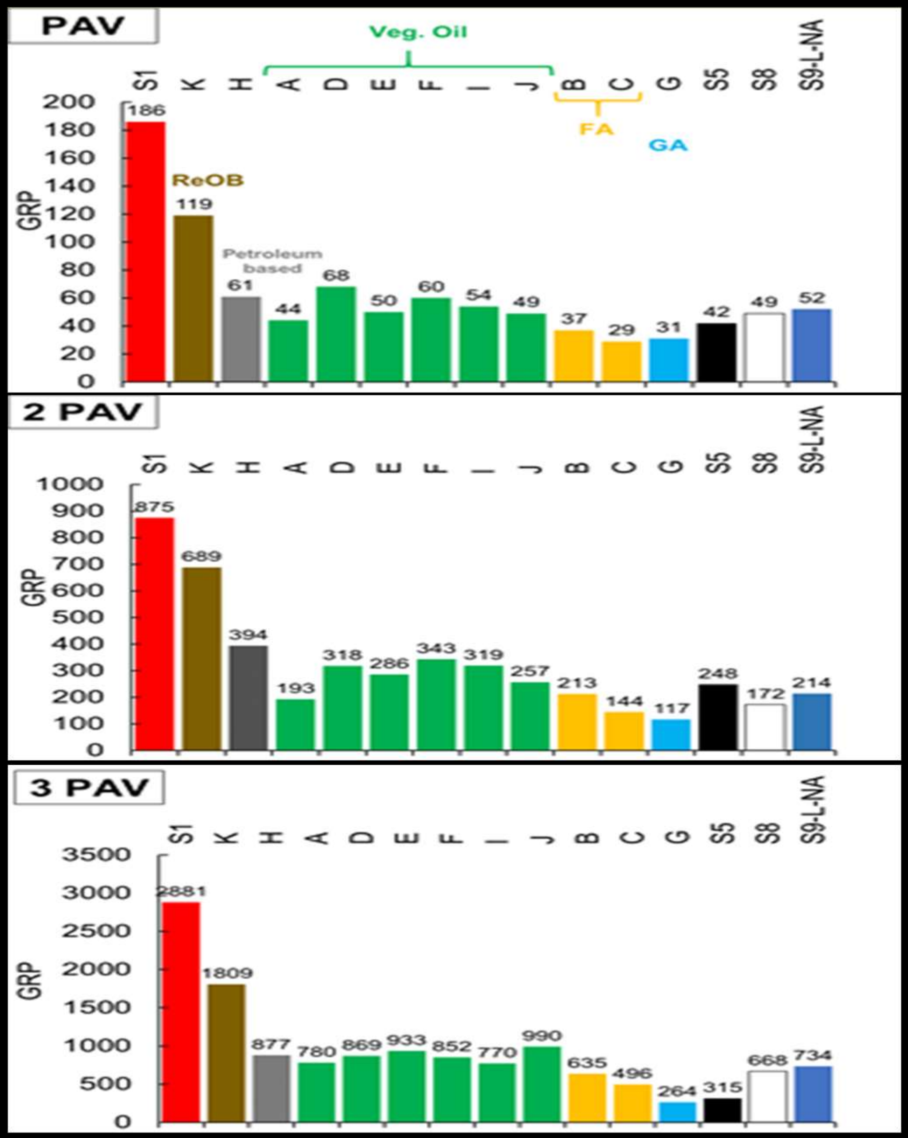


- Change in grade governed by m-value was most affected with aging
- Stiffness effect on grade with aging is insignificant

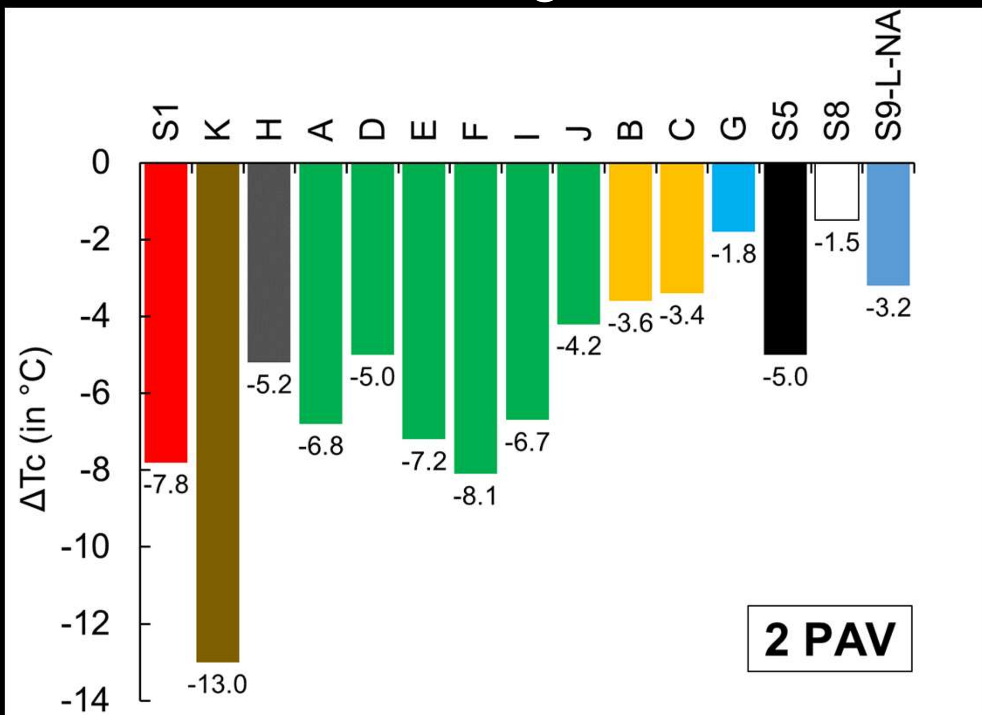
Glover Rowe Parameter

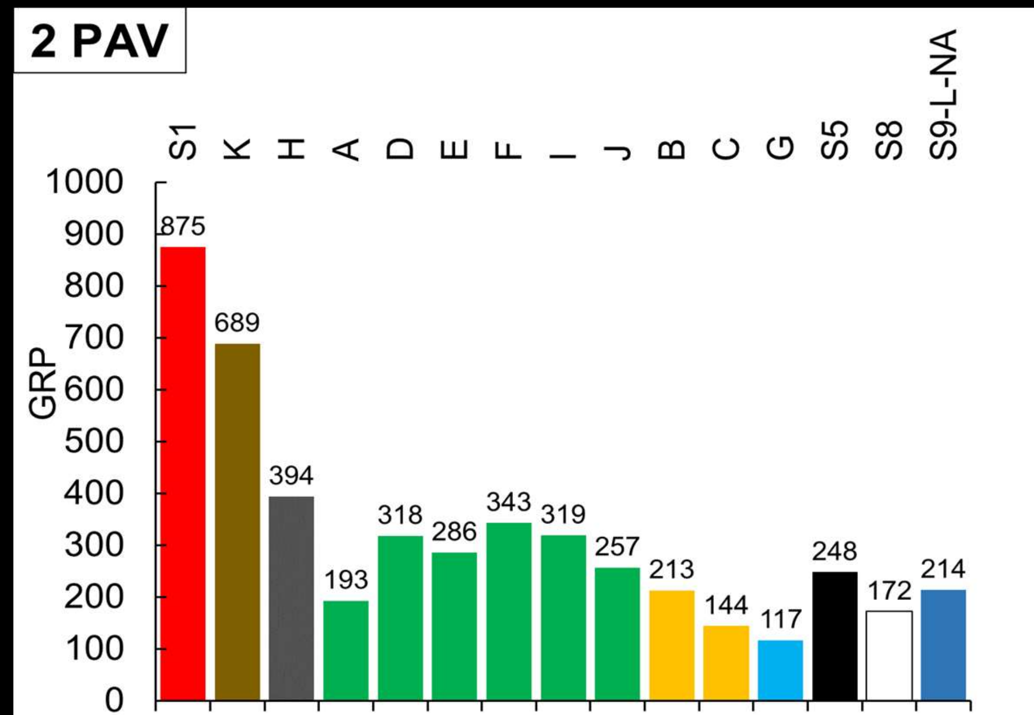
$$GR = G^* (\cos\delta)^2/\sin\delta$$

- Glycol amine and fatty acid derivatives shows lower GRs over vegetable oil-based modifiers
- Veg. oil clusters together
- ReOB shows higher GR in all aging conditions
- All PAV conditions yield comparable trends



BBR ΔT_c vs. Glover Rowe Parameter





Two criteria characterize the performance of the modified binders similarly and provide the same general trends.

Small-strain parameters – Vehicle loading

Not extreme temperatures – intermediate

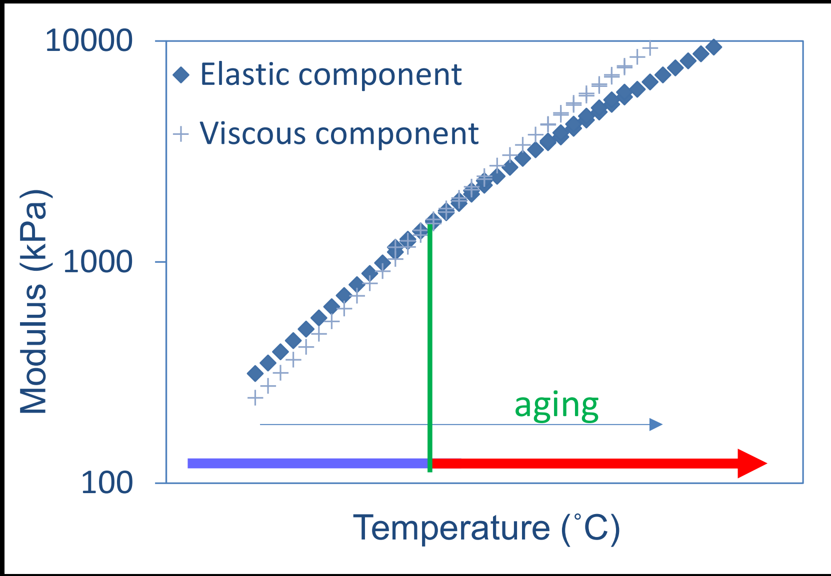
DSR: Frequency Sweeps

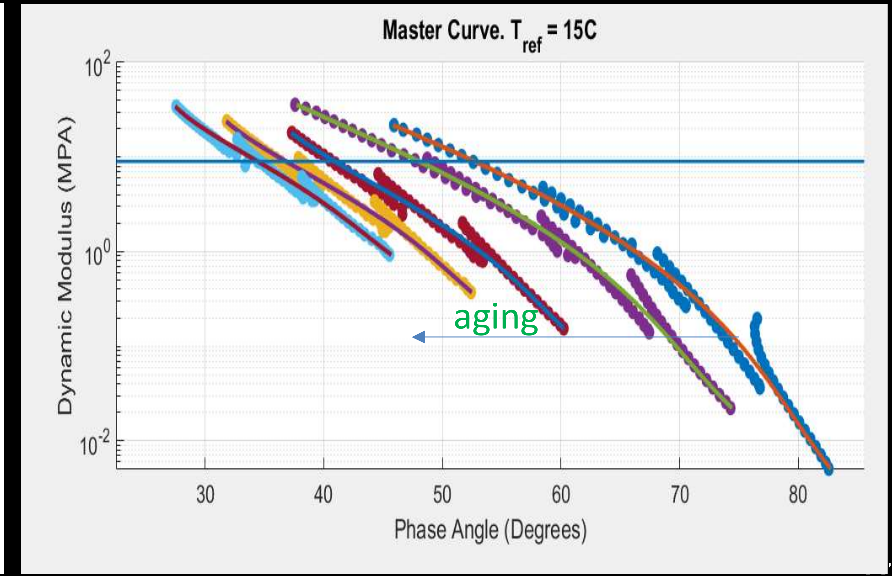
- Crossover parameters

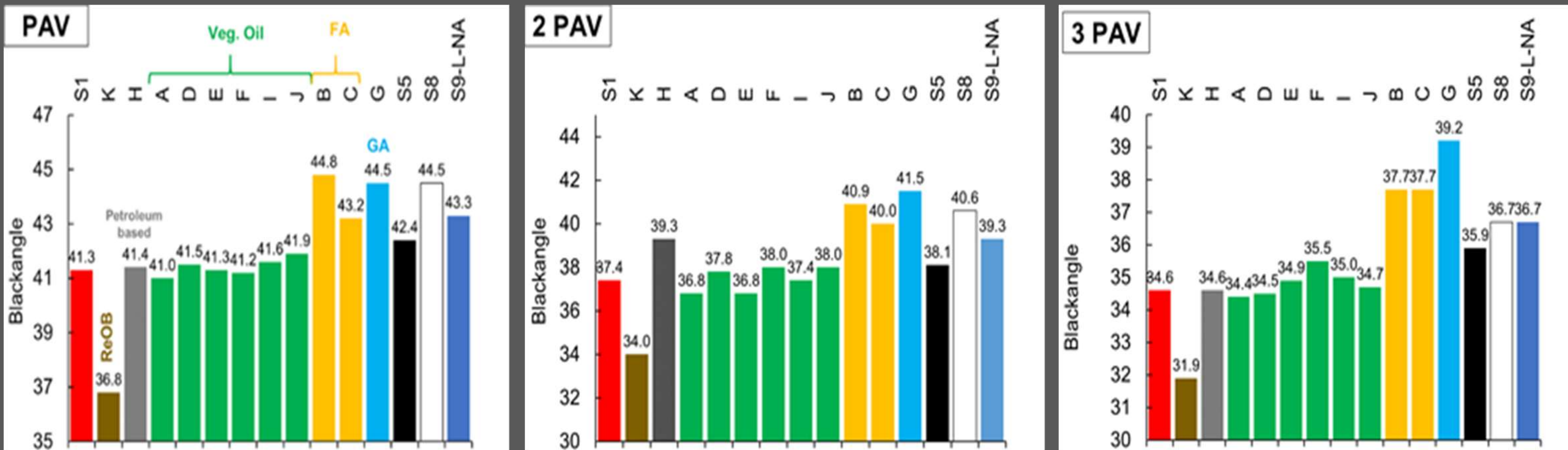
Viscoelastic Transition Temperature

- Black angle

Phase angle at G* = 8.96MPa







Black Angle:
Phase Angle @ 8.9 MPa

- ❖ Glycol Amine & fatty acid derivatives retains more viscous part than elastic compared to vegetable oil-based modifiers
- ❖ ReOB performs worst
- ❖ Phase angle for vegetable oils are in similar range
- ❖ Results of all PAV conditions are comparable, except H (2-PAV)

Linear Amplitude Sweep (LAS) Test

Testing parameters:

- **Sample size:**
  - 8 mm dia. 2-mm gap
- **Temperature: @ Intermediate PG**
  - For 58-28 – 19°C, 64-22 – 25°C
- **Frequency:**
  - 10Hz (62.8 rad/s)
- **Strain level:**
  - 0.1 to 30% in 300 seconds

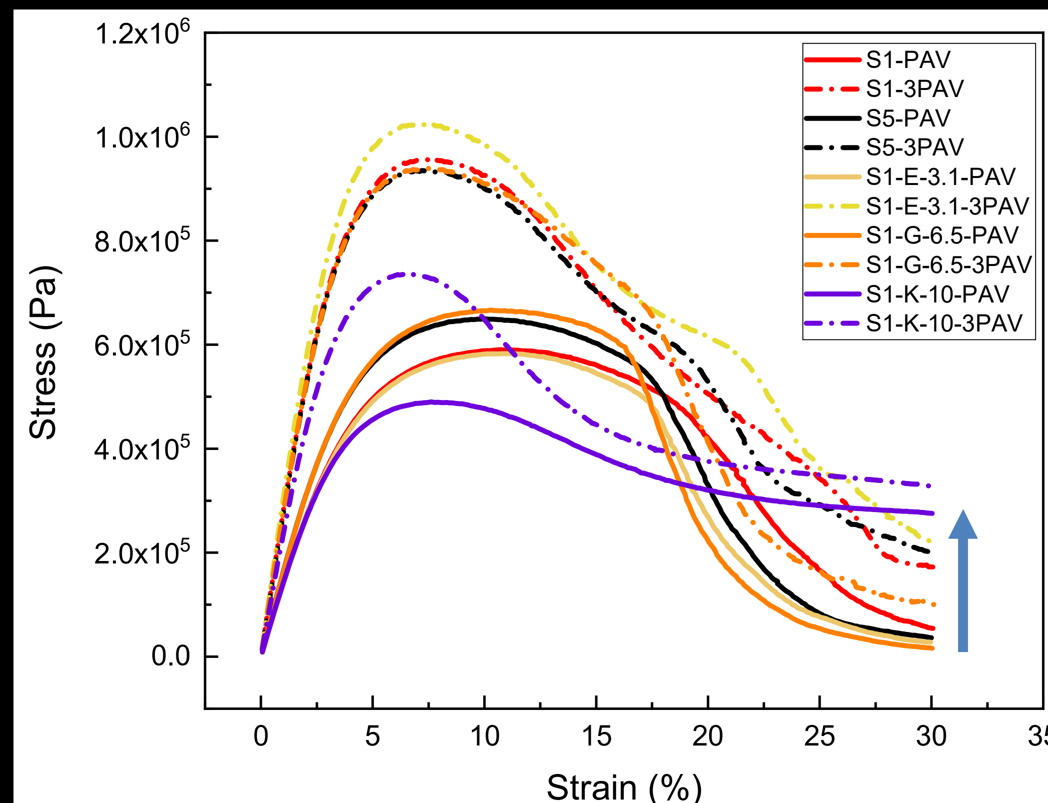
LAS Failure Investigation

Failure planes for PAV and 3 PAV significantly different

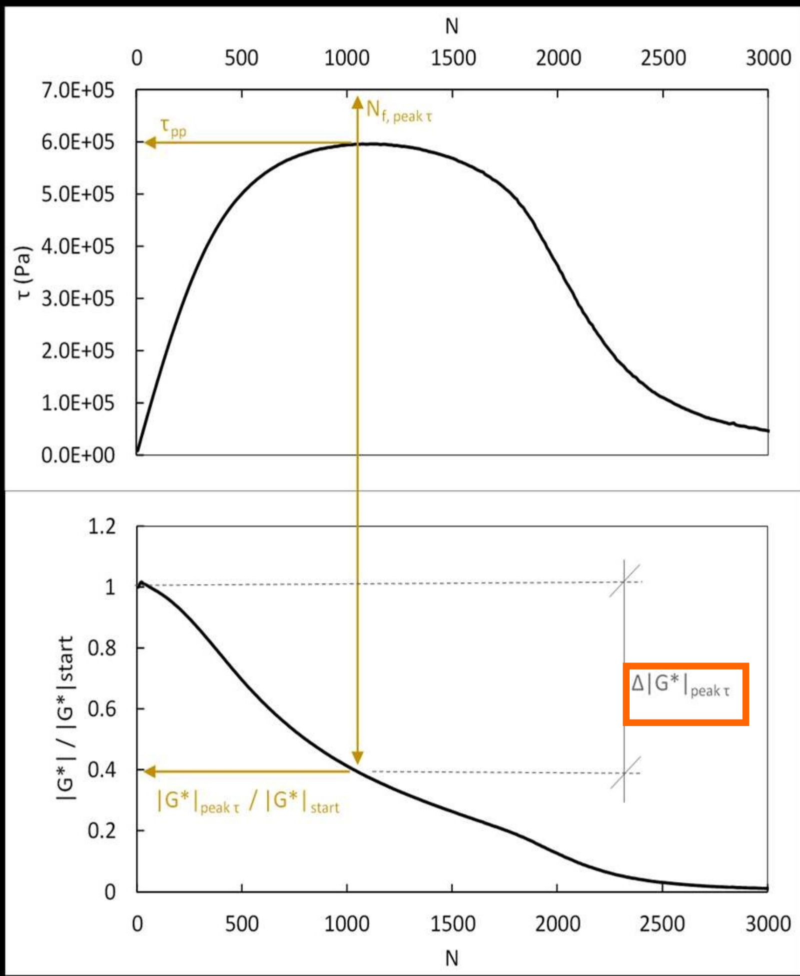
S1-D-3.1

S1-C-3.1

PAV 2-PAV 3-PAV



New parameter $\Delta\,|G^*|_{peak\ \tau}$



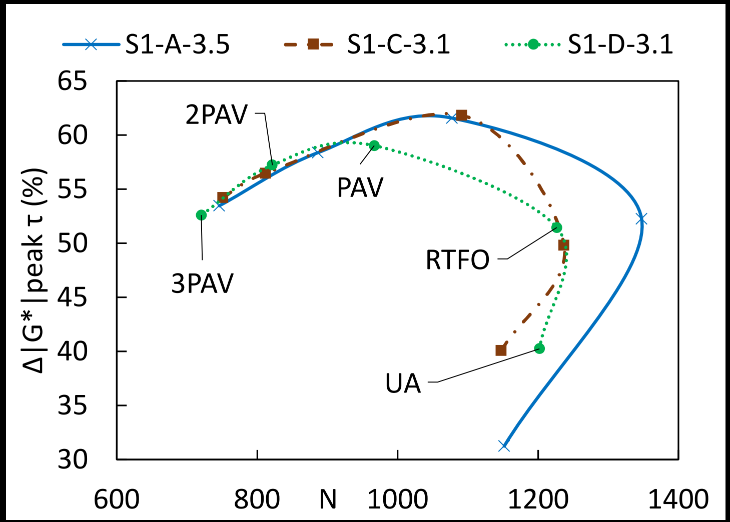
Δ |G*|peak $_{\tau}$ (delta G for short)

- ✓ **Data until peak stress**
  - ✓ Avoid 3-D stresses
  - ✓ Peak stress is an evident response phenomenon
- ✓ **State of the sample as indicator**
  - ✓ Not endurance
- ✓ **Not highly influenced by stiffness**
- ✓ **No convoluted post-processing**
- ✓ **Higher Δ |G*|peak $_{\tau}$ = Better performance**

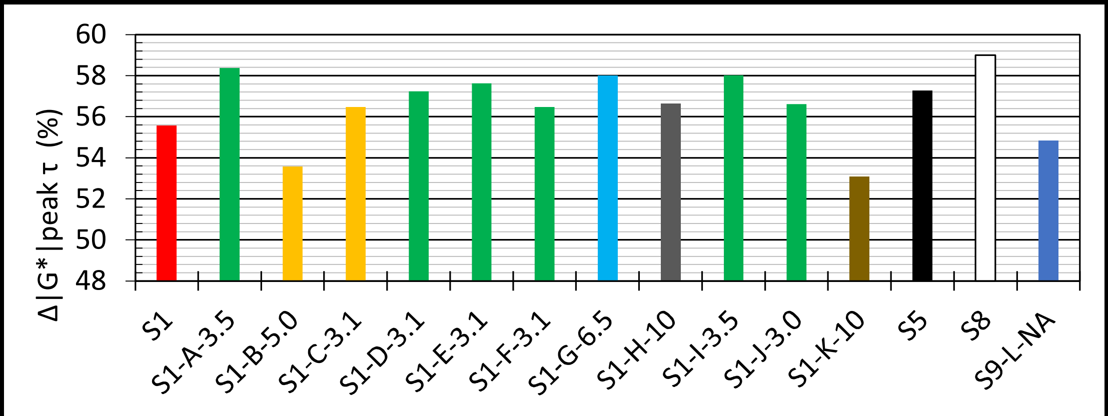
Findings enabled by Δ |G*|$_{\text{peak } \tau}$

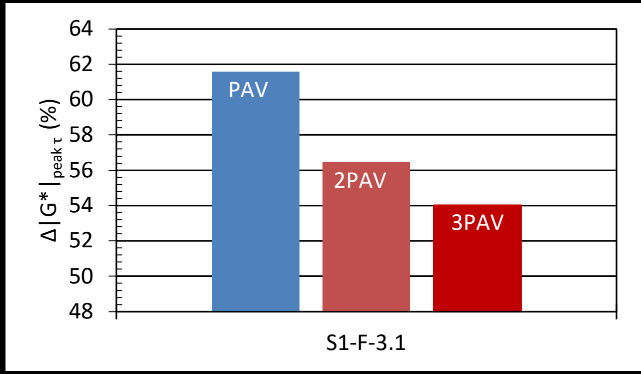
- **Optimum properties at almost-PAV-aging condition**
- **Consistent results that distinguish modified binders and aging**

Effect of aging



Effect of modification (2PAV)



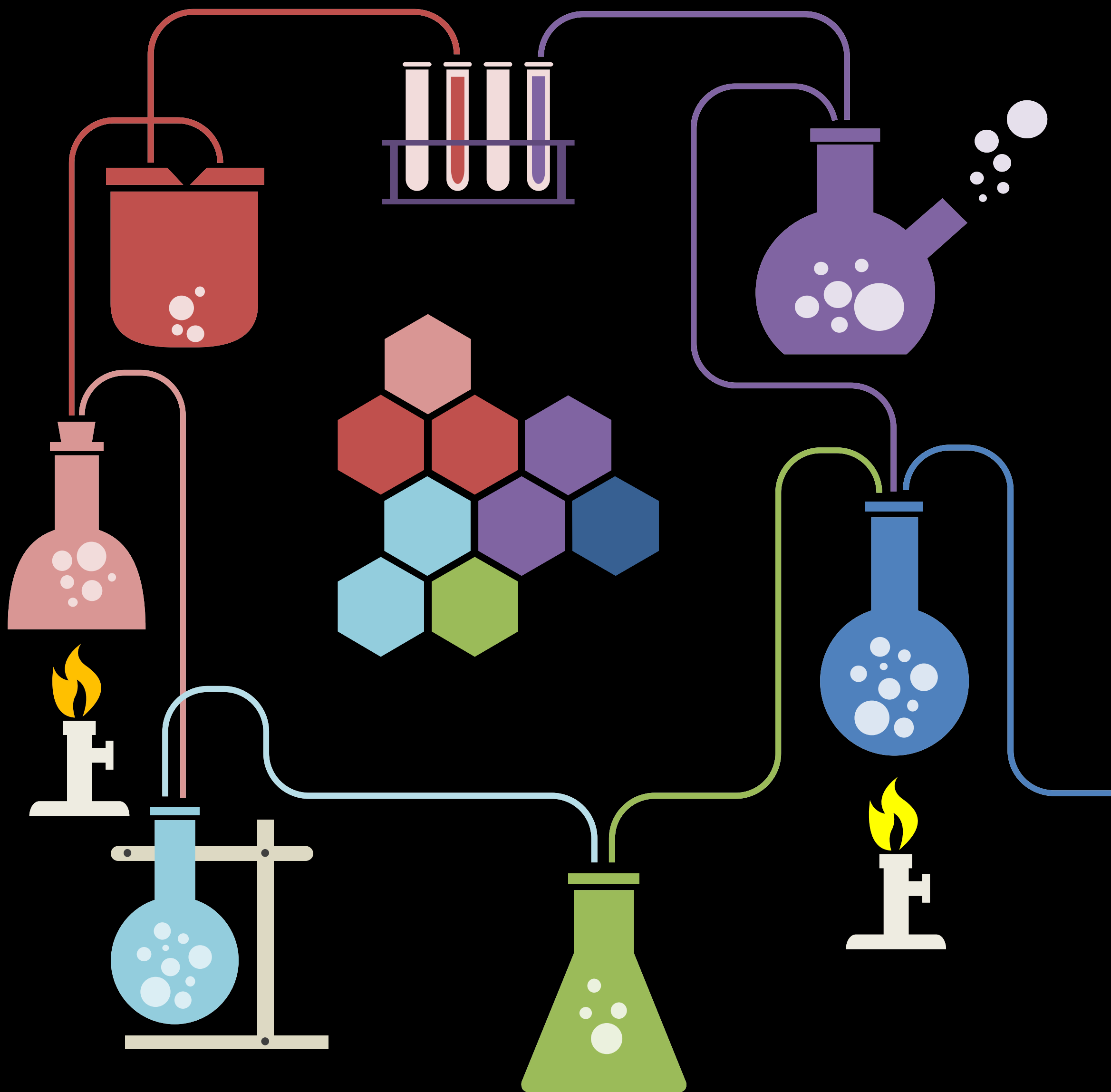


Summary of Rheology Work

- Modifier K (ReOB) could not be modified to 58-28 with S1
- ReOB modifier consistently worst rheological performer
- Modification of S1 improved ΔTc for all modifiers except K
- Glycol amine and fatty acid-based modifiers demonstrate better cracking resistance characteristics compared to vegetable oil-based modifiers.
- Small strain parameters: FS and ΔTc are promising indicators for rheological performance and correlate well.
- ΔTc trends for the modified binders are mostly consistent with aging, especially 2-PAV & 3-PAV
- m-value is the governing factor determining grade with long-term aging after 1PAV

Summary of Rheology Work

- Large strain parameters are indicators of different characteristics than small strain parameters.
- LAS and proposed $\mathbf{\Delta\ |G^*|}_{\mathbf{peak}\ \tau}$ shows excellent promise.It provides consistent trends with aging and known binder data from small strain tests. This parameter was able to distinguish some performance differences that the small strain parameters did not.

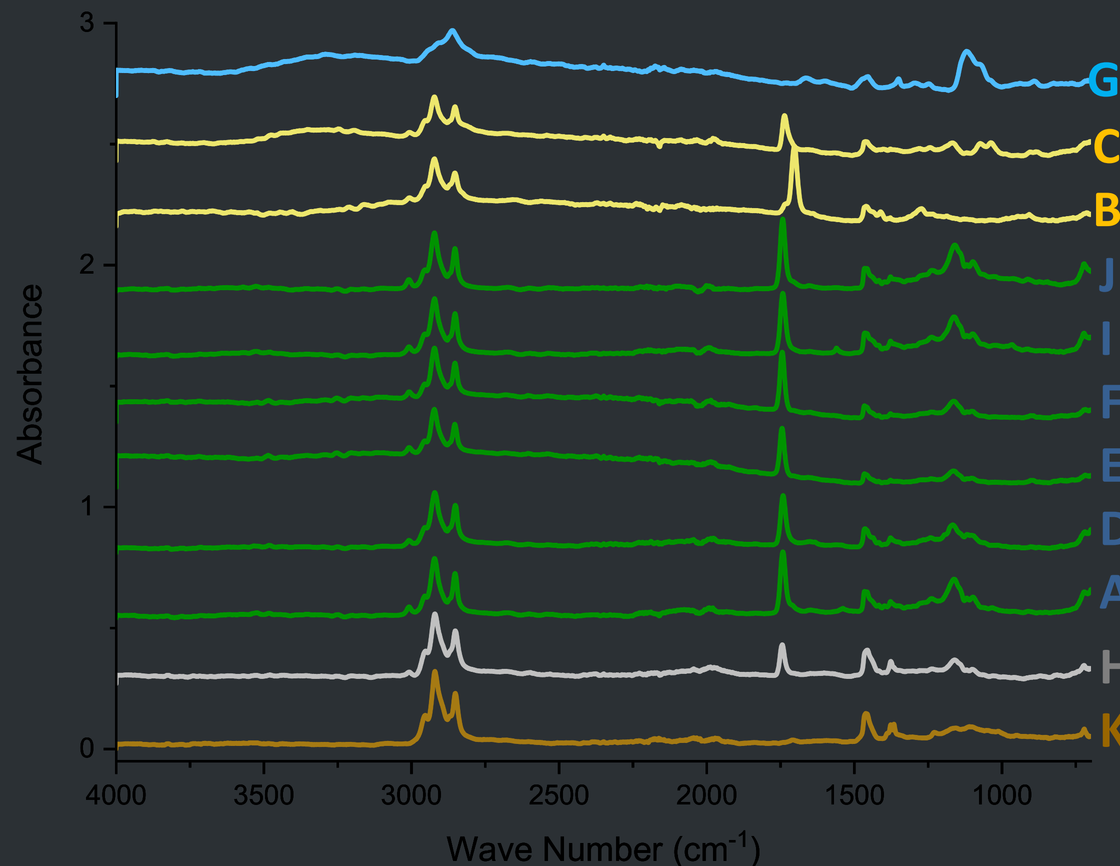


Modifier Chemistry Results

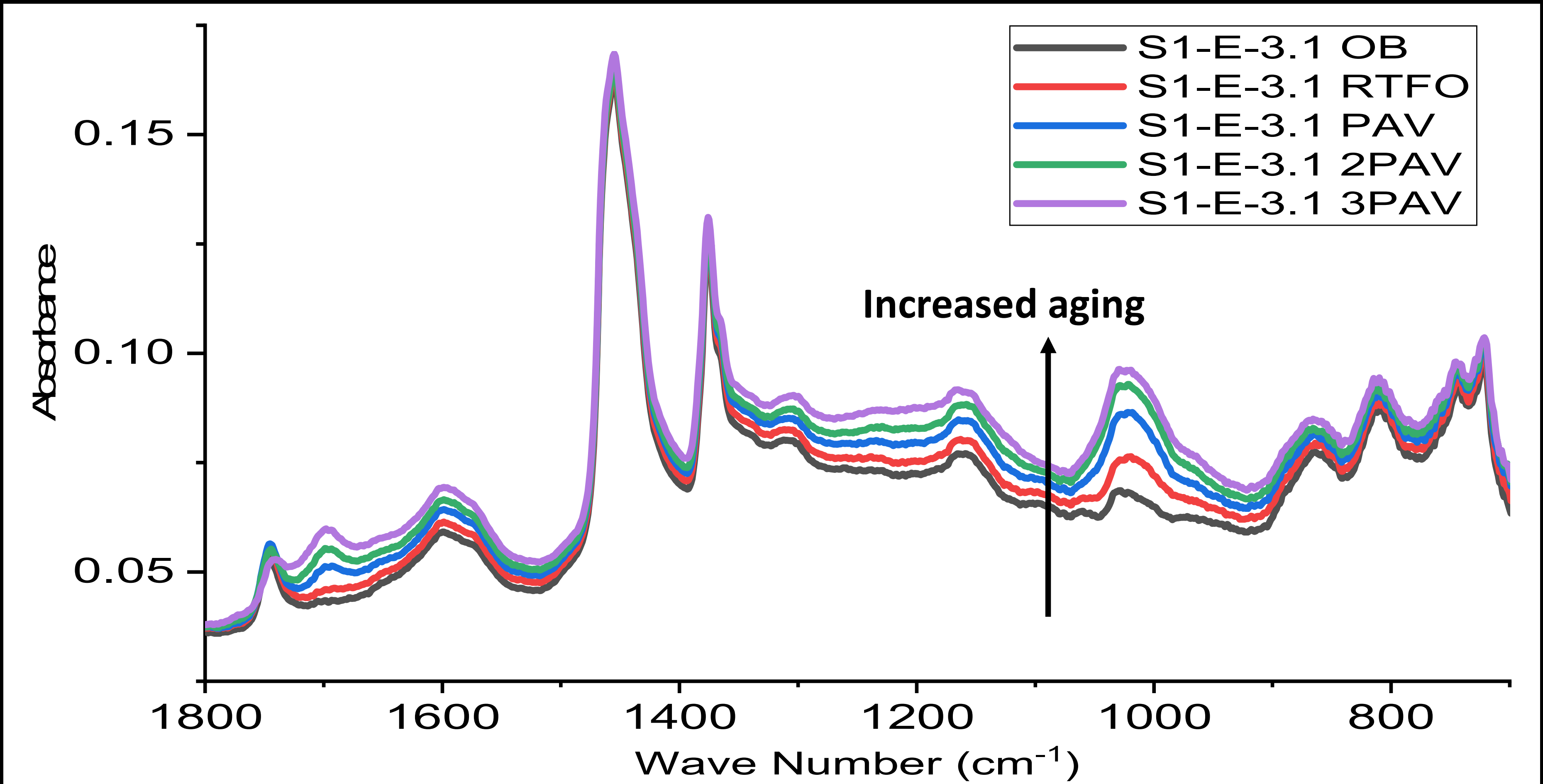
- ❖Six Modifiers Tested
- ❖Chemical Characterization
  - ❖CHNS
  - ❖FTIR
  - ❖TGA
  - ❖TLC-FID
  - ❖GPC
- ❖Develop a Fingerprint

Modifier Chemistry - FTIR

- Spectra of Veg. oil-based modifiers shows similar chemistry
- Fatty acid derivatives lacks –C-O- group, confirmed by spectra
- ReOB lacks carbonyl peak, indicating absence of bio-based source
- Modifier H, presumably petroleum derivative shows signs of bio-oil presence

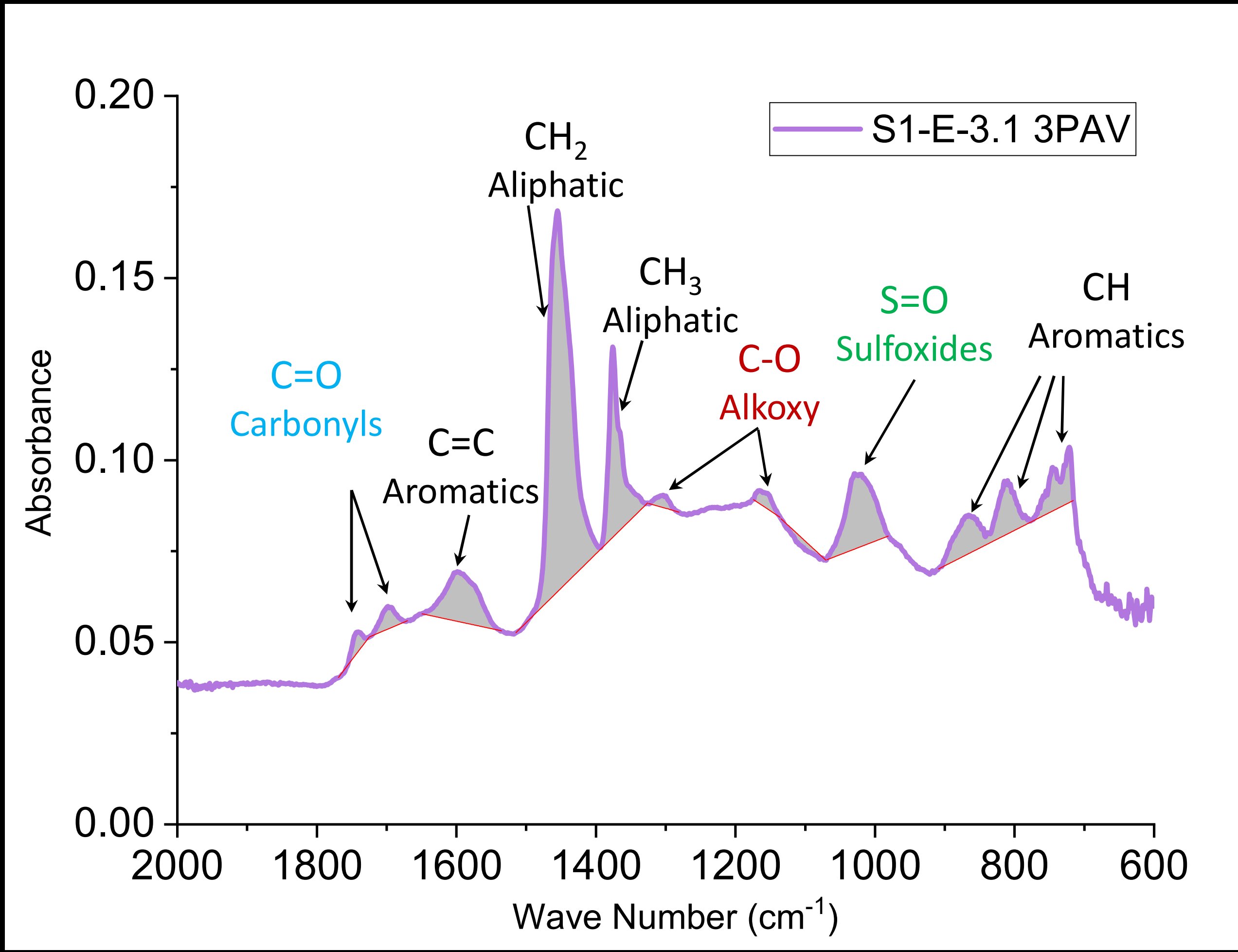


Impact of Aging on Binder Chemistry

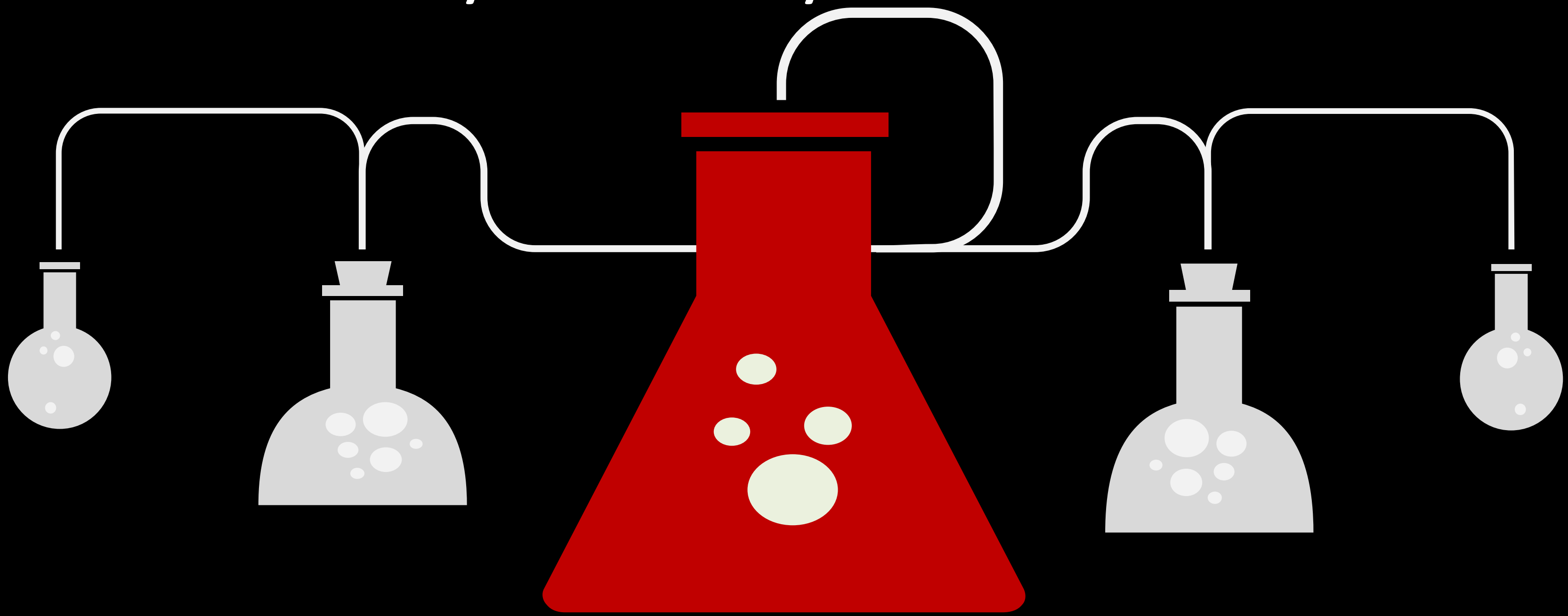


Oxidation Indices

- Carbonyl Index (ICO)
  - $$ICO = \frac{\sum A_{1770-1650}}{\sum A}$$
- Sulfoxide Index (ISO)
  - $$ISO = \frac{\sum A_{1070-990}}{\sum A}$$
- ICO + ISO
- ICO + ISO + Alkoxy

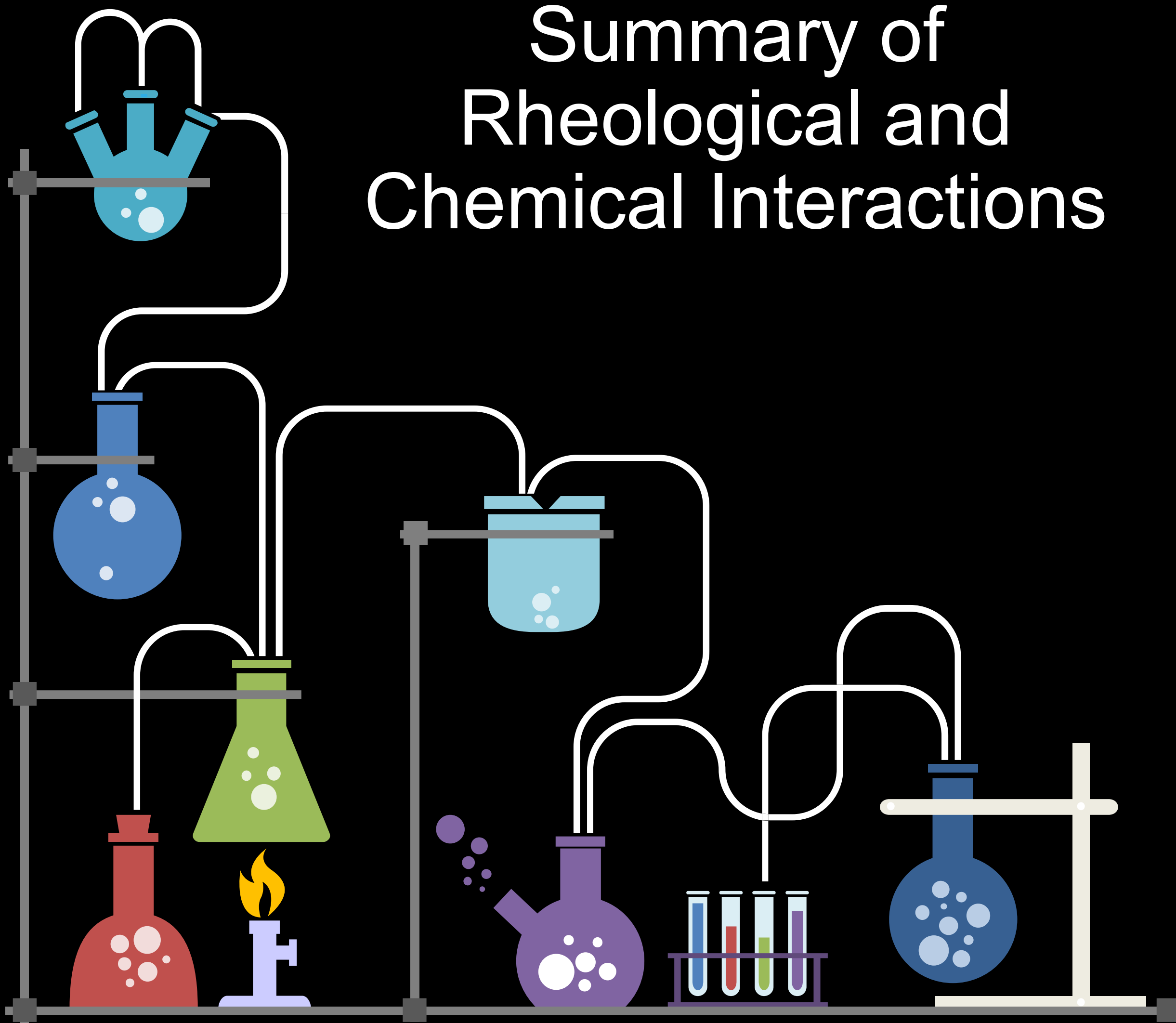


Modifier Chemistry Summary



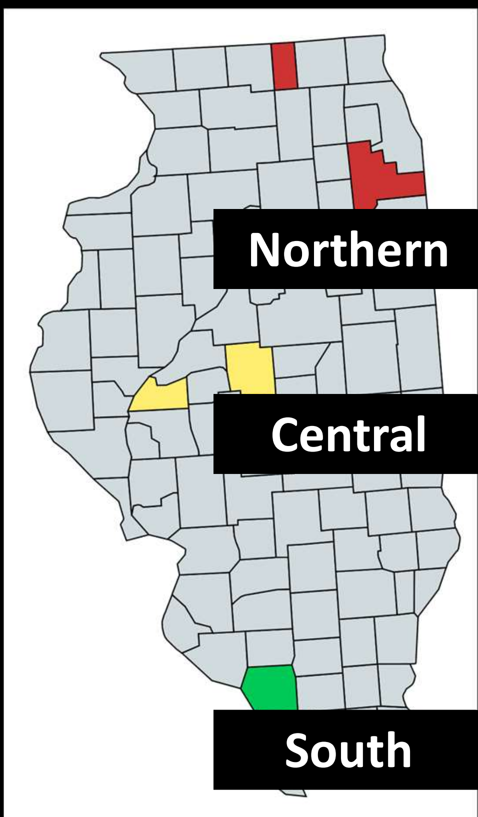
- Oxidation products increase with aging, shown with increase in carbonyls, sulfoxides, and alkoxy groups
- Petroleum-based (asphalt like) modifier had significantly high MW, however, its FTIR spectra shows the presence of bio-based oil
- Glycol amine (GA) modifier had the most distinct chemical functional groups compared to other modifiers, and it is high in nitrogen (retards aging).
- Vegetable oil-based modifiers have similar FTIR spectra and MW distribution
- Fatty acid based modifiers had similar FTIR spectra, however, with different MW distribution, suggesting different molecular species.

Summary of Rheological and Chemical Interactions



Aging results in increased oxidation products which increase brittleness. It also results in forming larger molecules.

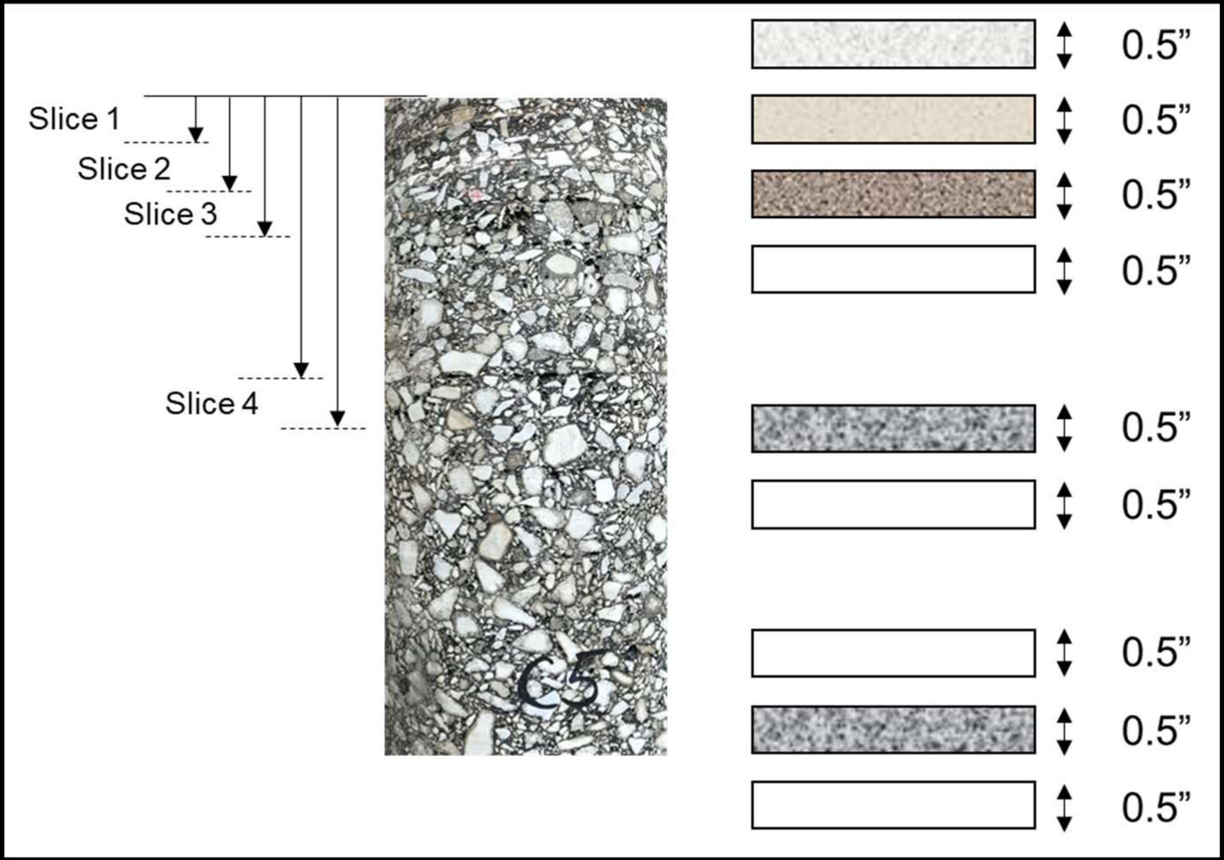
Field Core Inventory



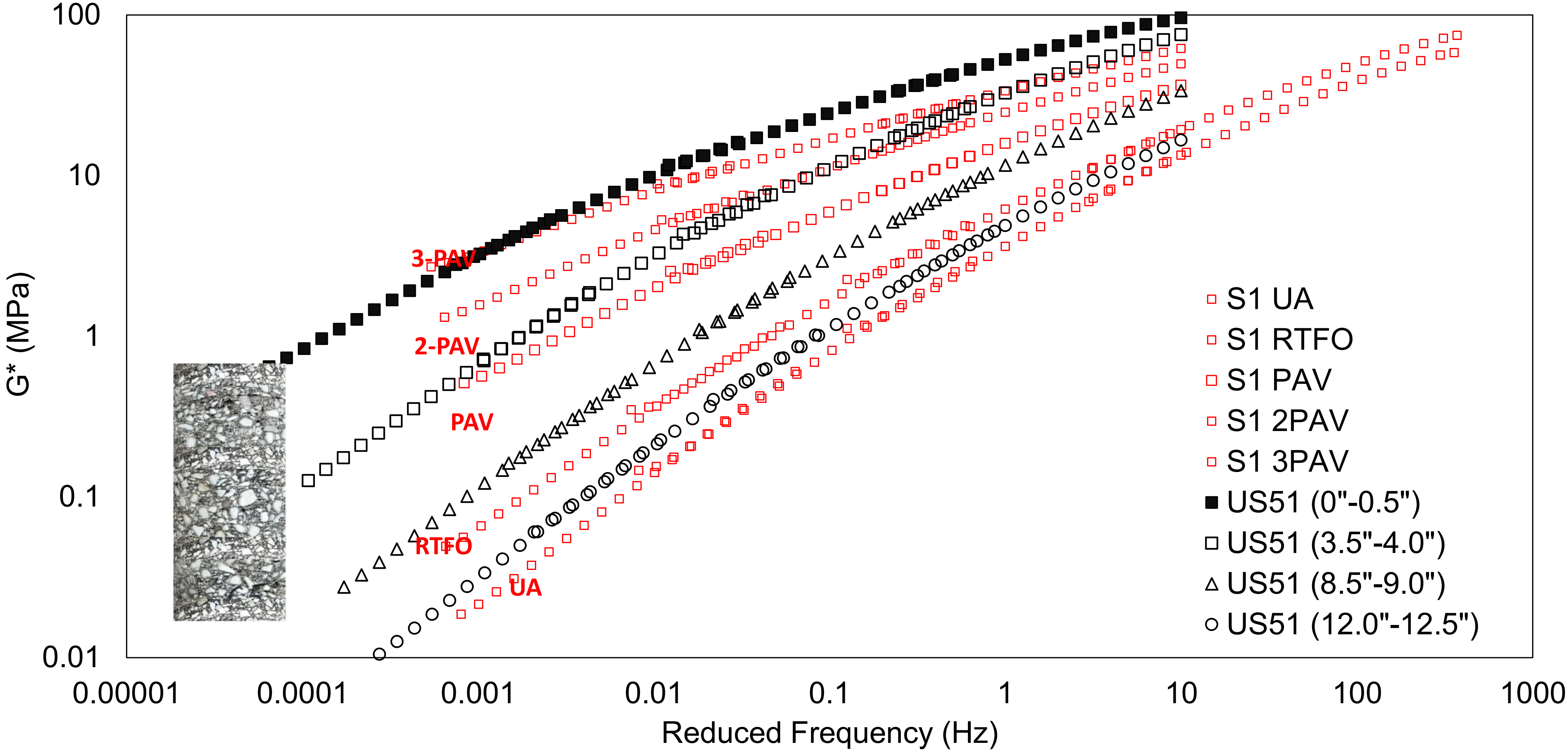
Field Core ID	District	Binder PG	Year of Construction	Year of Coring	Age
I-355	D2	64-22	2007	2018	11 yrs
I-90	D1	64-22	2006	2018	12 yrs
22STR2	D2	58-22	2004	2014	10 yrs
2RT26	D2	76-28	2004	2014	10 yrs
ICT L1	D5	64-22	2008	2019	11 yrs
ICT L2	D5	64-22	2009	2019	10 yrs
IL-125	D6	64-22	2009	2018	9 yrs
I-72 1E	D6	64-22	2003	2013	10 yrs
US-51	D8	64-22	2001	2018	17 yrs

Long-Term Field Aging

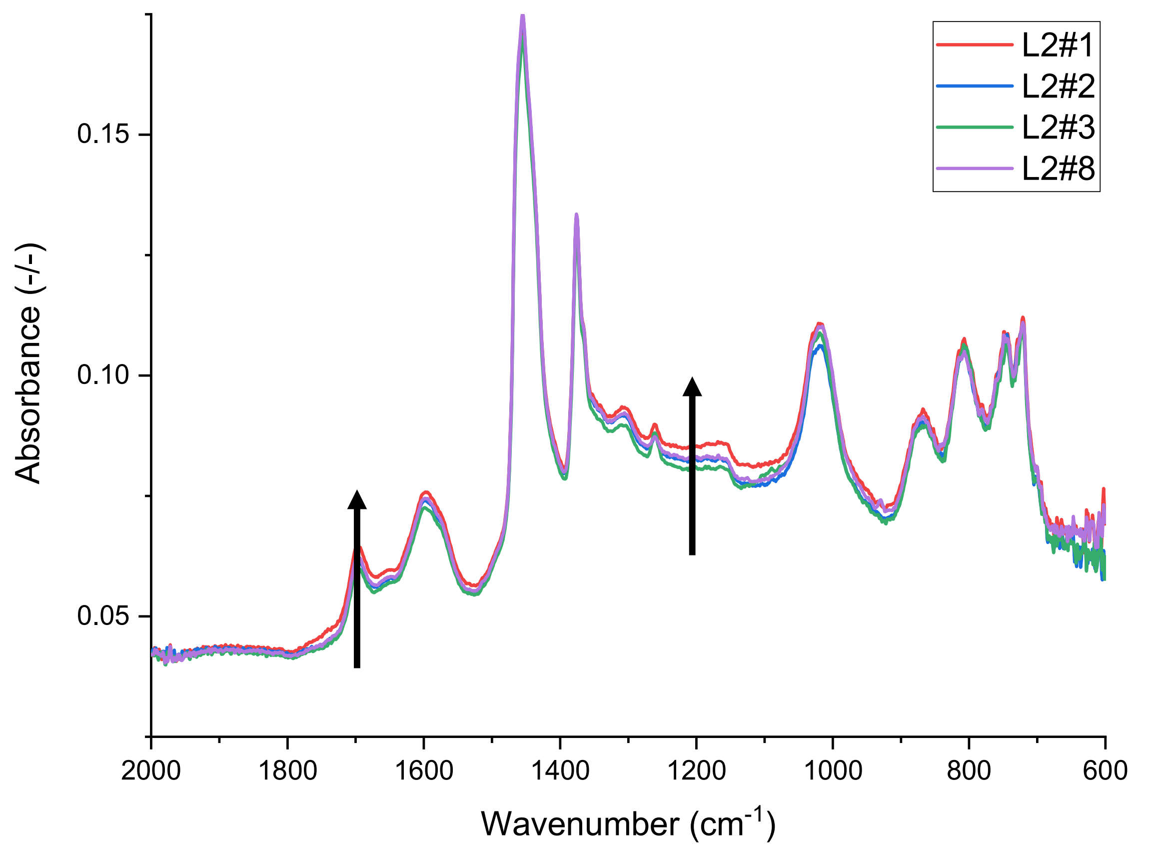
- Aging extent varies with AC layer depth
- Core sliced @ 0.5-in-depth to extract binder
- Top 0.5-in slices were considered for long-term aging characterization

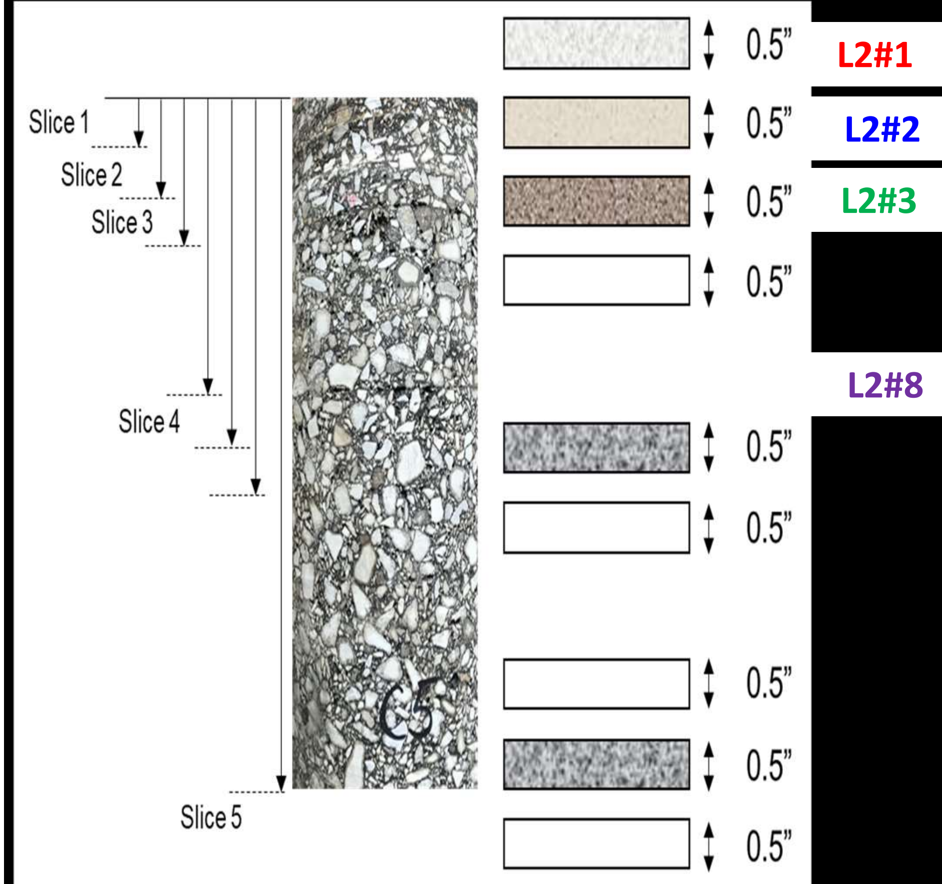


Aging Gradient with Depth



Field Core Chemistry

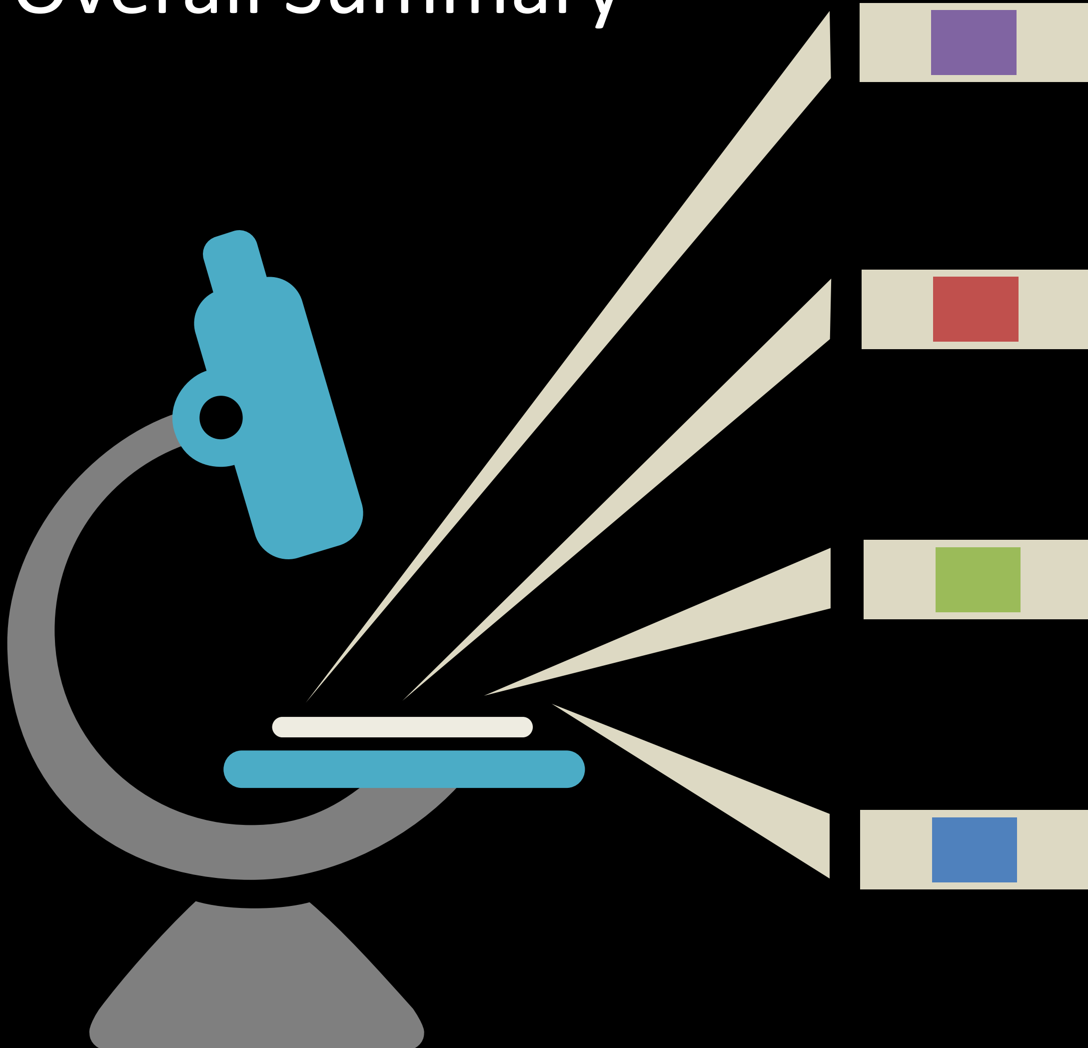




Field Aging of AC Surface

- Field-aged binder is different than laboratory-aged binder
- Field aging varies with depth
  - Almost equivalent to 3 PAV at top 0.5 inch
  - Minimal aging at bottom of the 12-inch core, less than RTFO but more than unaged binder
- Results suggest that single PAV may not represent realistic field aging.

Overall Summary



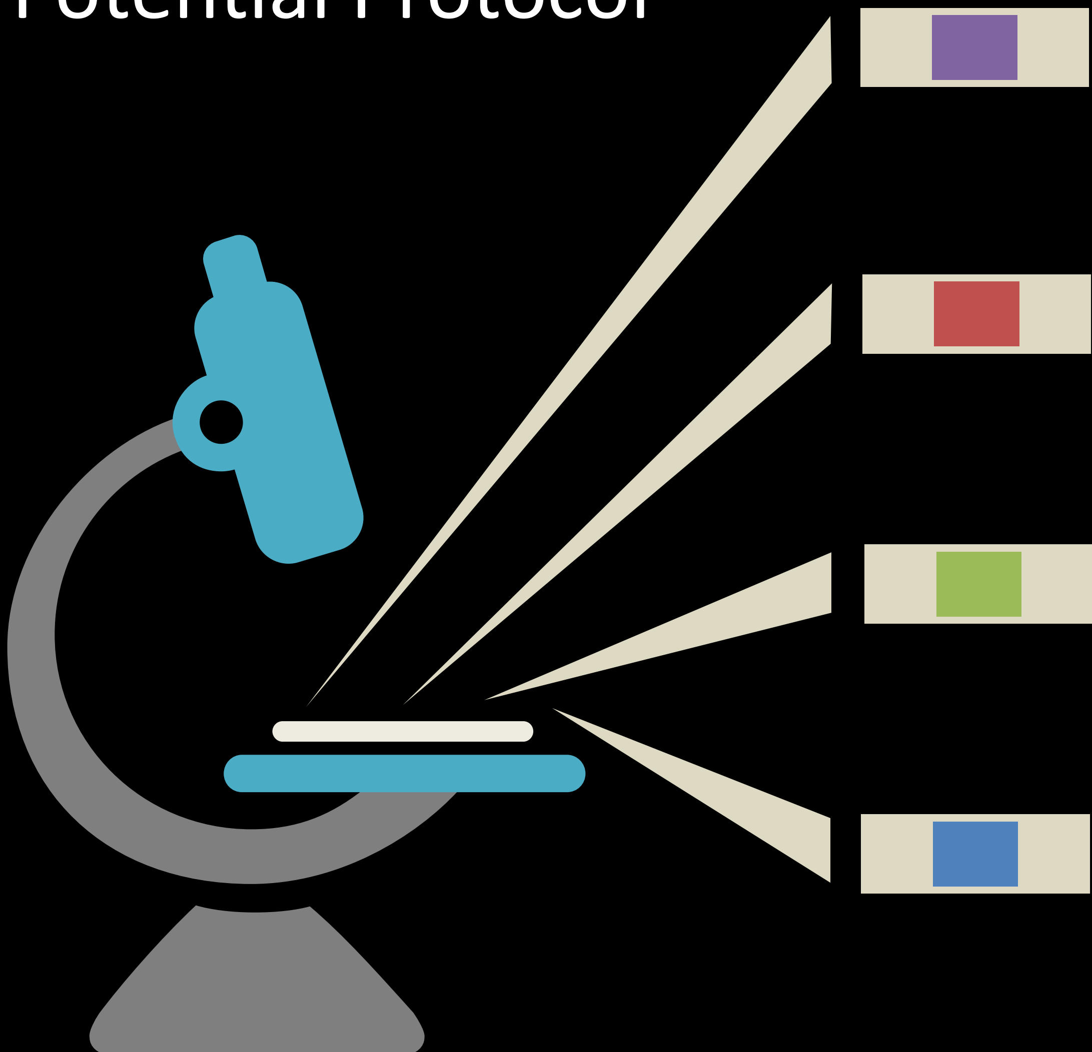
Rheology and chemistry tests presented distinct performance of the modifiers examined

All of the rheological parameters were significantly affected by aging, 2-3 PAV to represent field aging.

Three groups of modifiers emerged: Poor performing (ReOB), average performers (vegetable oils), and good performing (glycol amine & fatty acid derivatives)

Parameters like GR & ΔTc are consistent with each other and show similar trends for modified binders with aging

Potential Protocol



Asphalt Binder Fact Sheet

Superpave™ PG	**58-28 (60.3-30.4)**

Rheology

Cracking Parameters

Fatigue Cracking (Load Related)	*> 50%*
ΔG, LAS @ Int. temp. 2-PAV*	56%
Thermal Cracking (Non-Load Related)	*12,000 kPa*
GR, @ Int. temp, 10 rad/s, PAV/2-PAV	9,700 kPa
Low Temperature Cracking (Non-Load related)	*-2.5/-5.0°C*
ΔT_c, PAV/2-PAV	*-1.8/-3.1°C*

Advanced Rheology

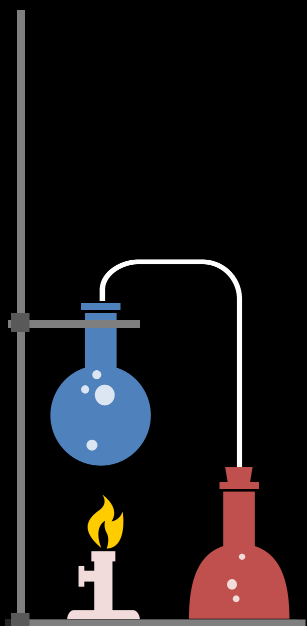
Thermal Cracking (Non-Load Related)	
VETT	
Black Angle, @ G = 8967 kPa*	*46° (min. 45°)*
GR, @ 15C, 0.005 rad/s, PAV/2-PAV	589 kPa *(max. 800 kPa)*

Composition & Chemistry

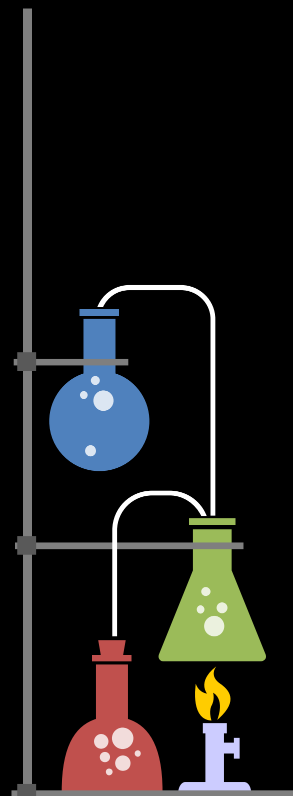
Oxidation Index

IDOT's Goal:

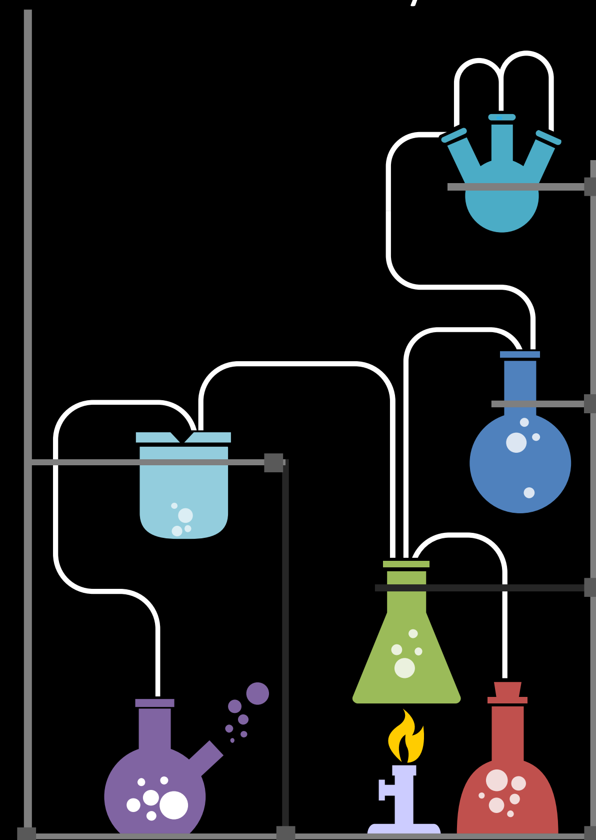
Implement a Protocol for testing and approving binder modifiers



Test approved modified binders in HMA and perform the long-term aging protocol and test for I-FIT



Provide Contractors binders with a known performance that can be used in mixed designs successfully



Illinois Department of Transportation
Kelly L. Morse
Chief Chemist
Bureau of Materials and Physical Research
126 East Ash St.
Springfield, IL 62704-4766
Tel: 217-782-1916 Fax: 217-782-2572
Cell: 217-725-5837
Kelly.Morse@illinois.gov

Questions?