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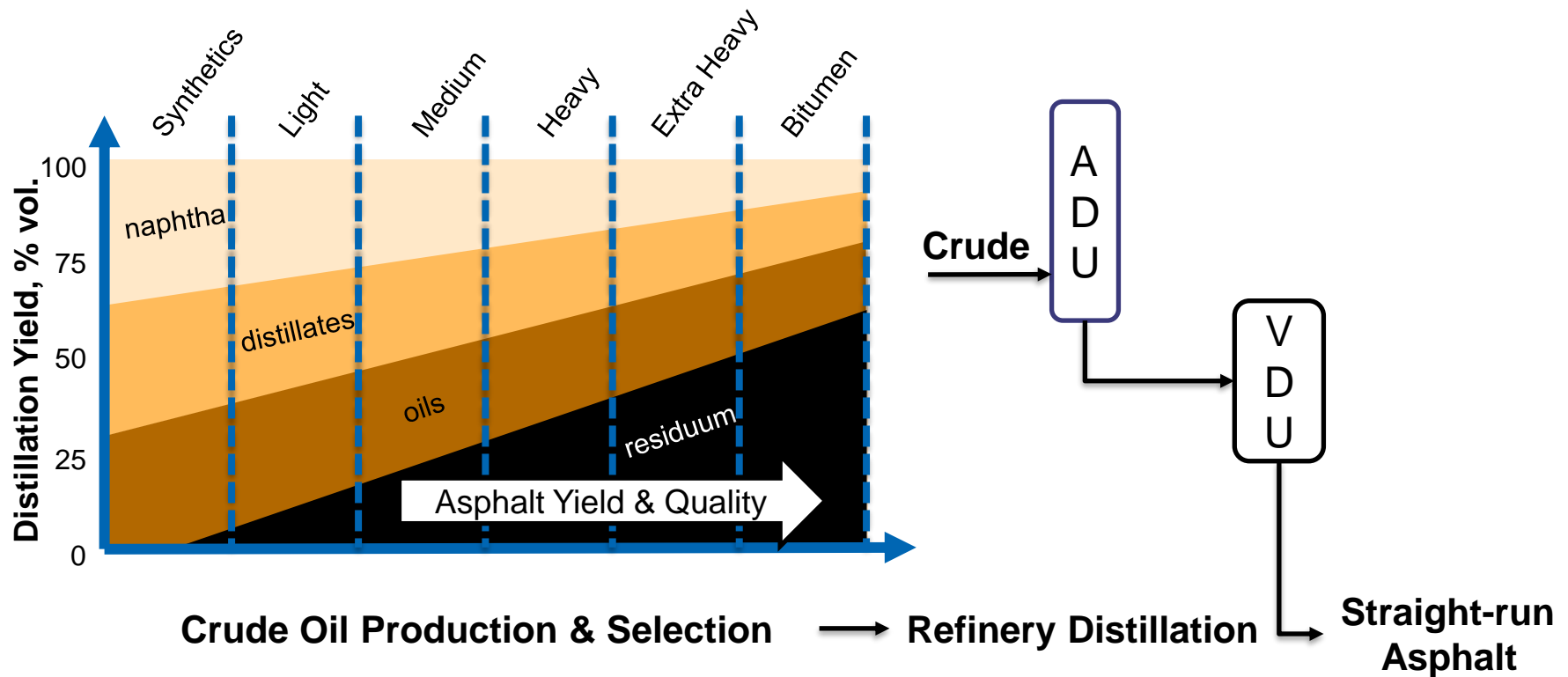
Use of Phase Angle for Evaluating Binder Stress Relaxation and Aging Susceptibility

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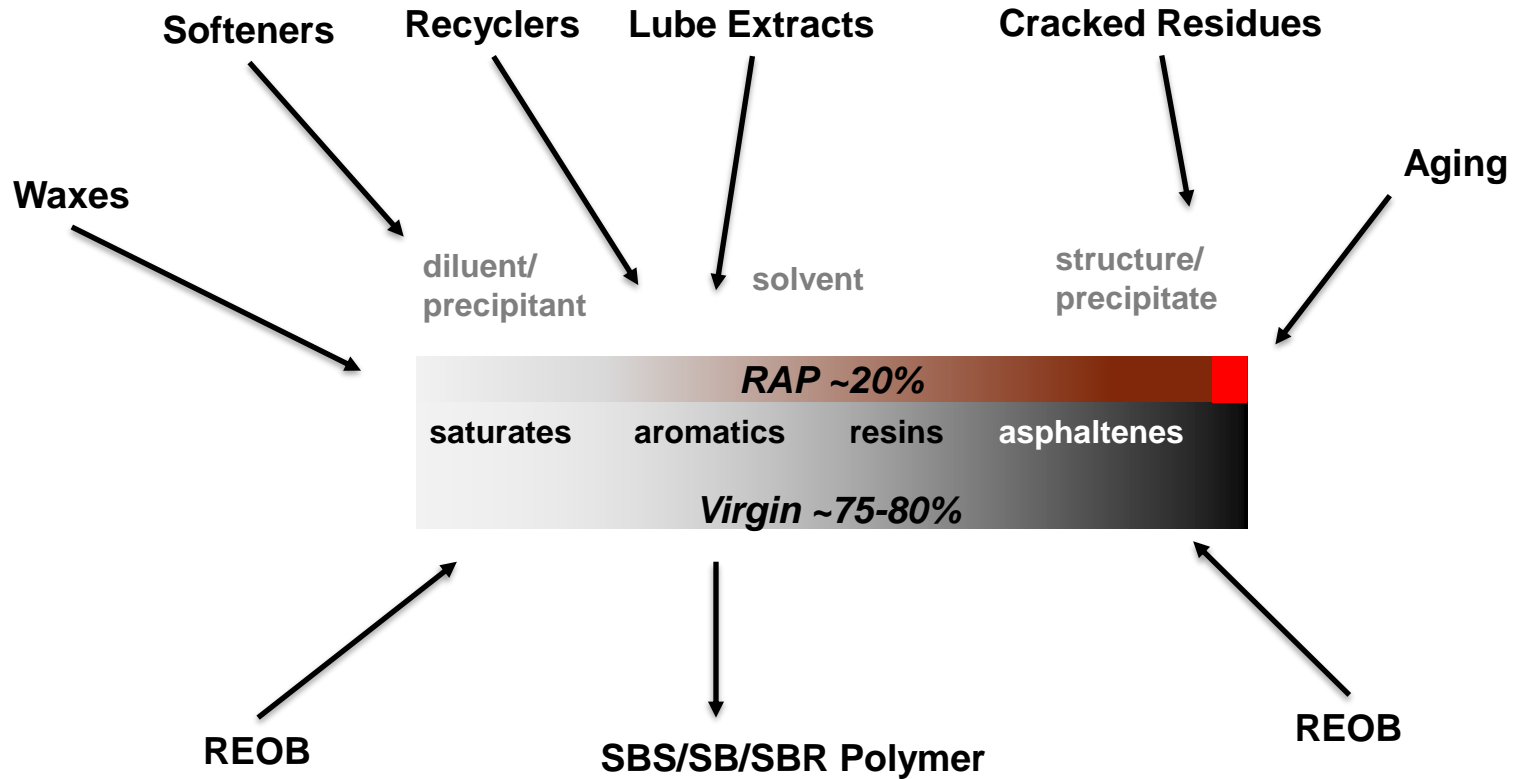
Proprietary

SuperPave™ Developed for Traditional Asphalts



- SuperPave™ binder specification was developed & field-validated for refinery produced asphalts of 1980s
 - Limited high wax, severely air-blown, cracked stocks
- Chemistry Changes → Recycling & Performance

Asphalt of Today → Competition for Solvency

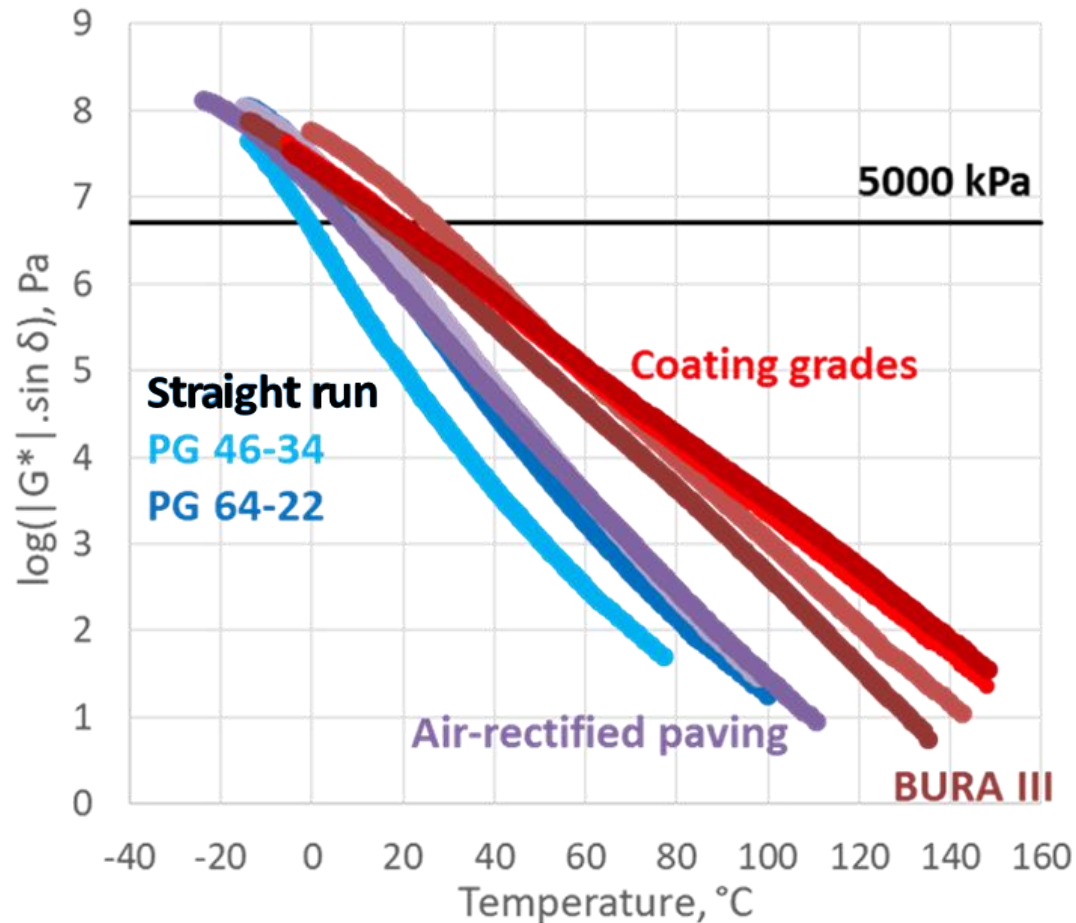


Other non-petroleum additives: Bio-, PPA, WMA...

Screening Phase Unstable Binders

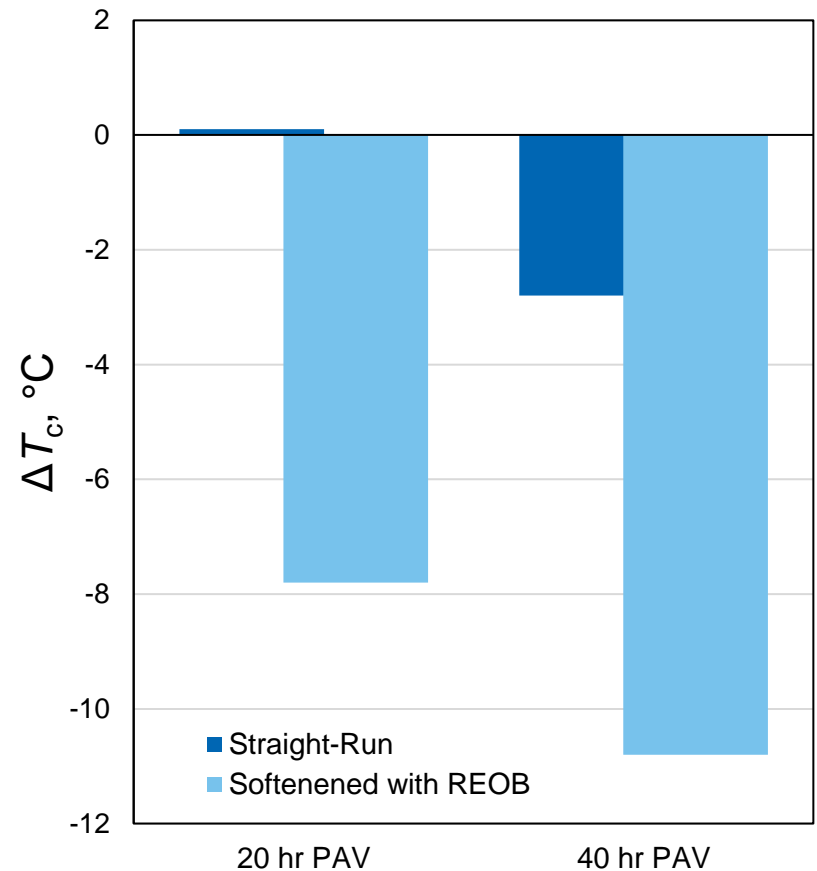
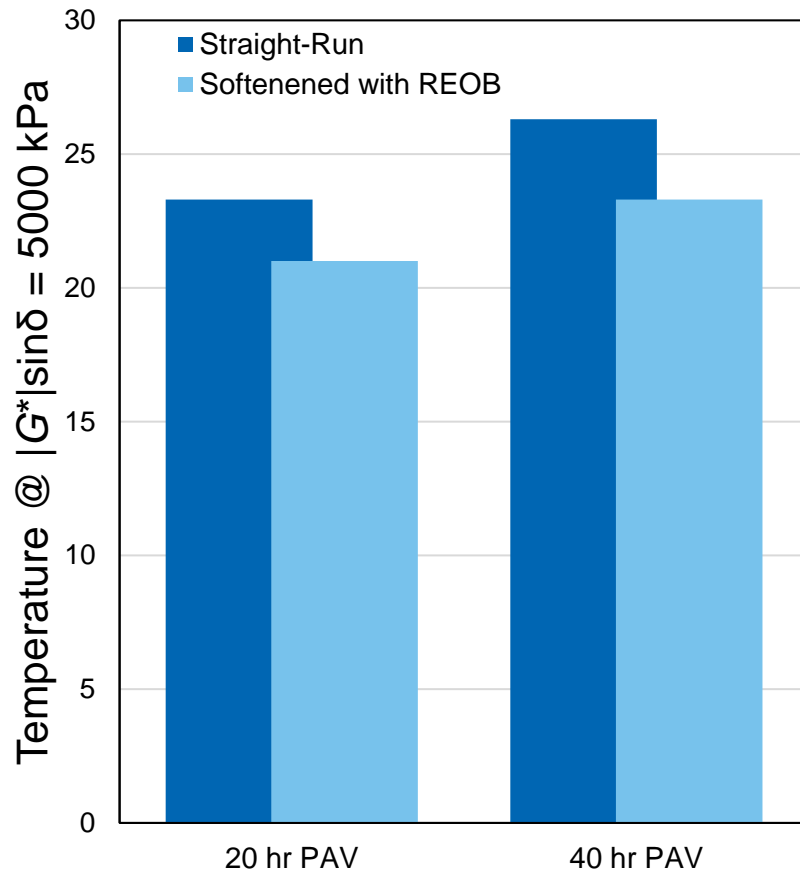
- Phase unstable asphalt binders are more susceptible to oxidative aging and can lead to phase separation, poor stress relaxation, and cracking
- Today, SuperPave™ uses DSR-PAV $|G^*|\sin\delta$ parameter to screen for binders with high potential for cracking
- Recent work has found that phase instability is demonstrated by more negative ΔT_c , higher aging index & lower phase angle
- It has been found that DSR-PAV $|G^*|\sin\delta$ parameter does not correlate with any of these parameters and does not effectively distinguish binders prone to cracking

$|G^*| \sin \delta$ does not Differentiate Binders



- DSR-PAV cannot discriminate poor-performing binders, namely phase instable binders exhibiting high cracking rates.

$|G^*| \sin \delta$ does not Correlate to Relaxation

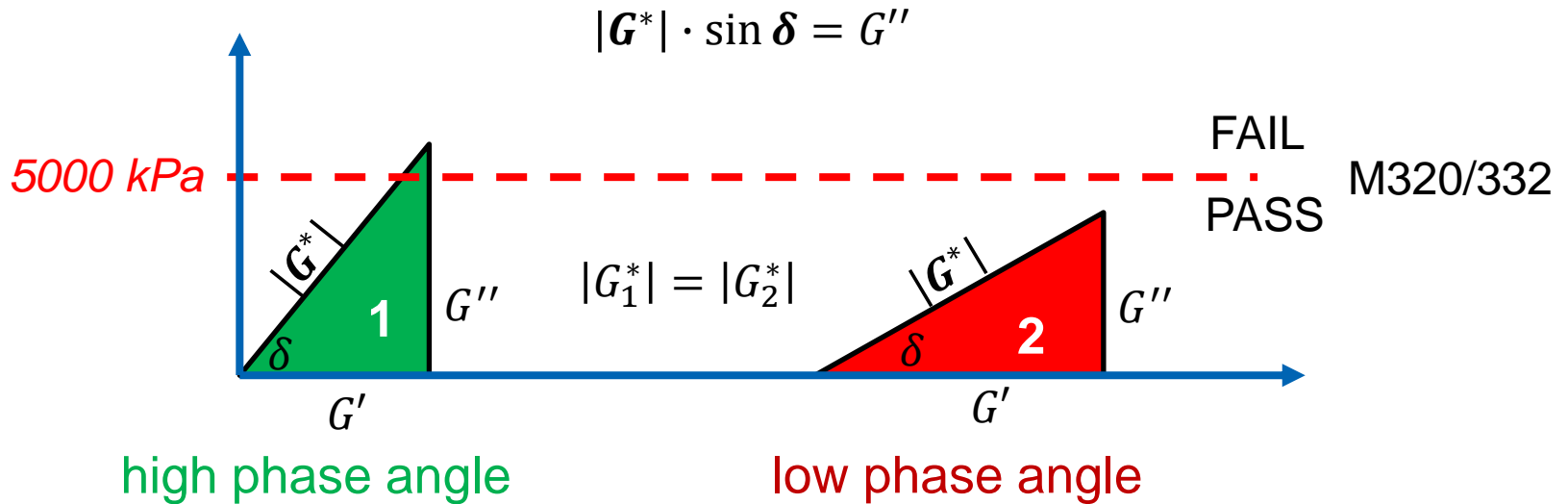


DSR-PAV Limiting Temperature

- Compare straight-run Cold Lake PG 64-22 to Cold Lake PG 70-XX softened to PG 64-22 with REOB

The Challenge with $|G^*| \sin \delta$

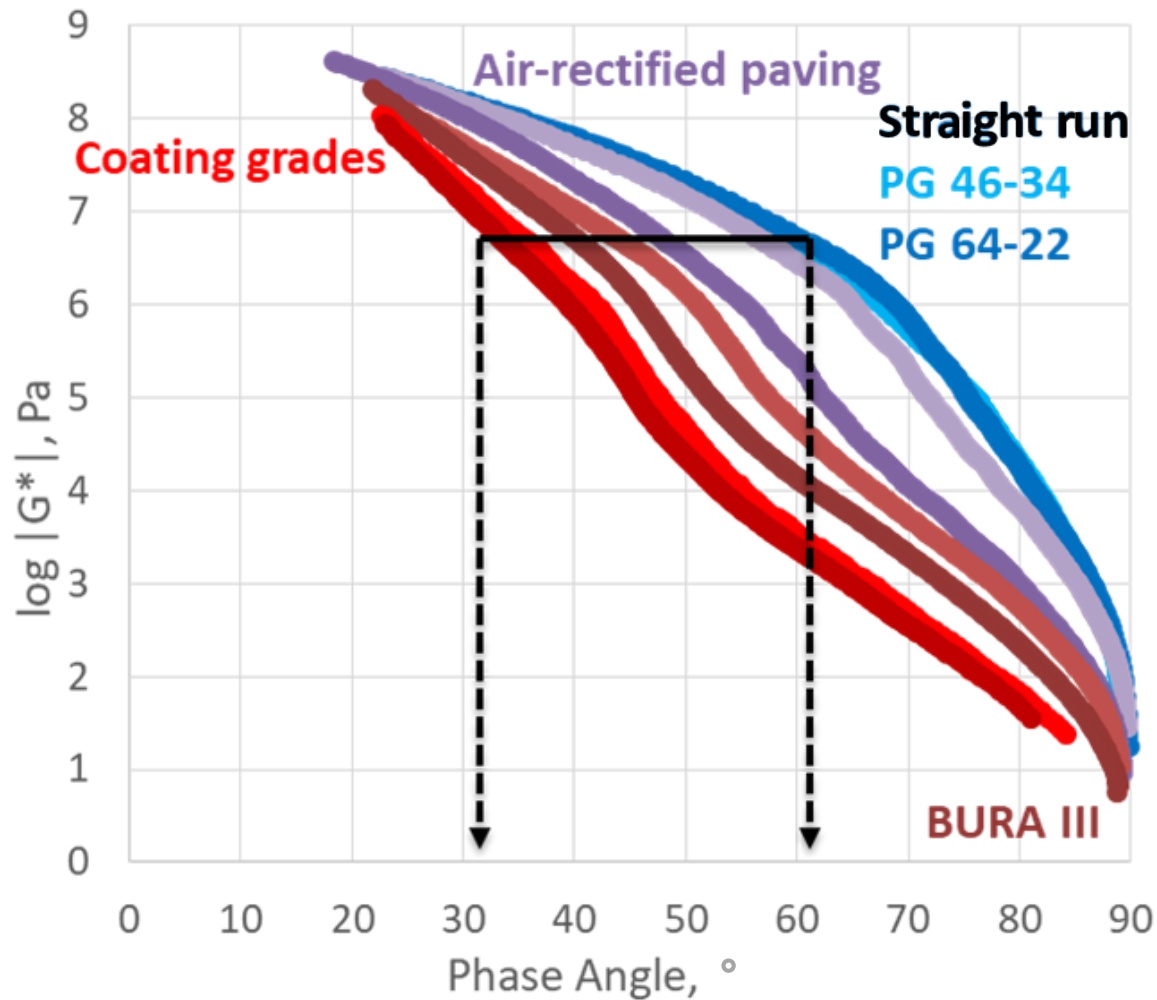
Two binders, same complex modulus, different phase angle



- SuperPave™ intention was to limit high stiffness, brittle binders
- Low phase angle binders are advantaged
- High quality **ductile** binders with high phase angle are disadvantaged.

Proposed Alternative: Measure and limit phase angle

Phase Angle Differentiates Binders



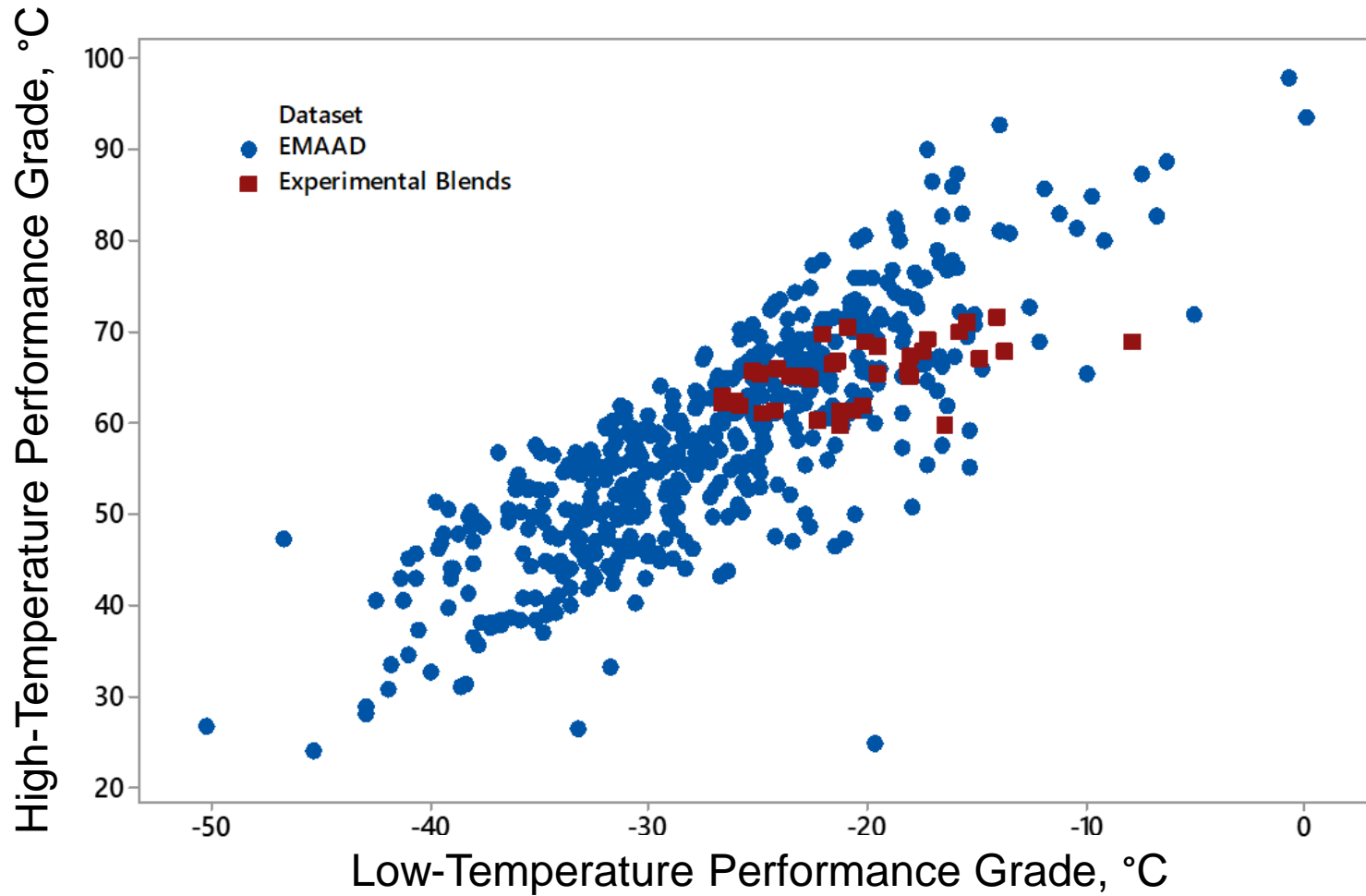
- Phase angle can better resolve binders based on quality

Verification with Two Datasets

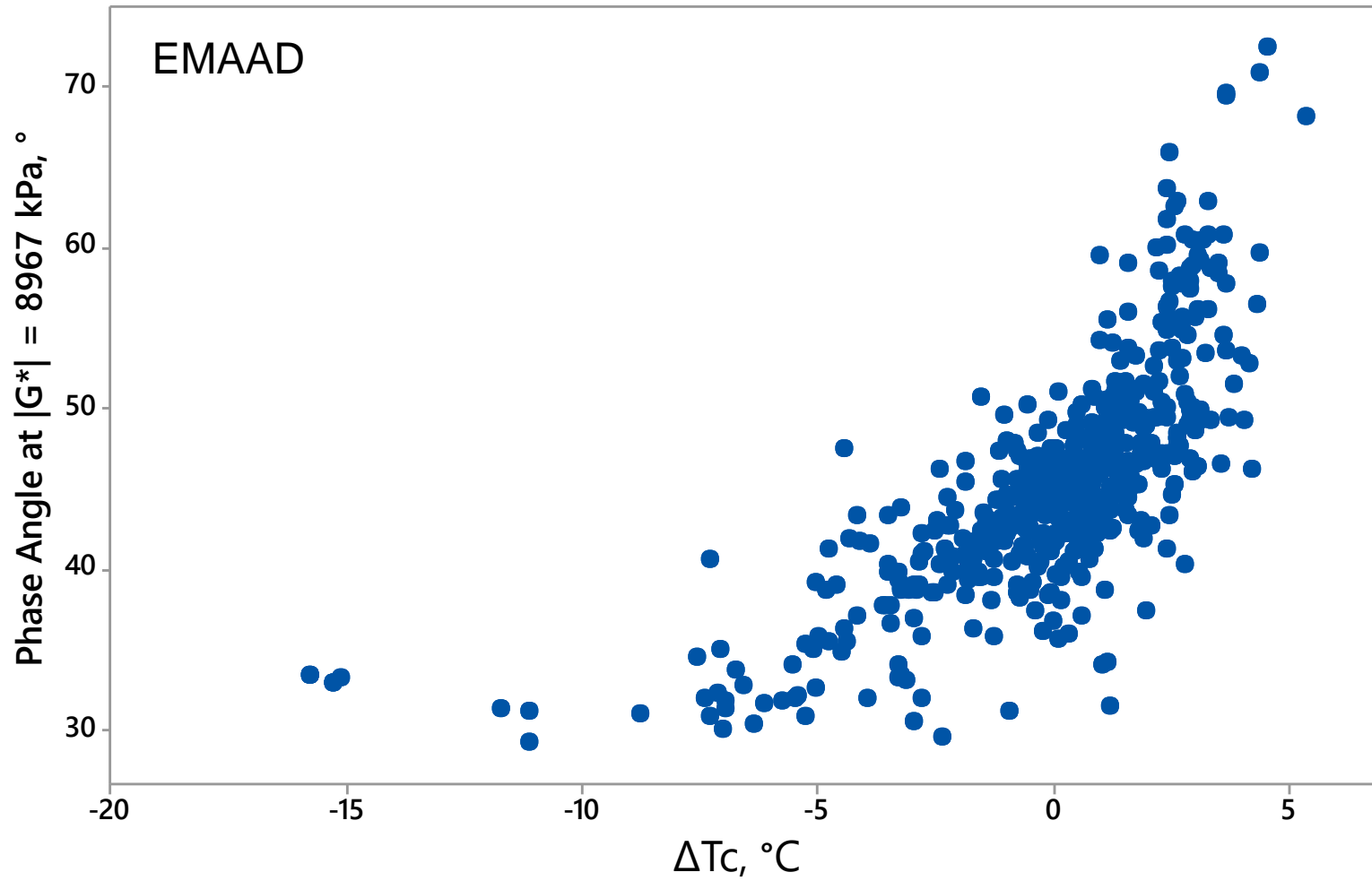
- 1) Experimental laboratory blends (37) → Wide range of phase compatibilities; components/methods include:
 - 'asphaltenes' fraction (12, 29 & 46 % n-Heptane insoluble)
 - 3 paraffinic oils (viscosity at 60 °C of 0.1, 0.07 & 0.02 Pa.s)
 - 3 straight-run asphalts
 - varying degrees of air-blowing

- 2) ExxonMobil Asphalt Assay Database (EMAAD): Laboratory prepared straight run asphalts (522)
 - Extremely diverse crude oil origins well beyond suitable asphalt blends

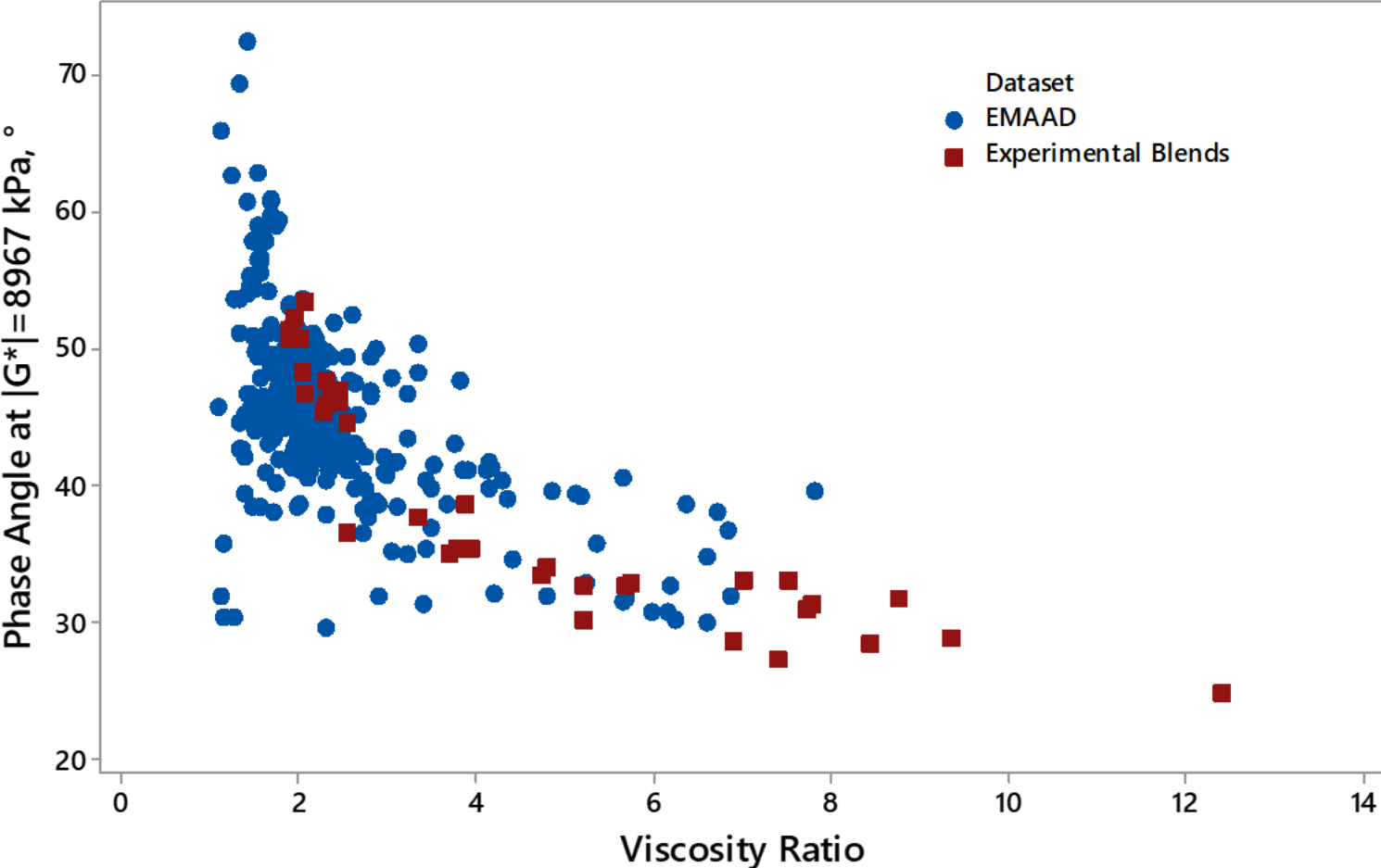
Performance Grade Distribution of Binders



Phase Angle versus Relaxation - ΔT_c



Phase Angle versus Aging Rate - Viscosity Ratio



Advantages of Phase Angle

1. Measured as part of T315/M320 since dawn of SuperPave™
2. Highly repeatable measurement
 - AASHTO precision for PAV residue (1s/d2s): 0.09°/0.25° and 0.76°/2.11° for single operator & multiple laboratories, respectively
 - 2.11° at 45° is 4.7% for phase angle vs. 40.2% for $|G^*|\sin\delta$
3. When determined at constant magnitude of complex modulus related to morphology/composition and not time/temperature
 - No need for somewhat arbitrary determination of DSR-PAV temperature

Summary

- SuperPave™ is highly sophisticated & functional system
- It has pre-built features at our fingertips we can use to better screen asphalts of today
- Minor modification to M320/M332 can be done easily to improve its selectivity to performance (i.e. replace $|G^*|\sin\delta$)
- Approach is practical & offers fast field validation
- Let's use what we already have

