



Toward Practical Binder Evaluation: Validating Newly Proposed Rheological Parameters Measured with a Simplified DSR Approach & Replacing BBR with a DSR- Based Method for Low-Temperature Grading

Northeastern States Materials Engineers' Association (NESMEA) Annual Meeting
Harrisburg, PA ♦ October 29th, 2025

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Introduction

- DOTs are moving to the Balanced Mix Design (BMD) method, which includes performance testing.
- A major challenge is ensuring binder consistency as changes in source or formulation for the same PG binder can unbalance the mix.

Previous Work

Previous Work:

- A previous study¹ proposed using two rheological parameters in tandem, **one point parameter** and **one shape parameter**, to better assess binder quality:
 - The Glover-Rowe (G-R) parameter at 15°C and 10 rad/s, representing binder stiffness in the high-stiffness region
 - The phase angle at a complex modulus of 10 MPa ($\delta_{10\text{MPa}}$), indicating the binder's stress relaxation capability

¹ Mogawer, W.S., G. Rowe, I. M. Abdalfattah, and A.J. Austerman. *Evaluating Asphalt Binder Quality: Point and Shape Rheological Parameters for Assessing Intermediate-Temperature Cracking Susceptibility*. Transportation Research Record: Journal of the Transportation Research Board, 2025. Volume: Asphalt Paving Technology 2024. <https://doi.org/10.1177/03611981251341339>

Previous Work (Continued)

Previous Work:

- These binder parameters were validated using mixture IDEAL-CT test results.
- A simplified Dynamic Shear Rheometer (DSR)-based protocol using temperature sweep testing at a single frequency of 10 rad/s was developed to calculate the parameters.
- The study was limited to a single performance test and one aging condition, long-term aging (LTA).

Objectives

1. Evaluate and validate the G-R parameter at 15°C and 10 rad/s and the $\delta_{10\text{MPa}}$ parameter under both short- and long-term aging.
2. Employ multiple mixture performance tests (IDEAL-CT, Texas Overlay, Dynamic Modulus, and Cyclic Fatigue) to capture different cracking mechanisms.
3. Extend the simplified DSR-based approach to low-temperature binder evaluation, offering a practical and efficient alternative to the Bending Beam Rheometer (BBR).

Binder Parameter Validation

Asphalt Binders Used for Validation

- Seven (7) asphalt binders were selected from the pool of twenty (20) binders used in the previous study.
- Binder selection reflected a broad range of expected cracking performance based on G-R and $\delta_{10\text{MPa}}$ rankings after 20-hour PAV aging.

Asphalt Binders Used for Validation

Binder Quality	Selected Binder	G-R at 15°C and 10 rad/s		Phase angle at 10 MPa ($\delta_{10\text{MPa}}$)	
		RTFOT	20h PAV	RTFOT	20h PAV
Good	PG64-28 Base	2084 (3)	12080 (6)	47.8 (3)	38.2 (4)
	PG64E-28	2776 (6)	9679 (3)	44.2 (5)	37.6 (5)
	PG52-34	551 (1)	5286 (2)	52.4 (1)	42.6 (2)
	PG76E-34	887 (2)	4651 (1)	47.1 (4)	40.7 (3)
Poor	PG64-22 Lab Formulated ¹	2231 (4)	11020 (5)	37.2 (7)	29.7 (7)
	PG64-28 Lab Formulated ¹	2247 (5)	10260 (4)	41.1 (6)	34.0 (6)
	PG64-16 ²	10910 (7)	41730 (7)	50.5 (2)	43.4 (1)

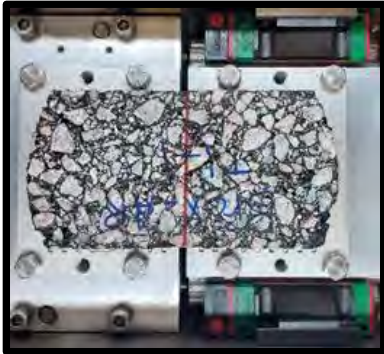
¹ Binders were artificially formulated in the lab using Re-refined Engine Oil Bottoms (REOB) and air-blown asphalt to simulate poor-performing materials.

² PG64-16 had known poor cracking performance (Sourced from the Western U.S.).

Superpave Mixture Design Used for Validation

- 12.5 mm dense-graded asphalt mixture with 15% RAP.
- To achieve the target gradation, virgin aggregates were sieved and batched by individual size fractions to ensure precise control during blending.
- Used the seven selected binders in validation.

Mixture Tests

	Intermediate Temperature Cracking	Reflective & Fatigue Cracking	Mixture Stiffness (Linked To Fatigue & Thermal Cracking)	Fatigue Cracking
Test	IDEAL-CT 	Texas Overlay Test 	Dynamic Modulus $ E^* $ 	Cyclic Fatigue Test 
Specification	ASTM D 8225	Tex-248-F	AASHTO TP 132	AASHTO T 411

Mixture Aging

Short-term Aging (STA) – AASHTO R 30

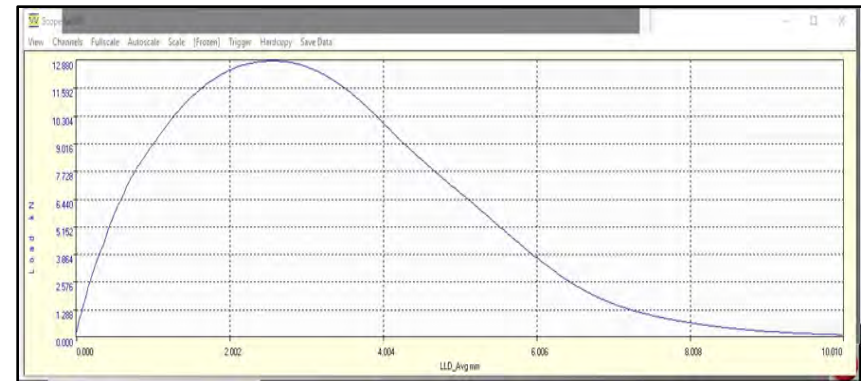
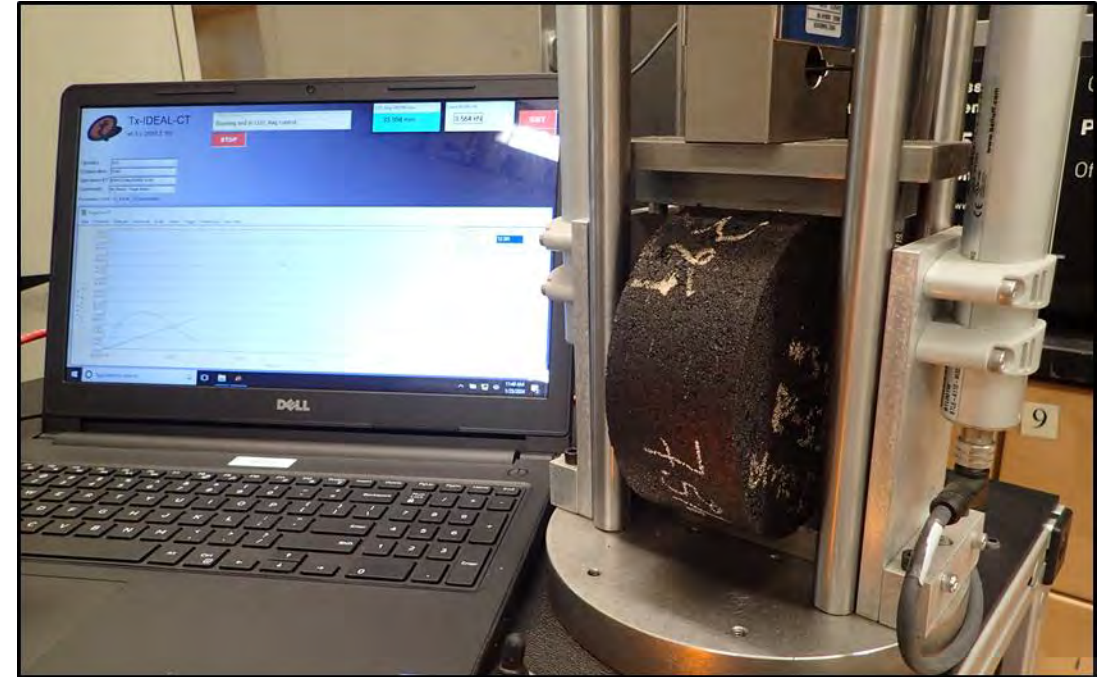
- Loose mixture aged at 135°C for 4 hours.

Long-term Aging (LTA) – AASHTO R 121

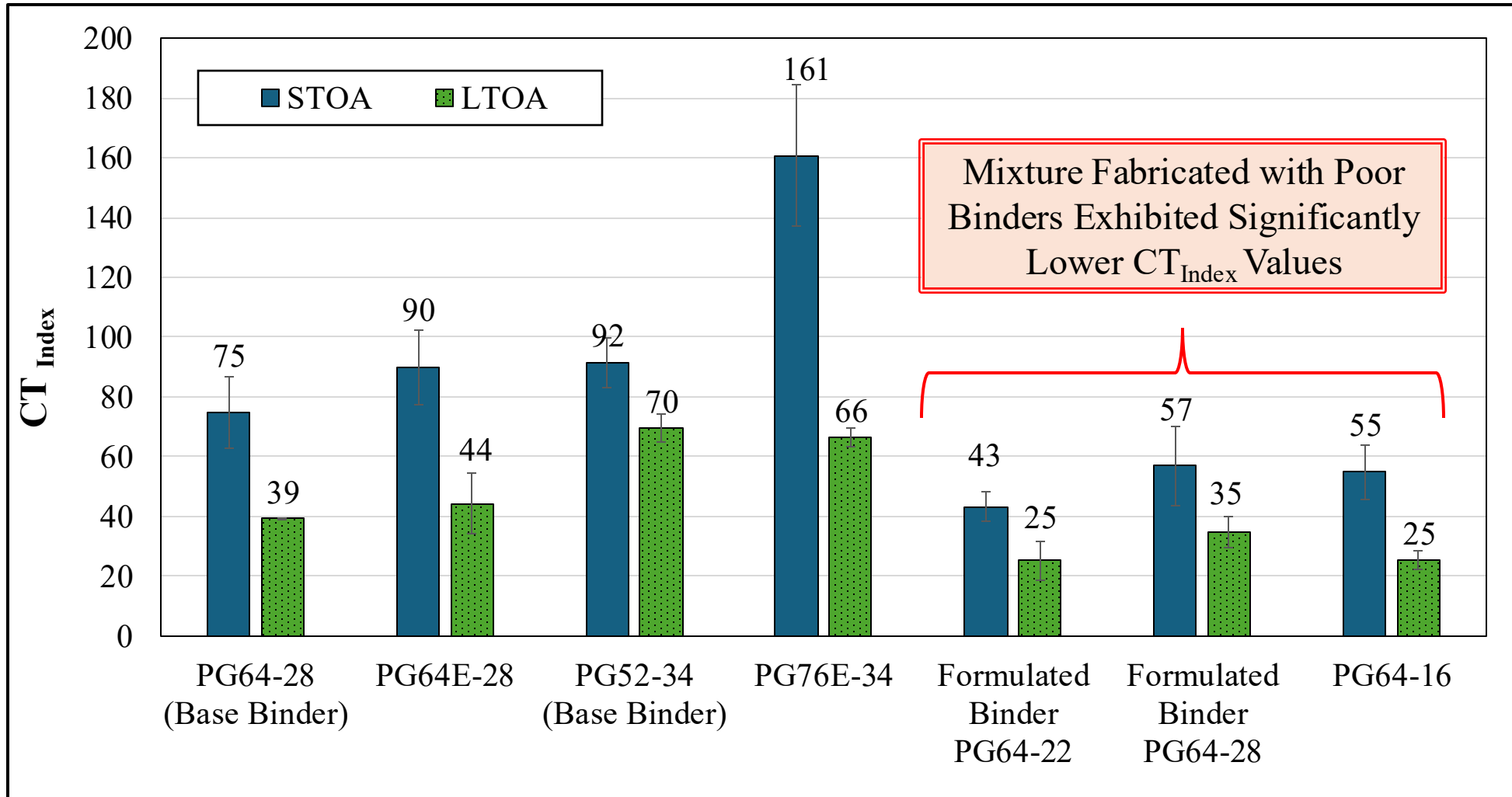
- STA aging followed by aging the loose mixture at 110°C for 20 hours.

IDEAL-CT Test - Overview

- ASTM D8225-19 method used for intermediate temperature cracking assessment.
- CT_{Index} : Higher values indicate better cracking resistance.
- Test temperature of 25°C.



IDEAL-CT Results



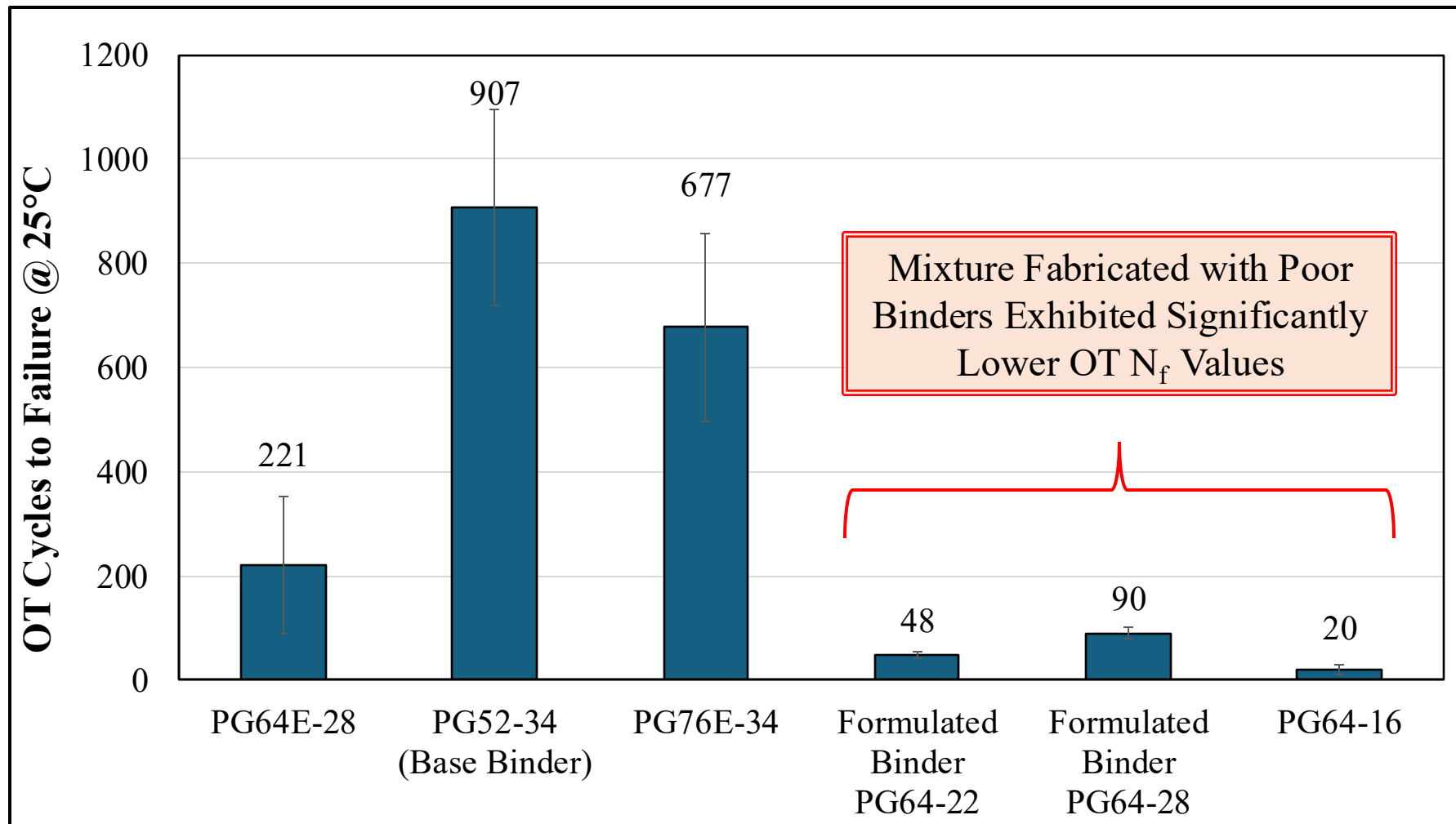
Error bars represent the standard deviation. Overlapping error bars suggest no statistically significant differences between mixtures.

Overlay Test (OT) - Overview

- Test temperature = 25°C.
- Test termination at 1,200 cycles or 93% load reduction.
- Testing in accordance with Tex-248-F with 5 replicates per binder.
- Higher values indicate better cracking resistance.
- Specimens tested after LTA only.
- PG 64-28 base binder mixture was not tested due to a shortage of that binder from the previous study. The supplier's current formulation available was different.



Overlay Test (OT) - N_f Results



Error bars represent the standard deviation. Overlapping error bars suggest no statistically significant differences between mixtures.

Dynamic Modulus & Cyclic Fatigue - Overview

Dynamic Modulus

- Dynamic Modulus ($|E^*|$) testing conducted per AASHTO TP 132.
- Three test temperatures and five frequencies: 15 temperature-frequency combinations per specimen.
- Average $|E^*|$ values from the four replicates were used to construct master curves using FlexMAT™ Cracking Version 2.2



Cyclic Fatigue

- Cyclic fatigue testing conducted per AASHTO T 411.

Data used to calculate the cyclic fatigue index parameter (S_{app}) - A mechanistic, performance-based index derived from the Simplified Viscoelastic Continuum Damage (S-VECD) model.

Binder to Mixture Parameter Comparison

Binder Quality	Selected Binder	Binder Shape Parameter		Mixture Shape Parameter
		Phase angle at 10 MPa ($\delta_{10\text{MPa}}$)		γ
		RTFOT	20h PAV	
Good	PG64-28 Base	47.8 (3)	38.2 (4)	-0.500 (3)
	PG64E-28	44.2 (5)	37.6 (5)	-0.424 (4)
	PG52-34	52.4 (1)	42.6 (2)	-0.522 (2)
	PG76E-34	47.1 (4)	40.7 (3)	-0.417 (5)
Poor	PG64-22 Lab Formulated	37.2 (7)	29.7 (7)	-0.380 (7)
	PG64-28 Lab Formulated	41.1 (6)	34.0 (6)	-0.399 (6)
	PG64-16	50.5 (2)	43.4 (1)	-0.524 (1)

Binder to Mixture Parameter Comparison

Binder Quality	Selected Binder	Binder Point Parameter		Mixture Point Parameter
		G-R at 15°C and 10 rad/s		$-\beta/\gamma$
		RTFOT	20h PAV	
Good	PG64-28 Base	2084 (3)	12080 (6)	-1.919 (4)
	PG64E-28	2776 (6)	9679 (3)	-2.259 (6)
	PG52-34	551 (1)	5286 (2)	-1.149 (1)
	PG76E-34	887.8 (2)	4651 (1)	-1.658 (2)
Poor	PG64-22 Lab Formulated	2231 (4)	11020 (5)	-2.020 (5)
	PG64-28 Lab Formulated	2247(5)	10260(4)	-1.728 (3)
	PG64-16	10910 (7)	41730 (7)	-2.634 (7)

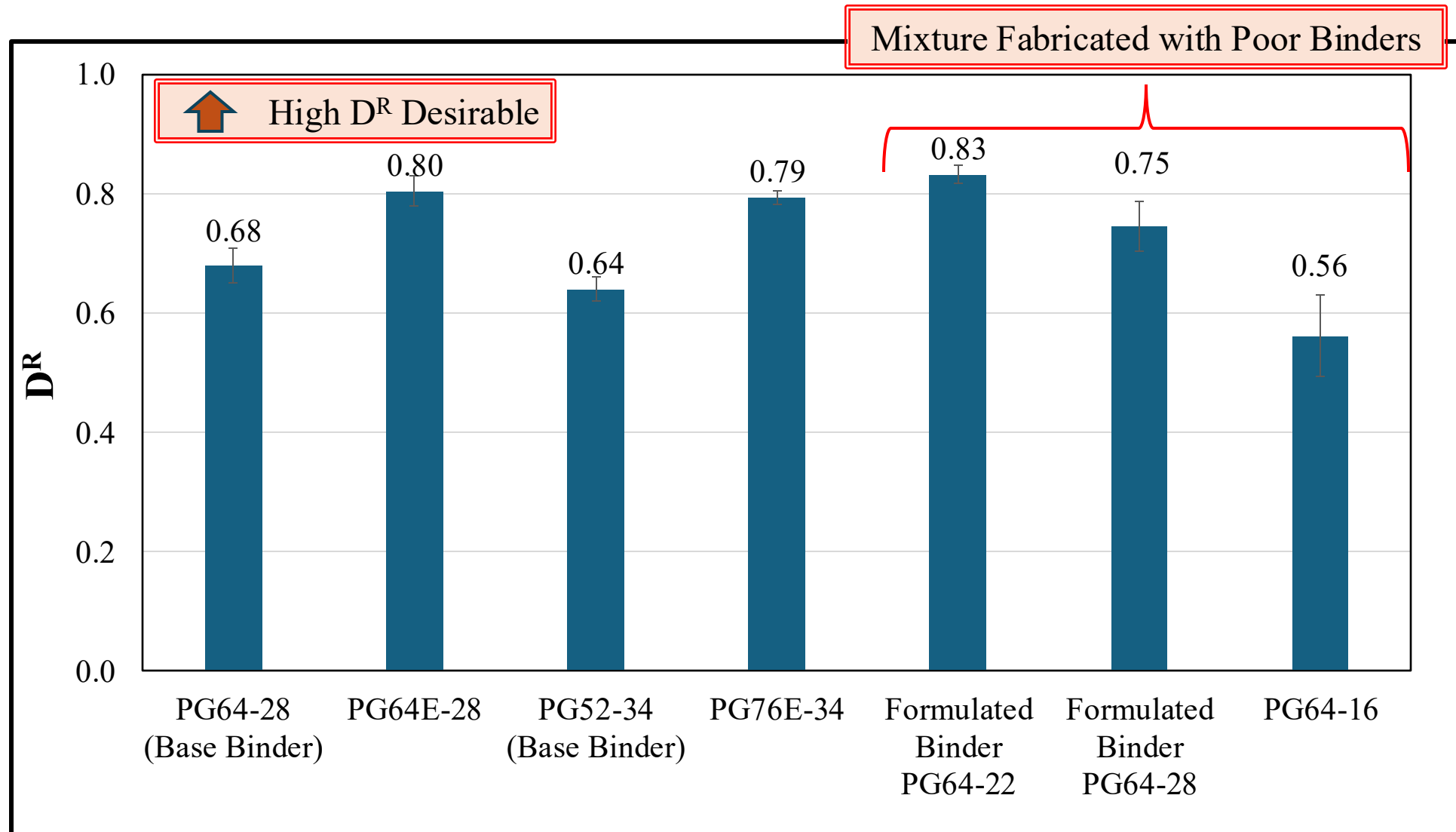
Binder to Mixture Parameter Comparison

- Strong agreement between the binder-based point and shape parameters ($G-R$ and δ_{10MPa}) and the mixture-based point and shape parameters ($-\beta/\gamma$ and γ) confirms the validity of using tandem binder parameters to assess binder quality and predict mixture cracking performance.

Cyclic Fatigue Analysis

- Test results were used to generate damage characteristic curves (C vs. S) and determine the fatigue failure criterion (D^R).
- The C vs. S curve plots pseudo-stiffness (C), a measure of material integrity, against internal damage (S), representing the accumulation of fatigue damage.
- The D^R value quantifies the average reduction in pseudo-stiffness up to failure. Higher D^R values are desirable (all other factors being the same) as they indicate better fatigue resistance under repeated loading.

Cyclic Fatigue Results



Simple Method For Measuring Binder Parameters

Determining the Point Parameter G-R at 15°C and 10 rad/s

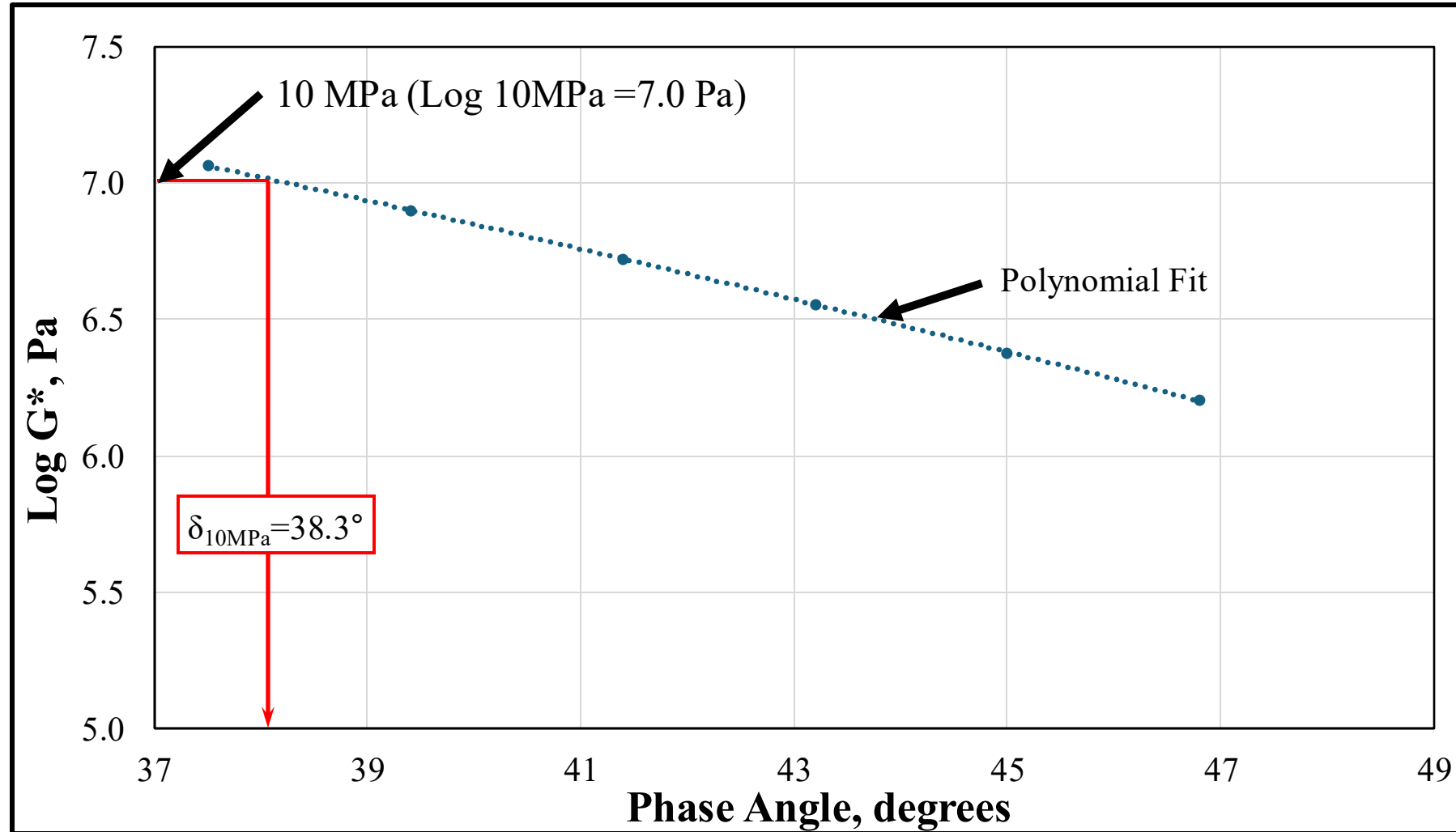
- Derived directly from binder DSR test data collected in accordance with AASHTO T 315 using an 8-mm plate geometry at 15°C and 10 rad/s. From the test results, the complex shear modulus (G^*) and phase angle (δ) are obtained and used to calculate G-R using the expression: $G^*(\cos\delta)^2/\sin\delta$.

Determining the Shape Parameter $\delta_{10\text{MPa}}$

- To calculate $\delta_{10\text{MPa}}$, G^* and δ are measured at multiple intermediate temperatures using a frequency of 10 rad/s. A polynomial function is then fitted to the log-transformed G^* versus δ data, and the phase angle corresponding to a modulus of 10 MPa is interpolated from this fitted curve. Accurate calculation requires the logarithmic value of $|G^*|$.

Example of Shape Parameter $\delta_{10\text{MPa}}$ Determination

Ex. Complex modulus (G^*) and phase angle (δ) are measured over a temperature range from 22°C to 7°C, in 3°C increments, at a frequency of 10 rad/s.



Extension of the Simplified DSR-Based Approach to Low Temperature Binder Evaluation

Extension of DSR-Based Approach

- Building on the simplified DSR protocol proposed, the research team extended the DSR-based approach to directly replace the BBR for Performance Grade (PG) determination in the low-temperature regime.
- The proposed method relies on typical relationships derived by converting BBR-based stiffness and relaxation properties [flexural stiffness (S) and an m -value measured at 60 seconds] into equivalent rheological values that can be obtained using a DSR.
- Based on earlier work, it was shown that these BBR limits correspond to a complex modulus (G^*) of approximately 111 MPa and a phase angle (δ) of 26.2° in shear loading.
- These values define a specific point on the binder's rheological spectrum within the high-stiffness region where thermal cracking is most critical. By identifying this point, the method enables direct comparison between BBR and DSR results and can establish a consistent threshold for binder acceptance at low temperatures.

Extension of DSR-Based Approach

- The principle of time–temperature superposition (TTS) was applied to translate the BBR’s long loading time and sub-zero temperature conditions into more practical DSR testing conditions at higher frequencies and above-freezing temperatures.
- The BBR’s loading time of 60 seconds, corresponding to a frequency of approximately 0.0167 rad/s, was converted into a DSR testing frequency of 10 rad/s.
- Using master curve data and accepted shift factor relationships based on the Kealble modification to the Williams-Landel-Ferry (WLF) equation, it was estimated that an increase from 0.0167 to 10 rad/s corresponds to a temperature shift of approximately 18°C.
- This shift allows equivalent DSR testing to be conducted 18°C warmer than the BBR test temperature while preserving the same rheological behavior in the high-stiffness region to a DSR frequency of 10 rad/s, which is commonly used in standard protocols.

Equivalent Test Temperatures

Low Temperature PG, °C	BBR, 60 seconds	DSR, 10 rad/sec
-34	-24	-6
-28	-18	0
-22	-12	6
-16	-6	12
-10	0	18

Example

A binder tested at -18°C in the BBR for PG-28 could instead be tested at 0°C using the DSR at 10 rad/s.

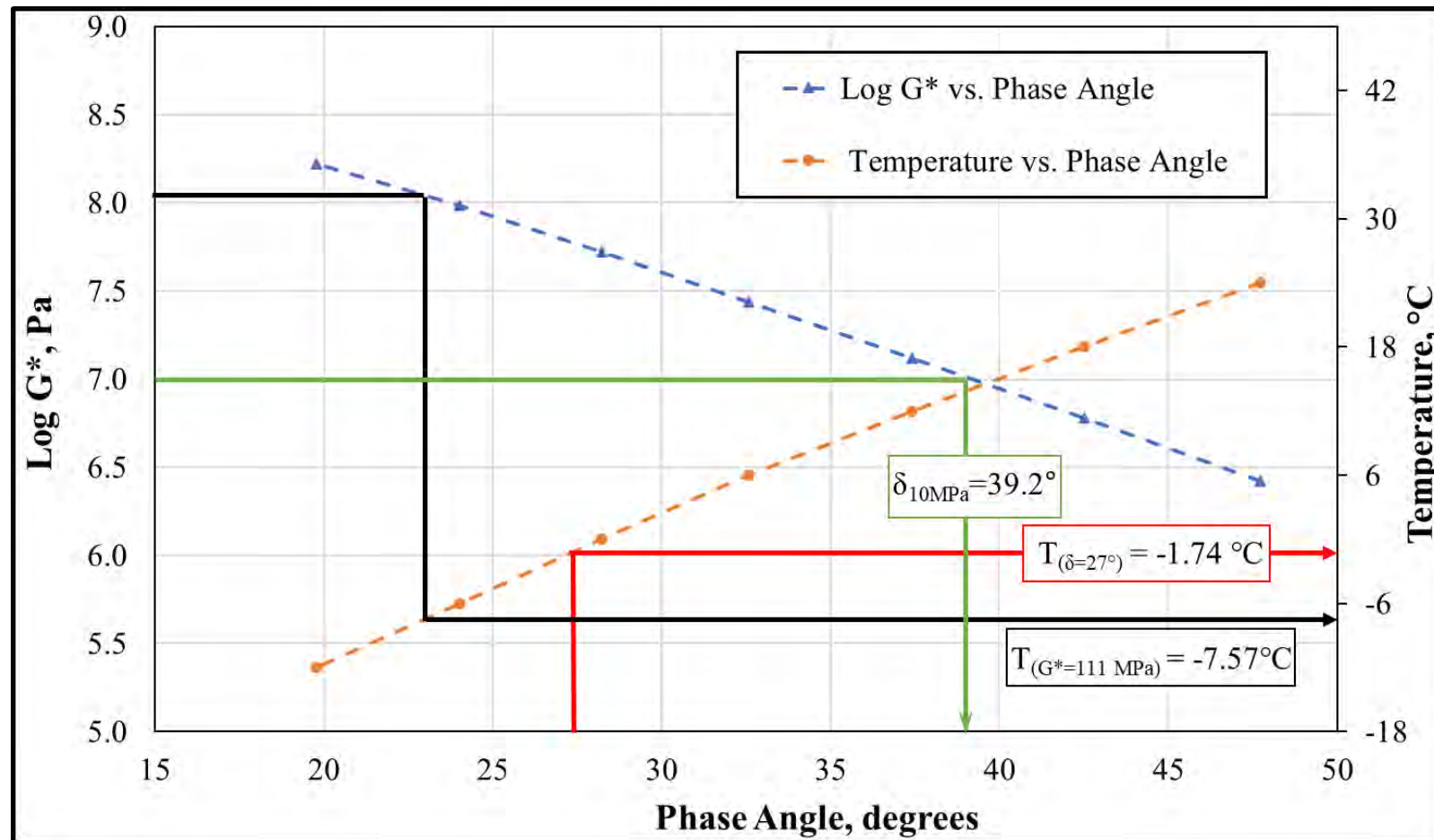
Performing the Approach

- Once the appropriate test temperature for the desired PG grade is identified, the simplified DSR-based method can be implemented using the standard 8-mm parallel plate geometry in accordance with AASHTO T 315.
- At each temperature, the complex modulus (G^*) and phase angle (δ) are measured at a loading frequency of 10 rad/s. A binder meets the grade if it satisfies both of the following criteria: $G^* \leq 111$ MPa and $\delta \geq 27^\circ$ (rounded from 26.2° for practical reproducibility).
- If needed, testing can be conducted at adjacent temperatures to interpolate the true critical grade, following procedures like traditional PG grading.

Example of Approach

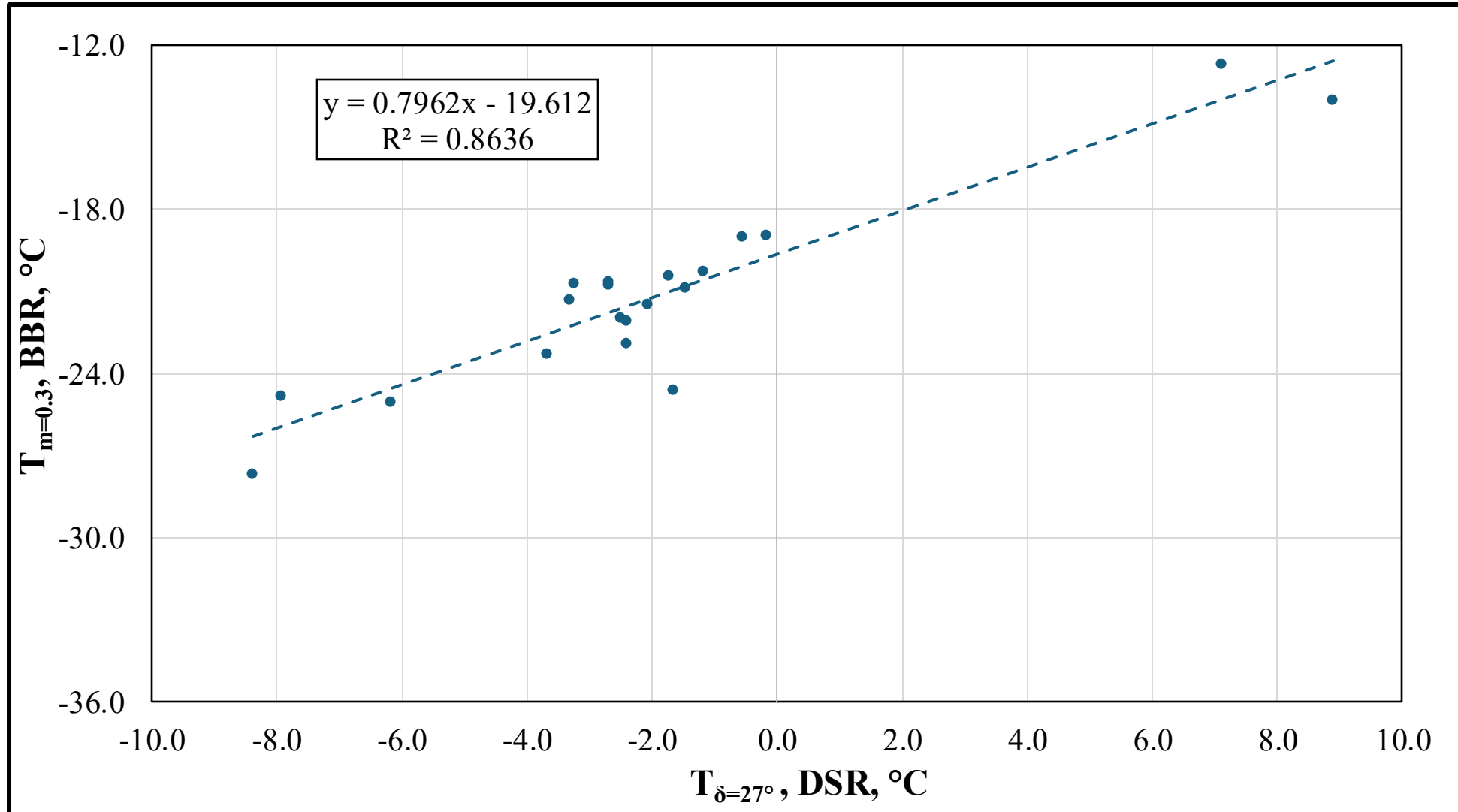
Example

1. G^* and δ are measured at multiple temperatures at 10 rad/s.
2. A linear regression is then fitted to the $\log |G^*|$ versus δ data, and the fitted equation is used to calculate $\delta_{10\text{MPa}}$ and to estimate the low-temperature grade corresponding to the S and m criteria ($G^* \leq 111 \text{ MPa}$ and $\delta \geq 27^\circ$).



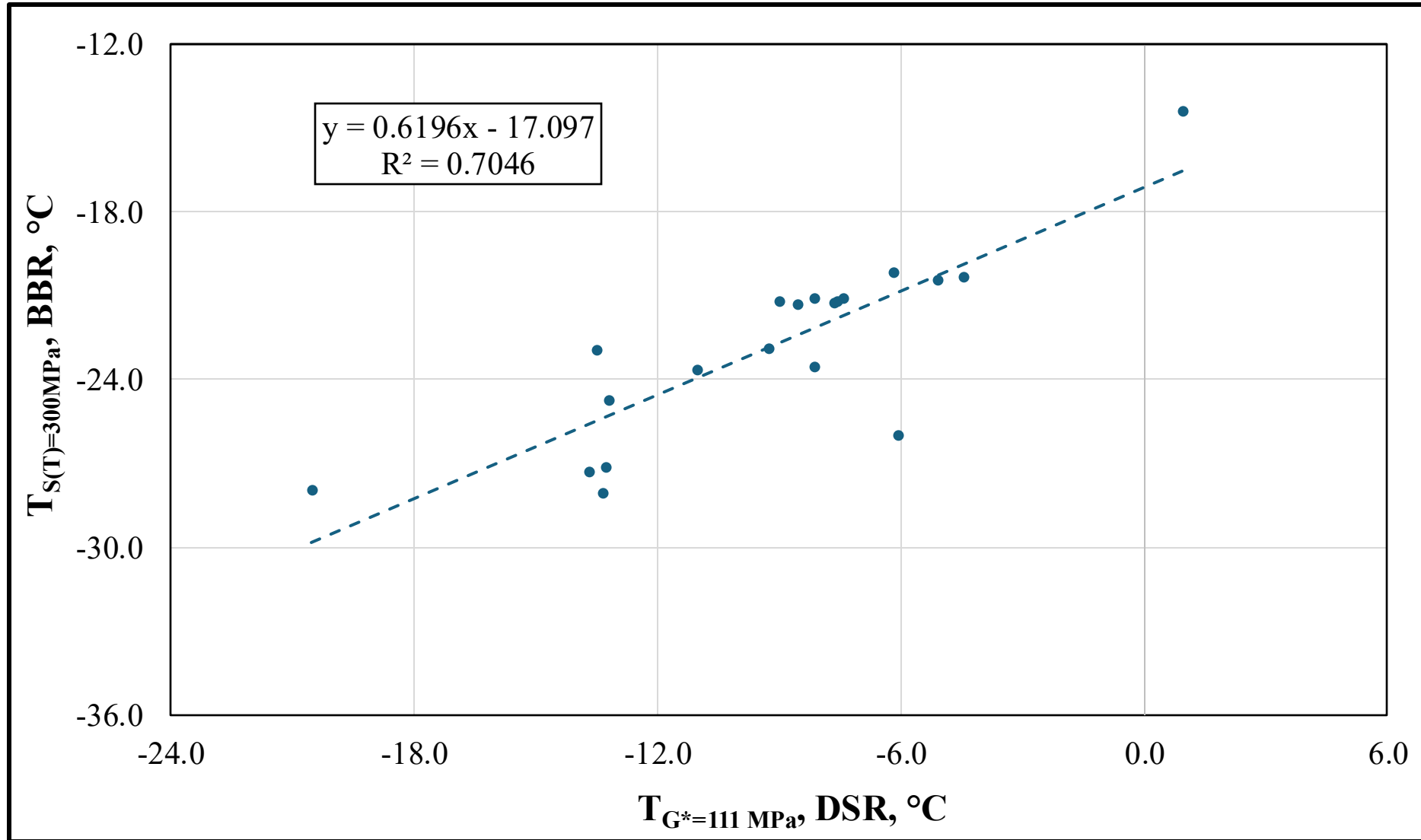
Correlation of Temperatures

DSR Approach to BBR m-value = 0.300



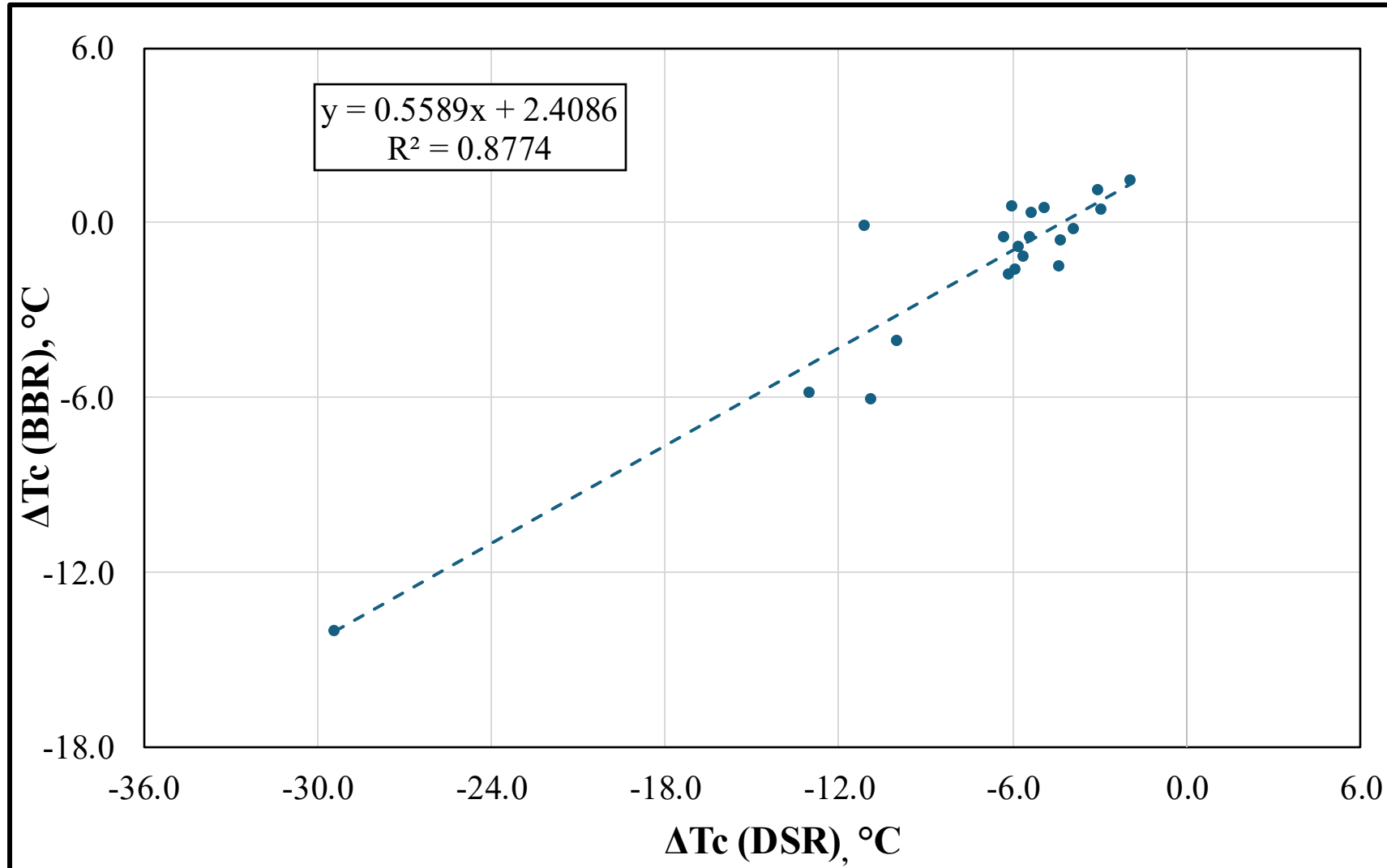
Correlation of Temperatures

DSR Approach to BBR S = 300



Correlation of ΔT_c Temperatures

DSR Approach to BBR Determined



Advantages of Approach

- Unlike BBR testing, which requires at least 11-15 g of PAV-aged binder, a full cooling and conditioning cycle, and precise sub-freezing temperature control, the DSR method can be completed using less than 2 g of binder, within approximately two hours, and with equipment and procedures already familiar to most asphalt laboratories.
- Method is entirely specification-ready, requiring no proprietary analysis software or specialized instrumentation.

Conclusions

1. Mixture performance tests generally agreed with the G-R parameter at 15°C and 10 rad/s and the $\delta_{10\text{MPa}}$ parameter. Mixtures containing poor-quality binders, as identified by these two parameters, performed worse than mixtures with good-quality binders. This consistency validated using these parameters in tandem. Both a shape and point parameter for binder is needed.
2. The agreement between binder and mixture point parameters, and between binder and mixture shape parameters, demonstrates that rheological measurements made on the binder can reliably predict mixture performance trends without the need for extensive mixture testing.

Conclusions

3. The simplified DSR protocol, extended to low-temperature grading via time–temperature superposition, replicated key BBR parameters (S , m -value, ΔT_c) with strong correlation while requiring less binder, lower testing time, and no additional equipment.
4. The unified DSR-based method enables intermediate- and low-temperature binder evaluation within a single, specification-ready framework, facilitating rapid, practical quality assurance.
5. Adoption of this framework in BMD and field acceptance can help agencies detect detrimental binder source or formulation changes that PG grading alone may overlook, thereby reducing cracking potential which can lead to extending pavement service life.

Thank You!



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