Prediction of Mix Performance from Modified Binder Properties

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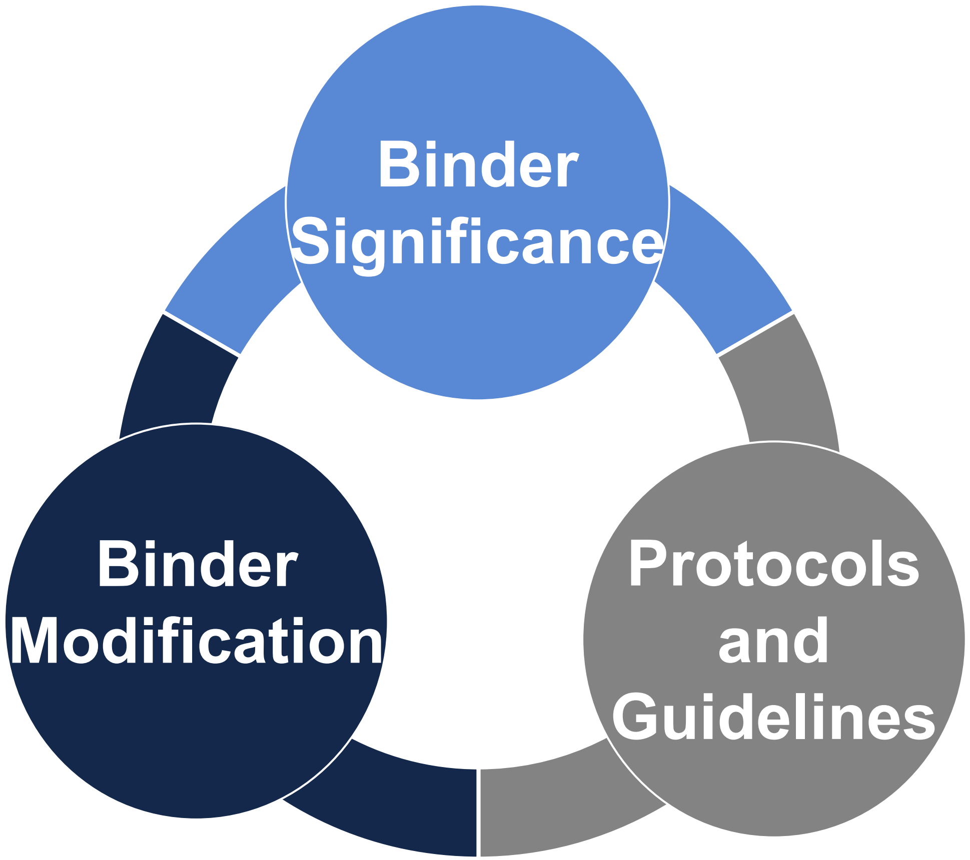
Motivation



Binder Significance

- It controls mixture behavior
- Affect cracking potential

Binder Modification

- Softeners offset RAP
- Polymers provide elasticity and reduces rutting potential

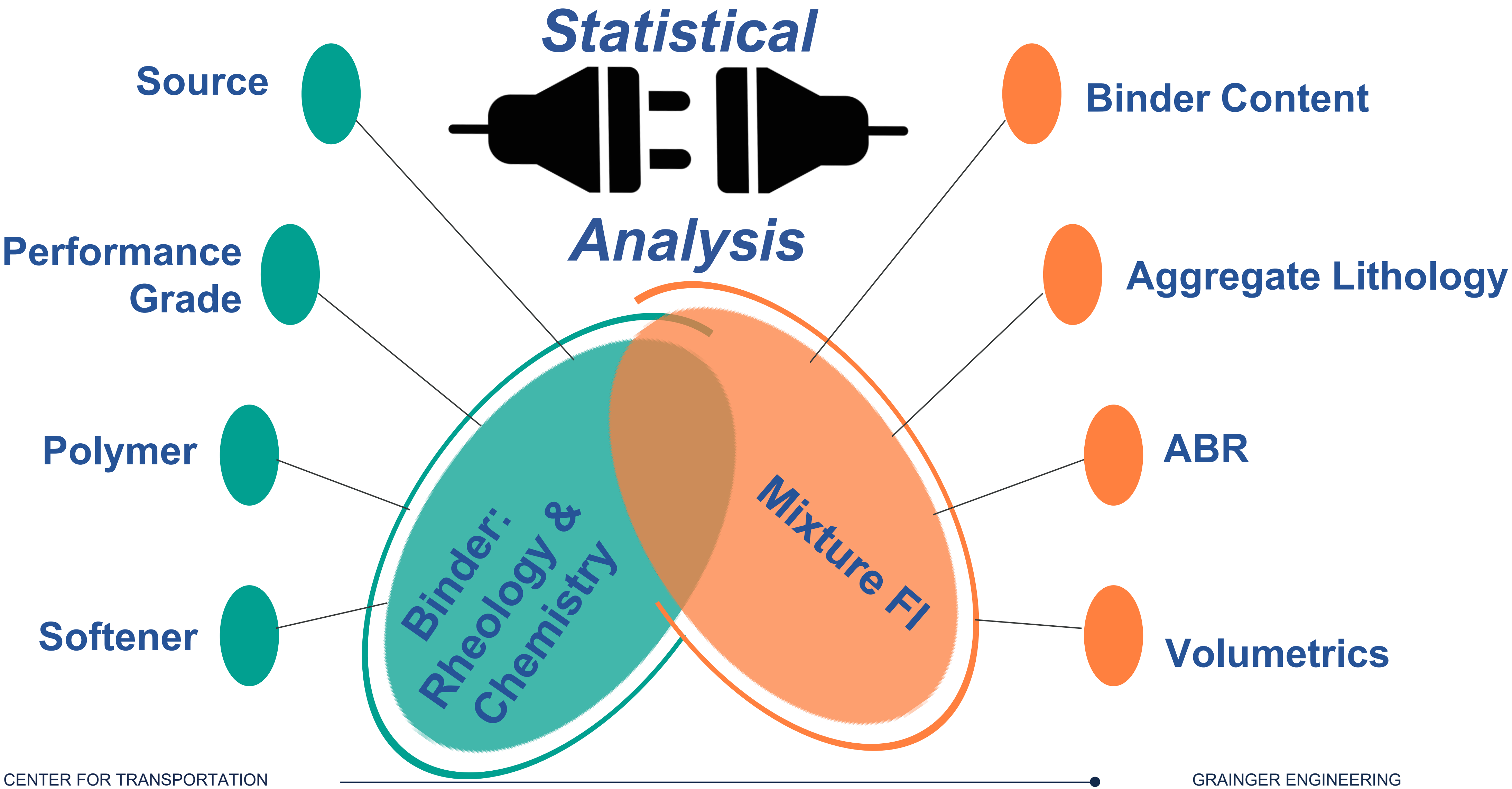
Protocols and Guidelines

- Agencies: Identify parameters and thresholds to screen modified binders.
- Contractors: Select binders, and pass I-FIT

Objective

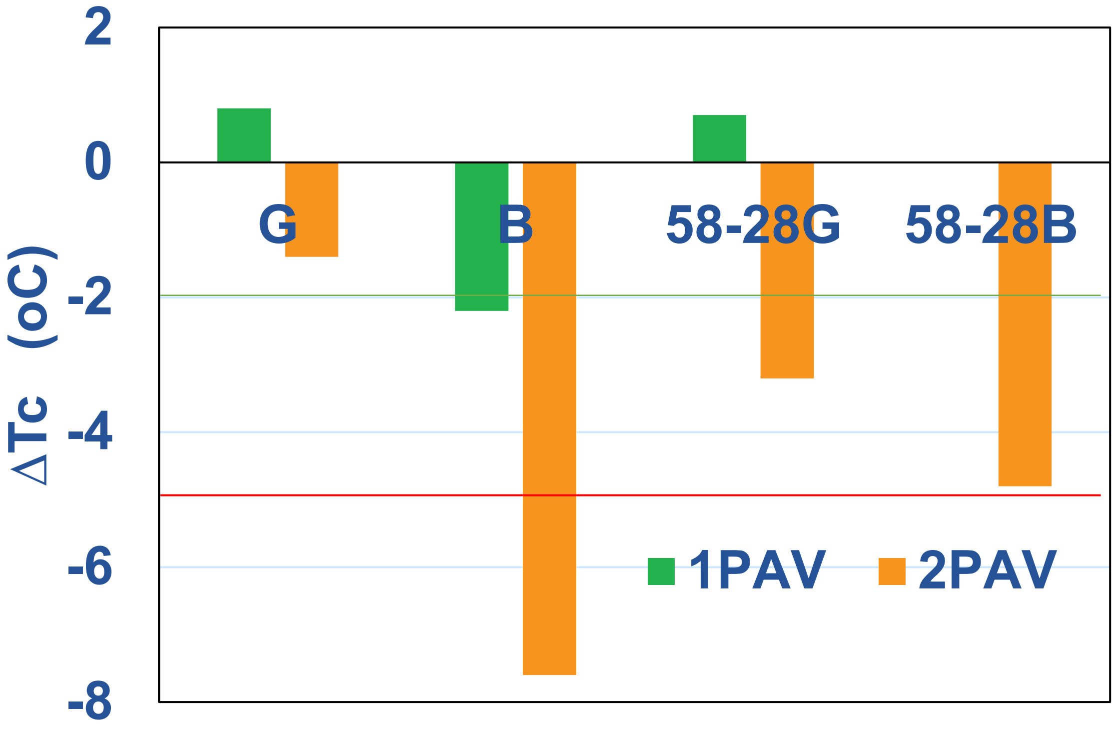
To provide a systematic procedure for **selecting and screening** quality asphalt binders, particularly **modified binders** incorporating polymers and softeners, to ensure **low cracking potential** and long-term pavement performance under Illinois climate and traffic conditions.

Methodology



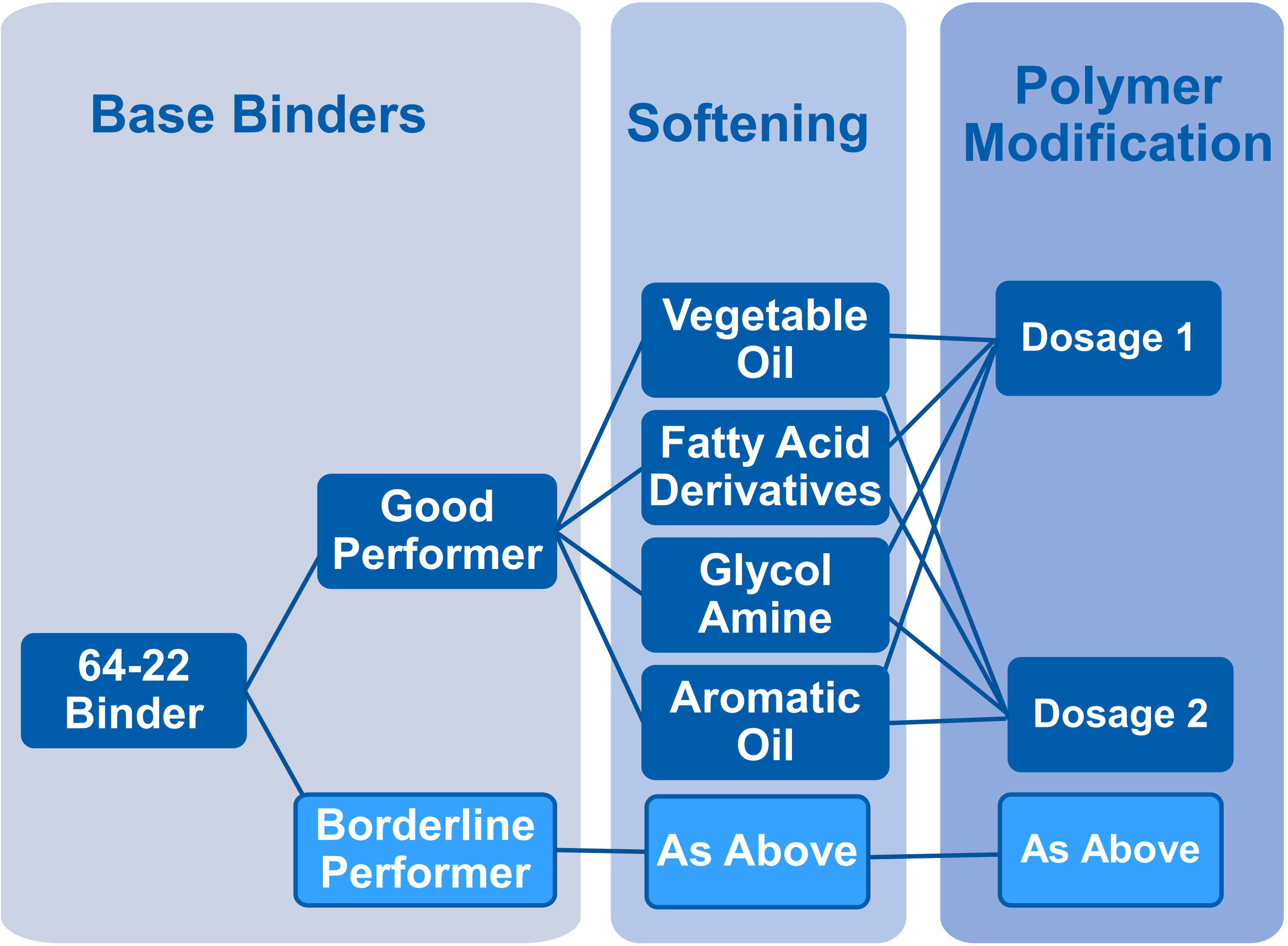
Binders: Base Binders

	Binder ID	1PAV ΔT_c	2PAV ΔT_c
Experimental (PG64-22)	G	0.8	-1.4
	B	-2.2	-7.6
Comparison (PG58-28)	58-28G	0.7	-3.2
	58-28B	0.0	-4.8



Binder Modification

- PG 64-22
- Modifications
  - Softener for low temperature (-22 to -28)
  - Polymer for high temperature (64 to 70/76)

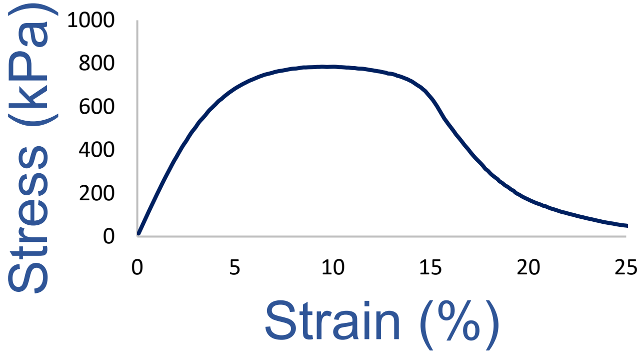


Binder Testing

1 Dynamic Shear Rheometer

- **Viscous** and **elastic behavior**
- **Medium to high temperatures**

3 Linear Amplitude Sweep (LAS)

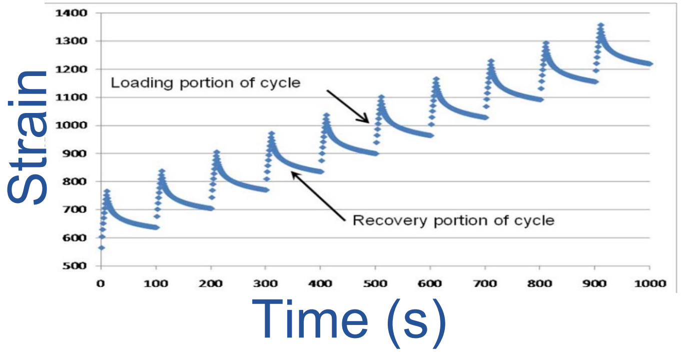


- **Fatigue resistance**

2 Bending Beam Rheometer

- **Low-temperature behavior**

4 Multiple Stress Creep Recovery



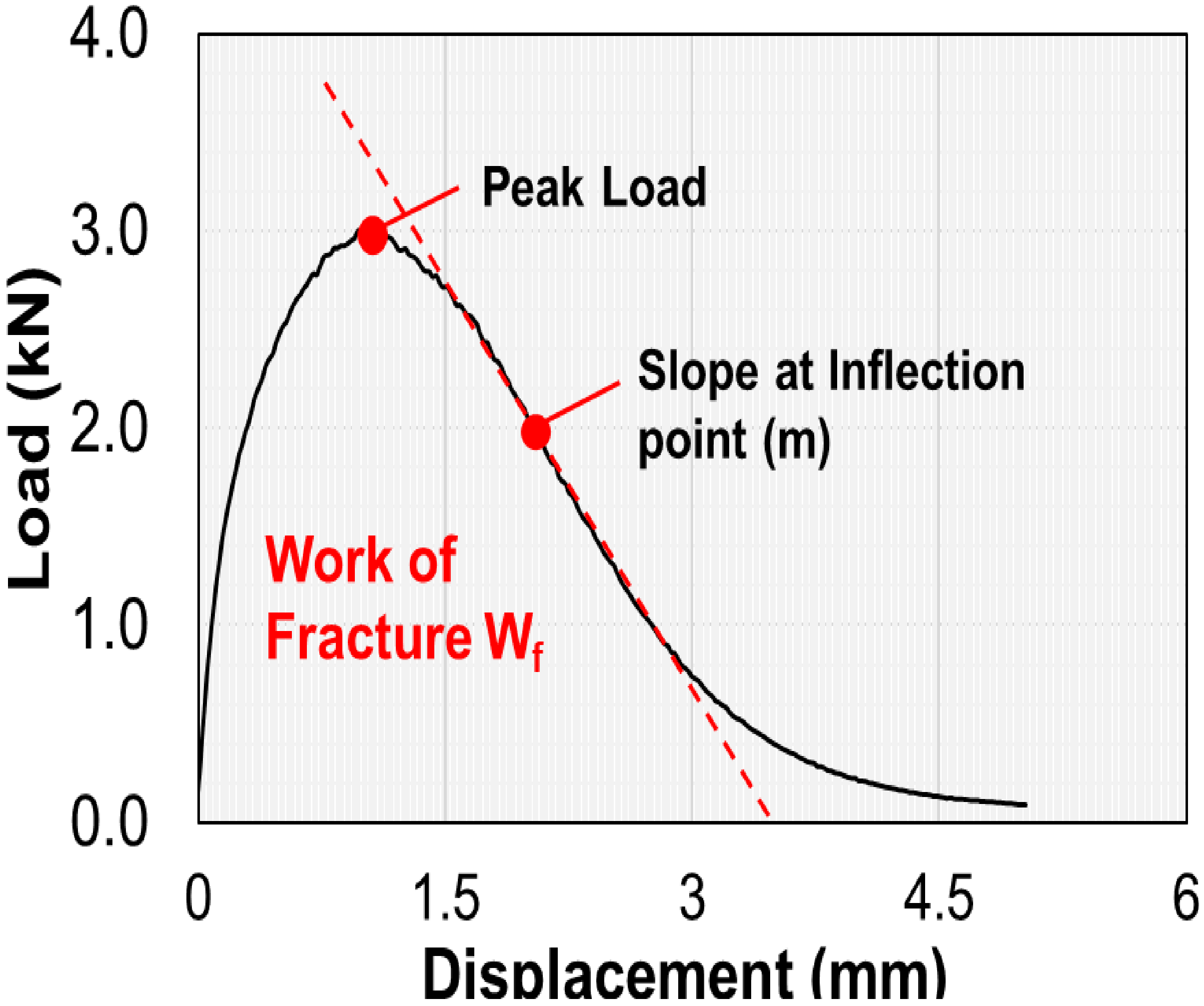
- **Rutting resistance**
- **Polymer identification**

Mixture: Types

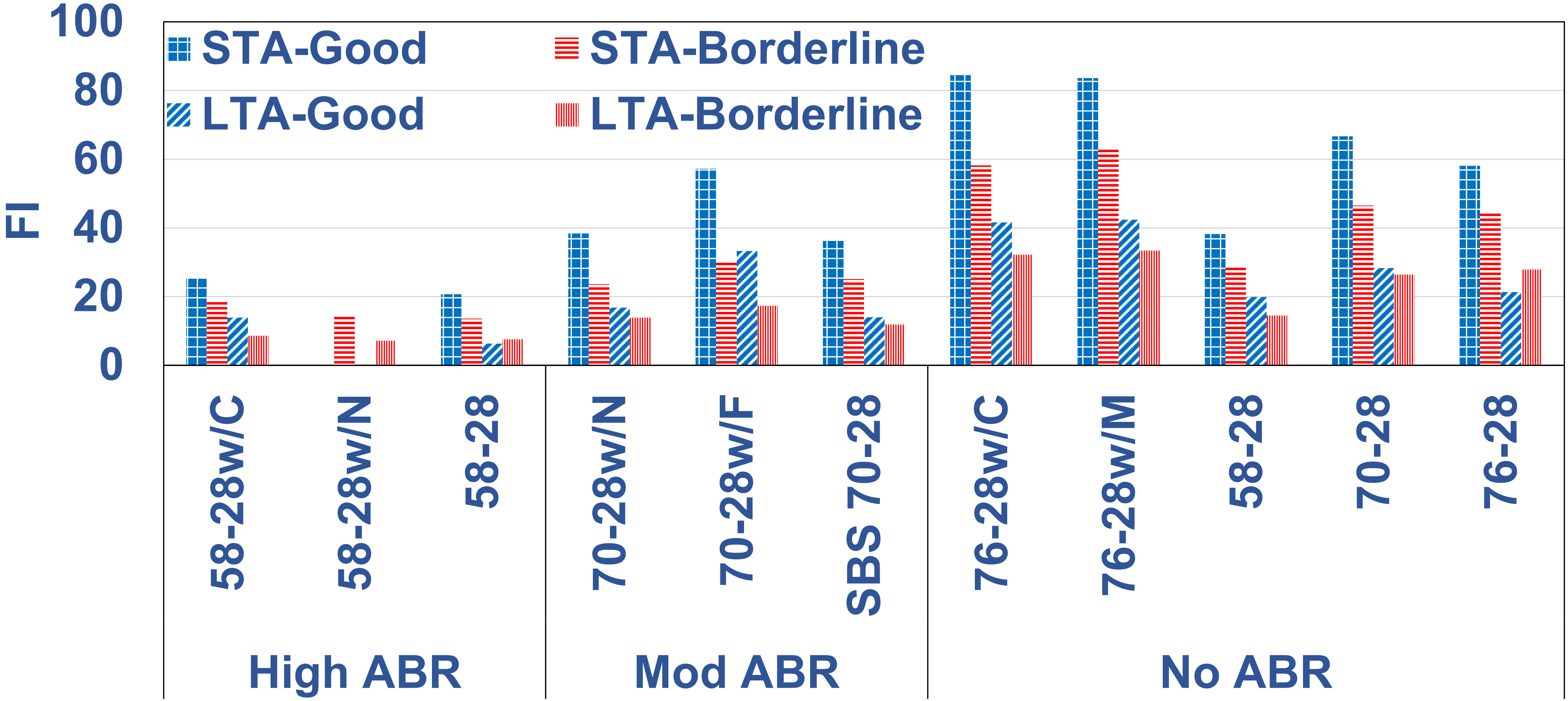
	Experimental	Comparison
Mix Design	**PG 64-22**	**PG 58-28**
High ABR (12)	PG 58-28 w/ Modifier C	
	PG 58-28 w/ Modifier N	
		Neat PG 58-28
Moderate ABR (12)	SBS PG 70-28 w/ Modifier N	
	SBS PG 70-28 w/ Modifier F	
		SBS PG 70-28
No ABR (20)	SBS PG 76-28 w/ Modifier C	
	SBS PG 76-28 w/ Modifier M	
		Neat PG 58-28
		SBS PG 70-28
		SBS PG 76-28

- **Two Aggregate Types: A limestone based mix and traprock based mix**

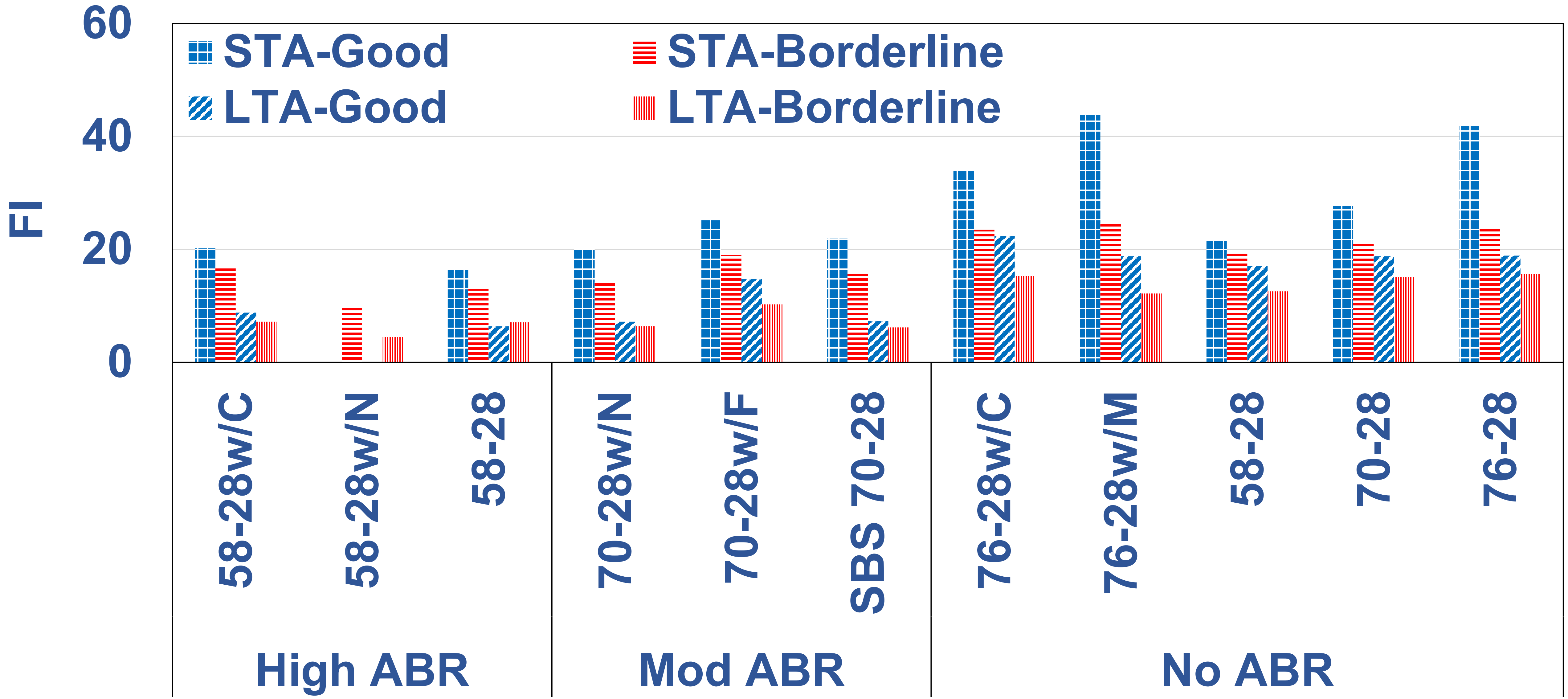
Cracking Potential (I-FIT)



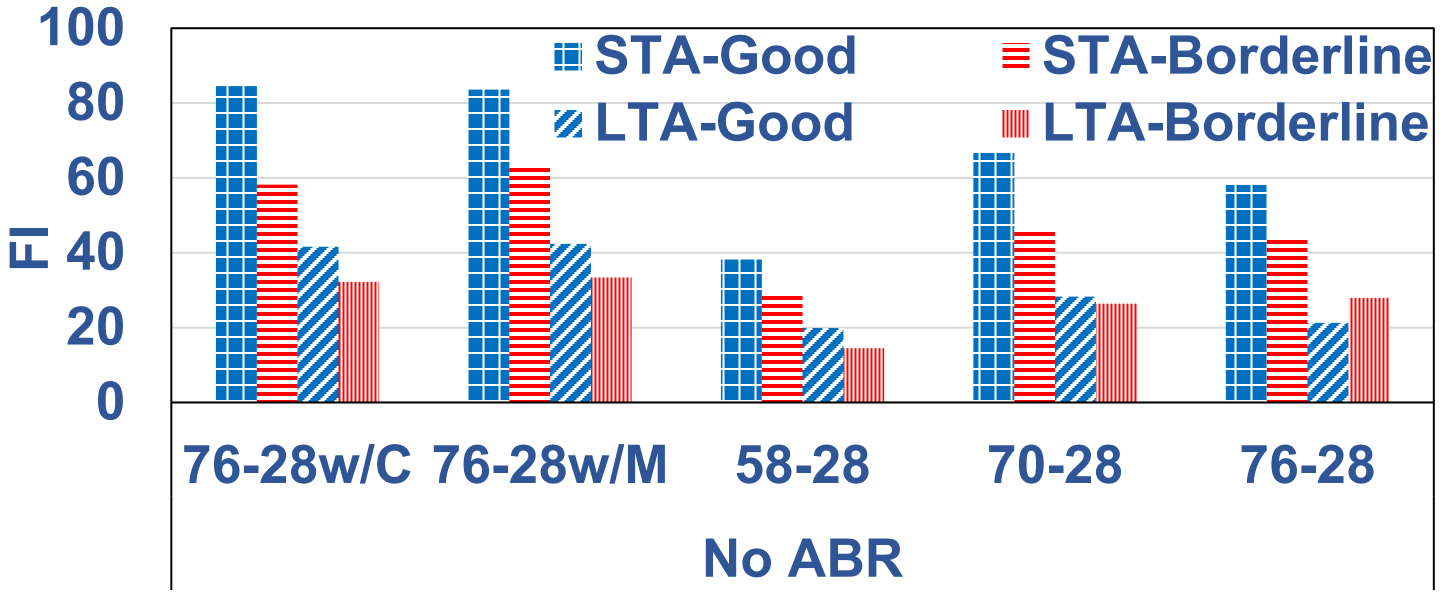
Limestone Mixes: Good Binder, Better Performance!



TrapRock Mixes: Good Binder Better Performance!

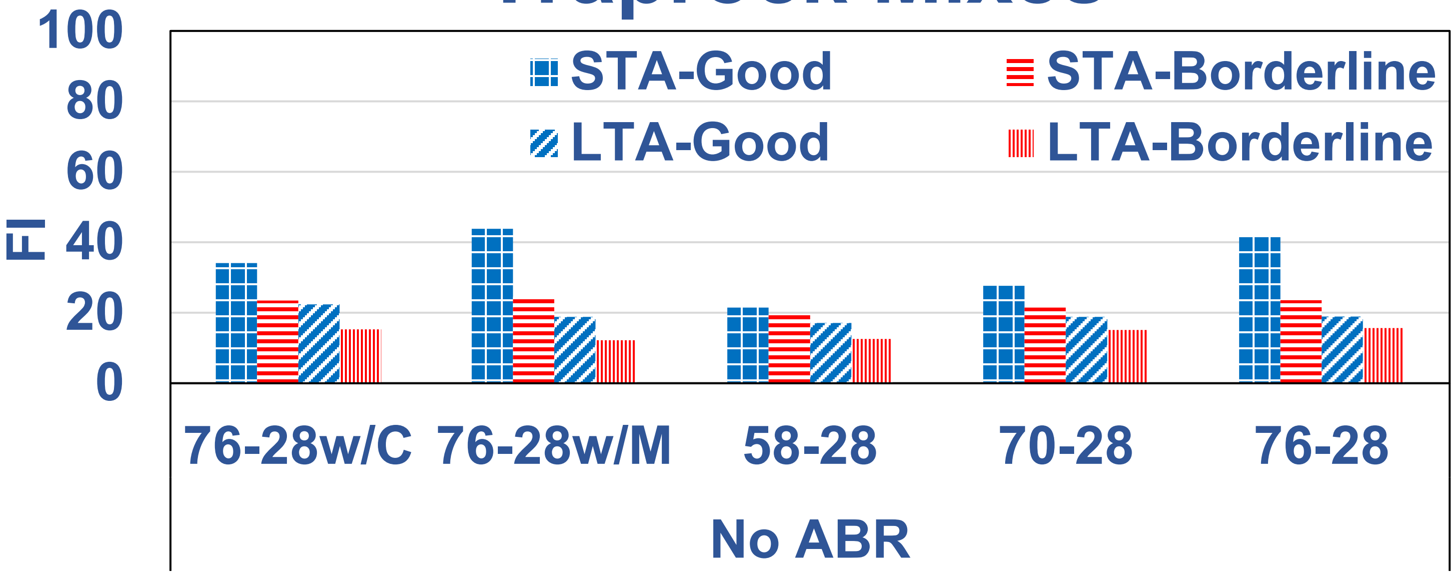


Mix Design and Aggregate Affect FI

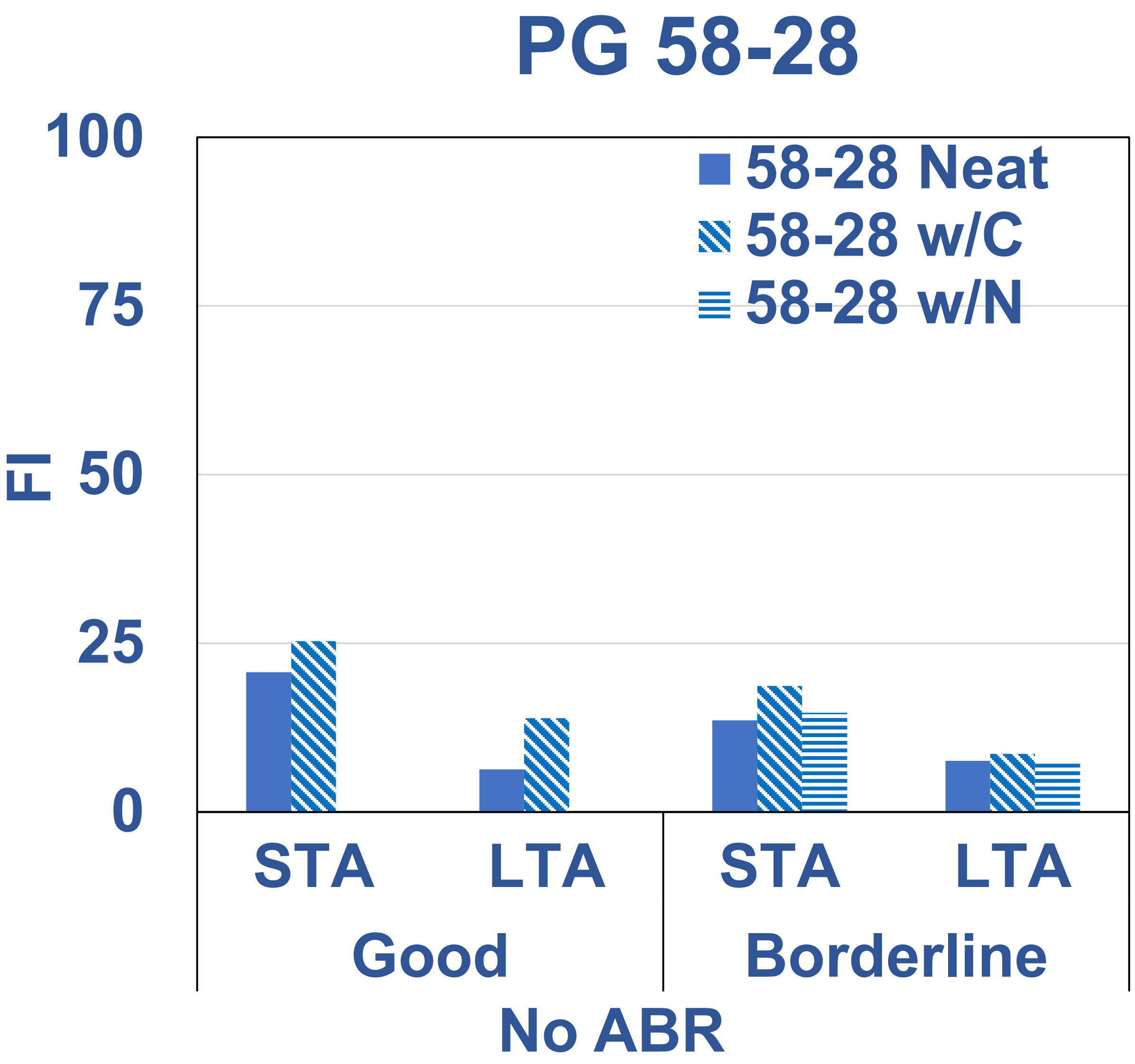


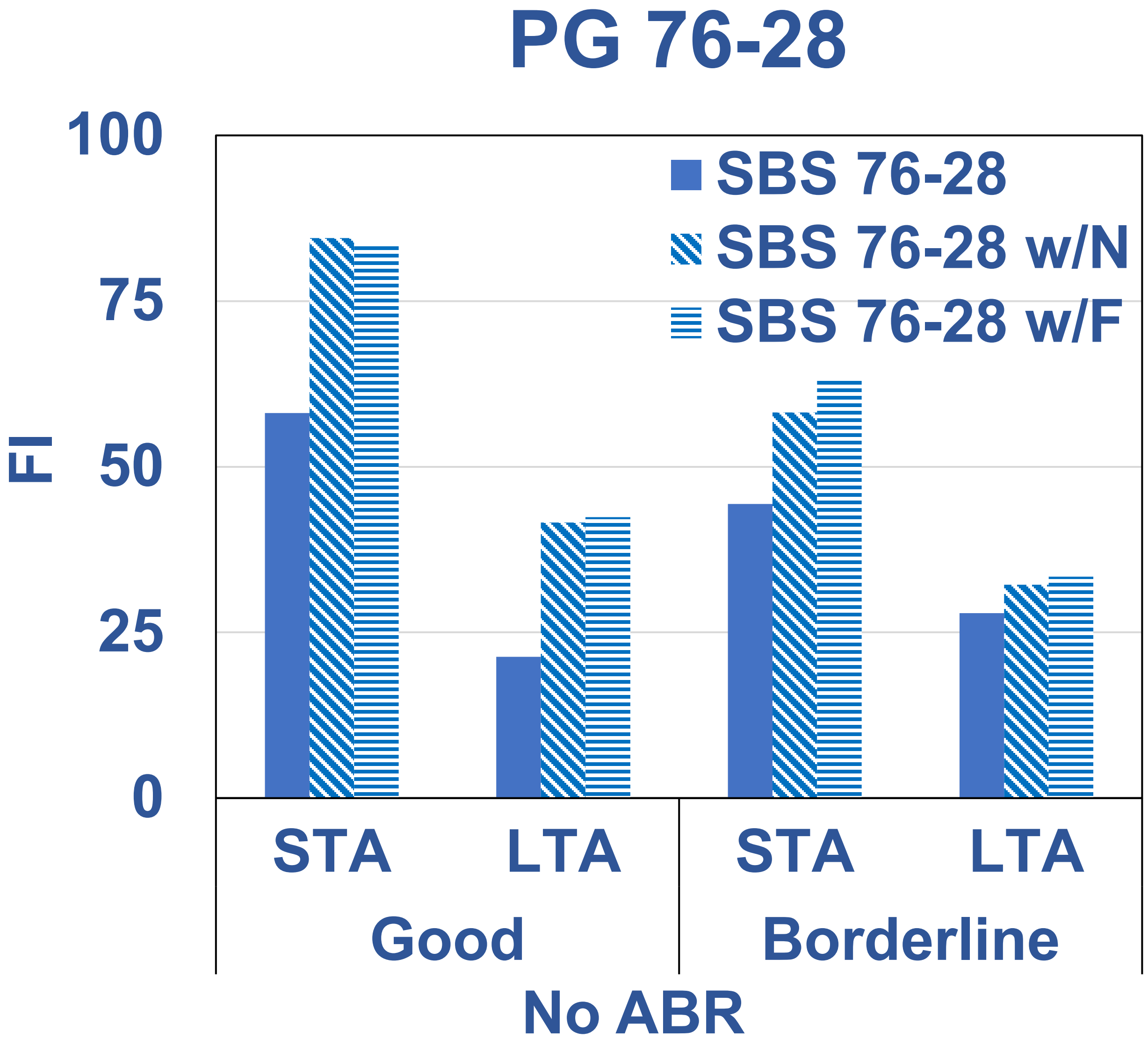
Limestone Mixes

Traprock Mixes

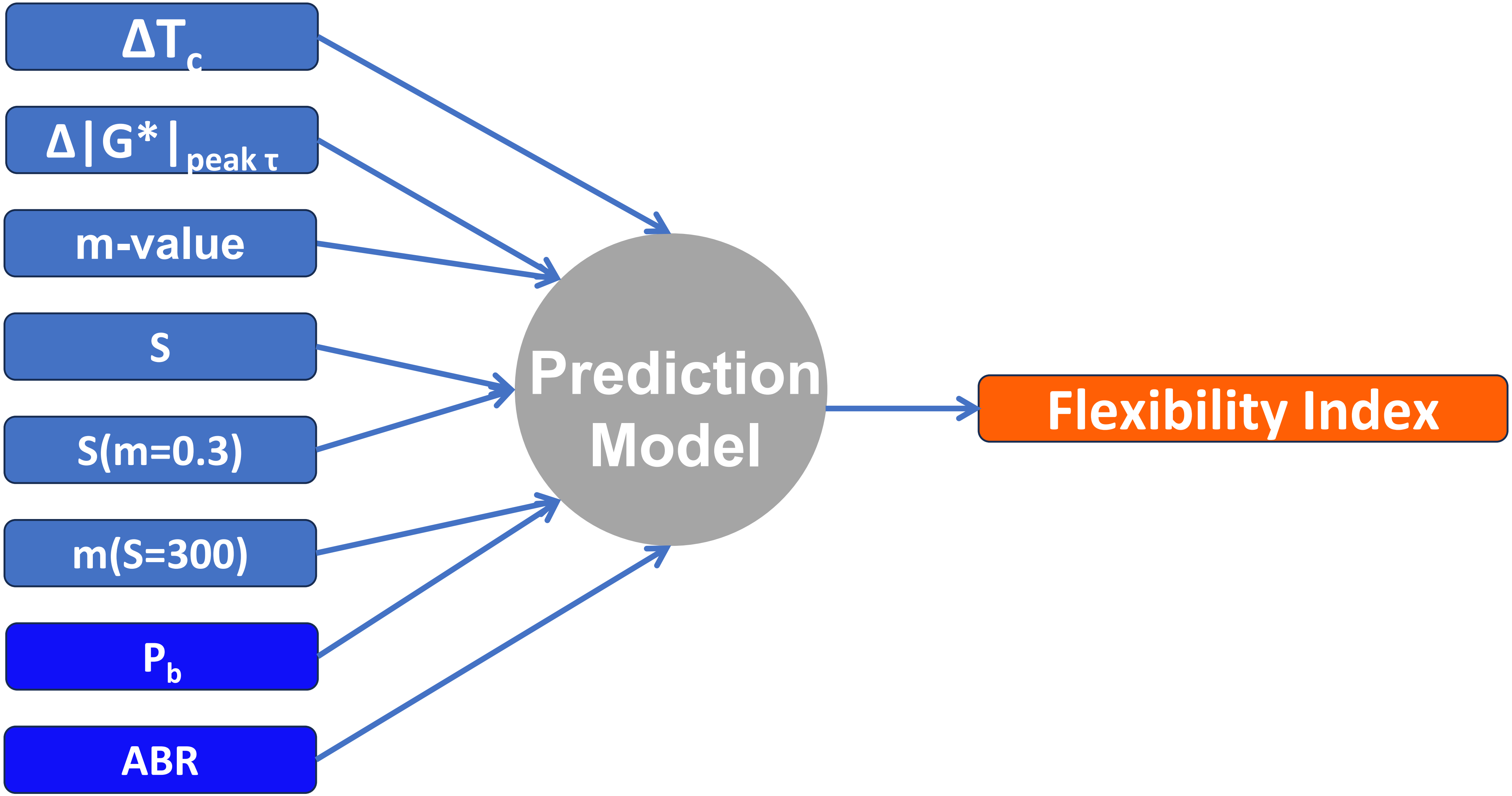


Modifiers Increased FI





Statistical Analysis: Input and Output Parameters



No strong Correlation between Individual Variables

$\Delta|G|_{peak\ T}$ shows strongest correlation with G_f

Metrics		1PAV				2PAV			
		ΔT_c	$\Delta\|G^*\|_{peak\ T}$	S(m=0.3)	m(S=300)	ΔT_c	$\Delta\|G^*\|_{peak\ T}$	S(m=0.3)	m(S=300)
STA	G_f	0.14	0.29	0.11	0.12	0.45	**0.57**	0.45	0.32
	FI	0.12	**0.10**	0.11	0.13	0.17	0.20	0.17	0.08
	Slope	−0.04	−0.09	0.02	0.00	−0.23	−0.16	−0.21	−0.2
	Strain	0.10	0.25	0.05	0.06	0.42	0.48	0.41	0.32
LTA	G_f	0.15	0.18	0.09	0.11	0.47	**0.60**	0.46	0.34
	FI	0.04	**0.24**	−0.00	0.01	0.16	**0.54**	0.12	0.09
	Slope	−0.03	0.19	−0.03	−0.04	−0.06	0.30	−0.10	−0.06
	Strain	0.18	−0.01	0.14	0.16	0.43	0.15	0.45	0.34

Variable Screening Framework

- **Considered Inputs:**
  - Binder: $\Delta|G^*|_{peak\ \tau}$, S, m, ΔT_c
  - Mix: P_b, ABR, Number of Gyrations (N_{des}).
- **Transformations Applied:**
  - Square, log, exponential, inverse, etc.
- **Screening Constraints**
  - One variable from each collinear group (e.g., S or S^2)
  - Variance Inflation Factor < 5 (multicollinearity check)
  - $R^2 > 0.70$

Statistical Analysis: Predictive FI model

Aging	Input Variables	σ^1_{input}	$\sigma^2_{residual}$	R^2	R^2 (cross validation)
STA FI (1PAV)	$\Delta\lvert G^*\rvert_{peak\ \tau}$, P_b, N_{des}, ABR, logS, logm	0.55	3.61	**0.77**	0.64
LTA FI (2PAV)	$\Delta\lvert G^*\rvert_{peak\ \tau}$, P_b, N_{des}, S, logm, 1/ABR	0.47	2.41	**0.84**	0.76

σ^1_{input} → variability of input parameters

$\sigma^2_{residual}$ → model residual variance

FI Prediction Uncertainty and Risk Estimation

FI Prediction

- Input: Binder and mix design variables (e.g., S-value, $\Delta|G|_{peak\ \tau}$, ABR content, P_b)
- Output: Predicted FI (STA / LTA)

Total Prediction Uncertainty

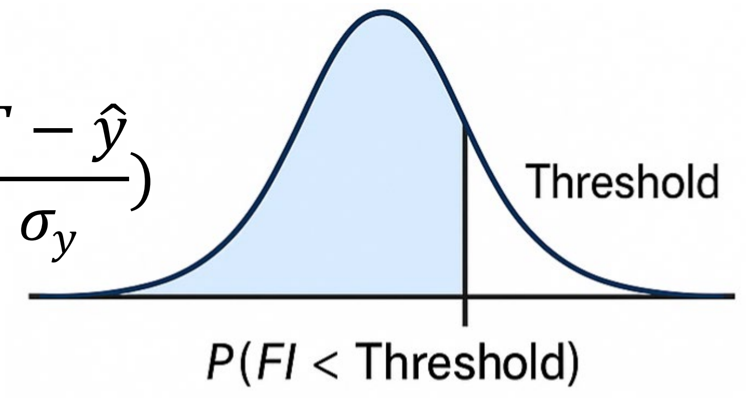
- Method: Error propagation via
- 1st-order Taylor expansion

$$\sigma_y = \sqrt{\sum_{i=1}^{p} (\beta_i^2 \cdot \sigma_{x_i}^2) + \sigma_{residual}^2}$$

Risk Estimation (One-Tailed)

- Compute P(FI<Threshold)
- Assumption: Normally distributed errors
- Threshold: STA = 8.0; LTA = 5.0

$$= \Phi(\frac{T - \hat{y}}{\sigma_y})$$

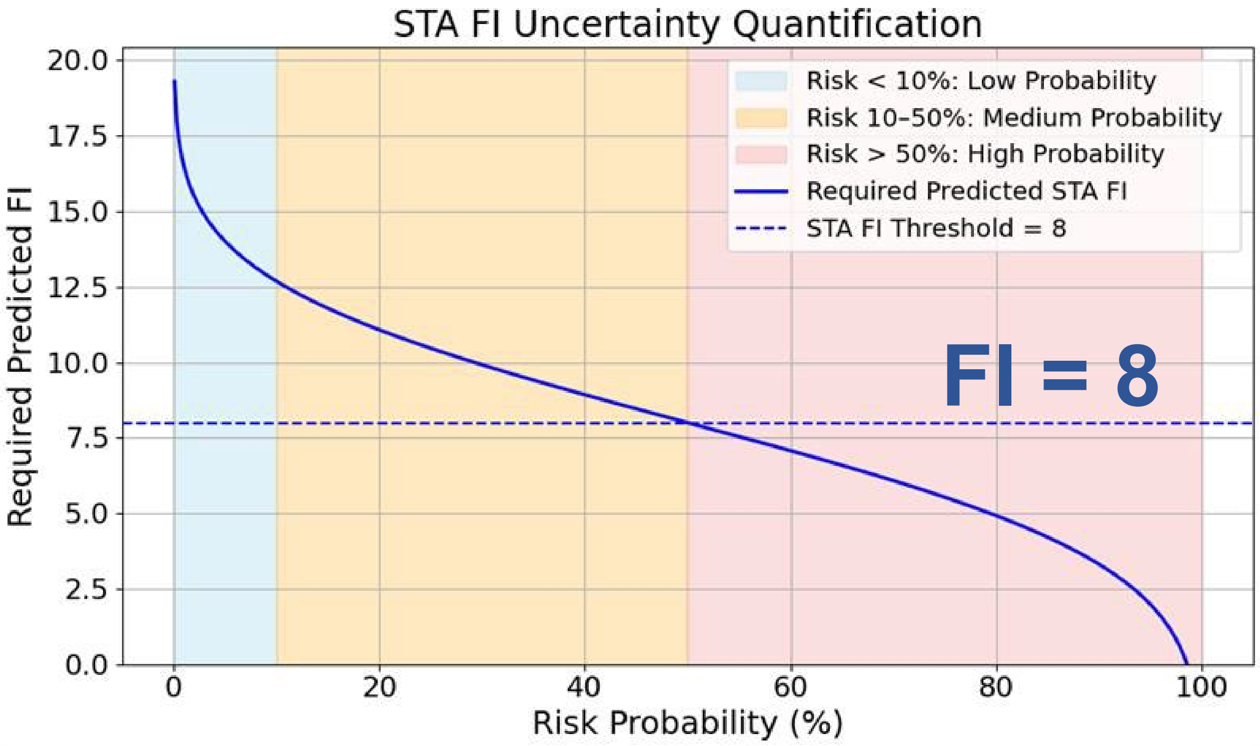


FI Prediction Uncertainty and Risk Estimation

Risk Level per Threshold Decision

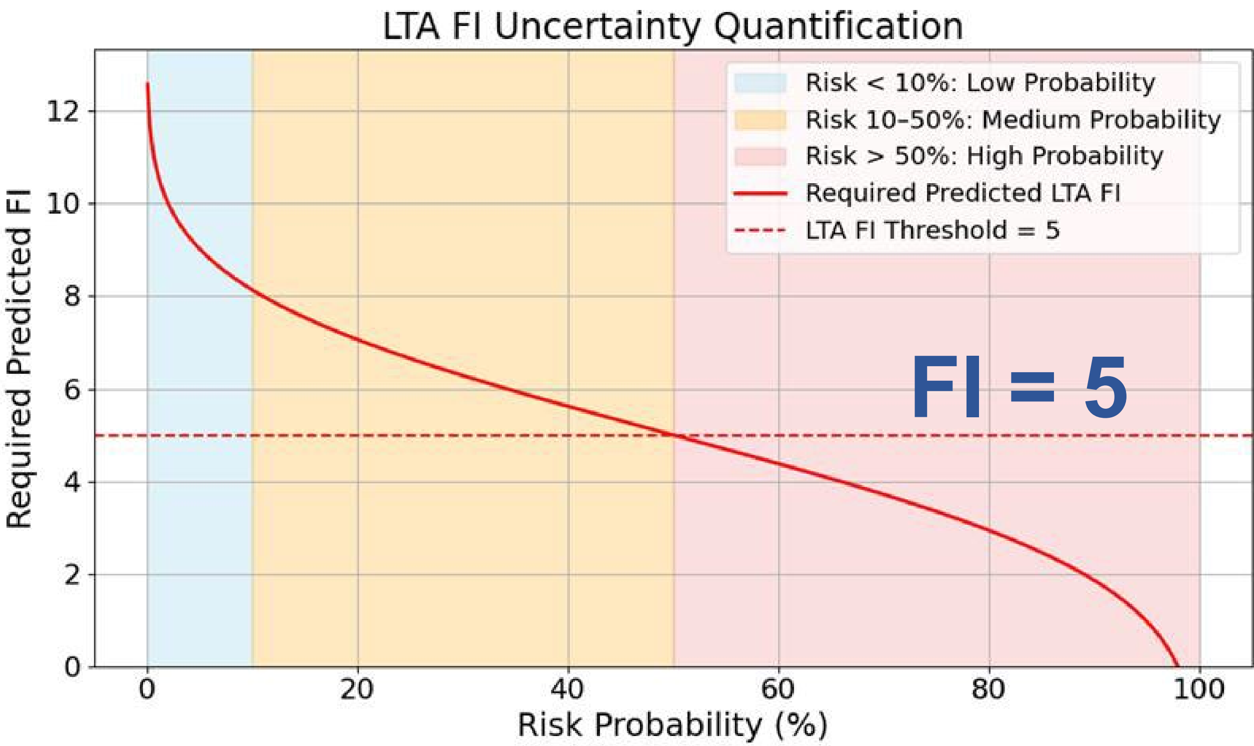
Risk	STA FI Value		LTA FI Value		Interpretation
	With $\Delta\|G^*\|_{peak\ \tau}$	Without $\Delta\|G^*\|_{peak\ \tau}$	With $\Delta\|G^*\|_{peak\ \tau}$	Without $\Delta\|G^*\|_{peak\ \tau}$	
> 50%	< 8.0	< 8.0	< 5.0	< 5.0	High Risk
10%–50%	8.0-12.7	8.0-12.7	5.0-8.1	5.0-8.6	Medium Risk
< 10%	>12.7	>12.7	>8.1	>8.6	Low Risk

FI Prediction Uncertainty and Risk Estimation



STA FI

LTA FI



Statistical Analysis: Demo

DEMO: https://binderselection.web.illinois.edu/Test

Summary

Binder rheology, in combination mixture/volumetric properties, can reliably predict HMA cracking potential through the FI, and the proposed risk-based framework makes the prediction directly usable for engineering decisions

IDOT IMPLEMENTATION PLAN

Kelly Senger, Chief Chemist, IDOT Central Bureau of Materials

Illinois Department of Transportation

IDOT Implementation of ICT Projects:

- R27-SP63, Data Analysis and Review of Multiple Stress Creep and Recovery (MSCR) vs. Performance-graded High temperature Test Results, Including Binder Elastic Behavior/Response

- R27-250, Using Advanced Binder Rheological Parameters to Predict Cracking Potential of Hot-Mix Asphalt Mixtures with Modified Binders

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R27-SP63, Data Analysis and Review of Multiple Stress Creep and Recovery (MSCR) vs. Performance-graded High temperature Test Results, Including Binder Elastic Behavior/Response

- IDOT requested a Special Project to evaluate years of IDOT collected MSCR data to transition from Elastic Recovery (ER).
- IDOT Source specific data to ensure new MSCR implementation represents currently qualified materials
- Allow IDOT to join the Regional movement towards MSCR

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R27-250, Using Advanced Binder Rheological Parameters to Predict Cracking Potential of Hot-Mix Asphalt Mixtures with Modified Binders

- IDOT project request to study the performance, stability and compatibility of Polymer and Softener Modification used in combination.
- This project was a continuation of work previously performed to establish IDOT's allowance of softener modifiers.
- Performance of polymer/softener modified binders in HMA
  - Cracking
  - Rutting

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BDE SPECIAL PROVISION

Special Provision for Performance Graded Asphalt Binder

DRAFT

BDE for PG Asphalt Binder

Regional Engineers

Jack A. Elston

Special Provision for Performance Graded Asphalt Binder

January 1, 2026

This special provision was developed by the Central Bureau of Materials to transition from Elastic Recovery (ER) to Multiple Stress Creep Recovery (MSCR) and add to the allowable asphalt binder modifications. The changed to MSCR will ensure the proper polymer content and characterize the polymer modified binder rutting resistance. The addition of polymer/softener combination modification will increase the options available to asphalt binder sources to achieved the performance expectations established for PG asphalt binder.

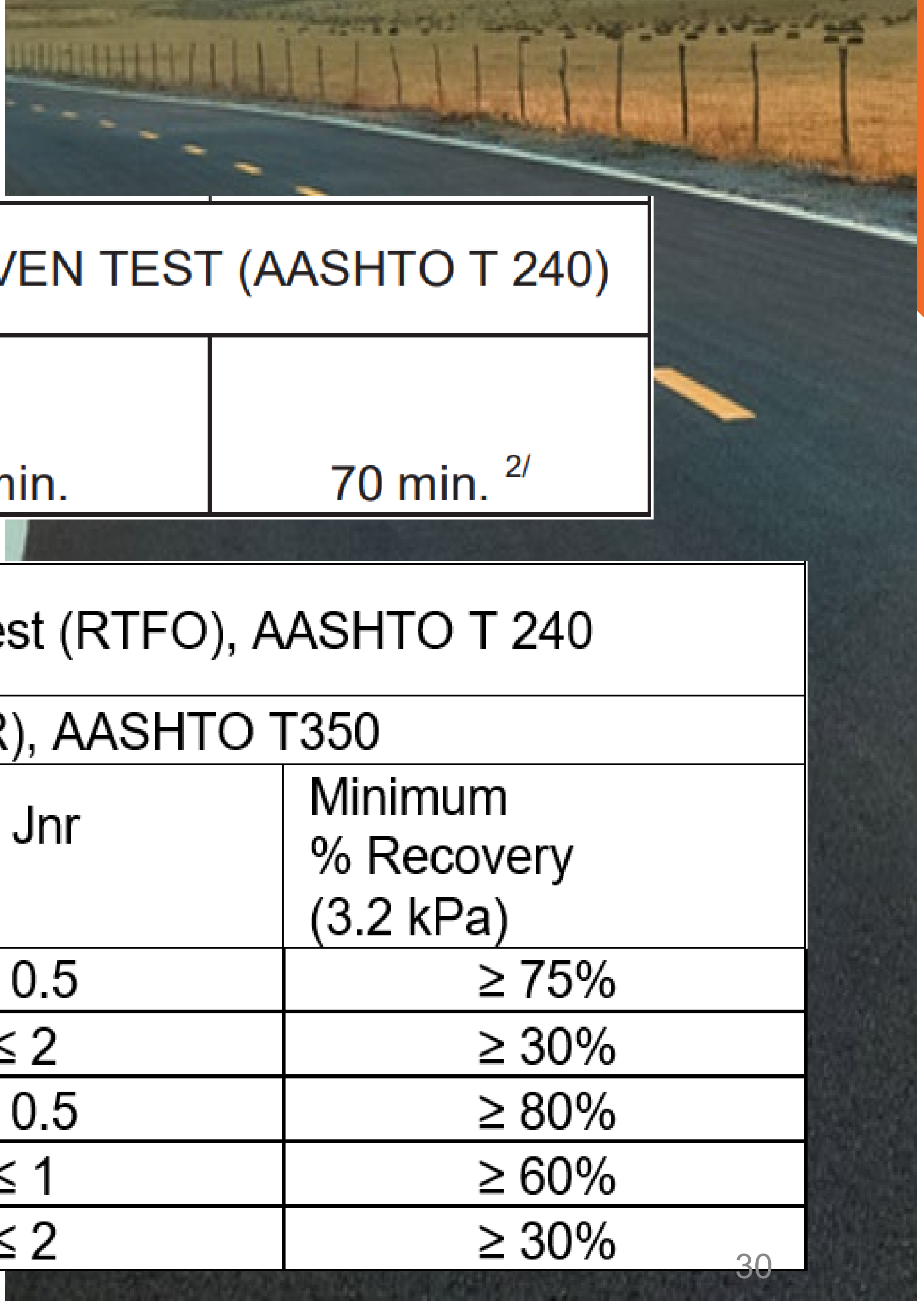
Special Provision for Performance Graded Asphalt Binder

- Changes are still in review with Industry!
- Transition from Elastic Recovery to Multiple Stress Creep Recovery
- Addition of Polymer/Softener Combination Modification
- Removes polymer modifier: styrene butadiene rubber (SBR) due to lack of use

Transition from ER to MSCR

TESTS ON RESIDUE FROM ROLLING THIN FILM OVEN TEST (AASHTO T 240)		
Elastic Recovery ASTM D 6084, Procedure A, 77 °F (25 °C), 100 mm elongation, %	60 min.	70 min. [2/]

Tests on Residue from Rolling Thin Film Oven Test (RTFO), AASHTO T 240			
Multiple Stress Creep Recovery (MSCR), AASHTO T350			
Asphalt Grade	Test Temperature (^oC)	Maximum Jnr (3.2 kPa)	Minimum % Recovery (3.2 kPa)
SBS 76-22	64^o C	≤ 0.5	≥ 75%
SBS 70-22		≤ 2	≥ 30%
SBS 76-28	58^o C	≤ 0.5	≥ 80%
SBS 70-28		≤ 1	≥ 60%
SBS 64-28		≤ 2	≥ 30%

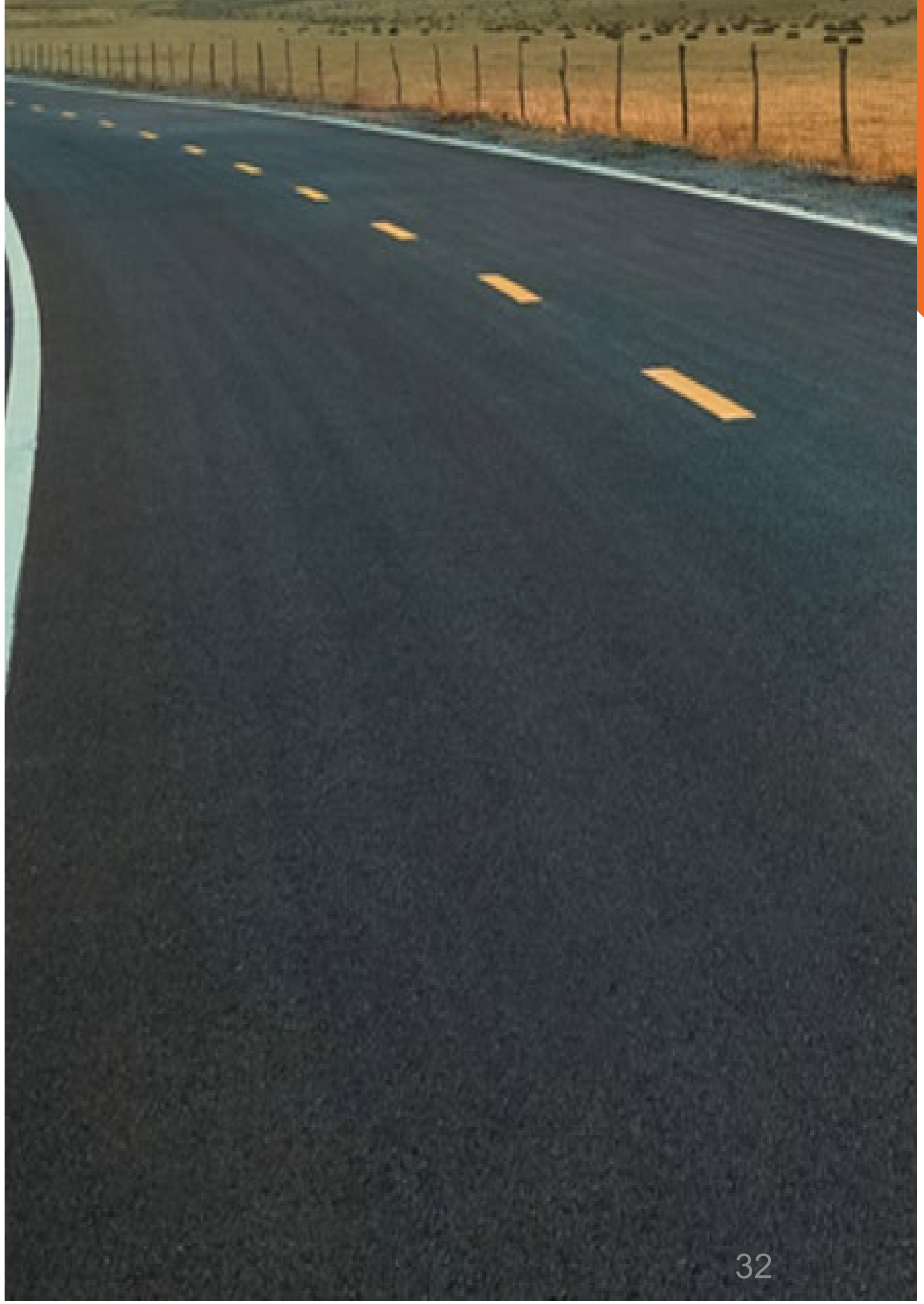


Elastic Recovery (ER)

- Request from Industry to move from ER to MSCR
- Uses AASHTO T240 RTFO residue
- ASTM D6084- Standard Test Method for Elastic Recovery of Asphalt Materials by Ductilometer
  - Time consuming test
  - Questionable characterization of polymer performance

Multiple Stress Creep Recovery (MSCR)

- Specification developed based on IDOT Source specific data
- Consultation with Combined State Binder Group (CSBG) participants MSCR specifications
- IDOT nomenclature, but close correlation with AASHTO M332 specifications
- Coordinating implementation with Industry Partners IAPA, Asphalt Institute and Tollway



Polymer/Softener Modification Combination

- ICT R27-250 project demonstrated the performance, stability and compatibility of Polymer and Softener Modification
- MSCR evaluation added to ensure polymer performance with the use of softener modifiers
- Project tied the rheological and performance properties of poly/softener combination modified binders to HMA performance.

Addition of Polymer/Softener Modification

(4) Polymer/Softener Modification (SBS/SM). Polymer/Softener modification is the addition of organic compounds, such as engineered flux, bio-oil blends, modified vegetable oils, amines, and fatty acid derivatives, used in combination with SBS modified PG asphalt binder as modified in accordance with 1032.05 (b)(1) to achieve the specified performance grade. Polymer/Softeners shall be compatible with each other and dissolved, dispersed, or reacted in the asphalt binder to enhance its performance and shall remain compatible with the asphalt binder with no separation. Polymer/Softeners shall not be added to modified PG asphalt binder as defined in Article 1032.05(b)(2).

Polymer/Softener Modification

<table>
<tr><th colspan="4">Table 4 - Requirements for Polymer/Softener Modified (SBS-SM) Asphalt Binders</th></tr>
<tr><td colspan="2">Test</td><td colspan="2"></td></tr>
<tr><td colspan="2">Separation of Polymer
ITP, "Separation of Polymer from Asphalt Binder"
Difference in °F (°C) of the softening point between top and bottom portions</td><td colspan="2">4 (2) max.</td></tr>
<tr><td colspan="4">Tests on Residue from Rolling Thin Film Oven Test (RTFO), AASHTO T 240</td></tr>
<tr><td colspan="4">Multiple Stress Creep Recovery (MSCR), AASHTO T350</td></tr>
<tr><td>Asphalt Grade</td><td>Test Temperature (°C)</td><td>Maximum Jnr (3.2 kPa)</td><td>Minimum % Recovery (3.2 kPa)</td></tr>
<tr><td>SBS-SM PG 76-22</td><td rowspan="2">64° C</td><td>≤ 0.5</td><td>≥ 75%</td></tr>
<tr><td>SBS-SM PG 70-22</td><td>≤ 2</td><td>≥ 30%</td></tr>
<tr><td>SBS-SM PG 76-28</td><td rowspan="3">58° C</td><td>≤ 0.5</td><td>≥ 80%</td></tr>
<tr><td>SBS-SM PG 70-28</td><td>≤ 1</td><td>≥ 60%</td></tr>
<tr><td>SBS-SM PG 64-28</td><td>≤ 2</td><td>≥ 30%</td></tr>
<tr><td colspan="2">Small Strain Parameter (AASHTO PP 113) BBR, ΔTc, 40 hrs PAV (40 hrs continuous or 2 PAV at 20 hrs)</td><td colspan="2">-5°C min.</td></tr>
<tr><td colspan="2">Large Strain Parameter (Illinois Modified AASHTO T 391) DSR/LAS Fatigue Property, Δ|G*|peak τ, 40 hrs PAV (40 hrs continuous or 2 PAV at 20 hrs)</td><td colspan="2">≥ 60 %</td></tr>
</table>

Polymer/Softener Modifier
Unaged, 20 Hr. PAV, 40 Hr. PAV

An Attenuated Total Reflectance-Fourier Transform Infrared spectrum (ATR-FTIR) shall be collected for both the polymer and the softening compound as well as the polymer/softener modified asphalt binder at the dose intended for qualification. The ATR-FTIR spectra shall be collected on unaged polymer/softener modified binder, 20-hour Pressurized Aging Vessel (PAV) aged polymer/softener modified binder, and 40-hour PAV aged polymer/softener modified binder. The ATR-FTIR shall be collected in accordance with Illinois Test Procedure 601. The electronic files spectral files (in one of the following extensions or equivalent: *.SPA, *.SPG, *.IRD, *.IFG, *.CSV, *.SP, *.IRS, *.GAML, *.[0-9], *.IGM, *.ABS, *.DRT, *.SBM, *.RAS) shall be submitted to the Central Bureau of Materials.

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QUESTIONS?