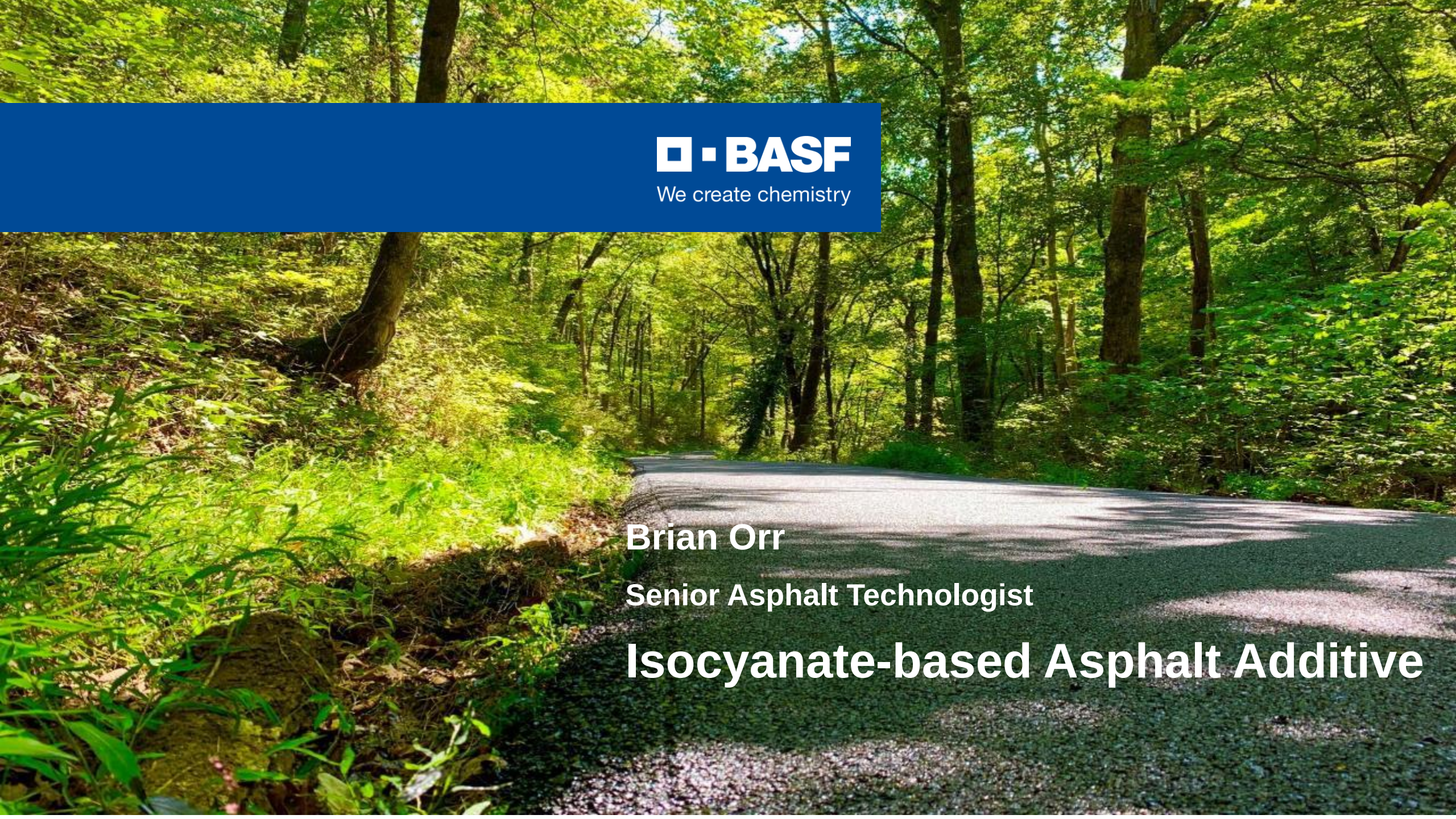
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Brian Orr
Senior Asphalt Technologist
Isocyanate-based Asphalt Additive

Agenda

Study Background

Research Project 1 — Binder Study and Assessment

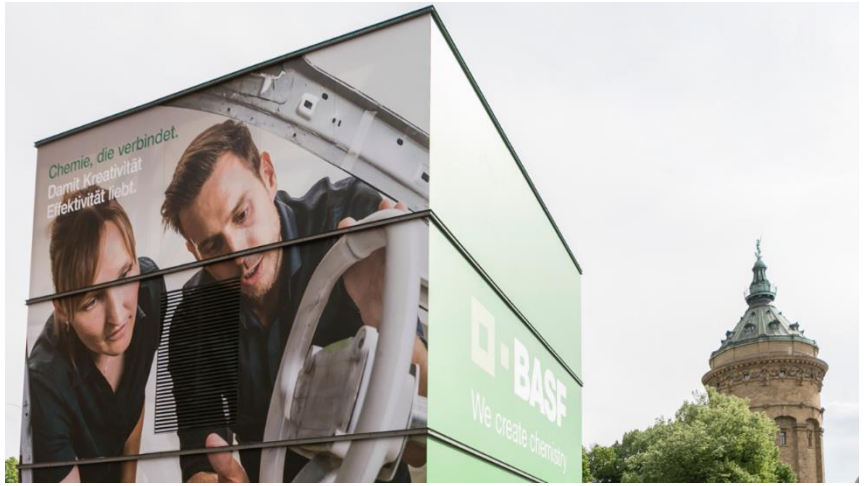
- PG Grading and UTI

Research Project 2 — Paving Trials

- Rutting & Cracking

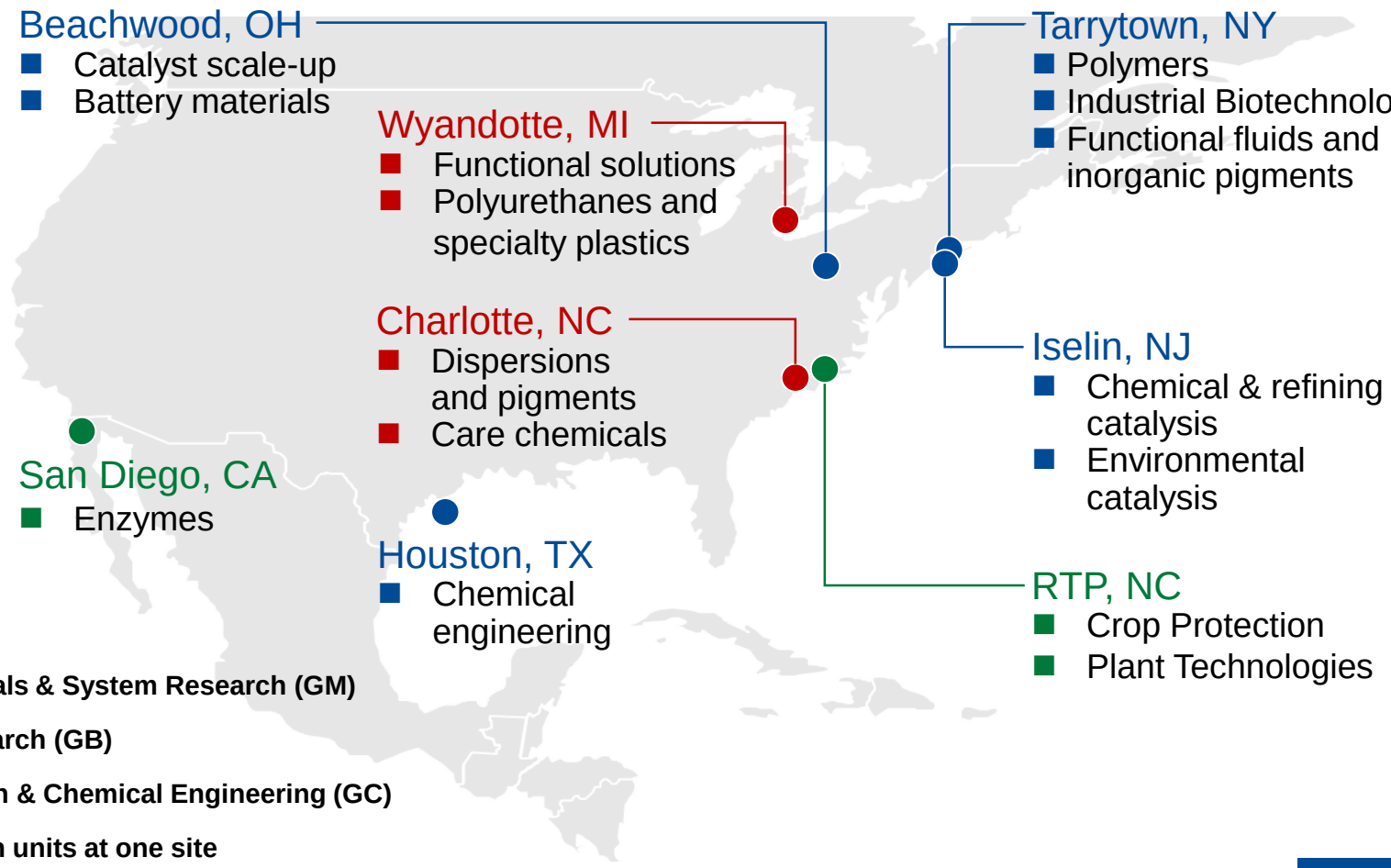
Research Project 3 — Formulation Study and Assessment

- SBS + Isocyanate-based Modification



Conclusion

BASF Study Sponsor Located In Wyandotte, MI



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Study Background

1. Asphalt has been modified since the 1960s to improve performance.

2. However, only a limited number of modifiers are approved in asphalt.

3. Use of alternative modifiers might yield several benefits.
   - Less disruption in construction due to shortage of modifiers
   - Improved performance
   - Reduced maintenance costs

PERFORMANCE MODIFIERS & ADDITIVES FOR IMPROVED SERVICE LIFE

Improve Binder Performance

Modifiers & Additives	Generic Examples	Applications
Elastic Polymers	SBS Block Copolymers SBR Latex & Natural Latex SB Diblock Reactive Terpolymers	Increase Binder Stiffness and Elasticity
Plastomers	Polyethylene & Other Alkenes Ethylene Vinyl Acetate (EVA) Ethylene propylene	Increase Binder Stiffness
Chemical Modifiers	Polyphosphoric Acid (PPA)	Increase Binder Stiffness
Organic Materials	Gilsonite	Increase Binder Stiffness
Low Temperature Modifiers	REOB Hard and natural asphalts Aromatic Oil Tall Oil Bio-based Oils	Reduce Low Temperature Stiffness
Recycle Materials	Ground Tire Rubber	Can Affect Elasticity

- Source: AMAP Modifier Brochure

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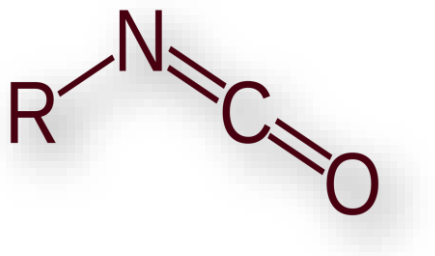
Reactive Modifiers Show Great Promise in Asphalt

Current Reactive Polymers used as alternative modifiers in asphalt

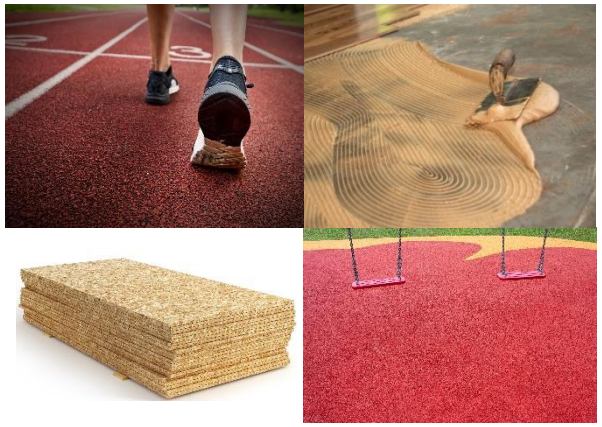
- **Reactive Terpolymers**
- **Reactive Copolymers**
- **Selected Epoxies**

Isocyanate-based reactive modifiers

- Can these modifiers improve binder properties?
- Can these modifiers make binders equivalent to or better than conventionally modified binders?



Isocyanate-based Chemistry is Very Flexible



Common Industries & Applications

Construction	Spandex (textile)	Tire Fill
Appliance	Fertilizer	Pipe Liners
Footwear	Automotive	Cast Elastomers
Synthetic leather	Roofing	Packaging

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Polyurethanes – Excellent Functional Properties

	Polyurethanes	Plastics	Rubber	Metal
Impact Resistance	+	-		
Elastic Properties (shape retention)	+	-		
Resilience (Rebound)	+	-		
Low Temperature Resistance	+	-		
Abrasion Resistance	+	-	-	
Load Bearing Capacity	+		-	
Chemical/Corrosion Resistance	+		-	-
Weight	+			-
Noise	+			-
Wear	+			-

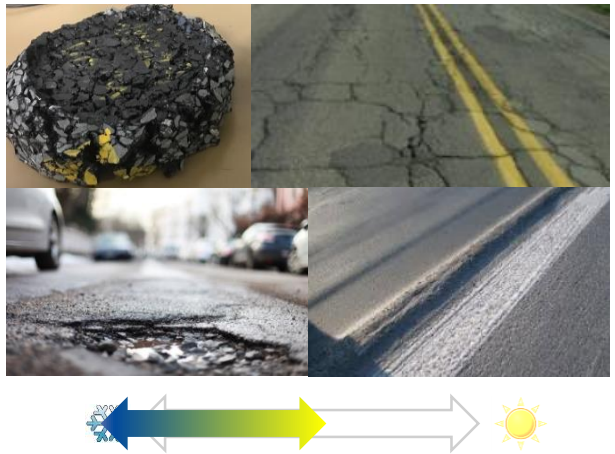
Isocyanate-based Asphalt Modification– A New Paradigm

Current modification paradigm	**Isocyanate-based** modification paradigm
ELASTOMER & PLASTOMER	**ADHESIVE**
DRY SOLID	**LIQUID**
INCREASES VISCOSITY	**LOW VISCOSITY**
BLENDED & CAN SEPARATE	**REACTIVE & DOES NOT SEPARATE**
THERMOPLASTIC	**THERMOSET**

Isocyanate-based chemistries demonstrate utility in asphalt applications

Isocyanate-based Modification Improves Functional Properties

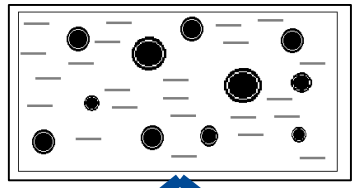
unmodified



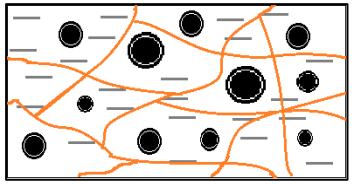
Isocyanate-based modification

- **Isocyanate-based modification uses crosslinking** instead of physical mixing – increased binder performance and durability
- **Isocyanate-based modification improves binder performance** – lower deformation of asphalt at high temperatures and same properties at low temperatures

Paving grade binder

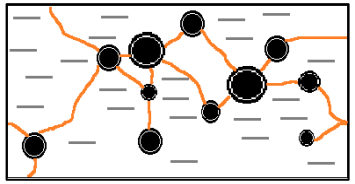


Physical mixing



Standard asphalt modifiers

Crosslinking



Isocyanate-based Modifier

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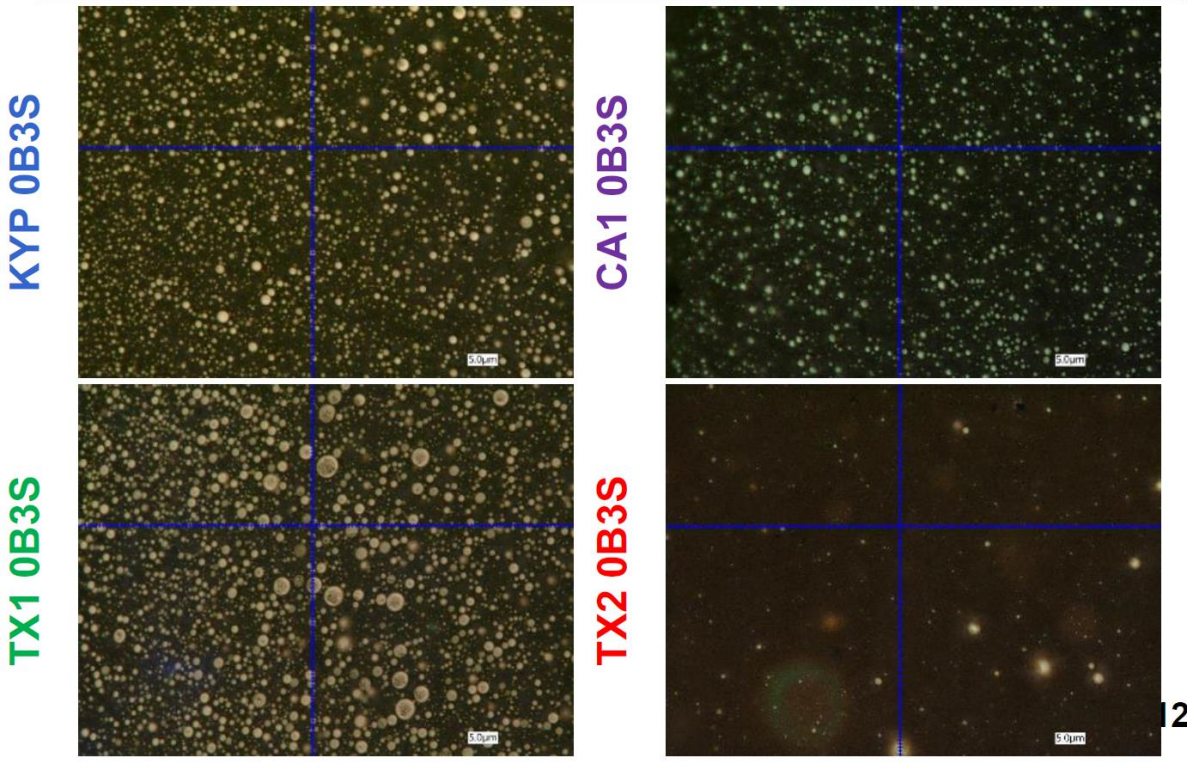
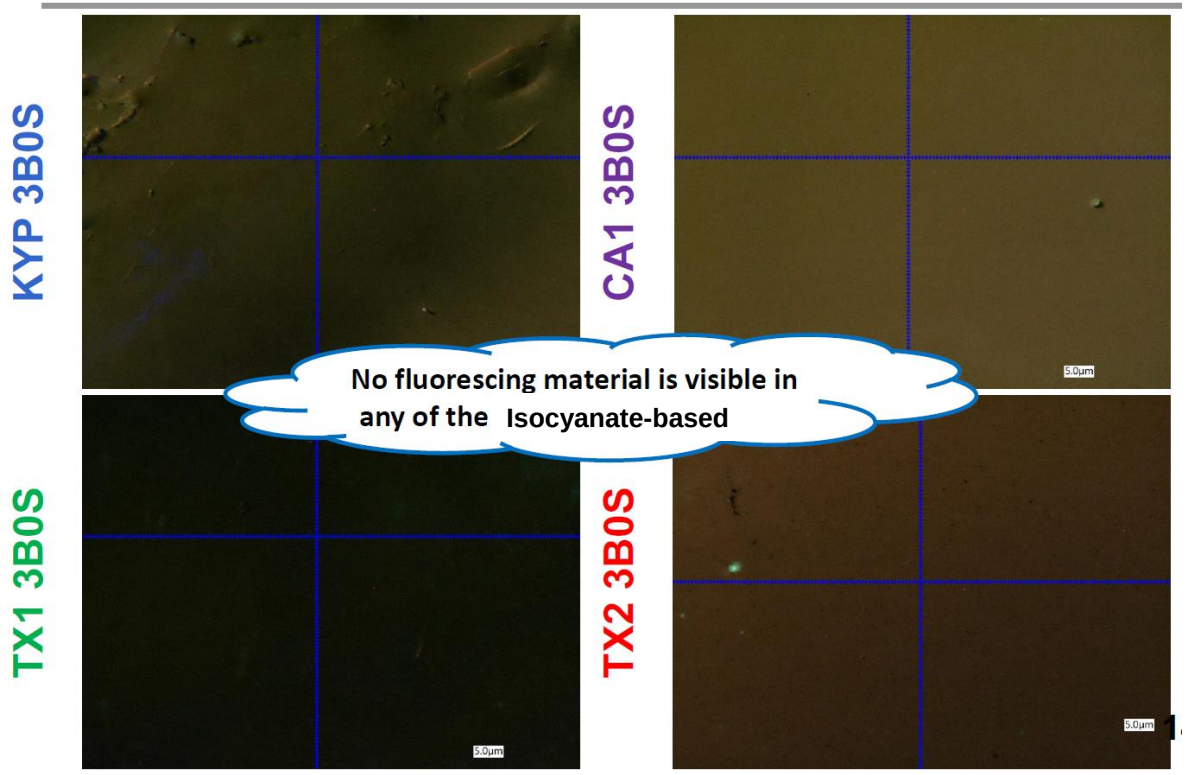
3% SBS or 3% Isocyanate-based Modification

WesternResearch INSTITUTE *UV Fluorescence Microscopy Images*



WesternResearch INSTITUTE *UV Fluorescence Microscopy Images*



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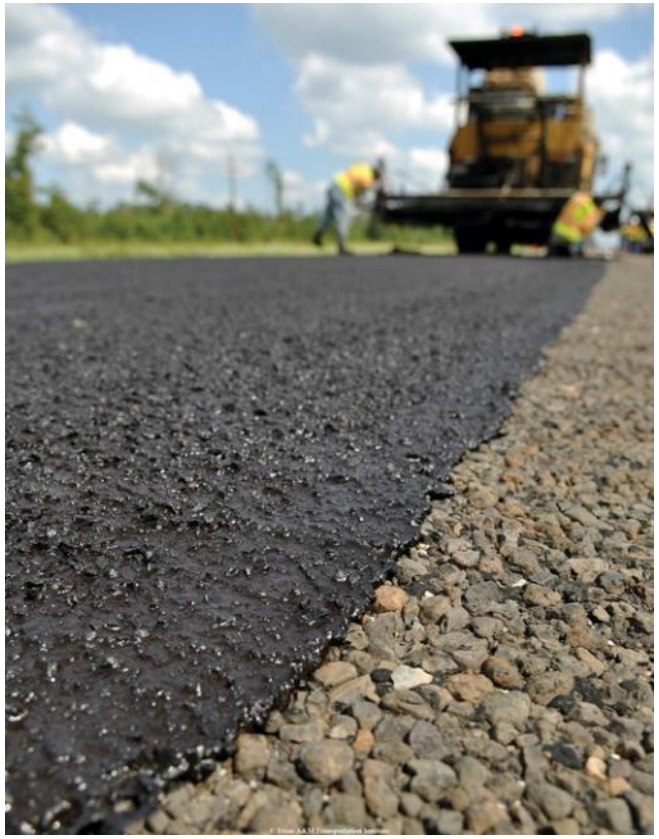
Binder Study and Assessment



2019 Petersen Asphalt Research Conference Summary

TTI RESEARCH TEAM:
Pravat Karki, PI
Edith Arámbula Mercado, PI
David E. Newcomb, Sr. PI

Western Research INSTITUTE

Texas A&M Transportation Institute

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TTI Research Objectives

Evaluate the performance of binders modified with SBS and binders modified with isocyanate-based modifier.

- Performance Grade
- UTI Expansion

Determine optimum dosage of isocyanate-based modifier that would yield similar binder properties as SBS.

Solid Asphalt Modifier

Liquid Asphalt Modifier

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TTI Experimental Materials

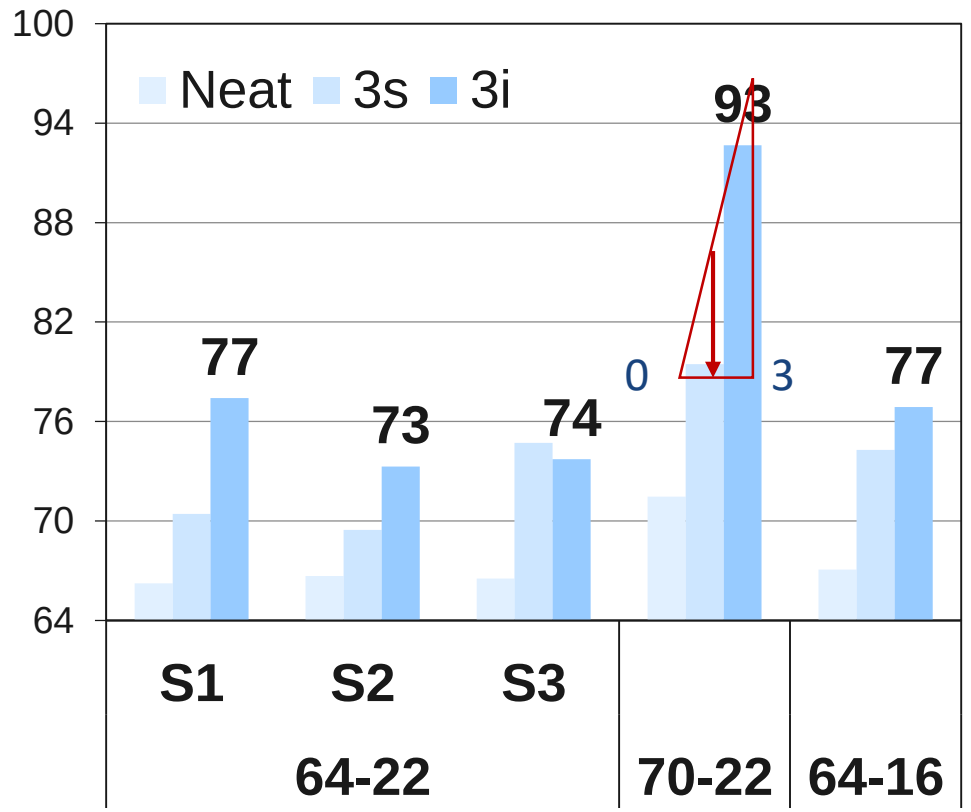
Binders	Modification	Aging	Tests
PG **64-22:** S1 PG **64-22:** S2 PG **64-22:** S3 PG 70**-22**: S4 PG **64**-16: S5	0% (Control) 3% SBS: *s* 3% Isocyanate: *i*	Unaged RTFO + PAV0 RTFO + PAV20	PG-High PG-Low

PG Testing: High Temperature

High temperature continuous grade

- Increased with SBS
- Increased more with isocyanate-based

Lower % isocyanate-based modification could yield equivalent high temperature PG.

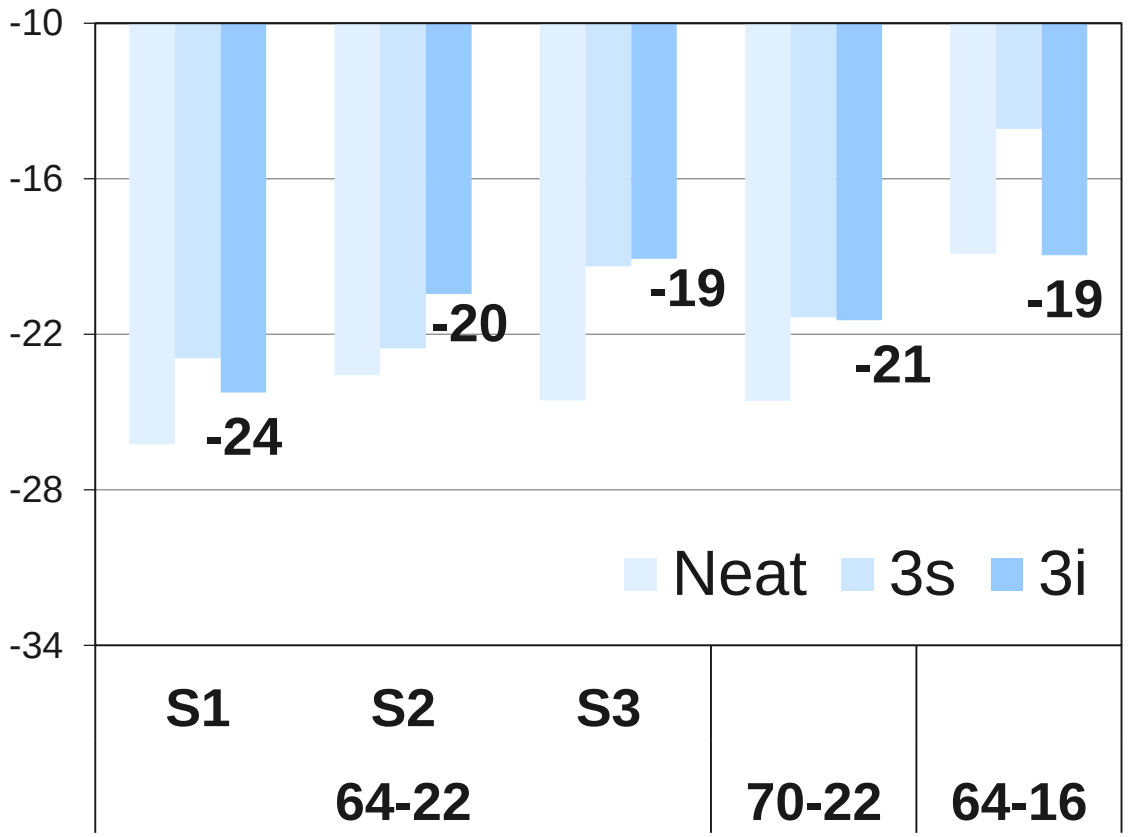


PG Testing: Low Temperature

Low temperature continuous grade

- Similar effects from SBS and isocyanate-based modifier

Lower % of isocyanate-based modifier could yield equivalent low temperature PG.

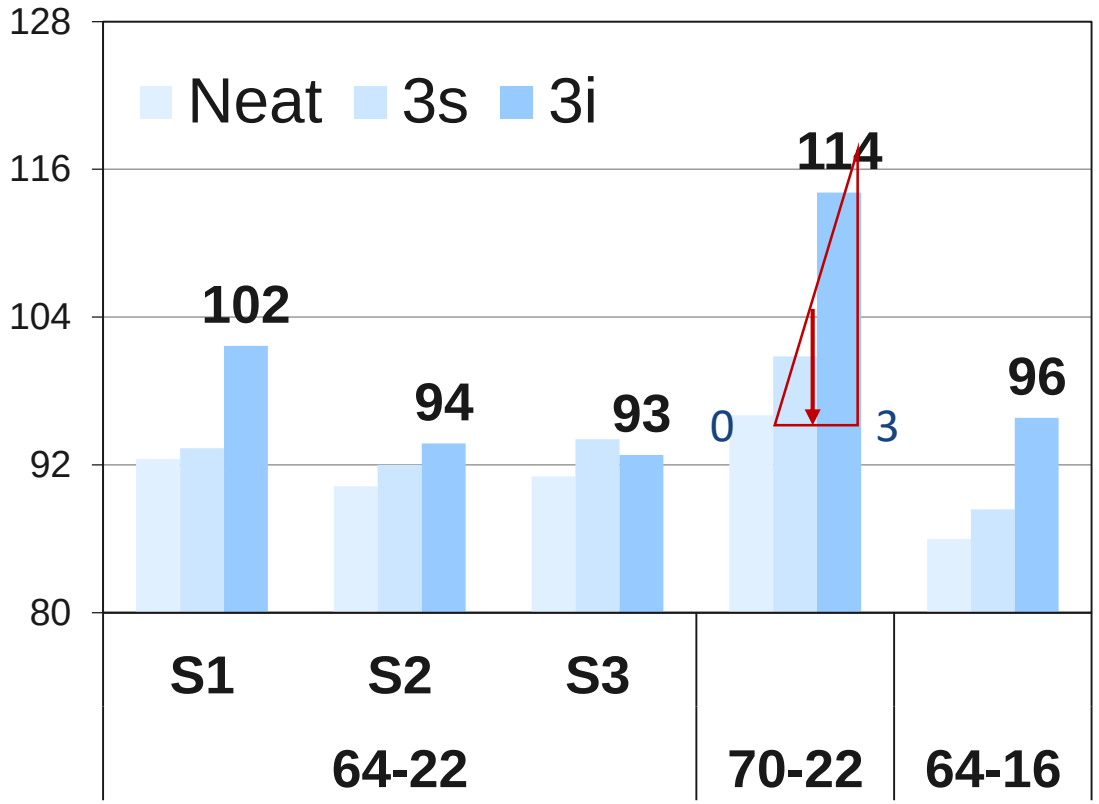


PG Testing: Useful Temperature Range

Useful Temperature Interval (UTI)

- Greater increase with Isocyanate-based modifier than with SBS at equivalent loading

Lower % isocyanate-based modifier could yield equivalent UTI.



TTI Conclusions

3% Isocyanate-based modifier compared to 3% SBS:

- Increased PG equivalent to same or more than SBS
- Increased UTI to equivalent to same or more than SBS

It may be possible to use less % of isocyanate-based modifier to achieve results equivalent to 3% of standard modification.

Paving Trials

Establishing Operational Feasibility

Summer & Fall 2019

BATT BLANKENSHIP ASPHALT TECH & TRAINING
Lab-to-Pavement Innovation

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Evaluating Operational Feasibility of Isocyanate-based Modification

Asphalt Terminal

Mix Plant

Construction

Stability
Mixing time
Reheat/recycle

Pumpability
Aggregate interaction
Stiffness

Performance
Compaction
Sticking/rolling

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2019 Isocyanate-based Paving Trials in Europe and North America

Jun 2019 – Bavaria

- PWC site at A96
- 230 m, one layer
- First public paving

Sep 2019 – Westphalia

- Regional road
- 100 m, two layers
- 2nd layer paved in Nov

Sep 2019 – Midwest 1

- Four rural roads
- 7 miles, one layer

Oct 2019 – Midwest 2

- Neighborhood road
- ½ mile one layer

Oct 2019 – Munich

- City Autobahn 96, 0.5 km
- Asphalt laydown at 140 °C instead of 170°C
- **Paving emissions reduced by 35-65%**

Anecdotal Feedback

"**Excellent workability** of mix while…, containing **50% reclaimed asphalt**"

"**Released well** from off-loader"

"**Less** asphalt **smell** and **odor**"

"Great **workability** of mix **at only 140 °C**"

Successful paving trials are crucial to assess environmental and paving conditions

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Rutting Assessment: Midwest 1 Paving Trial

Mixture	Air Voids (%)	Passes	Rut Depth, mm	Average
Control	7	20,000	3.32	3.4
12% RAP / 4% RAS			3.41	
Isocyanate-based modifier	7	20,000	4.04	3.9
12% RAP / 4% RAS			3.83	

Hamburg Wheel Tracker (HWT) @50°C with reheated field sample

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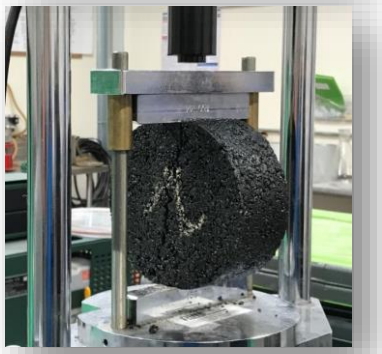
Cracking Assessment: Midwest 1 Paving Trial

Mixture	Air Voids (%)	Disp. (mm)	Post-Peak Slope (kN)	IDT Strength (kPa)	Fracture Energy, J/m^2	CT Index	Avg. CT Index	COV, %
Control	7.2	4.2	-4.1	867.6	6,658	45.7	41.6	6.6
	6.9	3.9	-4.2	901.6	6,696	41.8		
12% RAP / 4% RAS	7	3.9	-4.2	911.4	6,529	40.6		
	6.8	3.6	-4.5	984.7	7,109	38.1		
Isocyanate-based Modifier	6.8	4.5	-2.9	825.8	7,186	75.7	73.8	6.7
	6.5	4.9	-3.1	829.7	7,775	80.9		
12% RAP / 4% RAS	6.7	4.8	-3.2	845	7,031	69.6		
	6.9	4.6	-3.2	858.4	7,168	68.8		



IDEAL-CT at 25°C with reheated field sample

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Summary: Midwest 1 Paving Trial

County paving trial

- Compared PG 58-28 to same binder modified to PG 64-28
- Mix design: DOT design, all crushed aggregate
  - 12% RAP / 4 % RAS
- Same mix, only variable was adding isocyanate-based modifier

What was proven

- Normal paving, no surprises
- Little viscosity change when binder was modified
- No sticking, but very adhesive when cooled (tacky on shoes) → happy contractor
- Improvement in **IDEAL-CT (cracking resistance)**
- Similar **HWT** results (rutting/stripping)

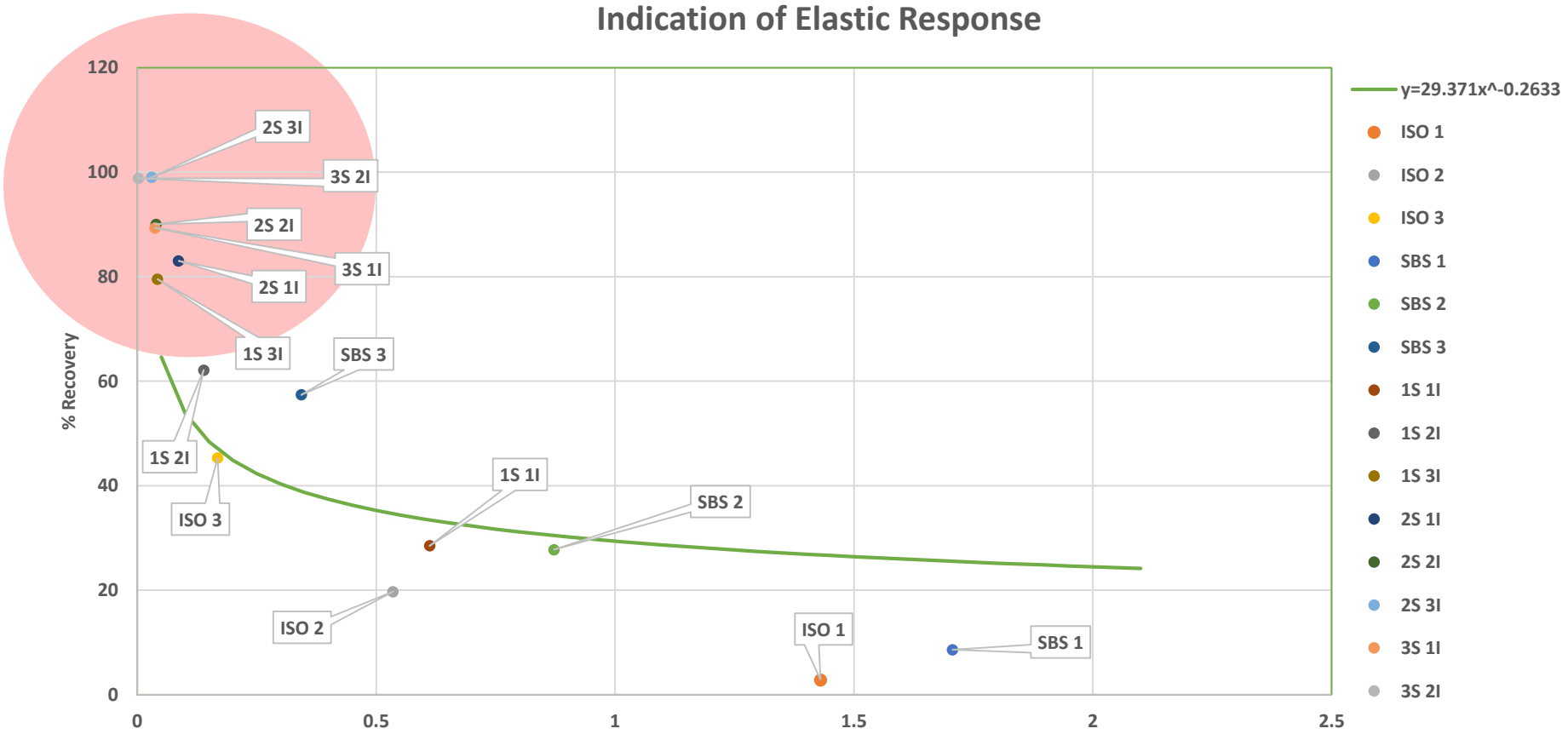
Formulation Study and Assessment

BASF Corporation Internal Study

Formulation Study: Isocyanate-based, SBS, and Combined (PG 64-22)

	Viscosity mPa.S (cP)	SHRP Grading	Temperature Range (°C)
Unmodified	404	64-22	91
1% Isocyanate-based Modifier	550	70-22	94
2% Isocyanate-based Modifier	675	70-22	97
3% Isocyanate-based Modifier	688	76-16	98
1% SBS	583	64-22	94
2% SBS	817	70-22	98
3% SBS	1138	76-22	101
1% SBS 1% Isocyanate-based Modifier	813	70-22	98
1% SBS 2% Isocyanate-based Modifier	938	76-22	105
1% SBS 3% Isocyanate-based Modifier	950	82-22	108
2% SBS 1% Isocyanate-based Modifier	1209	76-22	104
2% SBS 2% Isocyanate-based Modifier	1446	82-22	111
2% SBS 3% Isocyanate-based Modifier	1338	88-22	114
3% SBS 1% Isocyanate-based Modifier	1917	82-22	109
3% SBS 2% Isocyanate-based Modifier	2221	88-22	116

MSCR Results for SBS, Isocyanate-based, and Combined (PG64-22)



Key discovery: SBS + Isocyanate-based modification are highly complementary

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Isocyanate-based Modification Research Conclusions

Binder Improvements

1. SBS compatibility and enhancement.
2. Significantly increased UTI.
3. Does not separate when stored after modification.
4. Limited increase in viscosity after modification.
5. No change to Superpave testing and PG Grading.

Mix Improvements

1. Superior binder and aggregate adhesion.
2. IDEAL-CT cracking resistance improved.
3. Better HWT rutting and no stripping.
4. Improved compaction with less roller passes.
5. Less asphalt build-up on truck beds and/or hand tools.

Isocyanate-based modification is an extremely promising innovation for asphalt applications

Acknowledgements

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- Mr. Zachary McKay

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