Feasibility of Warm Mix Asphalt (WMA) in Arkansas

Presenter: Zahid Hossain, Ph.D. P.E.

Arkansas State University

Graduate Research Assistant: Mohammad Oyan

Project Sponsor: US DOT Through Tran-SET

Motivation

- WMA technologies can reduce mixing and compaction temperatures of Hot Mix Asphalt (HMA) ranging from 16 to 55 °C.
- Consequently, reduced energy consumption, less hazardous emission, better workplace environment, and extended paving season benefits are offered.
- However, performance data (additive-based) till now are not at hand for contexts of Arkansas. Oklahoma does use foam-based WMA.
- This study aims to generate such performance data based on laboratory tests of asphalt binder to reduce the research gap.

https://slidetodoc.com/warm-mix-asphalt-warren-carter-cassandra-simpson-andrew/

https://www.rasmussengroup.com/grimesasphalt/solutions/warm-mix-asphalt/

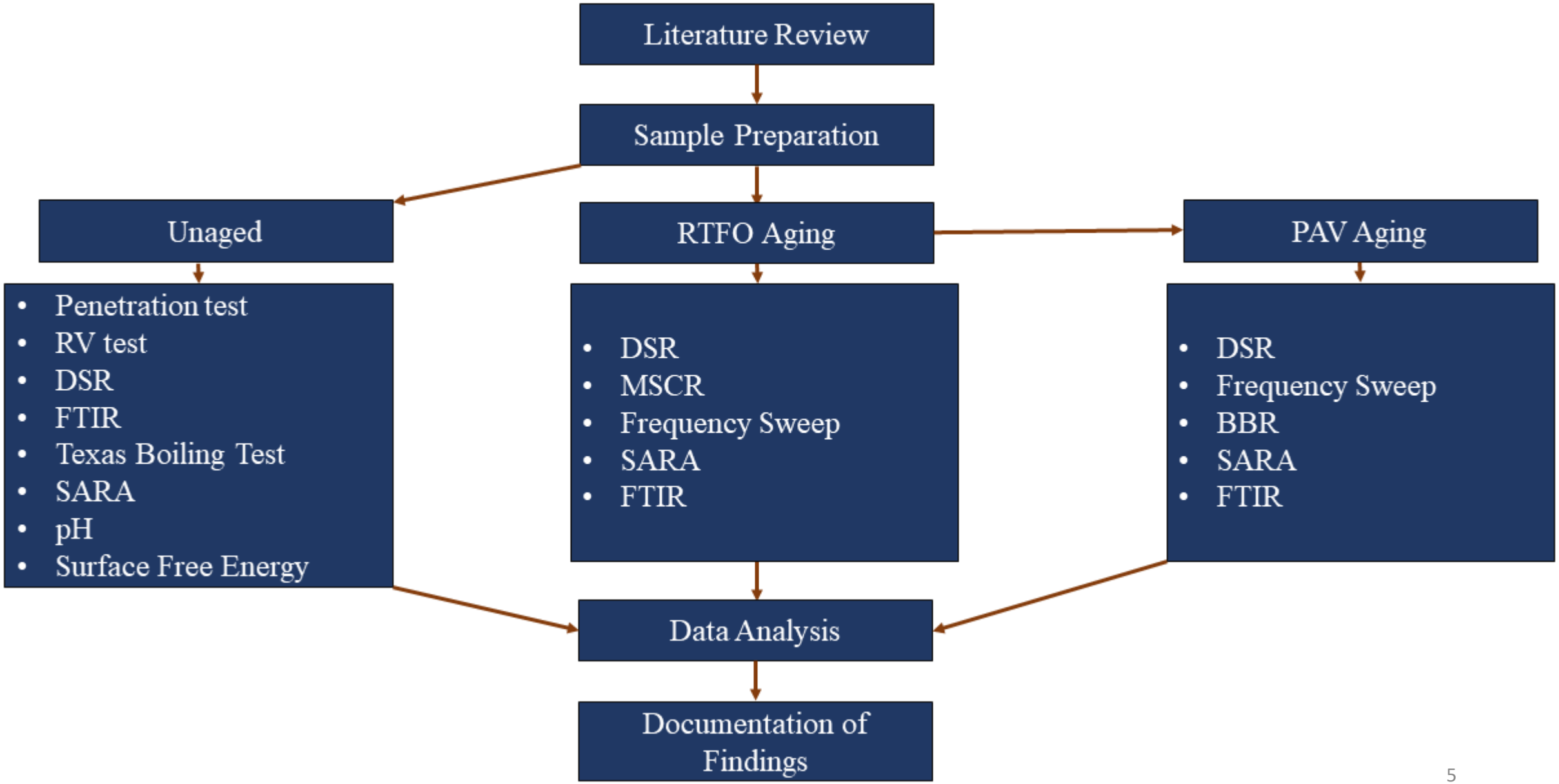
Background

Hurley and Prowell, (2005a, 2005b, 2006)	Sasobit®, Evotherm®, Aspha-min®	• Achieved mixing and compaction temperatures down to 129°C and 110°C. • Possible PG grade change
Wasiuddin et al., (2007)	Sasobit® , Advera®	• Sasobit® reduced viscosity than Aspha-min®. • Only, Sasobit® improved rutting parameter, G*/Sinδ.
Bennert et al., (2010)	Rediset® and Evotherm® 3G	• PG 76-22 binder coated aggregates easily at as low as 190 °F. • Reduced mixing (>300 °F) and compaction (>287 °F) temperatures
Hossain et al., (2013)	Sasobit®	• 9°C reduction in mixing temperature at 1.5% dosage (optimum). • Also, improved rut resistance • Over 1.5% detrimental to thermal cracking
Hossain et al., (2011, 2012)	Advera®	• Increased mixing and compaction temperatures by 5 and 6°C, respectively at 6% dosage level. (Lab experimental issue!) • Improved rut resistance and higher fatigue factor were observed.
Kassem et al., (2018)	Sasobit®,Evotherm® MA3, and Rediset®	• Decreased Surface Free Energy (SFE)
Rahmad et al., (2020)	Rediset® LQ-1106	• Improved moisture resistances and higher work of adhesion.

Objectives

- Evaluate changes in asphalt binder's viscosity => Mixing and compaction temperatures of WMA-additive modified binders;
- Evaluate the effect on high, low and intermediate temperature performances => changes in binder grade
- Determine changes in chemical compositions (SARA fractions and FTIR) => indicators of mechanical properties and stability of the asphalt binders
- Evaluate the compatibility of different aggregates and asphalt binders modified with WMA additives in presence of water => Stripping resistance.

Project Plan



Materials

Asphalt Binder Designation	Designation	Asphalt Binder Source
PG 64-22	B1	Each binder from two sources (refineries): Source 1: Ergon, Inc. Memphis, TN Source 2: Marathon Petroleum Corp., Memphis, TN
PG 70-22	B2	
PG 76-22	B3	

Aggregate Type	Source	General Characteristics
Sandstone	APAC-Central-Preston Quarry, Van Buren, AR	Siliciclastic sedimentary rocks, whose principal mineral constituents are quartz, feldspar, and rock fragments. Common heavy minerals include zircon, tourmaline, rutile, garnet, and magnetite.
Gravel	Capital Quarries Company, Pocahontas, AR	Mostly quartz (silicon dioxide, SiO_2) grains that are formed from weathering of rocks such as granite.
Limestone	White River Materials Inc., Cord, AR	Carbonate sedimentary rocks. They are mostly composed of calcite and aragonite minerals, which are different crystal forms of calcium carbonate ($CaCO_3$).
Dolomite	Capital Quarries Company, Pocahontas, AR	Anhydrous carbonate minerals that are composed of calcium magnesium carbonate, $CaMg(CO_3)_2$.

Materials

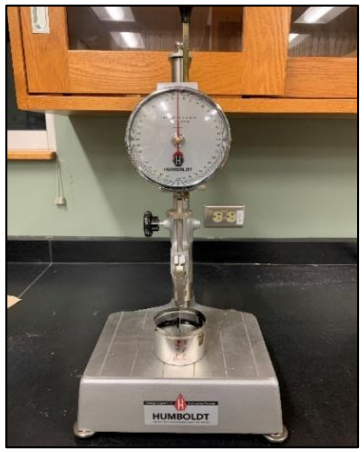
Additives / Properties	Sasobit®	Asphamin® (Advera® 401 PS)	Rediset® LQ – 1102C	Evotherm® P25
Types	Asphalt flow improver	Water based	Heat stable adhesion promoter, built-in anti-stripping effect	Adhesion promoter, built-in anti-stripping effect
Appearance	Solid	Powder	Liquid	Liquid
Color	Off-white to Yellow	White	Dark brown	Tan. Brown.
Chemical composition	FT hard wax, C_nH_{2n+2}, n= 45 - >100, apprx. 1000 g=mole	Zeolite (78 – 82 %), water, $Na_2Al_2Si_2O_8.xH_2O$	Proprietary alkoxylated fatty polyamines, Proprietary polyamines, and Diethylene glycol ($C_4H_{10}O_3$); Amine value (540-640 mg KOH/g)	Modified tall oil fatty acid (≥75% - ≤90%), Proprietary Alkyl acid phosphate (≥25% - ≤41%)
Recommended Dosages	0.8 –3.0% by weight of binder (Manufacturer)	0.05 – 0.3 % by weight of the asphalt mix	0.3 – 1.0 % by weight of basis binder (Manufacturer)	0.25–0.50% (Unmodified asphalt) 0.30–0.75% (PMB)
Images				

Sample Nomenclature

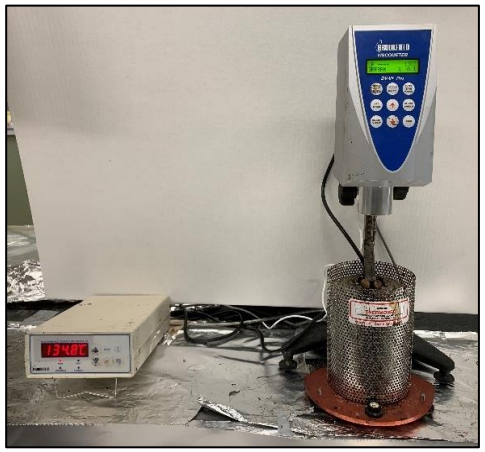
Final Sample Nomenclature			
Base Binder	Modification (by wt of asphalt binder)	Sample Nomenclature (Source 1)	Sample Nomenclature (Source 2)
PG 64-22	None	S1B1A0	S2B1A0
	Sasobit® 1.5%	S1B1A1	S2B1A1
	Advera® 6%	S1B1A2	S2B1A2
	Evotherm® 0.5%	S1B1A3	S2B1A3
	Rediset® 0.75%	S1B1A4	S2B1A4
PG 70-22	None	S1B2A0	S2B2A0
	Sasobit® 1.5%	S1B2A1	S2B2A1
	Advera® 6%	S1B2A2	S2B2A2
	Evotherm® 0.5%	S1B2A3	S2B2A3
	Rediset® 0.75%	S1B2A4	S2B2A4
PG 76-22	None	S1B3A0	S2B3A0
	Sasobit® 1.5%	S1B3A1	S2B3A1
	Advera® 6%	S1B3A2	S2B3A2
	Evotherm® 0.5%	S1B3A3	S2B3A3
	Rediset® 0.75%	S1B3A4	S2B3A4

Methodologies

Sample Blending



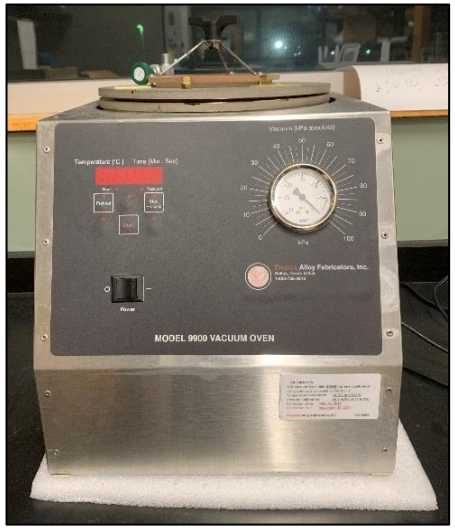
Penetrometer



Rotational Viscometer

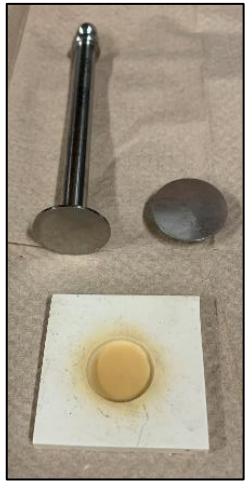
Rolling Thin-Film Oven (RTFO)

Pressure Aging Vessel (PAV)



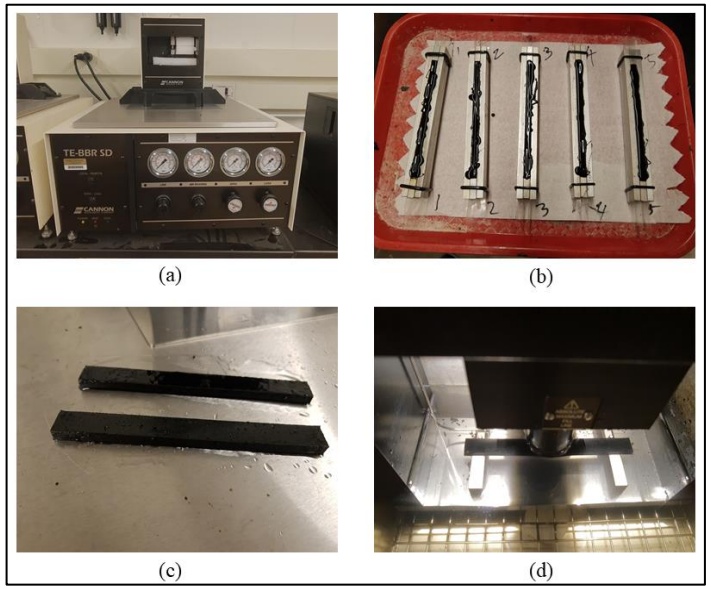
Degassing Oven

Dynamic Shear Rheometer (DSR)



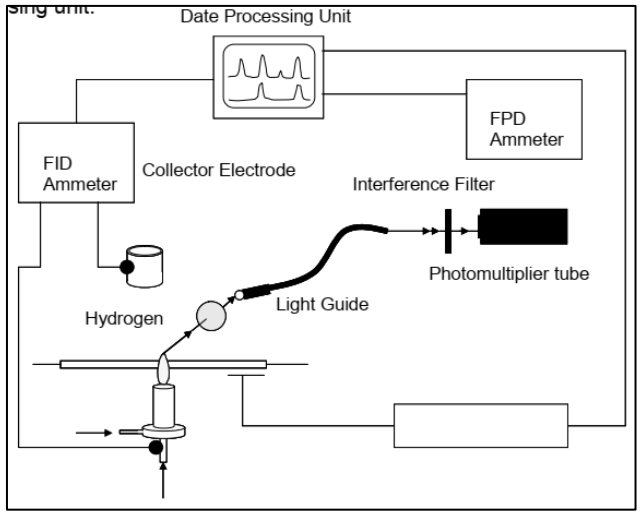
25-mm Plate Setup

8-mm Plate Setup



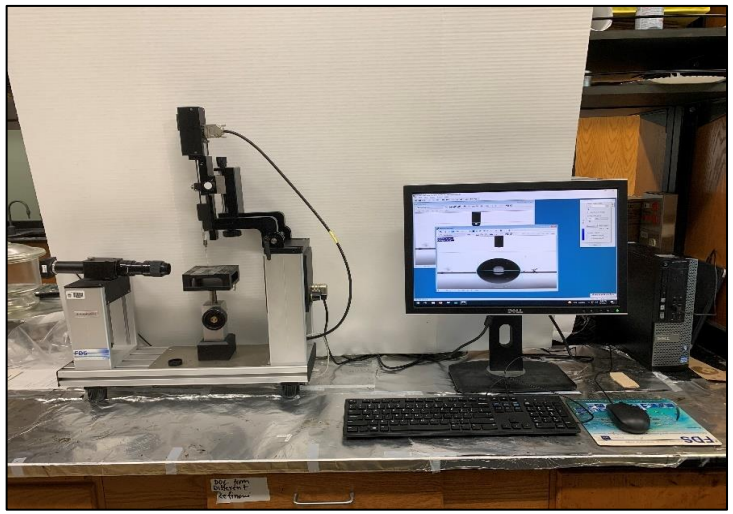
a) Bending Beam Rheometer (BBR), b) Sample Preparation, c) Test Sample, and d) Test Setup

Methodologies



IATROSCAN Working Principle

Nuclear Magnetic Resonance (NMR) Instrument

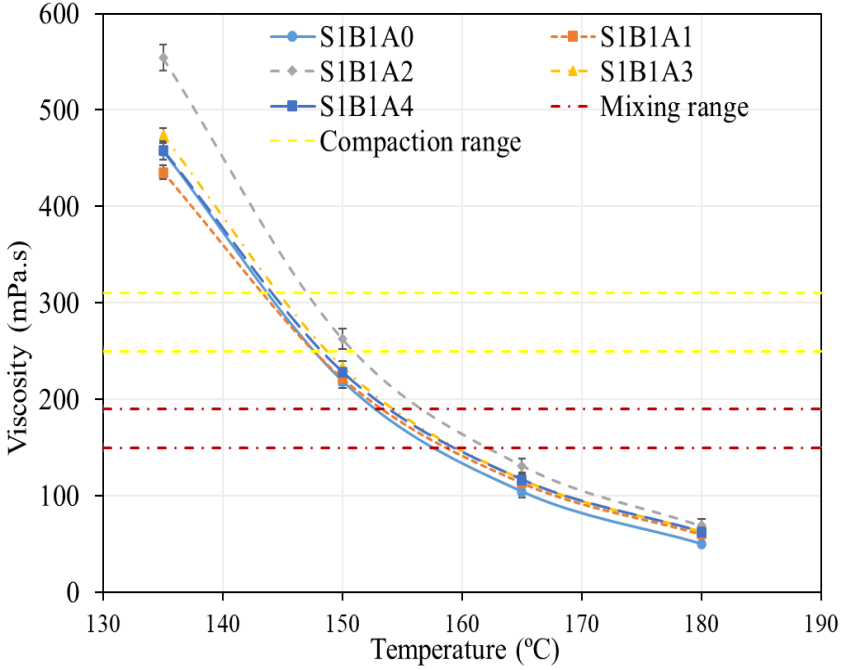


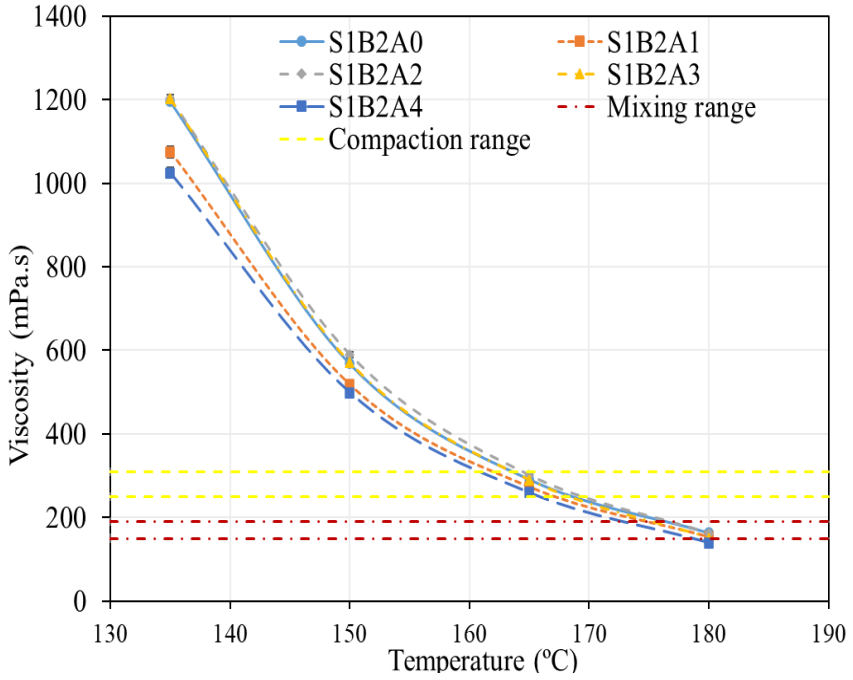
Optical Contact Angle (Sessile Drop) Measurement Test Setup

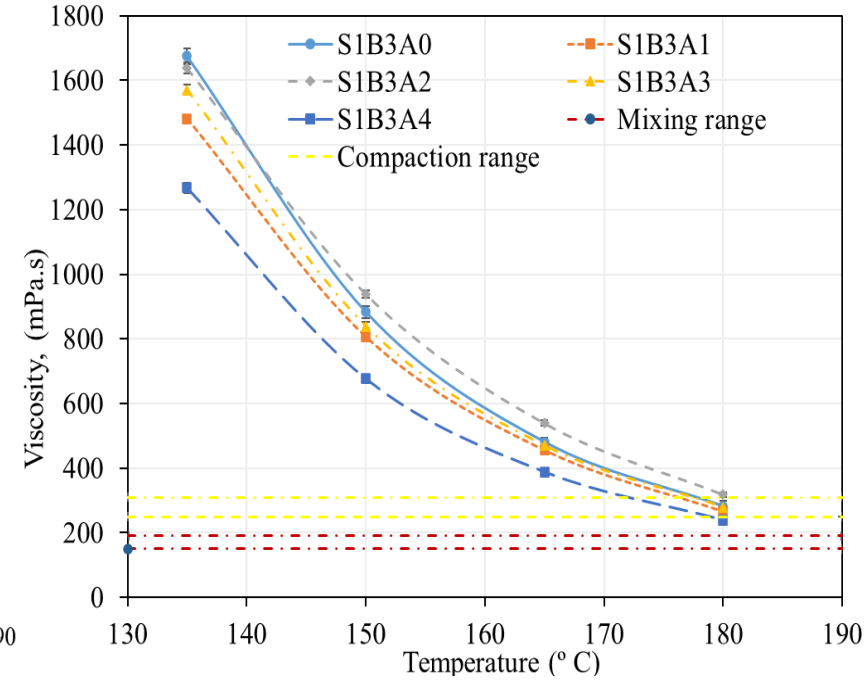
Texas Boiling Test

Acid Number (pH) Measurement Test Setup

Rotational Viscometer (RV) Test Results: Source 1



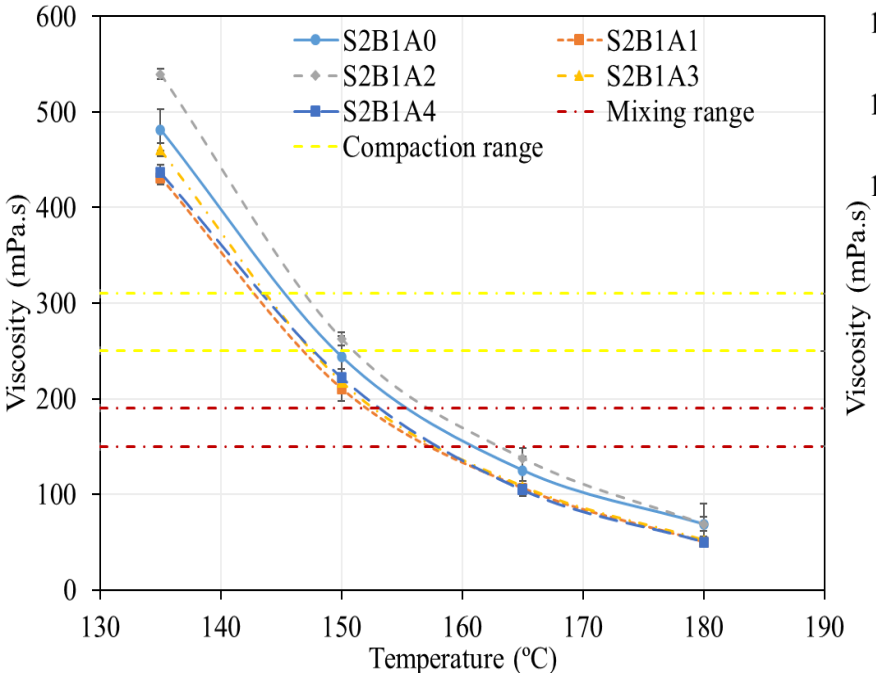


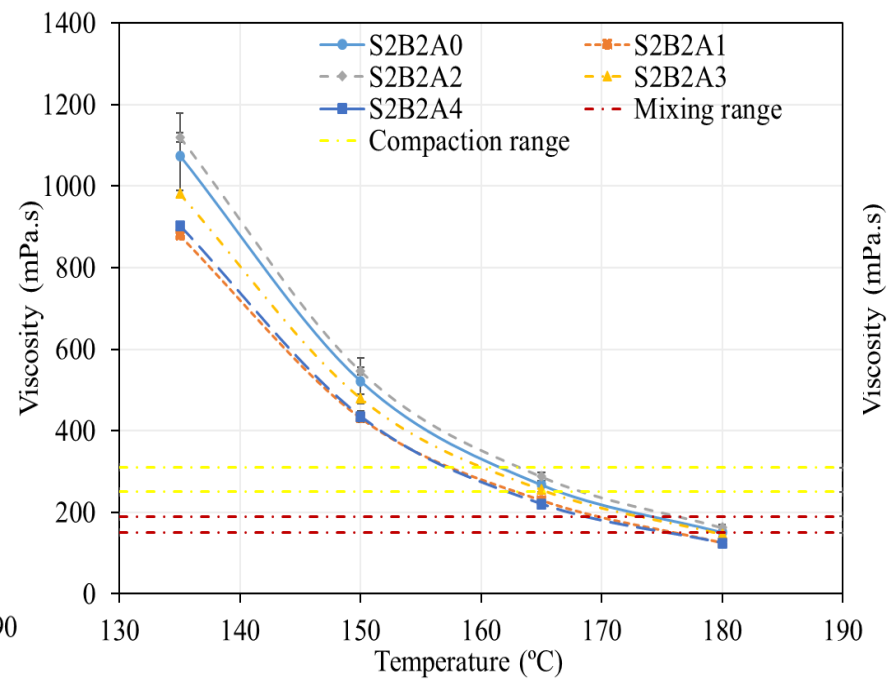


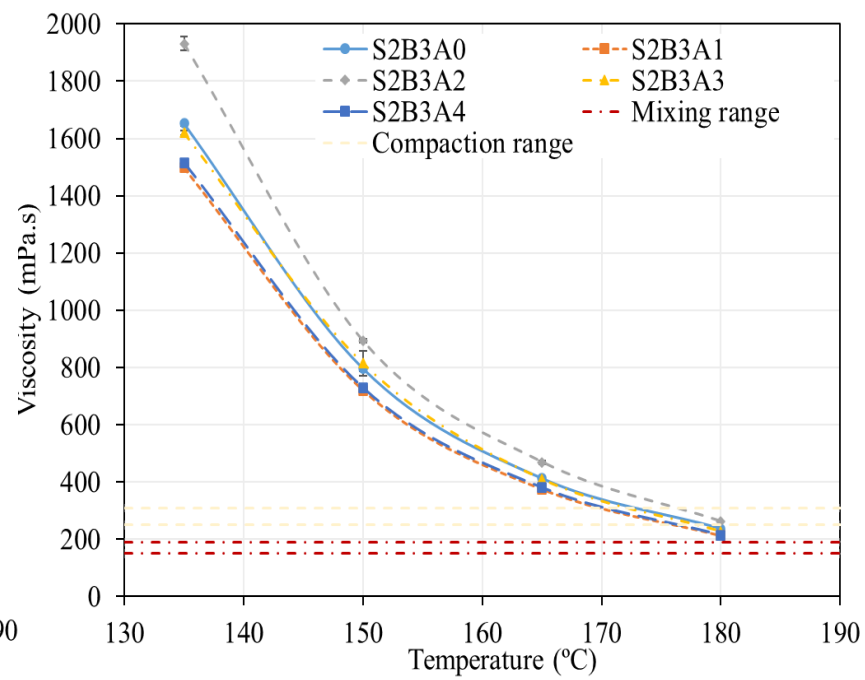
No Additive	**A0**
Sasobit® 1.5%	**A1**
Advera® 6%	**A2**
Evotherm® 0.5%	**A3**
Rediset® 0.75%	**A4**

- Sasobit® reduced viscosities for all PG binders
- Advera® mostly increased viscosities for all samples (again, laboratory testing issue!!)
- Evotherm®, and Rediset® had mixed effects on viscosities for the tested samples in this study

Rotational Viscometer (RV) Test Results: Source 2



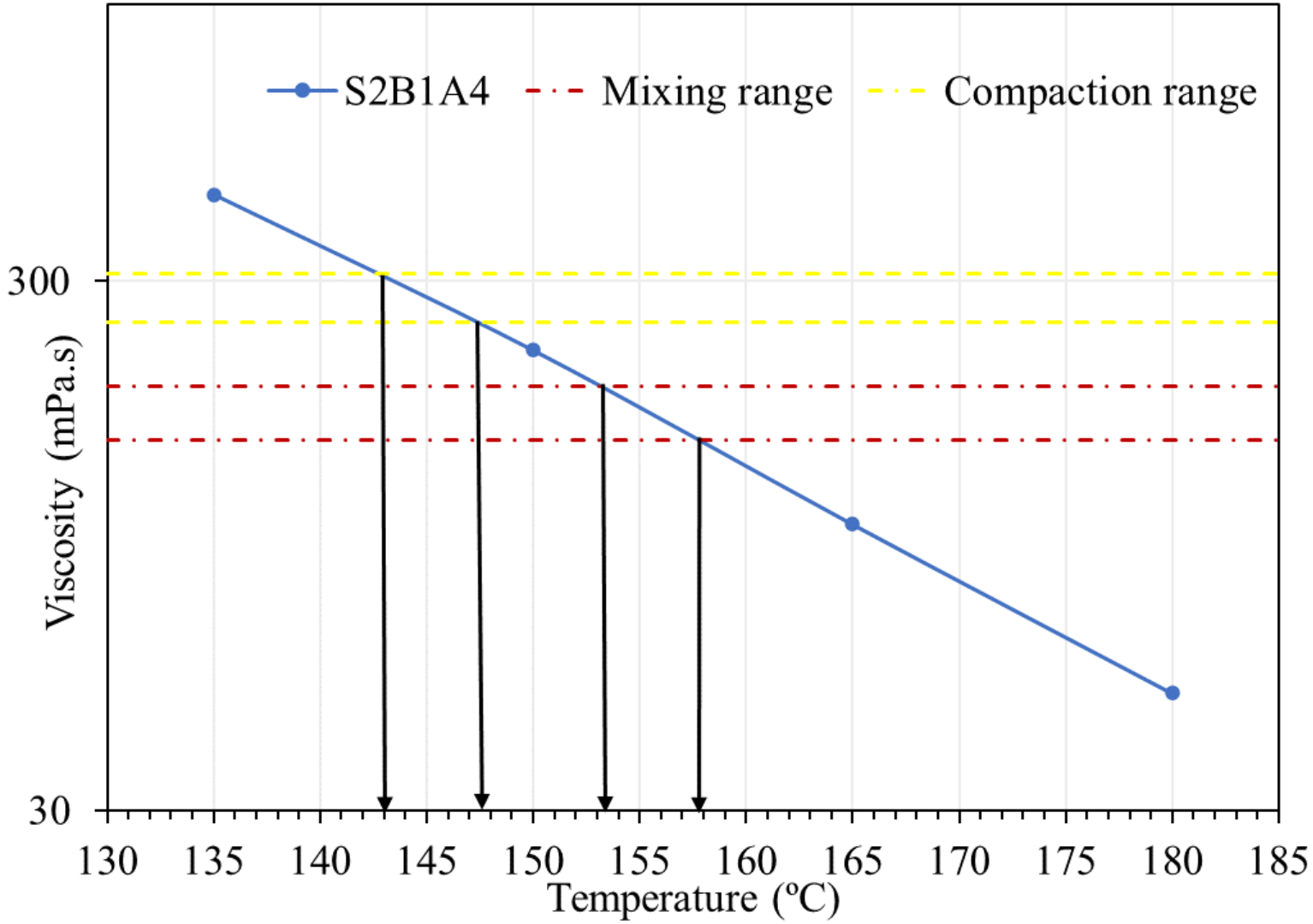




No Additive	**A0**
Sasobit® 1.5%	**A1**
Advera® 6%	**A2**
Evotherm® 0.5%	**A3**
Rediset® 0.75%	**A4**

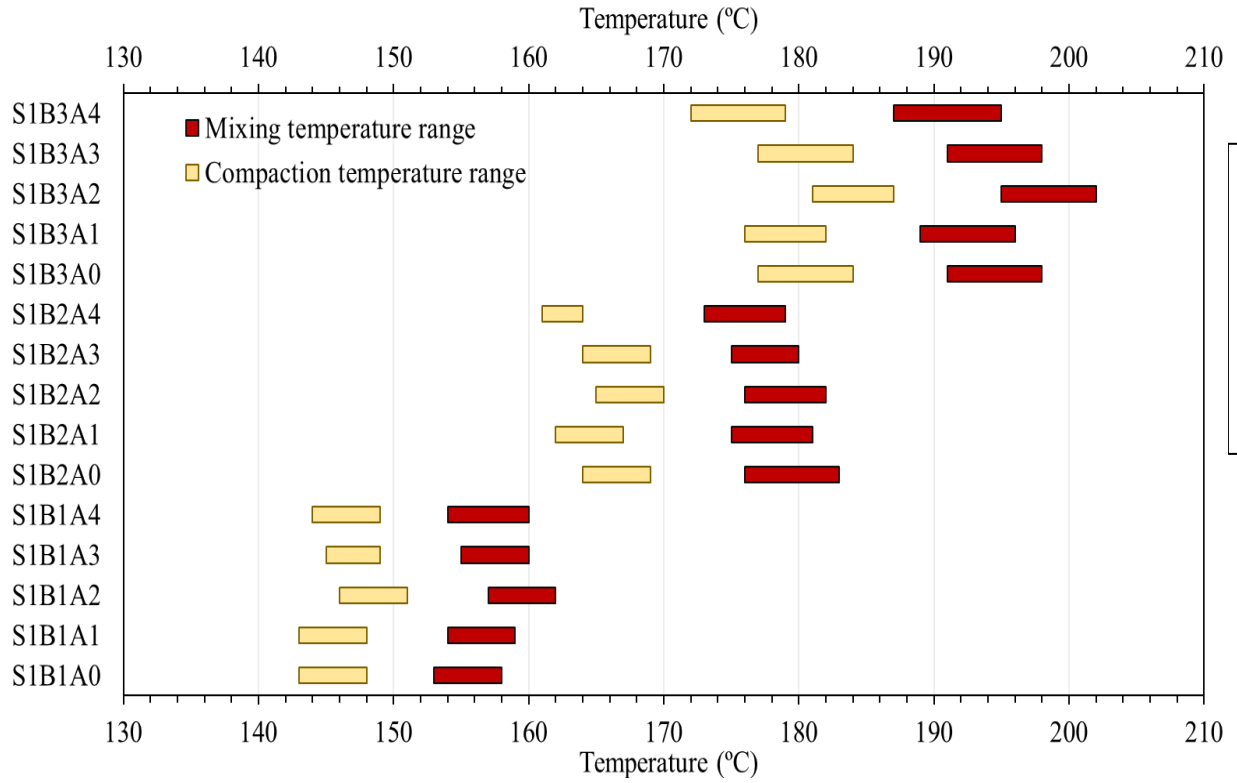
- Sasobit®, Evotherm®, and Rediset® reduced viscosities for all PG binders
- Advera® increased viscosities for all samples

Mixing and Compaction Temperatures



Viscosity (mPa.s)			
Mixing Range		Compaction Range	
190	150	310	250
Temperature (°C)			
Mixing Range		Compaction Range	
158	153.5	147.5	143

Effects on Production Temperatures

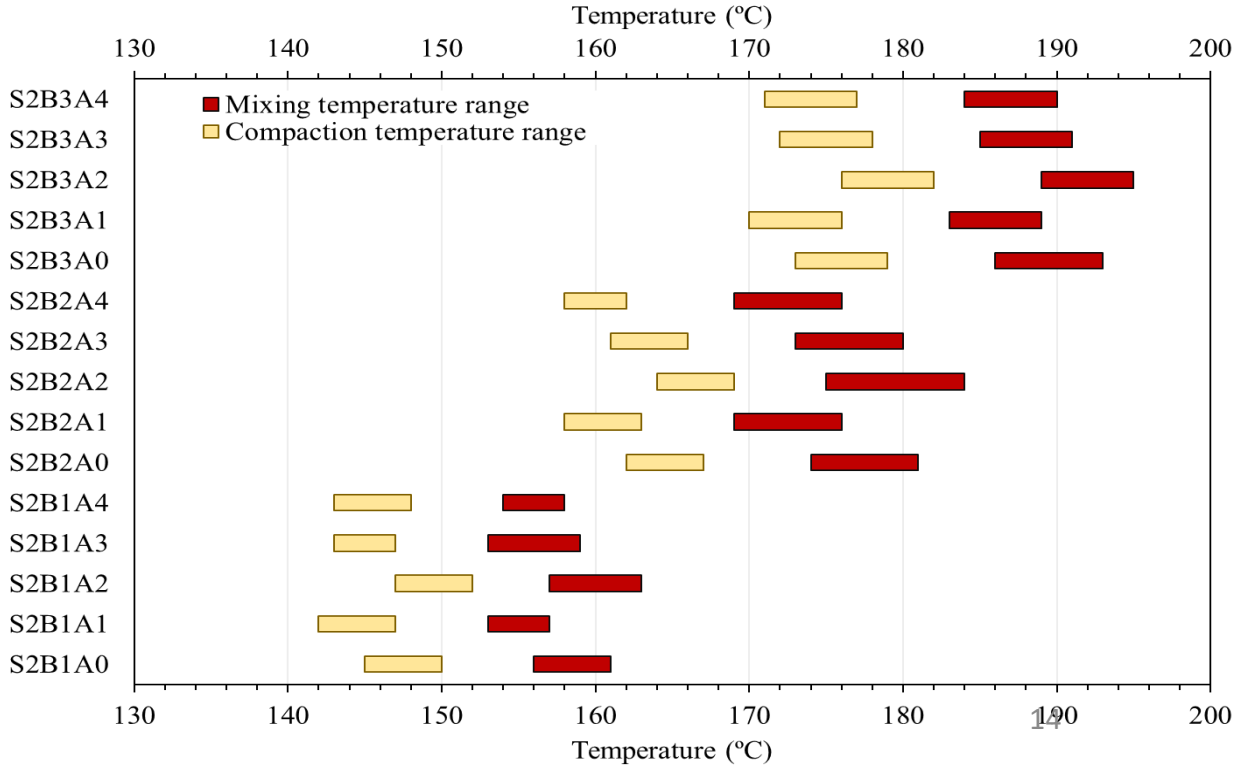


Source 1

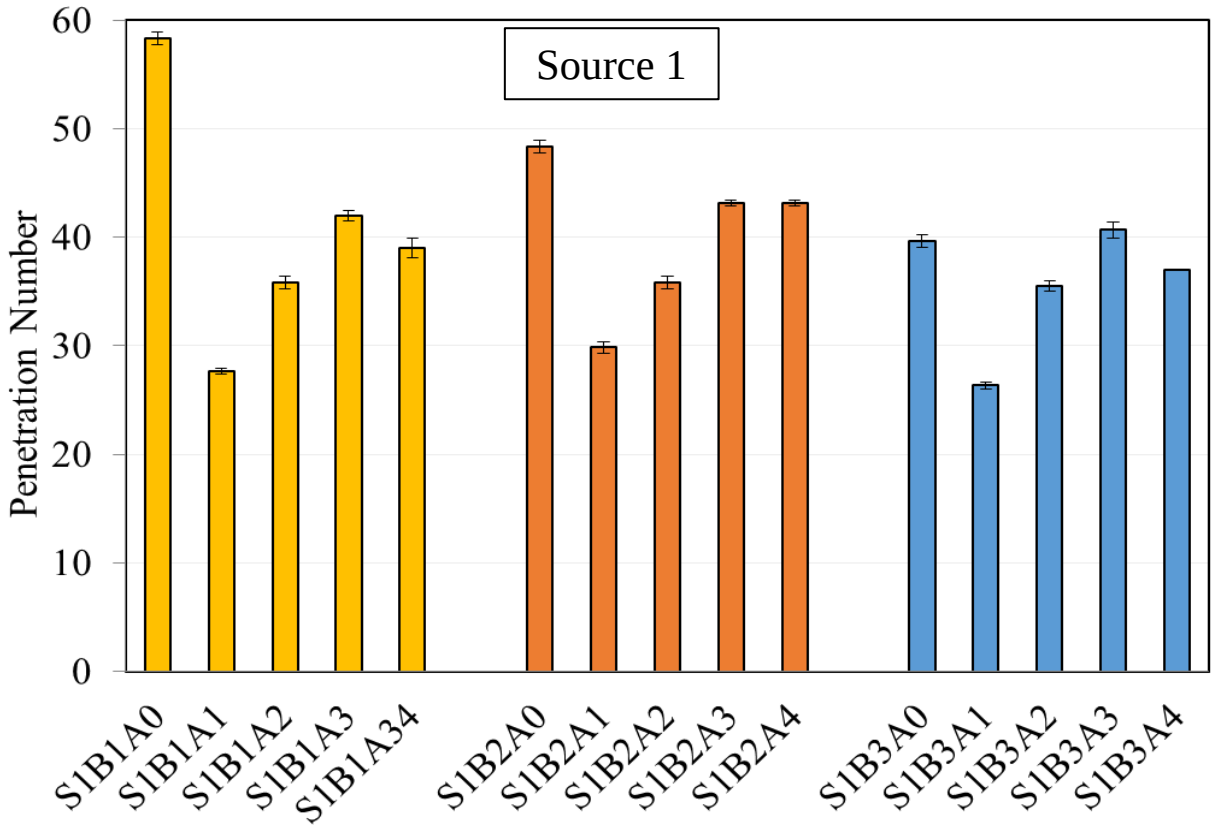
- Sasobit®, Evotherm®, and Rediset® reduced mixing temperature ranged in 1-5 ºC
- Advera® almost in all cases increased this value by 1-2 ºC

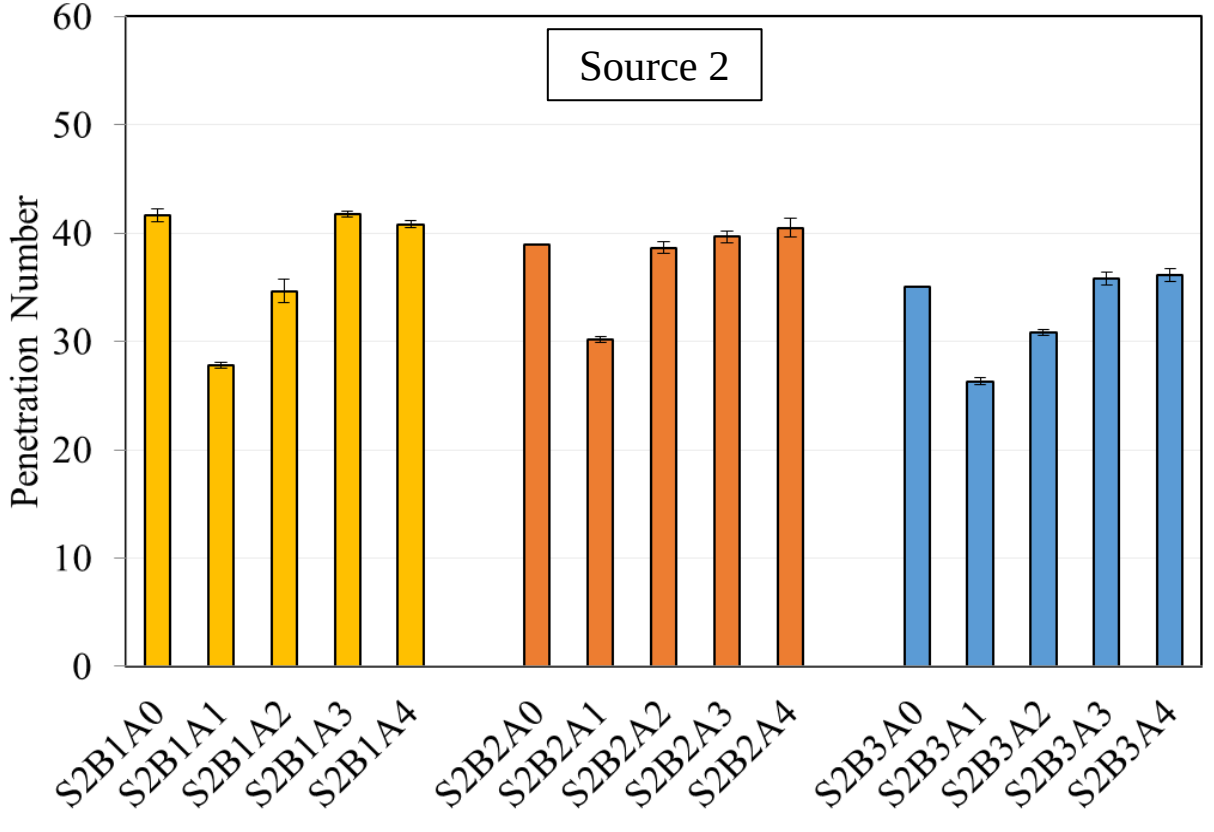
Source 2

- Sasobit®, Evotherm®, and Rediset® modified samples got reduced by 2-4 ºC
- Advera® increased this value by 1-2 ºC



Penetration Test Results

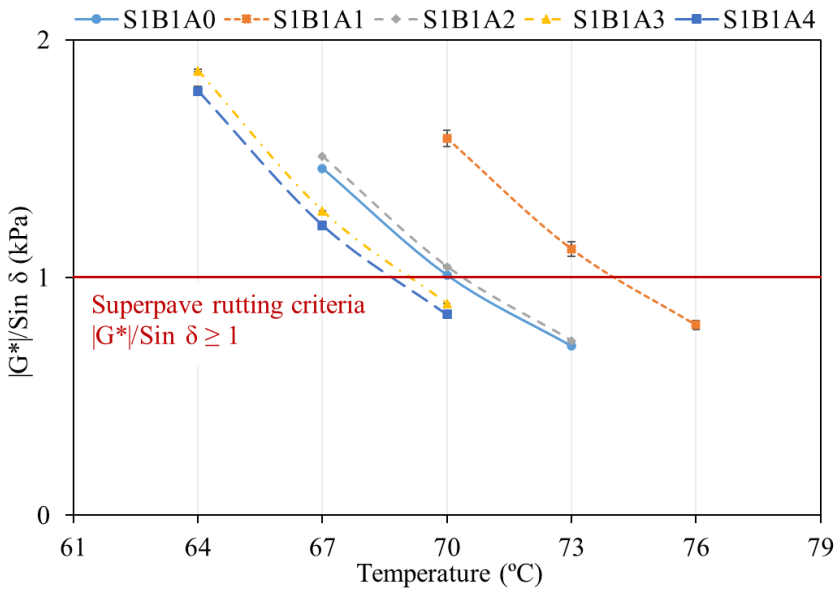


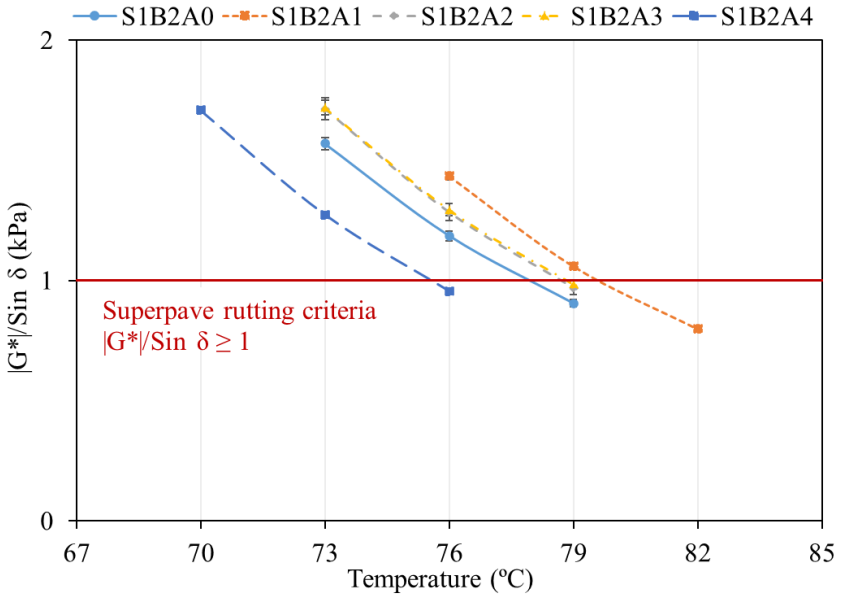


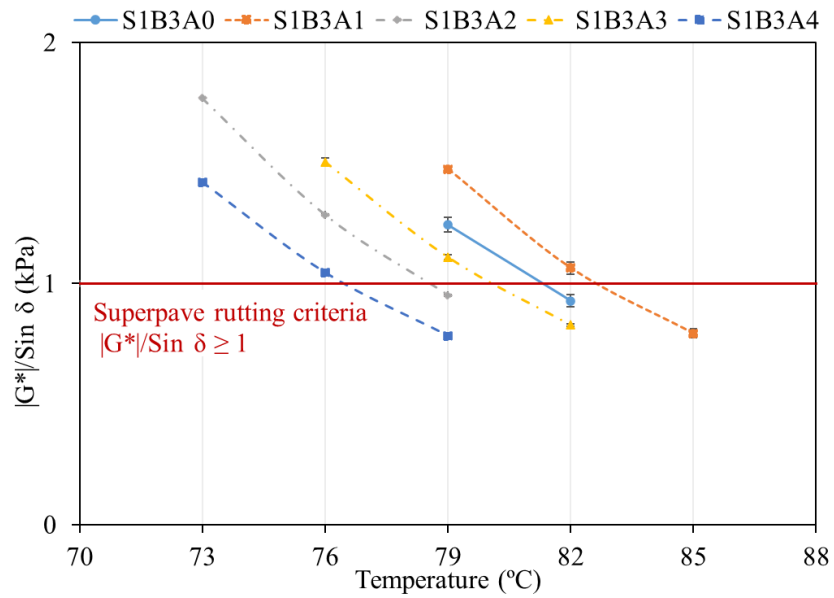
No Additive	**A0**
Sasobit® 1.5%	**A1**
Advera® 6%	**A2**
Evotherm® 0.5%	**A3**
Rediset® 0.75%	**A4**

- Sasobit® stiffened all the samples followed by Advera®
- Evotherm®, and Rediset® demonstrated similar effect on stiffness of all binder samples

Dynamic Shear Rheometer (DSR): Rutting Factors (Source 1)



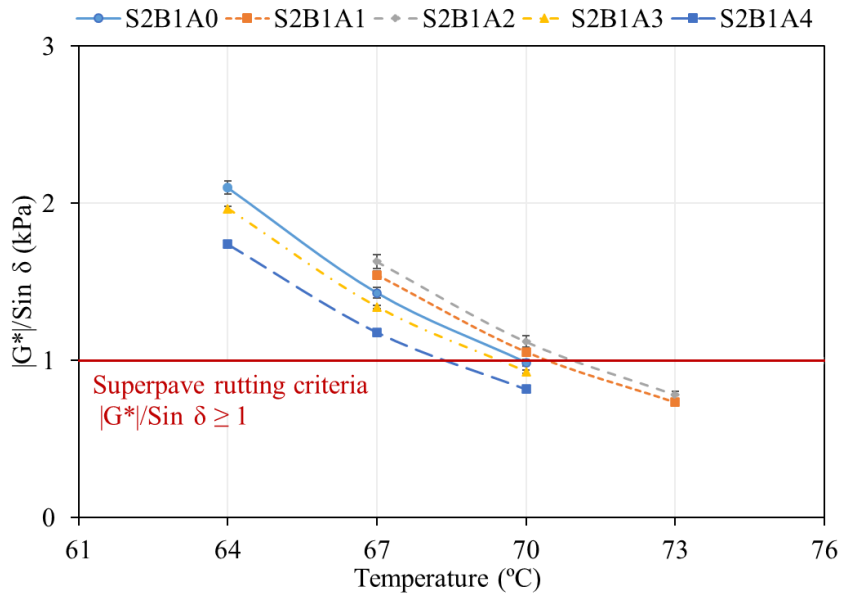


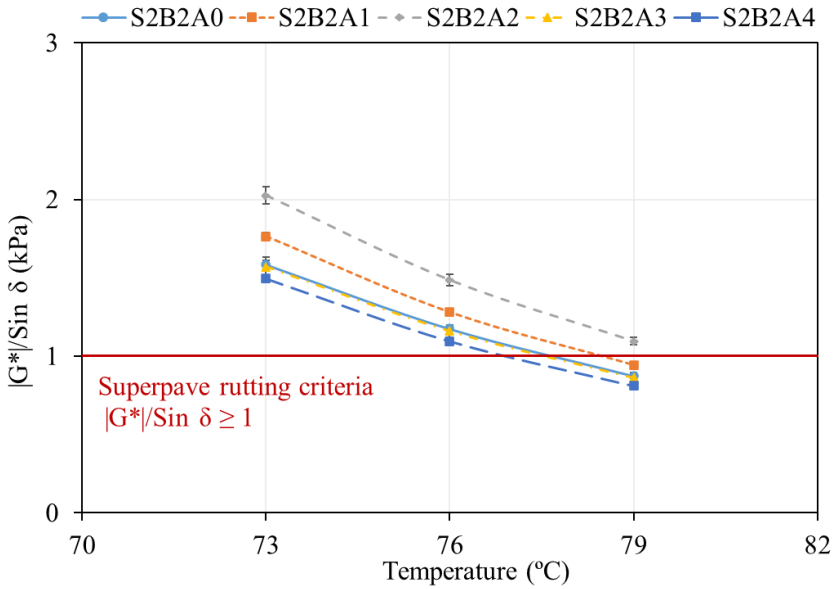


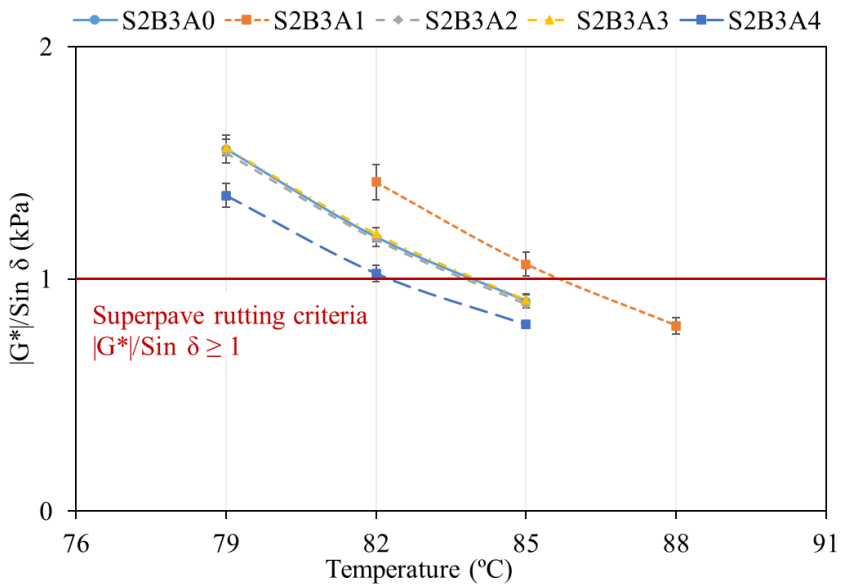
No Additive	**A0**
Sasobit® 1.5%	**A1**
Advera® 6%	**A2**
Evotherm® 0.5%	**A3**
Rediset® 0.75%	**A4**

- Sasobit® always decreased rut potential, and Advera® mostly decreased it.
- Rediset® always increased rut potential, and Evotherm® mostly increased it.

Dynamic Shear Rheometer (DSR): Rutting Factors (Source 2)

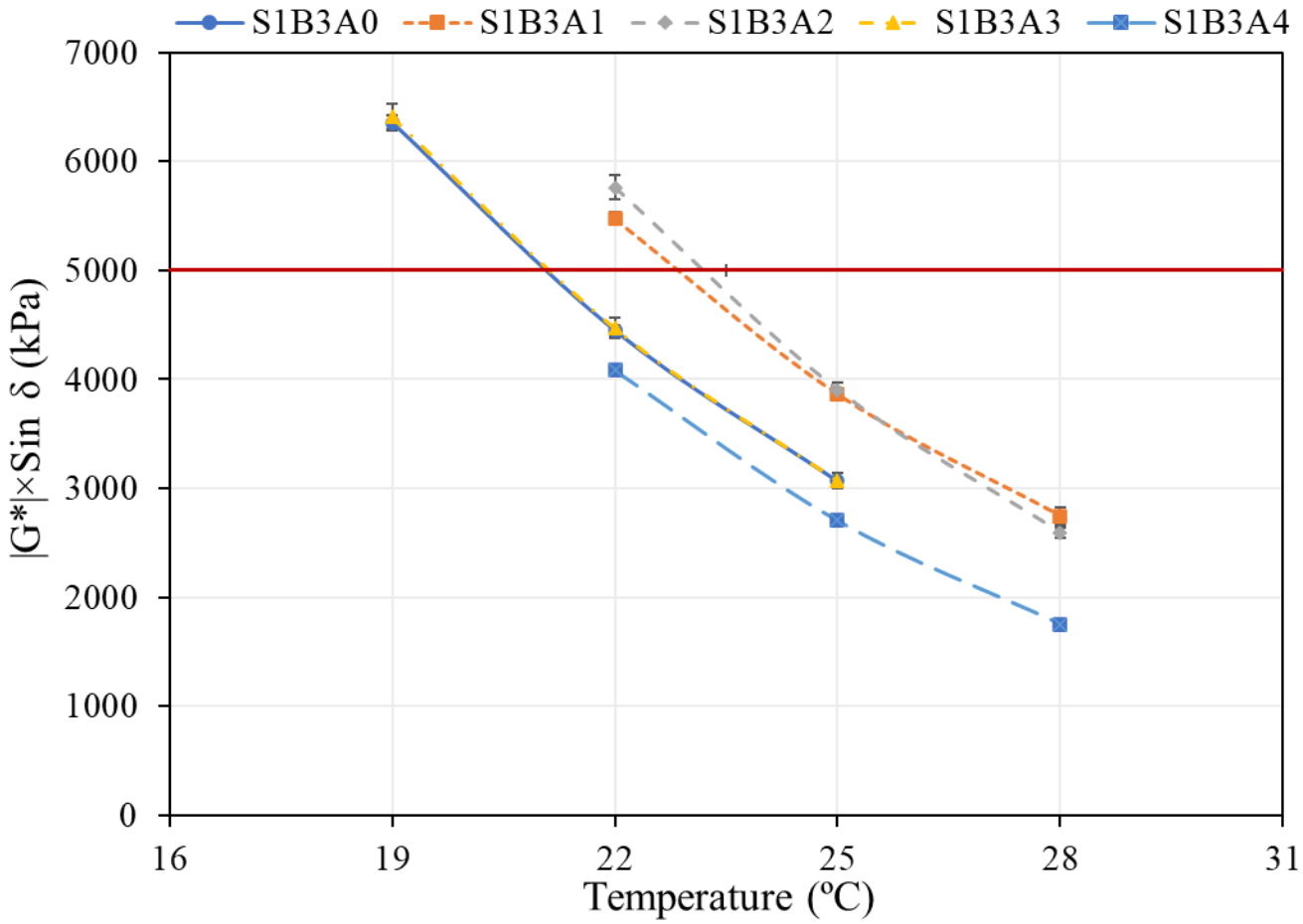






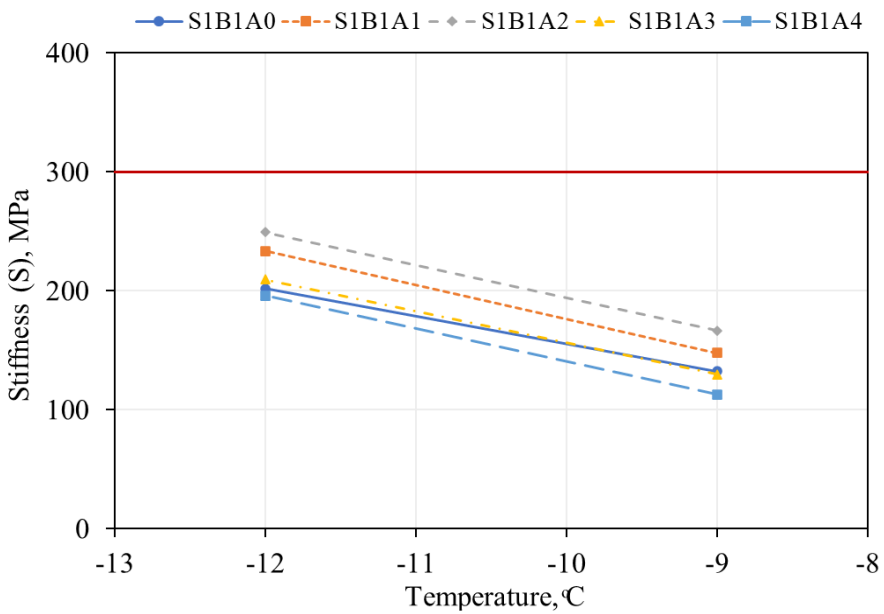
- Sasobit® always decreased rut potential
- Advera® mostly decreased it
- Rediset® always increased rut potential
- Evotherm® mostly increased it.

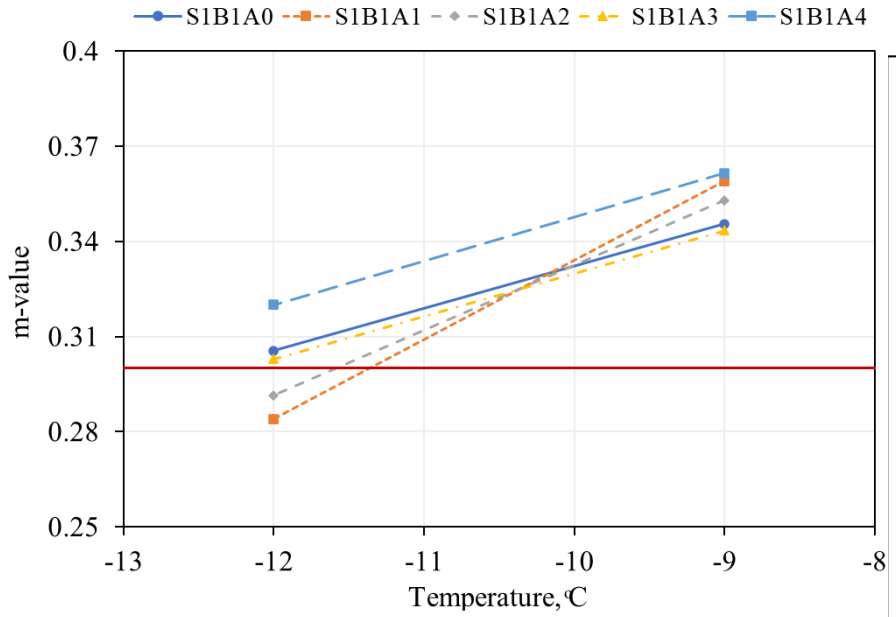
Dynamic Shear Rheometer (DSR): Fatigue Factors

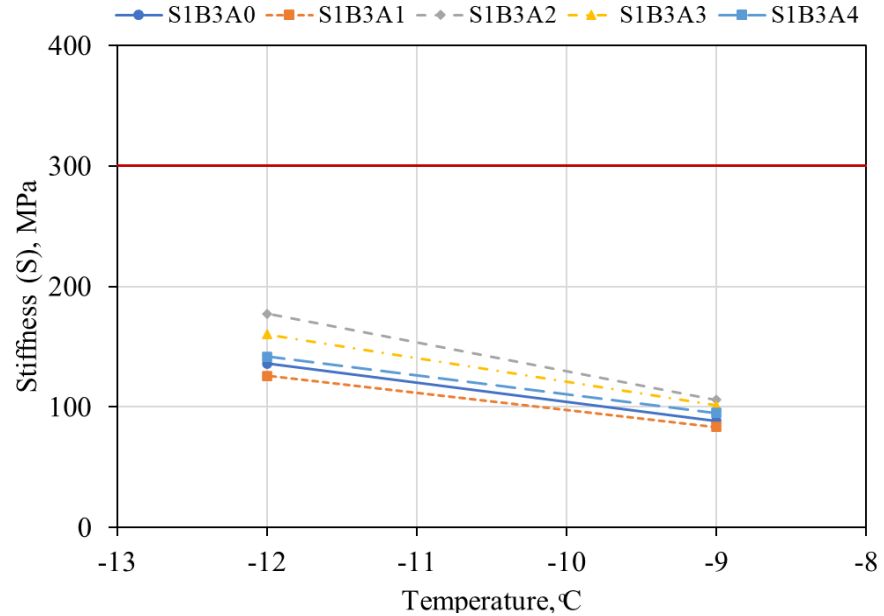


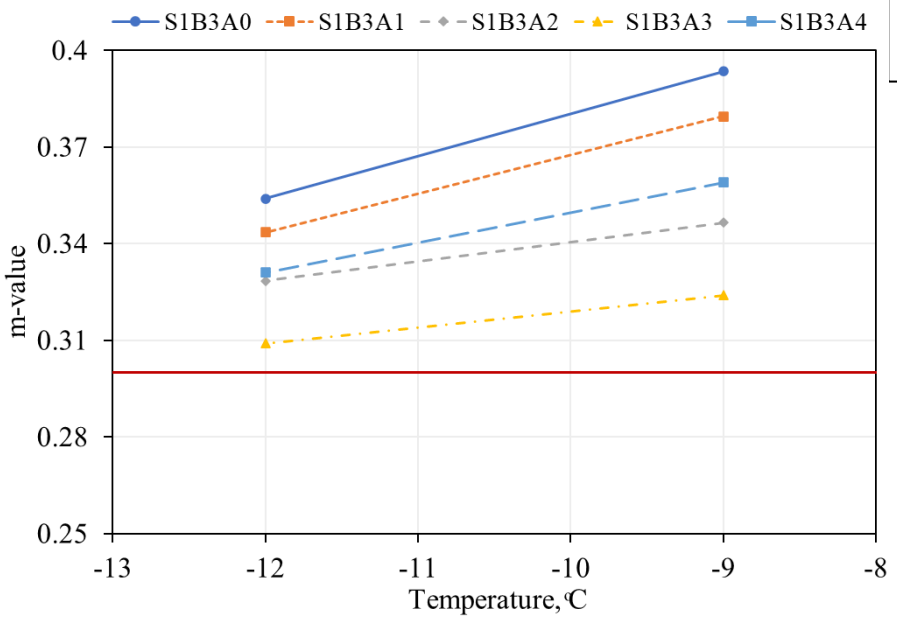
- Sasobit® and Advera® increased fatigue factors as well as critical intermediate temperature.
- Rediset® and Evotherm® reduced fatigue factors as well as critical intermediate temperature.

Bending Beam Rheometer (BBR): Low-Temperature Cracking









- Unimpaired low PG temperatures regarding stiffness values (Superpave S-value criterion)
- Sasobit®, and Advera® both increased low PG temperatures by less than 1 ° C for PG 64-22 binder samples (Superpave m-value criterion)

No Additive	A0
Sasobit® 1.5%	A1
Advera® 6%	A2
Evotherm® 0.5%	A3
Rediset® 0.75%	A4

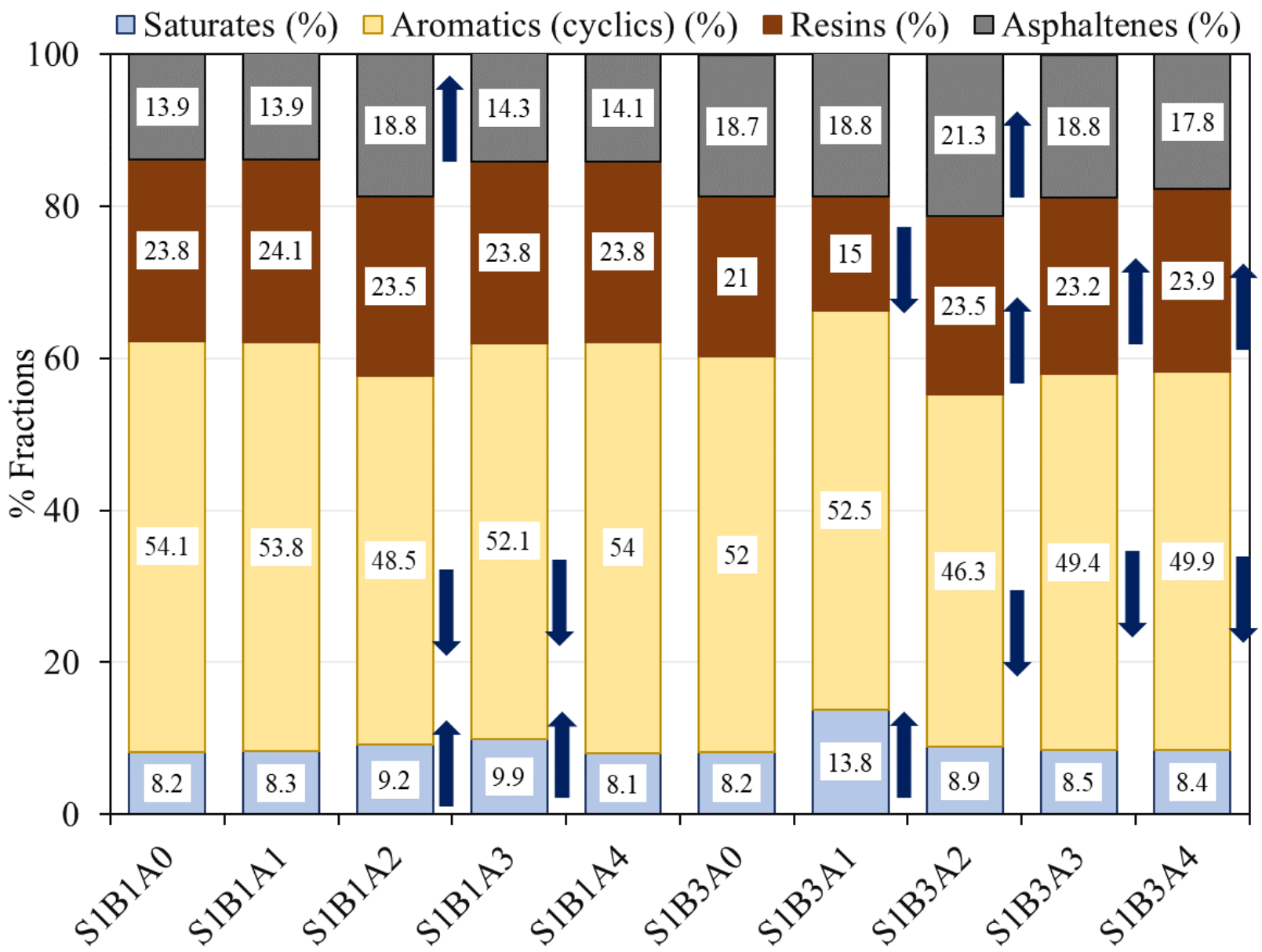
Multiple Stress Creep Recovery (MSCR)

Sample name	Jnr, 0.1 kPa	Jnr, 3.2 kPa	Jnr, diff	Stress Sensitivity (AASHTO M 332)	R100	R3200	Rdiff	MSCR line equation: 29.371*(Jnr3.2kPa) ^(-.2633)	% Recovery (Meets AASHTO T 350)	MSCR Grade
S1B1A0	2.19	2.39	9.07	YES	4.03	0.80	80.11	31.14	NO	PG 64S-YY
S1B1A1	1.75	2.14	22.38	YES	11.01	1.71	83.91	25.49	NO	PG 64S-YY
S1B1A2	1.97	2.13	8.59	YES	3.91	0.79	79.71	31.23	NO	PG 64S-YY
S1B1A3	2.25	2.47	9.91	YES	4.27	0.71	83.47	32.20	NO	PG 64S-YY
S1B1A4	2.58	2.96	9.11	YES	3.19	0.22	93.10	43.97	NO	PG 64S-YY
S1B2A0	0.29	0.34	17.79	YES	62.19	56.85	8.59	10.14	YES	PG 64E-YY
S1B2A1	0.19	0.25	30.49	YES	67.11	60.51	9.84	9.97	YES	PG 64E-YY
S1B2A2	0.45	0.52	17.39	YES	52.54	45.79	12.85	10.73	YES	PG 64V-YY
S1B2A3	0.33	0.40	20.35	YES	61.08	54.95	10.04	10.23	YES	PG 64E-YY
S1B2A4	0.73	0.93	28.20	YES	49.97	39.32	21.32	11.17	YES	PG 64V-YY
S1B3A0	0.33	0.43	30.47	YES	48.90	36.81	24.74	11.37	YES	PG 64E-YY
S1B3A1	0.12	0.22	80.32	NO	65.09	47.33	27.28	10.64	YES	PG 64E-YY
S1B3A2	0.38	0.51	34.54	YES	49.42	35.83	27.60	11.45	YES	PG 64V-YY
S1B3A3	0.26	0.33	27.88	YES	53.55	43.45	18.82	10.88	YES	PG 64E-YY
S1B3A4	0.50	0.72	44.11	YES	53.22	37.31	29.90	11.33	YES	PG 64V-YY

No Additive	A0
Sasobit® 1.5%	A1
Advera® 6%	A2
Evotherm® 0.5%	A3
Rediset® 0.75%	A4

- Sasobit® increased %R values for all binder samples
- Advera®, Evotherm®, and Rediset® reduced %R values for PG 64-22 and PG 70-22 binder samples
- Advera®, and Rediset® changed MSCR grading from "Extreme" to "Very Heavy" for polymer modified binder samples

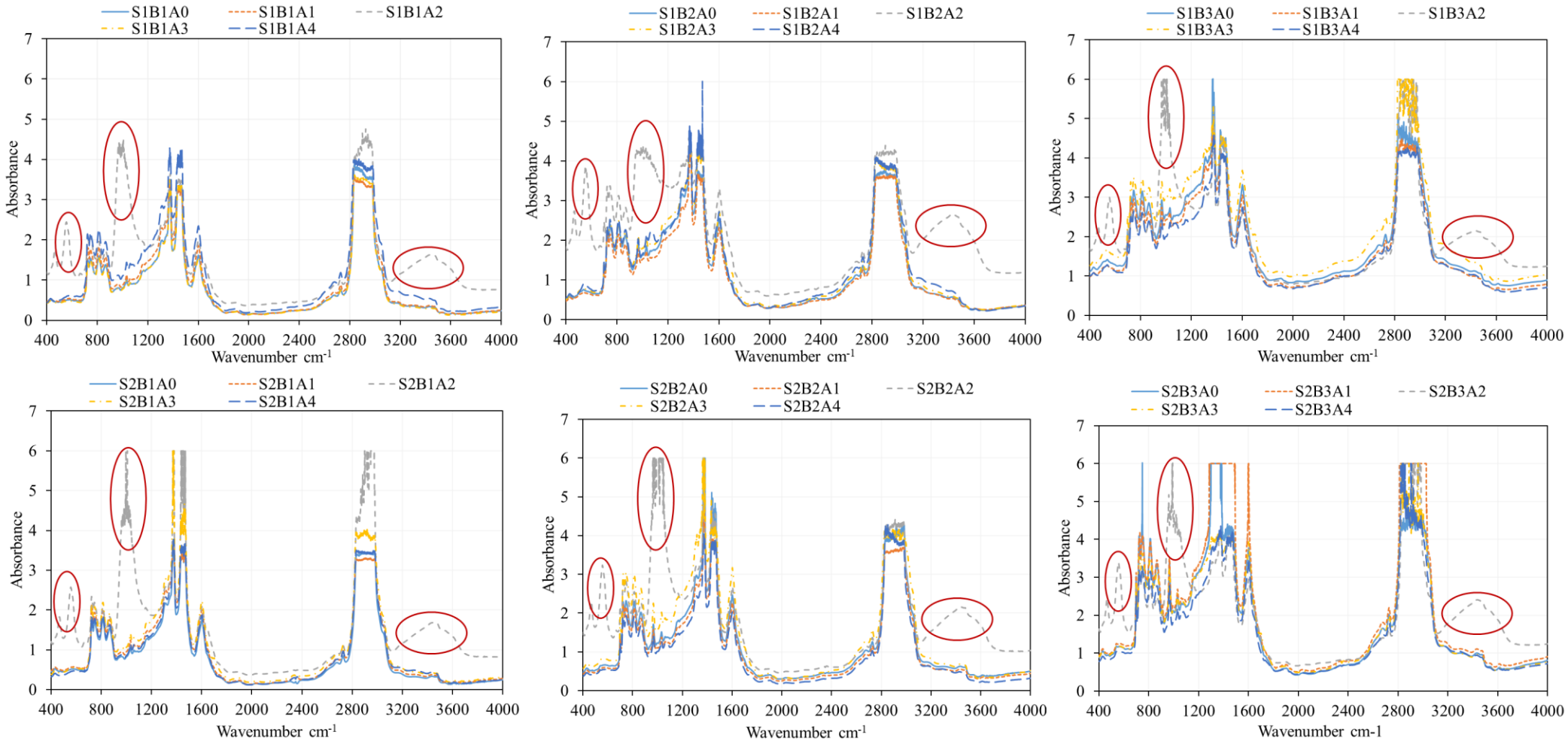
SARA Fraction Analysis (IATROSCAN)



No Additive	A0
Sasobit® 1.5%	A1
Advera® 6%	A2
Evotherm® 0.5%	A3
Rediset® 0.75%	A4

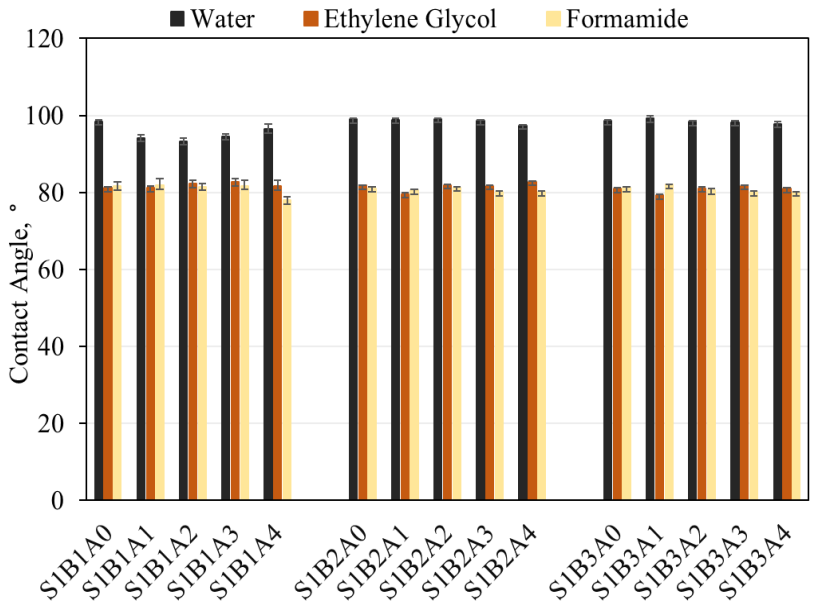
- Sasobit® increased %Saturates and decreased %Resin in PG 76-22 binder sample
- Advera® increased Asphaltenes and reduced the Aromatics for both binders
- %Resin was considerably increased and %Aromatics were decreased for PG 76-22 binder after modified by Advera®, Evotherm®, and Rediset®

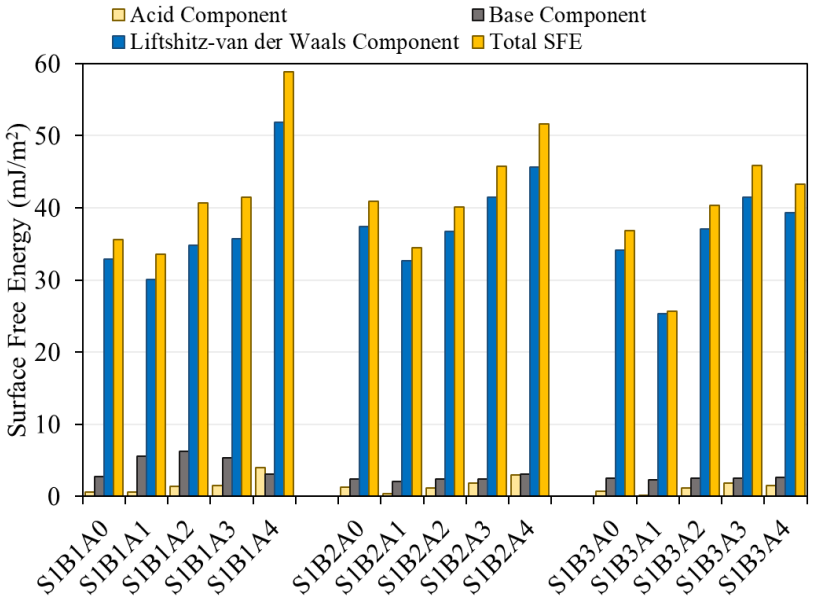
FTIR Test Results

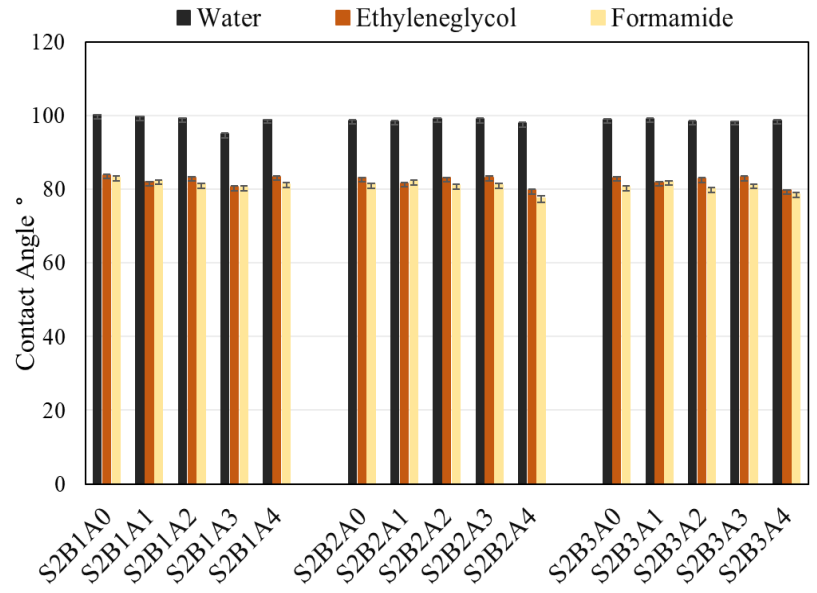


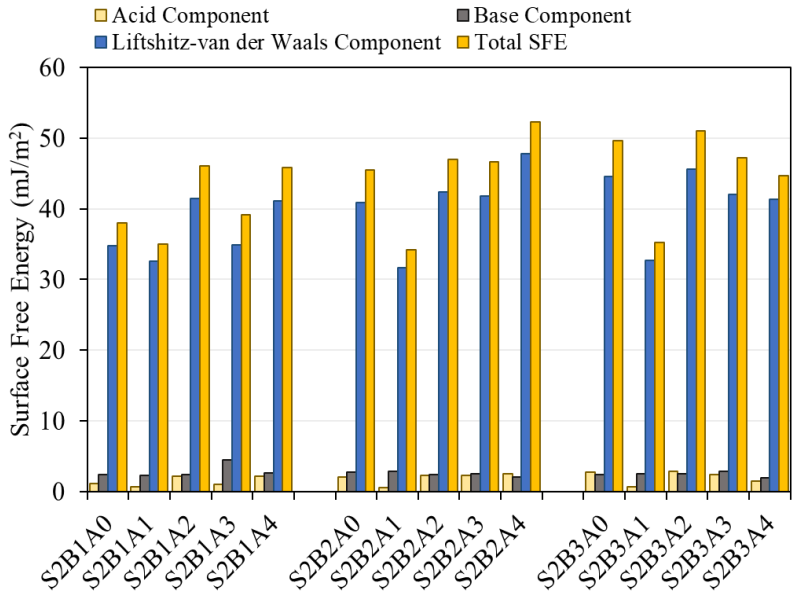
- Sasobit®, Evotherm®, and Rediset® could not introduce any new groups to binder samples
- Only, Advera® modification introduced sulfoxide (S=O) groups (1030 cm^{-1}) and hydroxyl (-OH) group (3400 cm^{-1}) to binder samples

Sessile Drop (Optical Contact Angle) Test results





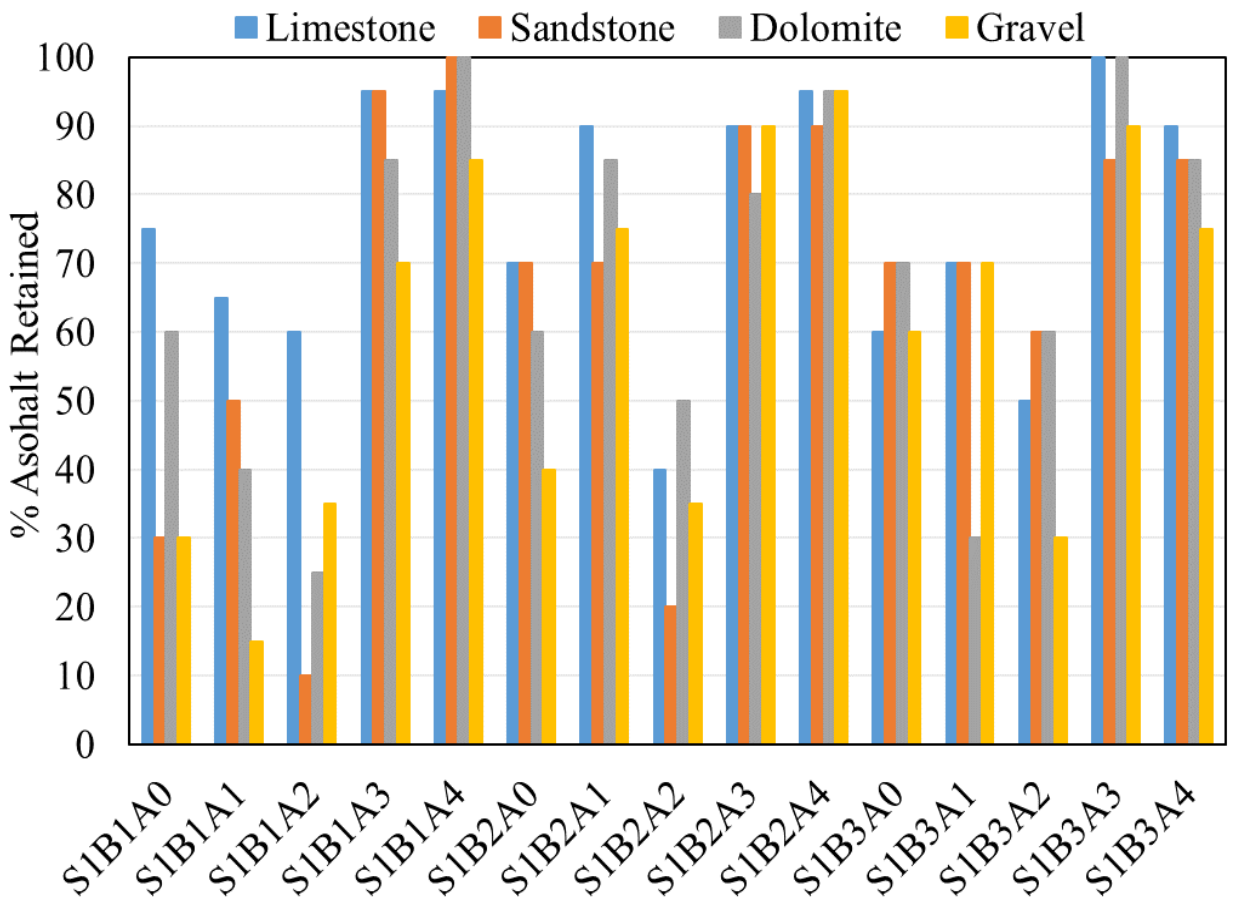


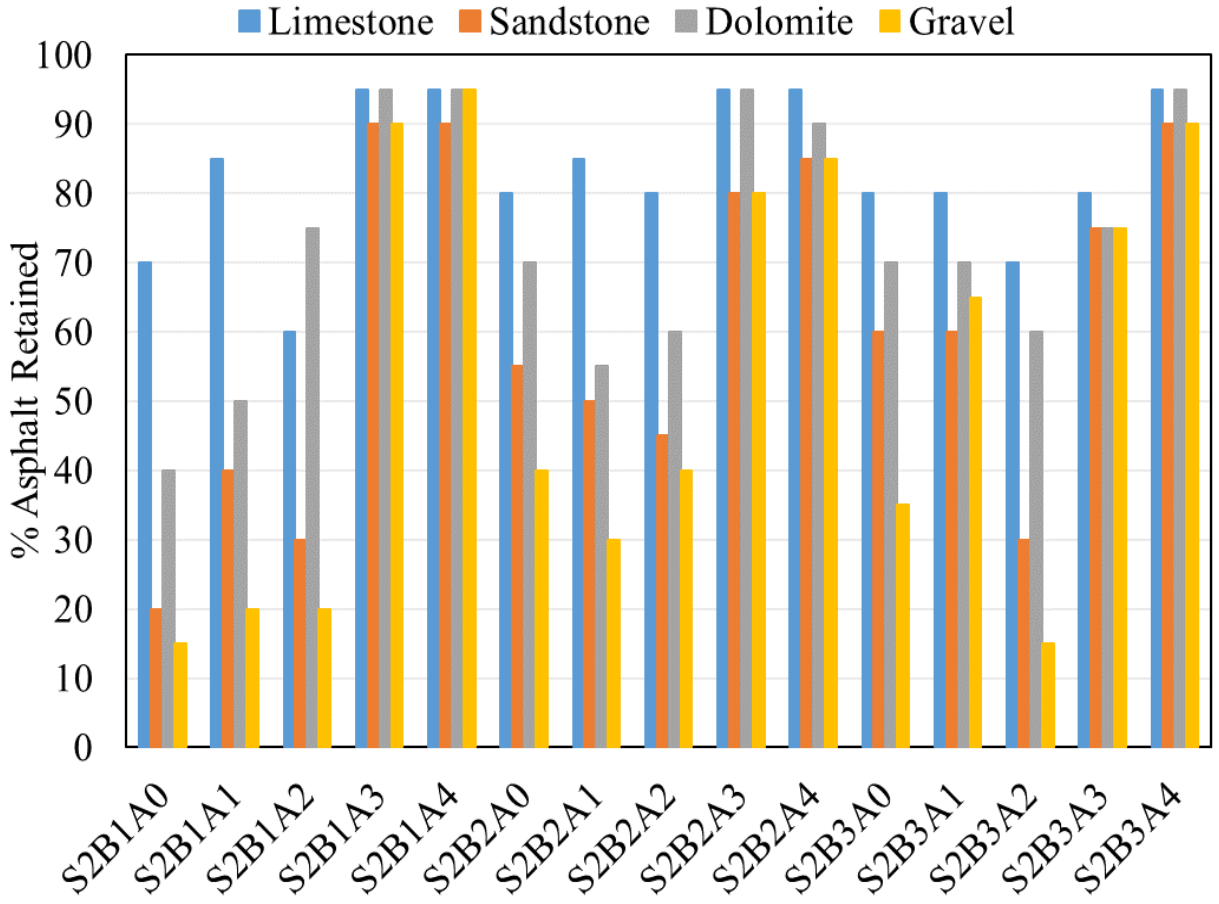


No Additive	**A0**
Sasobit® 1.5%	**A1**
Advera® 6%	**A2**
Evotherm® 0.5%	**A3**
Rediset® 0.75%	**A4**

- Higher Surface Free Energy (SFE) was observed for both Evotherm® and Rediset® modified asphalt binders for both sources
- Lowest SFE was calculated for Sasobit® modified samples
- Advera® mostly increased SFE
- Higher SFE indicates higher adhesive and cohesive bond; thus stronger moisture resistance

Texas Boiling Test results

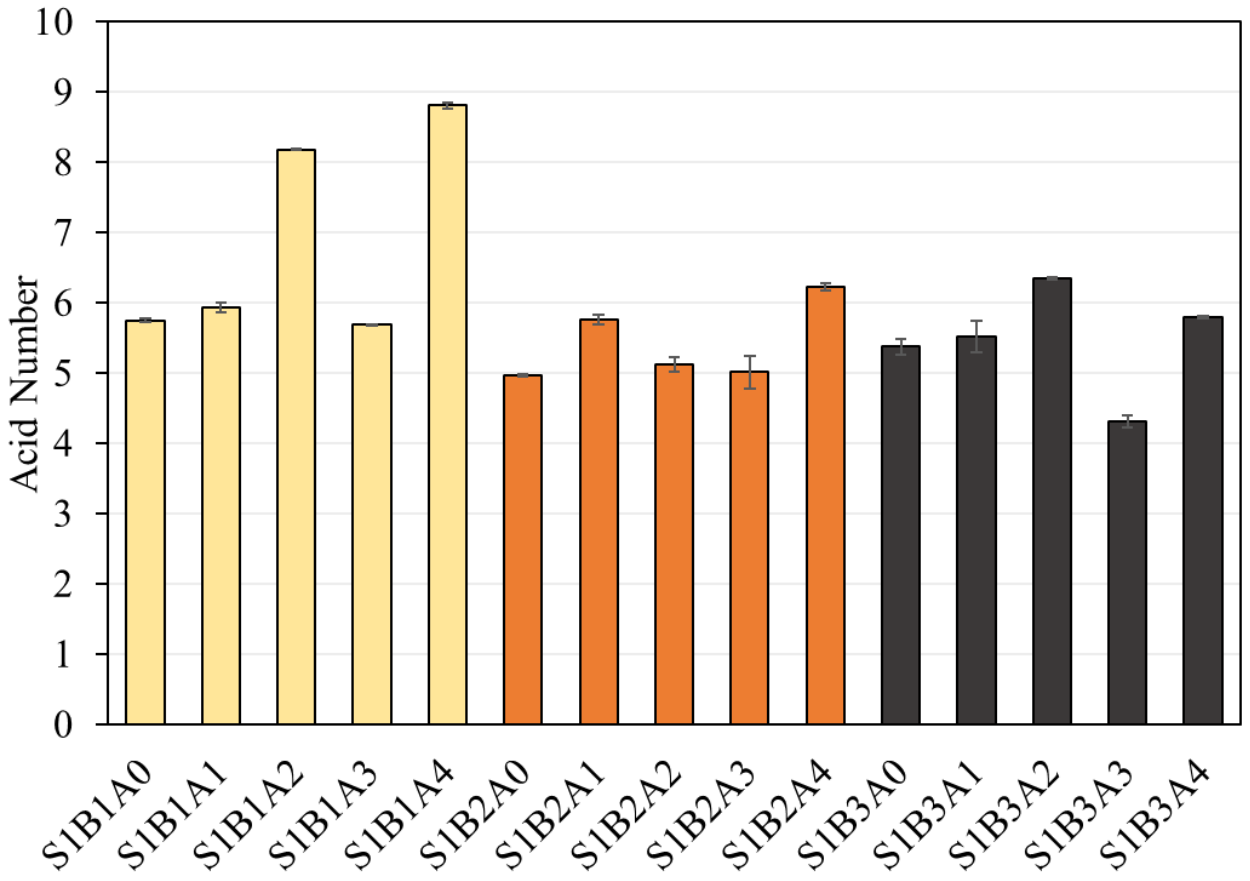


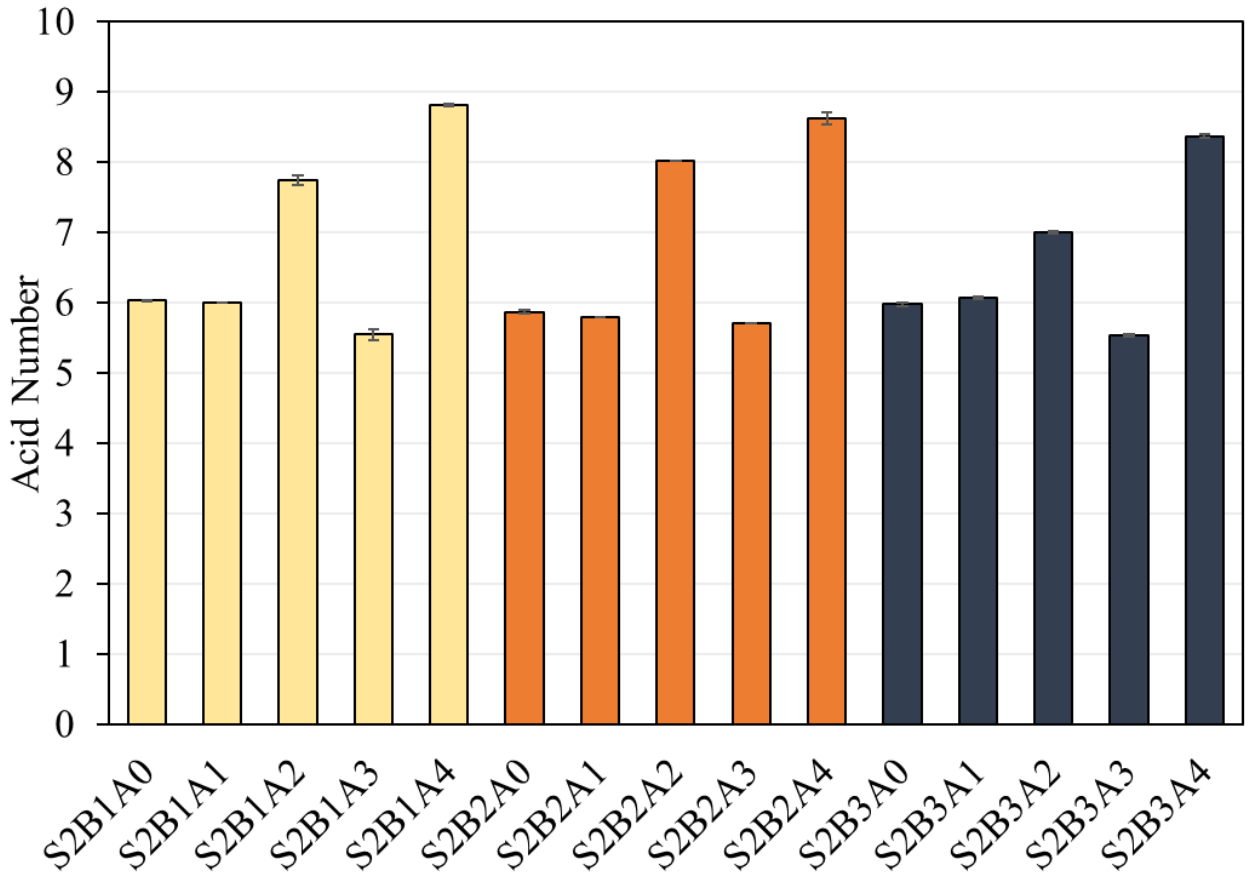


No Additive	**A0**
Sasobit® 1.5%	**A1**
Advera® 6%	**A2**
Evotherm® 0.5%	**A3**
Rediset® 0.75%	**A4**

- Sasobit® and Advera® showed mixed results e.g., Sasobit® improved moisture resistance for the S1B2 binder, whereas it deteriorated for S2B2
- Regardless of aggregate types, Rediset® and Evotherm® showed very high asphalt retention (> 80%)

Acid Number Test results





No Additive	**A0**
Sasobit® 1.5%	**A1**
Advera® 6%	**A2**
Evotherm® 0.5%	**A3**
Rediset® 0.75%	**A4**

- Advera® and Rediset® increased pH values
- Evotherm® reduced pH
- Sasobit® had mixed effect on pH values within the study premise

Conclusions

Rheological Analysis

- Penetration test: sasobit® stiffens all the binders the most, and it is followed by Advera®.
- Highest reduction in viscosity for Rediset®, followed by Sasobit®.
- Mixing and compaction temperatures decreased by 1-5 ℃. Higher reductions observed for Sasobit® and Rediset®
- Sasobit® and Advera® showed higher |G*|/sinδ values than unmodified samples
- Rediset® and Evotherm® improved fatigue resistance.
- Regarding, thermal cracking, Rediset® performed better (lower S and higher m-value) than others.
- MSCR test results showed that Sasobit® and Advera® were suitable for extreme traffic conditions.

Chemical Analysis

- Advera® and Rediset® increased pH. Evotherm® decreased pH values.
- Advera® increased Asphaltene but reduced Aromatic. Sasobit® increased Saturate but decreased Resin only for PG 76-22.
- Advera® introduced sulfoxide (S=O) groups (1030 cm^{-1}) and hydroxyl (-OH) group (3400 cm^{-1})
- The total SFE was governed by the Lifshitz-van der Waals component for all the samples. Rediset® and Evotherm® reduced the moisture susceptibility. Sasobit® may increase moisture susceptibility due to lower total SFE.

Loose Mixes

- Texas Boiling supports SFE data. Evotherm® & Rediset® showed better retention but Sasobit® & Advera® poor retention.

Issues and Future Work

Laboratory

- Use reduced RTFO Aging Temperature for WMA-additive modified binders
- Do Prolong (multiple cycles) of PAV-aging!!
- Advera (Volume expansion) is meant to add at the mixing plant
- Conduct Mixture testing – HWTD, TSR, etc.
- Prepare and test plant mixes

Field

- Pursue field demonstration project
- Collect and cylindrical and saw cut samples
- Monitor field performance

Acknowledgement

- Financial Support: Tran-SET – UTC at Region 6
- Industry Partners: Atlas Asphalt Inc., Asphalt Producer LLC, Delta Companies, Inc.
- Binder suppliers: Ergon Asphalt & Emulsion, Inc. Memphis, TN & Marathon Petroleum Corporation, Memphis, TN
- Aggregate supplies: APAC Central, Capital Quarries, White River Material
- Additive suppliers: Sasol Chemicals, PQ Corporation, Ingevity, and Nouryon
- Paragon Technical Services Inc. (PTSI)- SARA Analsyis
- Individuals: Dr. John E. Haddock, Purdue University - BBR, & Dr. Mohd Kotaiba Abugazleh, Department of Chem., Arkansas State University- FTIR, Dr. Gaylon Baumgardner and Dr. Codrin Daranga, PTSI.

Thank You