US FEDERAL HIGHWAY ADMINISTRATION STUDY ON LOW TEMPERATURE CHARACTERIZATION OF MODIFIED BITUMEN

Understanding the Performance of Modified Asphalt Binders in Mixtures: Low-Temperature Properties

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FOREWORD

This report documents the effects of polymer-modified asphalt binders on the low-temperature cracking resistances of asphalt mixtures. An emphasis was placed on evaluating the performances of mixtures containing polymer-modified asphalt binders with identical Superpave performance grades, but varied modification chemistries. This study is part of a larger study titled "Understanding the Performance of Modified Asphalt Binders in Mixtures," which is partially funded through the National Cooperative Highway Research Program (NCHRP) Project 90-07. The objective of NCHRP Project 90-07 is to determine if asphalt binder performance is correctly captured by the Superpave asphalt binder specification developed under the 1987 through 1993 Strategic Highway Research Program and modified under subsequent studies. This report will be of interest to highway personnel who use polymer-modified asphalt binders and Superpave.

The recently developed Superpave critical cracking temperature (T_{cr}) for asphalt binders agreed with mixture performance, except for one asphalt binder that is currently not used in practice. Several aggregate types were included in the study. The addition of hydrated lime to one of the aggregates significantly affected the low-temperature properties of the mixture. The mechanism for this is not clearly understood and will be investigated.

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1. **Objective**: The objective of this study was to evaluate the cracking temperatures for asphalt binders provided by the Bending Beam Rheometer (BBR) and Thermal Stress Analysis Routine (TSARTM). Low-temperature mixture properties provided by the Thermal Stress Restrained Specimen Test (TSRST) were used to validate these asphalt binder tests. An emphasis was placed on evaluating the performances of mixtures containing polymer-modified asphalt binders with identical Superpave performance grades (PG's) and similar base asphalts, but varied modification chemistries.

2. **BBR and TSARTM**: The BBR provides two cracking temperatures. One temperature is based on creep stiffness (S); the other temperature is based on the m-value. The BBR test is performed in accordance with AASHTO TP1. TSARTM is a computer program that performs AASHTO PP42-01.

3. **Asphalt Binders**: Eleven asphalt binders were tested. This included one air-blown asphalt and eight polymer-modified asphalt binders: (1) styrene-butadiene-styrene [SBS] Linear, (2) SBS Linear Grafted, (3) SBS Radial Grafted, (4) ethylene vinyl acetate [EVA], (5) EVA Grafted, (6) Elvaloy, (7) ethylene styrene interpolymer [ESI], and (8) chemically modified crumb rubber asphalt [CMCRA]. There were two control asphalt binders: an unmodified PG 70-22 and an unmodified PG 64-28. The eight polymer-modified asphalt binders include elastomeric and plastomeric modifiers, some with the same modifier but different

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geometries (linear vs. radial geometries). The term "grafted" includes any mode of chemically reacting a polymer with an asphalt binder, for example, vulcanization. The target PG for the polymer-modified asphalt binders was PG 73-28.

4. **Experiment Using Diabase Aggregate**: The mixtures consisted of diabase aggregate and the 11 asphalt binders. A minimum of three replicate beams at 7.0 ± 0.5-percent air voids were tested by the TSRST. The mixtures were subjected to 2 h of short-term oven aging (STOA) at 135°C before compaction. Two hours of STOA was found to provide the average amount of aging for pavements constructed in 1993 for a Federal Highway Administration (FHWA) Superpave validation study.

5. **Conclusions**: Aggregate type, and the associated changes in mixture composition, generally had no effect on the TSRST fracture temperature. The addition of hydrated lime increased the fracture temperatures of the mixtures with ESI and SBS Radial Grafted. STOA Study: Initially, mixtures with ESI, Elvaloy, and SBS Radial Grafted had lower TSRST fracture temperatures than the mixture with the unmodified PG 70-22 asphalt binder. However, increasing the STOA period from 2 h to 24 h aged the polymer-modified asphalt binders. After 24 h, all four mixtures had fracture temperatures that were not significantly different. CMCRA provided one of the higher TSRST fracture temperatures.

Table 1. Low-temperature asphalt binder properties vs. TSRST with the materials ranked according to mixture fracture temperature.

Asphalt Binder and Mixture Designation	Asphalt Binder Cracking Temperature After RTFO/PAV (°C)			Mixture Property After 2 h of STOA at 135°C							
	T_{cr}	BBR S	BBR m	TSRST Fracture Temperature and Ranking (°C)							TSRST Fracture Stress (kPa)
ESI	-29	-31	-31	-33	A						2320
Elvaloy	-34	-31	-34	-33	A	B					2240
SBS Linear Grafted	-34	-33	-34	-33	A	B	C				2310
EVA Grafted	-33	-32	-31	-31	A	B	C	D			1860
SBS Linear	-33	-32	-31	-30	A	B	C	D	E		2110
SBS Radial Grafted	-34	-32	-32	-30	A	B	C	D	E		2300
EVA	-31	-31	-31	-29		B	C	D	E		2790
CMCRA	-29	-29	-29	-29			C	D	E		1095
Air-Blown	-28	-30	-28	-27				D	E	F	1960
PG 64-28	-28	-28	-30	-26					E	F	1680
PG 70-22	-27	-28	-29	-24						F	2120

T_{cr} = Critical Cracking Temperature.
S = Creep Stiffness.
m = m-value.

Table 2. Low-temperature asphalt binder properties vs. TSRST with the materials ranked according to mixture fracture stress.

Asphalt Binder and Mixture Designation	Asphalt Binder Cracking Temperature After RTFO/PAV (°C)			Mixture Property After 2 h of STOA at 135°C					
	T_{cr}	BBR S	BBR m	TSRST Fracture Temperature (°C)	TSRST Fracture Stress and Ranking (kPa)				
EVA	-31	-31	-31	-29	2790	A			
ESI	-29	-31	-31	-33	2320	A	B		
SBS Linear Grafted	-34	-33	-34	-33	2310	A	B		
SBS Radial Grafted	-34	-32	-32	-30	2300	A	B		
Elvaloy	-34	-31	-34	-33	2240	A	B		
PG 70-22	-27	-28	-29	-24	2120		B		
SBS Linear	-33	-32	-31	-30	2110		B	C	
Air-Blown	-28	-30	-28	-27	1960		B	C	
EVA Grafted	-33	-32	-31	-31	1860		B	C	
PG 64-28	-28	-28	-30	-26	1680			C	
CMCRA	-29	-29	-29	-29	1095				D

T_{cr} = Critical Cracking Temperature.
S = Creep Stiffness.
m = m-value.

Best Performer

Worst Performer

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Table 3. TSRST fracture temperatures for individual beams with diabase.

Asphalt Mixture Designation	TSRST Fracture Temperature (°C)					
	Test #1	Test #2	Test #3	Test #4	s	CV
STOA = 2 h						
ESI	-32.7	-31.9	-33.2	-37.3	2.4	7.3
Elvaloy	-31.3	-35.4	-34.3		2.1	6.4
SBS Linear Grafted	-29.6	-34.0	-35.5		3.1	9.4
EVA Grafted	-31.1	-25.8	-36.3	-31.2	4.3	13.9
SBS Linear	-32.2	-30.1	-29.1		1.6	5.3
SBS Radial Grafted	-31.3	-26.1	-33.0		3.6	12.0
EVA	-29.6	-29.0	-30.4		0.7	2.4
CMCRA	-28.6	-29.7	-28.4		0.7	2.4
Air-Blown	-26.3	-27.8	-27.3		0.8	3.0
PG 64-28	-25.0	-27.1	-27.0		1.2	4.6
PG 70-22	-24.0	-24.0	-26.7	-23.0	1.6	6.7
STOA = 8 h						
ESI	-35.0	-30.7	-32.5		2.2	6.9
Elvaloy	-29.0	-27.6	-30.2		1.3	4.6
SBS Radial Grafted	-28.3	-30.9	-28.4		1.5	5.0
PG 70-22	-20.4	-20.2	-22.4		1.2	5.7
STOA = 24 h						
ESI	-23.4	-23.7	-24.5		0.7	2.3
Elvaloy	-25.8	-27.1	-26.8		0.7	2.6
SBS Radial Grafted	-22.9	-23.5	-25.1		1.1	4.8
PG 70-22	-19.3	-26.7	-21.4		3.8	16.9

Best Performer

Worst Performer

Table 4. TSRST fracture stresses for individual beams with diabase.

Asphalt Mixture Designation	TSRST Fracture Stress (kPa) (STOA = 2 h)					
	Test #1	Test #2	Test #3	Test #4	s	CV
EVA	2830	2650	2890		120	4.3
ESI	2260	2370	2480	2170	130	5.6
SBS Linear Grafted	2450	2210	2270		120	5.2
SBS Radial Grafted	2940	2080	1870		570	24.8
Elvaloy	2670	2000	2050		370	16.5
PG 70-22	2070	1910	2470	2030	240	11.3
SBS Linear	840[1]	2020	2210		120	5.7
Air-Blown	1770	1920	2190		210	10.7
EVA Grafted	1920	2440	1220		610	32.9
PG 64-28	1540	1940	1560		230	13.7
CMCRA	1290	1050	940		180	16.4

Table 5. Low-temperature binder properties vs. TSRST using four aggregates.

Asphalt Binder	Asphalt Binder Cracking Temperature After RTFO/PAV (°C)			TSRST Fracture Temperature After 2 h of STOA at 135°C (°C)				
	T_{cr}	BBR S	BBR m	Average of Four Mixes	Granite	Granite With Lime	Diabase	Limestone
ESI	-29	-32	-31	-33	-34	-29	-33	-36
Elvaloy	-34	-32	-34	-31	-24	-36	-33	-33
SBS Radial Grafted	-34	-32	-32	-30	-34	-26	-30	-32
Air-Blown	-28	-30	-29	-28	-29	-28	-27	-30

T_{cr} = Critical Cracking Temperature.
S = Creep Stiffness.
m = m-value.

Table 6. Effect of aggregate type on TSRST fracture temperature after 2 h of STOA at 135°C.

Aggregate Type	Fracture Temperatures for Each Asphalt Binder (°C)											
	ESI			Elvaloy			SBS Radial Grafted			Air-Blown		
Granite	-34	A		-24		B	-34	A		-29	A	
Granite With Lime	-29		B	-36	A		-26		B	-28	A	
Diabase	-33	A		-33	A		-30	A	B	-27	A	
Limestone	-36	A		-33	A		-32	A		-30	A	
Range in Temperature	7			12			8			3		

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Table 8. TSRST fracture temperatures for individual beams with granite and limestone.

Asphalt Mixture Designation	TSRST Fracture Temperature (°C)					
	Test #1	Test #2	Test #3	Test #4	s	CV
Granite Aggregate						
ESI	-33.1	-33.8	-36.0		1.5	4.4
Elvaloy (nine tests)[1]	-33.0	-21.0	-23.7	-22.2	5.4	22.5
	-28.3	-21.7	-16.5	-23.0		
	-31.8					
SBS Radial Grafted[2]	-36.9	-23.6	-34.0	-31.8	5.7	18.4
Air-Blown (six tests)[3]	-43.8	-35.1	-25.9	-30.2	6.6	21.3
	-27.1	-29.4				
Granite Aggregate With Hydrated Lime						
ESI	-28.8	-26.8	-32.8		3.1	10.4
Elvaloy	-34.2	-39.4	-35.9		2.6	7.3
SBS Radial Grafted	-26.7	-26.0	-25.3		0.7	2.4
Air-Blown	-28.2	-27.8	-27.6		0.3	1.2
Limestone Aggregate						
ESI	-36.8	-35.2	-36.0		0.8	2.2
Elvaloy	-30.6	-34.2	-34.1		2.1	6.4
SBS Radial Grafted	-32.1	-33.4	-32.1		0.8	2.5
Air-Blown	-30.0	-29.2	-30.8		0.8	2.7

Best Performer

Worst Performer

Table 9. Low-temperature binder properties vs. TSRST using three STOA periods.

Asphalt Binder and Mixture Designation	Asphalt Binder Cracking Temperature After RTFO/PAV (°C)			Mixture Property: TSRST Fracture Temperature (°C)			Mixture Property: Temp.
	T_{cr}	BBR S	BBR m	2-h STOA	8-h STOA	24-h STOA	2 h to 24 h
ESI	-29	-32	-31	-33	-32	-24	+9
Elvaloy	-34	-32	-34	-33	-28	-26	+7
SBS Radial Grafted	-34	-32	-32	-30	-29[a]	-24	+6
PG 70-22	-27	-29	-30	-24	-21	-22[b]	+2

[a]Based on peak stress. The temperature based on complete fracture was -33°C.
[b]Based on peak stress. The temperature based on complete fracture was -25°C.

T_{cr} = Critical Cracking Temperature.
S = Creep Stiffness.
m = m-value.

Table 10. Effect of STOA period on the TSRST fracture temperature of each mixture.

STOA Period at 135°C	Fracture Temperatures for Each Asphalt Mixture (°C): ESI			Elvaloy			SBS Radial Grafted			PG 70-22		
2 h	-33	A		-33	A		-30	A		-24	A	
8 h	-32	A		-28		B	-29	A		-21	A	
24 h	-24		B	-26		B	-24		B	-22	A	

Table 11. Effect of asphalt mixture on TSRST fracture temperature.

Asphalt Mixture	Fracture Temperatures at Each STOA Period (°C): 2 h, 135°C			8 h, 135°C			24 h, 135°C		
ESI	-33	A		-32	A		-24	A	
Elvaloy	-33	A		-28	A		-26	A	
SBS Radial Grafted	-30	A		-29	A		-24	A	
PG 70-22	-24		B	-21		B	-22	A	