STATE OF FLORIDA

Laboratory Evaluation of Polymer Modified Asphalt Mixture with Reclaimed Asphalt Pavement (RAP)

Research Report
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STATE MATERIALS OFFICE

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ABSTRACT

The reclaimed asphalt pavement (RAP) mixtures have shown good resistance to rutting for hot-mix asphalt pavement (HMA). Mixtures using polymer modified binders with styrene-butadiene-styrene (SBS) have also shown good performance in terms of rutting and cracking. This report presents the laboratory evaluations in order to determine the rutting and cracking performance of the RAP mixtures with SBS polymer modified binders as virgin binders. The asphalt pavement analyzer (APA) test and indirect tensile (IDT) test were used for the laboratory evaluation. In addition, the properties of SBS polymer modified binders blended with recovered RAP binders were also investigated. The binder tests included $G^*/\sin\delta$ and $G^*\sin\delta$, which respectively, are rutting and cracking parameters of the Superpave PG grade system, were performed. The multiple stress creep and recovery (MSCR) test, which has recently received attention as an indicator of the rutting potential of polymer modified asphalt binder, was also performed.

RAP mixtures with SBS polymer modified binders were fabricated containing different amounts of RAP materials: 0%, 15%, 25%, and 35%. From the APA and Superpave IDT tests, RAP mixtures with modified binders showed good performance regardless of amounts of RAP materials in HMA. Even though the parameters, $G^*/\sin\delta$, $G^*\sin\delta$, and the percent recovery indicated the different amounts of RAP binders in polymer modified binders, the relationship between these parameters and mixture performance was not clearly identified.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

From resurface and rehabilitation projects, plenty of asphalt pavement materials are removed and treated as waste. By the reason of the increase of the reclaimed asphalt pavement (RAP) and development of recycling technologies, RAP has been used as a substitute for the virgin asphalt binder and aggregates in hot mix asphalt (HMA) pavements under encouragement of the federal and state governments in the United States (US). In the meanwhile, the properties of RAP materials have been investigated and revealed by statewide research. In general, RAP materials show a positive effect on rutting resistance (*1*) and a negative effect on cracking resistance specially for temperature cracking (*2*, *3*). Hence, most of the states in the US have restrictions to limit the total amount of RAP materials used in asphalt mixtures.

Polymer modified binders have been used with success at locations of high stress, such as intersections of busy streets, airports, vehicle weight stations, and race tracks (*4*). Among them, styrene butadiene styrene (SBS) modifiers have become increasingly popular because of their achievement in mitigating rutting and cracking for HMA (*5*, *6*, *7*, *8*, *9*, *10*).

At this point, the readers may have a question about the performance of RAP mixtures with polymer modified binders in lieu of unmodified binders. The researchers at Louisiana State University investigated the use of recycled polymer modified asphalt binder in asphalt mixtures (*11*). They evaluated mixtures blended with SBS modified binders extracted from aged pavements, and virgin SBS polymer modified binder. It was concluded that the increasing of the percentages of recycled polymer modified binder in mixtures would increase the rutting resistance but decrease the fatigue resistance of the recycled polymer modified asphalt concrete mixtures by means of laboratory tests; Asphalt Pavement Analyzer (APA), indirect tensile strength and creep, beam fatigue, and repeated shear at constant height (RSCH). However, Huang et al. (*12*) reported that the inclusion of RAP into mixtures with SBS polymer modified binder increased resistance to fracture failure from the semi-circular notched fracture test. They insisted that caution needs to be applied for mixtures with more than 30% of RAP which tended to significantly change the mixtures' fatigue characteristics.

1.2 OBJECTIVES

At present, some agencies, including Florida Department of Transportation (FDOT), also specify the maximum amount of RAP (i.e., 15% for FDOT) for HMA with modified binders (i.e., PG76-22) due to the uncertainty of performance by diminishing the positive effect by stiffening and diminished amount of modified binder (*13*). However, if using more RAP with polymer modified binder exhibits reasonable performance, it will be also positive to environmental circumstances without sacrificing performance. Therefore, the effects of the SBS polymer modified binder on RAP mixtures needs to be examined. More specific objectives of this study include the following:

- Investigating the properties of binders combining SBS polymer modified binder and extracted binder from RAP,
- Evaluating the rutting performance of SBS polymer modified mixtures with the addition of RAP materials, and

- Evaluating the effect of RAP in mixtures with SBS polymer modified binders in terms of cracking performance.

CHAPTER 2

TEST MATERIALS AND DESIGN

The RAP materials used for this study were collected from the same source. Florida limestone was used for the virgin aggregates. As presented in Table 1, the mixture used was a 12.5 mm nominal maximum aggregate size mixture. All mixtures used the same gradation. The same sources of local sand and dust were used to match gradations for mixtures with different percentages of RAP. The recovered binder from RAP materials was graded as PG 82-16 and 133,512 poises for absolute viscosity at 60°C. The asphalt binder modified with SBS (3%) was graded as PG76-22. Four different percentages of RAP materials in the mixtures were evaluated: 0%, 15%, 25%, and 35%, by the weight of aggregates. The control mixture contained only virgin aggregates without RAP materials. All mixtures were designed for traffic level C, which is greater than or equal to 3 million and less than 10 million ESALs. Table 2 provides the volumetric mix design properties of mixtures tested in this study.

For the binder tests, SBS polymer modified binders were blended with different percentages of recovered binders from RAP materials to represent the binder contents in mixtures. Additionally, 100% RAP binder was tested.

The original Superpave specification for HMA design was developed based on the use of virgin materials. The usage of RAP, especially large percentages of RAP, in HMA necessitates a modified methodology taking into account the difference between RAP and virgin materials. The National Cooperative Highway Research Program (NCHRP) Project 9-12 (McDaniel and Anderson 2001), titled as "*Incorporation of Reclaimed Asphalt Pavement in the Superpave*

System", was funded to address this issue. The result from this research effort is reviewed in details.

2.1 MATERIALS

The majority of RAP aggregate used in Florida consisted of Florida limestone. However, with the proliferation of granite aggregate used in the production of asphalt, many projects are increasingly yielding more and more granite source RAP. Therefore, RAP materials used in this research also include both limestone and granite. Two types of RAP were used in terms of fraction: coarse RAP and fine RAP.

2.1.1 RAP Materials

The majority of RAP aggregate used in Florida consisted of Florida limestone. However, with the proliferation of granite aggregate used in the production of asphalt, many projects are increasingly yielding more and more granite source RAP. Therefore, RAP materials used in this research also include both limestone and granite. Two types of RAP were used in terms of fraction: coarse RAP and fine RAP. The recovered binder from RAP materials was graded as PG 82-16 and 133,512 poises for absolute viscosity at 60°C.

2.1.2 Virgin Aggregate Materials

The virgin aggregates used in the mix designs, were Florida limestone. Local sand and dust were used to match gradations among different % RAP mixtures. The detailed information of aggregate sources is presented in Table 1.

TABLE 1 Aggregate Sources

Type	FDOT code	Pit No.	Producer
Coarse RAP		A0721	P&S Paving
Fine RAP		A0721	P&S Paving
S-1-A	42	87-090	Rinker Materials Corp.
S-1-B	52	87-090	Rinker Materials Corp.
Screenings	21	87-090	Rinker Materials Corp.
Crushed Screen		87-090	Rinker Materials Corp.
Local Sand			P&S Paving

2.1.2 Virgin Asphalt Binder

The asphalt binder modified with SBS (3%) was graded as PG76-22. The details are included in appendix.

2.2 MIX DESIGN

As presented in Figure 1, the mixture used was a 12.5 mm nominal maximum aggregate size mixture. All mixtures used the same gradation. The same sources of local sand and dust were used to match gradations for mixtures with different percentages of RAP. Four different percentages of RAP materials in the mixtures were evaluated: 0%, 15%, 25%, and 35%, by the weight of aggregates. The control mixture contained only virgin aggregates without RAP materials. All mixtures were designed for traffic level C, which is greater than or equal to 3 million and less than 10 million ESALs. Table 2 provides the volumetric mix design properties of mixtures tested in this study.

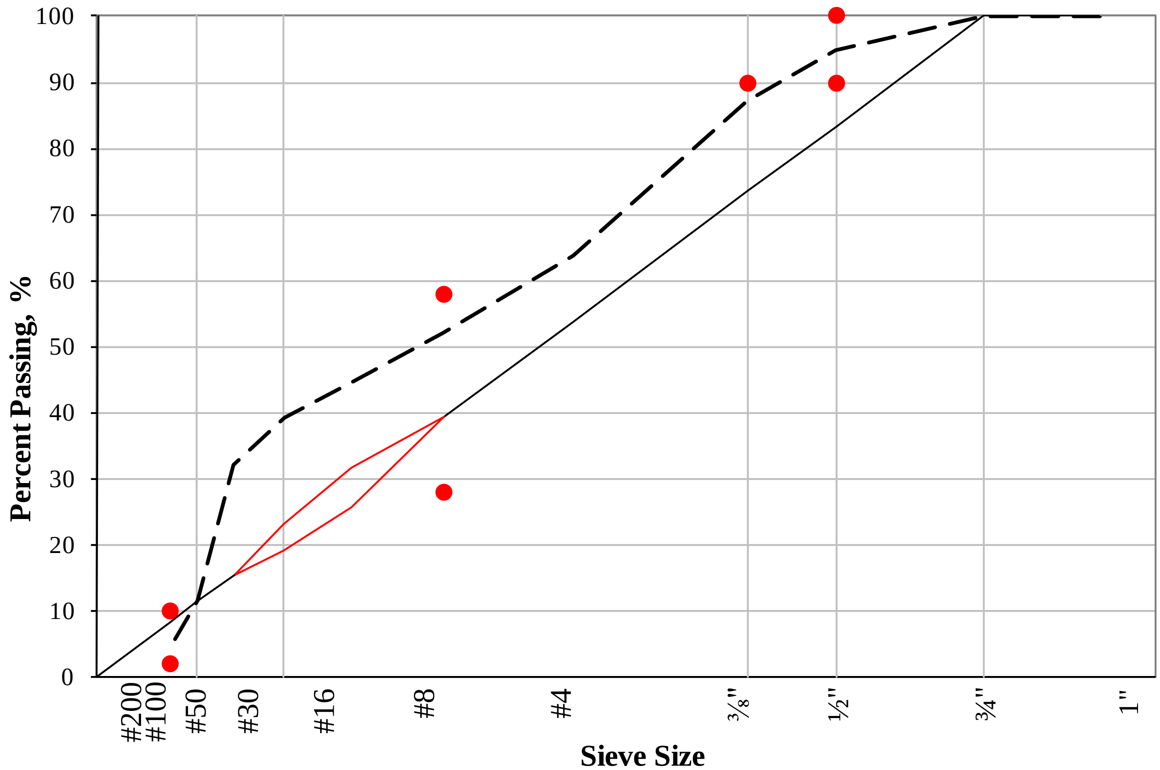

FIGURE 1 Job Mix Formula.

TABLE 2 Mix Design Volumetric Information

Mixture ID	Control	RAP 15%	RAP 25%	RAP 35%
RAP material, %	0	15	25	35
AC, %	6.5	6.5	6.3	6.0
VMA, %	15.1	15.0	14.4	14.0
VFA, %	73.4	73.1	72.3	71.4
Gmm	2.331	2.330	2.337	2.337

2.3 COMPACTION

The samples were compacted in the Servopac Gyratory Compactor (SGC). The three main parameters that control the compaction effort of this equipment for the Superpave design procedure are the vertical pressure, which is set at 600 kPa (87 psi), the angle of gyration, which is set at 1.25 degree, and the number of gyrations to get the desired air void content. In the process of compaction, the height of the specimen and the gyratory shear are measured for each gyration. After cooling the specimen at room temperature, it was cut to the required thickness for testing. The bulk specific gravity was determined to check if the air voids of the specimen are within the required range.

CHAPTER 3

TEST PROGRAM

3.1 ASPHALT BINDER TESTS

Many studies have found that the parameters G*/sinδ and G*sinδ for the temperature performance grade in the Superpave specification have not been sufficient to account for contribution of binders to rutting and cracking resistance of asphalt mixtures (*14, 15, 16*). Since the existing specifications did not fully account for the performance characteristics of modified binders, many states have adopted an additional test or parameter, which is typically one of the following: elastic recovery, force ductility, toughness and tenacity, or phase angle (*17*). The FDOT uses the maximum phase angle for the specification (*13*).

However, Shenoy (*15*) established a procedure to estimate the unrecovered strain for polymer modified asphalt binders during a creep recovery test from the material's volumetric-flow rate by using a new parameter |G*|/(1-(1-tanδ sinδ)). From NCHRP project 9-10, the repeated creep recovery test (RCRT) initially developed (*14*). Thereafter, Delgadillo et al. (*16*) and FHWA researchers (*18*) have evaluated the RCRT at various stress levels and temperatures. Recently, ASTM and AASHTO adopted the multiple stress creep and recovery (MSCR) test as a test protocol, which is fundamentally the same as the RCRT. The tests at the selected temperature apply a constant stress (i.e., 100 Pa or 3,200 Pa) of 1 second followed by a zero-stress recovery period lasting 9 seconds (ASTM D7405 or AASHTO TP70). The MSCR does not require new equipment except that the test program in the dynamic shear rheometer (DSR) is slightly changed. Figure 1 shows the typical data plot from the MSCR test.

In this research, the MSCR was used to test SBS polymer modified binders with the extracted binders from RAP materials. Table 3 shows the summary of testing methods and conditions for aging and temperatures. The different percentages of extracted binders from RAP materials were blended with modified binders at the mixing temperature. In terms of the temperature conditions, they were tested at 76°C after aging using a rolling thin-film oven (RTF, ASTM D2872), and at 25°C after aging using a pressurized aging vessel (PAV, ASTM D6521). The DSR tests (ASTM D7175) were also performed at the same conditions of temperature and aging as the MSCR was performed. In addition, MSCR at 10°C was tested after PAV aging to compare with the indirect tensile (IDT) test performed at the same temperature. The extracted RAP binder without modified binder (100% RAP) was also tested at 82°C, since the recovered binder from RAP materials used in this study was graded as PG82-16. The rotational viscosity (ASTM D4402) was tested at 135°C before aging.

TABLE 3 Summary of Testing Methods and Conditions

Condition	**Original**	**After RTF**		**After PAV**	
Method	Rotational Viscosity	DSR	MSCR	DSR	MSCR
Temperature	135°C	76°C	76 (82*)°C	25°C	25°C and 10°C

* : additional test temperature for 100% RAP binder

All tests were carried out for SBS polymer modified binders blended with different contents of binder recovered from RAP. The 100% RAP binder was also investigated. However, the percentages of the extracted RAP binder blended with SBS polymer modified binders were different from the percentages of RAP materials in mixtures which were calculated by weight of total aggregates in mixtures. Table 4 presents the contents of recovered RAP binders added in

SBS polymer modified binder by weight of total binders. All tests were conducted on two samples for each scenario and the results were averaged.

TABLE 4 RAP Binder Contents Used for Binder Tests

ID	Control	RAP 15%	RAP 25%	RAP 35%	RAP 100%
% of RAP Binder in Blending	0	10.0	16.8	24.4	100

3.2 APA FOR RUTTING PERFORMANCE

The Asphalt Pavement Analyzer (APA), shown in Figure 2, is equipment designed to test the rutting susceptibility or rutting resistance of hot mix asphalt (HMA). Rut performance tests are performed by means of a constant load applied repeatedly through a pressurized hose to a compacted test specimen. The cylindrical test specimens are 150 mm diameter by 115 mm tall. The target air void range is 4 ± 0.5%.

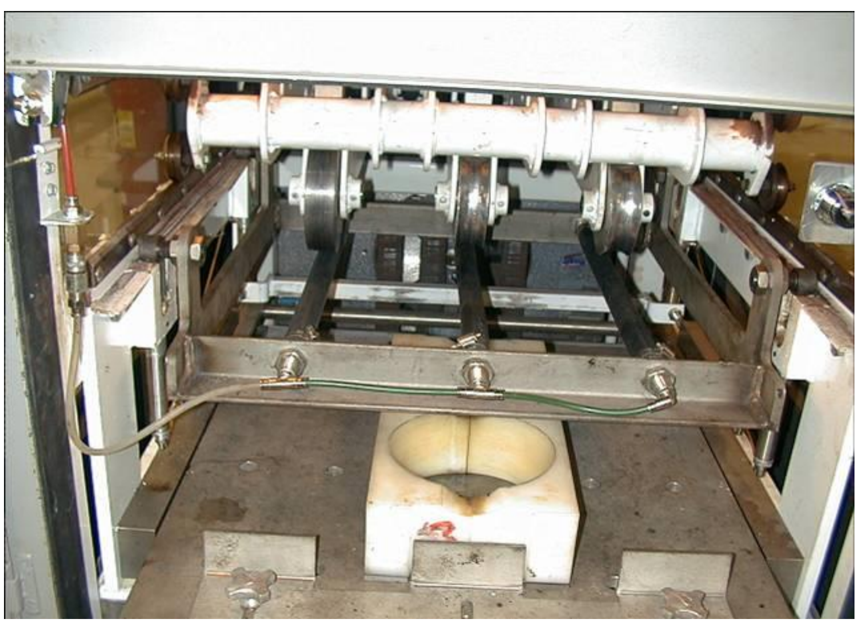

FIGURE 2 Asphalt Pavement Analyzer.

The steps for the APA testing procedure using the pressurized hose are outlined below:

- Preheat the specimen in the APA chamber to 64°C (147°F) for a minimum of 6 hours but not more than 24 hours before the test.
- Set the hose pressure gauge reading to 100±5 psi.
- Calibrate each wheel with the load cell to read a load of 100±5 lbs.
- Secure the preheated, molded specimen in the APA, close the chamber doors and allow about 10 minutes for the temperature to stabilize.
- Apply 25 load cycles and take initial measurements.
- Place the specimen back in the APA, close the chamber doors and allow about 10 minutes for the temperature to stabilize.
- Restart the APA and continue rut testing for 8,000 cycles.
- The difference between the initial and final rut depth are calculated and averaged.

3.3 SUPERPAVE IDT FOR CRACKING PERFORMANCE

The Superpave indirect tension test (IDT) shown in Figure 3 was used to evaluate the mixtures' resistance to cracking. This test was performed to obtain the mixture properties: resilient modulus (MR), creep compliance [D(t)], m-value, D1, tensile strength, fracture energy (FE), and dissipated creep strain energy (DCSE) to failure (Roque et al. 1997, Zhang et al. 2001a and 2001b). The air voids of test specimens were targeted at 7 ± 0.5%, and tests were conducted at 10°C. Figure 4 presents the schematic of Superpave IDT and determination of DCSE to failure based on indirect tensile strength test results.

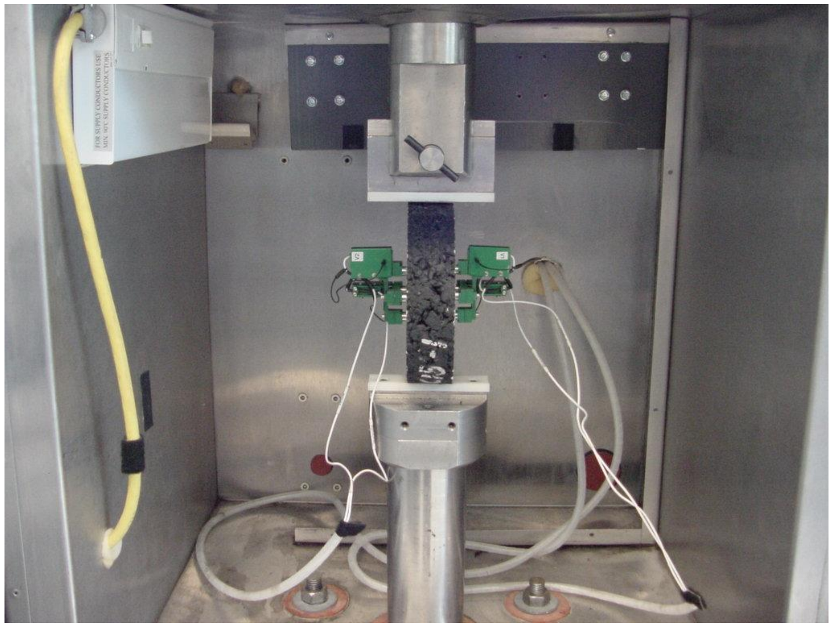

FIGURE 3 Superpave IDT.

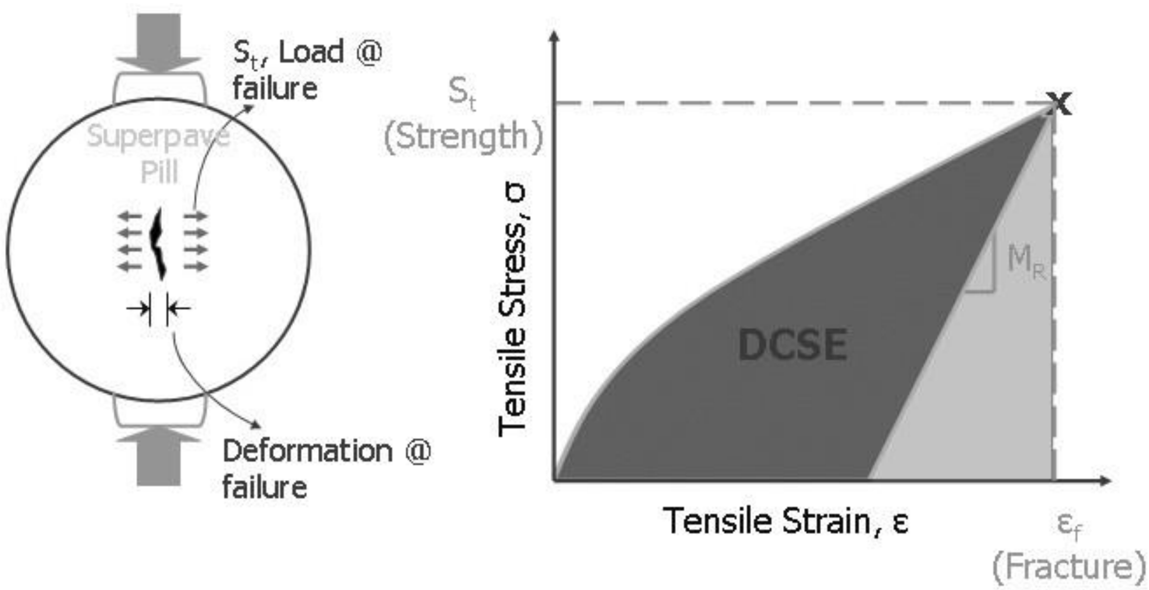

FIGURE 4 Schematic of Superpave IDT and Determination of DCSE to Failure.

The energy ratio (ER), which is defined as the DCSE threshold of a material ($DCSE_f$) divided by the minimum DCSE ($DCSE_{min}$) needed, is calculated from IDT results as follows (Roque et al. 2004).

$$ER = \frac{DCSE_f}{DCSE_{\min}}$$

The $DCSE_{min}$ is a function of material properties and the pavement structure.

$$DCSE_{\min} = \frac{m^{2.98} D_1}{A}$$

where, m and D1 are the creep compliance power law parameter.

Parameter "A" accounts for the tensile stresses in the pavement structure at the bottom of the asphalt layer and the tensile strength of the material. Unless the tensile stresses in the pavement structure are given, 150 psi is used for the default value.

$$A = 0.0299 \times \sigma^{-3.10} (6.36 - S_t) + 2.46 \times 10^8$$

where, σ is the applied tensile stress, S_t is the tensile strength.

Therefore, ER can be calculated directly once the mixture creep compliance parameters (m-value and D_1), the tensile stress, and the tensile strength are known. In Florida, ER values less than 1.0 have been associated with pavements that have exhibited poor cracking performance. Therefore, ER should be greater than 1.0 for the mixture to be acceptable

CHAPTER 4

TEST RESULTS

4.1 BINDER TEST RESULTS

Figure 5 shows results from the rotational viscosity tests. Even though the viscosity for 100% RAP binder was higher than others, values from 0% to 35% showed little or a slight increase by adding additional RAP binder. From the DSR test, G*/sinδ and G*sinδ increased as addition of RAP binder increased, as shown in Figure 6. Therefore, G*/sinδ and G*sinδ were found to fairly represent the presence of RAP binder, even in SBS polymer modified binders. Mohammad et al. (*11*) also reported that the same trends were found from recycled polymer modified binders with virgin polymer modified binders.

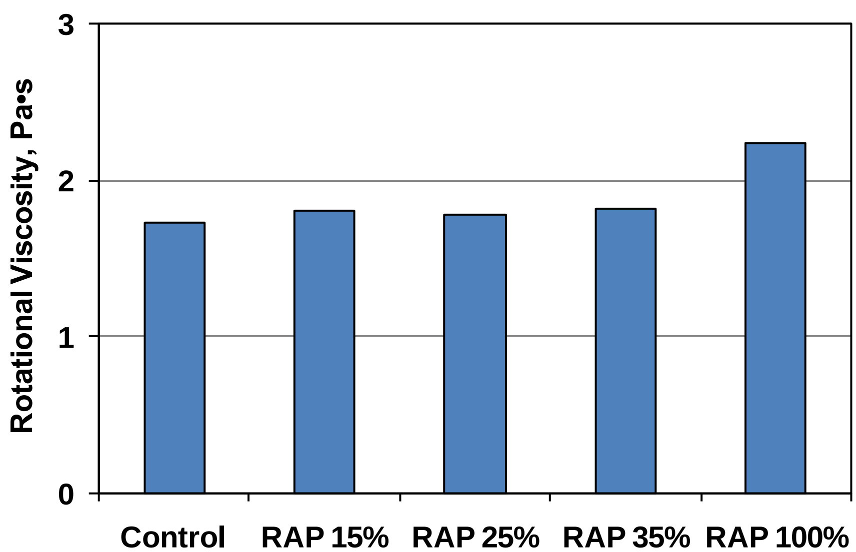

FIGURE 5 Rotational Viscosity Results.

Figure 7 shows the percent recovery for each binder from the MSCR test. For RTF binders at 76°C, the percent recovery decreases as the content of modified binder decreases (i.e., RAP binder increases). In contrast, the percent recovery of PAV binders for stresses with 100 Pa and 3200 Pa at 25°C and 10°C slightly increases as the content of RAP binder increases. The percent recovery values for 100% RAP binders tested at 82°C were 20.6% at 100 Pa and 11.1% at 3200 Pa. The minimum value of 15% recovered strain is recommended (*18*).

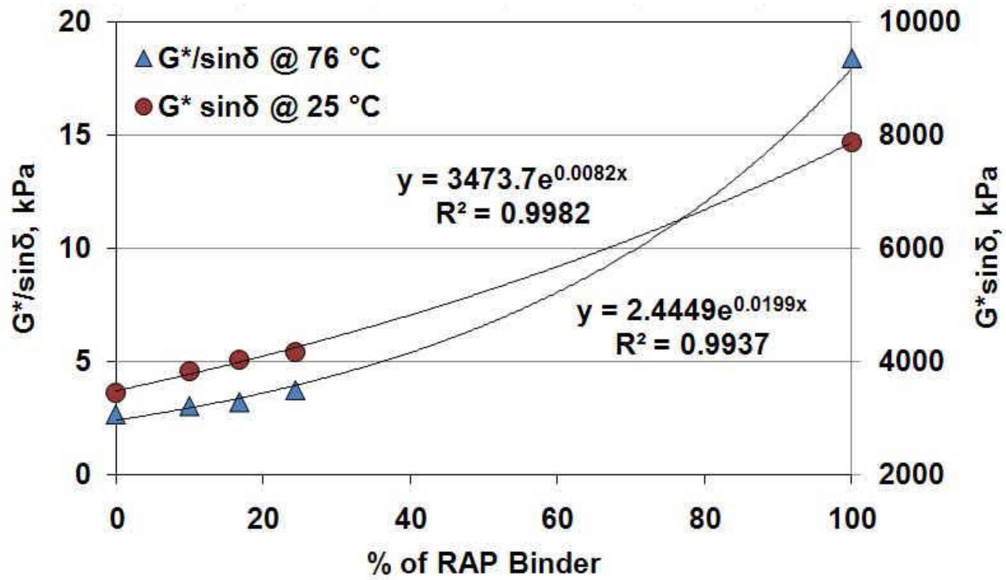

FIGURE 6 G*/sinδ and G*sinδ Results.

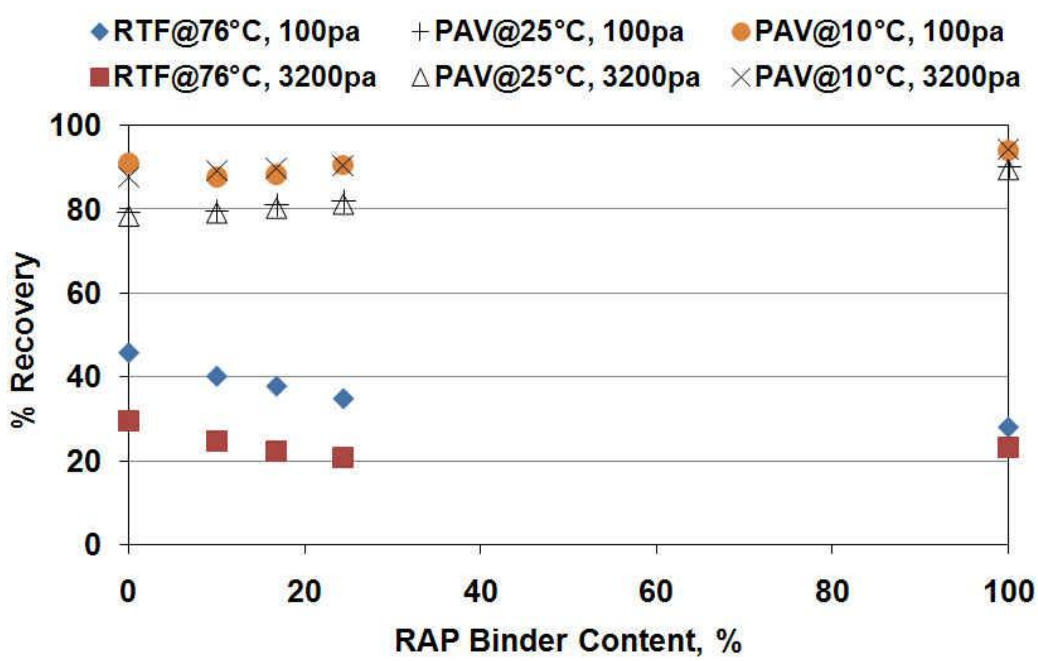

FIGURE 7 Percent Recovery from MSCR Test.

As shown in Figure 8, however, the maximum strains for PAV binders were significantly lower than RTF binders. As a result of PAV aging, modified binders stiffen significantly and show much lower strain, especially for the 100% RAP binder. This may induce erratic responses at lower temperatures (Figure 9). This unreliable strain response appeared at the lower stress and temperature (i.e., 100 Pa at 10°C). Therefore, a variety of stress levels needs to be tested to have a better understanding of the MSCR test results at the lower temperature.

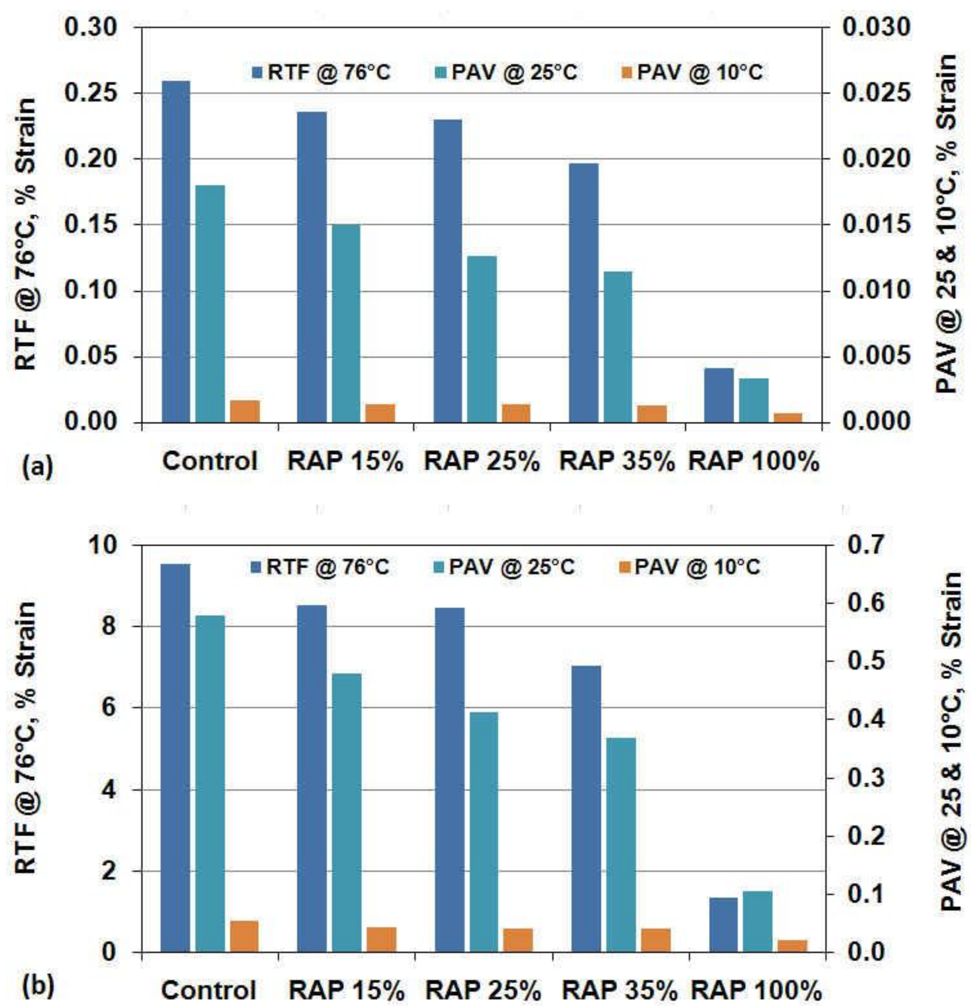

FIGURE 8 Maximum Strain from MSCR Test (a) stress = 100 Pa (b) stress = 3200 Pa.

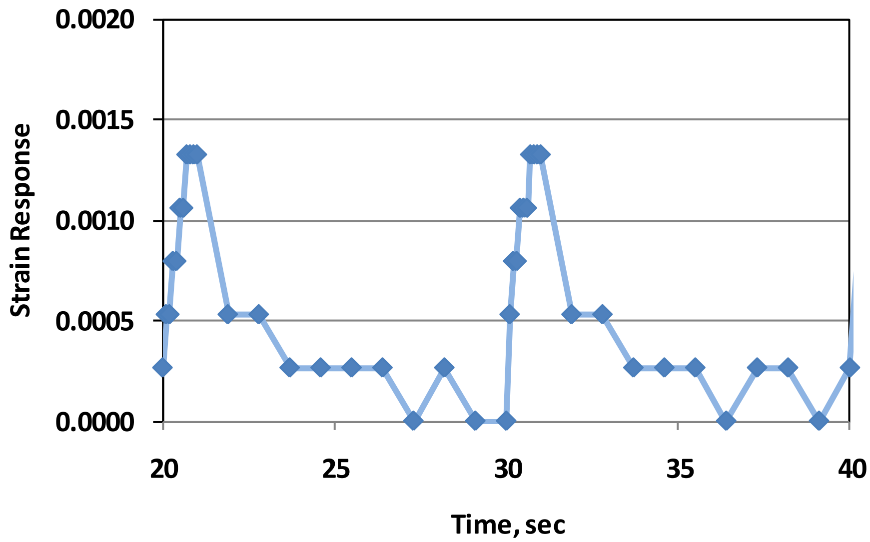

FIGURE 9 Example of Erratic Response (stress 100 Pa at 10°C with 15% RAP binder).

4.2 MIXTURE TEST RESULTS

Figure 10 presents rut depth results from the APA test. The 15% RAP mixture showed slightly higher rutting than average and the 25% RAP mixture showed slightly lower rutting than average, but not significantly. This result indicates that the modified binder in mixtures seems to have enough resistance to rutting even without RAP materials. As the content of RAP binder increased, G*/sinδ increased but percent recovery decreased (Figure 4 and 5). Even though G*/sinδ and percent recovery at 76°C indicated the different amounts of RAP binders with polymer modified binders in different ways, unfortunately, the result from the APA test was not sensitive enough to show any relationship between parameters and rutting performance. However, all values of G*/sinδ except 100% RAP were higher than the minimum value recommended by specification. The MSCR result also indicated that the percent recovery for all binders was higher than 15 percent at 76°C, which is recommended (*18*).

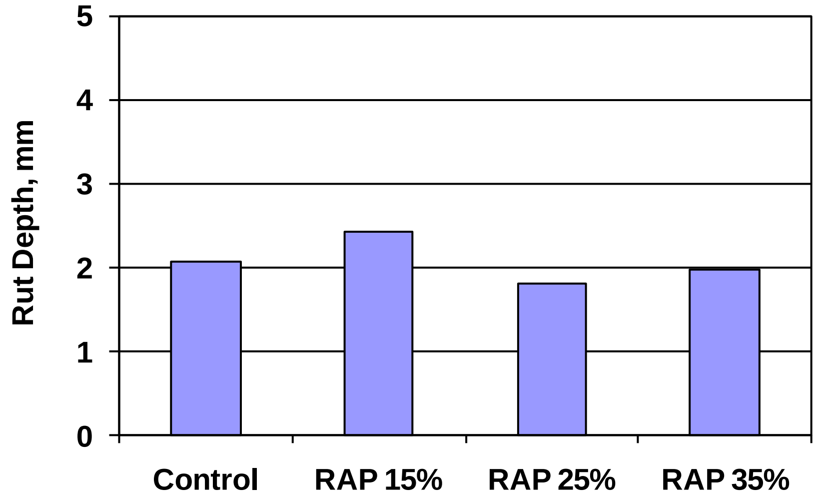

FIGURE 10 Rut Depth Results from APA Test.

Figure 11 shows the tensile strength results from the Superpave IDT test. There are slight increases as the percentage of RAP used in the mixture increases, but not significantly different.

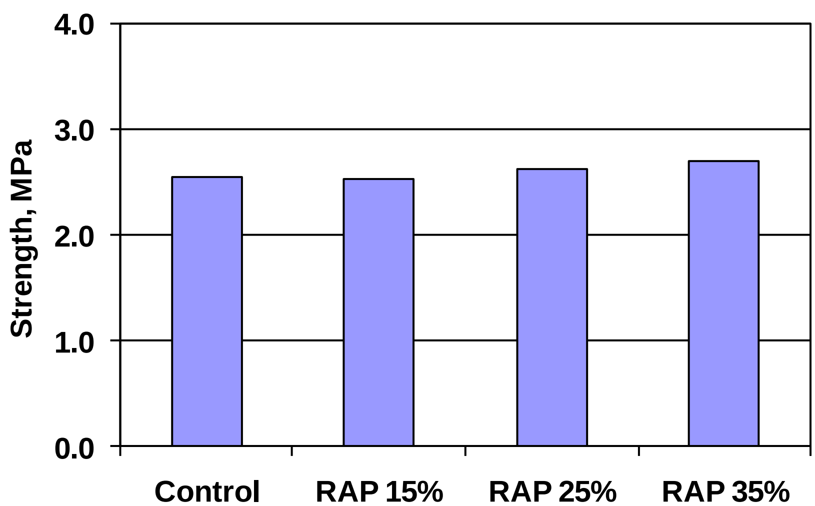

FIGURE 11 Indirect Tensile Strength.

Figure 12 shows that the $DCSE_f$ values were not significantly different, although the 35% RAP mixture exhibited a slightly lower value. The previous study (*23*) concluded that the polymer had almost no effect on the tensile strength or $DCSE_f$. However, more RAP materials in a mixture may be able to reduce $DCSE_f$ due to its brittleness.

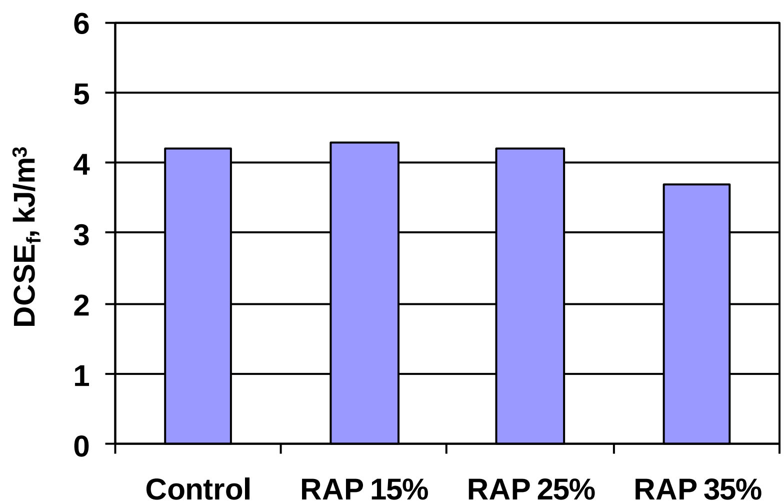

FIGURE 12 $DCSE_f$ Results.

From Figure 13, even though 25% RAP and 35% RAP mixtures showed slightly lower creep compliance rates, which is directly related to the rate of microdamage accumulation by adding more RAP materials, overall, all the mixtures showed relatively low values (i.e., below 1.0×10^{-8}). This seems to indicate that the SBS modifier has a greater influence on the time-dependent response, such as the creep response (*23*). From the MSCR results at 25 and 10°C (Figure 7), mixtures with more RAP materials showed slightly higher percent recovery that means lower non-recoverable creep strain. Consequently, all mixtures showed reasonably good values of ER over 4.0 (Figure 14). The 25% RAP and 35% RAP mixtures exhibited slightly higher ERs due to a little lower rate of creep compliance decreasing $DCSE_{min}$. Therefore, RAP mixtures with SBS polymer modified binders are able to show good cracking performance.

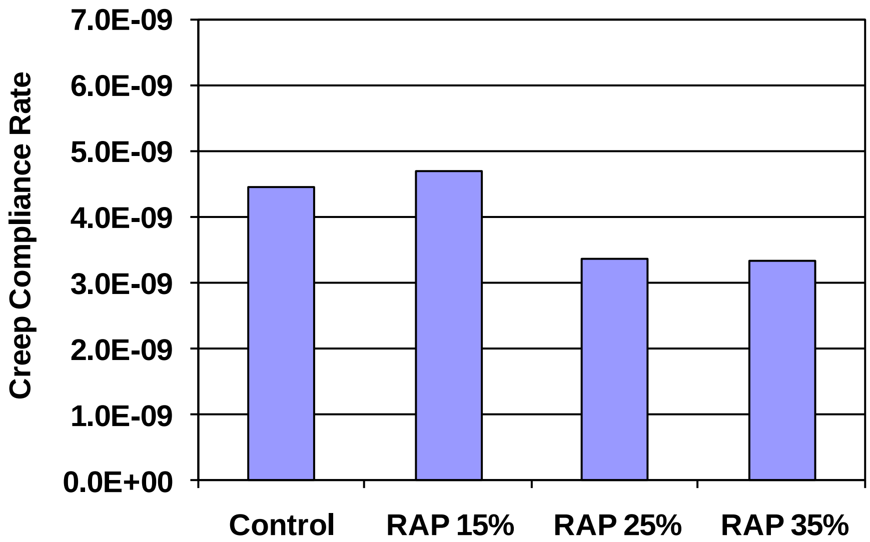

FIGURE 13 Creep Compliance Rate Results.

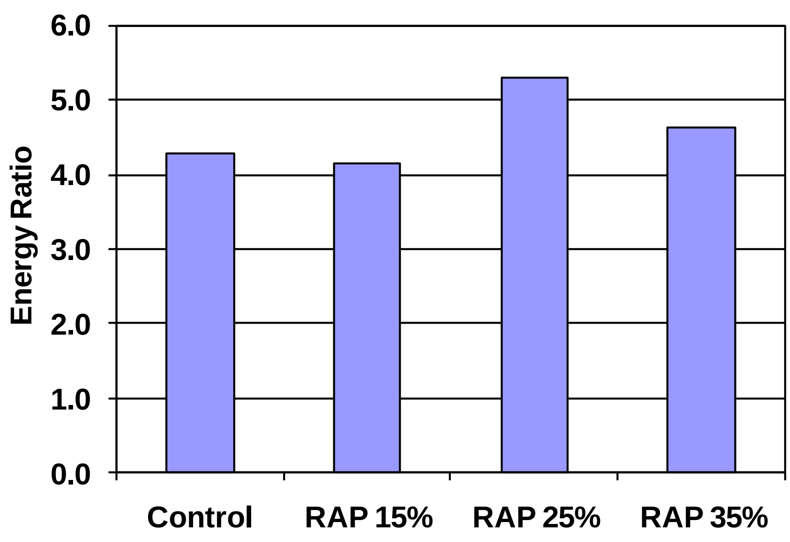

FIGURE 14 Energy Ratio Results.

CHAPTER 5

SUMMARY AND CONCLUSIONS

SBS polymer modified asphalt mixtures with various contents of RAP materials were evaluated in this study. The DSR test results showed that there was a relationship between the amounts of RAP binder as blended with modified binders, and G*/sinδ and G*sinδ, which are the rutting and cracking parameters of Superpave PG grade system.

However, from the APA test, the rut depth did not show the significant differences between different amounts of RAP materials in mixtures with polymer modified binders. From the Superpave IDT tests, the tensile strength increased slightly as RAP materials increased in a mixture but was not significant. Even though 25% and 35% RAP mixtures exhibited slightly higher ER due to lower creep compliance rates, generally, all RAP mixtures with SBS polymer modified binders performed well in the Superpave IDT tests. Therefore, the modified binder in mixtures seems to have enough resistance to rutting even without RAP materials. However, in lieu of comparison between binder properties and mixture performance results, G*/sinδ and G*sinδ did not represent as an indicator of the mixture performances which includes polymer modified binders and RAP materials. Even though the MSCR test showed the possibility to be a parameter to estimate the mixture performance, more research efforts are needed to have better understanding for MSCR at the lower temperature.

Since the scope of this study is limited, more varied materials and tests are recommended to have profound insights such as thermal and moisture effects.

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APPENDIX A

JMF

A.1 Control Mixture (0% RAP)

	Type of Material	FDOT Code	Producer	Pit
1.	S-1-A	42	Rinker	87-090
2.	S-1-B	52	Rinker	87-090
3.	Screenings	21	Rinker	87-090
4.	Local Sand		P & S Paving	
5.	Crushed Screens		Rinker	87-090

		Percent Passing						
Blend		11%	36%	31%	15%	7%		100%
Number		1	2	3	4	5	6	JMF
Sieve Size	3/4"	100	100	100	100	100		100
	1/2"	51	100	100	100	100		95
	3/8"	23	88	100	100	100		87
	# 4	4	29	100	100	100		64
	# 8	3	5	92	100	100		53
	# 16	2	2	69	100	100		44
	# 30	2	2	49	99	100		38
	# 50	2	1	31	91	99		31
	# 100	2	1	9	23	70		12
	# 200	1.5	1.0	2.2	1.7	38.0		4.1

A.2 15% RAP Mixture

	Type of Material	FDOT Code	Producer	Pit
1.	Coarse RAP		P & S Paving	A0721
2.	Fine RAP		P & S Paving	A0721
3.	S-1-A	42	Rinker	87-090
4.	S-1-B	52	Rinker	87-090
5.	Screenings	21	Rinker	87-090

Percent Passing								
Blend		5.6%	39.4%	8.1%	33.6%	13.3%		100.0%
Number		1	2	3	4	5	6	JMF
Sieve Size	3/4"	100	100	100	100	100		100
	1/2"	94	100	51	100	100		96
	3/8"	78	100	23	88	100		88
	# 4	37	93	4	29	100		62
	# 8	31	74	3	5	92		45
	# 16	27	61	2	2	69		36
	# 30	24	52	2	2	49		29
	# 50	19	41	2	1	31		22
	# 100	10	19	2	1	9		10
	# 200	5.6	9.6	1.5	1.0	2.2		4.8

A.3 25% RAP Mixture

	Type of Material	FDOT Code	Producer	Pit	Terminal
1.	Coarse RAP		P & S Paving	A0721	
2.	Fine RAP		P & S Paving	A0721	
3.	S-1-A	42	Rinker	87-090	
4.	S-1-B	52	Rinker	87-090	
5.	Screenings	21	Rinker	87-090	
6.	Local Sand		P & S Paving		
7	Crushed Screen		Rinker	87-090	

		Percent Passing							
Blend		9.9%	15.1%	9.5%	27.9%	18.3%	17.9%	1.4%	100.0%
Number		1	2	3	4	5	6	7	JMF
Sieve Size	3/4"	100	100	100	100	100	100	100	100.0
	1/2"	94	100	51	100	100	100	100	94.8
	3/8"	78	100	23	88	100	100	100	87.2
	# 4	37	93	4	29	100	100	100	63.8
	# 8	31	74	3	5	92	100	100	52.1
	# 16	27	61	2	2	69	100	100	44.6
	# 30	24	52	2	2	49	99	100	39.1
	# 50	19	41	2	1	31	91	99	31.9
	# 100	10	19	2	1	9	23	70	11.1
	# 200	5.6	9.6	1.5	1.0	2.2	1.7	38.0	3.7

A.4 35% RAP Mixture

	Type of Material	FDOT Code	Producer	Pit	Terminal
1.	Coarse RAP		P & S Paving	A0721	
2.	Fine RAP		P & S Paving	A0721	
3.	S-1-A	42	Rinker	87-090	
4.	S-1-B	52	Rinker	87-090	
5.	Screenings	21	Rinker	87-090	
6.	Local Sand		P & S Paving		
7	Crushed Screen		Rinker	87-090	

		Percent Passing							
Blend		15.0%	20.0%	8.7%	24.0%	15.1%	16.5%	0.7%	100.0%
Number		1	2	3	4	5	6	3	JMF
Sieve Size	3/4"	100	100	100	100	100	100	100	100.0
	1/2"	94	100	51	100	100	100	100	94.8
	3/8"	78	100	23	88	100	100	100	87.1
	# 4	37	93	4	29	100	100	100	63.8
	# 8	31	74	3	5	92	100	100	52.0
	# 16	27	61	2	2	69	100	100	44.5
	# 30	24	52	2	2	49	99	100	39.1
	# 50	19	41	2	1	31	91	99	31.9
	# 100	10	19	2	1	9	23	70	11.4
	# 200	5.6	9.6	1.5	1.0	2.2	1.7	38.0	4.0

APPENDIX B

BINDER TEST RESULTS

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
BITUMINOUS MATERIAL REPORT

Page 1

Project: RAP Mixtures with Polymer Modified Binder   Binder Type: "Control" (100% PG 76-22)

Submiter: Sungho Kim   Lab No.: 11685LB   Report Date: 06/17/08

Test		Test Results		SPECIFICATION
Tests on Original Binder:		***Test "A"***	***Test "B"***	
Rotational Viscosity @ 135°C, Pa•s		1.70	1.75	Max. 3 Pa•s

Tests on Rolling Thin Film Residue:		***Test "A"***	***Test "B"***	
RTF DSR @76°C	G*, (kPa)	2.490	2.467	
	δ, (degree)	68.5	68.6	
	G*/sinδ, (kPa)	2.679	2.649	Min. 2.20 kPa

Tests on 100°C PAV Residue:		***Test "A"***	***Test "B"***	
PAV DSR @25°C	G*, (kPa)	4869.1	4410.2	
	δ, (degree)	47.8	48.0	
	G*sinδ, (kPa)	3607.0	3279.9	Max. 5000 kPa

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
BITUMINOUS MATERIAL REPORT

Project: RAP Mixtures with Polymer Modified Binder   Binder Type: 15% RAP (blended 10% RAP)

Submiter: Sungho Kim   Lab No.: 11685LB   Report Date: 06/17/08

Test		Test Results		SPECIFICATION
Tests on Original Binder:		***Test "A"***	***Test "B"***	
Rotational Viscosity @ 135°C, Pa•s		1.73	1.89	Max. 3 Pa•s

Tests on Rolling Thin Film Residue:		***Test "A"***	***Test "B"***	
RTF DSR @76°C	G*, (kPa)	2.848	2.851	
	δ, (degree)	70.0	70.0	
	G*/sinδ, (kPa)	3.030	3.035	Min. 2.20 kPa

Tests on 100°C PAV Residue:		***Test "A"***	***Test "B"***	
PAV DSR @25°C	G*, (kPa)	5546.8	5067.2	
	δ, (degree)	46.0	46.5	
	G*sinδ, (kPa)	3989.7	3675.8	Max. 5000 kPa

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
BITUMINOUS MATERIAL REPORT

Project: RAP Mixtures with Polymer Modified Binder   Binder Type: 25% RAP (blended 16.8% RAP)

Submiter: Sungho Kim   Lab No.: 11685LB   Report Date: 06/17/08

Test		Test Results		SPECIFICATION
Tests on Original Binder:		***Test "A"***	***Test "B"***	
Rotational Viscosity @ 135°C, Pa•s		1.72	1.85	Max. 3 Pa•s

Tests on Rolling Thin Film Residue:		***Test "A"***	***Test "B"***	
RTF DSR @76°C	G*, (kPa)	3.033	3.013	
	δ, (degree)	70.4	70.7	
	G*/sinδ, (kPa)	3.220	3.191	Min. 2.20 kPa

Tests on 100°C PAV Residue:		***Test "A"***	***Test "B"***	
PAV DSR @25°C	G*, (kPa)	5806.8	5603.0	
	δ, (degree)	44.7	44.9	
	G*sinδ, (kPa)	4084.1	3954.6	Max. 5000 kPa

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
BITUMINOUS MATERIAL REPORT

Project: RAP Mixtures with Polymer Modified Binder   Binder Type: 35% RAP (blended 24.4% RAP)

Submiter: Sungho Kim   Lab No.: 11685LB   Report Date: 06/17/08

Test		Test Results		SPECIFICATION
Tests on Original Binder:		***Test "A"***	***Test "B"***	
Rotational Viscosity @ 135°C, Pa•s		1.75	1.88	Max. 3 Pa•s

Tests on Rolling Thin Film Residue:		***Test "A"***	***Test "B"***	
RTF DSR @76°C	G*, (kPa)	3.579	3.475	
	δ, (degree)	70.7	70.8	
	G*/sinδ, (kPa)	3.792	3.680	Min. 2.20 kPa

Tests on 100°C PAV Residue:		***Test "A"***	***Test "B"***	
PAV DSR @25°C	G*, (kPa)	6243.3	5691.3	
	δ, (degree)	44.2	44.4	
	G*sinδ, (kPa)	4350.4	3978.7	Max. 5000 kPa

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
BITUMINOUS MATERIAL REPORT

Project: RAP Mixtures with Polymer Modified Binder   Binder Type: RAP (100%)

Submiter: Sungho Kim   Lab No.: 11685LB   Report Date: 06/17/08

Test	Test Results		SPECIFICATION
Tests on Original Binder:	***Test "A"***	***Test "B"***	
Rotational Viscosity @ 135°C, Pa•s	2.14	2.33	Max. 3 Pa•s

Tests on Rolling Thin Film Residue:		***Test "A"***	***Test "B"***	***Test "C"***	**Specification**
RTF DSR @76°C	G*, (kPa)	17.797	16.656	16.555	
	δ, (degree)	69.6	69.5	70.7	
	G*/sinδ, (kPa)	18.984	17.780	17.546	Min. 2.20 kPa

Tests on 100°C PAV Residue:		***Test "A"***	***Test "B"***	***Test "C"***	**Specification**
PAV DSR @25°C	G*, (kPa)	14223.0	15495.0	14299.0	
	δ, (degree)	32.0	32.0	31.8	
	G*sinδ, (kPa)	7537.1	8203.2	7507.3	Max. 5000 kPa
Strain Amplitude recorded for test:		0.69%	0.64%	0.69%	1.00%

PAV DSR Results were flagged with the following note: "Unable to achieve target strain of 1.0%. Using measurement made at Maximum Stress amplitude of 98.4771 kPa."

MSCR Test Result

Aging		RTF		PAV			
Test Temp., °C		76		25		10	
Applied Stress, pa		100	3200	100	3200	100	3200
ID	% RAP	% Recovery					
Control	0	45.7	29.5	79.3	78.2	91.0	87.7
RAP 15%	10.0	40.1	24.7	79.6	79.0	87.6	89.2
RAP 25%	16.8	37.8	22.2	81.0	80.1	88.3	89.8
RAP 35%	24.4	34.8	20.8	81.9	81.1	90.6	90.3
RAP 100%	100	28.0	23.2	90.1	89.4	94.2	94.4

APPENDIX C

SUPERPAVE IDT TEST RESULTS

Mixture	m-value	D_1 (1/psi)	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	$DCSE_{HMA}$ (kJ/m^3)	Stress (psi)	a	$DCSE_{MIN}$ (kJ/m^3)	ER	Creep Rate	Failure Strain
Control	0.411	6.34E-07	2.55	10.17	4.5	4.2	150	4.58E-08	0.977	4.28	4.46E-09	2365.46
RAP 15%	0.401	7.34E-07	2.52	8.70	4.7	4.3	150	4.60E-08	1.045	4.15	4.70E-09	2529.72
RAP 25%	0.381	6.34E-07	2.62	10.05	4.5	4.2	150	4.55E-08	0.785	5.30	3.36E-09	2373.43
RAP 35%	0.366	7.28E-07	2.70	10.21	4.1	3.7	150	4.50E-08	0.809	4.63	3.34E-09	1999.33