

Study of the Effectiveness of Styrene-Butadiene Rubber Latex in Hot Mix Asphalt Mixes

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Many benefits are attributed to the use of styrene-butadiene rubber (SBR) latex in asphalt concrete pavements. These include decreased temperature susceptibility, increased rut resistance, and increased resistance to stripping. Potential benefits of SBR latex in hot mix asphalt mixtures were evaluated, and the results of the first 1½ years of a 5-year study are reported. Six existing test sites were identified and selected for evaluation. The test sites were located throughout Alabama, and each contained a control mixture and SBR latex modified mixture. Condition surveys were performed at each site to compare performance parameters such as rutting, transverse cracking, raveling, and bleeding. The Alabama Highway Department's pavement management data base provided additional data. The data base was investigated to compare performance of pavements with the department's 416 (control) and 417 (SBR latex modified) surface mixes. The parameters analyzed included mean (rut depth/sqrt ESAL), present serviceability index, friction number, condition rating, and transverse cracking. On the basis of preliminary results, no significant long term benefits can be attributed to the use of SBR latex in dense graded asphalt mixtures. However, further testing is required to verify the results.

Synthetic latexes have been used in asphalt pavements for a number of years. Evidence indicates that the use of synthetic latexes in surface treatments improves chip retention and results in improved performance. Synthetic latex has also been used with success on open-graded friction course projects to improve the adhesion of the asphalt cement to aggregate and reduce raveling. More recently, synthetic latex has been used in hot mix applications, and the reports to date indicate mixed performance. Sometimes the latex improves the performance of the mixture and sometimes it does not. Thus, it is not clear whether the increased cost of this additive is justifiable.

OBJECTIVES, SCOPE, AND PLAN

This study, the first of a two-phase research effort, was conducted to evaluate potential benefits from the use of styrene-butadiene rubber (SBR) latex in hot mix asphalt (HMA) mixtures. The cost-effectiveness of the use of SBR latex in Alabama will be determined at the end of Phase 2 and the completion of the study.

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Test plans and procedures used in this project were chosen to evaluate potential benefits from the use of SBR latex in HMA pavements. Condition surveys of six existing pavements modified with SBR latex were evaluated and their performance compared with that of appropriate control sections. Cores were taken from control and SBR latex-modified sections so that material and mixture properties could be characterized and evaluated on a rational basis. A laboratory investigation was performed to evaluate the effect of SBR latex on binder and mixture properties as well as design methodology. Finally, performance was assessed by comparing the pavement condition of the department's 417 (SBR latex-modified) mixes with that of 416 (control) surface mixes.

Condition surveys were performed at six test sites located throughout Alabama. The sites were evaluated for rutting, cracking, bleeding, and raveling. At Sites 1 through 4, 500-ft pavement test sections with control and SBR latex-modified mixes were selected for condition surveys. At Sites 5 and 6, 1,000-ft test sections from each mixture were selected for evaluation.

The Alabama Highway Department's pavement management data base was investigated to compare field performance of the department's 416 (control) and 417 (SBR latex-modified) mixes. The performance parameters analyzed included mean (rut depth/sqrt ESAL), present serviceability index, condition rating, friction resistance, and transverse cracking.

REVIEW OF LITERATURE

A variety of SBR latexes are in use today. They are distributed under a number of trade names. The Alabama Highway Department has had most experience with an anionic (negatively charged) latex developed for use in asphalt cements and asphalt emulsions.

Performance

Rutting, cracking, and stripping are principal concerns in asphalt pavement performance.

Lee and Demirel (1) compared the rut resistance of laboratory-prepared samples modified with various additives. For their comparison they used results from static uniaxial compression creep tests and the Shell pavement thickness design procedure (2) for a pavement structure. They found

that the addition of SBR latex to laboratory-prepared samples had no significant effect on rut resistance.

Epps et al. (3) analyzed the behavior of polyolefin and SBR latex-modified mixtures. They found that the addition of 3 percent latex improved the high temperature resilient modulus of laboratory-prepared specimens. Their conclusion, on the basis of this increase, was that SBR latex had the potential to reduce pavement rutting.

Button and Little (4) showed that blends of AC-5 with SBR latex respond with a creep compliance curve at 40°F, higher than an AC-20 control mixture. The more compliant nature of the SBR latex blend indicates a mixture better suited to resist thermal cracking. They used the modified Lottman moisture treatment to compare damage of specimens prepared with AC-5 and AR-1000 asphalts and a local river gravel. They found that the addition of SBR latex had little effect on moisture susceptibility.

Lee and Demirel (1) evaluated the effect of SBR latex on the resistance to moisture-induced damage by Marshall immersion (24 hr at 140°F) of asphalt concrete mixtures. In their analysis they used AC-5 and AC-20 grade binders (3 percent SBR latex and control) with gravel and limestone aggregate. They found that SBR latex slightly reduced the moisture resistance for gravel and limestone mixtures using the AC-5 binder, had no effect for the AC-20/gravel, and produced a slight improvement for the AC-20/limestone mixture.

CONSTRUCTION

The addition of SBR latex to asphalt cement increases viscosity. An increase in high temperature viscosity requires mixing at temperatures 30°F to 50°F above that for conventional HMA to achieve proper mixing and compaction. The higher mixing temperature may result in more emission problems than lower temperatures.

Blending of SBR latex and asphalt cement should be more efficient and consistent at the refinery than at the mixing plant. Latex blended with the asphalt cement at the refinery will prevent interruption of normal mixing operations at the plant. However, the heated storage life of the blend is somewhat limited since the enhanced properties of the modified binder may degrade with time (5).

A compatible blend of asphalt cement and SBR latex can be defined as a homogeneous mixture that neither separates during storage nor is altered chemically thereby diminishing the enhanced properties of the modified binder. If the blend is compatible, refinery blending ensures that the proper amount of SBR latex has been added to the asphalt cement and thoroughly dispersed in the blend.

SBR latex can be blended in-line with hot asphalt cement before injection into a drum mix plant. This method uses a cavity pump that continuously feeds and blends latex and asphalt cement in the proper proportions. The addition process is not entirely automated, and rates of flow of SBR latex must be changed to compensate for changes in plant production.

For batch plants, a double diaphragm pump is commonly used to inject the SBR latex directly into the pug mill. The addition of latex may alter required mixing time and temperature to achieve proper aggregate coating. The supplier

should be contacted for guidance in selecting dry and wet mixing times.

Compatibility of SBR Latex and Asphalt Cement

As described earlier, a compatible blend of asphalt cement and SBR latex is one that is homogeneous and neither separates nor is altered by chemical interaction during storage. If the SBR latex is preblended with the asphalt cement, as in the refinery blending process, compatibility of the blend must be verified.

Hazlett (6) showed that degradation of the physical properties of SBR latex-modified asphalt can result from prolonged storage at high temperatures. Bass (7) also found that compatibility of asphalt cement and SBR latex depends on asphalt source. Button and Little (4) found that prolonged hot storage of SBS/SB rubber-modified asphalt resulted in a significant decrease in viscosity, which later produced tender mixtures. Their laboratory data indicated that this could also occur with SBR latex.

Recycling Old Asphalt Pavements

With the depletion of the nation's basic road building materials, recycling asphalt pavements has proven to be cost-effective and environmentally sound. However, the use of rubber in asphalt pavements may present several design and recycling challenges.

Potential problem areas are in milling, stockpiling, mixture design, plant operations, laydown, and compaction. In the milling operation, the rubber may cause binding of the milling blades, and this could slow production. In the stockpiling, handling the material could potentially be more difficult if the rubber binds the fines together.

Currently, few laboratory data or construction records have been published regarding the recyclability of old asphalt pavements containing SBR latex. Because of the lack of information, a nationwide survey of highway departments was initiated to determine their experiences in recycling old asphalt pavements containing additives.

The survey was sent to the state highway departments and 44 responded. Of these, 41 had not tried to recycle old asphalt pavements with reclaimed mix modified with latex. A summary of the responses from the three states follows.

In the first state, a project containing 3 percent SBR latex additive in a friction course was milled and recycled in 1989. No problems were encountered during milling or production of the recycled mix. The very small amount of latex in the RAP did not appear to affect the rejuvenation of the RAP or cause any pollution problems.

In the second state, a section of pavement containing latex was milled but was not recycled. No problems were encountered during the milling operation.

In the third state, a section of pavement containing latex was milled and recycled. No problems were experienced during the milling or recycling.

Costs

The Alabama Highway Department experienced an approximate 14 percent increase in mix cost for construction of SBR

latex mixes in 1990. This implies that pavement performance must be increased by at least 14 percent (potentially greater because of inflation) for the additive to be cost-effective. Currently, no data are available concerning the cost-effectiveness of SBR latex-modified pavements.

FIELD INVESTIGATION

Six control and SBR latex-modified test sites, located throughout the state, were evaluated for rutting, transverse cracking, bleeding, and raveling to characterize the in-service performance of the Alabama Highway Department's 416 (control) and 417 (SBR latex-modified) surface mixes. All field measurements and observations were made in 1990.

Site Location Details

Each site was selected so that control and SBR latex-modified mixes were located end-to-end and placed at approximately the same time using the same materials. Figure 1 shows the location of these sites. Table 1 gives details for each site.

At Sites 1 through 4, 500-ft-long representative sections from the control and SBR latex-modified mixes were selected for condition surveys. At Sites 5 and 6, 1,000-ft-long sections were rated. Cores were taken from these last two sites so that a more detailed evaluation could be made of the material and mixture properties. Material and mixture properties determined from tests at Site 6 indicated that the control and SBR

TABLE 1 SITE LOCATION DETAILS

Site	Route	Division	County	Mix' Type	Date Placed	Milepost Location	AADT
1	US-31	1	Limestone	416	7/89	366.02	10,870
				417	9/88	364.00	12,850
2	US-231	1	Madison	416	7/89	311.00	41,070
				417	5/88	313.00	45,700
3	AL-69	3	Walker	416	9/85	209.15	3,980
				417	7/85	212.80	3,980
4	US-82	6	Autauga	416	8/89	141.05	8,500
				417	8/89	142.00	8,500
5	267	4	Lee	416	7/87	2.34	5,112
				417	1/87	1.95	5,112
6	AL-163	9	Mobile	416	6/85	27.00	8,730
				417	6/85	25.00	8,730

^a416 mix does not contain latex.

417 mix does contain latex.

latex-modified mixtures at this site were not comparable, and data obtained from this site were not included in the analysis.

Rutting

Maximum rut depth measurements were made with a 12-ft straightedge in both inside and outside wheelpaths at 50-ft intervals. The average rut depths for each site are given in Tables 2 and 3.

A statistical analysis of the average rut depth is given in Table 4. In this analysis, the *t*-test was used to test the significance of the difference between rut depth means for each site at 95 percent confidence. The *F*-test was used to test the significance of the variance difference. If the sample variances were found to be significantly different, an alternate form of the *t*-test was used. The analysis indicates a statistically significant difference between rut depth in control and latex sections at Sites 1 through 3 but no difference at Sites 4 and 5. A complete description of the statistical procedure can be found elsewhere (8).

The average rut depths given in Tables 3 and 4 indicate that more rutting is occurring in three of the five control sections and in two of the five SBR latex-modified sections. Rutting in two of the control sections is significantly larger than rutting in the SBR latex-modified mixes. At Site 2 the rutting in the SBR latex-modified section is statistically greater than rutting in the control section. At Sites 4 and 5 there is no statistical difference in rutting of control and SBR latex-modified mixes.

Cracking

Cracking was quantified by counting the number of half- and full-width transverse cracks for each test section. The total number of full-width transverse cracks at each site is given in Table 5. For Site 1 slightly more transverse cracks were observed in the control section. For Site 3 many more transverse cracks were observed in the control section. No transverse cracks were observed at Sites 2, 4, or 5 in either section.

Minimal raveling was observed on the condition survey sites. However, the raveling that was surveyed was usually located at longitudinal joints. The amount of raveling noted between the control and SBR latex-modified pavements was not visually different.

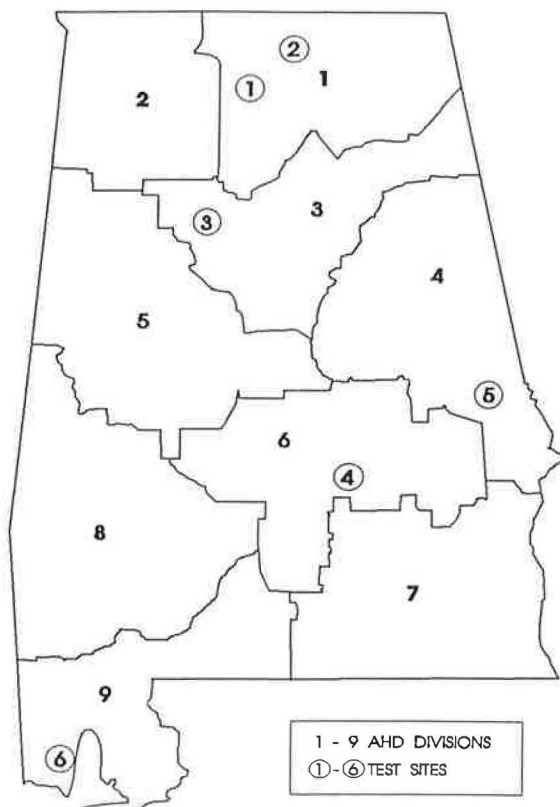


FIGURE 1 Site location map.

TABLE 2 AVERAGE RUT DEPTHS FOR CONTROL SECTIONS

Site #	Number of Measurements	Inside Wheel Path	Outside Wheel Path	Average
1	11	0.12	0.20	0.16
2	11	0.06	0.02	0.04
3	11	0.14	0.14	0.14
4	11	0.05	0.05	0.05
5	21	0.11	0.09	0.10

TABLE 3 AVERAGE RUT DEPTHS FOR SBR LATEX-MODIFIED SECTIONS

Site #	Number of Measurements	Inside Wheel Path	Outside Wheel Path	Average
1	11	0.03	0.10	0.06
2	11	0.13	0.11	0.12
3	11	0.01	0.06	0.04
4	11	0.08	0.08	0.08
5	21	0.14	0.04	0.09

TABLE 4 STATISTICAL ANALYSIS OF DIFFERENCE IN MEAN RUT DEPTHS FOR CONDITION SURVEY SITES 1 THROUGH 5

Site #	t	Significant $ t_{\alpha} ^1$	Difference
1	-7.155	2.179	Yes
2	5.852	2.086	Yes
3	-5.632	2.086	Yes
4	1.860	2.086	No
5	-0.582	2.021	No

¹ $\alpha = 0.05$

TABLE 5 NUMBER OF FULL-WIDTH TRANSVERSE CRACKS FOR CONDITION SURVEY TEST SITES 1 THROUGH 5

Site #	Control	Latex Modified
1	37.0	35.5
2	0.0	0.0
3	62.5	11.0
4	0.0	0.0
5	0.0	0.0

TABLE 6 AGGREGATE GRADATION DETERMINED FROM EXTRACTION OF CONTROL SECTIONS 1 THROUGH 5

Sieve Size	Site Number, Percent Passing				
	1	2	3	4	5
1"	100.0	100.0	100.0	100.0	100.0
3/4"	100.0	100.0	100.0	100.0	100.0
1/2"	94.4	92.7	98.1	94.3	96.2
3/8"	89.9	84.5	90.0	82.2	85.7
4	64.1	59.6	60.9	59.3	65.6
8	48.1	42.3	45.4	43.4	48.8
16	39.4	31.7	40.3	32.2	39.8
30	30.8	25.5	36.9	23.2	28.7
50	15.6	17.4	21.8	13.4	15.3
100	9.1	10.3	9.1	7.8	8.0
200	7.0	7.0	6.6	5.0	5.3
Binder, %	5.69	5.87	5.31	4.91	5.51

Mix Composition

Two extractions (ASTM D2172) were performed on samples from each of the control and SBR latex-modified sections for Sites 1 through 5. The gradations and binder contents are given in Tables 6 and 7.

Inspection of Tables 6 and 7 indicates more material passing the #100 and #200 sieves on all the control sections. This difference is probably caused by the rubber binding the smaller sized material and preventing removal during the extraction process. Considerable differences in binder content were also observed in the mixes from Sites 1, 2, and 4.

PAVEMENT MANAGEMENT DATA BASE ANALYSIS

In Alabama, distress measurements are made every 2 years in a statewide pavement condition survey on approximately 11,000 mi of pavement. These data have been compiled into a pavement management data base (PMD) by the Alabama Highway Department. The purpose of this section is to analyze and compare performance parameters surveyed for the department's 416 (control) and 417 (SBR latex-modified) surface mixes. The parameters investigated include mean (rut depth/sqrt ESAL), present serviceability index (PSI), condition rating, friction number, and transverse cracking. Much more 416 mix has been placed than 417 mix, and the sample sizes for the 417 mix may, in some cases, not be large enough to support definite conclusions.

In the PMD, a representative 200-ft sample section is selected within each lane mile of pavement. Since more rutting occurs in the outside lane, only those measurements in the outer lane were included in this analysis. Because of the extent of the data involved and the lack of 417 mixes on Interstate routes, only state route pavements rated in the 1988 data base (latest data in data base at the time the analysis was performed) were investigated.

Many variables influence the performance parameters investigated, such as amount of traffic, age of pavement, location of pavement within the state, and so forth. Therefore,

TABLE 7 AGGREGATE GRADATION DETERMINED FROM EXTRACTION OF SBR LATEX-MODIFIED MIXES, SECTIONS 1 THROUGH 5

Sieve Size	Site Number, Percent Passing				
	1	2	3	4	5
1"	100.0	100.0	100.0	100.0	100.0
3/4"	100.0	100.0	100.0	100.0	100.0
1/2"	91.2	93.6	96.8	95.4	98.5
3/8"	82.7	85.7	88.0	81.0	88.0
4	62.1	64.5	61.3	61.5	64.7
8	47.6	74.5	47.2	45.3	56.3
16	37.8	37.8	42.5	33.3	48.8
30	26.1	29.8	39.5	23.8	35.2
50	10.6	14.7	24.6	13.8	16.7
100	5.3	6.2	8.0	7.7	7.4
200	3.1	3.6	5.0	4.7	4.4
Binder, %	6.24	5.62	5.21	5.24	5.57

every effort was made to analyze the data so that a reasonable comparison could be made of the control and SBR latex-modified mixes. In this analysis the 416 and 417 mix performance data obtained from the state routes were sorted by division and year placed. A summary of performance data is given in Table 8, and the results of the statistical analysis of the data are given in Table 9.

In the PMD eight rut depth measurements are made in each lane within each 200-ft test section. Four of these measurements are from the inner wheelpath and four from the outer wheelpath. In this analysis the measurements from the outer wheelpath were averaged to yield the average rut depth. The average rut depth was then divided by the square root of the number of ESALs for the section of pavement being rated.

For mixes placed in 1985, the SBR latex-modified mixes statistically show an improvement in rut resistance in Divisions 2, 5, 6, and 7. However, in Divisions 3 and 4 the control mixes appeared to perform better. In Division 8 there was no statistical difference in mean (rut depth/sqrt ESAL).

For the mixes placed in 1986, there is a statistical difference in the mean (rut depth/sqrt ESAL) in Division 2, which showed

TABLE 8 SUMMARY OF PERFORMANCE PARAMETERS FOR CONTROL AND SBR LATEX-MODIFIED MIXES FOR DIVISIONS 1 THROUGH 9 AND OVERALL

Division	Year Placed	Mix Type	Rut Depth Sqrt ESAL (in.)	PSI	Condition Rating	Transverse Cracking (No./200 ft.)
2	1985	Control	2.2 E-04	3.70	83.76	1.96
		Latex	1.1 E-04	3.44	72.85	14.15
3	1985	Control	2.0 E-04	3.52	76.72	3.01
		Latex	3.1 E-04	2.85	73.77	6.93
4	1985	Control	2.5 E-04	3.41	71.34	10.40
		Latex	5.0 E-04	3.74	76.61	3.33
5	1985	Control	1.4 E-04	3.64	81.61	4.80
		Latex	7.3 E-05	3.83	75.67	12.28
6	1985	Control	2.7 E-04	3.72	82.66	2.71
		Latex	2.3 E-04	3.86	84.33	1.08
7	1985	Control	2.3 E-04	3.59	76.95	6.62
		Latex	1.4 E-04	3.58	78.00	0.95
8	1985	Control	2.9 E-04	3.62	81.26	0.81
		Latex	3.3 E-04	3.31	78.42	4.61
9	1985	Control	2.4 E-04	3.27	78.41	2.95
		Latex	5.1 E-04	3.06	72.25	0.58
Overall	1985	Control	2.3 E-04	3.55	78.00	5.09
		Latex	2.5 E-04	3.44	76.35	6.56
2	1986	Control	2.5 E-04	4.02	87.20	0.51
		Latex	1.5 E-04	3.66	86.55	0.05
Overall	1986	Control	2.4 E-04	3.60	80.93	3.31
		Latex	1.5 E-04	3.66	86.55	0.05
1	1987	Control	2.8 E-04	3.59	84.50	2.11
		Latex	1.5 E-04	3.43	85.15	0.22
2	1987	Control	3.0 E-04	3.64	86.36	0.02
		Latex	2.3 E-04	3.44	84.94	0.67
4	1987	Control	3.1 E-04	3.63	81.33	3.74
		Latex	2.5 E-04	3.40	84.64	0.00
Overall	1987	Control	3.0 E-04	3.52	82.15	2.54
		Latex	1.9 E-04	3.44	85.02	0.48
1	1988	Control	2.1 E-04	3.65	87.58	0.00
		Latex	4.1 E-04	3.50	86.98	0.15
2	1988	Control	1.8 E-03	3.08	80.50	1.50
		Latex	7.6 E-04	3.56	85.67	0.00
3	1988	Control	2.5 E-05	4.00	87.72	0.50
		Latex	3.0 E-04	4.00	84.86	1.63
Overall	1988	Control	4.3 E-04	3.78	86.68	0.66
		Latex	5.3 E-04	3.64	84.94	0.73

NOTE: Divisions that did not place latex sections in a given year are not shown in the table.

TABLE 9 STATISTICAL ANALYSIS OF PERFORMANCE PARAMETERS FOR CONTROL AND SBR LATEX-MODIFIED MIXES

	Rutting	PSI	Condition Rating	Friction Number	Transverse Cracking
Division 1					
1985	*	*	*	*	*
1986	*	*	*	*	*
1987	L	C	N	N	L
1988	C	N	N	L	N
Division 2					
1985	L	C	C	L	C
1986	L	C	N	N	L
1987	L	C	C	N	C
1988	N	L	L	C	N
Division 3					
1985	C	C	C	C	C
1986	*	*	*	*	*
1987	*	*	*	*	*
1988	N	N	C	N	C
Division 4					
1985	C	L	L	C	L
1986	*	*	*	*	*
1987	N	C	L	L	L
1988	*	*	*	*	*
Division 5					
1985	L	L	C	C	C
1986	*	*	*	*	*
1987	*	*	*	*	*
1988	*	*	*	*	*
Division 6					
1985	L	L	L	L	L
1986	*	*	*	*	*
1987	*	*	*	*	*
1988	*	*	*	*	*
Division 7					
1985	L	N	N	N	L
1986	*	*	*	*	*
1987	*	*	*	*	*
1988	*	*	*	*	*
Division 8					
1985	N	C	C	C	C
1986	*	*	*	*	*
1987	*	*	*	*	*
1988	*	*	*	*	*
Division 9					
1985	C	C	C	C	L
1986	*	*	*	*	*
1987	*	*	*	*	*
1988	*	*	*	*	*
Overall					
1985	N	C	C	C	C
1986	L	N	L	C	L
1987	L	C	L	C	L
1988	C	C	C	N	N

C - Control mixes performing better.

L - SBR latex modified mixes performing better.

N - Neither mix performing better than the other.

* - SBR latex modified mixes not placed during the indicated year.

the SBR latex-modified mixes were performing better. For the mixes placed in 1987 the SBR latex-modified mixes were performing better than the control mixes in Divisions 1 and 2. No statistical difference was found in the mean (rut depth/sqrt ESAL) for Division 4 in 1987. For the mixes placed in 1988, the control mixes were performing better in Division 1; however, in Divisions 2 and 3 the means were not statistically different.

The overall mean (rut depth/sqrt ESAL) for mixes placed between 1985 and 1988 indicates that for mixes placed in 1985 the overall mean is not statistically different between the control and the SBR latex-modified mixes. However, for the mixes placed in 1986 and 1987 the overall mean (rut depth/sqrt ESAL) is statistically greater for the control mixes. For mixes placed in 1988 the overall mean (rut depth/sqrt ESAL) is statistically greater for the SBR latex-modified mixes.

PSI

For pavements placed in 1985 the control mixes indicate higher PSI in Divisions 2, 3, 8, and 9. However, the SBR latex-modified mixes performed better in Divisions 4, 5, and 6. No significant difference was found for the mean PSI in Division 7. For those mixes placed in 1986, the control mixes show statistically better performance than the SBR latex-modified mixes in Division 2. For the mixes placed in 1987, the control mixes were performing better in Divisions 1, 2, and 4. For the mixes placed in 1988, the SBR latex-modified mixes were performing better in Division 2, whereas no significant difference was determined for the mean PSI in Divisions 1 and 3.

For mixes placed in 1985 the overall mean PSI is significantly greater for the control mixes. However, for mixes placed in 1986, no statistical difference was determined for the overall mean PSI. For the mixes placed in 1987 and 1988 the control mixes have a greater PSI than the SBR latex-modified mixes. Pavement PSI as used in the Alabama PMD system is a function only of rideability. The lower PSI values for latex-modified mixes may be due to increased placement and compaction difficulty.

Condition Rating

The pavement condition rating used by the Alabama Highway Department is primarily a function of distress variables with some influence from PSI. Higher numbers indicate better condition.

For mixes placed in 1985 the control mixes had a higher condition rating for Divisions 2, 3, 5, 8, and 9. The SBR latex-modified mixes had a higher condition rating in Divisions 4 and 6 for the mixes placed in 1985, whereas no statistical differences were determined for the mean condition rating in Division 7. For mixes placed in 1986, Division 2 shows no statistical difference in the mean condition rating. For mixes placed in 1987, the control mix was performing better in Division 2, whereas the SBR latex-modified mix was performing better in Division 4. No statistical difference was determined for the mean condition rating in Division 1 for 1987. For mixes placed in 1988, the control mixes had a higher condition rating for Division 3, whereas the SBR latex-modified mix had a higher condition rating in Division 2. No statistical difference in the mean condition rating was indicated in Division 1 for 1988.

For mixes placed in 1985 and 1988 the control mixes had a mean overall condition rating higher than the SBR latex-modified mixes. However, for mixes placed in 1986 and 1987 the overall condition ratings for the SBR latex-modified mixes were higher.

Friction Number

One of the primary functions of a flexible pavement is to provide good friction and steering qualities for the vehicle. The frictional qualities of a flexible pavement depend on the asphalt content and type of aggregate used in the mix. Friction

can be quantified by a friction number measured with a locked wheel skid trailer (ASTM E249).

Control mixes placed in 1985, 1986, and 1987 had an overall mean friction number higher than that for the SBR modified. However, for mixes placed in 1988 no statistical difference was determined in the mean friction numbers.

Transverse Cracking

In the PMD transverse cracking is divided into four severity levels beginning with hairline cracking. In this analysis the number of transverse cracks were totaled and then averaged per division.

For mixes placed in 1985 the control mixes had lower mean transverse cracking in Divisions 2, 3, 5, and 8. The SBR latex-modified mixes had a lower amount of transverse cracking in Divisions 4, 6, 7, and 9. For the mixes placed in 1986, in Division 2, the SBR latex-modified mixes had a lower average transverse cracking compared with the control mixes. For the mixes placed in 1987, the SBR latex-modified mixes had a lower mean transverse cracking count in Divisions 1 and 4. However, the control mixes had a lower mean in Division 2. For the mixes placed in 1988, the control mixes had a lower mean transverse cracking in Division 3, whereas there were no significant differences in Divisions 1 and 2.

For mixes placed in 1985 the mean overall transverse cracking is less for the control mixes. The SBR latex-modified mixes show less transverse cracking for 1986 and 1987. For mixes placed in 1988 there is no significant difference in the mean overall transverse cracking.

For the mixes placed in 1985, the control mixes appeared to perform better than the SBR latex-modified mixes (Table 8). For the mixes placed in 1986 and 1987 the SBR latex-modified mixes seemed to perform better overall. For the mixes placed in 1988, the control mixes performed better than the SBR latex-modified mixes. On the basis of these results the presence of SBR latex does not appear to significantly enhance the long-term performance of the pavements evaluated in this study.

CONCLUSIONS

The literature review indicated mixed performance in the use of SBR latex. Sometimes the use of this additive appears beneficial and sometimes it does not. The use of SBR latex increases the in-place mix cost. Alabama has experienced about a 14 percent increase in mix cost over that of a conventional mix.

The review of literature indicated that the compatibility of asphalt cement and SBR latex depends on the asphalt source. However, compatibility of the blend is more important if the SBR latex is added at the refinery. Rubber particles may settle out of the mixture during transportation to the job site if the blend is incompatible.

On the basis of results from the survey of state highway departments, there appears to be little experience with recycling old asphalt pavements that contain SBR latex. The effect on the recyclability of old asphalt pavements containing SBR latex is unclear at this time, but no significant problems have been identified.

The condition surveys indicate that for the three sites where the difference in rutting between the control and SBR latex-modified mixes was statistically significant, more rutting was occurring on two of the control sections and on one of the SBR latex-modified sections. The condition surveys indicated that more transverse cracking had occurred on the control sections at two sites and that no cracking had occurred in either section at the other three sites.

Analysis of the Alabama Highway Department's pavement management data base indicates mixed performance for the department's 416 (control) and 417 (SBR latex-modified) surface mixes. The use of SBR latex does not appear to consistently enhance mix performance, and in some cases it may adversely affect performance.

For the data analyzed thus far, the presence of SBR latex does not appear to enhance the long-term field performance of dense graded mixtures in Alabama. However, further study is required to establish these findings.

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REFERENCES

1. D. Y. Lee and T. Demirel. *Beneficial Effects of Selected Additives on Asphalt Cement Mixes*. Iowa Department of Transportation, 1987.
2. *Shell Pavement Design Manual*. Shell International Company Limited, London, 1978.
3. J. Epps et al. *Factors Affecting the Behavior of Polyolefin and Latex Modified Asphalt Concrete Mixtures*. (No date).
4. J. W. Button and D. N. Little. *Asphalt Additives for Increased Pavement Flexibility*. Research Report 471-2F. Texas Transportation Institute.
5. W. Siegel et al. *Properties of Latex Modified Asphalt Concrete Mixtures*. Presented at 67th Annual Meeting of the Transportation Research Board, Washington, D.C., 1988.
6. D. G. Hazlett. *Experimental Projects: Evaluation of Asphalt Latex Rubber Blends*. Texas State Department of Highways and Public Transportation, 1983.
7. D. A. Bass. *Experiences with Latex in HMA*. Texas State Department of Highways and Public Transportation, 1985.
8. L. Blank. *Statistical Procedures for Engineering, Management, and Science*. McGraw-Hill, New York, 1980.

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