Performance of Binder-Modifiers in Recycled Asphalt Pavement: Field Trial, 1987 to 1992

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A field trial of six binder-modifiers was performed in 1987. The binder-modifiers consisted of two types of SBS blocked copolymer, carbon black, SBR latex, polypropylene fiber, and ethylene vinylacetate copolymer resin. A summary of field and laboratory tests, conducted over a 5-year period, was made and the overall field performance of the binder-modifiers was compared with that of several control sections. The binder-modifiers did not appear to significantly improve field performance when compared with the control sections.

During the past decade, the Materials Branch of the Wyoming Transportation Department (WTD) has attempted to evaluate the effectiveness of various methods to prevent or reduce rutting in asphalt pavements. In 1987, the WTD, in association with Heritage Group West, Inc., undertook a major study to evaluate the effectiveness of asphalt binder-modifiers in recycled pavements. As a part of that study, nine test sections [each approximately 0.8 km (0.5 mi) long] were constructed on the east-bound lane of Interstate 80 beginning at Milepost (MP) 124.76 and ending at MP 130.59. A total of six binder-modifiers were evaluated in this experiment. Construction of the test sections consisted of cold milling a trench 4.3 m (14 ft) wide by 10.1 cm (4 in.) in the driving lane of the existing pavement and replacement with modified material in two 5.1-cm (2-in.) lifts. All test sections were placed about the same time in August 1987. Laboratory tests were conducted on asphalt binders and mixes before and after construction. Laboratory tests were conducted on core samples obtained in 1991. In addition, WTD has conducted field performance tests on all test sections over the past 4 years. This paper summarizes the results and findings of all field and laboratory tests.

BACKGROUND

The experimental section of Interstate 80 is approximately 20 mi east of Rock Springs, Wyoming. The average elevation of the project is 1981 m (6,500 ft) above sea level. The climatic region is characterized as dry, hard freeze, and spring thaw. In 1991, the yearly precipitation was 22.4 cm (8.8 in.). The average high temperature during the summer was 26°C (79°F). The average low temperature was 10°C (50°F). The maximum temperature in the summer was 35°C (95°F). By way of comparison, the lowest temperature in January 1991 was −38°C (−37°F).

This section of I-80 (MP 120 to MP 130) was originally opened to traffic in 1964 with second-stage surfacing completed in 1972. The cross section consisted of 1.9-cm (¾-in.) friction course, 8.9-cm (3½ in.) plant mix pavement, and 15.2-cm (6-in.) cement-treated base. In 1982, a 5.1-cm (2-in.) plant mix pavement overlay was applied to level rutted areas. The plant mix thickness after the overlay (including original wearing course) varied from 15.9 cm (6¼ in.) to 18.4 cm (7¼ in.). In 1987, continued rutting and minor cracking required the development of a rehabilitation project. The intent of the project was to mill a 10.1-cm (4-in.) trench in the driving lane and replace it with recycled plant mix material. The typical cross section is shown in Figure 1. Because of the repeated rutting problem on the section, it was decided to add asphalt binder-modifiers to the mix to evaluate rutting resistance. In total, nine test sections were included in this experiment. Six of these sections contained binder-modifiers in combination with 60 percent virgin materials and 40 percent recycled asphalt pavement (60/40). The remaining three test sections consisted of a 60/40 mix, a 50/50 mix, and a 100 percent virgin mix without asphalt modifier. These three sections were used as control sections. Before the construction of test sections in 1987, the roadway had sustained a total of 7,000,000 18-kip equivalent single-axle loads (ESALs). The estimated 18-kip ESALs applied to the test sections since construction is 2,650,000.

MATERIALS CHARACTERISTICS

The six binder-modifiers used in this experiment are commercially available. Table 1 gives their commercial names, manufacturers, and concentrations used. The Microfil 8 modifier (commonly referred to as carbon black) is a form of carbon, formed in the vapor phase from the decomposition of vaporized hydrocarbons (e.g., the soot from smoking candles or kerosene lamps). It is an intensely black, fine powdery substance manufactured in large volume and is a basic raw material for rubber, printing ink, and other industries. Carbon black is commercially available in pellet form (using a maltene binder) (*1*). The Kraton and Styrelf modifiers are commonly known as SBS blocked copolymers. The Kraton polymer, used here, is a thermoplastic block copolymer consisting of

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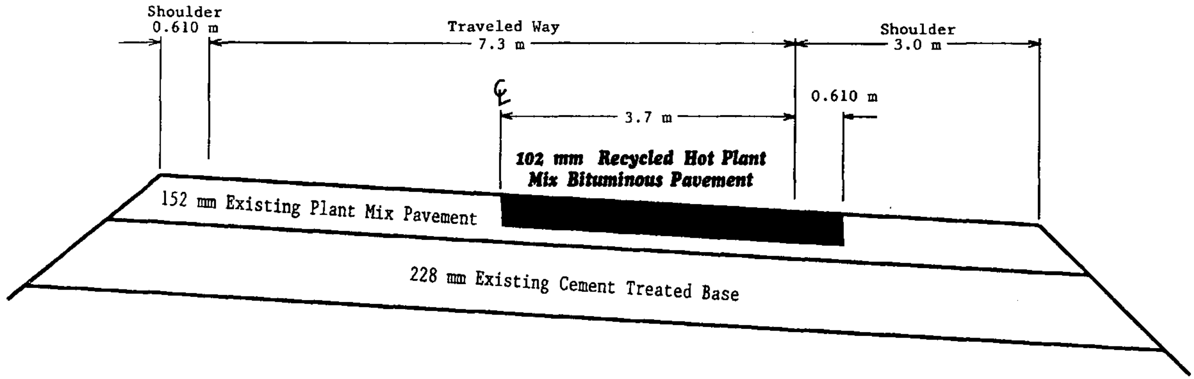

FIGURE 1 Typical section.

polystyrene end blocks and butadiene midblock. The Styrelf polymer is a vulcanized SB di-block copolymer modifier. The Dupont Elvax (150W) modifier (commonly referred to as EVA) is an ethylene vinylacetate copolymer resin. The Polysar Latex (PL 275) modifier (commonly referred to as SBR) is a styrene-butadiene latex. The Fiberpave modifier (commonly referred to as simply fibers) consists of a fine-denier short-length (1-cm) polypropylene fiber.

The asphalt used in this experiment was obtained from the Little America Refinery at Sinclair, Wyoming. AC-20 was used in the production of the three control sections, and the fibers, Styrelf, SBR, and EVA test sections. AC-10 was used with the Kraton and carbon black test sections. Table 2 gives the standard properties of virgin and modified asphalts. All asphalt tests were performed approximately 3.5 years after the samples were collected. The samples were stored in sealed metal containers in an unheated storage area before testing.

The force ductility test was also performed on all modified and virgin asphalts in a manner similar to AASHTO T51. This ductility test is normally used to measure the tensile strength of bituminous materials. Tests were performed at a temperature of 4°C (39.2°F) and a pulling rate of 5 cm (1.95 in.) per minute. Tensile load and deformation were recorded electronically at 1-sec intervals. Figure 2 displays the results from a typical force ductility test on a virgin asphalt (AC-20) and defines some of the features of the plot. Table 3 gives the defined features for all of the binder-modified asphalts.

Before construction of the test sections in 1987, penetration and viscosity tests were conducted on the recycled asphalt recovered using the Abson procedure (AASHTO T170). The following results were determined:

- Penetration at 25°C (77°F) (AASHTO T49), 56 dmm;
- Viscosity at 60°C (140°F) (AASHTO T202), 2028 poises; and
- Viscosity at 135°C (275°F) (AASHTO 201), 281 cSt.

Aggregate gradations for all mixes were determined after extraction with methylene chloride from samples collected

TABLE 1 Characteristics of Asphalt Materials Used in the Experiment

Section Number	Additive Type	% Recycled Materials	Asphalt Type	% Additive In Virgin Material	% Additive In Total Binder	Source Of Additive
1	SBS "Styrelf"	40	AC20	6	3.12	ELF ASPHALT
3	SBS "Kraton"	40	AC10	12 (a)	6.24 (a)	SHELL
5	50/50	50	AC20	N/A	N/A	N/A
7 (d)	SBR Lower Lift LATEX	40	AC20	2.3	1.2	POLYSAR
7 (d)	SBR Surface Lift LATEX	40	AC20	4.6	2.39	POLYSAR
9	Carbon Black "Microfil 8"	40	AC10	20 (b)	10.4 (b)	CABOT CORP
11	EVA "ELVAX"	40	AC20	6	3.12	E.I. DUPONT
12	"Fiberpave" (Polypropylene fibers)	40	AC20	3% By Wt of Total Mix (c)	3% By Wt of Total Mix (c)	HERCULES Inc.
13	100V	N/A	AC20	N/A	N/A	N/A
14	60/40	40	AC20	N/A	N/A	N/A

(a) Kraton was actually composed of 50% Kraton (D1101), 20% SF 371, and 30% DUT 728. The D1101 designation represented the SBS polymer constituent. The SF and DUT components were light aromatics used as a carrier for the D1101. Combined, the three constituents made up 12% by weight of the binder.

(b) 92% Carbon Black Microfiller and 8% Maltane Oil.

(c) 27.2 kg (60 lb) of fiber per 908 kg (2000 lb) recycled mixture.

(d) The reason for the different % additive in the top and bottom layers was that an error was made in preparing the binder-modifier asphalt and it wasn't discovered until after construction of the bottom lift.

TABLE 2 Binder-Modifier Properties

	AASHTO Spec.	Virgin AC20	AC20 SBR	AC20 EVA	AC20 Styrelf	AC10 Kraton	AC10 Carbon Black
Visc. 60° C	T202 (a)	2005	11844	2536	41084	13916	1609
Visc. 135° C	T201	386	4259	926	1457	980	677
Pen. 25° C	T49	37	50	80	65	75	140
Pen. 4° C	T49	20	6	24	25	33	52
Softening Point	T53	127	147°	119°	159°	168°	126°
Loss on Heat	T47	0.29	0.41	0.11	0.10	0.37	2.50
Pen. 4° C after L.O.H.	T49	16	19	7	22	21	16

a The viscosity tests at 60°C for the modified asphalts were performed using the Asphalt Institute Vacuum Viscometer.
The viscosity tests at 60°C for the virgin asphalt were performed using the Cannon–Manning Viscometer.
The viscosity tests at 135°C were performed using a Zeitfuch crossarm viscometer.

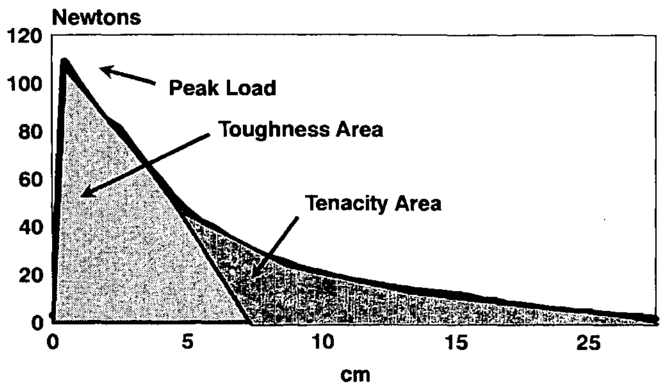

FIGURE 2 Force ductility test.

during construction. Figure 3 shows these gradations. The 60/40 gradation represents the average gradation for all the binder-modifier test sections. Minor differences existed between the 60/40, 50/50, and virgin gradations. The virgin aggregate that was combined with the recycled asphalt pavement (RAP) was obtained from a gravel pit. The gravel was scalped on a 3.17-cm (¼-in.) screen. The +3.17-cm (¼-in.) material was crushed and screened, whereas the −3.17-cm (−¼-in.) material was discarded. Figure 3 shows how all three gradations were close to the .45 power curve that resulted in dense graded mixes.

MARSHALL TESTING

Standard preconstruction Marshall (AASHTO T245) tests were performed to determine the optimum asphalt content for each test section. The optimum asphalt for the nine test sections ranged from 5.0 to 5.5 percent asphalt. It was deemed essential that the same asphalt content be used throughout the project to eliminate asphalt content as a confounding variable that would have made it difficult to evaluate the performance of the binder-modifiers. Initially, it was decided to use an asphalt content of 5.25 percent in all mixes. This percentage was later reduced during construction to 5.0 percent because Marshall field test results indicated a problem with low air voids. Table 4 gives the Marshall test results performed in the mobile field laboratory during construction. Test samples were collected from behind the paver and were immediately transported to the mobile laboratory for testing. During transport the test samples cooled and had to be reheated to proper test temperature for the Marshall test. The results are based on only one sample per test section, except for the Styrelf and Kraton test sections, in which two tests were performed. The relatively low voids in mineral aggregate (VMA) for all the test sections when combined with the low asphalt content contributed to the significant amount of raveling that was observed on most of the test sections.

PAVEMENT PERFORMANCE

Several tests were conducted to measure the field performance of all experimental mixtures. These tests included deflection, roughness, condition survey, and rut depth measurements. In addition, several core samples were collected to conduct resilient modulus and accelerated wheel track testings. The results from all of these tests are summarized in this section.

TABLE 3 Binder-Modifier Force Ductility Test Results

Test Section	Test Section	Peak Load (N)	Peak Load @ (cm)	Force Ratio	Peak Area (N•cm)	Tenacity Area (N•cm)	Total Area (N•cm)	Elasticity
Styrelf	1	52.4	0.70	0.59	209	1690	1899	0.890
Kraton	2	47.1	0.75	0.44	258	1170	1428	1.000
SBR	7	85.4	0.90	0.14	334	774	1108	0.630
Carbon	9	13.3	0.92	0.02	49	36	84	0.150
EVA	11	96.5	0.80	0.44	507	1486	1993	0.550
Virgin AC	5, 12, 13, & 14	125.8	0.75	0.007	480	205	689	0.001

Note – See Figure 2 for a definition of Peak Load, Force Ratio, etc.
1 cm = 0.39 in; 1 N = .225 lbs

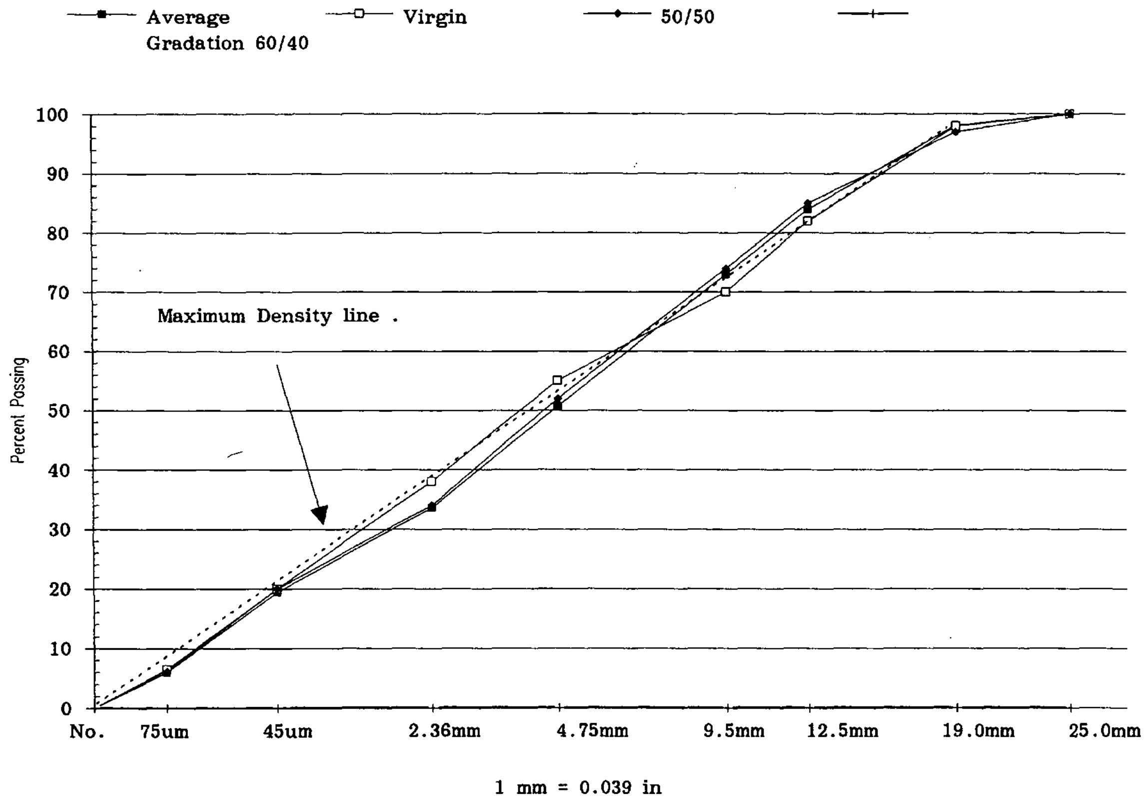

FIGURE 3 0.45 power gradation chart.

Rut Measurements

When the test sections were built, several rut measuring stations were established on each section. Rut measurements were subsequently made with a Rainhart transverse profilograph. The profilograph provides a continuous measurement of the rut across the length of the profilograph [approximately 3.9 m (13 ft)]. The term "rut depth" as used here refers to the difference in elevation from the high point between the wheelpaths to the low point in the wheelpath. After construction of the test sections in 1987, transverse profilograh data were collected periodically. Examination of the transverse profiles, taken over a period of 4 years, indicated that no significant rutting was occurring in any of the test sections except for the carbon black test section. Figure 4 shows typical transverse profiles for unrutted sections and the carbon black test section. The carbon black test section had an average rut depth of 1.3 cm (0.5 in.) in the left wheelpath and 1.0 cm (0.4 in.) in the right wheelpath. All test sections display a characteristic "hump" that was not noticed until several months

TABLE 4 Mobile Laboratory Marshall Results

Section Number	Test Section	• % AC	% Air Voids	% VMA	Bulk Den. (kg/cu. m)	Stability	Flow
1	Styrelf	4.9	3.0	13.0	2359	4159	11
3	Kraton	5.0	2.3	13.1	2356	3448	12
5	50/50	5.0	3.1	13.1	2356	2947	14
7	SBR	4.8	4.3	13.0	2348	3887	13
9	Carbon	5.3	2.1	12.4	2382	3311	14
11	EVA	4.4	4.6	13.2	2334	2911	13
12	Fibers	5.3	3.5	13.8	2339	3391	13
13	Virgin	4.6	4.0	13.4	2339	3213	13
14	60/40	4.7	3.6	12.6	2361	3075	14

Note: Tests based on samples collected from behind the paver during construcion. Fifty compaction blows on each end of the specimen.

• The asphalt content shown is essentially representative of the asphalt content for the test sections except in the case of the Carbon Black and EVA test sections. The average AC contents for these sections were: Carbon Black = 4.8 % and EVA = 5.0 %. These values are based on all the extraction and nuclear asphalt content gage tests performed.

1 kg/ cu. m = .062 pcf

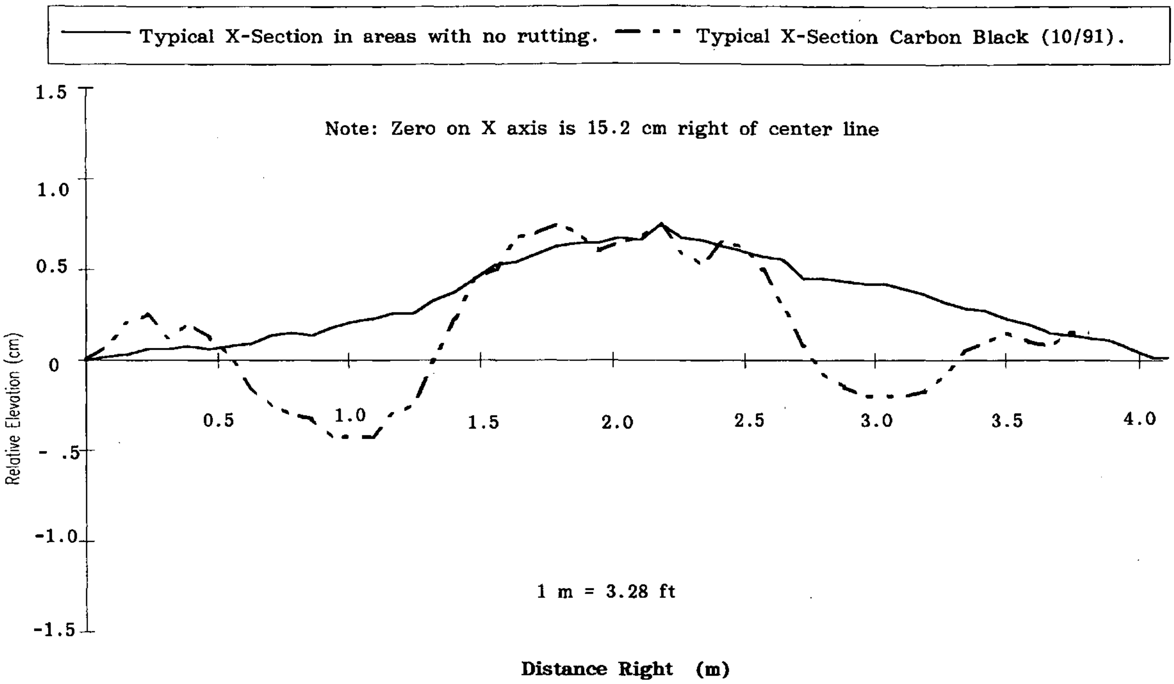

FIGURE 4 Typical cross sections in areas with and without rutting.

after construction. It is believed that this hump was a result of the rolling pattern that consisted of several passes along the edges of the trench before the center of the trench was compacted.

Because only one of the nine test sections showed significant rutting after several years in service, it was decided to use an accelerated laboratory rutting test. After reviewing several different types of wheel tracking devices, the "Hamburg device" was used. This device is manufactured by Helmut Wind, Inc., of Hamburg, Germany, to simulate tire pressure, loading conditions, and temperatures. Briefly, the test procedure involves placing the specimen in a 50°C water bath and applying a 64-kg (144-lb) load to the specimen through a wheel 20 cm (7.87 in.) in diameter by 4.7 cm (1.85 in.) wide. Loads are applied at 1 Hz until a total of 20,000 cycles. Deformation of the wheel into the specimen is recorded electronically (see Figure 5). According to information received from Elf Asphalt, Inc. (unpublished data), the following specifications are currently used in Hamburg:

	Good	*Very Good*
Maximum deformation	4.0 mm (0.16 in.)	2.5 mm (0.10 in.)
No. of passes	20,000	20,000
Test temperature	50°C (122°F)	50°C (122°F)

In addition to the total deformation after 20,000 passes, four other indexes can be measured from the graph of deformation versus the number of passes:

Index	*Interpretation*
Postcompaction consolidation	Not yet known
Inverse creep slope	Rutting resistance
Stripping inflection point	Moisture susceptibility
Inverse stripping slope	Moisture damage severity

Figure 5 shows the relationship of the four indexes; they are defined by Elf Asphalt, Inc., as follows:

- Postcompaction consolidation is the amount of deformation that rapidly occurs during the first few minutes of the test. The steel wheel has some compaction effects on the mixes. A point of inflection occurs after this initial consolidation is completed.
- Inverse creep slope is reported in passes per millimeter. A reported value of 3,000 passes per millimeter would indicate that 3,000 passes of the wheel are required to make a 1-mm deformation. Therefore, the higher this value is the more resistant the mix is to permanent deformation.
- Stripping inflection point is the number of passes at which moisture damage begins to adversely affect the mixture. The curve of deformation versus the number of passes abruptly turns downward. The stripping inflection point is related to the amount of mechanical energy required to produce stripping under the test conditions. A higher stripping inflection point means that a pavement is less likely to strip.
- Inverse stripping slope is similar to inverse creep slope in calculation. However, the slope is calculated after the stripping inflection point. The lower the inverse stripping slope, the more severe the moisture damage.

Testing is normally conducted on either laboratory-compacted specimens or 25.4-cm (10-in.) field cores. In 1991, WTD obtained two 25.4-cm (10-in.) cores from each of the nine test sections. All cores were sent to the Elf Aquitaine Asphalt Laboratory in Terre Haute, Indiana, where the wheel track testing was conducted. This was a blind study; the laboratory was not told the identities of the cores until after all testing had been completed and findings submitted. Table 5 shows the overall ranking of all nine test sections on the basis of the wheel track testing and includes the values for the above-defined indexes (the ranking was performed before Elf was told the identity of the cores). The Styrelf section was

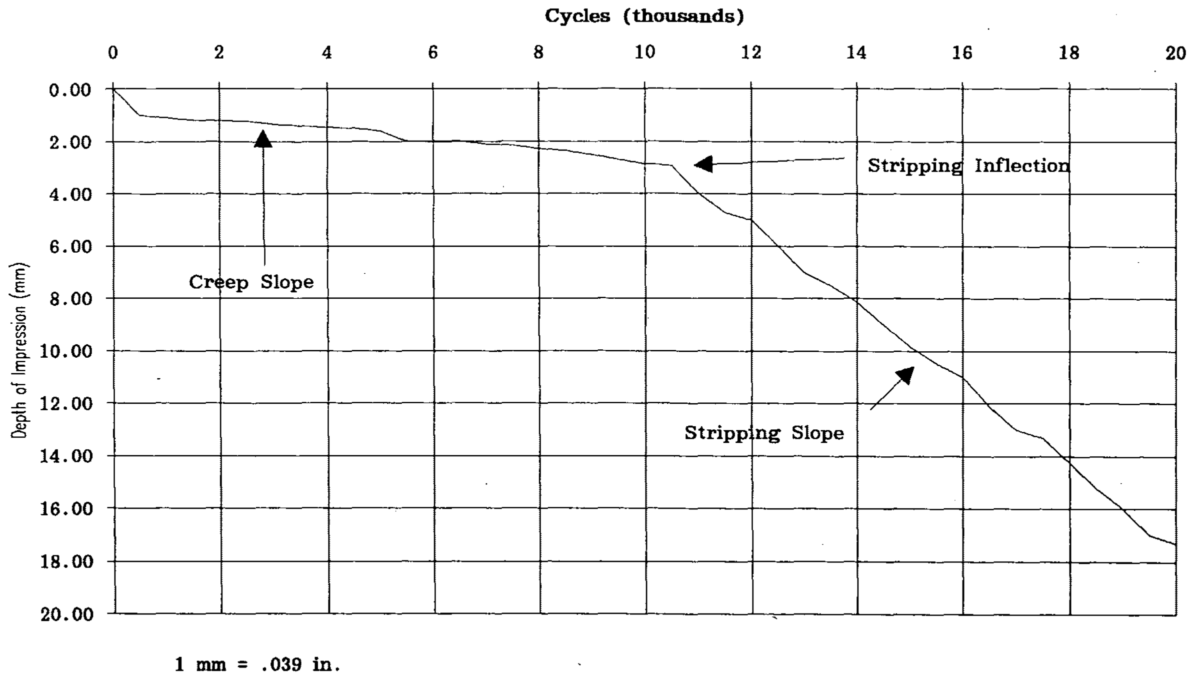

FIGURE 5 Data analysis: German rut device.

ranked first, the carbon black section was ranked last, and the 60/40 control section was ranked third. Results from the wheel tracking device correlated well with field measurements. The carbon black test section showed poor performance in the field and the laboratory testing, primarily with respect to rutting.

Pavement Serviceability Index

The WTD road profiler, built to the same specifications as the South Dakota road profiler, was used to measure the roughness of all test sections. Pavement serviceability indexes were then calculated on the basis of a relationship developed by the South Dakota Department of Transportation. There were no significant variations among the different sections.

Condition Survey

Pavement Condition Index (PCI) measures pavement surface conditions on the basis of visual observation of pavement distress type, severity, and extent (*2*). The surface conditions of all test sections were determined in 1991 by Shell Chemical Company (unpublished data). Three sample units were surveyed for distress in each test section, and the average PCI values were then calculated from these three sample units. These values ranged from 42 for the carbon black section to

TABLE 5 Hamburg Rut Test Results (Source: Elf Aquitane Asphalt Laboratory, Terre Haute, Indiana)

Section Number	Test Section	Overall Ranking	Total Deformation @ 20,000 cycles (mm) Test No.		Post Comp (mm) Test No.		Creep SL Cycles/(mm) Test No.		Strip Infl. Cycles Test No.		Strip SL Cycles/mm Test No.	
			1	2	1	2	1	2	1	2	1	2
1	Styrelf	1	1.1	1.1	0.5	0.3	24300	22100	N/A	N/A	N/A	N/A
3	Kraton	2	1.8	1.7	0.4	0.6	13800	19600	N/A	N/A	N/A	N/A
5	50/50	6 (a)	1.6	>20	0.4	0.5	16330	2680	N/A	10500	N/A	438
7	SBR	5 (a)	1.5	>20	0.5	0.5	19350	2680	N/A	10500	N/A	440
9	Carbon	9	>20	>20	1.3	1.5	1100	600	5000	2500	380	160
11	EVA	7	5.0	12.0	0.8	0.8	3500	11500	12000	16000	1000	1428
12	Fibers	4	1.9	2.6	0.8	0.7	17680	9820	N/A	N/A	N/A	N/A
13	Virgin	8	>20	>20	0.9	1.0	2272	4580	6250	9500	909	504
14	60/40	3	2.0	1.1	0.5	0.1	12000	17400	N/A	N/A	N/A	N/A

(a) Poor reproducibility between cores.

76 for the 50/50 section. All sections were rated as good to excellent except the carbon black section, which was rated as fair. The following four distress types were found in the test sections: alligator cracking, longitudinal and transverse cracking, weathering and raveling, and rutting. All test sections showed a significant amount of low-severity raveling, which covered 100 percent of some of the sections. On the other hand, only the carbon black section experienced medium- to high-severity rutting. Table 6 lists the PCI score for each test section. Figure 6 shows the PCI scores.

An evaluation of transverse cracking was conducted by WTD; the results are shown in Figure 7. The figure compares the preconstruction cracking to postconstruction cracking in 1992. The carbon black section, which was the only section that showed significant rutting, had the least transverse cracking return after 5 years.

Resilient Modulus

The resilient modulus test (ASTM D4123) is one of the more common methods of measuring the elastic stiffness of asphalt mixtures. In this research, the resilient modulus test was conducted on asphalt mix material obtained during construction and on 15.2-cm (6-in.) cores obtained from the roadway 3 years later. Table 7 compares the construction and postconstruction resilient modulus test results at 25°C (77°F). There appears to be a significant decrease in resilient modulus over the 3-year period. On average the decrease was 185 percent. The smallest decrease was in the Kraton section (−65 percent) and the largest decrease was in the fiber section (−326 percent). Certainly, some of the decrease may be attributable to the fact that the construction tests were performed on specimens compacted in the laboratory and that the postcon-

TABLE 6 Measured Distress Densities for All Test Sections (Source: Shell Chemical Company, Oak Brook, Illinois)

Sec. No.	Asphalt Type	PCI	Rating	Density Alligator Cracking			Density Long. & Tran. Cracking			Density Weathering And Ravelling			Density Rut		
				Low	Med.	High	Low	Med.	High	Low	Med.	High	Low	Med.	High
1	STYRELF	65	GOOD	2.32	0.05	0	0.05	7.22	0	66.30	1.28	0	0	0	0
3	KRATON	72	V.GOOD	0	0	0	2.07	3.13	0	99.36	0.64	0	0	0	0
5	50/50	76	V.GOOD	0	0	0	4.40	1.25	0	99.20	0.80	0	0	0	0
7	LATEX SBR	62	GOOD	1.26	0	0	0.82	7.30	0.11	100.0	0	0	0	0	0
9	CARBON	42	FAIR	2.67	1.78	1.78	0.47	1.72	0	78.45	0.18	0	0	5.17	5.17
11	EVA	67	GOOD	0.18	0	0	0.57	7.22	0	100.0	0	0	0	0	0
12	FIBERS	72	V.GOOD	1.1	0.11	0	1.06	1.34	0	99.2	0.80	0	0	0	0
13	100V	75	V.GOOD	1.17	0	0	0.23	2.13	0	66.93	0	0	0	0	0
14	60/40	72	V.GOOD	0.51	0	0	0.63	4.08	0	66.39	0.74	0	0	0	0

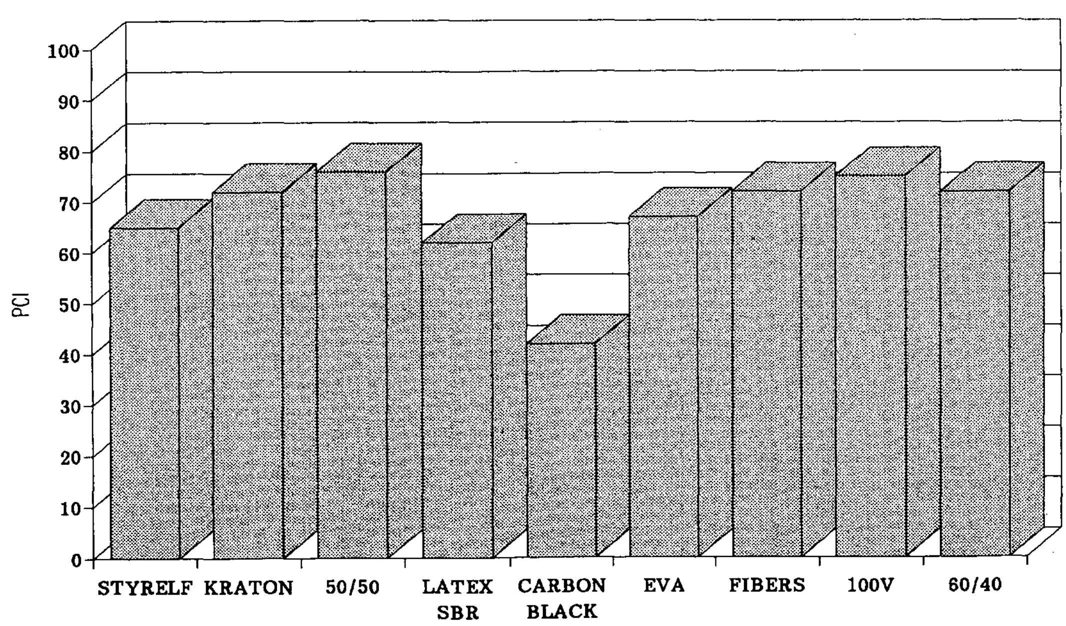

FIGURE 6 Comparison of PCI scores.

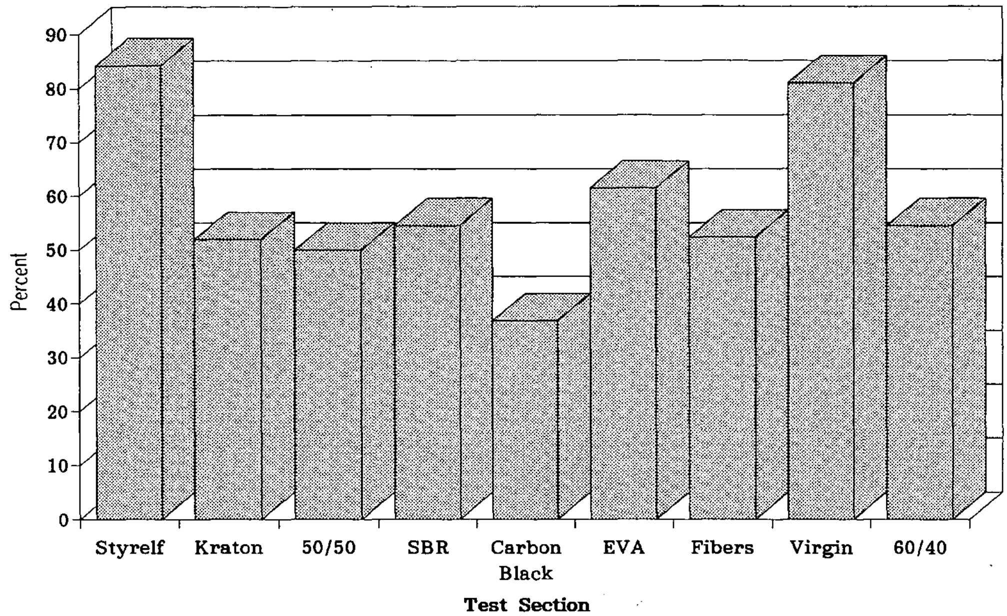

FIGURE 7 Transverse cracking after 5 years as percent of preconstruction transverse cracking.

struction tests were conducted on cores obtained from the roadway, but most of the decrease is probably attributable to the degradation of the material from repeated loading and environmental factors.

The computer program EVERCALC was used to backcalculate resilient modulus from falling weight deflectometer deflection basic measurements. The program was written by the University of Washington for the Washington Department of Transportation. The program uses an iterative approach in changing the moduli in a layered elastic solution to match the theoretical and measured deflection. Table 8 shows the backcalculated resilient modulus values. When comparing resilient modulus values from the laboratory and the backcalculation program, it was found that these values were close for the Styrelf, EVA, fibers, virgin, and 60/40 test sections. Backcalculated M_R values were significantly different from the laboratory M_R for the rest of the sections. It is not clear why some of the values were close and others varied significantly.

PERFORMANCE MODEL

Selected field and laboratory data were compiled in a computerized data base by the University of Wyoming. Several computer models were then generated to correlate field performance with the results from laboratory testing. The following model was found to be the most reliable:

$$\mathrm{PCI}' = -80.4 + 0.0838 * M_R + 0.13 * \mathrm{Pen} + 7.84 * \mathrm{VMA} - 0.00501 * \mathrm{Vis} \quad (1)$$

where

PCI = pavement condition index,
M_R = laboratory resilient modulus at 25°C (77°F),
Pen = penetration at 25°C (77°F),
VMA = voids in mineral aggregate, and
Vis = viscosity at 135°C (275°F).

TABLE 7 Resilient Modulus Immediately After Construction and 3 Years Later

Sec. No.	Asphalt Type	Resilient Modulus @ 25°C (*1000) Immediately after Construction (a)	Resilient Modulus @ 25°F (*1000) After 3 yrs. In Service (b)	% Difference
1	STYRELF	1129	527	-114
3	KRATON	904	549	-65
5	50/50	1757	621	-183
7	LATEX SBR	1540	674	-129
9	CARBON BLACK	1133	289	-292
11	EVA	1404	519	-171
12	FIBERS	1808	425	-326
13	100V	1209	533	-127
14	60/40	1458	409	-257

(a) Resilient Modulus tests were performed on loose paving mix collected behind the paver and compacted in the lab.

(b) Resilient Modulus tests were performed on 6" diameter cores taken from the pavement.

TABLE 8 Comparison Between Resilient Modulus Values from Laboratory Testing and Backcalculation

Section Number	Asphalt Type	MR From Cores @ 25°C (*1000 KPa)	Backcalculated MR (Evercalc) (*1000 KPa)	% Difference
1	STYRELF	3634	4137	12
3	KRATON	3785	2055	-84
5	50/50	4282	2544	-68
7	LATEX SBR	4647	6998	34
9	CARBON BLACK	1993	5006	61
11	EVA	3579	4220	15
12	FIBERS	2930	3254	10
13	100V	3675	3213	-14
14	60/40	2820	2827	0

R^2 for the above model is 91.6, which indicates a good correlation. However, the regression analysis is based on a relatively small sample, and so any extrapolation of this model to other pavements should be done with caution. The model indicates that PCI is positively correlated with resilient modulus, penetration, and VMA, and negatively correlated with viscosity at 135°C (275°F).

CONSTRUCTION PROBLEMS

The asphalt plant used in the production of asphalt mixes was a conventional dryer drum plant (split feed). The RAP entered the drum through a rotary center inlet via a separate cold feed bin and conveyor system. Virgin aggregate (two feed bins) and lime entered the drum at the burner end. The lime was added to the aggregate before entering the drum. The virgin aggregate was prewetted before the addition of the lime. A pug mill was used to mix the lime and virgin aggregate. There were few, if any, significant production problems, except for the fiber and carbon black mixtures.

The fibers were added to the RAP conveyor on top of the RAP. Almost immediately after starting production of the fiber mix, it appeared that the fibers were not mixing properly in the drum, causing a buildup of fibers at the outlet. The rate at which fibers were being added to the mix was checked, and the contractor performed some maintenance on the inside of the drum, which included adjusting the flights. The plant was then restarted and the problem appeared to be resolved. Also, it was noted that because they were being placed on top of the RAP, the fibers were very susceptible to being blown off by slight to moderate wind. Production of the fiber mix was performed on a calm day to overcome this problem. No additional problems were observed with the fiber mix production or laydown.

The main problem with the production of the carbon black mix was with the pumpability of the binder-modified asphalt. The amount of carbon black in the virgin AC-10 was approximately 20 percent by weight. This high concentration of carbon black in the virgin asphalt was required so that the overall concentration in the virgin asphalt and recycled asphalt would be around 10 percent. The viscosity of the virgin AC-10 with 20 percent carbon black was a moderate 600 poise at 135°C (275°F), but it appeared that the viscous shear resistance between the particles of carbon black made it difficult to pump the material. The first method used to alleviate the pumping problem was to heat the asphalt to a temperature of about 218°C (425°F). This method was unsuccessful. The second method, which was successful, consisted of placing the metering pump on the plant and a pump on a Bearcat asphalt distribution truck in tandem. The carbon black–AC-10 mixture was then pumped into the dryer drum without any further problems at a normal temperature. There was speculation that the initial pumping problems and high temperature reheating may have caused the carbon black to segregate from the asphalt before its introduction into the dryer drum. Subsequent reflux extraction tests performed by WTD, with methylene chloride and 25-μm rapid-flow filter paper, indicated that the carbon black had not segregated from the AC-10.

The distance for hauling from the plant to the construction site was a few miles, and temperature loss in the mix was negligible. Typical temperatures of the mix before entering the paver ranged from 118°C to 143°C (245°F to 290°F) with an average temperature of 132°C (270°F). Three vibratory steel wheel rollers were used to compact the plant mix material. Ten cores were taken from each test section: the average density of the top lift of the test sections was 94.6 percent of the maximum theoretical density, as determined by AASHTO test procedure T209, with a standard deviation of 1.1 percent. No problems with compaction were reported by the roller operators on any of the test sections. One percent lime, by weight of mixture, was included in all mixtures as an antistripping agent. Emulsified asphalt SS-1 was placed on the bottom of the trench and between lifts at a rate of approximately 0.13 kg/m² (0.25 lb/yd²).

CONCLUSIONS

On the basis of the field and laboratory testing performed in this study, the following conclusions were drawn.

- The field performance of the 60/40 control mix was as good as the performance of the modified mixes. Also, in a laboratory-accelerated load test the 60/40 control mix was ranked third (better than some of the modified mixes).
- The carbon black test section did not perform as well as expected and was the only section with significant rutting. (There was some minor rutting in the 50/50 test section in the left wheelpath, but not in the right wheelpath. Because it was confined to the left wheelpath, the rutting was attributed to a construction problem and not to the mix design itself.)

- No major problems with mixing, handling, or placing were experienced during construction. Double loading the content of the binder-modifier did not cause any construction problems except in the case of the carbon black. The fibers did not melt in the dryer drum as some had predicted.
- The dense gradation of the aggregate resulted in relatively low VMA. The performance model indicated that lower VMA resulted in lower PCI.
- The performance model indicated that PCI is positively correlated with the laboratory resilient modulus at 25°C (77°F), penetration at 25°C (77°F), and VMA and is negatively correlated with viscosity at 135°C (275°F).
- Results obtained from the German wheel track device correlated, to some extent, with the field performance of the mixes.

Several, if not all, of the binder-modifiers used in this research have been modified by their respective manufacturers since construction of the test sections. It is probable that the adjustments made will improve their overall performance. The results from this research should not be viewed alone but rather as simply one field trial among the many field trials recently completed or under way throughout the United States on binder-modifiers. Although in this study the asphalt additives did not result in any significant improvements, WTD is committed to using and monitoring the long-term performance of asphalt additives.

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