Field Trials of Plastic- and Latex-Modified Asphalt Concrete

K. B. KRATER, D. L. WOLFE, AND J. A. EPPS

Test strips of pavement, which contained seven combinations of a polyolefin (plastic) and a styrene-butadiene rubber, were laid in five states. The states were selected on the basis of climate so that the projects would represent the majority of climatic conditions encountered in the continental United States. Data were collected from preconstruction testing on laboratory-compacted samples and from pavement condition surveys of each site. Data on construction techniques were recorded, and postconstruction data from both field-mixed and laboratory-compacted samples and cores were collected. Testing included resilient modulus tests at 10°F, 34°F, 77°F, and 104°F; Hveem stabilities; tensile strength tests at 10°F and 77°F; and one cycle of the Lottman accelerated conditioning procedure. Preliminary conclusions are that construction using plastic and latex presents no major problems. The addition of plastic and latex in certain combinations will increase resistance to rutting while not increasing thermal cracking at low temperatures. These modified pavements offer better resistance to moisture susceptibility than does pavement with no additives. Finally, these improvements are highly asphalt source dependent.

The poor performance and premature failures of some asphalt paving mixtures in this country have led many field engineers to believe that asphalt cements, and thus asphalt concrete mixtures, have changed over time. Many engineers and field personnel attribute poor pavement performance to the oil companies' taking the "goodies" out of asphalt cement and using them as feedstock for the petrochemical industry. Another belief is that increases in construction and transportation costs have caused a decline in the quality of asphalt cement and asphalt concrete roadways. Field engineers point to several types of pavement distress as evidence of these concerns, including placement difficulties, excessive displacement under traffic (rutting), thermal cracking and raveling, and poor fatigue behavior. Results of these problems are higher maintenance costs, more frequent traffic interruptions during repairs, shorter times between major rehabilitations, and increased numbers of complaints by motorists.

Although the declining quality of asphalt cements is a logical explanation of the poor performance of roadways, several other possible causes must be considered. Greatly increased traffic volumes and loads, along with higher tire pressures, have occurred in the last 10 to 15 years, which has placed an increased demand on roads not originally designed for this magnitude of traffic (*1*). Also, construction equipment has been developed to improve production, air quality, and worker safety, causing an increased demand on materials. Increased transportation and construction costs allow less maintenance and rehabilitation to be done under local budgets that have not gone up proportionally, and quality aggregates are becoming more costly and harder to obtain in many locations where readily available supplies have already been used up (*2, 3*).

The modification of asphalt cements might alleviate several pavement performance problems (*4*). Although construction quality control, improved specifications, asphalt mix designs that correlate with field construction methods, and more accurate pavement design methods need to be examined, improved binder systems offer the potential for substantial improvements in binder systems and roadway performance.

Several asphalt modifiers exist today to improve one or more properties of asphalt cements or asphalt concrete mixes, or both. These modifiers include organic materials, metal compounds, fibers, fillers, sulfur, lime, elastomers, and polymers. Although considerable research has been performed on these modifiers in the laboratory, few field evaluations have been made. This paper gives results from several asphalt overlay projects, constructed in the United States, in which a "functionalized" polyolefin and a styrene-butadiene rubber (SBR) were used. These modifiers were incorporated into the mixtures in seven different combinations.

BACKGROUND

The goal of this research was to construct test strips around the country using two polyolefins (plastics) and an SBR (latex). Two plastics, chosen from an initial screening of twenty, were selected on the basis of mixture properties and high-temperature performance.

ADDITIVES STUDIED

The plastics contain ethylene and acrylic acid. Both plastics are semiclear solid pellets up to a temperature of 180°F and have a specific gravity of from 0.91 to 0.97. No handling problems should occur with expected pavement uses.

Latex had been previously tested and was incorporated into the project because of possible synergistic effects when combined with the polyolefins. Latex is a blend of water and rubber and is similar to water in most of its physical properties. Latex has a specific gravity of from 0.93 to 0.97, a boiling point of 212°F, and solidifies at 32°F. No handling problems should occur with expected pavement uses.

Further testing was done to determine which combinations and concentrations to use, mixing and compaction temperatures, order of additive addition, compaction temperature–air

K. B. Krater and J. A. Epps, Civil Engineering Department, University of Nevada-Reno, Reno, Nev. 89557. D. L. Wolfe, Specialties, Midland, Mich. 48674.

void relationship, and construction suitability (*5–8*). The following mixture combinations, listed by amounts of additives by total weight of binder system, were used:

1. A control section with no additives,
2. Five percent Plastic 1,
3. Five percent Plastic 2,
4. Three percent latex,
5. Five percent Plastic 1 + three percent latex,
6. Two percent Plastic 1 + three percent latex, and
7. Two percent Plastic 2 + three percent latex.

By using these combinations of additives, each with different asphalt cements and grades and different aggregates, in a variety of climates it was hoped that the following things could be determined:

1. Construction feasibility,
2. High-temperature performance,
3. Low-temperature performance, and
4. Moisture susceptibility.

RESEARCH PROCEDURE

Preconstruction

The first step was to conduct preconstruction testing on the Texas, Idaho, and Alabama field projects to

1. Determine the compatibility of the modifiers with the asphalt concrete mixtures,
2. Obtain results that could be compared with postconstruction results, and
3. Determine which of two methods to use to combine the modifier with the asphalt cement.

The first method of modifier addition involved retaining the amount of asphalt cement called for in the mix design and adding the modifier by weight of asphalt. The second method involved subtracting a like quantity of asphalt from the mixture so that the modifier and asphalt combined equaled the amount of binder called for in the mix design. Testing showed the latter method of addition to be the best. This method reduced tenderness problems that occurred when the modifier was added to the asphalt, as was done in the first method.

Pavement condition surveys, using the American Public Works Association PAVER method (*9*), were performed at each site. At the times of the surveys, crack maps were drawn to scale so that cracks occurring in the pavement after construction could be traced to determine amounts of reflective versus thermal cracking. The projects consisted of 1,000-ft sections for each of the seven different modifier combinations listed earlier. Each 1,000-ft section was divided into ten 100-ft sample units of which three were selected for sampling of cores and loose mix as well as the PAVER condition survey.

Construction

During construction, a representative from the research team was present to perform a variety of duties. The exact location of all sections was established and referenced for future testing. Samples from each of the selected sample units were obtained for laboratory compaction and testing. Construction rating sheets, listing variables such as mixture temperature, segregation of mix, and ease of compaction and workability of the mixture, were completed. Figure 1 is a copy of the rating sheet used on the projects.

Postconstruction

Nine samples from each of the sections, field mixed and compacted and field mixed and laboratory compacted, were tested from each of the seven sections from all five projects. The testing procedure is shown in Figure 2. The first group of three loose-mix samples was compacted using the standard Hveem compaction effort as described in ASTM D 1561. The *Annual Book of Standards* (*10*) lists all tests used in this project. The other six loose-mix samples were compacted using a reduced Hveem compaction effort of 30 strokes at 250 psi and a leveling load of 10,000 lb to produce sufficient air voids to conduct water sensitivity testing (Figure 3).

The first group of three samples, both cores and laboratory compacted, were tested for resilient modulus at temperatures of 10°F, 34°F, 77°F, and 104°F. Testing was performed according to ASTM D 4123, with a load cycle of 0.1 sec applied load and a 3-sec pause between loads. Splitting tensile strength was

DOW CHEMICAL - FIELD PROJECTS
CONSTRUCTION RATING

Location: Date:

Test Section	1	2	3	4	5	6
Design	CTRL	5P-1	5P-2	3%L	2P-2 3%L	2P-1 3%L
A. TRANSPORT						
1. Segregation in Truck						
2. Flow out of Truck						
3. Adhesion to side of Truck						
4. Temperature of Mix						
B. LAYDOWN MACHINE						
1. Segregation in Hopper						
2. Workability through Screed						
3. Surface Appearance						
4. Temperature						
C. COMPACTION						
1. Shoving						
2. Sticking on Roller						
3. Temperature						
D. JOINT						
1. Overall						
E. WORKABILITY						
1. Overall						
F. AFTER COMPACTION						
1. Surface Appearance						
2. Joint Appearance						

Rating: 8-10 Very Good; 6-8 Good; 4-6 Fair; 2-4 Poor; 0-2 Very Poor

FIGURE 1 Rating sheet.

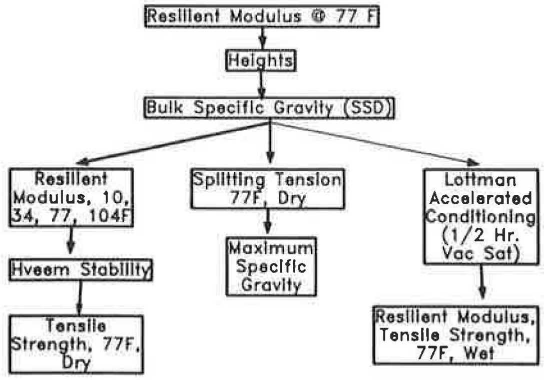

FIGURE 2 Testing outline.

	Construction		Postconstruction
	Standard Hveem	Modified Hveem	Cores
Texas	4.7 S=0.80	7.8 S=0.61	4.5 S=0.73
Idaho	7.4 S=1.03	11.6 S=0.41	9.5 S=0.89
Maine	0.7 S=0.27	3.8 S=0.29	5.9 S=0.78
Alabama	6.4 S=1.04	11.0 S=1.41	12.0 S=1.34
Michigan	0.6 S=0.36	2.8 S=0.74	4.9 S=1.01

FIGURE 3 Air void content.

determined next. Theoretical maximum specific gravities were determined by ASTM D 2041 and air voids were established.

The other six samples were run through one cycle of the Lottman accelerated conditioning procedure (*11*). Resilient modulus values and splitting tensile strengths were determined for dry and wet conditions at 77°F. Retained tensile strengths and modulus values were determined from the ratio of wet to dry test results.

Follow-up testing is expected to continue for 5 years. Cores will be taken at 1, 3, and 5 years, and pavement condition surveys will be conducted annually, using the APWA PAVER method.

PROJECT SITES AND CONSTRUCTION RESULTS

Selection of project sites was based on location, climate, construction equipment and methods available, and cooperation by state highway departments and highway districts. It was desired to find projects that could be constructed using a pug mill asphalt plant. This was necessary because the available plastic is in solid form, and mixing requirements necessitated dumping the plastic pellets directly into the mixer. Significant construction results are discussed separately by state.

Texas

The first highway project is located on US-83 in the lower Rio Grande River Valley near Mission, Texas. US-83 is a four-lane divided facility, with average daily traffic (ADT) of 14,600 in 1985. Extreme summer daytime temperatures are in the 90°F to 99°F range. Winter temperatures are typically in the 50s during the day and drop into the mid-40s at night. Average annual rainfall is 27.0 in. and is evenly distributed throughout the year. Construction consisted of a 2-in. overlay over a double asphalt-rubber seal coat. Existing distress consisted of low to medium severity transverse, longitudinal, and alligator cracking. The asphalt cement used is a Texas Fuel and Oil AC-20 and the aggregate a polished river gravel from the Fordyce pit near Mission, Texas. One percent hydrated lime by dry weight of aggregate was used in the control section to counteract the water susceptibility of the aggregate. Lime was not used in the sections containing modifiers. This was the only project constructed with lime.

The test sections were constructed in July 1986. The hot mix was produced in a plant that uses a continuous pug mill in conjunction with a drum mixer that heats and dries the aggregates. The plant was a DMC Drum Mix Coater manufactured by Astec Industries, Inc. Modifications were made to the plant to facilitate the introduction of the modifiers as necessary. The modifications made were minor and were done the evening before construction. The alteration consisted of cutting a hole on top of the coater unit and bolting on a variable speed auger. The plastic pellets were fed into a chute connected to the auger. The latex was introduced into the asphalt supply line using a metering device fed by a diaphragm pump. This same method was used to add the latex to the asphalt cement on all five projects.

No apparent problems were encountered at the plant when the additives were used. The modified mixes were virtually unnoticed by plant personnel. Three points about this project are worthy of note:

1. The wings of the paving machine were pulled to the center after each load, and the mixture remaining in the truck was emptied on the road surface and shoveled to the center of the lane. This resulted in an area of segregation in the pavement that could be easily identified at the end of each load in the compacted pavement.
2. Some areas of tender pavement occurred; these could be noted by observing the rut depth left by the breakdown roller. The tenderness problem was due to the smoothness of the polished river gravel. This tenderness effect was also observed during laboratory compaction.
3. Slight tearing and pulling behind the screed were noted in sections with 5 percent Plastic 1 plus 3 percent latex, 5 percent Plastic 1, and 5 percent Plastic 2.

Overall, construction personnel were satisfied with both plant operation and field construction.

Idaho

The second project is located in the Boise River Valley in Ada County, Idaho. The site is on Ustick Road between Eagle Road and Cloverdale and is a two-lane facility with a 1986 ADT of 3,700. Summer temperatures are generally mild with highs in the 80°F to 99°F range. Winter temperatures range in the 20s and 30s during the day and drop into the low teens and below at night, December through January. There are nearly 100 air freeze-thaw cycles per year in the area, most of which occur in the spring. Precipitation averages 11.7 in. per year. Construction

consisted of a 2-in. overlay over the existing roadway. Existing distress was medium to severe alligator cracking, medium rutting, medium raveling, and low to medium severity longitudinal and transverse cracking. The asphalt used was a Koch AC-10, and the aggregate a smooth polished river gravel obtained from the Nelson pit in Boise.

The test sections were constructed in July 1986. The hot mix was produced in a Barber-Greene 100-ton/hr drum plant modified to produce 150 tons/hr. The plastic pellets were preblended with the asphalt cement in a distributor truck normally used for emulsions. Mixing was not efficiently accomplished because of the small pumps on the truck, and approximately 8 hr were needed to mix the first batch, which contained 5 percent Plastic 1. The plastic pellets normally blend into the asphalt within 20 sec under high agitation during laboratory mixing. The asphalt was introduced as it was in the Texas project.

Because of the mixing problem with the plastic, this project was scaled back to four sections: the control section, 5 percent Plastic 1, 3 percent latex, and 3 percent latex plus 2 percent Plastic 1. No major problems were encountered during construction. Field personnel were only able to identify the section containing 3 percent latex by observing a slightly darker pavement. It was necessary to keep the pneumatic roller well back from the paver in sections containing latex because the mat tended to stick to the rubber tires. However, this was also noticed to some degree in the control section.

Maine

The third project is located on the southbound travel lane of I-95 in Bangor, Maine. I-95 is a four-lane divided facility with a 1985 ADT of 6,695. Summer temperatures range from the mid to the upper 70s, July through September. Winter daytime temperatures range from the low 30s to the low 20s and drop into the low teens and below at night. Precipitation averages 41.6 in. per year. Construction consisted of a 2-in. overlay on a milled and leveled surface. Existing distress consisted of medium to high severity transverse cracking that passed well into the milled surface. The asphalt used was an Irving Oil AC-20, and the aggregate a mixture of coarse sand from the Frink pit in Hermon, Maine, and a ledge sand and stone from the Odlin Road quarry in Hermon.

Construction was performed in September 1986. The asphalt mix was produced in a Stansteel 7,000-lb batch plant. The plastic pellets were introduced by hand into a hole in the pug mill in predetermined quantities. The only noticeable problems were ripples in the final two sections of the project, which were 3 percent latex plus 2 percent Plastic 1 and 3 percent latex plus 2 percent Plastic 2. This was most likely due to a problem with the screed on the paver rather than the mix. The breakdown roller operator commented on how well he thought the sections with plastic in them compacted.

Alabama

The fourth project is located on US-231 in Huntsville, Alabama. US-231 is a four-lane divided facility with a 1986 ADT of 12,000. Summer daytime temperatures range from the low to upper 90s June through August. Winter temperatures are in the 50s during the day and drop into the 30s at night. Precipitation averages 54.6 in. per year. Construction consisted of a 2-in. overlay over the existing roadway. Distress present before construction was low to high severity raveling. The asphalt is an AC-30 from the Hunt Refining Company, and the aggregate is a Vulcan Materials crushed gravel and coarse sand with 10 percent aggregate lime.

Construction was performed in October 1986. The asphalt mix was produced in a pug mill that generates 4 tons per batch. The plastic pellets were introduced by hand into a hole in the pug mill in predetermined quantities. No problems were encountered on this project. Field personnel could not identify any of the seven mixes, except for the 3 percent latex section that was slightly blacker and stickier than the other mixes.

Michigan

The final project is located on State Route M-35 near Marquette, Michigan. M-35 is a two-lane facility with a 1986 ADT of 2,900. Summer daytime temperatures are in the low to upper 70s, June through September. Winter temperatures range from the low to mid 20s during the day to near zero at night, December through January. Precipitation averages 30.4 in. per year. Construction consisted of a 1-in. leveling course and a 2-in. overlay on top of a milled surface. Existing distress included extensive low to medium severity longitudinal and transverse cracking with some alligator cracking. The asphalt is a 120-150 pen asphalt imported from Spain, and the aggregate a coarse gravel.

Inclement weather delayed the Michigan project until late October 1986, which is well into cool weather in northern Michigan. No serious problems were encountered on the Michigan project; research personnel felt comfortable with the operation after the previous four projects. The asphalt mix was produced in a pug mill that generates 3 tons per batch in the same manner as the one used in the Alabama project.

TEST RESULTS

Test results are discussed in terms of the variables investigated.

High-Temperature Performance

Results of high-temperature tests vary depending on which set of data is examined. However, review of preconstruction, construction, and postconstruction air void contents reveals differences in air void content great enough to account for the variance in test data (Figure 3).

Overall, 5 percent Plastic 2 and 2 percent Plastic 1 plus 3 percent latex show the greatest amount of 104°F modulus improvement for both the field-mixed, laboratory-compacted samples and the cores. However, as can be seen in Tables 1–10, the best modifier for any one project varies. There is no one best modifier to increase 104°F resilient modulus for all projects. Improvements are substantial enough to predict improved performance in terms of excessive displacement under traffic, and 104°F modulus gains of up to 50 percent can be expected in the field, according to the data.

Low-Temperature Performance

No long-term performance testing was done to predict low-temperature performance of the mixes in this research project. However, the cold-temperature resilient modulus data suggest that the modifiers are not detrimental to cold-temperature performance of the asphalt concrete. A majority of the results from both the 10°F and the 34°F resilient modulus test are within 10 percent of each other and within one standard deviation. Tables 1–10 give the results of 10°F resilient modulus tests.

Tensile strength tests at 10°F were performed on Maine, Alabama, and Michigan field-mixed, laboratory-compacted samples and Alabama cores. In general, tensile strengths are higher for modified mixes except for the Alabama field-mixed, laboratory-compacted samples, which are the same or slightly lower. Tables 1–10 give the results of 10°F splitting tensile test.

Intermediate Temperatures

Resilient modulus values for modified mixes are considerably higher than for control mixes, except for Texas, which has similar values for both modified and control mixtures. Tensile strengths at 77°F are generally the same for both modified and control mixtures.

Moisture Susceptibility

It was hoped that the polyolefin would coat the aggregate, causing an increased bonding effect between the aggregate and the asphalt cement and generating an increased resistance to stripping in the presence of water. Results of Lottman testing indicate that the modified mixtures have approximately the same retained modulus values (Tables 11–14). The absolute values of the modified mixes after one Lottman cycle are roughly 50 percent higher than those of the control mixes after one Lottman cycle.

The modified mixes have the same or slightly lower tensile strength ratios after one Lottman cycle (Tables 11–14), and the absolute values of the modified mixes after Lottman testing are slightly higher than those of the control mixes after one Lottman cycle.

The Texas data indicate that, although the additives studied offer improved antistripping properties compared with no modifier, lime is a better choice for problem mixtures. However, the modifiers are compatible with lime, as the Alabama study shows. Although the Alabama project contained no added lime, the aggregate did contain 10 percent aggregate lime.

TABLE 1 CONSTRUCTION RESULTS, STANDARD HVEEM COMPACTION, TEXAS

Test Section Number	Mixture	Resilient Modulus 10°F ksi	34°F ksi	77°F psi	104°F psi	Hveem Stability	Tensile Strength 77°F, psi	Air Voids percent
I	CONTROL	7,175	4,594	494,820	69,510	28.3	147.2	5.0
V	5%P-1	4,531	3,213	451,930	96,800	34.1	137.6	4.3
VI	5%P-2	5,503	3,698	478,400	80,520	29.7	135.5	4.4
II	3%LATEX	6,328	3,561	415,060	72,420	30.2	131.4	5.1
IV	5%P1+3%L	5,165	3,424	611,110	124,740	35.3	152.0	4.6
III	2%P1+3%L	4,999	3,110	462,110	91,230	32.2	140.6	6.0
VII	2%P2+3%L	4,569	3,606	467,810	92,380	28.1	156.3	3.2

TABLE 2 POSTCONSTRUCTION RESULTS, TEXAS

Test Section Number	Mixture	Resilient Modulus 10°F ksi	34°F ksi	77°F psi	104°F psi	Hveem Stability	Tensile Strength 77°F, psi	Air Voids percent
I	CONTROL	3,331	1,932	271,820	54,480	---	114.1	4.7
V	5%P-1	5,145	1,694	276,040	66,470	---	90.7	4.6
VI	5%P-2	3,123	3,193	334,400	65,890	---	127.2	4.2
II	3%LATEX	3,464	2,043	298,450	58,690	---	110.4	4.9
IV	5%P1+3%L	3,796	1,505	310,360	77,390	---	111.2	4.6
III	2%P1+3%L	3,717	2,013	343,590	66,890	---	106.2	5.7
VII	2%P2+3%L	3,518	2,904	361,980	60,880	---	126.0	3.1

Note: (---) indicates data not available.

TABLE 3 CONSTRUCTION RESULTS, STANDARD HVEEM COMPACTION, IDAHO

Test Section Number	Mixture	Resilient Modulus 10°F ksi	34°F ksi	77°F psi	104°F psi	Hveem Stability	Tensile Strength 77°F, psi	Air Voids percent
I & IV	CONTROL	2,902	2,586	239,015	31,767	36.8	94.4	6.4
II	5%P-1	3,504	3,239	426,436	75,883	40.1	115.0	7.1
	5%P-2	---	---	---	---	---	---	---
III	3%LATEX	2,304	2,384	201,278	35,901	39.6	73.8	9.1
	5%P1+3%L	---	---	---	---	---	---	---
V	2%P1+3%L	2,090	2,838	233,340	44,889	43.4	84.2	6.9
	2%P2+3%L	---	---	---	---	---	---	---

TABLE 4 POSTCONSTRUCTION RESULTS, IDAHO

Test Section Number	Mixture	Resilient Modulus 10 F ksi	34°F ksi	77°F psi	104°F psi	Hveem Stability	Tensile Strength 77°F, psi	Air Voids percent
I & IV	CONTROL	1,839	1,586	91,616	13,086	---	63.5	9.7
II	5%P-1	1,617	1,081	125,228	22,627	---	58.0	9.4
	5%P-2	---	---	---	---	---	---	---
III	3%LATEX	1,685	2,058	132,027	24,482	---	66.1	10.7
	5%P1+3%L	---	---	---	---	---	---	---
V	2%P1+3%L	3,454	---	165,334	---	---	---	8.2
	2%P2+3%L	---	---	---	---	---	---	---

Note: (---) indicates data not available.

TABLE 5 CONSTRUCTION RESULTS, STANDARD HVEEM COMPACTION, MAINE

Test Section Number	Mixture	Resilient Modulus 10°F ksi	34°F ksi	77°F psi	104°F psi	Hveem Stability	Tensile Strength 10°F, psi	Air Voids percent
I	CONTROL	4,220	2,927	342,899	55,555	7.8	528.7	0.8
II	5%P-1	5,467	3,489	688,763	145,855	10.0	697.2	0.5
III	5%P-2	5,479	3,176	693,118	173,149	10.4	718.1	0.5
IV	3%LATEX	4,362	3,090	511,072	80,626	5.9	703.9	0.5
VII	5%P1+3%L	3,906	2,511	611,539	128,202	5.9	668.6	0.8
VI	2%P1+3%L	6,326	3,602	726,940	120,522	7.5	689.2	1.3
V	2%P2+3%L	4,550	3,818	749,681	133,291	7.3	713.1	0.6

TABLE 6 POSTCONSTRUCTION RESULTS, MAINE

Test Section Number	Mixture	Resilient Modulus 10°F ksi	34°F ksi	77°F psi	104°F psi	Hveem Stability	Tensile Strength 77°F, psi	Air Voids percent
I	CONTROL	3,302	2,304	102,748	19,187	---	60.8	5.2
II	5%P-1	3,195	2,412	197,378	31,015	---	67.6	5.7
III	5%P-2	2,993	3,104	209,760	41,136	---	67.6	5.7
IV	3%LATEX	3,447	2,600	167,430	29,712	---	67.2	5.0
VII	5%P1+3%L	1,996	1,980	211,008	26,916	---	62.3	6.6
VI	2%P1+3%L	2,869	3,658	210,232	29,841	---	64.4	7.4
V	2%P2+3%L	2,951	3,173	206,651	32,908	---	70.2	5.5

Note: (---) indicates data not available

TABLE 7 CONSTRUCTION RESULTS, STANDARD HVEEM COMPACTION, ALABAMA

Test Section Number	Mixture	Resilient Modulus 10°F ksi	34°F ksi	77°F psi	104°F psi	Hveem Stability	Tensile Strength 10°F, psi	Air Voids percent
I	CONTROL	5,062	2,573	327,959	70,288	35.4	483.6	6.5
II	5%P-1	5,915	4,427	481,658	125,438	37.4	531.2	5.2
III	5%P-2	5,451	3,200	479,141	117,058	33.6	464.2	4.9
IV	3%LATEX	3,546	3,338	369,435	97,829	32.3	395.6	6.6
VII	5%P1+3%L	2,576	2,021	295,591	77,000	32.6	427.9	7.9
VI	2%P1+3%L	5,522	3,966	422,886	110,092	33.1	382.6	6.1
V	2%P2+3%L	3,125	2,320	380,128	95,259	35.0	383.8	7.6

TABLE 8 POSTCONSTRUCTION RESULTS, ALABAMA

Test Section Number	Mixture	Resilient Modulus 10°F ksi	34°F ksi	77°F psi	104°F psi	Hveem Stability	Tensile Strength 10°F, psi	Air Voids percent
I	CONTROL	2,352	2,411	143,071	32,768	11.1	189.6	13.5
II	5%P-1	2,766	1,643	171,360	39,073	20.3	266.7	10.7
III	5%P-2	2,184	1,376	160,766	45,871	---	---	14.2
IV	3%LATEX	2,059	1,303	185,839	44,507	---	---	12.8
VII	5%P1+3%L	2,264	2,284	215,290	37,502	19.0	277.8	11.4
VI	2%P1+3%L	2,362	2,560	230,341	53,015	14.8	274.5	11.1
V	2%P2+3%L	2,797	1,473	200,889	53,715	21.5	288.0	10.6

Note: (---) Indicates data not available.

TABLE 9 CONSTRUCTION RESULTS, STANDARD HVEEM COMPACTION, MICHIGAN

Test Section Number	Mixture	Resilient Modulus 77°F psi	10°F ksi	34°F ksi	104°F psi	Hveem Stability	Tensile Strength 10°F, psi	Air Voids percent
I	CONTROL	145,729	3,864	7,387	22,189	16.0	576.9	0.5
V	5%P-1	225,460	3,428	2,467	34,733	11.4	670.1	0.7
VI	5%P-2	242,775	3,964	2,605	43,321	19.0	642.1	0.3
II	3%LATEX	263,694	4,739	7,331	45,879	14.8	625.8	1.1
IV	5%P1+3%L	183,343	3,700	2,356	36,041	19.9	602.1	0.8
III	2%P1+3%L	338,767	4,149	2,679	70,219	14.7	659.8	1.0
VII	2%P2+3%L	232,462	3,490	2,778	43,777	11.2	671.3	0.0

TABLE 10 POSTCONSTRUCTION RESULTS, MICHIGAN

Test Section Number	Mixture	Resilient Modulus 77°F psi	10°F ksi	34°F ksi	104°F psi	Hveem Stability	Tensile Strength 77°F, psi	Air Voids percent
I	CONTROL	74,237	2,831	1,186	12,803	3.75" COR	51.5	3.2
V	5%P-1	94,803	2,956	1,244	18,201	N/A	50.1	5.9
VI	5%P-2	93,327	2,629	1,562	13,124	N/A	40.9	6.3
II	3%LATEX	129,125	3,123	1,443	17,635	N/A	53.9	4.4
IV	5%P1+3%L	74,332	2,772	1,206	13,494	N/A	46.4	5.7
III	2%P1+3%L	155,395	3,108	1,345	24,097	N/A	65.0	4.3
VII	2%P2+3%L	148,670	3,466	1,704	22,407	N/A	60.7	4.7

TABLE 11 CONSTRUCTION RESULTS, MODIFIED HVEEM COMPACTION, TEXAS

Test Section Number	Mixture	Resilient Modulus, psi 77°F Before	77°F After	Retained Strength percent	Tensile Strength, psi 77°F Before	77°F After	Retained Strength percent	Air Voids percent
I	CONTROL	255,200	86,980	34.1	77.3	73.1	94.6	8.1
V	5%P-1	301,490	49,420	16.4	84.2	22.7	27.0	7.7
VI	5%P-2	305,420	59,850	19.6	95.8	32.0	33.4	7.6
II	3%LATEX	287,370	41,380	14.4	80.2	19.7	24.6	8.3
IV	5%P1+3%L	468,370	77,690	16.6	106.6	36.6	34.3	7.8
III	2%P1+3%L	360,360	55,620	15.4	87.9	25.5	29.0	8.5
VII	2%P2+3%L	318,680	69,500	21.8	104.7	33.1	31.6	6.5

TABLE 12 POSTCONSTRUCTION, LOTTMAN RESULTS, TEXAS

Test Section Number	Mixture	Resilient Modulus, psi 77°F Before	77°F After	Retained Strength percent	Tensile Strength, psi 77°F Before	77°F After	Retained Strength percent	Air Voids percent
I	CONTROL	271,820	120,990	44.5	114.1	88.8	77.8	4.7
V	5%P-1	276,040	74,960	27.2	90.7	33.5	36.9	4.6
VI	5%P-2	334,400	149,420	44.7	127.2	70.8	55.7	4.2
II	3%LATEX	298,450	59,010	19.8	110.4	33.3	30.2	4.9
IV	5%P1+3%L	310,360	104,500	33.7	111.2	48.7	43.8	4.6
III	2%P1+3%L	343,590	83,340	24.3	106.2	36.2	34.1	5.7
VII	2%P2+3%L	361,980	135,040	37.3	126.0	51.0	40.5	3.1

TABLE 13 CONSTRUCTION RESULTS, MODIFIED HVEEM COMPACTION, IDAHO

Test Section Number	Mixture	Resilient Modulus, psi 77°F Before Lottman	77°F After Lottman	Retained Strength percent	Tensile Strength, psi 77°F Before Lottman	77°F After Lottman	Retained Strength percent	Air Voids percent
I & IV	CONTROL	166,945	23,384	14.0	59.2	17.2	29.0	11.8
II	5%P-1	204,454	37,964	18.6	54.1	32.8	60.5	11.5
	5%P-2	---	---	---	---	---	---	---
III	3%LATEX	131,565	19,714	15.0	50.8	15.6	30.8	12.1
	5%P1+3%L	---	---	---	---	---	---	---
V	2%P1+3%L	180,764	37,906	21.0	67.1	39.6	59.0	11.0
	2%P2+3%L	---	---	---	---	---	---	---

Note: (---) indicates data not available.

TABLE 14 POSTCONSTRUCTION, LOTTMAN RESULTS, IDAHO

Test Section Number	Mixture	Resilient Modulus, psi 77°F Before Lottman	77°F After Lottman	Retained Strength percent	Tensile Strength, psi 77°F Before Lottman	77°F After Lottman	Retained Strength percent	Air Voids percent
I & IV	CONTROL	91,616	46,733	51.0	63.5	36.2	56.9	9.7
II	5%P-1	125,228	56,620	45.2	58.0	39.7	68.5	9.4
	5%P-2	---	---	---	---	---	---	---
III	3%LATEX	132,027	45,758	34.7	66.1	29.2	44.2	10.7
	5%P1+3%L	---	---	---	---	---	---	---
V	2%P1+3%L	165,334	---	---	---	---	---	8.2
	2%P2+3%L	---	---	---	---	---	---	---

Note: (---) indicates data not available.

CONCLUSIONS

Seven mixes, made from various combinations of two "functionalized" polyolefins and a styrene-butadiene rubber, were evaluated in five field test strips in various parts of the country. Effects on high- and low-temperature properties as well as moisture sensitivity and construction feasibility were examined.

The following conclusions can be drawn from this research project:

1. Construction of pavements using polyolefins and latex is certainly feasible. Necessary planning includes testing to determine compatibility of modifiers and asphalt cements, methods of introducing the modifiers into the mixers, and changes in compaction methods to eliminate sticking of the modified mixes to rubber-tired rollers.
2. Resistance to thermal cracking should not decline with addition of a combination of polyolefin and latex.
3. Moisture susceptibility of mixes with polyolefins may or may not be decreased depending on how much higher the absolute strengths of the modified mixes are compared with mixes without modifiers.
4. Properties of modified mixtures are asphalt source dependent, and mix designs should be performed each time a new modifier is used to test for compatibility with the asphalt cement.
5. There is no one best polyolefin or polyolefin-latex combination that will improve all properties for any one mix.
6. To gain the maximum benefit from the inclusion of modifiers, good construction practices, including close attention to air void content, are necessary.
7. Further follow-up testing during the next 5 years of the project will yield much more significant conclusions.

REFERENCES

1. K. A. Godfrey, Jr. Truck Weight Enforcement on a WIM. *Civil Engineering,* ASCE, Nov. 1986, pp. 60–63.
2. J. A. Epps and W. J. Kari. Factors To Be Considered in Developing Performance Based Specifications. *Proc.,* Association of Asphalt Paving Technologists, Vol. 52, 1983.
3. J. A. Epps, J. W. Button, and B. M. Galloway. *NCHRP Report 269: Paving with Asphalt Cements Produced in the 1980's.* TRB, National Research Council, Washington, D.C., Dec. 1983.
4. J. A. Epps. Asphalt Pavement Modifiers. *Civil Engineering,* ASCE, April 1986, pp. 56–60.
5. K. B. Krater, D. A. Wolfe, D. E. Newcomb, and J. A. Epps. *Modification of Asphalt Concrete Mixtures Using Plastics.* Research Report Draft. University of Nevada-Reno, Jan. 1988.
6. K. B. Krater, D. A. Wolfe, D. E. Newcomb, and J. A. Epps. *Concentration Effect of Plastics on Asphalt Concrete Mixtures.* Research Report Draft. University of Nevada-Reno, Jan 1988.
7. K. B. Krater, D. A. Wolfe, D. E. Newcomb, and J. A. Epps. Effect of Addition Order of Polyolefins on Asphalt Concrete. Research Report Draft. University of Nevada-Reno, Jan. 1988.
8. K. B. Krater, D. A. Wolfe, D. E. Newcomb, and J. A. Epps. *Effect of Compaction Temperature on Polyolefin Modified Asphalt Concrete.* Research Report Draft. University of Nevada-Reno, Jan. 1988.
9. K. B. Krater, D. A. Wolfe, D. E. Newcomb, and J. A. Epps. *Paver: Pavement Condition Index Field Manual.* American Public Works Association, Chicago, Ill., July 1984.
10. *Annual Book of Standards.* ASTM, Philadelphia, Pa., 1986, Section 4, Vol. 04.03.
11. R. P. Lottman. *NCHRP Report 246: Predicting Moisture-Induced Damage to Asphaltic Concrete.* TRB, National Research Council, Washington, D.C. 1982.

Publication of this paper sponsored by Committee on Characteristics of Bituminous Paving Mixtures To Meet Structural Requirements.