Assessing Effects of Commercial Modifiers on Montana Asphalts by Conventional Testing Methods

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A laboratory investigation was undertaken into the effects of commercial modifiers on the physical properties of Montana asphalts. The purpose of the study was to select modifiers to combat the severe rutting problems of the highways of Montana. There are four different sources of asphalt in Montana: Cenex, Conoco, Exxon, and Montana Refining. These refineries use different crude sources and different refining processes. The 120/150 penetration grade of asphalt from each of the four refineries was treated with six different commercial modifiers. The modifiers were polyethylene (PE), two types of thermoplastic block copolymer (SBS), carbon black (CB), ethylene vinyl acetate (EVA), and styrene-butadiene rubber latex. Some modifiers were more compatible with a particular source of asphalt than others. The tests were limited to the conventional physical tests. The results showed that the modifiers reduced temperature susceptibility of all four Montana asphalts, but to varying degrees. A subjective weighting system, based on a composite performance model, was used to evaluate the effect of the modifiers on the physical properties of the asphalts. The effect of the modifier on the asphalt depended on the source of asphalt. SBS, CB, EVA, and PE weighted well with different asphalts in the weighting system, indicating changes in the physical properties that are thought to be related to rutting. SBS and EVA were selected for further laboratory testing and an experimental overlay project on a Montana Interstate highway.

Rutting and cracking of asphaltic concrete pavements are problems facing the highway industry. Simply stated, some pavements are too hard and brittle in the cold winter months, and cracking results. If softer asphalts are used, cracking may be reduced, but hot summer temperatures bring rutting. The soft asphalt provides flexibility at the lower temperatures, and the additive increases the viscosity at higher temperatures to reduce the potential for permanent deformation (*1*). Although the rutting is a function of aggregate texture, gradation, and mix properties, such as air void content, modified binder can improve resistance to rutting.

Commercially available modifiers have entered the market with claims that their addition to asphalt mixtures will decrease temperature susceptibility. Past studies and manufacturing literature contain valuable information on selection and use of modifiers. However, because of the diversity of asphalt from one geographical region to another, such information can only give general guidance to the new user of modifiers. To provide a point of departure in the use of asphalt modifiers, the Montana Department of Transportation (MDT) contracted with Montana State University to perform some basic investigations into modifiers with Montana asphalts.

On the basis of the literature review (Armijo and Pradhan, unpublished data), six modifiers were selected for modification of four Montana asphalts. Conventional physical tests were carried out on modified and unmodified asphalts. The Marshall stability and flow tests were used to evaluate the strength of molded specimens. A weighting scheme, based on the composite performance model, was then applied in an attempt to rate the modifiers. Although performance-based Strategic Highway Research Program (SHRP) tests may prove to be better indicators of the effect of modifiers on asphalts, the conventional physical test methods are still important because they provide a first line of testing in the selection of the modifiers. The information should provide valuable insight into the effect of modifiers with Montana asphalts from various sources.

MATERIALS

Asphalt

Four refineries in Montana produce asphalt from different crude oils. They are Cenex (Laurel), Conoco (Billings), Exxon (Billings), and Montana Refining (Great Falls). The sources of crude oil are Canadian crude, Wyoming's Elk Basin, and Montana sources. These crude oils yield 8 to 30 percent asphalt. The asphalt composition is a function of crude sources and may vary from refinery to refinery. The processes of asphalt production and storage in the four refineries are different. Some refineries use a propane deasphalting process, whereas others are limited to vacuum distillation (*2*). The asphalts differ broadly in their molecular size distribution, even when those asphalts are representative of the same penetration or viscosity grade (*3*).

Asphalt samples of penetration grades 85/100 and 120/150, obtained from each of the four Montana refineries, were sent to the manufacturers of modifiers for modification. Montana asphalts presented some unique compatibility problems, and selecting the match polymer required more than the usual effort.

Modifiers

The literature review (Armijo and Pradhan, unpublished data) resulted in the selection of six modifiers:

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1. Polyethylene finely dispersed in asphalt (PE)—Novophalt;
2. Thermoplastic block copolymer rubber (SBS1)—Kraton D4463X;
3. Thermoplastic block copolymer rubber (SBS2)—Kraton D4141G;
4. Pelletized carbon black (CB)—Microfil 8;
5. Copolymers of ethylene vinylacetate (EVA)—Polybilt 2,7; and
6. Styrene-butadiene rubber, latex (SBR)—Ultrapave 70.

The amount of modifier for each Montana asphalt was selected on the basis of the manufacturer's recommendation and the compatibility of the modifier with the asphalt source.

Novophalt

Matrecon, Inc., California, prepared modified asphalt samples using 5 percent PE from Novophalt America, Inc., and 95 percent 120/150 grade asphalt. Preparation of Novophalt involves a high-shear blending process, which breaks down the PE into very fine particles that are blended into the asphalt at temperatures near 171°C.

Kraton

Kraton rubber-asphalt mixtures were prepared by Shell Development Company using 6 percent by weight neat Kraton D4141G and D4463X. Kraton thermoplastic rubber polymers are a unique class of rubbers designed for use without vulcanization. D4141G andD4463X are both block SBS (styrene-butadiene-styrene) copolymers. D4141G contains about 29 percent oil, and D4463X contains about 53 percent by weight of oil. D4463X is especially designed for very rapid dispersion in asphalt under low shear mixing conditions.

Microfil 8

Matrecon, Inc., California, prepared modified asphalt samples using 15 percent pelletized carbon black, Microfil 8, and 85 percent 120/150 grade asphalts. Microfil 8 is produced specifically for asphalt modification by Cabot Corporation. Microfil 8 is 92 percent carbon and 8 percent maltene oil (similar to the maltenes portion of asphalt) (*4*).

Polybilt

Polybilt is an ethylene vinylacetate resin and encompasses a large family of petrochemical polymers and polymer concentrates designed for asphalt modification by Exxon Chemical Company. Two polymers were used—Polymer 2 and Polymer 7; both are EVAs but differ in molecular weight. Four percent Polymer 2 was used for the 120/150 grade asphalts from Cenex, Exxon, and Montana Refining, and 3.5 percent Polymer 7 was used for Conoco. Conoco was more compatible with Polymer 7.

Ultrapave

Ultrapave 70 is an anionic styrene-butadiene latex that contains about 70 percent rubber solids and 30 percent water. The supplier, Textile Rubber and Chemical Company, prepared the modifier-asphalt mixtures using 3 percent Ultrapave 70. The rubber particles are extremely small and uniform in latex form; a very high surface area is thus exposed to the bitumen during mixing, resulting in a rapid physical dispersion of rubber.

Aggregate

Because many of the rutting problems in Montana are in the eastern areas and involve Yellowstone River (YR) gravel, a representative of YR gravel was chosen. The aggregate conforms to an MDT specification for plant mix Grade B and is basically a well-graded ¾-in. minus aggregate, as shown in Figure 1. The plant mix Grade B aggregate gradation is obtained by mixing 45 percent coarse crushed aggregate, 40 percent crushed fine aggregate, and 15 percent natural fine (sand). For the laboratory specimen, a small batch of this mix was made and fabricated into mold specimen sizes. Each batch was tested for conformity of the specification (*5*). The aggregate gradation is shown in Table 1.

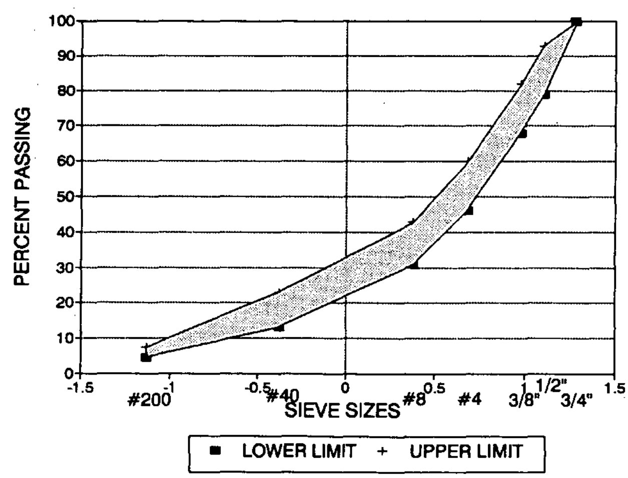

FIGURE 1 Plant mix Grade B aggregate gradation.

TABLE 1 Aggregate Gradation

Sieve Size	Percent Passing	
	Lower Limit	Upper Limit
3/4"	100	100
1/2"	79	93
3/8"	68	82
4M	46	60
8M	31	43
40M	13	23
200M	4.5	7.5

TESTS AND OBSERVATIONS

The study investigated modification of one penetration-grade asphalt, 120/150, from four Montana refineries. The investigation also included 85/100 grade unmodified asphalts for comparison purposes. The 120/150 grade was selected as the base asphalt with the assumption that this grade would provide low-temperature performance, whereas the modifier was selected to enhance the high-temperature characteristics (*1*).

The tests were divided into two basic groups: standard physical asphalt tests and molded specimen tests. The scope, principle, and procedure of the tests were strictly followed according to the AASHTO manual except for the adhesion test (*6*). The Montana method of test procedures was followed for the adhesion test (*7*).

Asphalt Tests

The following AASHTO tests were conducted on both grades of unmodified asphalt and modified 120/150 grade asphalt:

- T49-89—penetration of bituminous materials at 4°C and 25°C,
- T201-90—kinematic viscosity of asphalt at 135°C,
- T202-90—viscosity of asphalt by vacuum capillary viscometer,
- T51-89—ductility of bituminous material at 4°C and 25°C,
- T53-89—softening point of asphalt in ethylene glycol,
- T179-88—thin film oven tests, and
- MT309—adhesion of bituminous materials to aggregate.

The adhesion test is intended to evaluate the resistance of a bituminized mixture to its bituminous film removal by water. Approximately 150 g of aggregate and asphalt + ¼ in. in size is mixed at 120°C. The mixture is oven cured at 120°C for 1 hr, then stirred and left to cool at room temperature. The mixture is then immersed in a half-gallon can containing 1 quart of water at 15°C to 25°C for 24 hr. The mixture is shaken in a Red Devil paint shaker for 5 min, after which it is carefully washed to remove any loose bituminous material and placed in a doubled layer of paper toweling. A visual estimation of the portion of the remaining surfaces coated with bituminous material is made, and the results are expressed as percent adhesion.

Molded Specimen Tests

Testing and evaluation of molded asphalt-aggregate specimens (*6*) were done by the following tests:

- T245-90—resistance to plastic flow of bituminous mixtures,
- Use of Marshall apparatus (Marshall stability and flow),
- T166-88—bulk specific gravity of compacted bituminous mixtures,
- T209-90—maximum specific gravity of bituminous paving mixtures (Rice specific gravity),
- T269-80—percent air voids in compacted dense and open bituminous paving mixtures,
- T27-88—sieve analysis for fine and coarse aggregates.

The following AASHTO tests were repeated on the residues of T179-88 thin film oven tests (TFOTs): T49-89 penetration test, T201-90 kinematic viscosity, T202-90 viscosity, T51-89 ductility, and T53-89 softening point.

RESULTS

Tables 2 through 5 show the results of the conventional asphalt tests for unmodified and modified Cenex, Conoco, Exxon, and Montana Refinery asphalts. The modifiers behaved differently on each of the Montana asphalts. Some asphalts were more sensitive to a modifier than others and caused a greater degree of change in the test results.

The TFOT residues of both modified and unmodified asphalt represent approximate change in properties of asphalt during conventional hot mixing at about 150°C. The TFOT residue approximates the asphalt condition as incorporated in the pavement. For comparison of the effect of modifiers between the source of asphalts, the effect of modifiers on penetration at 4°C and 25°C, softening point, kinematic viscosity, viscosity at 60°C, and ductility at 4°C and 25°C, and the softening point of the TFOT residue are shown in Figures 2 through 8, respectively. The results of penetration grades 120/150 and 85/100 unmodified asphalts are also shown in the figures.

WEIGHTING SYSTEM

The composite performance model is used for the subjective weighting system to evaluate the effect of the modifiers on the physical properties of the asphalts. The modifiers reduced the temperature susceptibility of all four Montana asphalts, but to varying degrees. The effects of a modifier on the properties of asphalt as measured by various physical laboratory tests are different, depending on the source of the asphalt. The composite performance model is

$$W_{ij} = \sum_{k=1}^{n} T_k * P_{ij}$$

where

W_{ij} = composite weight of qualitative variable *asphalt* (i) modified with qualitative variable *modifier* (j),
T_k = subjective quantitative allocated weight (Table 6) for test k, and
P_{ij} = quantitative variable *performance rating* (A, B, C, D, E, or F).

TABLE 2 Results of Unmodified and Modified Cenex Asphalt

Test Description	Unmodified Cenex		Modified 120/150 Cenex					
			PE	SBS1	SBS2	CB	EVA	SBR
	120/150	85/100						
Asphalt:Modifier Ratio	100:0	100:0	95:5	94:6	94:6	85:15	96:4	97:3
Penetration at 25C (dmm)	137	89	69	121	79	99	91	105
Penetration at 4C (dmm)	42	24	29	63	37	37	39	45
Softening Point (C)	46	47	53	65	73	54	57	48
Kinematic Viscosity (CStoke)	236	318	816	922	1089	1605	388	452
Viscosity at 60C (Poise)	775	1426	2915	6241	9116	5798	1051	1719
Ductility at 25C (cms)	100	100	21	83	91	100	65	100
Ductility at 4C (cms)	100	15	8	100	92	64	12	100
Thin Film Oven Test (%)	-0.41	-0.37	-0.27	-0.50	-0.38	-0.49	-0.40	-0.32
Adhesion in (%)	80.0	65.0	75.0	20.0	90.0	95.0	75.0	85.0
RESULTS OF THIN FILM OVEN TEST RESIDUE								
Penetration at 25C (dmm)	85	54	57	89	64	68	59	71
Penetration at 4C (dmm)	31	20	24	41	35	28	29	37
Softening Point (C)	47	52	57	69	73	59	59	52
Kinematic Viscosity (CStoke)	309	426	1023	781	1254	4036	531	519
Viscosity at 60C (Poise)	1501	2851	4576	14892	16409	7360	5207	2458
Ductility at 25C (cms)	100	100	32	83	87	97	93	100
Ductility at 4C (cms)	12	NA	4	83	73	11	6	64
RESULTS OF MARSHALL TEST								
Optimum Asphalt Content (%)	5.8	6.9	5.7	5.6	5.7	6.0	5.6	6.0
Air Voids (%)	3.0	3.5	3.0	3.8	3.8	3.7	3.0	3.0
Unit Weight (gm/cc)	2.387	2.332	2.379	2.378	2.370	2.364	2.383	2.385
Unit Weight (pcf)	148.9	145.5	148.4	148.4	147.9	147.5	148.7	148.8
Marshall Stability (lbs)	2400	2480	2650	2550	3500	2890	2330	2370
Marshall Flow (1/100 in)	7.0	6.47	7.60	7.80	7.60	6.00	8.20	7.80

NA = Not Available

TABLE 3 Results of Unmodified and Modified Conoco Asphalt

Test Description	Unmodified Conoco		Modified 120/150 Conoco					
			PE	SBS1	SBS2	CB	EVA	SBR
	120/150	85/100						
Asphalt:Modifier Ratio	100:0	100:0	95:5	94:6	94:6	85:15	96.5:3.5	97:3
Penetration at 25C (dmm)	133	92	60	128	82	106	80	90
Penetration at 4C (dmm)	40	30	24	60	36	38	34	36
Softening Point (C)	45	49	57	75	82	58	71	54
Kinematic Viscosity (CStoke)	192	263	853	650	1159	2799	389	426
Viscosity at 60C (Poise)	550	1017	6435	3164	37463	3520	949	1390
Ductility at 25C (cms)	100	100	28	72	87	75	37	100
Ductility at 4C (cms)	100	14	6	100	94	24	9	100
Thin Film Oven Test (%)	-0.03	-0.05	-0.06	-0.19	-0.09	-0.15	-0.01	-0.06
Adhesion in (%)	90.0	55.0	85.0	50.0	85.0	90.0	65.0	85.0
RESULTS OF THIN FILM OVEN TEST RESIDUE								
Penetration at 25C (dmm)	94	68	47	98	67	69	62	69
Penetration at 4C (dmm)	31	19	30	43	39	30	26	25
Softening Point (C)	48	50	63	79	81	64	65	56
Kinematic Viscosity (CStoke)	237	312	980	663	1158	91760	460	488
Viscosity at 60C (Poise)	859	1680	4929	6292	19186	6812	1700	2262
Ductility at 25C (cms)	100	100	33	81	91	69	45	100
Ductility at 4C (cms)	15	6	4	85	70	6	6	100
RESULTS OF MARSHALL TEST								
Optimum Asphalt Content (%)	5.4	6.5	6.0	5.8	5.8	6.0	5.7	6.3
Air Voids (%)	3.6	3.1	2.6	2.0	3.0	3.5	3.2	3.6
Unit Weight (gm/cc)	2.388	2.361	2.384	2.382	2.373	2.380	2.376	2.342
Unit Weight (pcf)	149.0	147.3	148.8	148.6	148.1	148.5	148.3	146.1
Marshall Stability (lbs)	2060	2680	2330	2280	2418	2640	2640	1910
Marshall Flow (1/100 in)	4.2	6.8	8.0	7.0	7.5	5.4	6.8	5.0

TABLE 4 Results of Unmodified and Modified Exxon Asphalt

Test Description	Unmodified Exxon		Modified 120/150 Exxon					
	120/150	85/100	PE	SBS1	SBS2	CB	EVA	SBR
Asphalt:Modifier Ratio	100:0	100:0	95:5	94:6	94:6	85:15	96:4	97:3
Penetration at 25C (dmm)	134	89	72	119	73	99	84	108
Penetration at 4C (dmm)	44	27	27	66	43	43	41	49
Softening Point (C)	45	49	53	58	76	55	58	51
Kinematic Viscosity (CStoke)	261	321	945	639	1366	2460	421	509
Viscosity at 60C (Poise)	869	1916	3804	11070	9905	6236	1076	1947
Ductility at 25C (cms)	100	100	69	83	84	100	64	100
Ductility at 4C (cms)	100	13	5	100	62	42	10	100
Thin Film Oven Test (%)	0.03	0.05	0.01	-0.13	-0.03	-0.13	-0.04	0.01
Adhesion in (%)	90.0	75.0	75.0	80.0	85.0	85.0	75.0	90.0
RESULTS OF THIN FILM OVEN TEST RESIDUE								
Penetration at 25C (dmm)	87	64	70	103	68	78	64	76
Penetration at 4C (dmm)	33	24	27	49	40	38	29	30
Softening Point (C)	48	53	55	74	77	63	62	53
Kinematic Viscosity (CStoke)	325	423	1173	946	1242	9500	572	589
Viscosity at 60C (Poise)	1610	2920	6019	9075	115696	9706	1818	3995
Ductility at 25C (cms)	100	100	29	67	73	82	54	100
Ductility at 4C (cms)	12	6	5	67	82	9	6	86
RESULTS OF MARSHALL TEST								
Optimum Asphalt Content (%)	5.8	6.3	5.5	5.8	5.9	5.9	5.6	5.9
Air Voids (%)	2.3	3.4	3.5	2.5	2.7	3.2	3.0	4.8
Unit Weight (gm/cc)	2.388	2.349	2.375	2.363	2.368	2.385	2.375	2.343
Unit Weight (pcf)	149.0	146.6	148.2	147.5	147.8	148.8	148.2	146.2
Marshall Stability (lbs)	2090	2738	2320	2350	3060	2550	2750	1950
Marshall Flow (1/100 in)	9.5	6.2	5.0	7.2	7.6	7.5	5.5	5.8

TABLE 5 Results of Unmodified and Modified Montana Refining

Test Description	Unmodified Montana Refining		Modified Montana Refining					
	120/150	85/100	PE	SBS1	SBS2	CB	EVA	SBR
Asphalt:Modifier Ratio	100:0	100:0	95:5	94:6	94:6	85:15	96:4	97:3
Penetration at 25C (dmm)	129	87	59	115	75	89	93	111
Penetration at 4C (dmm)	32	29	27	63	42	35	36	48
Softening Point (C)	47	50	53	53	76	53	61	48
Kinematic Viscosity (CStoke)	270	358	1141	571	1365	1076	438	454
Viscosity at 60C (Poise)	827	1482	5065	26312	6684	5019	1124	1640
Ductility at 25C (cms)	100	100	24	94	86	98	53	100
Ductility at 4C (cms)	43	8	5	99	56	12	9	100
Thin Film Oven Test (%)	-0.18	-0.17	-0.13	-0.09	-0.17	-0.22	-0.15	-0.15
Adhesion in (%)	90.0	80.0	75.0	95.0	90.0	85.0	75.0	90.0
RESULTS OF THIN FILM OVEN TEST RESIDUE								
Penetration at 25C (dmm)	93	52	53	107	61	68	65	75
Penetration at 4C (dmm)	29	24	24	49	36	30	26	26
Softening Point (C)	50	53	58	68	75	59	60	51
Kinematic Viscosity (CStoke)	339	450	1173	780	1275	2225	500	491
Viscosity at 60C (Poise)	1465	2889	6653	5946	17647	8797	3522	2689
Ductility at 25C (cms)	100	100	36	85	82	83	53	100
Ductility at 4C (cms)	9	5	4	62	63	5	6	100
RESULTS OF MARSHALL TEST								
Optimum Asphalt Content (%)	5.5	5.9	5.4	5.5	5.7	5.9	5.5	6.3
Air Voids (%)	3.3	3.4	3.5	2.5	2.8	3.7	2.2	3.6
Unit Weight (gm/cc)	2.364	2.368	2.366	2.364	2.360	2.4	2.4	2.3
Unit Weight (pcf)	147.5	147.8	147.6	147.5	147.3	149.1	148.2	145.7
Marshall Stability (lbs)	2200	2984	2550	2340	2610	2790	2510	1430
Marshall Flow (1/100 in)	4.4	6.4	7.0	5.9	7.4	7.0	7.2	8.7

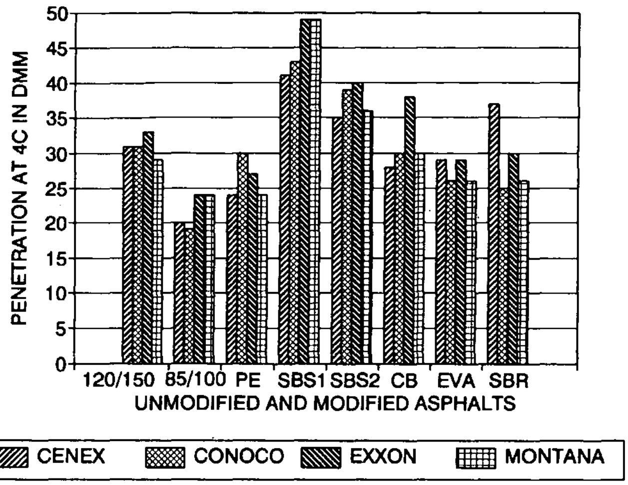

FIGURE 2 Penetration at 4°C of TFOT residues of unmodified and modified asphalts.

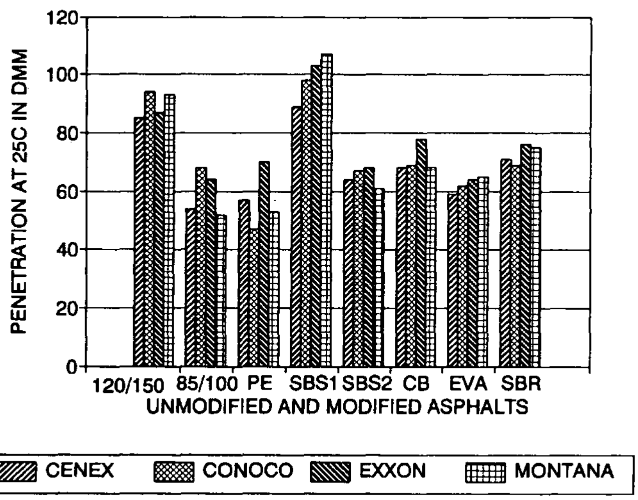

FIGURE 3 Penetration at 25°C of TFOT residues of unmodified and modified asphalts.

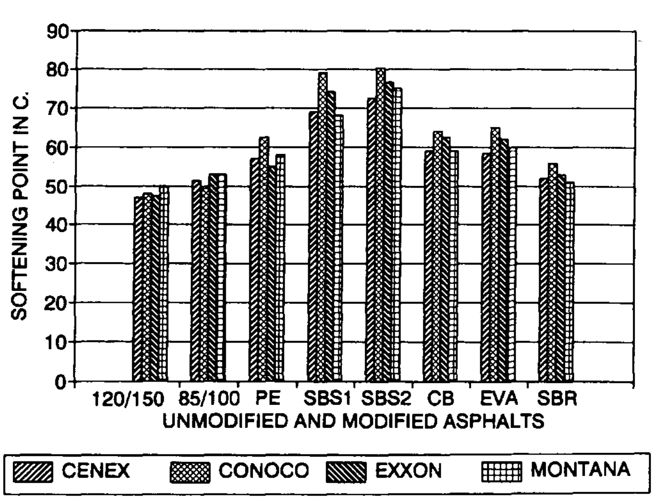

FIGURE 4 Softening point of TFOT residues of unmodified and modified asphalts.

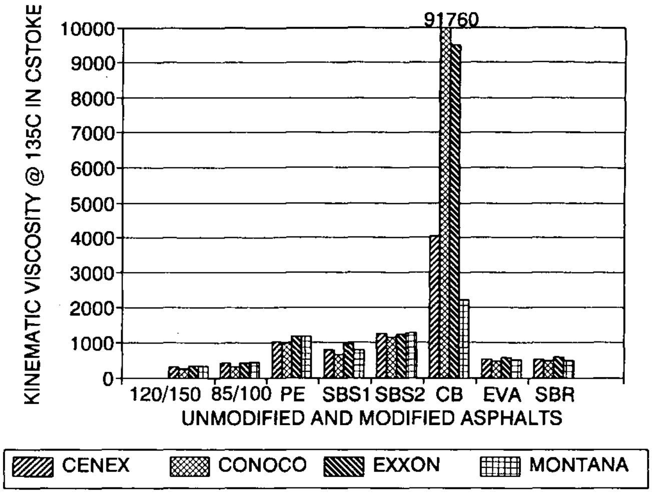

FIGURE 5 Kinematic viscosity of TFOT residues of unmodified and modified asphalts.

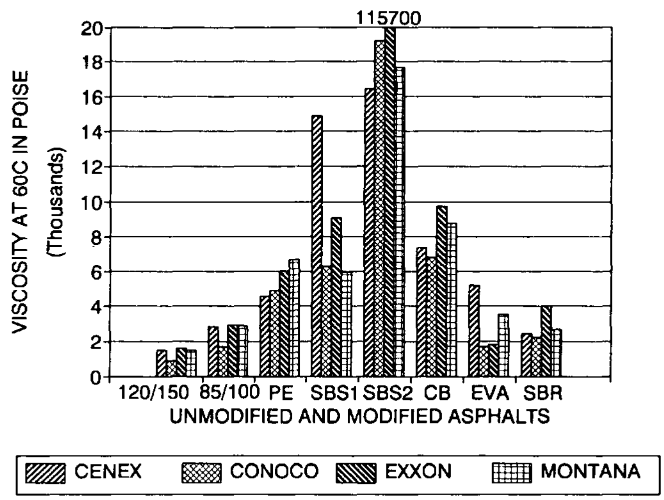

FIGURE 6 Viscosity at 60°C of TFOT residues of unmodified and modified asphalts.

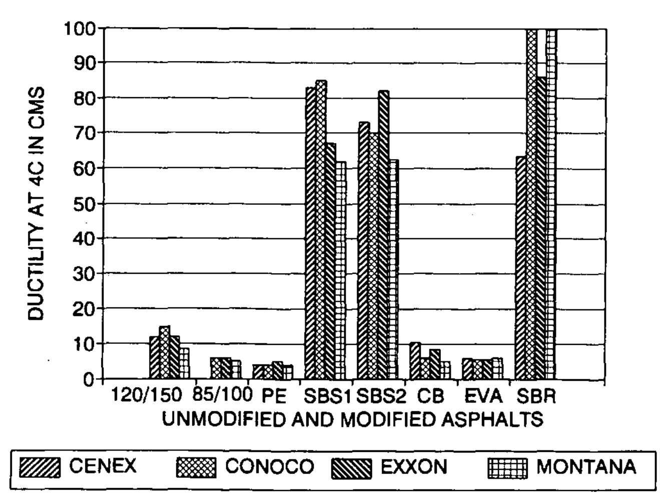

FIGURE 7 Ductility at 4°C of TFOT residues of unmodified and modified asphalts.

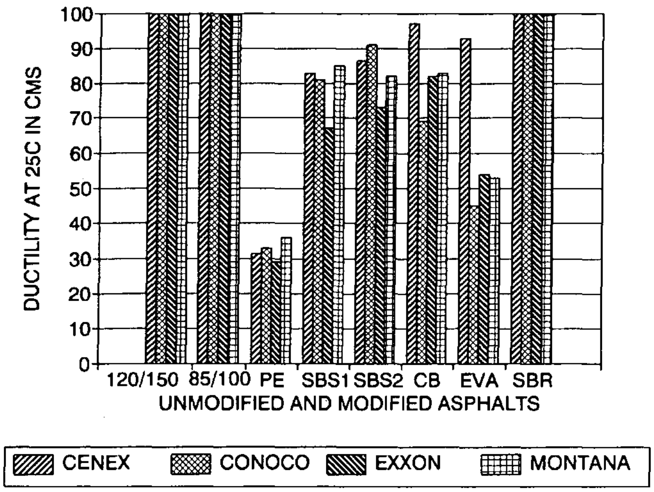

FIGURE 8 Ductility at 25°C of TFOT residues of unmodified and modified asphalts.

The meanings associated with *i*, *j*, and *k* are given in the following table.

Item	*Value*	*Meaning*
i	1	Cenex
i	2	Conoco
i	3	Exxon
i	4	Montana Refining
j	1	Novophalt
j	2	Kraton D4463X
j	3	Kraton D4141G
j	4	Microfil-8
j	5	Polybilt
j	6	Ultrapave
k	1	Penetration at 25°C
k	2	Penetration at 4°C
k	3	Softening point (°C)
k	4	Kinematic viscosity at 135°C
k	5	Viscosity at 60°C
k	6	Ductility at 25°C
k	7	Ductility at 4°C
k	8	Adhesion
k	9	Optimum asphalt content
k	10	Percent air voids
k	11	Marshall stability
k	12	Marshall flow

The reason for asphalt modification is to alter a soft asphalt in the higher temperature ranges while maintaining low-temperature properties. A comparison of the TFOT residue results of 85/100 penetration grade and modified 120/150 asphalts, in percentage difference with respect to unmodified 120/150 asphalt, was made for each of the four Montana asphalts. This resulted in the measurement of the changes in test values caused by modification with respect to the base asphalt. These changes are shown in Table 7 for modified Cenex asphalt. Similar changes in test values for modified Conoco, Exxon, and Montana Refinery asphalts were observed.

TABLE 6 Allocated Weight to Tests

Test Description	Weight
Penetration at 25C (dmm)	3
Penetration at 4C (dmm)	1
Softening Point (C)	3
Kinematic Viscosity (CStoke)	3
Viscosity at 60C (Poise)	3
Ductility at 25C (cms)	2
Ductility at 4C (cms)	2
Adhesion (%)	1
Optimum Asphalt Content (%)	1
Air Voids (%)	1
Marshall Stability (lbs)	3
Marshall Flow (1/100 in)	1

The modifiers altered the high temperature properties of asphalt by varying degrees. A letter grade was given to each of the modifiers. The modifier that most increased the values of physical parameter of the asphalt was given an A and the one that modified the values the least was given an F. The quantitative variable performance rating (A through F) was given a weight number. A modifier rated as A was given 4 points; B, 3 points; C, 2 points; and D, 1 point. E and F were considered to have made the least or no improvement and were given 0 points. The result of percent air voids of the Marshall specimen at optimum asphalt content larger than 3 percent was rated as A.

Some tests were considered to be more significant than others to describe the characteristics required for solving the problems, such as rutting, shoving, or cracking. A subjective weight was assigned to each test depending on the assumed significance of the test. Larger weights were allocated to the tests that altered the high-temperature characteristics (e.g., the penetration at 25°C, viscosity at both 135°C and 60°C, and softening point were allocated 3 points). Low-temperature characteristics cannot be ignored because the failure of pavement by low-temperature distress should be prevented while high temperature distresses are being addressed. The subjective quantitative weight allocated to each test for the purpose of analysis is shown in Table 6. The application of the weighting system, based on the composite performance model for the modified Cenex asphalt, is shown in Table 8. Each cell in the table represents the product of performance rating and weight allocated to the test. The total composite weight of a modifier is the summation of a respective column. Similar results of the weighting system were obtained for Conoco, Exxon, and Montana Refinery asphalts. The result of the weighting system is summarized as follows:

	Position Standing		
Asphalt	*1*	*2*	*3*
Cenex	Kraton D4141G	Microfil 8	Kraton D4463X
Conoco	Kraton D4141G	Microfil 8	Polybilt 7
Exxon	Kraton D4141G	Microfil 8	Polybilt 2
Montana	Kraton D4141G	Microfil 8	Novophalt

CONCLUSIONS AND RECOMMENDATIONS

The research provided important information in the selection of the modifiers for Montana asphalts. Effects of modifiers on Montana asphalts are source dependent. Some asphalts are more compatible with a particular modifier than others.

The composite performance model is an effective tool to ascertain the conclusive results of the effects of many tests. The subjective weight allocated to each test depends on engineering judgment. On the basis of the results of the subjective weighting system, Kraton D4141G and Microfil 8 im-

TABLE 7 Performance Rating of Modified Cenex Compared with Unmodified 120/150 Cenex

Test Description	Unmodified 85/100 Cenex	Modified 120/150 Cenex					
		PE	SBS1	SBS2	CB	EVA	SBR
Asphalt:Modifier Ratio	100:0	95:5	94:6	94:6	85:15	96:4	97:3
Performance Rating		A*	F*	C*	D*	B*	E*
Penetration at 25C (dmm)	-36.5	-32.9	4.7	-24.7	-20.0	-30.6	-16.5
Performance Rating		E*	F*	C*	B*	A*	D*
Penetration at 4C (dmm)	-35.5	-22.6	32.3	12.9	-9.7	-6.5	19.4
Performance Rating		E*	B*	A*	C*	D*	F*
Softening Point (C)	7.0	15.5	34.1	39.5	18.6	17.9	7.8
Performance Rating		C*	D*	B*	A*	E*	F*
Kinematic Viscosity (CStoke)	37.7	230.7	152.3	305.4	1205.0	71.7	67.6
Performance Rating		E*	B*	A*	C*	D*	F*
Viscosity at 60C (Poise)	89.9	204.8	891.9	993.0	390.2	246.8	63.8
Performance Rating		F*	E*	D*	B*	C*	A*
Ductility at 25C (cms)	0.0	-68.5	-17.0	-13.5	-3.0	-7.0	0.0
Performance Rating		F*	A*	B*	D*	E*	C*
Ductility at 4C (cms)	NA	-66.7	591.7	508.3	-12.5	-50.0	429.2
Performance Rating		E*	F*	B*	A*	D*	C*
Adhesion (%)	-18.8	-6.3	-75.0	12.5	18.8	-6.3	6.3
Performance Rating		B*	A*	B*	C*	A*	C*
Optimum Asphalt Content (%)	19.0	-1.7	-3.4	-1.7	3.4	-3.4	3.4
Performance Rating		A*	A*	A*	A*	A*	A*
Air Voids (%)	16.7	0.0	26.7	26.7	23.3	0.0	0.0
Performance Rating		C*	D*	A*	B*	F*	E*
Marshall Stability (lbs)	3.3	10.4	6.3	45.8	20.4	-2.9	-1.3
Performance Rating		B*	C*	B*	A*	D*	C*
Marshall Flow (1/100 in)	-7.6	8.6	11.4	8.6	-14.3	17.1	11.4

Negative % Difference = Decrease in value with respect to 120/150 Asphalt
Positive % difference = Increase in value with respect to 120/150 Asphalt
* Letter refers to performance rating - see discussion

TABLE 8 Result of Weighting System of Modified Cenex

Test Description	Weightage of Modified 120/150 Cenex					
	PE	SBS1	SBS2	CB	EVA	SBR
Penetration at 25C (dmm)	12	0	6	3	9	0
Penetration at 4C (dmm)	0	0	2	3	4	1
Softening Point (C)	0	9	12	6	3	0
Kinematic Viscosity (CStoke)	6	3	9	12	0	0
Viscosity at 60C (Poise)	0	9	12	6	3	0
Ductility at 25C (cms)	0	0	2	6	4	8
Ductility at 4C (cms)	0	8	6	2	0	4
Adhesion (%)	0	0	3	4	1	2
Optimum Asphalt Content(%)	3	4	3	2	4	2
Air Voids (%)	4	4	4	4	4	4
Marshall Stability (lbs)	6	3	12	9	0	0
Marshall Flow (1/100 in)	3	2	3	4	1	2
Total Weight	34	42	74	61	33	23

proved the physical properties related to the rutting problem of all Montana asphalts. Polybilt improved the physical properties of Conoco and Exxon asphalts, whereas Novophalt improved the Montana Refining asphalt. Therefore, the selection of the modifier should be based on the asphalt source.

Performance-based SHRP test methods may provide better understanding of the effect of modifiers on asphalts, whereas the conventional testing methods will still provide the basic guidelines for selecting the modifier for a particular source of asphalt.

Further studies, including performance-based tests, are being conducted with the Kraton and Polybilt modifiers on two of the Montana asphalts. In addition, an overlay test section on a Montana Interstate highway has been completed with Exxon asphalt modified by Kraton D4141G and Polybilt.

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