Predicting the Performance of Montana Test Sections by Physical and Chemical Testing

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Twenty test sections were constructed on a portion of Interstate 90 in south-central Montana. The objective was to compare the performance of asphalts from each of the state's four refineries in sections alone and with each of several additives including hydrated lime, fly ash, and an antistripping agent. Sections containing carbon black, ChemCrete, an 85-100 grade asphalt, and a blend designed by the high-performance gel permeation chromatography (HP-GPC) model to resist cracking were also constructed. Physical and chemical data available at the time of construction in 1983 are discussed in relation to the cracking and rutting performance evident after 4 years in service. The usefulness of these data for predicting performance is examined. In this data set, rutting is related to asphalt content, voids content, and possibly asphalt source. Cracking is related to asphalt source and, with one exception, to molecular size distribution from HP-GPC.

The Montana Department of Highways (MDOH) has frequently obtained quite different performances from materials that have met all existing specifications. Reasons for these differences in behavior have been difficult to pinpoint because of the variability inherent in field construction. In an effort to isolate factors that contribute to performance, MDOH constructed a series of test sections in which most factors were held constant and the key variables were asphalt source and type of additive.

Physical parameters normally obtained by the MDOH as well as some chemical parameters have been used to monitor the materials. Performance has been observed at regular intervals and clear-cut differences among the sections have now emerged. The rationale for the experimental sections is discussed in this paper, and details are given on the physical and chemical data available at the time of construction and their relation to performance 4 years later. The purpose of this approach is to find factors that might be used as predictive tools to the eventual end of reducing the chances of pavement failure.

EXPERIMENTAL DESIGN

Historically, virtually all of the paving asphalt used in Montana has been obtained from four refineries in the state. Three of these refineries are in the Billings area in south-central Montana; the fourth is in Great Falls in the north-central part of the state. No two of these refineries currently use the same crude blend, although parts of the crude slates of the Billings area refineries may overlap.

Two of the refineries use a propane deasphalting (PDA) process for all or part of their asphalt production. Asphalt may be made to grade from the PDA unit, or it may be blended to grade from a lower-penetration PDA product. The other manufacturers make asphalt to grade from the vacuum tower, although both may occasionally blend to achieve a desired grade.

Although the refining picture in the state is not as simple as might be hoped, and in spite of a few rather sharp changes that have occurred in either crude source or refining process, the products from each of the refineries were perceived to be remarkably stable before and during construction of the test sections. There was also a perception, based in part on asphalt analyses by high-performance gel permeation chromatography (HP-GPC) done in the laboratory (*1*, *2*) and in part on field observations, that there were differences in performance, especially with respect to cracking, of the products from the four refineries.

Therefore it was desired to check the validity of the HP-GPC studies and the more casual observations by constructing test pavements in which the four asphalts could be compared under conditions as nearly identical as possible in regard to design, construction, subgrade, climate, and traffic. The MDOH occasionally uses certain additives or fillers in its paving mixes. Their long-term effects on the performance of pavement would also be tested under similar field conditions. In addition, MDOH wished to observe the behavior of pavements containing the commercial materials ChemCrete (California) and Microfil 8 (carbon black, Cabot Corp.) as well as a harder grade of asphalt (85-100 pen) the use of which was being proposed as an aid in the prevention of rutting. Finally, a section was designated for an asphalt mixture that would be blended to match the HP-GPC model for crack-resistant performance in Montana.

Twenty test sections were selected for construction. The components of the sections are given in Table 1. A site on Interstate 90 in the south-central plains of Montana was chosen. At that location a 3.2-mi segment of four-lane pavement was scheduled for all new construction. The landscape of gently rolling hills presented no extremes of grade or alignment and no apparent drainage problems. The subgrade was prepared as uniformly as possible over the length of the site. This site was long enough to permit the construction of 20 test sections, each 1,250 ft long, separated by 500-ft transition zones. Ten sections were planned for the eastbound lanes and 10 for the westbound

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TABLE 1 COMPONENTS OF TEST SECTIONS

	Additive			
Refiner	None	Lime	Fly Ash	Antistripping Agent
C[a]	1	2	4	3
B[b]	15	16	14	17
A[c]	6	8	5	7
D[d]	10	9	12	11

NOTE: All are 120-150 grade AC.
[a]Blend.
[b]200-300 with Microfil 8.
[c]200-300 with Chemcrete.
[d]85-100.

lanes. Fortunately, traffic loads are similar in both directions. Construction was begun in 1982; all paving was accomplished in June and July 1983.

CONSTRUCTION

Much of this section is based on work by Bruce (*3*). High-quality aggregate was available near the site. The gradation and physical characteristics of the aggregate met MDOH specifications, and the entire supply was stockpiled to ensure uniformity throughout construction.

Base construction consisted of 1.35 ft of compacted crushed (1.5-in.) base course and 0.20 ft of crushed top surfacing. The plant mix paving was placed in two lifts totaling 0.40 ft. Mixing was done in a drum dryer type of plant at 275°F. Dry additives (hydrated lime, fly ash, Microfil 8) were fed directly into the drum dryer where the first contact was with asphalt cement. Liquid additives (antistripping agent, ChemCrete) were added to the asphalt cement by means of an in-line feeder located just before the entrance to the mixer.

Great care was exercised by the contractor to ensure that each section was paved uniformly with the desired mix. Compaction was accomplished with vibratory and static steel rollers. No surface treatment was used. It should be noted that no serious problems were encountered during paving. The sections have been marked by signing on the right-of-way fence as well as by marks painted on the pavement.

Each test section received an individual mix design (Marshall method) in an effort to achieve constant stability and voids content in the pavement throughout the sections.

PERFORMANCE TO DATE

Observations of the test sections are made at least once a year by a laboratory team and on other occasions by personnel from MDOH. Cores are obtained annually for both physical and chemical testing as well. Observations include a count of all transverse cracks in each section, notation of other types of cracking, measurement of rutting by means of a string-line in both passing and driving lanes at intervals of 300 ft in each section, and notation of flushing and other forms of surface distress. To date only transverse cracking, rutting, and flushing are evident. No stripping of cores has been apparent.

During the winter of 1983–1984, differences in the test sections became evident, notably in the severe transverse cracking of Sections 5, 6, 7, 14, and 15. During the following summer, some of these cracks "healed" under the influence of traffic and the summer sun. Nevertheless, these sections remain some of the more severely cracked of the set.

Performance data gathered in March 1987 are given in Table 2 for rutting and in Table 3 for transverse cracking. Notice that Test Section 19, which was constructed with ChemCrete, does not appear in these tables. This section began to experience rutting in the driving lane soon after it was opened to traffic. The rutting was not uniform and had reportedly reached depths of 0.75 in. at some places when an overlay was applied to the driving lane for reasons of safety. To date, only two or three short random cracks can be found. These unusual problems with ChemCrete probably stem from several sources: the use of asphalt that was too soft (200-300 pen); over-rolling, which may have sealed the surface to access of oxygen; inadequate curing time; or possibly an improper combination of asphalt type and carrier for ChemCrete.

TABLE 2 RUTTING MEASUREMENTS, MARCH 1987

Section No.	Components (asphalt/additive)	Rut Depth (in.)	
10	D	0.16	
12	D/fly ash	0.16	
2	C/lime	0.22	
16	B/lime	0.22	$\lesssim 0.25$
20	200-300/Microfil 8	0.24	
1	C	0.25	
18	85-100	0.25	
9	D/lime	0.27	
4	C/fly ash	0.33	
11	D/antistrip	0.33	
17	B/antistrip	0.34	$\lesssim 0.5$
3	C/antistrip	0.38	
8	A/lime	0.39	
13	Blend	0.43	
5	A/fly ash	0.52	
14	B/fly ash	0.52	
7	A/antistrip	0.56	> 0.5
15	B	0.56	
6	A	0.62	

RESULTS AND DISCUSSION

At the time of construction, the following types of data were available for correlation with performance.

- Penetration grade of asphalt;
- Additive type, if used;
- Marshall stability, field;
- Marshall flow, field;
- Penetration, 77°F, recovered;
- Viscosity, 275°F, recovered;
- Ductility, 40°F, recovered;
- Percentage of voids in finished pavement;
- Percentage asphalt in finished pavement;
- Penetration-viscosity numbers, original asphalts;
- Corbett analyses, original asphalts;
- Asphalt source; and
- HP-GPC analyses.

In this portion of the paper, these factors will be discussed in turn.

TABLE 3 CRACK COUNTS, MARCH 1987

Section No.	Components (asphalt/additive)	Total Cracks
2	C/lime	0
13	Blend	0
1	C	1
3	C/antistrip	1
12	D/fly ash	2
20	200-300/Microfil 8	8
9	D/lime	7
4	C/fly ash	7
5	A/fly ash	12
6	A	18
10	D	19
16	B/lime	19
11	D/antistrip	23
15	B	23
8	A/lime	28
7	A/antistrip	29
17	B/antistrip	33
14	B/fly ash	36
18	85-100	>52

Penetration Grade

Sixteen of the 20 sections were constructed with 120-150 penetration grade asphalt cement (AC). With regard to penetration, the data given in Tables 2 and 3 reveal no uniformity of performance among these sections. Sections that contain 120-150 AC and no additive rank among the most severely and least severely rutted and also display wide differences in the extent of transverse cracking. Section 18, which contains an 85-100 pen asphalt from Refiner B, is more severely cracked and less severely rutted than the comparable section paved with 120-150 pen asphalt from the same source, indicating that penetration grade may be useful in predicting the relative performance of two grades from the same refinery or crude source.

Types of Additives

Tables 4 and 5 give information about the effects of additives on cracking and rutting. Looking first at the transverse cracking results (Table 4), it is evident that the effects of additives are dependent on both the type of additive and the refiner or crude source. For example, asphalt from Refiner C is robust except in the presence of 1.9 percent fly ash. In contrast, asphalt from

TABLE 4 EFFECT OF ADDITIVES ON TRANSVERSE CRACKING

Refiner	Without Additive	With Lime	With Fly Ash	With Antistripping Agent
C	1	0	7	1
D	19	7	2	23
B	23	19	36	33
A	18	28	12	29

NOTE: Total number of transverse cracks per test section (full-width plus one-lane cracks).

Refiner D, which is a poor performer without additive and with antistripping agent (Acra), has significantly improved performance with lime and fly ash. Even though asphalts from Refiners A and B are generally poor performers, there clearly are additive effects that may either help or detract from their performance without additives. The important point here is that the cracking performance of a given asphalt may be significantly altered in a beneficial manner by the proper choice of additive. Unfortunately, the rutting results (Table 5) are not so readily related to additive type because of differences in asphalt content and percentage of voids.

Physical Parameters

Values for various physical parameters normally measured by MDOH are given in Table 6. To evaluate possible correlations between the physical parameters (percentage asphalt, Marshall stability, Marshall flow, percentage voids, penetration, viscosity or ductility) and either rutting or cracking, simple linear regression analyses were performed. Correlations (r^2) for cracking versus these parameters were all less than 0.2 (for example, voids: $r^2 = 0.06$; percentage AC: $r^2 = 0.12$). Results were stronger for the correlation of rutting with the various parameters (Table 7):

- Rutting versus percentage voids: $r^2 = 0.54$,
- Percentage asphalt: $r^2 = 0.51$, and
- Ductility at 40°F: $r^2 = 0.25$.

It is interesting that the correlation of voids with rutting associates higher voids content with less rutting. This might not be surprising if the voids contents were quite small. However, the in-place voids in these sections range from 5.8 to 10.8 percent.

It is important to note that these correlations are derived from the data in Table 6 that were obtained from cores taken

TABLE 5 EFFECT OF ADDITIVES ON RUTTING

Refiner	Without Additive	With Lime	With Fly Ash	With Antistripping Agent
C	0.25[a] (6.2;8.9)[b]	0.22 (6.5;9.5)	0.33 (6.0;8.7)	0.38 (6.9;9.3)
D	0.16 (6.6;9.0)	0.27 (6.7;7.6)	0.16 (6.9;7.8)	0.33 (7.1;8.9)
B	0.56 (6.8;6.4)	0.22 (6.5;10.8)	0.52 (7.5;7.7)	0.34 (7.0;6.8)
A	0.62 (7.6;6.1)	0.39 (7.2;8.5)	0.52 (7.2;6.2)	0.56 (8.0;5.8)

[a]Rut depth in wheelpath, inches.
[b](% asphalt; % voids).

TABLE 6 PHYSICAL TEST DATA (upper lift)

Test Section	Components (asphalt/ additive)	AC (%)		Additive (%)		Marshall Stability, Field	Marshall Flow, Field	Voids In-Place (%)	Penetration, 77°F (recovered)	Viscosity, 275°F (cSt)	Ductility, 40°F (cm)
		Design	In-Place	Design	Constructed						
1	C	6.6	6.2			1,637	8	8.9	60	437	9
2	C/lime	6.2	6.5	1.5	1.5	1,876	9	9.5	47	441	7
3	C/antistrip	6.6	6.9	1.0	1.0	1,952	8	9.3	50	440	7
4	C/fly ash	6.2	6.0	1.5	1.9	1,762	8	8.7	63	410	10
5	A/fly ash	6.3	7.2	1.5	1.8	1,801	8	6.2	77	344	26
6	A	6.8	7.6			1,419	8	6.1	69	368	17
7	A/antistrip	6.8	8.0	1.0	0.9	1,502	9	5.8	75	340	24
8	A/lime	6.6	7.2	1.5	1.6	1,967	9	8.5	54	421	8
9	D/lime	6.3	6.7	1.5	1.5	1,874	8	7.6	64	463	7
10	D	6.6	6.6			1,661	9	9.0	78	378	6
11	D/antistrip	6.5	7.1	1.0	0.9	1,432	9	8.9	54	409	6
12	D/fly ash	6.3	6.9	1.5	1.9	1,727	8	7.8	54	437	6
13	Blend	6.5	6.8			1,638	7	8.5	89	263	39
14	B/fly ash	6.2	7.5	1.5	1.8	1,763	8	7.7	62	318	10
15	B	6.8	6.8			1,814	9	6.4	59	361	7
16	B/lime	6.2	6.5	1.5	1.6	1,602	9	10.8	61	328	8
17	B/antistrip	6.8	7.0	1.0	0.9	1,551	9	6.8	84	249	28
18	85/100	6.5	6.4			1,777	8	8.9	52	396	7
20	200-300 Microfil 8	6.2	6.9	1.0	0.9	1,576	8	9.5	57	317	7

from the pavement immediately after construction. The Marshall stability and flow data are from on-site testing, not from in-place cores. An earlier report by Bruce (*3*) contained a similar set of data that, in contrast, were taken from on-site testing (Marshall stability, flow, voids) and plant operation (percentage AC). The percentages of asphalt and voids from the on-site testing trailer did not correlate with the rutting measurements (percentage voids: $r^2 = 0.31$, percentage AC: $r^2 = 0.25$).

Penetration-Viscosity

Table 8 gives the penetration-viscosity numbers (PVNs) of both the original asphalts and the asphalts recovered from postconstruction cores along with the number of cracks and depth of ruts in the corresponding sections with no additives. Original asphalts with PVNs from −0.64 to −0.72 have shown both poor and excellent crack and rut resistance. Asphalt B with a PVN of −0.93 is both severely cracked and rutted. Unfortunately no PVN is available for the original blended asphalt, but similar blends made more recently have shown PVNs of approximately −0.9.

TABLE 7 RUTTING MEASUREMENTS, ASPHALT AND VOIDS

Rut Depth[a] (in.)	Asphalt[b] (%)	Voids[b] (%)	Section[c]
0.16	6.6	9.0	10
0.16	6.9	7.8	12
0.22	6.5	9.5	2
0.22	6.5	10.8	16
0.24	6.2	9.8	20
0.25	6.2	8.9	1
0.25	6.4	8.9	18
0.27	6.7	7.6	9
0.33	6.0	8.7	4
0.33	7.1	8.9	11
0.34	7.0	6.8	17
0.38	6.9	9.3	3
0.39	7.2	8.5	8
0.43	6.8	8.5	13
0.52	7.2	6.2	5
0.52	7.5	7.7	14
0.56	8.0	5.8	7
0.56	6.8	6.4	15
0.62	7.6	6.1	6

[a]Measurements taken 3/87.
[b]From cores of initial pavement.
[c]See Table 2, 3, or 6 for identification of sections.

TABLE 8 RELATIONSHIP OF PVN AND PERFORMANCE

PVN				
Original	Recovered	Asphalt	Cracks[a]	Ruts[a]
−0.65	−0.5	D	19	0.16
−0.71	−0.65	C	1	0.25
−0.72	−0.74	A	18	0.62
−0.93	−1.06	B	23	0.56
—[b]	−0.99	B	0	0.43

[a]In sections with no additive.
[b]Not available.

If the PVN of recovered asphalts is considered, there is again no relational trend with cracking, but there is a trend toward increased rutting with increased temperature susceptibility. The apparent influence of asphalt content on rutting cannot be ignored, however. Thus, in this small data set, PVN is not a good predictor of cracking but shows some trends with regard to rutting.

Corbett Analyses

Corbett fractionations were conducted on the original asphalts. The fraction percentages are given in Table 9 in relation to the number of cracks and depth of ruts (inches) in the corresponding test section without additives. In this small sampling, higher resistance to cracking in C may be associated with relatively lower values for naphthene aromatics and higher values for asphaltenes and saturates. Likewise, better rutting resistance of C and D may be associated with relatively higher amounts of asphaltenes. As pointed out earlier, the percentage of asphalt has a fairly strong and perhaps overriding influence on rutting relationships.

TABLE 9 RELATION OF CORBETT FRACTION TO PERFORMANCES

	Original Asphalt				
	ASP (%)	PA (%)	NA (%)	SAT (%)	Asphalt
Cracks					
1	18	28	34	20	C
18	12	29	46	13	A
19	16	25	42	17	D
23	11	27	46	16	B
Rutting (in.)					
0.16	16	25	42	17	D
0.25	18	28	34	20	C
0.56	11	27	46	16	B
0.62	12	29	46	13	A

NOTE: ASP = asphaltenes, PA = polar aromatics, NA = naphthene aromatics, and SAT = saturates.

Asphalt Source

Another major variable to be considered in these experimental sections was asphalt source. In Figure 1, the depth of ruts in inches is plotted against the components of the test section. The sections containing 120-150 AC from each refiner are grouped together. These plots show the variability in rutting resistance associated with the additives. Beyond that, however, it may be generalized that relative resistance to rutting increases in the order A < B << C < D. (Note that C and D are also associated with higher asphaltene content, as mentioned previously, and that the relationships are complicated by the influence of asphalt content.)

Included in this plot are the sections containing the blend, the 85-100 grade AC, and the 200-300 pen section with Microfil 8. The blend, which was designed to resist cracking, is not particularly resistant to rutting. The 85-100 asphalt is showing good resistance to rutting. However, it is noteworthy that its performance in this regard is no better than that of some of the sections constructed with 120-150 asphalt or even with

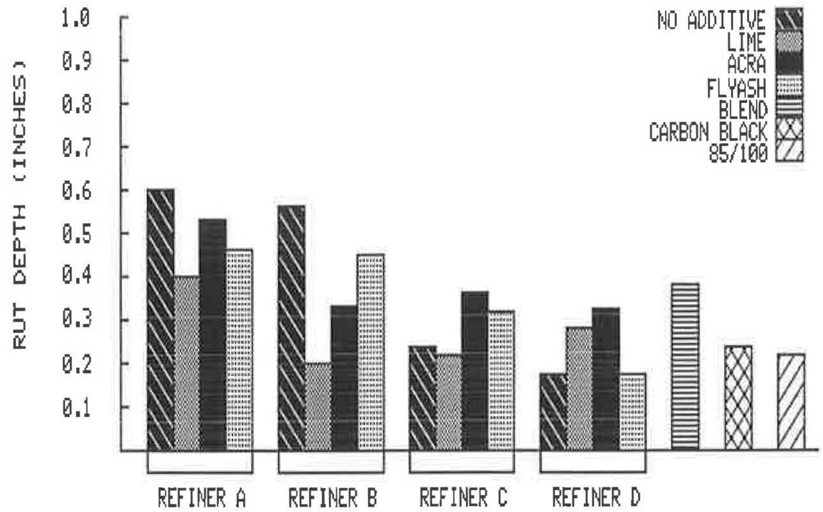

FIGURE 1 Rutting in test section pavements.

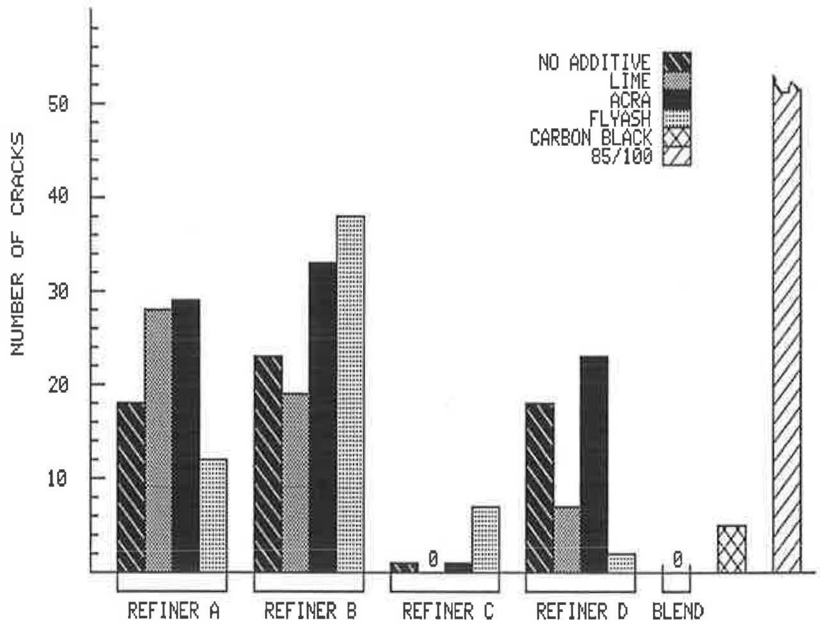

FIGURE 2 Cracking in test section pavements.

200-300 asphalt and Microfil 8. Moreover, its cracking performance is much worse than that of any of the other sections.

A similar plot of total number of transverse cracks versus components of the test section is shown in Figure 2. Again, the variability apparently introduced by additives is shown. In general, it may be seen that the resistance to cracking of the asphalts increases in the order B < A < D << C (C contains relatively lower concentrations of naphthene aromatics, as noted previously). The blend is resisting cracking, as expected, whereas severe cracking is evident in the 85-100 section. It should be noted that the source of the 85-100 and 200-300 grade asphalts is Refiner B and that the blend is composed of 75 percent B and 25 percent D, both of which are materials that tend to crack when used alone.

HP-GPC Analyses

Earlier work indicated that the ability of an asphalt to resist transverse cracking is related to its molecular size distribution as determined by HP-GPC (*1, 2*). More specifically, it has been shown that an excess of large molecular size (LMS) material above an optimum amount for a given climatic zone is associated with cracking. At the time of construction of the test sections, it was proposed that a virgin asphalt containing about 16 percent LMS would be likely to resist cracking in Montana. Indeed, the blend was designed to meet that criterion. In Figure 3, chromatograms of the virgin 120-150 asphalts and of the blend are compared. With the exception of Asphalt B, the theory that an excess of LMS material over the optimum amount is associated with cracking is supported.

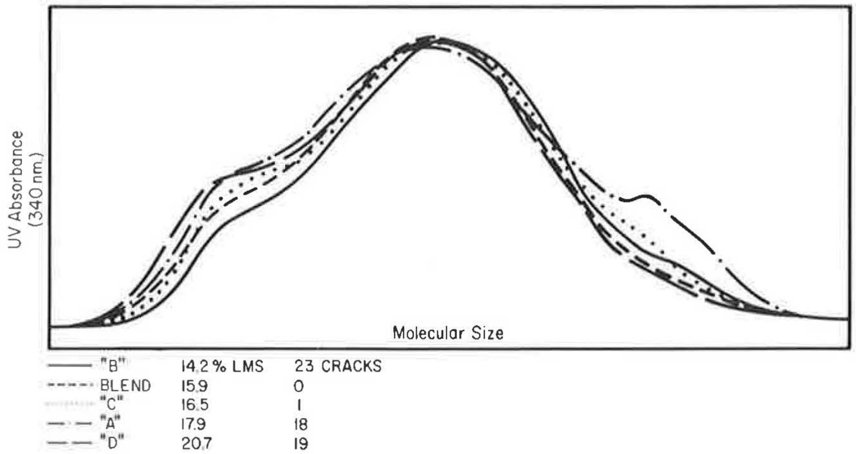

FIGURE 3 HP-GPC chromatograms for original asphalts.

Asphalt B is one of a small number of asphalts, found around the country by this research group, that are characterized by relatively high temperature susceptibility, relatively low asphaltene content, relatively low LMS content, and a tendency to crack severely quite early in their service lives. These particular asphalts are also products of propane deasphalting units. Thus interpretation of results with these asphalts should be guarded, especially regarding cracking.

Asphalt A, which shows a shoulder in the small molecular size (SMS) region of the chromatogram, can be seen from the traces to be rather similar to D in the LMS region. However, the LMS percentage is skewed to a lower relative amount by the presence of the SMS shoulder. This asphalt is also probably a product of propane deasphalting, and the shoulder apparently represents the blending stock. Its exact nature has not been determined. Both A and B are subject to early, severe cracking.

CONCLUSIONS

Use of the physical and chemical data available at the time of construction to predict performance after 4 years of service reveals that

1. Penetration grade may help to predict the relative performance of products from one refinery or crude source.
2. The effect of additives is both asphalt and additive dependent. The underlying chemical cause of this dependency is unknown. However, it may be extremely useful.
3. There is no apparent correlation of performance with Marshall stability, flow, penetration, and viscosity.
4. Although little correlation with ductility at 40°F is evident, asphalt content and voids content show good correlation with rutting. There is no correlation with cracking.
5. High PVN characterizes one of two asphalts that show early and severe cracking and one of three that have cracked to date, as well as one of two asphalts that have shown serious rutting tendencies.
6. Lower asphaltenes content from the Corbett separation characterizes the two asphalts that are rutting most severely. Resistance to cracking is associated with relatively lower concentrations of naphthene aromatics.
7. Within the 120-150 grade, both rutting and cracking differ with source. Performance is modified by additives.
8. Asphalts agreeing with the HP-GPC model have few if any cracks to date; those with more LMS than the model are demonstrating a tendency to crack and correlate well if Asphalt B, a known exception, is removed from consideration. Molecular size distributions vary with asphalt source.

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