Evaluation of Viscosity-Graded Asphalt Cements in Utah

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The methods commonly used to grade asphalts (penetration, viscosity, and ductility) were investigated to determine their effectiveness as indicators of performance. Although these parameters were found to be of value in establishing asphalt quality and in controlling mix and lay-down properties, new methods are needed to better predict asphalt performance. A new procedure called force ductility has been correlated to performance. This modification in the standard ductility test measures the force in the asphalt sample versus elongation and is based on the theory that an asphalt must be able to relax as strain from traffic loading and temperature shrinkage is applied to a pavement. Asphalts with lower forces performed best in the field. Other tests found to be indicative of performance were temperature susceptibility, shear susceptibility, ductility versus temperature, and chemical fractionation.

Asphalts exhibit complex flow properties, and different asphalts perform differently. Asphalts from different sources have different shear and temperature susceptibilities at temperatures below 60°C (140°F), which can and do affect performance. Low-temperature rheology and its relationship to performance are discussed extensively in a number of reports (1-8). The penetration test is run at 25°C (77°F) but fails to reflect consistency at other temperatures or at more than one rate of shear. It therefore cannot detect shear or temperature susceptibility. Fromm and Phang (4) reported that the amount of paraffin wax in the asphalt has a marked effect on the penetration test results. Research has shown that field performance, as evidenced by the amount of low-temperature cracking, is associated with certain asphalt sources (4, 6, 11).

Pavement test sections were investigated to determine the effectiveness of grading asphalts by viscosity. The state of Utah used modified research specifications in experimental sections that were constructed in 1968. This report is based on the evaluation of those experimental sections. Additional studies done on 108 pavements and 35 asphalts support the general relationships in this paper.

EVALUATION OF SURFACE DEFECTS

The results of the pavement rating effort are given in Table 1. Cracking was very extensive in sections 2 and 3, the Salt Lake City asphalt sections, and appeared to a much lesser degree in the Casper asphalt, sections 1 and 4. A chip seal was applied to the sections after the 57-month evaluation. The seal seemed to be more beneficial to section 1 than the others and reduced the cracking in that section.

The overall rating of the sections from best to poorest was as follows:

1. Section 1, Casper AC-6 (150 to 200 penetration);
2. Section 4, Casper AC-12 (85 to 100 penetration);
3. Section 3, Salt Lake City AC-12 (60 to 70 penetration); and
4. Section 2, Salt Lake City AC-6 (85 to 100 penetration).

Based on this ranking, one can conclude that the physical performance of the sections was affected more by the source of the crude oil than by the method by which it was graded.

FIELD AND LABORATORY RHEOLOGY

The difference in asphalt properties and the changes in these asphalt properties due to aging and temperature variations are of major concern in properly grading asphalts. Comparing the performance of the four sections with regard to these properties and changes in properties provides a better understanding of the causes of pavement distress and what constitutes good performance of an asphalt.

To supplement the field-aging analysis of the asphalt properties, samples taken from the storage tanks before mixing were subjected to the rolling thin film circulating (RTFC) oven, and laboratory tests were performed. Although application of the oven does not accurately simulate the field-aging of an asphalt, it is considered to be similar in effect to what happens during mixing in the pug mill.

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Percentage of loss in weight after 75 min in the RTFC oven was measured, and a much greater loss of volatiles occurred in the Salt Lake City asphalts than in the Casper source (Table 2). This loss of volatiles is most likely a cause of the more rapid hardening observed in the changes in asphalt properties (viscosity, ductility, and so on) for the Salt Lake City asphalts. To gain a better understanding of this hardening effect, samples of the four asphalts were aged in the RTFC oven for various times: 75, 100 and 125 min (plus 175 and 225 min for section 1 because of the slower aging observed). Tests were performed on these aged samples, and the results are given in Table 2.

A general reduction in penetration and cycling effect is evident in the plot of penetration versus time in service (Figure 1). Figure 1 shows asphalt hardening with time, and the cyclic trend is most likely due to seasonal changes, indicating an environmental effect on penetration; the relationship is similar to that shown in Figure 1.

Penetration values for the field and laboratory samples proved to be poor as performance indicators; the best performer, section 1, was highest in penetration, but the second and third performers, sections 4 and 3, were lower in penetration than the worst performing asphalt, section 2.

Absolute Viscosity at 60°C (140°F) and Kinematic Viscosity at 135°C (275°F)

Throughout the 4 years of testing an increase in both the absolute viscosity at 60°C (140°F) and the kinematic viscosity at 135°C (275°F) was observed in the field samples. The aging index (AI), which is the ratio of the viscosity after aging and the viscosity before aging, was used as an indication of aging rate. The aging index shows that the Salt Lake source increased at a faster rate than did the Casper source asphalts (Figure 3). Plots of the viscosity readings versus time in service for the two temperatures are very similar in shape, and the seasonal effect is present but more noticeable at 135°C (275°F) than at 60°C(140°F). There were general increases at 3, 12, and 24 months and decreases at 6 and 18 months.

Samples taken from the storage tanks show a higher average viscosity for the Salt Lake City asphalts than for the Casper asphalts for both AC-6 and AC-12 grades and at both of the test temperatures (Table 2). This again indicates a softer asphalt from the Casper source.

Ductility

The ductility readings at 4°C (39.2°F) remained reasonably constant, except for seasonal variation, throughout the testing in sections 2, 3, and 4. Section 1, however, the best performing section, demonstrated a definite increase during the first year of service and then abruptly dropped to nearly the same level as the other three sections (Figure 4). This is inconsistent with theory because ductility should generally decrease with time in service except for slight fluctuations due to seasonal effects. The raw data show a wide variation in test results in section 1 for the first year, which most likely caused the average of the tests to differ from theory. The general comparison of magnitudes, however, shows a correlation between ductility and cracking, and the second best performing asphalt, section 4, demonstrated the second highest ductility. The Salt Lake City asphalts in sections two and three were lowest in ductility.

A dramatic difference is noted between the Salt Lake City and Casper asphalts in the plot of ductility versus time in the thin film oven (Figure 5). The ductilities of the Salt Lake City asphalts in sections 2 and 3 were less than 10 initially, and they steadily decreased with time in the thin film oven. The Casper asphalts in sections 1 and 4 were measured in the 100+ range initially and decreased at a decreasing rate with hardening. This difference in the ductility change with aging for the two asphalt origins seems to be indicative of the excessive cracking in sections 2 and 3, the less ductile sections.

Force Ductility

A modification in the standard ductility test greatly improves the usefulness of this procedure. A linear variable displacement transducer (LVDT) was mounted in a proving ring and placed on the drive bar of the ductility apparatus (Figure 6). This setup, when linked to a strip chart recorder, measures the tension in the sample at any time as it is elongated. This force ductility test is based on the theory that an asphalt must be able to relax as strain from the traffic loading and temperature shrinkage is applied to the pavement, but it must possess enough tenacity to maintain a proper matrix.

Shortcomings of the standard ductility test have stimulated much criticism of its use. These problems are nonrepeatability, variance in the cross-sectional area of the sample, imprecise data such as 100+ rather than a definite number, and the breaking of samples at the shoulder rather than at the sample center. For the most part these problems are not critical in the force ductility test. Because the data points are measured in the first 10 or 15 cm (4 or 6 in) of the test, the differences in cross-sectional area from one sample to another are insignificant. For this reason the repeatability of the test is much better. Indefinite data such as 100+ are eliminated, and few shoulder breakages seem to occur, most likely because of the slight give in the proving ring.

The results of the force ductility test are shown in Figure 7 for the original, residue, and 66-month samples. The poorly performing Salt Lake City asphalts reach a high maximum tension when stretched and have a steeper recovery slope. The Casper asphalts reach a much lower maximum tension and have a smaller recovery slope. This relationship is consistent for both original and residue samples. The maximum readings for the residue are higher, however, and the hardening effect increases the force necessary to pull the sample. The Salt Lake City asphalts increased in maximum tension more with aging in the RTFC oven than did the Casper asphalts, indicating a more rapid hardening effect for the Salt Lake City asphalts. For the field samples extracted from the sections after 66 months, however, the asphalt in section 4 reached a maximum tension equal to that in section 2 but peaked at a greater elongation. Sections 1 and 3 remained lowest and highest in maximum tension and recovery slope respectively.

In general the force ductility test measures the consistency of the asphalts and changes in consistency with aging. Perhaps an optimum area between the very viscous and the very brittle exists in which optimum performance occurs in a given climate. Based on extensive study, the force ductility test seems to be an indicator of temperature-associated cracking.

Cannon Cone Viscosity at 25°C (77°F) and 0.05 s^{-1}

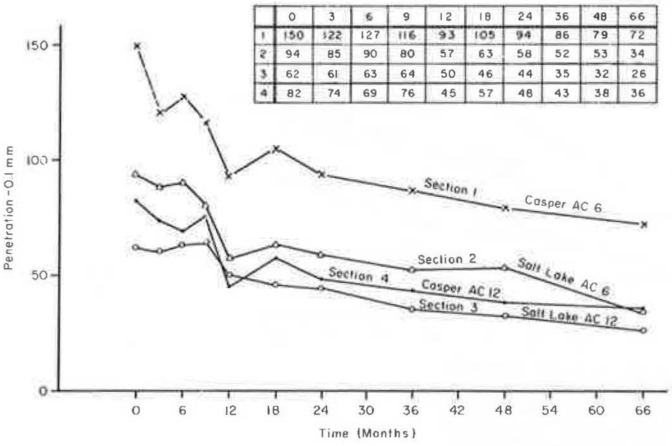
All sections demonstrate a definite seasonal variation in the Cannon cone viscosity test and an overall increase in viscosity with time in service for the field samples. The Salt Lake City asphalts were higher within each

Table 1. Performance data.

Sample	Section	Transverse Cracking (m/100 m)	Longitudinal Cracking (m/100 m)	Load Cracking (m^2/100 m)	Opening Rating	ABR-ERO Rating	Multiple Rating	Ruts (IWP)	Ruts (OWP)
57-month	1	17	31	0	3.0	4.0	4.0	0.81	0.33
	2	94	22	6.1	3.0	3.5	3.0	0.61	0.36
	3	60	0	0	2.0	3.0	4.5	0.69	0.56
	4	14	8	0	3.0	4.0	4.0	0.58	0.38
66-month	1	15	20	–	–	–	–	0.81	0.28
	2	133	82	–	–	–	–	0.66	0.38
	3	107	25	–	–	–	–	0.41	0.38
	4	26	12	–	–	–	–	0.53	0.36

Note: 1 m = 3.28 ft.

Figure 1. Penetration versus field aging.



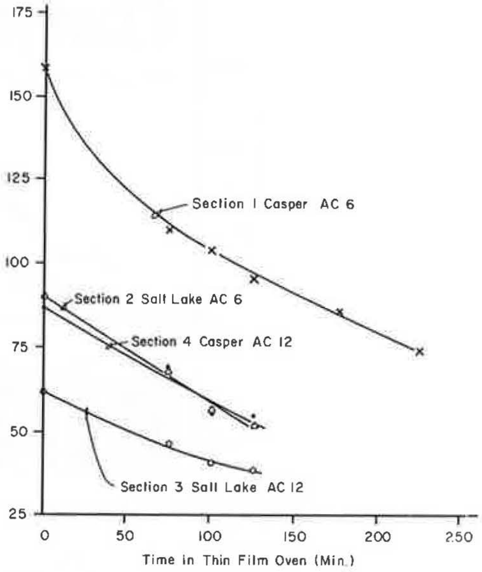
	0	3	6	9	12	18	24	36	48	66
1	150	122	127	116	93	105	94	86	79	72
2	94	85	90	80	57	63	58	52	53	34
3	62	61	63	64	50	46	44	35	32	26
4	82	74	69	76	45	57	48	43	38	36

Table 2. Test results of storage tank samples of asphalt cements.

Characteristic	Time in Oven (min)	Section 1	2	3	4
Penetration at 25°C, mm/0.1 mm	0	159	90	62	87
	75	111	63	46	68
	100	103	56	45	55
	125	96	52	38	54
	175	86	–	–	–
	225	74	–	–	–
Ductility at 4°C, cm	0	100+	9.25	7.0	100+
	75	100+	5.0	4.5	32.0
	100	64	4.0	3.0	9.5
	125	42	3.5	2.5	7.5
	175	20	–	–	–
	225	11	–	–	–
Ductility at 25°C, cm	0	150+	150+	150+	150+
Cannon cone viscosity at 25°C and 0.05 s^{-1}, kPa·s	0	29.9	115.0	345.0	101.2
	75	64.4	276.0	552.0	184.0
	100	73.6	345.0	667.0	253.0
	125	92.0	464.0	1012.0	322.0
	175	110.4	–	–	–
	225	184.0	–	–	–
Cannon cone viscosity at 16°C and 0.05 s^{-1}, kPa·s	0	299.0	1380.0	2162.0	920.0
Absolute viscosity at 60°C, Pa·s	0	66.0	72.0	134.8	137.5
	75	110.0	127.9	233.8	225.5
Kinematic viscosity at 99°C, cm^2/s	0	14.38	15.15	20.90	–
Kinematic viscosity at 135°C, cm^2/s	0	2.08	2.12	2.71	2.91
	75	2.58	2.60	3.27	3.44
Flash point, °C	0	450	500+	500+	500+
Percentage loss in oven	75	0.085	0.223	0.176	0.009
Specific gravity	0	1.024	1.013	1.018	1.029
Solubility (CCl_4)	0	99.89	99.86	99.88	99.95

Note: 1 mm = 0.039 in, 1 cm = 0.4 in, 1 Pa·s = 10 poises, 1 cm^2/s = 100 centistokes, and 1°C = (1°F - 32)/1.8.

Figure 2. Penetration versus thin film oven time.



grade, in both initial values of viscosity and rate of increase with time, indicating a faster hardening effect in the Salt Lake City sections (Figure 8).

Cannon cone viscosity versus time in the thin film oven is shown in Figure 9; no significant relationship with respect to aging index is observed. Cracking correlated better with the laboratory-aged than with field-aged samples; the best performing asphalts generally were lower in Cannon cone viscosity.

Cannon Cone Viscosity Versus Shear Rate

The standard Cannon cone test is performed at a shear rate of 0.05 s^{-1}. The literature revealed that, by varying this shear rate, a relationship with viscosity value is obtained that can be related to performance (12). The Cannon cone test was performed at shear rates of 0.01, 0.05, 0.10, 0.50, and 1.00 s^{-1} on original samples as well as samples aged 75, 100, and 125 min in the RTFC oven. Viscosity was plotted versus shear rate on a semilog grid, and straight-line relationships were obtained as shown in Figure 10 for the four asphalts at the various oven aging times. A least square curve fit was performed on the data, and a multiple R of more than 0.86 was generated for each curve. The slope of each line was calculated and used in the correlation matrix, which substantiated that steeper slopes on the plot generally correspond with poor performance.

The correlation between the slopes of the Cannon cone viscosity-shear rate relationships and the force ductility readings is highly significant. This points to the similar mechanism of the tests, the Cannon cone measuring shear stress and the force ductility measuring tensile stress.

Temperature Susceptibility

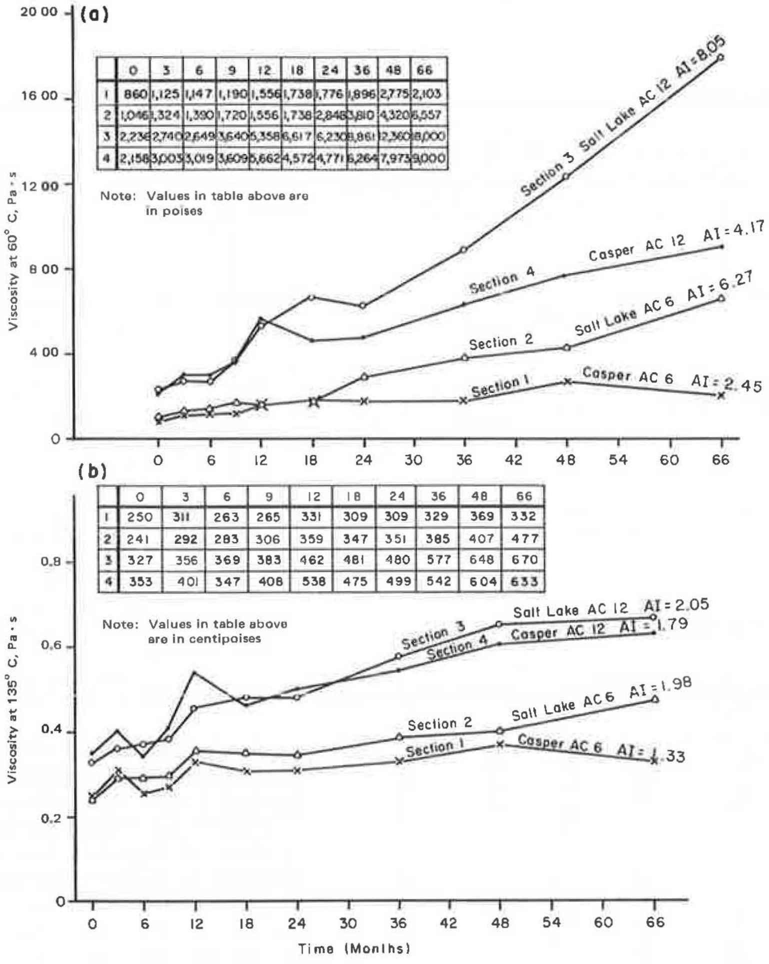
Temperature obviously has a substantial effect on the rheology of an asphalt. The extent of this effect is called temperature susceptibility (13) and is measured in this study by

$$\text{Temperature susceptibility} = \frac{\log \log \eta_2 - \log \log \eta_1}{\log T_2 - \log T_1}$$

where η_1 and η_2 (in square meters per second) are the viscosities at temperatures T_1 and T_2 (in absolute temperature).

Temperature susceptibility was calculated for the four

Figure 3. Viscosity at (a) 60°C (140°F) and (b) 135°C (275°F) versus time.



(a)

	0	3	6	9	12	18	24	36	48	66
1	860	1,125	1,147	1,190	1,556	1,738	1,776	1,896	2,775	2,103
2	1,046	1,324	1,390	1,720	1,556	1,738	2,846	3,810	4,320	6,557
3	2,236	2,740	2,649	3,640	5,358	6,617	6,230	8,861	12,360	18,000
4	2,158	3,003	3,019	3,609	5,662	4,572	4,771	6,264	7,973	9,000

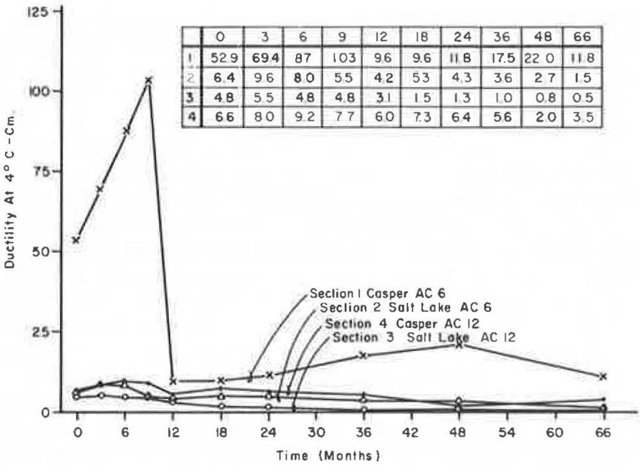
Note: Values in table above are in poises

(b)

	0	3	6	9	12	18	24	36	48	66
1	250	311	263	265	331	309	309	329	369	332
2	241	292	283	306	359	347	351	385	407	477
3	327	356	369	383	462	481	480	577	648	670
4	353	401	347	408	538	475	499	542	604	633

Note: Values in table above are in centipoises

Figure 4. Ductility at 4°C (39.2°F) versus field aging



	0	3	6	9	12	18	24	36	48	66
1	52.9	69.4	87	103	9.6	9.6	11.8	17.5	22.0	11.8
2	6.4	9.6	8.0	5.5	4.2	5.3	4.3	3.6	2.7	1.5
3	4.8	5.5	4.8	4.8	3.1	1.5	1.3	1.0	0.8	0.5
4	6.6	8.0	9.2	7.7	6.0	7.3	6.4	5.6	2.0	3.5

Figure 5. Ductility versus thin film oven time.

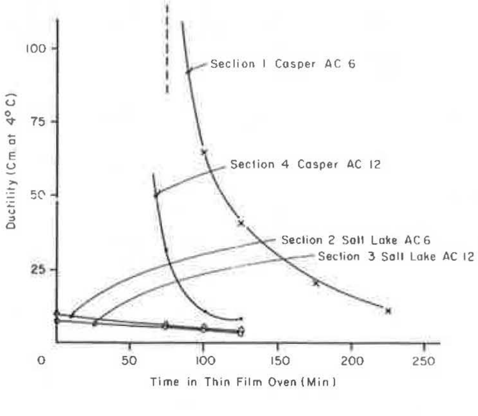


Figure 6. Force ductility apparatus.

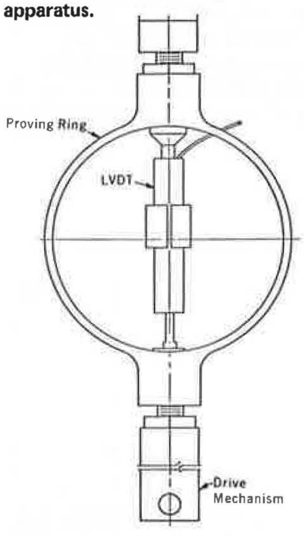
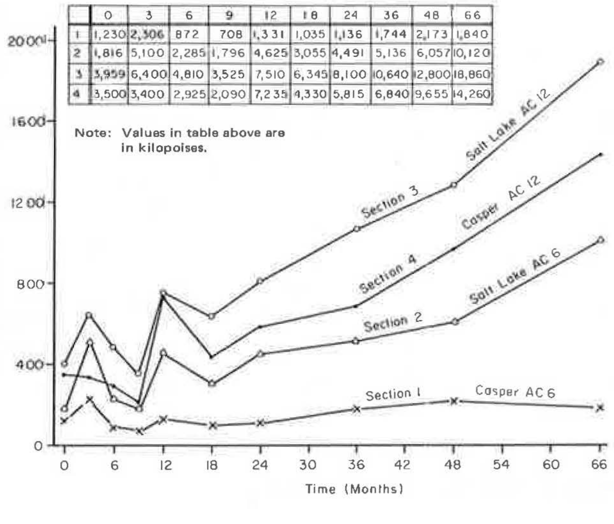


Figure 8. Cannon cone viscosity at 25°C (77°F) versus field aging.



	0	3	6	9	12	18	24	36	48	66
1	1,230	2,306	872	708	1,331	1,035	1,136	1,744	2,173	1,840
2	1,816	5,100	2,285	1,796	4,625	3,055	4,491	5,136	6,057	10,120
3	3,959	6,400	4,810	3,525	7,510	6,345	8,100	10,640	12,800	18,860
4	3,500	3,400	2,925	2,090	7,235	4,330	5,815	6,840	9,655	14,260

Note: Values in table above are in kilopoises.

Figure 9. Cannon cone versus thin film oven time.

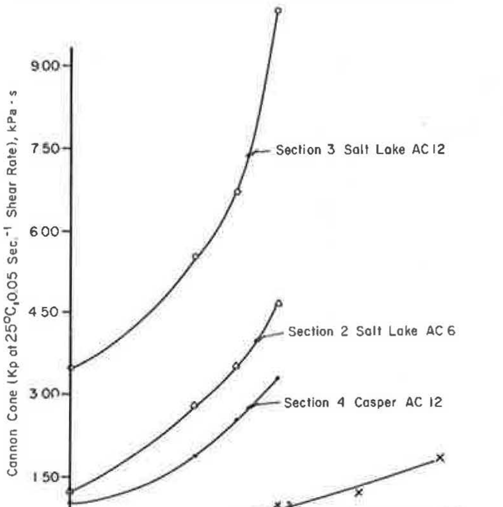
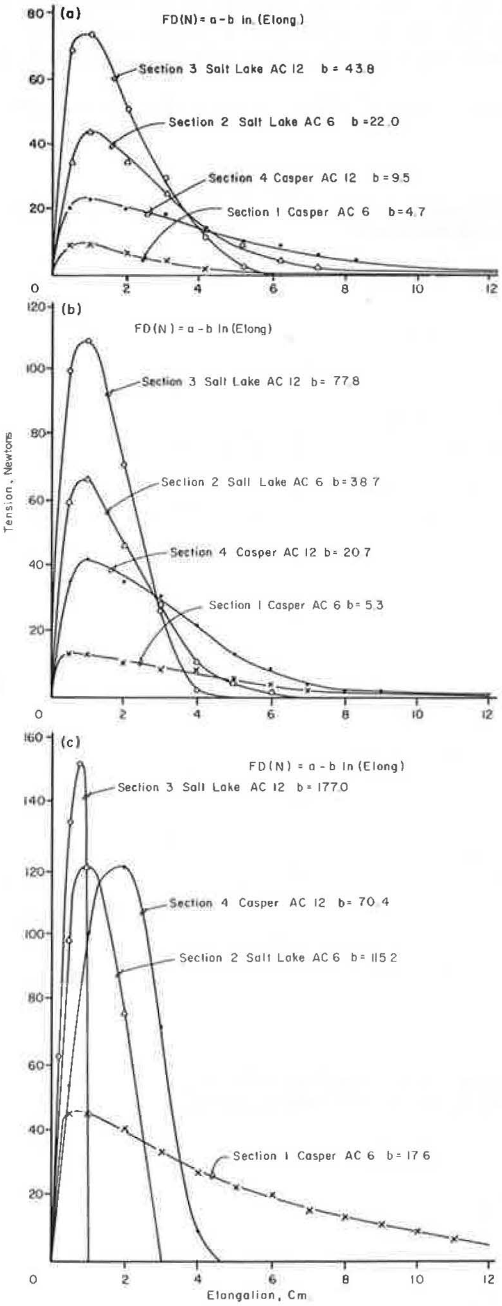


Figure 7. Force ductility of (a) original, (b) residue, and (c) 66-month samples.



asphalts for original, residue, and 66-month samples at 25 to 60°C (77 to 140°F), as well as 60 to 135°C (140 to 275°F). These values are shown in Figure 11.

Temperature susceptibility values for the original and residue samples are relatively the same for the four asphalts in the high temperature range. The temperature susceptibility of the original and residue samples in the low temperature range, closer to the actual pavement temperature range while in service, is greater for the Salt Lake City asphalts than for the Casper asphalts.

Temperature susceptibility values of the asphalts after 66 months in service show a somewhat different relationship from that of the original and residue samples.

A significant decrease is observed in temperature susceptibility; section 2 dropped to the same general range as the Casper asphalts, and section 3 decreased drastically to even a lower level than the Casper source. The AC-12 grades were higher in temperature susceptibility initially but decreased much more than the AC-6 grade to lower levels for the residue and 5½-year samples. Source is the more influential factor in this temperature range.

Temperature susceptibility values in the low temperature range correlate highly with the number of meters of transverse cracking present in each section. Sections 2 and 3, the more temperature-susceptible sections, had more cracking than the less temperature-susceptible sections, 1 and 4. Viscosity changes with temperature variation may be a major factor in predicting pavement performance.

Figure 10. Cannon cone viscosity versus shear rate of (a) original sample, (b) sample after 75 min in oven, (c) sample after 100 min in oven, and (d) sample after 125 min in oven.

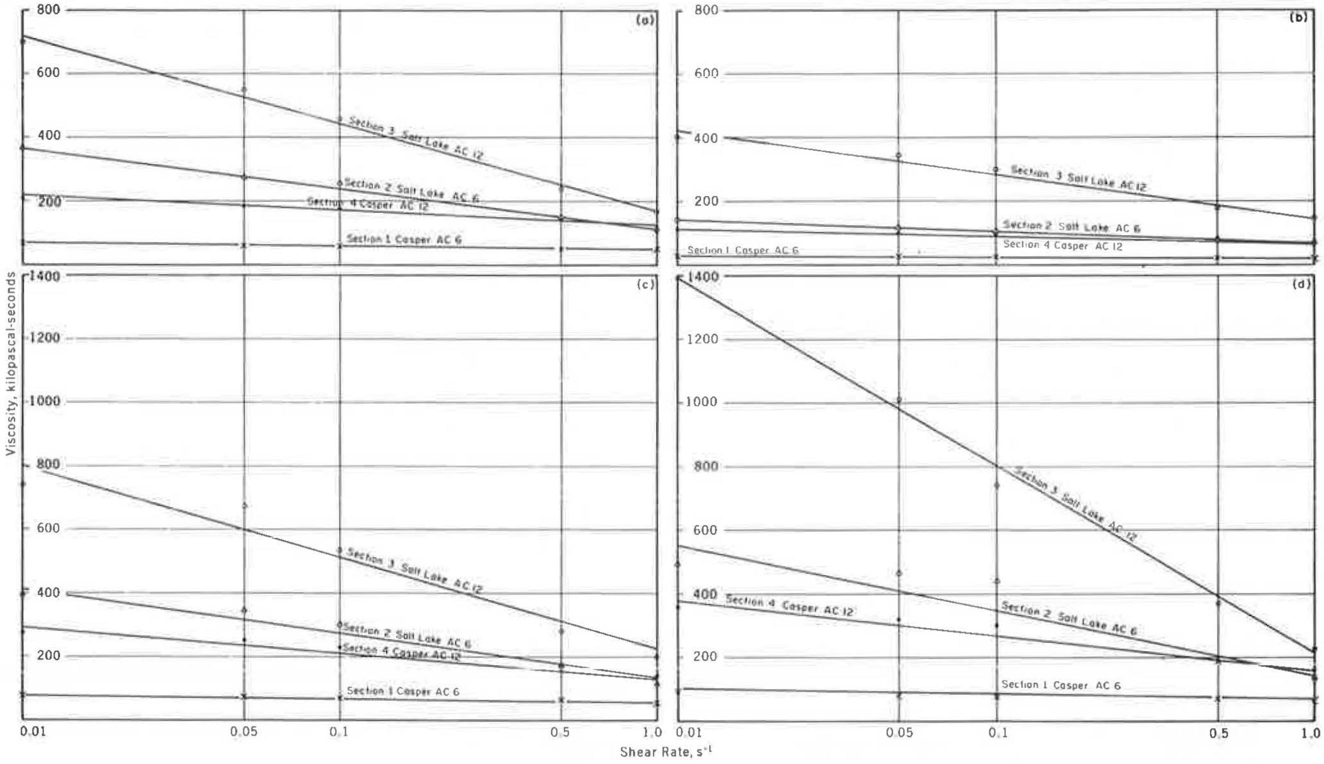


Figure 11. Temperature susceptibility at (a) 25 to 60°C (77 to 140°F) and (b) 60 to 135°C (140 to 275°F).

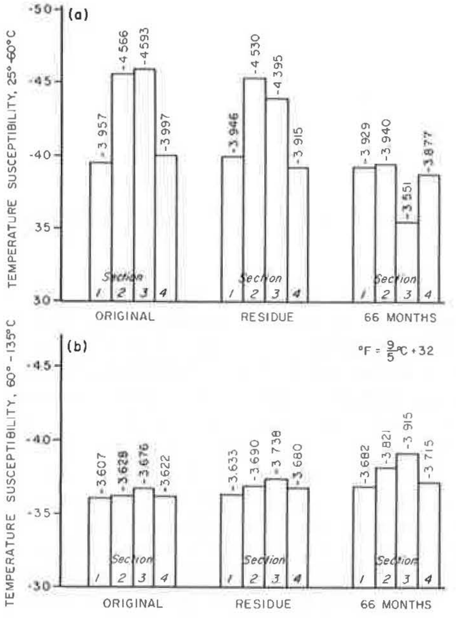
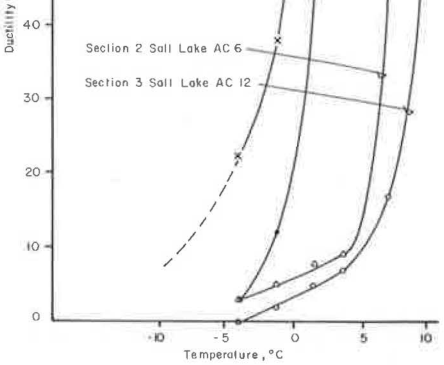


Figure 12. Ductility versus temperature.



TEMPERATURE	SECTION 1	2	3	4
-3.9	23.5	3.0	0	3.0
-1.1	38.0	5.0	2.0	12.0
1.7	100+	8.0	5.0	44.0
4.0	↓	9.3	7.0	100+
7.2		49.0	17.0	
10.0		100+	67.0	
12.8		↓	100+	↓

°F = 9/5°C + 32

To gain an indication of how temperature changes affect the ductility of the asphalts, ductility tests were run on storage tank samples at various water bath temperatures. This temperature-ductility analysis produced the curves shown in Figure 12. The Casper asphalts appear to remain ductile at a lower temperature than do the Salt Lake City asphalts. The AC-6 asphalts remained ductile at a lower temperature than the AC-12 asphalts within each source, but, as with temperature susceptibility, the source of the asphalts is a much more controlling factor.

CHEMICAL ANALYSIS

The asphalts were broken down chemically to determine why the origin of an asphalt has such an effect on its properties. In the analysis, the following five constituents were determined: asphaltenes (A), nitrogen bases (N), first acidaffins (A_1), second acidaffins (A_2), and paraffins (P). The percentages of each constituent for the original, residue, and 66-month field samples are shown in Figure 13. No effort was made to determine what portion of the changes was due to volatility and how much was due to chemical reactions.

The transverse cracking of the sections correlates with the paraffin content and inversely with the nitrogen base content. High correlations were found between

Figure 13. Asphalt composition of (a) original, (b) residue, and (c) 66-month samples.

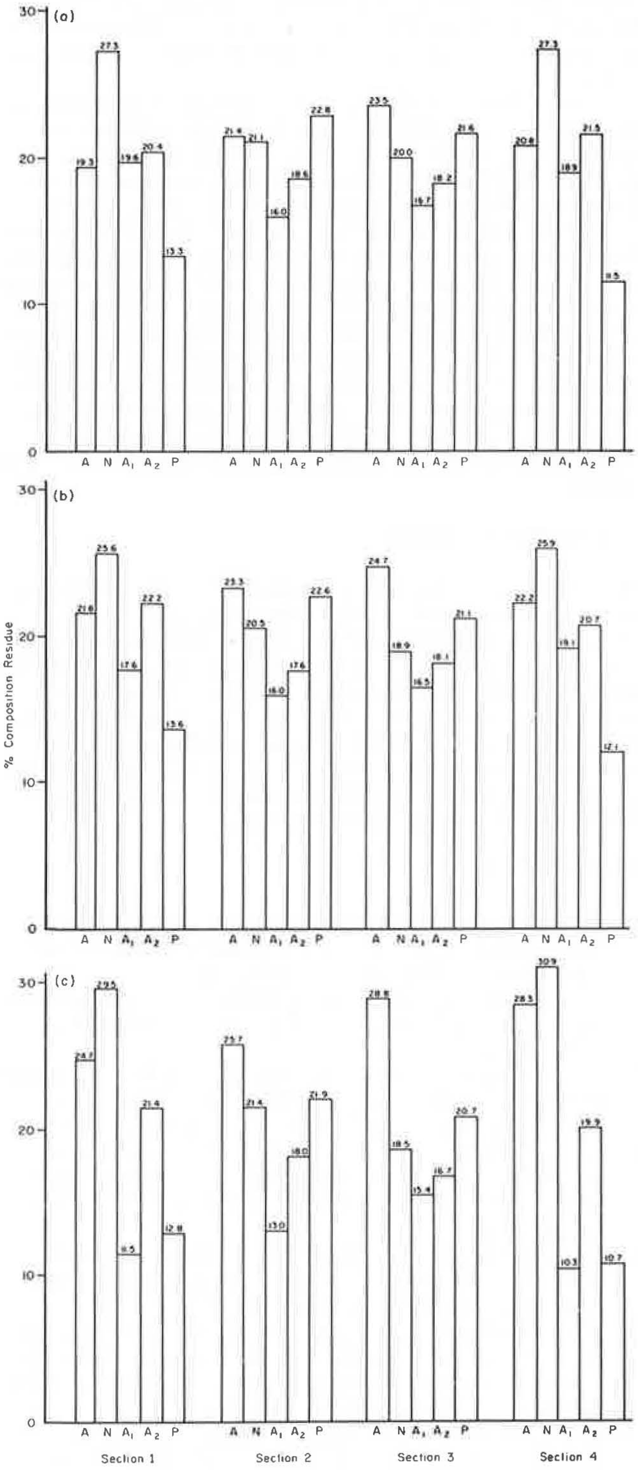


Table 3. t-test for comparison of group mean.

Item	D.F.	Student t Comparison of Sources	Student t Comparison of Viscosity Grading
Transverse cracking	2	-9.37[a]	1.48
Longitudinal cracking	2	-0.75	1.46
Rut depth	32	0.03	0.19
Profilograph	23	0.51	1.37
A			
Original, residue	16	-35.12[b]	-0.52
Original, field	16	-29.32[b]	-47.52[b]
Original, residue, field	24	-28.85[b]	-33.96[b]
N			
Original, residue	16	192.70[b]	18.84[b]
Original, field	16	293.85[b]	23.67[b]
Original, residue, field	24	238.48[b]	21.05[b]
A_1			
Original, residue	16	61.64[b]	-10.01[b]
Original, field	16	-4.12[b]	-6.47[b]
Original, residue, field	24	15.38[b]	-13.35[b]
A_2			
Original, residue	16	6.78[b]	1.65
Original, field	16	6.29[b]	1.02
Original, residue field	24	67.16[b]	10.84[b]
P			
Original, residue	16	-64.89[b]	18.54[b]
Original, field	16	-212.35[b]	35.24[b]
Original, residue, field	24	-172.71[b]	-24.36[b]
Penetration at 25°C			
Original, residue	2	13.08[c]	12.76[c]
Original, field	2	12.62[c]	12.80[c]
Original, residue, field	5	9.91[b]	9.53[b]
Viscosity at 60°C			
Original, residue	2	-1.85	-22.28[c]
Original, field	2	-8.57[a]	-12.50[c]
Original, residue, field	5	-4.37[c]	-6.96[b]
Viscosity at 135°C			
Original, residue	2	4.53[a]	-43.08[b]
Original, field	2	-1.61	-6.18[a]
Original, residue, field	5	-0.97	-5.06[c]
Cannon cone at 25°C			
0, 75, 100, 125 min	8	-12.55[b]	-9.34[b]
Original, field	2	-3.74	-5.57[a]
Original, residue, field	5	-2.09	-2.31
Slope			
0, 75, 100, 125 min	8	8.70[b]	5.87[b]
Original, field	2	9.92[c]	11.97[c]
Original, residue, field	5	5.49[c]	5.92[c]
Force ductility at 4°C			
Original, residue	2	-32.76[b]	-18.36[a]
Original, field	2	-2.98	-2.35
Original, residue, field	5	-3.78[a]	-2.70[a]
Temperature susceptibility at 25 to 60°C			
Original, residue	2	8.82[a]	-0.38
Original, field	2	0.70	-0.29
Original, residue, field	5	1.81	-0.50
Temperature susceptibility at 60 to 135°C			
Original, residue	2	4.86[a]	4.04
Original, field	2	2.60	1.09
Original, residue, field	5	4.07[c]	1.63

Note: 1°C = (1°F - 32)/1.8.

[a] At 5% significance. [b] At 0.1% significance. [c] At 1% significance.

transverse cracking and N/P. Holstead, Rostler, and White (14) found that the higher the value of $(N + A_1)/(A_2 + P)$ is, the more abrasion occurs in an asphalt concrete sample. The data here reveal that the higher $(N + A_1)/(A_2 + P)$ is, the less cracking present in the pavement. A definite relationship exists among compositional components, force ductility, temperature susceptibility, and transverse cracking of the pavements. It seems that the change in physical properties with changes in temperature, which is controlled by the chemical configuration of the asphalt, is critical in pavement cracking. This relationship may be one reason why the Salt Lake City source cracked more readily in Utah's severe high and low temperatures and many freeze-thaw cycles.

SOURCE VERSUS VISCOSITY

The data from sections 1 and 4 were grouped and analyzed against those from sections 2 and 3; then the sources were compared by using the Student t-test. Grouping sections 1 and 2 against sections 3 and 4 produced a viscosity comparison. The results of the t-test are given in Table 3 for selected performance variables, the compositional fractions, and the asphalt properties.

Based on the t-test, transverse cracking is significantly affected by the source of the asphalt and not by the viscosity grade. A significant difference between sources is observed for all of the compositional components; the same difference occurred in most cases when viscosity grades were compared. The fractions that appear to vary more with respect to source than viscosity grading are the nitrogen bases, second acidaffins, paraffins. This is also obvious upon inspection of Figure 13. These three components are correlated highly with respect to transverse cracking.

The test results from this study imply that the source of asphalt affects transverse cracking, temperature susceptibility, and compositional makeup more than viscosity grading does. This emphasizes the fact that viscosity grading cannot be relied on too heavily and further that new and better methods of grading asphalts are needed.

SUMMARY

It is widely accepted that new methods for grading asphalts are needed and would greatly improve highway performance, pavement design, and failure prediction. Penetration, viscosity, and ductility tests currently used to grade asphalts have been shown to be of value as indicators of asphalt quality but are limited in accuracy and repeatability.

The results of this study indicate that force ductility gives a good indication of pavement performance. The data obtained from the force ductility test are in a much more workable form than the standard ductility test. Results of the ductility test are somewhat vague and indefinite. Also, more accurate readings are obtained in the early stages of the force ductility test, where the cross-sectional areas are uniform for all samples. In theory the force ductility test is based on measuring the stress of a sample due to deformation. This stress in a pavement is caused by thermal expansion, traffic loading, or both.

The relationship between the Cannon cone viscosity and shear rate has been shown in recent publications to be of value in evaluating asphalts. This is generally true in this study; the better performing asphalts have a smaller slope on the viscosity-shear rate semilog plot. The slope of the viscosity-shear rate relationship increases with age, as expected.

Temperature susceptbibility appears to be a major factor in predicting pavement cracking in Utah. It is insufficient to determine an asphalt property at a single temperature and then to predict pavement cracking. By comparing trends in viscosity change with changes in temperature, a much more realistic view of pavement consistency at extreme temperatures is acquired.

Certainly chemical makeup of an asphalt, as suggested by Rostler and adopted here, is a useful tool in understanding the behavior of asphalt cements. Correlations exist among various chemical fractions, asphalt properties, and performance criteria.

Chemical makeup is related to the transverse cracking observed in the test sections. Higher paraffin content and lower nitrogen base and first acidaffin contents indicate more transverse cracking. Similarly, the higher the factors N/P and $(N + A_1)/(A_2 + P)$ are, the fewer are the number of transverse cracks that develop in the pavement.

In this study, penetration was not a good indicator of performance, but generally the higher penetration asphalts performed best. In Utah, chemical makeup, temperature susceptibility, and pavement cracking are influenced more by the source than by viscosity grading. A general comparison of the asphalts in this study shows that the softer the asphalt is, the better it will perform. The asphalts higher in penetration and ductility and lower in viscosity have less tendency to crack. Rutting, however, occurs if a pavement is too ductile, but, in the environment of the Green River test sections, rutting was not a problem for the grades and sources of asphalt used. Similar penetration and viscosity grades from other sources may perform differently in the same climate. Methods to better define these limits of performance are needed.

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