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Significant Studies on Asphalt Durability: Pennsylvania Experience

PRITHVI S. KANDHAL and WILLIAM C. KOEHLER

ABSTRACT

Because a widely accepted laboratory durability test for asphalt does not exist, many agencies including the Pennsylvania Department of Transportation (DOT) have resorted to controlled field experiments to evaluate and characterize those physical properties of the asphalt binder that are associated with aging and their relationship to pavement performance. Three asphalt durability projects undertaken by the Pennsylvania DOT are summarized in this paper: 1961-1962 test pavements, 1964 test pavements, and 1976 test pavements. The study was limited to the evaluation of dense-graded asphaltic concrete wearing courses in which a different asphalt source or type was used. Except for the 1961-1962 test pavements, the only significant variable was the asphalt type. Mix composition and construction techniques were held reasonably constant. After construction, periodical core samples were obtained from these pavements to determine the percentage of air voids and the rheological properties of the aged asphalts. It has been observed that aging of the pavements results in progressively lower penetration and higher viscosity, which exhibit a hyperbolic function with time. However, the accompanying decrease in low-temperature ductility after the penetration falls below 30, and the rate of gain in shear susceptibility relative to increase in viscosity at 77°F, have been found to be important factors that affect the pavement performance. Lower ductility values were associated with a higher incidence of load-associated longitudinal cracking. High stiffness modulus of the asphalt cement at low temperatures and a 20,000-sec loading time contributed to nonload-associated transverse cracking.

Durability of asphaltic concrete has been of considerable interest to the industry ever since asphalt paving became a common practice. A durable asphaltic pavement should be able to support traffic-induced stresses and strains as well as adverse effects of climatic conditions during its service life. Although the durability of asphaltic pavement is affected by other factors such as aggregate characteristics, mix design, and construction practices, most durability studies in the past have been confined to analyzing the properties of aging asphaltic binder as it is this main constituent that contributes to the cohesiveness and adhesiveness of the mixture and thereby affects pavement performance.

Because a widely accepted laboratory durability test for asphalt does not exist, many agencies [including the Pennsylvania Department of Transportation (DOT)] have resorted to controlled field experiments to evaluate and characterize those physical properties of the asphalt binder that are associated with aging and their relationship to pavement performance. Unlike many states that have limited sources of asphalt crudes, Pennsylvania, because of its geographical location, receives paving asphalts manufactured from a wide variety of crude sources such as mid-continent, South America, and the Middle East. Since the 1973 Arab oil embargo, blending of various crudes has also increased significantly. These factors have made the task of evaluating asphalt durability rather complex.

Although many asphalt durability projects have been undertaken by the Pennsylvania DOT since 1960, three projects have been studied in more detail. An attempt has been made to summarize these projects in this paper. More details such as mix composition, construction data, and periodical evaluation data can be obtained from the cited references.

1961-1962 TEST PAVEMENTS (1)

Two pavements were completed in October 1961 in Lycoming and Beaver counties, and two were constructed during June 1962 in Washington and Lebanon counties. These four test pavements were asphaltic concrete overlays, consisting of 2-in. binder and 1-in. wearing course, placed on 9-in. portland cement concrete pavements. This study was limited to the evaluation of dense-graded Pennsylvania type ID-2 bituminous wearing course surfaces, each containing a different type of asphalt. Slag aggregate was used in Beaver and Washington counties, whereas limestone aggregate was used in Lycoming and Lebanon counties. All mixtures were designed according to the Marshall method. Physical and chemical properties of the four asphalts used are given in Table 1.

TABLE 1 Asphalt Properties (1961-1962 pavements)

Property	Beaver 1	Lycoming 2	Washington 3	Lebanon 4
Penetration at 77°F, 100 g, 5 sec	96	69	76	76
Viscosity at 140°F, poises	2,570	4,024	3,163	3,000
Ductility at 60°F, 5 cm/min, cm	150+	150+	150+	150+
Ductility at 39.2°F, 5 cm/min, cm	12.5	8.0	5.9	7.8
Softening point, R & B, °F	118.0	122.0	123.2	126.4
Flash point, °F	510	505	580	585
Thin film oven test				
Percent loss by weight	0.135	0.368	0.040	0.060
Percent retained penetration	58.4	57.8	59.1	61.2
Rostler analysis				
Asphaltenes	26.3	26.4	19.3	22.2
Nitrogen bases	29.9	35.4	23.1	26.4
First acidaffins	14.0	9.5	5.9	8.4
Second acidaffins	22.7	20.2	38.4	31.2
Paraffins	7.1	8.5	13.3	11.8
Properties of asphalt after mixing in pugmill				
Penetration at 77°F, 100 g, 5 sec	60	47	67	56
Viscosity at 140°F, poises	7,273	15,158	3,800	5,100
Ductility at 60°F, 5 cm/min, cm	39	19	24	45
Ductility at 39.2°F, 5 cm/min, cm	5.3	4.2	4.7	5.4

The construction methods used on these four paving jobs were basically similar. The initial or breakdown roller was a 12-ton steel-wheel roller. This was followed by a pneumatic-tire roller with 90-psi contact pressure, and a steel-wheel finishing roller of 10-ton capacity. The average mix temperature was 295°F. The temperatures at the pavers varied from 260° to 290°F with an average temperature of 270°F.

The average daily traffic at the time of construction on these test pavements in Beaver, Lycoming, Washington, and Lebanon counties was 3,850, 6,600, 2,850, and 6,000 vehicles, respectively.

Since construction of the test pavements, periodical core samples were obtained to determine the percentage of air voids in the pavements and the rheological properties of the aged asphalts including ductility at 60°F at 5 cm/min. The pavements were studied for more than 10 years.

Pavement Air Voids

The decreasing trend of the air voids with time under traffic is shown in Figure 1. All pavements had relatively high air voids when constructed; however, after 10 years all pavements except the Washington county pavement attained air voids of 5 to 6.5 percent. The Washington pavement still had more than 10 percent air voids, which caused excessive asphalt hardening in this test pavement.

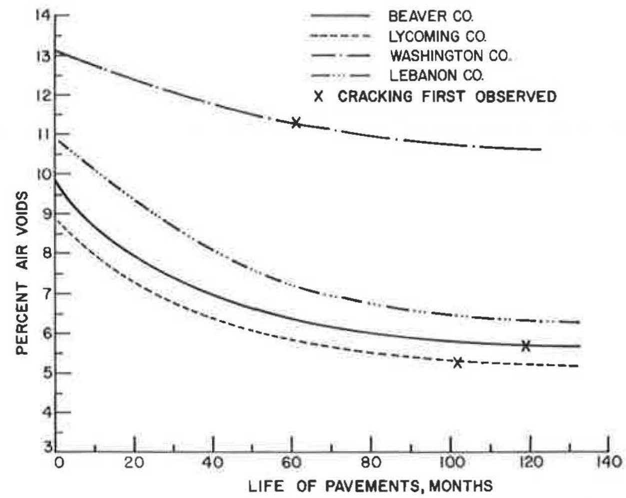

FIGURE 1 Percentage of air voids versus time in months, 1961-1962 pavements.

Penetration at 77°F

The decreasing trend of penetration with time is shown in Figure 2. Maximum drop in penetration occurred in Washington pavement due to higher air voids. The Beaver pavement had the highest penetration after 10 years.

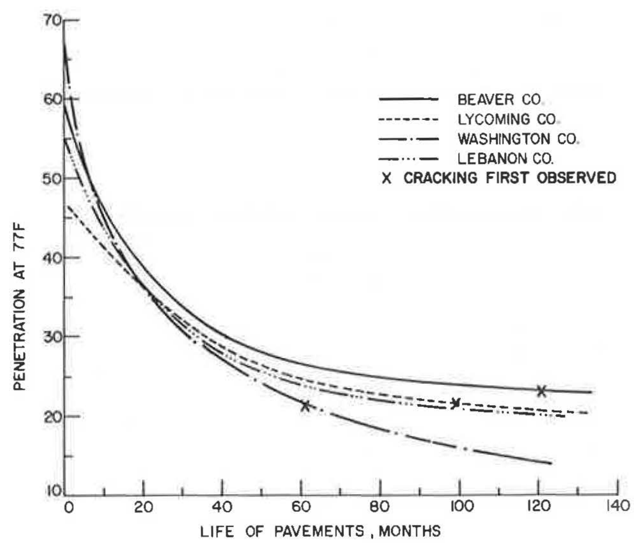

FIGURE 2 Penetration versus time in months, 1961-1962 pavements.

Viscosity at 140°F

Figure 3 shows the increase in viscosity at 140°F with time. The Washington pavement had the least viscosity at the time of construction, but after 10 years, it had the highest viscosity due to excessive air voids.

Ductility at 60°F

Ductility of the recovered asphalts was determined at 60°F at 5 cm/min. The decreasing trend of ductility with time in Beaver, Lycoming, Washington, and Lebanon pavements is shown in Figure 4.

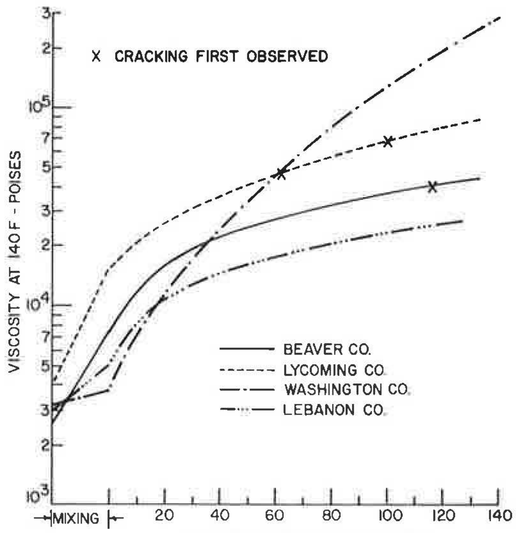

FIGURE 3 Viscosity at 140°F versus time in months, 1961-1962 pavements.

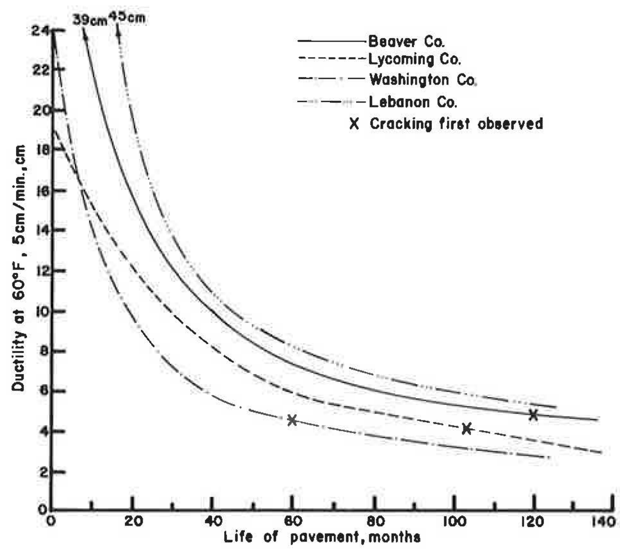

FIGURE 4 Ductility at 60°F versus time in months, 1961-1962 pavements.

Pavement Performance in Relation to Rheological Properties

When constructed in October 1961 and June 1962 and visually inspected during November 1963, all four test pavements appeared satisfactory. Pavement condition surveys have been conducted annually. Visual evaluation included riding quality, loss of fines, raveling, and cracking. After 10 years' service, the Lebanon pavement was rated the best followed by Beaver, Lycoming, and Washington pavements. The Washington pavement developed extensive cracking covering the entire riding surface after eight years in service. This pavement had to be resurfaced early. The ranking orders of pavement performance, percentage of air voids, penetration at 77°F, viscosity at 140°F, and ductility at 60°F, are given in Table 2. Pavements in Beaver, Lycoming, Washington, and Lebanon counties have been numbered 1, 2, 3, and 4, respectively.

It appears from the ranking orders that the asphalt ductility value obtained at 60°F is a good indicator of the pavement performance. Also, the viscosity at 140°F conforms to the pavement performance rankings; however, later studies have not always confirmed this relationship. It was noted that the pavement condition was satisfactory when ductility at 60°F was maintained above 10 cm. Load-associated cracking began to develop when the ductility value fell in the approximate range of 3 to 5 cm.

It was observed that the aging of the pavement results in progressively lower penetration and higher viscosity; however, an accompanying decrease in low temperature ductility is an important factor. After the penetration of asphalt drops below 30 due to hardening, the pavements containing asphalt with low ductilities are likely to show poorer service than pavements containing asphalts of the same penetration but with high ductilities. At lower temperatures, the ductility values are lower, more reproducible, and better-defined than ductility values are at higher temperatures such as 77°F.

TABLE 2 Ranking Orders (1961-1962 pavements)

Pavement Performance	Pavement Air Voids	Pentration at 77°F	Viscosity at 140°F	Ductility at 60°F, 5 cm/min
3 (poorest)	3 (highest)	3 (lowest)	3 (highest)	3 (lowest)
2	4	4	2	2
1	1	2	1	1
4 (best)	2 (lowest)	1 (highest)	4 (lowest)	4 (highest)

1964 TEST PAVEMENTS

Six test pavements, 3.67 miles long, are located in Clinton County on Legislative Route 219 (US-220) between Mill Hall and Beech Creek, Pennsylvania. The original pavement consisted of 8-in. reinforced concrete 18 to 20 ft wide. This pavement was resurfaced with 2 in. Pennsylvania type ID-2 binder and 1-in. wearing course during October 1964. This study was limited to the evaluation of six experimental sections of the dense-graded wearing course, each containing a different type asphalt. Average daily traffic on this road at the time of construction was 4,200 vehicles.

Properties of the six asphalts used in the project are given in Table 3. Excellent control was maintained throughout the entire project to ensure uniform construction of these six test pavements (2). In this closely controlled research project, the only significant variable was the asphalt type.

Since construction of these pavements, periodical core samples were obtained to determine the percentage of air voids in the pavements and rheological properties of the aged asphalt (3). The last core sampling was done in March 1974, 113 months after construction.

Test Data

Air voids data are shown in Figure 5. The recovered aged asphalt was tested for viscosity at 77°F (Figure 6) and 140°F (Figure 7). Shear susceptibility (or shear index) values were also determined for the six asphalt cements after increasing periods of aging. The value used in this study is the tangent of the angle of log shear rate versus log viscosity determined with the microviscometer. The relationship between shear susceptibility and viscosity at 77°F is shown in Figure 8. Aging indexes based on viscosity at 77°F (0.05 per sec shear rate) before and after aging, were also determined.

TABLE 3 Asphalt Properties (1964 pavements)

Property	Asphalt Type 1	2	3	4	5	6
A. Original asphalts						
Viscosity at 39.2°F at 0.05 per sec, poises	1.19×10^9	2.65×10^8	4.22×10^7	9.50×10^7	1.68×10^8	2.57×10^8
Viscosity at 77°F at 0.05 per sec, poises	3.05×10^6	1.06×10^6	4.83×10^5	9.15×10^5	1.32×10^6	1.85×10^6
Viscosity at 115°F at 0.05 per sec, poises	2.09×10^4	1.54×10^4	1.15×10^4	1.15×10^4	2.19×10^4	2.80×10^4
Viscosity at 140°F, poises	1,613	1,544	1,447	966	2,220	2,649
Viscosity at 275°F, centistokes	340	343	475	318	509	557
Penetration at 39.2°F, 200 g, 5 sec	9	11	28	19	15	12
Penetration at 77°F, 100 g, 5 sec	62	92	149	114	94	80
Ductility at 39.2°F, 1 cm/min, cm	14.0	53.3	101.0	23.5	68.3	21.9
B. After pugmill mixing						
Penetration at 77°F, 100 g, 5 sec	36	69	98	66	69	60
Viscosity at 140°F, poises	3,645	2,505	2,971	2,078	3,463	4,770
Viscosity at 77°F, 0.05 per sec, poises	1.01×10^7	2.01×10^6	1.21×10^6	3.02×10^6	2.77×10^6	3.52×10^6
Ductility at 39.2°F, 1 cm/min, cm	4.1	11.9	42.2	7.5	24.3	7.3

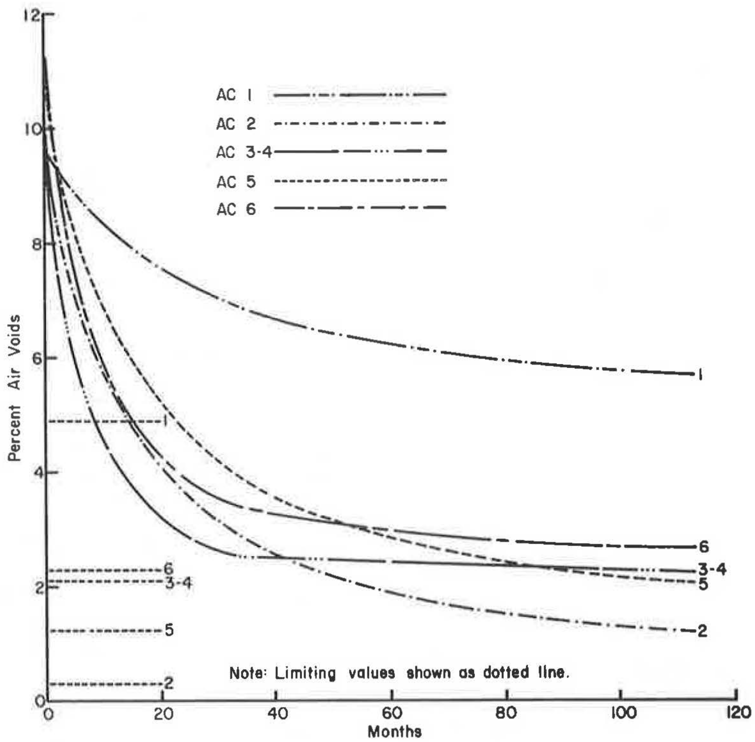

FIGURE 5 Percentage of air voids versus time in months, 1964 pavements.

Pavement Performance

No differences in texture or color tones were observed between the asphalts when the pavements were visually inspected just after construction and after one year of service. Visual evaluation during April 1967 (after 30 months of service) indicated that the entire road surface was good with the exception of the Asphalt 1 section, which showed some raveling. Although initial air voids in the six pavements when constructed were within the permissible range of Marshall design and control criteria, Asphalt 1 offered maximum resistance to compaction under traffic as will be discussed later.

The rating method suggested by Olson et al. (4) was used as a guideline to accomplish the visual pavement condition survey for evaluating the effects of asphalt aging. Visual evaluation included riding quality, raveling, spalling, loss of matrix, rutting, cracking (transverse, longitudinal, and alligator except reflection cracking), and surface texture. A team of five engineers evaluated these sections during 1971 (after 80 months of service) (2,5,6). The last performance evaluation was conducted in 1974 (after 113 months of service) by eight evaluators (3). The pavement performance ratings are given in Table 4 in ranking order. An ideal pavement according to this performance evaluation would rate 72.

Conclusions

The following conclusions were drawn from this study (3):

1. Changes in percentage of air voids and asphalt properties, such as viscosity and shear susceptibility, were found to follow the hyperbolic model suggested by Brown et al. (7) and Lee (8). If the changing asphalt properties are determined during the early life of the pavement (2 or 3 years),

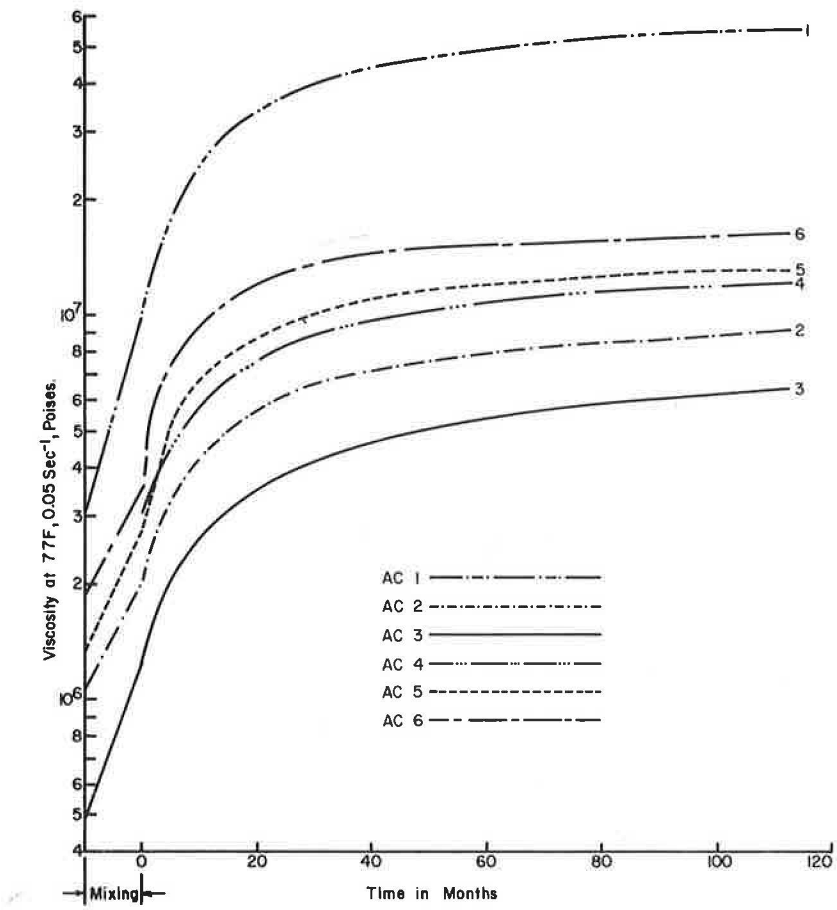

FIGURE 6 Viscosity at 77°F versus time, 1964 pavements.

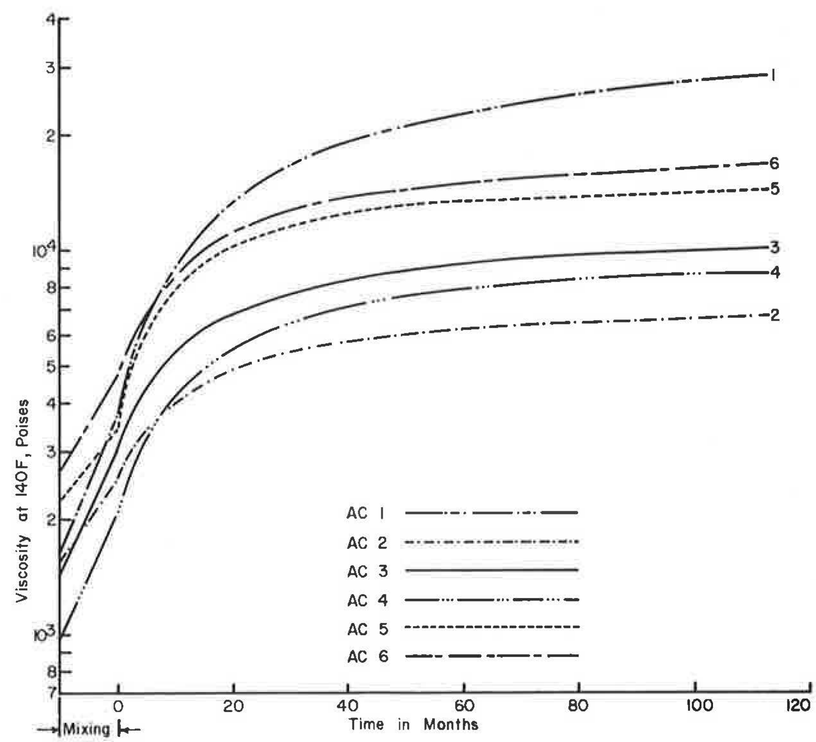

FIGURE 7 Viscosity at 140°F versus time, 1964 pavements.

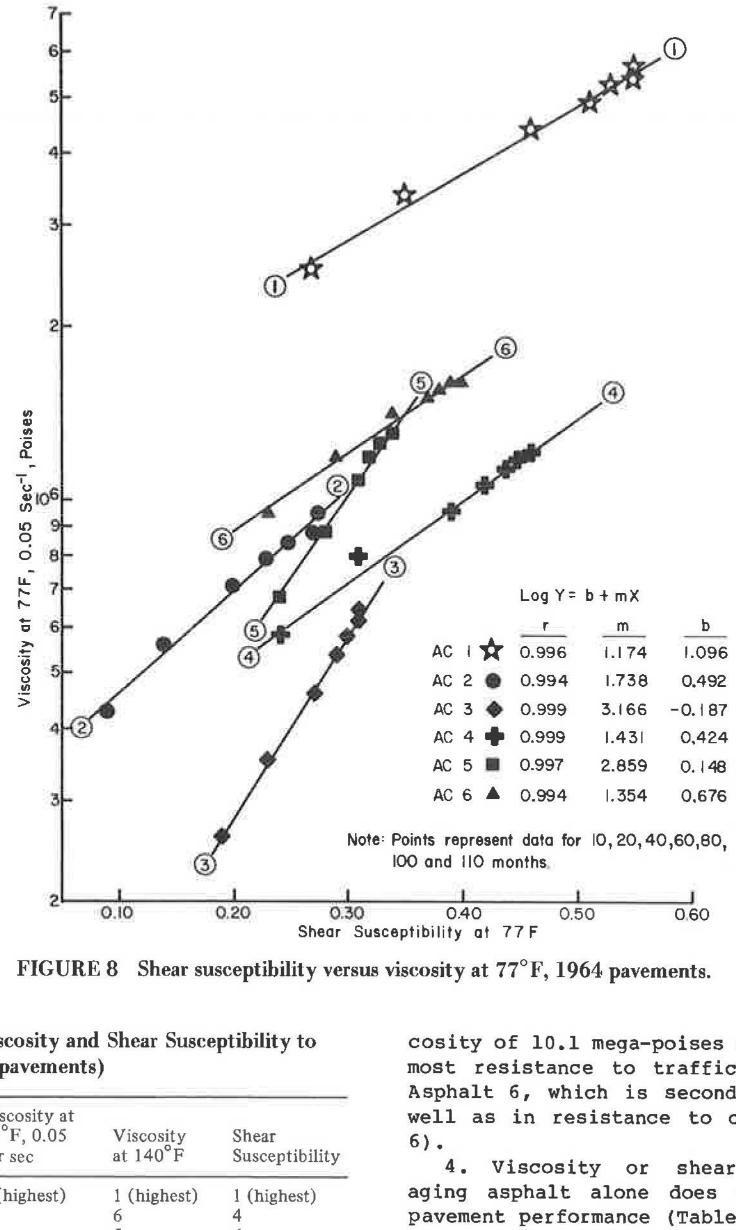

FIGURE 8 Shear susceptibility versus viscosity at 77°F, 1964 pavements.

TABLE 4 Relationship of Viscosity and Shear Susceptibility to Pavement Performance (1964 pavements)

Test Pavement	Performance Rating (113 months)	Viscosity at 77°F, 0.05 per sec	Viscosity at 140°F	Shear Susceptibility
1 (poorest)	51.1	1 (highest)	1 (highest)	1 (highest)
6	59.8	6	6	4
4	60.1	5	5	6
2	60.4	4	3	5
5	61.2	2	4	3
3 (best)	61.5	3 (lowest)	2 (lowest)	2 (lowest)

the changes to be experienced over later years can possibly be calculated from this relationship without waiting out the time.

2. Pavement performance is affected significantly by the extent of air voids in a pavement. The rate of hardening of asphalts is reduced considerably if the pavements can compact under traffic during the first 1.5 to 2 years, so as to have air voids of less than 5 percent.

3. Following optimum compaction during construction, the apparent viscosity at 77°F (after pugmill mixing) appears to control the capability of the pavements to compact further under traffic at ambient temperatures, all other factors affecting the compaction being the same. The percentage of air voids should, therefore, be considered a secondary control factor because it is affected by other primary parameters including the apparent viscosity at 77°F after mixing. Asphalt 1, with the highest viscosity of 10.1 mega-poises after mixing, offered the most resistance to traffic compaction, followed by Asphalt 6, which is second highest in viscosity as well as in resistance to compaction (Figures 5 and 6).

4. Viscosity or shear susceptibility of the aging asphalt alone does not necessarily indicate pavement performance (Table 4). The rate of gain in shear susceptibility relative to increase in viscosity at 77°F (indicated by slope m in Figure 8 and Table 5) appears to be one of the major factors affecting pavement performance. Relatively lower gain in shear susceptibility with the corresponding increase in viscosity is associated with better pavement performance in this study.

5. Asphalt ductility values, determined at 39.2°F before and after pugmill mixing and at 60°F after 113 months in service, appear to be consistent

TABLE 5 Relationship of Slope m (from Figure 8) to Pavement Performance

Test Pavement	Performance Rating (113 months)	Slope m (Figure 8)
1 (poorest)	51.1	1.174
6	59.8	1.354
4	60.1	1.431
2	60.4	1.738
5	61.2	2.859
3 (best)	61.5	3.166

with pavement performance (Table 6). Higher ductility values are associated with better pavement performance. It is possible that the ductility test results obtained at lower temperatures reflect indirectly the viscosity-shear susceptibility relationship at these temperatures.

TABLE 6 Ductility Data (1964 pavements)

		Ductility in cm		
		39.2°F, 1 cm/min		60°F, 5 cm/min,
Asphalt Type	Pavement Performance Rating	Original	After Mixing	After 113 Months
1 (poorest)	51.1	14	4.1	0
6	59.8	21.9	7.3	8
4	60.1	23.5	7.5	7
2	60.4	53.3	11.9	19
5	61.2	68.3	24.3	19
3 (best)	61.5	101.0	42.2	49

It should be mentioned that a subsequent study (9) of 20 AC-20 asphalt cements determined a fair correlation between the shear susceptibility and ductility at 60°F of thin-film oven (TFO) residues.

1976 TEST PAVEMENTS

This project is located in Elk County (north-central Pennsylvania) on traffic Route 219 just north of Wilcox. Six test pavements, each approximately 2,000 ft long, were constructed in September 1976 using AC-20 asphalt cements from different sources. The research project consisted of 1.5-in. dense graded asphalt concrete resurfacing of the existing structurally sound flexible pavement. Average daily traffic on this two-lane, 20-ft-wide highway was 3,700 vehicles at the time of construction (10). The mix composition and compaction levels were held reasonably constant on all test pavements. The only significant variable is the asphalt type or source.

AC-20 asphalt cements were supplied by five refineries. Asphalts T-1 and T-5 came from the same refinery. Table 7 gives the crude sources, methods of refining, and chemical compositions of the six asphalt cements. The properties of original asphalt cements sampled from the tankers at the bituminous concrete plant are given in Table 8. Asphalt was also recovered from cores taken just after construction; the recovered asphalt properties are given in Table 9.

The most recent cores were obtained in November 1982 (about 6 years after construction) for Abson recovery. The preliminary data on recovered asphalts are given in Table 10.

Pavement Performance

Periodical performance evaluation of these test pavements has been conducted by a team of 8 to 10 evaluators. The last inspection was made in October 1982. Performance ratings were determined (on a scale of one to ten) by evaluating four factors: loss of fines (matrix), raveling (loss of aggregate 0.25-in. and larger), transverse cracking, and longitudinal cracking. Results of this pavement condition survey and performance ratings are given in Table 11. An ideal pavement according to this performance evaluation would rate 40.

The 1976-1977 winter following the construction of these test pavements was very severe in Pennsylvania. Visual observation of the pavements after that winter revealed that two test pavements (T-1 and T-5) had developed extensive low temperature-associated transverse cracking. The critical temperature data obtained by a nearby thermocouple installation are given by Kandhal (10). Low ambient

TABLE 7 Crude Sources, Methods of Refining and Chemical Compositions (1976 pavements)

			Rostler Analysis[a], %					
Asphalt Type	Crude Sources (%)	Method of Refining	A	N	A_1	A_2	P	$(A_1+N)/(A_2+P)$
T-1	49 Sahara, 21 W. Texas, 21 Montana, and 9 Kansas	Vacuum Distillation and propane deasphalting	8.1	9.0	39.9	30.9	12.1	1.14
T-2	66-2/3 Texas Mid-Continent and 33-1/3 Arabian	Steam Distillation	22.4	17.4	24.4	24.4	11.3	1.17
T-3	85 Light Arabian and 15 Bachaquero	Vacuum Distillation	17.0	23.2	18.8	31.0	10.0	1.02
T-4	75 W. Texas Sour and 25 Texas and Louisiana Sour	Vacuum Distillation	19.4	23.1	17.0	27.7	12.8	0.99
T-5	49 Sahara, 21 W. Texas, 21 Montana, and 9 Kansas	Vacuum Distillation and propane deasphalting	15.9	28.7	18.2	27.7	9.4	1.26
T-6	Blend of Heavy Venezuelan and Middle East Crude	Vacuum Distillation	10.4	25.8	19.1	25.3	19.3	1.01

[a]A = asphaltense, N = nitrogen bases, A_1 = first acidaffins, A_2 = second acidaffins, and P = paraffins.

TABLE 8 Properties of Original AC-20 Asphalt Cements (1976 pavements)

	Asphalt Type					
Test	T-1	T-2	T-3	T-4	T-5	T-6
Penetration at 39.2°F, 100 g, 5 sec	2.0	7.4	6.2	6.7	3.4	7.5
Penetration at 60°F, 100 g, 5 sec	11.2	25.0	24.5	23.0	16.0	29.0
Penetration at 77°F, 100 g, 5 sec	42	64	72	65	54	80
Viscosity at 140°F, poises	2,710	2,284	1,764	1,705	1,759	1,982
Viscosity at 275°F, centistokes	420	402	393	355	356	406
Softening point (R and B), °F	123	122	120	122	124	121
PI (pen/pen)	-2.77	-0.71	-1.51	-1.05	-2.23	-1.29
PVN	-1.04	-0.70	-0.61	-0.86	-1.03	-0.45
TFO Residue						
Penetration at 77°F, 100 g, 5 sec	26	38	45	38	37	44
Viscosity at 140°F, poises	5,501	6,835	3,982	4,694	3,248	5,721
Viscosity at 275°F, centistokes	563	569	556	527	464	575
Ductility at 39.2°F, 1 cm/min, cm	3.5	3.5	4.6	5.2	8.6	12.4
Ductility at 60°F, 5 cm/min, cm	11.6	7.0	95.2	12.8	90.6	33.0

TABLE 9 Properties of Recovered AC-20 Asphalt Cements Just After Construction (1976 pavements)

	Asphalt Type					
Test	T-1	T-2	T-3	T-4	T-5	T-6
Penetration at 39.2°F, 100 g, 5 sec	1.5	4.5	4.5	4.0	2.0	5.8
Penetration at 60°F, 100 g, 5 sec	7	17	16	13	9	20
Penetration at 77°F, 100 g, 5 sec	24	40	43	34	29	49
Viscosity at 140°F, poises	5,525	5,729	3,789	3,829	4,019	4,611
Viscosity at 275°F, centistokes	565	569	526	487	488	576
Softening point (R and B), °F	134	128	129	128	130	129
Ductility at 39.2°F, 1 cm/min, cm	0.2	4.6	13.9	5.9	0.6	14.9
Ductility at 60°F, 5 cm/min, cm	8.3	7.2	48.5	10.0	15.5	34.0
Ductility at 77°F, 5 cm/min, cm	150+	80	150+	150+	150+	150+
PI (pen/pen)	-2.24	-0.80	-0.99	-0.65	-2.03	-0.64
PVN	-1.13	-0.68	-0.72	-1.03	-1.16	-0.47

TABLE 10 Properties of Recovered Asphalts After Six Years (1976 pavements)

	Asphalt Type					
Test	T-1	T-2	T-3	T-4	T-5	T-6
Penetration at 77°F, 100 g, 5 sec	15	26	35	25	22	35
Viscosity at 140°F, poises	13,339	20,556	7,422	14,418	6,495	11,263
Viscosity at 275°F, centistokes	815	858	721	781	583	815
Ductility at 60°F, 5 cm/min, cm	1.2	4.5	14.0	5.0	4.0	11.2

TABLE 11 Pavement Performance Evaluation (1976 pavements)

	Asphalt Type					
Observations	T-1	T-2	T-3	T-4	T-5	T-6
Loss of fines (matrix)	Slight to moderate	Slight	Slight	Slight	Slight	None to slight
Raveling (loss of particle .25-inch or larger)	Moderate	Slight	None to slight	Slight	Slight to moderate	Slight
Transverse cracking	Very severe	Slight	None	Slight to moderate	Very severe	Slight to moderate
Longitudinal cracking	Very severe[a]	Moderate	None to slight	Slight to moderate	Severe[a]	Slight
Overall rating number	18.4	29.4	36.2	30.5	20.8	31.7

[a] Mostly block-cracking resulting from low temperature shrinkage.

temperatures prevailed again at the experimental site during the second (1977-1978) and the third (1978-1979) winters. The temperature data are given by Kandhal (11). A periodical crack survey during this period indicated that test pavements T-1 and T-5 were developing more cracks and the existing cracks appeared to widen after each successive winter (11). Test pavements T-2, T-3, T-4, and T-6 had not developed any significant transverse or longitudinal cracking during the first 3 years. Since then, pavements T-2, T-4, and T-6 have gradually developed cracking to different degrees as indicated in Table 11. Pavement T-3 is rated the best with no transverse cracking and minimal longitudinal cracking.

Conclusions

Evaluation of these pavements is continuing. However, the following conclusions have been drawn from the data obtained to date:

1. Both direct measurements (11) and indirect methods (10) indicate that the stiffness modulus of the asphaltic concrete is a good indicator of potential low temperature cracking. Asphalts T-1 and T-5, which developed such cracking prematurely, had higher stiffness moduli at low temperatures compared to the remaining four asphalts. Limiting asphaltic concrete stiffness modulus criteria of 10^6 psi at the lowest pavement temperature for a loading time of 20,000 seconds to minimize low temperature cracking was verified on this project.

2. A maximum permissible stiffness modulus of 275 kg/cm^2 for original asphalt cement (at minimum pavement design temperature and 20,000 seconds loading time) was selected to develop AC-20 asphalt cement specifications for cold regions of Pennsylvania to minimize low temperature cracking.

3. Comparison of preliminary data on recovered asphalts after 6 years in service (Table 10) and pavement performance ratings (Table 11) indicates the following: (a) viscosity of the aging asphalt alone does not necessarily correlate with the pavement performance. Temperature-susceptible asphalts T-1 and T-5, although poor performers, do not exhibit comparatively higher viscosities at 140°F; (b) penetration at 77°F of the aging asphalt indicates a general trend: lower penetration associated with poor performance and vice versa. However, it appears to become insensitive and does not discern the relative performance rankings when the value drops below 30 (for example, asphalts T-2, T-3, and T-4); (c) asphalt ductility values, determined at 60°F after 6 years in service, appear to be consistent with the pavement performance. Higher ductility values are associated with better pavement performance, especially the resistance to load-associated longitudinal cracking.

SUMMARY

Three asphalt durability projects undertaken by the Pennsylvania Department of Transportation in 1961-1962, 1964, and 1976 are discussed briefly in this paper. Aging of the pavements results in progressively lower penetration and higher viscosity, which are a hyperbolic function of time and approach a definite limit with time. However, it has been demonstrated that the accompanying decrease in low-temperature ductility is an important factor. After the penetration of asphalt drops below 30 due to hardening, the pavements containing asphalt with low ductilities are likely to show poorer service than pavements containing asphalts of relatively the same penetration but with high ductilities.

Due to its empirical nature, it is not clearly understood what fundamental property is being measured by the ductility test although a fair correlation has been indicated between the ductility and shear susceptibility of TFO residues at 60°F. The 1964 test pavements showed that the rate of gain in shear susceptibility relative to increase in viscosity at 77°F was an important factor affecting the pavement performance.

Lower ductility values were associated with higher incidence of load-associated longitudinal cracking. High stiffness modulus of the asphalt cement at low temperatures and a 20,000-second loading time contributed to nonload-associated transverse cracking.

Because the asphalt cements from different sources age differently in service after the pugmill mixing, it appears that the tests on TFO residue are not completely reliable to predict the long-term asphalt durability. There is an urgent need to develop an accelerated laboratory aging procedure for asphalt cements that can closely simulate the hardening that takes place in the pavement under certain climatic conditions. The asphalts thus aged can then be tested for the desired durability parameters such as retained ductility at 60°F, and stiffness modulus at low temperatures.

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Discussion

Richard L. Davis*

The authors are to be congratulated on a fine, informative paper. In their Figures 2, 3, and 4 they show the relation between penetration, viscosity, and ductility values and time to first cracking observed. While although many factors can contribute to the cracking of pavements, these figures appear to confirm my experience that pavements begin to crack when a certain viscosity or stiffness is reached. The ductility test could serve as a viscometer if stress levels were recorded.

First cracking is usually observed in cooler weather when the viscosity of the asphalt is higher. I look on all three of these methods as attempts to estimate a critical viscosity at which cracking would occur even though this may not have been the intent of the authors. Because all these test methods are run at higher temperatures than the temperatures at which first cracking takes place, there is extrapolation involved.

Extrapolation widens the precision limits on a test method, and this appears to be true in Figures 2, 3, and 4. The greatest variation is shown at 140°F with less at 77° and 60°F. It would have been interesting to have measurements of viscosity at temperatures approaching the lowest that the pavement reached and to have compared these with first cracking.

In viewing Figures 2, 3, and 4, I could not help but wonder if there is any significant difference in the values for penetration, ductility, and viscosity. When one considers the effect on precision of extrapolation, there may not be any real difference in these values. Confidence limits would be helpful in deciding the significance of the observed variation.

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