EVALUATION OF PROPERTIES OF AC-20 ASPHALT CEMENTS

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In 1971, the Pennsylvania Department of Transportation adopted viscosity graded asphalt cement specifications similar to AASHTO M 226-70. AC-20 asphalt cement, most commonly used for paving in Pennsylvania, was supplied by the various refineries who used different blends of crudes and processing methods to meet the Pennsylvania DOT specifications. This study was undertaken to catalog and evaluate the physical properties of AC-20 asphalt cements as supplied in 1973 by the various refineries. The fundamental and empirical consistency data have been evaluated and compared so that a specification based entirely on fundamental units of measurement can be developed in future. The test data have been made available to other researchers and agencies that are in the process of adopting viscosity graded asphalt cements. No attempt has been made to relate the physical properties of the asphalts to mix characteristics or pavement performance. Very good correlations were obtained between (a) log viscosity and log penetration at 77 F (25 C), (b) log viscosity and log penetration at 60 F (15.6 C), (c) viscosity at 77 and 60 F (25 and 15.6 C), (d) temperature susceptibility in 77 to 140 F (25 to 60 C) and 140 to 275 F (60 to 135 C) ranges, and (e) viscosity ratio at 77 and 60 F. Regardless of crude source, the satisfactory correlation obtained between shear susceptibility at 77 F and ductility at 60 F on thin film oven residues indicates that, in the specifications, shear susceptibility can be used in place of the ductility requirement.

• VISCOSITY REQUIREMENTS were incorporated in the Pennsylvania Department of Transportation specifications for paving grade asphalt cements in 1966. Subsequently, AASHTO adopted Standard Specification M 226-70 for viscosity graded asphalt cements in 1970. In 1971, the Pennsylvania DOT adopted that specification except for its requirements on ductility. AC-20 asphalt cement was supplied by the various refineries who employed different blends of crudes and processing methods to meet the Pennsylvania DOT specifications.

The objectives of this study were (a) to catalog and evaluate the physical properties of AC-20 asphalt cements produced to meet the 1971 specification using viscosity grading at 140 F (60 C), (b) to evaluate and compare the fundamental and empirical consistency data so that a specification based entirely on fundamental units of measurement can be developed, and (c) to make the test data on AC-20 asphalt cement available to other researchers and agencies that are in the process of adopting viscosity graded asphalt cements.

Similar studies (1, 2) were conducted by the Bureau of Public Roads and the Asphalt Institute based on study specifications developed by the Asphalt Institute. This study was primarily concerned with the asphalts produced to meet AASHTO M 226-70 and represents most sources catering to the mid-Atlantic states. No attempt was made to relate the physical properties of the asphalts to mix characteristics or pavement performance.

ASPHALT CEMENTS AND TEST METHODS

Asphalt Cements

The 20 AC-20 asphalt cements included in this study were supplied by seven manufacturers during 1973 and represent their regular production during that year. Details of crude sources and methods of refining (Table 1) were obtained from the producers. Thus a wide range of properties (for example, 40 to 112 penetration) was involved in evaluating AC-20 asphalt cements. The asphalt cements were supplied to meet the 1971 Pennsylvania DOT specifications given in Table 2.

Test Methods

Standard AASHTO test procedures were used to obtain the data except for the absolute viscosities at 60 and 77 F (15.6 and 25 C) over a range of shear rates, which were determined by using the sliding plate microviscometer (both glass and stainless steel plates were used for these tests).

DESCRIPTION AND DISCUSSION OF TEST DATA

Data on physical properties of the original AC-20 asphalt cements are given in Tables 3 and 4. Properties of thin film oven (TFO) residue are given in Tables 4 and 5. Tables 6 and 7 give the correlations between various properties of these asphalts. Some of the correlations are shown graphically in Figures 1 through 4.

Flash Point and Softening Point

The flash point ranged from 510 to 640 F (265 to 338 C), average being 597 F (314 C). The softening point ranged from 125 to 138 F (52 to 59 C), averaging 132 F (56 C).

Penetration at 60 and 77 F

Penetration at 60 F (15.6 C) ranged from 11 to 43, and penetration at 77 F (25 C) ranged from 40 to 112 for all AC-20 asphalt cements (Table 3). Thus viscosity grading at 140 F (60 C) results in a wider range in consistency at temperatures below 77 F than was found for asphalts controlled by penetration at 77 F.

Viscosity at 60 and 77 F

Viscosity at 60 F (15.6 C) ranged from 7.29 to 80.72 megapoises (730 to 810 kPa·s) and viscosity at 77 F (25 C) ranged from 0.92 to 5.11 megapoises (92 to 510 kPa·s) at shear rates of 0.05 sec^{-1} (Table 4). This is understandable because of the differences in temperature susceptibility of AC-20 asphalt cements.

The sliding plate microviscometer, which used controlled rates of shear, provided a satisfactory method for determining viscosities at low temperatures. Viscosities at 60 and 77 F (15.6 and 25 C) have been determined for shear rates of 0.05 and 0.001 sec^{-1} and also at a constant shear stress of 16,300 $dynes/cm^2$ (1630 Pa). This shear stress value has no particular significance except that so far it has conveniently avoided any extrapolation of the test data at these temperatures. This constant shear stress system was reported by Chipperfield and Welch (3). Test data on original asphalts and their TFO residues are given in Table 4.

Viscosity at 77 F (25 C) showed very good correlation with viscosity at 60 F (15.6 C)

Table 1. Crude sources and methods of refining.

Sample	Crude Source	Method of Refining
R-1 through R-5	80 percent Canadian, 20 percent domestic	Propane deasphalting
R-6, 7, 9, 10, 16, 17, and 19	Blend of Argentinian and Middle East	Atmospheric and vacuum distillation
R-8	90 percent Arabian light, 10 percent Nepco	Straight vacuum steam distillation
R-11 and 14	80 percent Wyoming, 20 percent Arabian light	Straight vacuum steam distillation
R-12	Blend of Venezuelan and Arabian	Atmospheric and vacuum steam distillation
R-13	Venezuelan	Vacuum distillation
R-15	Mississippi crude	Atmospheric steam distillation
R-18	45 percent Wyoming, 40 percent Bow Canadian, 15 percent Arabian light	Straight vacuum steam distillation
R-20	Venezuelan	Atmospheric and vacuum steam distillation

Table 2. Pennsylvania DOT specifications for asphalt cements.

Property	Minimum	Maximum
Flash point, deg F	450	—
Absolute viscosity at 140 F, poises	1,600	2,400
Penetration at 77 F, 100 g, 5 sec	40	120
Kinematic viscosity at 275 F, stokes	21,000	—
Ductility at 60 F, 5 cm per min, cm	75	—
Solubility in trichloroethylene, percent	99.0	—
Thin film oven test at 325 F, 50 ml, 5 hours		
Ductility of residue at 60 F, 5 cm per min, cm	10	—
Absolute viscosity at 140 F, poises	—	8,000

Note: 1 F = 1.8 C + 32; 1 poise = 0.1 Pa·s; 1 stoke = 0.0001 m^2/s.

Table 3. Properties of original AC-20 asphalt cements.

Sample	Specific Gravity at 77 F	Flash Point (F)	Softening Point (F)	Penetration 77 F	Penetration 60 F	Absolute Viscosity at 140 F (poises)	Kinematic Viscosity at 275 F (stokes)	Ductility[a] at 60 F (cm)	Shear Susceptibility 77 F	Shear Susceptibility 60 F
R-1	1.024	570	136	40	11	1,726	2.80	150+	0.08	0.19
R-2	1.029	570	136	40	11	1,641	2.67	100+	0.10	0.24
R-3	1.025	575	130	46	12	1,673	2.82	100+	0.12	0.18
R-4	1.017	580	128	50	17	2,042	3.29	26	0.16	0.42
R-5	1.028	565	135	51	20	1,718	2.87	15	0.21	0.56
R-6	1.024	635	130	60	19	2,145	4.03	150+	0.03	0.24
R-7	1.024	640	132	64	19	2,214	4.26	150+	0.06	0.16
R-8	1.021	610	130	67	23	2,149	4.50	150+	0.04	0.23
R-9	1.024	635	135	68	22	1,978	4.13	150+	0.03	0.12
R-10	1.024	620	133	69	23	1,961	4.10	150+	0.04	0.13
R-11	1.018	605	125	71	24	2,128	4.24	150+	0.08	0.31
R-12	1.031	595	125	71	21	1,805	3.94	150+	0.08	0.22
R-13	1.030	600	126	71	20	1,907	4.54	150+	0.03	0.10
R-14	1.022	605	133	71	23	1,654	3.75	150+	0.02	0.12
R-15	1.025	595	133	75	24	1,890	4.30	150+	0.08	0.09
R-16	1.027	600	138	75	24	1,863	3.87	150+	0.03	0.11
R-17	1.024	615	136	79	25	1,731	3.68	150+	0.03	0.13
R-18	1.018	595	136	79	26	1,754	3.83	150+	0.03	0.18
R-19	1.024	625	136	88	27	1,698	3.97	150+	0.02	0.18
R-20	1.036	510	130	112	43	2,030	4.96	100+	0.14	0.25

Note: 1 F = 1.8 C + 32; 1 poise = 0.1 Pa·s; 1 stoke = 0.0001 m^2/s.

[a]Ductility at 77 F was 150+ cm for all samples.

Table 4. Viscosities at 77 and 60 F (in megapoises) of AC-20 asphalt cements.

Sample	Original Viscosity at 77 F			Original Viscosity at 60 F			Viscosity at 77 F, TFO			Viscosity at 60 F, TFO		
	0.05 Sec^{-1}	0.001 Sec^{-1}	Constant Stress	0.05 Sec^{-1}	0.001 Sec^{-1}	Constant Stress	0.05 Sec^{-1}	0.001 Sec^{-1}	Constant Stress	0.05 Sec^{-1}	0.001 Sec^{-1}	Constant Stress
R-1	5.11	6.98	5.30	72.48	153.31	150.01	10.59	17.82	13.0	119.0	630.0	190.0
R-2	4.93	7.28	5.10	80.72	206.28	219.47	11.57	14.85	12.8	110.0	394.0	870.0
R-3	4.07	6.45	4.20	64.42	131.23	124.26	11.54	15.97	12.8	129.0	413.0	600.0
R-4	4.78	9.07	5.10	35.67	184.57	196.00	11.82	35.54	19.2	59.6	821.6	1,200.0
R-5	4.32	9.98	4.60	28.90	256.15	440.49	11.21	49.94	24.0	48.0	573.0	3,600.0
R-6	2.48	2.80	2.50	29.48	75.56	59.00	6.59	8.86	6.8	58.0	283.3	260.0
R-7	2.30	2.90	2.20	28.22	52.52	42.00	5.93	8.16	6.3	52.0	243.0	300.0
R-8	2.00	2.90	1.95	19.95	49.54	34.00	6.34	10.63	7.0	42.0	200.0	230.0
R-9	2.10	2.40	2.10	27.97	44.50	37.00	5.03	7.19	5.3	40.4	177.1	190.0
R-10	2.05	2.85	2.00	22.20	36.90	29.42	6.06	8.88	6.5	48.9	222.2	263.4
R-11	2.20	2.95	2.10	20.19	68.05	53.00	6.25	12.39	7.0	40.2	250.6	356.1
R-12	1.80	2.97	1.69	19.52	46.57	32.50	4.64	6.42	4.8	47.7	142.5	132.0
R-13	1.50	1.70	1.48	18.46	27.48	22.60	3.60	3.97	3.6	37.8	98.4	83.6
R-14	1.50	1.65	1.50	19.39	30.82	24.80	3.38	3.75	3.4	31.4	68.2	55.0
R-15	1.20	1.60	1.13	16.54	23.94	19.90	4.90	6.49	5.0	38.0	111.7	98.0
R-16	1.55	1.78	1.50	17.06	26.18	21.00	4.51	5.83	4.9	37.6	136.4	1,220.0
R-17	1.42	1.65	1.40	15.88	26.82	20.20	4.83	6.16	5.0	37.9	169.6	174.6
R-18	1.43	1.61	1.39	14.52	29.88	20.50	4.66	7.00	4.8	34.3	150.9	140.0
R-19	1.50	1.65	1.40	15.16	31.13	21.50	4.87	7.25	5.2	35.1	126.7	110.2
R-20	0.92	1.60	1.10	7.29	19.48	9.42	3.96	9.35	4.2	23.6	105.5	80.1

Note: 1 F = 1.8 C + 32; 1 megapoise = 0.1 MPa·s.

Table 5. Properties of thin film oven residue of AC-20 asphalt cements.

Sample	Percentage of Loss	Absolute Viscosity at 140 F (poises)	Viscosity Ratio			Temperature Susceptibility at 77 to 140 F	Ductility at 60 F (cm)	Shear Susceptibility	
			140 F	77 F	60 F			77 F	60 F
R-1	0.040	3,015	1.75	2.07	1.64	-6.33	20	0.13	0.45
R-2	0.038	3,593	2.19	2.35	1.36	-6.19	11	0.06	0.33
R-3	0.043	3,312	1.98	2.84	2.00	-6.28	12	0.08	0.30
R-4	0.016	5,508	2.70	2.47	1.67	-6.29	7	0.28	0.67
R-5	0.006	4,359	2.54	2.59	1.66	-5.96	7	0.38	0.63
R-6	0.184[a]	3,741	1.74	2.66	1.97	-5.83	23	0.08	0.34
R-7	0.077	4,862	2.27	2.58	1.84	-5.48	41	0.08	0.40
R-8	0.156	4,462	2.08	3.17	2.11	-5.61	29	0.13	0.40
R-9	0.028	3,485	1.76	2.40	1.44	-5.75	54	0.09	0.38
R-10	0.056	3,864	1.97	2.96	2.20	-5.74	29	0.10	0.39
R-11	0.046[a]	4,157	1.95	2.84	1.99	-5.68	26	0.15	0.47
R-12	0.016	4,145	2.30	2.58	2.44	-5.51	43	0.08	0.28
R-13	0.039	3,770	1.98	2.40	2.05	-5.46	150+	0.03	0.24
R-14	0.141	2,924	1.77	2.25	1.62	-5.71	79	0.03	0.20
R-15	0.053	3,016	1.60	4.08	2.30	-5.89	150+	0.07	0.28
R-16	0.106	3,362	1.80	2.91	2.20	-5.72	117	0.07	0.33
R-17	0.015	2,760	1.59	3.40	2.39	-5.98	150+	0.06	0.38
R-18	0.019[a]	2,935	1.67	3.26	2.36	-5.89	108	0.10	0.38
R-19	0.066	4,068	2.40	3.25	2.32	-5.56	132	0.10	0.33
R-20	0.115	7,456	3.67	4.30	3.24	-4.80	22	0.22	0.38

Note: 1 F = 1.8 C + 32; 1 poise = 0.1 Pa·s.

[a]Gain in weight.

Table 6. Correlation coefficients of original properties.

X	Y	Correlation Coefficient
Log viscosity at 77 F (0.05 sec^{-1})	Log penetration at 77 F	-0.948
Log viscosity at 77 F (0.001 sec^{-1})	Log penetration at 77 F	-0.875
Log viscosity at 77 F (constant stress)	Log penetration at 77 F	-0.937
Log viscosity at 60 F (0.05 sec^{-1})	Log penetration at 60 F	-0.977
Log viscosity at 60 F (0.001 sec^{-1})	Log penetration at 60 F	-0.769
Log viscosity at 60 F (constant stress)	Log penetration at 60 F	-0.727
Viscosity at 77 F (0.05 sec^{-1})	Viscosity at 60 F (0.05 sec^{-1})	+0.868
Viscosity at 140 F	Kinematic viscosity at 275 F	+0.640
Viscosity at 77 F (0.05 sec^{-1})	Shear susceptibility at 77 F	+0.597
Shear susceptibility at 77 F	Shear susceptibility at 60 F	+0.809
Temperature susceptibility (77 to 140 F)	Temperature susceptibility (140 to 275 F)	+0.944

Note: 1 F = 1.8 C + 32.

Table 7. Correlation coefficients of thin film oven residue properties.

X	Y	Correlation Coefficient
Viscosity ratio at 77 F (0.05 sec^{-1})	Viscosity ratio at 140 F	+0.294
Viscosity ratio at 77 F (0.001 sec^{-1})	Viscosity ratio at 140 F	+0.170
Viscosity ratio at 77 F (constant stress)	Viscosity ratio at 140 F	+0.300
Viscosity ratio at 140 F	Percentage of loss in weight	-0.280
Viscosity ratio at 77 F	Percentage of loss in weight	-0.172
Viscosity ratio at 77 F (0.05 sec^{-1})	Viscosity ratio at 60 F (0.05 sec^{-1})	+0.829
Viscosity at 77 F (0.05 sec^{-1})	Shear susceptibility at 77 F (TFO)	+0.498
Shear susceptibility at 77 F	Shear susceptibility at 60 F	+0.872
Shear susceptibility at 60 F	Log ductility at 60 F	-0.635
Shear susceptibility at 77 F	Log ductility at 60 F	-0.653
Temperature susceptibility (77 to 140 F, original)	Temperature susceptibility (77 to 140 F, TFO residue)	+0.798

Note: 1 F = 1.8 C + 32.

Figure 1. Viscosity at 77 F versus penetration at 77 F for original asphalts.

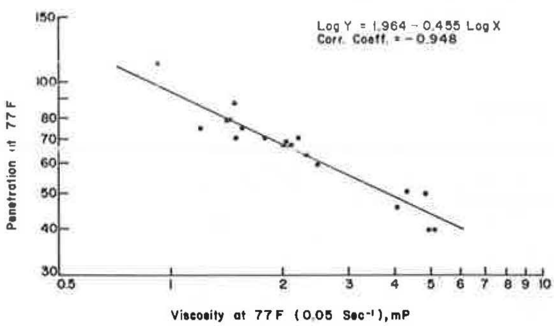


Figure 2. Viscosity at 60 F versus penetration at 60 F for original asphalts.

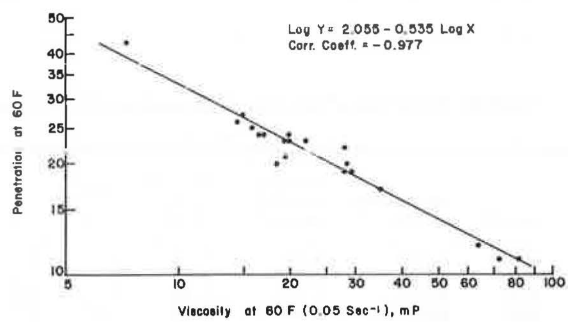


Figure 3. Shear susceptibility at 77 F versus ductility at 60 F for TFO residue.

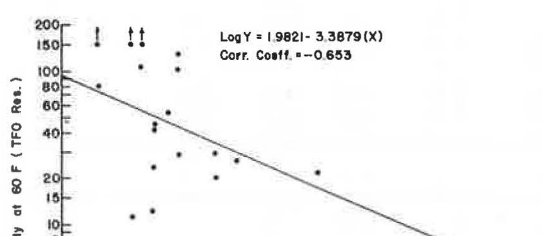
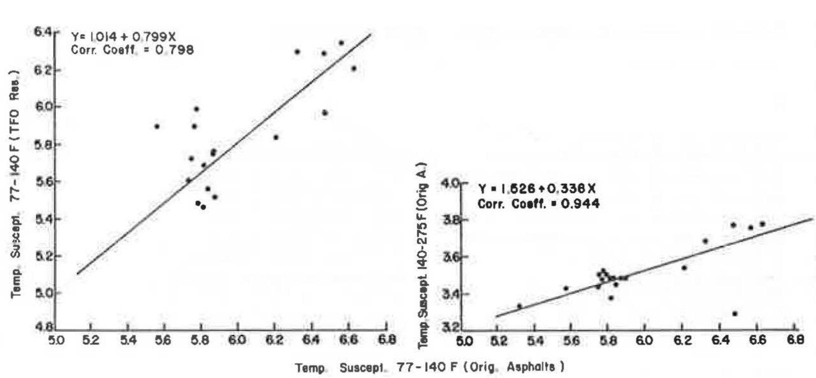


Figure 4. Temperature susceptibility of original asphalts and TFO residue.



(correlation coefficient of +0.868). Its correlation with viscosity at 140 F (60 C) is extremely poor, which indicates the necessity of consistency control at 77 F or lower temperatures for the asphalt cements graded by viscosity at 140 F. The correlation between viscosity and shear susceptibility at 77 F is fair (correlation coefficient of +0.597). This indicates that higher shear susceptibility is likely to be associated with higher viscosity at 77 F.

Viscosity at 140 and 275 F

Absolute viscosity at 140 F (60 C) ranged from 1,641 to 2,214 poises (164 to 221 Pa·s) averaging 1,885 poises (188 Pa·s); kinematic viscosity at 275 F (135 C) ranged from 26,700 to 49,600 stokes (2.7 to 4.9 m^2/s), averaging 38,300 stokes (3.8 m^2/s). Because of different temperature susceptibilities in the range of 140 to 275 F, the correlation between viscosities at 140 and 275 F was not very good (correlation coefficient of +0.340), which indicates that consistency control at 275 F is necessary.

Effects of Heating

Properties of the TFO residue of all these asphalts were determined (Tables 4 and 5), and correlations are given in Table 7. The viscosity ratio at 140 F (60 C), which appears in the specification, has extremely poor relation with the viscosity ratio at 77 F (25 C) (determined at two shear rates and at constant stress) after the thin film oven test. In some experimental test pavements, the aging indexes (viscosity ratio) based on viscosity at 77 F (25 C) were found to provide a more meaningful indication of pavement performance than aging indexes based on viscosity at 140 F (60 C) (4). In this study, the viscosity ratio ranged from 1.36 to 3.24 (average 2.04) at 60 F (15.6 C), from 2.07 to 4.30 (average 2.87) at 77 F, and from 1.59 to 3.67 (average 2.09) at 140 F. There was good correlation between viscosity ratios at 77 and 60 F.

Percentage of loss on heating in the thin film oven test has no relation with viscosity ratios at 77 and 140 F (Table 7). Thus, a higher percentage of loss on heating is not necessarily associated with a higher viscosity ratio.

Temperature Susceptibility

A double logarithm of viscosity in poises versus the logarithm of the absolute temperature expressed in degrees (empirical Walther's equation) was used to define the temperature susceptibility of the asphalt cements. The numerical values for slopes of these lines were indicated as the temperature susceptibility of the asphalt cements within the specified temperature ranges. At temperatures below 140 F (60 C), slopes of the lines tend to deviate from slopes as established at 140 F (60 C) and higher temperatures, because shear-dependent viscosities are encountered at lower temperatures. Therefore, temperature susceptibility data on original asphalts and TFO residues were determined separately for temperature ranges of 77 to 140 F (25 to 60 C) and 140 to 275 F (60 to 135 C). For original AC-20 asphalt cements, temperature susceptibility between 77 and 140 F ranged from -5.31 to -6.63 (-5.97 average). For the range of 140 to 275 F, the temperature susceptibility ranged from -3.29 to -3.77; -3.51 was average. Generally, temperature susceptibility in the range 77 to 140 F decreased after exposure to heat, averaging only -5.78. Temperature susceptibility before and after the TFO test correlated very well (Figure 4).

Shear Susceptibility

The shear susceptibility (or shear index) value used in this study is the tangent of the angle of log shear rate versus log viscosity as determined during performance of the viscosity test from the microviscometer. Shear susceptibility of asphalts has been related to pavement performance and thus is considered a specification requirement (5).

The observed range of shear susceptibility values was 0.09 to 0.56 at 60 F (15.6 C) and 0.02 to 0.21 at 77 F (25 C) for original AC-20 asphalt cements, averaging 0.21 and 0.11 respectively. For original asphalts, shear susceptibility at 77 F has good correlation with the shear susceptibility at 60 F (correlation coefficient of +0.809). However, in the case of TFO residues, there is very good correlation between the values at 77 and 60 F (25 and 15.6 C) (correlation coefficient of +0.872). Thus the specifications can have a requirement of shear susceptibility on TFO residue at 77 F rather than 60 F.

Normally for asphalts of high shear susceptibility, apparent viscosities at 77 F tend to be higher. This general trend has been confirmed in this study also (Table 6).

Relation Between Viscosity and Present Empirical Tests

The fundamental properties of AC-20 asphalt cements were compared to the characteristics measured by conventional empirical methods by examining the relationships of viscosity to penetration and ductility.

Penetration

The relation of penetration values to viscosity at 77 and 60 F (25 and 15.6 C) is shown in Figures 1 and 2. The figures show excellent correlations at both test temperatures. The equations derived by least squares for the relation between log viscosity and log penetration at each temperature are (in megapoises)

1. At 60 F, log penetration = 2.055 - 0.535 log viscosity and
2. At 77 F, log penetration = 1.964 - 0.455 log viscosity.

Thus the viscosity at 77 F (25 C) can be substituted for penetration at 77 F in the AC-20 asphalt cement specifications, and control checks on project samples can be exercised by conducting relatively simpler penetration tests.

Ductility

The value of ductility requirements in specifications has been the subject of debate. Some asphalt technologists believe that ductility, under the present standard method, is of little value as an indicator of asphalt quality. Others believe that asphalt ductility gives an asphalt pavement its quality of flexibility. Regardless of the merits of the various arguments, a number of studies (6, 7) have related ductility to pavement performance.

Ductility values at 60 and 77 F (15.6 and 25 C) for original asphalts and TFO residues of these asphalts are given in Tables 3 and 5. No correlation was found between ductility and viscosity at 60 F for asphalts from different sources. However, a relatively good correlation between ductility and shear susceptibility at 60 F was obtained on TFO residues.

Present specifications for AC-20 asphalt cement in Pennsylvania use ductility requirements on TFO residue at 60 F (15.6 C) in place of 77 F (25 C) as provided in the AASHTO Specification M 226-70. This has been done because, at temperatures as low as 60 F, ductility values are lower, better defined, and more reproducible than the values are at higher temperatures, which are determined on long, thin threads of asphalt. If the viscosity is determined at 77 F (25 C) as a substitution for penetration at 77 F, the value of shear susceptibility at 77 F is simultaneously obtained. The correlation between ductility at 60 F (15.6 C) and shear susceptibility at 77 F on TFO residue was therefore attempted and found to be satisfactory, considering poor repeatability of the ductility test especially for the values higher than 30 cm. The relationship is shown by the least square line,

$$\text{Log ductility (60 F)} = 2.527 - 2.481 \text{ (shear susceptibility at 77 F)}$$

SUMMARY AND CONCLUSIONS

The paper presented and evaluated the physical properties of AC-20 asphalt cements manufactured from various crude sources and supplied to the Pennsylvania Department of Transportation in 1973 in accordance with the viscosity graded asphalt cement specifications, which are similar to AASHO M 226-70 except for the ductility requirements. The principal findings for the 20 asphalts included in this study are summarized as follows:

1. Viscosity grading at 140 F (60 C) results in a wider range in consistency (penetration or viscosity) at temperatures below 77 F (25 C) than was found for asphalt controlled by penetration at 77 F (25 C). A specification requirement to control the low-temperature properties of AC-20 asphalt cements is apparently needed.
2. Viscosity at 77 F (25 C), determined by the sliding plate microviscometer, correlates well with viscosity at 60 F (15.6 C), both determined at a shear rate of 0.05 sec^{-1}.
3. A good correlation was obtained between log viscosity at a shear rate of 0.05 sec^{-1} and penetration at 60 and 77 F. Thus the viscosity at 77 F (25 C) can be substituted for penetration at 77 F (25 C) in the AC-20 asphalt cement specification, and project samples can be controlled by conducting relatively simpler penetration tests.
4. No correlation was obtained between viscosity ratio at 140 F (60 C) and that at 77 F (25 C) on TFO residues. A higher percentage of loss on heating is not necessarily associated with a higher viscosity ratio.
5. In general, AC-20 asphalt cements had lower temperature susceptibilities after they were exposed to heat.
6. Regardless of the crude source, satisfactory correlation was obtained between shear susceptibility at 77 F (25 C) and ductility at 60 F (15.6 C) on the TFO residues, which indicates that shear susceptibility can be used in place of a ductility test. If the viscosity at 77 F is determined in lieu of penetration, the shear susceptibility value is simultaneously obtained.

The data presented in this report on viscosity graded AC-20 asphalt cements can be applied to the development of optimum specifications based entirely on fundamental properties. More knowledge is needed to adequately correlate pavement performance with asphalt properties measured by the present empirical tests and those related to the fundamental characteristics. Attempts should be made to do so through closely designed experimental projects by using asphalts described on the basis of fundamental properties.

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