USE OF ASTM TESTS TO PREDICT LOW-TEMPERATURE STIFFNESS OF ASPHALT MIXES

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This investigation tested the reliability of ASTM tests to predict low-temperature stiffness of mixes made with a wide variety of asphalts. Mix stiffnesses obtained from creep tests performed with a new low-cost nondestructive method on ordinary Marshall or Hveem specimens were compared with ASTM stiffnesses. The relationship reported between thermally induced pavement cracking and T_L or the temperature at which the 10,000-sec asphalt stiffness is 20,000 psi (138 000 kPa) is qualitatively supported by field tests. T_L estimated from ASTM penetration at 39.2 F (4 C), along with the ASTM penetration at 77 F (25 C) or the viscosity at 140 F (60 C) on rolling thin film (RTF-C) oven residua, correlates well with the measured T_L. The use of penetration at 39.2 F (4 C) is supported as a specification requirement. Good correlation was also found on asphalts recovered from the mixes. T_L correlated poorly with penetration at 77 F along with softening point or viscosity at 140 F on both RTF-C and recovered residua. T_L estimated from viscosities at 140 F, along with viscosities at 275 F on RTF-C or recovered residua, show no correlation with measured T_L. Resistance to low-temperature thermally induced cracking should not be implied on diverse types of asphalts from high-temperature viscosity measurements. Ductilities at 45 F show no correlation with T_L. A modified asphalt test data chart that permits the low-temperature stiffness of asphalts to be determined from normal ASTM penetration tests is given.

•THERMALLY INDUCED cracking or transverse shrinkage cracking, caused by rapid drops in temperature of asphalt concrete pavements, occurs in Canada and in the northern parts of the United States and Europe.

Canadian researchers in particular have made extensive investigations (1-10) to determine the importance of a number of factors on the occurrence of thermally induced pavement cracking. Based on their findings, several factors are now considered in advanced pavement design systems in cold climates.

Stiffness of the asphalt-treated mix is the principal independent variable of those that can be controlled by the highway engineer. Although mix stiffness depends on the voids and asphalt content, it is primarily dependent on the stiffness of the asphalt. Therefore, most highway departments concerned with thermal cracking use the softest grade of asphalt that is consistent with the other mix property requirements.

Although thermally induced cracking can be markedly reduced by using a soft grade of asphalt, considerable reduction can also be obtained by choice of asphalt type. Maximum resistance to thermally induced cracking can be obtained by using the softest practical grade of asphalt having the lowest available temperature susceptibility.

A number of investigators (2, 3, 4, 5, 6, 7) have shown good agreement between measured stiffness and observed field cracking of asphalt-treated mixes. For the asphalt estimated by means of penetration at 77 F (25 C) together with the softening point and van der Poel's nomograph (11), only fair to poor agreement was obtained (8, 9, 10) between field cracking and stiffness. When low-temperature penetrations were used with an improved bitumen test chart by Heukelom (12), agreement was greatly improved (2, 7). Although Heukelom showed that his chart could be used with a wide variety of asphalts, its use to predict thermally induced cracking or to estimate the low-temperature stiffness of mixes was shown by others to be limited to a small variety of asphalts. Consequently, the extent to which the Heukelom chart and van der Poel's nomograph could be relied on was not clear.

The purpose of this investigation was to test the reliability of ASTM tests to predict low-temperature stiffness of mixes made with a wide variety of asphalts. Mix stiffness obtained from creep tests made with a new low-cost nondestructive method on ordinary Marshall or Hveem specimens is compared with ASTM stiffness. This provides a basis for selecting the most appropriate asphalt for use at the lowest pavement temperature expected.

RELATIONSHIP OF STIFFNESS TO PAVEMENT CRACKING TEMPERATURES

There are several methods for estimating the temperature at which thermally induced pavement cracking can be expected. Some methods assume, in the analysis, a linearly viscoelastic plate (13, 14) or beam (1, 7, 15). Necessary input includes the stiffness and tensile strength of the mix over the temperature range considered, a rate of temperature drop, and the coefficient of expansion of the mix (24).

An alternate approach is the limiting stiffness method, which relies on the concept that, on the average, a mix will not crack if its stiffness (for some appropriate loading time) does not exceed a certain value at the lowest expected field temperature. It is assumed (18) that pavement temperature drops at 10 deg/hour.

Although the maximum level of stiffness tolerable without cracking depends on the mix design, i.e., gradation, voids, and asphalt content, the effect of varying asphalt characteristics can be compared directly if the same mix design and aggregate are used in all specimens. Limiting stiffness can be expressed in terms of either mix stiffness (S_{LM}) or binder or asphalt stiffness (S_{LA}). Readshaw (21), who related S_{LA} to the thermally induced cracking observed in Canadian pavements, concluded that pavements will not crack if S_{LA} does not exceed 29,000 psi (200 000 kPa) at 7,200-sec loading at their lowest service temperature. Fromm and Phang (18) suggest a limiting (S_{LA}) of 20,000 psi (138 000 kPa) at a 10,000-sec loading time. McLeod (16, 17) suggests that S_{LM} equals 1,000 ksi (6900 MPa) at 20,000-sec loading. He uses indirect methods to calculate S_{LM} on a dense, well-graded mix from the asphalt properties. Fromm and Phang also calculate S_{LM} indirectly from asphalt properties; however, unlike McLeod, they use the properties of asphalt residua after a thin film oven (TFO) test and thus simulate the asphalt as it exists in the mix after hot-mix hardening.

These limiting stiffness values are about the same after they are adjusted for different loading times and by whether they reflect S_{LA} or S_{LM} values. Thus, any one of these limiting stiffness values can be used for comparison of the effect of asphalt properties on the relative temperatures at which thermally induced cracking can be expected. We have chosen to use Fromm and Phang's S_{LA} of 20,000 psi (138 000 kPa) at a 10,000-sec loading time. This is equivalent to S_{LM} of about 1,500 ksi (10 300 MPa) on the mix described later in this study. This equivalency was calculated by using Heukelom and Klomp's method (19) together with van Draat and Sommer's (20) correction for air voids greater than 3 percent.

Approach

As previously mentioned, the purpose of this investigation was to clarify the extent to which ASTM tests can be used to predict thermally induced pavement cracking. Tests were made on residua from the rolling thin film (RTF-C) oven exposures (California test method 346E) instead of residua from the TFO as used by Fromm and Phang and by Readshaw. Use of RTF-C exposure instead of the TFO exposure is recommended in the Pacific Coast uniform specification for paving asphalts. Although both oven exposures are about equally severe, the RTF-C test is more efficient and has better precision than the TFO test. For confirmation, tests were also made on residua recovered from specimens tested in creep.

From tests made on both the RTF-C residua and the recovered asphalts, the temperatures at which the 10,000-sec S_{LA} attains a 20,000-psi (138 000-kPa) value were estimated indirectly. This temperature is the limiting stiffness temperature T_L. T_L is estimated by using a Heukelom bitumen test data chart (12) along with a new chart derived from Heukelom's chart that permits ASTM penetration at 39.2 F (4 C) to be used. This new chart is shown in Figure 1. Values obtained from these charts are then used on van der Poel's nomograph (11) to obtain the temperature at which the asphalt stiffness at 10,000 sec is 20,000 psi (138 000 kPa). Thus, from several routine asphalt tests we estimate T_L at which thermally induced cracking might be expected to begin.

Indirectly determined T_L is compared with T_L obtained directly from creep measurements of mixes made with the same asphalts. The relationship of indirectly determined T_L to directly determined T_L is used as a test of the dependability of the indirect method.

Mix Used in Comparison

Extensive studies have been made on low void mixes. In our comparison a similar low void mix is used so that the S_{LM} and S_{LA} levels can be assumed to be the same as those established by other investigators. The characteristics of the mix are as follows:

ASTM Sieve Size	Percentage Passing	ASTM Sieve Size	Percentage Passing
5/8 in.	100	No. 10	40
1/2 in.	95	No. 40	18
3/8 in.	82	No. 80	11
1/4 in.	65	No. 200	5

(The aggregate density was 2.82. The asphalt content was 6.2 g/100 g of aggregate. Mixes were prepared and compacted according to California test method 304E.)

The mix is representative of the design mix used in the 1967 construction of I-90 in eastern Washington between Renslow and Rye Grass. A section of I-90 made with this aggregate developed excessive thermally induced cracks during the first and second winters after construction (22).

Asphalts Used in Comparison

Ten types of asphalt made from a wide variety of crude oils and processing methods were used. All of the asphalts have been used to build pavements in the United States or Canada. Two grades of most of these asphalts were included. Test properties of the asphalts used are given in Tables 1 and 2.

Retained samples of the asphalt used on I-90 were not available. However, asphalt 1 was similar to the asphalt used on I-90.

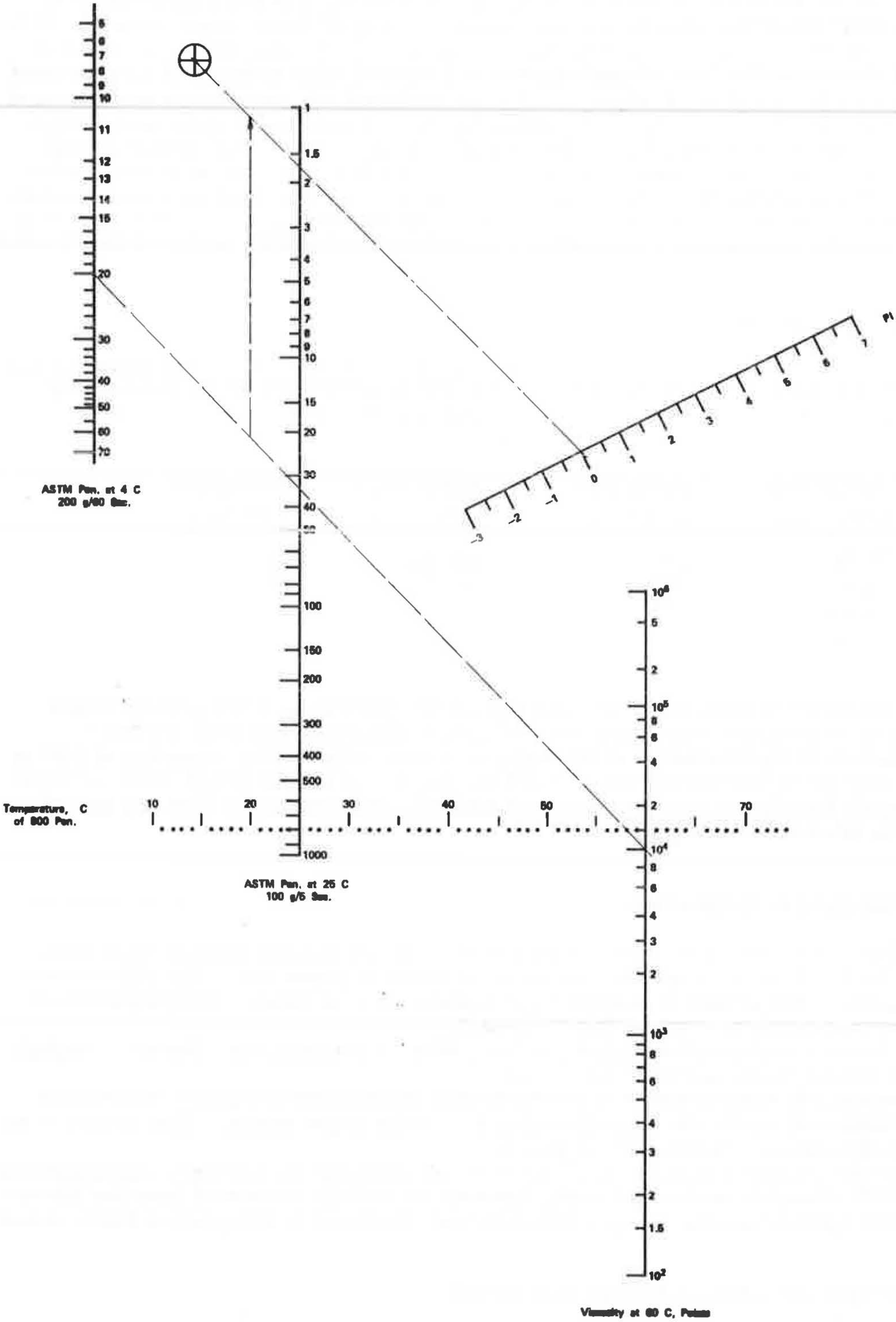
Asphalt 3 is representative of an asphalt that the Washington highway department associates with moderate thermally induced cracking in pavements. They associate no thermally induced cracking with asphalt 6.

Complete tests on asphalts 1, 3, and 6 are not available because there was insufficient material. Complete tests were made, however, on asphalts recovered from the laboratory mix specimens after creep modulus testing. Test results are given in Tables 1 and 2.

STIFFNESS OF ASPHALT-TREATED MIXES

Direct tensile creep measurements to obtain stiffness of asphalt-treated mixes are normally difficult and costly to do, particularly at the low creep rates found in the range of T_L. Tensile measurements are generally much easier and less costly when made on

Figure 1. Nomograph for obtaining PI and T_{800} penetration from ASTM tests.



cylindrical specimens tested in the split-tension or diametral configuration. In the diametral configuration a stress is applied across a vertical diameter of a cylinder, and the resultant deformation across the horizontal diameter is measured.

Very small deformations obtained at low temperatures require extra sensitive and stable instrumentation. An instrument having these requirements is routinely used to measure the dynamic stiffness or resilient modulus of Hveem or Marshall specimens (23). This instrument can also be used for creep measurements. Instead of the dynamic loads normally used with the resilient modulus device, a static load is applied to the specimen by an air-driven piston.

Deformations are determined at several temperatures and are recorded on a variable-speed strip chart. The data are translated into curves of stiffness versus time of loading. Subsequently, these curves are combined by the superposition shift method into a master curve. These master curves for each specimen permit the stiffness at any temperature or time of loading to be determined. As previously discussed, the loading time of interest is 10,000 sec. Superposition shifts can be omitted if the creep measurements are made in 10,000-sec time periods. Because this was not practical, generation of the master curve allows the 10,000-sec stiffness to be projected from shorter time data.

Curves of stiffness at 10,000 sec versus temperature were then constructed. An example of mixes used to make the previously described pavements in eastern Washington is shown in Figure 2. Each of these pavements had a different resistance to thermally induced cracking. The difference in field behavior (no cracking to severe cracking) is reflected by the 18-deg spread shown in T_L at which 10,000-sec S_{LM} equals 1,500 ksi (10 300 MPa). The laboratory specimens shown in Figure 2 were made from the same asphalts and aggregate used in the pavements. The 18-deg spread in T_L and reported field performance qualitatively support the idea that measured mix stiffness is related to thermally induced cracking.

Laboratory-prepared asphalt concrete specimens were made from each of the asphalts given in Tables 1 and 2 by using a Hveem kneading compactor. Densities and diametrally measured T_L values for each of these specimens are given in Tables 1 and 2.

ESTIMATING T_L INDIRECTLY FROM ASPHALT BINDER PROPERTIES

van der Poel's (11) nomograph was used to estimate the T_L of the asphalt binders for an S_{LA} of 20,000 psi (138 000 kPa) when stressed for 10,000 sec. The penetration indexes (PI) and temperature at which the penetration is 800 (T_{800}) used in van der Poel's nomograph were determined from Heukelom's bitumen test data chart (12) for showing the effect of temperature on the physical behavior of asphaltic bitumen. With Heukelom's chart, a number of different routine test results can be used to estimate the stiffness of the asphalt. This recent chart no longer requires that the penetration at 77 F (25 C) and softening point be the sole criteria of asphalt characteristics. Penetrations and viscosities at any temperature can be used. This allows the low-temperature stiffness to be estimated by a number of different combinations of test results.

Heukelom's test data chart does not provide for the use of the conventional ASTM low-temperature penetration, i.e., penetrations determined at a 200-g load for 60 sec. All penetration values on Heukelom's chart are for 5-sec, 100-g loading. Figure 1 is derived from the Heukelom test data chart and permits the conventional ASTM low-temperature penetrations to be used. The scale relating ASTM penetrations at 39.2 F (4 C) to the scale used by Heukelom was developed empirically by correlating a large number of penetration tests made at 39.2 F at both test conditions. This nomograph is used in the same way as the original Heukelom nomograph. That is, a line is drawn connecting a point representing the penetration at 39.2 F (4 C) with a point representing the penetration at 77 F (25 C) or with the viscosity at 140 F (60 C). The temperature of 800 penetration is taken from the intercept of this line with the horizontal scale. Another line is then drawn through the reference point parallel to the first line. The intercept with the PI scale gives the PI value.

Table 1. Properties of original asphalts and RTF-C oven residua.

	Original Asphalt					Residua From RTF-C Oven Exposure						
	Penetration (dmm)			Viscosity		Penetration (dmm)			Viscosity		Ductility (cm)	
Symbol on Figures	77 F, 100 g, 5 Sec	39.2 F, 200 g, 60 Sec	Softening Point (F)	140 F (poises)	275 F (stokes)	77 F, 100 g, 5 Sec	39.2 F, 200 g, 60 Sec	Softening Point (F)	140 F (poises)	275 F (stokes)	45 F, 1 cm/ Min	77 F, 5 cm/ Min
●	111	38	118.5	1,273	2.52	63	25	130.5	4,080	4.17	11	135
●	157	52	109.5	690	1.92	86	32	120.5	1,992	2.98	27	150+
×	121	38	117.5	777	2.10	70	20	124.5	1,955	3.25	20	150+
×	91	27	123.0	1,352	2.83	53	16	132.0	3,795	4.42	13	142
△	150	52	117.5	771	3.00	89	37	125.5	2,191	4.53	13	112
△	129	47	121.5	1,124	3.44	76	31	131.0	3,567	5.34	9	68
□	197	61	110.5	679	2.68	96	32	125.5	2,011	4.47	118	150+
+	36	7	129.5	2,903	3.48	25	7	136.0	6,687	4.83	4	106
○	278	84	105.5	556	2.52	105	35	122.5	2,241	4.93	36	150+
○	117	41	117.0	1,563	4.07	60	23	129.5	5,647	7.47	23	150+
▽	60	15	122.5	1,742	2.54	38	14	136.5	3,493	3.57	13	150+
▽	85	26	114.0	1,125	2.11	53	14	127.0	2,597	3.00	106	150+
⌓	106	29	119.5	795	2.53	68	18	121.5	1,386	3.11	30	150+
◡	217	67	106.5	565	2.17	104	38	120.5	1,940	3.62	78	150+
◡	150	51	112.5	913	2.80	75	27	127.5	3,683	5.22	24	150+
◇	72	19	124.5	1,550	3.33	40	10	134.0	3,881	4.70	7	150+
◇	105	25	118.0	916	2.58	60	13	128.0	2,009	3.58	8	150+
①	92	—	—	900	2.20	48	—	—	2,300	3.30	35	—
③	92	—	—	1,650	3.05	52	—	—	4,800	5.00	14	—
⑥	92	—	—	1,350	2.50	50	—	—	3,100	2.52	100+	—

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

Table 2. Properties of residua recovered from creep specimens and mix specimens tested in creep.

	Residua Recovered From Specimens Tested in Creep						Mix Specimens Tested in Creep		
	Penetration (dmm)			Viscosity					
Symbol on Figures	77 F, 100 g, 5 Sec	39.2 F, 200 g, 60 Sec	Softening Point (F)	140 F (poises)	275 F (stokes)	Ductility at 45 F, 1 cm/ Min (cm)	Density (lb/ft^3)	Volatile Fraction of Aggregate	T_L (F)
●	55	27	133.5	5,123	4.43	8	150.9	0.82	-13
●	92	37	123.0	1,750	2.89	44	150.7	0.82	-20
×	61	23	124.5	2,429	3.51	33	151.5	0.82	-6
×	60	17	135.5	7,103	5.79	8	151.7	0.82	0
△	115	46	121.5	1,468	3.76	24	149.7	0.81	-17
△	84	39	127.0	1,691	3.59	14	151.6	0.82	-15
□	87	34	125.0	2,912	5.32	38	153.5	0.83	-7
+	36	12	132.0	3,595	4.05	6	152.2	0.82	+10
○	104	39	122.0	2,091	4.64	101	151.4	0.82	-16
○	74	33	129.0	3,877	6.43	52	151.2	0.82	-10
▽	47	14	132.5	3,524	3.63	24	152.1	0.82	+4
▽	40	14	128.5	3,686	3.72	20	152.3	0.82	+2
⌓	62	20	128.0	1,993	3.39	18	151.4	0.82	+4
◡	125	44	116.5	1,360	3.25	139	153.4	0.83	-15
◡	90	35	118.5	2,349	4.19	127	153.5	0.83	-11
◇	38	15	132.0	4,453	4.89	7	153.4	0.83	+4
◇	64	22	120.5	2,044	3.63	23	154.6	0.84	0
①	32	12	133.5	4,336	4.16	17	154.3	0.83	+12
③	39	15	133.5	5,201	4.65	12	154.5	0.84	+1
⑥	50	19	130.0	3,841	4.42	14	154.3	0.83	-6

Note: 1 F = 1.8 C + 32; 1 poise = 0.1 Pa·s; 1 stoke = 0.0001 m^2/s; 1 lb/ft^3 = 16 kg/m^3.

Figure 2. Determination of T_L.

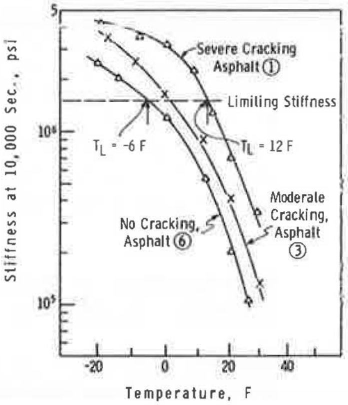


Figure 3. T_L predicted from penetrations at 77 F and 39.2 F of RTF-C residua.

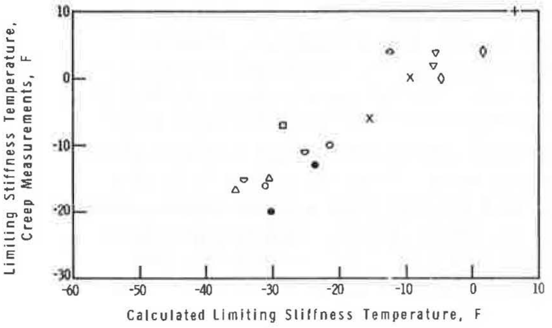
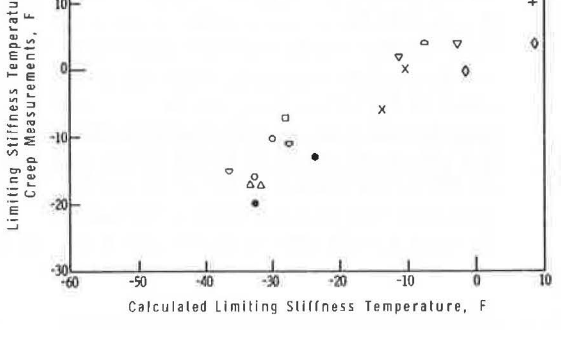


Figure 4. T_L predicted from penetrations at 39.2 F and viscosities at 140 F of RTF-C residua.



COMPARISON OF MEASURED T_L WITH T_L ESTIMATED FROM RTF-C RESIDUA

As previously discussed, the purpose of this investigation is to compare measured T_L with T_L estimated from ordinary ASTM asphalt tests.

Penetrations at 77 and 39.2 F (25 and 4 C)

A comparison of T_L values obtained by diametral creep measurements on the mixes with T_L values estimated from the ASTM penetrations at 77 and 39.2 F (25 and 4 C) of the RTF-C residua is shown in Figure 3. The correlation is good, but the relationship is shifted about 10 deg. There are no large outliers. A difference of 10 to 15 deg between the measured and calculated T_L values is an inherent limitation of estimating the stiffness of a mix from the stiffness of an asphalt. It is only expected to be accurate to within 2 or 3 deg of the actual stiffness of a mix. For this comparison, the same aggregate was used in all cases so that a consistent bias (or mix factor) exists in all samples.

Viscosity at 140 F (60 C) and Penetration at 39.2 F (4 C)

As shown in Figure 4, T_L values estimated from viscosity at 140 F (60 C) and penetration at 39.2 F (4 C) also correlate well with measured T_L values. Again there are no outliers.

Penetration at 77 F (25 C) and Softening Point

Figure 5 shows that T_L values estimated from penetration at 77 F (25 C) and softening point correlate poorly. Outliers are not limited to waxy asphalts.

Penetration at 77 F (25 C) and Viscosity at 140 F (60 C)

Figure 6 shows that T_L values estimated from penetration at 77 F (25 C) and viscosity at 140 F (60 C) also correlate poorly.

Viscosity at 140 F (60 C) and Viscosity at 275 F (135 C)

As shown in Figure 7, there is no correlation between the measured T_L and the T_L estimated from the viscosities at 140 and 275 F (60 and 135 C). These tests appear to be useless for estimating low-temperature stiffness.

Comparison of T_L and Ductility at 45 F (7.2 C)

Ductility at low temperature is often assumed to relate to pavement performance. No method is available to translate this property to a T_L; therefore, the significance of the ductility value could not be tested in the same way as were the other tests. Instead, the ductility values were plotted against the viscosity at 140 F (RTF-C residua). Ductility values were interpolated or extrapolated to 2,000 and 4,000 poises (200 and 400 Pa·s). (These are the center points of the viscosities of the AR-2000 and AR-4000 grades of asphalt as defined in the Pacific Coast uniform paving asphalt specification.) These adjusted ductility values are shown in Figures 8 and 9 versus measured T_L values (also interpolated to the same asphalt grades). No correlation is shown between ductilities at 45 F (7.2 C) and measured T_L for either the 2000 or 4000 grade asphalts.

Figure 5. T_L predicted from penetrations at 77 F and softening points of RTF-C residua.

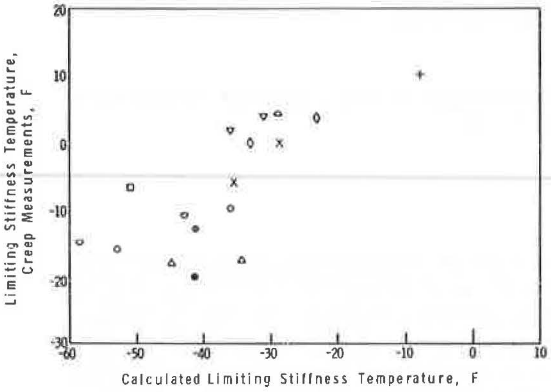


Figure 6. T_L predicted from penetrations at 77 F and viscosities at 140 F of RTF-C residua.

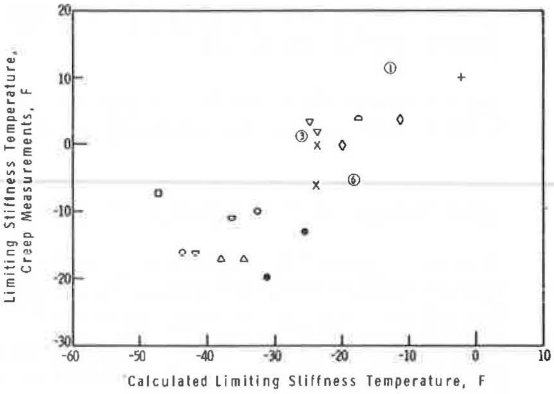


Figure 7. T_L predicted from viscosities at 140 F and 275 F of RTF-C residua.

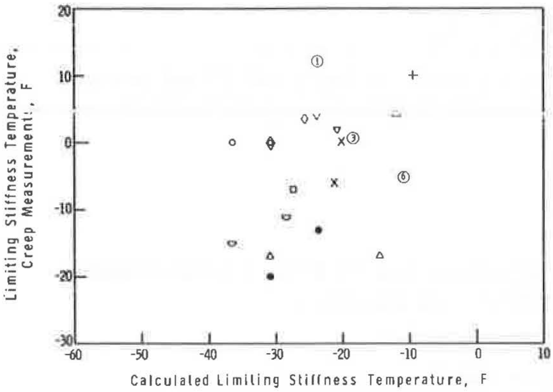


Figure 8. Relationship of T_L of pavements and ductilities at 45 F of RTF-C residua, AR-2000 graded asphalt.

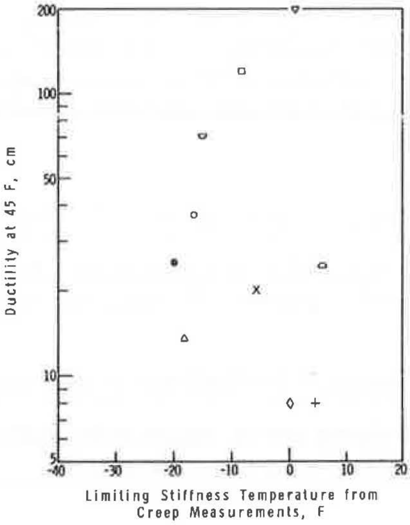


Figure 9. Relationship of T_L of pavements and ductilities at 45 F of RTF-C residua, AR-4000 graded asphalt.

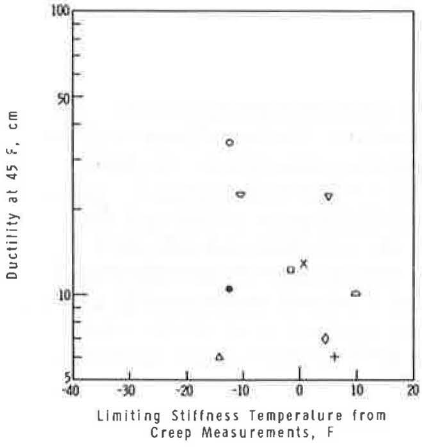
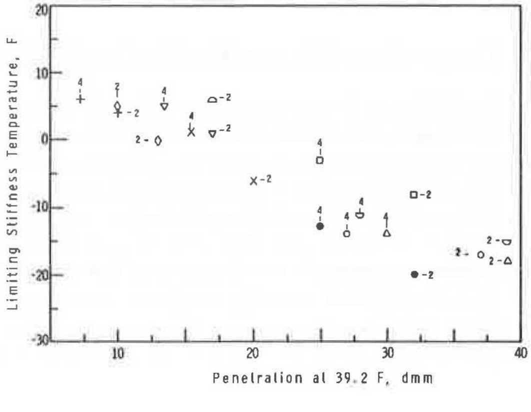


Figure 10. Relationship of T_L and penetrations at 39.2 F of RTF-C residua (2 = AR-2000 grade and 4 = AR-4000 grade).



A similar lack of correlation is shown when T_L and 45 F ductilities are adjusted to penetration grades. Fromm and Phang's extensive studies (10) also showed no correlation between low-temperature ductilities and the extent of thermally induced pavement cracking.

This lack of correlation is not surprising because the ductility test involves both the viscosity and the shear sensitivity of a material. A ductility value makes no distinction between these two properties. Ductility may be significant when it is determined at the same temperature as another test, such as the penetration test, which can be used to estimate stiffness. That is, for a given stiffness, the shear sensitivity as measured by ductility may be of significance. However, when comparisons are made at different stiffnesses, the meaning of ductility appears to be obscured.

COMPARISON OF MEASURED T_L AND PROPERTIES OF RECOVERED ASPHALTS

Measured T_L values were also shown to correlate well with the T_L values estimated from penetration at 39.2 F (4 C) with penetration at 77 F (25 C) or viscosity at 140 F (60 C) of residua recovered from the specimens.

Poor correlations were obtained for T_L estimated from penetration at 77 F and softening point or viscosity at 140 F. No correlation was found with T_L estimated from viscosities at 140 and 275 F. Also, no correlation was found between ductilities and T_L.

PRACTICAL USE OF ASTM 39.2 F (4 C) PENETRATION TO CONTROL T_L

The excellent correlation shown in Figure 4 between T_L obtained from penetration at 39.2 F (4 C) of the RTF-C residua and the viscosity at 140 F suggests that T_L can be obtained from the penetration at 39.2 F of an AR-graded asphalt (RTF-C residue viscosity at 140 F). Figure 10 shows this for the same series of asphalts interpolated for AR-2000 and AR-4000 grades. Both sets of data superpose to form a single band. The importance of using both a softer asphalt and one having a lower temperature susceptibility is evident.

This single curve supports the concept that specifying asphalts with higher penetrations at 39.2 F will limit thermally induced pavement cracking. The limits should be set at levels consistent with available asphalt supplies and the minimum pavement temperature expected.

CONCLUSIONS

1. The relationship reported between thermally induced pavement cracking and the T_L value at which the 10,000-sec asphalt stiffness is 20,000 psi (138 000 kPa) is qualitatively supported by field tests.
2. T_L estimated from ASTM penetration at 39.2 F (4 C), along with the ASTM penetration at 77 F (25 C) or with the viscosity at 140 F (60 C) on RTF-C oven residua, correlates well with measured T_L. This good correlation has no large outliers even though an extreme diversity of asphalt types was included. The use of penetration at 39.2 F (4 C) on an RTF-C residue is supported as a specification requirement for AR-graded asphalts. With penetration or AC-graded asphalts, penetration at 77 F or a viscosity at 140 F on the oven residue is also needed.
3. Good correlation is also found on asphalts recovered from the mixes.
4. Poor correlations are shown between T_L and penetration at 77 F along with softening point or with viscosity at 140 F on both RTF-C and recovered residua.
5. T_L estimated from viscosities at 140 F, along with viscosities at 275 F on RTF-C or recovered residua, shows no correlation with measured T_L. Resistance to low-

temperature thermally induced cracking should not be implied on diverse types of asphalts based on high-temperature viscosity measurements.

6. Ductilities at 45 F show no correlation with T_L, possibly because the ductility test cannot distinguish between the shear sensitivity and the viscosity or stiffness of asphalts. Despite the lack of correlation of the 45 F ductility with T_L, the conventional ductility test at 77 F together with a penetration test at 77 F may have significance in limiting types of pavement failure other than thermally induced cracking.

7. Tensile stiffness and, in turn, T_L of asphalt-treated aggregate mixes are readily measured by compression-stressing cylindrical specimens across a vertical diameter while the resultant tensile deformation across a horizontal diameter (i.e., diametral creep measurement) is measured.

8. The modified asphalt test data chart permits the low-temperature stiffness of asphalts to be determined from normal ASTM penetration tests.

ACKNOWLEDGMENT

The author greatly appreciates the help and suggestions given during the course of this project by R. V. Le Clerc and T. Marshall of the Washington State Highway Department.

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DISCUSSION

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This is a very fine paper that should be studied by all who have an interest in the low-temperature performance of asphaltic mixtures and in particular by those who have an interest in asphalt specifications. This paper shows the importance of measuring the stiffness or consistency of asphalt binders at lower temperatures to control the low-temperature properties of asphalt mixtures. Data shown in Figure 8 illustrate the point made at the Symposium on Viscosity Grading of Asphalts at the 1971 Highway Research Board Annual Meeting (25) that viscosities at 140 and 275 F (60 and 135 C) do not give satisfactory control of binder or mix properties at lower temperatures.

The nomograph shown in Figure 2 should be very helpful in making use of ASTM penetrations at 39.2 F (4 C). That the correlation between the calculated limiting stiffness and the measured limiting stiffness improves when lower temperature penetration test results are used in the calculations suggests the importance of investigating still lower temperature penetration methods.

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