Evaluation of Asphalt Cements for Low-Temperature Performance

SUI C. LEUNG AND KENNETH O. ANDERSON

The primary objective of this research project was an evaluation of the temperature susceptibility and low-temperature fracture characteristics of asphalt cements from heavy crude sources in western Canada. Six samples of asphalt of grades 85/100 and 200/300 formulated from crude oils from Cold Lake, Lloydminster, and Redwater sources were tested to determine their physical properties. They were also used to prepare Marshall specimens for testing by the low-temperature indirect tensile test method at temperatures of 0°C, –10°C, –20°C, and –30°C. From the results of the laboratory tests, it is concluded that the Redwater asphalt is the most temperature susceptible of the three asphalts studied. It was also confirmed that temperature as well as grade and crude source of asphalts have quite marked effects on the tensile properties of asphalt concrete mixtures. The asphalt cements produced from heavy crude sources of the Cold Lake and Lloydminster areas have been found to perform better at low temperature than those produced from the lighter crude source of the Redwater area. The 200/300 asphalt is also expected to perform better than the 85/100 asphalt. These observations are based on failure strain and stiffness values obtained by means of the indirect tensile test at various temperatures.

Low-temperature cracking of asphalt pavements in cold regions continues to be a major concern for highway and airfield authorities. Improvements in temperature susceptibility and other characteristics of asphalt cements could have a significant impact on performance and costs of these pavements.

The temperature susceptibility of paving asphalt cements has been shown to correlate well with low-temperature behavior of asphalt concrete pavements, particularly with regard to transverse cracking. Asphalt cements produced from heavy crude sources in western Canada have been reported to perform better than those manufactured from lighter crude oils *(1, 2)*.

The primary objective of this research project was an evaluation of the low-temperature performance of asphalt cements produced from different locally available crude sources in western Canada.

Asphalt cements produced from a variety of heavy crude sources were evaluated using conventional physical tests to define rheological properties and temperature susceptibility parameters. Methods used to describe temperature susceptibility over various temperature ranges have been reviewed extensively in the report by Button et al. *(3)*. Four of the mathematical formulas for calculating temperature susceptibility have been used to define these parameters for the asphalt cements studied.

A major problem with these methods is that physical tests are made at temperatures above the critical low-temperature range for expected pavement cracking. To provide information on the behavior of asphalt concrete mixes at temperatures from 0°C to –30°C, asphalt concrete specimens were prepared and tested to determine low-temperature tensile properties with the indirect tensile test used for many years at the University of Alberta *(4)*.

LABORATORY TESTS OF ASPHALTS

Testing Program

A laboratory testing program of selected asphalts was developed and conducted to fulfill several objectives. The first objective was to develop some test data on asphalts from identifiable crude sources. Such data would make possible comparison of the various common properties of other asphalt cements currently in use. The second objective was to evaluate the temperature susceptibility of asphalt cement produced from different crude oils. Last, attempts were made to evaluate the low-temperature tensile properties of the asphalt mixtures that contained asphalts from the different crude sources.

Two grades of asphalt cement samples from different crude sources, which represent asphalt cements of different temperature susceptibilities, were obtained from Esso Petroleum Canada and Husky Oil of Lloydminster.

Two types of laboratory tests were carried out. Conventional physical tests were carried out to define the rheological properties and temperature susceptibility parameters that were used in evaluating the low-temperature performance of the selected asphalt cements.

The indirect tensile test, as used at the University of Alberta and improved in this project, was used to test asphaltic concrete cylinders prepared from the different asphalt cements. The tensile properties obtained from the tests were also used in evaluating the asphalt cements for low-temperature performance.

Description of Asphalt Cement Samples

Two criteria were used for the selection of asphalt cements for laboratory testing. First, the samples were to represent a hard grade of asphalt cement (85/100) and a soft grade (200/300). Second, the selected samples within a given grade were to represent different temperature susceptibilities.

Asphalt cements manufactured from crude oils from different sources were chosen. The Cold Lake asphalt cement and

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Department of Civil Engineering, University of Alberta, Edmonton, Alberta T6G 2G7, Canada.

TABLE 1 PHYSICAL PROPERTIES OF ASPHALT SAMPLES

	Cold Lake Grade		Lloydminster Grade		Redwater Grade	
	85/100	200/300	85/100	200/300	85/100	200/300
Pen at 25°C (dmm)	95	263	94	254	93	242
Pen at 4°C (dmm)	9.0	19.3	6.8	26	5.7	10.3
Vis at 60°C (Pa/sec)[a]	158.2	43.4	189.0	44.8	52.9	19.5
Vis at 135°C (cSt)	340	187	391	202	169	104
Softening point (°C)	45.0	36.0	44.5	36.0	47.0	42.0
Ductility (cm)	+150	+150	+150	+150	+150	+150

[a] Pa/sec = 10 poise.

TABLE 2 TEMPERATURE SUSCEPTIBILITY PARAMETERS

	Cold Lake Grade		Lloydminster Grade		Redwater Grade	
	85/100	200/300	85/100	200/300	85/100	200/300
PI(dPen/dT)	−1.27	−1.89	−1.93	−1.06	−2.28	−2.96
PI(R&B)	−0.95	−0.61	−1.14	−0.81	−0.40	+1.87
PVN(25-60)	−0.36	−0.01	−0.19	−0.04	−1.56	−1.18
PVN(25-135)	−0.53	−0.25	−0.33	−0.16	−1.61	−1.46

the Redwater-Gulf blend asphalt cement were obtained from Esso Petroleum Canada. The Cold Lake asphalt cement, produced from heavy crude oils, was considered to have low-temperature susceptibility. The Redwater-Gulf blend asphalt cement was specially formulated from lighter crude oils to exhibit high-temperature susceptibility. This blend was chosen in order to have the greatest possible difference in temperature susceptibility among samples. For purposes of comparison, the asphalt cement produced from the heavy crude oils of the Lloydminster area was obtained from Husky Oil of Lloydminster. This asphalt cement was also considered to have low-temperature susceptibility. A total of six asphalt cement samples were chosen for laboratory testing.

Conventional Physical Tests

In this laboratory testing program, only the common physical tests of asphalt cements were carried out on the six samples. The primary emphasis was on the evaluation of the consistency properties of the materials, such as viscosity, penetration, and ductility, and the temperature susceptibility parameters of the materials, such as penetration index (PI) and pen-vis number (PVN).

Standard ASTM testing procedures were used for all of the physical tests. Penetration tests at 25°C and 4°C were made following ASTM D 5 procedures (loading the needle with 100 g for 5 sec). For viscosity tests at 135°C and 60°C, ASTM methods D 2170 and D 2171 were followed.

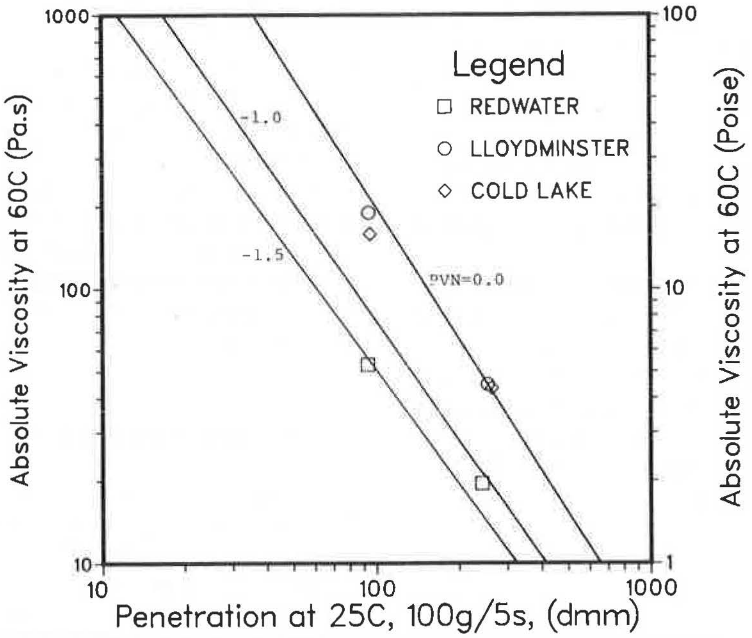

FIGURE 1 Relationship between absolute viscosity at 60°C and penetration at 25°C.

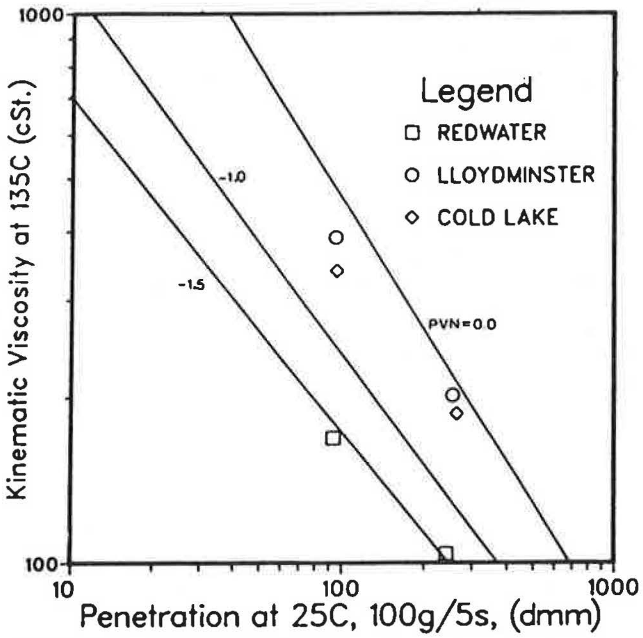

FIGURE 2 Relationship between kinematic viscosity at 135°C and penetration at 25°C.

DISCUSSION OF PHYSICAL TEST RESULTS

Physical Properties

Table 1 gives a summary of the results of the physical tests carried out in this phase of research. Reported values are averages of five individual tests, except for softening point and ductility.

From the table, it is noted that the penetration at 25°C of the asphalts from all sources is quite uniform. However, the penetration at 4°C differs substantially among sources of the same grade. The Redwater-Gulf blend asphalt has the lowest penetration value at 4°C of the three asphalts of each grade. This indicates that the Redwater-Gulf blend asphalt is harder than the Cold Lake and Lloydminster asphalts at low temperature even though they have similar penetration values at 25°C.

The viscosities (at both 135°C and 60°C) of the Redwater-Gulf blend asphalt are particularly low (for both grades) compared with the viscosities of the asphalts from Cold Lake and Lloydminster. The consistency measurements of the Cold Lake and Lloydminster asphalts are similar in most respects.

The Redwater-Gulf blend asphalt, particularly the 200/300 grade, has the highest ring-and-ball softening point of the three asphalts. The ductility of all of the asphalts meets the specification requirement of a minimum extension of 150 cm at 25°C.

Figures 1 and 2 show the absolute viscosity at 60°C and the kinematic viscosity at 135°C plotted against penetration at 25°C. The suppliers report slightly different values, but all are within acceptable multilaboratory precision.

Temperature Susceptibility Parameters

Table 2 gives the temperature susceptibility parameters, PVN(25-60), PVN(25-135), PI[ring and ball (R&B)] and PI(dPen/dT), using data from Table 1 and commonly used equations *(3)*.

The first two parameters are those introduced by McLeod *(5, 6)*, and the latter two are those developed by Pfeiffer and Van Doormal *(7*, p. 414) and Pfeiffer *(8*, p. 161). Numerous other investigators have used these methods to evaluate temperature susceptibility of asphalt cements, and for brevity further descriptions of the methods are not given in this paper.

The Redwater-Gulf blend asphalt is the most temperature susceptible in both grades according to the PVN and PI(dPen/dT) methods. On the contrary, the PI(R&B) method shows that this asphalt is the least temperature susceptible, which, obviously, is not correct. The Redwater-Gulf blend asphalt appears to be a waxy asphalt, which gives false R&B softening points that lead to erroneous values of PI(R&B).

The temperature susceptibilities of the Cold Lake and Lloydminster asphalts are quite similar, and the different parameters do not consistently distinguish the order of their temperature susceptibility. For the 85/100 asphalt samples, PVN-values indicate that the Cold Lake asphalt is slightly more temperature susceptible than the Lloydminster asphalt with a maximum numerical difference of PVN-values of 0.20. However, both the PI(dPen/dT) and the PI(R&B) values indicate the contrary. They indicate that the Lloydminster asphalt is more temperature susceptible as shown by the lower PI-values. The maximum numerical differences are 0.65 and 0.19, respectively.

For the 200/300 asphalt samples, PVN-values indicate that the temperature susceptibilities of both the Lloydminster and the Cold Lake asphalt are quite similar with a maximum numerical difference of only 0.09. However, the values of PI(dPen/dT) indicate that the Cold Lake asphalt is more temperature susceptible than is the Lloydminster asphalt whereas the values of PI(R&B) indicate the contrary. The PI(dPen/dT) of the Cold Lake sample is 0.83 more negative than the value of the Lloydminster sample whereas the PI(R&B) of the Lloydminster sample is 0.20 more.

The values of PVN(25-60) and PVN(25-135) are quite similar, and PVN(25-135) generally has a slightly lower value. The maximum numerical difference is 0.28.

The values of PI and PVN are not equal. The values of PI(dPen/dT) of all of the test samples are substantially lower than the corresponding values of PVN(25-60) and PVN(25-135). The maximum numerical difference is as much as 1.88. This observation is not surprising because Puzinauskas *(9)* has presented test results that show poor correlation between these parameters and others used to describe the temperature susceptibility of asphalts.

The difference may well be because the PI(dPen/dT) employs two penetration readings within the lower temperature range whereas the PVN methods use penetration and viscosity values within a higher temperature range. The lower values of PI(dPen/dT) indicate that the temperature susceptibility of these asphalts is greater at low temperature than at high temperature.

On the basis of these test data it may be observed that the values of PVN(25-135) are good indicators of temperature susceptibility in the high-temperature range; however, the PI using the slope of the log penetration versus temperature is a better indication of the temperature susceptibility of an asphalt over the lower temperature range.

INDIRECT TENSILE TEST

Summary of Method

The indirect tensile test method involves loading an asphalt concrete cylinder via loading strips across a diameter in a compression testing frame and within a controlled temperature chamber maintained at a constant low temperature. Output signals from a load cell and three linear variable differential transformers are recorded on floppy diskette by means of a datalog card installed on a microcomputer. Computer programs to analyze the test data developed for mainframe computers (*10*, p. 157) have been recently updated for microcomputer use (*11*). The raw data recorded in the diskette are processed using the Lotus 1-2-3 spreadsheet program, and the tensile failure stress, strain, stiffness, and stress-strain diagram are obtained.

Description of Asphalt Concrete Specimens

Two grades of asphalt from three different crude sources were used in preparing the laboratory asphalt concrete specimens. The rheological properties of these asphalts were described in the section on physical properties.

The laboratory specimens were prepared from locally available aggregates, TBG–Clover Bar 12.5-mm crushed gravel. The gradation of this aggregate is given in Table 3.

In accordance with standard Marshall design procedures (ASTM D 1559), an asphalt content of 6 percent by weight of aggregate was chosen as an approximate optimum content for the asphalt concrete mixtures. Twenty Marshall briquette specimens were fabricated with each of the six different asphalts. Each specimen was fabricated under the same conditions: 50 hammer blows at each end of the specimen and a compaction temperature of 130°C and 135°C, respectively, for the 200/300 and 85/100 asphalts.

The bulk specific gravity of each specimen was then determined by weighing each specimen in air and immersed in water. Groups of five specimens were arranged for testing at different temperatures according to their bulk specific gravities; each group had similar average densities.

TABLE 3 AGGREGATE GRADATION

Sieve Size (mm)	Approximate U.S. Standard	Percentage Passing
20	3/4 in.	100
12.5	1/2 in.	99.8
10.0	3/8 in.	95.4
5.0	No. 4	70.6
2.0	No. 10	50.6
0.800	No. 20	38.7
0.400	No. 40	28.9
0.160	No. 100	15.8
0.063	No. 230	11.2

Testing Conditions

All of the testing was carried out in accordance with the procedures described by Button et al. *(4)* and McLeod *(6)* at temperatures of 0°C, –10°C, –20°C, and –30°C.

The loading rate of the testing machine was set at a nominal rate of 1.5 mm/min and kept unchanged throughout.

A more comprehensive discussion of the test program and methods of testing is given in the thesis on which this paper is based (*12*, p. 164).

DISCUSSION OF INDIRECT TENSILE TEST RESULTS

Test Results

Table 4 gives a summary of the average stress, strain, and secant stiffness moduli of the test specimens at failure. Figures 3–5 show plots of average failure stress, failure strain, and failure stiffness modulus versus temperature for each of the six different asphalt concrete mixtures.

TABLE 4 AVERAGE FAILURE STRESS, STRAIN, AND STIFFNESS OF TEST SPECIMENS

		85/100			200/300		
Crude Source	Test Temp. (°C)	Failure Stress (kPa)	Failure Strain (x 10⁻⁴)	Failure Stiffness (mPa)	Failure Stress (kPa)	Failure Strain (x 10⁻⁴)	Failure Stiffness (mPa)
Redwater-Gulf Blend	0	1437	47	624	1049	87	236
	-10	2125	11	3895	2073	17	4706
	-20	2133	4	9639	2708	16	3282
	-30	2177	4	10019	2839	5	10242
Lloydminster	0	1258	102	236	660	140	91
	-10	2352	22	2468	1213	54	431
	-20	2554	7	7259	2815	40	1525
	-30	2406	6	7514	2770	4	12070
Cold Lake	0	1383	68	372	722	121	112
	-10	2179	23	1800	1640	28	1235
	-20	2616	6	8183	2424	21	2253
	-30	2710	6	9231	3013	6	9749

Conversions: 1 kPa = 0.145 psi 1 mPa = 145 psi

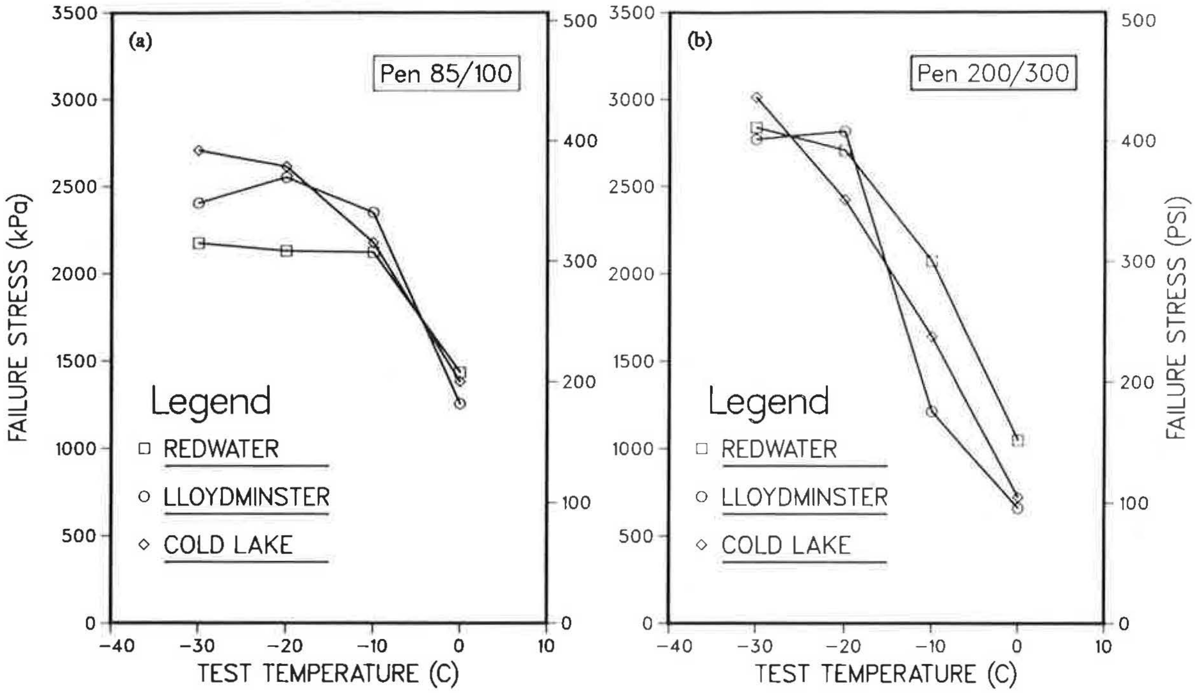

FIGURE 3 Failure stress–temperature relationships.

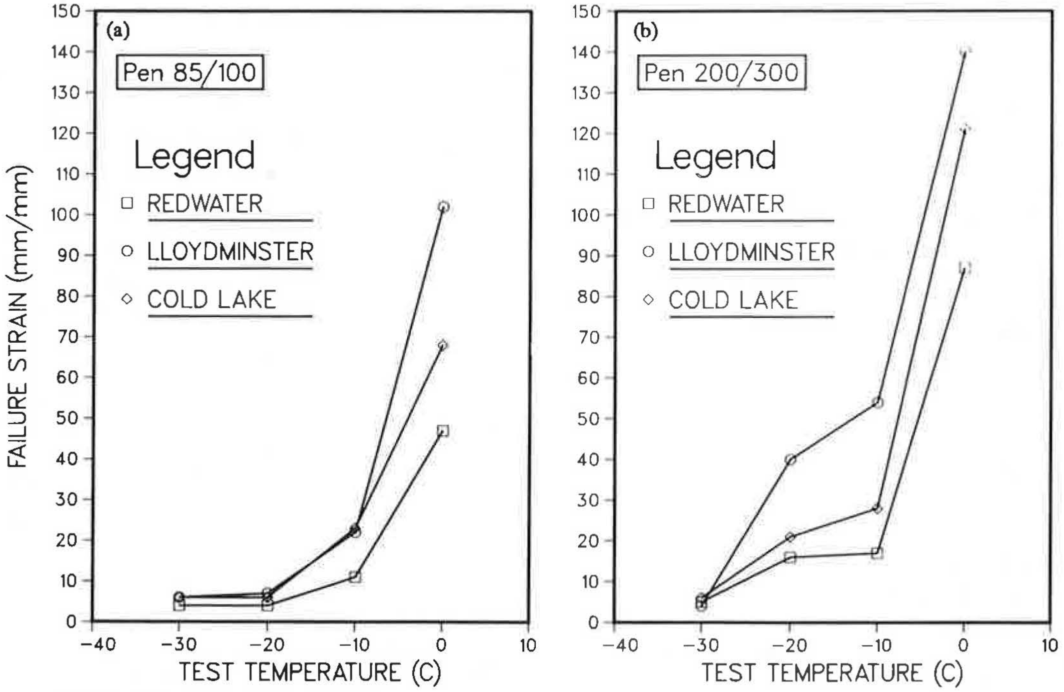

FIGURE 4 Failure strain–temperature relationships.

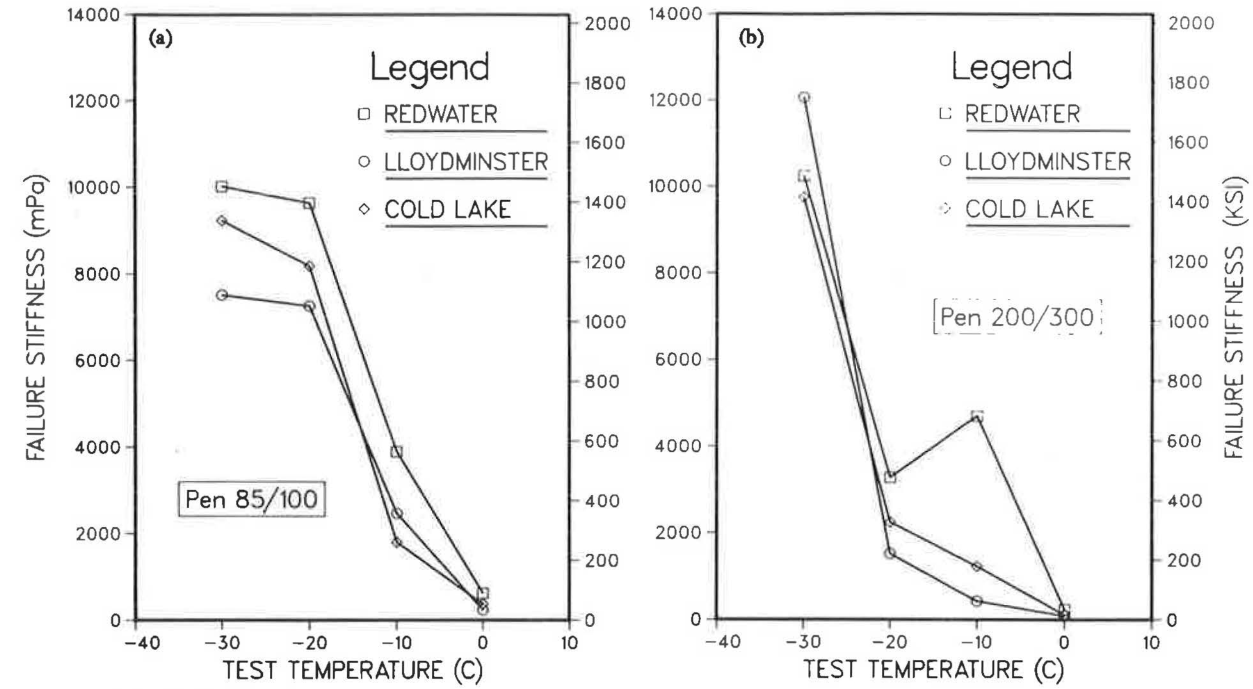

FIGURE 5 Failure stiffness–temperature relationships.

Failure Stress–Temperature Relationships

From the tabulated data and plots, it can be noted that test temperature has a quite significant effect on the failure stress of the asphalt concrete mixtures.

In general, failure stress increases as test temperature decreases. The trend is particularly apparent at moderately cold temperatures (i.e., 0°C to –10°C). At colder temperatures the rate of increase of failure stress with decreasing temperature appears to become smaller. From Figure 3, it can be noted that failure stress ceases to increase as rapidly at test temperatures below –10°C and –20°C for 85/100 and 200/300 asphalt mixtures, respectively.

Failure Strain–Temperature Relationships

The failure strain of the test specimens is also affected remarkably by test temperature. In general, failure strain decreases as test temperature decreases. The rate of decrease is large as the test temperature changes from 0°C to –10°C. The rate of change becomes smaller as the test temperature diminishes further. At very cold temperatures, for example below –20°C, the asphalt specimens show little strain at failure and the failure strain remains relatively constant.

It appears that there is some critical temperature below which failure strain remains relatively unchanged. This critical temperature appears to be a function of asphalt grade. For grade 85/100, this temperature is around –20°C, and for grade 200/300, it is approximately –30°C.

Failure Stiffness–Temperature Relationships

Figure 5 shows failure stiffness–temperature relationships for the two grades of asphalt cement. The stiffness value used has been considered the tensile stiffness modulus taking into account the biaxial state of stress in the cylinder under loading *(4, 5)*.

Failure stiffness generally increases as test temperature decreases. The 85/100 asphalt concrete mixture exhibits a rapid increase in stiffness when the test temperature drops from 0°C to –20°C. The increase in stiffness is only slight when the test temperature drops from –20°C to –30°C.

On the contrary, the 200/300 asphalt concrete mixtures show only slight increase in stiffness during a drop of test temperature from 0°C to –10°C, and there is a rapid increase in stiffness from –2°C to –30°C. There appears to be an anomaly with the Redwater material, which may be due in part to the lack of accuracy of the test method at these lower temperatures.

Effect of Crude Source

Figures 6–8 show the average stress-strain curves of the test specimens with asphalts from different crude source at different test temperatures.

For the 85/100 specimens, the average tensile failure stress is approximately the same irrespective of crude source. However, the average failure strain is markedly smaller for the Redwater asphalt concrete. The difference is greater at 0°C and –10°C and becomes negligible at –20°C and colder.

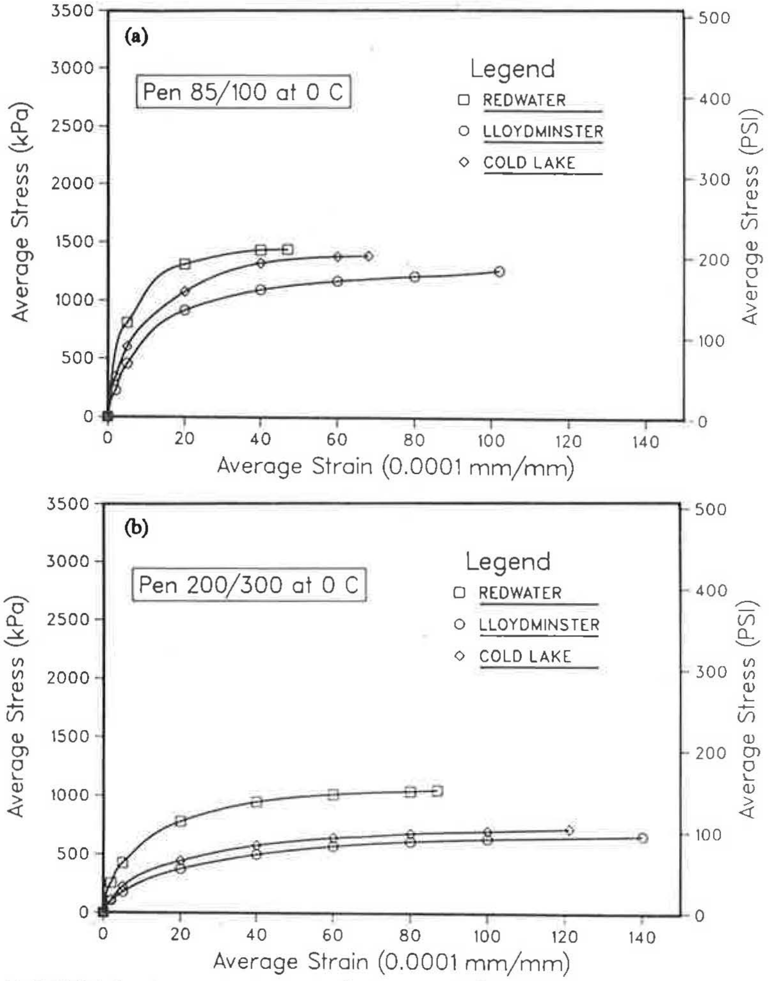

FIGURE 6 Average stress-strain curves at 0°C.

For the 200/300 specimens, the average tensile failure stress of the Redwater asphalt concrete is higher than that of the Cold Lake and the Lloydminster asphalt concretes at 0°C and –10°C. At temperatures of –20°C and colder, the difference becomes smaller. The average failure strain of the 200/300 Redwater specimens is similar to that of the 85/100 grade and is markedly smaller than that of the Cold Lake and Lloydminster mixtures. The difference is greater from 0°C to –20°C and becomes almost zero at –30°C.

The stiffness modulus of the Redwater asphalt concrete as shown in Figure 5 is slightly higher than those of the Cold Lake and Lloydminster mixtures at most test temperatures.

Effect of Asphalt Grade

Comparing Figures 3a and 3b, it can be noted that the failure stress of the softer grade asphalt concrete at 0°C and –10°C is smaller than that of the harder grade. Although this phenomenon is not unexpected, it is interesting to note that at –30°C the phenomenon is reversed and the failure stress of the 200/300 grade is higher than that of the 85/100 grade.

Again, comparing Figures 4a and 4b, it can be noted that the failure strain of the 200/300 grade is generally higher than that of the 85/100 grade except at a test temperature of –30°C. At –30°C the failure strains of both grades are quite similar.

Comparing Figures 5a and 5b, it can be noted that the failure stiffness modulus of the 85/100 grade is greater than that of the 200/300 grade at test temperatures about –20°C. At –30°C the 200/300 mixture becomes stiffer. This is in agreement with the results discussed previously.

Low-Temperature Performance of Asphalts

On the basis of the results of the laboratory tests to determine the tensile properties of asphalt cements and asphalt concrete mixtures, it is believed that the asphalt cements produced from heavy crude sources of the Cold Lake and Lloydminster areas perform better at low temperatures than do those produced from the lighter crude source of the Redwater area.

This observation is justified by the results of the indirect tensile test that show that the Cold Lake and Lloydminster asphalt concrete mixtures can sustain larger strain at failure. This is considered an important property for resistance to thermally induced cracking.

Furthermore, the lower tensile stiffness moduli of the Cold Lake and Lloydminster asphalt concrete mixtures imply that

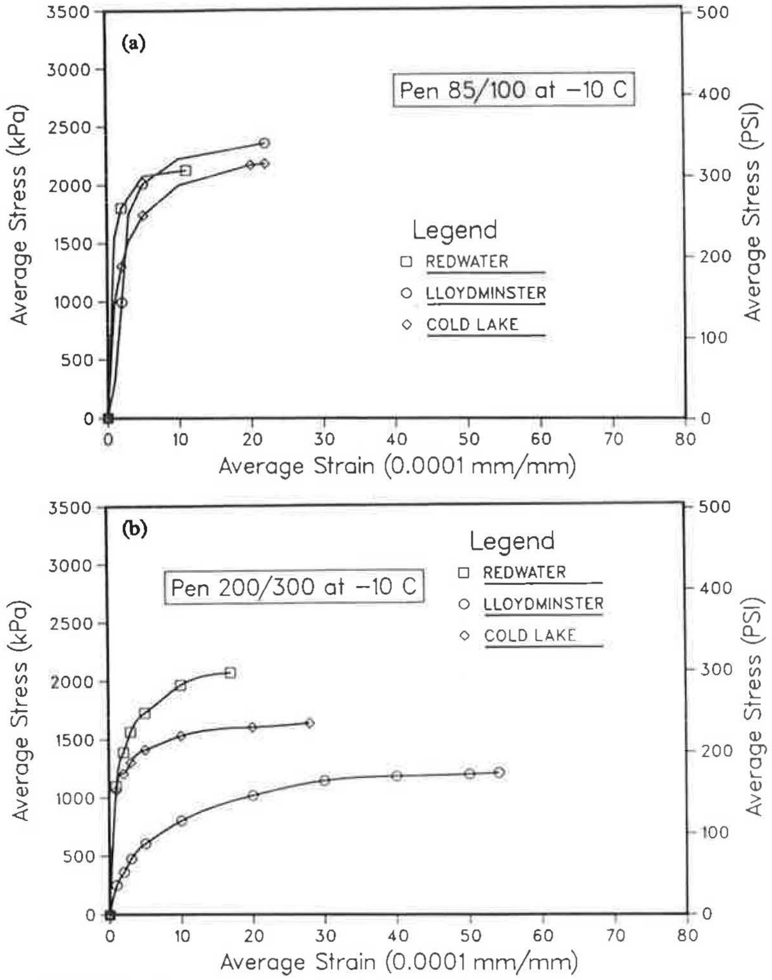

FIGURE 7 Average stress-strain curves at −10°C.

the induced tensile stresses due to temperature change in these mixtures will be smaller. This is advantageous in reducing the chance of thermal cracking because the tensile strength of the mixture will be less likely to be exceeded.

For similar reasons, the performance of the 200/300 asphalt at low temperatures is considered better than that of the 85/100 asphalt.

Data of this type have been used previously to compare observed cracking with that predicted by various stress analyses *(13)*. Such data have also been used with the distress prediction model COLD (COmputation of Low temperature Damage), developed by Finn et al. *(14)*, to estimate the cracking potential of a runway overlay *(11, 15*, p. 156). Further development and similar applications of these data are anticipated.

CONCLUSIONS

Asphalt cements of the same grade but produced from different crude oils possess different rheological properties. In this study, the properties of the Cold Lake and Lloydminster asphalts are found to be similar. The properties of the Redwater-Gulf asphalt are quite different from those of the Cold Lake and Lloydminster asphalts.

The specially formulated Redwater-Gulf blend asphalt is the most temperature susceptible of the three asphalts from the three different crude sources as shown by all of the temperature susceptibility parameters except the PI(R&B).

The PVN(25-135) is a good indicator of temperature susceptibility in the high-temperature range; however, PI using the slope of the log penetration versus temperature is a better indicator over the lower temperature range.

The indirect tensile test method employed in this study provides useful information for the evaluation of low-temperature tensile properties of asphalt cements and asphalt concrete mixtures.

Test temperature has a definite influence on tensile properties of asphalt concrete mixtures. Tensile failure stress increases with decreasing temperature. The rate of increase decreases as the temperature continues to drop.

Tensile failure strain decreases with decreasing temperature. It appears that there is some critical temperature below which failure strain remains unchanged with decreasing temperature. This critical temperature appears to be a function of asphalt grade.

Asphalt concretes made with the same grade but with asphalts from different crude sources have been shown to possess different indirect tensile properties.

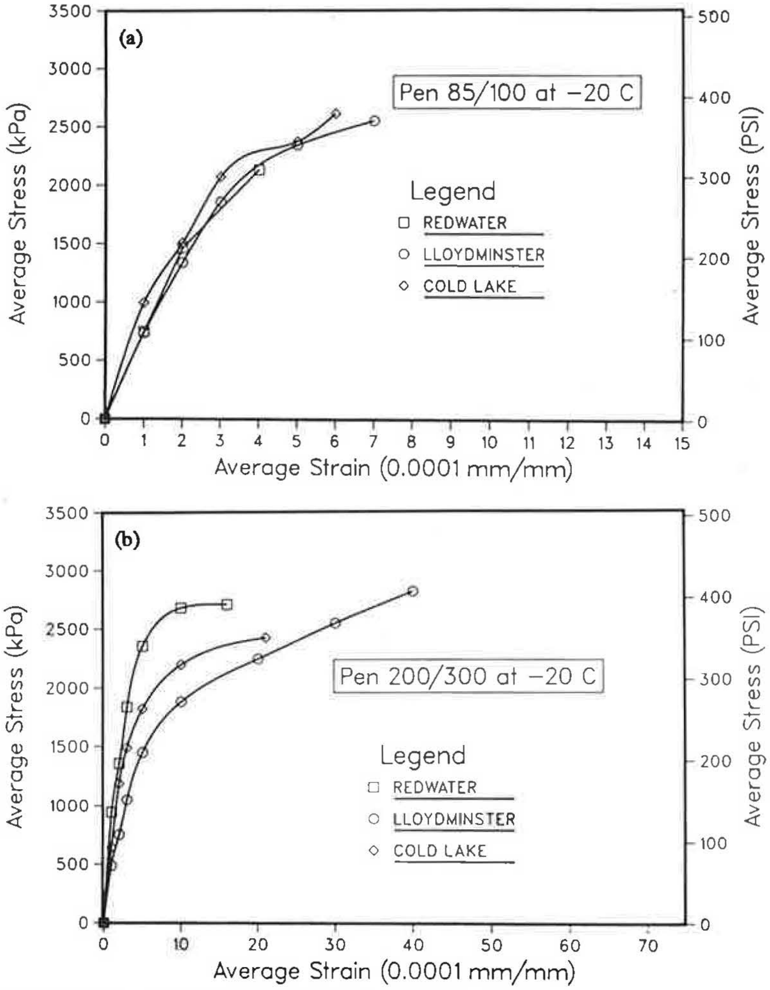

FIGURE 8 Average stress-strain curves at −20°C.

The tensile failure strain of the Redwater asphalt concrete is the smallest of the three different mixtures. The difference diminishes at very low temperatures.

Asphalt concretes made with different grades of asphalts also possess different tensile properties. At moderately cold temperatures, the harder grade asphalt concrete generally has higher failure stress and lower failure strain than does the softer grade. However, at very cold temperatures, the harder grade asphalt concrete has a slightly smaller failure stress, and the failure strains of both grades are similar.

On the basis of the results of the laboratory tests, it is believed that the asphalt cements produced from heavy crude sources of the Cold Lake and Lloydminster areas perform better at low temperature than do those produced from the lighter crude source of the Redwater area. The 200/300 asphalt is also expected to perform better than the 85/100 asphalt, provided both grades are produced from the same crude source.

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