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Low Temperature Properties of Asphalt Cements and Mixtures used in the C-SHRP Lamont Test Road in Alberta

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Abstract

The objective of this project was to undertake research into the low temperature performance and cracking of asphalt concrete pavements in Alberta that would be beneficial to Heilongjiang.

The scope of the project included a low temperature indirect tensile test program involving 140 asphalt specimens formed with seven different grade and source of asphalt cements, the binder being the only variable. Indirect tensile test results were analyzed and compared to the physical properties of the various binders.

A review of the various theoretical prediction methods were also undertaken and some conclusions were made on their relevance to the low temperature indirect tensile test results.

Key Words

low temperature performance, asphalt concrete, indirect tensile test, grade, source, asphal cements, prediction methods

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ALBERTA TRANSPORTATION AND UTILITIES

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LOW TEMPERATURE PROPERTIES

OF

ASPHALT CEMENTS AND MIXTURES

USED IN THE

C-SHRP LAMONT TEST ROAD

IN ALBERTA

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ABSTRACT

The objective of this project was to undertake research into the low temperature performance and cracking of asphalt concrete pavements in Alberta that would be beneficial to Heilongjiang. The scope of the project included a low temperature indirect tensile test program involving 140 asphalt specimens formed with seven different grade and source of asphalt cements, the binder being the only variable. Indirect tensile test results were analyzed and compared to the physical properties of the various binders.

A review of the various theoretical prediction methods for low temperature cracking were also undertaken and some conclusions were made on their relevance to the low temperature indirect tensile test results.

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1.0 INTRODUCTION

Low temperature cracking is a significant mode of failure of asphaltic concrete pavements. It occurs mainly in the cold regions of the world. These cracks permit the ingress of water, which may result in a depression at the crack because of the pumping action caused by traffic which results in the loss of support materials. During the winter months, deicing solutions can enter the cracks and ran cause localized thawing of the base and subsequent depressions at the crack. Water entering the crack may freeze, form ice lenses, and produce upward lipping at the crack edge. This results in poor ride quality and reduced pavement life.

Previous research identified that asphalt cement characteristics appear to have the greatest influence on the low temperature behaviour of asphaltic concrete pavements[1,2,3,4]. In Canada, asphalt cement specifications have been traditionally developed by individual provinces or by the Canadian General Standards Board (CGSB)[5]. In order to develop specifications that more closely reflect superior performance of the binder in asphalt pavement, an improved understanding of those fundamental properties of asphalt cements which correlate to performance, is required[6].

Although much research is currently under way in the U.S. Strategic Highway Research Program (SHRP)[7], a study focusing on asphalt predominantly from Canadian sources, without modification by polymers, is considered to be an important step toward such understanding. The Transportation Association of Canada has sponsored a study on behalf of the Canadian Strategic Highway Research Program (C-SHRP) entitled "Performance Correlation for Quality Paving Asphalt". The primary goal of this C-SHRP project is to address the issue of low temperature cracking and improve the understanding of how it relates to the quality of the asphalt cement used in the mixture.

The research documented in this report is separate from the above named study but is aimed at supplementing the information and research already identified under the C-SHRP project. It addresses cold temperature pavement cracking and performance predictions based on routine and special laboratory test results of the materials utilized on an Alberta test road near Lamont. The Lamont test road completed in early September, 1991, on SH637:02 East of Lamont (Figure I and 2) was designed to contain seven 400 metre long test sections. The experiment was designed to cover a wide range of penetration grades of asphalt cement as shown in Table 1. It was expected that the temperature susceptibility as expressed by the Penetration Index (PI) would range from -3.0 to +0.5. The same aggregate source was used in all seven test sections. The test road was to concentrate on the temperature susceptibility and "ageing" characteristics of pavements with the asphalt cement being the only variable.

Special instrumentation to monitor air, pavement and surface temperature as well as crack detection circuits were installed in four of the seven test sections. On-site visits during critical temperature periods have been carried out during the first winter to supplement instrumentation data. It is hoped that this project may be instrumental to developing a relationship between pavement cracking and the physical properties and temperature susceptibility of the asphalt cements, as expressed by the values of Penetration Index (PI), Penetration-Viscosity Number (PVN) or stiffness.

TABLE 1. ASPHALT CEMENTS SPECIFIED FOR THE ALBERTA TEST ROAD

Section No.	Supplier	Range of Penetration (dmm, 25EC)	Penetration Index	Specification Source
1	Imperial, Vancouver	80-100 Air Blown	-1.1 to -0.5	CGSB-16.3M90 (Visc. @ 135 C)
2	Montana Refining Montana	150-200 Group B	-1.6 to -0.9	CGSB-16.3M90 (Visc. @ 135 C)
3	Imperial, Edmonton	300-400A		A.T.&U. ASPH-1,2 & 3
4	Imperial, Vancouver	80-100 Group C	-3.0 to -2.0	CGSB-16.3M90 (Visc. @ 135 C)
5	Husky, Lloydminster	80-100 Air Blown	-0.5 to +0.5	CGSB-16.3M90 (Visc. @ 135 C)
6	Husky, Lloydminster	150-200A		A.T.&U. ASPH-1,2, & 3
7	By Tender	200-300A		A.T.&U. ASPH-1,2 & 3

2.0 PHYSICAL PROPERTIES OF ASPHALT CEMENTS USED IN THE TEST ROAD

2.1 PHYSICAL PROPERTIES TESTS OF ASPHALT CEMENTS BEFORE AND AFTER THIN FILM OVEN TEST

Both standard and special test results as well as the results of the thin film oven test are presented in Tables 2 and 3. These tests were performed by personnel of the Alberta Transportation and Utilities Laboratory in Edmonton.

The penetration values at 10EC and 5EC after the thin film oven test were calculated using the rate of penetration at 25EC for both the original and aged asphalt cements. The viscosity values at 135EC after the thin film oven test were also calculated using regression and the viscosity values of the original asphalt cements at 60EC and 135EC. The data was used to calculate the commonly used temperature susceptibility values PI and PVN.

Figures 3 and 4 show the absolute viscosity numbers at 60EC against the penetration numbers at 25EC before and after the thin film oven test (TFOT). From Figure 3, it can be seen that the asphalt cements used in the C-SHRP Alberta test section are evenly distributed across the groups of CGSB-166.3M90[5] (group A, B and C). This means that these asphalt cements have different temperature susceptibilities and are expected to have different low temperature cracking frequencies, thus they are ideal for assessing the low temperature performance of pavements built with these materials. When comparing Figure 4 to Figure 3, it is obvious that after the thin film oven test, all asphalt cements became harder than the original AC material as supplied (i.e. the penetration values are lower) and the viscosity values are greater.

TABLE 2. PHYSICAL PROPERTIES OF AS SUPPLIED ASPHALT CEMENTS

Section No.	**PEN 25EC (dmm)**	**PEN 10EC (dmm)**	**PEN 5EC *(dmm)***	**VIS.60EC (Pa.s)**	**VIS.135EC (cSt.)**	**SOFT.PT. (EC)**
1. Esso	100	22	13	96.0	277	46.1
2. Montana	150	20	11	59.8	214	41.9
3. Esso	333	58	36	31.3	163	30.7
4. Esso	93	12	6	74.9	219	49.7
5. Husky	88	21	14	321	530	49.8
6. Husky	176	28	17	83.8	280	36.5
7. Esso	241	45	25	47.1	195	34.1

TABLE 3. PHYSICAL PROPERTIES OF AGED ASPHALT CEMENTS (AFTER THIN FILM OVEN TEST

Section No.	PEN 25°C (dmm)	% RETAINED Pen	PEN 10°C* (dmm)	PEN 5°C* (dmm)	VIS. 60°C (Pa.s)	HARDENING Ratio	VIS. 135°C* (cst.)
1. Esso	65	65	12	9	268	2.85	470
2. Montana	75	50	10	6	164	2.75	343
3. Esso	156	47	27	17	94	3.00	258
4. Esso	*51*	53	5	4	197	2.52	383
5. Husky	48	*55*	12	8	1391	4.33	1846
6. Husky	97	55	15	9	187	2.23	371
7. Esso	125	51	20	14	125	2.72	296

NOTE: (*) – CALCULATED VALUE

2.2 TEMPERATURE SUSCEPTIBILITY PARAMETERS OF ASPHALT CEMENTS BEFORE AND AFTER THIN FILM OVEN TEST

In Table 4 and 5 the temperature susceptibility parameters of the seven asphalt cements are presented before and after the thin film oven test. The Penetration Viscosity Numbers (PVN) and the Penetration Index (PI) were calculated using the data from Tables 2 and 3 and equations (1) and (2) introduced by McLeod. The first PVN was calculated using the viscosity value at 135EC while the second one was calculated with viscosity values at 60EC. The Penetration Index was calculated using equation (3) as per references (BANDS)[5,8,9].

$$PVN = -1.5\frac{4.258 - 0.7967\,LOGP - LOGV_1}{0.795 - 0.1858\,LOGP} \qquad \mathbf{(1)}$$

$$PVN = -1.5\frac{6.489 - 1.590\,LOGP - LOGV_2}{1.050 - 0.2234\,LOGP} \qquad \mathbf{(2)}$$

$$P.I. = \frac{20 - 500A}{1 + 50A}; \qquad A = \frac{LOGP_2 - LOGP_1}{T_2 - T_1} \qquad \mathbf{(3)}$$

Where:

PVN = Penetration Viscosity Number

PI = Penetration Index

P = Penetration at 25°C, 5 sec, dmm

V_1 = Kinematic Viscosity at 135°C, cSt.

v_2 = Absolute Viscosity at 60°C, Poise (10 Poise = Pa.s)

T = Testing temperature correlating the penetration value (C).

The calculated PVN and PI values presented in Table 4 and 5 indicate that the asphalt cements used in section No. 4 (ESSO 80/100) and section No.2 (MONTANA 150/200) are the most susceptible to temperature.

The PI values of the test samples were found to be substantially lower than the corresponding PVN values. This is in agreement with Puzinauskas's research findings[10] which also found poor correlation between these parameters. The difference may well be due to the fact that the PI calculation is based on penetration values at a lower temperature range, whereas the PVN is calculated using penetration and viscosity values at a higher temperature range. The lower PI values indicate that the temperature susceptibility of these asphalt cements is greater at low temperature than at high temperature. From the data it seems that the PVN values are more representative of the temperature susceptibility of the asphalt cements in the high temperature range, while the PI value may represent the temperature susceptibility of an asphalt cement better over the lower temperature range.

The two PI values for the two temperature ranges of 25°C -10°C, and 25°C -5°C are similar, but they are different from the PI (R&B) value for the temperature range of 25°C ring and ball softening point (R&B). It is generally assumed that the penetration value is equal to 800 dmrn at the temperature of softening point. Many researchers[1,8,11] have indicated that the PI (R&B) is unsuitable for evaluating the temperature susceptibility of waxy asphalt cements. For this reason, we have adopted the values of PI (25-5) for further calculations in this study.

TABLE 4. TEMPERATURE SUSCEPTIBILITY PARAMETERS OF ASPHALT CEMENT SAMPLES

Section No.	PI (25-10)	PI (25-5)	PI (R&B)	PVN (135°C)	PVN (60°C)
1. Esso	-0.60	-0.67	-0.41	-0.76	-0.82
2. Montana	-2.33	-2.17	-0.48	-0.74	-0.67
3. Esso	-1.49	-1.21	-3.10	-0.17	0.05
4. Esso	-2.40	-2.50	+0.23	-1.24	-1.08
5. Husky	-0.23	+0.01	+0.23	+*0.05*	+0.27
6. Husky	-1.80	-1.51	-2.20	-0.09	+0.01
7. Esso	-1.30	-1.30	-2.20	-0.26	-0.09

TABLE 5. TEMPERATURE SUSCEPTIBILITY PARAMETERS OF ASPHALT CEMENT SAMPLES (AFTER THIN FILM OVEN TEST)

Section No.	PI (25-10)	PI (25-5)	PVN (135°C)	PVN (60°C)
1. Esso	-1.3	-0.47	-0.55	-0.42
2. Montana	-2.3	-2.00	-0.86	-0.69
3. Esso	-1.5	-1.20	-0.49	-0.07
4. Esso	-3.1	-2.00	-1.07	-1.08
5. Husky	-0.02	+0.19	+1.00	+0.73
6. Husky	-1.9	-1.60	-0.47	*-0.15*
7. Esso	-1.8	-1.10	-0.53	-0.15

3.0 PREDICTION OF CRACKING TEMPERATURE

Over the years researchers have addressed the problem of low temperature cracking and have made considerable progress. One approach used was to predict pavement cracking temperature based on the physical properties of asphalt cement. A total of six prediction methods were reviewed and compared in order to select the most suitable for our study.

3.1 REVIEW OF PREDICTION METHODS

3.1.1 Fromm and Phang's Method[1]

The Fromm and Phang prediction method is based on limiting the asphalt cement stiffness to $1.4 \times 10^8 N/m^2$ at 10^4 seconds loading time. It is assumed that when the stiffness value of asphalt cement is greater than the limiting stiffness value, it results in cracking of the asphalt pavement.

3.1.2 Readshaw's Method"21

Readshaw analyzed the low temperature cracking resistance of pavements in British Columbia and concluded, that cracking could be minimized by using an asphalt cement which can withstand 7200 seconds loading time without exceeding 2 x 10^{8} N/M^{2} stiffness values at the lowest temperature experienced.

3.1.3 Deme's Method[13]

Based on the results of the Ste Anne test road, Deme arrived at a limiting stiffness value of 1.0 x 10^{9} N/m^{2} at 1800 seconds loading time.

The above three methods are very similar in their approach and in their limiting stiffness criteria definitions.

3.1.4 Gaw's Method[1]

Gaw developed a cracking temperature prediction chart (Fig. 5-a) in which the pavement cracking temperature is given as a function of the asphalt penetrations at 25°C and 5°C.

3.1.5 Robertson's Method

In view of the shortcomings of the existing procedures for selecting asphalt for low temperature service, a design chart (Fig. 5-b) has been developed based on thermal stress calculation. The fracture temperature was defined as the temperature required to develop a tensile stress of 5 x 10^{5} N/m^{2}.

3.1.6 McLeod's Method[8]

By introducing a temperature susceptibility parameter, Penetration Viscosity Number (PVN), McLeod developed another chart for predicting the cracking temperature of asphalt pavements
(Fig. 6).

3.2 APPLICATION OF THE PREDICTION METHODS TO CALCULATE CRACKING TEMPERATURE

On the basis of above methods the cracking temperatures for the asphalt cements in our study were calculated and the cracking temperatures were changed into design temperature using the following equation:

Design temperature = Cracking temperature + 10°C **(4)**[1]

Using the computer software "BANDS"[9], the cracking temperatures (for Fromm, Readshaw-and Deme's methods) were determined in the following manner:

- By entering the penetration at 25°C and 5°C as well as the loading time, the stiffness and corresponding temperatures are read.
- Comparing the calculated stiffness with the limiting stiffness (such as 1.4 x $10^8 N/m^2$) the cracking temperature is determined. If the computed stiffness value is equal to the limiting stiffness value, the corresponding temperature is considered to be the cracking temperature. The cracking temperatures (for Gaw, Robertson and McLeod methods) were obtained directly from the charts.

  Using actual physical test data of the seven asphalt cements used on the test road, the cracking temperatures were predicted using the 6 prediction methods above. The results of the various predictions are shown in Tables 6 and 7. The results indicate that:

  - Cracking temperatures range between -21°C to -51°C for the same material depending on the method used.
  - After the thin film oven test, all predicted cracking temperature values increased. It is considered that there is a significant effect from the variance of penetration at 25°C.
  - Temperature susceptible asphalt cements have a higher cracking temperatures, such as the asphalt cement sample used in test section No.4 (ESSO 80/100).
  - Softer asphalt cements have lower corresponding cracking temperatures. An example is the asphalt cement sample used in the No. 3 test section (ESSO 300/400).

- Cracking temperatures predicted using Deme's and Gaw's methods are found to be overly optimistic, indicating crack free pavement down to -34°C and -55°C depending on the asphalt cement used. Perhaps a lower limiting stiffness value should be considered to obtain more realistic cracking temperature values.

- The predicted cracking temperature using McLeod's method is affected mainly by penetration at 25°C of asphalt cement samples.

- The predicted cracking temperatures obtained using Fromm's, Readshaw's and Robertson's methods are more realistic. These methods consider the effects of both penetration and temperature susceptibility of asphalt cement. The cracking temperature ranges are closer to experienced ranges. Determination of which prediction method is more indicative of field performance can be obtained after comparison with field data.

TABLE 6. PREDICTION OF CRACKING TEMPERATURE OF C-SHRP TEST SECTION ASPHALT SAMPLES (°C)

Section No.	(I)Fromm	(2)Readshaw	(3)Deme	(4)Gaw	(5)Robertson	(6)McLeod
1. Esso	-37	-39	-51	-45	-35	-21
2. Montana	-31	-30	-37	-36	-30	-30
3. Esso	-44	-45	-55	-*50*	-60*	-45
4. Esso	-26	-26	-32	-33	-23*	-20
5. Husky	-41	-43	-55	-44	-35	-22
6. Husky	-36	-37	-47	-42	-38	-40
7. Esso	-41	-42	-52	-48	-48	-42

NOTE: (*) - Value is not out of the given range

TABLE 7. **PREDICTION OF CRACKING TEMPERATURE OF C-SHRP TEST SECTION ASPHALT SAMPLES (° C)**
(AFTER THIN FILM OVEN TEST)

Section No.	(I)Fromm	(2)Readshaw	(3)Derne	(4)Gaw	(S)Robertson	(6)McLeod
1. Esso	-34	-36	49	-38	-28	>-22
2. Montana	-26.5	-25	-33	-32	-20*	>-22
3. Esso	-38	-39	-49	-42	-37	-33
4. Esso	-23	-24	-29.5	-28	-20*	> -22
5. Husky	-35	-37	-50.5	-38	-30	>-22
6. Husky	-30	-31	-41	-36	-27	-28
7. Esso	-36	-37.5	47.5	41	-34	-28

NOTE: (*) - Value is out of the given range

4.0 LOW TEMPERATURE INDIRECT TENSILE TEST PROGRAM

4.1 ASPHALT CONCRETE MIX DESIGN FOR TEST ROAD

The mix design for the Alberta test sections were prepared in the Transportation Lab of Alberta Transportation and Utilities. The same aggregate was used for all seven mixes - the asphalt cement being the only variable. The aggregate gradation used in the mix is given in Table 8, while the optimum asphalt content and other mix parameters are given in Table 9.

TABLE 8. AGGREGATE GRADATION

Sieve Size	**Aggregate**			**Combined**
(mm)	**Coarse**	**Fine**	**Sand**	**Grade**
12500	100	100		100
10000	80	99		88
5000	46	82		62
1250	24	46		38
630	19	32	100	31
315	14	22	56	25
160	8.9	13	41.3	13.4
80	5.3	8.3	7.7	6.4
Proportion	**60%**	**30%**	**10%**	**100%**

4.2 SAMPLE PREPARATION FOR THE INDIRECT TENSILE TEST

During the construction of the test road, asphalt concrete samples were taken from the construction site. These samples were reheated and a total of 140 Marshall specimens were fabricated in the Transportation Central Laboratory, for use in the indirect tensile test program.

Twenty Marshall briquette specimens were fabricated for each of the mixtures used on the test road. Compaction temperatures varied depending on the individual viscosities at 60°C and 135°C. The same 75 hammer blows at each end were used for compaction.

The bulk specific gravity was determined by weighing each specimen in air and immersing in water. Groups of five specimens were selected for testing at specified low temperatures. A program developed in BASIC computer language was used to determine grouping of the specimens according to their bulk specific gravities to ensure similar average densities within the group. The final groupings and density comparison table are shown in Appendix C and D respectively. These tables indicate that the laboratory samples tested generally had a higher density than the field samples.

TABLE 9. MIX DESIGN PARAMETERS OF ASPHALT CONCRETE SPECIMENS

			ASPHALT CEMENT			ASPHALT CONCRETE SPECIMENT			
Section No.	**Supplier**	**Grade**	**Specific Gravity**	**Asphalt Content %**	**Density @25°C kg/m^3**	**Stability N**	**Air Voids %**	**UMA %**	**Flow mm**
1	Esso	80/100. Air Blown	1.009	5.8	2360	18050	3.5	15.0	2.9
2	Montana	150/200 (B)	1.038	6.0	2368	11250	3.4	14.9	3.1
3	Esso	300/400	(The design of the mixture referring to the section No. 7)						
4	Esso	80/100 (C)	1.018	6.2	2354	11400	3.5	15.6	2.5
5	Husky	80/100 Air Blown	1.030	6.1	2356	14000	3.5	15.4	2.7
6	Husky	150/200A	1.030	6.0	2364	10850	3.5	15.1	2.7
7	Esso	200/300A	1.035	6.3	2360	10400	3.5	15.5	2.3

4.3 BRIEF DESCRIPTION OF TESTING METHOD

The low temperature indirect tensile test used in the program followed the method used at the University of Alberta[11,14,15]. This test method applies the load via loading strips across the diameter of the asphalt concrete cylinder in a compression testing frame within a controlled temperature chamber. Output signals from the load cell and three linear variable differential transformers (LVDT) are recorded and logged into the computer. After testing, the raw data can be processed with a special macro program developed using Lotus 1-2-3. After processing, tensile failure stress, failure strain and failure stiffness are readily available for further analysis. Graphs from this data file such as stress-strain diagrams, are obtained conveniently with the graphic function of Lotus 1-2-3. The details of this test method is included in Appendix A.

4.4 TESTING CONDITIONS

The low temperature indirect tensile tests were conducted at the Department of Civil Engineering, University of Alberta. Five specimens from each of the seven mixtures were tested at four different temperatures, 0°C, -10°C, -20°C and -30°C.

The loading rate of the testing equipment was set at a nominal rate of 1.15 mm/min and was kept unchanged throughout the test. A more comprehensive discussion of the indirect tensile test method is given in Appendix A. The calibration results of the low temperature indirect tensile test equipment is described in detail in Appendix B.

4.5 RESULTS OF LOW TEMPERATURE INDIRECT TENSILE TESTS

Table 10 summarizes the average failure stress, failure strain and failure stiffness of the test specimen in the program. The failure stress, failure strain and failure stiffness moduli as well as sample density of all 140 specimens are shown in Appendix E.

Based on the test results, the relationships of failure stress-temperature and failure straintemperature as well as failure stiffness-temperature were developed. These relationships are shown in Figures 7 to 9. The relationships of failure stress versus failure strain at different temperatures area shown in Figures 10 to 12.

4.6 DISCUSSION OF INDIRECT TENSILE TEST RESULTS

4.6.1 Failure Stress Temperature Relationships

From the data in Table 10 and Figure 7, it is evident, that the test temperature has a very significant effect on the failure stress of the asphalt concrete mixture.

In general, failure stress increases as the test temperature decreases. This trend in 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 seems to reduce and is more dependent on the type of asphalt cement used in mixture. This is rather evident in Figure 7, indicating that when the test temperature is lower than -10°C, the rate of failure stress of the harder grade asphalt concrete mixture, (80/100), becomes lower than that of the soft grade asphalt concrete mixture. The softer grade asphalt concrete mixture exhibits close to linear increase in failure stress with temperatures down to -20°C. Below -20°C, the rate of increase is less. From the distribution of failure stress at -30°C, it is noted that the mixtures made with softer grade asphalts have greater values of failure stress. It appears, that even within the same asphalt concrete mixture, the mixture that contains a greater PI value asphalt cement has greater value of failure stress when comparing the asphalt cement (grade 150/200) used on section No. 2 (Montana) with asphalt cement used on section No. 6 (Husky 150/200 A). These results suggest that the indirect tensile test is indicative of the low temperature behaviour of an asphalt mixture, and can be used to predict expected field performance.

TABLE 10. AVERAGE FAILURE STRESS, STRAIN AND STIFFNESS OF TEST SPECIMENS

	FAILURE STRESS (KPa)				FAULURE STRAIN (X104)				FAILURE STIFFNESS (MPa)			
Section No.	**0°C**	**-10°C**	**-20°C**	**-30°C**	**0°C**	**-10°C**	**-20°C**	**-30°C**	**0°C**	**-10°C**	**-20°C**	**-30°C**
1. Esso	2070	3810	4040	4380	43	19	5	4	920	4200	15000	34000
2. Montana	2300	4150	4620	4660	39	9	6	6	1100	5500	15000	18000
3 Esso	940	3190	4950	5430	74	60	5	5	250	1000	17000	23000
4 Esso	2690	4140	5200	4510	44	12	4	3	1200	7900	15000	37000
5 Husky	2070	3920	4400	4910	28	21	3	4	1400	3600	26000	26000
6 Husky	2000	4180	4440	5430	35	20	5	2	1200	4000	19000	63000
7 Esso	1470	3310	4560	5160	67	52	2	6	420	1200	39000	18000

4.6.2 Failure Strain Temperature Relationship

Figure 8, shows that Failure strain of an asphalt concrete mix is affected by test temperature. In general, failure strain decreases as test temperature decreases. According to Figure 8, the rate of decrease is considerably reduced when the temperature changes from 0°C to -30°C for all the asphalt mixtures. It is obvious that all test samples can be divided into three groups. The first group [Montana 150/200 and Esso 80/100 (C)] has the largest rate of decrease as the test temperature changes from 0°C to -10°C. The second group consisting of the Esso 80/100 (Air Blown), Husky 80/100 and Husky 150/200, has a slower rate of strain decrease over the temperature range of 0°C to -30°C. The third group consisting of the Esso 200/300 and Esso 300/400, exhibited the largest change in strain behaviour between -10°C and -20°C. When the test temperature reached below -20°C, the rate of change reduced considerably and all failure strain remained within a narrow range. The strain values for all asphalt grades became similar below -20°C.

4.6.3 Failure Stiffness Temperature Relationship

Figure 9, presents failure stiffness - temperature relationships for all mixes. The failure stiffness generally increases as the test temperature decreases with the exception of Husky 80/100 and to a lesser extent the Esso 200/300. The characteristics of increasing rate is opposite to the failure strain-temperature relationship.

4.6.4 Failure Stress vs. Strain Relationship

Figures 10 to 12 show the average stress-strain curves of the test specimen at different test temperatures. From these figures, it is clear that the effect of asphalt cement penetration grade is significant on the low temperature behaviour of an asphalt mixture. More specifically, some of the mixes exhibited considerable yielding down to -10.0°C. Below -20°C, all mixes exhibited very low strain properties.

5.0 PREDICTION OF CRACKING TEMPERATURES OF THE ASPHALT MIXTURES USED ON THE TEST ROAD BASED ON THE LOW TEMPERATURE INDIRECT TENSILE TEST RESULTS

5.1 DESCRIPTION OF PREDICTION METHOD

When the air temperature goes down, stress develops in the asphaltic concrete pavement. This stress is called thermally induced stress. Because most of the low temperature cracking occurs transversely, for the purpose of this calculation the asphalt pavement is assumed to be an infinite length of visco-elastic beam[16]. Using both superposition and relaxation principles[17,18], the cooling and thermally induced stress procedure is demonstrated in Figure 13 which has been previously developed in Reference[19]. The thermally induced stress can be expressed by the following equation:

$$s\,(t) = \int_o^t \frac{d \in (t)}{dt} S(T_1 t - t)\,dt \qquad \textbf{(5)}$$

where

$\sigma(t)$ - thermally induced stress at time t

$\varepsilon\ (t)$ - thermally induced strain at time t

$S(T_1 t)$ - stiffness modulus of asphaltic concrete at temperature T and time t.

By solving equation (5) with the numerical integration method, the thermally induced stress can be obtained at any given temperature or time. If defined failure occurs when the thermally induced stress is equal to the tensile strength of asphaltic concrete pavement, then the corresponding temperature is defined as the cracking temperature as shown in Figure 14.

In this report, the values of both asphalt cement stiffness and asphalt concrete stiffness were determined from nomographs developed by Van Der Poel and later modified by Heukelom and Klomp[9] .

5.2 PREDICTION PROCEDURE AND RESULTS

The prediction procedure and the results of the above calculations are shown in Figure 15 and Table 1 1. A cooling rate of 10°C/hr was assumed in the calculation of thermally induced stress. Comparing Table 6 with Table 1 1, it can be seen that the predicted cracking temperatures from the indirect tensile test program are similar to the predicted values obtained using Fromm, Readshaw and Robertson's method, previously given in Tables 6 and 7.

TABLE 11. PREDICTED CRACKING TEMPERATURES BASED ON THE LOW TEMPERATURE INDIRECT TENSILE TEST RESULTS

Section No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Cracking Temperature ('C)	-37	-31	-48	-22	-38	-44	-49

6.0 FIELD DATA

Within the scope of this study, it was intended to compare the results obtained from the various theoretical prediction models to the laboratory low temperature performance results and to actual field data. Due to the mild weather during the 1991/1992 winter season, no low temperature cracking occurred on the test road, so this part of the study could not be fulfilled at the time of reporting.

7.0 CONCLUSIONS

This study attempted to supplement the test program identified in the C-SHRP "Performance Correlation for Quality Paving Asphalt", and as such was able to compare the various prediction methods, and tie it in with actual low temperature indirect tensile test results. Field data collected in the C-SHRP program will be instrumental to the final acceptance of these findings. The following is a summary of our conclusions:

1) The results of the indirect tensile test program indicate that all asphalt cements used in the C-SHRP Alberta test road possess different rheological properties and temperature susceptibility. This program therefore will greatly improve the understanding of how the low temperature performance of asphalt pavements is influenced by the quality of the asphalt cement used in the mixture.

2) Six theoretical prediction methods were reviewed and utilized in predicting cracking temperatures of the seven mixtures used in the test sections. The range of predicted cracking temperatures were between -21°C to -60°C, depending on the asphalt cement and prediction method used. All predicted values of cracking temperature increased after the thin film oven test. (i.e. cracking at warmer temperatures).

3) Temperature susceptible asphalt cements were found to have higher cracking temperatures. An example is the asphalt cement sample used in the No. 4 test section (ESSO 80/100). For comparison, the softer asphalt cements had lower cracking temperatures. An example is the asphalt cement used in the test section No.3 (ESSO 300/400).

4) The low temperature indirect tensile test method used in this study provided useful information about the low temperature mechanical properties of asphalt mixtures used on the C-SHRPAlberta test road. The results indicate that test temperatures had a definite influence on the tensile properties of the asphalt mix. Tensile failure stress generally increased while tensile failure strain decreased with decreasing temperature. Based on their strain capacity at low temperature, the asphalts can be divided into three groups: high, medium and low strain capacity asphalts.

5) The predicted cracking temperatures based on the low temperature indirect tensile test results and induced stress calculation were found to be similar to those predicted using the methods suggested by Fromm, Readshaw and Robertson.

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