TEMPERATURE-SUSCEPTIBILITY CONTROL IN ASPHALT-CEMENT SPECIFICATIONS

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The introduction of some waxy asphalt cements into Ontario in the early 1950's caused some serious construction problems where these products were used. The problem was one of temperature susceptibility where the asphalt cements became very thin at high temperatures. This caused problems with drying and in laying and compacting the mix. A solution to the problem has been obtained by controlling the temperature susceptibility with a 2-point consistency specification. This consists of a minimum viscosity specification at 275 F in addition to the normal penetration at 77 F. The minimum specifications are above those recommended by The Asphalt Institute. Relationships have been determined between penetration at 77 F and viscosities at 77, 140, and 275 F for asphalt cements currently supplied in Ontario. A new criterion for low-temperature performance, critical temperature, T_c, is introduced. This is an indication of the low-temperature flow properties of the asphalt mix. A method is also suggested for the selection of a suitable asphalt-cement grade for various low temperature environments by using stiffness modulus.

•THE CONSISTENCY specifications for asphalt-cement grades have been written for half a century in terms of the penetration test (1), and much engineering data and experience have been accumulated regarding asphalts and road construction in terms of this test. Provided that asphalt properties remain reasonably consistent from one crude source to another, the penetration test is quite sufficient to specify consistency. With the introduction of many waxy crudes, however, this test alone is no longer adequate for controlling the desired consistency of asphalt cements.

A single-point consistency specification merely provides a pivot about which the viscosity (consistency)-temperature line may rotate when changes are made in the type of crude oil used. With the more temperature-susceptible asphalt cements, this line slopes more sharply upward, so that these asphalts are less viscous at the temperature used for road construction and much more viscous and brittle at low winter temperatures.

Within the past few years it has been suggested that asphalt cements should be specified by a viscosity range at 140 F rather than by a penetration range at 77 F. This change has been sponsored by several organizations, including The Asphalt Institute (2). One fact in favor of this move is that a fundamental property is specified rather than an arbitrary number, as is the case with the penetration test. The values obtained in the penetration test are influenced not only by the consistency of the asphalt cement but also by its composition. One of its ingredients, paraffin wax, has a marked effect in this test (3, 4). The adoption of viscosity grading of asphalt cements at 140 F would not, however, solve the problem of the more temperature-susceptible asphalts. This problem can only be solved by using a consistency specification that controls the temperature ranges at 2 or more different temperatures in order to limit the slope of the viscosity-temperature line. The current Asphalt Institute specification for asphalt

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cements lists a minimum viscosity at 275 F for each grade in addition to the regular consistency requirement (5). In the authors' opinion, these minimum viscosities are set much too low. The problem of eliminating the more temperature-sensitive asphalt cements and their attendant problems has been solved in Ontario by specifying a higher minimum viscosity at 275 F for each grade in addition to the normal penetration range.

ASPHALT-CEMENT SPECIFICATIONS

The current (1970) asphalt-cement specifications of the Department of Highways, Ontario, are given in Table 1. The first listed (60 to 70 penetration grade) is not used by the department but is included in the specifications for the convenience of the municipalities who quote Ontario specifications when ordering asphalt cements. The 85 to 100 and 150 to 200 penetration grades have been used by the department for many years, the former in the southern part of the province and the latter in the northern areas. The final grade given in Table 1 (300 to 400) was first specified in 1968 and is being used experimentally in an attempt to reduce the transverse cracking occurring to pavements in the northern part of the province. Several changes have been made to these specifications since 1956: changes were made in the thin-film oven test; the ductility at 77 F requirement was deleted in 1961 in favor of a ductility at 39.2 F; the ring-and-ball softening point was deleted at the same time; and the solubility in carbon tetrachloride was changed in 1970 in favor of one in trichloroethylene. The penetration ranges and the minimum flash points, however, have remained unchanged. The major changes have taken place in the viscosity specifications, which were nonexistent in 1956. These changes and the reasons for them are outlined in the following section.

VISCOSITY SPECIFICATIONS

The viscosity requirements incorporated into the department's asphalt-cement specifications resulted from the temperature-sensitive asphalt cements that were introduced into the province. The problems associated with these asphalt cements were first experienced in Ontario during the mid-1950's. The source of the problem was unknown initially, but construction difficulties appeared where certain types of asphalt cements were used. The source of the difficulties was later recognized as high temperature sensitivity. The situation was further complicated because asphalt cements,

TABLE 1

ONTARIO ASPHALT-CEMENT SPECIFICATIONS IN 1970

Specification Designation Requirements	60 to 70 Penetration		85 to 100 Penetration		150 to 200 Penetration		300 to 400 Penetration		ASTM Test Method (latest revised standards)
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
Flash point, COC, deg F	450	–	450	–	425	–	350	–	D 92
Penetration at 77 F, 100 g, 5 sec.	60	70	85	100	150	200	300	400	D 5
Kinematic viscosity at 275 F, centistokes	360	–	280	–	200	–	120	–	D 2170
Thin film oven test, 50 g, 325 F, 5 hr									
Percent loss in weight	–	0.80	–	0.85	–	1.3	–	1.3	D 1754
Percent retained penetration at 77 F	52	–	47	–	42	–	35	–	D 1754
Ductility of residue at 77 F, cm	50	–	75	–	100	–	100	–	D 113
Ductility at 39.2 F, 1 cm/min	4	–	6	–	10	–	15	–	D 113
Solubility in trichloroethylene, percent	99.5	–	99.5	–	99.5	–	99.5	–	D 2042

of both high and low temperature sensitivity (Venezuela and Mid-East crudes), were being used in the province.

The difficulties experienced with the temperature-sensitive asphalts were briefly as follows:

1. When hot mixes were produced at normal temperatures (275 to 300 F), these asphalt cements produced very fluid mixes that were hard to lay and compact. The mixes had slow setting times, and intermediate and finishing rollers had to be withheld 2 or 3 hours behind the paver. This increased construction costs. In one instance, the mix was unable to withstand normal truck traffic near the edge of the new pavement even several days after placement. In another case, the hot mix tore into small fissures directly behind the paver screed, producing a washboard pavement when compacted. These problems were resolved when the asphalt cement used in the mix was changed to one of lower temperature sensitivity. In other cases, a filler of ground limestone had to be added to the mix to speed up the setting time. Both of these actions had the effect of increasing the asphalt mix viscosity.
2. If the temperature at which the mix was produced in the asphalt plant was reduced to provide a more workable mix, aggregate drying problems were encountered. It was sometimes necessary to double-dry the aggregates (2 passes through the drier with a holding period between them) to produce the desired laying characteristics of the mix.
3. Pavements constructed with temperature-sensitive asphalt cements had a greater tendency to flush than those produced with less temperature-sensitive asphalt cements. Two different test pavements were laid by using the 2 types of asphalt cements, both of the same penetration grade. In both cases the more temperature-sensitive asphalt cements flushed after the first year. This resulted from the increased mobility of the cement under the summer temperatures and traffic volumes, which caused the asphalt cement to creep to the surface of the pavement.
4. Some pavements constructed with these temperature-sensitive asphalt cements exhibited very severe transverse cracking after only a few winters of use, suggesting that they were more brittle at low winter temperatures than the less temperature-sensitive cements.

A study of the viscosity at 275 F of all asphalt cements was undertaken. This disclosed that, of the 85 to 100 penetration asphalt cements, those that performed well had lower temperature sensitivity and viscosities (at 275 F) in the range of 360 to 460 centistokes, while those causing problems had viscosities in the range of 160 to 220 centistokes. For the 150 to 200 penetration cements, the problem group had viscosities around 120 to 160 centistokes, while the others had viscosities around 240 to 300 centistokes. It was also noted that, in the case of the 85 to 100 penetration cements, the ductility at 39.2 F was low (6 to 12 cm) for the temperature-sensitive asphalts and 15 cm or more for the less temperature-sensitive asphalt cements. This was taken to be indicative of greater hardening at low temperatures of these temperature-sensitive asphalt cements.

As a result of this investigation, specifications for viscosity were imposed that increased each year for 3 years until they reached the current levels in 1963. For the 85 to 100 penetration asphalt cements, the minimum viscosity at 275 F was set at 170 centistokes in 1961, raised to 190 in 1962 and finally set at 280 in 1963. For the 150 to 200 penetration asphalt cement, the minimum viscosity was set at 190 centistokes in 1962 and raised to 200 in 1963. When the 300 to 400 penetration cement was introduced in 1968, the minimum viscosity at 275 F was set at 140 centistokes. Some suppliers found this requirement impossible to meet and it was reduced to 120 centistokes in 1970. The latter value is more realistic and in accord with the viscosity specifications for other grades.

At the beginning of this investigation, it was observed that asphalt cements within a given grade that had low viscosity values at 275 F also had lower ducility values at 39.2 F. A ductility specification was, therefore, imposed at this temperature and the 77 F ductility requirement (which all cements always pass easily) was deleted to ensure that the material had some ductility at low temperatures. The minimum value was set in 1961 at 8 cm for the 85 to 100 grade and 12 cm for the 150 to 200 grade. Current values used since 1963 are 6 and 10 cm respectively.

In order to compare the penetration grading of asphalt cements supplied to the department with what might be obtained on a viscosity grading at 140 F, several selected asphalt cements were tested during the past 2 years for viscosity at different temperatures. The results of these tests are given in Table 2. The first column of the table lists the suppliers and, because a supplier may produce asphalt from several different locations, these were identified as A1, A2, and so on. The viscosities at 77 F were determined by using a sliding-plate microviscometer at a shear rate of 5×10^{-2} sec^{-1}. The viscosities at 140 F were measured with a vacuum-capillary Koppers tube, and the viscosities at 275 F were measured with a Zeitfuchs cross-arm viscometer.

ANALYSIS OF RESULTS

One of the chief arguments against grading asphalt cements by viscosity at 140 F has been the wide range of penetration values that can be associated with each viscosity grade. This is due to the varying temperature susceptibilities of the different asphalt cements. This point has been discussed by McLeod (6) and is shown in Figure 1 (6, 7). When the data given in Table 2 were plotted in a similar manner, the result shown in Figure 2 was obtained. In this instance, there is much less scattering of data, despite the fact that 10 sources were concerned and both Canadian and imported crude oils were used to produce the asphalt cements. Superimposed on this graph are 3 lines showing the viscosity-penetration relationship of asphalt cements with penetration indexes (PI) of 0.0, -1.0, and -1.5. These lines were calculated by Lefebvre (8). It will be observed that there is a clustering of data for each grade of asphalt, rather than a spread-out pattern as shown in Figure 1. This is because the temperature susceptibility has been controlled within prescribed limits by the use of a minimum viscosity specifica-

TABLE 2

CONSISTENCY TESTS ON ONTARIO ASPHALT CEMENTS

Supplier	Penetration at 77 F	Viscosity at 77 F (poises)	Viscosity at 140 F (poises)	Viscosity at 275 F (centistokes)
A1	62	2.12×10^6	2,736	461
	60	2.93×10^6	2,485	465
	56	2.35×10^6	2,636	453
	81	1.07×10^6	1,426	338
	90	1.14×10^6	1,415	340
	94	7.80×10^5	1,436	332
A2	86	9.60×10^5	1,809	410
	90	9.00×10^5	1,609	403
	98	9.21×10^5	1,710	402
	158	2.75×10^5	687	270
B1	155	3.00×10^5	632	236
	160	3.20×10^5	567	231
	364	5.26×10^4	247	146
	180	1.95×10^5	509	209
B2	94	8.35×10^5	1,395	348
	155	3.10×10^5	502	244
	169			247
	155	2.60×10^5		241
	287	9.8×10^4	286	163
	303			159
C1	93		1,545	349
	98	9.00×10^5	1,445	334
	96	9.00×10^5	1,566	338
	172	3.26×10^5	642	
	160	3.09×10^5	725	240
	153	2.53×10^5	661	245
	379	6.12×10^4	216	138
	370	7.00×10^4	223	138
	361		227	154
C2	187	2.00×10^5	604	231
	188	2.21×10^5	585	230
	164	2.32×10^5	657	240
	373		223	138
C3	81	1.12×10^6	1,389	346
	91	1.14×10^6	1,457	329
	88	9.25×10^5	1,217	328
D1	65	1.35×10^6	2,600	450
	89	1.25×10^6	1,698	377
	93		1,450	340
	142		797	265
	180	2.73×10^5	607	240
	167	2.25×10^5	625	230
	373	6.04×10^4	188	142
	342		250	146
D2	67	3.6×10^6	4,756	536
	86	7.35×10^5	1,414	315
	87	8.7×10^5	1,562	355
	93	1.0×10^6	1,612	352
	178	1.48×10^5	583	220
	173	2.90×10^5	801	237
	168	1.95×10^5	634	217
	410		200	143
E1	65	1.53×10^6	2,661	490
	95	9.70×10^5	1,419	360
	90	9.6×10^5	1,388	361
	95	9.3×10^5	1,437	351
	195	2.36×10^5	505	224
	180	2.20×10^5	510	228
	179	2.0×10^5	551	242
	381	7.56×10^4	231	156
	195	2.36×10^5	505	224
	349	7.35×10^4	234	159
	373	5.05×10^4	218	158

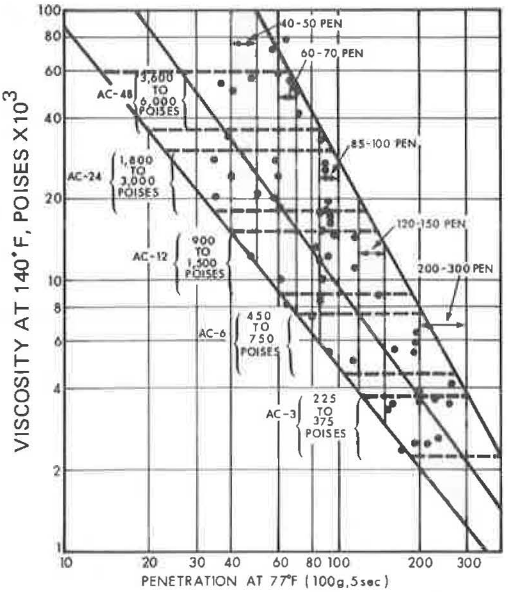

Figure 1. Correlation between viscosity at 140 F and penetration at 77 F for currently used asphalt cements (6).

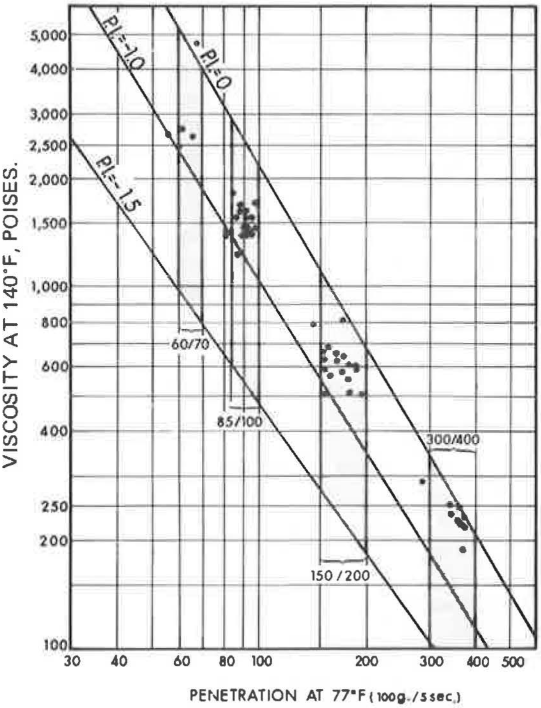

Figure 2. Viscosity at 140 F versus penetration at 77 F for Ontario asphalt cements used in 1969 and 1970.

tion at 275 F. This specification has nearly eliminated all asphalt cements with PI of less than -1.0. An upper value of viscosity has not yet been specified at 275 F because nearly no asphalt cements with a PI of more than 0 are available in Canada.

The relationship between viscosity, in poises, at 77 F and penetration at 77 F is shown in Figure 3. The line drawn through the plots is the linear regression line, and the dotted lines on either side of it are the 95 percent confidence limits. The equation of the regression line is

$$\log V = 9.889 - 2.00 \log P$$

where

V = the viscosity in poises at 77 F, and
P = the penetration in 0.1 mm at 77 F;

or this may be transformed for easier calculation to the form

$$V = \frac{7.75 \times 10^9}{P^2}$$

These results are in good agreement with those obtained by Carre and Laurent (9) in 1963. Their data, where the viscosities were obtained on an equiviscous shear rate for each penetration, have been recalculated by using viscosity as the dependent variable. Their equation, relating viscosity to penetration for penetrations above a value of 6.0, than becomes

$$\log V = 10.266 - 2.198 \log P$$

or

$$V = \frac{1.85 \times 10^{10}}{P^{2.198}}$$

This line lies well within the confidence bands shown in Figure 3. According to Carre and Laurent, this same relationship between viscosity and penetration holds at other temperatures reasonably close to 77 F.

The relationship between penetration at 77 F and viscosity at 275 F for the Ontario asphalt cements is shown in Figure 4. The lines of constant PI superimposed on the chart are again taken from Lefebvre (8). The current department specification limits for penetration and viscosity are shown also in this figure as shaded areas. The tight grouping of the plots for each grade of asphalt cement shows that the 2-point consistency specification has succeeded in its purpose of producing a reasonably regular quality for each grade of cement.

The current specifications issued by the department are producing the desired results. If the penetration at 77 F specification were to be superseded by a viscosity specification at, say, 140 F, then the new specifications would have to produce similar, or better, products. Some doubt has been expressed about the choice of 140 F as a suitable temperature at which to specify a viscosity range. It has been shown that a break occurs in the viscosity-temperature curve at, or just below, 140 F where waxy or blown asphalts are concerned (3, 4, 8). Some typical asphalt cements currently being supplied in Ontario are shown in Figure 5, in which pertinent data are plotted on a chart developed by Heukelom (3). The points used to plot these curves are penetration at 77 F, ring-and-ball softening point, and viscosities at 140 F and 275 F. All 3 types of asphalts described by Huekelom (3), S, B, and W types, are illustrated and are in regular use in Ontario. It can be seen from these figures that a transition is occurring within some asphalts at or below 140 F, causing the break in the curve. Heukelom (3) attributes it to the manner in which the waxes solidify and melt.

It is possible that the temperature of 140 F is above this transition range and will give an indication of how the asphalt will behave under the effects of traffic, as described by Krom and Dormon (10) and Heukelom (3). In view of the breaks that occur in the viscosity-temperature curves for certain asphalts, however, as shown in Figure 5, viscosity data at 140 F are not necessarily an indicator of the low-temperature performance of the asphalt cement. In the colder, northern regions of the United States and in all of Canada, good low-temperature performance is an important requirement of asphalt cements. Asphalts that become brittle at ambient winter temperatures tend to crack (11, 12) and lead to a more rapid deterioration of the pavement. At the present, the only tests of consistency at low temperatures, which are easily available, are the Fraass breaking point (which very few North American laboratories perform), the viscosity test with special apparatus for use at lower temperatures, and the penetration test. The most usual test made is the penetration test at 39.2 F with a 200 g load for 1 min. The results from this test unfortunately cannot be correlated with penetration results at 77 F because the time and the loading are different. Hence, they cannot help define the viscosity-temperature curve at low temperatures. Thus, at present, the majority of users of asphalt cements rely on the penetration at 77 F (or a combination of this with the penetration at 39.2 F) to give an indication of the low-temperature performance of the product.

At the Ontario Department of Highways, a new concept for determining low-temperature behavior of asphalt concrete (known as the critical temperature, T_c) is being investigated. This is defined as the temperature at which the asphalt cement can no longer flow fast enough to relieve the strains built up in the (restrained) asphalt concrete as it attempts to contract because of decreasing temperature. At this point, strains build up within the asphalt concrete; and if the temperature drops sufficiently, a transverse crack in the pavement results. The method of determining this property is described briefly in Appendix A.

The possibility of using the stiffness modulus to predict at what temperature a pavement will crack is also being investigated. By using this technique in reverse, an ap-

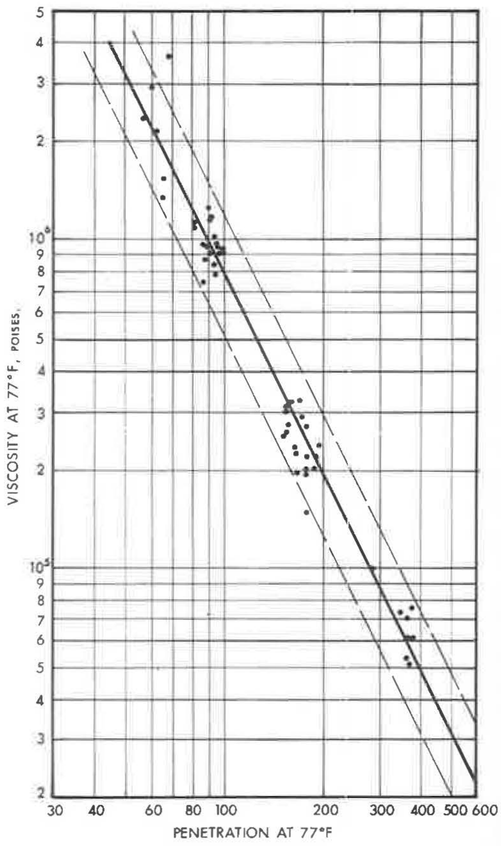

Figure 3. Viscosity at 77 F versus penetration at 77 F for Ontario asphalt cements used in 1969 and 1970.

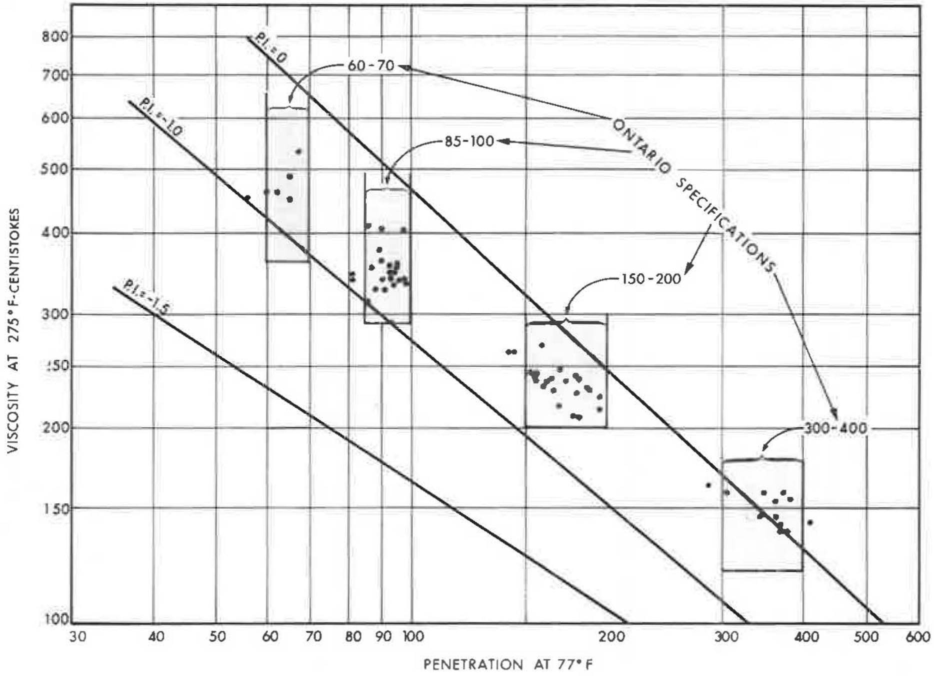

Figure 4. Viscosity at 275 F versus penetration at 77 F for Ontario asphalt cements used in 1969 and 1970.

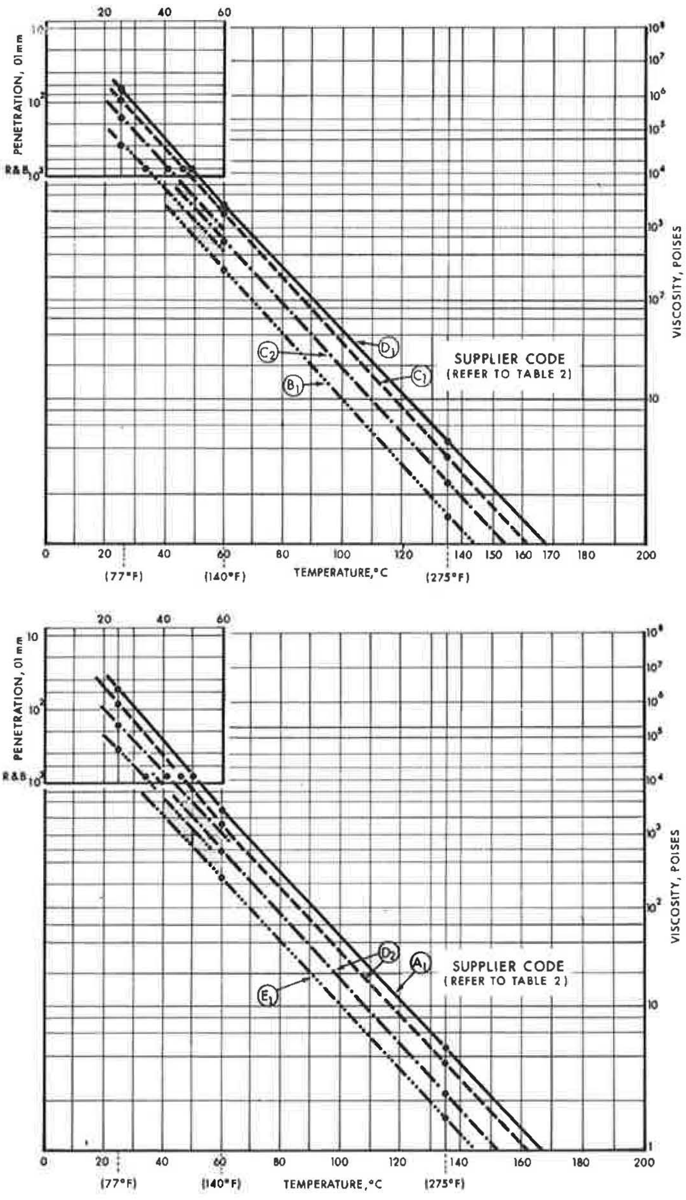

Figure 5. Temperature consistency relationships in Ontario asphalt cements.

propriate grade of asphalt cement can be selected that should yield a pavement with minimal susceptibility to cracking under a given temperature regime. This experimental design technique is described in detail in Appendix B. Briefly, the method is as follows:

It can be deduced from the report of Young et al. (12) that a pavement should still be crack-free when the stiffness modulus of the asphalt cement has reached 20,000 psi. By using this as a "safe" figure and a loading time of 10,000 secs and knowing the corrected penetration indexes of the available asphalt cements (3, 4, 8) McLeod's modified charts for stiffness modulus and PI (15) can be used in reverse to yield a penetration value for such an asphalt cement. This value is, of course, the penetration value of the aged asphalt cement, after it has passed through the hot-mix plant. A knowledge of the thin-film oven test characteristics of the bitumens of the asphalt cement will then make it possible to pick the correct grade for the temperature regime in question.

CONCLUDING REMARKS

The purpose of specifications is to promote a product that will meet the user's requirements. Among these, there are 3 main requirements for an asphalt cement. These are as follows:

1. Its viscosity-temperature characteristics must be such that, at a temperature sufficient to dry the aggregates, the viscosity must be in the range for good mixing and such that the mix can be laid and compacted without delay.
2. The viscosity must be such that the finished road surface will have a stiffness modulus at 140 F, which is sufficient to bear the designed traffic load without deformation.
3. In northern regions, the asphalt cement must retain sufficient flow properties to relieve the strains set up under falling winter temperatures so that cracking will be minimized under normal winter conditions.

Krom and Dormon (10) and Heukelom (3) have suggested values for these 3 ranges that depend on the traffic loading and the temperature regime. It is obvious that a single consistency specification, whether it be at 77 F, 140 F, or some other temperature, cannot ensure a product meeting all three of these requirements. The range of temperature susceptibilities available is too great.

The department's present 2-point consistency specifications do appear to be limiting the asphalt cements to those that are giving close to the desired performance under the temperatures prevailing throughout the province. If higher PI asphalts were available (above 0.0), then it might be possible to dispense with the 300 to 400 penetration grade. In the current state of affairs, uniformity of construction techniques is being achieved by the use of a viscosity specification at 275 F. It now remains to be seen how softer asphalts will perform in service and whether the transverse cracking of the pavements to the northern sections of the province can be reduced.

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Discussion

J. YORK WELBORN, Federal Highway Administration—The authors point out that the 1970 Ontario asphalt-cement specification has nearly eliminated the use of all asphalt cements having a PI of less than -1.0 by using appropriate limits for kinematic viscosity at 275 F. A comparison of the restrictions imposed on penetration-grade asphalts by high-temperature viscosity to similar restrictions that might be used in the AASHO Specifications for Viscosity Graded Asphalts is of interest.

Figure 2 of the author's report shows the relationship between viscosity at 140 F and penetration at 77 F and provides a basis for such a comparison. An asphalt cement of 2.5 grade is shown to compare with the soft asphalt of 300 to 400 penetration included in the Ontario specification. By using the AASHO viscosity limits at 140 F, the penetration ranges for the Ontario asphalts on a viscosity-graded basis would be as given in Table 3.

TABLE 3
PENETRATION RANGES FOR ONTARIO ASPHALTS

Viscosity Grade	Viscosity at 140 F	Penetration at 77 F	
		Ontario Asphalts	AASHO Specification
AC-2.5	200 to 300	220 to 420	—
AC-5	400 to 600	140 to 280	120+
AC-10	800 to 1200	90 to 180	70+
AC-20	1600 to 2400	60 to 120	40+
AC-40	3200 to 4800	40 to 80	20+

These data support our contention that higher minimum penetration requirements may be justified in the AASHO specification to reduce the thermal or transverse cracking problem. The higher minimum limits together with the addition of a lower viscosity grade, such as AC-2.5, should provide a more suitable specification for selecting and controlling asphalt cements for use in low-temperature environmental areas.

H. J. FROMM AND W. A. PHANG, Closure—As Welborn points out, the penetration requirements in the AASHO specification are not high enough for the corresponding gradings at 140 F if a higher PI asphalt with good low-temperature performance is desired. The AASHO specification permits asphalts with PI's down to -1.5. We believe some degree of PI control is necessary if we are to obtain good low-temperature performance and also a minimum of difficulties during the actual construction of the road.

Appendix A

Coefficient of Expansion

The Coefficient of Expansion of the asphalt concrete mix is needed to determine the amount of strain deformation built up in a restrained road slab as temperatures fall below the Critical Temperature, (T_c). Shrinkage in the material at temperatures above the T_c is accommodated by flow of the asphalt binder.

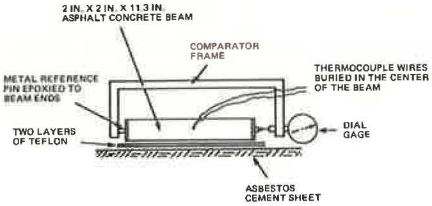


Figure A1, Apparatus for Determining the Coefficient of Expansion of Asphalt Concrete Mixes

The apparatus illustrated in Figure A1 is used for finding the coefficient of expansion of asphalt concrete mixes within a temperature range of −20 degrees F. to +20 degrees F. The asphalt beam is cooled to about −20 degrees F., then placed in the apparatus at room temperature, and the changes in length of the beam at increments of temperature change are recorded and used to determine the coefficient of expansion. Two teflon layers are needed to provide a base with a low restraint value; base restraint causes irregular motion and smaller movements.

Measuring Creep Deformation

The apparatus illustrated in Figure A2 is used for measuring the creep deformation of asphalt concrete mixes at low temperatures (−10 degrees F., to +40 degrees F.), under a constant small tensile stress. The load/unload cycle is monitored for deformation over the 30 minute load cycle (20 minute rest) and measurements are averaged over the second and third cycles, provided these are consistent. (Temperature variations of more than 1 degree F. over the test period result in inconsistent tests and further cycles must be run.) A typical creep deformation curve is illustrated in Figure A3, and the test is repeated at different temperatures. The viscous part of the creep curve is caused by the flow in the asphalt binder, and it is this quality of the mix which is of interest. If the flow which occurs in a unit length of mix over a time period of one hour is considered, this can be compared against the amount of shrinkage induced by the temperature change of the mix during the same one hour period if it had not been restrained. At temperatures higher than T_c it will be found that this viscous flow exceeds the induced shrinkage due to temperature change. As illustrated in Figure A4, however, at temperatures below T_c, the restrained temperature shrinkage cannot be accommodated by flow in the asphalt binder, and, instead, tensile strains must be developed in the restrained material. Of course, if temperatures fall low enough below this critical temperature, the induced tensile strains can cause cracks to form.

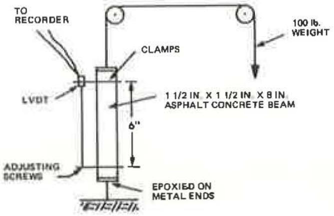


Figure A2, Apparatus for Measuring Creep Deformation Under Constant Tensile Stress

An examination of hourly temperature records from various locations in the Province indicate that the ambient temperature drop during a one hour period does not exceed 10 degrees F. at temperatures below 0 degrees F. The critical temperatures are therefore determined for the amount of induced shrinkage which would occur over a 10 degree F. temperature drop, i.e., for an hourly deformation of ten times the coefficient of expansion.

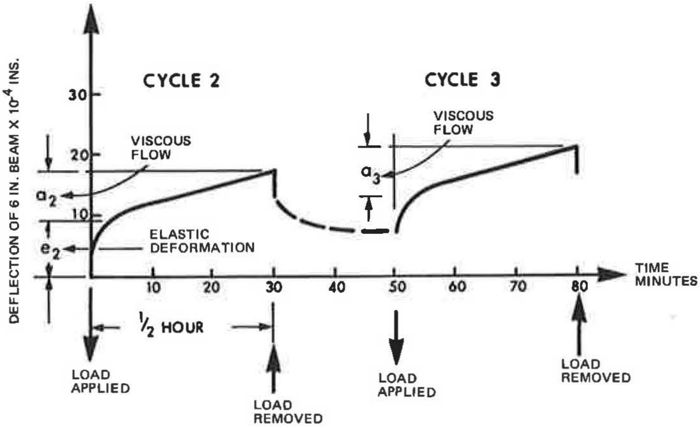


Figure A3, Example of a Creep Test Result

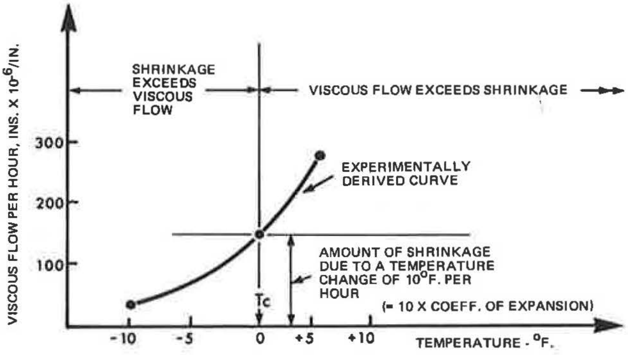


Figure A4, Example of a Critical Temperature Determination

Appendix B

The stiffness modulus of an asphalt binder is a function of its temperature and depends on the loading time [13], the penetration and the P.I. [14]. Figure B1 shows the stiffness modulus at various temperatures of the asphalt binders used at the Ste. Anne Test Road [12]. The difference in stiffness between the 150/200 pen. asphalts of high and low viscosities (temperature susceptibilities) can be seen to increase as the temperature decreases.

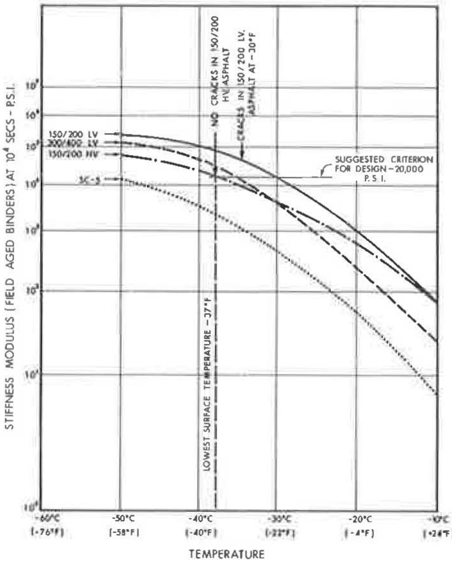


Figure B1, Suggested Stiffness Modulus Criterion (After Young et al - Ste. Anne Test Road, CTAA 1969)

Crack initiation in the 150/200 pen. LV asphalt occurred at a temperature of −30 degrees F. or at a stiffness modulus of about 40,000 psi. The 150/200 pen. HV asphalt did not crack even at a temperature of −37 degrees F. at which point the stiffness modulus was 20,000 psi.

It therefore appears possible to make an initial assumption that crack initiation in all binders will not occur at a stiffness modulus of less than 20,000 psi; this criterion can later be amended for other asphalt grades, temperature susceptibility and temperature environments as further observations prove the necessity.

Figures B2 and B3 are the modified nomographs suggested by McLeod [15] which can be used to characterise the rheological behaviour of asphalt binders. Plotted on Figure B3 is the low temperature failure criterion of a stiffness modulus of 20,000 psi or 1,400 Kg/cm^2. From this figure, if an asphalt with a P.I. of −1.5 is selected at a loading time of 10,000 seconds, the criterion gives a temperature of 72 degrees C. below the base temperature. This temperature is made up of three parts,

(a) the temperature difference in degrees C. between the base temperature and the temperature employed in the penetration test,

(b) The temperature (degrees C.) at which the penetration test is performed and,

(c) the temperature below 0 degrees C. at which the failure criterion applies.

As an example, if a design temperature of −30 degrees F. (−34 degrees C.) is assumed, and the penetration test is carried out at 25 degrees C., then the temperature difference between the base temperature and the temperature of the penetration test is 72 − (25 + 30) = 17 degrees C. Entering this temperature difference in Figure B2 and with the P.I. of −1.5, gives a penetration value of 110. Similarly, other penetration values for other design temperatures and P.I. values can be obtained, and these are shown plotted in Figure B4.

The stiffness modulus criterion of 20,000 psi was for the field-aged binder, so it is necessary to examine the specifications after the thin film oven test, which simulates the hardening of the binder during the mixing and laying process. The three shaded bands on Figure B4 represent the minimum conditions resulting from the D.H.O. specifications and it is now apparent from the diagram that satisfactory performance can be obtained at a particular design temperature, from a wide range of asphalt penetration grades, dependent on the P.I. value of the asphalt. It is also apparent that the degree of hardening which occurs during the mixing and placing is an extremely important factor which could largely influence the subsequent performance.

Figure B5 shows winter design temperatures for Canada compiled on a one percent basis by the National Research Council and the Department of Transport [16]. Using this map to determine the required design temperature, it is then possible to use Figure B4 to select the field-aged penetration of the asphalt cement and the P.I. Knowing the minimum specified percentage of retained pen., the penetration grade can be selected, and from the P.I. value, the minimum viscosity at 275 degrees F. can be determined from Figure 4.An asphalt cement which conforms with these requirements can then be selected from those available.

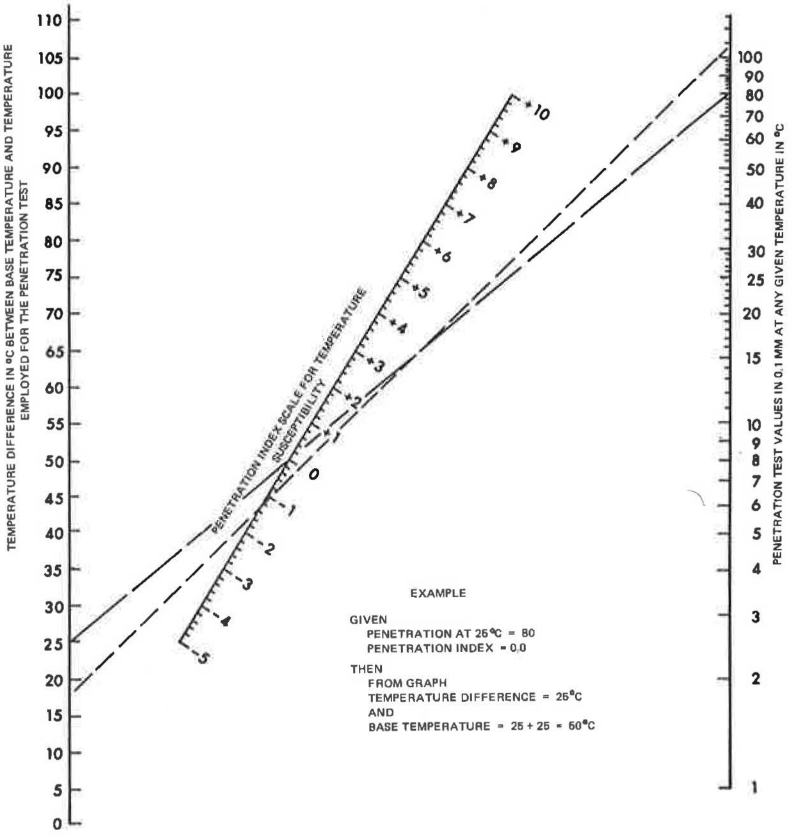
From Figure B4, it can be seen that crack initiation in the asphalts complying with the Ontario specifications would not occur at temperatures above the following limits:

300-400 pen. asphalt –33 degrees F.

150-200 pen. asphalt –24 degrees F.

85-100 pen. asphalt –12 degrees F.

From these limits, it is possible to designate construction areas in which specific asphalt cement grades can safely be used.

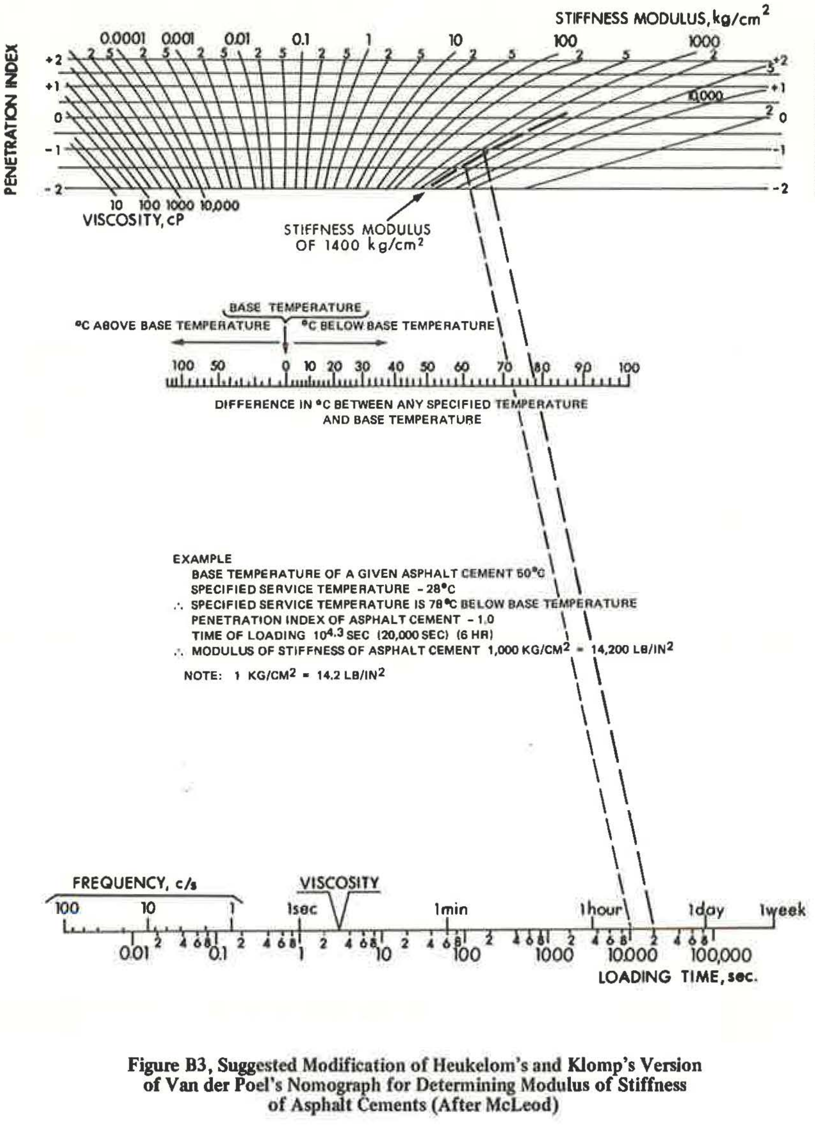


EXAMPLE

GIVEN
PENETRATION AT 25°C = 80
PENETRATION INDEX = 0.0

THEN
FROM GRAPH
TEMPERATURE DIFFERENCE = 25°C
AND
BASE TEMPERATURE = 25 + 25 = 50°C

Figure B2, Suggested Modification of Heukelom's Version of Pfeiffer's and Van Doormal's Nomograph for Relationship Between Penetration, Penetration Index and Base Temperature (After McLeod)

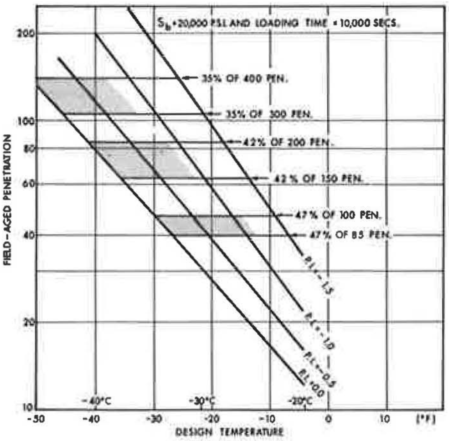


EXAMPLE

BASE TEMPERATURE OF A GIVEN ASPHALT CEMENT 50°C
SPECIFIED SERVICE TEMPERATURE - 28°C
∴ SPECIFIED SERVICE TEMPERATURE IS 78°C BELOW BASE TEMPERATURE
PENETRATION INDEX OF ASPHALT CEMENT - 1.0
TIME OF LOADING $10^{4.3}$ SEC (20,000 SEC) (6 HR)
∴ MODULUS OF STIFFNESS OF ASPHALT CEMENT 1,000 KG/CM^2 = 14,200 LB/IN^2

NOTE: 1 KG/CM^2 = 14.2 LB/IN^2

Figure B3, Suggested Modification of Heukelom's and Klomp's Version of Van der Poel's Nomograph for Determining Modulus of Stiffness of Asphalt Cements (After McLeod)



Note: Percentages are for Retained Penetration after Thin Film Oven Test - D.H.O. Specifications

Figure B4, Selecting Asphalt Cement from Design Temperature (1%)

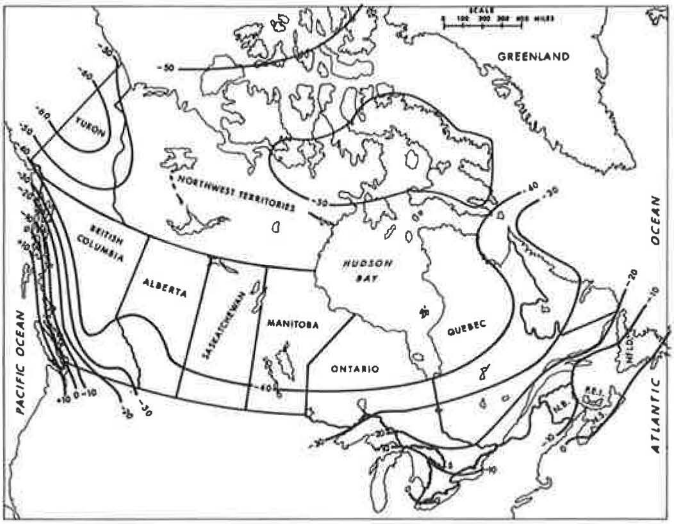


Figure B5, Winter Design Temperature 1% Basis (°F.)