EMPLOYING PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY IN THE STRUCTURAL DESIGN OF ASPHALT PAVEMENTS

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ABSTRACT

Paving asphalt temperature susceptibility is defined, and a simple method for its measurement is described.

The influence of paving asphalt temperature susceptibility on pavement design and performance in hot countries without frost, and in cold climates with frost is described.

Requirements for paving asphalt temperature susceptibility that can be added to or incorporated into a paving asphalt specification are proposed and discussed.

It is shown that by the addition of suitable polymers, the temperature susceptibilities of paving asphalts can be changed dramatically. This development implies that what has always been an asphalt supplier's market could be changed to an asphalt user's market.

In an Appendix, the validity of pen-vis number (PVN) as a measure of paving asphalt temperature susceptibility is examined, together with some of its implications for pavement design and pavement performance.

I. INTRODUCTION

This paper will indicate the important influence of paving asphalt temperature susceptibility on pavement moduli of stiffness requirements for heavy, medium and light traffic. It will also demonstrate the effect of the change in pavement temperature with pavement depth below the paved surface on the coldest and hottest days of the year, on the moduli of stiffness of the asphalt surface, binder and base course layers. Currently, neither ASTM nor AASHTO has a temperature susceptibility requirement in its paving asphalt specifications. In an Appendix, the validity of pen-vis number (PVN) as a measure of paving asphalt temperature susceptibility will be examined, together with some of its applications to pavement design and pavement performance.

II. WHAT IS PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY

As illustrated in Figure 1, the temperature susceptibility of a paving asphalt is the change in its consistency (penetration or viscosity) of the asphalt for a given change in temperature. In Figure 1, three paving asphalts, each with the same consistency at 25°C (77°F) but with quite different consistencies both above and below 25°C (77°F), are illustrated.

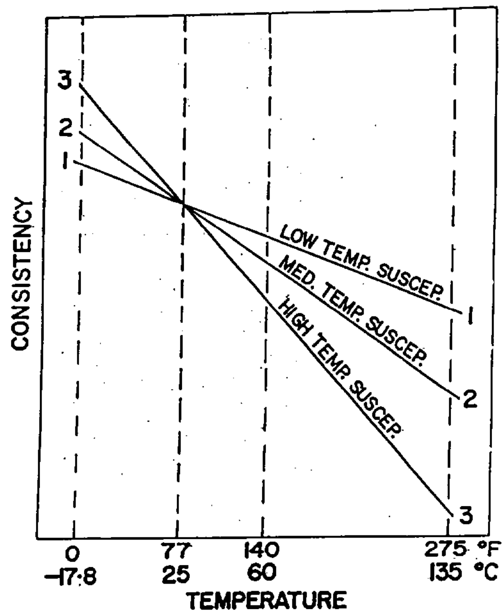

Fig.1 SKETCH ILLUSTRATING DIFFERENT TEMPERATURE SUSCEPTIBILITIES OF PAVING ASPHALTS

Because Asphalt 3 has the steepest slope of the three asphalts, its consistency changes the most over a given range of temperature, and it is said to have a high temperature susceptibility. In general, it will provide pavements that are harder and they will crack at higher winter temperatures than pavements containing the other two asphalts. It will also be more fluid thans Asphalts 1 and

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2 and will result in pavements of lower stability at all temperatures above 25°C (77°f).

The smallest change in consistency for a given change in temperature is shown by Asphalt 1. Pavements containing Asphalt 1 are less hard and therefore show less thermal cracking at any given temperature below 25°C (77°F), and are less fluid and therefore provide greater pavement stability at all temperatures above 25°C (77°F) than the other two asphalts.

The slope of Asphalt 2 in Figure 1 is intermediate between Asphalts 1 and 3 and it is said to have intermediate or medium temperature susceptibility. Pavements containing Asphalt 2 have properties between pavements made with Asphalts 1 and 3 at all temperatures below and above 25°C (77°F).

III. HOW IS PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY MEASURED

For reasons carefully explained in earlier papers (1,2), the writer measures paving asphalt temperature susceptibility in terms of their pen-vis number (PVN) values. By measuring and plotting the penetration at 25°C (77°F) of a paving asphalt, and its viscosity at 135°C (275°F) as the coordinates of a point on Figure 2, the PVN value of the paving asphalt can be read very closely by interpolation between the oblique lines representing different PVN values. A PVN of 0.0, for example, represents a paving asphalt of low temperature susceptibility, while a PVN of -1.5 indicates a paving asphalt of high temperature susceptibility. the PVN value of a paving asphalt can be calculated precisely from the equations shown at the top of Figure 2, as follows:

$$PVN = -1.5 \frac{[\log L - \log X]}{[\log L - \log M]}$$

Where

X = The viscosity in centistokes at 135°C (275°F) associated with the penetration at 25°C (77°F) of the paving asphalt for which the PVN value is required.

L = For the same penetration at 25°C (77°F), the corresponding viscosity in centistokes at 135°C (275°F) for which the PVN = 0.0, or = 4.25800 - 0.79674 logP.

M = For the same penetration at 25°C (77°F), the corresponding viscosity in centistokes at 135°C (275°F) for which the PVN = -1.5, or = 3.46289 - 0.61094 logP.

P = The penetration at 25°C (77°F) of the paving asphalt for which the PVN value is required.

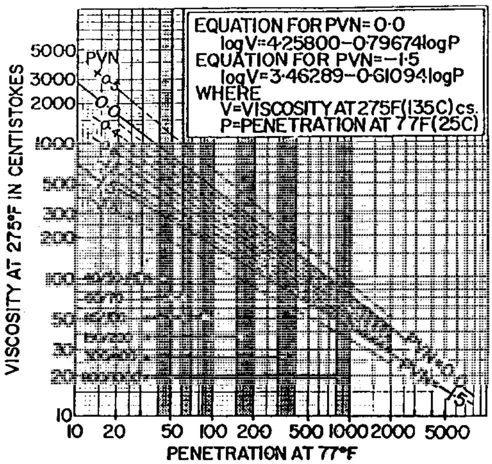

FIGURE 2 A CHART FOR THE DETERMINATION OF APPROXIMATE VALUES FOR PEN-VIS NUMBERS FOR ASPHALT CEMENTS.

Since penetration at 25°C (77°F) and viscosity in centistokes at 135°C (275°F) are usually measured during routine inspection of a sample of paving asphalt, no additional testing is needed to determine its PVN value.

More information on PVN is given in the Appendix.

IV. PAVEMENT STABILITY IN TERMS OF MODULUS OF STIFFNESS UNITS OF psi

In Canada, and in much of North America, paving mixture stability is expressed in pounds at 60°C (140°F) as determined by the Marshall Test. In this paper, pavement stabilities will be stated in moduli of stiffness expressed in units of psi, which are read from Van der Poel's nomographs

(3,4).

The following table will provide the reader with a very approximate relationship between Ontario's minimum Marshall Stability requirements at 60°C (140°F) for three categories of traffic and the roughly corresponding values for Van der Poel's moduli of stiffness in psi.

Ontario's Minimum Marshall Stabilities at 60°C (140°F) in Pounds	Roughly Corresponding Modulus of Stiffness in psi
Heavy Traffic 2000	20,000
Medium Traffic 1500	15,000
Light Traffic 1000	10,000

As shown immediately above, when compared very roughly, Van der Poel's moduli of stiffness values in psi for each of these three categories of traffic, are approximately ten times Ontario's corresponding minimum Marshall stability requirements in pounds.

V. APPLYING PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY IN HOT CLIMATES WITH NO FROST

Figure 3 illustrates the correct usage of paving asphalt temperature susceptibilities for pavements in hot climates where there is never any frost.

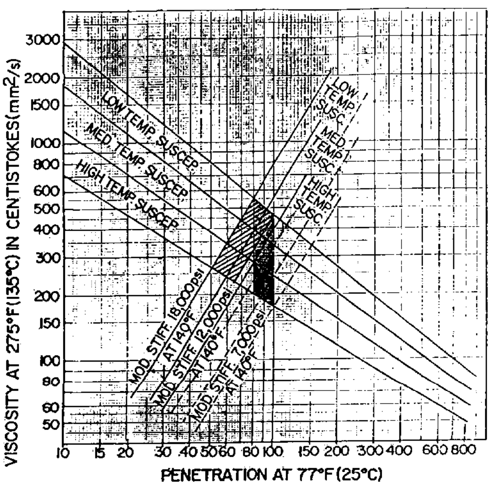

FIGURE 3 ILLUSTRATING HOW PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY CAN BE MADE TO WORK FOR OR AGAINST ENGINEERS IN WARM CLIMATES.

At present, paving asphalt for any paving project is usally specified and purchased as a single grade, e.g. 80/100 penetration, without the slightest regard for temperature susceptibility. Figure 3 demonstrates that in this case the pavement stability can range from a modulus of stiffness of 7,000 psi when the pavement contains 100 penetration asphalt with a high temperature suscep- tibility, PVN = -1.5, to a modulus of stiffness of 18,000 psi, if the pavement contains 80 penet- ration asphalt with a low temperature susceptibility, PVN = 0.0. These pavement stabilities are developed by fast heavy truck traffic travelling at 100 km/hr (60 miles/hr) when the pavement temperature is 60°C (140°F). It is obvious that if the pavement requires a paving asphalt with a penetration at 25°C (77°F) of 80, and a low temperature susceptibility, PVN = 0.0, to develop a needed modulus of stiffness of 18,000 psi at 60°C (140°F), the pavement stability and serviceability will not be very satisfactory if it contains an asphalt with a penetration at 25°C (77°f) of 100 and a high temperature susceptibility, PVN = -1.5, that develops a pavement modulus of stiffness of only 7000 psi. Neverthe- less, in the absence of temperature susceptibility requirements in paving asphalt specifications, this is what is happening. As illustrated by Figure 3, one solution for this problem requires that as the temperature susceptibility of the paving asphalt increases, its penetration at 25°C (77°F) must be decreased in order to maintain a constant pavement stability (modulus of stiffness).

VI. THE IMPORTANT INFLUENCE OF PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY ON PAVEMENT PERFORMANCE IN COLD CLIMATES

In Canada, when designing dense graded asphalt concrete paving mixtures, three basic objectives must or should be kept clearly in mind:

(a) How to avoid low temper- ature transverse pavement cracking in winter.

(b) How to provide adequate pavement stability for fast traffic at summer temperatures.

(c) How to prevent pavement rutting by warm weather traffic.

Every pavement should satisfy all of these three design requirements.

Figure 4, demonstrates that for at least two-thirds of the USA, exclusive of Alaska, the maximum depth of frost penetration ranges from 18 to 72 inches. Consequently, for a very large part of the USA, north of the Mason-Dixon line, the criteria for the design of dense graded asphalt concrete paving mixtures are the same as for Canada.

by paving asphalts to enable the pavements containing them to avoid low temperature transverse pavement cracking.

2. For example, if the minimum temperature at a paving site is -28.9°C (-20°F), only combinations of penetrations at 25°C (77°F) and PVN values (temperature susceptibilities) that lie on or to the right of the oblique line in Figure 5 labelled -28.9°C (-20°F) should be selected if the pavement is to avoid low temperature transverse pavement cracking at a minimum winter temperature of -28.9°C (-20°F). Grades of paving asphalts

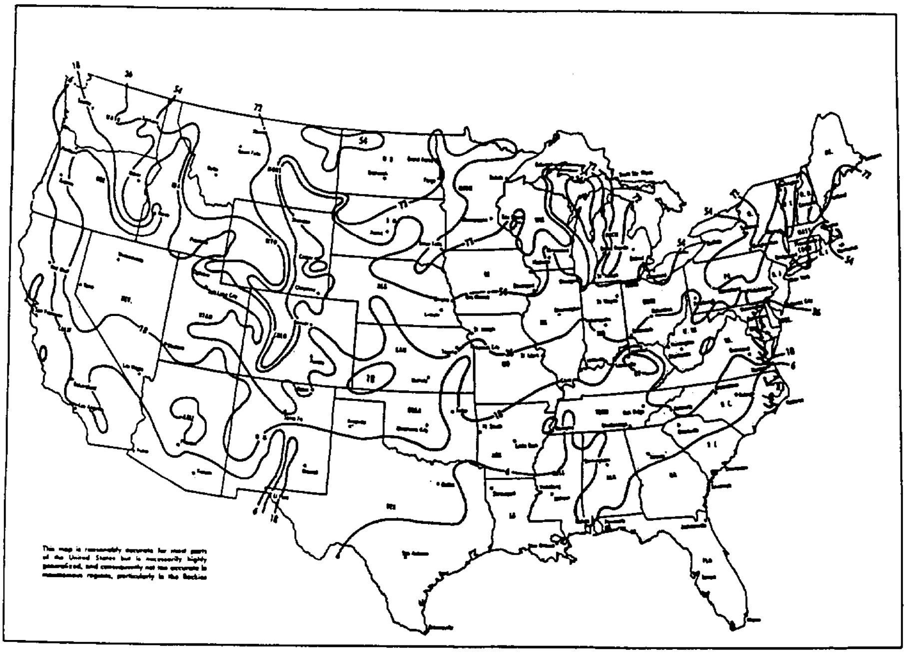

FIGURE 4 MAXIMUM DEPTH OF FROST PENETRATION, INCHES.

The practical significance of Figure 5 has been explained in detail in previous papers (1,2) and will be reviewed only briefly here.

1. Figure 5 is based on Test Road Data (5,6,7,8) and on the field performance of thousands of miles of paved roads, and represents the writer's best estimate of the combinations of penetrations at 25°C (77°F) and temperature susceptibility (PVN values) required with combinations of penetrations at 25°C (77°F) and PVN values that lie to the left of this line are too hard, and will result in low temperature transverse pavement cracking at an anticipated minimum pavement temperature of -28.9°C (-20°F). This is also true for the other oblique lines in Figure 5 representing other minimum pavement temperatures.

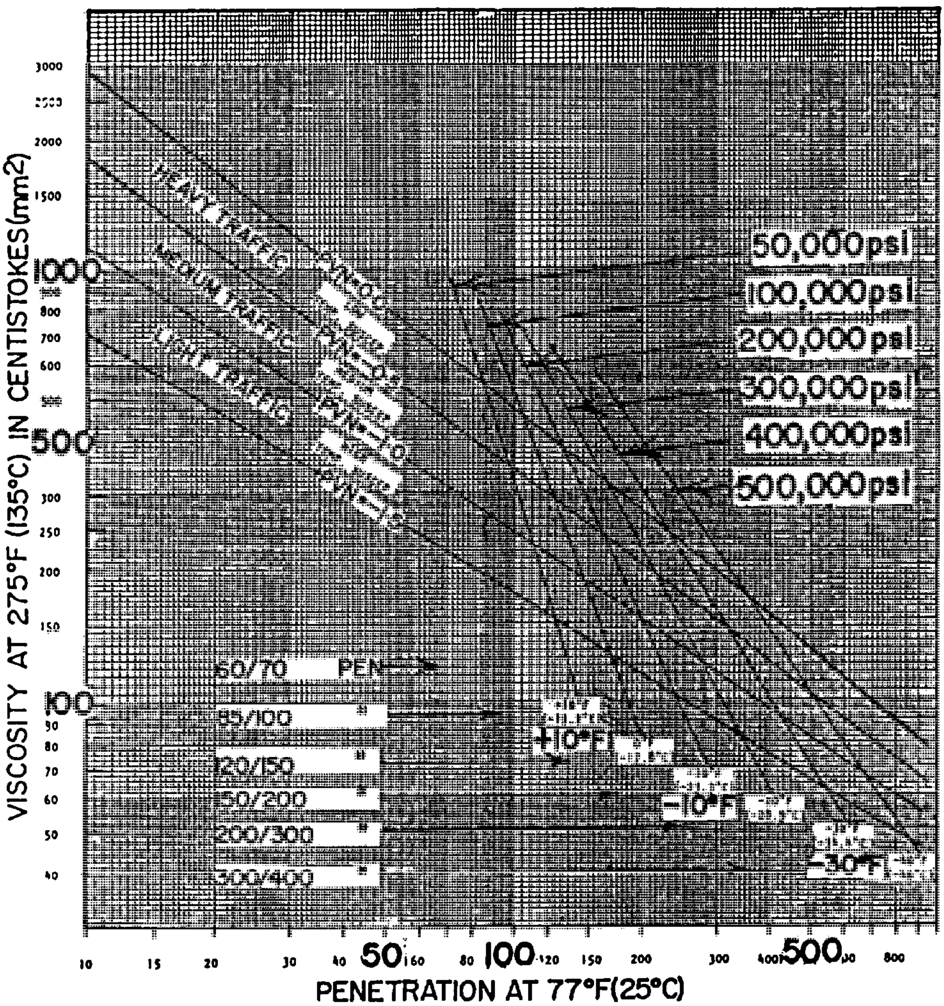

FIGURE 5 CHART FOR SELECTING PAVING ASPHALTS WITH VARIOUS COMBINATIONS OF TEMPERATURE SUSCEPTIBILITIES AND PENETRATIONS AT 25°C TO AVOID LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING AT SELECTED MINIMUM WINTER TEMPERATURES AND TO PROVIDE ADEQUATE PAVEMENT STABILITY AT SUMMER TEMPERATURES.

3. It is illustrated very clearly in Figure 5, that as the temperature susceptibilities of paving asphalts become higher and higher (PVN values become lower and lower) their penetrations at 25°C (77°F) must also become higher and higher in order to avoid low temperature transverse pavement cracking.

4. The numbers in the upper right of Figure 5 represent the modulus of stiffness values of paving mixtures containing the paving asphalts with the combinations of penetrations at 25°C (77°F) and PVN values represented by each oblique temperature

labelled line. For example, pavements containing paving asphalts having any combination of penetrations at 25°C (77°F) and PVN values that lie on the oblique line labelled -34.4°C (-30°F) will develop a pavement modulus of stiffness of 400,000 psi at a temperature of -34.4°C (-30°F), as indicated by Van der Poel's nomographs.

5. It should be particularly noted that <u>to obtain the highest pavement stabilities in warm weather, the combinations of penetrations at 25°C (77°F) and PVN values that lie exactly on each temperature labelled oblique line on Figure 5, should also be selected, because these will provide the lowest penetration at 25°C (77°F) and therefore the highest pavement stabilities that can be attained without causing low temperature transverse pavement cracking</u>.

6. In Figure 5, the temperatures for the temperature labelled oblique lines are intermittent values. In Figure 6, the data of Figure 5 have been rearranged so that the ordinate axis provides a continuous temperature scale.

7. Figure 7 is based at least in part on Figure 5. It shows an oblique line labelled -23.3 °C (-10°F) running from upper left to lower right to guide the selection of paving asphalts that will avoid low temperature transverse pavement cracking, Figure 5. Each of the oblique lines running from lower left to upper right represents a constant pavement stability value (modulus of stiffness value from Van der Poel's nomographs). It is clear that the pavement stability (modulus of stiffness) values represented by these oblique lines decrease in value when going from left to right. Therefore, these oblique lines indicate that as the penetrations at 25°C (77°F) become higher and higher and the corresponding temperature susceptibilities also become higher and higher (the associated PVN values become lower and lower), the affiliated pavement stability (modulus of stiffness) values become lower and lower.

Therefore, Figure 7 shows that for a paving site where the expected minimum pavement temperature will be -23.3°C

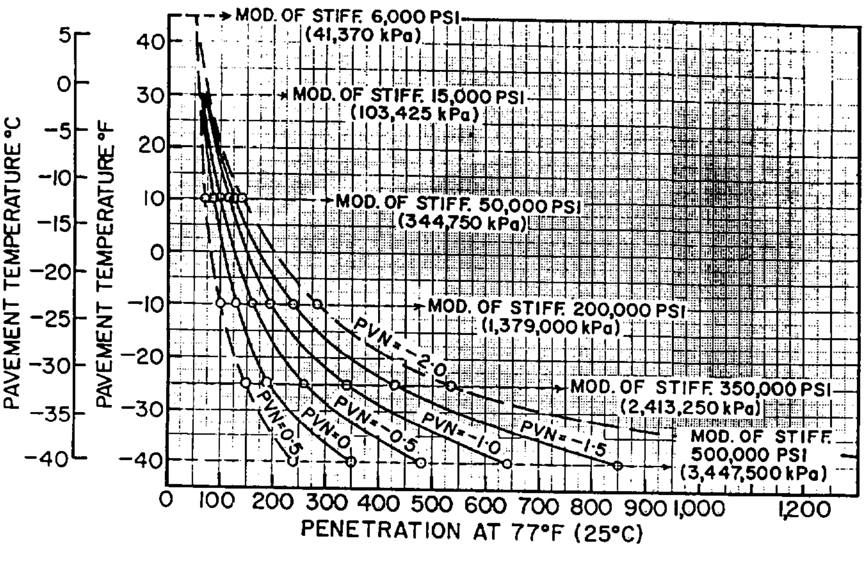

FIGURE 6 CONTINUOUS SCALE FOR LOW PAVEMENT TEMPERATURES VERSUS CORRESPONDING MINIMUM PAVING ASPHALT PENETRATIONS AT 77F (25C) TO AVOID LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING

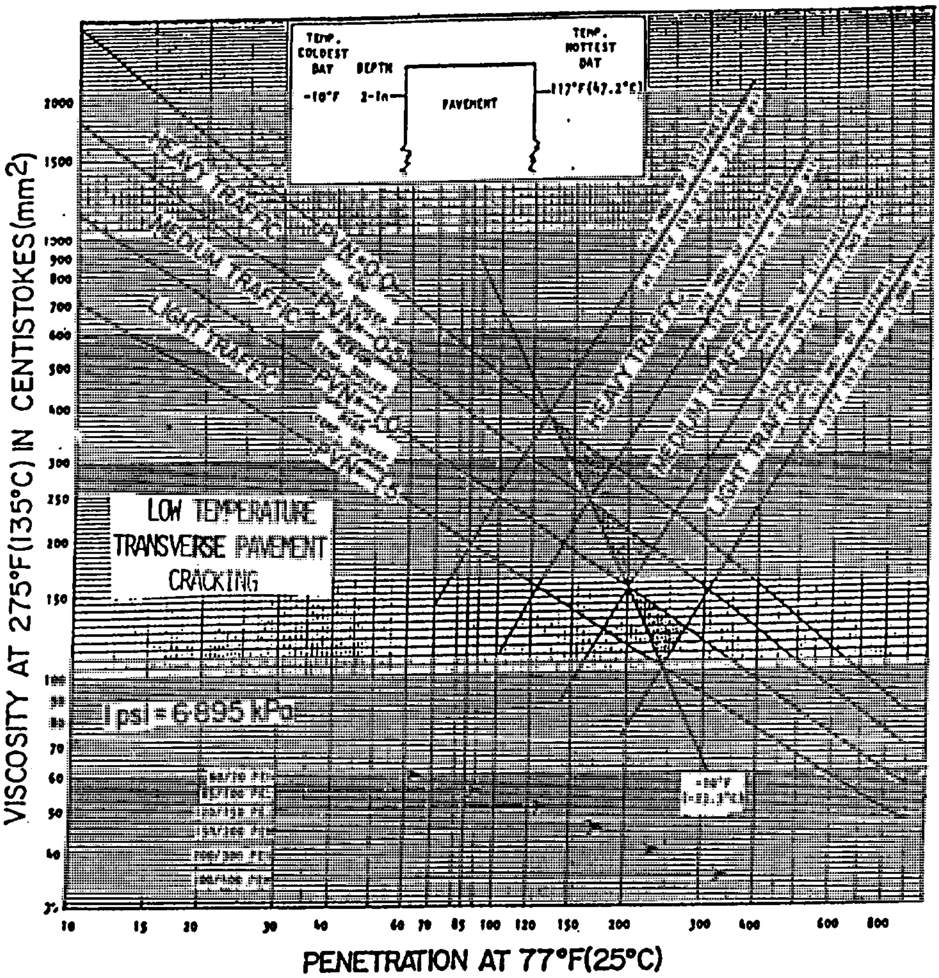

Figure 7 **Illustrating Selection of Combinations of Temperature Susceptibility (PVN) and Penetration at 25°F for Paving Asphalts For Heavy, Medium and Light Traffic in Cold Climates.**

(-10°F), for example, paving asphalts of low temperature susceptibility should be selected for surface courses for heavy traffic, because these paving asphalts have the lowest associated penetrations at 25°C (77°F) that will just avoid low temperature transverse cracking at -23.3°C (-10°F), and they will also provide the highest pavement stability (modulus of stiffness). For medium and light traffic, Figure 7 demonstrates that paving asphalts of medium and high temperature susceptibilities, respectively, can be used. Because these asphalts are on the oblique line labelled -23.3°C (-10°F), low temperature transverse pavement cracking will be avoided, and although because of their higher and higher penetrations at 25°c (77°F), they will provide lower and lower pavement stabilities, Figure 7 demonstrates that these stabilities, taken from Van der Poels nomographs, are still adequate for medium and light traffic.

VII. VARIATIONS OF PAVEMENT TEMPERATURE WITH PAVEMENT DEPTH BELOW THE PAVED SURFACE

Figure 8 illustrates the change in pavement temperature

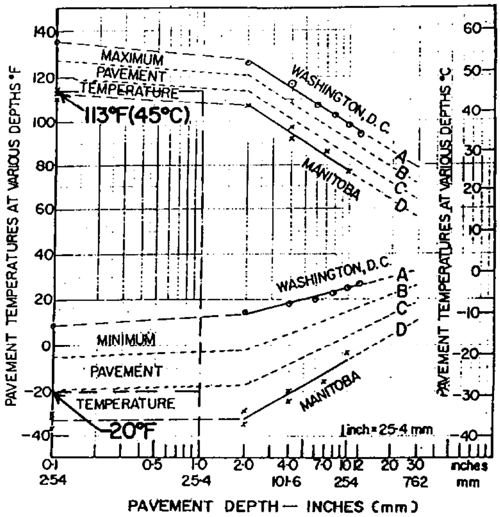

FIGURE 8 [illegible]

with pavement depth below the paved surface, that was measured hourly at intervals of 2 inches down to a depth of 12 inches, over a period of at least one year at Washington, D.C., by The Asphalt Institute (7), and similarly for pavements up to 10 inches in depth, at Ste. Anne, Manitoba jointly by the Manitoba Department of Transportation and Shell Canada (8,9).

Figure 8 demonstrates that on the coldest day of the year, pavement temperature gradually rises with increasing depth below the pavement surface, while on the hottest day of the year pavement temperature gradually drops with increasing depth of pavement below the surface.

Figure 8 contains valueable information for engineers. As described in Reference 10 and illustrated by Figure 9, paving asphalts of medium and high temperature susceptibility can be employed for binder and base course layers for deep strength and full depth asphalt pavements for heavy traffic, and for all three structural layers, if specified for medium and light traffic (1,2,10).

IX. TEMPERATURE SUSCEPTIBILITY AS A PAVING ASPHALT SPECIFICATION REQUIREMENT

It has been estimated (11) that in North America paving asphalts are presently manufactured from some 600 crude oil or crude oil blends. The property of paving asphalts that is most greatly affected by this wide variety of crude oil sources is its temperature susceptibility.

1	2	3	4	5	6	7
PAVEMENT LAYER	AVERAGE LAYER TEMPERATURE	AVERAGE PAVEMENT MODULUS OF STIFFNESS PSI				
		HEAVY TRAFFIC PAVEMENTS				
2-In Surface	113°F (45°C)	A* 24,500	A 24,500	A 24,500	A 24,500	
2-In Binder	105°F (40.6°C)	A 35,000	B* 26,000	B 26,000	C 19,000	
2-In Base	95°F (23°C)	A 69,500	B 50,500	C* 36,000	C 36,000	
		MEDIUM TRAFFIC PAVEMENTS				
2-In Surface	113°F (45°C)	B 18,000	B 18,000	B 18,000		
2-In Binder	105°F (40.6°C)	B 26,000	B 26,000	C 19,000	----	
2-In Base	95°F (35°C)	B 50,5000	C 36,000	C 36,000		
		LIGHT TRAFFIC PAVEMENTS				
2-In Surface	113°F (45°C)	C 12,750				
2-In Binder	105°F (40.6°C)	C 19,000	----	----	----	
2-In Base	95°F (35°C)	C 36,000				

TEMP. COLDEST DAY	DEPTH		TEMP. HOTTEST DAY
-20°F	1-In	SURFACE 2-In	113°F (45°C)
-14°F	3-In	BINDER 2-In	105°F (40.6°C
- 7°F	5-In	BASE 2-In	95°F (35°C)

*A - 2-In pavement layer contains paving asphalt of low temperature susceptibility, PVN = 0.0 to -0.5.
*B - 2-In pavement layer contains paving asphalt of medium temperature susceptibility, PVN = -0.5 to -1.0.
*C - 2-In pavement layer contains paving asphalt of high temperature susceptibility, PVN = -1.0 to -1.5.

FIGURE 9

SELECTING PAVING ASPHALTS OF DIFFERENT TEMPERATURE SUSCEPTIBILITIES FOR SURFACE BINDER AND BASE COURSE LAYERS

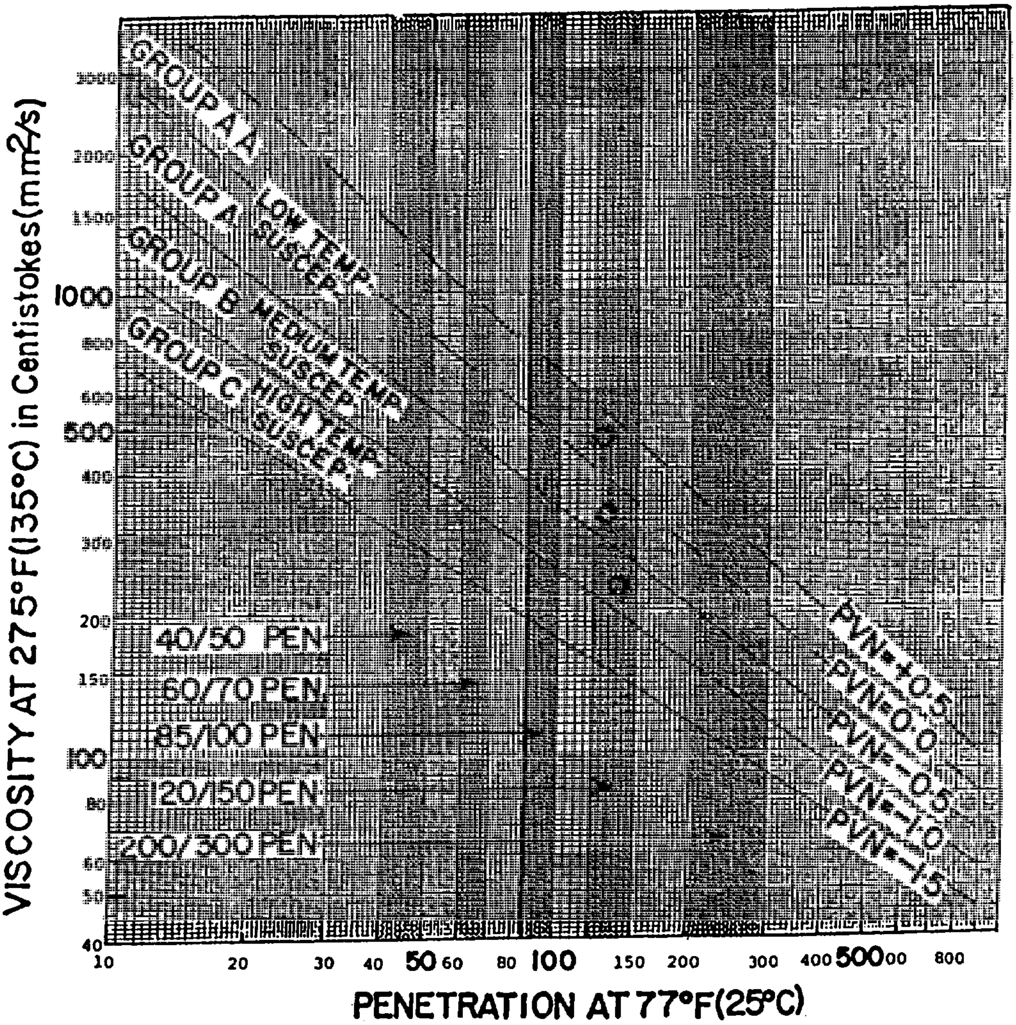

Figure 10 ILLUSTRATING A SPECIFICATION BASED ON PENETRATIONS AT 77°F (25°C), VISCOSITIES AT 275°F (135°C), AND TEMPERATURE SUSCEPTIBILITIES OF PAVING ASPHALTS.

While neither ASTM nor AASHTO currently includes an item for temperature susceptibility in their paving asphalt specifications, this property is now receiving so much attention that paving asphalt specifications containing temperature susceptibility requirements similar to those illustrated in Figure 10 are almost inevitable.

As demonstrated by Figure 10, paving asphalts with their wide range of temperature susceptibilities could be divided into three groups, Groups A, B and C. Group A would include paving asphalts of low temperature susceptibility with PVN values from 0.0 or 0.5 to -0.5. Possibly Group A asphalts should be divided into Group A with a PVN from 0.0 to -0.5 and Group AA with a PVN from 0.5 to 0.0. Paving asphalts of medium temperature susceptibility with PVN values from -0.5 to -1.0 would be placed in Group B, while Group C would contain paving asphalts of high temperature susceptibility with PVN values from -1.0 to -1.5.

Is there any way to improve the natural temperature susceptibilities of paving asphalts? Recently, our company has added a Ph.D. polymer chemist to our staff to investigate the improvement of paving asphalt properties by the addition of polymers. One of the first projects assigned to him was the improvement of paving asphalt temperature susceptibilities by the addition of small percentages of one or a combination of polymers. Already he has shown, as illustrated by small circles in Figure 10, that by adding about one percent of a certain polymer to a Group B asphalt, its temperature susceptibility can be changed to Group A, while the incorporation of about two percent of the same polymer improves the temperature susceptibility to Group AA.

If improving the temperature susceptibility and other properties of paving asphalts by incorporating small percentages of polymers turns out to be attractive on a cost/benefit basis, the control of the paving asphalt market could change from the asphalt suppliers, where it always has been, to the asphalt users.

For the first time, if an engineer decides that paving asphalt of a certain penetration at 25°C (77°F) and with a certain temperature susceptibility would be the optimum for a certain pavement, or even for a certain pavement layer, the asphalt supplier could no longer tell him that paving asphalt of that temperature susceptibility was not available. Its temperature susceptibility could be easily modified by adding a proper polymer.

SUMMARY

1. The temperature susceptibility of a paving asphalt is defined and its measurement is described.
2. For pavements in hot climates with no frost, to maintain a constant pavement stability, as a paving asphalt's temperature susceptibility increases, its penetration at 25°C (77°F) must be decreased.
3. In cold climates, to eliminate low temperature transverse pavement cracking in winter, and to provide adequate pavement stability for summer traffic, the penetration at 25°C (77°F) and temperature susceptibility must be carefully selected and coordinated for heavy, medium and light traffic.
4. On the coldest day of the year, pavement temperature increases with pavement depth below the surface, with the reverse occurring on the hottest day of the year. It is shown how this information can be utilized for the design of surface, binder and base course layers for heavy, medium and light traffic.
5. It is demonstrated that a temperature susceptibility item can be introduced into any paving asphalt specification in terms of Group A for low temperature susceptibility, Group B for medium temperature susceptibility, and Group C for high temperature susceptibility.
6. The natural temperature susceptibilities of paving asphalts can be changed dramatically by the addition of small percentages of certain polymers.
7. The use of polymer modified asphalts could change what has always been an asphalt suppliers' market into an asphalt users' market.

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APPENDIX

I. THE ORIGIN OF PVN

In 1960, the Ontario Ministry of Transportation and Communications constructed three 6-mile Test Pavements, about 40 miles apart on existing highways in southwestern Ontario, Figure A. As shown on the left side of Figure A, each 6 mile Test Pavement was divided into three 2-mile test sections. The pavement on each 2-mile test section contained a single 85/100 penetration asphalt with a single temperature susceptibility. Consequently, each 6-mile test road contained 2-miles of pavement made with 85/100 penetration asphalt of low temperature susceptibility, 2-miles of pavement made with 85/100 penetration asphalt having medium temperature susceptibility, and 2-miles of pavement made with 85/100 penetration of high temperature susceptibility. The same three paving asphalts were replicated in the three 6-mile Test Roads (1,2). Because of certain construction difficulties they were causing, the Ministry was tentatively expecting that the pavement test sections made with the asphalt of high temperature susceptibility would disintegrate rather quickly under traffic and weather, and thereby remove themselves as acceptable paving materials. However, this did not happen.

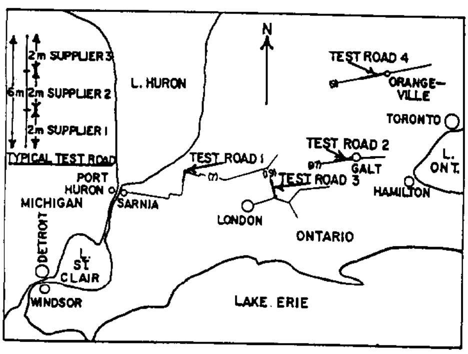


FIGURE A LOCATIONS OF FOUR ONTARIO TEST ROADS

Low temperature transverse pavement cracking was beginning to be a serious problem in Canada at that time. To refresh your memories, Figure B provides a very good example of low temperature transverse pavement cracking. The cracks are well marked by the crack filler that was applied.

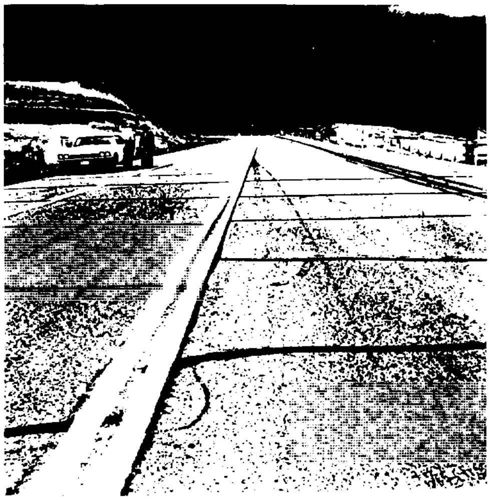


FIGURE B TYPICAL LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING

Figure C demonstrates that there are four types of low temperature transverse pavement cracks. Type 1 cracks cross the entire traffic lane. Type 2 cracks begin at the shoulder but go only part way across a lane. Type 3 cracks begin at the centre of a 2-lane pavement but also cross the lane only part way. Type 4 cracks are located in the centre of a a traffic lane but do not extend to either lane boundary.

In all of the work we have done on the problem of low temperature transverse pavement cracking, it appears that only Type 1 low temperature transverse pavement cracks can be significantly related to paving asphalt, or asphalt pavement properties.

In 1968, when the three Ontario Test Roads were 8 years old, the writer, who by this time had begun to take a serious interest in the problem of low temperature transverse pavement cracking, realized that these three projects

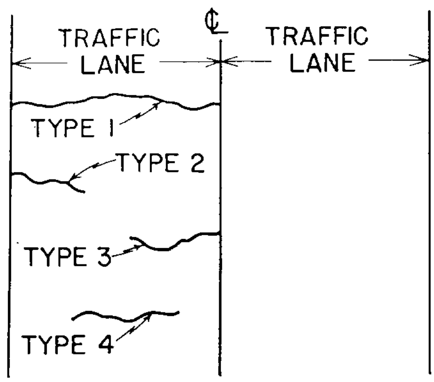


FIG. c TYPES OF TRANSVERSE PAVEMENT CRACKS.

provided an excellent field laboratory to follow the development of transverse pavement cracking at low temperatures. For the next 13 years, an annual crack survey was made by walking along the adjacent gravel shoulder with a tally pad in hand. Initially this meant 36 miles of walking on both gravel shoulders, which was usually spread over several weekends. Figure D illustrates the results of this crack survey for Test Road 2, which is representative of all three Test Roads (1,2).

It should be added that the asphalt pavement for these three Test Roads was laid on a strong granular base, and consisted of 1.5 inches of surface course on 2.0 inches of base course, both being dense graded asphalt concrete. Surveys showed that the traffic ranged from 2000 to 3000 vehicles per day with from about 10 to about 14 percent of heavy trucks.

It will be observed from Figure D, that the number of Type I low temperature pavement cracks per lane mile is plotted versus PVN values as measures of the temperature susceptibilities of the three 85/100 penetration paving asphalts. This is because only the order of the pen-vis number (PVN) values of the three paving asphalts agreed with the order of the numbers of low temperature transverse pavement cracking that had developed.

In 1968, the only measures of paving asphalt temperature susceptibility were penetration ratio (pen at 39.2°F divided by penetration at 77°F and multiplied by 100) and Pfeiffer and Van Doormaal's (3) penetration index, (PI) which was based on

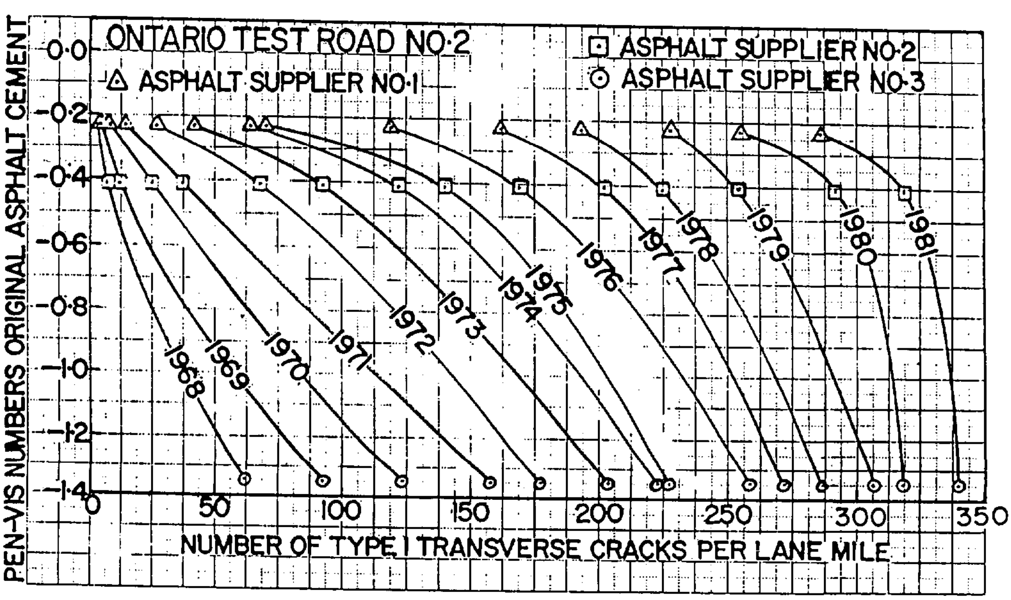


FIGURE D: INFLUENCE OF PAVING ASPHALT TEMPERATURE SUSCEPTIBILITIES ON ANNUAL COUNT OF TYPE 1 LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKS PER LANE MILE penetration at 77°F and the ring and ball softening point. However, as Table 1 indicates, neither the order of the penetration ratio values nor the order of the PI values agree with the order of the number of low temperature transverse pavement cracks shown in Figure D. The penetration ratio for asphalt from Supplier 2 was the highest value in Table 1, but it did not show the smallest number of low temperature transverse pavement cracks in Figure D.

tibility and the lowest PI, whereas Table 1 shows that it has the highest PI, and vice versa for the paving asphalt from Supplier 1.

One of the reasons for this is that the asphalt from Supplier 3 came from Western Canadian waxy light crude. This provides a false ring and ball softening point. The softening points are too high, which gives them a false temperature susceptibility rating that is much too low. Therefore, the Pfeiffer and Van

TABLE I

Inspection Data on Original 85/100 Penetration Asphalt Cements Used for Ontario's Three 1960 Test Roads

I.				
II	Supplier Number	1	2	3
III IV	Flash Point COC F.	585	525	615
V	Softening Point R and B, F.	115	115	119
	Penetration 100 gr. 5 sec. 77°F	83	96	87
VI	200 gr. 60 sec. 39.2°F	25	36	22
	200 gr. 60 sec. 32°F	22	26	19
	Penetration Ratio	30.2	37.5	25.3
	Ductility at 77°F., 5 cm/min	150+	150+	128
	Viscosity Centistokes at 275°F	460	365	210
	Centistokes at 210°F	3953	2763	1472
	Thin Film Oven Test			
	%loss by weight	0.1	0.3	0.0
	Residue			
	% Original Penetration at 77°F	67.5	60.4	61.0
	Ductility at 77°F, 5 cm/min	150+	110	115
	Solubility in n-hexane			
	% asphaltenes	19.7	24.7	18.8
	Penetration Index			
	Pfeiffer and Van Doormaal	-1.00	-0.57	-0.21
	Pen-vis number	-0.23	-0.41	-1.35

Similarly, the order of the values for PI in Table 1, are the complete opposite of the order for the numbers of low temperature cracks shown in Figure D. For example, Figure D shows that the asphalt from Supplier 3 has developed the highest number of Type 1 low temperature transverse pavement cracks per lane mile, and it should therefore have the highest temperature suscep-

Doorwaal penetration index cannot be used to determine the PI of asphalts from these waxy crude oils.

Consequently, the order of the temperature susceptibility ratings given in Table 1 for either penetration ratio or penetration index, PI, is not in agreement with the order of their ratings for low temperature transverse pavement cracking shown in Figure D.

Therefore, a new method for designating paving asphalt temperature susceptibility had to be devised, that would agree with the low temperature transverse pavement crack pattern of Figure D.

Ontario had observed that for a given penetration at 77°F a minimum viscosity requirement at 275°F would separate paving asphalts of high viscosity at this temperature from those of low viscosity, and would also eliminate some construction problems associated with these low viscosity binders. As a consequence, several years before, 1968, they had established a paving asphalt specification which rejected all 85/100 penetration paving asphalt, for example, that had a viscosity at 135°C below 140 seconds Saybolt Furol, later changed to 280 centistokes at 135°C. At the same time, if the author remembers correctly, the State of Connecticut was specifiying a minimum viscosity at 135°F of 150 seconds Saybolt Furol in its specification for 85/100 paving asphalt.

As a result, the writer (1,4) originated the term, pen-vis numbers (PVN), based on a paving asphalt's penetration at 25°C and its viscosity in centistokes at 135°C, to serve as a substitute for penetration ratio and penetration index, PI.

It should be added that the inspection data in Table 1, except for the PVN values that were added later by the writer, were obtained by Mr. J.A.A. Lefebvre, a very competent asphalt tecnhologist in Imperial Oil Limited's research laboratory at the time, whom some will recall.

Incidentally, Heukelom (5) recognized that because of the false ring and ball softening points for asphalts from waxy crude oils, that Pfeiffer and Van Doormaal's method for PI determination did not provide a universally acceptable measure of temperature susceptibility. Pfeiffer and Van Doormaal had found that for asphalts with normal ring and ball softening points, the softening point corresponded to a penetration of 800 or a viscosity of 13,000 poises at the softening point temperature. Heukelom therefore, discarded the softening point temperature as a requirement for PI, and substituted for it a method requiring the measurement of penetration (100 g 5 sec) at 4°C, 10°C and 25°C, and then drawing a best line through these measured values, projecting this line to a penetration of 800, and reading the corresponding temperature. This temperature is substituted for softening point temperature, and Pfeiffer and Van Doormaal's equations are then used to establish the PI value for a paving asphalt.

II. PEN-VIS NUMBER (PVN) AS A FINGER PRINT FOR PAVING ASPHALTS

PVN appears to be a finger print that follows a paving asphalt throughout its service life.

One indication of this is Figure E, taken from an AAPT paper by Anderson, Dukatz and Rosenberg (6). Figure E shows that the PVN of an asphalt's thin-film oven test residue, is the same as the PVN of the original asphalt. This is verified by data obtained in our own laboratory and in the laboratory of the British Columbia Department of Highways (7).

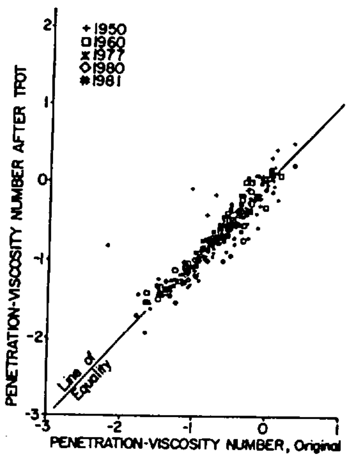


Fig. E Pen-Vis Number Before and After Thin-Film Oven Exposure.

Figure F, also by Anderson et al (6) shows that there is no similar close relationship for before and after the thin film oven test for penetration index, PI, (Pfeiffer and Van Doorwaal (3).

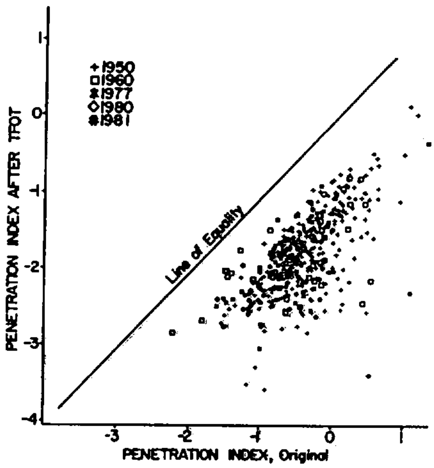


Fig. F Penetration Index Before and After Thin-Film Oven Exposure.

Table 2 presents PVN data obtained for asphalt recovered from samples from Ontario's three Test Roads after 8 years and after 15 years of service versus the PVN for the original 85/100 penetration asphalts (1,2). These data vary slightly from sample to sample, as might be expected, due to small errors introduced by pavement sampling and by asphalt recovery by the Abson Test. Nevertheless, the PVN relationship between the original 85/100 penetration binder and the asphalt recovered after 8 years and 15 years of service is so strikingly close that the writer commented on it (1).

Since the data of Table 2 were obtained by the writer's organization, it might be accused of bias. Therefore Tables 3 and 4 are listed, which contain data obtained on the original asphalts and after one year (8), and after seven (9) years of service by Kandhal of PenDot. In Table 2, Kandhal compares the temperature susceptibilities of six different asphalts as original materials and as recovered from the pavement after 1 year of service. He compares data for PI (Pen/Ring and Ball), (Pfeiffer and Van Doormaal) and PI (Pen/Pen) (Heukelom), with those for PVN. A similar comparison is made in Table 4 for PI (Pen/Pen) versus PVN after 7 years of service. In both Tables, Kandhal shows that there is a very close PVN relationship for original versus asphalt recovered after these periods of service, but a much less satisfactory relationship for PI for the original asphalts versus the PI of asphalts recovered after 7 years of service.

All of these data show therefore that PVN appears to be a paving asphalt finger print that remains unchanged throughout a pavement's service life, and appears to be much superior to even Heukelom's modified penetration index, PI, in this respect.

III. FURTHER SUPPORT FOR THE SUPERIORITY OF PVN AS A MEASURE OF PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY

Figure G represents a plot of PVN values versus PI values for about 200 samples of paving asphalts from all over the USA, with occasional samples from Canada, that were tested by Welborn, and Halstead (10) and by Welborn, Halstead and Boone (11), all of the old Bureau of Public Roads, and published in Public Roads magazine in 1959 and 1960 (10,11). The paving asphalts ranged from 60/70 to 150/200 penetration. The PVN values were calculated in the normal way from penetration at 25°C and viscosity in centistokes at 135°C. The PI values (Pfeiffer and Van Doormaal), were calculated by means of the usual equations:

$$B = \frac{\log 800 - \log (\text{pen at } 25°C)}{T(R \text{ and } B) - 25}$$

$$PI = \frac{20 - 500B}{50B - 1}$$

Where

B = the slope of the line representing penetration at 25°C versus softening point °C (Ring and Ball).

Figure H is a plot of the same data as Figure G, but the limits for the proposed three groups of temperature susceptibility have been added,

Table 3 Temperature Susceptibilities of Original and Aged Asphalt

Asphalt Type	PI (pen/R & B)		PI (pen/pen)		PVN	
	Original	Aged	Original	Aged	Original	Aged
T-1	-1.43	-1.18	-2.77	-2.24	-1.04	-1.13
T-2	-0.61	-0.91	-0.71	-0.80	-0.70	-0.68
T-3	-0.60	-0.61	-1.51	-0.99	-0.61	-0.72
T-4	-0.57	-1.24	-1.05	-0.65	-0.86	-1.03
T-5	-0.74	-1.30	-2.23	-2.03	-1.03	-1.16
T-6	-0.16	-0.32	-1.29	-0.64	-0.45	-0.47
Average	-0.68	-0.93	-1.59	-1.22	-0.78	-0.86

both with a PI of 0.0+ in terms of pavement performance. Will they both behave in the field as PI = 0.0+ paving asphalts? The answer is provided by Figure D. It happens that the circled asphalt in the lower right hand corner of Figures G and H is from a Western Canadian waxy light crude. So is the asphalt of highest temperature susceptibility PVN = -1.34 in Figure D. Consequently, the normal PI = 0.0 to -0.5 (Group A)

TABLE 4 TEMPERATURE SUSCEPTIBILITIES OF ORIGINAL AND AGED ASPHALTS

ASPHALT TYPE	PI (pen/pen)				PVN (Pen-Vis Number)			
	Original	Just After Construction	20 Months	Seven Years	Original	Just After Construction	20 Months	Seven Years
T-1	-2.77	-2.24	+0.36	+1.82	-1.04	-1.13	-1.07	-1.12
T-2	-0.71	-0.80	+1.22	+1.52	-0.70	-0.68	-0.54	-0.60
T-3	-1.51	-0.99	-0.12	-0.58	-0.61	-0.72	-0.65	-0.56
T-4	-1.05	-0.65	+0.93	+0.39	-0.86	-1.03	-0.76	-0.79
T-5	-2.23	-2.03	-0.32	-0.87	-1.03	-1.16	-1.07	-1.12
T-6	-1.29	-0.64	+0.60	-0.46	-0.45	-0.47	-0.40	-0.39

FIGURE G - COMPARISON BETWEEN PEN-VIS NUMBER VALUES (PVN) VERSUS PENETRATION INDEX VALUES (PI) FOR ABOUT 200 PAVING ASPHALTS MANUFACTURED BY STEAM OR VACUUM REDUCTION

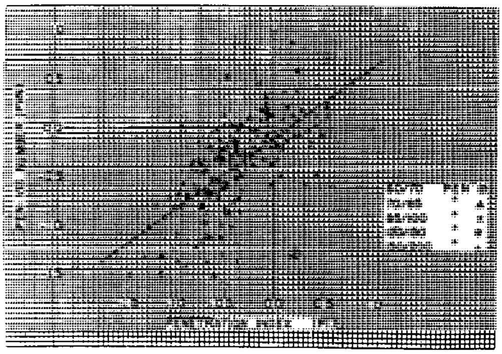
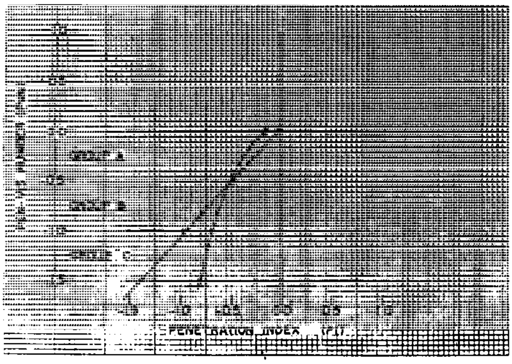
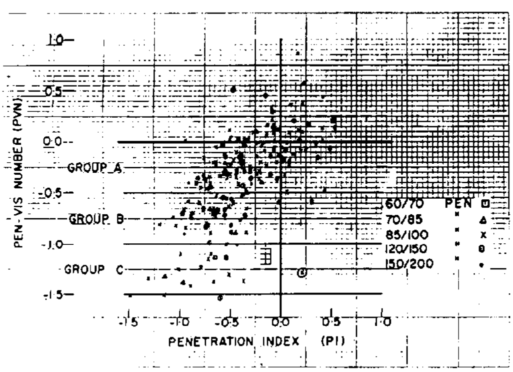


FIGURE I - COMPARISON OF AVERAGE PVN WITH AVERAGE PI VALUES



asphalts in Figure H have the low temperature transverse pavement cracking pattern of the asphalt of low temperature susceptibility, PVN = -0.23 in Figure D. On the other hand, the PI = +0.25 for the circled asphalt of Group C in Figure H,

FIGURE H - DATA OF FIGURE G DIVIDED INTO GROUPS A, B AND C



has the low temperature transverse pavement crack pattern of the asphalt of high temperature susceptibility, PVN = -1.34, in Figure D.

As a result, the low temperature field performance of the asphalts represented by Figures G, H and I are controlled by their PVN values, not by their PI values. Figures G, H and I also eliminate Pfeiffer and Van Doorwaal's equations for PI as an overall criterion for paving asphalt temperature susceptibility.

Incidentally, Figures G and H demonstrate that about 50 percent of the asphalts represented in the Figures are in Group A, about 25 percent in Group B, about 10 percent in Group C, while about 20 percent fall into Group AA.

IV. VAN DER POEL'S NOMOGRAPHS INDICATE PAVEMENT MODULUS OF STIFFNESS VALUES AT LOW TEMPERATURES

Since it is quite difficult to make significant measurements of viscosity at low temperatures, some have claimed that low temperature pavement performance cannot be forecast from tests made at

TABLE 2

EFFECTS OF AGING IN SERVICE ON PVN

BASIS OF COMPARISON RECOVERED ASPHALT
AFTER 8 YEARS AND AFTER 15 YEARS
OF SERVICE

AFTER 8 YEARS

ASPHALT SUPPLIER	PVN ORIGINAL ASPHALT	TEST ROAD 1	TEST ROAD 2	TEST ROAD 3
1	-0.23	-0.56	-0.44	-0.46
2	-0.41	-0.51	-0.51	-0.53
3	-1.35	-1.33	-1.36	-1.35

AFTER 15 YEARS

ASPHALT SUPPLIER	PVN ORIGINAL ASPHALT	TEST ROAD 1	TEST ROAD 2	TEST ROAD 3
1	-0.23	-0.42	-0.49	-0.41
2	-0.41	-0.58	-0.53	-0.41
3	-1.35	-1.29	-1.17	-1.08

Group A (PVN from 0.0 to -0.5), Group B (PVN from -0.5 to -1.0) and Group C (PVN from -1.0 to -1.5).

For Figure I, the data of Figure H have been separated into groups, PVN = 0.0 ± 0.25, PVN = -0.5 ± 0.25, PVN = -1.0 ± 0.25 and PVN = -1.5 ± 0.25. The mean or average values for PVN and PI within each of these groups were then calculated, and these average values for PVN and PI for each group have been plotted on Figure I.

It is clear from Figure I that these mean or average values for PVN and PI are practically identical, for Group A asphalts, but the values increasingly deviate from each other for Group B and Group C asphalts. This is believed to be due to the crude oil sources for the asphalts included in each Group, which range from asphaltic crudes for Group H, through mixed blend crudes for Group B, to waxy crude oils for Group C.

It should be noted that the PI = 0.25 of the circled asphalt in the extreme lower right hand corner for Group C, in Figures G and H, is the same as the PI = 0.0+ of the asphalts in the upper right hand corner, Group A. What separates them is that the Group A asphalts, PI = 0.0+, in the upper right have a high viscosity at 135°C. This indicates that the penetration at 25°F and ring and ball softening point, as stipulated for PI by Pfeiffer and Van Doorwaal, are unable to distinguish between these two very unlike PI = 0.0+ asphalts. It is necessary to separate them by a completely different test, a viscosity test at 135°C.

However, there is still the problem of separating these Group C and Group A asphalt ordinary temperatures.

Figure J appears to refute this.

Figure J is a plot of moduli of stiffness values taken from Van der Poel's nomographs versus the number of type 1 low temperature transverse pavement cracks per lane mile that have developed in all three Test Roads over a period of 8 years, and a period of 15 years at an average minimum temperature of -19.7°C (-3.5°F). The order of low temperature transverse cracking is the same in Figure J as in Figure D. It ranges from the smallest number of Type 1 low temperature transverse pavement cracks per lane mile for the three test sections made with 85/100 penetration asphalt of lowest temperature susceptibility (PVN = -0.23), to the highest number of the same cracks per lane mile for the three pavements made with 85/100 penetration of highest temperature susceptibility, PVN = -1.35.

Furthermore, some years ago, based on field observations and tests that had been made up to that time, the writer suggested that substantial low temperature transverse pavement cracking would not occur until the pavement modulus of stiffness, due to asphalt hardening in service and low winter temperatures, reached one million psi. This criterion appears to hold very well for the data in Figure J. These data show that only pavements made with the low and medium temperature susceptibility asphalts (PVN = -0.23 and PVN = -0.41) from Suppliers 1 and 2, remain below the critical modulus of stiffness of one million psi for some 8 years.

Figure J therefore demonstrates that Van der Poel's nomographs are quite valid at least to temperatures as low as -20°C.

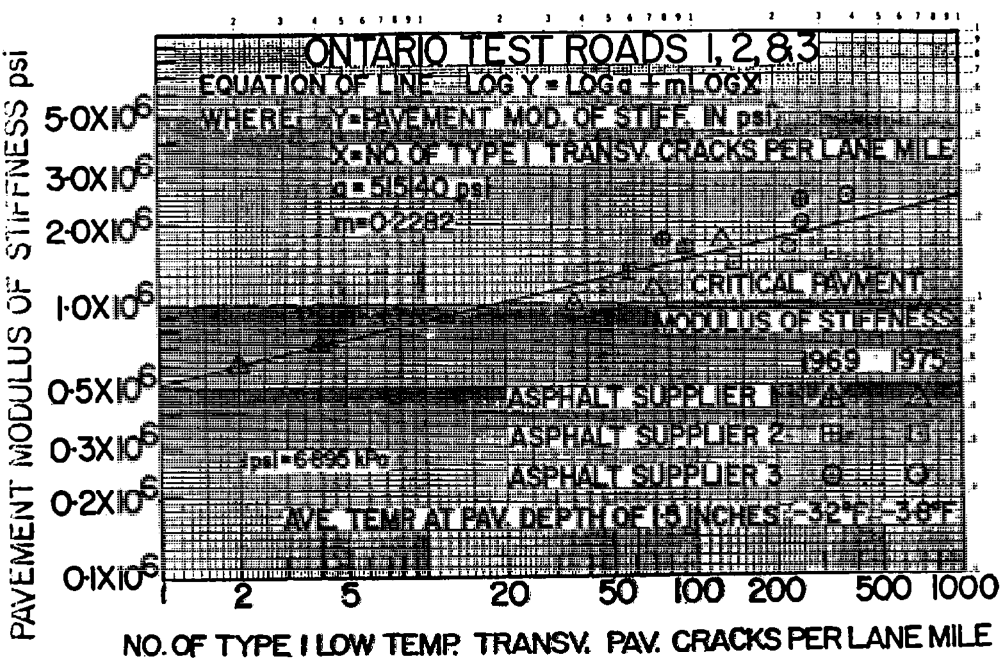


FIGURE J - PAVEMENT MODULI OF STIFFNESS VALUES VERSUS LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING AFTER 8 YEARS AND 15 YEARS OF SERVICE

VI LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING IS CONTROLLED BY THE PROPERTIES OF THE PAVING ASPHALT

It has been suggested seriously that low temperature transverse pavement cracking could be eliminated merely by changes in the design of the paving mixture, without any consideration for the properties of the paving asphalt.

Figure K has been prepared from test data provided by the three Ontario Test Roads. The data illustrated in Figure K are for Test Road 2, but similar data have been published for all three Test Roads (2).

Figure K illustrates data for the annual change in the number of low temperature transverse pavement cracks per lane mile over an 11-year period. The best lines through the data were determined by the method of least squares. For the paving asphalts of low and medium temperature susceptibility (PVN = -0.23 and PVN = -0.41, respectively), there is an annual average increase in the number of low temperature transverse pavement cracks that have developed. On the other hand, for the pavements containing the 85/100 penetration paving asphalt of highest temperature susceptibility, (PVN = -1.35), there is an average annual decrease in the number of low temperature transverse pavement cracks that have occurred.

Based on the data in Figure K, the writer would like to ask how any dense graded paving mixture design that could be devised could take into account, the variable low temperature transverse pavement crack development illustrated in this Figure?

The writer believes that

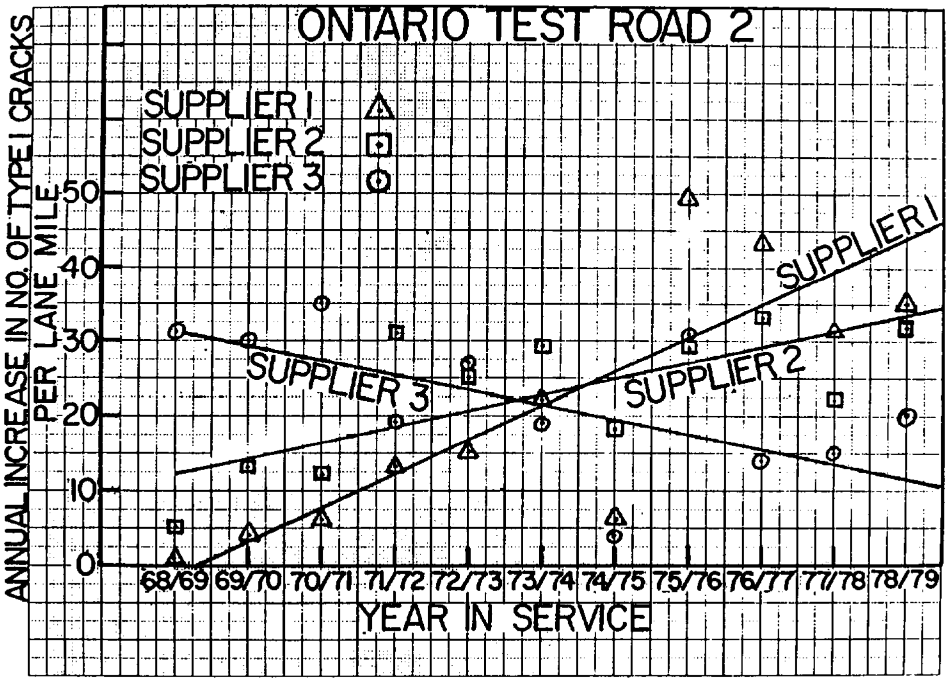


Figure K Annual Increase in New Type 1 Low Temperature Transverse Pavement Cracks Per Lane Mile - Test Road 2 the data of Figure K demonstrate conclusively that the properties of the paving asphalt are the principal cause of low temperature transverse pavement cracking.

VII. PVN FROM VISCOSITY AT 135°C VERSUS PVN FROM VISCOSITY AT 60°C

Currently, PVN values for paving asphalts are determined by means of viscosities measured at either 60°C or 135°C, although originally PVN was based on viscosity at 135°F.

At present, and much more so in the future, asphalt pavement construction will include pavement recycling. It is just as important to know the properties, including PVN, of the recovered hard asphalt from pavements to be recycled as it is to know the properties of asphalt for a pavement to be made with completely new materials.

Figure L indicates that at 135°C, all paving asphalts are Newtonian fluids, for which

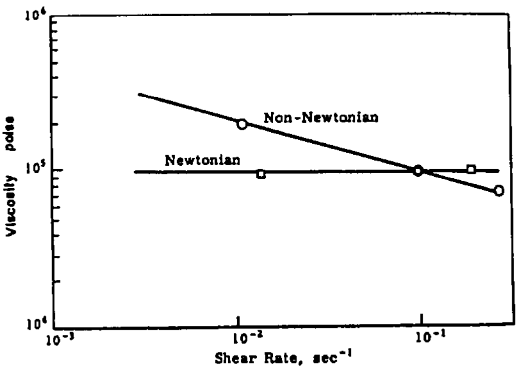


Fig. L Examples of Newtonian and Non-Newtonian Asphalts.

viscosity is independent of rate of shear.

On the other hand, the hard asphalts recovered from many in-place pavements behave as non-Newtonian fluids if an attempt is made to measure their viscosity at 60°C. That is, their viscosity varies with the rate of shear used for the test. Consequently, any rate of shear used for a viscosity test at 60°C is not necessarily related to any of the variable rates of shear to which asphalt in a pavement is exposed in service.

Accordingly, PVN values should be determined at 135°C, where paving asphalts are Newtonian fluids, and where their viscosity is independent of rate of shear.

VIII. INCREASING PVN BY THE ADDITION OF POLYMERS

It was pointed out earlier that there are three important paving mixture design requirements for every asphalt pavement placed in a cold climate. These are:

(a) Avoid low temperature transverse pavement cracking at low winter temperatures.
(b) Provide adequate pavement stability for fast traffic at high summer temperatures, and
(c) Prevent pavement rutting in warm weather, which is a serious problem all around the world.

Referring to Figure 7, low temperature transverse pavement cracking can be avoided by selecting paving asphalt on or to the right of the line labelled -23.3°C (-10°F), or on or to the right of other oblique temperature labelled lines in Figure 5 representing other minimum winter temperatures.

Referring to Figures 7 and 10 for heavy traffic, Figure 7 shows that the asphalt should be selected as close as possible to the temperature labelled oblique line -10°F (-23.3°C), but on its right side (to avoid low temperature transverse pavement cracking) and as near as possible to a PVN of 0.0, in order to obtain the highest stability for heavy traffic in summer. Similar selection of the paving asphalt can be made for medium and light traffic.

Figure 10 shows that if there is no asphalt available with a PVN from 0.0 to -0.5 this temperature susceptibility could be achieved by the addition of a polymer.

However, by adding a polymer to Group B asphalt, medium traffic will not increase the stability (modulus of stiffness) of the corresponding paving mixture, unless as shown by Figure 7, the polymer addition moves the polymer modified asphalt to the left from the medium to the heavy traffic category.

Paving asphalt can exhibit two rheological properties. Under very fast traffic it will react as an elastic material. However, under slower loading it no longer behaves as a purely elastic material, but also shows its viscous properties, which allow the asphalt mixture to flow under load, causing rutting. The extreme case is a parking area, where cars are stationary for long periods of time, and the reaction of the asphalt binder is almost entirely viscous. It follows therefore, that for slow loading, the lower the viscosity of the paving asphalt, the lower is the resistance of the paving mixture containing it to rutting.

Therefore, one of the more important contributions of polymer modified asphalts to an increase in temperature susceptibility, could be the accompanying increase in viscosity provided. Figure 10 indicates that the increase in viscosity can easily be from one and one-half to two times.

This also applies to the selection of paving asphalts for pavements in hot climates with no frost.

As a final comment, it can be pointed out that at an AAPT meeting in 1985, Marks and Huisman (12) from Iowa, after four years of investigating the problem of low temperature cracking in that state, conclude that, "The PVN is an effective measure of the temperature susceptibility of asphalt cements". Reference has already been made to the very favourable remarks made by Kandhal of PenDot in 1978 (8) and in 1986 (9) on PVN versus PI as a measure of temperature susceptibility. The U.S. Corps of Engineers has had a PVN requirement in its paving asphalt specifications for about 10 years.

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