Reducing the Adverse Effects of Transverse Cracking

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ABSTRACT

This research was initiated to identify methods of reducing the occurrence of transverse cracking. Eight (four repetitive) research sections were established to study three variations in the asphalt concrete pavement. The first variation was the comparison of low- and high-temperature-susceptible asphalt cement (AC) from two different sources. The second variable was to saw and seal transverse joints at spacings varying from 40 to 100 ft. The third variable was to increase the AC content in the asphalt treated base by 1 percent. The research sections were constructed with relatively few problems. Crack and joint surveys have been conducted on all research sections at intervals of less than 1 year since construction. No cracking was identified after the first winter season. The sawed joints also remained sealed through the first winter. At an age of approximately 1 1/2 years there was substantial cracking of the high-temperature-susceptible AC sections and substantial failure of the sealant material in the sawed joints. After almost 4 years, the asphalt pavement constructed with the high-temperature-susceptible AC produced a crack interval of 35 ft, the low-temperature-susceptible AC yielded an interval of 170 ft, and the low-temperature-susceptible AC with an increased AC content yielded an interval of 528 ft. The Pen-Vis number is an effective measure of temperature susceptibility of asphalt cements. The frequency of transverse cracking is affected by the temperature susceptibility of the AC. An increased AC content also reduces the frequency of transverse cracking.

Over the years there have been a number of changes in asphalt paving. Lake asphalts were used before 1900 when AC from refined crude oil became available. The introduction and acceptance of AC from crude oil increased the supply but also presented many more variables in the characteristics of AC. There were substantial variations in the raw product from "heavy" to "light" crude oils. This variation in crude oils necessitated differences in the refinery process that, coupled with preferential differences, yielded a wide variation in AC.

Much of the early asphalt concrete paving in the United States was 2 to 4 in. thick. It has, therefore, commonly been referred to as flexible pavement and rightly so. When these pavements were subjected to heavy loads during periods of unstable subgrade conditions, the structure was inadequate and the result was failure. The design has been changed to greater thickness or full-depth asphalt concrete pavements to provide more structural capacity. These full-depth designs are less flexible and present problems commonly encountered in rigid pavements.

PROBLEM

One of the most serious problems of asphalt pavements today is related to transverse cracking and subsequent crack deterioration. Heavier vehicles required thicker sections and greater stability to carry their loads without permanent distortion. These changes have produced a pavement that generally exhibits transverse cracks at a relatively uniform spacing on any individual project. The spacing is apparently dependent on many factors but is quite related to pavement thickness.

The uniformly spaced transverse cracks do not initially present any objectionable conditions. Water movement through the cracks results in stripping of the AC. Further pumping or hydraulic pressure dislodges and expels aggregate and fine material from the crack. This action can result in a large void that, given time, will result in sloughing, producing a dip. Even though the crack itself is not detrimental, subsequent deterioration results in an unacceptable riding quality and intense maintenance. This reduces the effective life of an otherwise structurally sound roadway.

OBJECTIVE

The objective of this research project was to identify a method of reducing the adverse effect of transverse cracking and to improve the performance of asphalt pavement. This objective can be achieved either by reducing the occurrence of transverse cracking or by preventing deterioration of joints sawed to take the place of random cracking.

PROJECT LOCATION AND DESIGN

The research was incorporated in Jones County asphalt concrete paving project F-64-1(12)--20-53 on IA-64 from US-151 (Anamosa) to the west junction of IA-38. This project was selected because it is typical of many Iowa primary roadways with 3 in. of asphalt surface over 8 in. of asphalt treated base (ATB) and granular surfaced earth shoulders (Figure 1). The research section is currently (1982 data) carrying 1,160 vehicles per day with 13 percent trucks.

CONTRACTOR AND CONTRACTUAL ARRANGEMENTS

The successful bidder for the project was Cessford Construction Company of LeGrand, Iowa. The research was added by extra work order. The sawing and seal-

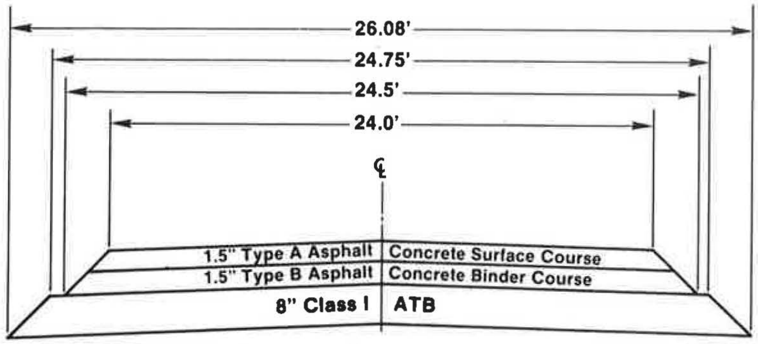

FIGURE 1 Typical section.

ing portion of the research was subcontracted to Concrete Specialists of Cedar Rapids.

RESEARCH OVERVIEW

The research involved three variations from the contractor's planned operation. Briefly, they were

1. Use of another asphalt cement,
2. Sawing and sealing transverse joints, and
3. Increased asphalt cement content.

The research was carried out between the stations noted (Figure 2):

1. Sugar Creek asphalt cement
   a. Stations 150+00 to 169+00
   b. Stations 210+00 to 230+00
2. Transverse joints
   a. Stations 170+00 to 193+60
   b. Stations 230+00 to 253+20

Each research section includes:

- 15 joints at a 40-ft spacing
- 10 joints at a 60-ft spacing
- 7 joints at an 80-ft spacing
- 6 joints at a 100-ft spacing

3. Increased asphalt cement content
   a. Stations 193+60 to 208+50
   b. Stations 253+20 to 270+00

Use of Another Asphalt Cement

Substantial study of stiffness and temperature susceptibility of asphalt cements has been conducted by Norman W. McLeod (1). The results of these studies provide a quantitative number for describing the temperature susceptibility of an AC. This aspect of the research was developed to determine if a relationship could be identified between temperature susceptibility as determined by the Pen-Vis number (PVN) at penetration (77°F) and viscosity (140°F) and the frequency of transverse cracking. McLeod established the PVN = 0 to represent an excellent AC with low temperature susceptibility and PVN = -1.5 to represent an AC with very high temperature susceptibility (Figure 3). Iowa DOT personnel have been determining the PVN of all asphalt cements used in Iowa in recent years by the McLeod graph. Even though it is accepted that there are probably many factors that affect the frequency of transverse cracking, a trend seemed to indicate that transverse cracking did relate to the PVN. Research was needed in which all other factors were held constant.

The contractor had normally used a relatively high-temperature-susceptible AC meeting Iowa DOT specifications. Initial plans for the research were based on this assumption. An AC produced by Amoco Oil Company at the Wood River, Illinois, refinery was partly blown and exhibited one of the lowest temperature susceptibilities of any asphalt cement commonly used in Iowa. Plans were to require a Wood River AC in both the base and the surface courses for two 2,000-ft sections.

Immediately following the preconstruction conference, information became available showing that, due to current economic conditions, the AC in the contractor's storage was predominantly the low-temperature-susceptible Wood River bitumen. Research plans were changed to require an AC from Amoco Oil Company of Sugar Creek, Missouri, (a high-temperature-sus-

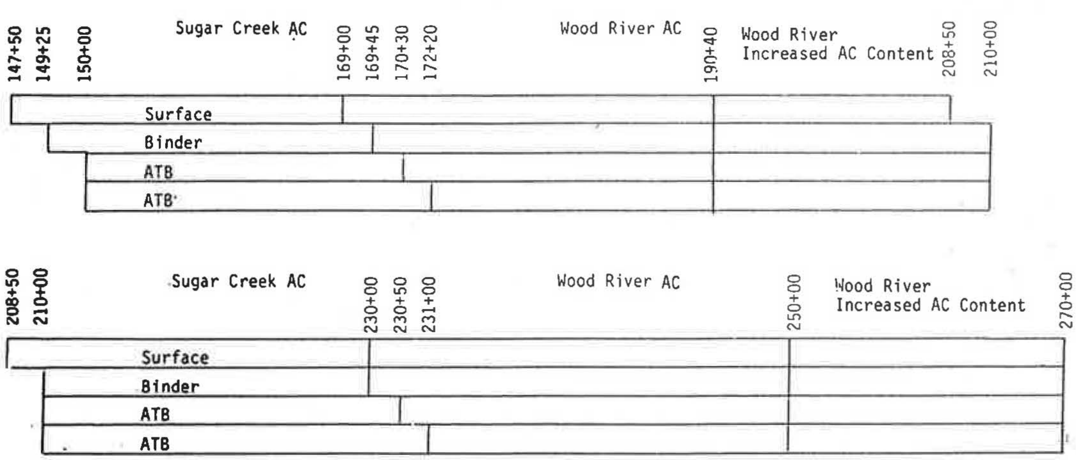

FIGURE 2 Schematic layout of asphalt cement sources.

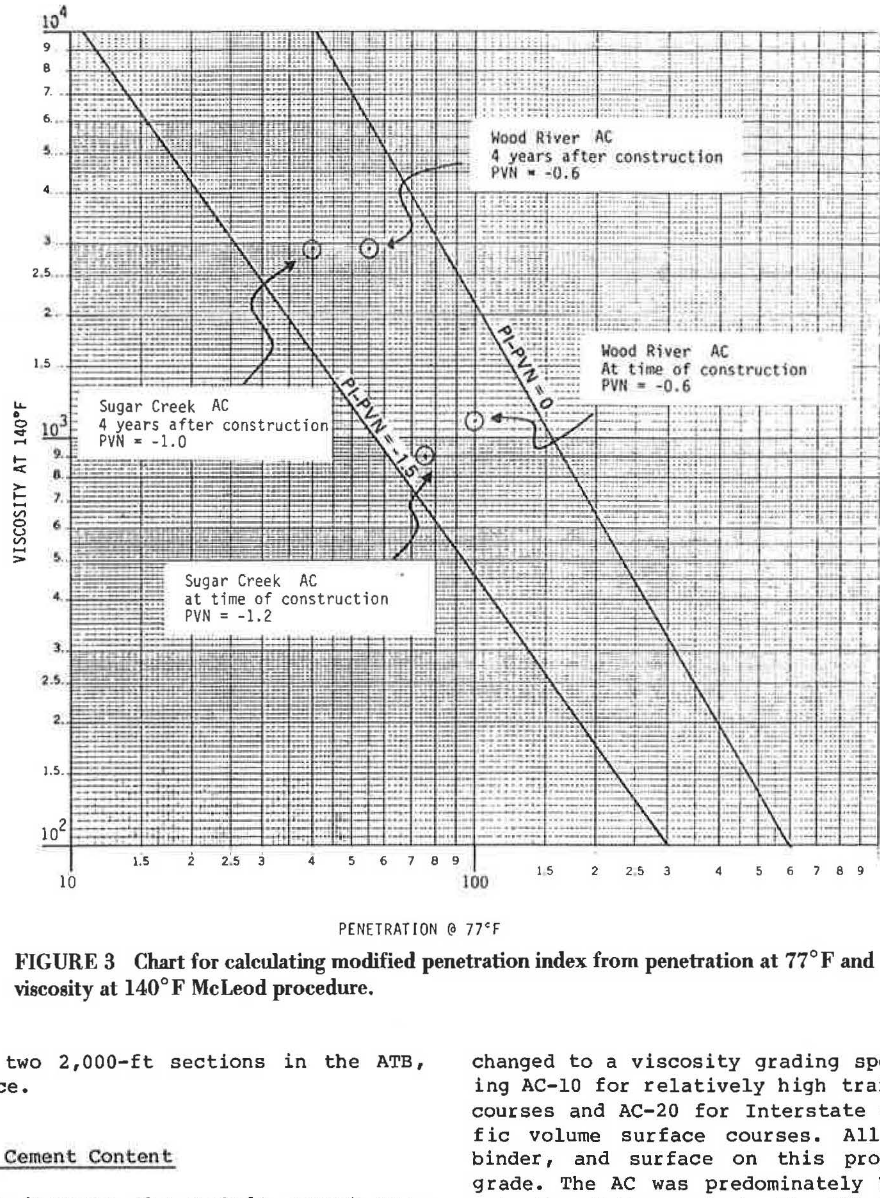

FIGURE 3 Chart for calculating modified penetration index from penetration at 77°F and viscosity at 140°F McLeod procedure.

ceptible AC) for two 2,000-ft sections in the ATB, binder, and surface.

Increased Asphalt Cement Content

The intent was to increase the asphalt cement content in the base by 1 percent with some increase in the binder and surface. An additional mix design for the surface was made, and the results were not favorable for increased AC content. Consequently, the AC content was increased 1 percent for the ATB with no increase for the binder or surface.

Sawing and Sealing Transverse Joints

Transverse joints were cut in the surface at spacings of 40, 60, 80, and 100 ft. The saw cut was a nominal 1/4 in. wide and a minimum of 3 in. deep. This research is similar to earlier Minnesota research (2) except for sealing. In this research, the joints were sealed with an upgraded rubber asphalt sealant meeting Iowa DOT Standard Specification 4136.02A.

MATERIALS

Before 1975 Iowa DOT specifications had required 85 to 100 penetration grade AC for surface courses on high traffic volume roadways. In 1975 the Iowa DOT changed to a viscosity grading specification requiring AC-10 for relatively high traffic volume surface courses and AC-20 for Interstate or very high traffic volume surface courses. All AC for the ATB, binder, and surface on this project was an AC-10 grade. The AC was predominately Wood River for the majority of the project. The PVN (Figure 3) for Wood River averaged -0.6 (Pen = 100 Vis = 1100). The high-temperature-susceptible AC was from Sugar Creek with a PVN of -1.2 (Pen = 75 Vis = 900). The contractor used two storage tanks at the plant site. One tank was used for Sugar Creek AC only and the other only for the predominately Wood River AC. Delivery tankers were scheduled carefully to maintain an adequate AC supply.

The ATB was a 3/4-in. Class I produced from 65 percent crushed limestone and 35 percent sand, both from the B.L. Anderson Quarry at Anamosa. The intended AC was 4.75 percent for all ATB except the two increased AC sections placed at 5.75 percent. The typical aggregate gradations for the ATB are given in Table 1.

Two different mix combinations were used for the 3/4-in. Type B binder. Both mixes were produced from crushed limestone and sand from the B.L. Anderson Anamosa Quarry.

1. The strengthening and leveling binder mix was 60 percent crushed limestone and 40 percent sand with an intended AC content of 5.75 percent. The typical aggregate gradations for that mix are given in Table 1.

TABLE 1 Typical Gradations for ATB and Binder Mixes

Sieve Size	Crushed Lime-stone	Sand	ATB (65% limestone 35% sand)	Type B Binder (60% limestone 40% sand)	Type B Binder (50% limestone 50% sand)
3/4 in.	100		100	100	100
1/2 in.	84		90	90	92
3/8 in.	65	100	77	79	82
No. 4	36	98	57	60	66
No. 8	25	87	47	50	56
No. 16	19	73	38	41	46
No. 30	17	48	28	29	32
No. 50	16	15	16	16	16
No. 100	15	1.6	10	9.6	8.3
No. 200	10	0.5	6.7	6.2	5.2

2. A 50 percent crushed limestone and 50 percent sand mix with an AC content of 6.25 percent was used for the 1 1/2-in.-thick Type B binder course. The typical gradations for that mix are given in Table 1.

The 1/2-in. Type A surface mix was produced using 65 percent crushed limestone from the B.L. Anderson Anamosa Quarry and 35 percent sand from the B.L. Anderson Ivanhoe Pit in Linn County. An AC content of 6.00 percent was used for the 1 1/2-in.-thick lift. The typical gradations are given in Table 2.

TABLE 2 Typical Gradations for Type A Surface Mix

Sieve Size	Percent Passing: 65% Crushed Limestone	35% Sand	Type A
1/2 in.	100		100
3/8 in.	88	100	92
No. 4	52	98	68
No. 8	32	90	52
No. 16	24	75	42
No. 30	21	46	30
No. 50	18	13	16
No. 100	16	1.6	11
No. 200	9.0	0.5	6.0

The filler-to-bitumen ratio (percentage of material passing the No. 200 screen divided by the percentage of AC by weight) ranged from 1.08 to 1.44 for the Type A surface.

All prime and tack coat bitumen was diluted SS1 emulsified asphalt.

CONSTRUCTION

Construction of the ATB began on June 16, 1980. The final lift of the asphalt concrete surface was laid on August 22, 1980. Most of the construction operation was standard practice. All asphaltic concrete mix was produced in a Cedar Rapids batch plant located at the B.L. Anderson Anamosa Quarry.

All asphalt layers were laid full width (24-ft traveled roadway) with a Cedar Rapids laydown machine. A Dynapac CC 50A in the vibratory mode was used for breakdown compaction followed by intermediate compaction with a pneumatic roller and final compaction with an 8-10 ton static steel Bomag roller.

The subcontractor cut the transverse joints with a 1/4-in carborundum blade without water. Initially, there were substantial problems because the cutting residue would adhere tightly to the surfaces within and adjacent to the cut. It appeared that this operation would not provide a satisfactorily clean saw cut for sealing. The subcontractor added compressed air cleaning immediately following the cutting operation and this removed the cutting residue.

An excess of sealant material was used leaving some along the joint and allowing traffic to carry some down the roadway.

Except for the changes required for the research sections, the construction problems were minimal. The general appearance of the asphalt paving in the research area was good.

EVALUATION

Post Construction Testing

Cores were drilled from each layer of the asphalt pavement soon after construction. Density, percentage of laboratory density, and voids were determined. For research evaluation purposes, eight (four repetitive) sections were established. Two-thousand-foot sections of standard design and construction (control section) at both ends of the research were included for comparison. A summary of the core data is given in Table 3. The Iowa DOT laboratory density for this rural primary highway with less than 5,000 vehicles per day is determined from a 50-blow Marshall specimen.

Two cores drilled through the asphalt pavement verified that the transverse joints were the specified nominal 1/4 in. width and minimum 3 in. depth and the sealant filled the entire saw cut. Further testing demonstrated that the sealant was bonded to both faces extremely well.

Periodic Field Reviews

Construction of the asphalt concrete surface was completed in August 1980. No distress was identified in any of the research sections during the late fall and early winter of 1980. Temperatures in Iowa during the 1980-1981 winter season were relatively mild.

Transverse Joints

All transverse joints appeared to be well sealed during a field review on January 22, 1981. They continued to provide a tight seal through October 1981.

Iowa experienced an extended period of severely cold temperatures during the winter of 1981-1982. A visual review of the joints on March 1, 1982, revealed substantial failure of the sealant material. There are a total of 76 joints and only 14 (18 percent) remained sealed. There were 22 (29 percent) with partial failure and 40 (53 percent) that were essentially unsealed. The bond between the sealant and the face of the saw cut failed due to the thermal contraction stress from the severe temperatures.

A survey on November 17, 1982, revealed failure of all 38 of the joints between Stations 170+00 and 193+60. The joints between Stations 230+00 and 253+20 were in slightly better condition. At the time of the survey, essentially all of the joints at 80-ft and 100-ft spacings (14 joints) had failed. Five of the ten joints at 60-ft spacings had failed. Six of the fourteen joints at 40-ft spacings had failed. Considering all 76 joints, 63 (83 percent) had failed and those at a shorter spacing were performing slightly better than those at longer intervals.

This difference between sections may relate to the cutting and cleaning procedure used by the subcontractor during construction. The cutting residue was more effectively expelled from the joints be-

TABLE 3 Core Density Summary

Section	Experimental Feature	Station	Course	Density (g/cm^3)	Percentage of Laboratory Density	Voids (%)
1A	Sugar Creek AC	150+00 to 169+00	ATB 1st	2.24	95.2	11.3
			ATB 2nd	2.24	96.1	11.8
			Type B	2.19	94.2	11.2
			Type A	2.29	95.4	6.6
1B	Sugar Creek AC	210+00 to 230+00	ATB 1st	2.28	96.1	9.8
			ATB 2nd	2.22	95.0	
			Type B	2.22	95.3	9.9
			Type A	2.32	96.7	5.4
2A	Transverse joints	170+00 to 193+60	ATB 1st	2.27	96.1	10.7
			ATB 2nd	2.23	95.2	12.3
			Type B	2.25	97.0	8.9
			Type A	2.30	95.8	6.2
2B	Transverse joints	230+00 to 253+20	ATB 1st	2.26	95.2	10.6
			ATB 2nd	2.30	96.8	8.3
			Type B	2.17	93.5	12.1
			Type A	2.31	95.8	6.2
3A	Increased AC	193+60 to 208+50	ATB 1st	2.30	95.8	6.6
			ATB 2nd	2.29	96.4	5.2
			Type B	2.22	95.7	10.1
			Type A	2.28	95.0	7.0
3B	Increased AC	253+20 to 270+00	ATB 1st	2.29	96.7	
			ATB 2nd	2.25	96.7	8.2
			Type B	2.20	96.6	11.1
			Type A	2.31	95.8	6.2
4A	Control	130+00 to 147+40	ATB 1st	2.27	96.7	9.9
			ATB 2nd	2.24	96.0	11.9
			Type B	2.21	92.1	10.2
			Type A	2.28	95.0	7.0
4B	Control	270+00 to 290+00	ATB 1st	2.23	96.3	11.5
			ATB 2nd	2.17	93.9	
			Type B	2.21	95.2	10.5
			Type A	2.30	95.4	6.6

tween 230+00 and 253+20 than from those between 170+00 and 193+60.

The last survey of January 25, 1984, during another severely cold winter period, showed that essentially all joints had failed. Some of the joints that had been sawed 1/4 in. wide had thermal movement, leaving openings of up to 1 in.

There are no transverse cracks between any of the sawed transverse joints. The joints will be resealed during 1985 in an effort to prevent deterioration.

Asphalt Source and Content

Crack surveys have been conducted on all research sections at less than 1-year intervals since construction (Table 4). No cracking was identified in any of the sections on January 22, 1981, after most of one relatively mild winter. An October 16, 1981, crack survey still did not identify any cracking.

The severely cold 1981-1982 winter period did cause substantial cracking in both sections constructed with Sugar Creek AC. In March 1982 there were a total of 110 transverse cracks in 3,900 linear feet or an average crack interval of 35 ft. One crack occurred in the standard Wood River AC section. There were no cracks in the Wood River AC section with increased AC content in the ATB.

Visual crack surveys were made on November 17, 1982, and June 2, 1983, with cracking in addition to that noted in March 1982. The winter of 1983-1984 had an extended period of severely cold weather (-20°F) and produced additional transverse cracking. The standard Wood River AC section had a total of 22 cracks in 3,740 ft. There were six cracks in the 3,170 ft (two sections) of Wood River at an increased AC content for the ATB. No additional cracking was identified in the Sugar Creek AC section. The crack intervals for the three research variables 3 1/2 years after construction are

Variable	Crack Interval (ft)
Sugar Creek AC	35
Standard Wood River AC	170
Wood River increased AC content	528

The rutting of all research sections was determined on November 6, 1984. Rut depths under a 4-ft straightedge were measured in all four wheelpaths. The average rut depth was

Standard project construction	0.04 in.
Highly temperature susceptible AC	0.05 in.
Increased AC in ATB	0.10 in.
AC pavement with transverse joints	0.07 in.

TABLE 4 Summary of Transverse Cracking

Research Section	Beginning Milepost	Stations	No. of Cracks 1-22-81	10-16-81	3-1-82	11-17-82	6-2-83	1-25-84
Standard Wood River AC	2.1	130+00 to 147+40	0	0	1	1	1	4
	4.7	270+00 to 290+00	0	0	1	1	1	18
Wood River	3.3	193+60 to 208+50	0	0	0	0	0	1
Increased AC in the ATB	4.4	253+20 to 270+00	0	0	0	0	0	5
Sugar Creek AC	2.5	150+00 to 169+00	0	0	41	41	41	41
	3.6	210+00 to 230+00	0	0	69	69	69	69

TABLE 5 Summary of Tests on Asphalt Cement Extracted from Cores Drilled April 5, 1984

Core No.	Station	Research Section	Course	Penetration	Viscosity	PVN
3	155	Sugar Creek AC	Surface	31	3720	−1.10
			Binder	36	3320	−1.00
4	160		Surface	52	1830	−1.06
			Binder	41	2480	−1.08
7	215		Surface	35	3560	−1.00
			Binder	45	2190	−1.08
8	225		Surface	32	4210	−0.96
			Binder	49	2080	−1.02
Sugar Creek average				40	2924	−1.04
5	200	Increased AC (Wood River)	ATB	74	1990	−0.52
6	205		ATB	66	2440	−0.48
9	260		ATB	72	1880	−0.58
10	265		ATB	79	1620	−0.60
Increased AC average (Wood River)				73	1983	−0.55
1	135	Control (Wood River)	Surface	45	3450	−0.68
			Binder	51	3910	−0.45
2	140		Surface	63	2090	−0.68
			Binder	65	2290	−0.56
11	275		Surface	52	3290	−0.56
			Binder	47	3460	−0.65
12	280		Surface	65	2100	−0.63
			Binder	53	2750	−0.66
Control average (Wood River)				55	2918	−0.61

Analysis of Extracted Asphalt Cement

Cores were drilled from all research sections with asphalt mix variables on April 5, 1984, almost 4 years after construction. The penetration (77°F) and viscosity (140°F) were determined for asphalt cement extracted from various layers (Table 5). The average values were

Sugar Creek--binder and surface

Penetration	40
Viscosity	2924
PVN	-1.04

Wood River--binder and surface

Penetration	55
Viscosity	2918
PVN	-0.61

Wood River increased AC content--ATB

Penetration	73
Viscosity	1983
PVN	-0.55

DISCUSSION OF RESULTS

There is no cracking between any of the transverse joints, and the longest spacing is 100 ft. This is not unexpected because the average crack interval of the comparative Wood River section is 170 ft at an age of 3 1/2 years. At the present time there is no apparent deterioration of the joints. There is a potential problem in that they are essentially unsealed. The cracks on this project have incurred no noticeable depressions to date. Depressions ranging from 0.1 to 0.2 in. have developed at the joints.

The sealant failure may have been affected by the subcontractor's difficulty in removing the cutting residue from the dry sawing operation. Cores drilled soon after construction showed that a tight bond was achieved. After 1 to 1 1/2 years the seal of many joints had failed. The section between 170+00 and 193+60 where dry cutting was initiated without intermediate compressed air cleaning failed more rapidly than the 230+00 to 253+20 section with improved cleaning. This would indicate that the cutting residue affected the bond between the sealant and the asphalt concrete. If this research were repeated, wet cutting should be required. An improved high-modulus sealant should be used. The joints will be resealed in an effort to prevent surface water infiltration.

This research documented the effect of some asphalt cements on the frequency of transverse cracking. The only difference between the Sugar Creek and Wood River sections was the AC source. The Sugar Creek sections exhibited severe transverse cracking at an average interval of 35 ft in less than 2 years whereas the Wood River section exhibited only one crack in 3,740 ft. In 3 1/2 years the average crack interval for the Wood River section was 170 ft compared to 35 ft for the Sugar Creek that had remained constant. There is no significant difference in rut depths of the various research sections at this time.

Average viscosities of the Sugar Creek and Wood River asphalt cements after almost 4 years are nearly the same at 2924 and 2918, respectively. Viscosity alone is, therefore, not a good measure of the potential of an AC to yield transverse cracking.

This research indicates that both the penetration and the PVN of the extracted AC relate well to the frequency of transverse cracking. The penetration continues to decrease due to oxidation. In almost 4 years the penetration of Sugar Creek had decreased from 75 to 40 and that of Wood River from 100 to 55. The PVN, on the other hand, remains relatively constant as documented by Iowa DOT experience in recent years. The Sugar Creek PVN at construction was -1.2 (based on a very limited number of penetration tests) and -1.0 4 years later (Figure 3). The PVN for Wood River was -0.6 both at time of construction and after 4 years. For this reason it would appear that the PVN is a more desirable measure of the potential for transverse cracking. An increased AC content in the ATB has reduced or retarded the incidence of transverse cracking. The average crack interval of the standard project construction with Wood River asphalt was 170 ft. An average crack interval of 528 ft was obtained with everything but

the AC content remaining constant. The increased AC content resulted in a reduced ATB void content (Table 3) from an average of 11.1 percent for the control to 6.7 percent for the increased AC section. This may be an important factor in the improved performance.

CONCLUSIONS

This research on transverse cracking and the temperature susceptibility of asphalt cement supports the following conclusions:

1. An improved sealant or sealing procedure is needed if transverse joints are to be used in asphalt pavements.
2. The PVN is an effective measure of the temperature susceptibility of asphalt cements.
3. The use of a high-temperature-susceptible asphalt cement produced severe transverse cracking.
4. The use of asphalt cements with low temperature susceptibility will reduce the frequency of transverse cracking.
5. An increased asphalt cement content in the ATB will reduce the frequency of transverse cracking.

RECOMMENDATIONS

Earlier Iowa DOT specifications for asphalt cement did not ensure the best possible pavement. A recommendation for an improved specification was made on the basis of this research. A change from AASHTO M226 Table 1 requirements to Table 2 requirements has been adopted for 1984 projects.

Before this project the AC content specified for ATB was 4.75 percent. Mix designs are now used to determine the AC content and limit the void content. This should yield improved performance and extended life of full-depth asphalt pavements.

ACKNOWLEDGMENTS

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Laboratory Evaluation of an Asphalt-Rubber SAL

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ABSTRACT

The evaluation of a mixture of asphalt and rubber to serve as a strain attenuating layer (SAL) in asphaltic concrete overlays is discussed. The mixture consisted of a blend of asphalt and rubber and the SAL was made with and without stone chips. The tests used for the evaluation were developed to simulate certain pavement loadings and they were classified as repeated vertical shear, static horizontal shear, repeated horizontal shear, and flexure fatigue. Calculations were carried out to determine the effects of the SAL on stresses in the laboratory models and also in flexible layered pavement systems. The laboratory test results showed that the layers without the stone chips had the best performance. The calculations for the laboratory and pavement models indicated that the greatest effect brought about by the attenuating layer was in reduction of horizontal shear at the overlay-asphalt-rubber layer interface and that there must be a limiting thickness of that layer to prevent tensile overstress of the bottom surface of the asphaltic concrete overlay.