Changes in Physical Properties of Asphalt Pavement with Time

J. R. BISSETT, *Professor of Civil Engineering, University of Arkansas*

This paper reports the study of approximately 60 mi of asphaltic concrete pavement under actual traffic conditions. The pavements vary from 3 to 8 years of age and represent seven construction projects. Recovery of the asphalt cement was accomplished by a simplified Abson method. Check tests were made on this method to determine any effect it might have on Arkansas asphalts. Density, asphalt content, and gradation of aggregate of the pavements were determined. The asphalt cement recovered from the pavements were subjected to penetration, ductility, softening point, and ash content tests. In some cases the thin-film oven test was also made. Generally, the results indicate a rapid reduction in the ductility of the asphalt with time. There is also a decided but less rapid reduction in the penetration of the asphalt. Samples of the pavement were heated, remolded, and tested by the Marshall method. Usually, the stabilities were quite high.

• THIS REPORT is part of a study at the University of Arkansas on the performance of flexible pavements. It is a joint effort of the University of Arkansas, the Arkansas Highway Department, and the U.S. Department of Commerce, Bureau of Public Roads. The purpose of the study is to evaluate the performance of flexible pavements and to determine some of the factors that cause pavement failures. The physical properties and conditions of the various parts of the pavement structure are being examined and evaluated so that the design methods may have a more rational basis. This paper is concerned with the asphalt pavement only. A separate report of the study of other parts of the pavement structure is being prepared.

PAVEMENT SAMPLING

All pavements studied were hot-mix asphaltic concrete. Some of the pavements were made with uncrushed gravel as the aggregate, some were made with crushed gravel, and others with a mixture of crushed gravel and crushed syenite.

Six construction projects totaling 47 mi are discussed in this report. All of the projects were regular State highway jobs constructed by the highway department under contract in the normal way. At the time the jobs were constructed it was not known that they would be used as future test projects. At the time the samples were taken, the pavements varied in age from 2 to 7 years. Samples about 15-in. square were cut

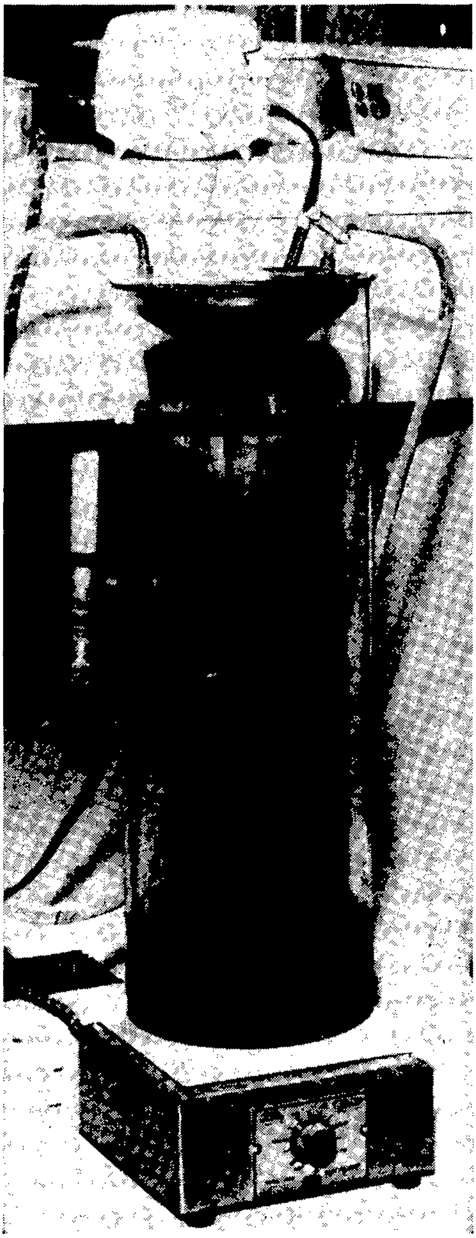

Figure 1. Faulwetter apparatus.

from the pavement at intervals of 0.4 to 0.6 mi. All pavement samples were taken in the center of the traffic lane between the two wheelpaths. The samples were taken in the late fall or early spring while the pavements were cold. They were cut from the pavement with an ordinary paving breaker equipped with a spade bit. The samples came out in one solid piece and showed no cracks or evidence of fracturing. Reasonable care was taken in handling and transporting the samples to the laboratory. The samples were placed in paper bags and kept in a horizontal position to reduce disturbance as much as possible.

Numbers were painted on the pavement at each 0.2 mi for the purpose of identifying test locations. Samples were then taken at intervals of either two or three 0.2-mi stations.

METHOD OF ASPHALT CEMENT RECOVERY

A modification of the Abson process was used for recovering the asphalt cement from the pavement samples. For this recovery the Faulwetter apparatus was used to extract the asphalt cement from the pavement. This apparatus is shown in Figure 1. Trichloroethylene was the solvent used. The Faulwetter apparatus consists of two wire cone-shaped baskets suspended in a glass jar. The solvent is placed in the bottom of the jar and a metal cone-shaped water-cooled condenser is used for a cover at the top of the jar. The jar is 18 in. high and 6 in. in diameter. The sample is placed in the wire baskets with three-ply filter paper between the sample and the wire of the basket. An electric hot plate is used to heat the apparatus. The solvent is condensed on the cone-shaped condenser at the top of the apparatus and drips into the baskets containing the sample. If medium

density filter paper is used, the solvent will flow out of the baskets at a sufficiently slow rate so that the baskets will remain full of the solvent. This leaching process is continued until the solvent flowing from the baskets is clear. This usually requires about 3 hr. The solution is settled by centrifuging as specified in the standard method AASHO T 170-55 before the asphalt cement is recovered from the solution by distillation.

Method AASHO T 170 for recovering the asphalt cement from solution was modified only to the extent that the oil bath is eliminated and a glass tube with a bulb on the end is substituted for the brass ring in admitting carbon dioxide to the boiling solution. The solution boils at 190 F until practically all the solvent is driven off The rate of distillation is not controlled while the temperature is maintained at 190 F. The temperature rises rapidly from 190 F to 300 F. Carbon dioxide is introduced into the distillation flask when the temperature reaches 220 F. Figure 2 shows the apparatus used for recovering the asphalt cement from the solution.

Abson and Burton (*1*) report that trichloroethylene did not change the

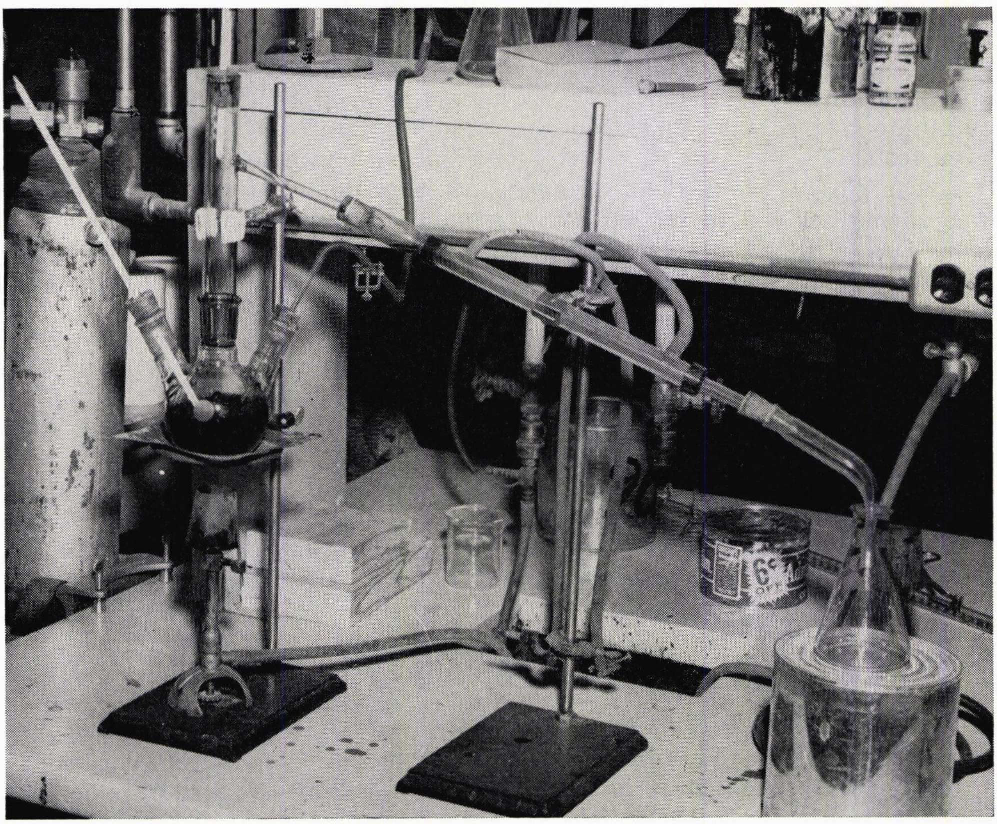

Figure 2. Distillation apparatus.

TABLE 1

CHECK ON METHOD OF RECOVERY

Brand	Penetration			Ductility			Softening Point			Ash	Thin-Film Oven		
	Orig.	8-Hr	7-Day	Orig.	8-Hr	7-Day	Orig.	8-Hr	7-Day	Orig.	Orig.	8-Hr	7-Day
A	73	73	74	150+	150+	150+	48	49	48	0	0	0.06	0.10
B	71	71	71	150+	150+	150+	51	51	52	0	0	0.03	0.07
B	63	62	59	150+	150+	150+	52	52	55	0	0	0.03	0.02
C	65	65	65	150+	150+	150+	50	48	49	0	0	0.03	0.10

physical properties of asphalt cement when used as the solvent for recovering the asphalt cement. A series of check tests were made on Arkansas asphalts to determine any changes that might be caused by the method of recovery that was proposed. Table 1 gives the results of these tests. The three brands of asphalts are the only ones produced in Arkansas. For this test, samples of the asphalts were subjected to penetration, ductility, softening point, ash, and thin-film oven tests.

A sample of the asphalt cement was then dissolved in trichloroethylene. One series of distillations were then made completing the entire process and testing in an 8-hr period. Another series of tests were made in which the solution of asphalt cement and trichloroethylene was prepared and stored in the laboratory 7 days. The results are the averages of the three sets of tests in each case. In recovering the asphalt cement from the pavement samples as reported hereafter, the entire process was completed in one 8-hr day.

PAVEMENT TESTS

Part of the samples of pavement taken from the roadway were used for the purpose of determining the condition of the mixture at the present time. A sample of the pavement weighing from 500 to 700 g was used to determine the specific gravity of the pavement. The sample was weighed in air, then coated with paraffin and weighed in water for this determination. Another sample of the pavement was heated in an oven to approximately 240 F and then molded for Marshall stability specimens. The percent voids, Marshall stability, and flow were then determined. Only two Marshall stability test specimens were made from each sample because there was not enough material available to make the third specimen. The asphalt cement content of the pavement was determined by Method AASHO T 164-55. Carbon tetrachloride was used as the solvent. A screen analysis was made of the aggregate.

ASH CONTENT

Investigations under way in the laboratory indicate that ash contents up to about 1.3 percent have no effect on the penetration or ductility of asphalt cement. Both limestone dust and portland cement were used to mix with the asphalt cement to produce the ash. This percent may not be the upper limit as there have been no tests completed in which the ash content was above 1.3 percent.

TABLE 2
PROPERTIES OF RECOVERED ASPHALT CEMENT

Job	Age (yr)	Tests on Orig. AC			Location	Tests on Recovered AC			
		Pen.	Duct.	Brand		Pen.	Duct.	Soft Point [1]	Ash Content
M	2.8	64	100+	C	1	50	67	59	0.87
					4	34	21	64	0.81
					8	42	8	67	1.20
					12	30	7	65	1.09
					14A	36	24	67	2.27
					17	41	39	63	0.76
					20	42	24	63	1.08
					23	39	36	62	0.79
					26	35	10	64	1.11
					29	35	13	65	1.63
					34	42	32	63	1.27
					37	43	33	62	1.36
					Avg.	39	26	64	1.19
J	5.7	68	100+	A	1	28	8	58	0.53
					4	25	5	—	0.44
					8	20	4	—	0.41
					10	27	9	65	0.51
					13	20	7	69	0.59
					17	26	40	62	0.54
					20	27	26	62	0.47
					23	26	20	62	0.68
					26	25	15	64	0.78
					28	27	14	63	0.52
					Avg.	25	15	63	0.55
F	5.3	65	100+	C	2	24	5	77	0.47
					8	29	6	—	—
					11	30	8	74	0.97
					14	26	6	—	—
					17	16	2	—	—
					20	26	6	72	0.43
					23	23	5	—	—
					26	25	8	77	0.49
					29	29	9	—	—
					32	20	3	—	—
					35	25	6	73	0.12
					Avg.	24	6	75	0.50
I	7.2	66	100+	C	2	40	30	61	0.35
					5	33	14	64	0.45
					8	23	5	74	0.29
					11	39	24	61	0.34
					14	40	33	58	0.53
					17	34	12	63	0.30
					20	29	8	62	0.31
					24	22	5	72	0.26
					27	21	4	75	0.28
					29	36	19	59	0.42
					33	28	8	68	0.28
					36	27	3	70	0.39
					42	25	5	69	0.32
					45	30	7	66	0.33
					Avg.	31	13	66	0.35
A	6.8	75	100+	C	3	25	0	74	0.40
					5	26	0	—	—
					7	23	0	—	—
					9	23	0	75	0.51
					11	24	5	—	—
					13	29	7	—	—
					15	24	6	73	0.65
					17	24	4	—	—
					19	20	5	—	—
					21	13	2	78	0.99
					23	18	3	—	—
					25	23	5	—	—
					27	27	7	—	—
					29	18	3	—	—
					31	—	0	—	—
					33	22	5	—	—
					35	25	5	—	—
					39	26	5	—	—
					Avg.	23	3	75	0.64
B	7.7	74	100+	C	2	20	6	75	0.41
					5	19	0	—	—
					8	20	5	72	0.56
					12	24	6	—	—
					15	24	6	—	—
					18	19	5	74	0.35
					21	24	5	—	—
					24	23	5	—	—
					Avg.	22	5	74	0.44

[1] R&B.

RESULTS

The properties of the recovered asphalts are given in Table 2. The penetration, ductility, and softening point were determined by standard AASHO methods. Tests on the original asphalt cement, as taken from the job records, are also given. The original penetration as indicated is an average of all the job tests. In no case was the maximum variation more than ±3, and in only one case was the variation this large.

Table 3 summarizes the results given in Table 2. Figure 3 shows the ductility and percent decrease in penetration with age. It was not possible to determine the amount of change in ductility and softening point. The original ductility was determined as 100+ cm. The softening point test was not made as a routine

TABLE 3
SUMMARY

Job	Age (yr)	Penetration			Ductility	Ash (%)	Softening Point
		Orig.	Final	Decrease (%)			
M	2.8	64	39	39	26	1.19	64
J	5.7	68	25	63	15	0.55	63
A	6.8	75	23	69	3	0.64	75
F	5.3	65	24	63	6	0.50	75
I	7.2	66	31	53	13	0.35	66
B	7.7	74	22	70	5	0.44	74

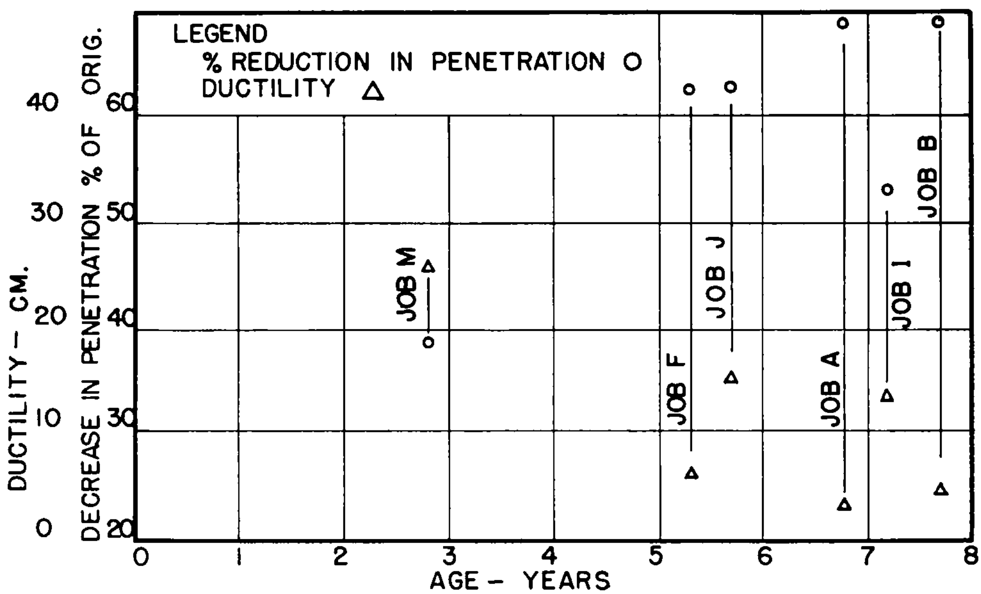

Figure 3. Change in ductility and penetration with age.

procedure by the highway department laboratory. The decrease in penetration is shown as a percent of the original penetration. It was necessary to show the change in penetration this way because two different penetration grades were used on the projects. The asphalts showing the highest percent decrease in penetration were both 74 or 75 penetration when placed.

The results are interesting when compared with the condition of the pavement at the present time. Jobs A, B, and F show the lowest ductility and the highest decrease in penetration. The loss in penetration for Job J is high, but the ductility is still comparatively high. Jobs A, B, and F have extensive surface cracking. These are single, isolated cracks and are roughly parallel to the centerline or normal to it. The minimum spacing of the transverse cracks is about 17 ft. The longitudinal cracks appear near the centerline of each traffic lane and near the centerline of the pavement. Not all of the pavement is cracked this way but the cracking is so extensive that it is difficult to find a quarter-mile section on which there are no cracks. Often the transverse cracks will extend from the edge of the pavement to the centerline and in some cases the crack extends the entire width of the pavement. Jobs M, J, and I do not show any of this type of cracking.

Job I is somewhat older than some of the other jobs, yet it is in excellent condition and shows very few patches. The few patches that do show are in the outer wheelpath.

A comparison of Jobs A and F shows the effects of different types of maintenance. Job A was sealed about three years ago with a light shot of asphalt cement and covered with pea gravel. Within one year the cracks were showing through the seal coat, but at the end of the second year traffic had sealed most of these cracks to the extent that there were no signs of distress in the pavement. The cracks on Job F were not sealed. Rainwater has seeped through the cracks on this job and caused numerous base failures. The failures are so extensive that the surfacing is in very poor condition; in fact, it is almost a total loss.

A search of the construction records does not indicate any reason why some of the jobs have very low ductilities and others such as Job I in the same group still have appreciable ductility remaining. It is doubtful that the ash contents as given in Table 3 are having any material effect on the measurement of the ductility.

Current investigations in the laboratory show that the loss in penetration during mixing and placing was about 28 percent. The original penetration averaged 63, and the penetration of asphalt cement recovered from the pavement one week after placing was 45. The ductility of the recovered asphalt cement was 104. These figures are the average of several tests on each of two construction projects. The aggregate used was limestone and the temperature was closely controlled at 300 F during mixing.

The conclusion drawn from these data is that the early loss of penetration and ductility causes cracking of the pavement surface. It may be the loss of ductility that causes this cracking. The results of Job J indicate this as the ductility is still high, but the decrease in penetration has been considerable. This job does not

TABLE 4
PAVEMENT SAMPLE TEST RESULTS

Job	Design	Job Tests				Sample Tests					
		AC Brand	Pen.	AC (%)	Voids (%)	Loc.	Voids (%) Lab.	Voids (%) Pvt.	AC (%)	Marshall Stab. (lb)	Flow (0.01 in.)
M	Marshall stab., 1,400 lb; flow, 9; voids, 3.5-4.0%; AC, 5.5%; crushed limestone and local sand	C	64	5.3-5.5	4.0-6.0	4	4.6	7.4	5.9	2,060	11
						12	3.3	3.9	6.0	3,050	8
						17	4.8	7.3	5.5	2,950	9
						23	5.2	7.8	5.5	2,220	9
						29	4.0	6.4	5.0	2,220	12
						37	1.3	6.7	6.2	4,430	9
						Avg.	3.9	6.6	5.7	2,822	10
J	Marshall stab., 1,300-1,400 lb; flow, 9; voids, 4.0%; AC, 5.8%; crushed syenite and local fine sand	A	68	5.5-5.7	9.5-10.5	4	7.0	10.1	6.1	2,100	12
						13	8.4	10.6	5.9	2,890	11
						20	9.2	12.8	5.9	2,110	9
						28	5.3	8.2	5.6	2,870	10
						Avg.	7.5	10.4	5.9	2,493	11
A	Marshall stab., 950 lb; flow, 5; voids, 6-7%; AC, 6.0%; partially crushed gravel, local pit	C	75	5.7-6.0	9.1-11.6	5	7.0	10.5	6.7	3,360	7
						9	8.9	10.9	5.4	3,900	15
						21	8.8	9.8	6.0	4,750	13
						25	6.2	11.6	6.1	2,650	7
						33	6.9	8.5	5.9	3,650	7
						Avg.	7.6	10.3	6.0	3,662	10
F	Marshall stab., 1,050 lb; voids, 6.5%; AC, 6.0%; partially crushed gravel, local sand	C	65	5.9	8.2-10.2	2	9.0	12.0	5.7	1,820	8
						11	10.2	9.0	6.4	2,650	13
						20	6.4	10.9	6.2	2,700	8
						26	6.4	10.7	5.9	3,150	10
						35	6.9	11.3	6.1	2,800	9
						Avg.	7.8	10.8	6.1	2,624	10
I	Marshall stab., 1,200 lb; flow, 10; voids, 6.4%; AC, 6.0%; crushed syenite and local fine sand	C	66	5.7-6.0	8.5-9.5	8	8.3	11.2	6.4	3,920	7
						14	4.7	7.5	6.9	2,220	7
						20	5.2	10.4	6.5	2,350	9
						29	3.2	8.6	6.6	2,200	12
						36	1.2	5.4	6.1	3,360	8
						45	7.9	13.0	6.0	3,150	10
						Avg.	5.0	9.4	6.4	2,867	9
B	Not available	C	74	5.7-5.8	7.3-11.4	2	7.8	10.1	5.9	3,260	7
						8	7.6	9.9	6.0	2,860	7
						21	8.7	13.7	6.0	2,630	8
						Avg.	8.0	11.2	6.0	2,917	7

TABLE 5
COMPARATIVE SCREEN ANALYSIS

Sieve	Percent Retained									
	Job I		Job J		Job M		Job A		Job F	
	Constr.	Present	Constr.	Present	Constr.	Present	Constr.	Present	Constr.	Present
½	0	0	0	0	8	7	24	20	21	0
⅜	3	3	3	1	22	18	32	28	30	25
4	24	24	29	22	40	37	46	41	44	38
10	50	46	51	48	53	51	52	48	52	48
40	77	76	76	76	77	74	77	74	78	90
80	90	90	90	93	87	90	94	97	93	96
200	93	94	94	96	92	91	95	98	95	98
AC (%)	5.75	6.4	5.5	5.9	5.3	5.9	5.9	6.0	5.6	6.1
Voids (%)	9.0	9.4	9.5	10.4	4.2	6.6	11.6	10.4	10.2	10.8

show any cracking of the surface at this time even though it is as old as the job that shows serious cracking. The base material, subgrade, and climatic conditions are approximately the same for all of these jobs.

Table 4 gives the results of the tests made on the pavement samples. The percent voids are those determined in the laboratory from a remolded sample and from an undisturbed sample of the pavement. The job tests made by the inspector at the time the pavement was constructed, and the original job mix design are also given. These results show that there is good agreement between the tests made on the pavement at the time of construction and tests made after several years' service. These tests indicate that there has been practically no increase in the density of the pavement between the time it was placed and the present.

It should be remembered that all these samples were taken in the center of the traffic lane between the wheelpaths. It is probable that densification has taken place in the wheelpaths. All of these samples were taken in the same relative location for the sake of uniformity. The increase in Marshall stability is attributable to the decrease in ductility and penetration of the asphalt cement. All of these samples had good workability when heated for remolding. The samples were remolded by being placed in an oven at 240 F for a period of about 1½ hr.

Table 5 shows a comparison of screen analyses made during constuction and at the present time. The asphalt cement content and the percent voids determined on these samples are also indicated. In many cases agreement between construction analyses and the present analyses is as good as that between the analyses made at different times during the construction. Little or no degradation of aggregate is apparent from these tests.

The present void content of the pavement indicates that there is little or no densification in the pavement between the wheelpaths. The tentative conclusion here is that the flow may contribute to this, as the flow on all of these jobs was 10 or below at the time they were placed. This lack of densification does not seem to impair the quality of the pavement in any way. The riding surface remains excellent.

CONCLUSIONS

Two tentative conclusions are drawn from the results of these tests.

1. An early loss of ductility and penetration causes surface cracking of the pavement.

2. Very little densification occurs in the pavement outside the wheelpaths where the asphaltic concrete mix has low flow.

REFERENCE

1. ABSON, G., AND BURTON, C., "The Use of Chlorinated Solvents in the Abson Recovery Method." *Proc., Assn. Asphalt Paving Tech.,* 29:246 (1960).