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Bituminous Patching Mixtures And Seal Coats

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Bituminous Patching Mixtures And Seal Coats

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Cutback Asphalt Patching Mixtures

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Asphalt patching mixtures should be satisfactory for use at all seasons of the year and should have suitable stability if used immediately after mixing or after storage for long periods of time. The additional requirements are that local materials must be used wherever possible and the mixture should be satisfactory for preparing by the maintenance forces in the districts.

In the study reported, one aggregate was chosen for all phases of the project. This material was a hard dolomitic limestone.

Two methods of curing were used for all cutback. The first method was that of curing the prepared mixes in ovens at a constant temperature of 140 F. The second method of curing was in lengths of stovepipe placed upright on screen wire on the roof of the laboratory and protected from rain. Thus, the mixture was exposed to the air at both ends of the stovepipe.

Series of mixes using both MC cutter stocks and RC cutter stocks were used. The rate of curing of the MC cutbacks indicated that these mixtures could be stored for long periods of time and still be used, but they would cure so slowly in a stockpile that they would not be useable for some time after mixing. Mixes using the RC cutter stocks cured too rapidly.

A Marshall stability of 500 lb was chosen as the desirable minimum stability satisfactory for patching.

A comparison of the distillation curves of RC cutter stocks and MC cutter stocks indicated that the ideal cutter stock would be one having the characteristics of the lighter ends of an RC with the heavy ends of an MC. A blend of 40 percent of RC, 50 percent MC and 10 percent SC cutter stocks produced a distillation curve approximating the desired characteristics.

Patching mixtures prepared with blended cutback gave the desired results. From 30 to 40 percent of the volatile matter was lost during mixing and storing. At this point the Marshall stabilities ranged between 400 and 500 lb. Beyond this point the rate of curing was slow, thus providing a long period of storage where needed.

A tentative specification for cutback asphaltic patching materials was derived from the study. The specification varies from the usual specification in several important points and is very restrictive. Field use will be required for improvement of the specification.

● THIS paper represents some of the results of a research project at the University of Arkansas sponsored jointly by the Arkansas Highway Department and the United States Bureau of Public Roads. The work was under the supervision of the Civil Engineering Department. The laboratory equipment was furnished by the three asphalt producers in Arkansas.

OBJECTIVE

This work was undertaken with the view of producing a cutback asphalt mixture for use in patching highways. The mixture was to meet four conditions:

1. It must be suitable for road mixing or plant mixing by the maintenance forces in the field.

2. Local materials were to be used wherever possible.
3. The mixture should be suitable for use at all times of the year.
4. The mixture must have suitable stability for use soon after mixing yet it must retain enough workability so that it can be used after long periods of storage.

Some of the cutback asphalt presently produced can be used for patching mixtures that will meet some of these conditions—for instance—any of the less viscous cutbacks can be used for road mix under the usual conditions. Also local materials are commonly used for this type of work. The fourth condition imposes the greatest limitation. If early stabilities are to be obtained the cutback should be of the RC type so that the volatile matter will evaporate rapidly, but with the RC cutbacks all of the volatile material evaporates rapidly thus reducing the length of storage that is possible. If MC cutbacks are used the rate of curing is very slow and the material must be aerated or stored for some time before it can be used satisfactorily.

METHODS OF CURING

Two methods of curing the mixtures were used. In the first method small batches of the mixture were prepared and cured at a constant temperature in electric ovens. The temperature chosen for curing was 140 F. These batches were removed from the oven at intervals and weighed. When a predetermined amount of the volatile matter had been driven off, the specimens were molded and tested. The second method of

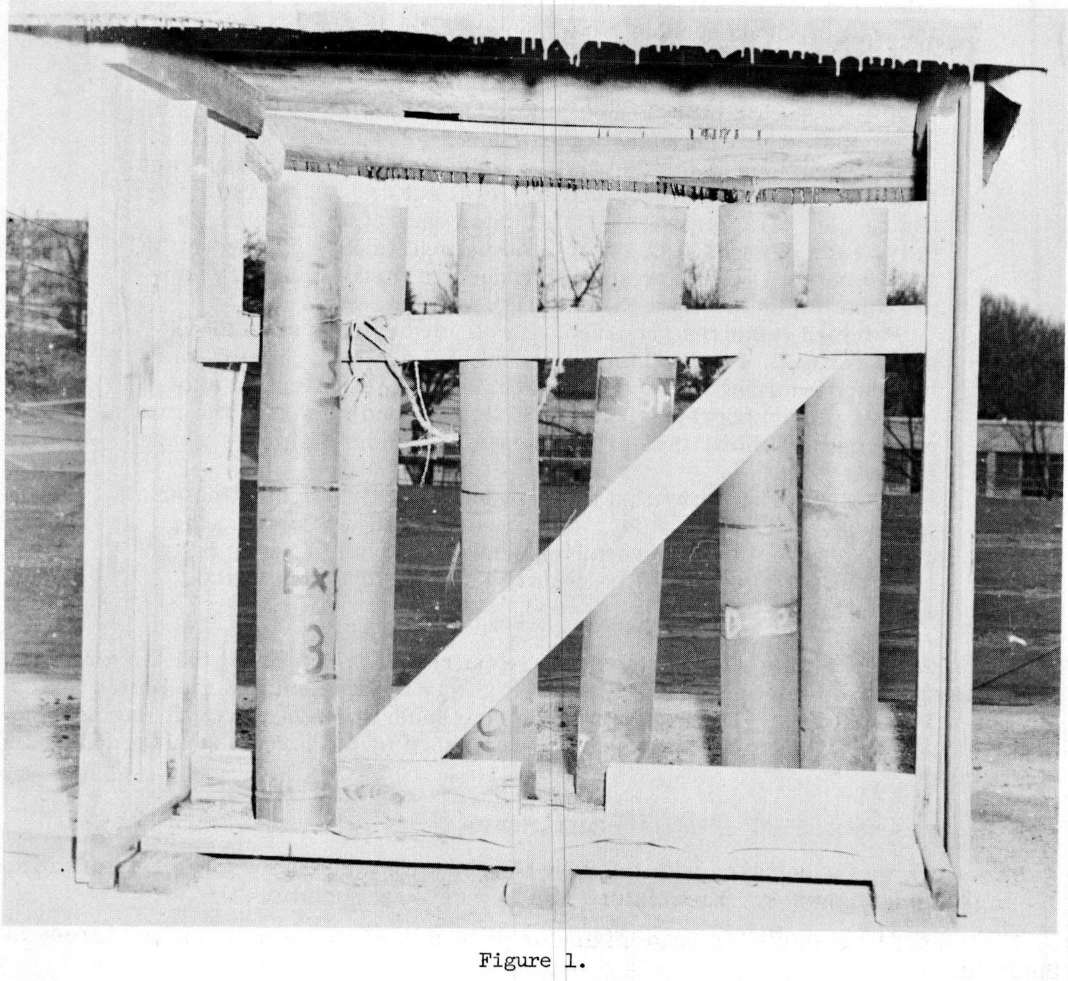

Figure 1.

curing the mixtures was to place these mixtures in lengths of stovepipe placed on the roof of the laboratory. The stovepipes were 6 in. in diameter and 26 in. high. In some cases double lengths of stovepipe were fitted together for providing more capacity. These stovepipes were placed on a coarse screen wire placed 2 in. above the roof. A shelter was placed over the top of the stovepipes to prevent rain from entering. This roof was approximately 18 in. above the top of the stovepipe. Figure 1 shows these stovepipes.

TABLE 1
PROPERTIES OF AGGREGATE USED IN BITUMINOUS MIXTURES

Type	Crushed Limestone
Aggregate Gradation:	
Screen	Percent Passing
½ in.	100.0
⅜ in.	76.0
No. 4	55.0
No. 10	40.0
No. 40	25.5
No. 100	16.5
No. 200	2.5
Los Angeles Abrasion	26%
Bulk Specific Gravity of Above Gradation	2.58
Absorption of Coarse Aggregate in 24 Hours	2.0%

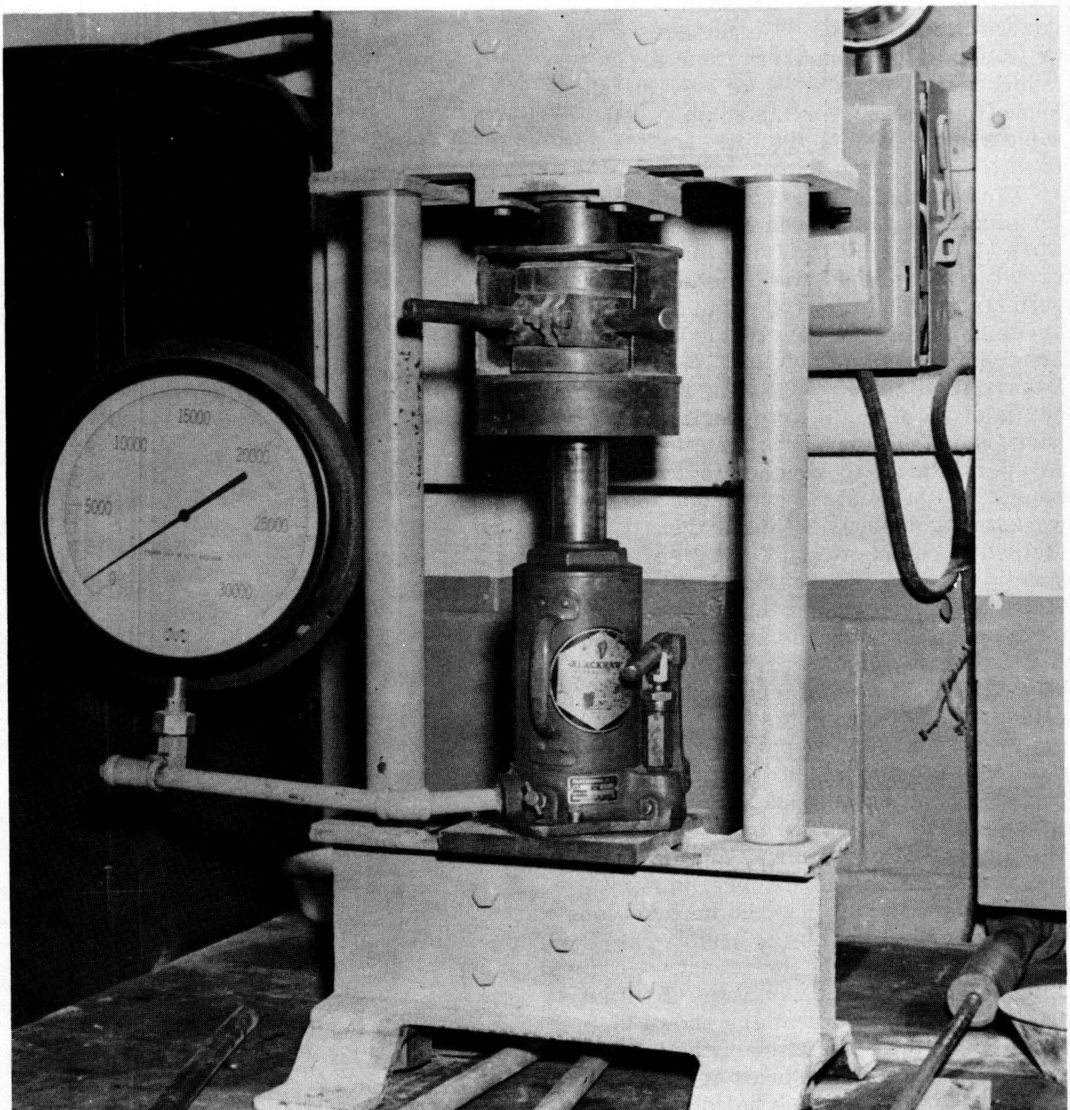

Figure 2.

One aggregate was chosen for use throughout the first phase of this work. This aggregate was a hard dolomitic limestone produced locally. Table 1 gives the properties and gradations of this aggregate. The gradation chosen for use in most of this work was one that gave very nearly the maximum dry rodded density for the material of one-half inch maximum size. The gradation producing the maximum density for the coarse aggregate was determined by plotting the densities of various mixtures on a triaxial chart. After the maximum density of the coarse aggregate was determined the next smaller size aggregate was added in small increments until the dry rodded density began to decrease. The gradation varies from this maximum density gradation only in very minor respects. The percentage of the different materials was adjusted to produce a gradation having a smooth curve. The maximum size coarse aggregate was chosen as one-half inch because many of the patches would be feather edged.

All of the asphalt materials used were commercial products furnished by the producers in Arkansas. The cutbacks were prepared in the laboratory from asphalt cements and solvents. The solvents and asphalt cements from the same producer were always combined to produce the cutback.

The Marshall Method of stability determinations was chosen for use in this work (1). A stability of 500 lb as measured by this method was considered as satisfactory stability for patching. The specimens were molded by the Gyratory Method as developed by the Texas Highway Department (see Fig. 2). The kneading action of the Gyratory compaction produced more uniform specimens especially as the mixtures approached the cured out point. As the mixture cured out and the workability decreased, the Marshall Method of compaction did not give as good specimens. In many cases there were voids and often crushed aggregate in specimens compacted by the Marshall Method. All of the specimens were tested for stability at 140 F. The specimens were raised to this temperature by immersion in a water bath. This part of the investigation was carried out to determine the curing characteristics of MC cutter stocks under the laboratory conditions. The MC-1 grade of cutback was not used in this investigation because preliminary trials indicated that it would take too long to cure these mixes in the oven. The properties of the asphalt cement used in this cutback are shown in Table 2. The properties of the solvent are shown in Table 3 and the properties of the laboratory prepared liquid asphalt are shown in Table 4. A series of partial distillation tests were made on prepared cutbacks to determine the volatile loss as a percent

TABLE 2

PROPERTIES OF ASPHALT CEMENT USED IN PREPARING CUTBACKS

Producer "C"

Penetration (77 F, 100 g, 5 sec)	100
Specific Gravity (77/77)	1 0191
Melting Point, F	115
Flash Point, F	635
Fire Point, F	705
Percent Soluble in Carbon Tetrachloride	99.63
Spot Test (naptha solvent)	negative

TABLE 3

PROPERTIES OF KEROSENE USED IN PREPARING CUTBACKS

Producer "C"

Specific Gravity (77/77)		0.8018
Flash Point, F		145
Distillation:		
	Percent Over	Temperature, F
	I. B. P.	358
	10	384
	20	392
	30	398
End Point: 526 F	40	406
Recovery: 99%	50	414
Residue: 1%	60	422
	70	432
	80	447
	90	472
	95	500

TABLE 4

PROPERTIES OF LABORATORY PREPARED MEDIUM CURING LIQUID ASPHALTS

Producer "C"

	Cutback Grade	
	MC-2	MC-3
Viscosity, Furol at 140 F, sec	170	299
Distillation:		
Initial Boiling Point, F	454	464
Distillate (percent of total distillate to 680 F)		
To 437 F	0	0
To 500 F	44 3	34.8
To 600 F	85.0	81.5
Residue from distillation to 680 F		
Volume percent, by difference	74.6	78.6
Penetration of residue (77 F, 100 g, 5 sec)	202	196
Specific gravity of residue (77/77)	1 013	1.014
Specific gravity of distillate (77/77)	0.791	0.788
Temperature, F at 115 sec Viscosity, Furol	155	165
Volatiles evaporated at 120 sec		
Float test, percent of total cutback	21.0	16.8
Texas curing index:		
By evaporation test	600	425

TABLE 5

RELATION OF STABILITY TO CURING OVEN CURED MIXES

Volatiles Lost				
Percent of Total Volatiles	Percent of Total Cutback	Marshall Stability, lb	Flow 0.01 in	Density, percent
MC-2				
12	3	300	21	100
27	7	500	15	100
59	15	500	9	97.5
79	20	475	9	94
MC-3				
23	5	600	16	99.8
56	12	500	10	96.4
84	18	500	9	94.5

by volume of the cutbacks at the cured out point. The cured out point was taken from Hank's work as 120 sec float test at 122 F (2). Hank learned from field experience that RC-2 cutbacks were satisfactorily cured out when approximately 80 percent of the volatiles had been evaporated. At this point the consistency of the residues from the cutbacks averaged a float test of 120 sec at 122 F. He then assumed this point as the cured out point and designated the time required to reach this 120 sec float test as the curing index in comparing RC and MC cutbacks. Experience indicates that this arbitrary cured out point will not apply to cutbacks prepared with asphalt cements with either a very high or a very low penetration. The cured out point was not used as a marker in the subsequent parts of this study so the variation did not affect the work.

Ten mixes were prepared using the MC-2 cutback and nine using the MC-3 cutback. These mixes were designed to have a residual asphalt cement content of 5.0 percent by weight. This asphalt cement content was determined from a series of optimum asphalt determinations for this gradation. Each sample weighed 2,500 grams. Both the aggregate and the asphalt were heated to a temperature that would give the cutback a viscosity of 115 sec. For the MC-2 this temperature was 155 F and for the MC-3 the temperature was 165 F.

The mixes were removed from the oven and weighed at intervals so that a check could be kept on the percentage of volatile matter lost. When the mix had lost a predetermined percentage of the volatiles it was removed from the oven and molded immediately for stability determination. Six hundred hours in the oven were required for the MC-2 mixes to reach the cured out point. About 400 hours in the oven were required to cure out the MC-3 mixes.

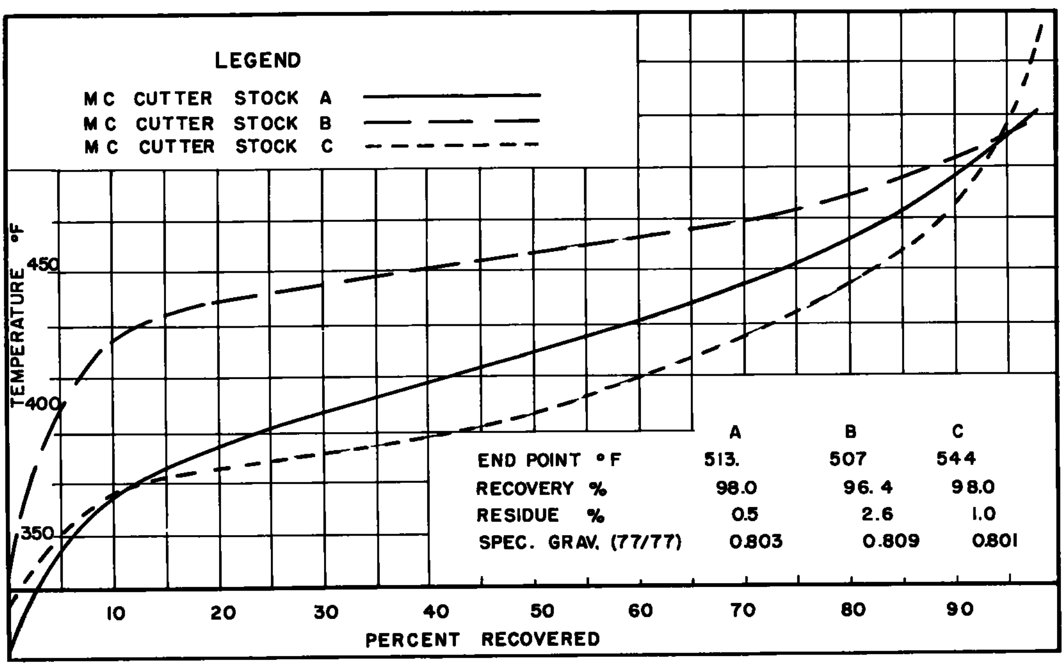

Figure 3. Distillation curves, MC cutter stock.

Table 5 shows the averages of the test specimens at different times of curing.

For each of these cutbacks the 500-lb stability was obtained when less than 30 percent of the volatile matter had been evaporated. In the case of the MC-2 this percentage was 27 percent and the MC-3 was 23 percent. For higher percentage of volatile matter evaporated, the stabilities did not increase. Part of this could be attributed to the lack of good compaction. At temperatures of 140 F it was not possible to get as good compaction as would have been obtained with higher temperatures.

TABLE 6

ROOF STORAGE MIXES

PROPERTIES OF ASPHALT CEMENT USED IN PREPARING CUTBACKS

Brand of Asphalt Cement	A	B	C
Penetration (77 F, 100 g, 5 sec)	126	129	124
Specific Gravity (77/77)	1 0213	1 0132	1 0713
Softening Point, F (R and B)	109	111	109
Flash Point, F	661	653	644
Fire Point, F	727	721	700
Spot Test (naphtha solvent)	Neg	Neg	Neg
Ductility, cm (77 F, 5 cm/min)	150+	150+	150+
Percent Soluble in Carbon Tetrachloride	99.9	99 8	99 7

STOVEPIPE METHOD OF CURING

The mixes were placed in a stovepipe and stored on the roof of the laboratory for curing in an attempt to simulate some of the conditions found in the center of a stockpile. Observation of stockpiles indicated that the surface formed a hard crust while the center of the stockpile remained very workable. Fifty-pound batches were prepared in a laboratory type pugmill and placed on the roof of the laboratory. Seven samples were mixed on August 4 and 5. These samples were immediately placed in the stovepipes on the roof of the laboratory. The gradation was the same as used in the oven-cured mixes previously reported, but three brands of cutback asphalt were used in these mixes. These brands were listed as A, B, and C. Figure 3 shows the distillation curves of the solvent used in these mixes. Table 6 shows the properties of the cutback asphalts and Table 7 indicates the test results of the prepared cutbacks. The residual asphalt content of these mixes was 5.0 percent by weight.

Samples were taken from the batch as soon as it came out of the pugmill for the purpose of determining the percent of volatile matter that was lost during mixing.

At intervals varying from two to three weeks, samples were taken from the bottom of the stovepipes for the purpose of determining stabilities and loss of volatiles. Table 8 shows the results of the stability determinations and the volatiles lost. The volatile contents of the samples were determined by AASHO Method T110-42. The specimens were all compacted at 100 F and stabilities were determined by the Marshall Method at 140 F. Compaction was by the Gyratory Method.

The length of storage of these mixes indicated that it was possible to obtain satisfactory storing periods with mixes prepared from MC cutbacks. It was also apparent

TABLE 7

ROOF STORAGE MIXES

CUTBACKS USED IN BITUMINOUS MIXES

Blend Number	1A	2A	3A	2B	2C
Furol Viscosity					
122 F, sec	94	139			125
140 F, sec	58	79	148	132	71
Distillation					
Distillate (percent of total distillate to 680 F)					
To 437 F	2.0	7.4	0	0	0
To 500 F	49.4	55.0	44.8	27.0	48.8
To 600 F	85.5	88.7	84.4	79.9	84.3
Residue from distillation to 680 F volume percent by difference	68.9	71.4	76.0	74.5	69.8
Penetration of Residue (77 F, 100 g, 5 sec)	213	196	173	220	219
Volatiles in cutback at 120 sec float test at 122 F of total cutback	26.6	25.4	19.8	23 4	26.6
Calculated Texas Curing Index using 120 sec float test at 122 F as cured out point	360	320	280	980	480

TABLE 8

ROOF STORAGE MIXES

STABILITY VERSUS VOLATILE CONTENT

Flow	Marshall Stability	Percent of Total Volatiles Lost	Volatiles Lost Percent Total Cutback
Mix 1A Mixed August 4, 1952 Last sample taken May 8, 1953 Total storage time 277 days			
During mixing		23	7
15	540	54	17
13	440	54	17
14	565	55	17
17	545	57	18
11	700	83	26
Mix 2B Mixed August 4, 1952. Last sample taken May 8, 1953 Total storage time 277 days			
During mixing		20	5
17	470	32	8
19	530	36	9
16	490	41	10
21	555	45	11
12	700	57	15
Mix 2C Mixed August 4, 1952 Last sample taken April 8, 1953 Total storage time 247 days			
During mixing		30	9
21	345	38	11
20	565	52	16
17	460	54	16
16	530	56	17
Mix 2A-1 Mixed August 4, 1952 Last sample taken April 10, 1953 Total storage time 249 days			
During mixing		23	7
12	610	42	12
14	590	43	12
13	525	49	14
12	730	54	15
Mix 2A-2 Mixed August 5, 1952 Last sample taken April 10, 1953 Total storage time 248 days.			
During mixing		19	5
11	520	41	12
15	500	44	13
13	760	55	16
11	670	57	16
Mix 3A-1 Mixed August 4, 1952 Last sample taken April 13, 1953 Total storage time 252 days			
During mixing		23	6
12	660	34	8
10	625	41	10
11	730	47	11
10	665	48	12
Mix 3A-2 Mixed August 4, 1952 Last sample taken April 13, 1953 Total storage time 251 days			
During mixing		27	6
11	630	43	10
15	750	49	12
13	635	54	13
14	1,000	69	17

that the flash-off of volatile matter during mixing would not be sufficient to produce satisfactory stabilities. It appeared from these mixes that satisfactory stabilities with the medium curing cutbacks would not be attained until about 40 percent of the volatile matter has been lost.

BLENDED CUTTER STOCKS

It is evident from the curing characteristics of the first storage mixes that approximately 40 percent of the volatiles would need to be driven off before minimum stabilities could be obtained. The rate of curing beyond this point was satisfactory, indicating that if there were about 60 percent medium curing cutter stock in the cutback a satisfactory curing period would result. The ideal curve would be one in which about 35 percent to 40 percent of the volatile matter were lost fast and then the curing rate slowed down to that of an ordinary MC cutter stock. The first part of the curve should resemble that of an RC cutter stock. From this it was decided to blend RC and MC cutter stocks to form a solvent for preparing cutbacks. A curve for an ideal solvent based on the characteristics stated above was drawn. Blends of RC, MC and in some cases SC cutter stocks were then made and their distillation curves compared with the desired distillation curve.

Several blends of cutter stocks were tried and their distillation curves plotted. Table 9 shows some of the blends of cutter stock from producer A and producer B. It was determined from the distillation curves that some of these blends would not be satisfactory and were considered no further. Actually the blends shown here were only a few of the large number that were tried. From the results of those tried, one blend was chosen from producer A and one blend from producer B with which to produce cutbacks for further study. Figure 4 shows the curves of these two blended cutter stocks. Also shown is the curve D-223, a solvent prepared by one of the producers. This solvent was prepared to match the curve of the proposed ideal solvent. Table 10 shows the physical properties of the asphalt cement and Table 11 shows the properties of cutbacks prepared with these blended cutter stocks.

Several pan mixes were prepared using blends 4A and 2B for testing the stability and the rate of curing of the actual asphaltic concrete mixes. The batches were mixed at 140 F and were cured in ovens at 140 F. The approximate loss of volatile matter was determined by weighing the pans from time to time. Four different volatile contents were chosen at which specimens would be tested. Test specimens were chosen when approximately 30 percent of the volatile matter had been evaporated. Other specimens were taken when 50 percent, 75 percent and 90 percent of the volatile mat-

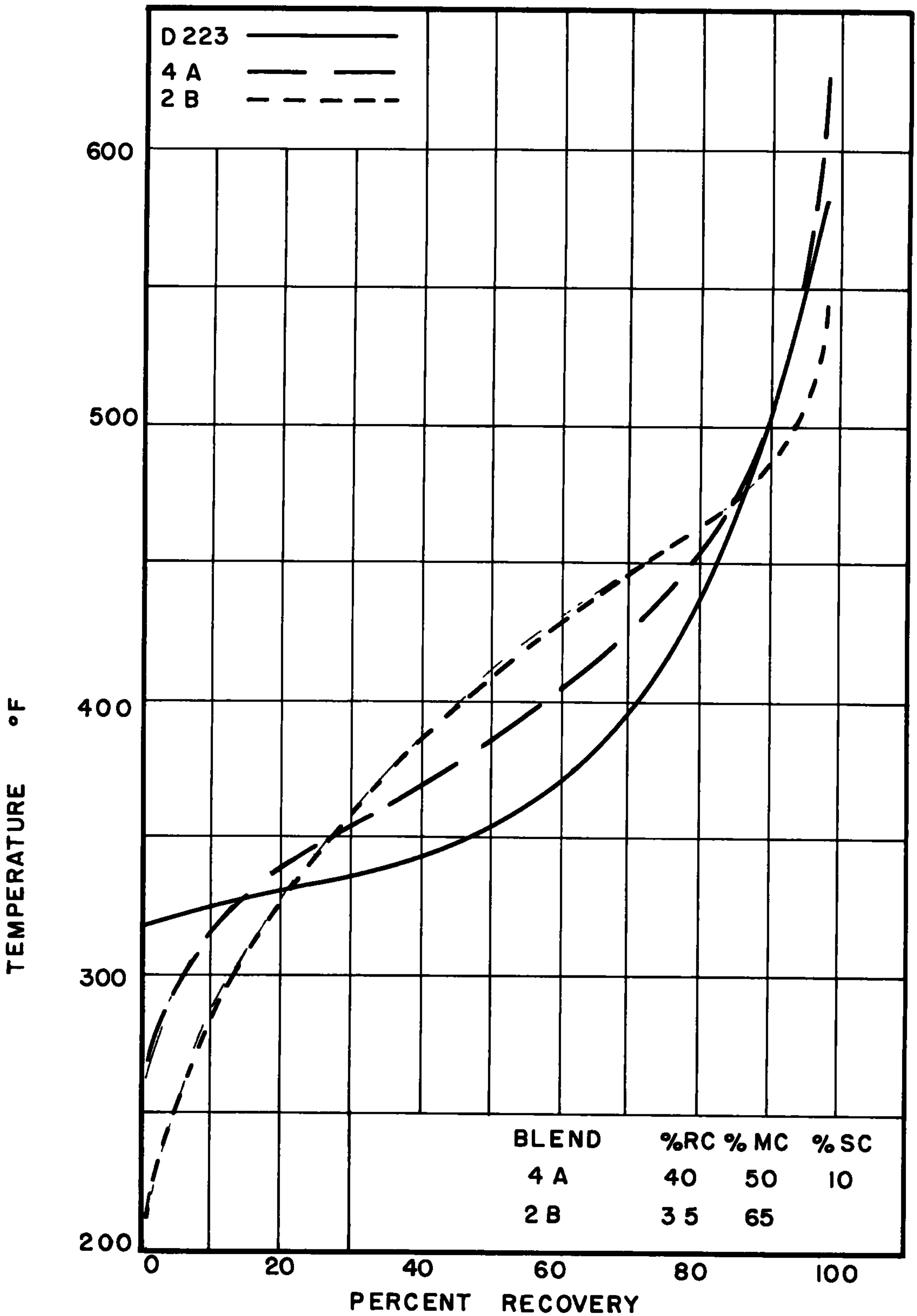

Figure 4. Distillation curves, blended cutter stocks.

TABLE 9

PROPERTIES OF BLENDS OF CUTTER STOCKS

Blend	2A	4A	5A	1B	2B
Percent Over			Temperature F (corrected for barometric pressure)		
I. B. P.	262	257	264	275	212
10	327	322	329	374	293
20	349	336	349	401	330
30	365	356	363	419	361
40	378	370	379	433	387
50	390	385	399	444	408
60	408	403	419	455	430
70	430	424	444	464	446
80	451	453	473	477	462
90	480	507	518	495	482
End Point	518	621	606	547	538
Recovery, percent	99.0	98.5	98.0	97.0	98.5
Residue, percent	0.6	1.1	1.6	2.9	1.2
Distillation Loss, percent	0.4	0.4	0.4	0.1	0.3
Specific Gravity (77/77) F	0.789	0.790	0.794	0.790	0.780

Blend	Percent RC	Percent MC	Percent SC
2A	30	70	0
4A	40	50	10
5A	30	60	10
1B	10	90	0
2B	35	65	0

ter had been driven off. Because of the size of the mixes and sensitivity of the scales used, it was not possible to determine accurately the percentage of volatile matter driven off from these mixes. Two distillation tests were made on each sample taken for stability tests to give a more accurate indication of the percent of volatile matter lost. Three specimens were prepared for testing by the Marshall Method and three specimens were prepared for testing by the Hveem Method, from each pan mixed. All of these stability specimens were compacted by the Gyratory Method and tested at 140 F, after being brought to temperature in a water bath. Table 12 indicates results of the tests. Figure 5 indicates the rate of loss of volatiles from these two mixes. The percent relative stability by the Hveem Method was determined from curves of

TABLE 10

PROPERTIES OF ASPHALT CEMENT USED IN PREPARING CUTBACKS

Brand of Asphalt Cement	A	B
Penetration (77 F, 100 g, 5 sec)	120	129
Specific Gravity	1.0176	1.0132
Softening Point F (R and B)	110	111
Flash Point, F	662	653
Fire Point, F	729	721
Spot Test (naphtha solvent)	Neg	Neg
Ductility, cm (77 F, 5 cm/min)	150	150+
Percent Soluble in Carbon Tetrachloride	99.8	99.8

TABLE 11

CUTBACKS USED IN BITUMINOUS MIXES

Blend	4A	2B
Furol Viscosity		
122 F, sec	187	268
140 F, sec	108	140
Distillation		
Distillate (percent of total distillate to 680 F)		
To 437 F	15	12
To 500 F	31	25
To 600 F	43	41
Residue from distillation to 680 F volume, percent by difference	75	75
Tests on Residue		
Penetration (77 F, 100 g, 5 sec)	265	260
Volatiles in cutback at 120 sec float test at 122 F, percent of total cutback	23	22
Calculated Texas Curing Index using 120 sec float test at 122 F as cured out point	390	370

TABLE 12

STABILITY RESULTS USING BLENDED CUTTER STOCKS

Mix	Marshall Stability lb	Flow	Percent by Volume, total volatiles off	Percent by Volume, total cutback off	Percent Theoretical Density
	465	17	37	9	100
	560	8	43	11	100
	600	12	42	11	100
	630	9	48	12	99.6
	645	10	46	12	98.7
	710	9	52	13	99.1
	920	8	93	23	96.2
4A	Percent Hveem Stability				
	35		40	10	99 6
	36		43	11	100
	41		57	14	98.7
	43		80	20	96.2
	51		94	24	95.0
	52		98	24	95.0
	535	13	39	10	100
	655	10	48	12	99.1
	690	7	51	13	100
	800	8	73	18	96 2
	830	8	78	20	97.0
	875	9	93	23	95.8
2B	Percent Hveem Stability				
	29		36	9	100
	35		41	10	100
	42		52	13	100
	44		76	19	97.0

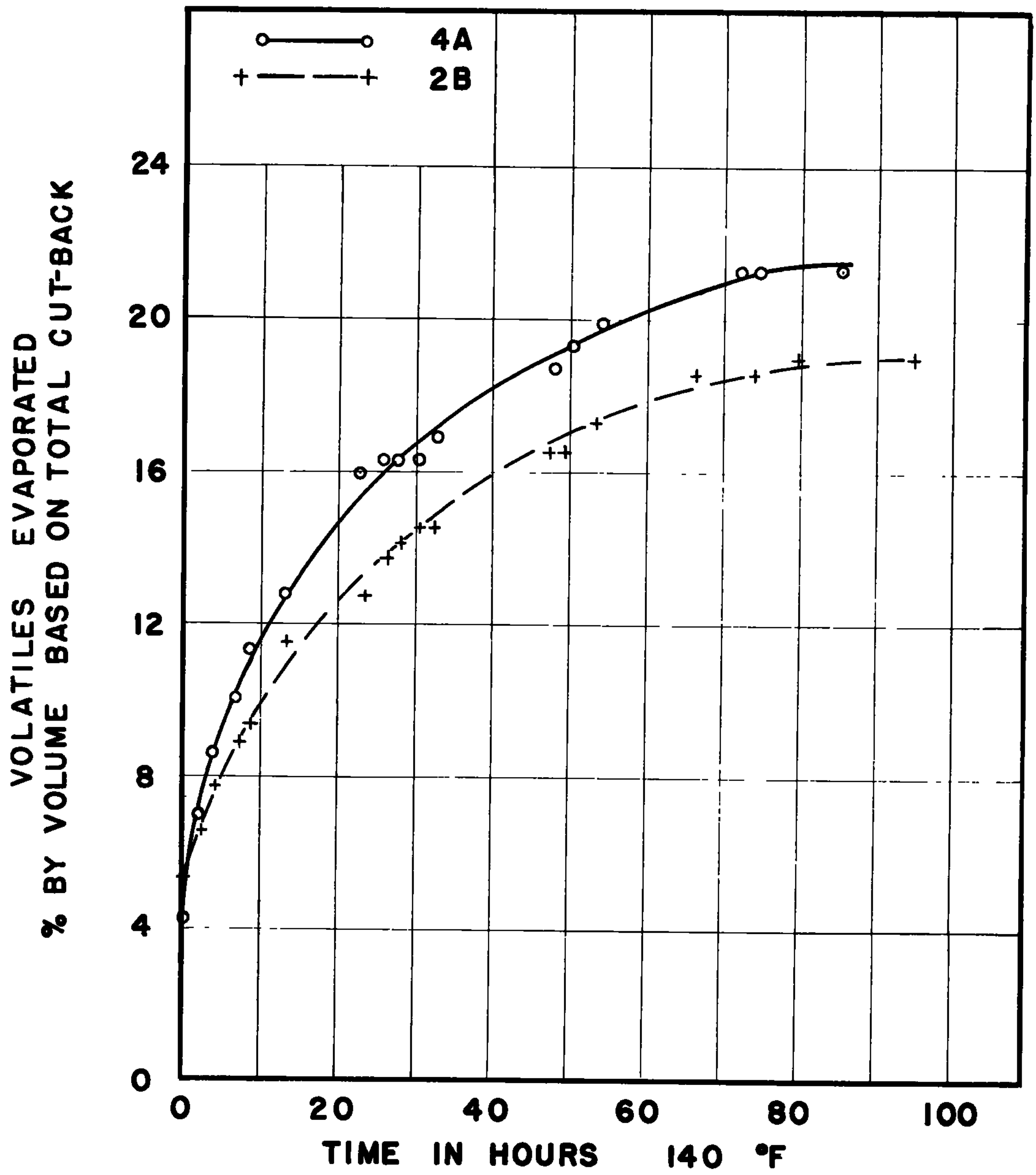

Figure 5. Evaporation curves, pan mixes, blended cutter stocks.

final displacement plotted against Hveem stabilometer gauge reading at 400 psi applied vertical load. These curves were taken from Martin's work at Oklahoma State University (3).

The results obtained from the oven-cured pan mixes were used as a guide in preparing the stovepipe mixes. For this series of stovepipe mixes it was desired to obtain as long a curing period as possible. Therefore two joints of stovepipe were placed together forming a length of about 4 ft. These were mixed in two 50-lb batches in an electrically heated laboratory pugmill. Mixing was accomplished at 140 F. Small samples were taken from each of these mixes at frequent intervals during the early curing period and at much longer intervals of time as curing proceeded. Distillation tests were run on these samples to determine the amount of volatiles lost. Only three

TABLE 13

ROOF-STORED MIXES USING BLENDED CUTTER STOCK

Age Days	Point of Sampling	Percent Volatiles Evaporated	Percent Total Cutback	Stability	Flow	Density
			Mix 4A-1			
0	Pugmill	27.3	6.8			
3	Bottom of pipe	38 0	9.3			
5	Bottom of pipe	32	8.0	630	11	
33	Bottom of pipe	93	23.0			
93	Center of pipe	43.5	10.7			
173	Center of pipe	56.3	13 9			
361	Center of pipe	66.3	16.4			
634	Center of pipe	87.5	21 7	980	10	97.2
634[a]	Center of pipe	87.5	21.7	610	9	94.2
			Mix 4A-2			
0	Pugmill	28.8	7.2			
3	Bottom of pipe	39.0	9.6			
4	Bottom of pipe	32.0	8.1	745	10	
34	Bottom of pipe	64 5	16.2			
174	Center of pipe	60.0	15 0			
635	Center of pipe	90.0	22.5	900	11	93.4
635[a]	Center of pipe	90.0	22.5	670	10	91.2
			Mix D-223			
0	Pugmill	32.8	6.9			
3	Bottom of pipe	37.3	7.9			
11	Bottom of pipe	58.2	12.3			
72	Center of pipe	36.6	7.7			
136	Center of pipe	59.7	12.5			
324	Center of pipe	74.6	15.6			
597	Center of pipe	85.1	17.8	770	10	96.6
597[a]	Center of pipe	85.1	17.8	620	10	94.9

[a] These specimens were molded at 65 F and tested at 140 F.

different samples were prepared for stovepipe curing. Table 13 shows the results of these tests. Two of the mixes were identical with the exception that mix 4A-2 had a residual asphalt content of only 4.0 percent. Mix 4A-1 had a residual asphalt content of 5.0 percent. The mix having the same constituents as mix 4A of the oven-cured mixes, lost 27 percent of its volatiles during the mixing process. At the end of five days, 32 percent of the total volatiles or 8 percent of the total cutback had been evaporated. At this time stability determinations were made. The stability was found to be 630 lb Marshall. Samples taken from the center of the stovepipe at the age of 93 days showed a loss of 43.5 percent of the total volatiles or 10.7 percent of the total cutback. At the age of 173 days these figures were 56 percent and 13.9 percent. At 361 days the figures were 66 percent and 16.4 percent and 634 days 87.5 percent of the total volatiles had been evaporated. At this age samples were compacted for the stability determination. Specimens compacted at 100 F and tested at 140 F gave a stability of 980 lb and a flow of 10. The density was 97.2 percent. One group of samples were compacted at 65 F to observe their workability at lower temperatures. Mix 4A-1 gave a stability of 610 Marshall and a flow of nine under these conditions. The density was 94.2 percent.

It was observed that a crust formed on the top and bottom of these mixes more rapidly than it did on the mixes where a commercial MC cutter stock was used. The depth of this crust did not appear to vary from that of previously observed mixes. When the stovepipe was removed from the roof and placed in the laboratory the temperature in the laboratory was approximately 70 F. When first removed from the stovepipe the mixes were consolidated and very resistant to breaking down. In some cases a hammer had to be used to break them down prior to molding. After the samples were heated to 100 F they became friable and could be easily broken down with the hands.

MIXES EXPOSED TO THE ELEMENTS

At the conclusion of the tests of the blended cutter stock an attempt was made to check this blended cutter stock with aggregates from various areas. Five different aggregates were used. Table 14 shows the physical properties of the aggregates.

The crushed limestone No. 1 is the same aggregate that was used in all of the previous work. All of the aggregates had the same gradation as used in the previous work. Samples of each aggregate weighing 7,000 grams were proportioned and placed in large mixing pans. Cutback 4A was added to each sample in the amount to yield 5.0 percent residual asphalt. The aggregate and the cutback were at a temperature of 140 F when mixed. The aggregate and cutback were thoroughly mixed for a period of seven minutes with a large laboratory spoon. After the aggregate and cutback 4A were thoroughly mixed, the mixture was placed in a wooden container measuring 15- by 11-in. and 5-in. deep. The containers were approximately half full. The bottom of each container was covered with ¼-in. wire screen mesh. The purpose of the screen was to allow air and precipitation to pass through the container. The wooden containers were stored on the roof of the laboratory, on 4- by 4-in. timbers in such a manner that there was free circulation of air under the mixes. These mixes were placed on the roof of the laboratory on September 26, 1955, and removed from the roof on March 15, 1956. No protection whatsoever was placed over the samples so that they were completely exposed to the elements. At the end of this period of exposure there was no evidence of stripping in any of the mixtures. A 1,200 gram sample of each mix was obtained and heated to 140 F in electric ovens. Each heated sample was then compacted by the Gyratory Method. The stability and flow of each compacted specimen was obtained by the Marshall Method. Volatile contents were determined by the Method AASHO T110-42. Table 15 gives the results of these tests. Each stability shown is the average of three specimens.

The visual examination of the crushed syenite indicated that this material had very poor crushing characteristics. A majority of the crushed material was elongated slivers or flat plate shaped particles. At high volatile content this mix had no stability at all. The optimum asphalt contents for these same materials and gradation varied from 5.0 percent for the crushed limestone No. 2 to 6.5 percent for the crushed river gravel.

PROPOSED SPECIFICATION

The results of these studies indicated that there was a need for better control of the manufacture of material if it were to give best results under general conditions. The proposed cutback asphalt specification (Fig. 6) is rather restrictive and it is possible

TABLE 14

Type of Aggregate	Bulk SG for Gradation	Percent Wear L.A. Abrasion	Percent Absorption 24 hours	Soundness (% loss)
Crushed River Gravel	2.545	36	2.3	4.9
Crushed Sandstone	2.537	31	2.3	4.6
Crushed Syenite	2.615	24	0.4	5.6
Crushed Limestone No. 1	2.575	26	2.0	1.0
Crushed Limestone No. 2	2.668	50	0.7	3.5
Type of Aggregate		**Unit Weight (pcf)**		**Percent Voids**
Crushed River Gravel		114.8		27.7
Crushed Sandstone		115.9		26.8
Crushed Syenite		117.8		27.8
Crushed Limestone No. 1		118.6		26.2
Crushed Limestone No. 2		126.8		23.9

TABLE 15

RESULTS OF TESTS ON MIXES EXPOSED TO ELEMENTS

171 Days Exposure—Specimens Molded and Tested at 140 F

Type of Aggregate	Marshall Stability (lb)	Flow (0.01 in.)	Percent Theoretical Density	Percent Volatiles Evaporated
Limestone No. 2	1,165	13	96.8	96.4
Limestone No. 1	1,054	11	94.7	95.3
Crushed Syenite	705	11	93.5	91.7
Crushed River Gravel	496	10	91.8	89.3
Crushed Sandstone	746	11	93.9	84.6

that some relaxing of parts of this specification will be necessary. This specification varies in two places from the usual cutback asphalt specifications. In the first place this specification requires the fractions from the distillation tests be given as the percentage of the total cutback. It is desirable that this be done so that the people using the material will have some idea of how much volatile matter is in the cutback, and that the volatile matter be controlled a little more closely. It is customary in many cases in the field to shoot a given quantity of cutback regardless of the asphalt content of this cutback. It is felt desirable to control the solvent as far as practical. Experience in the laboratory indicates that the solvents presently in use vary widely. It was found in a few cases that an MC solvent from one producer would very nearly match the RC solvent from another producer. This is indicated from the variations in the curing index of the materials shown in Table 7.

PROPOSED SPECIFICATION FOR

CUTBACK ASPHALT

FOR PREPARATION OF PREMIX MATERIAL WITH CRUSHED AGGREGATE

This cutback shall be prepared from a steam and vacuum straight-reduced asphalt, and a petroleum solvent:

The cutback shall meet the following requirements.

Flash, Tag Open Cup, Min.	95°F
Viscosity, S. Furol at 140°F, Sec.	90-130
Distillation (ASTM D402, excepting fraction as percentage of cutback).	
Initial boiling point, Min.	375°F
To 374°F, %	0
437°F, %	7-10
500°F, %	15-17
600°F, %	21-24
680°F, %	24-27
Test on residue from distillation	
Penetration at 77° F, 100g., 5 sec.	200/300
Ductility at 77° F,	60+
Spot Test	Neg.
Solubility in Carbon Tetrachloride	99.5+
The solvent shall meet the following requirements:	
By AASHO Distillation T 115	
Initial Boiling Point ° F,	300+
Temperature at 40% Recovery ° F,	340-365
Temperature at 80% Recovery ° F,	425-460
End Point ° F	600-650

Figure 6.

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2. Hank, R. J., "Curing of Cutback Asphalt," Texas Highway Department, Stencil 11-43-1172.
3. Martin, J. Rogers, "Some Fundamental Principles in Relation to Asphaltic Concrete Pavements as Applied to the Hveem-Gyratory Method of Design," Publication No. 69, Engineering Experiment Station, Oklahoma State University.

Seal Coats: Laboratory Contributions Toward Better Performance

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Success or failure of a seal coat can often be traced to lack of control of material and condition of the equipment. Field tests are needed to enable the engineer to have more positive means for evaluating the actual quality of the work as it is performed. This paper discusses in detail a method for checking the uniformity of the transverse and longitudinal spread rates of the asphalt distributor.

Additional studies and experiments relating to seal coats are described, such as variation in temperatures of the bituminous binder from the time it comes in contact with the pavement to the time of rolling the screenings, degradation of screenings due to rolling and traffic, seasonal effect on performance of seal coats and permeability of pavements. The use of atmometers for determining drying conditions and setting time of the bituminous binder, particularly asphaltic emulsions, was investigated. The possible use of a simple centrifugal test which can be performed in the field to predict the adherence of screenings is discussed. This test should provide the engineer with some evidence as to a proper waiting time before opening the newly placed seal coat to traffic.

● SEAL COATS or light surface treatments in one form or another and for various purposes have been placed for many years in the conventional ways without any particular effort having been exerted to obtain better performance through more scientific control or test methods. Specifications are in many cases rather loose, leaving construction details to the judgment of the engineer, and the success or failure of the job frequently can be directly related to the experience of the field engineer.

The expanded program of highway construction makes it mandatory that the more experienced engineers be assigned to the multimillion dollar freeway projects. This leaves the relatively small and often considered unimportant seal coat jobs to the less experienced engineers. The young engineer may be very conscientious and eager to learn but even a job as lowly as a seal coat requires considerable "know how" to be successful.

As pointed out in the "Symposium on Surface Treatments" (1), "What seems to be needed is to bring the work of the testing laboratory closer to the field . . . and removing the need for guesswork on the part of those less experienced." It is hoped that this group especially will benefit from development of new tests and procedures.

Many of the staff of the California Division of Highways have long been aware of the need for improvement and more scientific methods in seal coat construction. Laboratory studies and field investigations have been conducted over a period of about ten years and a report outlining some of the factors involved in the design of seal coats was published in 1949 (2). The solving of many of these problems has not proved to be easy and a comprehensive study of all the variables involved could easily embrace a considerable number of separate investigations. The more pertinent points which affect the performance of seal coats and which warrant study and investigation in the laboratory as well as in the field are outlined in Appendix A.

It might be well to mention that the term "seal coat" as used in this paper denotes a single application of bituminous binder covered with a single application of screenings. Its purpose may be to "seal" the road surface but more often than not the "seal coat" is placed for other reasons. The screenings or stone chips used in seal coats in

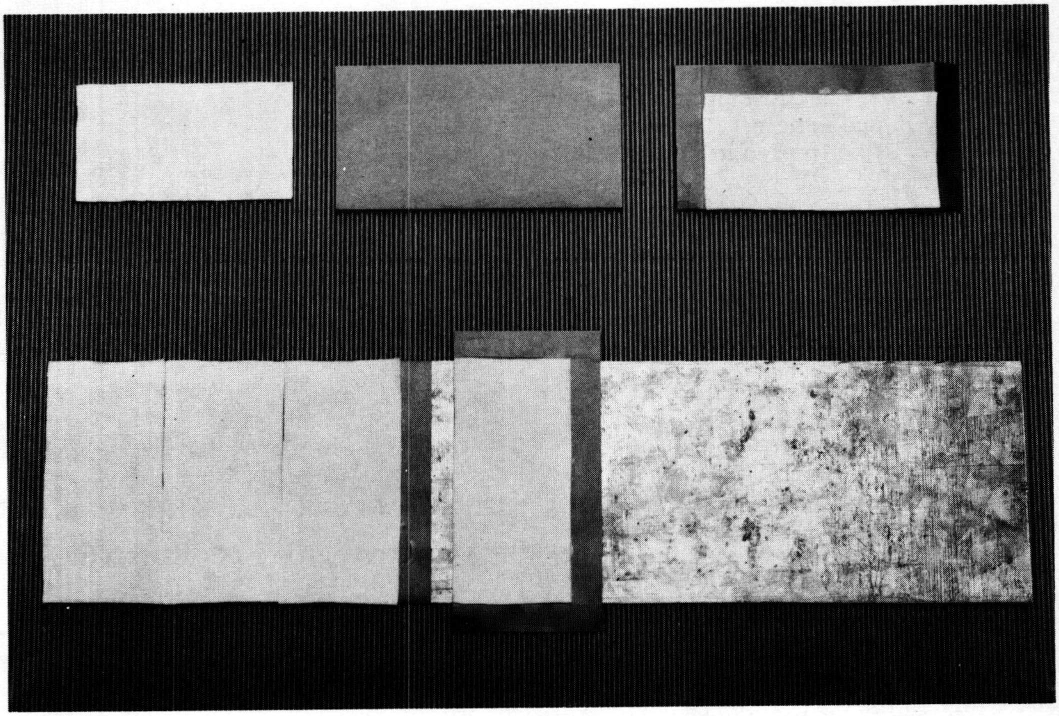

Figure 1. Placing 4- by 8-in. pads on metal strips for transverse spread (Method 1).

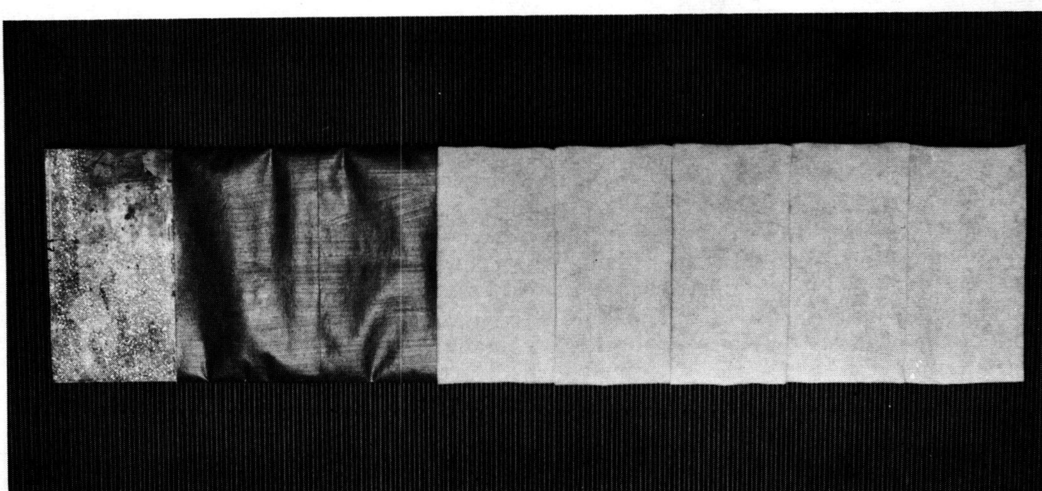

Figure 2. Placing 4- by 8-in. pads on metal strips for transverse spread (Method 2).

California are of smaller particle size than those generally used in many other parts of the United States and are specified as either fine ($^1/_4$-in. by No. 10) or medium-fine ($^5/_{16}$-in. by No. 8) size. Complaints from the traveling public of damage to car windshields by flying screenings, particularly during the whipoff period, has discouraged the use of larger size chips in California. Also the coarser stone creates unpleasant car rumble and increased tire wear.

The purpose of this paper is to report certain laboratory techniques and field studies relating to the construction of seal coats. The outline, as shown in Appendix A, lists some 20 separate and distinct investigations and studies. Although considerable time has been devoted to some of these factors, it would be difficult to treat all adequately in one article. Therefore, this paper will be limited to the following subjects:

1. Method for checking transverse and longitudinal spreads of asphalt distributors.
2. Temperature study of bituminous binders from time of application of binder to rolling of screenings.
3. Degradation of screenings due to rolling and traffic.
4. Absorptiveness and permeability of pavements.
5. Rate of curing ot bituminous binder and adherence of screenings.
6. Seasonal effects on performance of seal coats.

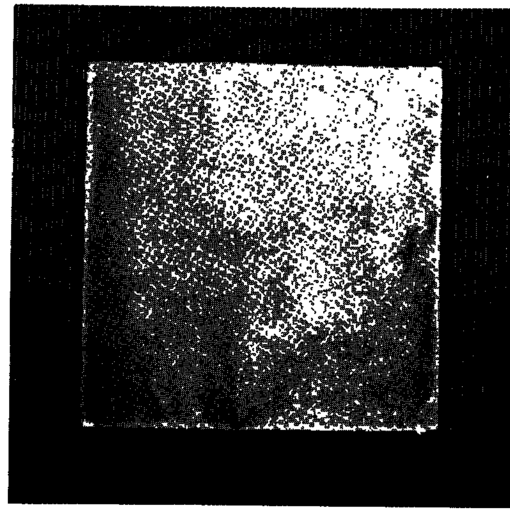

Figure 3. 12- by 12-in. pans with paper liner for longitudinal spread.

Some attempts were not entirely successful. However, they are included in this report to illustrate the difficulties encountered in developing simple and workable field methods. These trials are mentioned with the thought that they may save some time and effort on the part of others who might have similar ideas or who may pursue the experiments further and perhaps devise more simplified and better field methods.

Method of Checking Distributor Spread Rate

The proper and uniform application rate of the bituminous binder may easily be the deciding factor in the satisfactory performance of a seal coat. Excess asphalt may result in bleeding of the surface and insufficient application in raveling of the seal coat. Irregularities in the transverse rate of spread may result in parallel ridges or rough areas due to variations in the quantity of screenings retained.

Failure to apply the binder at the desired rate may be caused by a number of factors, most of which are correctable. Good equipment, kept in proper condition and operated efficiently, is one of the basic requirements for a uniform spread.

For some time, the development of a procedure for determining uniformity of both the transverse and longitudinal spread rates has been of concern. In the determination of transverse spread rate it is desirable to have a complete record across the full width of the roadway, since random measurements may not provide a satisfactory indication of deviations from the desired spread rate.

At present, the street inspector makes random spread rate determinations from tank "stabbings" and visually notes deviations, but neither of these observations are very satisfactory. It is also possible to make the average spread per square yard coincide exactly with the intended rate of application by adjusting a combination of spread, pressure, rate of speed of truck, etc. This still permits sizeable variations in each individual short stretch of application. It would be very desirable for the street inspector to have available a rapid and more accurate method for determining the average spread.

When the field study of seal coats was instigated several years ago, a method of checking distributors reported from England (3) was given considerable consideration. In their procedure, permanent testing stations are set up at convenient locations. The checking procedure consists of collecting the bitumen sprayed into a row of pans set under the spray bar. Each pan covers a transverse width of about 2 in. and is calibrated so that the contents may be either weighed or gauged. This method gives quite accurate results since the sampling pans do have a relatively large capacity. The method, however, has some distinct disadvantages. A considerable investment in equipment is required. A test on a single distributor could very easily involve the taking of 50 to 100 gal samples and equipment to handle this waste material must be provided. Steam or a large solvent bath would be required to clean the pans and other equipment. A major disadvantage of this system is that it does not indicate the ability of the operator to put down a uniform spread of binder in the field. Also, a distributor in good operation today, may not remain in this condition a day or two hence. This difficulty was overcome to some extent by testing on the job, taking samples on a series of small pads or strips of paper placed directly on the pavement.

Although the British method gives an accurate picture of the quality of the spread, it is not completely satisfactory because of the time and sensitive equipment required. If the street inspector were to make a check of the spread rate, to be practicable the method should be considerably shorter and simpler. With this in mind, several approaches were studied and new methods are still being considered.

One of the more rapid methods tried for checking the spread or film thickness of the binder consists of a small wheel used to measure thicknesses of paint coatings (Fig. 4). However, due to the unevenness of the pavement surface, accurate measurements could not be obtained. Although this was partially overcome by placing a sheet of metal or cardboard on the pavement prior to the passage of the distributor, this method still proved to be unsatisfactory.

Using the same basic principle, a large wheel (about 6-in. diameter) was made by cutting the surface of a cone into the outside of a cylinder (Fig. 4). As the cylinder is rolled over the surface the depth of binder is indicated by the point on the cone which contacts the surface of the binder. This apparatus has the same fault as the preceding in that it gives an irregular reading on rough pavement surfaces.

Another variation involved the use of a short straightedge mounted on two handle bars so that one end of the straightedge is flush with the surface and the other a certain distance above the surface (Fig. 4). It is so calibrated that when placed flat on a surface the point at which the binder contacts the straightedge indicates the rate of spread. Erratic results were obtained due to irregularities in the pavement surface.

After many trials, the best solution seemed to be the use of a modified paper strip method for transverse spread measurements and the use of metal pans for the longitudinal spread. Although this operation is time consuming, it is the best found so far and it does provide quite accurate information. Therefore, this method is described in the following pages for possible adoption for field use. A detailed description and list of equipment required for performing this test is given in Appendix B.

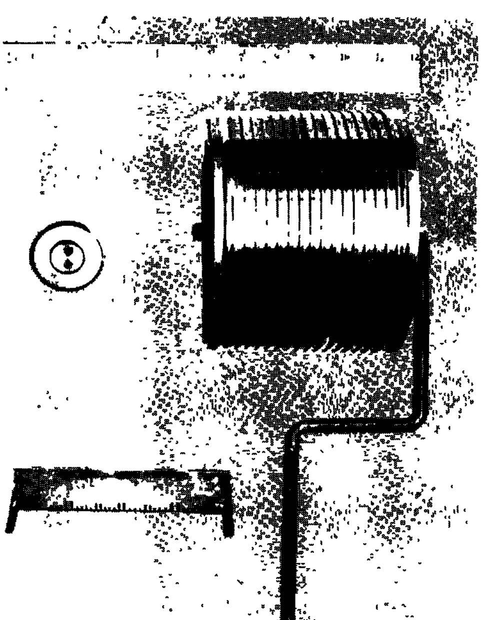

Figure 4. Gauges for measuring thickness of oil film.

The procedure as developed has been used on about a dozen seal coat contracts during the past two years. The tests are carried out during the normal operation of the distributor.

The transverse spread is determined from samples caught on 4- by 8-in. cotton pads (or 2- by 8-in. if greater accuracy is desired), glued to sheets of paper which in turn are attached to strips of sheet metal and placed transversely across the pavement (Figs. 5 and 6). The cotton fibers prevent the binder from flowing. The pads with the attached sheets of paper are removed after passage of the distributor and weighed to determine quantities.

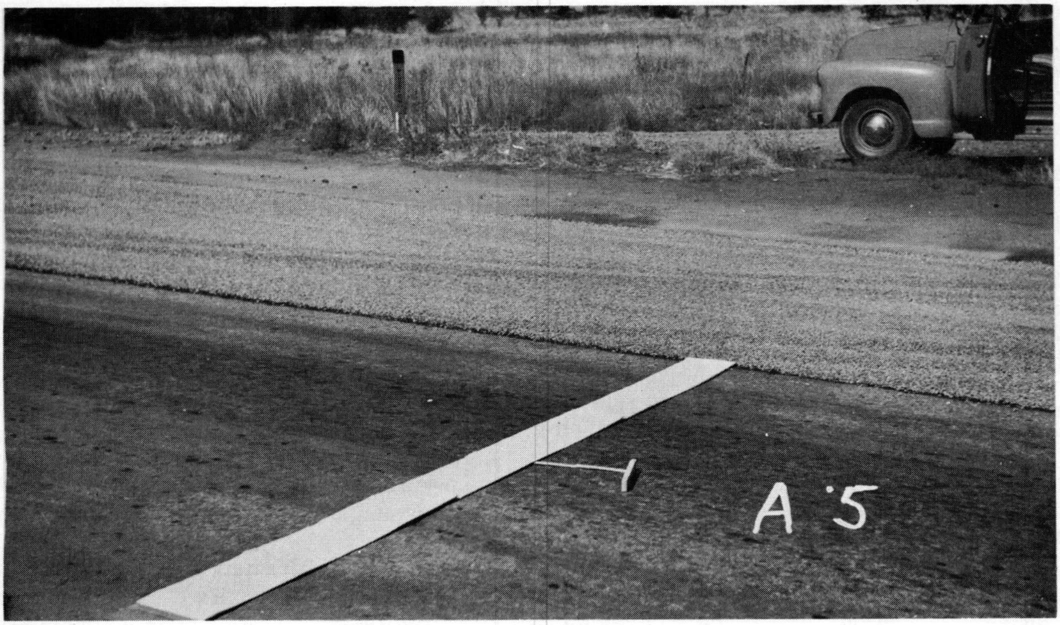

Figure 5. Transverse sample pads in position.

Figure 6. Distributor just before passing over sample pads.

Ordinary paper, it was found, would not work with the type of binder, especially asphalt emulsion that was used since the asphalt tends to spread or flow off the sample pad. The small cotton pads made especially for cleaning multigraph machines worked very well in retaining the binder (see Figs. 1 and 2). The pads cost about \$0. 018 each. Since 36 pads are required for a 12-ft width of pavement, the cost in pads for each sampling is \$0. 65. Considerable hand labor is involved in fastening the pads to the paper and sheet iron backing as well as in removing the samples and weighing them.

Longitudinal spread measurements are obtained by taking samples in 12- by 12-in. shallow metal pans (Fig. 3) placed at 100- to 150-ft intervals along the highway. They are lined with heavy wrapping paper and a ¼-in. lip around the edge of the pan helps to hold the paper liner in place and also prevents the collected binder from running out. Quantities are determined by weight.

The advantage of the paper strip method is that it can be performed in the field as often as deemed necessary with little interference during sealing operation. After the samples have been weighed they can be disposed of with a minimum of inconvenience.

The question of what is a permissible deviation is appropriate. This rests on two factors: (1) the best that can be expected from an average distributor operated by an average crew, and (2) the maximum deviation from the desired spread that can be permitted without danger of distress or failure in the finished product. Final answers to

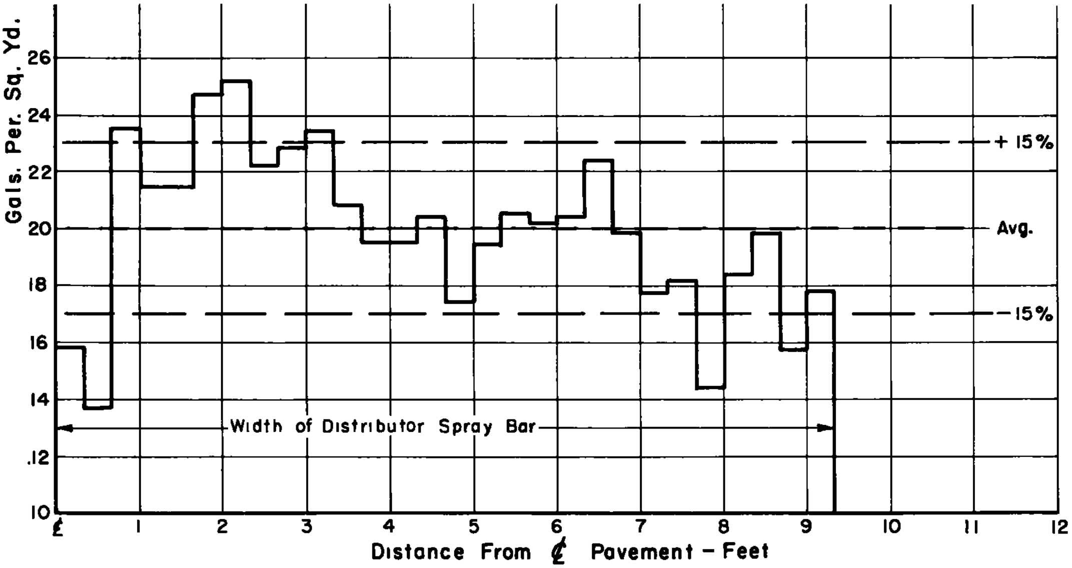

Figure 7. Transverse variation in spread rate of binder, Distributor A.

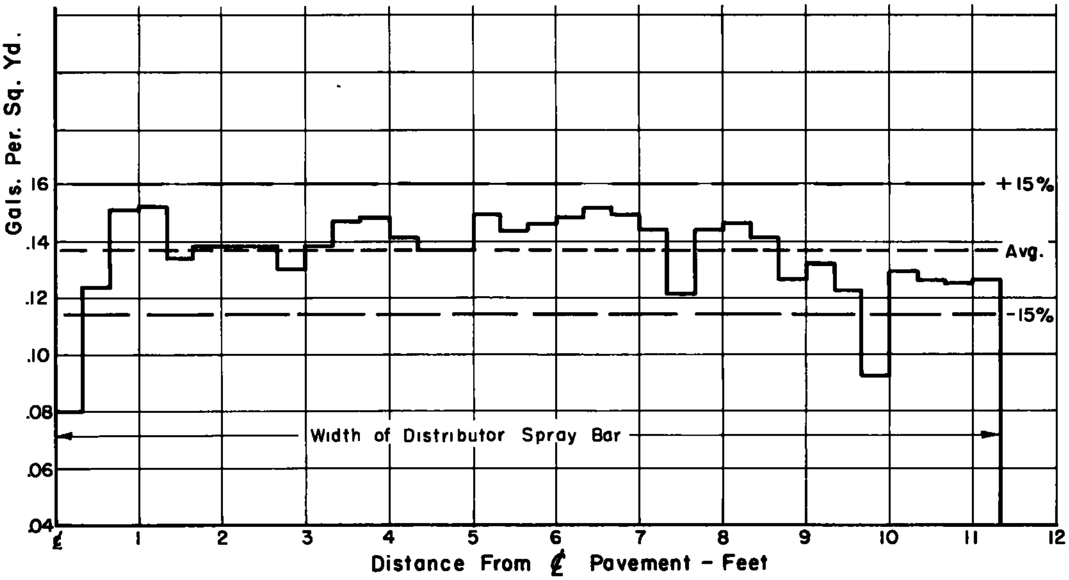

Figure 8. Transverse variation in spread rate of binder, Distributor B.

TABLE 1

SPREAD RATES FOR DISTRIBUTOR A

Pad No.	Data for Figure 7			Data for Figure 9			
				Variation			Cumulative Percent of Spread Width
	Total Weight of Pad, grams	Net Weight Bitumen, grams	Net Weight Bitumen, gal/sq yd	± from Average, gal/sq yd	Percent from Average	Percent Average Ascending Order	
1	21.7	14.8	0.158	0.040	20.2	0	0
2	19.7	12.8	0.137	0.051	25 8	0.5	3 7
3	29.0	22 1	0.235	0.037	18 7	2 2	7 4
4	27.0	20.1	0.215	0.017	8.6	2.2	11.1
5	27.0	20.1	0.215	0.017	8.6	2.2	14.8
6	30.0	23.1	0.247	0.049	24.8	2.5	18.5
7	30.5	23.6	0.252	0 054	27.2	3 0	22 2
8	27.7	20.8	0.222	0 024	12.1	3 0	25 9
9	28 2	21.3	0 228	0.030	15.1	3 5	29.6
10	27.7	21 8	0.234	0.036	18.2	5 1	33.3
11	26.3	19.4	0.208	0 010	5.1	7.6	37.0
12	25.0	18.1	0.194	0.004	2.2	8.1	40.7
13	25.0	18.1	0.194	0.004	2.2	8.6	44.4
14	26.0	19.1	0.204	0 006	3.0	8.6	48.1
15	23.3	16.4	0.175	0.023	11.6	9 6	51.8
16	24.9	18 0	0 193	0.005	2.5	10.6	55 5
17	26.1	19 2	0 205	0.007	3.5	11.6	59.2
18	25 8	18.9	0 202	0 004	2.2	12.1	62 9
19	25.9	19.0	0.204	0.006	3.0	13 1	66.6
20	27.9	21.0	0 224	0.026	13.1	15.1	70 3
21	25.4	18 5	0 198	0.000	0	18.2	74 0
22	23.4	16 5	0.177	0.021	10.6	18.7	77.7
23	24.0	17.1	0.182	0.016	8.1	20.2	81.4
24	20.4	13.5	0.144	0.054	27.3	24.8	85 1
25	24.0	17 1	0 183	0.015	7.6	25.8	88 8
26	25.5	18.6	0 199	0.001	0.5	25.8	92.5
27	20.6	13.7	0.147	0.051	25 8	27.2	96 2
28	23.6	16.7	0.179	0.019	9.6	27.3	100 0
29	10.8	3.9	0.042	These samples at the edge have been omitted.			
30	7 3	0.4	0.004				

Average spread rate 0.198 gal per sq yd

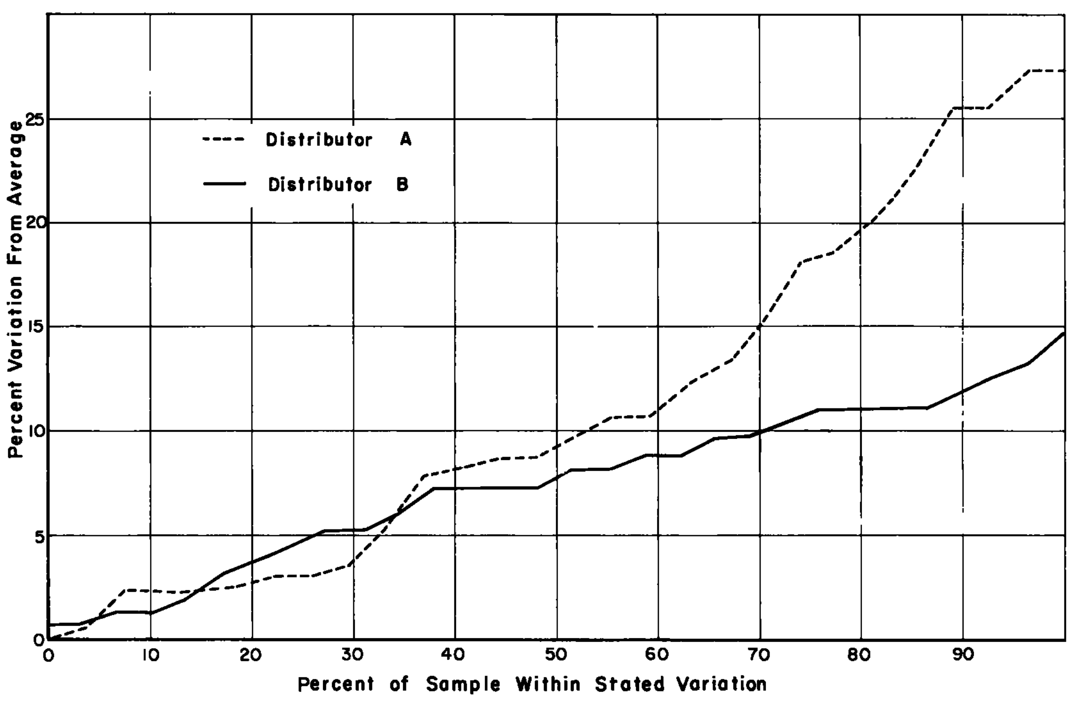

Figure 9. Variation in transverse spread rate from stated average.

these questions can be given only after study of many seal coat jobs. For example, the English recommended a maximum allowable variation of ± 15 percent from the average spread. Argentine engineers have reported that they control variation within 10 percent. For illustration purposes the transverse spread of two different distributors are shown in Figures 7 and 8. The spread rates, as shown in Figure 7, were taken from a distributor that had all the outward appearance of being in very poor condition, and an inspection of the curve will verify this fact. The distributor with a spread pattern as shown in Figure 8 was clean and in every way seemed to be in good operating condition and as will be noted in the curve only one sample other than at the edge of the pavement varied from the ± 15 percent of the average.

In order to compare variations in spread rates, these results have been recalculated on a percentage basis (see Table 1 for example) and plotted as shown in Figure 9. The curves provide a measure of the percentage of the samples that fall within a given limit, above or below the average. In plotting these curves it has been customary to calculate the average spread, after adding in the binder falling onto the feathered edge.

Attention was recently directed to a seal coat job which exhibited the appearance of rich, closely spaced, longitudinal ridges within a day or two after construction. Hot oil, grade SC-6 and fine screenings ¼ in. by No. 10 were used. Regular transverse spread tests using the 4-in. pads were made and in order to obtain a closer pattern of the actual spread the 4-in. pads were cut in half and thus made it possible to determine the spread rate for each 2-in. interval. The bituminous binder showed very little flowing on the pads and thus permitted the cutting of the paper strips. The values obtained are plotted in Figure 10. As can be seen from the chart there is considerable variation in the transverse spread. This spread pattern was then compared with the actual appearance on the road and it was noted that the majority of rich spots coincide very closely with the high spots on the graph. Instead of adhering to the binder, the screenings were completely submerged in the excess asphalt. Although the spread rate was excessive according to standards used, this irregular spread pattern presented a very unsightly appearance of the finished seal coat. Many of these rich streaks have to some extent been ironed out by traffic. A photograph, Figure 11, taken three months after construction still very clearly illustrates the uneven distribution pattern.

It is believed that the ± 15 percent variation from the average spread might be per-

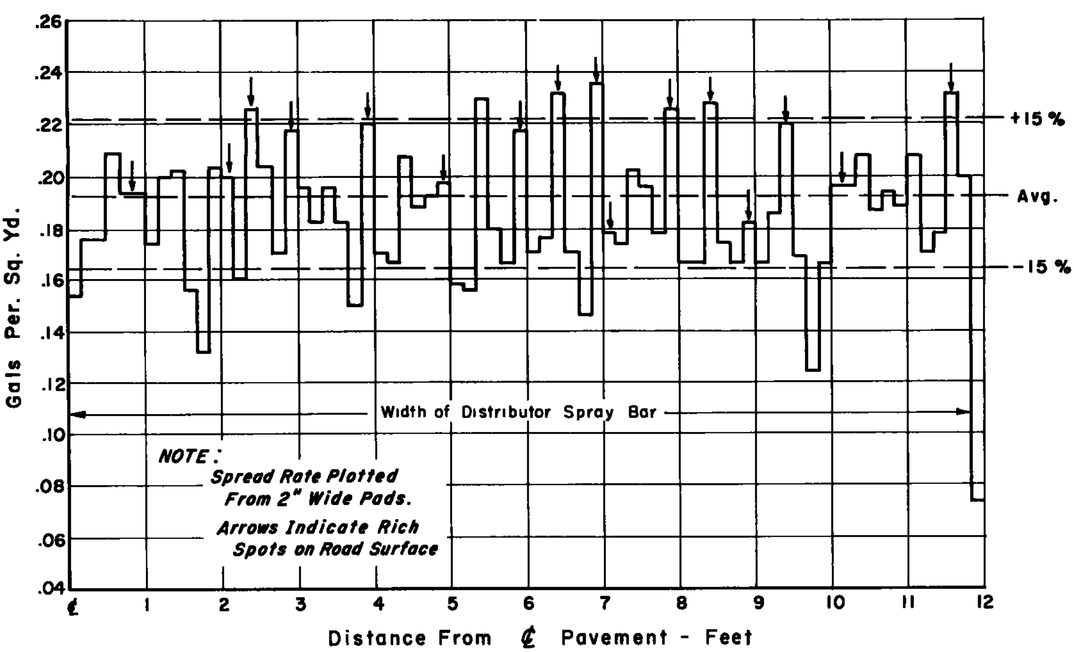

Figure 10. Transverse variation in spread rate of binder, Distributor C.

Figure 11. Appearance of seal coat three months after construction, Distributor C.

missible for asphaltic emulsion in the transverse pattern where the variations in depth of spread tend to even out by the flowing together of the binder. For paving asphalts or heavier grades of liquid asphalts which chill rapidly and assume the temperature of the pavement almost immediately, as shown later under temperature studies, the transverse variation should perhaps not exceed 10 percent from the average spread. In the longitudinal spread the limits should be more restrictive, possibly not over 10 percent for all types of binders since any variation of this nature would be more extensive and would tend to affect the over-all success of the seal coat.

If this method were adopted as a routine procedure, sampling of the transverse and longitudinal spread would require more personnel than is customarily assigned to seal coat jobs. Furthermore, there is some doubt as to whether the average construction engineer would have the patience to glue the little cotton pads in just the right places. Depending upon local conditions and policies it is thought that a trained laboratory crew equipped for making these tests should calibrate the distributor trucks.

What can be expected from the sampling of distributor spreads? The answer is: little or nothing unless the engineer takes the necessary steps to see that serious deviations are corrected, or if necessary, unsatisfactory asphalt distributors be barred from the job.

It might be mentioned that the mere presence of laboratory personnel checking the spread rates, seems to put the contractor as well as the engineer on the alert. Apparently, due to this "influence," an improvement in operation covering all phases of seal coat construction was noted on several jobs.

Temperature Studies During Seal Coat Operations

The general consensus of opinion of engineers dealing with seal coat construction is that the chips should be applied immediately or as soon as possible after the bituminous binder has been spread. This applies particularly to hot oil.

In order to study the rate of temperature change of the bituminous binder after application on the road, the variation on one job was determined by means of thermocouples glued to the pavement surface and connected to a micromax recorder powered by a storage battery (Fig. 12). Temperatures were taken as frequently as one minure intervals. The oil used was an RC-5 and applied at a temperature of 255 F. The screenings were slightly damp. The air temperature ranged between 90 and 100 F and the pavement temperature between 115 and 140 F.

An inspection of the data in Figure 13 and Table 2 indicates that the temperature of the bituminous binder after application drops almost immediately (within one minute) to the pavement surface temperature. The temperature of the binder is further lowered upon application of the screenings. This drop depends somewhat upon the temperature of the screenings themselves whether they are taken from the outside of the stockpile warmed by the sun, or from the damp and cool center of the pile. The temperature of the bituminous binder then will slowly increase until it nearly reaches the pavement temperature.

On the particular job studied the chip spreader consisted of a 12-ft Buckeye Spreader operated from the rear of the truck. Although considerable difference in time elapsed between application of the oil and the screenings, no adverse results were noted in this particular case. It should be noted, however, that the studies were made under ideal weather conditions and very good traffic control and it is quite possible that the results might have been quite different in case of adverse conditions. Today,

Figure 12. Micromax with thermocouples glued to pavement surface.

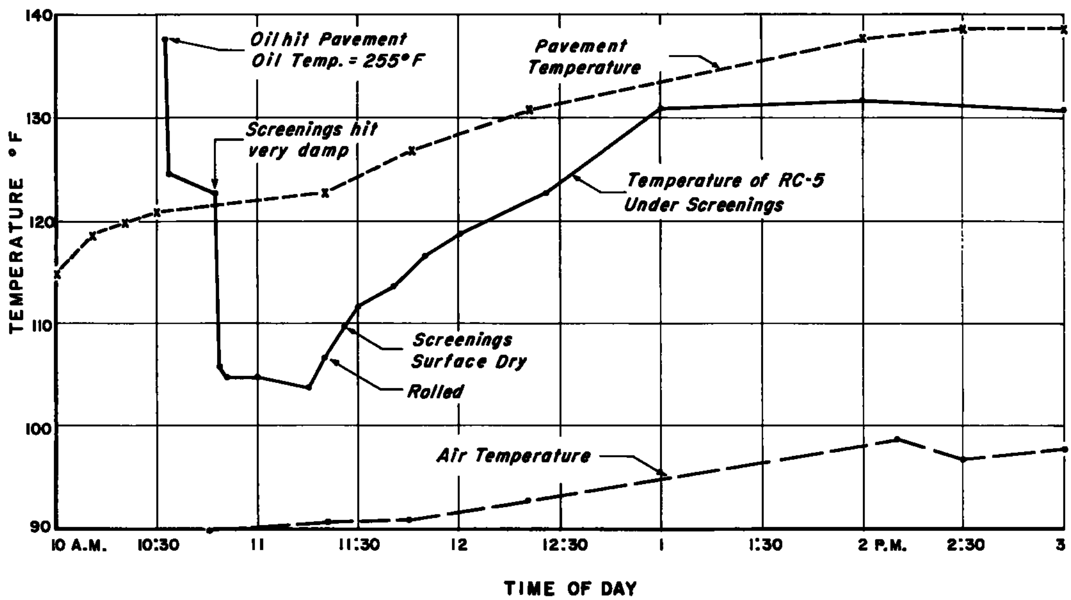

Figure 13. Temperature-time study for RC-5 binder; weather clear, hot, slight wind.

TABLE 2

SHOWING CHANGES IN TEMPERATURE OF RC-5 BINDER DURING SEAL COAT CONSTRUCTION

Time	Air Temperature	Original Pavement Temperature	Oil Temperature		Remarks
			In Distributor	On Pavement	
10:00		115			July 16, 1952 a. m. spread
10:10		119			
10:20		120			
10:30		121			
10:32			255	138	Oil hit surface
10:33				125	
10:34				124	
10:35				125	
10:45	90				
10:47				123	Screenings hit surface
10:48				106	
10:50				105	
11:00				105	
11:15				104	
11:20	91	123		107	Rolled
11:25				110	Surface appeared dry
11:30				112	
11:40				114	
11:45	91	127			
11:50				117	
12:00				119	
12:20	93	131			
12:26				123	
1:00				131	
2:00		138		132	
2 10	99				
2:30	97	139			
3:00	98	139		131	
4:00	98	135			

when most contractors in this state use the mechanical Spread-master the time interval between application of the bituminous binder and screenings can be reduced, by proper coordination, to less than one minute. However, if the Spread-master is operated too fast, as may be accomplished by the installation of special sprockets, the momentum imparted to the falling screenings will have a tendency to make them roll or turn over after hitting the binder covered surface instead of sticking immediately upon hitting the pavement. This tendency is greatest when particles strike on unbroken emulsion. The bituminous covered stone tends to adhere to vehicle tires and recently one bad failure was attributed to loss of screenings by this mechanism.

The studies would indicate that the change in temperature of the road surface after the application of screenings is of greater importance than the ambient temperature which is usually specified as a control. In other words, ideal conditions would be increasing temperature on cool days and decreasing temperature on extremely hot days.

This study would also suggest that equipment similar to the Spread-master, but equipped with heating units to warm the screenings and a blower to remove dust would greatly enhance the success of seal coat performance. This would be especially beneficial when the bituminous binder consists of paving grade asphalt or the more viscous liquid asphalts, and the seal coat is being placed under somewhat less than favorable weather conditions. Heated screenings were used on two or three small experimental jobs with excellent success (4).

Degradation of Screenings Due to Rolling and Traffic

There is no question that a certain amount of degradation of aggregates occurs under the roller and progresses with time due to traffic, but how much? Generally, the degradation shows some relationship to the hardness of the aggregate which is commonly measured by the Los Angeles Rattler or Deval Wet Shot Test, and most specifications contain maximum limits of loss under these tests. In some states or areas where a few types of aggregates predominate, this relationship might not be too difficult a matter to determine and papers showing satisfactory correlation have been published on this subject.

The California Division of Highways generally uses crushed aggregates having a good service record and are normally obtained from commercial sources. However, in taking advantage of local aggregates whenever possible, particularly in outlying areas, a wide variety of stone types ranging from lightweight volcanic cinders to crushed river gravel have been used. Trying to correlate the Los Angeles Rattler or Wet Shot Test results with the degree of degradation of these aggregates having decidedly varying surface and hardness characteristics, being placed under varying conditions of construction, degrees of rolling, and traffic, is not a simple matter. By recovering screenings from the pavement at various intervals of time an attempt has been made to establish some correlation.

The rate of chip spread on various jobs was determined by removing the screenings from 18- by 18-in. or 24- by 24-in. areas immediately after rolling but before the binder had set. A grading analysis was made on these samples and the surface area calculated.

It was found that the percent increase in surface area due to breakdown during rolling under actual field conditions was comparatively small on all jobs and did not amount to over 75 percent increase when compared to the surface area of the samples taken from the spreader box.

TABLE 3

DEGRADATION BY ROLLING AND TRAFFIC

Job No	No. of Test Sites	Type of Roller	L.A. Rattler, percent loss		Wet Shot Percent Loss	Rolling			Traffic					
						Average Surface Area sq ft/lb			Pavement Age Month	Screening Quantity				Percent Increase in S A by Traffic
										After Spread	After Traffic			
			100 Rev	500 Rev		Orig.	After Rolling	Percent Inc.		lb/sq yd	lb/sq yd	Percent Decrease	Decrease Minus Whipoff	
A	2	S	6.8	27.0	12.1	6.1	7.6	24	28	16.4	7 9	51	36	169
B	4	S	3.2	13.8	7 6	3.7	6 2	67	12	24.1	7 7	68	53	248
C	2	S	4.2	21.0	18.0	6.0	7.8	30	9	12.5	8.8	30	15	133
D	5	S & P	4 8	20.8	12 4	9.4	10.0	6	9	15.0	11 9	27	12	65
E	2	S & P	2 6	12.8	3.7	6.5	7 6	17	9	12.7	12 4	2	-	73
F	1	S	4.6	20.0	20.9	5.7	8 4	47	9	13.0	9 5	27	12	61
G	3	P	4 3	24.4	21.3	6.8	8.7	28						
H	3	P	5 0	21.2	13.6	7.1	10.1	42	9	17.0	10 0	41	26	91
I	4	P	5 8	23.6	11.1	9.1	8.8	-	9	14.2	7 8	45	30	148
J	2	P	4.2	21.8	10.6	5.6	9 8	75						
K	3	P	3 2	14.2	6.4	5.2	8 0	54						

S = Steel wheel roller, P = Pneumatic.

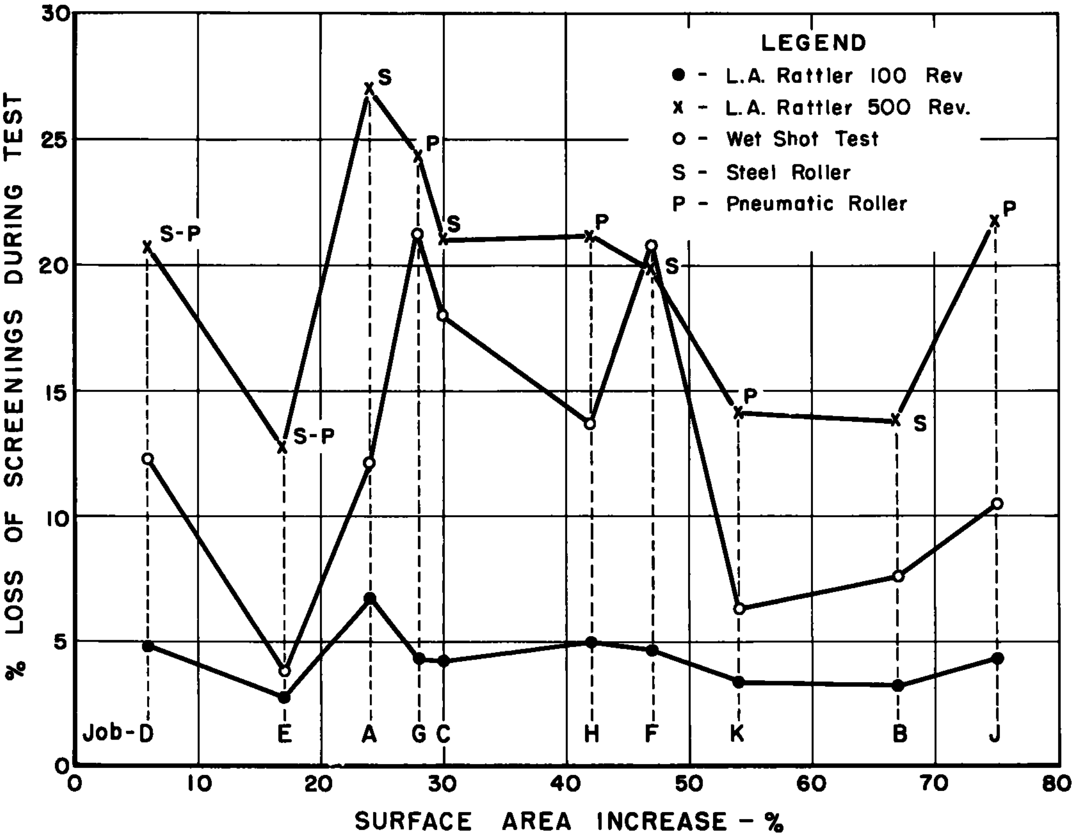

Figure 14. Comparison of hardness test versus degradation under rolling.

The Los Angeles Rattler and the Deval Wet Shot Tests were performed on aggregates from 11 different projects. The data and relationship between these tests and the breakdown or increase in surface area after rolling are shown in Table 3 and Figure 14. There is no apparent trend in either the results from the Los Angeles Rattler at 100 or 500 revolutions or the Wet Shot Test.

The results on the increase in surface area in relation to the Los Angeles Rattler Test are somewhat at variance as reported by others (5). It should be pointed out, however, that in this investigation the screenings as used, are considerably finer than are commonly reported from other states and the amount of rolling less, consisting of only two or three passes of a light steel or pneumatic type roller.

A heavier roller will break more particles during rolling and probably less subsequent degradation takes place under traffic; whereas, a light roller will degrade the aggregate less but with further breakdown occurring under traffic. The same applies to soft and hard particles.

To further study degradation under traffic, samples from the above jobs were removed after certain intervals. The total weight per square yard and surface area of the screenings remaining on the pavement were determined.

The results of the Los Angeles Rattler and Wet Shot Tests were compared with the decrease in quantity of screenings and the increase in surface area. The only apparent relationship was noted when the Rattler results at 100 and 500 revolutions were compared with the decrease in the quantity of screenings, as shown in Figure 15. The results indicate a rather marked change in degradation under traffic for small changes in Los Angeles Rattler test values and at levels far below those normally considered critical.

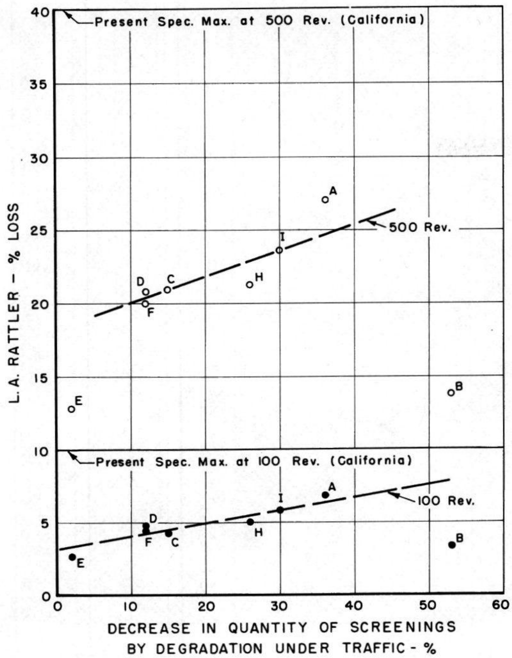

Figure 15. Degradation under traffic versus loss in Los Angeles Rattler.

Absorptiveness and Permeability of Bituminous Pavements

In order to calculate the optimum bitumen demand, some allowance has to be made for the surface characteristics of the existing pavement such as absorptiveness, permeability, and texture. The surface may be porous to such an extent as to absorb some of the binder, leaving an insufficient amount to bond the chips. This applies particularly to road mixed jobs which often use local, absorptive aggregates and as a result in many cases are under oiled. Empirical curves for this purpose are provided in "The Design of Seal Coats and Surface Treatments" (2). However, the field engineer must estimate the porosity of the existing surface by visual means and select the proper curve. The success of this type of examination depends on the experience of the observer and other factors which cannot be determined visually and may lead to an improper estimate of the degree of absorptiveness. Therefore, a simple field test method that will provide an average value for the absorption factors is needed for seal coat construction.

In attempts to provide simplified methods a number of ideas were tried. One method involved the use of a stack of filter papers placed on the pavement surface wetted with a light lubricating oil or kerosene. It was hoped that the number of soaked filter papers should be in inverse ratio to the absorptiveness of the pavement. However, nonuniform contact due to uneven pavement surface resulted in inconsistent values. Absorbent cotton, held down with a weight, showed some improvement, although high areas prevented securing good contact.

Various solvents and water, with and without a wetting agent, were spread on different types of pavement textures and the relative rates of absorption noted. It was observed that water containing a wetting agent was absorbed at a fairly fast rate by the pavement surface. Water was finally selected as the liquid for the test procedure to which was added 0.5 percent of a detergent.

The relatively high rates obtained on some of the pavement surfaces although indicating some degree of absorption, really are more a measure of the porosity or permeability of the pavement than true absorption of the surface layer. However, this seems to be a practical method which at least measures some of the factors involved and establishes the need for sealing the pavement. With this in mind, this procedure was used to evaluate the permeability of pavements.

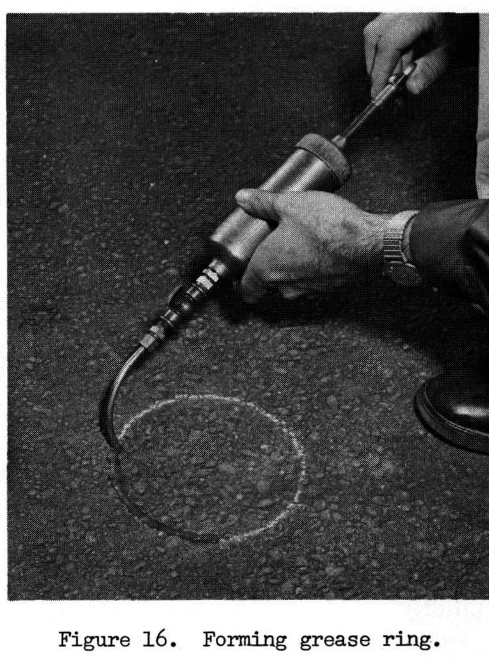

Figure 16. Forming grease ring.

In order to confine the liquid to a definite area on the pavement, a ring made by extruding a light grade of cup grease from a grease gun formed a very satisfactory dam or impermeable barrier.

A grease gun fitted with a short piece of ¼-in. copper tubing is used to spread the ring, about ⅛ in. high, following a previously drawn outline of a 6-in. diameter circle (Fig. 16).

Water containing 0.5 percent of a detergent, sold under the trade name "Vel," is poured within the grease ring from a known quantity of the liquid. (It is planned to substitute a definite chemical for the Vel.) As fast as the solution is absorbed by the pavement it is replaced (Fig. 17). The procedure has been to limit the period of absorption to 2 min.

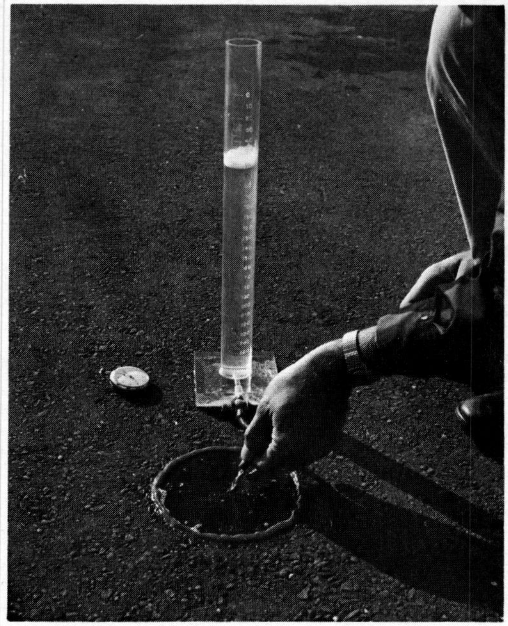

Figure 17. Applying water solution to pavement surface.

At the end of the period the amount of the solution in milliliters absorbed per minute is determined and used as a measure of the permeability of the existing surface. A detailed test procedure is given in Appendix C.

It should be pointed out that some of the relatively high porosities obtained on pavements do not necessarily indicate that rain water will percolate at such a rate. Once the interconnected void spaces in a mix are filled with water, a relatively slow rate of further percolation is established. This is borne out by the fact that some pavements, although possessing a relatively high rate of porosity, did not exhibit an unusually high moisture content in the well-compacted base material.

Although this test is used to determine whether or not a pavement is porous and will benefit by a seal coat, a scale of allowable permeability values has not yet been established. The readings obtained are relative and further field work is necessary.

Other adaptions of this test have been made in exploring pavement failures by adding a small amount of water soluble dye and tracing cracks in surface courses or cement treated bases.

A limited number of trials also indicate that this test procedure might be suitable for determining the degree of compaction obtained on newly placed bituminous surfaces. The amount of solution permeating is some indication of the voids or density of the mix.

Rate of Curing of Bituminous Binder

The retention of screenings by the bituminous binder immediately after placing or within a few hours thereafter depends to a large extent upon the "setting up" qualities of the bituminous binder. There seems to be no question that screenings from different sources or different types or grades of binder react differently under identical curing conditions.

A test procedure developed in the laboratory and used for the last 15 years makes it possible to determine the rates of setting of the bituminous binder under controlled conditions by mixing the binder with Ottawa sand and measuring the extrusion rate on the so-called Cohesiograph (6). This method, however, is not applicable to field use and it was felt that a more rapid means should be provided the engineer so he can be reasonably sure that the binder has set sufficiently to resist whipoff by traffic.

In the field the rate of setting is influenced by the types of aggregate used, relative humidity, amount of sunshine, wind velocity, and the pavement temperatures.

Some indications of the rate of setting or drying can be provided by use of the

Livingston Atmometers (7), which have been employed in the field at various times for the past 20 years (Fig. 18). A porous porcelain bulb evaporates water at a given rate depending upon the combined drying effects of air temperature, wind and relative humidity. Good drying weather shows an evaporation rate of roughly 10 ml or more per hour; whereas, during cloudy or overcast days and nights this evaporation rate usually drops to zero. However, the bulbs are sensitive to dust and dirt and cleaning very often changes their evaporation rate. A number of attempts have been made to construct self-recording evaporation devices (Fig. 18) using this principle but an instrument sufficiently free from trouble to make it practicable for field use has not as yet been developed.

Such an evaporation measuring device, although no assurance against possible whip-off by fast uncontrolled traffic, at least does indicate very positively to the resident engineer whether or not he has good drying weather. This device, of course, is most useful when asphaltic emulsion is used as the bituminous binder. Hot oil or asphalt may not "set up" in the summertime under ideal drying conditions due to extremely high ambient and comparatively high night temperatures.

For some time experimentation has been made, as time permits, with a method for testing adherence of chips by means of a small hand-operated centrifuge. In this test, specimens of seal coat were prepared and spread on the lids of gallon paint cans which, after the desired period of curing, were centrifuged at 7.4 x G with the plane of the specimen at right angles to the direction of force. This test, although showing definite differences between a short and long cure, was entirely too severe and test results could not be correlated with actual field conditions. In the present studies the method was reconsidered and tests were made with 6- by 6-in. square plates placed at an angle of 15 percent with the horizontal (Fig. 19). In this way the keying effect of the particles or rock is tested as well as the bond, also different portions of the plate are subjected to a varying amount of centrifugal force. The inner edge of the plate nearest the cen-

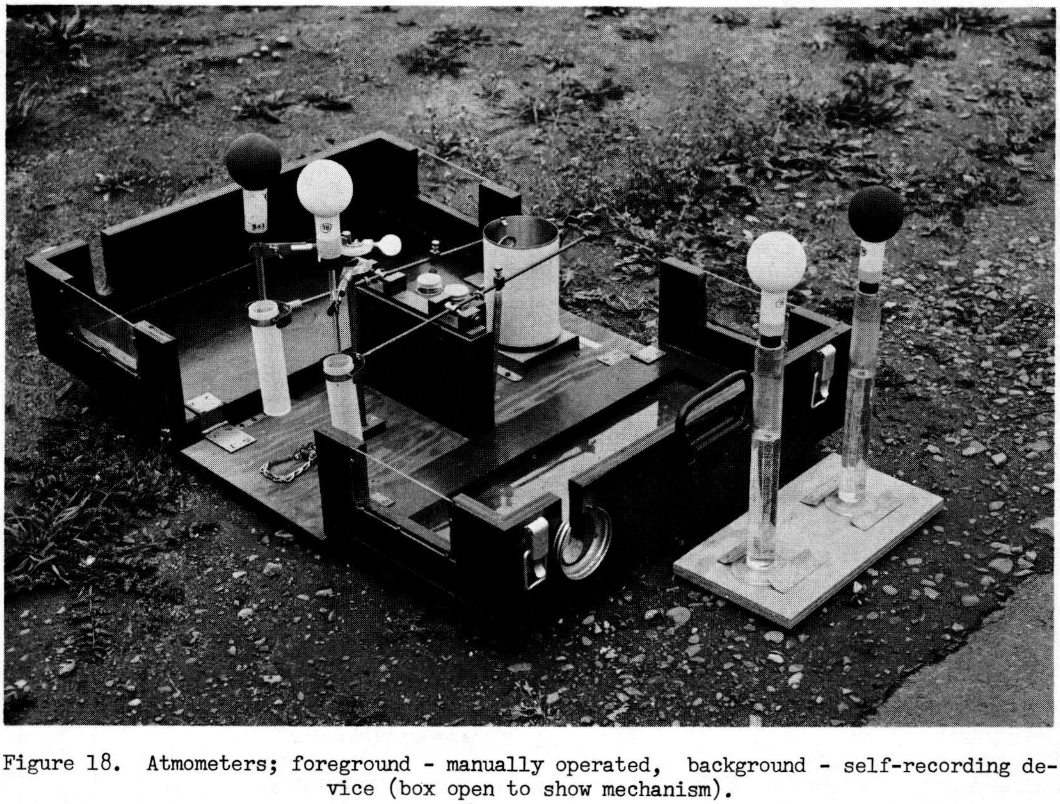

Figure 18. Atmometers; foreground - manually operated, background - self-recording device (box open to show mechanism).

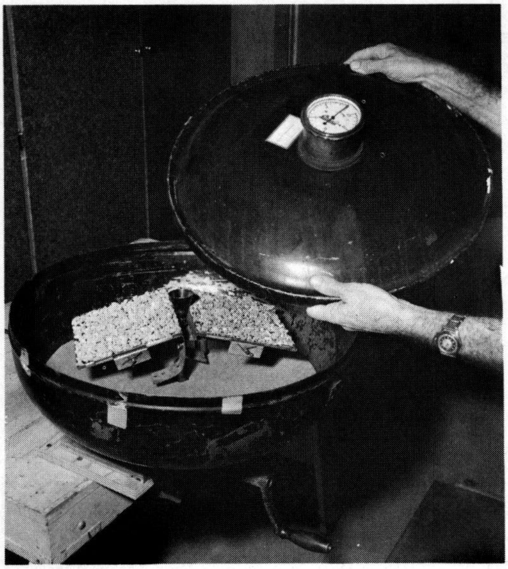

Figure 19. Hand operated centrifuge to determine adherence of screenings.

TABLE 4

Screening Source	79 F Dry RH 46 Percent		Remarks
	Moisture Lost in Emulsion, percent	Screenings Retained, percent	
A	29	90	Soft, absorbent. Failed in L. A. Rattler Test.
B	40	81	
C	35	27	
D	31	18	
E	33	10	Mostly quartz. Failed in stripping test.

ter of rotation is subjected to about 2 x G and the outer edge to about 12 x G. The specimens are centrifuged for one minute.

It is believed that this test might be used in the field to determine the time at which the seal coat may be opened to traffic. Plates or asphalt sheeting (simulating a roadway surface) can be placed directly on the pavement during sealing operations and be tested at certain intervals directly on the job site. However, some allowance will be necessary to correct for the amount and speed of traffic as well as for superelevation and grades where whipoff is usually most severe.

Some of the data obtained with the centrifuge have been quite interesting. In testing various kinds of screenings it was found that under identical curing conditions and using the same asphalt emulsion the percentage of screenings retained varied considerably as shown in Table 4.

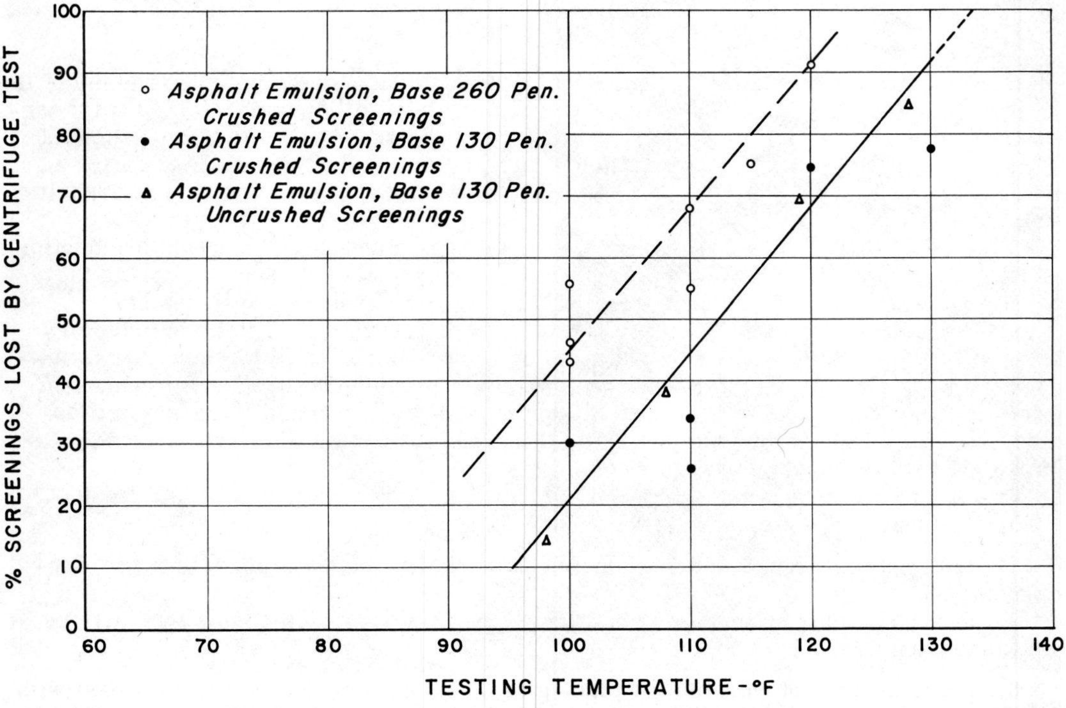

Figure 20. Effect of test temperature on screenings loss.

In seal coat work the general policy in California is to use as soft a binder as possible. Some difficulty has been encountered occasionally with "setting up" of the binder during the summertime where high daytime temperatures coupled with comparatively high nighttime temperatures prevail. To overcome this problem it is necessary at times to revert to a somewhat heavier base stock. A few tests made with the centrifuge on an asphaltic emulsion with a base stock of 130 and 260 penetration asphalt indicate that the degree of whipoff appears to be related to the penetration of the base stock (see Fig. 20).

The test also appears to correlate with the rate of break of the asphaltic emulsion or, in other words, the amount of water retained by the emulsion. Figure 21 illustrates a fairly constant relation between the percentage of screenings retained and the percent of moisture remaining in the emulsion.

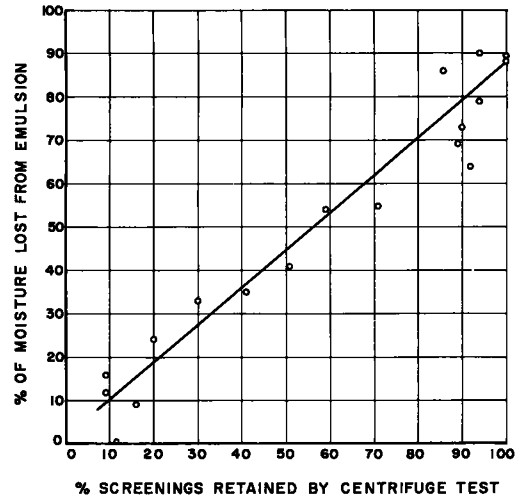

Figure 21. Relation of percent moisture in emulsion to retention of screenings.

Studies made so far indicate that this method has some promise, at least for laboratory work, to test the adhesiveness of different types of screenings or the bituminous binder with or without admixtures such as rubber or anti-stripping agents employing various curing temperatures, effect of moisture, humidity, etc.

These studies are to be continued and it is hoped that a procedure will be developed which will, when correlated with field performance, provide an answer for the engineer on one of the most difficult problems; namely, when is it safe to open the seal coat to traffic?

Seasonal Effects on Performance of Seal Coats

Even with the introduction of better tools and methods and the solving of many of the present problems there still remains the weather as the major variable and least controllable factor affecting the success or failure of the seal coat. However, some of the potential failures can be avoided by prohibiting the placing of seal coats after a certain calendar date. This is particularly true when the binder consists of asphaltic emulsion.

Most seal coat work in California is now performed under contract and every effort is made to award the contracts early so that the work can be performed during the summer season and thus minimize the detrimental effects of cold fall weather.

Although the daytime temperatures in the fall may still appear to be satisfactory for good sealing, the night and early morning temperatures are low, humidity is increased and an occasional shower, particularly at the higher altitudes all represent conditions not conducive to good seal coat performance. A chart, Figure 22, illustrates a definite trend towards possible failure of seal coats as the fall season approaches with its variable weather conditions.

Based on California weather conditions, the following tentative schedule for the placing of seal coats has been established:

1. Seal coat construction using emulsified asphalts should be terminated by September 1st.
2. Seal coat construction using cutback asphalts of the rapid curing type may be extended until October 15th.

If conditions are unfavorable for placing of a seal coat such as along the coast with its summer fog or on the Redwood Highway along the northwest coast where much of the pavement is shaded by the big Redwood trees, an open-graded, hot, plant-mix seal of about ½-in. thickness is recommended. This open-graded seal, of course, does not "seal" the underlying pavement against the entrance of surface water and therefore some judgment on its application should be exercised. Many miles of this plant-mixed open-graded mix have been placed in northern California with excellent success. The cost is somewhat higher than ordinary seal coat work but may well compensate by reducing the chance of failure.

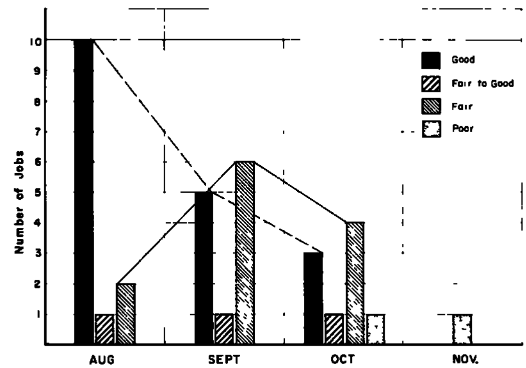

Figure 22. Seal coat studies; final condition of seal coats compared with construction dates.

SUMMARY

The subjects discussed in this paper may be summarized as follows:

1. A method for determining the uniformity of transverse and longitudinal spread rates of bituminous distributors is presented. Although not considered the ideal solution, it is the best available field method developed to date which will provide accurate information. A variation in transverse spread of ± 10 to ± 15 percent of the average rate can be tolerated. The longitudinal spread variation should not exceed ± 10 percent.
2. Hot road oil or asphalt, after spreading, will assume the temperature of the pavement almost instantaneously. Its temperature will further be influenced by the temperature of the screenings. At the time of seal coating and shortly thereafter, the surface temperature of the pavement seems to be of greater importance than minimum ambient temperatures which are generally specified.
3. Degradation studies on screenings made following rolling did not show any correlation between increase in surface area and loss in the Los Angeles Rattler or Wet Shot Test. The study was made on eleven jobs picked at random under varying field conditions and employing miscellaneous rolling equipment. The degradation occurring under traffic showed some relationship to the Los Angeles Rattler Test.
4. A rapid field test, employing water to which a detergent is added for determining the relative permeability of pavements, is described.
5. A centrifugal test method for field use to determine the adherence of screenings is discussed. Coupled with proper traffic control, it should provide the engineer with the answer as to when it is safe to open a newly placed seal coat to traffic.
6. Besides the subjects discussed, the weather is one of the most important but the least controllable factor. In order to minimize seal coat failures due to weather conditions, no seal coat work should be performed after a certain calendar date.

ACKNOWLEDGMENTS

The work described herein was performed under the general direction of F. N. Hveem, Materials and Research Engineer, California Division of Highways, who over the years has shown a keen interest in improving tests and methods which will assure better seal coats.

Acknowledgment is made to John Skog for his many contributions and assistance. G. R. Kemp participated in collecting some of the field data. The writer wishes to especially acknowledge the work of R. M. Hammond for developing some of the mechanical devices and working out the details of the laboratory and field methods discussed.

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Appendix A

OUTLINE OF LABORATORY AND FIELD STUDIES RELATED TO SEAL COAT CONSTRUCTION

I. Laboratory Investigations.
   A. Develop method for measuring shapes of screenings and their effect on retention and skid resistance.
   B. Develop method for measuring rate of polish and wear of screenings and their effect on skid resistance.
   C. Studies and measurements of the rate of cure of bituminous binders used in seal coats and the effect on screening retention.
   D. Development of better test methods for measuring the effect of water on seal coat durability.
   E. Develop method for measuring absorptive capacities of old pavements.
   F. Devise and test new binder compositions to obtain an adhesive having the following desirable properties:
      1. Uniform spreading qualities at average temperatures.
      2. Rapid set after application of screenings under unfavorable climatic conditions.
      3. Low temperature susceptibility and good durability of binder in terms of hardening rate.

II. Field Studies
   A. Investigations just prior to seal coat operations on original surface to be sealed.
      1. Permeability and absorptiveness studies.
      2. Surface roughness studies for possible increase of spread rate of bituminous binder.
      3. Skid resistance studies.
   B. Investigations during seal coat operations.
      1. Distributor spread rate accuracy and uniformity by various methods.
      2. Screenings spread accuracy and uniformity by various methods.
      3. Study of effect of time intervals between bitumen and screenings application and rolling.
      4. Degradation studies. Selection of short test sites where rolling will be increased in definite steps, using steel and pneumatic rollers and combination of both, followed by removal of screenings for analysis.
      5. Temperature studies involving pavement surface, air temperature, chilling of bitumen, screenings temperature and relationship between these variables. Effects of warm night temperatures on screening retention.

6. Rate of set of bituminous binder, especially asphalt emulsion in relation to weather condition. Determine drying or setting up condition by use of atmometer or automatic recording units.

C. Investigations following seal coat operations.
   1. Immediate.
      a. Condition of seal coat during curing period. Changes in consistency of binder during curing stages and its relation to screenings loss. Effect of temperature and evaporation conditions on such curing rates.
      b. Initial determination of skid resistance following final curing stage and completion of whipoff.
   2. Long range.
      a. Periodic condition survey including skid resistance studies and development of wear and polish tests under traffic. Effects of water. Appearance of seal coat due to possible maldistribution of asphaltic binder.
      b. Rate of hardening of bitumen.

Appendix B

TENTATIVE METHOD OF FIELD TEST FOR THE DETERMINATION OF DISTRIBUTOR SPREAD RATE

Scope

This description covers the procedure for determining the transverse and longitudinal spread rate in gallons per square yard of bituminous distributors by weighing small samples which are caught on uniformly sized paper strips.

Procedure

Part I. Transverse Spread Rate Determination.

A. Apparatus.
   1. Balance sensitive to 0.1 g.

B. Materials.
   1. Cotton pads 4- by 8-in. These pads are especially made for use in cleaning multigraph machines and have clean sharp edges. They are currently purchased from Bauer and Black Company, San Jose, California, under part number 200-847.
   2. 5- by 10-in. sheets cut from heavy wrapping paper.
   3. 8- by 60-in. plates cut from 20 gauge galvanized iron sheets.
   4. Masking tape, ½-in. width.
   5. Suitable adhesive for fastening cotton pads to paper. Latex, rubber cement, or asphalt emulsion have been used.

C. Preparation of test panels.
   1. First method.
      a. Cotton pads are attached to the paper strips with the adhesive leaving a 1-in. margin on three sides, see Figure 1.
      b. The paper strips, with cotton pads attached, are then fastened to the metal plates by folding the ends over the plate and attaching with masking tape. Each strip overlaps the exposed paper on the previous strip, see Figure 1.
   2. Second method.
      a. Paper strips (without cotton pads) are attached to the metal plates, each sheet overlapping the adjacent sheet 1 in.
      b. After all paper strips are attached to the metal plates the top surface is coated uniformly with the adhesive. The cotton pads are then placed on the paper so that each pad covers exactly the exposed 4- by 8-in. paper surface. Figure 2 shows

the paper strips on the metal plate and part of the cotton pads in place.

3. Several of the pads with the paper backing should be weighed after they are thoroughly dry, to determine the average tare weight.

D. Sampling.

1. Just before the distributor passes, the test panels are placed across the lane to be sealed, see Figure 5. Figure 6 shows the distributor spray bar just prior to passing over the test panels.
2. As soon as the distributor has passed, the test panels shall be removed from the pavement and the paper and cotton pads removed from the metal backing. As each pad is removed it should be folded so as to cover the binder and prevent loss of volatiles before the sample has been weighed.
3. Weigh each sample pad to the nearest 0.1 g.

E. Calculations.

1. Subtract the average tare weight from the gross weight of each pad and multiply the results by 0.0107 to obtain the spread rate in gallons per square yard.
2. Determine the average spread rate in gallons per square yard by dividing the total quantity of binder collected on the pads by the number of pads.

F. Precautions.

1. Traffic should not be allowed to drive over the test panels. The relatively slow moving distributor truck does not usually disturb the panels.
2. In a very hot climate the work of removing and weighing the sample pads should be done in the shade and with as little delay as possible. If much delay occurs a control sample should be prepared with a known weight of binder and weighed at intervals to determine the evaporation loss rate and a correction made.

G. Reporting of results.

1. The uniformity of transverse distribution is determined by plotting the quantity of binder on each pad against the transverse distance of the pad from the inner edge of distributor spread. The average spread rate and the variation value of ± 15 percent from the average shall also be drawn on the chart.

Part II. Longitudinal Spread Rate Determination.

A. Apparatus.

1. Balance sensitive to 0.1 g.

B. Materials.

1. Square pans 12- by 12-in. with a ¼-in. lip (see Fig. 3).
2. Heavy wrapping paper for liners. Pans may be used without liners but time is saved if they are lined with paper. The paper may be held in place with masking tape.

C. Sampling.

1. Determine tare weight of pans to ± 0.1 g.
2. Place pans approximately 100 ft apart and equidistant from the centerline or edge of the pavement.
3. After the distributor has spread the binder, remove pans and immediately weigh to ± 0.1 g.

D. Calculations.

1. Subtract the tare weight of the pans from the gross weight and multiply the results by 0.00238 to obtain the spread rate in gallons per square yard.
2. Calculate the average and determine the variation from the average for each pan.

E. Precautions.

1. Care should be taken to place all of the pans an equal distance from

either the centerline or edge of the pavement in order that the same jets of the distributor will pass over all the pans.

2. The pans should be placed so that the distributor tires do not pass over them.

F. Reporting of results.

1. Record the average longitudinal spread rate in gallons per square yard and the variation from the average for each individual pan used in the test. The variation from the average shall not exceed ± 10 percent for any one pan.

Appendix C

TENTATIVE METHOD OF TEST FOR MEASURING THE PERMEABILITY OF BITUMINOUS PAVEMENTS

Scope

This method is intended to serve as a rapid field test to determine the relative permeability of bituminous pavements.

Procedure

A. Apparatus

1. Screw type grease gun with regular tip replaced by a valve and a short piece of curved ¼-in. copper tubing.
2. Plastic graduated cylinder. Any cylinder with a capacity from 250 to 500 milliliters is suitable. The cylinder is fitted at the base with a valve from which extends a piece of tubing, 8-in. long and ¼-in. diameter.
3. One standard 250 ml graduated cylinder (glass or plastic) for refill purposes.
4. Template for making a 6-in. diameter circle and yellow marking crayon.
5. Suitable container for holding the "Vel" solution.
6. Stop watch.

B. Materials

1. Medium weight chasis grease.
2. Detergent which is sold under the trade name of "Vel." (It is planned to substitute a definite chemical for the Vel.)
3. Supply of distilled water.

C. Preparation of Test Solution

1. Prepare test solution by mixing 5 g of Vel powder per liter of distilled water.

D. Test Procedure

1. With the crayon and template, draw a 6-in. diameter circle on the pavement to be tested.
2. Extrude grease from the grease gun on the circle. The diameter of the grease on the ring should be about ¼ in. (Fig. 16).
3. Run the finger around the outside edge of the grease ring, pushing a small amount of grease into the pavement. This will form a sealed reservoir for the testing solution.
4. Fill special plastic graduated cylinder and regular graduated cylinder with the Vel solution.
5. Start stop watch and run solution from the plastic graduated cylinder onto the area within the grease ring, keeping this area covered constantly with the solution for two minutes. Refill plastic cylinder if necessary (Fig. 17). Note: At the end of the test the pavement in the grease ring should have an unflooded wet appearance.
6. At the end of the two minute test period, determine the total amount of solution used.

E. Calculations

1. Divide the total quantity of solution used during the test period by two and record the relative permeability in milliliters per minute.

F. Precautions

1. The test should not be performed when the air temperature is below 55 F because of the possible marked increase in viscosity of the Vel solution at lower temperatures.

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