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D. M. BEACH, *Editor*

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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THE PROPERTIES OF THE RESIDUES OF 50–60 AND 85–100 PENETRATION ASPHALTS FROM OVEN TESTS AND EXPOSURE[1]

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by **R. H. LEWIS**, Chemist, and **J. Y. WELBORN**, Assistant Highway Engineer

In recent years the value of the standard oven heat test for the prediction of the probable hardening of asphalts in the mixing and laying operations and under service conditions has been seriously questioned.

Many investigators have resorted to oxidation tests to study the hardening and weathering properties of asphalts. Specifications are now in use that limit the loss in penetration and ductility that an asphalt can undergo either in a laboratory mixing test or in a plant-prepared hot-mix surfacing sampled immediately after laying.

This report presents the results of tests on 50–60 and 85–100 penetration asphalts made on the residues from the standard oven test as well as on the residue from 50-gram samples exposed to the same conditions in films approximately 1/8 inch thick. Changes in the properties of 85–100 penetration asphalts after exposure in 1/8-inch films for 15 weeks during the hot summer months are also shown.

Although the residues from the standard oven test are not greatly altered, the residues from the 1/8-inch film oven tests, especially in the case of some 50–60 asphalts, are highly altered. Results of tests on the residues of 50–60 asphalts from the thin-film oven tests, when compared with the results of tests on bitumens extracted from both laboratory-prepared mixtures and from mixtures from commercial paving plants, indicate that the 1/8-inch film oven test produces alterations in the asphalts similar to the changes in properties that occur during the mixing process. It is believed, therefore, that a thin-film oven heat test may prove of value in predicting the probable behavior of asphalts under processing and service conditions.

THIS REPORT describes a continuation of studies previously reported, (*11*)[2] together with the results of tests on other asphalts before and after their incorporation in hot paving mixtures prepared in laboratory and plant mixers.

Since the early days of the asphalt paving industry some form of laboratory heat test has been used in specifications for asphalt cements to indicate the probable hardening of the asphaltic binder when subjected to high temperatures and to exposure in service. In 1897 Allen W. Dow enumerated essential characteristics that asphalts should have to insure satisfactory pavements. Among the many desirable properties, he included stability when exposed to high temperatures for appreciable periods of time. Although at that time there were no standard tests for asphalt cements, Dow suggested the following methods for determining the stability of asphalts at high temperatures.

Method 1.—Weigh 20 grams of asphalt into a 2-ounce glass retort and place this in an air bath at a temperature of 400° F. for 30 hours. Determine the loss of weight and measure the consistency of the residue with a penetrometer.

Based on this method, the specifications of the District of Columbia for 50 to 120 penetration asphalts required that the loss of heating should be not more than 8 percent and that the percentage of original penetration retained should be not less than 75. The relatively high loss permitted was, no doubt, due to the use of fluxing oils in the preparation of asphalt cements from hard native asphalts.

Method 2.—Mix the asphalt and sand, in the proportions to be used, at a temperature of 300° F. Divide the finished mix into two parts. Allow one part to cool to room temperature, and hold the other part at 300° F. for 30 minutes and then allow it to cool. Extract the asphalt from the two mixtures with carbon disulfide and recover the asphalt by distilling to a maximum temperature at 300° F. Determine the hardening of the asphalt by comparing the penetrations of the two recovered residues.

Although there is no record of this method having been used in specification requirements, it is of interest because so many present-day investigators have resorted to similar types of tests to study the behavior of asphalts in the processing of hot-mix pavements.

VALUE OF STANDARD LOSS ON HEATING TEST QUESTIONED

Before 1911 many different methods were used to determine the loss on heating and the drop in penetration. Temperatures, time of heating, size of containers, and methods of heating varied considerably. In 1911 the American Society for Testing Materials issued a provisional method for the determination of the loss on heating of oil and asphaltic compounds, in which a 20-gram sample was placed in a flat-bottomed tin 6 centimeters in diameter and 2 centimeters deep, and heated for 5 hours at 163° C. (325° F.).

In 1916 the loss on heating test was made A. S. T. M. Standard Test Method D6–16. The size of the sample tested was increased to 50 grams, and the 3-ounce tin in use today was specified. The oven temperature and time of heating were unchanged, being respectively 163° C. (325° F.) and 5 hours. Although there have been refinements in the testing oven from time to time, the basic conditions of the test method (D6–16) have not been altered. The present A. S. T. M. designation for this test is D6–39T.

In recent years the value of the standard oven test for predicting the probable hardening of asphalts in the mixing and laying operations and under service conditions has been seriously questioned. Victor Nicholson (*14*) has stated that use of the 50-gram sample does not give as sharp a differentiation in the hardening properties of asphalts as the 20-gram sample did. He has also stated that the properties of asphalts recovered from pavements cannot be correlated with the test for loss on heating and that the test is retained in the specifications of the City of Chicago merely to check the

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[1] Paper presented at the meeting of the Association of Asphalt Paving Technologists, Dallas, Texas, December 9–13, 1940.

[2] Italic figures in parentheses refer to bibliography, p. 46.

hardening action of heat on the asphalt in the storage kettle at the paving plant.

Raschig and Doyle (*17*) concluded, after examination of the extracted bitumens from paving mixtures immediately after mixing and after various periods of service, that an asphalt that showed an excessive drop in penetration after the standard loss on heating test would probably have an unsatisfactory service record.

In the previous report (*11*) it was noted that all the asphalts of both the 50–60 and 85–100 grades had lower percentages of loss in the standard oven test and retained greater percentages of their original penetration than were required by the most stringent specification. The range in the percentage of loss on heating and the drop in penetration was too narrow to evaluate adequately the probable hardening properties of the various asphalts.

The inability of the present test for loss on heating to furnish adequate indications of the hardening of asphalts in the mixing operation and in service has led to numerous investigations of this problem by laboratory mixing methods, oxidation tests, and the study of mixtures freshly laid and after service in the pavement. An excellent bibliography on the behavior of asphalts during the processing of mixtures and in service is appended to a report by J. R. Benson (*3*). The work of F. C. Lang and T. W. Thomas (*6*), C. L. Shattuck (*19*), and the reports by H. A. Juhlin (*5*), E. B. Tucker (*21*), R. Vokac (*22*), J. G. Schaub and W. K. Parr (*18*) are additional evidence of the interest in this particular subject.

Steinbaugh and Brown (*20*), in enumerating the major causes for the cracking of asphalt pavements, concluded that the failure of surfaces because of excessive oxidation or "loss of life" of the asphaltic binder was difficult to control or to predict. They added that the changes in the asphalt residue from the oven heating test may approach the changes that take place during mixing and laying; but they doubted whether the oxidation of the mass of asphalt in the test sample is similar to that occurring in a paving mixture, with the asphalt in the film stage. For this reason, they concluded that it must be demonstrated that an oven heat test can give significant results.

RESIDUES FROM STANDARD AND THIN-FILM OVEN TESTS COMPARED

The information obtained from the standard oven test has been limited to loss of volatile matter and drop in penetration. This study was undertaken to determine if a better evaluation of the relative durability of asphalts might be made with other tests on the residues from the standard oven test or on the residues from an oven test so modified as to accelerate the changes that occur.

The study was made with the same asphalt cements of the 50–60 and 85–100 penetration grades that were included in the previous investigation (*11*). The sample identification numbers used in this report are the same as those used in the previous report and these numbers, together with the designated grade, will be used to identify the various asphalt cements.

This investigation included tests on the residues obtained from the standard test for loss on heating (A. S. T. M. Method D6–39T) and from oven tests made with the asphaltic material exposed in a film ⅛-inch thick. Tests on the residues of the 85–100 penetration asphalts after exposure to light, heat, and air, were also made. Throughout this report the above tests will be referred to, respectively, as the standard oven test, the thin-film oven test, and the exposure test. Comparative data on the physical properties of other asphalts before and after subjection to the thin-film oven test and after extraction from mixtures from hot-mix pavements and from laboratory mixtures prepared by the Shattuck method (*19*) will be presented.

The test procedure used in making the thin-film oven tests was as follows:

Fifty milliliters of the asphalt to be tested were weighed into a flat-bottomed aluminum container, 5.5 inches in inside diameter and ⅜ inch deep. This volume gave a film thickness of approximately ⅛ inch. A special rotating shelf was installed in the oven to carry four of these 5.5-inch containers. In other particulars the testing procedure of the standard oven test was followed.

In order further to accelerate the effects of exposure to high temperature, the thin-film test was modified in some cases by using aluminum containers 7.78 and 11.0 inches in diameter, in which 50 milliliters of asphalt gave film thicknesses of approximately $\frac{1}{16}$ and $\frac{1}{32}$ inch, respectively. The larger containers were placed on a special stationary shelf immediately below the rotating shelf.

In order to determine the effects of outdoor exposure on asphalt cements, the 85–100 penetration asphalts used in this investigation, with the exception of sample 40, were exposed out of doors, under glass, to the action of sunlight, heat, and air, under conditions similar to those of previous investigations that have been reported (*7, 8, 9, 10*). The asphalts were exposed in ⅛-inch films in containers 5½ inches in diameter for a period of 15 weeks during the summer months.

The temperatures of the air and asphalt within the exposure boxes were recorded continuously during the entire 15 weeks by means of automatic temperature recorders. One element of the recorder was placed in the air and the other element was immersed in a container of asphalt. The range and average in maximum and minimum daily temperatures for both the air and asphalt are given in table 1. As determined from United States Weather Bureau reports, the asphalts were subjected to 875 hours of sunlight during the 15-week period.

TABLE 1.—*Range of and average daily maximum and minimum temperatures during exposure of 85–100 penetration asphalts*

	Maximum temperature		Minimum temperature	
	Air [1]	Asphalt [2]	Air	Asphalt
	°*F.*	°*F.*	°*F.*	°*F.*
Maximum	195	210	75	75
Minimum	70	70	40	45
Average	168.2	175.6	60.1	62.4

[1] Recorder placed in air inside exposure box.
[2] Recorder placed in asphalt inside exposure box.

DROP IN PENETRATION IN OVEN TEST NOT DUE TO VOLATILITY

Steinbaugh and Brown (*20*) have shown the effect of the mixing operation on the penetration and ductility of asphalts, and Shattuck (*19*) has included the determination of the softening point in his investigation. These tests, as well as the determination of organic matter insoluble in 86° B. naphtha, were made on the residues from both the standard and thin-film oven tests and on the residues from exposure. The exposure residues were also tested for penetration at 95° F. (35° C.), organic matter insoluble in carbon tetrachloride, and the reaction to the Oliensis test, including the determination of the xylene equivalent.

The physical properties of the 50–60 and 85–100 penetration asphalts before and after the oven tests are given in tables 2 and 3, respectively. The results of tests on the 85–100 penetration asphalts after exposure, as well as the results of special tests made on the original materials, are shown in table 4.

In order to indicate the extent of the alterations in test characteristics that occurred in the asphalts during the oven and exposure tests, the test results given in tables 2 to 4 have been expressed as percentages of the test results for the original materials. These percentages for penetration, softening point, ductility, and insolubility in 86° B. naphtha are shown for the 50–60 asphalts in table 5 and for the 85–100 penetration asphalts in table 6.

In figures 1 to 6, the percentage of original penetration, the softening point, and ductility values are shown by bar diagrams. The figures give a graphical presentation of the relative behavior of asphalts from each source. Figures 1 to 3 show the source of the base petroleum in relation to the effect of the oven tests on the penetration, softening point, and ductility of the 50–60 penetration asphalts. Figures 4 to 6 show the same data for the 85–100 penetration asphalts, as well as the same test data on the exposure residues. Average values for each test for the asphalts as a group are indicated for each condition of test.

The test results given in tables 5 and 6 show that the loss by volatilization in the standard oven test was very low. Only one asphalt, sample 40 of the 50–60 and 85–100 grades, had a loss of more than 0.25. The loss by volatilization during the thin-film oven test was not much greater in many cases than the loss in the standard oven test. There were 17 asphalts of the 50–60 grade that had lower losses in the thin-film oven test than in the standard oven test, and the residues of 9 asphalts increased in weight during the testing period. For the 85–100 penetration grade, 14 asphalts had lower thin-film oven losses than were obtained in the standard test and 11 of these gained in weight in the oven. Those asphalts of both grades that gained in weight when exposed in thin films had low losses in the standard oven test. Those asphalts with relatively high losses in the standard oven test had still higher losses in the thin-film oven test. Considering the penetration drop under both tests, it is apparent that for petroleum asphalts the relative hardening of the asphalts cannot be correlated with the volatility of the materials in the oven heat tests.

As shown in table 5 and figure 1, the percentage of original penetration retained by the residues of the 50–60 asphalts in the standard oven test varied from 70 to 94 with an average of 85. The residues from the thin-film oven test retained from 38 to 73 percent, with an average of 62 percent, of the original penetration.

TABLE 2.—*Effect of the standard and thin-film oven tests on the 50–60 penetration asphalts*

Identification No.	Original asphalt				Standard oven test					Thin-film oven test				
						Tests on the residue					Tests on the residue			
	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per min.	Organic matter insoluble in 86° B. naphtha	Change in weight	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per min.	Organic matter insoluble in 86° B. naphtha	Change in weight	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per min.	Organic matter insoluble in 86° B. naphtha
		°F.	*Cm.*	*Percent*	*Percent*		*°F.*	*Cm.*	*Percent*	*Percent*		*°F.*	*Cm.*	*Percent*
1	57	119	250+	10.7	−0.13	48	120	250+	11.5	−0.40	33	125	250+	14.5
2	61	118	250+	10.6	−.05	50	120	250+	11.8	−.04	36	126	250+	14.3
3	61	118	250+	10.0	−.05	50	121	250+	14.3	+.01	39	125	250+	14.0
4	60	118	250+	11.8	−.06	50	120	250+	12.7	−.08	38	125	250+	15.2
5	58	120	250+	12.6	−.07	46	122	250+	14.2	−.06	31	129	250+	17.4
6	52	126	250+	18.1	−.06	46	130	250+	19.5	−.00	35	137	129	21.5
7	58	132	197	28.2	−.07	49	134	235	29.8	−.26	38	141	73	29.0
8	56	130	68	30.9	−.11	46	139	19	32.0	−.22	34	152	8	35.2
9	53	132	218	29.3	−.08	46	139	175	31.5	−.20	35	145	98	31.7
10	56	131	215	28.8	−.12	45	139	200	30.1	−.34	33	145	70	32.2
11	54	132	180	28.1	−.11	44	137	140	31.1	−.26	30	146	52	34.1
12	55	132	250+	28.0	−.06	46	135	140	29.8	−.17	34	144	118	31.4
13	51	132	140	27.5	−.11	44	139	23	29.8	−.24	31	152	8	30.7
14	52	126	250+	21.7	+.01	46	130	250+	23.2	+.09	33	135	200	24.9
15	52	126	181	24.8	−.02	47	132	97	25.8	−.00	27	140	30	28.4
16	48	132	57	25.6	−.03	41	139	24	26.8	−.03	31	148	10	28.8
17	48	128	250+	22.9	−.02	43	133	160	23.6	−.02	34	140	92	23.8
18	51	129	250+	24.8	−.05	46	132	140	25.9	−.06	34	140	68	28.1
19	57	125	220	19.7	−.00	49	129	250+	20.6	+.10	39	133	240	22.3
20	58	137	36	30.8	−.12	53	140	22	27.8	−.46	39	146	8	29.8
21	57	130	232	24.2	−.02	50	131	160	24.3	+.05	40	138	41	25.4
22	57	137	96	27.9	−.04	48	138	41	27.5	−.00	40	145	18	29.1
23	60	120	202	21.6	−.10	42	128	24	24.4	−.21	30	142	8	24.0
24	54	131	84	20.4	−.04	48	137	29	21.1	−.01	38	144	12	22.7
25	58	127	116	17.3	−.07	49	135	84	18.6	−.00	38	137	38	18.7
26	53	129	78	25.4	−.09	44	137	23	26.4	−.20	33	143	11	25.4
27	49	131	226	19.3	−.03	43	136	112	21.0	+.03	32	141	32	21.1
28	58	126	244	23.0	−.12	45	132	90	25.1	−.36	31	138	19	24.3
30	48	131	170	23.3	−.03	45	135	58	23.6	+.05	34	138	28	26.3
31	59	133	41	30.2	−.08	51	140	22	31.9	−.25	34	152	8	32.5
32	49	128	159	21.4	−.05	44	135	44	22.3	+.08	33	137	24	23.8
33	46	127	27	24.5	−.04	40	140	8	27.8	+.05	33	152	6	27.1
34	58	128	112	28.5	−.05	46	136	53	30.2	−.04	32	148	11	32.5
35	57	123	219	19.1	−.06	52	126	230	19.4	−.10	41	129	165	20.9
36	55	125	190	20.9	−.07	50	129	131	19.6	+.02	40	136	61	22.1
37	52	132	137	27.0	−.06	44	139	58	29.2	−.13	31	146	25	30.2
38	55	132	120	25.7	−.08	46	140	20	27.6	−.20	36	146	11	29.3
39	47	129	121	23.0	−.05	44	130	160	24.9	−.07	23	141	19	27.0
40	50	123	250+	31.9	−.48	37	135	92	31.9	−2.09	19	153	6	31.4

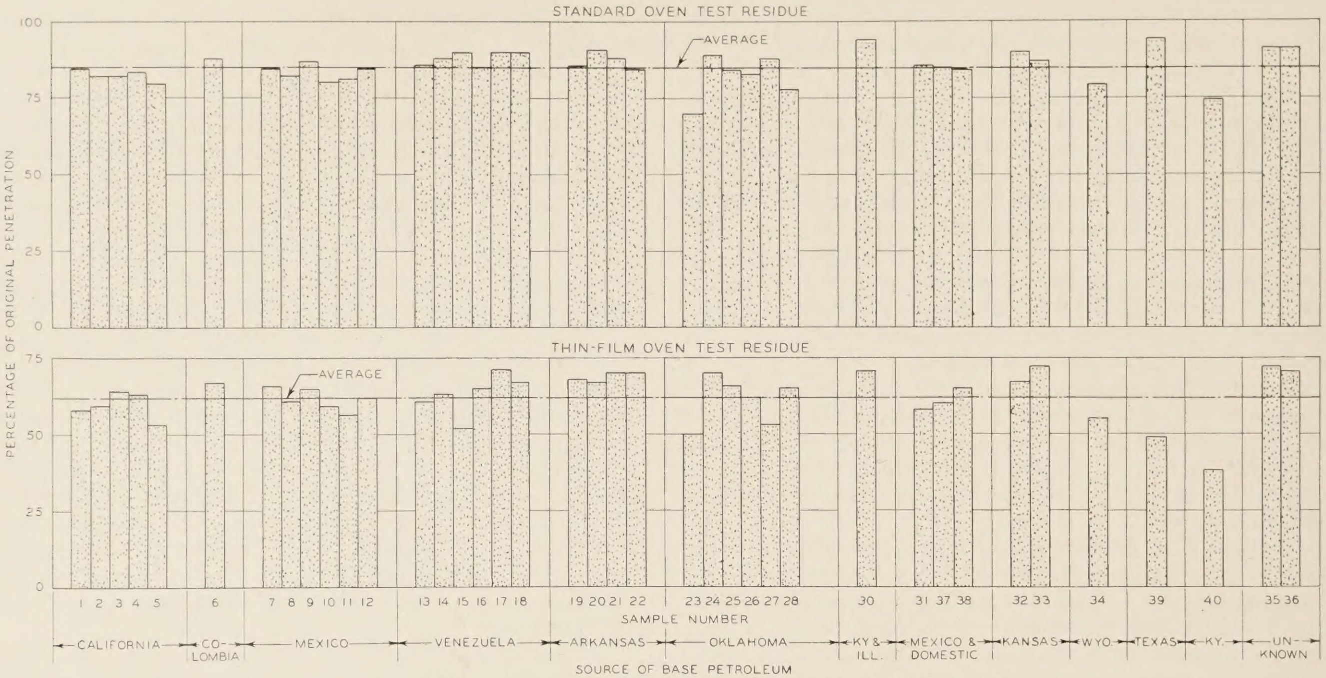

FIGURE 1.—SOURCE OF THE BASE PETROLEUM IN RELATION TO THE EFFECT OF OVEN HEAT TESTS ON THE PENETRATION OF THE 50–60 PENETRATION ASPHALTS.

TABLE 3.—*Effect of the standard and thin-film oven tests on the 85–100 penetration asphalts*

Identification No.	Original asphalt				Standard oven test					Thin-film oven test				
						Tests on the residue					Tests on the residue			
	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per min.	Organic matter insoluble in 86° B. naphtha	Change in weight	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per min.	Organic matter insoluble in 86° B. naphtha	Change in weight	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per min.	Organic matter insoluble in 86° B. naphtha
		°F.	*Cm.*	*Percent*	*Percent*		*°F.*	*Cm.*	*Percent*	*Percent*		*°F.*	*Cm.*	*Percent*
1	85	113	223	10.5	−0.16	69	114	250+	11.8	−0.55	48	121	250+	13.2
2	96	111	193	10.1	−.07	79	113	240	13.0	−.17	54	119	215	13.7
3	95	112	204	9.9	−.07	80	113	190	13.2	−.14	56	119	244	13.8
4	92	112	227	11.5	−.08	75	115	250+	13.6	−.21	55	120	250+	14.7
5	91	113	197	14.7	−.08	74	116	245	16.7	−.15	47	123	250+	19.7
6	92	117	185	14.3	−.05	73	120	250+	17.5	+.04	58	124	210	17.6
7	96	120	220	26.4	−.10	76	124	160	29.4	−.44	55	133	132	30.0
8	96	121	102	28.0	−.21	66	129	50	31.1	−.46	43	144	11	33.0
9	96	121	230	26.2	−.13	75	125	182	29.7	−.55	51	135	106	30.3
10	95	121	192	26.4	−.19	70	126	162	29.7	−.68	49	136	125	32.3
11	97	119	209	26.4	−.12	75	124	193	29.7	−.41	51	134	143	31.0
12	97	119	242	25.5	−.13	74	124	240	29.7	−.45	52	132	130	30.9
13	94	117	192	23.1	−.05	70	123	220	26.1	−.11	47	133	34	27.8
14	95	115	192	20.4	−.01	73	119	205	22.3	+.08	56	124	212	23.0
15	92	115	187	21.7	−.04	71	121	245	25.2	+.01	52	126	205	25.4
16	94	117	107	22.0	−.03	72	123	65	24.7	−.00	55	128	53	25.8
17	92	118	191	18.0	−.04	72	121	190	22.7	−.04	57	127	252	22.6
18	85	123	196	24.6	−.17	65	126	176	28.7	−.51	47	134	108	29.8
19	90	116	179	19.0	−.02	74	120	215	20.9	+.09	61	124	235	21.1
20	90	121	139	25.4	−.15	79	126	131	26.8	−.59	61	132	36	27.2
21	97	115	178	20.2	−.05	78	121	191	22.1	−.02	62	124	225	22.7
22	96	117	211	21.4	−.03	79	123	203	24.7	+.03	64	126	173	27.2
23	91	112	223	15.9	−.04	62	120	180	21.6	−.05	42	128	42	21.2
24	94	118	162	16.6	−.04	74	122	120	19.1	−.13	52	132	60	21.1
25	94	118	152	12.7	−.08	76	122	176	14.9	−.01	61	126	130	14.5
26	84	119	172	18.2	−.08	65	123	148	21.1	−.16	53	129	76	21.6
27	93	116	164	13.2	−.02	75	119	158	14.9	+.07	60	122	225	17.6
28	92	115	184	15.1	−.06	73	118	237	17.8	−.09	54	123	250+	18.7
29	92	113	200	18.5	−.10	60	120	250+	23.4	−.13	40	129	52	25.7
30	90	116	163	18.3	−.03	77	122	180	20.5	+.08	62	129	145	23.1
31	93	120	101	27.7	−.08	70	130	55	29.3	−.26	51	141	20	31.9
32	85	119	173	18.9	−.02	64	126	150	21.6	+.09	53	132	66	22.9
33	83	119	125	22.5	−.04	54	133	15	25.1	+.06	50	139	10	26.2
34	94	116	170	26.3	−.02	68	125	192	27.9	+.04	49	133	95	29.4
35	96	116	186	18.7	−.07	80	120	180	20.1	−.14	65	124	198	22.0
36	92	121	115	21.2	−.03	74	127	32	22.4	+.02	59	136	18	23.4
37	96	118	193	24.7	−.07	75	126	200	27.0	−.12	56	134	66	28.3
38	95	121	120	23.6	−.13	76	128	86	25.0	−.37	58	137	29	26.2
39	86	116	141	19.9	−.14	65	122	203	21.7	−.15	48	128	165	23.6
40	87	113	250+	25.8	−.53	61	124	250+	27.1	−2.17	28	139	24	29.2

TABLE 4.—*Effect of outdoor exposure on the characteristics of asphalts of the 85–100 penetration grade*

Identification No.	Change in weight	Tests on the exposure residue									Additional tests on the original asphalt			
		Penetration 100 gm.; 5 sec.		Slope of the log-penetration temperature curve	Softening point	Ductility at 77° F. 5 cm. per min.	Organic matter insoluble in CCl_4	Organic matter insoluble in 86° B. naphtha	Oliensis test		Slope of the log-penetration temperature curve	Organic matter insoluble in CCl_4	Oliensis test	
		At 77° F.	At 95° F.						Character of spot	Xylene equivalent			Character of spot	Xylene equivalent
	Percent				*°F.*	*Cm.*	*Percent*	*Percent*				*Percent*		
1	+0.5	23	75	0.0285	134	79.0	0.29	19.5	Positive	0-2	0.0323	0.05	Negative	
2	+1.2	19	56	.0261	139	100.0	.16	22.8	Negative		.0314	.07	do	
3	+.9	19	54	.0252	140	78.0	.15	22.7	Positive	0-2	.0324	.07	do	
4	+.9	20	56	.0248	140	110+	.14	24.1	do	12-16	.0315	.08	do	
5	+1.0	17	44	.0229	146	14.0	.30	27.7	do	12-16	.0313	.08	Positive	0-2
6	+.9	24	57	.0209	146	12.0	.13	22.8	Negative		.0267	.12	Negative	
7	+.5	40	83	.0176	145	15.0	.24	32.5	do		.0219	.06	do	
8	+.7	25	41	.0119	172	4.0	.34	37.3	Positive	28-32	.0211	.07	Positive	24-28
9	+.4	35	79	.0196	147	19.0	.36	33.0	Negative		.0217	.05	Negative	
10	+.3	38	77	.0170	147	13.0	.37	33.0	do		.0220	.07	do	
11	+.6	34	67	.0164	151	15.0	.39	34.6	do		.0219	.06	do	
12	+.5	34	71	.0178	149	13.0	.42	33.8	do		.0219	.05	do	
13	+.9	27	52	.0158	158	5.5	.29	32.8	Positive	12-16	.0221	.10	Positive	2-4
14	+1.1	21	47	.0194	153	6.0	.34	30.8	do	12-16	.0248	.05	Negative	
15	+.8	19	46	.0213	153	7.0	.24	31.8	do	20-24	.0248	.05	Positive	2-4
16	+.8	25	51	.0172	154	7.0	.34	31.6	do	12-16	.0236	.07	do	2-4
17	+.9	22	52	.0208	153	7.5	.25	29.3	do	0-2	.0246	.09	Negative	
18	+.4	29	65	.0195	151	13.5	.41	34.4	do	0-2	.0226	.10	do	
19	+1.0	27	64	.0208	146	9.5	.24	28.3	Negative		.0235	.11	Positive	0-2
20	+.4	37	77	.0177	148	7.5	.15	30.1	do		.0189	.09	Negative	
21	+1.0	27	56	.0176	146	9.5	.20	29.2	do		.0230	.15	do	
22	+.9	33	66	.0167	148	9.5	.16	30.2	do		.0214	.17	do	
23	+.7	29	62	.0183	142	8.0	.48	24.5	Positive	72-76	.0277	.08	Positive	44-48
24	+1.1	31	63	.0171	150	6.5	.35	23.1	Negative		.0226	.20	Negative	
25	+.7	31	75	.0213	143	14.0	.33	19.5	do		.0228	.29	do	
26	+.8	27	57	.0180	150	6.8	.51	25.6	Positive	4-8	.0231	.22	Positive	2-4
27	+1.0	27	63	.0204	142	18.5	.14	20.2	Negative		.0256	.05	Negative	
28	+.6	25	63	.0223	141	17.5	.27	23.0	Positive	8-12	.0272	.12	Positive	4-8
29	+.4	28	62	.0192	141	11.0	.42	25.7	do	100+	.0266	.15	do	[1] 56-60
30	+.8	33	71	.0185	142	15.8	.14	23.1	Negative		.0245	.07	Negative	
31	+.7	31	54	.0134	160	4.8	.42	34.9	Positive	4-8	.0205	.06	do	
32	+.9	30	61	.0171	147	9.0	.20	24.9	Negative		.0225	.11	do	
33	+.6	33	67	.0171	195	4.0	.75	29.4	Positive	100+	.0219	.42	Positive	[1] 60-64
34	+1.1	26	42	.0116	159	5.0	.19	35.1	do	32-36	.0227	.04	do	12-16
35	+.6	37	75	.0170	141	11.5	.11	25.0	Negative		.0224	.18	Negative	
36	+.8	34	57	.0125	158	5.0	.26	27.0	do		.0192	.16	Positive	0-2
37	+.4	37	77	.0177	146	9.0	.30	30.3	Positive	0-2	.0200	.03	Negative	
38	+.7	33	55	.0123	141	5.0	.35	30.5	do	2-4	.0188	.08	do	
39	+.7	23	49	.0182	148	10.0	.26	28.6	do	36-40	.0277	.07	Positive	16-20
40											.0261	.38	do	80-84

[1] Maximum value same as spot with 100 percent xylene.

TABLE 5.—*Changes in test characteristics of 50–60 penetration asphalts after oven tests*

Identification No.	Change in weight		Test values expressed as a percentage of test values on original materials							
			Penetration at 77 degrees F., 100 gm., 5 sec.		Softening Point		Ductility at 77 degrees F., 5 cm. per min.		Organic matter insoluble in 86 degree B. naphtha	
	Standard oven test	Thin-film oven test	Standard oven test	Thin-film oven test	Standard oven test	Thin-film oven test	Standard oven test	Thin-film oven test	Standard oven test	Thin-film oven test
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	-0.13	-0.40	84	58	101	105	100±	100±	107	136
2	-.05	-.04	82	59	103	107	100±	100±	111	135
3	-.05	+.01	82	64	103	107	100±	100±	118	140
4	-.06	-.08	83	63	103	107	100±	100±	108	129
5	-.07	-.06	79	53	102	108	100±	100±	113	138
6	-.06	00	88	67	103	109	100±	52-	108	119
7	-.07	-.26	84	66	102	107	119	37	106	103
8	-.11	-.22	82	61	107	117	28	12	104	114
9	-.08	-.20	87	66	105	110	83	47	108	108
10	-.12	-.34	80	60	106	111	93	33	105	112
11	-.11	-.26	81	56	104	111	78	29	111	121
12	-.06	-.17	84	62	102	109	56-	47-	106	112
13	-.11	-.24	86	61	105	115	16	6	108	112
14	+.01	+.09	88	63	103	107	100±	80-	107	115
15	-.02	00	90	52	105	111	54	17	104	115
16	-.03	-.03	85	65	105	112	42	18	105	113
17	-.02	-.02	90	71	104	109	64-	37-	103	104
18	-.05	-.06	90	67	102	109	56-	27-	104	113
19	00	+.10	86	68	103	106	114+	109	105	113
20	-.12	-.46	91	67	102	107	55	20	90	97
21	-.02	+.05	88	70	101	106	80	21	100	105
22	-.04	00	84	70	101	106	43	19	104	104
23	-.10	-.21	70	50	107	118	12	4	113	111
24	-.04	-.01	89	70	105	110	35	14	103	111
25	-.07	00	84	66	106	108	72	33	108	108
26	-.09	-.20	83	62	106	111	30	14	104	100
27	-.03	+.03	88	53	104	108	51	15	109	109
28	-.12	-.36	78	65	105	110	40	8	109	106
30	-.03	+.05	94	71	103	105	34	16	101	113
31	-.08	-.25	86	58	105	114	54	20	106	108
32	-.05	+.08	90	67	105	107	26	14	104	111
33	-.04	+.05	87	72	110	120	32	24	113	111
34	-.05	-.04	79	55	106	116	47	10	106	114
35	-.06	-.10	91	72	102	105	105	75	102	109
36	-.07	+.02	91	73	104	109	69	32	94	106
37	-.06	-.13	85	60	105	111	42	18	108	112
38	-.08	-.20	84	65	106	111	17	9	107	114
39	-.05	-.07	94	49	101	109	132	16	108	117
40	-.48	-2.09	74	38	110	124	37-	2-	100	98

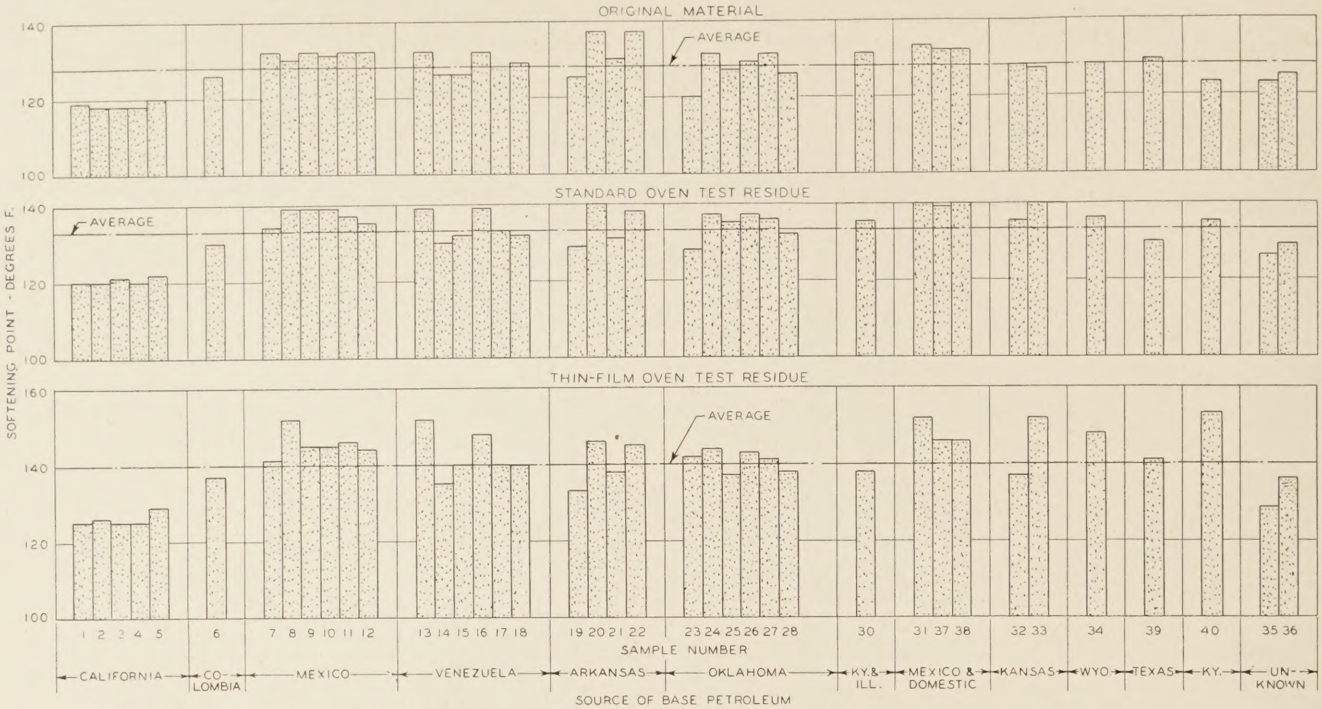

Figure 2.—Source of the Base Petroleum in Relation to the Effect of Oven Heat Tests on the Softening Point of the 50–60 Penetration Asphalts.

Table 6.—*Changes in test characteristics of 85–100 penetration asphalts after oven and exposure tests*

Identification No.	Change in weight			Test values expressed as a percentage of test values on original materials											
				Penetration at 77° F. 100 gm., 5 seconds			Softening point			Ductility at 77° F., 5 cm. per minute			Organic matter insoluble in 86° B. naphtha		
	Standard oven test	Thin-film oven test	Exposure test	Standard oven test	Thin-film oven test	Exposure test	Standard oven test	Thin-film oven test	Exposure test	Standard oven test	Thin-film oven test	Exposure test	Standard oven test	Thin-film oven test	Exposure test
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	−0.16	−0.55	+0.50	81	56	27	101	107	119	112+	112+	35.4	112	126	186
2	−.07	−.17	+1.20	82	56	20	102	107	125	124	111	51.8	129	136	226
3	−.07	−.14	+.9	84	59	20	102	107	126	93	120	38.2	133	139	229
4	−.08	−.21	+.9	82	60	22	104	108	126	110+	110+	48.5	118	128	210
5	−.08	−.15	+1.0	81	52	19	103	109	129	125	127+	7.1	115	134	188
6	−.05	+.04	+.9	79	63	26	103	106	125	135+	114	6.5	122	123	159
7	−.10	−.44	+.5	79	57	42	103	111	121	73	60	6.8	111	114	123
8	−.21	−.46	+.7	69	45	26	107	119	142	49	11−	3.9	111	118	133
9	−.13	−.55	+.4	78	53	36	103	112	122	79	46	8.3	113	116	126
10	−.19	−.68	+.3	74	55	40	104	112	122	84	65	6.8	112	122	125
11	−.12	−.41	+.6	77	53	35	104	113	127	92	68	7.2	112	117	131
12	−.13	−.45	+.5	76	54	35	104	111	125	99	54	5.4	116	121	133
13	−.05	−.11	+.9	74	50	29	105	114	135	115	18	2.9	113	120	142
14	−.01	+.05	+1.1	77	59	22	103	113	133	107	110	3.1	109	113	151
15	−.04	+.01	+.8	77	57	21	105	115	133	131	110	3.7	116	117	147
16	−.03	0	+.8	77	59	27	105	114	132	61	50	6.5	112	117	144
17	−.04	−.04	+.9	78	62	24	103	112	130	100	134	3.9	126	126	163
18	−.17	−.51	+.4	76	55	34	103	109	123	90	55	6.9	117	121	140
19	−.02	+.09	+1.0	82	68	30	104	108	127	120	131	5.3	110	111	149
20	−.15	−.59	+.4	88	68	41	104	109	122	94	26	5.4	106	107	119
21	−.05	−.02	+1.0	80	64	28	105	108	127	107	126	5.3	109	112	145
22	−.03	+.03	+.9	82	67	34	105	108	127	96	82	4.5	115	127	141
23	−.04	−.05	+.7	68	46	32	107	114	127	81	19	3.6	136	133	154
24	−.04	−.13	+1.1	79	55	33	104	112	127	74	37	4.0	115	127	139
25	−.08	−.01	+.7	81	65	33	104	107	121	116	86	9.2	117	114	154
26	−.08	−.16	+.8	77	63	32	104	108	126	86	44	3.9	116	119	141
27	−.02	+.07	+1.0	81	65	29	103	105	123	96	137	11.3	113	133	153
28	−.06	−.09	+.6	79	59	27	103	107	123	129	136+	9.5	118	124	152
29	−.10	−.13	+.4	65	43	30	106	114	125	125+	26	5.5	126	139	139
30	−.03	+.08	+.8	86	69	37	105	111	122	110	89	9.8	112	126	126
31	−.08	−.26	+.7	75	55	33	107	117	132	54	20	4.7	106	115	126
32	−.02	+.09	+.9	75	62	35	106	111	124	87	38	5.2	114	121	132
33	−.04	+.06	+.6	65	60	40	112	117	164	12	8	3.2	112	116	131
34	−.02	+.04	+1.1	72	52	28	108	115	137	113	56	2.9	106	112	133
35	−.07	−.14	+.6	83	68	39	103	107	121	97	107	6.2	107	118	134
36	−.03	+.02	+.8	80	64	37	105	112	131	28	16	4.4	106	110	127
37	−.07	−.12	+.4	78	58	39	107	114	124	104	34	4.7	109	115	123
38	−.13	−.37	+.7	80	61	35	106	113	117	72	24	4.2	106	111	129
39	−.14	−.15	+.7	76	56	27	105	110	128	144	117	7.1	109	119	144
40	−.53	−2.17	----------	70	32	----------	110	123	----------	100±	10	----------	105	113	----------

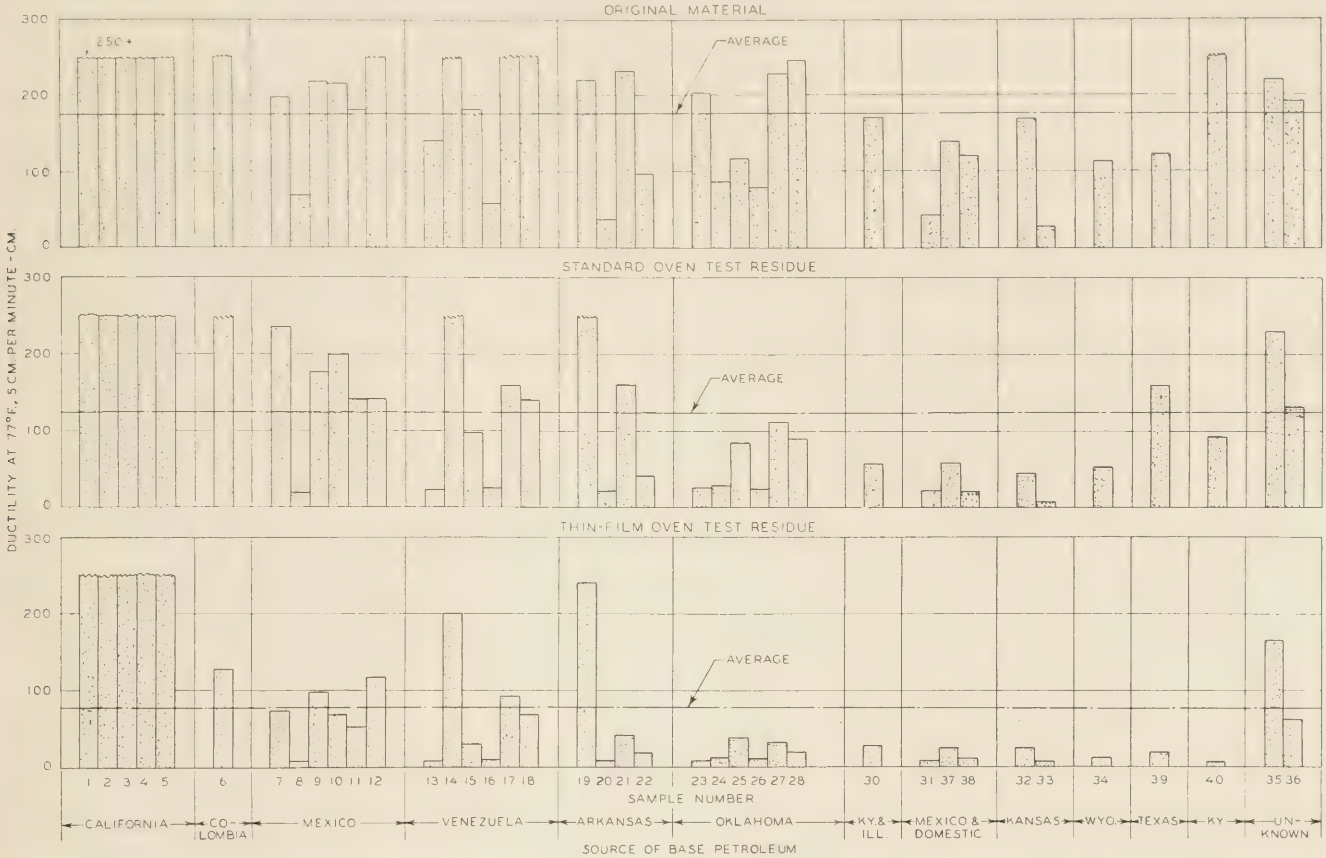

Figure 3.—Source of the Base Petroleum in Relation to the Effect of Oven Heat Tests on the Ductility of the 50–60 Penetration Asphalts.

Figure 4.—Source of the Base Petroleum in Relation to the Effect of Oven Heat and Exposure Tests on the Penetration of the 85–100 Penetration Asphalts.

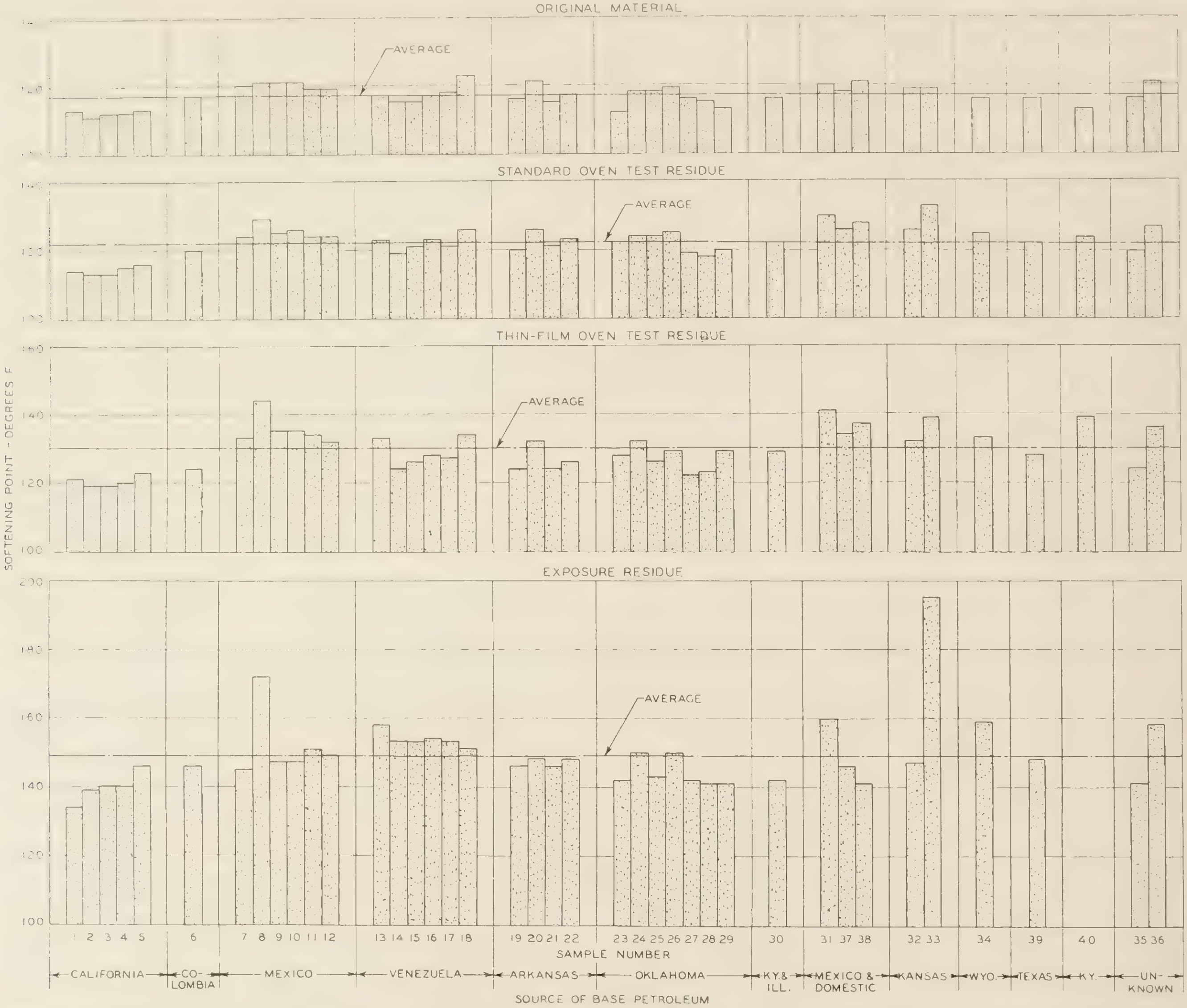

Figure 5.—Source of the Base Petroleum in Relation to the Effect of Oven Heat and Exposure Tests on the Softening Point of the 85–100 Penetration Asphalts.

The percentage of original penetration for the 85–100 penetration asphalts, as shown in table 6 and figure 4, varied from 65 to 88 with an average of 78 for the standard oven test and from 32 to 69 with an average of 58 for the thin-film residues. The range in percentage of original penetration retained by the exposure residues was from 19 to 42, with an average of 31. Only two asphalts of the 50–60 grade and four of the 85–100 grade retained less than 50 percent of their original penetration after the 5-hour heating in thin films.

THIN-FILM OVEN TESTS GREATLY REDUCED THE DUCTILITY OF SOME ASPHALTS

The range in the values for retention of original penetration for both grades of asphalt is greater for residues from the thin-film test than for the residues from the standard oven test, indicating that the thin-film oven test provides a somewhat sharper differentiation between the various asphalts with respect to resistance to hardening. The difference between maximum and minimum values for percentage of original penetration is greater for the thin-film residues of 85–100 penetration asphalts than for the residues from the exposure test.

The softening point values shown in tables 2 and 3 and in figures 2 and 5 indicate that the range in values is somewhat greater for the residues from the thin-film oven test than for the residues from the standard oven test, further indicating that the thin-film oven test provides a sharper differentiation between the asphalts with respect to their resistance to hardening. As compared to the residues from the thin-film oven test, the range in penetration of the exposure residues was reduced, while the range in softening point has increased considerably. This indicates that continued exposure produces changes that affect the softening point values to a greater extent than the consistency as measured by penetration. For instance, the exposure residues of samples 8 and 33 had penetrations slightly under and over the average for all the asphalts, respectively, but these two materials developed residues having the highest softening points.

Figures 3 and 6 show the effects of the oven and exposure tests on the ductility of the 50–60 and 85–100 penetration asphalts. These figures show that the ductilities of many of the asphalts were greatly changed in these tests. Although the average ductility of the

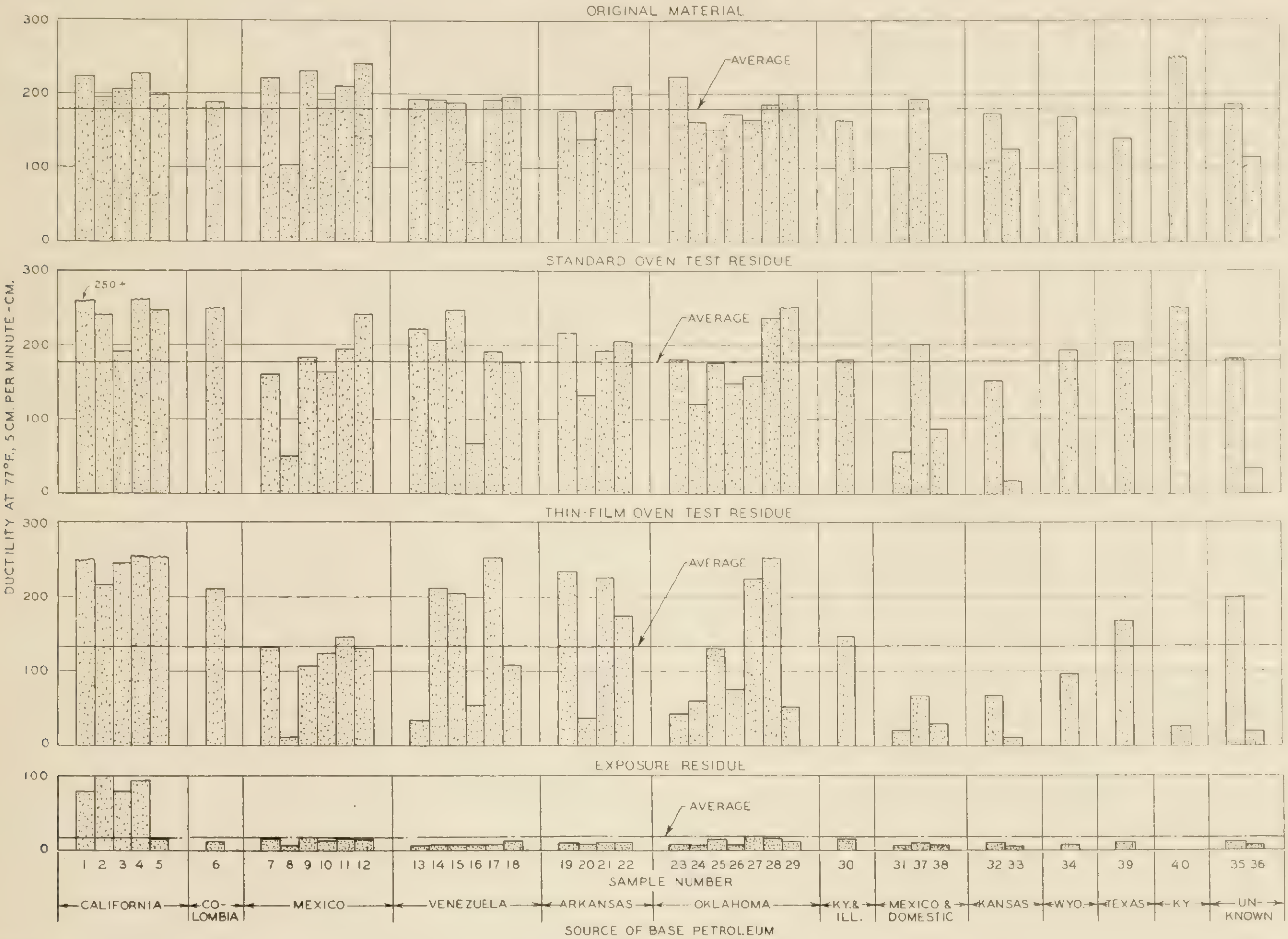

Figure 6.—Source of the Base Petroleum in Relation to the Effect of Oven Heat and Exposure Tests on the Ductility of the 85–100 Penetration Asphalts.

original 50–60 and 85–100 penetration asphalts was nearly the same (176 and 180 centimeters, respectively) the reduction in ductility was greater for the 50–60 penetration asphalts than for the 85–100 penetration asphalts. The average ductility of residues of the 50–60 asphalts from the standard oven test dropped to 123 centimeters, but the average ductility of the 85–100 residues was practically unchanged, being 177 centimeters.

This low reduction in the average ductility for the asphalts of the 85–100 grade after heating indicates that many of the original asphalts were of too soft a consistency at 77° F, to develop their maximum ductility, and the additional hardening made the residues more ductile at 77° F. than the original asphalts. In the thin-film oven test the average ductilities of the 50–60 and 85–100 penetration residues were 77 and 132 centimeters, respectively. Although the average ductility for the 85–100 penetration asphalts had been materially reduced, many of these residues still had higher ductilities than the original asphalt. The ductilities of all the exposure residues of the 85–100 penetration asphalts were greatly reduced. The average ductility was 18 centimeters, and 33 of the 39 asphalts tested had ductilities under the average. Only six asphalts representing four of the five materials produced from California petroleums, one from Mexico and one from Oklahoma, had ductilities higher than the average.

Tables 5 and 6 show the percentage of increase in organic matter insoluble in 86° B. naphtha due to alterations occurring in the oven and exposure tests. With the exception of samples 20, 36, and 40 of the 50–60 grade, all the residues had the same or greater amounts of insoluble material than the original asphalts. The average percentage of increase for residues from oven tests was greater for the 85–100 penetration grade. Figure 7 shows the relation between the amount of organic matter insoluble in the original material and the percentage of change in the insoluble matter in the oven and exposure residues for the 85–100 penetration asphalts. This figure indicates that there is a tendency for the insolubility of the residues from those asphalts with an initial low insolubility to increase more than in the case of asphalts containing higher percentages of insolube matter. The difference between maximum and minimum values for the naphtha-insoluble matter of the original materials and the oven and exposure residues remains practically the same.

OXIDATION RESPONSIBLE FOR ALTERATIONS IN ASPHALTS ON EXPOSURE

Table 4 shows the slope of the log-penetration temperature curves for the 85–100 penetration asphalts before and after exposure. The values for the slope of the curves are of interest in evaluating the alterations that occurred during the exposure not only in the case of the individual asphalts but for the asphalts as a group.

J. P. Pfeiffer and P. M. Van Doormal (*15, 16*) proposed the penetration index for the classification of

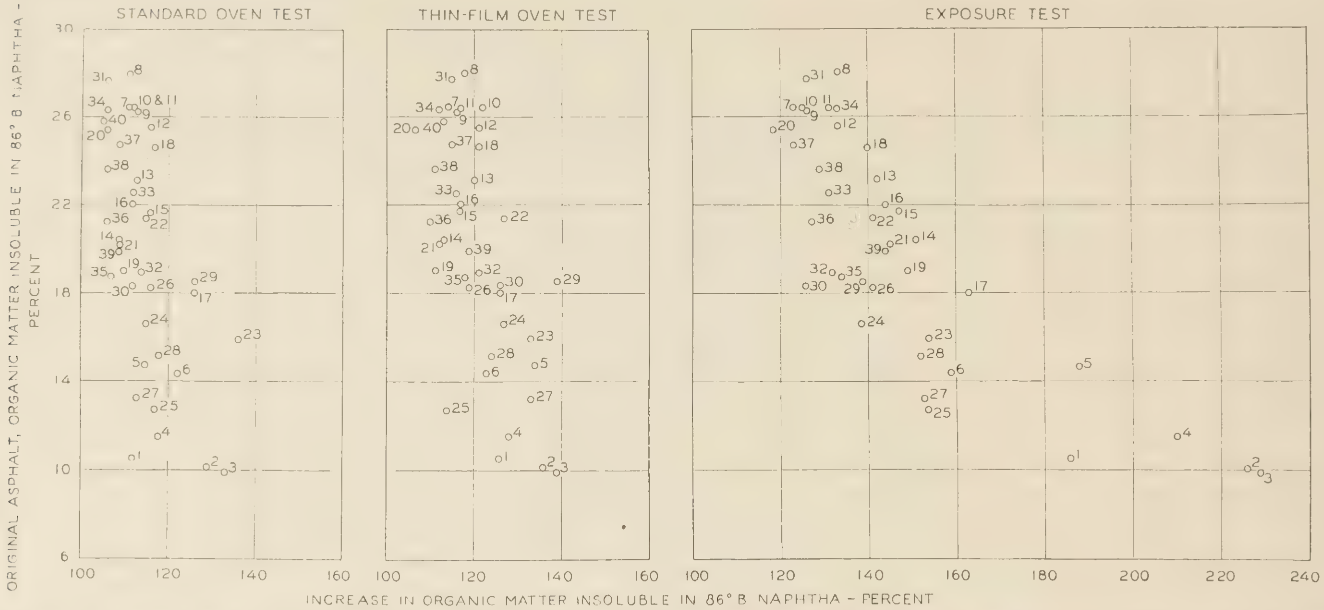

Figure 7.—Effect of 86° B. Naphtha Insoluble Matter in the Original 85–100 Penetration Asphalts on the Increase of 86°B. Naphtha Insoluble Matter Due to Oven and Exposure Tests.

asphalts according to their susceptibility to change in consistency with change in temperature. They stated that an asphalt with a penetration index of from −1.0 to +1.0 has normal susceptibility (N type). Asphalts with penetration indexes of less than −1.0 or of more than +1.0 have high susceptibility (Z type) or low susceptibility (blown or R type), respectively. The slope of the log-penetration temperature curve can be used to calculate the true penetration index which differs slightly from the one calculated by the Pfeiffer and Van Doormal formula (*11*). Using the values proposed by Pfeiffer and Van Doormal for asphalts of different susceptibilities, a slope of more than 0.0259 indicates high susceptibility, from 0.0259 to 0.0192 normal susceptibility, and of less than 0.0192 low susceptibility.

As indicated in table 4, the slope of the curves for all the asphalts was reduced by the exposure. The residues became less susceptible to change in consistency as a result of the exposure. The extent of the reduction in slope may be considered as a measure of the resistance of the various asphalts to oxidation.

Considering the values for the slopes of the curves and the Pfeiffer and Van Doormal classification (*15*, *16*), it will be noted that 10 of the 39 asphalts exposed were originally of the Z (high susceptibility) type, 27 were of the N (normal) type and 2 were of the R (blown) type. After 15 weeks of exposure, 2 were of the Z type, 14 of the N type, and 23 of the R type. These changes tend to substantiate the conclusion that oxidation is responsible for the alterations occurring in asphaltic materials under exposure conditions.

As compared with the original materials, with few exceptions, the exposure residues from the 85–100 penetration asphalts showed some increase in the amount of organic matter insoluble in carbon tetrachloride. However, the extensive carbonization that has been observed previously in similar tests on slow-curing oils (*7*, *8*), having approximately the same initial insolubility in carbon tetrachloride, did not take place in these semisolid asphalts.

In table 4 the results of the Oliensis spot test on the asphalts before and after exposure are given. Fourteen of the 39 asphalts gave positive spots before exposure. Two of the asphalts, samples 19 and 36, with xylene equivalents of 0–2, gave positive spots before exposure but had negative spots after exposure. Samples 29 and 33 gave positive spots in 100 percent xylene under both conditions. The xylene equivalents of the exposure residues that gave positive spots were higher than those of the original materials but there does not appear to be any relationship between the initial xylene equivalent and the increase shown in the exposure residues. In previous work with all types of liquid asphaltic materials (*8*), residues of all materials that were originally negative gave positive spots after only 5 weeks of exposure. The greater resistance of these semisolid asphalts to changes that are indicated by their reaction to the Oliensis test is shown by the fact that 16 of them gave negative spots both before and after exposure. This emphasizes the lower durability of fluid asphaltic materials.

It is evident from the study of the data presented that even though additional tests, such as ductility and softening point, were made specification requirements for the residues from the standard oven test, no sharp differentiation in the hardening properties of the various asphalts is possible. Tests on the residues from the thin-film oven test, however, do show wide differences in resistance to change in original characteristics.

ALTERATIONS IN RESIDUES GREATLY AFFECTED BY TIME OF HEATING

In order to study more thoroughly the effect of the thin-film oven test on the characteristics of the asphalts used in this investigation, 16 asphalts of the 50–60 penetration grade were selected for further study. These asphalts represented materials from a majority of the sources of base petroleums covered by this investigation. In cases where two or more asphalts from the same source showed considerable difference in behavior in the 5-hour thin-film tests, two materials from the same source were selected.

These 16 samples were heated in ⅛-inch films at 325° F. for various periods of time up to 10 hours or until the ductility of the residue was reduced to a relatively low value. Those materials that did not show an appreciable reduction in ductility at the end of 7- or 10-hour test periods were heated, in a few instances, in ¹⁄₁₆- or ¹⁄₃₂-inch films for periods of 7 hours. The results of tests on the residues of the 16 selected asphalts for various periods of heating and thickness of film are given in table 7. Values for the penetration at 77° F., ductility at 77° F., and softening point,

TABLE 7.—*Effect of heating typical 50–60 penetration asphalts in thin films for various periods of time and film thicknesses*

Identification No.	Source of base petroleum	Time in oven at 325° F.	Film thickness	Tests on residue		
				Penetration at 77° F., 100 gm.; 5 sec.	Ductility at 77° F., 5 cm. per min.	Softening point
		Hours	*Inches*		*Cm.*	*°F.*
3	California	0		61	250+	118.0
		5	⅛	39	250+	125.0
		7	⅛	30	250+	131.9
		10	⅛	24	250+	135.5
		7	¹⁄₁₆	20	250+	136.7
		7	¹⁄₃₂	16	27.5	142.8
6	Colombia	0		52	250+	126.0
		2	⅛	40	240	132.0
		5	⅛	35	129	137.0
		7	⅛	33	88	141.5
		10	⅛	27	24	146.0
		7	¹⁄₁₆	25	10	151.5
8	Mexico	0		56	68	130.0
		2	⅛	43	22	141.2
		5	⅛	34	8	152.0
		7	⅛	29	5.3	160.8
		10	⅛	25	4.3	169.3
9	do	0		53	218	132.0
		2	⅛	44	195	137.0
		5	⅛	35	98	145.0
		7	⅛	30	30	149.3
		7	¹⁄₁₆	23	9.5	163.7
13	Venezuela	0		51	140	132.0
		2	⅛	40	20.5	144.6
		5	⅛	31	8	152.0
		7	⅛	28	5.5	162.5
		10	⅛	24	4.3	172.8
14	do	0		52	250+	126.0
		5	⅛	33	200	135.0
		7	⅛	31	95	139.9
		7	¹⁄₁₆	22	9	149.8
19	Arkansas	0		57	220	125.0
		2	⅛	43	250+	130.9
		5	⅛	39	240	133.0
		7	⅛	33	128	139.0
		10	⅛	31	48	141.0
		7	¹⁄₁₆	29	18	146.8
20	do	0		58	36	137.0
		2	⅛	49	16	142.8
		5	⅛	39	8	146.0
		7	⅛	38	6.3	155.5
23	Oklahoma	0		60	202	120.0
		1	⅛	37	26.5	131.0
		2	⅛	34	13	135.4
		5	⅛	30	8	142.0
		10	⅛	27	4	161.8
27	do	0		49	226	131.0
		2	⅛	41	173	134.7
		5	⅛	32	32	141.0
		7	⅛	31	23	145.5
30	Kentucky and Illinois	0		48	170	131.0
		2	⅛	43	90	136.6
		5	⅛	34	28	138.0
		7	⅛	35	27	145.3
32	Kansas	0		49	159	128.0
		2	⅛	44	69	134.3
		5	⅛	33	24	137.0
		7	⅛	32	15	145.2
3	do	0		46	27	127.0
		2	⅛	42	12	134.9
		5	⅛	33	6	152.0
35	Unknown	0		57	219	123.0
		5	⅛	41	165	129.0
		7	⅛	38	65	134.2
		10	⅛	35	46	137.8
36	do	0		55	190	125.0
		2	⅛	46	170	132.2
		5	⅛	40	61	135.9
		7	⅛	37	26	139.0
		10	⅛	33	21	141.5
37	Mexico and domestic Gulf coast.	0		52	137	132.0
		2	⅛	43	91	138.8
		5	⅛	31	25	146.0
		7	⅛	30	11	151.9

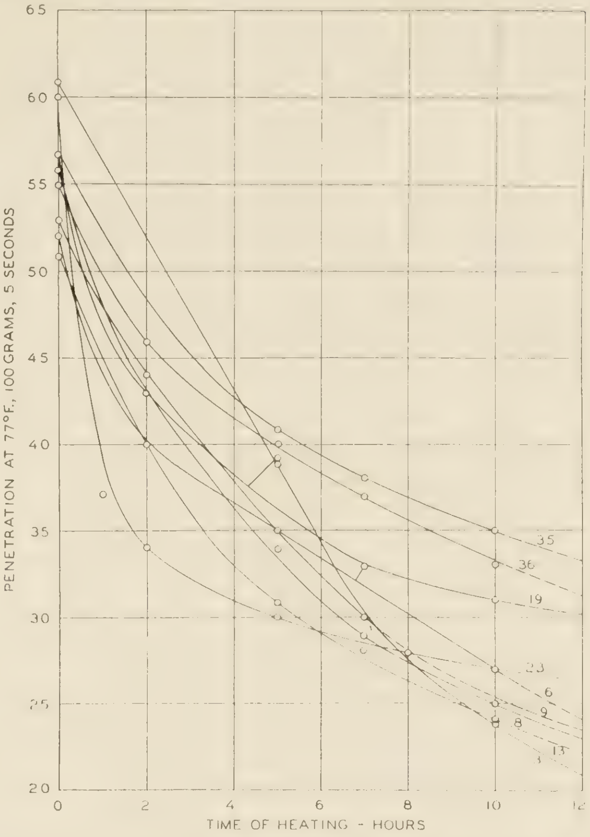

FIGURE 8.—EFFECT OF TIME OF HEATING IN ⅛-INCH FILMS ON THE PENETRATION OF TYPICAL 50–60 PENETRATION ASPHALTS.

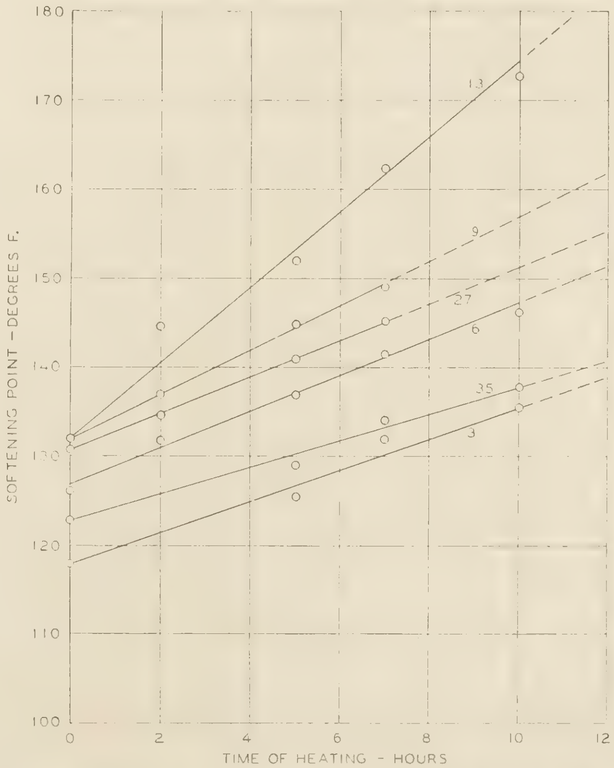

FIGURE 9.—EFFECT OF TIME OF HEATING IN ⅛-INCH FILMS ON THE SOFTENING POINT OF TYPICAL 50–60 PENETRATION ASPHALTS.

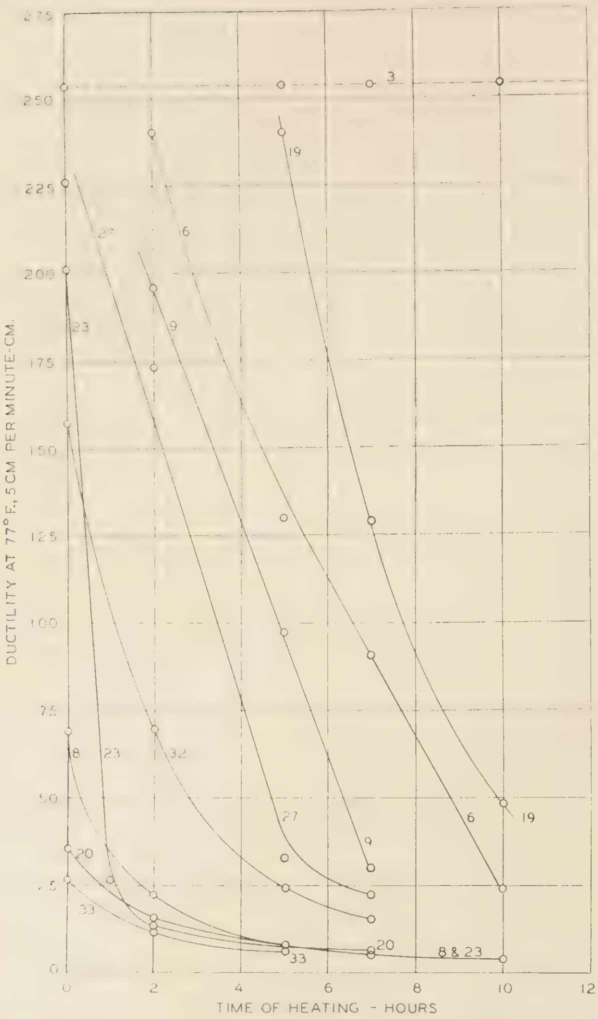

Figure 10.—Effect of Time of Heating in ⅛-Inch Films on the Ductility of Typical 50–60 Penetration Asphalts.

are given for the original materials and for the residues. The effects of time of heating in ⅛-inch films on the properties of some of these asphalts are given in figures 8, 9, and 10.

In figure 8, the results on nine of the asphalts are used to illustrate the effect of time of heating on the penetration of the residues. The time-penetration curves for the other asphalts, with the exception of sample 33, are between the upper and lower curves shown. All the curves indicate that the asphalts had a high initial drop in penetration and, as the time of heating increased, the rate of drop in penetration decreased. Sample 23 had a very high initial drop in penetration up to 2 hours and then a more gradual drop up to 10 hours. The California asphalt (sample 3) showed a uniform rate of hardening up to 7 hours and then a decreased rate. In general, the difference between the high and low values of penetration, for any given time of heating, are approximately the same throughout the range of time covered by these tests. These curves are similar to curves showing the penetration versus time of mixing, one of which for bituminous concrete is charted in the report by Schaub and Parr (*18*) on changes in physical characteristics of paving asphalt cements and their relation to service behavior. In this case, an 85–100 penetration asphalt showed a 27 point decrease in penetration in the first 30 seconds of mixing and a decrease of only 10 points in the next 150 seconds.

In figure 9 are representative curves showing the relation between softening point and time of heating in the thin-film test. The plotted points for these asphalts, and the others of table 7, fall approximately on straight lines.

In figure 10 are representative curves showing the relation between time of heating in the thin-film test and ductility at 77° F. It is apparent that the time of heating has a much more variable effect on ductility than on softening point or penetration. Sample 3 (California) retained a ductility of more than 250 centimeters over the whole 10-hour period while all the other samples showed a large reduction in ductility during this period. Sample 6 (Columbia) lost ductility at a fairly constant rate with increase in time of heating, while the ductility of sample 23 (Oklahoma) dropped from 202 to 26.5 centimeters in 1 hour and from 26.5 to 4 centimeters in the succeding 9 hours. Table 7 shows that samples 8, 13, 20, 23, and 33, with initial ductilities of 27 to 202 centimeters, had ductilities of 8 ticenmeters or less after heating for 5 hours in ⅛-inch films.

In order to show the effect of the thin-film oven test on the ductility-penetration relationship, some of the data given in table 7 have been plotted in figure 11. If the penetrations are plotted against the corresponding log ductility for the residues after various periods of heating, a straight line can be drawn that will pass approximately through the points, except for the higher values of ductility. The data for the majority of 16 selected asphalts can be plotted to show a straight line relationship between penetration and logarithm of ductility when the ductility had been reduced below 100 centimeters. The penetration-ductility curves for the other asphalts are distributed between the extremes shown in figure 11. This figure and the data given in table 7 show that the conditions of the thin-film oven test produced wide differences in the penetration log-ductility relationships of these typical 50–60 penetration asphalts.

EFFECT OF MIXING ON CHARACTERISTICS OF ASPHALTS INVESTIGATED

The relation between the penetration and softening point of the various thin-film residues, data for which are given in table 7, is also of interest in showing the difference in behavior that occurred when these materials were heated under comparable conditions. In figure 12 the softening points of the various residues have been plotted against the logarithms of the corresponding penetrations and the points connected by smooth curves. Several asphalts, of which sample 23 is one, show a uniform rate of change in the earlier periods of heating, but when reduced to a certain penetration the curve breaks, and thereafter shows a greater increase in softening point for a given drop in penetration. Of the materials that show a uniform rate of change, sample 3 shows a very much lower increase in softening point for a corresponding drop in penetration than does sample 20 or sample 33. The curve for the latter is not shown in this figure. In general, the data indicate that asphalts having a low rate of increase in softening point with decrease in penetration retain a high ductility when reduced to low penetrations, but those that increase rapidly in softening point with decrease in penetration do not retain their ductility as well.

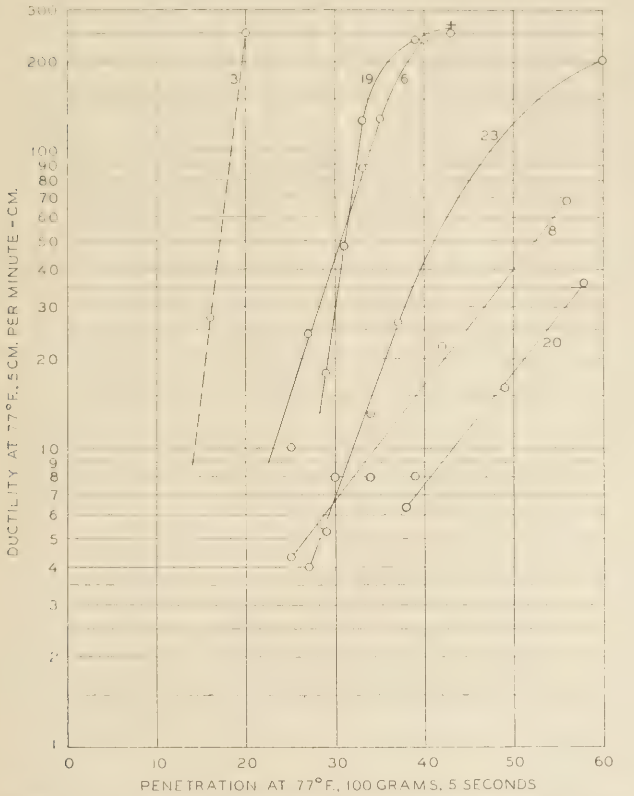

Figure 11.—Relation Between Penetration and Ductility of Typical 50-60 Penetration Asphalts When Heated in Thin Films at 325° F. for Various Periods of Time.

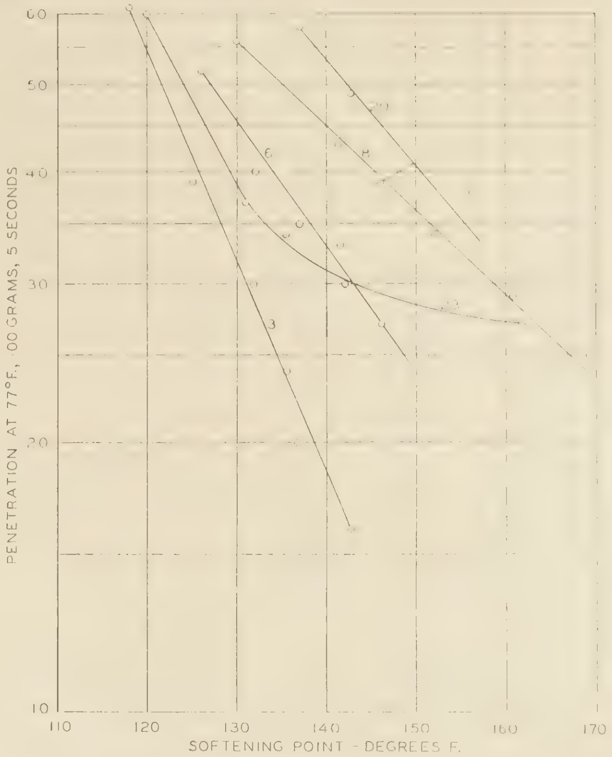

Figure 12.—Relation Between Softening Point and Penetration of Typical 50-60 Penetration Asphalts When Heated in Thin Films at 325° F., for Various Periods of Time.

Bateman and Delp (*1*) and Bateman and Lehmann (*2*) have shown the effect of the mixing process on the physical properties of the asphalt and the effect of the mixing temperatures on the penetration, the softening point, and the ductility of the asphalt extracted from the mixtures with carbon disulfide and recovered by a vacuum distillation. This work was confined to one type of asphalt and they concluded that penetration and ductility of the asphalt were decreased and the softening point was increased by the mixing operation and that these changes were affected by the mixing temperature. In recent years, with improvement in the technique of recovering the bitumens from solutions, investigations of asphalt from laboratory and plant mixes and from pavements have been made. Many of these investigations have been confined to the determination of drop in penetration only. Steinbaugh and Brown (*20*) included ductility determinations, and Shattuck (*19*) made softening point determinations on the recovered bitumen, as well as ductility and penetration tests.

The work of Steinbaugh and Brown led to the adoption by the Michigan Highway Department of a specification requirement that the penetration of the bitumen extracted from a pavement immediately after laying shall be not less than 50 percent of the original and that the ductility shall be not less than 40 centimeters.

A specification requirement of this type appears to be logical. Its use, however, introduces a practical difficulty that has been quite generally recognized. The responsibility for compliance with the test requirement is divided between the producer who furnishes the asphalt and the contractor who uses it. Shattuck (*19*) has developed a laboratory mixing test in which the probable loss in penetration and ductility of the asphalt to be furnished during the mixing and laying operations can be predetermined. Shattuck stated that an asphalt that failed to meet a specified drop in penetration and ductility when subjected to his laboratory mixing test would not meet the requirement outlined in some specifications for the ductility and penetration of bitumen extracted from the pavement after laying.

In the Shattuck mixing test (*19*) a 2,000-gram mixture, containing 94 percent of standard Ottawa sand and 6 percent of the asphalt to be tested, is mixed for 1 minute in a small laboratory rotary mixer, 6 inches in diameter and approximately 10 inches long. The air temperature of the mixer is brought to 275° to 300° F. The sand and asphalt are brought to temperatures of 400° and 300° F., respectively, before placing in the mixer. After mixing, the asphalt mixture is placed in a shallow pan, 7 by 11 by 1¼ inches, and is held in a constant-temperature oven at 350° F. for 30 minutes. After cooling to room temperature the bitumen is extracted and recovered by the Abson method. The recovered bitumen is tested for penetration, ductility, and softening point. Bituminous mixes, using proportions of aggregate, dust, and asphalt specified for the particular project, may also be tested in the same manner. Bituminous concrete containing aggregate from 1 inch to dust has been handled satisfactorily in this mixer.

The Public Roads Administration cooperated with Shattuck in the investigation (*19*) of his laboratory mixing test. Comparison was made of the properties of the residues from the thin-film oven tests with those of the asphalts recovered from the Ottawa sand and sheet asphalt sand mixtures used in the Shattuck test. Eight asphalts were selected from those used in Shattuck's work. The characteristics of these asphalts after

Table 8.—*Test characteristics of asphalts after exposure to Shattuck's mixing test and thin-film oven tests*

Identification No.	Source of base petroleum	Tested by laboratory	Penetration at 77° F., 100 gm., 5 sec.					Ductility at 77° F., 5 cm. per min.					Softening point				
			Original asphalt	Recovered bitumen		Residue from thin-film oven tests		Original asphalt	Recovered bitumen		Residue from thin-film oven tests		Original asphalt	Recovered bitumen		Residue from thin-film oven tests	
				Ottawa sand mix	Sheet asphalt mix	5 hours	7 hours		Ottawa sand mix	Sheet asphalt mix	5 hours	7 hours		Ottawa sand mix	Sheet asphalt mix	5 hours	7 hours
								Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
3	California	A	53	25	38	------	------	110+	110+	110+	------	------	124	135	130	------	------
		B	54	25	36	34	30	250+	250+	250+	250+	250+	119.6	134.5	128.1	129.3	130.8
4	West Texas	A	51	26	31	------	------	110+	7	13.5	------	------	128	141	133.1	------	------
		B	52	36	38	37	34	250+	66	193	77	40.5	126	137.8	133.6	137.5	140.3
6	Colombia	A	51	25	31	------	------	110+	13	32.5	------	------	126.1	146	141.8	------	------
		B	56	30	36	35	30	250+	20.5	137	105	61	126.8	145.3	139.0	141.0	144.5
6-A	Venezuela	A	52	26	32	------	------	110+	15.5 16.5	25 35	------	------	126	146.2	143	------	------
		B	54	27	33	35	32	250+	19.5	58	145	126	127.5	149.8	142.7	141.3	143.1
8	East Texas	A	51	29	34	------	------	107	7 10	10.5 12	------	------	136	160	153.3	------	------
		B	51	34	36	33	30	99	16.5	16.5	15	10.5	136	150.8	148.5	154.0	155.0
10-A	Venezuela	A	54	23	37	------	------	110+	7.5 8	39 40	------	------	131.1	159	142	------	------
		B	58	22	30	33	30	250+	7	20	62	22	127.4	158.3	148.4	146.0	147.0
12	Unknown	A	50	32	38	------	------	74	5	11 15	------	------	139.1	153.2	147.2	------	------
		B	51	34	42	36	33	84	7	23	10	8	135.9	153.1	141.5	150.0	154.0
12-B	do	A	50	35	37	------	------	110+	110+	110+	------	------	120.4	126	124	------	------
		B	51	29	34	34	31	250+	222	250+	250+	250+	120.5	130	125	127.8	130.5

making the mixing test and thin-film oven test are given in table 8. Test results for penetration, ductility, and softening point are shown for the original asphalt and the bitumen recovered from the Ottawa sand and sheet asphalt mixes, as determined in both laboratories, and for the residue from the thin-film oven tests for 5- and 7-hour periods as determined in the Public Roads laboratory.

THIN-FILM OVEN TEST FURNISHES INDICATION OF ASPHALT BEHAVIOR IN MIXING OPERATIONS

In general, the penetrations and softening points of the residues from the oven tests are approximately comparable to the penetrations and softening points of the bitumens recovered from the mixes. Except for sample 6-A, the ductilites of the thin-film residues are also generally comparable to the ductilites of the bitumens recovered from the mixes. The similarity of the reduction in penetration and ductility and the increase in softening point that occurred in these tests are better shown in figures 13 and 14 for 2 of the 8 asphalts (samples 6 and 12) tested in this manner.

In figure 13 the penetration of the asphalt recovered by both laboratories and the penetration of the residues from the 5- and 7-hour thin-film oven tests are plotted against the logarithms of their ductilities. The majority of these points for each asphalt fall closely along a straight line similar to those shown in figure 11 where the relationship is shown for residues from the thin-film tests only.

Figure 14 shows the relationship between softening point and penetration of samples 6 and 12 when subjected to the Shattuck mixing tests and the thin-film oven test. This figure shows the similarity between the reduction in penetration and increase in softening point that occurred under both testing conditions.

During 1935 and 1936 test sections of sheet asphalt pavement were constructed in Washington, D. C. Tests were made to determine the alterations in the physical properties of the asphalt during the mixing, laying and service of the paving mixture. The behavior of the asphalt in the thin-film oven tests also was determined. Samples were taken immediately after the hot mix was laid and compacted. Following construction, samples were taken at the end of 12, 18, 24, and 30 months of service. These samples were extracted and the asphalt recovered by the Abson method. The original asphalts were heated at 325° F. in $\frac{1}{8}$-, $\frac{1}{16}$-, and $\frac{1}{32}$-inch films for 2, 5, and 7 hours. The asphalts recovered from the pavement and the residues from the thin-film oven tests were tested for penetration, ductility, and softening point. The results of these tests, as well as the tests on the original asphalt, are given in table 9.

The relations between the penetration and ductility of the original asphalt, the bitumens from the pavement, and the residues from the thin-film oven test, are shown in figure 15. A majority of the points for the thin-film tests fall close to or on the line drawn. The points for the asphalts recovered from the pavement are approximately along the same line as the points for the thin-film residues. The reduction in penetration and ductility of the $\frac{1}{8}$-inch film residue, heated for 5 hours, was approximately the same as the reduction that occurred during mixing and laying. While there was no uniform reduction in penetration and ductility with increased age in the pavement, two samples from the 24-month period had considerable decreases. Schaub and Parr (*18*) noted the difficulty of determining the progressive hardening of asphalt in sheet asphalt pavements on city streets because of the great possibility of contamination in these areas.

Figure 16 shows the relation between softening point and penetration of the bitumen recovered from the pavement and the residues from the thin-film oven test. This figure furnishes additional evidence of the similarity of the behavior of asphalts when heated at 325° F. in thin films and their behavior during the mixing and laying operations and in service.

On the basis of data obtained from tests of freshly laid sheet asphalts from other projects, and from the Shattuck mixing tests, it is believed that the alterations in penetration, ductility, and softening point that occur in 50–60 penetration asphalt cements during the processing and laying of sheet asphalt pavements in accordance with present standard practice can be predicted from tests made on the residues from the thin-film oven test. It has been noted that when some asphalts are merely dissolved in benzene and recovered by the Abson method a marked reduction in ductility occurs, even though the asphalt has not been exposed to the mixing operation or to service, indicating that the Abson recovery method itself may change the asphalt. It is therefore believed that the thin-film oven test may be more generally indicative of the actual alterations that occur than is the Shattuck test.

TABLE 9.—*Test characteristics of an asphalt before and after thin-film oven tests and of the same asphalt recovered from the pavement after various periods of service*

TESTS ON ORIGINAL ASPHALT

Sample	Penetration at 77° F., 100 gm., 5 sec.	Ductility at 77° F., 5 cm. per min.	Softening point
		Cm.	*°F.*
A	57	250+	126.0
B	56	205	126.0
C	56	226	127.0

THIN-FILM OVEN TESTS ON RESIDUE

Film thickness	Time of heating at 325° F.	Penetration at 77° F., 100 gm., 5 sec.	Ductility at 77° F., 5 cm. per min.	Softening point
Inches	*Hours*		*Cm.*	*°F.*
⅛	2	42	118.0	136.4
	5	32	28.5	144.9
	7	28	14.0	150.9
1/16	2	37	63.0	141.0
	5	26	8.0	155.0
	7	21	6.0	163.4
1/32	2	30	15.0	149.8
	5	18	4.0	175.6
	7	16	3.3	185.0

TESTS ON RECOVERED BITUMEN FROM PAVEMENT SAMPLES

Age of pavement	Penetration at 77° F., 100 gm., 5 sec.	Ductility at 77° F. 5 cm. per min.	Softening point
Months		*Cm.*	*°F.*
0	31	29	143
	34	40	143
	33	80	141
	33	36	145
	33	35	144
	36	39	142
	32	33	145
12	35	85	141
	32	41	145
	34	51	143
	36	48	141
	31	27	146
18	34	30	144
	34	57	142
24	29	30	145
	26	12	151
	29	28	145
	30	36	146
	26	14	150
30	32	26	144
	38	100	139

REQUIREMENTS FOR 50-60 PENETRATION ASPHALTS MAY NOT BE APPLICABLE TO OTHER GRADES

The 5-hour, ⅛-inch film test appears to have possibilities for predicting the resistance of asphalts to the hardening and oxidizing influence of heat during the normal mixing process, thus providing essential information for the adjustment of temperature or construction features that tend to destroy ultimately the life of pavements containing highly susceptible materials. The test results given in table 10 and plotted in figure 17, for a series of Mexican asphalts, show, however, that any specification requirement based on the behavior of 50–60 penetration asphalts may not be applicable to those of other consistency grades. Figure 17 shows the percentage loss in penetration and ductility and percentage gain in softening point produced by the 5-hour thin-film oven test, plotted against the con-

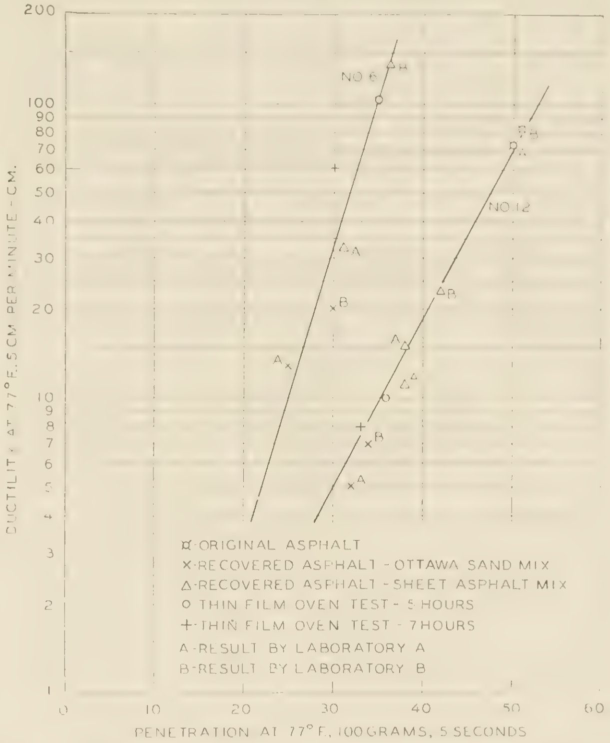

FIGURE 13.—RELATION BETWEEN PENETRATION AND DUCTILITY OF ASPHALTS SUBJECTED TO THE SHATTUCK TEST AND THIN-FILM OVEN TEST.

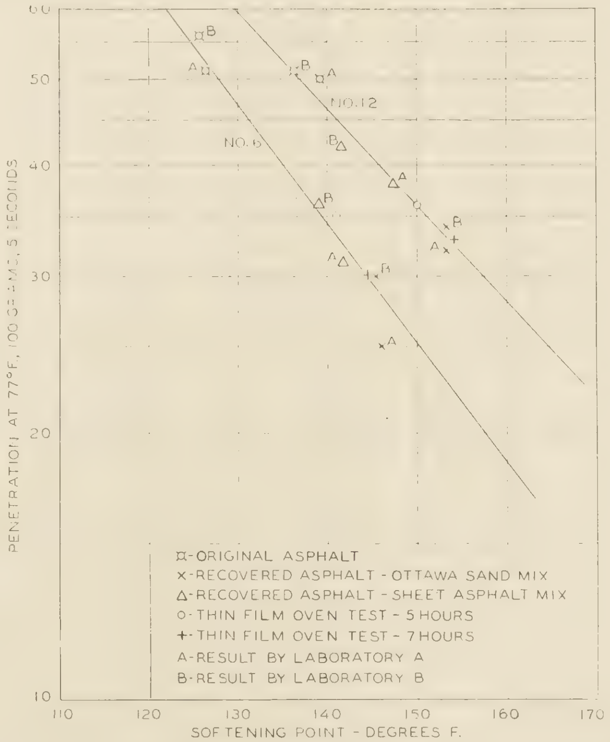

FIGURE 14.—RELATION BETWEEN SOFTENING POINT AND PENETRATION OF ASPHALTS SUBJECTED TO THE SHATTUCK MIXING TEST AND THIN-FILM OVEN TESTS.

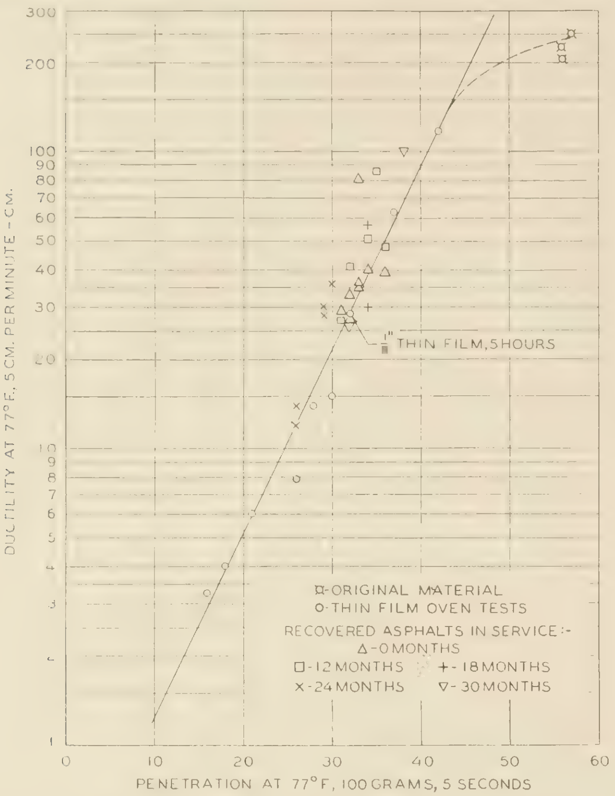

Figure 15.—Relation Between Penetration and Ductility of Bitumen Recovered From the Pavement and the Same Asphalt Heated in Thin Films at 325° F.

sistency of the original asphalt. The percentage loss in penetration and gain in softening point increases, but the percentage loss in ductility decreases, as the penetration of the original asphalt increases. The ductilities of the 150–180 and 180–200 grades are more than the ductilities of the original asphalts and are indicated by the negative values.

Table 10.—*Effect of thin-film oven tests on the characteristics of various grades of Mexican asphalt*

Penetration grade	Material tested	Penetration at 77° F. 100 gm. 5 sec.	Ductility at 77° F. 5 cm. per min.	Softening point	Loss in penetration by heating	Loss in ductility by heating	Gain in softening point by heating
			Cm.	*°F.*	*Percent*	*Percent*	*Percent*
30–40	Original asphalt	38	194	139.0			
	Residue from 5-hour test	24	25	153.5	36.8	87.1	10.4
50–60	Original asphalt	55	215	131.0			
	Residue from 5-hour test	33	70	145.0	40.0	67.4	10.7
70–80	Original asphalt	74	197	126.2			
	Residue from 5-hour test	42	81	140.3	43.2	58.9	11.2
85–100	Original asphalt	89	192	121.0			
	Residue from 5-hour test	49	125	135.9	44.9	34.9	12.3
120–150	Original asphalt	135	153	113.6			
	Residue from 5-hour test	66	132	132.2	51.1	13.7	16.4
150–180	Original asphalt	160	135	110.4			
	Residue from 5-hour test	71	137	131.2	55.6	[1] −1.5	18.8
180–200	Original asphalt	182	134	108.8			
	Residue from 5-hour test	78	135	128.3	57.1	[1] −0.7	17.9

[1] Ductility greater than original.

A recent project in which the Public Roads Administration was interested involved an asphaltic concrete

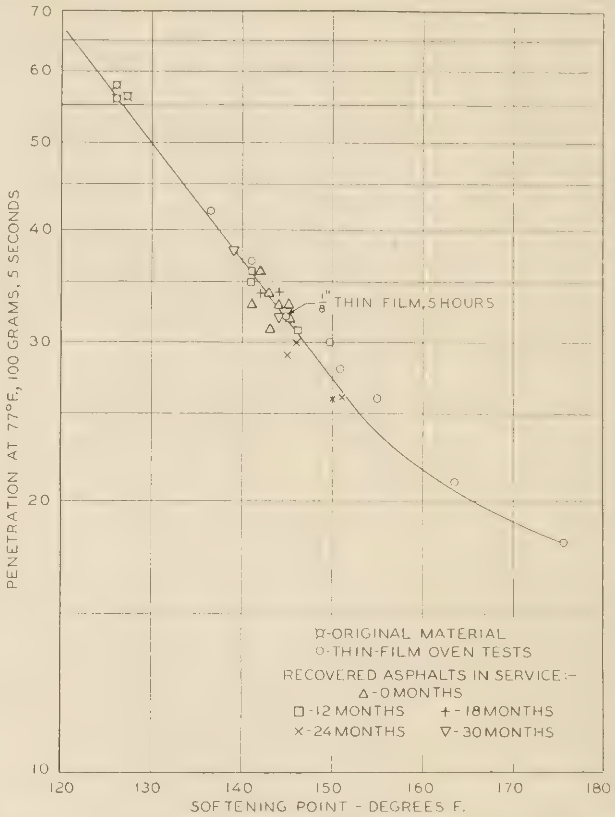

Figure 16.—Relation Between Softening Point and Penetration of Bitumen Recovered From the Pavement and the Same Asphalt Heated in Thin Films at 325° F.

mixture graded from ¾-inch to dust and containing approximately 6 percent asphalt cement of 120–150 penetration grade. The specification required that the extracted bitumen from a sample of the mixture taken from the finished pavement within 24 hours should have a penetration of not less than 50 percent of the penetration of the original material and a ductility of not less than 100 centimeters. The data given in tables 11 and 12 show that neither the Shattuck mixing test with Ottawa sand nor with the aggregate specified, when run with the standard temperatures for this test, namely, 400° F. for the aggregate, 300° F. for the asphalt, and 350° F. for the oven, nor the ⅛-inch film test, gave an approximate indication of the hardening that occurred. Although the plant mix was made with the asphalt and aggregate at approximately 275° F., the bitumens recovered from the pavement samples had penetrations approximately the same as the asphalt recovered from the mixture made in the Shattuck test, in which the temperature of the asphalt, aggregate, and curing oven were at a temperature of 200° F.

ABILITY TO RETAIN ORIGINAL CHARACTERISTICS CONSIDERED A MEASURE OF DURABILITY

It should be noted that the extracted bitumen of the lower penetrations had much higher ductility than those of higher penetration. It has been shown that if there has been no great change in susceptibility, the softer grades of asphalt will have lower ductilities than the harder grades. For most asphalts, the maximum ductility is obtained when the penetration is considerably below 100 (*11*). Accordingly, it may be quite difficult to set satisfactory limits for the ductility of

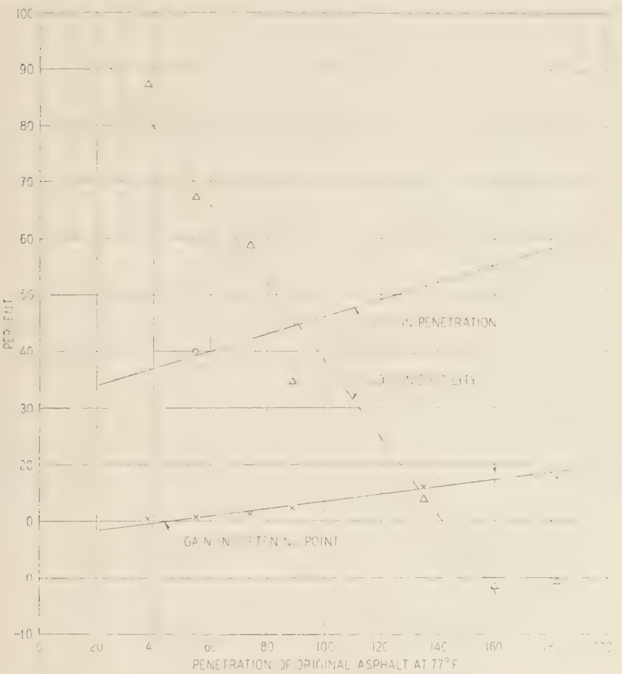

FIGURE 17.—EFFECT OF THE ORIGINAL CONSISTENCY OF VARIOUS GRADES OF MEXICAN ASPHALT ON THE CHANGES IN TEST CHARACTERISTICS PRODUCED BY THE 5-HOUR THIN-FILM OVEN TEST.

TABLE 11.—*Properties of 120–150 penetration asphalt after thin-film oven tests and after plant and laboratory mixing*

Identification No.	Source of material for tests	Tests on residue		
		Penetration at 77° F. 100 gm. 5 sec.	Ductility at 77° F. 5 cm. per min.	Softening point
			Cm.	*° F.*
	Original asphalt	134	134	104.2
R-1	Recovered from pavement immediately after laying [1]	126	160	108.5
R-2	do	129	131	107.5
M-1	Recovered from laboratory mixes [2]	126	138	108.4
M-2	do	121	138	107.2
M-3	do	58	250+	120.9
M-4	do	45	190	125.5
TF-1	Thin-film oven test, ⅛ inch film, 5 hours	77	203	116.6
TF-2	Thin-film oven test, 1/16-inch film, 5 hours	49	250+	123.5
TF-3	Thin-film oven test, 1/32-inch film, 5 hours	39	250+	128.0

[1] Recovered by Abson's method.
[2] Prepared by Shattuck's method; data on mixes given in table 12.

TABLE 12.—*Data on laboratory mixes prepared by Shattuck's method*

Identification No.	Temperature of aggregate	Temperature of asphalt	Temperature of oven	Aggregate used
	° F.	*° F.*	*° F.*	
M-1	200	200	200	¾-inch to dust.[1]
M-2	250	250	250	Do.
M-3	400	300	350	Do.
M-4	400	300	350	Ottawa sand.

[1] Approximately same grading as used on construction.

the extracted bitumen, if the softer grades of asphalt cements are used in hot-mix pavements.

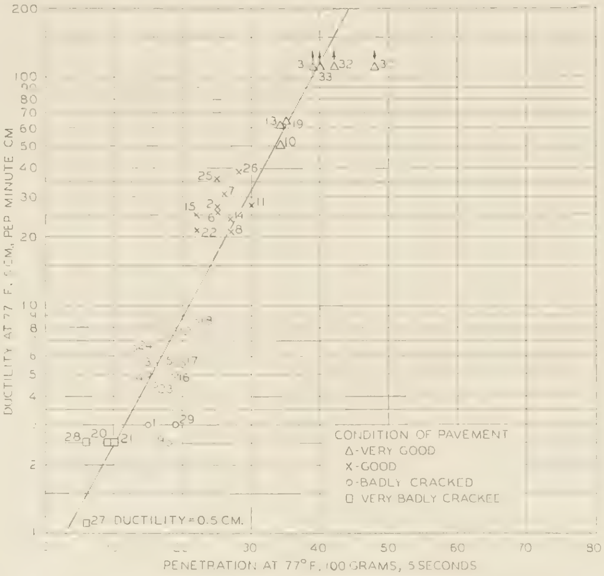

FIGURE 18.—RELATION BETWEEN PENETRATION AND DUCTILITY OF RECOVERED BITUMENS COMPARED WITH CONDITION OF DETROIT PAVEMENTS.

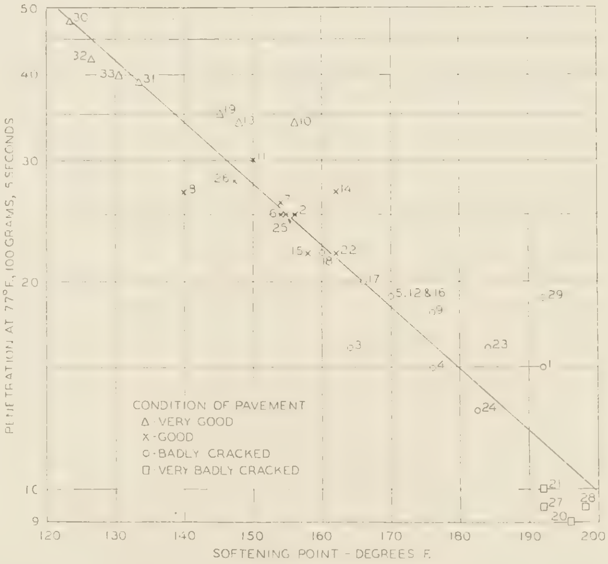

FIGURE 19.—RELATION BETWEEN SOFTENING POINT AND PENETRATION OF RECOVERED BITUMEN COMPARED WITH CONDITION OF DETROIT PAVEMENTS.

The examination of pavements by Shattuck (*19*) and by Vokac (*22*) show that the extracted bitumens in the pavements that have failed through cracking have lower penetrations, lower ductilities, and higher softening points than the bitumens in pavements that are satisfactory. The data given in table 1 of Shattuck's report on sheet asphalt pavements prepared with 40–45 and 50–55 penetration asphalts have been plotted in figures 18 and 19 to show the penetration-ductility and penetration-softening point relationships of the extracted bitumen. The condition of the pavement from which the asphalt was recovered is indicated. It will be seen that the majority of the points fall close to the average line. These figures show that not only the penetration but also the softening point and ductility can be closely correlated with the condition of the pavement.

The correlation of pavement condition, as shown in these figures, with the test characteristics of the extracted bitumen is in substantial agreement with the conclusions by Vokac (*22*) relative to penetration and ductility but not to softening point. Vokac stated that when the penetration of the extracted bitumen is less than 25, the ductility is less than 24 centimeters and the softening point is more than 160° F., the pavement containing asphalt of this character is of the cracking type. He also concluded that a softening point of less than 146° F. on the extracted bitumen is indicative of pavement that may shove. Shattucks' report *(19)* does not note this type of failure.

It has been demonstrated by many investigators that a major portion of the alterations that occur in the asphalt of hot-mix pavements that show a tendency to early cracking in service, occurs during the fabrication of the pavement. Accordingly, since it is indicated by the data presented that the thin-film oven tests develop residues with properties similar to those of the bitumens extracted from both laboratory and plant mixtures, a requirement limiting the loss in penetration and ductility could readily be applied to the residues from the thin-film oven test. A requirement of this sort would be of value in preventing the use of materials that are seriously impaired in the normal mixing operations, or it would serve as a warning that less damaging temperatures or more efficient plant design are necessary successfully to employ the particular material.

Lang and Thomas *(6)* and E. B. Tucker *(21)* have recently emphasized the necessity for considering the viscosity of asphalts at the mixing temperatures in general use for hot-mix pavements. Lang and Thomas showed, in a series of laboratory mixing tests on asphalts typical of those in use throughout the country, that the alterations that occurred in the highly susceptible asphalts when a constant mixing temperature was employed, were materially reduced when the mixing temperatures were adjusted to provide a uniform viscosity for all the asphalts during the tests. Specification requirements for hot-mix pavements should be drawn so that the particular asphalt to be used can be handled efficiently with as little change in original properties as possible.

In the previous report *(11)* the failure of these 50–60 and 85–100 penetration asphalts to pass many of the special test requirements that have been proposed for adequate control was discussed. The conclusion was drawn that these special tests were essentially tests that assist in the identification of source or the method of processing or that they were measures of special qualities. The opinion was expressed that they were not true measures of quality or durability. The term quality or durability was not defined. But on the basis of the data presented in this report and the work of other investigators, the ability of asphalts to retain their original characteristics in the fabrication of hot-mix pavements and in subsequent service may reasonably be considered as one measure of quality.

As previously noted, the specifications of the Michigan Highway Department require that the bitumen recovered from freshly laid pavements shall have a ductility of not less than 40 centimeters and a penetration of not less than 50 percent of that of the original asphalt. Hubbard and Gollomb *(4)* have concluded that for satisfactory hot-mix pavements the penetration of the recovered bitumen should be not less than 30. Miller, Hayden and Vokac *(13)* have used 29 and Vokac *(22)* later used 25 as the minimum satisfactory penetration.

Shattuck's investigation, the results of which are shown in figures 18 and 19, indicates that in the best pavements the ductility is greater than 40 centimeters and the penetration is more than 30. In general, these figures apply to hot-mix construction with asphalt having an initial penetration of 40–60. Therefore, it appears that an indication of the probable satisfactory performance of 50–60 penetration asphalts would be obtained by requiring that the residue from the thin-film oven test (⅛-inch film, 5-hour heating at 325° F.) should have a ductility of not less than 40 centimeters and a penetration not less than 50 percent of the original penetration. Concerning the desirable characteristics of the thin-film residues from 85–100 penetration asphalts very little is known, but for the time being it is suggested that it would not be unreasonable to adopt the same limit for loss in penetration as for asphalts of the 50–60 penetration grade and to require that the ductility of the residue should be not less than 100 centimeters. It will be of interest to observe the effect of such requirements on the 50–60 and 85–100 penetration asphalts included in this investigation.

ALTERATIONS IN ASPHALT IN HOT-MIX PROCESSES NOT PREDICTABLE FROM USUAL TESTS

In table 13 is listed the number of special tests, listed in table 14, that each asphalt failed to meet, and the number that would not meet the requirements proposed for the residues from the thin-film oven test. Eighteen of the 50–60 and 24 of the 85–100 penetration asphalts, failing from 1 to 11 and from 0 to 7 of the special tests, respectively, met the requirements stipulated for the thin-film oven test. Only 2 samples of the 50–60 grade and 4 samples of the 85–100 grade failed to meet the penetration requirement and these also failed to meet the ductility requirements. Twenty-one asphalts of the 50-60 grade and 16 asphalts of the 85–100 penetration grade failed to meet the ductility requirements indicating that these requirements are more severe than those for penetration and that the requirement of a minimum ductility of 40 centimeters for the 50–60 penetration grade is more severe than the minimum of 100 centimeters for the 85–100 penetration grade. Except for sample 29, which was not represented in the 50–60 grade, there was only one asphalt (sample 36) that failed in the 85–100 grade but did not fail in the 50–60 grade.

In table 14 the special tests and the usual specification requirements proposed for them are given. The number of samples failing or passing the thin-film oven tests and the number failing or passing each individual special test are indicated. The results of the Oliensis test appear to give the most consistent indication of the probable behavior in the thin-film oven test. There were 13 of 14 asphalts of the 50–60 grade and 10 of 15 asphalts of the 85–100 penetration grade that failed to pass the Oliensis test and also failed to meet the penetration and ductility requirements for the thin-film residues. Twenty-five asphalts of each grade passed the Oliensis test and of these 17 of the 50–60 grade and 19 of the 85–100 grade also passed the requirements for the thin-film test.

If the alterations occurring in these thin films are accepted as indications of the changes occurring in asphalts during fabrication of hot-mix pavements, it can be seen that the use, as specification requirements, of the special tests listed in table 14 will not entirely

Table 13.—*Comparison of samples failing special test requirements and those failing the thin-film oven test*

Identification No.	50–60 grade: Number of special tests each sample fails to pass	50–60 grade: Samples failing to pass thin-film oven test requirement for— Penetration 50+ percent	50–60 grade: Samples failing to pass thin-film oven test requirement for— Ductility 40+ cm.	85–100 grade: Number of special tests each sample fails to pass	85–100 grade: Samples failing to pass thin-film oven test requirement for— Penetration 50+ percent	85–100 grade: Samples failing to pass thin-film oven test requirement for— Ductility 100+ cm.
1	11			7		
2	11			5		
3	11			6		
4	11			6		
5	9			7		
6	6			5		
7	2			0		
8	7		X	5	X	X
9	3			1		
10	2			1		
11	2			1		
12	1			1		
13	4		X	4		X
14	5			3		
15	6		X	3		
16	5		X	4		X
17	4			3		
18	3			1		
19	5			5		
20	5		X	4		X
21	5			2		
22	3		X	2		
23	10		X	8	X	X
24	6		X	5		X
25	7		X	7		
26	8		X	5		X
27	6		X	5		
28	7		X	6		
29				9	X	X
30	4		X	5		
31	5		X	4		X
32	7		X	5		X
33	9		X	8		X
34	5		X	5		X
35	7			3		
36	7			7		X
37	3		X	4		X
38	4		X	5		X
39	9	X	X	6		
40	10	X	X	5	X	X

Table 14.—*Number of asphalts that pass or fail the thin-film oven test compared to the number that pass or fail the various special tests*

Special test	Proposed test requirement	Penetration grade	Fail thin-film requirement: Fail special test	Fail thin-film requirement: Pass special test	Pass thin-film requirement: Fail special test	Pass thin-film requirement: Pass special test
Fluidity factor	140+	50–60	12	9	10	8
		85–100	16	0	18	6
Float test index	90+	50–60	12	9	12	6
		85–100	0	16	1	23
Pen. 39.2° F., 200 gm., 60 sec. / Pen. 77° F., 100 gm., 5 sec.	30+ percent	50–60	0	21	4	14
		85–100	2	14	7	17
Pen. 115° F., 50 gm., 5 sec.—Pen. 32° F., 200 gm., 60 sec. / Pen. 77° F., 100 gm., 5 sec.	4.2—	50–60	11	10	16	2
		85–100	----	----	----	----
Ductility, 39.2° F., ¼ cm. per min.	1/10 pen. at 77° F	50–60	5	16	0	18
		85–100	3	13	0	24
Ductility 32° F., ¼ cm. per min.	1/10 pen. at 77° F.-1.	50–60	14	7	8	10
		85–100	11	5	3	21
Do	1/10 pen. at 77° F.	50–60	21	0	12	6
		85–100	13	3	5	19
Ductility 39.2° F., 5 cm. per min.	1/10 pen. at 77° F.	50–60	21	0	18	0
		85–100	15	0	23	1
Toughness test	10+	50–60	3	18	6	12
		85–100	1	15	4	20
Organic matter insoluble in 86° B. naphtha.	15–29 percent	50–60	4	17	6	12
		85–100	0	16	8	16
Fixed carbon	8–17 percent	50–60	0	21	4	14
		85–100	0	16	4	20
Sulfur	3+ percent	50–60	11	10	8	10
		85–100	12	4	13	11
Film test	Shall not coagulate.	50–60	3	18	0	18
		85–100	4	12	0	24
Oliensis test	Shall be negative	50–60	13	8	1	17
		85–100	10	6	5	19

insure asphalt of good durability. For instance, C. L. McKesson (*12*) concludes that sulfur probably contributes to early hardening and loss of ductility in asphaltic binders. Table 14 indicates that the sulfur content alone is not a true indication of the probable behavior of asphaltic materials. Of the 18 asphalts of the 50–60 grade that met the requirements of the thin-film test, 10 contained more than 3 percent of sulfur and of the 24 asphalts of the 85–100 grade that passed the thin-film test, 11 contained more than 3 percent of sulfur.

It is interesting to note that the asphalts that were the least susceptible to temperature change, as determined by the slope of the log penetration-temperature curve (*11*), consistently failed to pass the requirements proposed for the residue from the thin-film oven test. There were 10 asphalts of the 50-60 grade and 5 of the 85–100 grade that had slope values less than 0.021 and these all failed to pass the proposed limits set for the residue from the thin-film oven test.

Undoubtedly, under service conditions asphalts continue to show varying resistance to alterations depending on the character of service and the type of pavement. Asphalt technologists have centered their interest on changes in characteristics of asphalts chiefly in relation to the durability of hot-mix, dense-graded pavements, although the initial properties and the changes in properties of asphalt used in such pavements as penetration macadam and liquefier-type bituminous concrete probably contribute to the ultimate failure of these types of pavements. The data in this report and the facts generally known indicate that asphalts have different resistances to change. There is the possibility that those asphalts that are highly susceptible to the action of heat can be handled at such temperatures and in such manner that they reach the finished pavement with a minimum change in their original properties. This is a problem that the producer and the user dependent on such material must eventually meet.

CONCLUSIONS

1. The present standard test for loss on heating and degree of hardening does not furnish adequate information concerning the probable behavior of asphalts for use in hot-mix paving.
2. The relations between penetration and ductility and penetration and softening point determined from oven tests with thin films appear to be of value for predicting the changes in characteristics of asphalts that take place during mixing and after exposure to service conditions.
3. The changes that occur during the thin-film oven test (5 hours, ⅛-inch films) in asphalts of the 50–60 grade are comparable to the changes that may be expected to occur in bitumen recovered from mixtures prepared in paving plants or from laboratory mixes prepared to duplicate paving plant practice.
4. The ability of asphalts to retain their original characteristics as measured by tests for penetration, ductility, and softening point, after the 5-hour, ⅛-inch film oven tests, offers a means of evaluating their relative durability.
5. A specification requirement based on the decrease in penetration and ductility and the increase in softening point that occurs during the 5-hour, ⅛-inch film oven test should prevent the use of asphalts that are

injured by normal mixing temperatures, or should indicate the need for more moderate temperatures or better equipment to permit the asphalt to be incorporated in the pavement with a minimum of change.

6. Many of the special test requirements that have been proposed by various agencies for control of asphalt cement are not adequate measures of durability.

7. Lower mixing temperatures and improvement in equipment will prevent undue alterations occurring in those asphalts highly susceptible to change in the mixing operation.

8. Most of the producers furnished asphalt having high ductility but, in many cases, the ductile properties were materially reduced in both the thin-film residues and in the bitumen recovered from mixes.

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HIGHWAY CONSTRUCTION SPECIFICATIONS AVAILABLE

Specifications for construction of main highways through national parks and forests are now available in printed form from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. The price is $1.00 per copy—there is no free supply.

This 500-page publication is arranged in three parts. The first part contains general requirements on bidding, responsibility to the public, patents, liquidated damages, payments, etc.

The second part on construction details lists 27 items under earthwork; 12 under base courses; 18 under surface courses and pavements; 27 under structures, such as bridges, culverts, and retaining walls; and 38 under incidental construction, such as piling, curb and gutter, riprap, and sidewalks. No specifications are given for concrete road surfaces. Some of the listed items are preferred in all construction; others were included to meet local conditions and needs.

The third part is a sample bid schedule.

Issued by the Public Roads Administration, Federal Works Agency, the publication is titled, Specifications for Construction of Roads and Bridges in National Forests and National Parks.

Orders for the new publication should not be addressed to the Public Roads Administration.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF MARCH 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 282,122	$ 282,039	4		5	$ 655,601	$ 635,608	5	1	2	$ 45,132	$ 45,132			8	$ 1,114,605
Arizona	203,065	195,699	3		2	333,076	327,274	2			31,082	31,082		1	2	217,126
Arkansas	656,196	654,552	6	1	11	985,421	981,479	10		1	158,875	158,820	1		5	349,302
California	463,251	463,251	4		11	1,019,517	825,141	7	1		700,713	700,713	2		15	1,462,144
Colorado	2,410	2,410			1	296,835	296,835	1		1	469,151	469,151	3		2	694,227
Connecticut	622,002	611,366	5	1		166,222	165,415	2								615,261
Delaware	77,997	77,997	4		13	122,489	122,489	1		3	2,332	2,332			1	560,221
Florida	217,540	213,042	2		3	102,816	102,291	1	1		277,706	277,706	2		28	1,363,692
Georgia	209,905	209,810	4	2	13	1,278,713	1,278,713	11	7		27,484	27,484			6	2,168,865
Idaho	286,450	283,021	5		32	14,943	14,943				15,726	15,726			5	569,399
Illinois	1,770,151	1,688,952	9	1	63	1,321,951	1,096,496	4	1	81	419,181	397,155	2		41	2,653,066
Indiana	712,640	710,840	3	2	85	1,003,159	976,359	8	1	9	48,153	48,153			15	1,001,043
Iowa	492,562	467,338	4		87	370,426	342,594	4	1	11	174,811	173,876	1	1	17	1,363,796
Kansas	765,493	762,083	10		16	384,623	384,623	3	2	3	353,603	353,603	10		6	1,255,500
Kentucky	576,713	574,909	8		12	973,054	973,054	9			162,066	157,343	2		3	456,303
Louisiana	100,158	100,158	1			535,658	482,163	6			601,158	543,433	5		2	969,016
Maine	159,988	159,070	1	1	6	132,646	132,646	1	1							393,580
Maryland	180,997	180,993	1		2	485,009	453,216	2	2	7	60,550	60,550			12	920,364
Massachusetts	16,588	16,588		1		342,715	332,292	1			90,040	89,740	1			2,319,006
Michigan	1,156,339	1,113,193	8	1	36	1,447,042	1,447,042	2	5	3	338,600	338,600	2		4	942,999
Minnesota	1,443,430	1,433,048	12	2	19	621,477	621,477	4	4	1	658,018	658,018	3	3	2	1,053,609
Mississippi	263,360	263,360	3	1	1	674,834	674,834	9			62,999	62,999	1	1	5	759,480
Missouri	1,207,495	1,207,495	6	4	1	1,764,741	1,309,321	5	2		159,799	106,400		1		1,462,467
Montana	434,356	434,356	5		4	88,047	88,046	1			2,474	2,474			1	609,220
Nebraska	421,252	418,758	3	1	10	889,429	889,429	15	1	3	64,196	64,196	1		14	509,952
Nevada	72,617	72,617	1		20	70,501	70,501	1			71,448	71,448	1		5	154,921
New Hampshire	104,313	104,277	3		1	146,134	145,314	3			2,703	2,703			1	426,747
New Jersey	280,886	280,886	2		4	857,018	857,018	4	1		335,976	207,931	2		1	1,108,667
New Mexico	242,979	242,979	2		6	183,821	175,247	3			159,723	159,723	1			493,568
New York	1,229,561	1,186,966	7	5	8	3,712,833	3,656,862	7	16		172,900	172,400		1		3,559,087
North Carolina	578,938	578,875	8	3	25	632,989	632,749	6	3	6	198,385	198,385		3	34	1,200,318
North Dakota	426,458	424,555	5		22	390,220	390,220	4		1	78,223	78,223	1			813,593
Ohio	1,170,693	1,099,741	7	1	17	2,420,125	2,396,650	12	2		512,977	505,840	2			2,621,961
Oklahoma	613,845	611,471	10	1	38	390,096	386,680	3		12	196,054	196,054	1		42	2,181,198
Oregon	208,639	117,537	3			295,958	270,633	3			43,497	43,497	1		4	486,172
Pennsylvania	1,387,269	1,377,793	13	2		2,236,683	2,232,855	16			1,848,997	1,731,097	8			2,658,484
Rhode Island	8,220	7,406				206,703	206,703		1							177,279
South Carolina	447,320	446,917	4	3	21	201,460	201,460	3	1	2	274,995	257,395	1	1	31	983,216
South Dakota	136,127	133,502	2	1	4	564,332	563,472	16			104,420	88,470	2		1	1,017,636
Tennessee	245,718	241,009	2	2		225,803	216,803	1	3		235,009	235,009	3			1,874,209
Texas	1,480,753	1,474,324	12	1	10	1,336,470	1,323,890	15			557,950	556,460	5		1	2,172,328
Utah	87,141	86,930			32	72,826	72,084	2		22	84,753	84,753			31	304,788
Vermont	117,101	116,931		1	8	139,735	139,735		1	4	16,478	16,478			4	295,642
Virginia	205,954	204,508	2	2	7	741,175	740,955	6	2	5	69,632	69,632		1	5	869,365
Washington	363,183	361,168	4	2	10	438,515	438,515	3	3		11,529	11,529			4	451,739
West Virginia	12,130	12,130			3	532,452	526,832	5			116,160	116,160	2		4	991,751
Wisconsin	825,078	809,586	6	4	7	455,699	426,689	3		5	631,809	554,140	2	2	38	1,321,946
Wyoming	6,984	6,979			2	560,904	560,904	6			2,158	2,158			1	297,140
District of Columbia	56,868	56,868	1			2,193	2,193									275,206
Hawaii	8,416	8,141			2	194,767	194,759	2			272,046	210,000	2			181,413
Puerto Rico						584,007	579,336	11			133,350	132,170	2			450,269
TOTALS	23,039,651	22,588,424	205	46	680	33,603,863	32,362,839	249	63	182	11,055,021	10,486,341	72	15	401	53,152,886

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF MARCH 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 190,944	$ 95,263	9.4	$ 1,331,757	$ 665,858	60.8				$ 630,254
Arizona	240,851	169,479	23.6	198,250	119,359	5.4				426,637
Arkansas	416,160	179,101	14.8	460,066	229,180	32.8				309,298
California	894,281	488,989	38.0	1,022,836	705,275	13.6	$ 364,076	$ 191,240	7.9	743,343
Colorado	65,231	36,764	5.7	284,457	159,802	8.2	11,736	6,614	3.8	395,119
Connecticut	370,531	179,413	4.6	225,884	103,652	4.3	74,247	33,840	1.7	186,667
Delaware	127,253	55,913	12.7	46,219	22,675	2.8	82,663	37,626	6.9	313,605
Florida	63,276	31,230	1.6	1,022,611	478,979	18.7	85,045	42,523	.2	326,157
Georgia	147,024	72,610	18.6	954,275	462,138	76.2	166,693	83,347	21.1	1,384,580
Idaho	154,346	91,644	24.0	227,701	137,044	10.3	72,833	4,293	3.5	289,389
Illinois	1,743,814	823,679	80.6	1,017,450	493,725	35.4	448,990	203,400	31.9	704,993
Indiana	470,402	224,327	31.0	286,764	148,839	15.9	285,410	142,635	14.0	1,141,656
Iowa	2,364,931	1,120,985	500.6	608,169	289,200	184.9	192,990	80,260	56.3	496,305
Kansas	321,133	160,232	49.0	916,584	464,112	46.8	194,188	97,094	53.0	1,560,127
Kentucky	797,730	268,935	65.5	688,737	185,095	21.6	275,661	72,251	20.7	539,979
Louisiana	105,321	52,661	10.9	192,608	96,249	14.9				718,901
Maine	303,299	142,929	17.0	40,606	20,303	1.5				157,363
Maryland	128,300	64,150	5.5	98,390	49,195	4.5	225,000	97,500	12.6	452,165
Massachusetts	456,347	225,862	10.3	244,546	138,203	3.6	40,000	20,000	.7	658,018
Michigan	1,543,568	756,191	128.6	531,712	277,930	23.8	378,700	189,350	39.5	777,910
Minnesota	780,978	381,051	117.6	665,386	332,693	88.7	423,082	211,541	45.4	1,148,350
Mississippi	270,229	133,851	12.5	776,452	373,126	42.1	357,200	166,965	19.2	673,023
Missouri	733,428	362,715	96.5	136,270	68,135	13.4	542,988	232,778	50.5	1,018,872
Montana	641,506	362,577	80.3	131,028	73,938	9.3	430,412	243,726	78.0	731,303
Nebraska	575,564	276,209	107.0	573,693	286,624	60.1	198,900	99,098	25.1	479,779
Nevada	199,750	165,179	40.9	178,899	155,725	14.3				236,648
New Hampshire	143,639	68,883	3.4	71,533	34,946	3.6				223,280
New Jersey	389,276	194,533	15.3	287,722	160,375	6.7	346,390	173,195	6.8	517,436
New Mexico	180,724	95,310	20.0	644,662	356,677	25.5				326,218
New York	2,027,020	964,858	67.9	1,399,674	726,144	40.0	172,260	62,297	.6	804,647
North Carolina	946,814	471,235	82.2	427,713	216,468	42.5	260,344	99,325	16.5	509,936
North Dakota	42,143	23,432	.3	172,658	94,136	3.6				1,276,486
Ohio	1,711,142	852,793	59.8	1,775,720	886,600	53.7	200,100	100,050	11.3	1,268,410
Oklahoma	791,152	419,012	57.1	232,076	122,583	14.1	183,600	96,969	12.4	1,161,756
Oregon	371,724	205,456	56.4	300,440	151,654	24.5	240,849	111,122	21.0	362,178
Pennsylvania	1,741,032	856,391	59.9	747,296	373,648	13.4	1,281,082	638,911	30.6	292,316
Rhode Island	262,488	120,687	3.6	93,806	50,516	.9	4,740	2,370		122,054
South Carolina	572,292	209,926	79.0	485,240	170,890	37.6	395,667	174,800	35.9	237,042
South Dakota	3,714	3,624		25,302	15,768	9.0				1,543,134
Tennessee	150,956	72,135	8.7	287,466	143,733	10.0	97,118	48,559	3.2	1,187,186
Texas	1,415,529	693,036	193.1	1,196,786	592,790	108.3	193,830	86,630	24.2	1,573,168
Utah	88,404	49,100	9.5	185,785	123,660	22.1	193,545	72,831	12.1	249,359
Vermont	331,430	111,393	13.1	193,984	56,234	7.6				94,677
Virginia	387,164	181,027	24.8	549,368	256,641	19.7				511,438
Washington	609,592	320,705	31.0	343,673	212,028	25.6	56,751	30,400	.5	308,248
West Virginia	338,126	168,327	18.5	90,300	45,150	2.4	26,300	13,150		608,814
Wisconsin	328,957	163,259	7.4	768,024	391,013	25.5	588,597	271,260	28.4	717,583
Wyoming	433,021	260,037	42.8	259,381	139,362	12.2	95,766	20,000	6.6	218,678
District of Columbia	112,164	56,082	1.4	2,192	1,096		62,564	24,737	.6	91,208
Hawaii	264,732	132,578	8.6	1,096	1,096					250,559
Puerto Rico	143,800	70,400	6.4	213,613	104,380	9.7				167,407
TOTALS	27,893,232	13,686,158	2,377.0	23,616,860	11,964,642	1,332.1	9,250,317	4,282,687	702.7	31,123,659

U. S. GOVERNMENT PRINTING OFFICE 1941

PUBLICATIONS *of the* PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP. . Roadside Improvement. 10 cents.

No. 272MP. . Construction of Private Driveways. 10 cents.

No. 279MP. . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF MARCH 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 4,061,349	$ 1,917,944	101.2	$ 5,314,223	$ 2,648,070	190.4	$ 1,653,060	$ 821,650	60.7	$ 2,942,093
Arizona	1,266,080	880,867	53.5	1,836,963	1,212,237	78.6	428,157	266,227	9.7	1,718,750
Arkansas	5,068,643	2,323,583	125.2	1,280,844	638,716	56.3	126,384	63,151	3.0	1,729,539
California	6,922,594	3,534,472	132.8	8,118,332	4,298,692	125.2	1,865,238	972,433	30.4	3,963,139
Colorado	2,220,542	1,194,180	189.1	2,104,392	1,223,566	91.9	1,141,972	643,812	92.2	3,057,843
Connecticut	1,936,006	938,685	16.2	1,187,936	580,855	11.3	699,854	338,145	7.5	1,327,326
Delaware	1,854,252	926,347	28.3	338,421	142,552	4.2	363,173	177,192	11.8	1,359,124
Florida	2,512,745	1,248,025	62.5	2,017,139	1,029,357	72.6	600,927	300,463	12.9	3,589,656
Georgia	2,979,846	1,442,934	184.8	7,191,776	3,596,388	282.4	1,598,960	799,480	74.7	7,034,729
Idaho	1,560,205	924,308	151.0	1,040,215	640,970	56.9	698,728	424,829	19.1	2,175,303
Illinois	6,630,811	3,252,337	152.0	7,441,576	3,721,373	144.5	2,608,600	1,304,300	78.2	5,040,682
Indiana	5,154,984	2,534,678	120.9	7,452,303	3,619,933	108.7	1,835,833	761,433	36.4	2,345,244
Iowa	5,488,199	2,572,928	193.0	4,139,791	1,805,341	129.9	1,111,874	522,900	57.4	2,410,406
Kansas	4,503,844	2,202,666	385.9	5,561,032	2,822,183	304.9	2,391,248	1,183,590	134.6	5,123,646
Kentucky	3,044,711	1,513,679	91.1	3,057,383	1,539,372	86.9	3,437,784	1,718,892	110.1	2,913,214
Louisiana	1,270,088	629,985	16.1	12,582,422	3,340,198	64.9	930,859	457,742	33.1	4,240,969
Maine	1,297,724	633,944	29.2	1,599,027	821,653	21.0	18,200	9,100	.6	1,046,043
Maryland	1,270,568	623,817	29.1	3,296,959	1,647,361	25.9	374,303	187,151	4.0	1,889,340
Massachusetts	1,835,469	914,828	22.9	2,237,791	1,140,056	13.1	451,920	225,930	2.8	4,079,708
Michigan	6,151,906	2,871,499	215.0	8,385,010	4,179,905	198.9	1,891,210	945,605	32.5	2,400,486
Minnesota	6,032,441	2,918,243	459.5	4,174,545	2,083,890	232.9	3,207,795	1,602,835	154.8	4,408,545
Mississippi	2,954,906	1,274,662	124.5	6,755,974	3,157,497	378.4	1,835,120	894,760	101.5	2,152,235
Missouri	3,393,135	1,679,332	169.2	8,959,755	4,205,807	223.7	4,814,220	1,996,662	150.5	4,724,478
Montana	4,123,613	2,334,341	285.2	2,510,524	1,416,687	129.6	1,104,081	625,657	49.7	4,515,111
Nebraska	4,684,818	2,214,912	549.5	4,159,522	2,099,799	463.2	2,543,430	1,271,715	251.7	3,281,142
Nevada	1,568,973	1,338,924	80.0	1,469,766	1,279,599	73.2	515,124	392,001	20.6	1,260,057
New Hampshire	1,436,947	705,498	36.4	416,295	206,110	9.0	118,536	59,125	.7	1,358,573
New Jersey	2,277,954	1,117,617	11.8	6,832,152	3,415,996	52.2	9,945	4,972		1,750,074
New Mexico	2,316,417	1,401,463	188.5	1,528,856	939,597	62.2	323,691	209,299	25.9	2,188,977
New York	11,495,431	5,564,413	199.0	11,176,318	5,562,460	137.6	629,727	313,109	12.0	5,051,912
North Carolina	4,350,900	2,173,697	233.2	4,920,122	2,445,935	210.8	948,838	473,485	37.0	3,076,451
North Dakota	1,869,206	996,382	191.9	2,595,236	1,488,768	197.4	2,836,094	1,455,965	232.5	4,475,472
Ohio	7,207,318	3,602,840	93.1	12,396,990	6,171,616	99.0	6,849,493	3,279,090	53.7	3,987,081
Oklahoma	3,029,510	1,605,209	134.0	2,790,654	1,436,429	84.1	1,977,200	1,029,825	101.0	5,307,772
Oregon	3,277,276	1,959,171	155.9	2,818,825	1,506,569	73.2	1,523,137	866,020	45.3	1,363,609
Pennsylvania	6,241,430	3,082,407	80.7	13,341,298	6,621,635	109.1	3,927,165	1,850,054	40.4	3,784,215
Rhode Island	1,294,668	644,176	13.2	928,546	463,642	7.9	67,790	33,895	.6	1,225,431
South Carolina	1,984,214	955,732	143.1	2,900,697	1,374,625	126.8	1,080,910	476,143	53.8	2,612,659
South Dakota	3,134,346	1,771,172	530.9	3,930,873	2,466,093	479.3	1,219,600	707,480	176.4	3,295,110
Tennessee	2,706,986	1,342,667	58.1	4,176,138	2,088,069	146.5	1,535,736	767,868	22.4	4,501,646
Texas	8,322,487	4,033,525	479.4	11,525,132	5,693,599	536.3	3,770,243	1,836,360	149.0	8,247,432
Utah	997,642	709,126	73.1	1,097,600	822,629	46.0	359,100	155,180	7.0	1,677,271
Vermont	1,194,683	560,795	36.6	873,155	442,716	23.7	348,476	174,238	9.4	592,788
Virginia	2,568,018	1,197,907	72.5	4,376,798	2,073,975	74.6	398,487	152,208	4.7	2,619,036
Washington	3,308,178	1,693,052	86.8	3,052,642	1,621,649	27.8	15,022	6,900		1,902,577
West Virginia	2,133,911	1,063,369	75.7	3,385,934	1,686,765	73.0	939,976	465,890	8.8	1,901,516
Wisconsin	5,254,548	2,563,710	182.5	2,621,338	1,299,038	98.6	1,551,132	718,390	49.3	4,818,930
Wyoming	1,801,984	1,106,448	196.2	1,184,199	763,574	137.3	585,584	374,955	37.7	1,455,838
District of Columbia	498,667	249,021	5.1	603,588	301,209	.8	224,623	112,300	1.8	555,731
Hawaii	236,412	115,318	4.1	590,134	314,078	7.8	138,944	69,472	2.5	1,954,355
Puerto Rico	519,644	257,240	10.9	1,520,252	750,590	22.2	259,640	128,190	2.6	934,119
TOTALS	169,247,229	85,314,075	7,260.4	215,797,393	106,849,423	6,412.7	69,887,143	34,628,068	2,615.0	151,367,383