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FURTHER STUDIES OF LIQUID ASPHALTIC ROAD MATERIALS

BY THE DIVISION OF TESTS, U. S. BUREAU OF PUBLIC ROADS

Reported by R. H. LEWIS Associate Chemist, and W. O'B. HILLMAN, Assistant Highway Engineer

IN A REPORT recently published by the Bureau of Public Roads on A Study of Some Liquid Asphaltic Materials of the Slow-Curing Type,[1] it was shown that the action of sunlight, heat, and air on these materials when exposed in relatively thin films produced residues with physical and chemical characteristics differing greatly from those of the residues developed in the usual laboratory heat tests. It was also shown that when these materials were mixed with a standard sand, molded into cylinders by the Hubbard-Field method, and subjected to the same exposure conditions as the thin films, they developed stability, or bonding strength that could not be attributed entirely to the loss of volatile matter.

MATERIALS STUDIED TYPICAL OF ALL CLASSES OF LIQUID ASPHALTIC MATERIALS FROM PRINCIPAL PRODUCING AREAS

The materials used in the earlier investigation were slow-curing liquid asphalts. They were the products of 10 refineries located in the far and middle West. In further studies conducted in 1933, that are the subject of this report, 32 materials typical of the slow-, medium-, and rapid-curing types of liquid asphaltic materials were used. These samples are identified in table 1 and were the products of 25 refineries located in all sections of the country and probably were made from petroleums of widely different bases and by various refining processes.

TABLE 1.—*Products tested*

Sample identification	Laboratory number	Type of material	Producer	Refinery	Location of refinery	Remarks
1	36626	SC-2	1	1	Oklahoma	
2	34354	SC-2	2	2	Missouri	
3	35130	SC-2	2	3	Illinois	
4	35481	SC-3	3	4	do	
5	36425	SC-3	3	5	Wyoming	
6	36045	SC-3	4	6	Arkansas	
7	36945	[1] SC-2	5	7	do	
8	36598	SC-2	6	8	Oklahoma	
9	35195	[1] SC-2	7	9	West Virginia	
10	35334	[1] SC-2	8	10	Rhode Island	
11	35200	[2] SC-1	9	11	Louisiana	
12	35396	[1] SC-2	9	11	do	
13	36026	SC-3	9	11	do	
14	35351	SC-2	2	12	Indiana	
15	35180	SC-2	2	13	Wyoming	
16	35181	SC-2	2	14	do	
17	35103	SC-2	10	15	Indiana	Included in 1932 exposure.
18	35367	SC-2	10	16	Illinois	do.
19	34322	SC-2	11	17	do	do.
20	36089	SC-2	12	18	California	do.
21	39161	SC-2	13	19	do	Steam-reduced California residual oil.
22	39162	[2] SC-3	13	19	do	
23	39068	[1] SC-2	7	20	South Carolina	
24	34285	RC-2	14	21	New Jersey	
25	36762	[2] RC-2	3	22	do	
26	35345	RC-2	2	12	Indiana	
27	35352	[2] MC-1	2	12	do	
28	35247	RC-2	7	23	Maryland	
29	36771	RC-2	15	24	do	
30	33607	[3] MC-2	16	25	Wyoming	
31	32916	MC-2	2	13	do	
32	32622	MC-2	13	19	California	

[1] Furol viscosity was below specification limit.
[2] Furol viscosity was above specification limit.
[3] Penetration of distillation residue was below specification limit.

As shown in table 1, 23 of the materials were of the slow-curing type, of which 4 samples were tested in 1932 and were included in this study for comparative purposes. Four were of the medium-curing type and five were rapid-curing products. They met the provisional specifications, as given in table 2, of the Bureau of Public Roads and the Asphalt Institute, except as noted in table 1. Samples 21 and 22 were the only slow-curing products for which there was any definite information as to origin or method of manufacture. Both of these materials were steam-reduced California residuals without subsequent blending. All of the rapid-curing products were prepared from 85–100 penetration asphalt and solvent naphtha. The composition of sample 27 was unknown but the other medium-curing products, samples 30, 31, and 32, were, respectively, 110–120 penetration asphalt, 94+ asphaltic road oil, and 100–120 penetration asphalt fluxed with a heavy grade of kerosene. These three medium-curing materials, although subjected to all of the laboratory tests, were exposed only under special conditions that are described later in this report.

TABLE 2.—*Specification requirements for grades of liquid asphaltic road materials investigated*

	SC-1	SC-2	SC-3	MC-1	MC-2	RC-2
Flash point, °F	150+	200+	200+		150+	80+
Furol viscosity at 77° F., seconds	20–150			40–150		
Furol viscosity at 122° F., seconds		200–320				200–400
Furol viscosity at 140° F., seconds			150–300		150–250	
Total distillate to 437° F., percent by volume		2−	2−	10−	2−	10+
Total distillate to 600° F., percent by volume		15−	10−	25+	10–20	20+
Total distillate to 680° F., percent by volume	50−	25−	20−	50−	27−	35−
Tests on distillation residue:						
Float at 122° F., seconds	50−	25+	25+			
Penetration at 77° F				70–300	100–300	60–120
Ductility at 77° F., centimeters				60+	60+	60+
Soluble in CS_2, percent	99.0+	99.0+	99.0+	99.5+	99.5+	99.5+

The test procedure followed that of the 1932 study except that the fixed-carbon test was omitted as the changes in inherent characteristics that occurred under laboratory and exposure conditions appeared to be more strikingly illustrated by the test for solubility in 86° B. naphtha. Two new tests were added. The Oliensis test[2] for heterogeneity was made on the original materials and on all of the residues, except those from the 50-gram oven-loss test and the 10-week exposure test, and the original materials were examined microscopically. The results of the tests on the original materials are given in table 3 and a detailed analysis of the residues obtained in the routine laboratory tests is given in table 4.

[1] R. H. Lewis and W. O'B. Hillman, PUBLIC ROADS, June 1934, vol. 15, no. 4.

[2] A qualitative test for determining the degree of heterogeneity of asphalts. G. L Oliensis, Proc. A. S. T. M., vol. 33, pp. 715–728.

TABLE 3.—*Results of tests on original materials*

Sample identification	Specific gravity at 77° F.	Flash point	Float at 77° F.	Furol viscosity: At 122° F.	Furol viscosity: At 140° F.	Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B. naphtha	Characteristic by Oliensis test [1]	Microscopic smear test	Distillation: Initial boiling point	Distillation: Distillate by volume: At 374° F.	Distillation: Distillate by volume: At 437° F.	Distillation: Distillate by volume: At 600° F.	Distillation: Distillate by volume: At 680° F.	Distillation: Distillate to 680° F. (by weight)	Distillation: Loss on cooling (by weight)	Distillation: Total loss (by weight)	Distillation: Tests on distillate: Specific gravity at 77° F.	Distillation: Tests on distillate: Index of refraction	Distillation: Float of residue at 122° F.	Distillation: Penetration of residue at 77° F., 100 g, 5 sec.	Loss at 325° F., 5 hours: 50-gram sample: Loss	Loss at 325° F., 5 hours: 50-gram sample: Float of residue at 122° F.	Loss at 325° F., 5 hours: 50-gram sample: Penetration of residue at 77° F., 100 g, 5 sec.	Loss at 325° F., 5 hours: 20-gram sample: Loss	Loss at 325° F., 5 hours: 20-gram sample: Float of residue at 122° F.	Loss at 325° F., 5 hours: 20-gram sample: Penetration of residue at 77° F., 100 g, 5 sec.	Asphaltic residue: Time of reduction	Asphaltic residue: Amount of residue
		° F.	Sec.	Sec.	Sec.	Pct.	Pct.	Pct.			° F.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.			Sec.		Pct.	Sec.		Pct.	Sec.		Min.	Pct.
1	0.965	430	100	294	146	----	0.22	6.3	H	Clear---	680+	----	----	----	----	----	2.8	2.8	----	----	24	----	0.5	24	----	0.8	27	----	280	71.9
2	1.056	300	52	303	139	0.19	1.11	26.1	H	----	600	----	----	----	8.0	6.4	4.6	11.0	0.911	1.5146	60	----	3.5	35	----	6.6	57	----	40	74.7
3	1.056	330	50	274	123	.11	.46	21.8	H	----	628	----	----	----	3.0	2.4	4.4	6.8	.926	1.5246	43	----	2.6	30	----	4.6	38	----	47	71.7
4	1.043	340	63	404	174	.13	.47	16.5	H	----	625	----	----	----	2.0	1.7	4.0	5.7	----	1.5120	45	----	2.6	39	----	4.5	51	----	60	74.7
5	.998	275	36	331	160	----	.10	13.7	H	Clear---	525	----	----	1.3	10.0	8.6	5.0	13.6	.886	1.4930	58	----	5.1	36	----	8.6	57	----	80	70.6
6	.974	340	21	335	170	----	.09	9.4	O	---do---	594	----	----	----	3.0	2.5	4.9	7.4	----	1.4794	21	----	3.0	17	----	4.9	20	----	236	62.4
7	.960	255	9	181	104	----	.11	10.6	SH	---do---	515	----	----	7.0	20.5	18.3	5.1	23.4	.868	1.4809	62	----	8.0	18	----	14.3	34	----	140	64.8
8	.957	355	60	277	146	----	.09	6.7	O	---do---	620	----	----	----	2.0	1.6	4.8	6.4	----	1.4748	27	----	2.1	25	----	3.3	27	----	275	65.3
9	1.032	250	33	175	87	.38	2.39	18.1	H	----	500	----	----	1.0	7.0	5.6	5.3	10.9	.864	1.4858	44	----	4.4	29	----	6.9	45	----	48	69.0
10	.963	160	11	197	110	----	.10	13.9	O	Clear---	450	----	----	13.0	19.5	16.9	5.4	22.3	.837	1.4615	87	----	12.7	42	----	16.6	74	----	70	65.9
11	1.010	245	4	50	31	----	.20	7.6	H	---do---	520	----	----	7.5	22.0	20.5	4.5	25.0	.956	1.5445	34	----	8.8	10	----	15.2	20	----	93	53.2
12	.963	265	13	182	100	----	.09	10.7	O	---do---	525	----	----	2.5	13.5	12.2	5.7	17.9	.866	1.4770	38	----	6.6	18	----	10.2	27	----	121	61.8
13	1.010	320	41	406	195	----	.09	11.3	H	---do---	600	----	----	----	5.5	4.8	4.5	9.3	.958	1.5460	37	----	3.7	30	----	6.2	36	----	110	66.8
14	1.060	350	49	278	124	.09	.09	17.6	H	----	665	----	----	----	1.0	.9	4.2	5.1	----	1.5268	36	----	2.4	31	----	4.2	39	----	60	69.5
15	.979	285	21	219	117	----	.08	11.6	O	Clear---	580	----	----	.5	12.0	10.2	5.2	15.4	.871	1.4785	41	----	5.0	24	----	8.6	30	----	113	61.7
16	.970	360	38	217	115	----	.11	9.6	SH	---do---	670	----	----	----	1.0	1.0	5.8	6.8	----	1.4755	25	----	1.9	17	----	3.5	24	----	176	62.0
17	1.013	255	20	205	110	.17	2.17	16.1	H	----	536	----	----	7.0	20.0	16.3	4.3	20.6	.853	1.4714	110	----	8.8	42	----	14.1	112	----	34	71.9
18	.955	200	9	199	106	----	.11	4.6	SH	Clear---	482	----	----	13.5	19.3	16.5	1.2	17.7	.821	1.4529	60	----	10.7	26	----	15.6	55	----	420	75.1
19	1.082	300	75	320	137	.08	2.88	25.8	H	----	599	----	----	----	8.3	7.0	2.9	9.9	.937	1.5364	57	----	4.9	48	----	7.9	79	----	30	75.9
20	.960	275	46	300	149	----	.08	7.5	SH	Clear---	576	----	----	----	10.8	9.4	4.5	13.9	.849	1.4665	50	----	6.0	34	----	8.3	52	----	103	68.9
21	.972	295	23	293	137	----	.06	5.4	O	---do---	580	----	----	----	11.0	9.8	5.0	14.8	.890	1.4859	41	----	5.7	26	----	10.7	39	----	83	62.6
22	.976	310	60	768	331	----	.09	6.5	O	---do---	600	----	----	----	6.0	5.1	4.7	9.8	.889	1.4852	56	----	4.3	42	----	7.7	58	----	83	70.6
23	1.012	260	12	123	63	----	.07	7.9	H	---do---	530	----	----	1.3	8.5	7.3	4.2	11.5	.882	1.4904	27	----	5.5	22	----	9.1	30	----	97	60.9
24	.972	85	14	241	133	----	.10	17.3	H	---do---	332	3.0	13.5	23.8	27.0	21.7	3.1	24.8	.799	1.4420	----	76	20.6	----	152	22.2	----	80	13	77.2
25	.946	80	31	472	229	----	.15	20.9	O	---do---	250	11.5	18.5	25.3	27.5	21.6	2.2	23.8	.763	1.4203	----	77	21.5	----	99	22.4	----	56	14	78.2
26	.949	115	35	351	185	----	.11	18.2	O	---do---	370	----	11.0	23.8	26.5	21.7	1.7	23.4	.782	1.4320	----	84	20.7	----	113	22.4	----	55	11	78.4
27	.988	170	3	47	30	----	.11	14.5	H	---do---	420	----	.5	28.0	32.5	27.1	3.0	30.1	.829	1.4606	----	87	22.1	100	----	27.8	----	41	22	72.6
28	.954	80	19	303	170	----	.19	17.6	O	---do---	270	10.5	18.0	23.0	24.5	19.6	1.5	21.1	.763	1.4256	----	65	19.8	----	85	20.4	----	50	11	80.4
29	.960	80	17	260	148	----	.13	20.8	H	---do---	----	15.0	21.0	25.5	27.0	21.0	2.5	23.5	.751	1.4156	----	72	21.1	----	94	21.9	----	53	15	78.5
30	.978	200	39	350	173	----	.09	20.8	H	---do---	430	----	----	21.0	26.5	22.2	3.4	25.6	.837	1.4668	----	81	17.6	186	----	23.8	----	56	16	75.8
31	.994	205	37	431	216	----	.12	19.7	H	---do---	450	----	----	16.0	21.5	17.3	2.9	20.2	.827	1.4600	----	205	14.5	144	----	19.1	----	100	30	78.9
32	.968	195	25	331	162	----	.15	10.5	SH	---do---	360	----	----	13.5	21.0	17.9	4.2	22.1	.831	1.4568	----	298	13.6	87	----	18.5	----	235	23	75.0

[1] H = Heterogeneous; O = Homogeneous; SH = Slightly heterogeneous.

DISTILLATION CURVES CLEARLY DISTINGUISH SLOW-, MEDIUM-, AND RAPID-CURING MATERIALS

The distillation curves for the various materials, plotted in figure 1, serve to distinguish the three classes of materials according to their curing properties. It will be noted that the initial boiling points of the slow-curing products, samples 1 to 23, inclusive, were all above 450° F. and in only two instances were they less than 500° F. The medium-curing materials, samples 27, 30, 31, and 32, had initial boiling points as low as 360° F. with none above 450° F.; and the rapid-curing products, samples 24, 25, 26, 28, and 29, all had initial boiling points below 370° F.

With all three classes of materials, the percentage of distillate increased as the temperature increased but not at the same rate. For the slow-curing materials the rate continued fairly uniform up to 680° F., but with the medium- and rapid-curing products it decreased as the temperature approached 680° F. The decrease in rate was more pronounced for the rapid-curing products. The rate of distillation may be illustrated by expressing the amount of distillate off at any temperature in terms of the total distillate recovered at 680° F. For the medium-curing materials the amount at 600° F. was 65 to 85 percent of the total. For rapid-curing materials the amount was 0 to 50 percent at 374°F., 41 to 85 percent at 437° F., and 88 to 94 percent at 600° F. The residues from the distillation of the slow-curing products were all fluid, while those of the medium- and rapid-curing materials were semisolid.

That portion of the total loss in the distillation test designated as loss on cooling depends upon the amount of material boiling off immediately above 680° F. As would be expected from the slope of the distillation curves, this loss was greater for the slow-curing products than for the medium- and rapid-curing products. It ranged from 1.2 percent to 5.8 percent with an average of 4.5 percent for the slow-curing products, from 2.9 percent to 4.2 percent with an average of 3.4 percent for the medium-curing products, and from 1.5 percent to 3.1 percent with an average of 2.2 percent for the rapid-curing products.

The total volatile matter in the slow-curing materials as determined by the distillation test, including both the distillate recovered and the loss on cooling, ranged from 2.8 percent to 25 percent with an average of 13.8 percent for the group. The average loss on cooling of 4.5 percent actually represented 36 percent of the total volatile matter in the average slow-curing material used in this study. While this loss on cooling may be unimportant in estimating the relative volatility of various liquid asphalts, it must be considered if the results of the distillation test are to be compared directly with the results of other laboratory and exposure tests.

The different classes of materials are also readily identified by the results of the volatilization and asphaltic-residue tests. The slow-curing products lost in the 50-gram volatilization test from 53 to 76 percent, the medium-curing products from 73 to 80 percent, and the rapid-curing products from 92 to 97

Table 4.—*Results of tests on laboratory residues*

Distillation

Sample identification	Total loss in distillation test	Tests on residue: Float at 122° F.	Tests on residue: Penetration at 77° F., 100 g, 5 sec.	Tests on residue: Penetration at 32° F., 200 g, 60 sec.	Tests on residue: Softening point	Tests on residue: Ductility at 5 centimeters per minute at 77° F.	Tests on residue: Ductility at 5 centimeters per minute at 34°–35° F.	Tests on residue: Organic matter insoluble in CS_2	Tests on residue: Organic matter insoluble in CCl_4	Tests on residue: Insoluble in 86° B. naphtha
	Pct.	Sec.			° F.	Cm	Cm	Pct.	Pct.	Pct.
1	2.8	24	----	----	----	-----	-----	-----	0.10	6.9
2	11.0	60	----	----	----	-----	-----	0.16	.81	32.2
3	6.8	43	----	----	----	-----	-----	.17	.41	24.3
4	5.7	45	----	----	----	-----	-----	.15	.34	21.0
5	13.6	58	----	----	----	-----	-----	-----	.17	16.1
6	7.4	21	----	----	----	-----	-----	-----	.08	10.9
7	23.4	62	----	----	----	-----	-----	-----	.13	14.5
8	6.4	27	----	----	----	-----	-----	-----	.10	7.8
9	10.9	44	----	----	----	-----	-----	.31	2.37	24.1
10	22.3	87	----	----	----	-----	-----	-----	.11	18.3
11	25.0	34	----	----	----	-----	-----	-----	.09	10.3
12	17.9	38	----	----	----	-----	-----	-----	.12	12.7
13	9.3	37	----	----	----	-----	-----	-----	.10	11.7
14	5.1	36	----	----	----	-----	-----	.15	.15	18.0
15	15.4	41	----	----	----	-----	-----	-----	.10	14.0
16	6.8	25	----	----	----	-----	-----	-----	.15	10.7
17	20.6	110	----	----	----	-----	-----	.38	1.83	21.3
18	17.7	60	----	----	----	-----	-----	-----	.09	7.2
19	9.9	57	----	----	----	-----	-----	.08	4.54	35.2
20	13.9	50	----	----	----	-----	-----	-----	.09	9.5
21	14.8	41	----	----	----	-----	-----	-----	.13	6.1
22	9.8	56	----	----	----	-----	-----	-----	.09	6.7
23	11.5	27	----	----	----	-----	-----	-----	.12	9.6
24	24.8	-----	76	18	117	110+	0.0	-----	.12	23.0
25	23.8	-----	77	28	122	110+	4.5	-----	.18	25.4
26	23.4	-----	84	28	116	110+	4.0	-----	.12	21.0
27	30.1	-----	87	15	109	110+	.0	-----	.13	26.8
28	21.1	-----	65	20	122	110+	.5	-----	.16	21.8
29	23.5	-----	72	25	121	110+	4.5	-----	.16	29.0
30	25.6	-----	81	25	117	99	2.5	-----	.16	29.0
31	20.2	-----	205	41	101	110+	15.0	-----	.10	24.5
32	22.1	-----	298	55	93	75	90+	-----	.23	12.2

Loss at 325° F., 5 hours

Sample identification	50-gram sample: Loss	50-gram sample, tests on residue: Float at 122° F.	50-gram sample, tests on residue: Penetration at 77° F., 100 g, 5 sec.	50-gram sample, tests on residue: Penetration at 32° F., 200 g, 60 sec.	50-gram sample, tests on residue: Softening point	50-gram sample, tests on residue: Ductility at 5 centimeters per minute at 77° F.	50-gram sample, tests on residue: Ductility at 5 centimeters per minute at 34°–35° F.	20-gram sample: Loss	20-gram sample, tests on resdue: Float at 122° F.	20-gram sample, tests on resdue: Penetration at 77° F., 100 g, 5 sec.	20-gram sample, tests on resdue: Organic matter insoluble in CS_2	20-gram sample, tests on resdue: Organic matter insoluble in CCl_4	20-gram sample, tests on resdue: Insoluble in 86° B. naphtha
	Pct.	Sec.			°F.	Cm	Cm	Pct.	Sec.		Pct.	Pct.	Pct.
1	0.5	24	----	----	----	-----	-----	0.8	27	----	-----	0.03	9.7
2	3.5	35	----	----	----	-----	-----	6.6	57	----	0.23	5.05	28.3
3	2.6	30	----	----	----	-----	-----	4.6	38	----	.19	3.51	23.7
4	2.6	39	----	----	----	-----	-----	4.5	51	----	.20	1.91	19.7
5	5.1	36	----	----	----	-----	-----	8.6	57	----	-----	.14	18.9
6	3.0	17	----	----	----	-----	-----	4.9	20	----	-----	.11	11.9
7	8.0	18	----	----	----	-----	-----	14.3	34	----	-----	.15	15.2
8	2.1	25	----	----	----	-----	-----	3.3	27	----	-----	.06	10.0
9	4.4	29	----	----	----	-----	-----	6.9	45	----	1.17	5.31	21.7
10	12.7	42	----	----	----	-----	-----	16.6	74	----	-----	.13	19.8
11	8.8	10	----	----	----	-----	-----	15.2	20	----	-----	.14	12.2
12	6.6	18	----	----	----	-----	-----	10.2	27	----	-----	.10	13.4
13	3.7	30	----	----	----	-----	-----	6.2	36	----	-----	.16	14.1
14	2.4	31	----	----	----	-----	-----	4.2	39	----	.26	1.10	20.9
15	5.0	24	----	----	----	-----	-----	8.6	30	----	-----	.15	15.2
16	1.9	17	----	----	----	-----	-----	3.5	24	----	-----	.21	12.1
17	8.8	42	----	----	----	-----	-----	14.1	112	----	.28	4.88	23.3
18	10.7	26	----	----	----	-----	-----	15.6	55	----	-----	.02	8.8
19	4.9	48	----	----	----	-----	-----	7.9	79	----	.69	7.35	31.4
20	6.0	34	----	----	----	-----	-----	8.3	52	----	-----	.12	11.1
21	5.7	26	----	----	----	-----	-----	10.7	39	----	-----	.23	8.4
22	4.3	42	----	----	----	-----	-----	7.7	58	----	-----	.20	9.1
23	5.5	22	----	----	----	-----	-----	9.1	30	----	-----	.19	11.2
24	20.6	----	152	35	111	110+	9.0	22.2	----	80	-----	.24	25.5
25	21.5	----	99	33	126	110+	4.5	22.4	----	56	-----	.27	28.4
26	20.7	----	113	30	120	110+	3.8	22.4	----	55	-----	.16	24.6
27	22.1	100	----	----	----	-----	-----	27.8	----	41	.18	.59	27.5
28	19.8	----	85	23	123	110+	.0	20.4	----	50	-----	.20	24.9
29	21.1	----	94	24	124	110+	4.5	21.9	----	53	-----	.17	32.8
30	17.6	186	----	----	----	-----	-----	23.8	----	56	-----	.14	29.5
31	14.5	144	----	----	----	-----	-----	19.1	----	100	-----	.07	26.3
32	13.6	87	----	----	----	-----	-----	18.5	----	235	-----	.13	16.4

Asphaltic residue

Sample identification	Loss	Tests on residue: Penetration at 77° F., 100 g, 5 sec.	Tests on residue: Penetration at 32° F., 200 g, 60 sec.	Tests on residue: Softening point	Tests on residue: Ductility at 5 centimeters per minute at 77° F.	Tests on residue: Ductility at 5 centimeters per minute at 34°–35° F.	Tests on residue: Organic matter insoluble in CS_2	Tests on residue: Organic matter insoluble in CCl_4	Tests on residue: Insoluble in 86° B. naphtha
	Pct.			° F.	Cm	Cm	Pct.	Pct.	Pct.
1	28.1	96	37	121	40	3.5	-----	0.19	24.9
2	25.3	100	15	109	110+	.0	0.16	2.16	35.2
3	28.3	105	15	107	110+	.0	.16	1.50	32.5
4	25.3	107	18	108	110+	.0	.19	1.62	25.5
5	29.4	105	28	113	100	4.5	-----	.12	24.2
6	37.6	99	41	116	110+	5.0	-----	.14	22.6
7	35.2	92	28	118	110+	.5	-----	.19	22.7
8	34.7	100	34	114	53	3.8	-----	.15	22.1
9	31.0	86	17	110	113	.0	.55	3.81	28.5
10	34.1	106	35	117	98	6.0	-----	.12	25.6
11	46.8	84	21	113	110+	.1	-----	.03	21.1
12	38.2	97	35	119	110+	6.5	-----	.12	24.7
13	33.2	93	27	115	110+	1.0	-----	.09	22.7
14	30.5	93	13	110	110+	.0	.16	.72	31.1
15	38.3	103	25	115	110+	4.5	-----	.03	23.1
16	38.0	109	36	117	100	5.3	-----	.03	24.2
17	28.1	81	15	114	110+	.0	.60	3.41	29.2
18	24.9	88	27	120	110+	4.8	-----	.15	18.5
19	24.1	92	11	109	110+	.0	.24	3.84	39.4
20	31.1	102	21	114	110+	.8	-----	.04	19.5
21	37.4	110	18	109	110+	.0	-----	.04	15.3
22	29.4	113	23	109	110+	.0	-----	.05	14.5
23	39.1	98	17	110	110+	.0	-----	.05	20.8
24	22.8	101	22	115	110+	.5	-----	.10	22.9
25	21.8	94	35	125	110+	4.8	-----	.09	25.7
26	21.6	95	32	121	110+	3.8	-----	.08	22.6
27	27.4	90	12	109	110+	.0	.40	.34	25.6
28	19.6	97	34	118	110+	5.5	-----	.06	21.1
29	21.5	100	23	120	110+	6.0	-----	.18	26.6
30	24.2	104	30	118	110+	4.3	-----	.09	27.1
31	21.1	112	22	115	110+	4.3	-----	.11	24.9
32	25.0	101	16	111	110+	.0	-----	.27	15.7

percent as much as they lost in the 20-gram volatilization test. The residues from both volatilization tests of the slow-curing products were fluid; those of the medium-curing products were fluid in the 50-gram volatilization test and semisolid in the 20-gram volatilization test; and those of the rapid-curing products were both semisolid. For the slow-curing products, the loss in neither volatilization test amounted to as much as that in the asphaltic residue test. For the medium-curing products, the loss in the 20-gram volatilization test approximated the loss in the asphaltic-residue test, while for the rapid-curing products the losses in all tests, including the distillation test, were approximately the same. The loss in the 20-gram volatilization test, while always greater than that in the 50-gram volatilization test, was always less than in the distillation test. The residue from the 20-gram volatilization test may, however, be harder or softer than the residue from distillation.

The slow-curing products were reduced to a residue of 100 penetration in from 30 to 420 minutes, with an average of 126 minutes. In producing residues of the same consistency medium-curing products took from 16 to 30 minutes, with an average of 23 minutes and the rapid-curing products took from 11 to 15 minutes, with an average of 13 minutes. When making the asphaltic-residue test on the rapid-curing products, difficulty was experienced in obtaining a residue that was not too hard, since the high volatility of the solvent caused the cut-back materials to be reduced to 100 penetration before the temperature for making the test was reached.

MAJORITY OF MATERIALS SHOWED A CLEAR FIELD ON MICROSCOPIC EXAMINATION

The microscopic test, adopted by one State highway department for the detection of cracking-coil products, was made on all materials. The specification of the State did not set up an exact procedure. It merely stated that a freshly prepared smear of the asphaltic material diluted with carbon tetrachloride should show a clear field free from carbonaceous matter when subjected to a magnification of 200 diameters. In the work covered by this report, the test was standardized by using 2 parts by weight of carbon tetrachloride and 1 part by weight of asphaltic material in preparing the slides for observation. When prepared in this manner all of the materials but seven showed a clear field. In preparing the slides for the photomicrographs illustrated in figure 2, 6 parts by weight of carbon tetrachloride and 1 of the asphaltic material were used.

Because carbon tetrachloride has both solvent and flocculent properties, its use as a diluent was questioned. Therefore, slides were also prepared with the undiluted materials and it was found that only those materials that showed flecks when undiluted showed

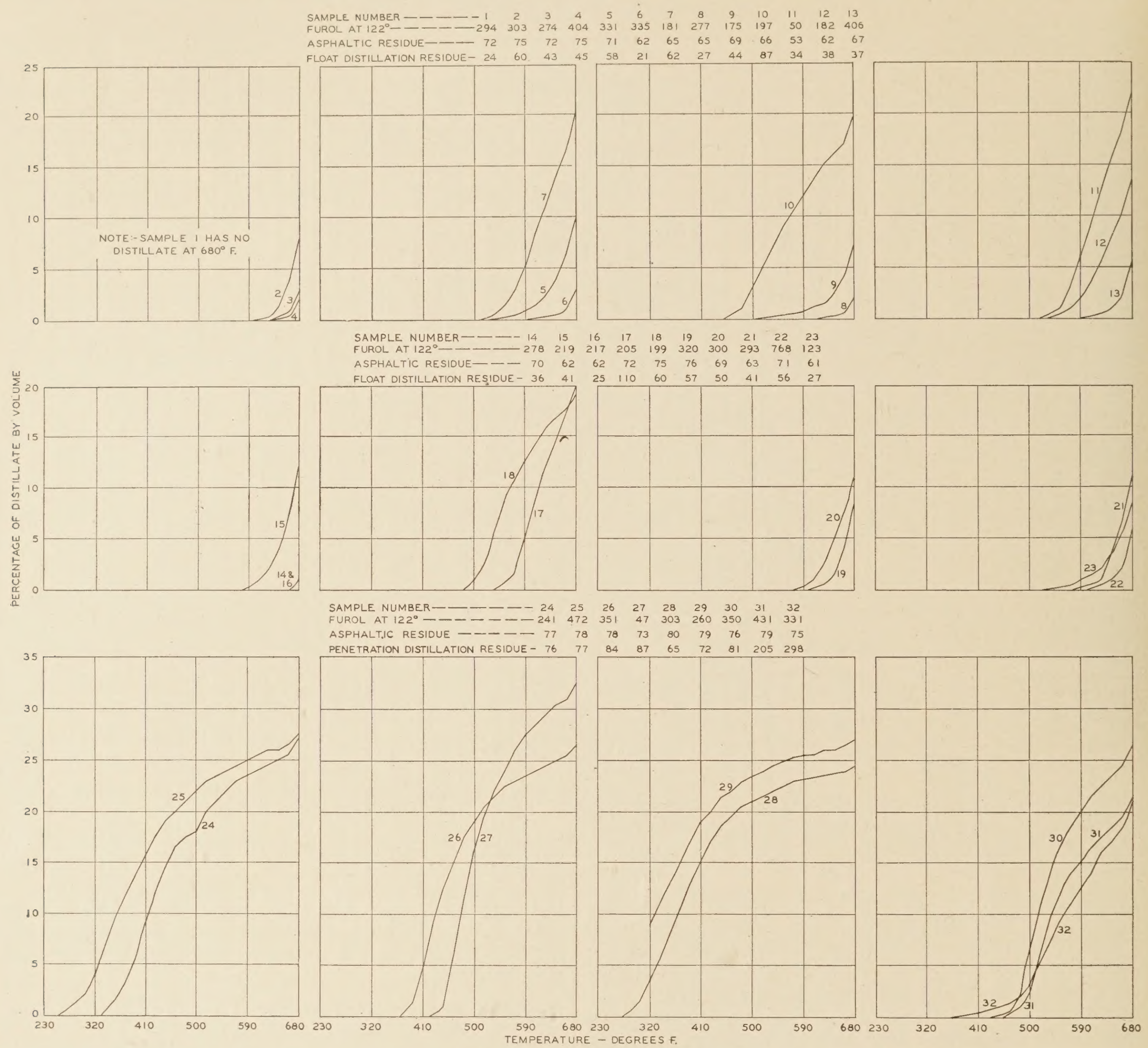

Figure 1.—Relation of Percentage of Distillate by Volume to Distilling Temperature.

them in the 2 to 1 and 6 to 1 dilutions. This indicates that the insoluble matter was already flocculated and that carbon tetrachloride, in the quantities used, did not precipitate carbonaceous flecks in those materials not containing them when undiluted. Recently a sample was tested that contained flecks when undiluted that disappeared on dilution with carbon tetrachloride; and another sample that was practically clear when undiluted contained flecks when diluted. In the first case, the poor solvent properties of the distillate used in the material were responsible for incomplete solution of the base asphalt, that immediately went into solution with the addition of carbon tetrachloride. In the second case it was quite evident that the carbon tetrachloride acted as a flocculent. However, since 6 of the 7 samples that contained carbonaceous material had relatively high percentages of material insoluble in carbon tetrachloride, it is probable that the flecks shown are particles of free carbon and carbenes.

In conducting the exposure tests three samples of each material were placed in seamless, flat-bottom tins having a diameter of 5½ inches and a depth of five-eighths inch. Fifty cubic centimeters of material were used to obtain a uniform film or layer thickness of about one-eighth inch. The samples were then placed in exposure boxes made of wood. A plate-glass cover resting on strips of felt fastened to the edges of each box made a tight joint and excluded all dust and dirt. A current of air was passed through a wash bottle containing sulphuric acid to remove dust and eliminate moisture, and was admitted through the bottom of the boxes and escaped through slots in the sides, thus serving to carry off the vapors formed. The slots were protected from rain by thin boards extending from the top of the box downward at an

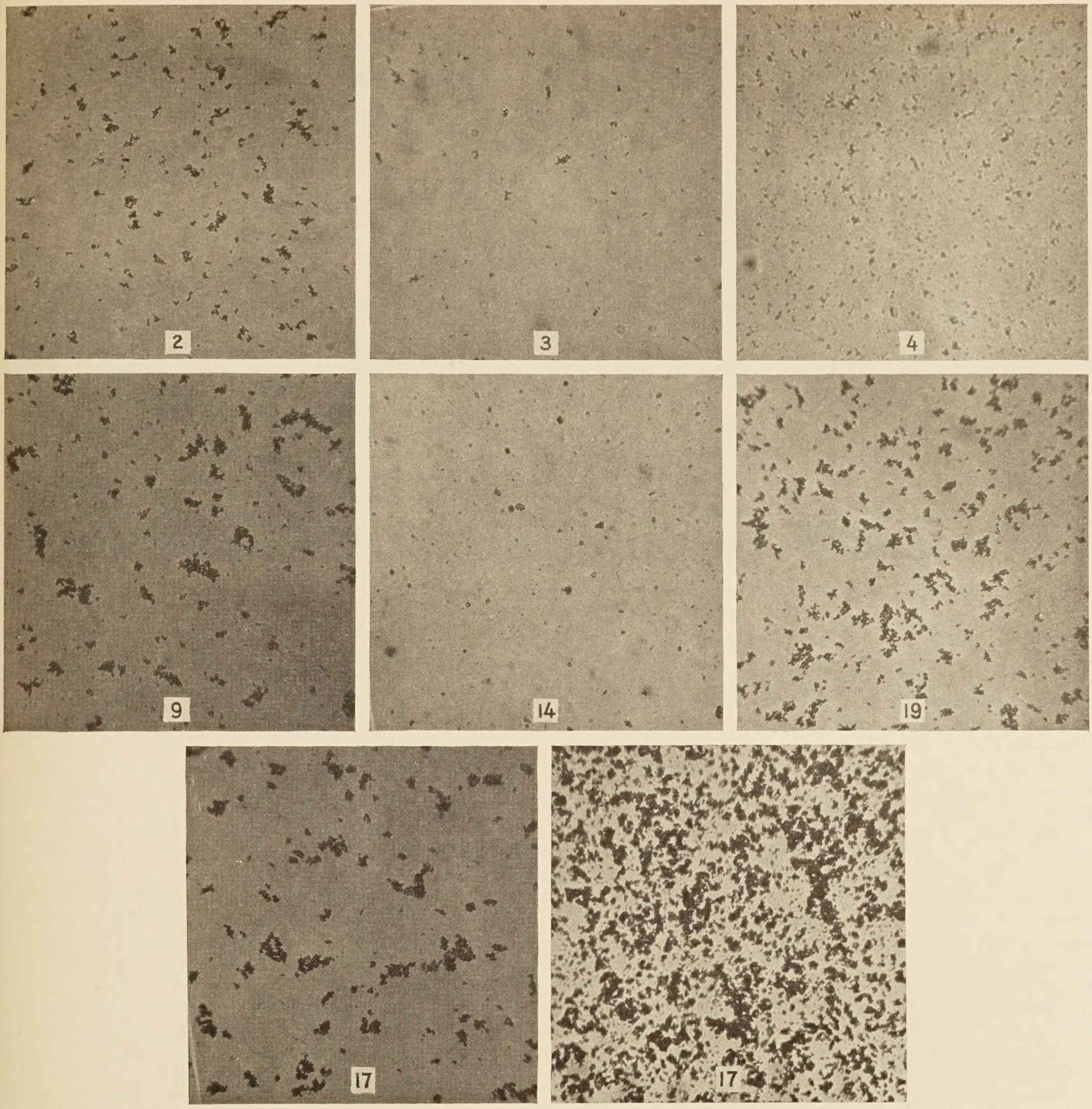

Figure 2.—Photomicrographs of Materials Containing Carbonaceous Matter (Magnified 200 Times). The Lower Two Illustrations Show Results Obtained With Sample 17; in the One on the Left the Material Was Diluted with Carbon Tetrachloride and the One on the Right Shows Undiluted Material.

angle of about 45°. Cotton batting inserted in the slots excluded dust. A thermometer in each box provided a means of determining the temperature. The assembly of the boxes is shown in figure 3.

DIFFERENCES FOUND BETWEEN SLOW-CURING AND CUT-BACK PRODUCTS AFTER EXPOSURE

The samples were placed in the boxes on June 15, 1933, and were weighed periodically to determine the loss in weight. A complete set of samples was removed and tested at the end of 5 weeks, another set at 10 weeks, and the last set at 15 weeks. The temperature of the boxes was dependent entirely upon the radiant heat of the sun and varied with the amount of sunshine. On clear days the temperature was extremely high, the maximum recorded being 196° F., but on days with no sunshine the temperature in the boxes was the same as that of the air. During the period of exposure the average maximum daily air temperature was 85° F. The samples exposed for 5 weeks were subjected to 333 hours of sunlight and those exposed for 10 and 15 weeks were subjected to 611 and 866 hours of sunlight, respectively. The percentage of loss at different periods of exposure is given in table 5 and the results of tests on the residues are given in table 6. Photographs of typical surfaces at the end of 15 weeks are shown in figure 4.

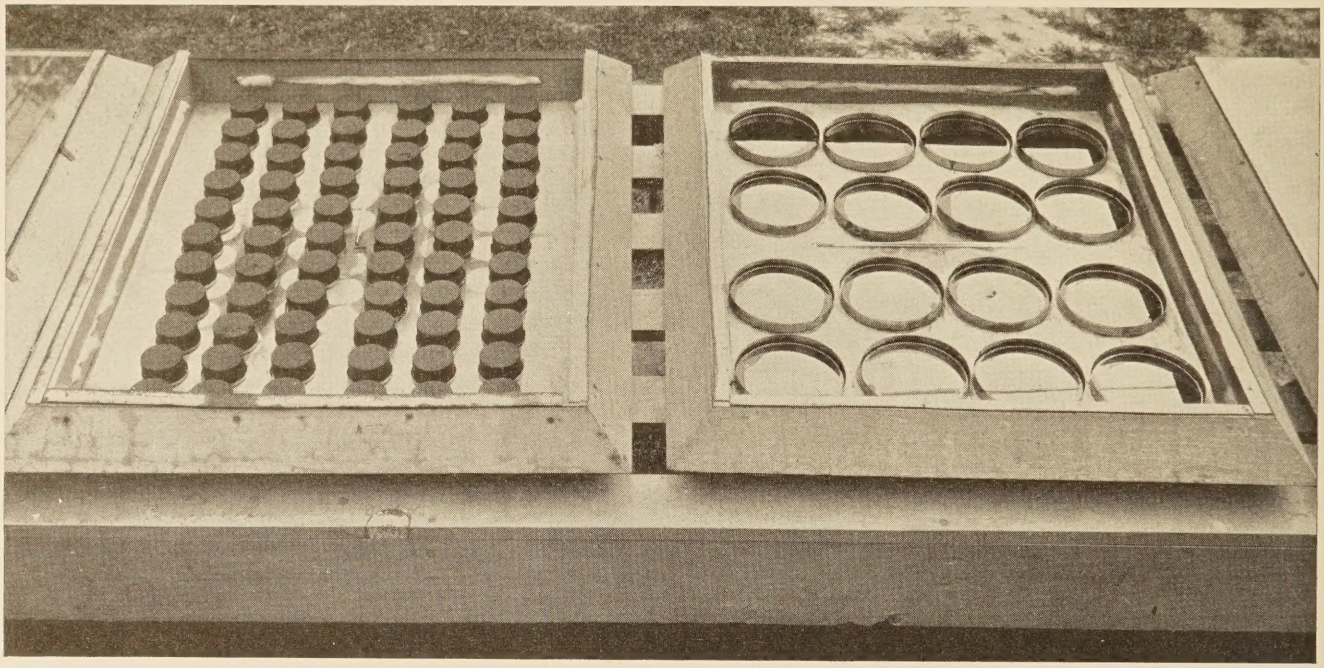

Figure 3.—Stability Specimens and Thin Films of Material Exposed to Sunlight.

While the majority of the materials progressively lost weight during the period of exposure, a number of them actually gained at first, although they later lost more than the amounts gained. An exception to this was sample 1, which had gained 3.6 percent at the end of 8 days and at the end of 15 weeks still showed a slight gain. The samples exposed for 15 weeks were used in determining the loss at 2, 8, 15, 22, 50, and 105 days, while the percentage of loss given for the 35- and 70-day exposures was based on samples used for test at the end of 5 and 10 weeks, respectively. This was done to eliminate errors in calculating the results of subsequent tests made upon the respective residues and accounts for slight variations that may appear to indicate gains instead of losses.

As was expected, the cut-back products lost weight very rapidly. At the end of 2 days they had lost from 86 to 92 percent of their maximum loss with an average of 89 percent, and at the end of 35 days they had lost from 97 to 100 percent with an average of 99 percent. For the slow-curing products the rate of loss was much less, but was considerably more variable. In 2 days those samples that had undergone a loss had lost from 3 to 60 percent of their maximum loss with an average of 35 percent. In 15 days they had lost from 16 to 84 percent with an average of 50 percent, in 35 days from 63 to 100 percent with an average of 82 percent, and in 70 days from 74 to 100 percent with an average of 89 percent. Some idea of the relative speed of curing or volatility of the two types of material may be obtained by comparing their losses under these exposure conditions. The slow-curing materials took 70 days to lose an average of 89 percent of their volatile matter, while the cut-back materials underwent the same percentage loss in 2 days.

Table 5.—*Loss in thin film exposure*

Sample identification	Loss on exposure for—							
	2 days	8 days	15 days	22 days	35 days	50 days	70 days	105 days
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	−2.6	−3.6	−3.4	−3.4	−3.0	−2.7	−2.7	−0.9
2	1.9	4.3	5.7	7.6	9.5	10.3	10.2	12.4
3	−.2	2.0	2.9	4.7	6.6	8.0	8.0	9.4
4	--------	1.5	1.7	3.2	5.1	4.4	5.8	5.8
5	2.6	5.4	6.5	8.2	9.5	9.8	9.9	11.5
6	−.3	1.2	2.0	4.1	5.1	6.1	8.5	8.2
7	7.8	12.9	14.6	17.7	20.2	20.0	21.0	21.5
8	−1.8	--------	--------	--------	2.3	--------	1.8	2.0
9	.3	2.4	4.0	5.3	8.1	8.2	9.6	10.7
10	11.0	14.4	14.5	15.7	16.4	16.7	16.8	17.3
11	7.8	14.7	16.4	18.2	20.4	21.0	21.6	22.3
12	4.6	8.9	9.4	11.8	13.7	13.4	13.8	15.2
13	.4	2.6	4.3	6.1	7.3	10.1	8.5	9.8
14	−1.3	.2	1.3	3.4	5.2	6.9	6.0	8.1
15	1.9	5.5	6.9	8.4	9.3	12.1	10.6	13.3
16	−3.5	−1.5	−1.0	1.8	4.6	5.7	5.7	6.7
17	8.6	12.6	14.4	15.9	18.5	18.9	18.7	19.5
18	11.5	15.7	16.5	17.4	18.2	19.2	17.7	19.0
19	1.4	5.0	6.1	8.6	10.1	12.4	12.0	13.8
20	2.3	6.8	7.8	9.8	11.7	12.6	11.5	13.6
21	−1.1	3.7	6.4	8.2	12.5	13.6	12.9	14.3
22	.6	3.4	5.1	6.7	8.5	9.8	9.1	10.5
23	1.3	3.7	4.6	6.6	8.3	10.6	13.1	11.2
24	19.4	21.2	21.5	22.0	22.2	22.2	22.5	22.5
25	20.1	21.6	21.9	22.1	22.2	22.0	22.0	22.2
26	20.5	21.6	21.8	22.1	22.4	22.1	22.1	22.0
27	26.1	27.1	27.3	27.5	27.6	27.6	28.3	27.8
28	17.7	19.6	19.9	20.0	19.9	20.1	20.0	20.1
29	19.2	20.8	21.3	21.4	21.6	21.4	21.4	21.4

LOSS IN DISTILLATION TEST MOST NEARLY APPROXIMATED LOSS IN 15 WEEKS' EXPOSURE FOR ALL TYPES OF MATERIALS

Figure 5 shows the relation between the percentage of loss upon exposure and loss in the distillation test, loss in the two oven tests, and loss in the asphaltic-residue test. Figure 5 indicates that for the slow-curing products the loss in 15 weeks' exposure was about 2½ times as great as that in the oven test on a 50-gram sample, about 1½ times as great as that in the oven test on a 20-gram sample, and about the same as the loss in the distillation test. No relationship was apparent between the loss in the exposure and asphaltic-residue tests. The loss in the latter test was, however, invariably greater, ranging from 1⅓ to 14 times the loss occurring in 15 weeks' exposure with an average of 2½ times this loss. For the cut-back products the loss in all tests was approximately the same. In all the materials studied, both in 1932 and 1933, the total loss in

TABLE 6.—*Results of tests on exposure residues*

5-week exposure

Sample identification	Loss	Float at 122° F.	Penetration: At 77° F., 100 g, 5 sec.	Penetration: At 32° F., 200 g, 60 sec.	Softening point	Ductility at 5 centimeters per minute: At 77° F.	Ductility at 5 centimeters per minute: At 34°-35° F.	Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B. naphtha
	Pct.	*Sec.*			*°F.*	*Cm*	*Cm*	*Pct.*	*Pct.*	*Pct.*
1	−2.6	68	-----	---	----	-----	-----	-----	-----	15.4
2	9.5	-------	86	34	108	63.0	1.5	2.74	9.23	30.2
3	6.6	153	-----	---	95	-----	-----	2.93	8.44	28.0
4	5.1	-------	152	39	106	22.0	4.0	1.28	5.95	25.6
5	9.5	200	-----	---	96	-----	-----	-----	-----	25.9
6	−0.3	34	-----	---	----	-----	-----	-----	-----	15.3
7	20.2	123	-----	---	----	-----	-----	-----	-----	21.0
8 [1]	2.3	163	-----	---	96	-----	-----	-----	.25	18.7
9 [2]	8.1	1,000+	300+	---	110	-----	-----	3.22	7.51	26.4
10	16.4	-------	189	80	106	95.0	5.0	-----	-----	26.6
11	20.4	131	-----	---	----	-----	-----	-----	-----	23.8
12	13.7	110	-----	---	----	-----	-----	-----	-----	21.0
13	7.3	129	-----	---	----	-----	-----	-----	-----	21.8
14	5.2	105	-----	---	----	-----	-----	1.63	5.69	29.4
15	9.3	150	-----	---	----	-----	-----	-----	-----	25.9
16	4.6	70	-----	---	----	-----	-----	-----	-----	19.9
17	18.5	-------	51	22	136	6.0	.0	1.81	7.57	30.8
18	18.2	197	-----	---	93	-----	-----	-----	-----	14.8
19	10.1	-------	156	28	98	-----	1.0	4.60	11.69	34.4
20	11.7	179	-----	---	95	-----	-----	-----	-----	21.4
21	12.5	106	-----	---	----	-----	-----	-----	-----	18.2
22	8.5	150	-----	---	87	-----	-----	-----	-----	19.1
23	8.3	116	-----	---	----	-----	-----	-----	.15	24.7
24	22.2	-------	21	9	146	17.0	.0	.21	.28	32.4
25	22.2	-------	29	14	155	5.0	.0	.38	.50	31.7
26	22.4	-------	26	14	151	4.5	.0	.23	.20	29.0
27	27.6	-------	18	7	138	4.0	.0	.32	2.21	27.9
28	19.9	-------	21	9	151	7.0	.0	.23	.23	28.2
29	21.6	-------	23	13	154	7.0	.0	.39	.39	34.7

10-week exposure

Sample identification	Loss	Float at 122° F.	Penetration: At 77° F., 100 g, 5 sec.	Penetration: At 32° F., 200 g, 60 sec.	Softening point	Ductility at 5 centimeters per minute: At 77° F.	Ductility at 5 centimeters per minute: At 34°-35° F.	Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B. naphtha
	Pct.	*Sec.*			*°F.*	*Cm*	*Cm*	*Pct.*	*Pct.*	*Pct.*
1	−2.7	110	-----	----	94	-----	-----	-----	-----	20.1
2	10.2	-------	33	15	142	0.5	0.0	5.08	13.34	34.5
3	8.0	-------	62	22	127	5.0	.0	4.46	11.29	31.3
4	5.8	-------	112	33	134	4.3	.0	2.46	7.41	29.3
5	9.9	-------	97	37	118	87.0	3.8	-----	-----	30.5
6	7.4	44	-----	----	----	-----	-----	-----	-----	17.0
7	21.0	163	-----	----	93	-----	-----	-----	-----	22.1
8 [1]	1.8	356	300+	----	129	3.5	2.3	.26	.88	22.5
9 [2]	9.6	1,000+	300+	97	139	1.0	.5	5.16	10.49	30.2
10	16.8	-------	95	53	129	10.0	3.5	-----	-----	29.4
11	21.6	-------	73	35	121	17.0	1.5	-----	-----	29.3
12	13.8	203	-----	----	105	-----	-----	-----	-----	23.9
13	8.5	-------	89	39	119	40.0	3.5	-----	-----	27.3
14	6.0	-------	126	31	103	105.0	2.5	3.08	7.94	31.5
15	10.6	-------	105	47	117	53.0	3.5	-----	-----	30.3
16	5.7	218	-----	----	101	-----	-----	-----	-----	23.7
17	18.7	-------	36	14	170	.5	.0	3.17	9.66	36.2
18	17.7	-------	152	43	105	110+	7.5	-----	-----	17.3
19	12.0	-------	44	10	121	110+	.0	6.50	16.02	38.7
20	11.5	-------	136	41	112	90.0	3.8	-----	-----	24.2
21	12.9	170	-----	----	95	-----	-----	-----	-----	22.3
22	9.1	-------	157	42	104	110+	7.3	-----	-----	23.2
23	13.1	-------	27	14	147	1.0	.0	.20	2.91	32.8
24	22.5	-------	12	10	161	5.5	.0	.45	.47	36.9
25	22.0	-------	25	13	158	4.8	.0	.43	.43	33.9
26	22.1	-------	20	13	163	3.5	.0	.35	.41	31.5
27	28.3	-------	12	6	158	.0	.0	.34	2.26	30.5
28	20.0	-------	16	9	163	4.5	.0	.45	.45	31.0
29	21.4	-------	18	13	169	4.5	.0	.51	.50	27.9

15-week exposure

Sample identification	Loss	Float at 122° F.	Penetration: At 77° F., 100 g, 5 sec.	Penetration: At 32° F., 200 g, 60 sec.	Softening point	Ductility at 5 centimeters per minute: At 77° F.	Ductility at 5 centimeters per minute: At 34°-35° F.	Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B. naphtha
	Pct.	*Sec.*			*°F.*	*Cm*	*Cm*	*Pct.*	*Pct.*	*Pct.*
1	−0.9	-------	197	74	114	20.0	3.0	-----	0.19	23.0
2	12.4	-------	20	9	154	.3	.0	5.71	15.36	40.6
3	9.4	-------	49	15	144	.8	.0	5.69	12.08	36.6
4	5.8	-------	59	18	153	.5	.0	3.36	8.40	34.6
5	11.5	-------	52	23	135	21.0	.5	-----	.17	35.0
6	8.2	71	-----	-----	----	-----	----	-----	.13	18.7
7	21.5	-------	195	76	107	85.0	6.5	-----	.12	23.9
8 [1]	2.0	1,000+	300+	104	133	3.5	2.0	.45	1.48	25.0
9 [2]	10.7	-------	199	60	156	.5	.0	5.48	11.34	32.5
10	17.3	-------	76	47	135	7.5	3.0	-----	.24	31.2
11	22.3	-------	51	22	130	9.0	----	-----	.12	32.2
12	15.2	-------	175	84	115	41.0	4.5	-----	.16	24.7
13	9.8	-------	72	33	126	16.0	3.0	-----	.13	29.6
14	8.1	-------	80	21	112	97.0	----	3.07	8.61	33.4
15	13.3	-------	64	30	133	8.0	.5	-----	.23	33.2
16	6.7	-------	245	99	109	47.0	5.0	-----	.08	25.1
17	19.5	-------	29	12	168	.5	.0	3.30	9.88	35.4
18	19.0	-------	93	28	116	110+	4.3	-----	.10	18.8
19	13.8	-------	29	7	128	110+	.0	7.50	18.15	39.9
20	13.6	-------	84	28	120	72.0	3.0	-----	.09	27.2
21	14.3	-------	166	48	103	110+	8.5	-----	.08	23.7
22	10.5	-------	112	28	111	110+	5.0	-----	.10	24.2
23	11.2	-------	49	22	129	7.0	.0	.28	.81	30.2
24	22.5	-------	13	6	160	5.0	.0	.63	.73	37.4
25	22.2	-------	24	13	163	4.0	.0	.72	.70	34.2
26	22.0	-------	22	13	161	3.8	.0	.47	.51	31.4
27	27.8	-------	14	5	153	.3	.0	.57	2.40	31.6
28	20.1	-------	17	8	168	3.8	.0	.44	.52	32.8
29	21.4	-------	17	11	172	4.0	.0	.69	.83	39.3

[1] The 10- and 15-week exposure residues of this sample were nonhomogeneous.

[2] None of the residues after exposure of this sample was homogeneous.

the distillation test most nearly approximated the loss in 15 weeks' exposure.

At the end of 15 weeks' exposure the surfaces of the samples varied greatly in appearance, as shown by the typical photographs in figure 4. The appearance of sample 14 was typical of samples 1, 2, 3, 4, 5, 6, 7, 9, 12, 18, 19, 20, 21, and 22. However, there were some variations in actual appearance that could not be shown in a photograph. Samples 1, 2, and 3 had mottled, slightly greasy surfaces. Samples 4, 9, and 19 had mottled, slightly greasy surfaces that were slightly iridescent. Samples 14, 21, and 22 had mottled, iridescent surfaces that were not greasy. Sample 5 had a uniformly mottled appearance neither iridescent nor greasy. Samples 6, 7, 12, 18, and 20 were smooth and glossy.

Sample 23 was mottled and slightly greasy, like samples 1, 2, and 3, but had some dull areas as shown. Sample 13, while smooth and glossy, had some dull areas as shown; sample 16 was similar although it was slightly mottled.

Samples 10, 11, and 15 were checked over most of the area of their surfaces; their condition is shown by the photograph of sample 15. The unchecked areas in samples 10 and 11 were glossy but in sample 15 the surface was neither dull nor glossy. Samples 8 and 17 had very rough surfaces, shrunken and pitted as shown by their photographs. The material in the bottom of the cracks was soft but the outer surface was very hard. The cut-back products were all very rough and wrinkled, as shown by the photographs of samples 26, 27, and 28. The material in the cracks was glossy while the outer surface was dull.

At the end of 15 weeks all of the cut-back products were exceedingly hard. As they were originally combinations of semisolid asphalt and volatile fluxes and became semisolid in the laboratory tests, it would be expected that a semisolid residue would rapidly develop upon exposure. It has been believed generally that the asphalt base used in cut-back materials is relatively resistant to changes caused by weathering and that after the cutting medium is removed the character of the material changes but little. The six cut-back materials used in this study, while losing but little weight after 2 days, were much harder and had much less ductility at the end of 5 weeks' exposure than the asphalt used as base material.

The slow-curing products varied as greatly in consistency as in the rate and amount of volatile matter given off during exposure. At the end of 5 weeks all of them were harder than the residues from the distillation and oven tests, but only 5 had a penetration at 77° F. of less than 200. The consistency varied from a float of 34 seconds at 122° F. to a penetration of 51 at 77° F. At the end of 15 weeks only 3 materials had a penetration at 77° F. of over 200 and one of these materials had disintegrated to such an extent that no true penetration test was possible. The consistency ranged from a float of 71 seconds at 122° F. to a penetration of 20 at 77° F. In the previous work, the slow-curing materials all developed residues after 15

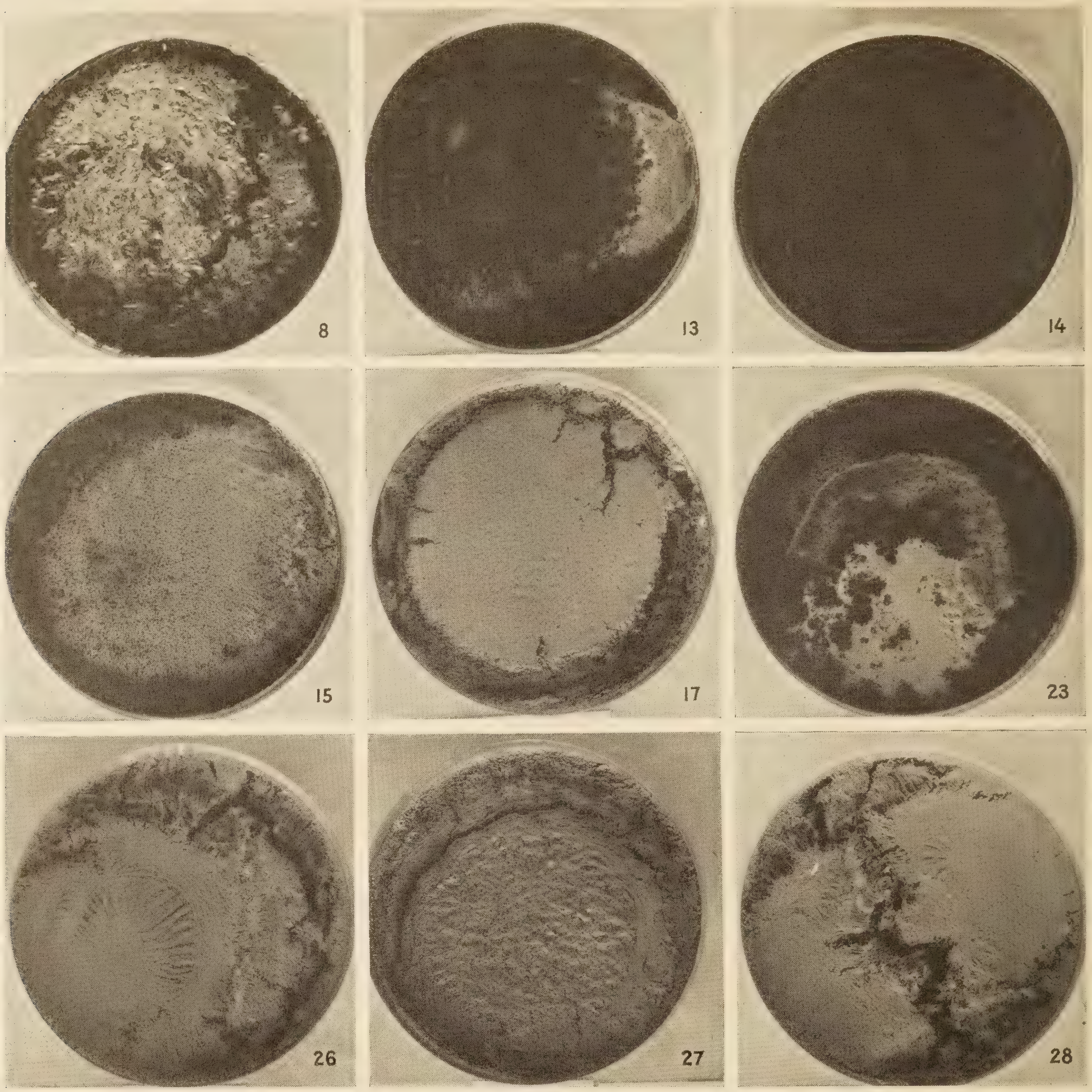

FIGURE 4.—CONDITION OF SURFACES AFTER 15 WEEKS OF EXPOSURE.

weeks that were as hard as or harder than their asphaltic residues of 100 penetration. It seems that it is impossible to predict, from the results of any of the laboratory tests, the consistency of the residues after exposure. Generally, however, those materials that took a long time to be reduced to 100 penetration in the asphaltic-residue test and those whose residues from the distillation and oven tests had a low float-test value were the softest or most fluid at the end of 15 weeks.

ASPHALTIC RESIDUES DIFFERED IN CERTAIN RESPECTS FROM RESIDUES AFTER EXPOSURE OF ABOUT THE SAME PENETRATION

A comparison of the residues after exposure and asphaltic residues is of interest. All but 5 of the asphaltic residues had ductilities at 77° F. of more than 110 centimeters and 15 had ductilities at 34°–35° F. of 3½ centimeters or more. After 15 weeks' exposure only 7 products had ductilities at 77° F. over 50 and only 4 over 110. Only 6 had ductilities at 34°–35° F. over 3½. These differences in ductilities may, in a number of instances, have been caused by differences in the consistencies of the residues after exposure and asphaltic residues.

However, in some cases one of the residues from exposure had approximately the same penetration as the asphaltic residue and the laboratory residues and residues after exposure may be compared directly. Table 7 shows the results of tests on both such residues and indicates that the two residues from the same material, although having the same consistency, varied considerably in other respects.

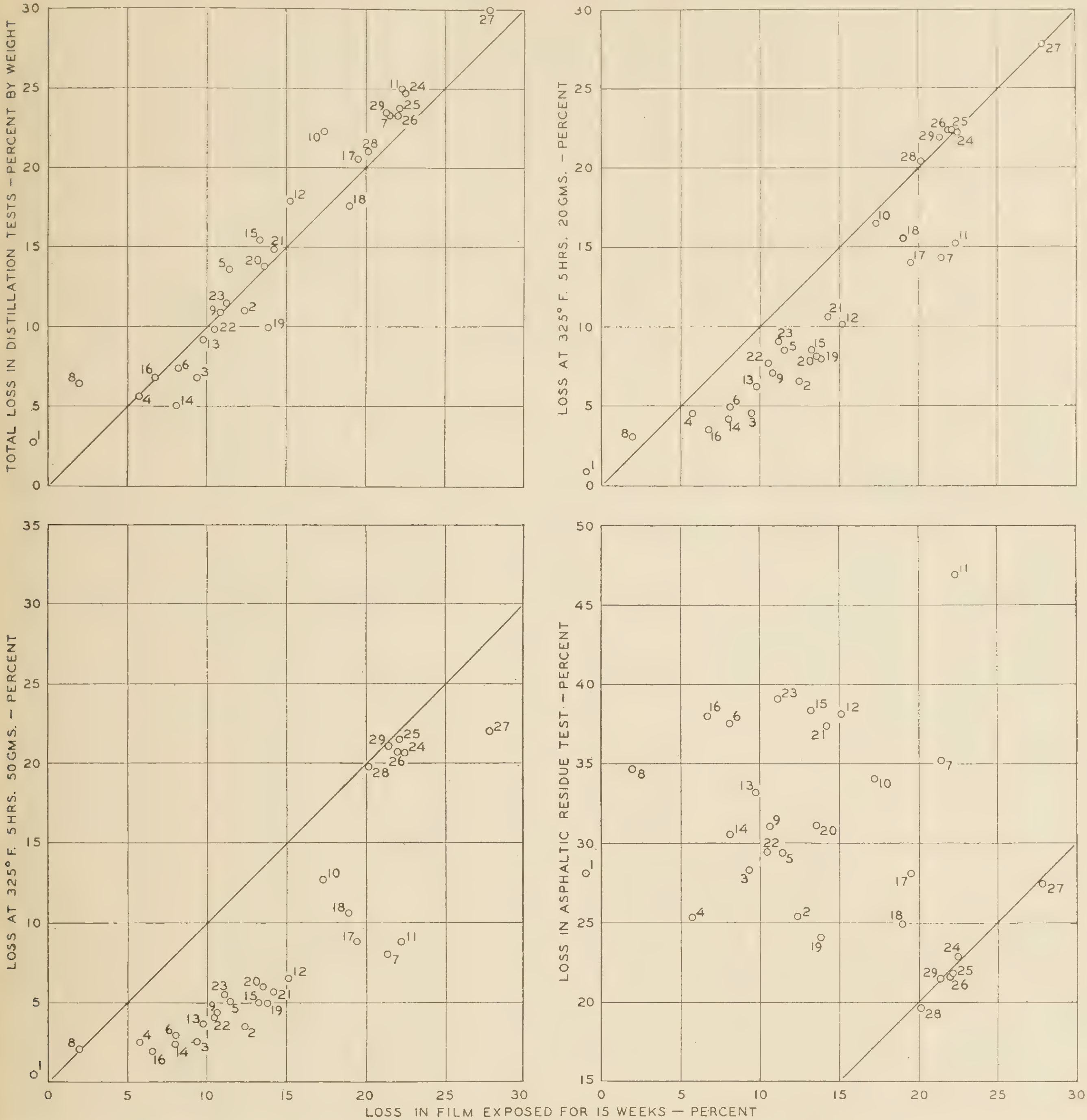

FIGURE 5.—COMPARISON OF THE PERCENTAGE OF LOSS AFTER 15 WEEKS OF EXPOSURE WITH LOSS IN THE LABORATORY EVAPORATION TESTS.

The ratio of the penetration at 77° F. to that at 32° F. was always lower for the residue from exposure. The ductility at 77° F. of the residue from exposure was less than that of the asphaltic residue in all but two cases, and for these the ductility of both residues was 110+. In five cases the ductility at 34°–35° F. of the residue from exposure was greater than that of the asphaltic residue. In every case except two the percentage of material insoluble in naphtha was greater for the residue from exposure than for the asphaltic residue. In every case where there was an appreciable amount of material insoluble in carbon tetrachloride and carbon disulphide, the percentages were much greater for the residues from exposure.

Figure 6 shows the development of free carbon, carbenes, and asphaltenes in laboratory and exposure tests for the samples that originally contained or finally developed carbenes in appreciable amounts. Samples 8, 23, and 27 developed only relatively small amounts of carbenes and the development of the insoluble constituents is shown only for sample 27. In figure 6 the volatile matter and the material insoluble in carbon disulphide, carbon tetrachloride, and 86° B. naphtha are plotted for the original materials and their residues.

TABLE 7.—*Comparison of residues of approximately the same penetration from the asphaltic-residue test and from exposure*

Sample identification	Asphaltic residue: Penetration: At 77° F., 100 g, 5 sec.	Asphaltic residue: Penetration: At 32° F., 200 g, 60 sec.	Asphaltic residue: Ratio: Pen. at 77° F. / Pen. at 32° F.	Asphaltic residue: Softening point	Asphaltic residue: Ductility, 5 cm per minute: At 77° F.	Asphaltic residue: Ductility, 5 cm per minute: At 34°-35° F.	Asphaltic residue: Insoluble in 86° B. naphtha	Asphaltic residue: Organic matter insoluble in CCl_4	Asphaltic residue: Organic matter insoluble in CS_2	Residue from exposure: Penetration: At 77° F., 100 g, 5 sec.	Residue from exposure: Penetration: At 32° F., 200 g, 60 sec.	Residue from exposure: Ratio: Pen. at 77° F. / Pen. at 32° F.	Residue from exposure: Softening point	Residue from exposure: Ductility, 5 cm per minute: At 77° F.	Residue from exposure: Ductility, 5 cm per minute: At 34°-35° F.	Residue from exposure: Insoluble in 86° B. naphtha	Residue from exposure: Organic matter insoluble in CCl_4	Residue from exposure: Organic matter insoluble in CS_2	Time of exposure
				°F.	Centimeters	Centimeters	Per cent	Per cent	Per cent				°F.	Centimeters	Centimeters	Per cent	Per cent	Per cent	Weeks
2	100	15	6.7	109	110+	0.0	35.2	2.16	0.16	86	34	2.5	108	63.0	1.5	30.2	9.23	2.74	15
3	105	15	7.0	107	110+	.0	32.5	1.50	.16	62	22	2.8	127	5.0	.0	31.3	11.29	4.46	10
4	107	18	5.9	108	110+	.0	25.5	1.62	.19	112	33	3.4	134	4.3	.0	29.3	7.41	2.46	10
5	105	28	3.8	113	110+	4.5	24.2	.12	--------	97	37	2.6	118	87.0	3.8	30.5	--------	--------	10
10	106	35	3.0	117	98	6.0	25.6	.12	--------	95	53	1.8	129	10.0	3.5	29.4	--------	--------	10
11	84	21	4.0	113	110+	.1	21.1	.03	--------	73	35	2.1	121	17.0	1.5	29.3	--------	--------	10
13	93	27	3.4	115	110+	1.0	22.7	.09	--------	89	39	2.3	119	40.0	3.5	27.3	--------	--------	10
14	93	13	7.2	110	110+	.0	31.1	.72	.16	80	21	3.8	112	97.0	.0	33.4	8.61	3.07	15
15	103	25	4.1	115	110+	4.5	23.1	.03	--------	105	47	2.2	117	53.0	3.5	30.3	--------	--------	10
18	88	27	3.3	120	110+	4.8	18.5	.15	--------	93	28	3.3	116	110+	4.3	18.8	.10	--------	15
20	102	21	4.9	114	110+	.8	19.5	.04	--------	84	28	3.0	120	72.0	3.0	27.2	.09	--------	15
22	113	23	4.9	109	110+	.0	14.5	.05	--------	112	28	4.0	111	110+	5.0	24.2	.10	--------	15

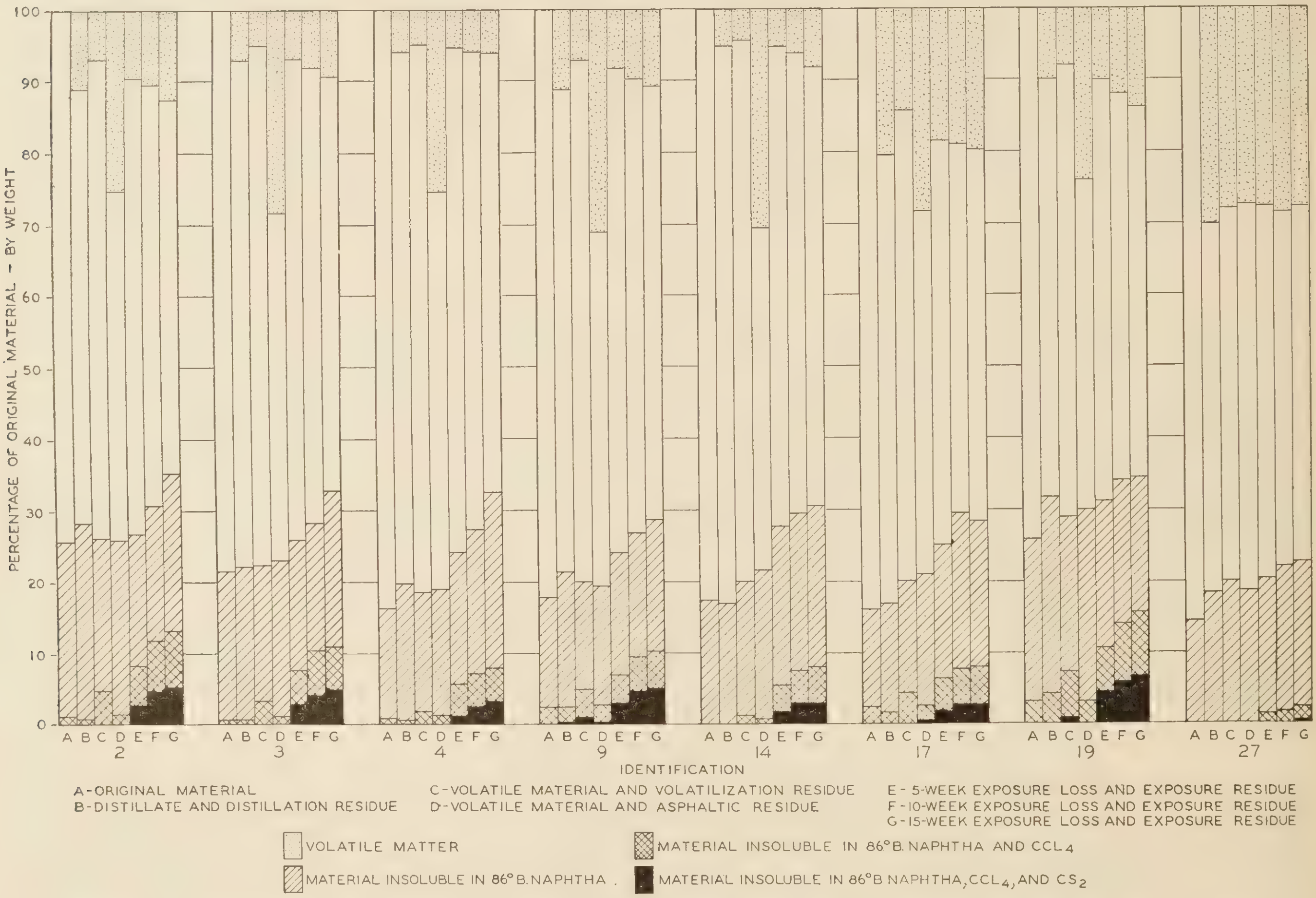

FIGURE 6.—COMPOSITION OF SELECTED MATERIALS AND THEIR RESIDUES AS DETERMINED BY SOLUBILITY TESTS.

All percentages are expressed in terms of the weight of the original material.

The solid portion in each vertical column represents free carbon or material insoluble in carbon disulphide. The remainder represents bitumen or material soluble in carbon disulphide. The double cross-hatched portion represents carbenes or bitumen insoluble in carbon tetrachloride, and the single and double cross-hatched portions together represent asphaltenes or bitumen insoluble in 86° B. naphtha. The remainder of the column represents material soluble in 86° B. naphtha that, in the original material, includes the more volatile hydrocarbons vaporized and lost under test conditions, as shown by the dotted area. The materials soluble in 86° B. naphtha have been termed "malthenes" by Richardson.[3] This designation, however, has not been generally accepted in the United States.

[3] Clifford Richardson, The Modern Asphalt Pavement, p. 544 (2d ed.).

As shown by figure 6, the material insoluble in naphtha included carbenes and free carbon; in fact, in the residue from 15 weeks' exposure of sample 19 the material insoluble in naphtha contained 19 percent free carbon and 27 percent carbenes. The term asphaltenes also includes carbenes. Nellensteyn [4] has stated that asphaltenes, carbenes, and free carbon all consist of the same matter, that is, dispersed carbon in decreasing states of protection. The so-called "protective bodies" he designates as "micelles." He states that when extracted asphaltenes are heated at a temperature of 527° F. they will be changed largely to free carbon, but a normal asphaltic material can be heated at 662° F. for a long period with little production of free carbon. The reason for this is that in normal asphalts the amount of protective bodies, or micelles, is such that the decomposition of part of them influences their protective qualities only slightly. Marcusson [5] states that the material soluble in 86° B. naphtha (malthenes) is composed essentially of oily constituents and asphaltic resins. As the time of exposure increased, the percentage of asphaltenes, carbenes, and free carbon increased while the percentage of malthenes decreased.

In the 1932 investigation only those materials that had high specific gravities and initially contained some material insoluble in carbon disulphide with appreciable amounts insoluble in carbon tetrachloride developed carbenes either in laboratory or exposure tests. In the present study some of the materials such as samples 14 and 27, that originally had high solubilities in carbon disulphide and carbon tetrachloride, developed carbenes even during some of the laboratory tests. In those materials in which carbenes and free carbon were developed, it may be considered that the amount or the protective quality of the micelles was insufficient to prevent carbonization.

All of the rapid-curing products at the end of 15 weeks had developed residues containing about 0.5 percent of material insoluble in carbon disulphide and carbon tetrachloride. For all materials the solubility in carbon disulphide was almost the same as the solubility in carbon tetrachloride, indicating the almost complete absence of carbenes.

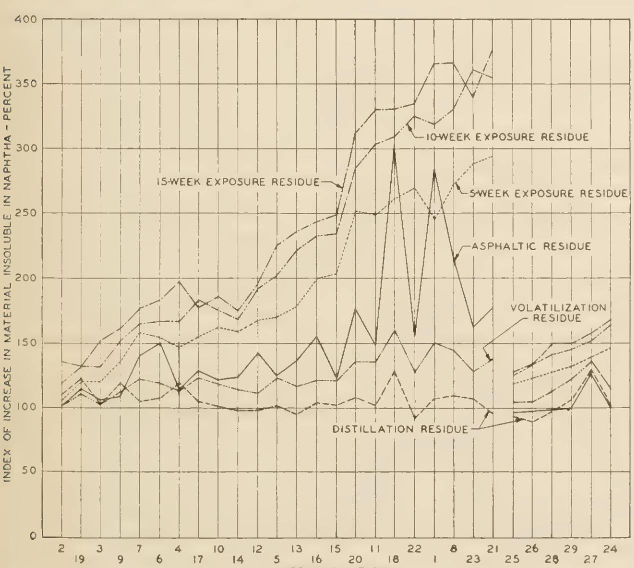

FIGURE 7.—INDEX OF INCREASE IN MATERIAL INSOLUBLE IN NAPHTHA IN THE VARIOUS RESIDUES.

MATERIAL INSOLUBLE IN NAPHTHA DEVELOPED MOST UNDER EXPOSURE AND LEAST IN THE DISTILLATION TEST

In figure 6, where all the percentages are expressed in terms of the weight of the original material, if the percentage of material insoluble in naphtha in any residue is divided by the percentage of material insoluble in naphtha in the original material and multiplied by 100, the result is the index of increase in material insoluble in naphtha. An index of 100 therefore indicates no change in the amount of material insoluble in naphtha. This index for all the samples is plotted in figure 7 and shows that generally there was an increase in material insoluble in naphtha during the various tests. Generally, this index was least for the distillation test and greatest for the 15-week exposure test. In the distillation test it ranged from 88 to 129.

While inaccuracies in testing may account for indexes of less than 100 in the distillation residues, it is possible for indexes actually to be below 100. Several samples of very viscous, slow-curing asphaltic material, really semisolid asphalts, were recently subjected to the distillation test. The materials did not yield any distillate but there was considerable loss on cooling. Nevertheless, the residues were softer than the original materials and contained less material insoluble in naphtha.

In the oven-loss test on 20-gram samples the index varied from 101 to 161 and in the asphaltic residue test it varied from 96 to 302. In the case of the asphaltic residue the index was low when the time of reduction was low, and for the cut-back materials the asphaltic residue test was the least severe of all tests, although there is not much difference between this and the distillation test. The index was high when the time of reduction was high, as indicated by sample 18 which took 420 minutes to come to 100 penetration and had an index of 302, and by sample 1 which took 280 minutes and had an index of 284. The index varied from 105 to 294 for 5 weeks' exposure, from 119 to 361 for 10 weeks' exposure, and from 133 to 376 for 15 weeks' exposure. Except for four samples, the index of increase was greater for 5 weeks' exposure than for any of the laboratory tests. In the exposure tests, products originally containing the highest percentages of material insoluble in naphtha generally had the smallest indexes of increase.

OLIENSIS TEST INVESTIGATED

An interesting development in the study of asphaltic materials is the test for determining heterogeneity. This test has been called the Oliensis or spot test. The method of making the test and the interpretation of the results were outlined in a paper read before the 1933 meeting of the American Society for Testing Materials. In making this test on the original material, one part by volume of the asphaltic material was treated with 5.1 parts by volume of a special naphtha at such a temperature that solution or dispersion was complete in 6 to 8 minutes. After cooling to room temperature and adding fresh naphtha to replace any losses, a drop of the mixture was allowed to drop on a filter paper (J. H. Munktells, No. OO). The appearance of the resulting stain varied from a uniformly colored spot, in-

[4] Report by F. J. Nellensteyn and R. Loman, Sixth Congress, Permanent International Association of Road Congresses, first section, second question, paper 2–O.
[5] See Asphalts and Allied Substances by Herbert Abraham, third edition, p. 755.

dicating complete dispersion, to stains in which the center was black and rough and surrounded by a lighter-colored ring. When an entirely uniform stain was obtained another test was made after the mixture had stood for 24 hours. The appearance of the central spot was taken as an indication of the degree of heterogeneity, and those materials that gave a uniform stain after standing 24 hours were considered as homogeneous.

The test is presumed to give an insight into the conditions of manufacture. The types of asphaltic products that should be expected to appear homogeneous are as follows:

1. Steam-refined residuals known to have been refined without serious cracking.
2. The bitumen of certain native asphalts.
3. Some types of slightly oxidized residuals from asphaltic-base crude oils.

The materials that should be expected to appear heterogeneous are:

1. Steam-refined residuals that have been overheated during the refining process.
2. Cracking-coil residuals.
3. Highly blown residuals

The test was initially developed and used to determine whether or not petroleum asphalts had been subjected to higher temperatures than usually occur in steam refining. It has been used by some States as an identification test for the control of liquid asphaltic materials. Recently the test procedure has been standardized by a group of Middle-Western States. In applying the test to slow-curing materials they state that if the material has less than 15 percent of distillate by volume at 680° F., the test may be made on the original material. For all other materials of the slow-, medium-, or rapid-curing classes the test shall be made on the distillation residue. The presence of the volatile distillate in these types of materials was thought to interfere with the sensitivity of the test. It will be noted that in the case of the slow-curing materials investigated the test may be run on 18 samples as received, since in only 5 cases was the percentage of distillate by volume at 680° F. more than 15 percent.

The identification of the character of the manufacturing process was the main object of this test, and for this purpose it should be made only on the finished products as they leave the refinery and not after they have been subjected to various laboratory heat tests. However, in order to determine if the character of the materials underwent a change during the laboratory tests and under exposure, the residue from the distillation test, the 20-gram oven-loss test, and the asphaltic-residue test, as well as the residues from the 5-week and 15-week exposures were subjected to the Oliensis test.

For the original materials 5.1 parts of naphtha by volume were mixed with 1 part of asphaltic material. For the various residues the volume of naphtha was kept constant and the weight of a unit volume of the original material minus the weight of volatile matter that occurred in producing the residue was used. Table 8 shows the ratio of naphtha to asphaltic material used for each sample. Only in the case of the asphaltic residue of sample 11 did the ratio of naphtha to asphaltic material exceed 7 to 1 by weight, the proportion that was being used by one State at the time these tests were made. It is thought that the variations in proportions of naphtha used in this work were not sufficiently wide to affect the character of the stains obtained. Table 9 gives a classification of the stains and figures 8, 9, and 10 show stains typical of those obtained with the various samples and their residues.

Since the results of the tests were based upon the appearance of the stain as interpreted by the observer, it is difficult if not impossible to distinguish between border-line materials or to express clearly the apparent degree of heterogeneity that may be indicated by the varying degrees of nonuniformity in the stain. The classification given in table 8 should be understood to mean that, in the judgment of the observers, the materials and their residues gave stains that appeared either entirely uniform throughout or were only slightly non-

TABLE 8.—*Ratio of naphtha to asphaltic material in Oliensis test*

Sample identification	Original material [1] (by weight)	Distillation residue		20-gram loss residue (by weight)	Asphaltic residue (by weight)	Residue from exposure for—	
		By weight	By volume			5 weeks (by weight)	15 weeks (by weight)
1	4.10	4.21	-------	4.12	5.69	4.10	4.10
2	3.74	4.20	5.83	4.01	5.00	4.13	4.27
3	3.74	4.01	5.51	3.92	5.22	4.00	4.13
4	3.79	4.01	-------	3.96	5.07	3.99	4.02
5	3.96	4.58	6.04	4.33	5.61	4.37	4.47
6	4.06	4.38	-------	4.26	6.49	4.35	4.42
7	4.11	5.37	6.90	4.30	6.37	5.15	5.24
8	4.13	4.51	-------	4.27	6.32	4.20	4.22
9	3.83	4.29	5.86	4.11	5.55	4.16	4.28
10	4.10	5.28	6.84	4.92	6.22	4.90	4.96
11	3.91	5.22	6.94	4.61	7.35	4.91	5.03
12	4.10	4.99	6.38	4.57	6.68	4.75	4.84
13	3.91	4.31	5.68	4.17	5.86	4.21	4.33
14	3.73	3.92	-------	3.89	5.36	3.93	4.06
15	4.03	4.77	6.18	4.42	6.54	4.44	4.65
16	4.07	4.37	-------	4.22	6.56	4.26	4.37
17	3.83	4.82	6.80	4.52	5.18	4.70	4.76
18	4.13	5.02	6.42	4.95	5.52	5.07	5.10
19	3.65	4.05	5.76	3.97	4.73	4.06	4.23
20	4.12	4.78	6.05	4.53	5.95	4.65	4.76
21	4.06	4.77	6.07	4.55	6.52	4.64	4.74
22	4.05	4.48	5.70	4.38	5.76	4.42	4.52
23	3.90	4.41	5.86	4.29	6.44	4.25	4.40
24	4.06	5.40	7.40	5.22	5.27	5.22	5.24
25	4.17	5.48	7.24	5.38	5.34	5.36	5.36
26	4.16	5.44	7.14	5.36	5.31	5.37	5.34
27	3.99	5.72	7.98	5.54	5.50	5.52	5.54
28	4.14	5.24	6.90	5.20	5.15	5.17	5.18
29	4.11	5.38	7.29	5.24	5.24	5.24	5.24

[1] All original material 5.1 naphtha to 1 of sample by volume.

TABLE 9.—*Character of original materials and residues as determined by the Oliensis test* [1]

Sample identification	Original material	Distillation residue	20-gram loss residue	Asphaltic residue	5-week exposure residue	15-week exposure residue
1	H	H	H	H	H	H
2	H	H	H	H	H	H
3	H	H	H	H	H	H
4	H	H	H	H	H	H
5	H	H	H	H	H	H
6	O	O	O	O	SH	H
7	SH	O	O	O	H	H
8	O	SH	SH	SH	H	H
9	H	H	H	H	H	H
10	O	SH	SH	O	H	H
11	H	H	H	H	H	H
12	O	O	SH	SH	H	H
13	H	H	H	H	H	H
14	H	H	H	H	H	H
15	O	SH	SH	SH	H	H
16	SH	SH	SH	H	H	H
17	H	H	H	H	H	H
18	SH	SH	O	O	SH	H
19	H	H	H	H	H	H
20	SH	SH	O	O	H	H
21	O	O	O	O	H	H
22	O	O	O	O	H	H
23	H	H	H	H	H	H
24	H	H	H	H	H	H
25	O	O	O	O	SH	SH
26	O	SH	SH	O	SH	SH
27	H	H	H	H	H	H
28	O	O	O	O	SH	SH
29	H	H	H	H	H	H

[1] H=Heterogeneous; O=Homogeneous; SH=Slightly heterogeneous.

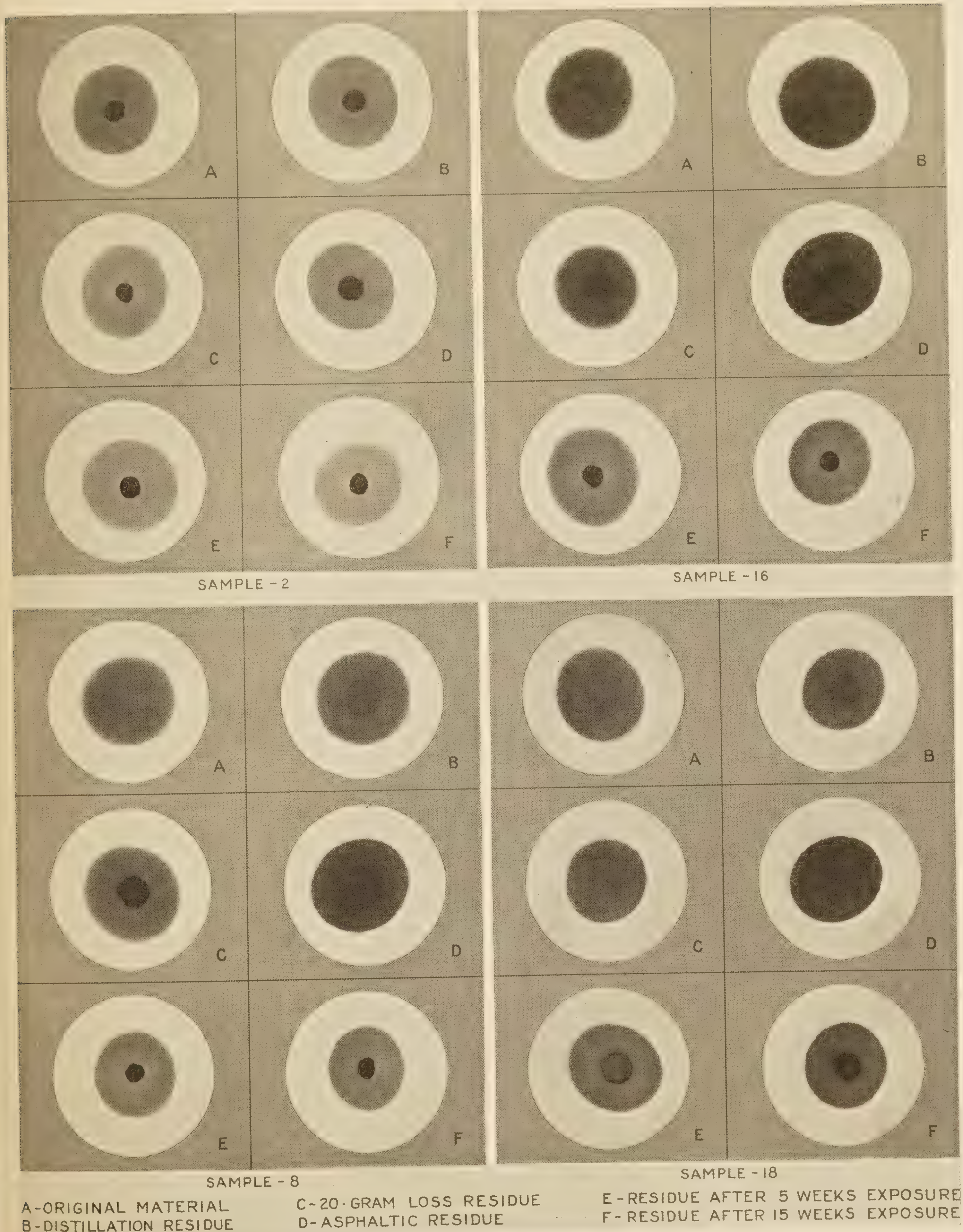

FIGURE 8.—TYPICAL OLIENSIS STAINS.

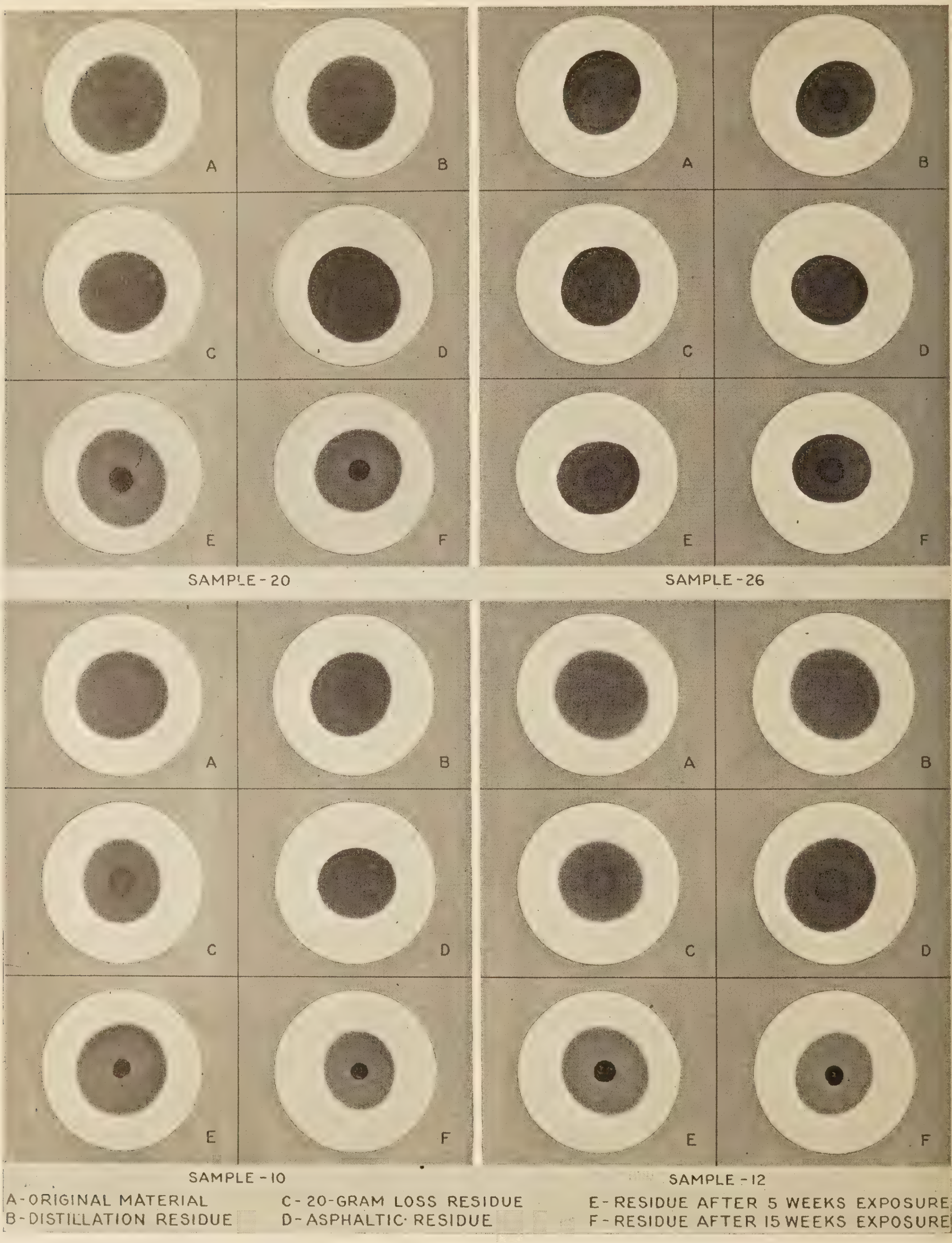

Figure 9.—Typical Oliensis Stains.

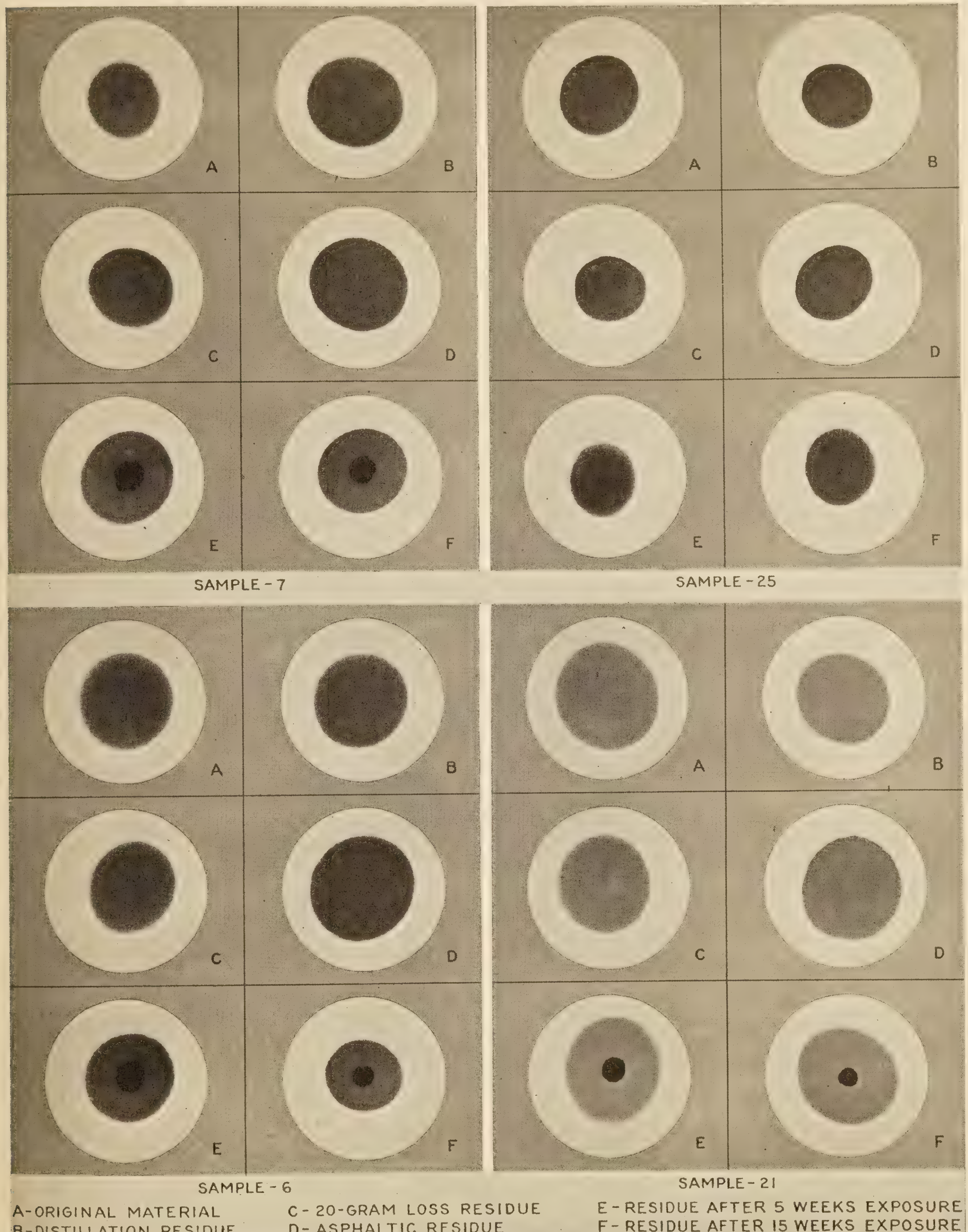

Figure 10.—Typical Oliensis Stains.

uniform, having a slightly darker, more-pronounced center, or else they had a definite dark to black center surrounded by a uniformly lighter-colored stain and were consequently classified as homogeneous, slightly heterogeneous, and heterogeneous, respectively. No attempt was made to indicate the extent or degree of heterogeneity other than to classify as slightly heterogeneous those materials and residues giving stains only slightly nonuniform.

ALL EXPOSURE RESIDUES FOUND TO BE HETEROGENEOUS

A study of the results of the Oliensis test shows that of the 29 materials, 10 were homogeneous, 4 slightly heterogeneous, and 15 definitely heterogeneous in their original state. All the residues from exposure were heterogeneous or slightly heterogeneous. Of the 10 materials appearing homogeneous in their original state, 5 developed homogeneous residues in all 3 laboratory loss tests, 2 developed slightly heterogeneous residues in all 3 tests, 2 developed slightly heterogeneous residues in the oven test and distillation test but not in the asphaltic-residue test, and 1 developed slightly heterogeneous residues in the oven test, and asphaltic-residue tests but not in the distillation test.

Of the 4 materials appearing slightly heterogeneous in their original state, 1 developed homogeneous residues in all 3 laboratory tests, 2 developed homogeneous residues in the asphaltic-residue and loss tests but remained heterogeneous in the distillation test, and one material remained heterogeneous in all tests. The 15 materials that appeared heterogeneous in their original state all developed heterogeneous residues.

A comparison of these materials according to the character of the stains produced in the laboratory and their behavior under laboratory and exposure conditions may be of interest. Nine of the materials, samples 2, 3, 4, 9, 14, 17, 19, 23, and 27, were heterogeneous originally and had heterogeneous residues. The photograph of sample 2 in figure 8 is typical. All of the above samples, except 23 and 27, showed micropscopic flecks as shown in figure 2 when examined under the microscope. All except samples 14 23, and 27 had appreciable amounts of material insoluble in carbon tetrachloride in the original sample. Samples 14, 23, and 27 developed carbenes at the end of 15 weeks of exposure and the other samples showed an increase in carbenes and free carbon.

All of the nine samples, except sample 23, had high percentages of material insoluble in naphtha. All had specific gravities greater than 1.01, except sample 27. This material has a very high specific gravity for a fluid cut-back and its behavior and characteristics place it in this group having high specific gravities. The asphaltic residues of the 9 samples showed the effect of changes in temperature, having low penetration at 32° F. and no ductility at 34°–35° F., although all had ductilities of over 110 at 77° F.

After 15 weeks' exposure all the materials were very hard, except sample 9, which, at the end of 5 weeks, had separated into two parts, one hard and brittle, the other soft and oily. It was impossible to flux these two parts so that, while having a float at 122° F. of over 1,000 seconds at the end of 5 weeks, it was impossible to get a penetration until the end of 15 weeks. When running the softening point test on the residues of this sample, after exposure, the material did not flow slowly to the bottom but dropped immediately at the temperature reported in table 5. Ductility tests were made on this sample but the results are unimportant as no true ductility value was obtained. The residues after 15 weeks' exposure of samples 2, 3, 4, 17, 23, and 27 had very low ductility at 77° F. but samples 14 and 19 had ductilities at 77° F. of 97 and 110+, respectively. None of the residues had any ductility at 34°–35° F.

Three of the materials, 5, 11, and 13, gave Oliensis stains identical with those of the preceding samples. They did not, however, have as high specific gravities, were clear in the microscopic test, and did not, even at the end of 15 weeks, develop any carbenes. Their asphaltic residues had some ductility at 34°–35° F. and, at the end of 15 weeks, while having low ductility at 77° F., samples 5 and 13 had some ductility at 34°–35° F.

The remaining 17 materials all had low specific gravities, were clear in the microscopic test, did not have carbenes, and, with 1 exception, did not develop them. They showed various types of stains in the Oliensis test although all were heterogeneous at the end of 5 weeks. Their asphaltic residues varied in ductility and effect produced by changes in temperature as did their residues after exposure.

The stains of samples 1, 24, and 29, while resulting in photographs similar to those of the high-gravity materials, did not have the nuclei as raised or as rough as the stains of the materials with high specific gravities. The producers of the cut-back asphalt designated as sample 24 stated that their plant had no cracking equipment. This material, therefore, had evidently become heterogeneous in the refining process because of overheating, since the residue obtained in laboratory tests had good ductility, indicating that it had not been overblown. Sample 29 likewise was a cut-back asphalt with a ductile base. Sample 16 was slightly heterogeneous originally, produced slightly heterogeneous residues by distillation and volatilization, and produced a heterogeneous asphaltic residue. The asphaltic residues of these four samples were not especially affected by temperature change, having some ductility at 34°–35° F., although the asphaltic residues of samples 1 and 16 had comparatively low ductilities at 77° F. The residues of samples 1 and 16 after exposure had low ductility at 77° F. Those of samples 24 and 29 (cut-back asphalts) were very hard and consequently had very low ductility.

OLIENSIS TEST MORE SENSITIVE THAN MICROSCOPIC TEST IN DETECTING OVERHEATED MATERIALS

Samples 8 and 15 were homogeneous but all of their residues from laboratory tests were slightly heterogeneous. The asphaltic residue of sample 8 had relatively low ductility at 77° F. but that of sample 15 had good ductility. Both asphaltic residues had good ductilities at 34°–35° F. The residue of sample 15 after exposure had low ductility at 77° F. Sample 8, the only material of low specific gravity to develop carbenes, separted in the exposure test in the same manner as sample 9.

Samples 18 and 20 were both slightly heterogeneous but their asphaltic and loss-test residues were homogeneous. Their asphaltic residues and their residues after exposure had good ductility at 77° F. Although the asphaltic residue of sample 20 had a ductility of only three-fourths centimeter at 34°–35° F., the ductility of its residue after exposure, as well as the ductility of the two residues of sample 18, was good at 34°–35° F. Sample 18 developed a residue at the end of 5 weeks' exposure that was the least heterogeneous of any of the residues from the slow-curing materials.

Samples 10 and 26 and their asphaltic residues were homogeneous. The asphaltic residues of both samples had good ductility at 77° F. and 34°–35° F. At the end of 15 weeks, sample 10 had low ductility at 77° F. but good ductility at 34°–35° F., while sample 26, a cut-back asphalt, was extremely hard and nonductile.

Sample 12 was homogeneous as was its residue after distillation. Its asphaltic residue had good ductility at 77° F. and 34°–35° F. and the residue after exposure had fair ductility at 77° F. and good ductility at 34°–35° F.

Sample 7 was slightly heterogeneous but all of its residues from laboratory tests were homogeneous. Its asphaltic residue was ductile at 77° F. but only slightly so at 34°–35° F. and its residue after 15 weeks of exposure had good ductility at 77° F. and at 34°–35° F.

Samples 6, 21, 22, 25, and 28 were homogeneous with homogeneous residues from laboratory tests. All of their asphaltic residues had good ductility at 77° F. and all except those of samples 21 and 22, the California residuals, had good ductility at 34°–35° F. At the end of 15 weeks, sample 6 was still fluid, while the cut-back asphalt samples 25 and 28 were very hard and nonductile. Samples 21 and 22 had good ductility at 77° F. and at 34°–35° F. although their asphaltic residues were nonductile at 34°–35° F.

It is readily apparent that the laboratory tests did not produce residues that gave stains in the Oliensis test radically different from the stains of the original materials. The behavior of the residues from exposure showed, as did the other tests, that outdoor exposure alters asphaltic materials far more than any of the laboratory heat tests. This was strikingly shown by the decidedly heterogeneous stains obtained with the residues from exposure, especially in the case of the materials originally homogeneous. It is not believed, however, that it is possible to predict the physical and chemical characteristics of the material after exposure from the results of the Oliensis test, whether made on the original material, the residues from laboratory tests or both. Residues having what are believed to be desirable qualities were obtained from both homogeneous and heterogeneous materials, although heterogeneous materials undoubtedly have a more pronounced tendency to carbonize and their slow-curing products generally develop a less-ductile residue.

For detection of materials that have been inadvertently or intentionally subjected to too high a temperature during the refining process, the Oliensis test seems to be more sensitive than the microscopic test. All of the materials that had the characteristics of overheated or cracked materials were heterogeneous in the Oliensis test but only seven of them showed microscopic flecks.

HUBBARD-FIELD STABILITY TEST USED TO MEASURE BONDING STRENGTH AND DEVELOPMENT OF BONDING STRENGTH UPON EXPOSURE

Cylinders were made according to the Hubbard-Field method and tested to determine the adhesiveness or bonding strength of the original material, the residue after distillation and the asphaltic residue, and the development of bonding strength by the original materials after exposure. The first series, for the determination of bonding strength, consisted of 3 sets of 3 cylinders each for each material. The first and second sets contained 16.6 percent by volume of the original material and distillation residues respectively mixed with 83.4 percent of a standard sand. The third set contained the same percentage of asphaltic residue by weight as was contained in the cylinders made with the original materials that gave an almost constant percentage of bitumen by volume in the cylinders of this set. All cylinders of series 1 were tested immediately for stability at 77° F.

The second series of cylinders, for determination of the development of bonding strength, likewise consisted of 3 sets of 3 cylinders using the same aggregate used in the first series and the same percentage of the original materials by volume. These three sets were placed in the exposure boxes and subjected to the same exposure conditions as the thin films. One set was removed at the end of 5, 10, and 15 weeks. The cylinders were weighed before and after exposure and the loss in weight was expressed as a percentage of the bituminous material present in the cylinder as made. After weighing, the cylinders were tested for stability at 77° F.

For comparative purposes two additional sets of cylinders were made, using as a binder the amounts of distillation residue and asphaltic residue that would have been obtained if the bitumen in the cylinders containing the original material had been subjected to the distillation or asphaltic-residue test. The aggregate used was a Potomac River sand that had been separated on standard sieves and recombined to give the following grading:

	Percent
Passing no. 10, retained on no. 20	3. 7
Passing no. 20, retained on no. 30	10. 3
Passing no. 30, retained on no. 40	18. 1
Passing no. 40, retained on no. 50	21. 3
Passing no. 50, retained on no. 80	36. 6
Passing no. 80, retained on no. 100	6. 1
Passing no. 100, retained on no. 200	3. 2
Passing no. 200	. 7

This sand had a specific gravity of 2.666 and the voids in the mineral aggregate, determined on the compacted cylinders of both series, were 38 percent for the cylinders made with the original materials, 37.4 percent for the cylinders made with the distillation residue, and 36.9 percent for the cylinders made with the asphaltic residue.

The method of mixing and molding the cylinders was the same as that used in 1932. The results of the tests on the cylinders of series 1 and 2 are given in tables 10 and 11, respectively. All results are the averages of three tests.

The results of tests on the cylinders of series 1 are shown graphically in figure 11. The stability of the cylinders at 77° F. was plotted against the Furol viscosity at 122° F., and the results of the float test at 77° F. for the cylinders made with the original materials and against the float test results at 122° F. and the penetration at 77° F. for the cylinders made with the distillation residue. Since the asphaltic residues are all of approximately the same consistency, the stabilities were plotted for each sample independently.

Figure 11 shows that although the stability of the mixtures was roughly proportional to the consistency of the contained bitumen, materials having the same consistency as measured by viscosity at 122° F., float test at 77° F. and 122° F., and penetration at 77° F. had different stabilities. This was especially noticeable

TABLE 10.—*Results of tests on series 1 cylinders*

Sample identification	Original material			Distillation residue			Asphaltic residue	
	Stability at 77° F.	Float at 77° F.	Furol viscosity at 122° F.	Stability at 77° F.	Float at 122° F.	Penetration at 77° F.	Stability at 77° F.	Penetration at 77° F.
	Pounds	*Seconds*	*Seconds*	*Pounds*	*Seconds*		*Pounds*	
1	75	100	294	125	24		2,275	96
2	125	52	303	400	60		3,975	100
3	125	50	274	200	43		3,775	105
4	150	63	404	250	45		3,600	107
5	125	36	331	325	58		2,575	105
6	75	21	335	150	21		2,275	99
7	75	9	181	375	62		2,575	92
8	100	60	277	100	27		2,100	100
9	100	33	175	200	44		3,500	86
10	75	11	197	475	87		2,425	106
11	25	4	50	175	34		3,175	84
12	100	13	182	200	38		2,450	97
13	150	41	406	200	37		2,775	93
14	125	49	278	150	36		3,675	93
15	75	21	219	175	41		2,675	103
16	75	38	217	100	25		2,225	109
17	150	20	205	1,000	110		2,700	102
18	125	9	199	400	60		1,900	100
19	175	75	320	475	57		3,775	102
20	100	46	300	350	50		2,325	104
21	75	23	293	200	41		2,375	110
22	150	60	768	325	56		2,325	113
23	75	12	123	150	27		2,700	98
24	75	14	241	3,925		76	2,950	101
25	275	31	472	3,225		77	2,825	94
26	150	35	351	3,025		84	2,725	95
27	25	3	47	3,800		87	3,850	90
28	200	19	303	3,775		65	3,725	97
29	275	17	260	3,850		72	3,650	100
30	125	39	350	3,475		81	3,000	104
31	100	37	431	2,325		205	2,950	112
32	75	25	331	1,500		298	3,075	101

TABLE 11.—*Results of tests on series 2 stability cylinders*

Sample identification	Cylinders made with the original materials							Cylinders made with distillation residue		Cylinders made with asphaltic residue	
	Stability at 77° F.				Loss of bitumen			Stability at 77° F.	Theoretical loss of bitumen	Stability at 77° F.	Theoretical loss of bitumen
	When made	In 5 weeks	In 10 weeks	In 15 weeks	In 5 weeks	In 10 weeks	In 15 weeks				
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Per cent*	*Per cent*	*Per cent*	*Lbs.*	*Per cent*	*Lbs.*	*Per cent*
1	75	300	300	425	0	3	1	125	3	1,975	28
2	125	900	1,100	1,300	7	12	12	425	11	3,575	25
3	125	750	1,000	1,150	6	10	11	250	7	3,075	28
4	150	600	750	850	3	6	6	300	6	3,150	25
5	125	675	1,025	1,275	6	11	11	475	14	2,400	29
6	75	225	250	300	4	9	9	175	7	1,975	38
7	75	425	550	600	15	20	21	425	23	2,075	35
8	100	250	300	300	3	5	6	175	6	1,750	35
9	100	550	775	800	7	12	12	325	11	3,075	31
10	75	775	950	1,250	14	18	18	550	22	2,175	34
11	25	425	500	800	18	21	22	275	25	2,450	47
12	100	350	425	550	10	14	15	275	18	2,050	38
13	150	650	700	875	6	10	10	275	9	2,350	33
14	125	650	900	1,025	4	8	8	225	5	2,900	30
15	75	475	550	600	8	12	13	300	15	2,325	38
16	75	250	325	350	4	8	9	175	7	1,875	38
17	150	950	1,000	1,200	15	19	21	1,275	21	2,325	28
18	125	825	950	1,200	16	20	20	500	18	1,750	25
19	175	1,650	2,525	3,075	7	11	11	625	10	2,825	24
20	100	725	1,000	1,250	8	12	13	350	14	2,050	31
21	75	525	700	850	8	13	14	300	15	1,950	37
22	150	775	1,075	1,400	5	9	9	350	10	2,100	29
23	75	275	550	750	7	11	11	200	12	2,175	39
24	75	4,275	4,325	5,200	20	23	22	3,650	25	2,800	23
25	275	3,700	3,750	3,850	17	19	19	3,025	24	2,650	22
26	150	3,500	3,125	3,550	21	24	23	2,800	23	2,775	22
27	25	1,450	1,500	1,650	28	30	29	2,875	30	3,600	27
28	200	4,650	4,250	4,975	16	18	18	3,400	21	3,475	20
29	275	4,400	4,100	4,825	13	16	16	3,250	24	3,400	21
30	125							3,175	26	2,700	24
31	100							2,075	20	2,675	21
32	75							1,425	22	2,775	25

in the results with the cylinders made with the asphaltic residue. Although all of these residues had approximately the same penetration, the stability of the cylinders varied from 1,900 pounds for sample 18 to 3,975 pounds for sample 2.

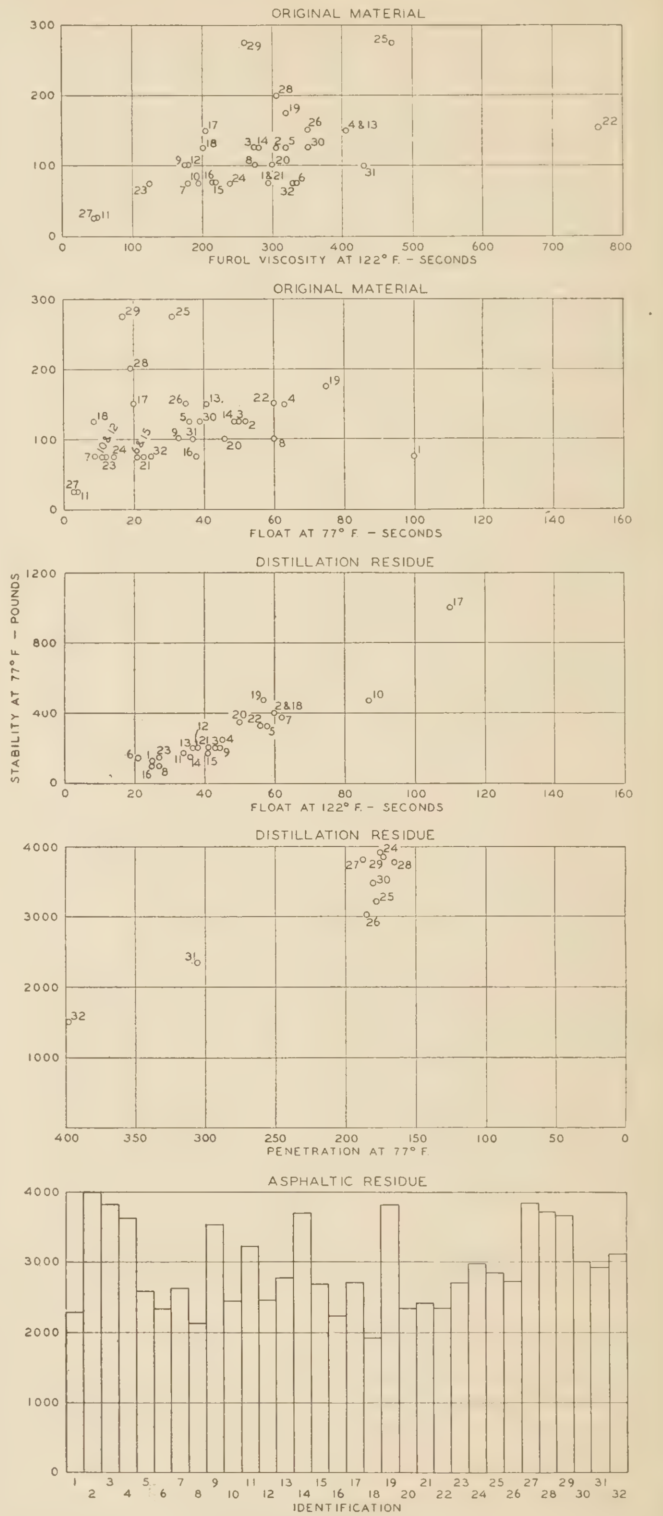

FIGURE 11.—RELATION BETWEEN THE CONSISTENCIES OF ORIGINAL MATERIALS, DISTILLATION RESIDUES, AND ASPHALTIC RESIDUES AND THE STABILITY AT 77° F. OF CYLINDERS OF SERIES 1.

It is seen that the cylinders made with the asphaltic residues of samples 2, 3, 4, 9, 11, 14, and 19 all had stabilities of over 3,000 pounds. All of these materials were heterogeneous originally, all were materials of high specific gravity, and all except sample 11 contained or developed carbenes and free carbon. Sample 11 had a relatively high specific gravity but did not develop

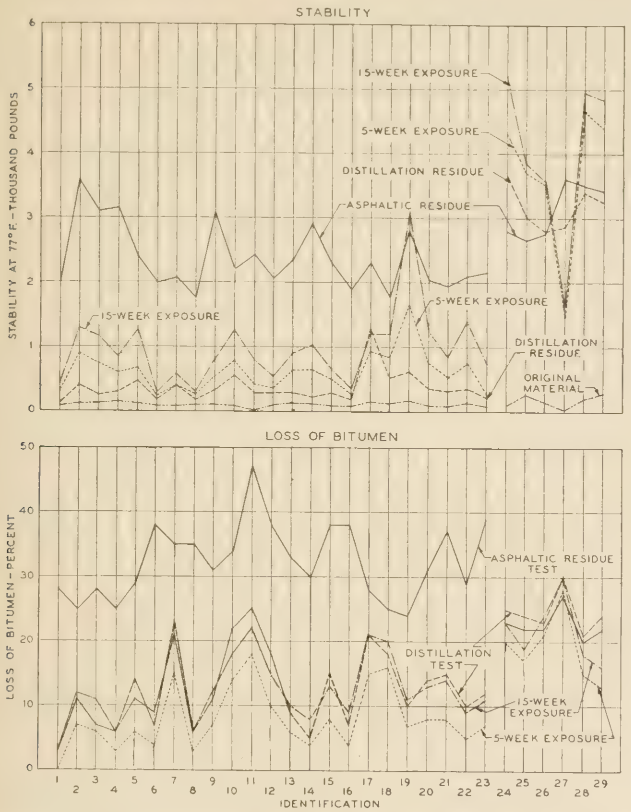

FIGURE 12.—COMPARISON OF LOSS OF BITUMEN AND STABILITY OF SERIES 2 HUBBARD-FIELD CYLINDERS.

carbenes. Samples 5, 7, 13, 15, 17, and 23 had stabilities between 2,500 and 3,000 pounds. Samples 17 and 23 were heterogeneous materials of high specific gravity that contained or developed carbenes. Samples 5 and 13 were heterogeneous materials of fairly high specific gravity but they did not develop carbenes, and samples 7 and 15 were materials of low specific gravity. All of the cut-back products had asphaltic residues giving stabilities of 2,500 pounds or over and five gave stabilities of 3,000 pounds or over.

Figure 12 shows the results of stability tests on the cylinders of series 2. The loss of bitumen in 5 and 15 weeks of exposure and the theoretical loss of bitumen in the cylinders made with the distillation and asphaltic residues were plotted for each sample. The stabilities at 77° F. for each sample were also plotted.

In this figure it is seen that, in the case of the slow-curing materials, although the loss of bitumen in the exposed cylinders was approximately the same as the loss in the distillation test, the exposed cylinders had greater stability than the cylinders made with the distillation residue except in the case of sample 17. This sample, even in 15 weeks, did not attain as high a stability as the cylinders made with the distillation residue. It is also seen that the loss in 15 weeks' exposure did not approach the loss in the asphaltic residue test and that the stability of the exposed cylinders did not approach the stability of the cylinders made with the asphaltic residue, except in the case of sample 19.

For the cut-back materials the indicated losses were probably in error due to unavoidable loss of volatile matter while mixing and molding the cylinders. The losses in 5 and 15 weeks of exposure probably should have been about the same as the losses in the distillation and asphaltic residue tests. The stabilities at 5 weeks were higher than the stabilities of cylinders made with the asphaltic and distillation residues except in the case of sample 27.

SATISFACTORY CHECKS OBTAINED WITH RESULTS OF 1932 TESTS

After the exposure tests had been started, a question was raised concerning the use of plate glass covers for the exposure cabinets because it prevented the active ultra-violet rays from acting on the materials. Fused quartz glass not being available, Vita glass, which, after a short stabilization period, is guaranteed to permanently transmit an effective volume and combination of wave lengths of active ultra-violet light, was used to determine the effect of the passage of more active light. Duplicate sets of 10 of the slow-curing materials, 2 of the rapid-curing materials, and sample 27 and 3 new medium-curing materials, samples 30, 31, and 32, were exposed under both Vita and plate glass for 5- and 10-week periods. The materials were exposed in thin films and also admixed with the standard sand in the form of Hubbard-Field cylinders.

This exposure was started August 28, 1933. During the first 5-week period the average maximum air temperature was 80° F. and the number of sunlight hours was 266. During the 10-week period the average maximum air temperature was 73° F. and the number of sunlight hours was 512. The results of the tests on the thin films are given in table 12, and those on the Hubbard-Field cylinders in table 13.

As shown by tables 6 and 12, the materials did not lose as much nor get as hard in 10 weeks as they did in the original 5 weeks of exposure. This was due to the lower air temperature and also to the fact that the sun's rays striking at an oblique angle did not cause the material to get as hot as earlier in the summer. There was little if any difference between the materials exposed under the different types of glass. The samples exposed under Vita glass had a little more material insoluble in carbon disulphide and carbon tetrachloride and generally had a little more material insoluble in naphtha. Each solubility reported was the average of 3 or more tests. The results of the stability tests do not show that there was any difference between the two types of glass. The comparative study of the effectiveness of Vita glass and plate glass as cover for the exposure of the samples did not produce differences great enough to indicate their relative efficiency for this purpose.

As stated previously, four of the samples tested in 1932 were included in the 1933 work and the results obtained, as shown in table 14, were in remarkably close agreement with the previous tests. In the case of samples 17 and 19 the residues from the 1933 exposure tests had greater percentages of free carbon and carbenes than did residues from the 1932 exposure tests.

The results of the two sets of stablity tests were not in such close agreement because the aggregate used in the 1933 tests was somewhat coarser than that used in 1932. In 1932, cylinders made with sample 17 were the only ones that, after 15 weeks' exposure, had a stability about the same as those made with the distillation residue. In 1933 the cylinders made with sample 17, after 15 weeks' exposure, had less stability than the cylinders made with the distillation residue. Cylinders of sample 19 that in 1932, after 15 weeks' exposure, had a stability approaching that of the asphaltic-residue cylinders, in 1933, after 15 weeks' exposure, had a stability higher than that of the asphaltic-residue specimens.

TABLE 12.—*Results of tests on plate and Vita glass exposure residues*

5 WEEKS' EXPOSURE

Sample identification	Plate glass										Vita glass									
	Loss	Float at 122° F.	Penetration		Softening point	Ductility at 5 cm per minute		Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B. naphtha	Loss	Float at 122° F.	Penetration		Softening point	Ductility at 5 cm per minute		Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B. naphtha
			At 77° F., 100 g, 5 sec.	At 32° F., 200 g, 60 sec.		At 77° F.	At 34°–35° F.						At 77° F., 100 g, 5 sec.	At 32° F., 200 g, 60 sec.		At 77° F.	At 34°-35 °F.			
	Percent	*Seconds*			*°F.*	*Centimeters*	*Centimeters*	*Percent*	*Percent*	*Percent*	*Percent*	*Seconds*			*°F.*	*Centimeters*	*Centimeters*	*Percent*	*Percent*	*Percent*
1	−2.5	50								12.7	−3.3	46								13.4
2	6.7	113						0.82	6.86	29.9	4.5	92						1.22	6.85	29.2
13	4.5	61								18.4	2.2	54								17.8
14	2.2	53						.29	2.68	24.8	1.6	47						.47	2.73	23.4
17	12.4	140						1.08	4.09	26.8	12.4	156						1.28	4.64	28.3
18	16.0	110								12.2	14.9	104								12.9
19	6.4	105						1.68	9.63	32.6	5.6	98						2.00	10.22	33.6
20	7.9	103								17.2	6.5	96								17.0
21	8.0	53								14.1	5.7	49								13.7
23	6.0	52								19.2	5.6	50								19.2
26	21.5		37	18	143	8.5	0.0	.13	.33	27.3	21.5		33	16	147	10	0.0	.26	.15	27.6
27	27.4		46	14	124	17.0	.0	.19	.56	27.7	26.2		39	14	126	12	.0	.31	.64	28.0
29	18.5		40	17	141	11.0	.0			33.3	18.8		59	21	134	18	.0			31.7
30	22.6		38	16	136	18.0	.0			32.7	22.1		40	20	138	15	.0			33.5
31	17.6		61	18	124	110+	.0			29.7	17.3		52	17	126	110+	.0			30.5
32	17.7		122	24	106	110+	1			19.8	17.5		123	28	106	110+	5			20.8
10 WEEKS' EXPOSURE																				
1	−2.5	54							0.14	14.1	−3.3	56							0.22	14.6
2	7.1	152						1.42	7.77	30.2	4.1	141						1.73	8.13	30.5
13	5.1	85							.04	19.6	3.2	71							.05	20.2
14	2.2	64						.50	3.16	23.9	2.3	65						.55	3.45	24.1
17	12.9	178						1.03	5.16	28.1	12.6	297						1.24	5.39	29.1
18	16.4	144							.12	12.9	16.1	154							.16	13.9
19	7.6	145						2.92	10.42	34.3	6.9	133						2.99	10.61	33.7
20	8.3	135							.07	19.4	8.0	125							.11	19.0
21	8.7	70							.09	15.0	8.7	74							.12	15.9
23	6.1	71							.10	20.4	6.1	84							.08	21.3
26	21.4		32	17	147	6.3	.0	.42	.36	28.0	21.5		30	16	149	6	.0	.31	.25	28.7
27	26.4		31	13	128	8.5	.0	.25	.73	29.9	26.7		26	13	130	7	.0	.30	.59	31.1
29	19.3		42	17	141	13.5	.0		.22	33.4	18.9		52	19	136	16	.0		.24	33.3
30	22.6		32	14	142	8.3	.0		.23	33.9	22.3		34	15	141	11	.0		.20	35.3
31	17.8		39	14	131	33.0	.0		.13	33.7	17.3		44	15	131	32	.0		.14	33.0
32	18.1		87	22	115	63.0	.0		.17	22.2	18.0		73	17	117	65	.0		.15	23.7

CONCLUSIONS

The results of this investigation substantiate most of the conclusions arrived at in the 1932 investigation, modify two of the conclusions, and indicate some new conclusions. The conclusions substantiated are:

1. Materials of high specific gravity and their residues are, in general, more susceptible to changes in temperature than materials of low specific gravity and their residues.

2. Hardening due to causes other than loss of volatile matter, and changes in inherent characteristics that may be attributed to oxidation, polymerization, and carbonization, occur to the greatest extent upon exposure and least during distillation.

3. The development of a ductile residue either in the asphaltic-residue test or, in the case of cut-back materials, in the distillation test, does not indicate that the material will develop a ductile residue upon exposure.

4. The bonding strength of the original materials and their residues is roughly proportional to their consistencies, but materials having the same consistency as measured by the present tests do not always give the same stability. The reasons for these differences in stability cannot be determined under the present methods of testing.

The following conclusions are somewhat modified from 1932:

TABLE 13.—*Results of stability tests on cylinders exposed under plate and Vita glass*

Sample identification	Loss of bitumen				Stability at 77° F.			
	In 5 weeks		In 10 weeks		In 5 weeks		In 10 weeks	
	Plate	Vita	Plate	Vita	Plate	Vita	Plate	Vita
	Percent	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	2	1	2	1	225	250	275	375
2	8	5	8	7	850	700	850	800
13	7	4	6	5	450	450	500	425
14	4	2	4	3	475	400	500	450
17	13	12	15	13	650	700	650	700
18	18	16	18	17	500	500	525	500
19	8	6	8	8	1,075	1,000	1,250	1,275
20	8	7	8	8	550	500	500	525
21	8	7	8	8	325	350	350	350
23	5	4	6	5	225	200	250	250
26	21	21	24	23	2,775	2,650	3,550	3,500
27	28	28	30	30	1,225	1,225	1,575	1,350
29	12	12	14	13	3,775	3,725	4,600	4,575
30	23	23	24	24	2,575	2,550	2,850	3,025
31	18	19	20	20	2,325	2,375	2,725	3,125
32	18	17	19	20	1,675	1,725	2,200	2,675

5. The relative rates of volatilization of the various materials can be anticipated most readily from the distillation curves. The different classes of material may be differentiated in the loss and asphaltic-residue tests, especially if the time of reduction to 100 penetration is considered. However, sharp distinctions in initial curing properties, that may be of importance in some types of construction, can be determined only from the distillation curves.

6. Carbonization generally occurs in materials that originally contain some material insoluble in carbon disulphide and carbon tetrachloride, but some materials with exceptionally high solubility in these solvents show a tendency to carbonize under both laboratory and exposure conditions.

The following conclusions are developed upon the basis of the data collected in 1933 only:

7. The Oliensis test is more sensitive than the microscopic test in the detection of materials that have been subjected to excessively high temperatures in manufacture. However, neither test seems definitely to distinguish products that will weather badly.

8. The use of Vita glass in place of plate glass for the cover of the exposure boxes did not materially change the results. However, because of the lateness in the year when these tests were started the results are considered inconclusive.

9. If like periods of the year are used for exposure, satisfactory check tests can be obtained with the exposure assembly used in these investigations.

Many of the laboratory heat tests have been criticized as producing conditions dissimilar to and more severe than service conditions. These investigations have shown that the physical and chemical characteristics generally believed to belong to unsatisfactory materials are developed upon exposure in many products that satisfactorily withstand laboratory testing. While it is possible, by the utilization of identification tests, to restrict materials to a limited number of sources or manufacturing processes, it is impossible to predict, with any degree of accuracy, the weather-resisting properties of the material thus obtained. It is believed that efforts should be directed to the modification of some of the present laboratory heat tests so that differences in the tendency of various materials to develop unsatisfactory residues may be recognized.

TABLE 14.—*Comparison of 1932 and 1933 exposure tests*

TESTS ON RESIDUES AFTER EXPOSURE

Test characteristic	Sample identification							
	17		18		19		20	
	1932	1933	1932	1933	1932	1933	1932	1933
Loss in 10 weeks, percent	18.3	18.7	18.5	17.7	13.3	12.0	13.1	11.5
Penetration at 77° F	41	36	132	152	40	44	95	136
Penetration at 32° F	17	14	37	43	9	10	30	41
Softening point, °F	163	170	106	105	121	121	115	112
Ductility at 77° F., centimeters	1.0	0.5	110+	110+	110+	110+	65.0	90.0
Ductility at 34°–35° F., centimeters	.0	.0	1.5	7.5	.0	.0	3.3	3.8
Insoluble in CS_2, percent	1.06	3.17	------	------	5.96	6.50	------	------
Insoluble in CCl_4, percent	8.27	9.66	.10	------	14.94	16.02	.05	------
Insoluble in 86° B. naphtha, percent	34.8	36.2	17.6	17.3	41.1	38.7	26.8	24.2
Loss in 15 weeks, percent	19.8	19.5	18.7	19.0	13.7	13.8	13.7	13.6
Penetration at 77° F	19	29	93	93	28	29	67	84
Penetration at 32° F	12	12	29	28	8	7	24	28
Softening point, °F	181	168	113	116	129	128	121	120
Ductility at 77° F., centimeters	0.3	0.5	86.0	115.0	110+	110+	42.0	72.0
Ductility at 34°–35° F., centimeters	.0	.0	4.0	4.5	.0	.0	1.3	3.0
Insoluble in CS_2, percent	2.50	3.30	------	------	6.17	7.50	------	------
Insoluble in CCl_4, percent	9.11	9.88	.17	.10	15.61	18.15	.14	.09
Insoluble in 86° B. naphtha, percent	37.2	35.4	19.6	18.8	38.8	39.9	28.5	27.2

TESTS ON HUBBARD-FIELD CYLINDERS

Loss of bitumen:								
In 5 weeks, percent	15	15	18	16	8	7	9	8
In 10 weeks, percent	18	19	19	20	10	11	12	12
In 15 weeks, percent	21	21	21	20	14	11	13	13
Stability at 77° F.:[1]								
Original cylinders, pounds	275	150	200	125	325	175	225	100
After 5 weeks' exposure, pounds	1,100	950	800	825	1,375	1,650	775	725
After 10 weeks' exposure, pounds	1,575	1,000	1,125	950	3,175	2,525	1,525	1,000
After 15 weeks' exposure, pounds	1,550	1,200	1,650	1,200	4,050	3,075	1,975	1,250
Series 2, distillation residue cylinders, pounds	1,475	1,275	750	500	800	625	500	350
Series 2, asphaltic residue cylinders, pounds	4,050	2,325	2,925	1,750	4,900	2,825	3,325	2,050

[1] Differences in stability probably are caused by differences in grading of the sand.

MOTOR-FUEL CONSUMPTION, 1934

[Compiled for calendar year from reports of State authorities]

State	Gross amount reported by State [1]	Exempted from payment of tax [2]		Shrinkage allowance, discounts, etc.[3]		Gross amount assessed for taxation	Subject to refund of entire tax		Amount on which tax was earned	Classification of taxed motor fuel: By rate of tax				Classification of taxed motor fuel: By use [5]			Percentage change in fuel consumption from previous year [6]
										At full rate	At reduced rates [4]			For highway use [5]	For other uses		
		Amount	Classes of use	Percentage	Amount		Amount	Classes of use			Amount	Rate per gallon	Classes of use		Amount	Classes of use	
	1,000 gallons	*1,000 gallons*			*1,000 gallons*	*1,000 gallons*	*1,000 gallons*		*1,000 gallons*	*1,000 gallons*	*1,000 gallons*	*Cents*		*1,000 gallons*	*1,000 gallons*		
Alabama	154,977					154,977			154,977	154,977							15.8
Arizona	*75,502	3,944	F	1	713	70,845	10,280	NH, E	60,565	60,565				60,565			13.0
Arkansas	*134,249	3,444	F, E	1	1,276	129,529	3,953	[7] NH, C	125,576	108,414	17,162	6, 5, 4, 2	(8)	[9] 119,680	[9] 5,896	NH	4.3
California	1,356,386	22,361	F	1	13,340	1,320,685	122,030	NH	1,198,655	1,198,655				1,198,655			2.1
Colorado	*172,672	2,016	F	2	3,353	167,303	24,013	NH, D, E	143,290	74,381	68,909	4	(4)	143,290			7.6
Connecticut	*308,239	50,757	F, E	1	2,549	254,933	6,275	NH	248,658	248,658				248,658			3.4
Delaware	41,556					41,556	2,042	NH	39,514	39,514				39,514			5.2
Florida	246,387	7,564	F, P	(10)	3,125	235,698			235,698	235,698							15.8
Georgia	243,823	2,203	F	(10)	2,185	239,435			239,435	239,435							13.7
Idaho	65,828	2,314	F			63,514	5,961	NH	57,553	57,300	253	2½	AV	57,300	253	AV	25.5
Illinois	1,025,751					1,025,751	54,877	NH	970,874	970,874				970,874			4.6
Indiana	465,638					465,638	26,895	NH	438,743	438,743				438,743			7.8
Iowa	423,886	7,366	F, P	3	12,717	403,803	28,805	NH	374,998	374,998				374,998			20.0
Kansas	*378,781	87,330	F, NH, IC	2	7,575	283,876			283,876	283,876				283,876			10.1
Kentucky	184,369					184,369			184,369	184,369							10.9
Louisiana	183,977			3	5,519	178,458	1	F	178,457	178,434	23	4	(11)				9.4
Maine	116,994	1,200	F			115,794			115,794	110,924	4,870	1	NH	110,924	4,870	NH	8.7
Maryland	207,652	1,373	F			206,279	10,616	[12] NH	195,663	193,961	1,702	3	U	[12] 195,663			8.6
Massachusetts	*590,625	2,797	F, E			587,828	21,093	F, NH	566,735	566,735				566,735			3.8
Michigan	735,593					735,593	35,763	NH	699,830	698,681	1,149	1½	AV	698,681	1,149	AV	7.7
Minnesota	419,454	1,908	(13)	3	12,534	405,012	43,500	NH	361,512	361,512				361,512			8.3
Mississippi	130,156	2,180	F	2	2,547	125,429			125,429	112,666	12,763	1	NH	112,666	12,763	NH	16.5
Missouri	505,677			3	15,170	490,507	11,743	NH	478,764	478,764				478,764			5.4
Montana	*90,567	2,562	F, E	2	2,523	85,482	12,211	NH	73,271	73,271				73,271			33.2
Nebraska	*224,195	798	F	3	6,726	216,671	2,414	E, D	214,275	214,257							11.2
Nevada	*27,204	2,497	F, E, IC			24,707	2,352	NH	22,355	22,355				22,355			28.5
New Hampshire	70,652					70,652	2,011	NH	68,641	68,641				68,641			16.8
New Jersey	*732,761	164,922	[14] F, P, NH, E			567,839			567,839	567,727	112	2	B	567,727	112	B	3.9
New Mexico	*60,997	3,922	F, E, IC	2	898	56,177	5,043	NH	51,134	51,134				51,134			12.9
New York	1,569,141	52,511	F, P	1	15,167	1,501,463	37,221	NH	1,464,242	1,464,242				1,464,242			1.3
North Carolina	284,214	2,540	F, AV	1	1,877	279,797			279,797	273,686	6,111	1	NH	273,686	6,111	NH	11.2
North Dakota	96,875					96,875	21,485	NH	75,390	75,390				75,390			17.6
Ohio [15]	*1,303,642	239,900	F, E, IC	3	31,912	1,031,830	673	D, R	1,031,157	910,214	120,943	1	NH	910,214	120,943	NH	8.6
Oklahoma	*312,165	33,748	F, IC, NH	3	7,985	270,432			270,432	270,432				270,432			7.5
Oregon	*165,978					165,978	20,464	NH, E	145,514	144,917	597	1	AV	144,917	597	AV	6.7
Pennsylvania [16]	1,136,343			2	22,714	1,113,629			1,113,629	1,113,629							8.7
Rhode Island	*233,167	124,303	F, E			108,864	6,030	NH, E	102,834	102,834				102,834			9.3
South Carolina	130,606					130,606	1,960	F	128,646	128,646							15.6
South Dakota	103,122			4	4,125	98,997			98,997	89,245	9,752	2	NH	89,245	9,752	NH	13.9
Tennessee	207,857	4,148	F, P	1	2,075	201,634	7	D, R	201,627	201,627							8.7
Texas	893,802	9,824	F	1	8,840	875,138	84,133	NH	791,005	791,005				791,005			11.1
Utah	64,836			3	1,978	62,858			62,858	62,858							14.9
Vermont	48,550					48,550			48,550	48,550							10.0
Virginia	264,102					264,102	14,562	NH	249,540	249,540				249,540			12.6
Washington	260,778					260,778	21,591	NH	239,187	239,187				239,187			10.1
West Virginia	147,610					147,610	5,217	NH	142,393	142,393				142,393			15.8
Wisconsin	431,513			2½	10,788	420,725	35,744	NH	384,981	384,981				384,981			1.5
Wyoming	44,111					44,111			44,111	44,111							25.5
District of Columbia	147,607	42,186	F, P	2	1,601	103,820	691	NH	103,129	103,129				103,129			−0.9
Total	17,220,567	882,618			201,812	16,136,137	681,656		15,454,481	15,210,135	244,346			12,485,421	162,446		7.5

The following symbols are used to designate certain classes or uses of motor fuel exempted from tax payment, subject to refund of the tax, or taxed at a lower rate:

F—Sales to Federal Government.
P—(Public) sales to State, county, or municipal governments.
E—Fuel exported to other States or countries.
IC—Fuel moving through the State in interstate commerce.
NH—Uses other than for propelling motor vehicles on the highways.
C—Use in public construction.
AV—Aviation use.
U—Use in vehicles licensed to operate exclusively in cities.
B—Motor-boat use.
D—Fuel destroyed by fire, acts of God, etc.
R—Routine refunds (overpayment, etc.).

[1] In this column is given the total amount of motor fuel reported, prior to deduction of exempted fuel, allowance for shrinkage, etc., and amount subject to refund. Wherever possible, fuel exempted because of export or interstate movement, or to avoid duplication of tax payment, has been eliminated, in order that the total may represent as closely as possible the total consumption of motor fuel in the State. Starred items indicate that unknown amounts of export sales or fuel moving in interstate commerce are included in the total shown.

[2] A number of States failed to report exempted fuel. Symbols are given only where amounts are reported.

[3] Allowances for loss by leakage, evaporation, etc., and percentage discounts allowed to distributors. Percentages are given only where amounts are reported. In some States the percentage is computed on the gross reported; in others on the net after deduction of exempted fuel. In some States the percentage is fixed; in others it is the maximum allowable.

[4] In the case of Arkansas and Colorado, where the rate was changed during the year, the amounts taxed at the lower rates, 6 and 4 cents, respectively, are shown under this heading.

[5] The purpose of this classification is to distinguish between the consumption of taxed motor fuel by motor vehicles operating on the highways, and consumption for other purposes. In the case of States which do not make this distinction, the classification is omitted.

[6] These percentages are based on the amount taxed for highway use, except in the case of those States in which there is no classification by use. In those cases the percentage is based on the total amount on which tax was earned. The total on which the Nation-wide percentage is based is 15,292,035,000 gallons. A decrease (District of Columbia only) is indicated by a minus sign.

[7] Refunds on nonhighway use not allowed after Feb. 12, 1934.

[8] 7,412,000 gallons at 6 cents prior to Feb. 13, 1934. Taxed at reduced rates at State borders: At 5 cents, 138,000 gallons; at 4 cents, 8,677,000 gallons; at 2 cents, 935,000 gallons.

[9] Estimated by State.

[10] Actual allowance reported; no fixed percentage.

[11] Rate of 4 cents per gallon applies to any gas-generating liquid having a flash point below 110° F. Additional 1-cent rate applies only to liquid fuels commonly used to propel motor vehicles or motors.

[12] Refunds are made on all nonhighway uses with the exception of fuel used in commercial motor boats.

[13] Railroad usage.

[14] Also fuel used in busses which pay a municipal or franchise tax.

[15] A 3-cent tax is imposed on motor-vehicle fuel, and a 1-cent tax on all liquid fuels, including fuel oil and kerosene. The gross amount of liquid fuel reported was 1,303,642,000 gallons; the gross amount of motor-vehicle fuel reported was 1,254,786,000 gallons.

[16] Tax is imposed on all liquid fuels, including fuel oil and kerosene, usable in internal-combustion engines.

STATE MOTOR-FUEL TAX EARNINGS, 1934

[Compiled for calendar year from reports of State authorities [1]]

State	Tax rate per gallon: On Jan. 1	Tax rate per gallon: On Dec. 31	Date of rate change	Gross tax assessed [4]	Refunds earned or paid [5]	Net earnings on all motor-fuel taxed [4]	Classification of tax earnings [1]: By rate of tax: At full rate	By rate of tax: At reduced rates [6]: Rate per gallon	By rate of tax: At reduced rates [6]: Amount	By use of fuel [2]: For highway use [2]	By use of fuel [2]: For other uses	Other earnings in connection with motor-fuel tax [3]: Distributors' licenses	Dealers' licenses	Inspection fees	Other fees, etc.	Total	Grand total earnings
	Cents	Cents		1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	Cents	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars
Alabama	6	6		9,299		9,299	9,299										9,299
Arizona	5	5		3,542	514	3,028	3,028			3,028					1	1	3,029
Arkansas	6	6½	Feb. 3	8,118	254	7,864	7,047	6, 5, 4, 2	[7] 817	[8] 7,481	[8] 383						7,864
California	3	3		39,621	3,661	35,960	35,960			35,960		10				10	35,970
Colorado	[9] 4	4	Feb. 1 and Sept. 1.	7,591	1,116	6,475	3,719	[6] 4	2,756	6,475							6,475
Connecticut	2	2		5,099	126	4,973	4,973			4,973			(10)				4,973
Delaware	3	3		1,246	61	1,185	1,185			1,185							1,185
Florida	7	7		16,499		16,499	16,499						[11] 35			35	16,534
Georgia	6	6		14,366		14,366	14,366										14,366
Idaho	5	5		3,169	298	2,871	2,865	2½	6	2,865	6				1	1	2,872
Illinois	3	3		30,772	1,646	29,126	29,126			29,126					5	5	29,131
Indiana	4	4		18,626	1,076	17,550	17,550			17,550					20	20	17,570
Iowa	3	3		12,114	864	11,250	11,250			11,250		1			4	5	11,255
Kansas	3	3		8,516		8,516	8,516			8,516		5		76	37	118	8,634
Kentucky	5	5		9,218		9,218	9,218								3	3	9,221
Louisiana	5	5		8,923		8,923	8,922	4	1								8,923
Maine	4	4		4,632	146	4,486	4,437	1	49	4,437	49						4,486
Maryland	4	4		8,251	442	7,809	7,758	3	51	[12] 7,809							7,809
Massachusetts	3	3		17,635	633	17,002	17,002			17,002							17,002
Michigan	3	3		22,068	1,090	20,978	20,961	1½	17	20,961	17		4		2	6	20,984
Minnesota	3	3		12,150	1,305	10,845	10,845			10,845			1	97		98	10,943
Mississippi	6	6		7,519	631	6,888	6,760	1	128	6,760	128				[13] 137	137	7,025
Missouri	2	2		9,810	235	9,575	9,575			9,575				98	8	106	9,681
Montana	5	5		4,274	610	3,664	3,664			3,664							3,664
Nebraska	4	4		8,667	97	8,570	8,570							85	1	86	8,656
Nevada	4	4		988	94	894	894			894							894
New Hampshire	4	4		2,826	80	2,746	2,746			2,746							2,746
New Jersey	3	3		17,035	1	17,034	17,032	2	2	17,032	2		25	39		64	17,098
New Mexico	5	5		2,809	252	2,557	2,557			2,557		9	9			18	2,575
New York	3	3		45,044	1,117	43,927	43,927			43,927			58			58	43,985
North Carolina	6	6		16,788	306	16,482	16,421	1	61	16,421	61			[14] 704	5	709	17,191
North Dakota	3	3		2,906	644	2,262	2,262			2,262							2,262
Ohio	4	4		38,982	1,364	37,618	36,409	1	1,209	36,409	1,209						37,618
Oklahoma	4	4		10,817		10,817	10,817			10,817					4	4	10,821
Oregon	5	5		8,299	1,047	7,252	7,246	1	6	7,246	6						7,252
Pennsylvania	3	3		33,409		33,409	33,409								4	4	33,413
Rhode Island	2	2		2,177	120	2,057	2,057			2,057			3			3	2,060
South Carolina	6	6		7,836	117	7,719	7,719										7,719
South Dakota	4	4		3,960	195	3,765	3,570	2	195	3,570	195						3,765
Tennessee	7	7		14,114		14,114	14,114										14,114
Texas	4	4		35,005	3,365	31,640	31,640			31,640					111	111	31,751
Utah	4	4		2,514		2,514	2,514						1			1	2,515
Vermont	4	4		1,942		1,942	1,942										1,942
Virginia	5	5		13,205	728	12,477	12,477			12,477							12,477
Washington	5	5		13,039	1,080	11,959	11,959			11,959							11,959
West Virginia	4	4		5,905	209	5,696	5,696			5,696		2	5		1	8	5,704
Wisconsin	4	4		16,829	1,430	15,399	15,399			15,399							15,399
Wyoming	4	4		1,764		1,764	1,764					[15] 3			1	4	1,768
Dist. of Columbia	2	2		2,077	14	2,063	2,063			2,063							2,063
Detailed totals [16]										434,634	2,056						
Grand totals	[17] 3.66			591,995	26,968	565,027	559,729		5,298			30	141	1,099	345	1,615	566,642

[1] See preceding table for gross gallons of motor fuel reported, exemptions, allowances, etc., gross gallons taxed, gallons subject to refund, net gallons taxed, and information regarding classes of use exempted, subject to refund, or taxed at lower rates.

[2] The purpose of this classification is to distinguish between the tax earnings on motor fuel sold for use in motor vehicles on the highways and tax earnings on motor fuel sold for other uses. In the case of those States that do not make this distinction, the classification is omitted.

[3] Amounts less than $500 not tabulated.

[4] In the great majority of cases the assessments or earnings of the calendar year were reported. A few States reported the actual collections of the year, which lag the assessments by 1 to 2 months.

[5] In most cases the refunds reported were those actually paid during the year, rather than refunds claimed on motor fuel purchased during the year. The error involved in deducting refunds paid from gross tax assessed tends to balance over an annual period. The refunds tabulated include both refunds of the entire tax and partial refunds.

[6] In the case of Arkansas and Colorado, where the rate was changed during the year, the tax earnings at the lower rates, 6 and 4 cents, respectively, are shown under this heading.

[7] Includes $445,000 on 6-cent tax prior to Feb. 13, 1934, and amounts at reduced rates at State borders, as follows: At 5 cents, $7,000; at 4 cents, $347,000; at 2 cents, $18,000.

[8] Estimated by State.

[9] Rate was 5 cents from Feb. 1 to Aug. 31, 1934.

[10] Retail gasoline station licenses, $45,000, included in report on motor-vehicle receipts.

[11] Includes distributors' licenses.

[12] Refunds are made on all nonhighway uses with the exception of fuel used in commercial motor boats. Earnings on motor-boat fuel (amount not reported) are included.

[13] Includes $138,560, earnings on special gasoline tax collected in Gulf Coast counties (Hancock, Harrison, and Jackson) for seawall protection, and $1,559 in penalties, less $2,629, refunds for notary fees.

[14] Inspection fees on gasoline and kerosene; bulk of receipts on gasoline.

[15] Includes dealers' licenses.

[16] Classification by use includes 36 States and the District of Columbia.

[17] Weighted average rate.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF JULY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 6,527,856	$ 3,460,745	$ 139,902	358.2	$ 2,147,304	$ 460,140	$ 1,364,071	109.8	$ 20,073	$ 195,768	11.8	$ 6,795	$ 430,180
Arizona	3,855,555	1,338,712	5,076,955	3,829,744	563,373	362.8	902,109		775,339	32.2	15,039			10,772	
Arkansas	3,334,167	1,714,000	3,828,359	2,576,551	629,904	184.5	1,662,770	700,927	742,291	76.2	39,563	229,602	6.2	17,126	112,202
California	7,912,928	3,713,643	11,199,998	7,789,341	609,765	370.4	3,163,930	122,227	2,122,000	55.5		906,903	22.8	1,360	74,974
Colorado	3,437,265	2,424,504	5,475,319	3,357,026	1,895,044	262.3	625,115	77,176	516,692	30.5				3,063	12,768
Connecticut	1,404,213	607,500	1,135,531	1,109,185		20.8	1,137,322	295,028	554,726	17.1					52,774
Delaware	877,566	461,697	1,204,411	868,470	316,118	45.6	149,545	8,477	140,992	3.2	578			40	4,589
Florida	2,469,370	1,116,600	3,437,615	2,355,070	271,538	125.7	711,020	66,825	606,649	30.1	23,968	205,345	2.8	23,507	33,068
Georgia	5,045,592	2,556,745	4,984,069	3,977,140	769,641	338.9	1,865,325	922,864	859,437	86.1	6,394	185,822	3.8	139,193	741,845
Idaho	2,166,858	1,131,910	2,462,814	2,027,114	363,290	205.7	681,542	131,759	517,743	39.7		1,670	.1	7,986	249,207
Illinois	4,408,827	2,408,778	2,583,089	2,391,815	145,249	40.3	4,088,825	2,002,682	2,086,143	67.4	3,000	177,386	.1	11,330	
Indiana	5,018,921	2,688,633	4,415,382	4,243,283	47,038	123.3	3,018,635	635,108	2,330,037	149.6	77,951	238,513	12.8	62,579	73,043
Iowa	5,027,830	2,217,361	5,508,127	4,978,830	394,520	331.3	2,002,083	49,000	1,555,141	103.1		13,700			254,000
Kansas	5,044,802	2,354,131	5,933,599	5,004,394	796,564	637.9	1,630,648	31,530	1,531,325	125.1		26,242	.9	8,878	
Kentucky	3,751,605	1,302,209	3,856,210	3,408,445	196,985	283.3	1,398,252	287,374	977,685	63.9		14,820	1.2	55,786	112,718
Louisiana	2,693,135	1,380,419	2,864,278	2,399,450	93,648	78.3	1,434,550	234,221	1,047,066	27.3	51,291		1.3	8,173	239,706
Maine	1,567,012	782,195	1,890,999	1,541,605	319,285	52.7	472,624	11,351	461,258	11.6				14,056	1,652
Maryland	1,782,263	289,609	916,280	791,495	123,550	18.6	1,030,226	900,555	129,670	19.3				90,213	36,389
Massachusetts	1,101,716	1,582,874	1,473,517	1,048,966		37.4	1,099,880	52,687	995,371	20.2				63	587,503
Michigan	6,051,533	3,226,284	5,670,800	5,213,496	143,650	242.3	3,441,400	782,950	2,637,386	145.9		313,975	14.3	55,087	131,272
Minnesota	4,561,011	2,533,733	6,200,552	4,266,504	1,740,036	960.4	846,799	217,577	626,499	110.1	60,000	141,226	28.5	16,930	25,971
Mississippi	3,489,337	2,832,182	5,647,003	2,682,221	688,779	292.9	2,523,432	723,191	1,276,205	144.1	23,588	601,627	30.3	60,337	265,571
Missouri	5,237,532	2,890,666	5,254,610	4,409,896	232,942	217.8	2,541,590	501,643	1,881,117	78.2	245,950	776,607	26.0	80,043	
Montana	4,463,849	2,714,208	6,580,382	4,345,161	1,764,369	577.3	897,888	4,129	791,682	58.7	63,005	140,318	17.3	51,554	17,839
Nebraska	3,914,481	1,982,182	5,154,215	3,889,875	216,519	378.1	2,054,603	21,644	1,688,363	96.4		75,122	4.8	2,963	2,178
Nevada	2,909,387	1,350,356	3,442,296	2,666,269	703,321	332.7	884,019	204,818	626,302	147.2	17,734	13,205	2.8	20,566	7,528
New Hampshire	692,118	465,404	937,865	692,118	201,292	15.8	243,690		240,113	7.5					24,000
New Jersey	3,173,019	951,379	2,247,203	2,025,846	29,746	38.1	1,770,707	1,113,074	560,860	14.5		10,167		34,100	350,605
New Mexico	2,846,648	1,676,769	4,093,367	2,835,025	1,047,273	374.7	631,786		629,496	52.7	11,623				
New York	10,465,672	3,673,231	11,942,977	9,094,974	457,330	219.2	7,064,830	1,123,792	3,027,452	133.4	9,000	18,900	.2	237,906	169,549
North Carolina	4,761,147	1,930,365	5,168,217	3,684,500	423,710	645.2	1,435,381	663,506	665,944	127.4	91,438	322,565	21.1	321,703	518,146
North Dakota	2,902,224	1,469,484	3,428,060	2,643,198	315,993	1,165.4	536,450	74,036	324,435	178.6	143,824	151,500	82.3	41,167	677,556
Ohio	7,277,758	3,539,255	7,683,377	7,036,839	252,630	203.0	3,255,174	227,251	2,692,721	62.1		600		13,669	593,305
Oklahoma	4,608,399	2,342,590	5,005,045	4,249,815	616,650	330.6	2,000,652	348,296	1,436,273	70.7	6,016	143,167	7.9	4,272	146,499
Oregon	3,053,448	1,452,741	3,584,581	2,905,698	279,440	193.9	1,292,234	102,555	1,103,852	55.4				45,196	69,449
Pennsylvania	6,691,194	4,554,082	7,956,871	6,457,583	1,086,377	149.9	3,548,329	172,976	3,266,673	71.0	2,126	4,409		58,508	196,623
Rhode Island	979,367	474,772	1,136,743	899,627	168,738	25.6	391,854	79,740	295,834	9.3					10,200
South Carolina	2,729,583	940,954	2,638,860	2,359,621	214,683	223.4	5[illegible]1,548	315,630	275,918	49.6	18,520	51,578	1.9	35,811	398,775
South Dakota	3,005,739	1,523,821	3,514,733	2,532,214	493,190	625.0	1,285,130	426,644	809,360	192.4		96,982	11.0	46,881	124,290
Tennessee	4,246,309	2,105,454	5,226,315	3,999,811	577,343	201.7	1,508,309	176,547	1,235,361	53.3	2,195	183,445	2.0	67,756	109,304
Texas	11,588,643	6,858,253	13,416,341	11,305,035	1,503,032	1,161.1	4,673,720	247,933	4,226,173	338.2	35,675	694,311	47.4		434,738
Utah	2,367,205	1,066,345	3,170,271	2,322,418	572,525	274.7	480,185	37,000	341,550	28.4		17,000	1.1	7,787	135,271
Vermont	928,184	466,042	1,135,574	912,376	124,795	53.2	356,137		331,049	14.1	4,042	3,866		11,766	6,333
Virginia	3,731,207	1,916,178	4,340,679	3,412,159	632,668	183.1	1,447,575	198,838	1,043,045	69.7	92,935	153,378	9.1	27,273	87,087
Washington	3,057,934	1,553,206	3,329,879	2,830,012	474,277	114.9	1,286,948	227,922	938,447	15.1		130,598	.3		9,884
West Virginia	2,013,405	1,140,167	2,301,844	1,900,800	359,092	86.5	496,108	82,643	413,465	14.8	27,869	47,222		2,093	320,389
Wisconsin	4,697,518	1,818,970	4,971,601	4,392,512	361,138	238.6	1,707,503	273,603	1,354,392	67.4	25,000	69,796	3.1	6,403	33,644
Wyoming	2,250,663	1,686,368	2,947,719	2,105,140	679,195	539.9	1,095,104	141,021	927,921	193.5		43,808		4,502	35,444
District of Columbia															
Hawaii	1,693,344	598,778	829,029	526,724		19.3	1,430,996	1,126,854	99,424	20.3	20,973	183,992	1.4	18,793	315,362
TOTALS	185,235,236	93,935,660	213,731,417	165,756,136	24,036,147	13,962.3	80,941,786	16,605,744	55,080,948	3,693.4	1,139,370	6,585,135	378.6	1,733,986	8,233,430

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF JULY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,064,961	$ 2,000,380	$ 1,872,024	$ 119,375	49.1	$ 786,135	$ 463,060	$ 323,075	23.4	$ 29,878	$ 122,470	3.1	$ 24,965	$ 500,041
Arizona	756,982	305,191	738,883	622,804	86,475	15.1	323,930	129,322	156,833	.5				4,857	61,883
Arkansas	1,964,534	857,025	1,902,827	1,591,572	210,081	48.3	510,198	248,967	259,979	8.5	101,076	311,035	5.7	22,919	75,931
California	4,213,986	2,219,360	5,358,835	3,849,724	847,032	65.8	2,680,138	356,840	1,070,344	8.0		194,200	5.5	7,422	107,784
Colorado	1,718,633	190,000	1,937,435	1,672,058	169,411	40.4	11,229	11,229		.8				35,346	20,589
Connecticut	802,407	426,500	838,549	802,407	9,362	10.2	193,692		142,521	1.6		134,613	1.3		140,004
Delaware	460,409	230,849	542,664	460,282	73,875	8.1	18,165		18,165	1.1				127	138,809
Florida	1,459,648	501,200	1,839,561	1,439,771	102,827	21.4	166,128	2,324	163,804	1.4		139,600	2.2	17,554	94,969
Georgia	2,724,620	1,278,373	2,414,917	2,232,880	148,915	74.8	703,177	275,754	404,136	18.2		31,607	1.2	215,987	693,715
Idaho	1,197,829	321,126	1,222,156	1,151,479	27,081	20.9	190,673		189,485	.5		35,000	3.2	46,349	69,560
Illinois	7,381,910	2,230,350	6,593,153	6,285,871	8,850	66.5	2,121,438	1,036,345	1,085,092	11.1	47,260	620,357	3.1	12,435	516,050
Indiana	4,287,050	2,248,858	3,615,513	3,362,976	104,496	70.4	2,280,824	748,415	1,532,231	29.0	148,115	329,789	5.5	27,544	282,342
Iowa	2,614,472	1,311,000	2,303,093	2,105,968	101,635	58.9	1,408,378	508,465	808,800	23.1		137,700	.1	39	262,865
Kansas	2,522,401	1,432,949	3,007,698	2,473,482	377,503	45.8	1,059,769		1,044,466	11.3	48,919	10,980	1.2		
Kentucky	1,927,828	958,599	1,607,817	1,476,834	71,226	35.8	945,972	389,559	528,141	9.9	30,000	145,906	3.5	31,436	213,325
Louisiana	1,708,577	744,560	948,832	793,980	147,468	23.5	1,197,913	896,730	259,141	14.9	10,666	203,681	2.7	7,200	134,271
Maine	960,426	484,379	925,109	872,233	47,377	17.5	360,761	83,155	271,842	3.3		158,253	2.7	5,038	6,907
Maryland	891,132	452,515	390,021	384,017		3.6	1,075,978	262,457		.9				244,658	452,515
Massachusetts	5,007,199	847,600	2,249,980	2,102,182	98,359	14.9	3,071,272	2,876,372	169,924	5.0				28,646	579,317
Michigan	3,500,637	1,613,142	3,392,363	3,118,335	133,100	40.2	1,642,750	342,450	1,262,400	17.2	19,400	130,975	2.3	20,453	86,667
Minnesota	3,719,143	1,421,494	3,575,293	3,136,040	376,049	113.9	1,183,363	513,160	575,719	17.1	4,220	54,188	3.0	65,722	415,538
Mississippi	1,744,669	354,022	1,166,485	1,033,466	114,956	37.0	817,550	626,097	120,417	23.0	36,943	18,487	2.5	48,163	100,163
Missouri	4,019,501	919,152	3,101,773	3,001,268	24,854	52.9	1,142,578	867,762	228,978	12.4		665,320	3.1	150,471	
Montana	1,115,962	113,092	1,093,057	1,016,328	49,238	36.6	94,702	64,410	15,352	6.0	2,474	7,553	1.0	32,749	40,949
Nebraska	1,957,240	991,091	2,498,414	1,915,583	548,278	45.3	296,070		296,070	4.5				41,657	146,743
Nevada	500,051	100,000	539,562	473,901	57,842	10.8					26,150	41,402	.6		756
New Hampshire	740,335	242,465	845,980	668,776	173,847	18.7	53,951		53,741	.5	13,044		.4	58,515	14,877
New Jersey	3,117,921	1,809,500	3,080,011	2,810,715	108,606	22.9	1,225,905	182,690	804,667	5.9		631,441	.9	124,515	264,787
New Mexico	1,674,158	529,506	1,778,171	1,595,354	180,097	40.2	69,432		69,432	1.7	1,010	183,963	1.1	77,794	96,014
New York	8,255,661	3,961,690	8,085,610	7,217,830	384,600	63.4	3,994,541	875,017	2,964,090	22.9		219,150	.2	162,814	393,850
North Carolina	2,380,573	1,210,236	2,791,849	2,135,990	634,661	96.8	548,276	103,576	426,700	13.4	91,217	91,264	2.1	49,790	57,611
North Dakota	1,451,112	734,741	1,341,415	1,241,533	92,515	54.5	188,029	99,844	88,185	9.9	87,346	190,563	16.4	22,388	363,480
Ohio	4,335,686	2,359,504	5,155,741	4,238,314	434,145	69.0	1,611,417	93,352	1,374,172	13.5		80,000	.3	4,020	471,186
Oklahoma	2,304,200	1,171,295	2,415,796	2,112,039	220,827	49.2	786,181	192,161	575,152	9.0		126,468	1.9		248,847
Oregon	1,526,724	867,977	1,617,923	1,415,650	150,853	32.8	619,349	66,635	544,705	9.3	518	80,000	.2	43,921	92,418
Pennsylvania	4,854,988	2,397,703	5,208,661	4,279,869	725,785	72.7	1,354,210	511,144	749,944	11.8		288,881	.9	63,976	633,092
Rhode Island	579,625	285,760	555,890	518,991	36,001	8.0	105,759		105,759	.9				60,634	144,000
South Carolina	1,364,791	488,000	1,226,620	1,199,812	23,620	38.2	420,872	156,274	251,547	12.8	8,705	15,412	.1		197,422
South Dakota	1,502,870	761,911	1,232,982	1,188,674	43,905	41.5	241,429	77,024	164,405	9.2	40,456	125,639	7.4	196,716	427,962
Tennessee	2,123,155	1,121,789	2,209,866	1,921,523	264,518	28.3	696,283	201,632	494,651	7.6		115,946	.7		246,675
Texas	6,642,863	1,795,000	6,049,343	5,708,102	216,679	134.6	1,662,930	671,837	814,902	21.3	16,465	398,296	8.7	246,459	365,123
Utah	778,826	533,173	812,144	649,146	97,066	20.8	650,283	129,130	433,800	13.5				550	2,306
Vermont	500,509	240,611	636,840	458,671	96,285	15.5	137,402	26,801	105,082	2.7		39,244	.9	15,036	
Virginia	1,948,780	956,021	2,266,435	1,681,361	352,905	34.1	702,604	246,442	396,439	10.3	13,975	155,506	4.2	7,002	51,170
Washington	1,977,260	776,603	2,330,254	1,922,046	385,313	42.5	412,559	53,369	359,190	5.0		7,370		1,845	24,730
West Virginia	1,342,270	570,085	1,108,178	1,042,973	28,109	18.6	494,743	270,594	224,149	6.8	28,642	47,791	.6	61	270,035
Wisconsin	2,596,143	1,379,513	3,102,009	2,509,104	514,579	62.2	629,047		629,047	8.9	57,664	215,499	4.2	29,375	20,389
Wyoming	1,125,332	29,416	977,168	971,191	2,784	22.5	162,381	147,667	14,132	3.4				6,474	12,500
District of Columbia	946,445	181,051	877,332	696,281	181,051	6.5	250,164	250,164		.2					
Hawaii															
TOTALS	115,617,401	48,020,938	111,510,588	97,431,410	9,404,416	2,021.2	41,300,530	15,058,226	22,570,806	453.2	• 864,143	6,505,549	104.7	2,263,622	9,540,167

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF JULY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 2,016,508	$ 1,803,119	$ 196,710	143.0	$ 822,670	$ 187,785	$ 634,885	52.6		$ 128,940	10.6	$ 41,549	$ 104,426
Arizona	599,423	998,032	985,299	530,962	357,034	88.5	648,037	45,000	563,989	45.8				23,461	77,009
Arkansas	1,449,634	857,024	1,382,268	1,249,425	125,693	176.3	650,656	147,095	501,385	68.9		229,946	27.1	53,114	
California	3,480,440	1,999,203	4,050,207	3,154,843	216,000	180.1	1,833,841	323,897	1,364,725	56.4		262,527	9.4	1,700	155,951
Colorado	1,718,632	871,502	2,601,784	1,608,632	551,362	272.6	550,809	110,000	320,140	39.2					
Connecticut	659,120	420,868	697,300	659,120	12,889	14.9	222,880		222,880	4.5					185,099
Delaware	481,113	230,849	460,022	265,665	186,544	57.1	265,716	215,448	41,690	14.2					2,615
Florida	1,302,816	1,043,543	1,626,676	1,279,756	331,480	88.5	704,065		656,064	41.3		33,738	2.7	23,060	22,261
Georgia	2,320,973	1,278,373	1,668,552	1,590,474	53,108	125.3	1,060,362	620,788	439,574	74.6				109,711	785,690
Idaho	1,121,562	824,450	1,670,559	1,094,530	398,344	196.8	247,061		247,061	27.0				27,032	179,044
Illinois	5,760,033	4,282,273	3,633,423	3,495,503	91,822	205.0	5,648,367	2,265,472	3,382,895	286.5		473,156	7.8	19,058	334,400
Indiana	731,872	151,472	469,232	421,674	5,500	49.7	378,598	274,972	103,626	50.2				35,227	42,347
Iowa	2,413,358	1,590,000	2,799,645	2,293,399	431,850	445.7	1,555,581	119,252	1,141,950	246.0		16,200	8.6	707	
Kansas	2,522,401	1,330,595	2,325,666	2,173,449	149,358	234.7	1,486,690	305,453	1,181,237	77.8	$ 43,499		1.6		
Kentucky	1,837,926	1,557,503	2,175,313	1,772,049	275,369	241.3	1,341,513	46,363	1,211,984	167.8		29,555	2.5	19,513	40,596
Louisiana	1,426,879	838,953	1,198,264	1,086,013	101,176	50.5	799,670	209,970	589,699	38.7	130,522	129,772	9.3	374	18,305
Maine	842,479	445,012	1,346,314	842,404	390,302	103.1	59,505		51,608	3.4				76	3,102
Maryland	891,132	1,067,934	973,930	865,179	60,271	68.5	375,243	16,123	359,120	15.3	9,800	222,970	6.3	30	425,574
Massachusetts	438,185	920,000	477,470	469,741		15.2	523,663		523,663	15.9		313,670	4.6	18,443	82,667
Michigan	3,184,057	1,613,142	3,275,590	2,937,940	103,450	207.7	1,672,644	205,227	1,467,417	84.9		42,275	8.0	40,890	
Minnesota	2,376,415	1,470,324	2,951,675	2,175,738	640,518	318.0	927,833	149,444	701,289	89.1		112,651	9.2	51,183	15,866
Mississippi	1,744,669	354,023	1,265,297	1,248,797	16,500	143.1	546,437	460,584	85,852	40.9		156,539	16.5	35,288	95,132
Missouri	2,923,273	2,363,922	3,194,579	2,686,006	431,784	673.2	1,998,538	235,551	1,707,303	359.5		224,335	29.0	1,716	
Montana	1,859,937	942,434	2,324,901	1,740,693	575,525	283.4	311,474		311,474	31.9	82,163	55,435	11.7	37,081	
Nebraska	1,957,240	991,091	2,472,284	1,957,240	498,603	430.2	405,493		405,493	58.8		37,414	12.2		49,581
Nevada	1,136,479	852,000	1,588,093	1,113,353	447,688	189.2	199,878	12,000	180,528	28.0	8,413	169,589	15.2	2,683	54,195
New Hampshire	477,386	261,593	570,258	448,386	74,757	28.3	206,460	29,000	174,655	6.4					12,181
New Jersey	55,099	460,000	56,528	55,099		.5	107,525		107,525	1.7		170,412	1.1		182,063
New Mexico	1,272,129	735,425	1,606,584	1,235,198	371,386	253.0	388,751	36,931	351,820	41.4					12,218
New York	3,608,768	3,693,000	4,111,171	3,027,536	573,549	119.5	4,153,510	515,500	3,038,790	257.0	65,732		7.4		80,662
North Carolina	2,380,573	1,700,340	2,868,726	2,176,724	687,943	319.4	1,023,042	160,265	862,777	101.6		134,315	9.6	43,584	15,304
North Dakota	1,451,112	734,742	1,217,254	1,170,548	46,074	387.3	201,949	151,236	50,713	54.6	100,391	305,995	93.0	28,938	328,960
Ohio	3,871,148	1,966,253	4,172,803	3,751,018	169,850	322.6	1,418,066	49,860	1,318,823	89.8		27,200	6.2	70,269	450,380
Oklahoma	2,304,199	1,171,295	2,304,496	2,052,553	70,199	273.4	1,299,063	251,646	898,864	56.1		27,349	4.2		174,863
Oregon	1,526,724	777,096	2,115,745	1,494,881	447,577	154.9	402,753	19,526	328,814	19.0				12,317	705
Pennsylvania	7,344,822	2,639,003	6,718,399	6,207,932	341,038	555.1	3,353,144	1,093,809	2,160,362	198.5		137,603	7.0	43,080	
Rhode Island	439,716	254,040	449,748	439,716		33.1	212,563		212,563	6.7		36,815	1.4		4,663
South Carolina	1,364,791	1,342,000	1,214,563	1,086,655	127,275	130.1	1,450,097	263,518	1,148,229	167.5				14,619	66,495
South Dakota	1,502,870	761,911	1,458,798	1,325,467	131,244	436.9	573,960	174,741	399,219	159.9		140,098	22.1	2,661	91,350
Tennessee	2,123,155	1,075,748	2,004,529	1,771,569	165,906	148.9	837,013	269,714	567,299	37.6	17,894	121,139	5.1	63,978	221,404
Texas	6,012,518	3,638,000	7,114,265	5,952,792	694,201	872.7	2,911,390	34,517	2,866,130	170.8		50,500	10.6	25,209	27,169
Utah	1,048,677	533,173	1,487,378	954,655	277,173	217.4	407,861	94,022	255,000	46.8					1,000
Vermont	438,880	241,354	694,760	435,862	166,042	47.9	80,229		74,410	5.3				3,019	903
Virginia	1,736,770	893,188	1,716,601	1,551,099	105,009	216.3	653,915	112,886	531,717	69.3	54,644	198,855	15.0	18,141	57,607
Washington	1,080,673	776,603	1,376,024	1,080,673	267,589	102.1	515,250		507,750	22.7					1,264
West Virginia	1,118,559	570,083	839,957	795,133		43.5	664,854	318,088	346,766	28.0		47,548	7.3	5,338	175,768
Wisconsin	2,431,220	1,743,354	2,644,458	2,151,288	308,635	179.7	1,661,381	258,460	1,196,317	56.7		123,338	.3	21,472	115,064
Wyoming	1,125,332	571,928	1,200,239	1,047,457	135,376	156.8	450,373	75,284	374,548	115.2		40,927	5.2	2,590	21,077
District of Columbia	972,024	792,791	1,160,963	971,729	189,234	10.4	393,065		393,065	2.5		75,395	.6	295	135,097
Hawaii	177,718	351,000	178,209	177,718		4.9						161,653	4.6		189,347
TOTALS	93,147,363	58,043,402	98,913,307	81,877,442	11,998,937	10,021.3	48,603,438	9,859,427	36,564,187	3,734.3	513,088	4,440,854	393.0	897,406	5,039,424

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

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 Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

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

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

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

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

DEPARTMENT BULLETINS

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No. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

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

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Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

Supplement No. 1 to Federal Legislation and Regulations Relating to Highway Construction.

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The Taxation of Motor Vehicles in 1932. 35 cents.

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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).

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

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF JULY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 10,544,744	$ 7,135,888	$ 455,986	550.3	$ 3,756,109	$ 1,110,985	$ 2,322,031	185.9	$ 49,951	$ 447,178	25.4	$ 73,309	$ 1,034,647
Arizona	5,211,960	2,641,935	6,801,137	4,983,509	1,006,882	466.5	1,874,076	174,322	1,496,161	78.5	15,039			39,090	138,892
Arkansas	6,748,335	3,428,049	7,113,454	5,417,547	965,678	409.1	2,823,623	1,096,989	1,503,655	153.6	140,639	770,583	39.1	93,159	188,133
California	15,607,354	7,932,206	20,609,040	14,793,908	1,672,798	616.3	7,677,909	802,964	4,557,069	120.0		1,363,631	37.7	10,482	338,709
Colorado	6,874,530	3,486,006	10,014,539	6,637,716	2,615,817	575.4	1,187,154	198,405	836,831	70.5				38,409	33,357
Connecticut	2,865,740	1,454,368	2,671,380	2,570,712	22,251	46.0	1,553,894	295,028	920,127	23.2		134,613	1.3		377,877
Delaware	1,819,088	923,395	2,207,097	1,594,418	576,536	110.8	433,426	223,925	200,847	18.5	578			167	146,013
Florida	5,231,834	2,661,343	6,903,853	5,074,597	705,845	235.6	1,581,213	69,148	1,426,517	72.7	23,968	378,683	7.8	64,121	150,298
Georgia	10,091,185	5,113,491	9,067,538	7,800,494	971,664	539.0	3,628,865	1,819,406	1,703,148	178.9	6,394	217,429	5.0	464,891	2,221,250
Idaho	4,486,249	2,277,486	5,355,529	4,273,123	788,715	423.4	1,119,277	131,759	954,290	67.2		36,670	3.3	81,367	497,811
Illinois	17,570,770	8,921,401	12,809,664	12,173,189	245,922	311.8	11,858,629	5,304,498	6,554,131	364.9	50,260	1,270,898	11.0	42,823	850,450
Indiana	10,037,843	5,088,963	8,500,128	8,027,933	157,034	243.3	5,678,057	1,658,495	3,965,895	228.8	226,066	568,302	18.4	125,350	397,732
Iowa	10,055,660	5,118,361	10,610,864	9,378,197	928,005	835.9	4,966,043	676,717	3,505,891	377.2		167,600	8.7	746	516,865
Kansas	10,089,604	5,117,675	11,266,962	9,651,326	1,323,424	918.4	4,177,107	336,982	3,757,029	214.1	92,417	37,222	3.8	8,878	
Kentucky	7,517,359	3,818,311	7,639,339	6,657,329	543,581	560.4	3,685,737	723,296	2,717,809	241.6	30,000	190,281	7.3	106,735	366,639
Louisiana	5,828,591	2,963,932	5,011,374	4,279,444	342,291	152.3	3,432,133	1,340,921	1,895,906	80.9	192,479	333,452	13.4	15,747	392,282
Maine	3,369,917	1,711,586	4,162,421	3,256,241	756,964	173.3	892,890	94,506	784,708	18.2		158,253	2.8	19,170	11,661
Maryland	3,564,527	1,810,058	2,280,231	2,040,690	183,820	90.8	2,481,446	1,179,136	488,790	35.5	9,800	222,970	6.3	334,901	914,478
Massachusetts	6,597,100	3,350,474	4,200,967	3,620,889	98,359	67.6	4,694,815	2,929,059	1,688,958	41.0		313,670	4.6	47,152	1,249,487
Michigan	12,736,227	6,452,568	12,338,753	11,269,771	380,200	490.3	6,756,794	1,330,627	5,367,203	247.9	19,400	487,225	24.5	116,430	217,939
Minnesota	10,656,569	5,425,551	12,727,520	9,578,333	2,756,603	1,392.2	2,957,995	880,181	1,903,508	216.3	64,220	308,065	40.7	133,835	457,375
Mississippi	6,978,675	3,540,227	8,078,785	4,964,483	820,235	473.0	3,887,419	1,809,872	1,482,473	208.1	60,531	776,653	49.3	143,788	460,866
Missouri	12,180,306	6,173,740	11,550,962	10,097,170	689,581	943.8	5,682,707	1,604,956	3,817,898	450.1	245,950	1,666,261	60.1	232,230	
Montana	7,439,748	3,769,734	9,998,341	7,102,183	2,389,133	897.3	1,304,064	68,540	1,118,507	96.6	147,641	203,306	29.9	121,384	58,788
Nebraska	7,828,961	3,964,364	10,124,912	7,762,697	1,263,400	853.6	2,756,165	21,644	2,389,925	159.7		112,536	17.0	44,620	198,502
Nevada	4,545,917	2,302,356	5,569,952	4,253,523	1,208,851	532.7	1,083,897	216,818	806,830	175.3	52,327	224,197	18.6	23,249	62,479
New Hampshire	1,909,839	969,462	2,354,103	1,809,280	449,896	62.7	504,101	29,000	468,508	14.5	13,044		.4	58,515	51,058
New Jersey	6,346,039	3,220,879	5,383,742	4,891,660	138,352	61.4	3,104,136	1,295,764	1,473,052	22.1		812,020	2.1	158,615	797,455
New Mexico	5,792,935	2,941,700	7,478,122	5,665,578	1,598,756	672.9	1,089,970	36,931	1,050,748	95.9	12,633	183,963	1.1	77,794	108,232
New York	22,330,101	11,327,921	24,139,758	19,340,340	1,415,479	402.1	15,212,881	2,514,309	9,030,332	413.3	74,732	238,050	7.7	400,720	644,061
North Carolina	9,522,293	4,840,941	10,828,792	7,997,214	1,746,315	1,061.5	3,006,699	927,348	1,955,421	242.4	182,655	548,144	32.8	415,077	591,061
North Dakota	5,804,448	2,938,967	5,986,728	5,055,278	454,581	1,607.2	926,427	325,115	463,333	243.2	331,561	651,058	191.7	92,493	1,369,996
Ohio	15,484,592	7,865,012	17,011,922	15,026,171	856,625	594.5	6,284,657	370,463	5,385,716	165.4		107,800	6.5	87,958	1,514,871
Oklahoma	9,216,798	4,685,180	9,725,336	8,414,407	907,677	653.1	4,085,897	792,103	2,910,290	135.8	6,016	296,985	14.0	4,272	570,229
Oregon	6,106,896	3,097,814	7,318,249	5,816,229	877,871	381.6	2,314,336	188,715	1,977,371	83.7	518	80,000	.2	101,434	162,572
Pennsylvania	18,891,004	9,590,788	19,883,931	16,945,385	2,153,200	777.7	8,255,684	1,777,929	6,176,980	281.2	2,126	430,893	7.9	165,564	829,715
Rhode Island	1,998,708	1,014,572	2,142,381	1,858,334	204,739	66.7	710,175	79,740	614,156	16.9		36,815	1.4	60,634	158,863
South Carolina	5,459,165	2,770,954	5,080,044	4,646,088	365,578	391.7	2,462,517	735,422	1,675,694	229.9	27,225	66,990	2.1	50,430	662,692
South Dakota	6,011,479	3,047,643	6,206,513	5,046,355	668,338	1,103.5	2,100,519	678,409	1,372,984	361.5	40,456	362,719	40.4	246,258	643,602
Tennessee	8,492,619	4,302,991	9,440,710	7,692,903	1,007,766	378.9	3,041,605	647,892	2,297,311	98.5	20,090	420,530	7.8	131,734	577,383
Texas	24,244,024	12,291,253	26,579,948	22,965,929	2,413,912	2,168.4	9,248,040	954,287	7,907,205	530.3	52,140	1,143,107	66.7	271,668	827,030
Utah	4,194,708	2,132,691	5,469,792	3,926,218	946,763	512.9	1,538,328	260,153	1,030,350	88.7		17,000	1.1	8,337	138,577
Vermont	1,867,573	948,007	2,467,174	1,806,908	387,121	116.6	573,768	26,801	510,540	22.1	4,042	43,110	.9	29,821	7,236
Virginia	7,416,757	3,765,387	8,323,716	6,644,620	1,090,583	433.4	2,804,093	558,166	1,971,201	149.2	161,555	507,740	27.9	52,416	195,864
Washington	6,115,867	3,106,412	7,036,158	5,832,732	1,127,179	259.5	2,214,757	281,291	1,805,387	42.9		137,968	.3	1,845	35,878
West Virginia	4,474,234	2,280,335	4,249,980	3,738,906	387,201	148.5	1,655,705	671,325	984,380	49.5	56,511	142,561	7.9	7,492	766,192
Wisconsin	9,724,881	4,941,837	10,718,068	9,052,904	1,184,352	480.6	3,997,931	532,063	3,179,755	133.1	82,664	408,632	7.6	57,250	169,097
Wyoming	4,501,327	2,287,712	5,125,126	4,123,788	817,355	719.2	1,707,858	363,973	1,316,601	312.1		84,735	5.2	13,566	69,021
District of Columbia	1,918,469	973,842	2,038,295	1,668,009	370,286	16.9	643,229	250,164	393,065	2.7		75,395	.6	295	135,097
Hawaii	1,871,062	949,778	1,007,238	704,442		24.2	1,430,997	1,126,855	99,424	20.8	20,973	345,645	6.0	18,793	504,709
TOTALS	394,000,000	200,000,000	424,155,312	345,064,988	45,439,500	26,004.8	170,845,754	41,523,397	114,215,941	7,880.9	2,516,601	17,531,538	876.3	4,895,014	22,813,021

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