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BITUMINOUS MACADAM SURFACING ON A SECTION OF U S 60 IN WEST VIRGINIA

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In This Issue

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A STUDY OF ROAD TARS

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

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

THE Federal specifications used by the various agencies of the Federal Government include a number of standard specifications for tar products used in road construction. The road tar specifications that are in current use are summarized in table 1. This table lists the specification designation, the requirements for the physical and chemical properties of materials meeting particular grades, and the kinds of tars to be used in the preparation of the finished products.

While there may be considerable variation in test limits, the tests required by the Federal specifications are typical of those usually included in tar specifications throughout the United States. Some English and other European specifications limit the amount of ammonia, tar acids, naphthalene, and anthracene in their road tars, but American specifications generally do not.

The characteristics of the various grades of tars are dependent on the physical and chemical properties of the base tars used in their preparation. As shown in table 1, the materials that are generally specified for production of road tars are coal tars, either gas-house or coke-oven, and water-gas tars. The standard definitions of these products, A. S. T. M. designation D 8–33 are as follows:

Gas-house coal tar: Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Coke-oven tar: Coal tar produced in byproduct coke ovens in the manufacture of coke from bituminous coal.

Water-gas tars: Tars produced by cracking oil vapors at high temperatures in the manufacture of carbureted water gas.

The properties of these tars can be greatly altered not only by the character of the oil or coal used but also by the methods and temperatures involved in the various processes used in their production. For instance, for many years carbureted water gas was manufactured using gas oil, a fraction of petroleum distillate coming off immediately after the kerosene fraction. In recent years fuel oil, which is either a heavier distillate or a mixture of distillate with a base petroleum, has also been utilized for carburetion. The tars resulting from the use of the two types of oil have widely different properties.

J. Edwards has stated [1] that while the usual laboratory tests are of value, future control must not be limited to laboratory tests only. He intimated that the amount and kind of base tar and the kind and quantity of blending oils should also be specified, since these are vital factors that determine the suitability of the tar for a particular use. Some States have already adopted such specifications. The following 1934 specification of a State highway department for a coal-tar cutback is of this type and not only sets specification limits for the finished product but also specifies the test characteristics of the base and flux used in producing the material.

STATE SPECIFICATION FOR COAL-TAR CUTBACK DISCUSSED

This specification covers coal-tar cutback for treatment of earth roads as follows: This material shall contain not less than 40 nor more than 90 percent by volume of refined coal-tar base, fluxed with a tar material (liquid at 60° F.), which shall make a homogeneous mixture. The flux shall be a water-gas tar or either distillates of water-gas tar or coal tar or a combination of water-gas tar and the above distillates. The flux, base, and mixture shall conform to the requirements shown in table 2, in which the specific viscosity of the mixture will be subject to variation within the limits designated, as may be directed.

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[1] Prepared Tars and Their Application to Road Construction. Roads and Road Construction, vol. XIII, no. 147. March 1935.

TABLE 1.—*Summary of Federal specifications for tar products used in road construction*

Federal specification designation	Consistency				Specific gravity at 25°/25° C.	Bitumen (soluble in CS_2)	Total distillate (by weight)—				Softening point of distillation residue	Water	Produced from
	Engler specific viscosity		Float test				To 170° C.	To 235° C.	To 270° C.	To 300° C.			
	At 40° C.	At 50° C.	At 32° C.	At 50° C.									
			Seconds	*Seconds*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*° C.*	*Percent*	
TC-1-25	8-13	--------	--------	--------	1.090+	90+	7−	--------	32−	42−	60−	2−	Gas-house, coke-oven, water-gas and/or similar tars.[1]
TC-2-25	13-18	--------	--------	--------	1.090+	90+	5−	--------	30−	40−	60−	2−	
TC-3-25	18-25	--------	--------	--------	1.100+	90+	5−	--------	30−	40−	60−	2−	
TC-4-25	25-35	--------	--------	--------	1.10-1.18	90+	3−	--------	30−	40−	60−	2−	
TM-1	--------	16-26	--------	--------	1.10-1.22	87+	5−	--------	25−	[2] 35−	35-60	2−	Gas-house, coke-oven, and/or water-gas tars.[1]
TM-2	--------	26-36	--------	--------	1.10-1.22	87+	5−	--------	25−	[2] 35−	35-60	2−	
TR-1-25	35-60	--------	--------	--------	1.09-1.19	80+	2-8	8-20	16-28	36−	65−	2−	Refined gas-house, coke-oven and/or water-gas tars fluxed with suitable distillates.[1]
TR-2-25	60-80	--------	--------	--------	1-10-1.20	80+	2-8	8-20	16-28	36−	65−	2−	
TH-1 [3]	--------	--------	60-150	--------	1.140+	85+	1−	--------	15−	25−	65−	0	Gas-house, coke-oven, water-gas, and/or similar tars.[4]
TP-1-25	--------	--------	--------	100-160	1.15-1.20	95+	1−	--------	10−	20−	65−	0	Refined water-gas tar.[4]
TP-2-25	--------	--------	--------	100-160	1.20-1.26	80-95	1−	--------	10−	20−	65−	0	Gas-house and/or coke-oven tar.[4]
TP-3-25	--------	--------	--------	130-190	1.15-1.20	95+	1−	--------	10−	20−	65−	0	Refined water-gas tar.[4]
TP-4-25	--------	--------	--------	130-190	1.20-1.26	80-95	1−	--------	10−	20−	65−	0	Gas-house and/or coke-oven tar.[4]
TP-5-25	--------	--------	--------	160-220	1.15-1.20	95+	1−	--------	10−	20−	65−	0	Refined water-gas tar.[4]
TP-6-25	--------	--------	--------	160-220	1.20-1.26	80-95	1−	--------	10−	20−	65−	0	Gas-house and/or coke-oven tar.[4]

[1] The material shall be homogeneous.

[2] Specific gravity of total distillate 38°/38° C. minimum (water free), 0.96.

[3] The Federal specifications designate this material as refined hot-application tar. For convenience, the designation TH-1 is used in this report.

[4] The material shall be homogeneous and free from water.

TABLE 2.—*Requirements for flux, base, and mixture of a coal-tar cutback*

	Flux		Base		Mixture	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Water, percent by weight						2.0
Specific gravity at 25°/25° C	1.00	1.12	1.14	1.22	1.11	1.16
Specific viscosity, Engler:						
50 cubic centimeters at 50° C			6.0	30.0		
50 cubic centimeters at 40° C	1.1	3.6			5.0	8.0
Soluble in carbon disulphide, percent by weight	95		88	97	89	98
Distillation (A. S. T. M.):						
0–170° C., per cent by weight		7		4.5		7
0–300° C., per cent by weight	25	87		35		45
Specific gravity at 38°/38° C. of total distillate (water free) to 300° C			1.00		0.96	
Softening point of distillation residue, ° C. (ring and ball method)				65	35	60

Where the consumer has adqeuate facilities for plant inspection, a specification of this type may be advantageous. However, with the usual laboratory control, test requirements on the finished products will usually prove satisfactory. As shown in table 1, the Federal specifications give the tar refiners considerable leeway in the manufacture of the various grades of road tar from their available sources of crude tar. With the exception of the TP grades 1, 3, and 5, that require the materials to be refined water-gas tar, and the TP grades 2, 4, and 6, that require the materials to be refined from suitable gas-house and/or coke-oven tars, all other grades allow the producer to use a tar from a single source or to blend such materials as any of the above with or without suitable distillates as may be necessary to meet the specification.

The Federal specifications, as well as specifications of the special type already described, control the quality and grade of tar products suitable for various types of road construction by consistency tests, such as the viscosity and float tests, by determination of free carbon,[2] and by an accelerated laboratory evaporation test. The evaporation test in general use for all tar products is the distillation test, which not only gives the amount of total volatile matter present in the tar but also indicates the probable rate at which these volatile constituents may be lost under service conditions. A softening point determination on the residue from distillation has been considered as a measure of consistency of the material that would be present as active binder when the volatile matter has evaporated from the road surface.

In order to determine how present-day tars conform to the Federal specifications, 35 tar products were obtained from 5 of the leading tar refiners. The laboratory study of these materials is the subject of this report.

TYPICAL GRADES OF ROAD TAR FROM MAJOR PRODUCERS STUDIED

In table 3 the samples of these road tars are grouped according to their conformity to Federal specification grades, and the composition of the materials as reported by the producers is shown. The intended use of the Federal specification grades, as well as the use recommended by the producers, are also given. Samples 22, 23, and 31, submitted by producer C and designated as "special", did not meet any particular specification.

TABLE 3.—*Comparison of road tars with standard Federal specifications*

Bureau laboratory no.	Identification	Standard Federal specification		Information furnished by producer		
		Grade	Intended use	Produced by	Produced from—	Intended use
37996	7	TC-1-25	Prime	B	Water-gas tar	Prime.
39003	14			C	Bunker C tar+water-gas tar	Do.
39009	20			C	Coal tar+water-gas tar	Do.
39016	24			D	Coal tar+water-gas tar and/or distillate.	Do.
37990	1	TC-2-25	Surface treatment	A	Coal tar+water-gas tar [1]	Do.
39004	15			C	Bunker C tar+water-gas tar	Light surface treatment.
39010	21			C	Coal tar+water-gas tar	Do.
39028	33			E	do.[2]	Light surface treatment and prime.
39005	16	TC-3-25	do	C	Bunker C tar+water-gas tar	Heavy surface treatment and honing.
39017	25			D	Coal tar+water-gas tar and/or distillate.	Cold surface treatment.
37992	3	TC-4-25	do	A	Coal tar+water-gas tar [1]	Do.
39006	17			C	Bunker C tar+water-gas tar	Mulch honing.
37997	8	TM-1	Mixed-in-place surfaces, open-graded aggregate.	B	Water-gas tar	Cold surface treatment. Reclamation work.
38000	11			B	do	Retread or mixed-in-place.
39007	18			C	Bunker C tar+water-gas tar	Mulch honing.
39030	35			E	Coal tar+water-gas tar [2]	Retread or mixed-in-place.
37994	5	TM-2	do	A	do.[1]	Retread construction.
39008	19			C	Bunker C tar+water-gas tar	Mixed-in-place with broken stone.
39018	26			D	Coal tar+water-gas tar and/or distillate.	Mixed-in-place and drag surface treatment.
37998	9	TR-1-25	Repair work (used cold)	B	Water-gas tar	Patching (used cold).
37995	6	TR-2-25	Repair work (usually warmed)	A	Coal tar+distillate [1]	Repair work.
37999	10			B	Water-gas tar	Repair work (used warm).
39019	27			D	Coal tar+distillate	Repair work (used cold).
37991	2	TH-1	Hot surface treatment	A	Coal tar [1]	Hot surface treatment.
39001	12			B	Water-gas tar	Hot surface treatment and seal coat.
39027	32			E	Coal tar+water-gas tar [2]	Hot surface treatment; wearing coat or seal.
39020	28			D	Coal tar	Hot surface treatment; second application for mixed-in-place.
39002	13	TP-1-25	Bituminous macadam	B	Water-gas tar	Penetration macadam.
39021	29	TP-2-25	do	D	Coal tar	Hot repair and crack filler.
37993	4	TP-4-25	do	A	do.[1]	Penetration macadam.
39022	30	TP-6-25	do	D	do	Do.
39029	34			E	Coal tar+water-gas tar [2]	Do.
39011	22	Special		C	Coal tar	
39012	23	do		C	Thin water-gas tar	Flux for samples 14, 15, 16, 17, 18, and 19.
39026	31	do		C	Bunker C tar	Base for samples 14, 15, 16, 17, 18, and 19.

[1] No information furnished. Classification based on test results.
[2] Classification based partly on information furnished by producer and partly on test results.

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[2] Free carbon in tars is defined by the American Society for Testing Materials designation D 8–33 as organic matter that is insoluble in carbon disulphide. The term will be so used in this report.

One or more of the other samples represented each of the specification grades shown in table 1, except grades TP–3 and TP–5. These grades are for refined water-gas tars that have the same range in consistency as the coal tar grades TP–4 and TP–6, respectively.

The laboratory study of these road tars included tests to determine their conformity with the particular Federal specifications, and other tests which, although not usually made on road tars, might develop information of value relative to their physical and chemical characteristics. In order to determine how these materials lose their volatile matter under accelerated weathering conditions and to determine the character of the resulting residues, all of the tars were exposed in thin films to the action of air, light, and solar heat. The residues from exposure and the distillation residues were subjected to the same laboratory tests so that the physical and chemical characteristics of the residues obtained by both methods might be compared.

In order to determine the binding values of the original materials and of their distillation residues, Hubbard-Field stability cylinders were made with these materials combined with a standard sand and the stability of these cylinders was determined. Cylinders containing the original tars and exposed under the same conditions as the thin films were tested for stability to determine the development of binding value under accelerated weathering.

The laboratory tests made on the 35 tar products to show their conformity to the various Federal specification grades were as follows:

Specific gravity at 25°/25° C.
Specific viscosity, Engler, at 40° C. and 50° C.
Float test at 32° C. and 50° C.
Solubility in carbon disulphide.
Distillation test, A. S. T. M. D 20–30.
Softening point of distillation residue.

The laboratory tests made to obtain data of special interest were:

Specific viscosity, Engler, at 60° C.
Saybolt-Furol viscosity at 25°, 40°, 50°, and 60° C.
Specific gravity at 38°/38° C. of total distillate.
A. S. T. M. method D 402–34 T of pouring distillation residue.
Softening point of residue obtained under above method.
Ductility at 10°, 15°, 20°, and 25° C. on residues from A. S. T. M. D 20–30 distillation.

The A. S. T. M. and A. A. S. H. O. designations of methods of making these tests are given in table 4.

TABLE 4.—*Tests methods used in studying road tars*

Test	Method of test	
	A. S. T. M. designation	A. A. S. H. O. designation
Specific gravity	D 70–27	T–43.
Specific viscosity, Engler		T–54.
Saybolt-Furol viscosity	D 88–33	T–72.
Float test	D 139–27	T–50.
Penetration	D 5–25	T–49.
Softening point, ring and ball	D 36–26	T–53.
Ductility	D 113–26 T.	
Solubility in CS_2	D 4–27	T–44.
Water	D 95–30	T–55.
Distillation	D 20–30	T–52.
Do	D 402–34 T.	T–78.

TARS STUDIED WERE IN GENERAL CONFORMANCE WITH FEDERAL SPECIFICATIONS

The results of laboratory tests made to determine conformity with Federal specifications are given in table 5 and show that only four of the road tars failed to meet all of the requirements of the specifications for the appropriate grades of material. The softening point of the distillation residue of sample 17 was 0.4° C. over the maximum limit for TC–4 material. The amount of distillate of sample 27 up to 170° C. was 0.51 percent under the minimum limit for TR–2 material. The float of sample 28 was 215 seconds, or 65 seconds greater than the specification requirement for TH–1 material. Sample 13 failed to meet the specification for TP–1 material which requires the solubility in carbon disulphide to be greater than 95 percent. The three specifications for TP materials produced from water-gas tars require high solubility in carbon disulphide.

Samples 22, 23, and 31 did not meet any particular specification. The tests on sample 22, a heavy, dehydrated coal tar, indicated that it had too high a free carbon content to be satisfactorily processed, without fluxing, to meet any of the Federal specifications. Sample 23 was a very thin, water-gas tar, too fluid for direct use in road construction. Sample 31, while meeting the specification for TH–1 material except that its residue from distillation had too high a softening point, was submitted with sample 23 as the base and flux, respectively, which producer C used in the road tars represented by samples 14 to 19 inclusive. Using the specific gravities of samples 23 and 31 and assuming no change in volume when mixing these two products, samples 14, 15, 16, 17, 18, and 19 contained approximately, by weight, 30, 35, 40, 45, 50, and 55 percent, respectively, of sample 31 as the base in the blended tars. Although the percentage composition of the other blended tars could not be definitely established, the more fluid materials having the lowest densities were perhaps chiefly water-gas tars. The blends of water-gas tars, bunker C water-gas tar, and the blends of coal tar and water-gas tars had high densities.

The percentage of free carbon has been limited to a great extent by specifications, there being still a considerable difference of opinion as to whether a high or a low free-carbon tar is more suitable for a particular purpose. For the heavier grades of tar, such as refined tars of the TP grades, the Federal specifications provide for a coal tar of high free-carbon content and a water-gas tar of low free-carbon content. For the other grades, the minimum amount of free carbon permissible is not limited. A study of the solubility of these tars submitted by the various producers indicates that in general the percentage of insoluble material is well under the maximum allowable by the Federal specifications.

Comparing the materials meeting the various specification grades as a group, it will be seen that the TC materials were most soluble in carbon disulphide and the TR and TP materials the least soluble. The TM materials had a solubility close to the TC tars, and the solubility of the TH products was slightly more than that of the TR and TP samples. The average solubilities for the various grades were as follows: TC, 93.56 percent; TM, 92.21 percent; TR, 88.01 percent; TH, 89.58 percent; and TP, excluding sample 13, 88.02 percent. All of the materials, except sample 13, had solubilities in carbon disulphide well within the specification limits for their particular grades.

MOST FLUID TARS HAD GREATEST LOSS ON DISTILLATION

The distillation test has been generally used in the testing of tars to determine the amount of volatile matter and to determine the probable rate of volatilization of the constituents having low boiling points.

TABLE 5.—*Results of laboratory tests on road tars, showing conformity with Federal specifications*

Type of material	Identification	Specific gravity at 25°/25° C	Engler specific viscosity—		Float test—		Carbon disulphide solubility [1]			Water	Distillation (by weight)[1]					Specific gravity of distillate at 38°/38° C	Softening point of residue
											Total distillate				Residue		
			At 40° C	At 50° C	At 32° C	At 50° C	Bitumen	Free carbon	Inorganic matter insoluble		To 170° C	To 235° C	To 270° C	To 300° C			
					Seconds	*Seconds*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*		*°C*
TC-1	(2)	1.090+	8-13				90+			2–	7–		32–	42–			60–
	7	1.108	9.2				91.77	8.15	0.08	1.3	2.00	14.67	25.79	35.15	64.10	0.971	45.0
	14	1.115	10.7				93.77	6.10	.13	1.4	1.16	12.67	26.56	37.42	61.96	.975	54.8
	20	1.138	9.5				95.22	4.71	.07	.6	.89	11.68	22.27	31.76	67.94	1.002	47.4
	24	1.150	11.8				93.27	6.61	.12	0	.29	12.70	25.22	34.02	65.65	1.013	45.2
TC-2	(2)	1.090+	13-18				90+			2–	5–		30–	40–			60–
	1	1.132	15.9				93.78	6.06	.16	.8	.42	7.46	21.25	32.86	66.81	.992	44.6
	15	1.123	15.5				93.41	6.45	.14	1.3	1.04	11.36	25.50	35.78	63.66	.978	55.6
	21	1.151	17.3				94.51	5.42	.07	.7	1.00	10.55	20.88	28.91	70.75	1.016	50.8
	33	1.138	16.2				96.13	3.76	.11	.3	.17	6.85	18.63	29.54	70.08	1.009	37.0
TC-3	(2)	1.100+	18-25				90+			2–	5–		30–	40–			60–
	16	1.127	21.2				93.05	6.75	.20	1.4	.99	9.38	23.54	34.50	64.50	.980	57.1
	25	1.162	20.7				92.56	7.17	.27	0	.25	10.98	22.94	31.34	68.11	1.017	46.6
TC-4	(2)	1.10-1.18	25-35				90+			2–	3–		30–	40–			60–
	3	1.150	34.9				92.43	7.50	.07	.7	.84	7.11	19.59	28.25	70.90	.999	45.0
	17	1.135	32.5				92.88	6.91	.21	1.0	.83	8.92	22.68	34.21	65.22	.982	60.4
TM-1	(2)	1.10-1.22		16-26			87+			2–	5–		25–	35–		.96+	35-60
	8	1.129		21.1			91.14	8.73	.13	0	.77	6.99	17.62	25.98	73.95	1.004	41.0
	11	1.135		24.8			91.33	8.57	.10	0	0	3.76	16.45	27.13	72.43	.991	42.0
	18	1.140		22.6			92.42	7.33	.25	1.1	.68	7.34	21.03	32.15	66.58	.984	59.4
	35	1.159		22.2			95.19	4.70	.11	.5	.39	5.30	15.92	25.39	74.69	1.019	39.6
TM-2	(2)	1.10-1.22		26-36			87+			2–	5–		25–	35–		.96+	35-60
	5	1.166		27.4			91.69	8.23	.08	.5	.61	5.08	16.29	25.08	74.27	1.007	46.1
	19	1.145		31.6			92.35	7.44	.21	1.3	.74	7.73	20.20	31.09	68.11	.986	60.0
	26	1.189		32.0			91.32	8.44	.24	0	.19	4.02	13.96	23.04	76.60	1.030	43.2
TR-1	(2)	1.09-1.19	35-60				80+			2–	2-8	8-20	16-28	36–			65–
	9	1.136	44.5				88.05	11.67	.28	0	5.09	15.69	21.56	27.30	72.25	.963	60.0
TR-2	(2)	1.10-1.20	60-80				80+			2–	2-8	8-20	16-28	36–			65–
	6	1.175	60.7				83.79	16.21	.00	.6	2.34	10.83	17.38	25.19	74.10	.987	53.1
	10	1.130	73.1				91.59	9.16	.25	0	2.31	12.29	18.76	24.90	74.48	.948	55.8
	27	1.180	63.1				88.61	11.34	.05	0	1.49	12.95	18.46	25.16	74.55	.988	55.4
TH-1	(2)	1.140+			60-150		85+			0	1–		15–	25–			65–
	2	1.214			129		85.21	14.79	.00	0	0	4.16	11.65	19.23	80.20	1.034	51.7
	12	1.166			102		89.60	10.22	.18	0	0	1.36	5.84	15.16	84.46	.999	41.6
	32	1.187			80		93.19	6.81	.00	0	0	.55	3.42	10.81	88.88	1.044	33.1
	28	1.222			215		90.31	9.65	.04	0	0	1.33	5.69	13.89	85.63	1.053	47.0
TP-1	(2)	1.15-1.20				100-160	95+			0	1–		10–	20–			65–
	13	1.174				107	89.09	10.73	.18	0	0	1.03	4.37	11.60	88.21	1.002	49.0
TP-2	(2)	1.20-1.26				100-160	80-95			0	1–		10–	20–			65–
	29	1.223				126	88.70	11.22	.08	0	0	1.13	4.47	11.40	88.28	1.055	49.6
TP-4	(2)	1.20-1.26				130-190	80-95			0	1–		10–	20–			65–
	4	1.237				167	83.56	16.37	.07	0	0	.95	4.08	12.21	86.80	1.043	56.1
TP-6	(2)	1.20-1.26				160-220	80-95			0	1–		10–	20–			65–
	30	1.219				194	87.76	12.23	.01	0	0	.25	2.02	8.41	91.28	1.058	51.8
	34	1.206				165	92.06	7.91	.03	0	0	.20	1.42	5.72	94.10	1.019	44.1
Special	22	1.233			45	30	78.84	21.09	.07	.20	.43	5.28	13.22	19.71	80.38	1.018	58.5
	23	1.082	2.0				94.74	5.03	.23	.8	1.29	18.46	35.17	47.37	52.15	.965	39.1
	31	1.196			117		87.15	12.74	.11	0	.71	5.25	9.97	18.11	81.10	.998	73.3

[1] Water-free basis.

[2] Federal specification.

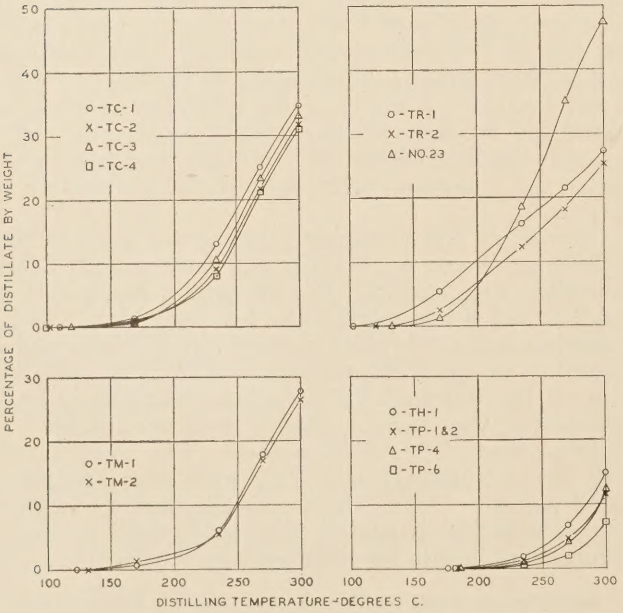

FIGURE 1.—RELATIONS BETWEEN AMOUNT OF DISTILLATE BY WEIGHT AND DISTILLING TEMPERATURE FOR VARIOUS GRADES OF ROAD TARS.

The average distillation curves for the various grades of road tars are shown in figure 1. For the different materials of the same grade the amount of distillate at the temperatures used for fractionating was fairly close to the average value shown by the curves, except for the TH materials.

It will be seen from figure 1 that there is a relation between the distillation loss at 300° C. and the consistency of the original material—the TC–1 grade, which was the most fluid, had the greatest loss and the TP–6 grade, which was the most viscous, had the smallest loss. Of the tars for cold application[3] only the TR–1 and TR–2 grades had a uniform rate of loss from 170° C. to 300° C. and both types of material, used primarily for patch work, had distilled off a greater percentage of their total distillate at 170° C. than did the other cold-application materials. The TC grades had given off a relatively small amount of their total distillate at 170° C. The curves for TM–1 and TM–2 products are similar to the TC curves.

All of the tars for hot application showed no distillate to 170° C. and the rate of loss increased from 235° C.

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[3] In the following discussion the TC, TM, and TR grades are referred to as tars for cold application or cold tars, and the TH and TP grades as tars for hot application or hot tars.

to 300° C. for all grades. The curves, as a whole, show that the cold-application tars contained a relatively high percentage of constituents having low boiling points, and that in service their ultimate consistency is reached almost entirely through the loss of their volatile matter. For the hot-application tars the high boiling point of the contained distillates and the smaller percentage of total distillate to 300° C., together with the more viscous consistency of the various grades, indicate that their binding properties while increasing with service are, initially, not dependent upon the loss of the more volatile constituents.

Although the Federal specifications for road tars do not contain requirements for the specific gravity of the total distillate except for the TM grades, this requirement appears in many State specifications for tar products. The determination of specific gravity at 38°/38° C. was made on the recovered distillate of all the tars tested.

The data obtained are tabulated in table 6 and may be of some assistance in identifying the types of materials used in the manufacture of road tars. The materials classed as water-gas tars, which include the mixtures of water-gas tar with bunker C tar, had distillates ranging in specific gravity from 0.948 to 1.004 with an average of 0.982. The mixtures of coal tar and water-gas tar had distillates ranging in specific gravity from 0.992 to 1.044 with an average of 1.014. The distillates from coal tars and coal tars thinned with distillate ranged in specific gravity from 0.987 to 1.058 with an average of 1.030.

There is undoubtedly considerable overlapping in the range in values of specific gravity of the distillates of the tars in each classification. However, as shown in table 6, where two or more types of materials met a single specification grade, the distillates of the water-gas tars had the lowest specific gravity, the distillates of the coal tar and water-gas tars, with the exception of the TH-1 grade, were next, and the coal-tar distillates had the highest. While a specification limit for the specific gravity of the total distillate is only required in the TM grades of the Federal specifications, the test is considered of value by the producers and by others. When properly correlated with other test data it can be used to identify the type of tar. A specific gravity test of the distillate can also be used to detect the presence of petroleum admixtures.

TABLE 6.—*Specific gravities of total distillates from A. S. T. M. D 20–30 distillation test*

Grade	Type of material					
	Water-gas tar		Coal tar and water gas tar		Coal tar	
	Identification	Specific gravity at 38°/38° C.	Identification	Specific gravity at 38°/38° C.	Identification	Specific gravity at 38°/38° C.
TC-1	7	0.971	20	1.002		
	14	.975	24	1.013		
TC-2	15	.978	1	.992		
			21	1.016		
			33	1.009		
TC-3	16	.980	25	1.017		
TC-4	17	.982	3	.999		
TM-1	8	1.004	35	1.019		
	11	.991				
	18	.984				
TM-2	19	.986	5	1.007		
			26	1.030		
TR-1	9	.963				
TR-2	10	.948			6	0.987
					27	.988
TH-1	12	.999	32	1.044	2	1.034
					28	1.053
TP-1	13	1.002				
TP-2					29	1.055
TP-4					4	1.043
TP-6			34	1.019	30	1.058
Special	23	.965			22	1.018
Do	31	.998				
Average		.982		1.014		1.030

The consistency of the distillation residue is usually determined by a softening-point test. The softening point of the distillation residues ranged from 37.0 to 60.4, with an average of 49.9 for the cold-application materials, and from 33.1 to 56.1, with an average of 47.1 for the hot-application materials. It will be seen from table 5 that, in each grade, the road tars from producer E had the softest residues.

SAYBOLT-FUROL VISCOSIMETER SATISFACTORY FOR DETERMINING CONSISTENCIES OF FLUID ROAD TARS

One of the most important characteristics of road tars is the consistency or degree of fluidity. Road tars are used as penetrative treatments, as surface treatments and seals, and as binders in road-mix or premix construction. The ease of application, the workability of the mixes, and the development of stability in the road surface are to a great extent dependent upon the initial consistency of the tar used.

Many different tests to measure the consistency of road tars have been developed. E. O. Rhodes,[4] working with normal byproduct coke-oven tars, showed the interrelationship of test values obtained with different instruments used to measure consistency. Although he did not stress either the accuracy of the various tests or the speed or ease of making them, he reached the following conclusion: "The use of the Engler specific viscosities at 40° C. and at 50° C., and the float tests at 32° C. and 50° C., discarding all other consistency measurements, would contribute greatly to the simplification and improvement of road-tar specifications."

The materials meeting the Federal specifications and the road-tar specifications of most States generally have been controlled by a determination of the Engler specific viscosity or the float test as proposed. Although the Saybolt-Furol viscosimeter has been adopted by the State and Federal testing laboratories for determining the consistency of liquid asphaltic road materials, the Engler specific viscosity determination has been generally retained in road-tar specifications. Since the Saybolt-Furol instrument has many advantages over the Engler instrument all of the tars used in this investigation, with the exception of the tars for heavy construction, were tested by both methods. The more viscous products were subjected to the float test. All of the consistency determinations on the original materials are given in table 7.

In order to determine the relation between test values as obtained with the two viscosimeters, the data in table 7 have been plotted in figures 2 and 3.

In figure 2 the Saybolt-Furol viscosity in seconds at 40° C., 50° C., and 60° C. is compared with the Engler specific viscosity at the same temperature for each particular tar. The points fall quite close to a straight line having a slope of 1 to 4, that is, the Saybolt-Furol viscosity in seconds at the temperatures used is approximately 4 times the Engler specific viscosity at the same temperature. The viscosity values obtained on

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[4] A Discussion of Road Tar Consistency Relationships, Engineering News-Record, vol. 111, no. 16, October 19, 1933.

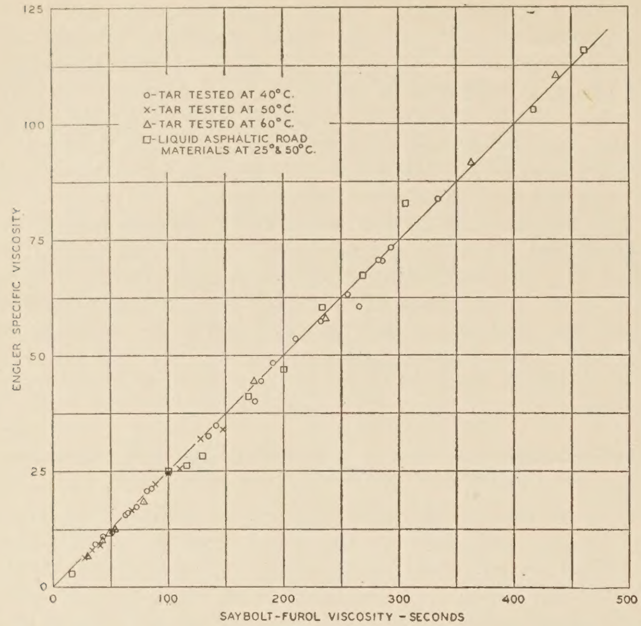

FIGURE 2.—COMPARISON OF SAYBOLT-FUROL AND ENGLER SPECIFIC VISCOSITIES OF ROAD TARS.

TABLE 7.—*Consistencies of the original materials*

Type of material	Identification	Engler specific viscosity—			Saybolt-furol viscosity—				Float test—	
		At 40° C.	At 50° C.	At 60° C.	At 25° C.	At 40° C.	At 50° C.	At 60° C.	At 32° C.	At 50° C.
					Seconds	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*
TC-1	7	9.2	------	------	88	37	------	------	------	------
	14	10.7	6.3	------	118	44	------	------	------	------
	20	9.5	------	------	142	41	------	------	------	------
	24	11.8	6.3	------	167	51	28	------	------	------
TC-2	1	15.9	8.0	------	238	65	34	------	------	------
	15	15.5	8.5	------	185	64	------	------	------	------
	21	17.3	8.4	------	342	73	36	------	------	------
	33	16.2	8.0	------	263	67	32	------	------	------
TC-3	16	21.2	11.2	6.6	277	86	47	30	------	------
	25	20.7	9.5	------	322	82	40	------	------	------
TC-4	3	34.9	15.4	8.0	652	142	63	35	------	------
	17	32.5	16.5	9.5	490	136	68	40	------	------
TM-1	8	40.1	21.1	11.6	647	176	84	49	------	------
	11	53.5	24.8	13.4	------	212	100	53	------	------
	18	48.5	22.6	12.5	------	192	93	53	------	------
	35	57.4	22.2	10.0	------	233	90	43	------	------
TM-2	5	70.4	27.4	12.9	------	287	116	54	------	------
	19	70.6	31.6	16.7	------	283	129	68	------	------
	26	83.7	32.0	14.5	------	334	129	62	------	------
TR-1	9	44.5	22.0	13.6	------	181	105	55	------	------
TR-2	6	60.7	26.9	12.9	------	267	114	56	------	------
	10	73.1	32.7	18.5	------	294	149	78	------	------
	27	63.1	25.5	13.1	------	256	111	56	------	------
TH-1	2	------	------	91.4	------	------	------	363	129	58
	12	------	------	110.5	------	------	------	436	102	51
	32	------	------	57.6	------	------	------	237	80	43
	28	------	------	------	------	------	------	------	215	78
TP-1	13	------	------	------	------	------	------	------	------	107
TP-2	29	------	------	------	------	------	------	------	633	126
TP-4	4	------	------	------	------	------	------	------	1,977	167
TP-6	30	------	------	------	------	------	------	------	------	194
	34	------	------	------	------	------	------	------	------	165
Special	22	------	------	44.7	------	------	------	175	45	30
	23	2.0	------	------	15	12	------	------	------	------
	31	------	------	142.7	------	------	------	520	117	51

some liquid asphaltic materials fall along the same line. This indicates that the relation between the two viscosity tests made on both types of bituminous materials at the same test temperature is quite close.

Frequently it is desired to convert the viscosity at one temperature to the viscosity at another temperature. Many temperature-viscosity conversion tables and charts for both asphaltic and tar products have been published but, as stated by E. O. Rhodes,[4] they are accurate only when materials from the same source and method of manufacture are compared.

The relations existing between the Saybolt-Furol viscosities at different temperatures are shown in figure 3. Because of the varied sources of material and methods of blending no satisfactory average curve could be drawn for all materials, although a definite trend is indicated. This makes it possible to distinguish to a certain degree the source of the various tars. Those materials that are known to be water-gas tars are in

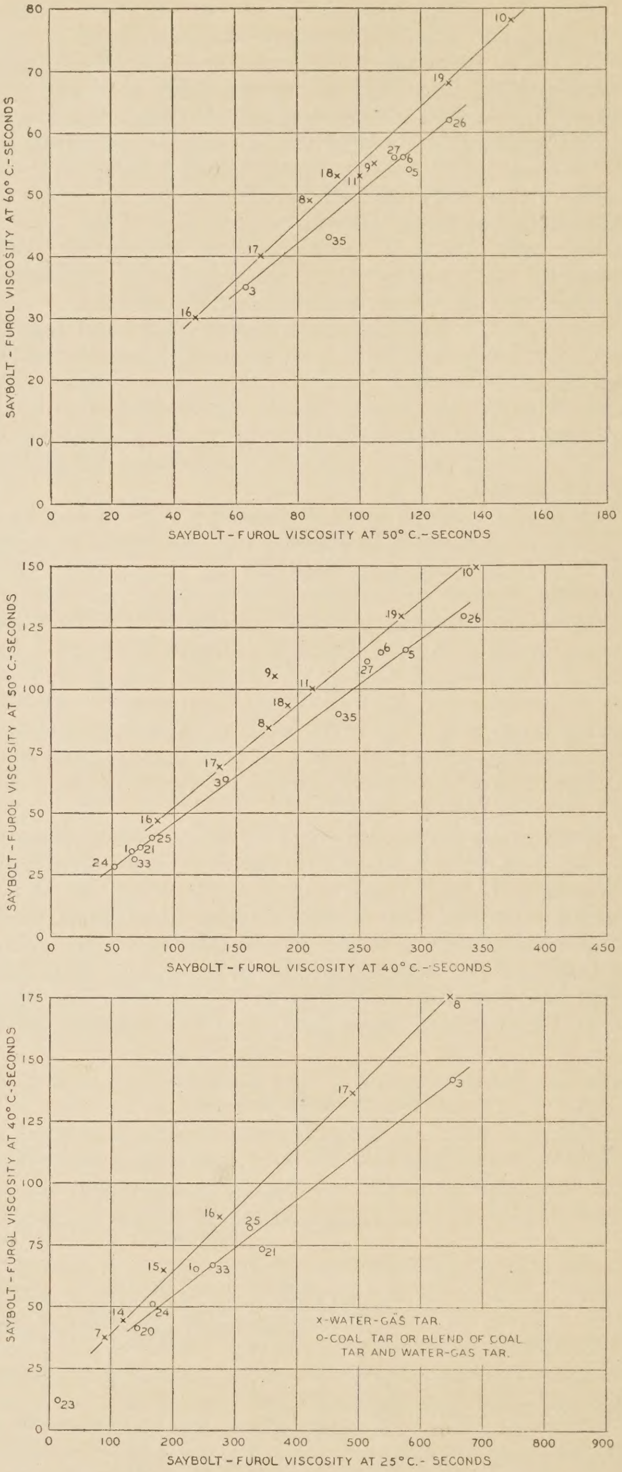

FIGURE 3.—RELATIONS BETWEEN SAYBOLT-FUROL VISCOSITIES OF VARIOUS ROAD TARS AT VARIOUS TEMPERATURES.

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[4] A Discussion of Road Tar Consistency Relationships. Engineering News-Record, vol. 111, no. 16, October 19, 1933.

nearly every case above the location of an average curve. Below the average curves are those materials known to be, or interpreted from results of tests to be, coal tars or blends of coal tars. In other words, based on viscosity tests, water-gas tars are somewhat less susceptible to temperature change than are the coal tars or coal-tar blends.

TEST PROCEDURE FOR TARS SUBSTANTIALLY DIFFERENT FROM THAT FOR ASPHALTIC MATERIALS

The float test at 32° C. has been generally adopted as a measure of consistency for the tars for hot surface treatments although the data in table 7 show that the use of Saybolt-Furol viscosity at 60° C. might also be satisfactory. However, for the heavy construction tars of the TP grades, the standard Saybolt-Furol test would not be suitable. The specifications of the American Society for Testing Materials for materials of this type require a softening point determination as a measure of consistency with the option of using the float test at 50° C., while the Federal specifications control consistency by means of the float test at 50° C. only. As indicated by table 7, the use of 50° C. as the temperature for the float test is to be preferred to 32° C. because of the greatly reduced time involved in making the test.

On the basis of the data developed by this investigation, it is believed that the float test at 32° C. and 50° C. is a satisfactory test for the consistency of the hot-application tars. Since the Saybolt-Furol viscosimeters with thermostatic control can be operated to give close checks on duplicate tests, require less material for test, and greatly shorten the time of testing, the adoption of Saybolt-Furol viscosity for cold application road tars, as has been done for liquid asphaltic road materials, would be a pronounced advance toward the general simplification and standardization of tests for this type of bituminous material.

In connection with this discussion of the measurement of consistency, mention should be made of a new viscosimeter.[5] This instrument is designed to measure the viscosity of all grades of bituminous material at a single temperature and the results are expressed in terms of the absolute viscosity, the poise. Much preliminary work must be done before general adoption of this new test can be expected, but its possibilities are such that it merits serious consideration. It presents a possible means of overcoming the present disadvantages of using several methods for measuring consistency and several temperatures for each method.

While there do not appear to be any practical reasons why all bituminous materials should not be tested in the same manner, for years the test procedure for tars has been substantially different from that for asphaltic materials. For tars, the amount of volatile matter has been determined by the distillation test and the materials have not usually been submitted to the volatilization test (loss on heating at 163° C.) which has been extensively used for liquid asphaltic materials. The volatilization test has been discarded rather generally, especially for the more rapid-hardening, liquid asphaltic products, and a distillation test has been substituted to determine the amount and rate of loss of volatile matter.

The method of making the distillation test for liquid asphaltic materials is described in A. S. T. M. Tentative Method of Test for Separation of Liquid Asphaltic Products, designation D 402–34 T, while the distillation test for tars is A. S. T. M. Standard Method of Test for Distillation of Bituminous Materials Suitable for Road Treatment, designation D 20–30. There are some essential differences that might lead to the belief that the results obtained by the two methods would be radically different.

Both methods use the same flask and thermometer. Method D 20–30 requires an air condenser; method D 402–34 T requires a water condenser. In the tar distillation the top of the bulb of the thermometer is at the bottom of the tubulature and the vapor temperature controls the distillation cuts and end point. In the liquid asphalt distillation the bottom of the bulb of the thermometer is ¼ inch above the bottom of the flask and the distillation fractions and end point are controlled by the temperature of residue or the liquid temperature. In the distillation of tars a 100-gram sample is used, while in the distillation of liquid asphaltic materials a 200-cubic centimeter sample is used.

The percentage of distillate is reported by weight in the tar distillation and by volume in the distillation of the liquid asphaltic material. The end point for the distillation of tar products is 300° C. (572° F.) vapor temperature. The end point of the distillation of asphaltic materials is 360° C. (680° F.) liquid temperature. The tar residue is cooled in the flask below 125° C. (257° F.) before pouring for further tests. The asphaltic residue is poured as quickly as possible after the end point of the distillation is reached.

In order to make some comparison of the results obtained by the two methods, 100-gram samples of one tar of each grade were distilled with two thermometers in the flask, so that the vapor temperature at the tubulature and the liquid temperature ¼ inch above the bottom of the flask could be determined. The relations between the vapor and liquid temperature are shown in figure 4.

METHOD OF POURING DISTILLATION RESIDUES AFFECTS THEIR PROPERTIES

The curves indicate quite clearly that for these tars, with one exception, a vapor temperature of 300° C. (572° F.) corresponds to a liquid temperature somewhat below 360° C. (680° F.). The one exception is the tar of the TC grade for which the vapor temperature of 300° C. corresponds to a liquid temperature slightly in excess of 360° C. The rather close agreement between a vapor temperature of 300° C. and a liquid temperature of 360° C. indicates that for these tar products there can be no great difference either in the amount of distillate or character of the residue, due solely to the difference between a vapor end point of 300° C. and a liquid end point of 360° C.

However, figure 4 does indicate that if arbitrary intermediate cutting points are taken, based on liquid temperature control, the fractions of distillate may be composed of constituents having widely different boiling points. For instance, if a liquid temperature cut is made at 225° C. (437° F.), the fraction below this temperature will contain material with a maximum boiling point in the case of the TC product of 125° C. (257° F.) and in the case of the TR product of 180° C. (356° F.), a spread of 55° C. Also, if a vapor temperature cut is made at 150° C., the spread between the TR and TP materials is 40° C. Therefore, it would seem that vapor temperature distillation control would be slightly the more preferable if it is desired to determine the character of the fractions obtained at various cutting temperatures, especially when comparison of

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[5] New Viscosimeter for Bitumens Has Extended Range, by E. O. Rhodes, E. W. Volkmann, and C. T. Barker. Engineering News-Record, vol. 115, no. 21, Nov. 21, 1935.

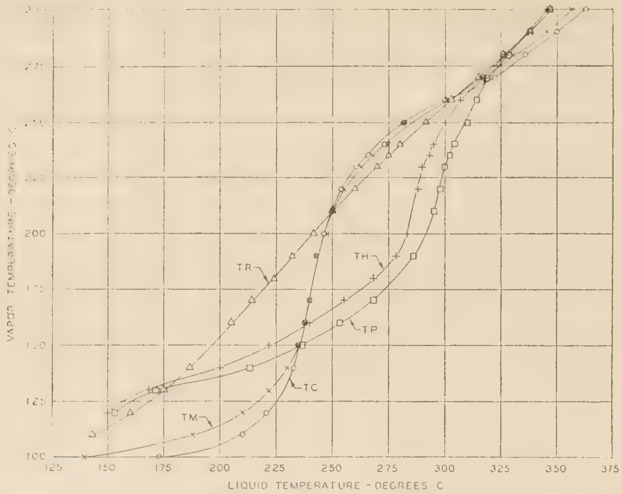

FIGURE 4.—COMPARISON OF LIQUID TEMPERATURE ONE-FOURTH INCH ABOVE BOTTOM OF FLASK AND VAPOR TEMPERATURE AT TUBULATURE FOR VARIOUS ROAD TARS.

the distillates from materials of widely different composition is desired.

Similar tests on a few samples of liquid asphaltic materials of the slow-curing, medium-curing, and rapid-curing types gave similar results. The curves showing the relation between liquid and vapor temperatures were of different shape for the different types of materials and also for different materials of the same type. There was also the same general agreement between a vapor temperature of 300° C. and a liquid temperature of 360° C., the vapor temperature of 300° C. corresponding to a liquid temperature of 360° C. or less.

Having established that there is no wide difference between a vapor end point of 300° C. (572° F.) and a liquid end point of 360° C. (680° F.), the effect on the character of the residue obtained by pouring as required by A. S. T. M. method D 20–30 and by A. S. T. M. method D 402–34 T was determined. The results of tests made on residues poured after they had cooled below 125° C. (257° F.) and when the residues were poured immediately after a vapor temperature of 300° C. (572° F.) was reached, are given in table 8.

The difference in the percentage of volatile matter lost in pouring and cooling the residues by the two methods varied from 0.83 to 4.15 percent of the total sample for all the materials tested, with an average difference of 2.37 percent. The losses in volatile matter in A. S. T. M. method D 20–30 are unavoidable losses caused by retention of distillate in the condenser. The effect of the greater loss of volatile matter that occurs when residues are poured according to A. S. T. M. method D 402–34 T is shown by the harder consistency of the corresponding residues. The softening points of the residues poured immediately were from 2.3° to 21.1° C., with an average of 6.8° C., higher than those poured in the usual procedure for tars. The penetration values also show the greater hardness of the residues poured immediately, the decrease in penetration ranging from 0 to 120 with an average of 26.3. Due to this increase in hardness, the softening point values of six of the residues from the TC and TM grades of tar, were increased until they exceeded the maximum allowed by the Federal specifications.

When an asphalt has been blended with a naphtha to produce a liquid asphalt of the rapid-curing type, it has been found that by pouring the residue immediately after the end point is reached the penetration of the residue is in very close agreement with the penetration of the base asphalt used in producing the blend. However, no information on the consistency of the base materials in medium-curing and slow-curing liquid asphaltic products is obtainable, even with this method

TABLE 8.—*Effect of method of pouring distillation residues upon their properties*

Type of material	Identification	Total loss in distillation test			Loss of volatile matter during test			Softening point			Penetration at 25° C., 100 g, 5 sec.		
		A. S. T. M. D 20–30	A. S. T. M. D 402–34 T	Difference	A. S. T. M. D 20–30	A. S. T. M. D 402–34 T	Difference	A. S. T. M. D 20–30	A. S. T. M. D 402–34 T	Difference	A. S. T. M. D 20–30	A. S. T. M. D 402–34 T	Difference
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*° C.*	*° C.*	*° C.*			
TC-1	7	35. 90	37. 29	1. 39	0. 75	1. 58	0. 83	45. 0	54. 0	9. 0	38	21	17
	14	38. 04	38. 90	. 86	. 62	2. 79	2. 17	54. 8	61. 7	6. 9	25	9	16
	20	32. 06	35. 64	3. 58	. 30	3. 30	3. 00	47. 4	55. 4	8. 0	38	12	26
	24	34. 35	37. 95	3. 60	. 33	2. 58	2. 25	45. 2	54. 4	9. 2	50	13	37
TC-2	1	33. 19	34. 55	1. 36	. 33	2. 59	2. 26	44. 6	50. 1	5. 5	38	30	8
	15	36. 34	37. 66	1. 32	. 56	2. 44	1. 88	55. 6	62. 7	7. 1	20	8	12
	21	29. 25	31. 75	2. 50	. 34	2. 94	2. 60	50. 8	57. 0	6. 2	27	8	19
	33	29. 92	34. 07	4. 15	. 38	2. 84	2. 46	37. 0	58. 1	21. 1	138	36	102
TC-3	16	35. 50	36. 69	1. 19	1. 00	2. 83	1. 83	57. 1	63. 1	6. 0	18	7	11
	25	31. 89	34. 15	2. 26	. 55	2. 89	2. 34	46. 6	52. 2	5. 6	42	19	23
TC-4	3	29. 10	31. 82	2. 72	. 85	3. 07	2. 22	45. 0	54. 0	9. 0	53	16	37
	17	34. 78	35. 44	. 66	. 57	2. 65	2. 08	60. 4	64. 4	4. 0	12	5	7
TM-1	8	26. 05	28. 80	2. 75	. 07	1. 96	1. 89	41. 0	48. 4	7. 4	71	39	32
	11	27. 57	30. 06	2. 49	. 44	2. 32	1. 88	42. 0	49. 2	7. 2	74	41	33
	18	33. 42	34. 59	1. 17	1. 27	3. 40	2. 13	59. 4	64. 1	4. 7	15	6	9
	35	25. 31	28. 97	3. 66	. 00	4. 15	4. 15	39. 6	48. 2	8. 6	97	36	61
TM-2	5	25. 73	27. 74	2. 01	. 65	2. 56	1. 91	46. 1	52. 5	6. 4	46	18	28
	19	31. 89	32. 45	. 56	. 80	2. 31	1. 51	60. 0	65. 8	5. 8	12	5	7
	26	23. 40	26. 07	2. 67	. 36	3. 54	3. 18	43. 2	50. 7	7. 5	62	25	37
TR-1	9	27. 75	29. 82	2. 07	. 45	1. 92	1. 47	60. 0	65. 0	5. 0	12	7	5
TR-2	6	25. 90	28. 33	2. 43	. 71	3. 67	2. 96	53. 1	60. 4	7. 3	20	5	15
	10	25. 52	27. 78	2. 26	. 62	2. 15	1. 53	55. 8	61. 0	5. 2	18	9	9
	27	25. 45	27. 36	1. 91	. 29	3. 48	3. 19	55. 4	59. 5	4. 1	15	6	9
TH-1	2	19. 80	21. 89	2. 09	. 57	3. 31	2. 74	51. 7	58. 1	6. 4	26	9	17
	12	15. 54	16. 58	1. 04	. 38	1. 55	1. 17	41. 6	44. 8	3. 2	89	67	22
	32	11. 12	15. 71	4. 59	. 31	3. 68	3. 37	33. 1	39. 7	6. 6	218	98	120
	28	14. 37	15. 82	1. 45	. 48	3. 12	2. 64	47. 0	52. 8	5. 8	43	21	22
TP-1	13	11. 79	13. 10	1. 31	. 19	1. 49	1. 30	49. 0	54. 0	5. 0	38	22	16
TP-2	29	11. 72	14. 77	3. 05	. 32	3. 68	3. 36	49. 6	56. 0	6. 4	30	10	20
TP-4	4	13. 20	15. 63	2. 43	. 99	4. 74	3. 75	56. 1	60. 1	4. 0	12	5	7
TP-6	30	8. 72	10. 88	2. 16	. 31	3. 57	3. 26	51. 8	56. 8	5. 0	25	12	13
	34	5. 90	9. 38	3. 48	. 18	3. 42	3. 24	44. 1	54. 4	10. 3	71	13	58
Special	22	19. 62	21. 50	1. 88	. 00	2. 31	2. 31	58. 5	61. 6	3. 1	15	6	9
	23	47. 85	49. 23	1. 38	. 48	2. 80	2. 32	39. 1	52. 7	13. 6	84	26	58
	31	18. 90	19. 79	. 89	. 79	2. 58	1. 79	73. 3	75. 6	2. 3	1	1	0

of pouring. Most road tars have tar pitches as bases which contain some volatile matter to 300° C. (572° F.) and it is doubtful if the true consistency of the base material can be approximated by either method of pouring the residue.

Liquid asphaltic materials have been classified according to the consistency of the residues from the D 402–34 T distillation test as follows: [6]

Group 1.—Liquid residue, float test less than 25 seconds at 122° F. (50° C.), nonhardening or extremely slow hardening.

Group 2.—Float residue, float test more than 25 seconds at 122° F. (50° C.) and penetration of more than 300 at 77° F. (25° C.), medium hardening.

Group 3.—Penetration residue, penetration less than 300 at 77° F. (25° C.), rapid hardening, the speed of hardening being dependent on the amount and volatility of the distillate.

Under the above classification, it will be seen from table 8 that all of the road tars included in this investigation, even if the softer consistencies of the residues obtained by the D 20–30 method of pouring are considered, are of the rapid-hardening type of bituminous material.

DISTILLATION RESIDUES HAD GOOD DUCTILITY AT NORMAL TEMPERATURES

For some time specifications for many asphaltic materials have included a ductility requirement as a means of control and as an indication of the adaptability of the products to particular uses. Asphaltic cements, and usually the distillation residues and asphaltic residues of liquid asphaltic materials, are required to show a certain ductility at 25° C. (77° F.) and for some purposes at lower temperatures such as 1.5° C. (34.7° F.) or 4° C. (39.2° F.). While the ductility test has been criticised as not being a good measure of the resistance to the stresses to which asphalts in road surfaces are subjected, its use as a laboratory test for these materials is widespread.

If the asphalts used in particular types of road construction must meet a ductility requirement, it is logical that tar products for similar use should also meet a ductility requirement. At the present time the only tars that are tested for ductility are the tar pitches used in roof construction and for water-proofing structures. Few data are available regarding the ductility of road tars. In order to obtain as much information as possible on the physical properties of these tar products, the residues obtained in the standard A. S. T. M. D 20–30 distillation test were tested for ductility.

The ductility tests were made on each distillation residue at several temperatures in order to obtain some idea of its temperature-ductility curve. The tests were made at 10° C., 15° C., 20° C., and 25° C. and the results are given in table 9.

In order to compare the results of the ductility test with the other tests made on the distillation residues, the data in table 9 have been grouped according to the index shown in table 10. An index of 1 represents the most ductile residue at low temperature and an index of 7 the least ductile.

The ductility index and the other test results on the distillation residues are given in table 11. It is evident that consistency as measured by the softening point or penetration is related to the ductility of these tar pitches. At a given temperature, the harder the material the less ductility it possesses. It is indicated that the free carbon content also influences the ductility. In general, as the percentage of free carbon increases the ductility decreases.

TABLE 9.—*Ductilities of the A. S. T. M. D 20–30 distillation test residues*

Type of material	Identification	At 25° C.	At 20° C.	At 15° C.	At 10° C.
		Cm	*Cm*	*Cm*	*Cm*
TC-1	7	83	90	55	1.5
	14	74	66	0.25	0
	20	110+	110+	110+	0
	24	110+	110+	110+	0
TC-2	1	110+	110+	110+	0
	15	73	66	0	0
	21	110+	110+	0	0
	33	110+	110+	110+	110+
TC-3	16	54	0	0	0
	25	110+	110+	110+	0
TC-4	3	110+	110+	110+	0
	17	52	0	0	0
TM-1	8	48	65	66	92
	11	73	55	67	110+
	18	56	0	0	0
	35	110+	110+	110+	110+
TM-2	5	110+	110+	110+	0
	19	56	0	0	0
	26	110+	110+	110+	0
TR-1	9	43	0	0	0
TR-2	6	110+	0.75	0	0
	10	79	1.5	0	0
	27	110+	70	0	0
TH-1	2	110+	110+	0	0
	12	53	40	71	110+
	32	110+	110+	110+	110+
	28	110+	81	0	0
TP-1	13	52	60	7.5	0
TP-2	29	110+	110+	0.25	0
TP-4	4	110+	0.5	0	0
TP-6	30	110+	110+	0	0
	34	110+	110+	110+	0.75
Special	22	100+	0.25	0	0
	23	110+	110+	110+	110+
	31	0	0	0	0

TABLE 10.—*Ductility index for distillation residues of tars*

Index	Ductility (cm)	
1	90+ at 10° C.	
2	55–110+ at 15° C.	0–1½ at 10° C.
3	110+ at 20° C.	0–¼ at 15° C.
4	52–110+ at 25° C.	60–81 at 20° C.
5	110+ at 25° C.	¼–¾ at 20° C.
6	43–79 at 25° C.	0–1½ at 20° C.
7	0 at 25° C.	

TABLE 11.—*Range in test values of the A. S. T. M. D 20–30 Distillation test residues grouped according to ductility index*

Ductility index	Softening point			Penetration at 25° C.			Free carbon		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
	° *C.*	° *C.*	° *C.*				*Per cent*	*Per cent*	*Per cent*
1	33.1	42.0	39.1	71	218	110	1.3	11.7	8.3
2	43.2	47.4	45.2	38	71	49	9.1	13.0	11.4
3	49.6	51.8	51.0	25	30	27	13.0	18.7	15.5
4	47.0	55.6	52.4	15	43	28	11.4	17.5	13.3
5	53.1	58.5	55.9	12	20	16	20.3	30.1	23.8
6	55.8	60.4	58.8	12	18	15	11.4	14.3	13.3
7			73.3			1			20.1

EFFECTS OF EXPOSURE ON TAR PRODUCTS HAVE BEEN STUDIED EXTENSIVELY

W. H. Flood [7] has stated that the great majority of asphalts of the 40–50, 50–60 and 60–70 grades used in road construction have ductility values beyond the limits of the ductility machine. He has shown that materials meeting these penetration grades have ductility values at 60° F. (15.5° C.) averaging from 10.5

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[6] Rationalization and Simplification of Test Requirements for Liquid Asphaltic Materials, by E. F. Kelley and Prevost Hubbard. PUBLIC ROADS, vol. 13, no. 6, August 1932.

[7] Ductility at Low Temperatures. 1935 Proceedings of the Association of Asphalt Paving Technologists.

centimeters to 75.4 centimeters, and at 39.2° F. (4° C.) values averaging from 3.2 centimeters to 4.8 centimeters for the different consistency ranges and sulphur contents. When these figures are compared to the results obtained on the tar residues having a ductility index of 2 and a range in penetration of 38 to 71, it is seen that tars have a more rapid and abrupt loss of ductility when the test temperature is reduced than do asphalts. This is the result, no doubt, of the greater susceptibility of tars to temperature change, causing a more rapid transition of these materials from a semisolid to a solid state. The tests show that nearly all of the residues have good ductility at 25° C., but, in general, this ductility is rapidly lost when the temperature of test is reduced.

In recent years much thought has been given to the changes that take place in bituminous materials under service conditions. The initial bonding strength of a tar product when applied to the road surface is developed in different ways, depending not only on the type of original material but also on the way it is used and the climatic conditions to which it is subjected. All grades of road tar lose a certain amount of volatile matter. This tends to stiffen or harden the material. After the initial bond has been developed, either by evaporation, cooling, or a combination of both, certain hardening takes place because of inherent changes brought about by weathering.

Early investigators have done much work to substantiate these facts. Hubbard and Reeve[8] published a paper in 1913 regarding the effect of exposure on bitumens. Included in this investigation were three tar products; namely, a refined coal tar, a refined water-gas tar, and a refined mixture of coal tar and water-gas tar. The authors made the following conclusion:

> It is apparent from these results that the hardening of all bitumens upon exposure is not due to loss by volatilization of the lighter constituents, alone, although in tars such loss is probably responsible to a considerable degree for the hardening of these products. The hardening of petroleum and asphalt products is undoubtedly due to oxidation which proceeds slowly at comparatively low temperatures but increases at higher temperatures. It seems probable that oxidation also plays a part in the hardening of tars although the preceding data does not absolutely prove this fact.

Later Reeve and Lewis[9] substantiated and amplified the previous data which showed that upon exposure bituminous materials undergo changes caused by factors other than loss of the more volatile constituents. They also showed that the insoluble organic matter in the bitumens they examined increased materially in a closed oven where the chances of oxidation are reduced to a minimum. The authors stated that while oxidation plays a part in the changes that occur, they were led to the conclusion that polymerization and intermolecular reactions induced by heat, and possibly increased by the action of light, are also very largely responsible for such changes, in addition to those accounted for by simple evaporation.

Reeve and Anderton,[10] while noting that the action of air and sun upon bitumens in their original state is probably quite different than might be expected in actual service, concluded that: (1) Upon exposure tar products harden to a much greater extent than could be attributed to the loss of volatile matter alone; (2) changes are accompanied by formation of material insoluble in carbon disulphide; (3) the development of free carbon was greater in water-gas tar than in coal tar; and (4) the comparative consistency of the residues from distillation to a single arbitrary end temperature did not represent the relative behavior of tars in service.

More recent investigations [11] [12] by the Bureau on the effects of exposure on liquid asphaltic materials of the slow-curing, medium-curing, and rapid-curing types have indicated that many materials that have similar characteristics as determined by the usual laboratory tests behave quite differently when exposed in thin films or in mixtures with a standard aggregate.

Exposure tests on the tars were made in boxes of the same type as were used in previous investigations of the Bureau. A sketch of the box is shown in figure 5. The boxes were constructed of ¾-inch wood, the interior dimensions being 30 by 24 by 3 inches. A hole in the center of the bottom of each box served to admit a stream of clean, dry air to carry away any collected vapors. Outlets for the air were made by cutting slots in the sides of the boxes. These were packed with cotton batting to prevent the entrance of dust. Plate glass, resting on thin strips of felt placed along the edges of the boxes, served as covers.

Three 50-cubic centimeter samples of each tar were placed in seamless flat tins, 5½ inches in diameter and ⅝ inch deep. This amount of material gave a uniform film thickness of ⅛ inch. The exposure boxes containing the three sets of exposure samples, one each for 5-, 10-, and 15-week periods, are shown in figure 6.

ULTIMATE LOSS ON EXPOSURE CLOSELY APPROXIMATED LOSS IN A.S.T.M. D 20-30 DISTILLATION TEST

The samples were placed in the exposure boxes on June 15, 1933. During the following 15 weeks the hourly temperatures within the boxes were recorded daily from 9 a. m. to 4 p. m. The maximum temperature reached during this time was 196° F. (91° C.) occurring on a clear day with a maximum of sunshine. On cloudy days the temperature within the boxes was the same as the outside air temperature. The average maximum daily air temperature was 85° F. (30° C.). As determined from United States Weather Bureau reports for the period of exposure, the samples from the 5-, 10-, and 15-week periods were subjected to 333, 611, and 866 hours of sunlight, respectively.

The samples tested at the end of 15 weeks of exposure were weighed at various intervals to determine the loss of volatile matter at all intermediate periods except the 35-day and 70-day periods (5 and 10 weeks). The losses at these two periods were determined on the samples removed for test at that time, so that the percentage of loss obtained could be correlated accurately with the test values on the residues. This procedure, no doubt, accounts for variations in losses between the 35- and 70-day tests that appear to indicate gains in weights rather than continued losses. The percentages of loss at different periods are tabulated in table 12 and the average for each grade of material is shown graphically in figure 7.

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[8] The Effect of Exposure on Bitumens, by Prevost Hubbard and C. S. Reeve. Industrial and Engineering Chemistry, vol. 5, no. 1, January 1913.

[9] The Effects of Exposure on Some Fluid Bitumens, by C. S. Reeve and R. H. Lewis. Journal of Industrial and Engineering Chemistry, vol. 9, no. 8, August 1917.

[10] The Effects of Exposure on Tar Products, by C. S. Reeve and B. A. Anderton. Journal of Franklin Institute, vol. 182, no. 10, October 1916.

[11] A Study of Some Liquid Asphaltic Materials of the Slow-Curing Type, by R. H. Lewis and W. O'B. Hillman. PUBLIC ROADS, vol. 15, no. 4, June 1934.

[12] Further Studies of Liquid Asphaltic Materials, by R. H. Lewis and W. O'B. Hillman. PUBLIC ROADS, vol. 16, no. 6, August 1935.

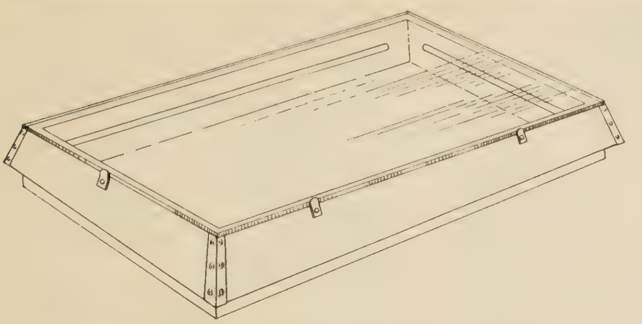


Figure 5.—Box Used in Exposure Tests.

Table 12.—*Rate of loss of volatile matter in thin-film exposure of road tars*

Type of material	Identification	Time of exposure in days							
		2	8	15	22	35	50	70	105
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
TC-1	7	23.9	31.4	32.4	32.9	33.2	33.5	34.4	34.0
	14	24.1	31.5	31.9	32.7	33.1	33.2	33.7	33.6
	20	22.3	29.5	31.2	32.9	33.9	33.9	33.3	34.5
	24	22.9	30.5	32.8	34.9	35.3	36.0	35.3	36.3
TC-2	1	19.2	26.6	28.7	30.9	31.4	31.8	31.1	32.3
	15	21.5	30.1	30.3	31.0	30.5	31.4	30.7	31.7
	21	18.7	26.1	27.4	29.4	29.2	30.1	29.1	30.7
	33	17.2	24.3	27.3	30.4	30.8	31.6	32.7	30.5
TC-3	16	21.6	29.2	29.3	29.9	28.8	30.3	29.5	30.9
	25	19.2	26.9	28.6	30.6	31.6	32.4	31.3	32.7
TC-4	3	17.0	24.1	25.9	27.4	26.2	28.5	23.4	28.6
	17	21.6	26.8	27.0	27.5	26.0	28.2	27.1	28.4
TM-1	8	13.5	22.2	23.1	24.9	23.1	25.5	25.4	26.3
	11	11.9	20.3	22.7	25.0	23.6	25.8	25.2	26.7
	18	20.9	24.6	24.9	25.3	24.3	25.9	26.5	26.4
	35	13.0	19.9	21.3	23.6	25.1	24.8	25.3	25.6
TM-2	5	13.3	19.3	20.9	22.4	22.4	23.7	23.3	24.0
	19	17.6	22.4	22.8	23.4	23.1	24.0	23.7	24.3
	26	11.1	17.9	20.0	22.7	23.0	25.0	24.9	25.4
TR-1	9	16.8	21.3	21.5	22.1	21.5	22.8	22.4	23.3
TR-2	6	14.7	20.1	21.2	22.4	22.0	22.8	22.3	23.5
	10	13.6	19.1	19.5	19.8	19.8	20.6	20.0	21.3
	27	15.3	19.4	20.9	22.1	21.2	22.6	22.6	22.7
TH-1	2	7.6	12.5	13.7	15.2	14.2	15.8	15.4	16.2
	12	4.1	8.4	11.0	13.4	12.3	14.1	14.6	14.7
	32	2.0	8.2	10.8	14.3	15.0	18.2	19.9	19.7
	28	4.2	8.8	10.7	12.8	12.6	14.0	15.0	14.5
TP-1	13	2.3	5.3	7.3	8.3	7.1	8.9	9.4	9.9
TP-2	29	2.7	6.4	7.9	9.8	10.4	11.4	10.6	11.7
TP-4	4	2.7	5.3	6.4	7.7	7.4	8.2	7.6	8.7
TP-6	30	1.2	4.3	5.3	6.5	6.8	7.5	7.1	8.2
	34	.7	3.4	4.8	7.2	8.7	9.7	9.6	10.5
Special	22	7.3	12.2	13.5	14.9	14.2	15.7	15.3	16.0
	23	29.9	41.4	44.4	45.4	46.6	46.1	48.4	46.3
	31	2.9	6.2	6.4	7.0	6.7	7.8	6.0	8.1

Figure 6.—Exposure Boxes Containing Tar Samples and Hubbard-Field Specimens During an Exposure Test.

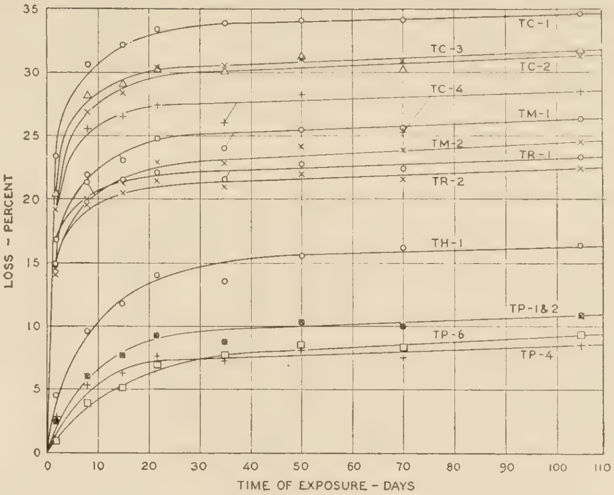


Figure 7.—Rate of Loss in Thin-Film Exposure of Various Road Tars (Values Are Averages for Each Grade).

During exposure a skin was formed on the surface of the samples, the thickness of the skin increasing as the loss of the volatile constituents increased. The thickness of the skin had increased noticeably by the end of each exposure period, the depth of softer material on the bottom of the pan being correspondingly reduced. Photographs showing the condition of the film surfaces after 15 weeks exposure are shown in figures 8 to 11 inclusive.

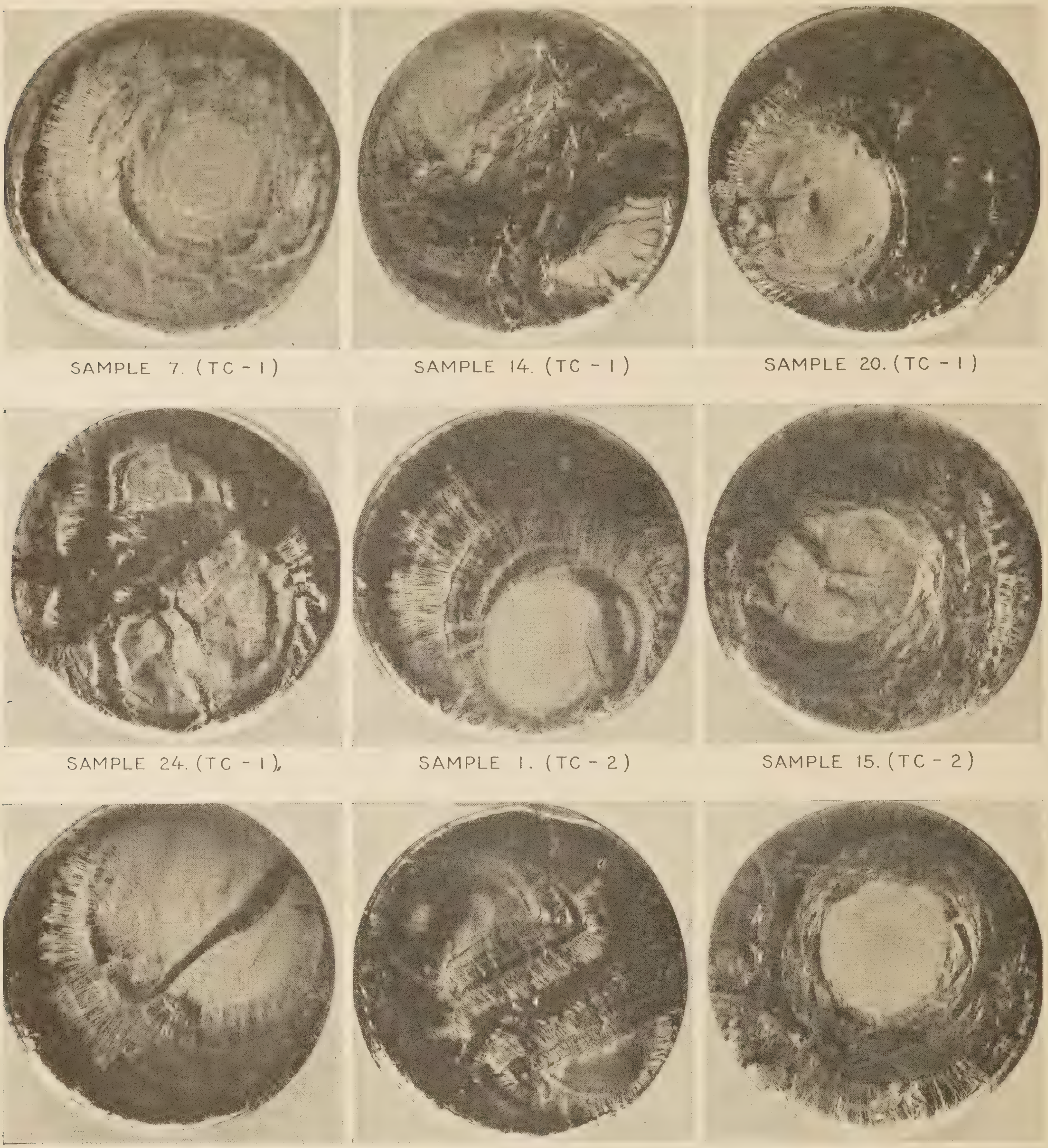
It will be noticed from table 12 and figure 7 that all of the tars lost weight rapidly at first and then more slowly as the time of exposure increased. Based on the loss after 15 weeks, the maximum loss in 2 days was 79.2 percent, the minimum 6.7, and the average loss for the 32 tars meeting some specification was 51.7 percent. In 15 days the maximum loss was 95.6, the minimum 45.7, and the average 84.1 percent. Beyond the 15-day period all samples lost weight very slowly. At the end of the 50-day period the average loss for all samples was 97.4 percent of the loss at 15 weeks. The cold-application tars showed a much higher rate of loss than did the hot-application tars. At the end of 8 days the former showed an average loss of 86.1 percent of their ultimate loss, while the nine hot tars required a period of 22 days to show an average loss of 83.2 percent.

In order to make comparisons of the characteristics developed by 5-, 10-, and 15-week exposures and by the distillation test, the respective residues were subjected to the same tests. These data are shown in table 13.

EXPOSURE RESIDUES WERE HARDER AND DEVELOPED MORE FREE CARBON THAN DISTILLATION RESIDUES

The average total loss in the distillation test, A. S. T. M. D20–30, for the 32 tars that substantially met the Federal specifications was 25.3 percent as compared to the average loss of the same samples for 5, 10, and 15-week exposure periods of 22.3, 23.2, and 24.0 percent, respectively. Since the average total loss in the distillation test, when the residue was poured immediately, was 27.5 percent for these same samples, it is seen that the ultimate loss as determined at the end of the 15-week period was in closer agreement with the loss obtained in the standard method of distilling tar products. Figure 12 compares the total loss in the distillation test, A. S. T. M. D20–30, with the loss occurring in thin films at the end of 15 weeks of exposure. Samples 32 and 34 were the only tars to show an appreciably greater loss under exposure than occurred in the distillation test. All other materials had losses approximately equal to or less than the losses in distillation.

Although the loss of volatile matter in 5 weeks was practically equal to or less than the loss in the distillation test, except for samples 32 and 34, all the residues from this period except for samples, 9, 10, 22, and 31, had penetrations equal to or lower and softening points



SAMPLE 7. (TC - 1)

SAMPLE 14. (TC - 1)

SAMPLE 20. (TC - 1)

SAMPLE 24. (TC - 1)

SAMPLE 1. (TC - 2)

SAMPLE 15. (TC - 2)

SAMPLE 21. (TC - 2)

SAMPLE 33. (TC - 2)

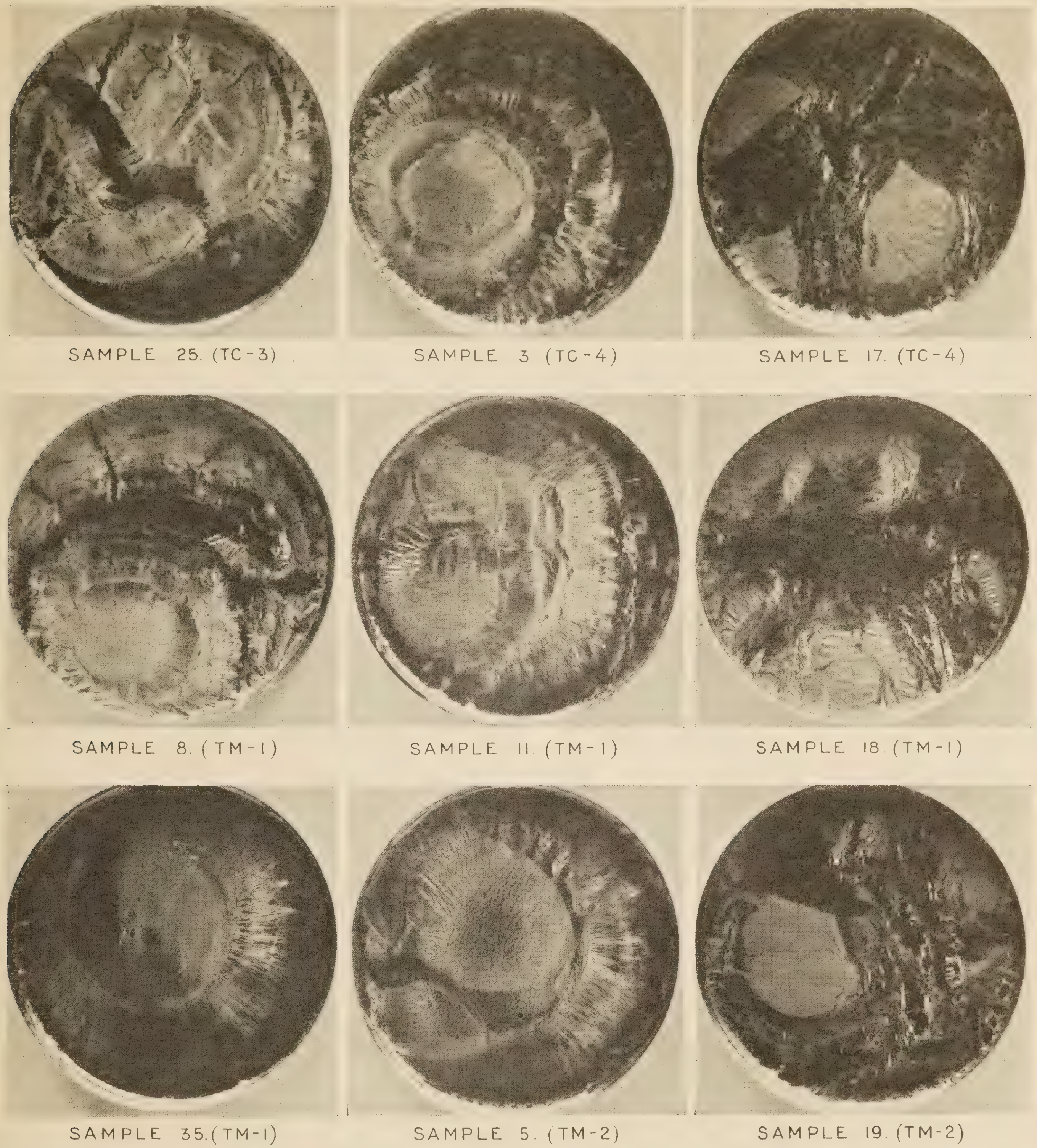
SAMPLE 16. (TC - 3)

Figure 8.—Appearance of Surfaces of Tar Samples After 15 Weeks of Exposure. The Figures in Parentheses Are the Federal Specification Grades to Which the Samples Conform. The Centers of the Spots on Samples 7 and 1 Were Highly Carbonized. All of the Other Samples were Slightly Carbonized.

equal to or higher than the corresponding distillation residues.

The greatest difference in penetration occurred in the exposure residues of samples 23, 24, 26, 32, 33, 34, and 35, their penetrations ranging from one-ninth to one-twenty-fifth of the penetrations of their corresponding distillation residues. At the end of 10 weeks only the residue of sample 31 had a softening point appreciably lower than that of its distillation residue. The softening point of the exposure residue of sample 22 was approximately the same as that of its distillation residue. After 15 weeks of exposure all residues, except that of sample 31, were considerably harder than their corresponding distillation residues.

A comparison of the softening points and penetrations of the distillation residues and the 15-week exposure



SAMPLE 25. (TC-3)

SAMPLE 3. (TC-4)

SAMPLE 17. (TC-4)

SAMPLE 8. (TM-1)

SAMPLE 11. (TM-1)

SAMPLE 18. (TM-1)

SAMPLE 35. (TM-1)

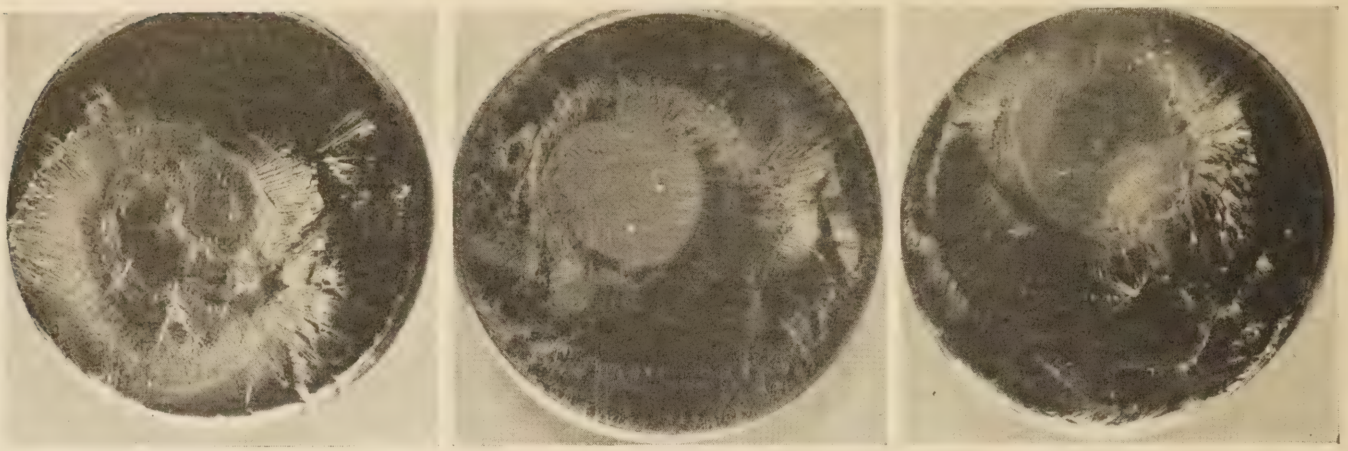
SAMPLE 5. (TM-2)

SAMPLE 19. (TM-2)

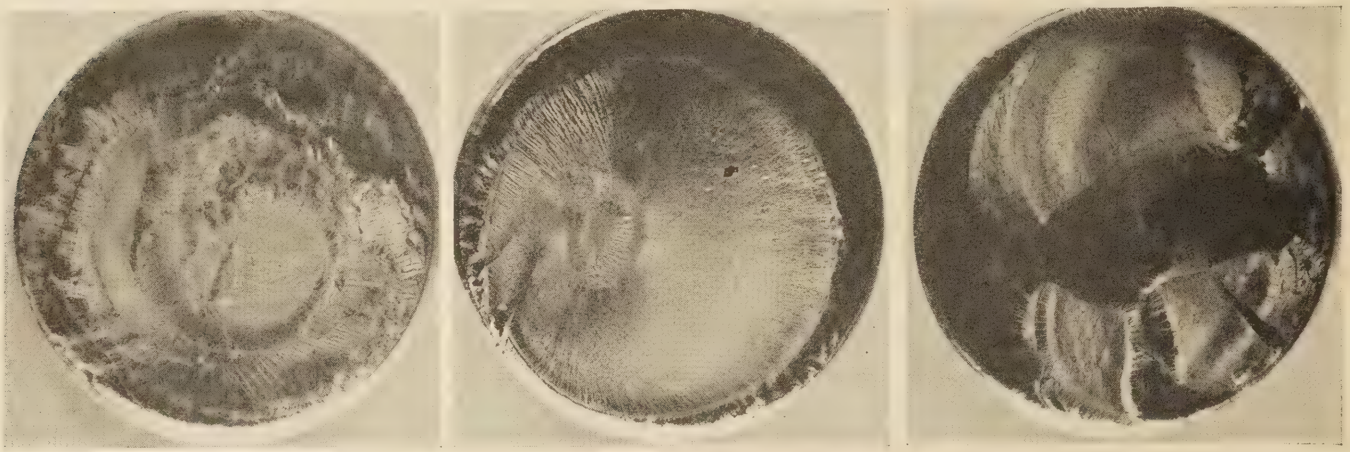
Figure 9.—Appearance of Surfaces of Tar Samples After 15 Weeks of Exposure. The Figures in Parentheses Are the Federal Specification Grades to Which the Samples Conform. The Center of the Spot on Sample 8 Was Highly Carbonized and the Rough Areas on Sample 11 Were Carbonized. All of the Other Samples Were Slighlty Carbonized, and in Addition Sample 5 was Fluorescent and Sample 25 was Partially Fluorescent.

residues substantiates the conclusion of Reeve and Anderton that the comparative consistencies of the residues from distillation to a single arbitrary temperature do not represent the relative behavior of tars in service. The average softening point of the distillation residues of samples 7, 14, 20, and 24 meeting TC-1 specification was 48.1° C., and the average softening point of the residues after 15 weeks of exposure was 74.5° C. The distillation residues of the five TP products, samples 4, 13, 29, 30, and 34, had an average softening point of 50.1° C., but the average softening point of their exposure residues was slightly under 65° C.

Early investigators, as previously mentioned, noted that tar products on exposure developed considerable



SAMPLE 26. (TM-2) SAMPLE 9. (TR-1) SAMPLE 6. (TR-2)



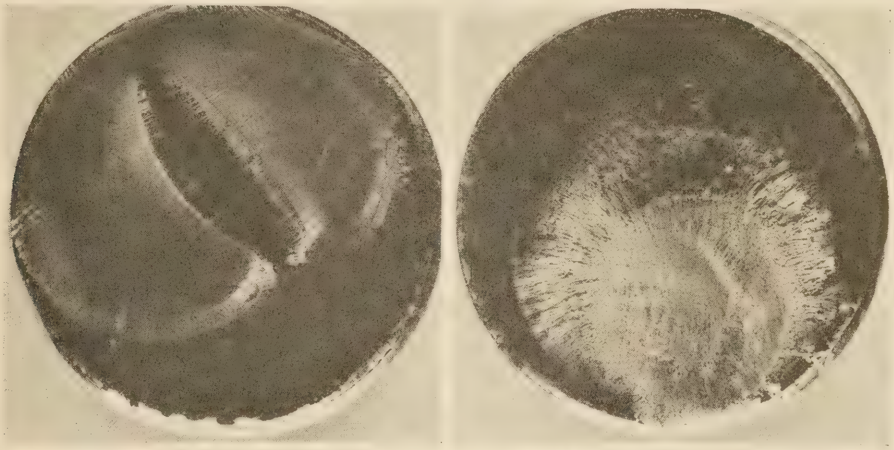
SAMPLE 10. (TR-2) SAMPLE 27. (TR-2) SAMPLE 2. (TH-1)

SAMPLE 12. (TH-1) SAMPLE 28. (TH-1) SAMPLE 32. (TH-1)

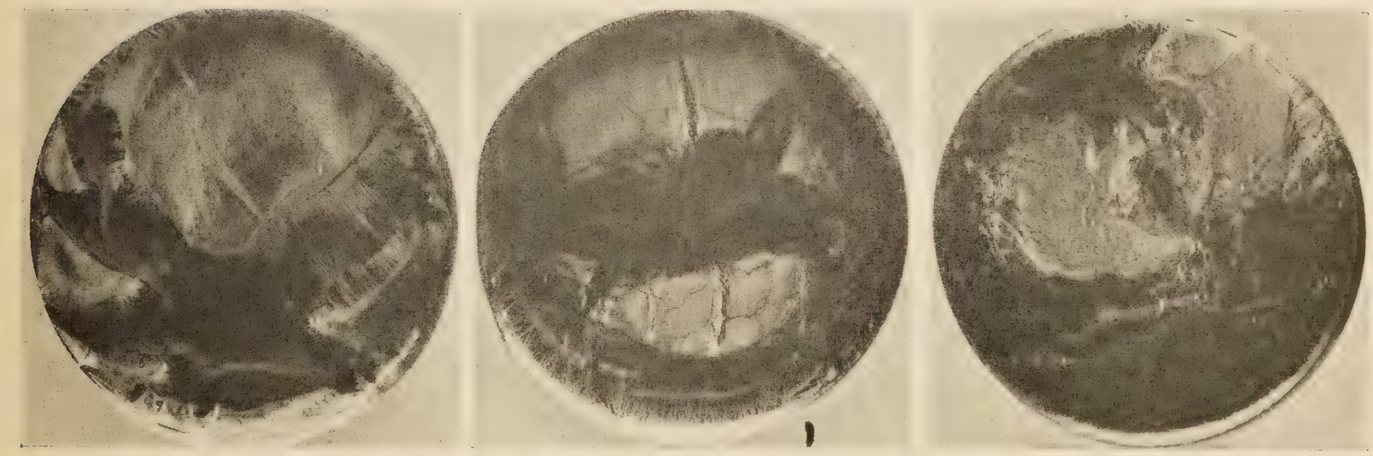
Figure 10.—Appearance of Surfaces of Tar Samples After 15 Weeks of Exposure. The Figures in Parentheses Are the Federal Specification Grades to Which the Samples Conform. The Concentric Circles on Sample 12 Show Increasing Carbonization Toward the Center, and the Spots on Samples 9 and 10 Were Carbonized. All of the Other Samples Were Slightly Carbonized, and in Addition, Samples 26 and 27 Were Fluorescent.

quantities of free carbon. In order to see if this production of organic material was more pronounced under exposure conditions than under the accelerated laboratory heat test (the distillation test), determinations of solubility in carbon disulphide were made on all residues thus obtained. By expressing the percentage of free carbon in any residue in terms of the weight of the original material, then dividing by the percentage of free carbon in the original material and multiplying by 100, the result is the index of increase in free carbon. An index of 100 indicates that no increase nor decrease has taken place. The indexes of increase in free carbon for the various residues are given in table 14.

SAMPLE 13. (TP-1) SAMPLE 29 (TP-2) SAMPLE 4. (TP-4)



SAMPLE 30. (TP-6) SAMPLE 34. (TP-6)



SAMPLE 22 (SPECIAL MATERIAL) SAMPLE 23 (SPECIAL MATERIAL) SAMPLE 31 (SPECIAL MATERIAL)

FIGURE 11.—APPEARANCE OF SURFACES OF TAR SAMPLES AFTER 15 WEEKS OF EXPOSURE. THE FIGURES IN PARENTHESES ARE THE FEDERAL SPECIFICATION GRADES TO WHICH THE SAMPLES CONFORM. THE CENTER OF THE SPOT ON SAMPLE 13 WAS CARBONIZED; SAMPLES 34, 23, AND 31 WERE SLIGHTLY CARBONIZED; AND ALL OF THE OTHER SAMPLES WERE VERY SLIGHTLY CARBONIZED. IN ADDITION, SAMPLES 29 AND 30 WERE SLIGHTLY FLUORESCENT.

LOSS OF VOLATILE MATTER, OXIDATION, AND POLYMERIZATION CAUSE CHANGES UPON EXPOSURE

This table indicates that the distillation residues of samples 6, 7, 8, 9, 10, 11, 12, 13, and 23 and the residues from exposure of sample 7 at 5 and 10 weeks and of sample 9 at 15 weeks had indexes of increase of less than 100. These apparent decreases in free carbon may, in the majority of cases, result from slight inaccuracies in the carbon-disulphide solubility tests. In the case of sample 23, repeated check tests on both the original material and the distillation residue indicated that the free carbon content of this material was greatly reduced

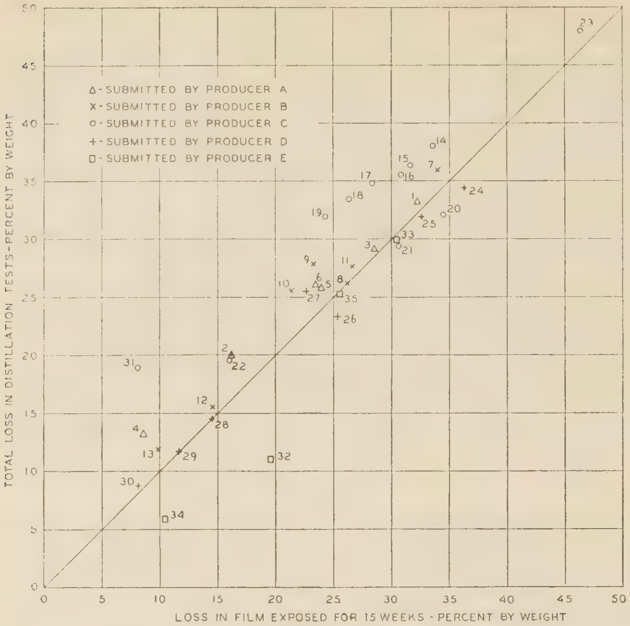


Figure 12.—Comparison of the 15-Week Exposure Loss With the Total Loss in Distillation.

during distillation. This sample under exposure rapidly developed material insoluble in carbon disulphide. For all materials, except samples 7 and 31, the index of increase in free carbon is least in the distillation residues and greatest in the 10- or 15-week exposure residues.

Table 14.—*Index of increase in free carbon for various residues*

Type of material	Identification	Distillation residue	Exposure residues: 5 weeks	Exposure residues: 10 weeks	Exposure residues: 15 weeks
		Percent	*Percent*	*Percent*	*Percent*
TC-1	7	92	79	93	116
	14	116	131	154	184
	20	172	262	294	328
	24	126	194	210	220
TC-2	1	100	152	169	169
	15	120	139	162	155
	21	170	258	287	302
	33	121	216	245	339
TC-3	16	122	140	163	172
	25	122	185	190	205
TC-4	3	103	133	156	163
	17	130	148	162	172
TM-1	8	96	118	126	129
	11	93	120	130	133
	18	125	148	166	178
	35	123	189	202	240
TM-2	5	104	138	142	152
	19	126	145	164	168
	26	119	176	193	201
TR-1	9	88	109	110	94
TR-2	6	93	109	113	117
	10	93	112	111	120
	27	116	132	143	145
TH-1	2	101	122	122	128
	12	97	120	134	131
	32	112	191	205	237
	28	121	153	169	173
TP-1	13	98	119	--------	129
TP-2	29	120	144	149	161
TP-4	4	112	121	118	127
TP-6	30	113	132	136	150
	34	110	162	176	189
Special	22	115	118	122	127
	23	14	210	188	214
	31	128	123	131	141

As measured by the softening point, the hardness of the 5-week exposure residues of samples 1, 20, 23, 24, 25, 26, 32, 33, 34, and 35 exceeded the hardness of their distillation residues by the greatest amounts, the difference in softening points ranging from 14.4° C. to 26.4° C. The softening points of the 15-week exposure residues of these same materials exceeded the softening points of the distillation residues by amounts ranging from 21.9° C. to 41.4° C. With the exception of sample 21, the difference between the index of increase in free carbon for the exposure and distillation residues was also greatest for these materials. For the 5-week

Table 13.—*Results of laboratory tests on distillation and exposure residues*

Type of material	Identification	Distillation residue (A. S. T. M. D 20–30): Total loss	Distillation residue: Penetration at 25° C., 100, g., 5 sec.	Distillation residue: Softening point	Distillation residue: Free carbon	5-week exposure residue: Loss	5-week: Penetration at 25° C., 100, g., 5 sec.	5-week: Softening point	5-week: Free carbon	10-week exposure residue: Loss	10-week: Penetration at 25° C., 100, g., 5 sec.	10-week: Softening point	10-week: Free carbon	15-week exposure residue: Loss	15-week: Penetration at 25° C., 100, g., 5 sec.	15-week: Softening point	15-week: Free carbon
		Percent		*°C.*	*Percent*	*Percent*		*°C.*	*Percent*	*Percent*		*°C.*	*Percent*	*Percent*		*°C.*	*Percent*
TC-1	7	35.90	38	45.0	11.7	33.2	15	58.0	9.8	34.4	5	69.4	11.6	34.0	2	73.3	14.4
	14	38.04	25	54.8	11.4	33.1	13	61.0	11.9	33.7	--------	69.2	14.1	33.6	2	74.3	16.9
	20	32.06	38	47.4	11.9	33.9	6	62.9	18.6	33.3	2	68.7	20.7	34.5	1	74.2	23.5
	24	34.35	50	45.2	12.6	35.3	2	66.7	19.8	35.3	--------	70.8	21.4	36.3	1	76.3	22.8
TC-2	1	33.19	38	44.6	9.1	31.4	9	59.3	13.5	31.1	5	66.7	15.0	32.3	2	71.9	15.2
	15	36.34	20	55.6	12.2	30.5	19	57.9	12.9	30.7	7	65.0	15.1	31.7	4	70.4	14.8
	21	29.25	27	50.8	13.0	29.2	6	61.1	19.6	29.1	--------	66.8	21.8	30.7	1	75.2	23.5
	33	29.92	138	37.0	6.6	30.8	7	59.4	11.8	32.7	--------	67.3	13.8	30.5	2	71.5	18.6
TC-3	16	35.50	18	57.1	12.8	28.8	16	59.5	13.4	29.5	6	68.0	15.7	30.9	3	75.9	17.0
	25	31.89	42	46.6	12.9	31.6	3	64.9	19.4	31.3	--------	67.3	19.9	32.7	1	74.2	22.0
TC-4	3	29.10	53	45.0	11.2	26.2	12	56.9	13.5	23.4	2	68.8	15.3	28.6	2	71.3	17.1
	17	34.78	12	60.4	13.8	26.0	17	59.0	13.6	27.1	--------	68.5	15.3	28.4	--------	74.2	16.6
TM-1	8	26.05	71	41.0	11.2	23.1	31	51.3	13.4	25.4	--------	62.9	14.7	26.3	5	66.4	15.2
	11	27.57	74	42.0	11.0	23.6	35	50.2	13.5	25.2	15	59.3	14.9	26.7	6	65.3	15.6
	18	33.42	15	59.4	13.6	24.3	15	60.0	14.3	26.5	5	70.6	16.5	26.4	2	74.9	17.6
	35	25.31	97	39.6	7.8	25.1	9	57.5	11.9	25.3	--------	61.6	12.7	25.6	4	64.5	15.2
TM-2	5	25.73	46	46.1	11.4	22.4	16	54.5	14.6	23.3	--------	61.1	15.1	24.0	3	65.4	16.4
	19	31.89	12	60.0	13.7	23.1	14	59.7	13.9	23.7	8	65.7	15.8	24.3	4	68.4	16.4
	26	23.40	62	43.2	13.0	23.0	7	60.0	19.2	24.9	--------	67.7	21.6	25.4	2	71.8	22.6
TR-1	9	27.75	12	60.0	14.3	21.5	25	55.5	16.3	22.4	--------	62.9	16.6	23.3	6	68.0	14.4
TR-2	6	25.90	20	53.1	20.3	22.0	12	57.8	22.5	22.3	7	63.1	23.6	23.5	3	67.5	24.7
	10	25.52	18	55.8	11.4	19.8	27	54.0	12.8	20.0	10	59.5	12.8	21.3	6	67.0	14.0
	27	25.45	15	55.4	17.5	21.2	10	58.3	18.9	22.6	--------	65.1	20.9	22.7	2	66.4	21.2
TH-1	2	19.80	26	51.7	18.7	14.2	15	56.0	21.1	15.4	4	64.1	21.4	16.2	2	67.4	22.7
	12	15.54	89	41.6	11.7	12.3	49	47.6	13.9	14.6	18	57.6	15.9	14.7	15	59.0	15.7
	32	11.12	218	33.1	8.6	15.0	17	53.0	15.3	19.9	--------	65.7	17.4	19.7	2	68.7	20.1
	28	14.37	43	47.0	13.7	12.6	13	57.0	16.9	15.0	--------	64.7	19.3	14.5	2	65.2	19.7
TP-1	13	11.79	38	49.0	11.9	7.1	41	49.3	13.7	9.4	11	61.4	--------	9.9	8	63.4	15.2
TP-2	29	11.72	30	49.6	15.2	10.4	5	59.9	18.0	10.6	--------	63.1	18.7	11.7	3	66.6	20.4
TP-4	4	13.20	12	56.1	21.1	7.4	13	56.4	21.4	7.6	8	60.7	21.0	8.7	2	64.0	22.9
TP-6	30	8.72	25	51.8	15.1	6.8	12	56.5	17.3	7.1	--------	59.5	17.9	8.2	4	64.0	19.9
	34	5.90	71	44.1	9.2	8.7	5	58.5	14.0	9.6	--------	62.9	15.4	10.5	2	66.0	16.6
Special	22	19.62	15	58.5	30.1	14.2	40	50.0	29.0	15.3	--------	57.6	30.3	16.0	5	63.0	31.9
	23	47.85	84	39.1	1.3	46.6	6	65.5	19.6	48.4	--------	77.6	18.2	46.3	1	80.5	20.0
	31	18.90	1	73.3	20.1	6.7	42	51.7	16.7	6.0	--------	59.4	17.7	8.1	3	68.5	19.5

exposure residues the difference ranged from 52 to 196 and for the 15-week exposure residues the difference ranged from 69 to 218.

It was shown by Reeve and Anderton[10] that water-gas tars low in free carbon increased in free-carbon content to a much greater extent than coal tars high in free carbon when exposed under conditions comparable to those of this investigation. Because of the large number of blended tars and the wide range in consistency of the materials covered in this study, the relations between free carbon in the original materials and the free-carbon content of the residues after exposure only indicate a general trend that the lower the free-carbon content of the original material the higher the index of free carbon in the exposed residue. This trend is shown by table 15, which is based on the test data given in tables 5 and 14.

S. Sabrou,[13] in reporting on a study of the aging of road tars, drew the following conclusions, based on laboratory studies. When a tar is spread on a road and subjected to the climatic conditions prevailing in France, it undergoes an aging which is not attributed to polymerization due either to heat or the ultra violet light of the sun, but which is attributed to slow and slight oxidation and above all to the evaporation of the lighter constituents. He intimated that the effect of evaporation is at least 100 times that of oxidation.

Some of the inherent changes developed on exposure can probably be traced to the high loss of volatile matter which occurred early in the exposure period, thereby causing a considerable reduction in film thickness. This reduction in film thickness undoubtedly caused the material to weather more rapidly. An example of this is shown by the test results on the four samples submitted by producer E. These data are shown in table 16.

Since these materials are probably from the same base, they may be assumed to be comparable. The figures show that as the loss of volatile material increases with attendant decrease in film thickness, the index of increase in free carbon also increases. Thus it is indicated that the more viscous tars, which lose less volatile material and produce greater film thicknesses, should weather less rapidly than the lighter tars.

Table 15.—*Comparison of free carbon content of original material and index of increase in free carbon for exposure residues*

Number of samples	Free carbon in original materials			Index of increase in free carbon for residues after 15 weeks' exposure		
	Maximum	Minimum	Average	Maximum	Minimum	Average
	Percent	*Percent*	*Percent*			
5	5.42	3.76	4.72	339	214	285
12	7.91	6.06	6.92	237	155	184
12	11.67	8.15	9.68	201	94	141
6	21.09	12.23	15.57	150	117	132

Table 16.—*Results of tests on the 15-week exposure residues of samples obtained from producer E*

Sample no.	Loss	Softening point	Index of increase in free carbon
	Percent	° *C.*	
33	30.5	71.5	339
35	25.6	64.5	240
32	19.7	68.7	237
34	10.5	66.0	189

Table 17.—*Comparison of averaged*[1] *test results on distillation and exposure residues*

Test	Average total loss	Average penetration of residue	Average softening point of residue	Average index of increase in free carbon
	Percent		° *C.*	
Distillation	25.3	46.7	49.0	114
5-week exposure	22.3	15.5	57.5	150
10-week exposure	23.2		64.9	164
15-week exposure	24.0	3.3	69.1	176

[1] Data for samples 22, 23, and 31 excluded.

A general comparison of the effects of exposure as compared to the effects produced by the distillation test may be clearly seen in table 17. This table shows that the 5-week exposure residues are considerably harder than their corresponding distillation residues.

The continued increase in hardness and the increase in free-carbon content of the residues exposed for longer periods without much additional loss of volatile matter indicate that the changes in the character of the residues after exposure are due to other causes than mere loss of volatile matter. There is evidence that both oxidation and carbonization are responsible for the changes that take place when bituminous materials are exposed to air and sunlight. The great increase in the free-carbon content of the tars subjected to exposure, as well as the greater hardness of the exposed residues, indicates quite clearly that mere evaporation is not responsible for the highly altered residues obtained.

HUBBARD-FIELD STABILITY TEST USED TO DETERMINE BONDING STRENGTH BEFORE AND AFTER EXPOSURE

This and previous investigations have shown that on exposure tars develop free carbon in excess of that caused solely by concentration. No efforts have been made to determine the character of this free carbon. G. T. Gilbert and J. G. Mitchell[14] have stated that quantitative determinations show that tars oxidize in the dark and that this oxidation is accelerated by light with the formation of material insoluble in benzene (free carbon). These writers have advanced a new conception of tars based on the solubility of tar in various solvents. They indicate that free carbon is of four types: C_1, insoluble in all solvents; C_2, insoluble in benzol (C_6H_6) but soluble in pyridine; C_3, insoluble in ethyl ether but soluble in benzene; and C_4, insoluble in light naphtha (40°–60° C. boiling point) but soluble in ether. They intimated that the formation of this benzene-insoluble free carbon can be detected by determining the C_1 and C_2 content of the original and exposed tars. The ratio $\frac{C_1+C_2}{C_1}$ then gives a measure of increase distinct from that caused by simple concentration resulting from evaporation. The character of the free carbon formed in exposed tars, based on the solubility of the original material and the residue from exposure in benzene or carbon disulphide and pyridine, may prove of value in detecting the internal alterations that accompany the weathering of tars.

Road tars when used in the road surface develop adhesiveness or binding strength in various ways de-

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[10] The Effects of Exposure on Tar Products, by C. S. Reeve and B. A. Anderton Journal of Franklin Institute, vol. 182, no. 10, October 1916.

[13] Congres de l'Industrie de Gaz, Paris 5–10, Juin 1934.

[14] The Constituents of Tar, Highways and Bridges, vol. II, no. 53, June 19, 1935.

pending upon the grade of tar and the type of construction in which it is used. The tars that are used in penetrative treatments such as primers, those used as binders for cover stone in surface treatments and seal coats, and those used as binders for coarse open-graded mixtures, either plant or road mixed, and in some cases for closely graded mixtures, all develop their initial binding strength through the loss of their more volatile constituents, or through stiffening of the material on cooling, or a combination of both.

Cold-application tars have little bonding strength when first applied to the road, but by rapid loss of volatile matter soon provide a very stable surface. Hot-application tars of both the surface treatment and construction grades possess sufficient bonding strength when cooled in the road surface to withstand immediately the stress of traffic, although the initial bonding strength of the hot-surface-treatment tars may be further increased by the loss of volatile matter. The ultimate bonding strength of all road tars is undoubtedly increased by a continued loss of volatile matter and by inherent changes when exposed to service conditions.

In order to determine the initial bonding strength and its development, a series of tests were made using the Hubbard-Field stability apparatus. This equipment has been extensively used to study the effects of various physical properties of asphaltic materials on the stability or resistance to displacement of fine-graded asphaltic mixtures.[15]

Determinations of the bonding strength or adhesiveness of the 35 tars were made by preparing Hubbard-Field stability cylinders containing 16.6 percent by volume of original materials and their residues from distillation and 83.4 percent of a standard sand. These molded specimens are designated as series 1 cylinders.

The development of bonding strength was determined by preparing cylinders using the same percentage of original materials and sand as stated above and exposing the compressed specimens to the same conditions as the thin films. For comparative purposes cylinders were prepared using the amount of each distillation residue that would have been present had the percentage of tar in the cylinders containing the original material been subjected to the distillation test. These specimens, together with the exposed cylinders are designated as series 2 cylinders.

The aggregate used in making these tar mixes was the same Potomac River sand used in the previous work on liquid asphaltic mixes.[12] The sand was washed, separated into various sizes, and recombined to give the following grading:

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

The tar products and sand were thoroughly mixed by hand. Three cylinders were prepared for each test condition. All cylinders were compacted under a load of 3,000 pounds per square inch. Since the 35 tars varied greatly in consistency, the test procedure for making and testing the Hubbard-Field specimens varied as follows:

1. The original materials intended for cold application were mixed and compressed at room temperature.
2. The original materials intended for hot application were mixed and compressed at 40° C.
3. All distillation residues were mixed and compressed at 80° C.
4. In forming cylinders containing the original materials, the pressure was released as soon as the required total load was reached. For the cylinders containing the distillation residues the total load was held for 2 minutes, and the mold was flooded with cold water to chill the specimens.
5. The bonding strength or stability of the cylinders containing the original materials was determined at 25° C. only. The cylinders from the 5-week period of exposure were tested for stability at 25° C. and, if the total load was over 10,000 pounds on the first specimen, the other two specimens were tested at 60° C. The cylinders containing the distillation residues were tested at 60° C. except in a few cases where one of the three cylinders was tested at 25° C. The stabilities of the cylinders exposed for 10 and 15 weeks were all determined at 60° C.

EXPOSED CYLINDERS HAD MUCH HIGHER STABILITIES THAN CYLINDERS MADE WITH DISTILLATION RESIDUES

The results of the stability tests on cylinders of series 1 are given in table 18, and those on series 2 are given in table 19. These data have been plotted in figures 13, 14, and 15.

In figure 13 the stability of the cylinders made with the cold-application tars has been plotted against

TABLE 18.—*Results of tests on series 1 cylinders*

Type of material	Identification	Original material			Distillation residue [1]			
					Stability			
		Stability at 25° C.	Specific viscosity at 40° C.	Float at 50° C.	Tested at 60° C.	Tested at 25° C.	Softening point	Penetration at 25° C.
		Pounds		*Seconds*	*Pounds*	*Pounds*	° C.	
TC-1	7	0	9. 2	--------	800	--------	54. 0	21
	14	0	10. 7	--------	1, 475	--------	61. 7	9
	20	0	9. 5	--------	850	--------	55. 4	12
	24	0	11. 8	--------	925	--------	54. 4	13
TC-2	1	15	15. 9	--------	513	8, 100	50. 1	30
	15	10	15. 5	--------	1, 513	--------	62. 7	8
	21	25	17. 3	--------	790	--------	57. 0	8
	33	60	16. 2	--------	398	--------	58. 1	36
TC-3	16	63	21. 2	--------	1, 617	--------	63. 1	7
	25	70	20. 7	--------	585	10, 000+	52. 2	19
TC-4	3	87	34. 9	--------	650	--------	54. 0	16
	17	90	32. 5	--------	1, 833	--------	64. 4	5
TM-1	8	100	40. 1	--------	525	6, 050	48. 4	39
	11	80	53. 5	--------	538	6, 900	49. 2	41
	18	90	48. 5	--------	1, 567	--------	64. 1	6
	35	117	57. 4	--------	375	9, 100	48. 2	36
TM-2	5	153	70. 4	--------	608	--------	52. 5	18
	19	133	70. 6	--------	2, 030	--------	65. 8	5
	26	173	83. 7	--------	488	9, 800	50. 7	25
TR-1	9	153	44. 5	--------	1, 892	--------	65. 0	7
TR-2	6	178	60. 7	--------	1, 150	--------	60. 4	5
	10	153	73. 1	--------	1, 260	--------	61. 0	9
	27	163	63. 1	--------	1, 010	--------	59. 5	6
TH-1	2	580	--------	58	1, 110	--------	58. 1	9
	12	380	--------	51	475	5, 800	44. 8	67
	32	310	--------	43	225	4, 200	39. 7	98
	28	783	--------	78	550	--------	52. 8	21
TP-1	13	1, 200	--------	107	800	--------	54. 0	22
TP-2	29	1, 958	--------	126	883	--------	56. 0	10
TP-4	4	2, 842	--------	167	1, 375	--------	60. 1	5
TP-6	30	3, 417	--------	194	800	--------	56. 8	12
	34	2, 258	--------	165	625	--------	54. 4	13
Special	22	310	--------	30	1, 700	--------	61. 6	6
	23	0	2. 0	--------	892	--------	52. 7	26
	31	1, 360	--------	51	4, 867	--------	75. 6	1

[1] Residue from A. S. T. M. D 402-34 T distillation test.

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[12] Further Studies of Liquid Asphaltic Materials, by R. H. Lewis and W. O'B. Hillman. PUBLIC ROADS, vol. 16, no. 6, August 1935.

[15] A Study of Certain Factors Affecting the Stability of Asphalt Mixtures, by Prevost Hubbard and F. C. Field. Proceedings A. S. T. M., vol. 26, pt. II, 1926.

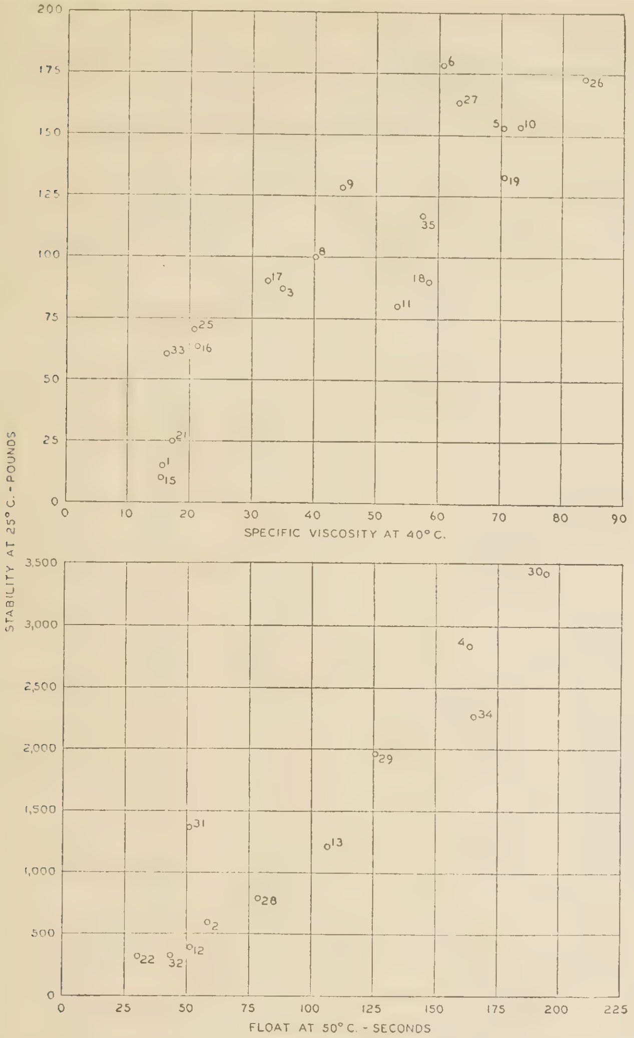

FIGURE 13.—RELATIONS BETWEEN THE CONSISTENCIES OF ORIGINAL MATERIALS AND THE STABILITY AT 25° C. OF SERIES 1 CYLINDERS.

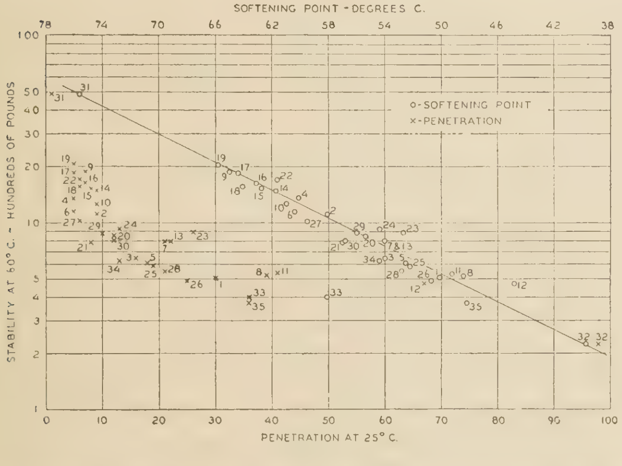

FIGURE 14.—RELATIONS BETWEEN CONSISTENCIES OF THE DISTILLATION RESIDUES AND STABILITY AT 60° C. OF SERIES 1 CYLINDERS.

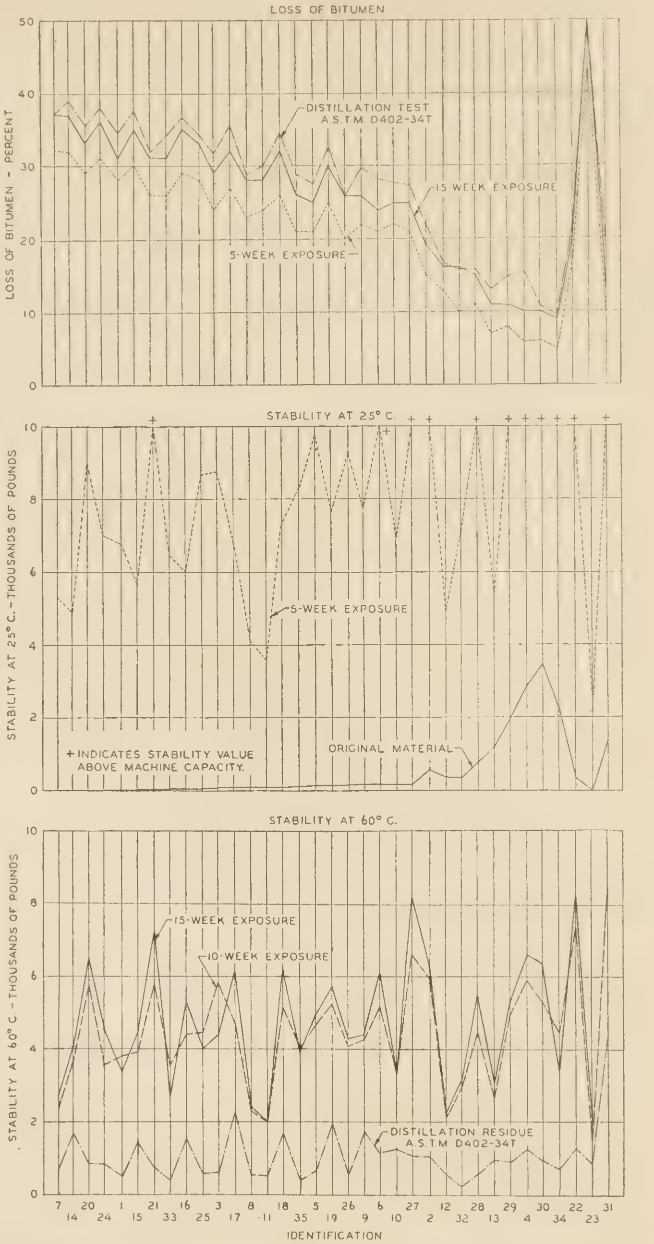

FIGURE 15.—COMPARISON OF LOSS OF BITUMEN AND STABILITY OF SERIES 2 HUBBARD-FIELD CYLINDERS.

the Engler specific viscosity at 40° C. of the contained tar, and for the cylinders made with the hot-application tars the stability is plotted against the float test in seconds at 50° C. The stability values obtained on the cylinders containing the cold-application materials are low since the viscosity range indicates relatively fluid products. The greater consistency of the hot-application materials results in higher stability values. Generally, with both types of material the higher the consistency of the tar used as binder the higher was the stability. A comparison of the two curves clearly illustrates the difference in binding ability of cold- and hot-application materials immediately after being applied. The cold-application materials must rapidly lose much of their volatile constituents to increase the stability of the road surface.

The stability of the cylinders containing the distillation residues was plotted against the softening point and penetration of the contained tar pitch, as shown in figure 14. The softening point value showed a more constant relation than did the penetration value, indicating that the softening point value of a tar pitch is the better measure of its relative bonding strength. The relation between stability and penetration did

TABLE 19.—*Results of tests on series 2 cylinders*

Type of material	Identification	Cylinders made with the original materials								Cylinders made with distillation residue [1]		
		Stability					Loss of bitumen in—			Stability		Theoretical loss of bitumen
		As made, tested at 25° C.	5 weeks		10 weeks, tested at 60° C.	15 weeks, tested at 60° C.	5 weeks	10 weeks	15 weeks	Tested at 60° C.	Tested at 25° C.	
			Tested at 60° C.	Tested at 25° C.								
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Percent*
TC-1	7	0		5, 300	2, 400	2, 725	32	36	37	700		37
	14	0		4, 950	3, 675	4, 075	32	35	37	1, 693		39
	20	0		8, 950	5, 725	6, 475	29	33	33	858		36
	24	0		7, 000	3, 575	4, 475	31	36	36	850		38
TC-2	1	15		6, 800	3, 800	3, 375	28	32	31	500	8, 500	35
	15	10		5, 600	3, 925	4, 475	30	33	35	1, 478		38
	21	25	3, 900	10, 000+	5, 775	7, 225	26	29	31	758		32
	33	60		6, 450	3, 575	2, 725	26	32	31	425		34
TC-3	16	63		6, 000	4, 400	5, 325	29	34	35	1, 475		37
	25	70		8, 650	4, 425	4, 000	28	33	33	600	8, 800	34
TC-4	3	87		8, 750	5, 825	4, 400	24	28	29	633		32
	17	90		6, 850	4, 675	6, 125	27	30	32	2, 225		35
TM-1	8	100		4, 100	2, 300	2, 375	23	27	28	563	5, 550	29
	11	80		3, 600	2, 000	1, 975	24	28	28	525	5, 900	30
	18	90		7, 350	5, 150	6, 225	26	30	32	1, 683		35
	35	117		8, 300	3, 950	3, 800	21	26	26	400	7, 100	29
TM-2	5	153	2, 500	9, 750	4, 600	4, 975	21	26	25	667		28
	19	133		7, 650	5, 250	5, 725	25	30	30	1, 917		32
	26	173		9, 200	4, 075	4, 275	20	26	26	563	8, 900	26
TR-1	9	153		7, 750	4, 250	4, 375	22	26	26	1, 725		30
TR-2	6	178	4, 450	10, 000+	5, 200	6, 075	21	25	24	1, 138		28
	10	153		6, 950	3, 325	3, 350	22	25	25	1, 250		28
	27	163	4, 375	10, 000+	6, 575	8, 150	21	25	25	1, 098		27
TH-1	2	580	4, 200	10, 000+	5, 975	6, 175	15	19	19	1, 033		22
	12	380		4, 950	2, 100	2, 250	13	16	16	538	5, 800	17
	32	310		7, 050+	2, 900	3, 125	10	17	16	225	3, 650	16
	28	783	2, 600	10, 000+	4, 475	5, 425	11	15	15	600		16
TP-1	13	1, 200		5, 450	2, 625	3, 050	7	9	11	983		13
TP-2	29	1, 958	3, 750	10, 000+	4, 925	5, 325	8	11	11	917		15
TP-4	4	2, 842	4, 325	10, 000+	5, 900	6, 600	6	10	10	1, 267		16
TP-6	30	3, 417	3, 900	10, 000+	5, 225	6, 350	6	9	10	925		11
	34	2, 258	2, 200	10, 000+	4, 425	3, 375	5	10	9	708		9
Special	22	310	4, 975	10, 000+	7, 300	8, 175	17	20	20	1, 288		22
	23	0		2, 500	1, 525	2, 000	43	47	50	883		49
	31	1, 360	7, 200	10, 000+	8, 300		10	14	13	4, 317		20

[1] Residue from A. S. T. M. D 402-34 T distillation test.

show, however, that for equal penetrations the water-gas tar residues generally gave higher stabilities than the residues from coal tars or coal-tar blends.

The Hubbard-Field stability values for the series 2 cylinders are shown in figure 15, along with the percentages of volatile matter lost under test conditions. Although in the cylinders made with the original materials the loss of volatile matter after exposure was very close to the loss in the distillation test, the stabilities of the cylinders exposed for 15 weeks were much greater than the stabilities of the cylinders prepared with the distillation residues. This shows that changes other than loss of volatile matter have produced a condition in the mixture that results in a greater bonding strength, just as greater hardening and internal alterations in the exposed films tended to produce residues dissimilar to those developed in the laboratory distillation tests.

The loss of volatile matter for the cylinders exposed for 10 weeks is not shown in figure 15 since it closely approximated the loss at 15 weeks. But figure 15 shows that in the cylinders of many materials there were increases in stability from 10 to 15 weeks that may be attributed to additional hardening or change in the contained tar residue without corresponding loss of volatile matter.

W. E. Cone has stated [16] that: "The ease and facility with which tar wets a particular surface and retains the full value of its adhesive properties while being gradually changed to a solid is one of its most striking characteristics."

While testing exposed cylinders that initially contained liquid asphaltic material even of the rapid-curing type, it was observed that while a hardened crust formed, which in some cases was very thick, the mixture in the center of the test specimens was plastic after 15 weeks of exposure. The exposed cylinders containing these tar products, in many cases after 5 weeks of exposure and in all cases after 15 weeks, appeared to be uniformly hard and solid throughout the entire mass, indicating that ultimate hardening of the contained tar is not materially retarded by the formation of a surface crust.

Some idea of the rapid development of binding strength in the exposed tar cylinders may be obtained by comparing the stabilities obtained for the tar mixtures with the stabilities obtained on similar cylinders made with slow- and rapid-curing liquid asphaltic materials and exposed at the same time. Cylinders made with 23 slow-curing liquid asphaltic materials that had initial stabilities of from 25 to 175 pounds, had developed stabilities at the end of 15 weeks of from 300 to 3,075 pounds. Cylinders made with six medium- and rapid-curing liquid asphaltic materials had initial stabilities of from 25 to 275 pounds and developed stabilities ranging from 1,650 to 5,200 pounds at the end of 15 weeks.

At the end of 5 weeks the cylinders containing the TC, TM, and TR tars had developed stabilities ranging from 3,600 pounds to more than 10,000 pounds at the test temperature of 25° C., which was also the control temperature of the tests on the cylinders containing the asphaltic materials. For these cold-application materials, only cylinders containing tars 8, 11, and 14

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[16] The Qualities of Tars for Use in Roads and Streets. Canadian Engineer, vol. 67, no. 4, July 24, 1934.

had lower stabilities after 5 weeks of exposure than the maximum value obtained on the asphaltic materials for 15 weeks of exposure. At the end of 15 weeks, the cylinders containing the cold grades of tar had developed stabilities ranging from a minimum of 1,975 to a maximum of 8,150 pounds at 60° C., the minimum stability being many times greater than the maximum developed with the asphaltic materials. These data seem to substantiate the fact that tar products in service harden more rapidly and ultimately produce harder and less plastic road mixtures than do asphaltic materials.

CONCLUSIONS

The data obtained on these tar products when submitted to laboratory tests and when subjected to exposure conditions justify the following conclusions.

1. The road tars submitted by the five producers were, with few exceptions, well within the limits of the various grades of materials meeting the Federal specifications.
2. The Saybolt-Furol viscosimeter is well adapted to the determination of the consistency of fluid tars.
3. The vapor end point of 300° C. (572° F.) as required by distillation method A. S. T. M. D 20–30 is approximately equivalent to a liquid end point of 360° C. (680° F.) as required by distillation method A. S. T. M. D 402–34 T. However, the control of intermediate cutting points by the temperature of the liquid residue may result in fractions with widely different boiling points so that the character of the distillates from various materials cannot be accurately determined.
4. The greatest difference in results obtained by the two distillation methods is caused by the different methods of pouring the residues. A. S. T. M. method D 402–34 T results in residues that have undergone a greater loss of volatile matter and are correspondingly harder as measured by the softening point and penetration tests.
5. The residues from distillation generally have good ductility at 25° C., but this ductility is rapidly lost when the temperature of test is reduced.
6. When thin films of these tars were subjected to the exposure conditions of this investigation it was indicated that:

   (*a*) The ultimate loss on exposure approximates the total loss of volatile matter in the A. S. T. M. D 20–30 distillation test.

   (*b*) The greater hardness of the residues from exposure as compared with the hardness of the distillation residues results from causes other than the mere loss of volatile matter.

   (*c*) The increased hardness of the exposure residues was accompanied by an increase in free carbon content much greater than the amount that was caused by concentration, this being attributed to oxidation, carbonization, or both.

   (*d*) The test data indicate that in general the index of increase of free carbon in the residues from exposure is higher for those tars having initially low free carbon contents.
7. While the initial stability or binding value of the sand mixtures containing the more fluid tars is relatively low, it is roughly proportional to the consistency of the tar used.
8. The bonding strengths of the distillation residues are more nearly proportional to their softening point values than to their penetrations.
9. The development of stability or bonding strength in the tar and sand mixtures proceeded rapidly under the exposure conditions of this investigation, producing stability values much higher than could be obtained by mere loss of volatile matter and developing specimens which, when broken, gave no evidence of retaining plastic properties.
10. The amount of volatile matter and the consistency of the residues from the laboratory distillation test, together with the behavior of these materials in thin films and in molded specimens, indicate that road tars are rapid-hardening types of bituminous materials.

PRESERVE BENCH MARKS FOR FUTURE USE

By HOWARD S. RAPPLEYE, Chief, Section of Leveling, United States Coast and Geodetic Survey

IN THE extension of its system of control surveys over the United States, the Coast and Geodetic Survey has run many hundreds of lines of levels, of first- or second-order accuracy, which now form a great net over the entire country with the lines spaced, except in some of the more inaccessible regions in the West, at intervals of about 25 miles. Bench marks are spaced along these lines at intervals of from 1 mile or less to a maximum distance of 3 to 5 miles.

These bench marks and their published descriptions and elevations represent a vast outlay for field work, computation, and adjustment. In order that the results of this work may be useful to all engineers throughout the Nation the marks must remain in place undisturbed or be relocated in such a manner as to preserve their usefulness.

In spite of the extreme care exercised by the field parties, in placing bench marks where they are likely to remain undisturbed for a long time, it sometimes becomes necessary to destroy them to make way for construction, repair, or maintenance work of various kinds. A bench mark once disturbed, without transfering its elevations to some other mark which is set to preserve it, is a total loss and leaves a gap in the line of levels which requires extra running for all engineers who may be called on to do leveling in the locality at any future time.

It is to the interests of all concerned to relocate bench marks which are in the way of construction rather than to allow them to be completely destroyed. The Coast and Geodetic Survey does not have funds available for placing parties in the field to go about and relocate bench marks which must be moved to avoid their destruction. On the other hand, since the marks are chiefly useful to practicing engineers, whether public or private, we look to all engineers throughout the country for cooperation in preserving these useful marks in their own interests as well as in the interests of their government.

A routine method of handling cases of this sort has been worked out and if followed out, as outlined below, the loss of bench marks and its accompanying inconvenience and loss to the engineers and surveyors of this country will, to a large extent, be avoided.

As soon as it becomes known that a mark must be moved, a letter should be sent to the Director, United States Coast and Geodetic Survey, Washington, D. C., attention Section of Leveling, stating the necessity for moving the mark and giving its designation. The designation consists of the letters and numbers found to have been stamped with dies on the disk. It is desirable to furnish a rubbing of the disk as well. A rubbing can be made by placing a piece of medium-weight paper over the disk and then rubbing over the paper with a hard pencil to bring out the legend cast in the disk, especially the letters and numbers stamped on it with dies.

Upon receipt of this information, this office will send out a new disk properly stamped to show that it has been reset. Necessary instructions for the establishment of the new mark and the transfer of elevation will also be sent. The proper procedure, in most cases, is to establish the new mark in a safe place nearby and transfer the elevation from the old mark to the new one by means of an engineer's level and rod. The levels should be run in duplicate to avoid the possibility of large errors, and all readings should be made to three decimal places in order to preserve the accuracy of the original elevation.

The old mark should not be disturbed until the observations involved in the transfer have been checked by the observer or the recorder. An assumed elevation for the old mark may be used in the transfer, since what we are primarily concerned with in a case of this sort is the difference in elevation between the old mark and the new one established to replace it.

After the new mark has been established and the elevation transferred to it, the old disk should be broken out and returned to this office in a franked mailing sack which will be supplied for the purpose. A complete report on the action taken, including a description of the location in which the new mark is established and a copy of the field notes involved in the transfer of elevation, should also be forwarded to this office; a franked envelope will be furnished for this purpose.

The cooperation which individuals and organizations may extend to this office in preserving the benchmarks will be a service not only to this bureau and other government surveying organizations but to anyone who may have occasion to use the marks.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS
1936 AND 1937 FUNDS

AS OF JUNE 30, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 5,208,287				$ 78,130	$ 39,065					$ 5,169,222
Arizona	3,564,709	$ 1,051,145	$ 784,504	70.0	982,902	832,267	31.5	$ 4,812	$ 3,327		1,944,610
Arkansas	4,275,929										4,275,929
California	9,508,671	565,511	326,945	9.5	6,435,811	3,689,093	146.7	1,480,136	814,330	33.3	4,678,303
Colorado	4,575,144	1,567,253	877,141	69.4	1,554,737	866,533	43.1	302,945	169,908	7.0	2,661,562
Connecticut	1,582,913				857,841	426,718	9.2	230,938	115,469	5.7	1,040,726
Delaware	1,218,750				439,749	219,874	34.4	59,102	29,551	.1	969,325
Florida	3,315,558	518,283	259,142	17.9	574,442	287,221	18.4				2,769,195
Georgia	6,336,443	157,625	78,812	10.7	1,298,920	618,936	91.1	1,457,654	728,827	73.9	4,909,868
Idaho	3,065,304	470,022	270,544	75.3	1,481,250	884,287	103.0	413,569	240,480	24.9	1,669,994
Illinois	10,325,922	695,063	347,531	17.3	6,746,796	3,371,042	104.3	2,501,483	1,213,741	41.5	5,393,607
Indiana	6,184,258	1,618,666	808,060	54.2	4,098,795	2,049,365	143.4	355,931	177,892	7.9	3,148,940
Iowa	6,466,628	389,534	187,819	112.8	5,984,426	2,816,470	260.2	466,381	220,010	80.2	3,242,329
Kansas	6,631,085	368,261	184,096	207.7	3,390,933	1,695,466	268.4	3,578,707	1,532,499	434.8	3,219,024
Kentucky	4,611,955	1,104,625	549,480	74.1	1,105,767	537,889	68.9	1,396,340	663,889	36.2	2,860,697
Louisiana	3,557,930	616,385	308,193	23.4	1,553,970	776,985	52.7	1,018,497	509,249	31.6	1,963,504
Maine	2,177,197	381,923	190,654	10.7	1,519,948	759,974	47.0				1,226,569
Maryland	2,050,870							181,230	90,615	3.3	1,960,255
Massachusetts	3,485,364				333,935	166,968	3.1	273,447	136,723	1.9	3,181,673
Michigan	7,668,768	1,458,485	727,746	52.0	5,202,068	2,598,309	198.6	6,853,189	3,426,595	207.0	916,119
Minnesota	6,849,307	1,122,548	515,029	115.2	5,526,783	2,529,117	340.6	467,650	231,875	17.4	3,573,286
Mississippi	4,387,636										4,387,636
Missouri	7,601,200	1,374,961	686,250	242.1	3,757,847	1,878,923	146.0	2,286,155	1,142,972	72.3	3,893,055
Montana	5,122,333	957,816	536,149	169.3	2,955,676	1,654,883	205.1	693,945	354,318	54.7	2,576,984
Nebraska	5,167,930	1,090,522	545,181	71.7	1,218,229	628,477	140.9	871,472	435,736	116.8	3,558,536
Nevada	3,189,479	681,448	588,620	113.5	866,531	750,155	86.7	264,361	228,857	69.0	1,621,847
New Hampshire	1,218,750	157,857	77,485	3.8	590,517	290,355	18.4	141,629	70,736	1.9	780,174
New Jersey	3,352,469	87,925	43,962	1.0	2,030,222	1,015,111	28.9	1,321,388	574,164	10.4	1,719,232
New Mexico	3,990,023	701,386	426,511	74.1	2,233,377	1,380,410	121.3	247,411	150,475	7.5	2,032,626
New York	12,306,710	55,200	27,600	.1	11,442,550	5,663,272	198.2	835,519	409,520	14.7	6,206,317
North Carolina	5,879,466	537,045	268,430	84.5	2,294,213	1,144,733	293.1	1,428,620	699,196	131.7	3,767,106
North Dakota	3,918,269				186,166	101,206	.1				3,817,063
Ohio	9,131,204				5,587,349	2,680,876	72.9	1,912,415	828,319	20.7	5,622,009
Oklahoma	5,884,927	848,455	445,863	31.5	1,480,709	775,858	41.1	1,261,362	661,092	47.7	4,002,115
Oregon	4,089,711	520,308	315,246	20.2	2,814,750	1,635,489	85.7	122,949	66,767	4.4	2,072,209
Pennsylvania	10,695,448	231,817	115,640	4.2	7,055,945	3,527,973	102.6	1,849,557	921,988	29.7	6,129,848
Rhode Island	1,218,750										1,218,750
South Carolina	3,381,337				50,787	25,393		247,279	111,275	26.1	3,244,668
South Dakota	4,078,647				1,173,391	672,472	136.2	267,769	146,818	44.4	3,259,357
Tennessee	5,268,270	555,020	276,938	24.5	1,141,552	570,776	41.6	476,618	238,309	20.8	4,182,247
Texas	15,548,821	4,977,366	2,484,703	266.2	7,432,956	3,710,933	417.9	2,242,186	1,101,887	95.3	8,251,298
Utah	2,826,960	396,384	278,469	23.3	1,402,465	1,009,301	96.1	90,496	61,317	8.7	1,477,873
Vermont	1,218,750	107,721	53,194	8.3	1,089,340	544,670	51.0	12,262	6,094		614,792
Virginia	4,559,200	116,618	58,309	4.2	2,153,428	1,074,360	85.6	628,175	314,087	19.8	3,112,444
Washington	3,904,738	861,209	452,792	25.0	2,320,438	1,220,949	88.9	6,280	3,300		2,227,697
West Virginia	2,716,754	87,161	43,581	3.0	863,374	431,675	41.6	632,462	315,731	11.5	1,925,768
Wisconsin	6,090,504	616,271	308,135	20.6	3,147,514	1,552,485	110.8	2,888,784	1,345,219	124.5	2,884,665
Wyoming	3,121,972	1,590,876	979,363	178.0	935,091	555,380	96.6				1,587,229
District of Columbia											
Hawaii	1,218,750				298,606	146,767	4.3	168,350	83,746	3.9	988,237
TOTALS	243,750,000	28,638,695	15,428,117	2,289.3	115,690,226	59,808,461	4,676.2	41,939,465	20,576,903	1,943.2	147,936,519

U S GOVERNMENT PRINTING OFFICE 38004

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JUNE 30, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$4,151,115				$3,386,254	$3,386,254	105.2	$374,953	$374,953	13.0	$389,909
Arizona	2,569,841	$970,451	$927,032	64.5	1,956,748	1,397,356	125.2	232,846	127,105	11.0	118,348
Arkansas	3,352,061	657,603	656,894	41.8	1,934,222	1,916,902	211.4	723,246	721,083	102.8	57,183
California	7,747,928	653,155	610,958	60.6	5,413,193	5,258,862	160.2	1,732,902	1,704,711	33.2	173,397
Colorado	3,395,263	675,363	674,972	54.9	1,152,787	1,152,787	31.6	195,775	195,775	10.6	1,371,730
Connecticut	1,418,709	4,268	3,995		285,188	263,674		198,505	185,394	2.2	965,646
Delaware	900,310				460,139	460,139	45.3	79,046	79,046	13.6	361,125
Florida	2,597,144	63,820	63,820	5.5	2,029,423	2,011,551	72.5	241,062	241,062	5.9	280,711
Georgia	4,988,967	49,637	49,637	.7	561,240	561,240	42.7	305,997	305,997	14.3	4,072,093
Idaho	2,222,747	84,630	83,910	8.4	1,896,034	1,789,472	153.9	162,375	120,000	11.4	229,365
Illinois	8,694,009	610,970	610,970	44.9	6,758,462	6,758,462	355.0	1,321,010	1,321,010	72.3	3,567
Indiana	4,941,255	133,889	133,889	2.9	4,473,052	4,473,052	214.3	513,234	312,121	16.0	22,193
Iowa	4,991,664	172,442	162,450	64.3	3,031,242	2,888,616	263.9	1,149,415	1,108,475	87.7	832,123
Kansas	4,994,975	284,119	284,119	60.9	4,268,678	4,268,678	293.1	441,745	431,935	20.6	10,244
Kentucky	3,726,271	237,380	237,380	48.9	1,949,714	1,949,714	226.8	720,967	720,967	51.4	818,210
Louisiana	2,890,429				1,029,228	872,117	61.1	2,010,202	1,780,510	113.4	237,802
Maine	1,676,799	119,750	119,750	6.5	1,091,691	1,091,143	46.5	395,784	395,784	17.3	70,122
Maryland	1,750,738				306,885	306,885	11.3	1,061,650	908,825	26.7	535,028
Massachusetts	3,262,885				117,754	117,754	1.1	1,018,779	1,018,779	4.0	2,126,352
Michigan	6,301,414	477,500	477,500	25.6	5,621,171	5,561,141	252.6	128,800	128,800	9.3	133,973
Minnesota	5,277,145	664,022	576,080	154.3	3,801,549	3,410,255	488.0	1,169,181	762,895	222.5	527,915
Mississippi	3,457,552	108,921	108,921	5.3	2,846,675	2,843,252	190.6	161,912	161,912	11.8	343,466
Missouri	6,012,652	1,063,760	1,063,459	348.7	3,343,165	3,343,165	377.8	1,486,260	1,483,253	63.7	122,776
Montana	3,676,416	563,103	563,103	34.3	3,012,254	3,012,254	150.2	46,981	46,981	1.0	54,078
Nebraska	3,870,739	49,519	44,866	4.7	2,582,237	2,545,966	277.8	735,859	735,859	80.4	544,048
Nevada	2,243,074	962,035	945,035	32.6	839,408	816,839	55.9	168,524	168,524	9.4	312,676
New Hampshire	945,225	16,529	15,547	1.3	382,700	369,687	13.4	127,156	119,934	10.2	440,057
New Jersey	3,129,805				2,103,777	2,103,777	13.7	99,211	99,211	5.3	926,817
New Mexico	2,871,397	724,350	724,350	74.4	1,339,706	1,339,706	74.2	230,294	230,294	23.1	577,047
New York	11,046,377	403,833	403,833	4.1	9,776,465	9,364,664	144.4	358,160	358,160	11.9	919,719
North Carolina	4,720,173	209,500	209,500	21.6	3,103,021	3,070,432	208.1	476,192	460,019	23.2	980,222
North Dakota	2,867,245	246,308	246,308	32.0	782,701	780,331	97.4	1,400,192	1,400,192	155.3	440,414
Ohio	7,670,815	181,530	181,530	2.4	3,812,283	3,804,554	41.6	1,517,555	1,434,151	152.3	2,250,579
Oklahoma	4,580,670	149,074	149,074	16.3	2,165,898	2,163,484	176.9	1,355,611	1,355,382	175.6	912,729
Oregon	3,038,642	17,113	17,113		2,612,478	2,522,111	113.7	680,338	399,337	53.1	100,080
Pennsylvania	9,347,797	146,301	120,538	3.7	1,798,204	1,762,308	65.5	879,872	875,834	57.4	6,589,117
Rhode Island	989,208	15,934	15,934		962,220	962,220	18.9	9,192	9,192	.2	1,863
South Carolina	2,702,012	70,779	69,576	8.6	1,614,564	1,578,063	147.9	528,395	527,657	57.3	526,716
South Dakota	2,976,454	381,805	381,805	131.9	1,497,787	1,497,757	231.4	476,432	476,432	59.5	620,459
Tennessee	4,192,460	230,293	230,293	3.4	2,104,321	2,104,321	91.4	781,033	781,033	31.3	1,076,813
Texas	11,989,350	1,770,922	1,599,770	204.7	10,057,284	9,197,487	839.0	1,105,507	1,027,619	63.0	164,474
Utah	2,067,154	430,274	430,108	22.4	983,668	936,732	95.9	382,812	287,175	36.9	413,139
Vermont	924,306	145,039	136,731	3.6	747,102	640,126	15.9	126,396	112,062	2.3	35,387
Virginia	3,652,667	572,532	558,617	272.9	1,959,359	1,929,586	650.1	765,329	749,682	93.0	414,782
Washington	3,026,161	454,903	442,622	33.4	2,287,994	2,031,275	108.0	447,281	387,871	14.1	164,393
West Virginia	2,231,412				1,278,020	1,274,524	49.0	513,683	513,641	25.8	443,247
Wisconsin	4,823,884	278,186	257,269	16.1	4,173,577	3,775,249	272.8	846,859	665,678	41.3	125,688
Wyoming	2,219,155	56,249	56,247	20.0	1,856,072	1,856,054	107.7	69,397	69,396	1.5	237,458
District of Columbia	949,496	600,609	600,609	5.1	377,395	318,389	3.4				30,498
Hawaii	926,033				643,277	622,181	8.9				303,852
TOTALS	195,000,000	15,708,400	15,246,114	1,948.2	122,568,266	118,462,548	7,803.2	29,953,907	27,881,708	2,119.1	33,409,630

U S GOVERNMENT PRINTING OFFICE 33873

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JUNE 30, 1936

STATE	APPORTIONMENT	COMPLETED					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER			Estimated Total Cost	Works Program Funds	NUMBER			Estimated Total Cost	Works Program Funds	NUMBER			
				Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 9,124	$ 9,124	1			$ 3,175,940	$ 3,175,940	32			$ 649,186	$ 649,186	7		5	$ 200,367
Arizona	1,256,099	47,412	47,412	1			994,878	925,734	10								282,953
Arkansas	3,574,060	344,478	344,210	8			1,221,787	1,217,822	23	4		1,849,214	1,846,228	22	1	3	165,801
California	7,486,362	179,113	173,867	3	2		6,427,095	6,188,037	33	5		806,253	803,410	16			321,048
Colorado	2,631,567	168,864	168,864	2			1,218,052	1,197,052	20			128,712	128,712	1			1,136,939
Connecticut	1,712,684											158,451	158,451	1	1		1,554,233
Delaware	418,239											143,486	120,000	1			298,239
Florida	2,827,883	15,489	15,489		1		1,592,776	1,590,465	15	4		490,339	490,339	11			731,590
Georgia	4,895,949						214,669	214,669	4			209,578	209,578	4	1		4,471,702
Idaho	1,674,479						1,046,976	1,027,849	18	1							646,630
Illinois	10,307,184						4,928,578	4,928,578	46	2		2,633,406	2,633,406	14	1		2,745,200
Indiana	5,111,096						3,502,651	3,380,006	28	7		1,941,453	1,702,123	10	3	127	28,967
Iowa	5,600,679	7,303	7,000		1		2,516,366	2,413,775	51	4		2,459,825	2,436,150	44	5		743,754
Kansas	5,246,258						3,971,118	3,971,118	37	1		1,275,335	1,275,140	16		3	
Kentucky	3,672,387	15,290	15,290	1			2,407,425	2,117,693	16			199,802	199,802	6	2		1,339,602
Louisiana	3,213,467						579,848	579,848	5			1,852,784	1,804,129	16	4		829,490
Maine	1,426,861						465,638	465,305	10			501,018	500,324	8			461,232
Maryland	2,061,751						414,161	414,161	3	2		967,014	944,545	3	2	11	703,045
Massachusetts	4,210,833						1,227,840	1,227,840	8	2		385,208	385,208	5			2,597,784
Michigan	6,765,197	447,400	447,400	3	1		5,057,152	5,057,152	32	7		606,350	561,850	5	1		698,795
Minnesota	5,395,441	154,269	154,269	2		1	2,645,661	2,639,611	53	6	4	729,307	729,307	13	3	26	1,872,255
Mississippi	3,241,475						1,930,102	1,930,102	41	3		207,952	207,952	4		1	1,103,421
Missouri	6,142,153						4,616,091	4,605,451	28	1		1,524,391	1,521,763	12			14,940
Montana	2,722,327	222,343	222,343	3			2,378,433	2,378,433	33	6							121,551
Nebraska	3,556,441	148,501	148,501	3			1,955,805	1,955,805	62	1		1,320,661	1,320,661	11	1	22	131,475
Nevada	887,260	185,753	185,753	4			497,919	497,919	6								203,587
New Hampshire	822,484						351,777	351,777	3	3		13,154	13,154			1	457,553
New Jersey	3,983,826						1,024,099	1,024,099	5	2		381,836	381,836	3	1		2,577,892
New Mexico	1,725,286	203,329	203,329	5			762,768	762,768	6	1		519,778	519,778	4			239,410
New York	13,577,189						8,906,354	8,645,808	29	27		1,491,550	1,491,270	2	9		3,440,111
North Carolina	4,823,958	69,554	69,554		2		1,446,849	1,446,849	20	5		685,293	685,293	9	4		2,622,262
North Dakota	3,207,473	39,335	39,335	1			761,541	761,541	18			899,072	899,072	17			1,507,525
Ohio	8,439,897						899,207	899,207	5	1		2,609,347	2,443,544	19	2		5,097,145
Oklahoma	5,004,711	219,766	219,766	5			1,382,850	1,382,850	26	1		1,900,567	1,900,567	23	2		1,501,528
Oregon	2,334,204						1,956,186	1,831,474	12	6		437,198	437,198	4		2	65,531
Pennsylvania	11,483,613	10,836	10,836	3			3,419,427	3,229,856	26	6		2,294,680	2,000,183	13	5		6,242,738
Rhode Island	699,691						654,008	654,008	4	1							45,683
South Carolina	3,059,956						1,260,469	1,249,503	22	4		211,922	211,868	8	1		1,598,586
South Dakota	3,249,086	51,774	51,774	1			854,322	854,322	23			41,601	41,601	1			2,301,389
Tennessee	3,903,979						535,673	535,673	12	1		441,019	441,019	11	1	11	2,927,287
Texas	10,855,982	235,840	226,386	7			5,179,734	4,996,144	64	11		5,566,129	5,463,758	52	4	83	169,693
Utah	1,230,763	29,757	29,757		1		609,078	597,024	9			108,047	100,000	1			503,982
Vermont	729,857	122,871	122,871	3	2		339,140	337,782	4	3		59,630	58,666	2		7	210,538
Virginia	3,774,287	103,940	103,940	6			1,259,501	1,188,637	21	2		619,167	578,007	20		9	1,903,703
Washington	3,095,041	77,705	77,705	1			1,800,209	1,795,378	15	6	1	583,785	583,785	4	1	6	638,174
West Virginia	2,677,937						276,542	276,542	2	1		491,749	491,749	3			1,909,645
Wisconsin	5,022,683	69,151	69,151	1			2,752,192	2,752,192	27	5		449,314	449,314	3	1		1,752,026
Wyoming	1,360,841	55,366	55,365	2			325,014	325,011	3								980,465
Dist. of Columbia	410,804						170,643	170,643	2			253,264	238,616	1			1,545
Hawaii	453,703						296,218	295,333	3			215,430	158,369	2			1
TOTALS	196,000,000	3,234,563	3,219,291	66	10	1	92,210,762	90,464,786	975	142	5	41,313,257	40,216,911	432	56	317	62,099,012

U. S. GOVERNMENT PRINTING OFFICE 74849

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)

AS OF JUNE 30, 1936

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	$ 14,437,208	$ 8,203,671	$ 2,839,626	736.4	$ 1,061,087	$ 160,296	$ 900,791	38.2		$ 462,532	2.9	$ 6,167	$ 56,893
Arizona	5,211,960	2,641,935	8,907,481	5,204,513	2,547,540	545.4	90,115		45,376	.8				7,447	49,019
Arkansas	6,748,335	3,428,049	10,738,841	6,615,913	3,152,044	608.8	224,772	21,152	203,565	10.6		50,937	1.1	111,270	21,503
California	15,607,354	7,932,206	29,241,878	15,589,248	7,458,664	758.8	1,474,347		418,015	1.6		820		18,106	54,706
Colorado	6,874,530	3,486,006	11,159,370	6,831,431	3,439,853	636.3	6,817		6,500					43,099	39,653
Connecticut	2,865,740	1,454,868	4,061,007	2,790,584	857,732	69.3	482,547		453,705	4.7				75,156	143,432
Delaware	1,819,088	923,395	2,643,857	1,819,088	782,660	128.3	88,530		88,530	.5		52,205	1.1		
Florida	5,231,834	2,661,343	8,654,439	5,183,596	2,120,961	296.7	468,781		437,733	12.2		15,955	.8	48,239	86,693
Georgia	10,091,185	5,113,491	12,093,980	9,128,958	2,471,303	683.2	1,901,442	551,957	1,282,280	108.3	$ 248,169	191,940	30.4	162,101	1,167,968
Idaho	4,486,249	2,277,486	6,624,597	4,416,568	1,792,123	496.8	429,790		425,402	4.7	42,905	2,881		26,776	57,080
Illinois	17,570,770	8,921,401	23,699,848	16,320,923	6,602,441	649.3	3,388,715	1,098,790	2,187,512	45.4	55,756	18,740	21.2	95,301	112,708
Indiana	10,037,843	5,088,963	13,783,867	9,705,689	3,442,674	429.9	1,840,290	276,180	1,497,760	58.6		134,587	.4	55,973	13,942
Iowa	10,055,660	5,118,361	15,333,142	10,055,660	4,681,121	1,215.5	197,598		181,041	3.5		196,600	5.0		59,599
Kansas	10,089,604	5,117,675	15,281,745	9,932,696	5,005,778	1,117.5	249,550	107,706	106,757	16.0	9,000	5,140	.9	40,201	
Kentucky	7,517,359	3,818,311	11,119,506	7,087,455	3,211,511	793.6	772,476	411,849	327,475	16.8	5,298	184,829	2.0	12,757	94,497
Louisiana	5,828,591	2,963,932	8,619,310	5,617,484	2,382,247	230.4	460,000	138,621	321,379	20.2	43,118	85,263	8.9	29,368	175,043
Maine	3,369,917	1,711,586	5,208,075	3,337,541	1,642,714	193.1	7,234		7,234		10,573			21,803	61,638
Maryland	3,564,527	1,810,058	4,566,259	2,899,421	688,143	119.8	1,107,732	582,686	473,331	35.6		202,667	4.6	82,420	445,916
Massachusetts	6,597,100	3,350,474	7,491,290	4,596,874	2,252,100	112.4	2,701,150	1,896,851	804,299	2.9		34,376	.2	103,376	259,699
Michigan	12,736,227	6,452,568	18,875,715	12,532,714	4,936,168	688.7	1,640,525	163,400	1,419,147	79.6		30,825	.1	40,113	66,427
Minnesota	10,656,569	5,425,551	15,504,623	9,925,146	4,723,885	1,632.7	831,555	589,493	208,244	13.1	3,168	125,320	.6	138,762	368,103
Mississippi	6,978,675	3,540,227	11,693,232	6,572,233	2,240,612	666.6	1,622,786	336,141	1,217,679	77.4	6,555	37,157	.9	63,745	44,779
Missouri	12,180,306	6,173,740	16,709,649	11,175,592	4,466,671	1,421.4	2,766,383	937,703	1,603,634	29.9		103,435	.4	67,011	
Montana	7,439,748	3,769,734	11,122,346	7,333,301	3,120,340	1,029.6	629,892	37,320	592,572	16.6	19,000	2,000	10.3	50,127	54,822
Nebraska	7,828,961	3,964,364	12,404,673	7,709,817	3,428,874	995.4	781,732	70,773	506,111	47.9		24,955	.2	48,371	4,425
Nevada	4,545,917	2,302,356	6,745,067	4,473,433	1,988,495	741.9	333,192	26,150	279,791	12.7		5,250		46,333	28,821
New Hampshire	1,909,839	969,462	2,973,832	1,904,951	937,585	77.7								4,889	31,877
New Jersey	6,346,039	3,220,879	7,678,270	6,132,040	1,050,400	81.0	1,868,176		1,669,223	6.3		303,276	6.6	213,999	197,980
New Mexico	5,792,935	2,941,700	8,668,002	5,624,746	2,818,758	762.8	50,695		33,709	2.3				168,189	89,232
New York	22,330,101	11,327,921	38,028,504	21,535,626	9,859,764	801.8	2,174,190	548,520	1,268,899	15.3	125,154	78,420	6.2	120,801	120,838
North Carolina	9,522,293	4,840,941	14,526,302	9,040,046	4,264,537	1,329.3	508,028	206,852	294,640	21.0	97,130	205,439	5.6	178,266	76,325
North Dakota	5,804,448	2,938,967	7,649,643	5,567,198	1,391,771	2,009.0	843,711	73,071	717,631	111.1	36,901	265,450	20.3	127,278	564,115
Ohio	15,484,592	7,865,012	23,344,935	15,302,317	6,304,456	757.6	1,506,317	44,450	1,378,877	36.8	51,500	58,624	1.7	86,324	123,055
Oklahoma	9,216,798	4,685,180	13,848,919	9,053,666	3,822,748	794.9	741,912	147,072	593,106	11.3		6,250	.4	16,060	263,076
Oregon	6,106,896	3,097,814	9,528,859	5,969,480	2,656,217	462.4	448,303	64,950	287,815	6.0		38,544	.4	72,466	115,238
Pennsylvania	18,891,004	9,590,788	27,432,920	17,860,232	8,283,625	993.0	1,600,137	736,539	751,286	65.8	13,076	212,794	2.1	281,157	343,083
Rhode Island	1,998,708	1,014,572	2,994,178	1,998,708	860,741	88.0	139,983		139,983	1.1					13,848
South Carolina	5,459,165	2,770,954	7,328,249	5,226,451	1,880,377	589.2	751,053	101,841	627,252	31.8	30,353	79,597	5.9	100,520	183,727
South Dakota	6,011,479	3,047,643	8,564,243	5,717,672	2,273,513	1,491.1	725,063	103,357	621,706	47.3	10,867	73,940	14.1	179,583	78,484
Tennessee	8,492,619	4,302,991	12,598,156	8,368,445	3,326,701	474.8	1,031,391	124,174	811,418	17.9		22,482	.2		142,389
Texas	24,244,024	12,291,253	36,803,831	23,842,043	11,108,867	2,753.4	1,508,008	325,282	1,087,761	32.7		500	7.1	76,698	94,126
Utah	4,194,708	2,132,691	7,149,296	4,162,416	1,973,869	586.5	202,180		156,741	4.3	32,292	1,853			228
Vermont	1,867,573	948,007	3,031,551	1,863,531	839,662	137.6	110,521	3,922	91,982	2.4		8,040	1.0	120	8,323
Virginia	7,416,757	3,765,387	11,388,302	7,216,130	3,225,650	585.1	288,187	40,037	240,322	30.3	53,539	24,235	3.0	107,051	275,181
Washington	6,115,867	3,106,412	9,238,359	6,098,252	2,910,054	302.5	121,627		115,530	.3	13,790	660		3,825	80,168
West Virginia	4,474,234	2,280,335	5,653,418	4,287,913	1,131,244	189.9	1,019,252	112,719	830,932	32.0	9,941	218,830	1.3	63,661	99,329
Wisconsin	9,724,881	4,941,837	15,009,736	9,676,693	4,537,248	610.6	341,449	7,300	291,707	9.1		72,897		40,888	39,985
Wyoming	4,501,327	2,287,712	6,847,243	4,474,802	2,163,929	1,035.9	36,744	5,780	30,962	1.4	5,949	30,155	.4	14,797	62,666
District of Columbia	1,918,469	973,842	2,747,515	1,909,584	837,795	20.8	120,199		84,699	1.5				8,885	51,348
Hawaii	1,871,062	949,778	2,520,198	1,793,257	180,263	49.4	803,632	63,609	736,463	6.1	13,517	23,433	.2	679	9,619
TOTALS	394,000,000	200,000,000	592,275,466	379,685,748	160,916,054	33,982.1	42,499,796	10,116,543	28,858,507	1,151.9	937,551	3,693,833	168.5	3,260,158	6,531,606

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