Comparison of Properties of Coal-Modified Tar Binder, Tar and Asphalt Cement

WOODROW J. HALSTEAD, EDWARD R. OGLIO, and ROBERT E. OLSEN, U.S. Bureau of Public Roads, Washington, D.C.

This paper gives the results of a laboratory study of the properties of a coal-modified tar binder, produced by the high-temperature digestion of finely divided coal in tar and high-boiling tar oils.

Comparisons were made of the properties of this binder with a normal tar pitch, an RT-12 road tar, and an 85-100 penetration grade of asphalt cement. The properties of laboratory mixes made with the modified binder, road tar, and asphalt cement were also compared.

The results indicate that the coal digestion improves the properties of a tar with respect to increasing its resistance to hardening and apparently makes the material somewhat less brittle than a normal tar pitch. However, the improvements are not considered sufficient to warrant considering the material equal to an asphalt cement with respect to these properties.

Immersion-compression tests indicate that the mixtures made with the modified-tar binder have greater resistance to deterioration from water than similar mixtures made with asphalt cement.

• CONSIDERABLE interest was aroused when the Curtiss-Wright Corporation announced the development of a new coal-based road binder. This was the result of the research program it conducted in an effort to find new uses for coal and coal products. The great interest in this material by groups in several States (especially those seeking ways to use more coal in distressed coal-producing areas) and the potential effect of such a binder on the National Highway Program prompted the Physical Research Division of the Bureau of Public Roads to follow this development very closely. This report summarizes the results of the tests made and the findings of the Bureau concerning this material.

The basic principle used in preparing the new binder is the simultaneous digestion of powdered coal in coal tar and tar oils at a temperature of 500 to 600 F. It was claimed that by adjusting the proportions of tar, tar oils, and coal, binders could be prepared covering the same penetration range as asphalt cements. It was the intent of the developer that the modified binders would be used in the same manner as asphalt cements in hot plant mixtures.

The digestion of powdered coal in tars and pitch has been used for a number of years in pipeline coatings and in pitches for steep, built-up roofs. No previous attempt has been made in the U.S. to use this principle in the manufacture of a binder for pavements although studies of the effects of powdered coal on road tar properties have recently been conducted in South Africa (1).

The details of the manufacture of the binder and background information concerning its development are discussed elsewhere (2) and the description of the construction and performance of the first experimental pavements built with the new binder is given in two reports by the Kentucky Department of Highways (3, 4).

Through the courtesy of the Curtiss-Wright Corporation and the Kentucky Department of Highways, samples of the coal-modified tar binder and various materials were obtained for this study. Laboratory studies were conducted to determine the physical properties of the new binders and to compare these with the properties of normal tar and asphalt cement. Two series of tests were made. In the first, a sample of the coal-modified tar binder obtained directly from Curtiss-Wright Corporation was compared with a water-proofing tar pitch. In the second series, tests were made to compare the modified binder, the base tar, and the asphalt cement used in one of the experimental pavement sections constructed in Kentucky.

COMPARISON OF MODIFIED BINDER WITH PITCH

In the first series of tests, the properties of the coal-modified tar binder were compared to the properties of a tar pitch meeting AASHO specification M-118, Type B. Table 1 gives the results of these tests.

The tar pitch used in these comparisons was selected so as to have the same softening point as the modified binder. The penetration at 77 F is also about the same for both materials. However, the absolute viscosity results, determined by the Koppers vacuum-operated capillary tube viscometer (5), show the modified tar binder to have a somewhat lower viscosity-temperature susceptibility. Values of -4.71 and -4.99 were obtained for the coal-modified binder and the tar pitch, respectively, when log log absolute viscosity was plotted against log absolute temperature in degrees Rankine (F plus 459.7).

Penetration tests made at different temperatures also indicated lower susceptibility for the modified binder, the slope of the log penetration vs temperature curves being 0.0258 and 0.0427 for the modified binder and tar pitch, respectively.

The thin film oven test (⅛ in. 5 hr) run at the standard temperature of 325 F (AASHO T-179), showed very high losses and extreme hardening for both materials. Because this temperature is higher than would likely be used for materials of this nature, tests were repeated at 250 F. The results at this temperature showed a greater resistance to hardening for the modified binder. Impact resistance, as measured by the height at which a 1-lb steel ball produced fracture of a rigidly supported ½-in. cube of material at the indicated test temperature, showed the modified binder to have better resistance to impact than the pitch. Except for ductility, the results of tests made on the residues from the thin film oven tests at 250 F showed the same general trends as the results of tests on the original materials. No specific conclusions regarding comparable ductility can be drawn. The original ductility of the modified binder was higher at 77 F than that of the tar pitch, but at 60 F the reverse was true. At 77 F, the 250 F residue of the tar pitch was more ductile than the modified tar binder even though harder as judged by penetration test. At 60 F the tar pitch had no ductility compared to 8 cm for the coal-modified tar material.

This series of tests confirmed the improved properties of the modified binder over those for a normal tar pitch and indicated that further research to compare the properties of the new binder with asphalt cement and their relative behavior when used in paving mixtures was warranted.

COMPARISON OF PROPERTIES OF MODIFIED BINDER, NORMAL ROAD TAR, AND ASPHALT CEMENT

The second and more extensive series of tests was made on samples of materials used in the Kentucky experimental paving project 11 (urban) located on US 25 in London, Ky. The materials included the modified binder, the RT-12 road tar used as the base for the binder, the 85-100 penetration asphalt cement used in the control sections, the powdered coal, and the aggregate used in the mixtures. The properties of the three binders were determined to show their relative viscosity-temperature susceptibilities

TABLE 1

COMPARISON OF PROPERTIES OF COAL-MODIFIED BINDER WITH TAR PITCH

Property	Coal-Modified Binder	Waterproofing Pitch
Softening point (R & B) (°F)	117	117
Specific gravity at 77/77 F	1.248	1.269
Solubility in CS_2 (%)	74.6	81.1
Distillate to 572 F (AASHO T 52) (%)	2.4	6.7
Absolute viscosity (poises):		
At 140 F	1,335	747
149 F	594	310
158 F		160
167 F	130	80.1
173.5 F	92.7	
176 F		44.0
Viscosity-temperature susceptibility[1]	- 4.71	- 4.99
Penetration:		
At 77 F, 100 g, 5 sec	63	62
53.4 F, 100 g, 5 sec	15	6
39.2 F, 200 g, 60 sec	23	11
Penetration-temperature susceptibility[2]	0.0258	0.0427
Ductility, 5 cm/min (cm):		
At 77 F	51	41
60 F	30	59
Impact resistance[3] (in. to fracture):		
At 77 F	9+	5
60 F	5	2
53.5 F	5	2
Thin-film tests at 325 F (1/8-in. film, 5 hr):		
Loss (%)	11.4	9.4
Softening point of residue (° F)	170	162
Penetration of residue, 100 g, 5 sec at 77 F	0	0
Thin-film tests at 250 F (1/8-in. film, 5 hr):		
Loss (%)	1.4	2.9
Penetration of residue:		
At 77 F, 100 g, 5 sec	27	15
53.4 F, 100 g, 5 sec	5	1
39.2 F, 200 g, 60 sec	8	1
Retained penetration at 77 F (%)	43	24
Penetration-temperature susceptibility[2]	0.0310	0.0498
Ductility, 5 cm/min (cm):		
At 77 F	38	61
60 F	8	0
Impact resistance[3] (in. to fracture):		
At 60 F	2	3/4
53.4 F	1 1/4	1

[1] Viscosity-temperature susceptibility $= \dfrac{\log \log v_2 - \log \log v_1}{\log T_2 - \log T_1}$;

v = viscosity in centipoises;
T = temperature in degrees Rankine (F + 459.7).

[2] Penetration-temperature susceptibility $= \dfrac{\log P_2 - \log P_1}{t_2 - t_1}$;

P_1 = penetration at temperature t_1;
P_2 = penetration at temperature t_2;
t = temperature, degrees F.

[3] One-pound steel ball on 1/2-in. cube.

and degree of hardening when heated. Comparisons were made of the properties of laboratory mixtures made with each binder and the aggregate used in Kentucky. Other selected aggregates were also used with the binders in making the comparisons.

Table 2 gives the results of the tests made on the binders. These include normally determined physical characteristics and absolute viscosities in poises at various temperatures ranging from about 60 to 350 F. To determine viscosities over this wide range of temperatures three instruments were used—the Shell sliding plate microviscometer (6) at the lower temperature range (60 to 115 F), the Koppers vacuum capil-

TABLE 2

TEST PROPERTIES OF KENTUCKY BINDERS

Property	RT-12 Tar	Coal-Modified Binder	Asphalt Cement
Specific gravity 77/77 F	1.265	1.267	1.019
Pen. 77 F, 100 g, 5 sec	235	71	92
Softening point (R&B) (°F)	96	115	116
Ductility 77 F, 5 cm/min (cm)	--	54	182
Solubility in CS_2 (%)	79.5	71.3	99.9[a]
Organic insoluble	20.5	28.0	0.1
Distillation test (AASHO T 52):			
To 455 F (%)	0.0	0.0	--
518 F (%)	0.3	0.3	--
572 F (%)	3.8	2.7	--
Residue (%)	95.7	97.2	--
Softening point of residue (°F)	113	128	--
Absolute viscosity (poises):			
At 61.5 F	1,500,000	24,500,000	8,800,000
77 F	160,000	2,300,000	1,200,000
86 F	42,000	660,000	418,000
95 F	17,500	200,000	169,000
105 F	--	56,000	44,000
115 F	--	28,000	20,000
123.6 F	492	--	--
149.4 F	65.7	--	--
157.9 F	40.9	--	--
160.3 F	--	217	--
180 F	10.3	60.1[b]	169[b]
195 F	4.92	29.0[c]	--
210 F	2.77	12.8	43.2[d]
250 F	--	2.52	--
275 F	--	1.26	4.35
300 F	--	--	2.18
350 F	--	--	0.747
Viscosity-temperature susceptibility[e]	-4.78	-4.38	-3.51

[a] Solubility in carbon tetrachloride.
[b] Actual temperature = 180.8 F.
[c] Actual temperature = 195.9 F.
[d] Actual temperature = 211.7 F.
[e] $\dfrac{\log \log v_2 - \log \log v_1}{\log T_2 - \log T_1}$

v = viscosity in centipoises;
T = absolute temperature in degrees Rankine (F + 459.7).

lary viscometer in the intermediate range (115 to 200 F), and the Saybolt-furol viscometer (with conversions to absolute values) in the higher range (200 to 350 F).

Figure 1 shows the viscosity-temperature relations of the three Kentucky materials. Although viscosity in poises and temperature in degrees Fahrenheit are indicated in the figure, these curves were obtained by plotting log log viscosity in centipoises against log of absolute temperature in degrees Rankine (F + 459.7). There is a good straight line relation indicated by the data points for all the binders even though they were obtained by the different instruments as mentioned. The difference in slope of the curves for the asphalt and the coal-modified binder is significant. The RT-12 has substantially lower viscosity values for the same temperatures but it is only slightly more susceptible to temperature than the coal-modified material. The calculated slopes of these lines are -4.78, -4.38, and -3.51 for the tar, coal-modified binder, and the asphalt cement, respectively.

Figure 2 shows the furol viscosity values for the three materials. These curves were used to determine the various mixing temperatures for the studies of laboratory mixtures to be discussed later. Furol viscosity is directly related to kinematic viscosity in Stokes rather than absolute viscosity in poises. The data points shown in

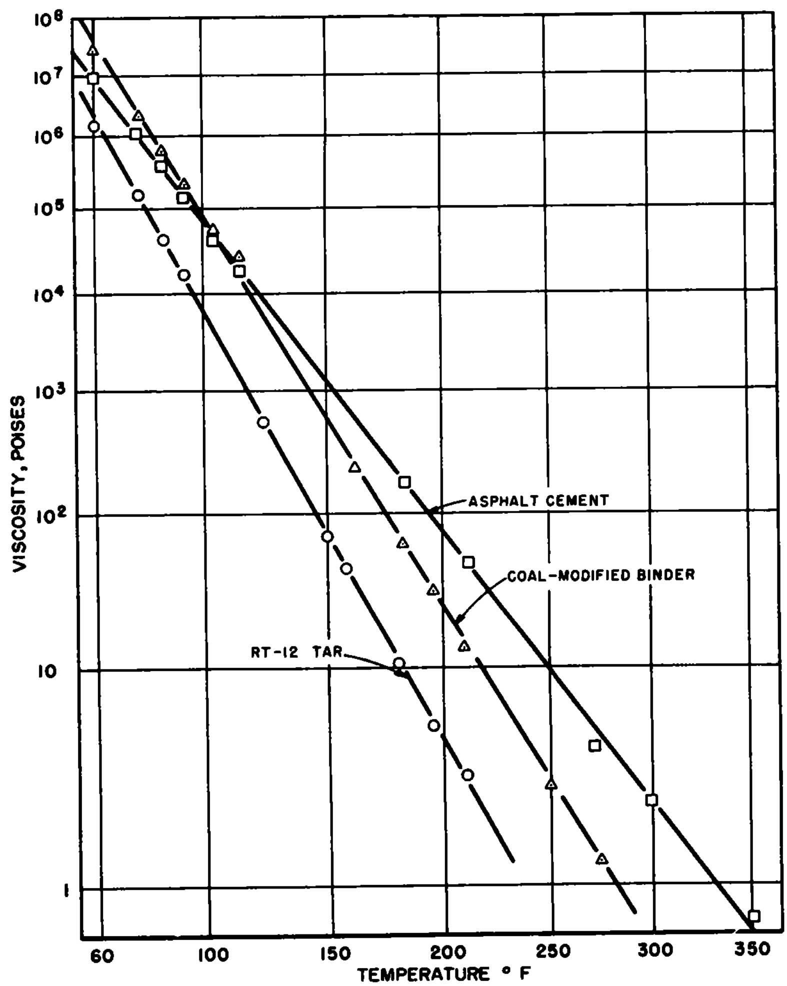

Figure 1. Viscosity-temperature relationships for binders used in Kentucky experimental projects.

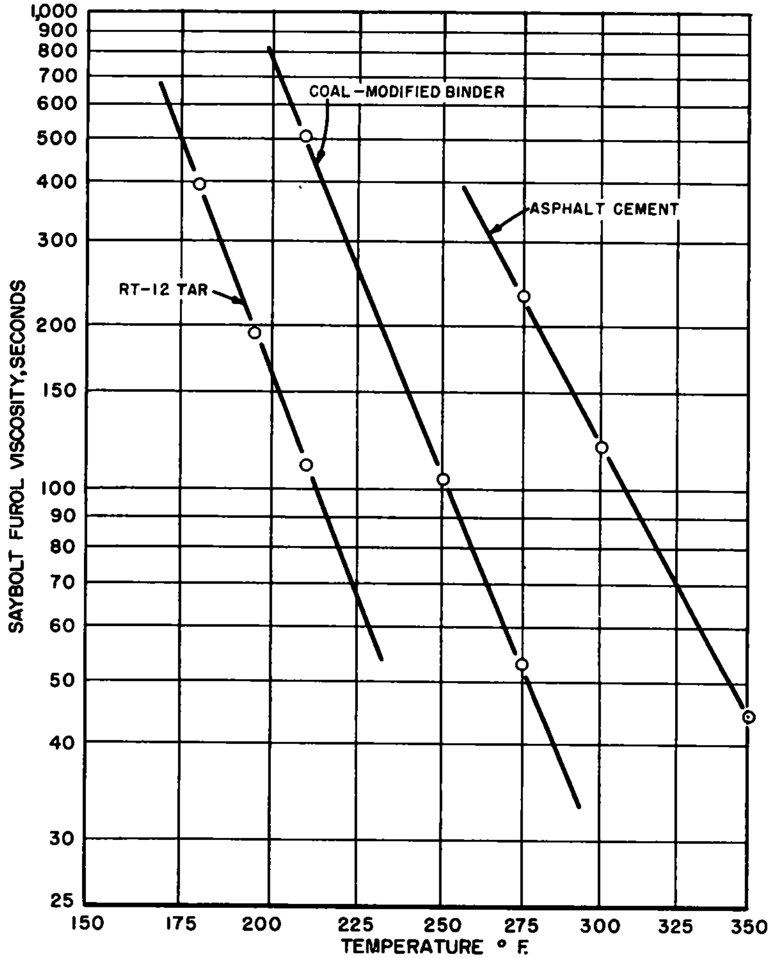

Figure 2. Furol viscosity of binders at various temperatures.

these curves are the basis for the absolute viscosities in poises given in Table 2 for the temperatures indicated.

Although it is well recognized that tars are more volatile than asphalt, and that they should not be subjected to as high temperatures as asphalts during the manufacture of hot paving mixtures, one of the claims stressed by the press releases of the developers, which was the basis of much of the interest in this material, was that it could be used in the same manner as asphalt cement in bituminous concrete construction. Thus it was of interest to compare the materials with respect to their relative resistance to hardening when subjected to heat.

For this purpose, the thin film oven test (⅛ in., 5 hr) which is commonly used as a specification test to evaluate the hardening characteristics of asphalt cements was employed. Tests were made at temperatures ranging from 210 to 325 F on the three binder materials. In addition, the standard AASHO oven-loss test (T-47) was made on the modified tar binder and the asphalt cement. The results of these tests are given in Table 3.

Figure 3 shows the comparison of the weight loss during the thin film tests of the asphalt cement, the modified binder, and the RT-12 tar at the various test temperatures. Even though this particular asphalt cement showed small gains in weight, most asphalt cements of this grade have small weight losses in this test. In the study of

TABLE 3

EFFECT OF OVEN EXPOSURE AT VARIOUS TEMPERATURES

Test	RT-12 Tar	Coal-Mod. Binder	Asphalt Cement[1]
Oven loss test (AASHO T-47):			
Loss (%)	--	2.36	0.02
Penetration of residue, 100 g, 5 sec, 77 F	--	40	80
Retained penetration, percent	--	56	65
Thin film tests (1/8-in. film, 5 hr)			
At 210 F:			
Loss (%)	1.46	1.05	+0.08
Penetration of residue, 100 g, 5 sec, 77 F	128	50	79
Retained penetration (%)	54	70	86
Ductility, 5 cm per min, 77 F (cm)	73	46	228
Softening point (° F)	103	121	119
At 250 F:			
Loss (%)	3.60	2.68	+0.23
Penetration of residue, 100 g, 5 sec, 77 F	71	31	75
Retained penetration (%)	30	44	82
Ductility, 5 cm per min, 77 F (cm)	151	42	239
Softening point (° F)	114	129	121
At 275 F:			
Loss (%)	5.67	4.47	+0.25
Penetration of residue, 100 g, 5 sec, 77 F	41	18	68
Retained penetration (%)	17	25	74
Ductility, 5 cm per min, 77 F (cm)	75	27	230
Softening point (°F)	122	137	122
At 325 F:			
Loss (%)	11.35	9.98	+0.11
Penetration of residue, 100 g, 5 sec, 77 F	3	2	60
Retained penetration (%)	1	3	65
Ductility, 5 cm per min, 77 F (cm)	1	--[2]	247
Softening point (°F)	150	164	126

[1] Plus sign indicates gain in weight.

[2] Not run; specimen could not be prepared properly.

asphalt cements recently conducted by the Bureau of Public Roads (7), the highest loss shown by any of the 85-100 penetration grade asphalts was 2.18 percent. Eighty-seven percent of the 85-100 materials in that investigation had losses of 0.5 percent or less. Because the loss for the modified binder was 10 percent at 325 F, it is evident that it is quite different from asphalts with respect to its volatility. The loss for the RT-12 was 11.3 percent at 325 F. Thus the results for the two tar materials are generally comparable.

Figure 4 shows the relative hardening characteristics of the three materials as measured by the percent of original penetration retained after the thin film test at various test temperatures. The wide differences between the tar products and the asphalt is again illustrated. Different asphalts, of course, show different percentages of retained penetration, but in no case would the percentage be as low as that shown by the tar products. For example, the asphalt already mentioned as showing the highest loss encountered with 85-100 penetration grade materials had a retained penetration of 33 percent. This is considerably higher than the 1 and 3 percent shown by the two tar materials under the same conditions.

Although the hardening in the thin film oven test has been shown to relate to the hardening in an asphalt during mixing in a hot plant, there is no information concerning the relation of the hardening of tar materials in such tests to the actual hardening in

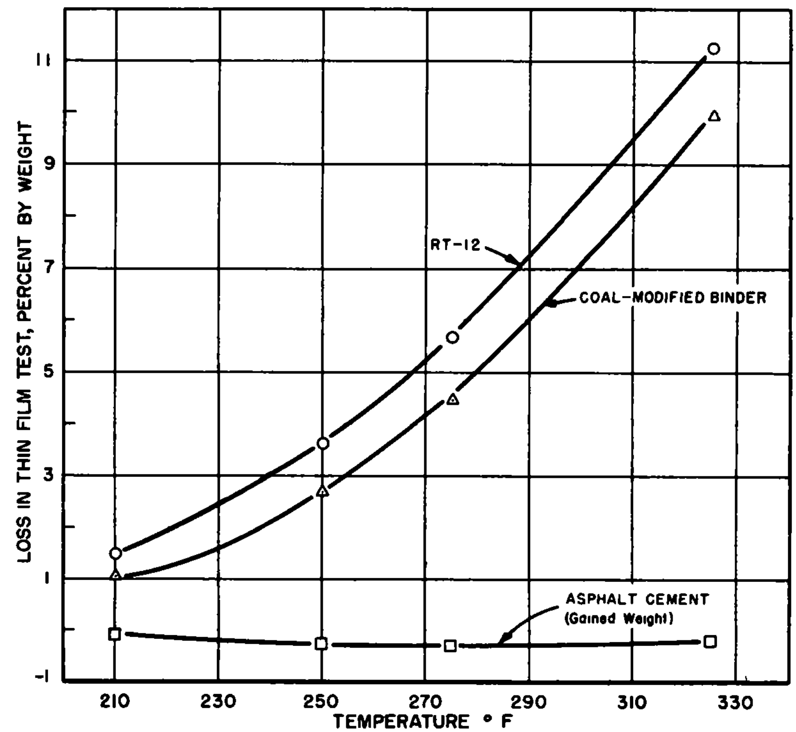

Figure 3. Weight loss in thin film test at various temperatures.

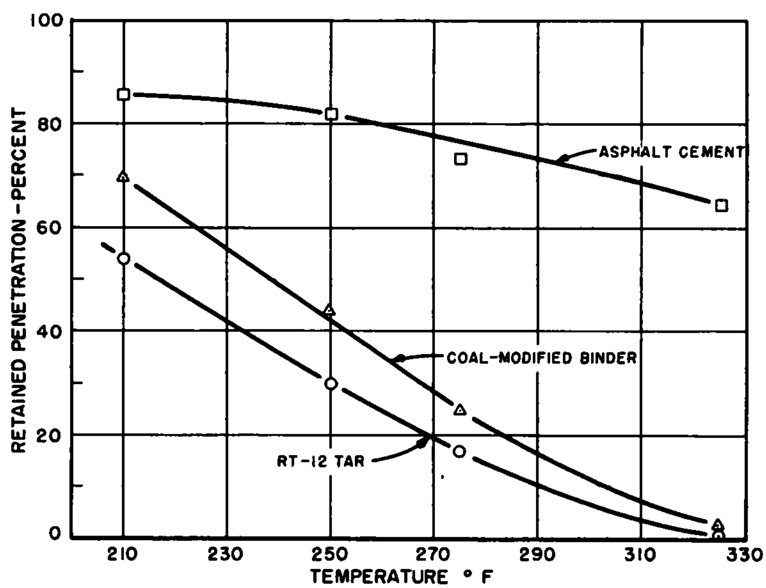

Figure 4. Resistance to hardening at various test temperatures (1/8-in. film, 5 hr).

the mixing and laying operations with this class of materials. Because of the relatively large amount of volatile matter in tar products, it is quite possible that the long time of oven exposure compared to the time the mixture is at high temperature prior to compaction on the road would produce considerably greater hardening in these materials than is actually encountered in construction operations. Nevertheless, it is believed that the relationships shown are important. They emphasize the fact that the modified binder has quite different properties from asphalt; therefore it is not realistic to consider it as an alternate to asphalt in all respects.

STUDIES OF LABORATORY MIXTURES

To further compare the behavior of the coal-modified tar binder, RT-12 tar, and asphalt cement, the characteristics of laboratory-prepared mixtures made with each binder were compared under several conditions. The changes in stability after various periods of oven aging and after various periods of immersion in water were determined. Another series of stability tests at different temperatures was made to evaluate the effect of the observed differences in the viscosity-temperature relations of the binders.

Because of the relatively wide difference in the specific gravity of the three binders, all of the laboratory mixtures prepared for the various phases of this part of the study were designed using equal volumes of binder per unit weight of aggregate (5.85 ml of binder per 100 g of aggregate). This was considered to provide a better basis for comparison than tests on mixtures prepared with percentages of binder on an equal weight basis. Because of the difference in temperature susceptibility the mixing and molding temperatures were controlled so that the furol viscosities of the binders were approximately the same for each individual phase of the study.

The aggregates for all of the mixtures were heated overnight at the predetermined mixing temperatures. The binders were heated to this mixing temperature just prior to mixing with the preheated aggregates in a modified Hobart mechanical mixer. The mixing period was 2 minutes. Marshall specimens were prepared in a mechanical compactor with 50 blows of the hammer applied to each face of the specimen. The specimens for the unconfined compression test were molded by the double plunger method with a 3,000-psi load held for 2 minutes.

EFFECT OF AGING AT 140 F ON MARSHALL STABILITY

To determine the effect of laboratory-aging tests on strength of mixtures, as measured by Marshall stability, specimens were prepared with the three binders as received, and with the RT-12 tar in which 10 percent of the tar was replaced by powdered coal. The latter tests were made to obtain some measure of the filler effect of the coal.

As indicated earlier, all the mixtures were proportioned with the binder on an equal volume basis and were mixed and molded at an approximately equal furol viscosity. After molding, one group of specimens was tested immediately and the balance were aged in an oven at 140 F for periods ranging from 1 to 30 days. After each aging period, Marshall stability was determined at 140 F. The stability values obtained, along with pertinent information on proportioning and mixing, are given in Table 4. Figure 5 shows that the stability for all materials increases with aging in the oven, and that the increase for the modified tar binder is significantly greater than that obtained with both the asphalt and the RT-12 tar.

Oven loss tests previously indicated the RT-12 tar had slightly greater volatility than the modified tar binder, and therefore a somewhat greater increase in stability would be expected for the RT-12 mixture if such increases were attributed to volatility alone. Also, if the effect of the powdered coal was primarily a "mechanical" effect of increased fine material, stabilities of the RT-12 mixtures to which the coal was added should be more nearly equal to those obtained with the coal-modified material than the stabilities of the RT-12 mixtures. This is not the case. Although the specimens containing the powdered coal did have higher stabilities for the same conditions, the difference accounted for only a very small proportion of the total

TABLE 4

EFFECT OF OVEN AGING AT 140 F ON MARSHALL STABILITY VALUES

Property	RT-12 Tar	RT-12 plus Coal[1]	Coal-Mod. Binder	Asphalt Cement
Specific gravity binder at 77 F	1.265	--	1.267	1.019
Weight of binder per 100 g of agg. (g)	7.40	--	7.41	5.96
Volume of binder per 100 g of agg. (ml)	5.85	--	5.85	5.85
Mixing temperature[2]	210	210	243	300
Marshall stability at 140 F (lb)				
After aging in oven at 140 F[3]:				
For 0 days	132	139	321	238
1 day	180	210	532	292
3 days	243	304	817	336
10 days	311	456	1,334	410
30 days	571	856	2,569	574

[1] 10 percent by weight of the tar replaced by powdered coal used in manufacturing coal-modified binder.

[2] Mixing temperature used to give approximate equal viscosity for all binders (120 Saybolt furol-seconds).

[3] Each value is average of 4 specimens. Aggregate was same as used in Kentucky experiment and was graded as follows:

Passing Sieve	Percent
1/2-in.	100
3/8-in.	98
No. 4	72
10	47
20	34
40	17
80	3
200	1.4

increase shown by the modified-tar mixture. These results indicate some factor (such as the development of internal structure) is present in the modified-tar binder which contributes to the considerably greater increase in stability than can be accounted for by the effect of coal as filler or by the increase in viscosity due to loss of volatile matter.

In an effort to explore further the relative tendency of the three binders to exhibit a difference in aging characteristics, a special series of viscosity tests was conducted. These tests were made as follows: Sliding plate viscosity specimens were prepared in the usual manner for viscosity determination with the microviscometer and the initial viscosity was determined at 77 F within 15 minutes after preparation of the specimens was completed. The sides of the glass plates were then taped with a nonpermeable plastic tape to minimize volatile losses and the specimens placed in an oven at 110 F. Absolute viscosity determinations at 77 F were made on the same specimen after periods of 1, 5, 8, and 13 days. Immediately after the viscosity determination on the 13th day, the specimens were heated above their softening points (to a temperature of 150 F) and viscosity at 77 F redetermined. This was done to obtain a measure of the nonpermanent hardening that had occurred. These results are given in Table 5 and shown in Figure 6. The vertical components of the lines in the figure at the 13-day period indicate the change in viscosity after the specimens were heated.

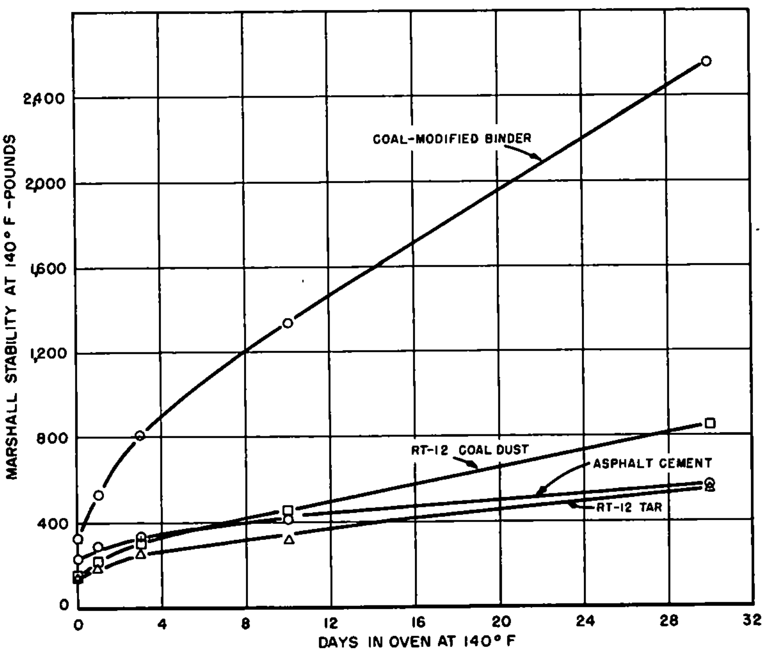

Figure 5. Increase in Marshall stability during time of aging in oven.

Although there are some inconsistencies in the data, all three binders increased in viscosity during oven aging. For the RT-12, the viscosity increased when the specimen was heated above its softening point after 13 days of aging. Thus any possible development of structure or "reversible" hardening was masked by a permanent hardening probably caused by an unavoidable loss of volatile matter. However, both the asphalt cement and the coal-modified tar binder gave significant decreases in viscosity at 77 F after heating to a temperature above the softening point and recooling. This decrease amounted to approximately 64 percent of the total increase for the modified binder and 22 percent of the increase for the asphalt cement.

TABLE 5

INCREASE IN VISCOSITY WITH TIME OF OVEN-AGING AT 110 F

Aging Period[a] (days)	Viscosity at 77 F ($x10^3$ poises)		
	RT-12 Tar	Coal-Mod. Binder	Asphalt Cement
0	163	1,890	1,230
1	380	2,690	1,520
5	392	2,830	1,870
8	609	4,220	1,840
13	921	6,770	2,480
13-X[b]	1,050	3,660	2,210

[a]Sealed specimens aged in oven at 110 F.
[b]Specimens heated to 150 F after 13 days determination and viscosity determination repeated.

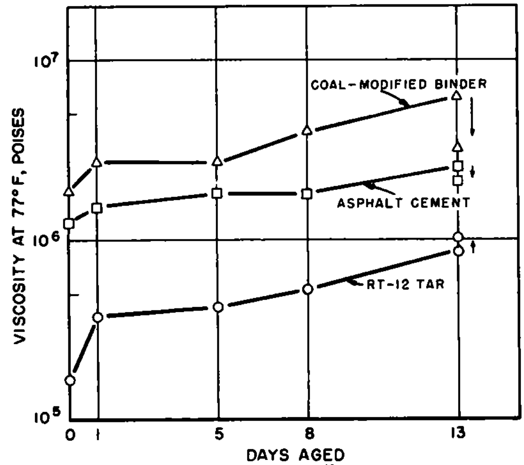

Figure 6. Effect of aging at 110 F on binder viscosity.

The tendency for bituminous materials to exhibit such hardening through the development of internal structure with time is well recognized. Lee and Dickinson (8) attributed this phenomenon in tars to possible crystallization of constituents or a change in degree of dispersion of colloidal constituents. Brown, Sparks, and Smith (9) in discussing the phenomenon in asphalts attributed it to "internal physical reorientation and reorganization at the atomic, molecular, and micelle levels, of the components of the asphalt." Although this study is not conclusive, the results of oven aging tests on both the mixtures and the binders indicate that the coal-modified tar binder may exhibit the tendency to develop such "structural" hardening to a much greater extent than either a normal tar or an asphalt. The effect of this phenomenon on the behavior of the materials in pavements should be considered in any further research on such materials.

EFFECT OF WATER ON COMPRESSIVE STRENGTH

The ability to resist loss of strength in the presence of water is an important property of a bituminous mix. To show this characteristic, immersion-compression tests were made using two types of aggregates, a quartzite and a granite, both of which had been shown to be relatively sensitive to water by previous BPR studies. Each aggregate was crushed and recombined to the same grading as the aggregate obtained from the experimental project in London, Ky. Only the modified tar and asphalt binders were used in this phase of the study.

Table 6 gives the results of compressive strength tests before and after immersion in water at 120 F for periods up to 18 days. The retained strengths and percentages of swell after each period also are given along with information concerning the mixture composition and mixing temperatures.

The results of the compressive strength test at 77 F and percent of retained strengths after various periods of immersion are plotted in Figure 7, which shows that the modified tar binder has higher initial strengths than the asphalt cement with each aggregate. The percentages of retained strengths were also higher for each of the mixtures containing the modified tar binder than for comparable specimens made with the same aggregate and asphalt. Although the results for the mixtures made with quartzite aggregate and modified binder were somewhat erratic, the strengths at 4 days being less than those at 12 and 18 days, they appeared to be little affected by water.

EFFECT OF VARYING TEST TEMPERATURES ON UNCONFINED COMPRESSIVE STRENGTH

Because of the differences in viscosity-temperature susceptibility of the coal-modified tar, RT-12, and asphalt binders, the relative change in stability with temperature was of interest. For this series of tests 3- by 3-in. compressive strength specimens were used. As with the other series, the binders were added on an equal volume basis and the mixtures were prepared at equal furol viscosities.

The aggregate for this series of tests consisted of crushed granite as the coarse aggregate, river sand as the fine aggregate, and limestone dust as the mineral filler.

The specimens were tested for stability by unconfined compressive strength tests over a range of temperatures from 0 to 100 F. The results of these tests together with mixture composition and mixing conditions are given in Table 7.

The relationships of strength to temperature for the three binders are shown in Figure 8. These results follow the generally expected pattern. They are in the same order as viscosity-temperature susceptibility of the binders themselves. Compressive strength decreases as the temperature increases with the rate of decrease being greatest for the RT-12 tar and least for the asphalt cement. Further, when the curves for the asphalt and modified tar binders are extended, the modified binder shows higher strength at 140 F, the maximum temperature usually found in pavements. Thus it is indicated that the modified tar binder of the consistency used in these tests would provide higher stabilities than the 85-100 penetration asphalt at any temperature that would be encountered in service. This is not true for the RT-12 which intersects the

TABLE 6

EFFECT OF IMMERSION IN WATER AT 120 F ON COMPRESSIVE STRENGTH

Property	Quartzite[1]		Granite[1]	
	Coal-Mod Binder	Asphalt Cement	Coal-Mod Binder	Asphalt Cement
Weight binder per 100 g agg (g)	7.41	5 96	7.41	5 96
Volume binder per 100 g agg (ml)	5 85	5 85	5.85	5.85
Mixing temperature[2]	240	300	240	300
Compressive strength before immersion[3]	258	151	363	257
Results[3] after 4 days immersion				
Compressive strength (psi)	223	100	237	163
Retained strength (%)	86	66	65	63
Swell (%)	0 1	0 5	1.0	1 0
Results[3] after 11 days immersion·				
Compressive strength (psi)	239	93	212	131
Retained strength (%)	93	62	58	51
Swell (%)	0 2	0 8	1 3	1.5
Results[3] after 18 days immersion·				
Compressive strength (psi)	237	84	209	129
Retained strength (%)	92	56	58	50
Swell (%)	0 2	1 4	1.4	1 5

[1] Gradation of both mixtures as follows:

Passing Sieve	Percent
1/2-in	100
3/8-in.	98
No 4	72
No 10	47
No 40	17
No. 80	3
No. 200	1 4

[2] Mixing temperature to give approximate equal binder viscosity (120 to 150 Saybolt-furol seconds)

[3] All results based on average of three 4- by 4-in. cylinders tested at 77 F

asphalt curve at a temperature of 67 F, indicating that this material would have significantly lower stability at 140 F. Of further interest are the extremely high compressive strength values for the coal-modified tar and the RT-12 at 0 F. These are approximately double those of the asphalt and are in the range of the strength of portland cement concrete.

The relation of the values obtained in these laboratory tests to stability values of the pavement after construction is not known. However, the conditions of laboratory mixing, compaction, and testing are such that the hardening occurring would most likely be less than that which actually occurred in construction. It would also be expected that the tar materials would exhibit greater differences between laboratory and field specimens than asphalts. Thus it can be surmised that actual differences in the stabilities of pavements made with the different materials were greater than those indicated by these tests.

Because no evaluation of the brittleness or resistance to abrasion of the various mixtures was made, stability

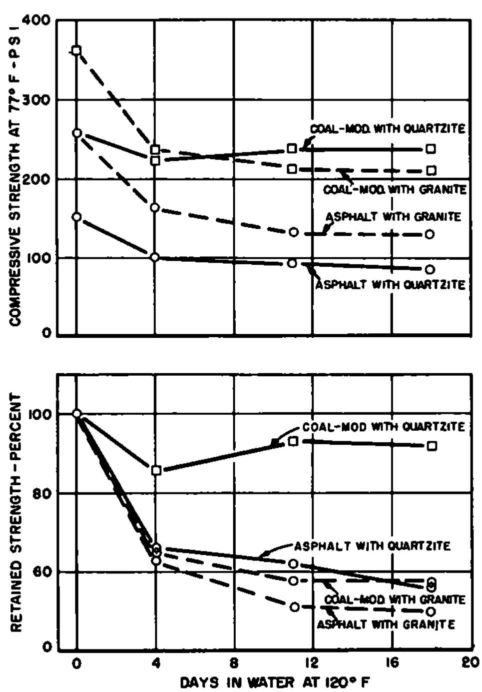

Figure 7. Effect of water immersion on stability.

TABLE 7

VARIATION OF COMPRESSIVE STRENGTH WITH TEST TEMPERATURE

Property	RT-12 Tar	Coal-Mod Binder	Asphalt Cement
Specific gravity binder at 77 F	1 265	1 267	1 019
Wt of binder per 100 g agg (g)	7 40	7 41	5 96
Vol. of binder per 100 g agg. (ml)	5 85	5 85	5 85
Mixing temperature[1]	220	265	320
Unconfined compressive strength (psi)[2]			
At 0 F	5,197	5,446	2,568
36 F	1,503	2,358	912
75 F	220	544	291
100 F	86	236	143

[1] Mixing temperature adjusted to give approximately equal viscosities for all binders (70 to 100 sec)

[2] Each value represents average of three test results on 3- by 3-in. cylinders Aggregate composed of 58 percent crushed granite (1/2-in No 10), 37 percent river sand (passing No 10) and 5 percent limestone dust. Gradation was as follows

Passing Sieve	Percent
1/2-in	100
3/8-in	90
No 4	57
No 10	42
No. 20	23
No 40	20
No 80	7
No 200	5.2

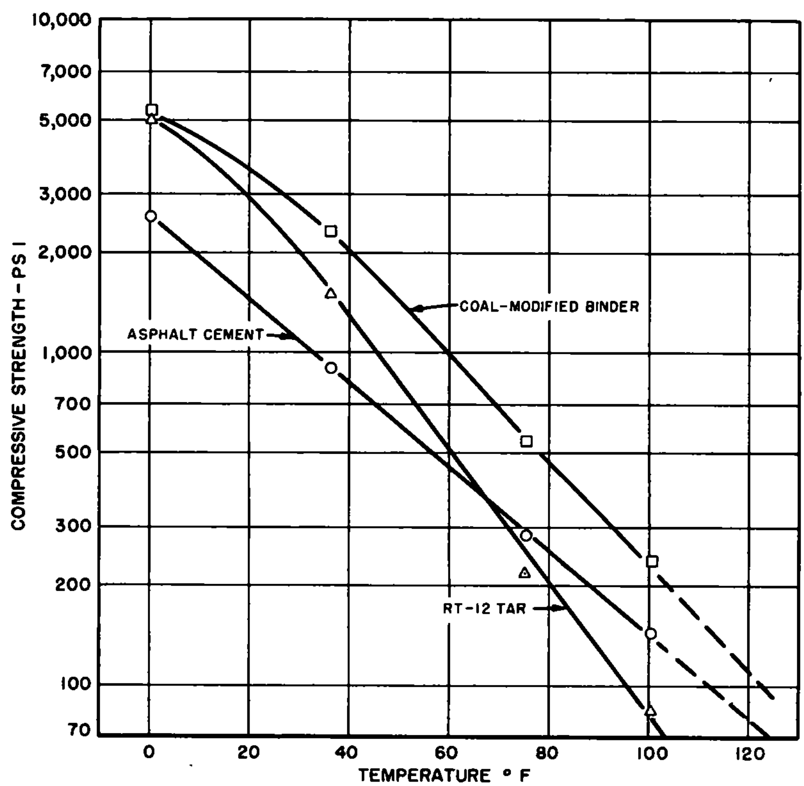

Figure 8. Variation of compressive strength with temperature.

values of the magnitude indicated by the tar materials at low temperatures should not necessarily be construed as being advantageous. It is quite likely that pavements containing such mixtures would be subject to abrasion losses and cracking at low temperatures, and such distress would be accelerated by any hardening of the binders in service. As a matter of fact, the performance of these materials in the Kentucky experiments indicated deficiencies in these respects.

SUMMARY AND CONCLUSIONS

The comparative tests made in this study showed that the coal digestion and the addition of high-boiling tar oils employed in the manufacture of the coal-modified tar binder reduced the viscosity-temperature susceptibility of the tar and made it somewhat more resistant to hardening at high temperatures. However, comparison with asphalt of a similar softening point (85-100 penetration grade) showed that the modified binder retained characteristics more nearly equal to those of the tar than those of the asphalt. In particular, the volatile loss and hardening in heat tests of the two tar products were about the same but were significantly different from results of similar tests on asphalts. Stability values at the same temperature for the modified tar binder were higher than those for the asphalts. However, the values obtained at low temperatures were such that a lack of flexibility resulting in possible brittleness might be suspected. The behavior of the materials in the Kentucky experiments indicated that this was the case.

These results in general show that coal-modified tar binders such as the Curtiss-Wright material should be considered as an improved tar. It would be expected to perform better than unmodified tars in a number of applications. However, it was also indicated that the precautions normally employed when using tars should be employed when using this material rather than attempting to substitute it for penetration grade asphalts.

REFERENCES

1. Karius, H., and Dickinson, E. J., "The Effect of Coal and Long-Chain Polymers on the Characteristics of Bituminous Road Binders." Jour. Appl. Chem., 9: No. 10 (Oct. 1959).
2. "Coal Based Binders for Bituminous Concrete Pavements." Research Division, Curtiss-Wright Corporation (Dec. 1960).
3. Hardymon, J. F., "Experimental Paving Projects Using Curtiss-Wright's Coal-Modified, Coal-Tar Binder (Construction Phase)." Highway Res. Lab., Kentucky Department of Highways.
4. Hardymon, J. F., "Experimental Paving Projects Using Curtiss-Wright's Coal-Modified, Coal-Tar Binder (First Year Performance)." Highway Res. Lab., Kentucky Department of Highways.
5. Lewis, R. H., and Halstead, W. J., "Determination of the Kinematic Viscosity of Petroleum Asphalts with a Capillary Tube Viscosimeter." Public Roads, 21: No. 7 (Sept. 1940).
6. Griffin, R. L., Miles, T. K., Penther, C. J., and Simpson, W. C., "Sliding Plate Microviscometer for Rapid Measurement of Asphalt Viscosity in Absolute Units." ASTM Special Tech. Publ. 212.
7. Welborn, J. Y., and Halstead, W. J., "Properties of Highway Asphalts—Part 1, 85-100 Penetration Grade." Public Roads, 30: No. 9, (Aug. 1959). Also Proc. AAPT, Vol. 28 (Jan. 1959).
8. Lee, A. R., and Dickinson, E. J., "The Durability of Road Tar." Road Res. Tech. Paper 31, Department of Scientific and Industrial Research (Great Britian), Road Research Laboratory (1954).
9. Brown, A. B., Sparks, W. W. and Smith, F. M. "Steric Hardening of Asphalts." Proc., AAPT, Vol. 26 (1957).